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WORLD BANK WORKING PAPER NO. 151

Weather and Climate Services in Europe and Central Asia

A Regional Review

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THE WORLD BANK
Washington, D.C.

Manufactured in the United States of America
First Printing: June 2008

printed on recycled paper

1 2 3 4 5 11 10 09 08

ISBN-13: 978-0-8213-7585-3
eISBN: 978-0-8213-7586-0
ISSN: 1726-5878 DOI: 10.1596/978-0-8213-7585-3

Cover Photo: Meteorological station in Volgogradskaya oblast (by Petr Lurye).

Library of Congress Cataloging-in-Publication Data has been requested.

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Acknowledgments

A number of people contributed to this study, and we would like to thank them all. Our first thanks go to the leadership and staff members of RosHydromet, who suggested that the Bank consider a deeper involvement in the sector globally.

The authors also thank the meteorological agencies of the European Union. The UK Met Office lent us the template we used for a survey of severe weather warnings, explained a number of technical issues, and helped us to understand issues of aviation cost recovery and emergency management. The UK Met Office also helped develop our work on climate change adaptation, working with us to maximize national capacity building in that respect. Météo-France has been a strong support; in the weather agencies of Europe and Central Asia, the gifts of France make a crucial difference to many. German DWD has also been generous, particularly with respect to work on local area modeling. Our regional cooperation study began under the auspices of the warm hospitality of the Government of Austria. Finland is of course one of the most important global donors to meteorology. The Finnish Meteorological Institute (FMI), has patiently responded to every request for information, feedback on initial findings, and perspectives on emerging issues. We have consulted FMI on technology issues, disaster management, and cooperation, among other issues. The Government of Finland was particularly helpful in supporting work on regional cooperation in South Eastern Europe. The European Center for Medium-range Weather Forecasting, the lead forecasting agency of Europe, was generous in answering technical questions concerning numerical modeling. The Government of the Netherlands was a key financier of the IDA work undertaken in this study through the Bank-Netherlands Partnership Program (BNPP). This support enabled a deepening of consultation and country knowledge concerning national capacity, climate change, severe weather warnings, and economic benefits of hydromet services.

More than any other advisor, we thank the national meteorological service directors and the national experts of the countries involved, who went far beyond their duties to illustrate the status and needs of weather forecasting in Europe, aiming to support not only their own agencies but also others. These interviews underpinned our confidence that Bank work on a cooperative effort among these agencies will be productive.

Outside ECA, we consulted with the United Nations World Meteorological Organization (WMO). WMO President A. Bedritsky gave strong support to our original proposal and has encouraged us at every stage. We received important support in concept development from Rodolfo de Guzman of WMO. Petteri Taalas and Dusan Hrcek have devoted time and energy to promoting a good outcome of our effort. Yinka Adebayo, David Rogers, and Haleh Kootval provided very helpful comments on early drafts of this effort.

The Government of Canada supported a study of drought mitigation and management in Central Asia, and development of a network of community-monitored stations in Georgia, contributing to the understanding of options for climate change risk mitigation.

We consulted with U.S. NOAA and NASA. The National Weather Service (NWS) was generous toward our effort, ensuring we made contacts with agencies outside ECA that have experience in relevant issues, with modelers, and with technical experts as needed. NWS has offered its software, its experts, and answers to as many technical questions as we could pose. We also received help from the National Center for Atmospheric Research

(NCAR) concerning modeling and from NOAA's Chief Economist's office in support of economic benefits studies. Finally, we also consulted NASA concerning satellite data.

We thank Bank management for its support of what seemed to some a novel topic and of uncertain interest. This study is part of an ongoing Regional Working Paper Series sponsored by the Chief Economist's Office in the Europe and Central Asia Region of the World Bank. Marjory-Anne Bromhead, Joseph Goldberg, and Juergen Voegele, ECSSD Sector Managers, provided critical support during the course of implementation period, encouraged our view that the subject matter is of high priority because of its close link to MDGs and Bank objectives, and gave us every practical help to ensure success.

With help from all those listed and many others, the report was written by Lucy Hancock, Vladimir Tsirkunov, and Marina Smetanina. Sergey Ulatov, Alexander Korshunov, and Jeffrey Lazo provided significant input to the development of methodology and undertaking economic assessments described in Chapter 5.

Sometimes the weather community is asked to do the impossible, as in the case of the snowboarders who reportedly conducted a demonstration last winter at the weather service's headquarters in Bucharest until promised that the agency would take up the matter of not enough snow with the higher authorities. Subsequently snow did fall, vindicating the authorities consulted. We also have completed a challenging task, and likewise acknowledge the support of the same authorities.

Abbreviations and Acronyms

A1, A1BAIM, A1FIMI	Economic scenarios used for climate change projection (a subset)
A2, A2AIM, A2AIMI, A2ASF	Economic scenarios used for climate change projection (a subset)
AMDAR	Aircraft Meteorological Data Reporting
AMS	American Meteorological Society
AR4 TS	Fourth Assessment Report of the IPCC–Technical Summary
B1, B1AIM, B1MES	Economic scenarios used for climate change projection (a subset).
B2, B2AIM, B2MES	Economic scenarios used for climate change projection (a subset).
BAMS	Bulletin of the American Meteorological Society
CBA	Cost-benefit analysis
CCSM	Community Climate System Model
CIS	Commonwealth of Independent States
CMA	China Meteorological Service (NMS of China)
CSM 98	A general circulation model
DWD	Deutsche Wetterdienst (NMS of Germany)
EBRD	European Bank for Reconstruction and Development
ECA	Europe and Central Asia
ECH395	A general circulation model
ECH498	A general circulation model
ECMWF	European Center for Medium-range Weather Forecasting
ECSSD	Sustainable Development Department, Europe and Central Asia Region
EU	European Union
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FAO	Food and Agriculture Organization
FYR	Former Yugoslav Republic (as, FYR Macedonia)
GCM	General circulation model
GDP	Gross domestic product
GEOSS	Global Earth Observation System of Systems
GFDL	Geophysical Fluid Dynamics Laboratory (U.S.)
GFDL 90	A general circulation model
GIS	Geographic Information System
GRADS	Grid Analysis and Display System (software for visualization of data)
GTS	Global Telecommunication System
HAD295	A general circulation model
HAD300	A general circulation model
HH	Hazardous weather events
HR	Human resources

IBRD	International Bank for Reconstruction and Development
ICEED	Informal Conference of (South) Eastern Europe Directors of Hydrometeorological Services
IDA	International Development Association
IPCC	Intergovernmental Panel on Climate Change
IT	Information technology
LAM	Local area model—a numerical weather prediction model that is not global
MAGICC	Model for the Assessment of Greenhouse-gas-Induced Climate Change
MDG	Millennium Development Goals
NAO	North Atlantic Oscillation
NCAR	National Center for Atmospheric Research (U.S.)
NCEP	National Centers for Environmental Prediction (U.S.)
NMHS	National meteorological and hydrological service
NMS	National meteorological service
NOAA	National Oceanographic and Atmospheric Administration (U.S.)
NWS	National Weather Service (NMS of U.S.)
R&D	Research and development
RHMP	Russian Hydromet Modernization Project
RHMS	Republic Hydrometeorological Service (NMHS of Serbia)
SCENGEN	Software to generate global and regional scenarios of climate change
SEE	South Eastern Europe
SMOK	Monitoring, Forecasting and Warning System (of the NMHS of Poland)
SYNOP	Surface synoptical observations (WMO coded format)
UCAR	University Corporation for Atmospheric Research (U.S.)
UHC	Unfavorable weather conditions
UK	United Kingdom
UKMO	United Kingdom Met Office (NMS of the UK)
UN	United Nations
UNISDR	United Nations International Strategy for Disaster Reduction
WMO	World Meteorological Organization—a United Nations agency
WRF	Weather Research and Forecasting (a weather model)
WRM	Water resource management
WTP	Willingness to pay

Key Definitions

Formal definitions of meteorological terms can be found in the online Glossary of Meteorology, http://amsglossary.allenpress.com/glossary. For ease of presentation, we include here an informal summary of some key terms used in this report.

Weather and climate

Weather means the state of the atmosphere at a given time and place. *Climate* means average weather, including not only average values of weather variables, but also statistics describing the frequency and magnitude of extremes, trends, variability, and the like. *Climatology* means knowledge of climate. The notion of *microclimate* refers to the influence of land cover and topography on climate, differences that fade with height in the atmosphere but are significant at the earth's surface.

Models, initial conditions, boundary conditions, ingesting data, grid spacing, and resolution

Numerical weather prediction models are something like economic models. A numerical weather model can take as input to its calculations a set of measurements of the atmosphere at some point in time, and then, on the basis of a theory of how the atmosphere develops, compute a forecast of the state of the atmosphere at selected future time steps. In such a computation, the input data (describing the system as it was at the first time step of the calculation) would be called *initial conditions*. Initialization of a weather model by global data obtained *simultaneously* and at *even spacing* has therefore long been a modeling ideal, accounting for the fact that data gathering is globally synchronized. More recently, numerical weather models can incorporate input gathered over a wide range of time and spacing intervals. In light of the way recent models are computed, it is no longer precise to say that input data "initializes" the model. A broader and not inaccurate reference to the linkage is to say that the model *ingests* data.

Global models have *grid spacing* of about 25–100 km at present. The meaningful *resolution* of a model is about six to eight times the *grid spacing.* That scale of *resolution* cannot be expected to yield forecasts that are very useful on the ground: weather is nonlinear, so small features often have an important local effect and can have a global effect as well. Yet it is computationally difficult to increase *resolution*: high *resolution* requires not only computation at the many additional *grid* points, but also of additional intermediate time steps for every one, because as the *grid* points are nearer, mutual effects are more rapid. Global high-*resolution* models would take so much time to compute that the output could not be delivered in a timely way. Therefore, current modeling practice goes in two stages: delivery of low-*resolution* global model output, followed by computation of higher-*resolution* local models "nested" within the global output, that is, constrained to match it. One says that global model output provides *boundary conditions* to constrain local models. In the second step, local models are calculated at *grid spacing* from 16 km down to 1 km (at present). The two-step process enables high-*resolution* forecasts that incorporate global effects.

Weather prediction is the archetypal nonlinear problem, illustrated by the archetypal "*butterfly effect*" whereby a mismeasurement difference between the measured atmosphere and the real one that is as small as the impulse from a butterfly's wing can evolve into distinction between two future states of the atmosphere that is dramatically large. Given the nonlinearity of the problem, it is impossible—not merely difficult but impossible—to measure the atmosphere precisely enough to compute its future state more than about a week to ten days in advance. Yet, such forecasts are made, and are becoming skillful. How is that? The advance comprises the use of multiple model runs, each assuming slightly different initial states of the atmosphere (all within the realm of what measurements say might be true). From the range of results from these many model runs, the forecaster can see that some events are quite likely—robustly forecast across a range of assumptions—while other events are very sensitive to input conditions and so should not be forecast with much certainty. Success in stating these probabilities does not violate the theoretical time limit on the value of a single model run. It is called *ensemble* forecasting. This type of *probabilistic* forecast can say true and useful things about future weather for lead times that are beyond the time limit on single model runs (which are sometimes called *deterministic* calculations).

Nowcasting, hindcasting, forecasting, re-analysis, and projection

Forecasters predict the weather on different time frames. *Nowcasting,* or very short-range forecasting, refers to forecasts of weather for the next zero to 12 hours; *short-range* forecasts are those addressing lead times of 12 to 72 hours; *medium-range* forecasts, three to seven days; *extended* forecasts, the second week ahead. Beyond that are monthly and seasonal forecasts.

Climate change *projections* are a different category of calculation about the future. As in economics, a projection is to be understood as the modeled outcome of one set of economic choices among several that are reasonably possible.

The term *hindcasting* describes a "forecast" made for a past time on the basis of historical data. For example, one might make a hindcast of Hurricane Katrina, using data from the days leading up to it, in order to assess whether some new weather forecasting model would have been better or worse at predicting landfall than the weather models in use at the time.

Re-analysis is a mix of hindcasting and modeling of past weather. Its motivation is that, for several applications, one may ask what the weather was in the past, in some unmonitored region or variable. One may suppose that it should be possible to reconstruct past weather from historical data, filling in regional data gaps or unmeasured variables by taking into account measurements around the data gap, and considering what must have happened in the blank region. Such a reconstruction of global weather is called a *re-analysis*. Several re-analyses have been carried out by global agencies, considering time ranges from 1940 onward.

Skill, accuracy, usefulness, and lead time of forecasts

It is easy to understand the concept of accuracy, which means the same thing in weather forecasting as elsewhere. However, another measure of forecaster effectiveness is needed, because accuracy is intrinsically much easier in some places than others. For example, suppose one guesses that tomorrow's weather will be like today's. This is called the *persistence* forecast. Or suppose one guesses tomorrow's weather simply by looking up past averages. This is called a forecast based on *climatology*. Either method would accurately forecast precipitation in middle of the Kara Kum Desert, for example: it won't rain. Thus, a forecast can be very accurate under some circumstances without indicating the existence of *skill* in the sense of a correct analysis of current weather patterns. However, in the mountains of Bosnia, rain varies significantly day to day, week to week, year to year, so neither *persistence* nor *climatology* would provide an *accurate* rain forecast. Thus, equally-accurate forecasts of precipitation in Bosnia and the Kara Kum would indicate far greater *skill* in Bosnia than in the Kara Kum. By the same token, temperatures in Kazakhstan are much more variable than in Bosnia; and so equally-accurate forecasts of temperature would indicate greater *skill* in Kazakhstan. *Skill* is a measure of accuracy *above* the accuracy of forecasts based on "blind" guesses such as *persistence* and *climatology.* A forecasting product with a history of significant *skill* is considered *useful*.

The *lead time* for a forecast of an event is the length of time between the issuance of the forecast and the projected time of the event. Forecasting skill is highest for short *lead times* (the near term) and declines as *lead time* increases. For example, the forecast for tomorrow is likely to be very skillful and therefore *useful*; a forecast made today for next week may have significant skill and some *usefulness*; a forecast made today for the weather ten days from now will be statistically better than a blind guess, but much less skillful and *useful* than forecasts for the shorter lead times.

Cyclones, anticyclones, intrusions, boras, and crivats

Atmospheric air circulation manifests some recurring patterns in certain locations. Generally, air is warmed at the equator, and then, pushed steadily upward by a continuing inflow of air warmed below, finally flows away from the equator and poleward, eventually to sink, cool and flow back. This circulation does not occur smoothly. It picks out some geographic regions as places where air masses tend to rise over warm surfaces, initiating *cyclonic* (anticlockwise) circulation at the surface as air converges to take the place of the rising air mass. For example, there is a recurrent Genoa Cyclone: over the Gulf of Genoa in winter, air warmed by the water rises, and as a result, air near the sea surface tends to develop low pressure systems, storms, clouds and precipitation. Over plains areas in summer, air is warmed, causing it to rise and initiate local storms.

At the other extreme, there are places with a strongly recurrent pattern of air masses cooling and sinking. Thus, over Siberia during the winter, one finds a recurrent Siberian *Anticyclone*: air is cooled as it comes in contact with the earth's surface, then it subsides and diverges, moving away from the high pressure zone along the earth's surface—clear cold air with little precipitation. When cold air moves away from the Siberian *Anticyclone*, part of it moves to the southwest. The cold air pushed away from the far north may also be pulled south by a local cyclone in Southern Europe. In this case, the *intrusion* of north/northeastern air to the south can become a freezing wind, such as the *crivats* of Romania and Moldova. The *boras* of South Eastern Europe can also begin when air masses from the north or northeast, pushed south by the Siberian anticyclone, are also pulled south by a southern cyclone. In a bora, cold air piles up on the north side of the east-west mountain range, so dense with cold that when the air mass overtops the mountain range and "falls" downslope, it is not warmed enough by the higher pressure of decreasing altitude as it falls downward to reach ambient temperatures. Instead, colder and denser than surrounding air, it continues to "fall" downward until it drops off land over the Sea. These events are experienced as heavy, freezing, multi-day, often dangerous wind events.

Teleconnections

The El Niño/La Niña phenomenon is an example of an atmospheric *teleconnection*, a linkage between ongoing weather patterns in widely separated areas of the globe.

Aerosols

The atmosphere is approximately a gas, but it is not a pure gas. Liquid and solid particles are suspended in it. Such a suspension is called an *aerosol.* Usually, reference to *atmospheric aerosols* means suspensions of small solid particles such as soot, dust or ice. (Formally, it could mean suspended water—clouds and fog—but conventionally it does not.) These suspensions play several important roles in weather. For one, they serve as "seeds" promoting the development of precipitation. For another, some *aerosol* particles reflect the Sun's light, thus cooling the atmosphere; others absorb the Sun's light, thus warming the atmosphere.

Human activity is a source of particles that become suspended in the atmosphere's lower layers. Human-generated *aerosols* commonly persist for weeks but not years in the atmosphere. When pollution is reduced (as in Europe during the transition), the atmospheric *aerosols* comprised of pollutants change proportionately on a time frame of weeks. On the other hand, natural events, such as volcanoes, are a source of particulates that rise into the atmosphere with such momentum that they become suspended in *aerosols* at higher layers of the atmosphere. Such *aerosols* can persist for years, as after the eruption of Mount Pinatubo in the 1990s.

Observing networks

In order to assess the dynamics of a weather system, it is necessary for forecasters to sample the system, not just in one place, but in an array of stations sampling the characteristic length scales over which the weather system changes. When a national weather agency chooses where to put weather stations, it is designing a "network" that will combine observations and jointly achieve adequate sampling of the weather systems that affect the country, enabling forecasts of what the systems will do next. Because there are different phenomena to be captured and studied, one may speak of different *observing networks:*

- Every country has a *network of surface weather stations* that is aimed to capture everyday weather changes by measuring basic variables: temperature, pressure, wind speed and direction, relative humidity (a measure of how much water air is holding, compared to how much it could hold at the same temperature and pressure without commencing precipitation), cloudiness and precipitation.
- Most agencies studied here are also responsible for the national *hydrological network*, the set of hydrological stations and hydroposts that record precipitation and the levels of rivers and streams. This task slightly overlaps the work of the surface weather stations and is sometimes combined with it.

- Some agencies manage an *agrometeorological (agromet) network*, usually a subset of the surface weather stations that, in addition to the basic variables, also measure soil moisture at various depths. This enables assessment of water lost from the surface through evaporation into the atmosphere (the latter is called *evapotranspiration*). Some agromet stations also record the progress of key crops grown at the stations (a study called *phenology*), as a practical double-check to detect the onset of drought or other conditions affecting agriculture.
- There may be an *actinometric network*, comprising stations that measure how much solar radiation (direct versus *diffuse*), is received. As with the other networks, this network comprises sensors that may be co-located with the surface weather network and/or other networks, but in principle could stand alone.
- *Radar networks* are important to illuminate dangerous weather patterns that are underway. In general, radar technology is something like flashbulb-assisted photography on a very large scale, although the pictures are taken in radio frequencies instead of the frequencies of visible light and the analysis is more detailed. Data from a radar network may be assembled into a *radar mosaic*, a single combined image. *Doppler-capable* radars enable calculation of the speed of an illuminated event toward or away from the radar. This is useful in assessing the travel of a storm.
- *Weather balloons* are launched one to four times a day simultaneously over the Earth by many countries, which then share the data immediately over the Global Telecommunications System. The weather balloon stations comprise a *network of "upper-air" stations,* so named because the balloons float from the surface to 25–30 km above the surface. Packages of sensors that they carry broadcast data back to Earth: temperature, relative humidity and sometimes pressure. By also transmitting their changing location, the weather balloon packages effectively indicate wind speed and direction. This program is called "*sounding*" the *upper atmosphere*, and the instrument package a *sonde*. The balloons ascend through the troposphere, which is the atmospheric layer where weather events felt at the surface happen. The balloon ascents also traverse part of the layer above the troposphere, the stratosphere, which has an important influence. The balloons tend to explode at about 30 km altitude. Balloon launches are expensive, and so alternative means of upper-atmosphere sounding are continually sought. One useful system is that aircraft drop sondes through the atmosphere on approach to airports. This system is called AMDAR (Aircraft Meteorological Data Relay). While it is limited in space and time, this system can help to patch data gaps.
- *World Weather Watch* is a cooperative program of the World Meteorological Organization that coordinates a global observing system comprised of subsets of the national networks, preparation of forecasts and analyses, and a Global Telecommunication System by which meteorological data and analyses can be collected and disseminated.

Metrology

Metrology is the science of measurement. It is of great importance in meteorology, where a single mismeasurement or low-quality data point has been observed to lead a forecast astray, with disastrous consequences.

Executive Summary

This paper reviews the status of weather and climate services in Europe and Central Asia (ECA).[1] Worldwide, the accuracy and value of weather and climate services are rising, bringing great economic benefits. However, many national hydrometeorological services (NMHSs) in Europe and Central Asia are in decline. As a result, these potential gains are often missed. Much more could be done to mitigate weather disasters, support the productivity of smallholding and commercial agriculture, conserve energy, and promote safe aviation and transport by road and rail. Although NMHS capacity deficiencies are serious, they could be significantly remedied by relatively modest—but sustained—investments. Economic assessments indicate substantial benefit-to-cost ratios for such initiatives.

The climate of ECA is varied, and so is the dependence of each country's economic structure on weather information. Accordingly, each national situation highlights different services as especially valuable, such as forecasting of floods or frosts, or high-resolution routine forecasting. Despite this variety, the forecasting task is broadly comparable everywhere, as are NMHS structures. Urgent capacity issues in Europe and Central Asia fall within three main categories:

- deficient IT and numerical modeling capacity;
- sparse, deteriorating monitoring networks and weak telecoms;
- workforce training that is far out of date, leading to an inadequate mix of staff skills.

Underlying these capacity issues is the recent neglect of the sector by national policy makers, particularly during the uneasy transitional era, which has enabled a pattern of persistent, systematic underfunding to develop. The scope of the accumulated problem is so great that without massive modernization and capacity building, NMHSs in some ECA countries are likely to become completely dysfunctional. Urgent investments are required to modernize infrastructure, operational routines, and staff capacity. To maintain the sustainability of NMHS operations, agency financing models should also be reevaluated by national governments.

A strategy for NMHS service improvement requires assessment of national climate, user needs, NMHS status and provision of services, and the economic benefits of an upgrade to weather and climate services. Recommendations for agency modernization should include (a) a prioritized plan for improving data delivery to national users, (b) identification of the highest-priority infrastructure investments, and (c) a reasonable phasing plan for overall modernization. Following a brief sector overview, these priority areas and approaches are described below in more detail.

1. Countries reviewed include: Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, Uzbekistan (Central Asia); Armenia, Azerbaijan, Georgia (Caucasus); Belarus, Moldova, Ukraine (European CIS); Russian Federation; Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Macedonia, Montenegro, and Serbia (South Eastern Europe).

The Worldwide Rise in Accuracy of Weather Forecasting

The accuracy of weather forecasting has risen steeply in the last few decades. Seven-day forecasts today are almost as accurate as three-day forecasts were in the early 1980s. Even ten-day weather forecasts are becoming useful (significantly more accurate than guessing based on statistics). The improvement in accuracy has been enabled by advances in high technology. Since numerical weather prediction based on computers became a public service in 1955, accuracy has steadily improved as the process drew in turn upon telecommunications, radar, computers, artificial satellites and supercomputing. An accurate five-day forecast of local weather requires supercomputer integration of a complex numerical model supplied with measurements of the weather of the whole world obtained in the past few hours. Today, it has become possible to undertake exactly that, on a routine basis.

Key Sectors in ECA Likely to Benefit

Worldwide, economic sectors are making use of improved weather forecasts to optimize operations.

Agriculture. ECA's agriculture sector could be a major beneficiary. Accurate forecasts would enable timely sowing, plowing, irrigation, and harvesting of crops. Increased accuracy would assist in the timing of applying fertilizer, in pest and disease control, and in avoiding over-applications that are washed or blown away. Forecasting could guide cost-effective use of special preventive measures to mitigate the damage from frost, hail, erosion caused by wind and precipitation, and drought. Forecasting could be applied to optimize storage and transport of agricultural produce, reducing post-harvest losses. Forecasting could also enhance pasture and animal production and fish catches—rainfall affects the availability of forage, and animal health depends on management that takes temperature and wind into consideration (Dzama and Chimonyo 2007).

Disaster Mitigation. According to the United Nations International Strategy for Disaster Reduction (UNISDR), up to 35 percent of flood damage can be mitigated if flood warnings are made in advance; in the United States, as little as one hour of lead time can result in a ten percent reduction in flood damage (UNISDR 2004). Forecasting of severe weather enables emergency management teams to be put in place, mitigation measures to be prepared, and evacuation to be undertaken. However, public surveys undertaken within the scope of this study indicated that, in many cases, little lead time is supplied. In the countries surveyed, 25 to 50 percent of respondents found out about severe weather on the day it occurred, compared to six percent in the United Kingdom. Weather events are different from country to country, and to some extent, these statistics do not refer to similar events. Nevertheless, available data suggests a great disparity in the timeliness of severe weather warnings, a disparity that cannot be remedied without reinforcement of ECA's weakening weather services.

Water Resource Management. Forecasts of precipitation can be used to help forecast the level of rivers by assessing the runoff that will result from precipitation. This method is becoming useful in basins where dangerous flows form rapidly and there are few gauges in place.

Aviation. Aviation is an important client of hydrometeorological (hydromet) services, because safe aviation depends on weather forecasting. Weather-balloon data is particularly necessary for aviation forecasting, because it probes the atmosphere *in situ.* But weather-balloon data is expensive to collect. Many of these stations have been closed in ECA since the early 1990s.

Many other sectors would benefit.

- *Oil and gas extraction.* Turkmenistan, Kazakhstan, Azerbaijan and Russia have each indicated the value of better forecasting to oil and gas extraction. Better marine forecasting, for example, would assist the management of Caspian Sea rigs in extreme winds and wave heights. Better forecasting of temperatures would be useful for protecting infrastructure for oil and gas extraction.
- *Insurance,* an emerging client of NMHSs, is a large, capable stakeholder interested in reducing weather-related damage that is insured.
- *Road, rail, and marine transport* make use of forecasts and information about current conditions, such as slippery surfaces, obscured visibility, and high winds. Icing of ships in ECA's northern water bodies is dangerous, especially to fishing boats. Furthermore, models to forecast the spread of oil slicks or other pollution in the Baltic and Black Seas depend on accurate wind forecasts.

Forestry benefits from short-term weather forecasts of wind speed, temperature, precipitation and humidity that enable accurate forecasts of forest fires and smoke transport.

The *health sector* is also making increasing use of weather alerts and advisories.

Challenges Posed by ECA's (Changing) Climate

ECA's climate subregions pose different forecasting challenges. For example, South Eastern Europe and the Caucasus are vulnerable to large variations in runoff; therefore, flood and drought forecasting capacities are particularly important. Central Europe is a climate change transition zone, where climate change projections are relatively weak on pinpointing future trends. Therefore, analysis of past weather data would be particularly important to establish on-the-ground trends indicating how climate change is unfolding. Central Asia is affected by variable runoff in mountain regions where lakes and rivers multiply the impact of flooding in upper watersheds. The NMHSs of eastern Central Asia are among those most affected in ECA by the trend toward decline in all NMHSs. A reversal of this trend would benefit these agricultural economies.

NMHS capacity will be essential for national adaptation to ongoing climate change. ECA's economic sectors must move away from planning that is based on past average weather, now understood to be a weak guide to future average weather. They should also avoid relying on climate change projections alone. While some climate models have had success in modeling recent decades' rise in temperature, some experts doubt whether this is matched by success in modeling economically important variables such as precipitation and wind speed, even at gross scales. For the foreseeable future, adaptation to climate change must incorporate (i) better awareness of on-the-ground climate trends, (ii) development and dissemination of the best possible forecasts with timeframes ranging from short-term to seasonal, and (iii) national expertise conversant with the physical models and their linkages and uncertainties.

Capacity Deficiencies in ECA

Twenty to thirty years ago, weather forecasting and overall provision of hydromet services in many ECA countries were at the leading edge of world capacity. However, the bulk of regional infrastructure is finally wearing out, and training is far out of date. IT is often inadequate for up-to-date models (such as those successfully run by the staffs of some NMSs in Africa and Latin America). Many surface data collection stations have closed and the surface stations that remain open record a more limited set of parameters, less frequently, using instruments that are aging and failing. Communications equipment to convey station data to headquarters for analysis is often obsolete, unreliable, labor-intensive, and expensive. Ongoing training is inadequate to keep the skills of senior staff current, or to prepare an adequate number of incoming staff. Some agencies are on the brink of collapse.

To assess the strengthening needed, it is necessary to consider which functions of NMHSs are most likely to persist into the future. The weather and climate services sector is divided into several domains in which certain tasks are carried out by nations, another set of tasks is undertaken by global and regional agencies, and a third set of tasks is performed by private services. It seems likely that following a period of exchanging clients among agencies and enterprises, the ECA countries' national services will continue to provide key public goods, including: (a) forecasting at the shortest timeframes and at high resolution over all populated areas, (b) outputs needed by users of national importance that are not able to pay, such as smallholding agriculture and households with low to average incomes, and (c) monitoring of the atmosphere over national territory in coordination with the standards of the global system.[2] The NMHSs' tasks may indeed grow to meet ever growing increasing demands from users and to encompass better management of historical records.

Better services would not be prohibitively expensive. Weather satellites, supercomputing and models are in many cases available to low-income countries for little more than the incremental cost of connecting to the system. Transboundary institutions for data exchange would improve the accuracy of forecasting in some regions. Most importantly, broad modernization to enable NMHSs to deliver a normal range of services would bring benefits that exceed the costs. Support provided on a one-off basis may miss the target: several ECA NMHSs have been beneficiaries of donations that the agencies could not subsequently sustain. Improved capacity will require ongoing public financing of agency operations. Another difficulty common to public agencies in transitional economies is that forecasting operations depend on cutting-edge technology and skills, but government agencies have difficulty retaining highly qualified staff, who are attracted to the private sector by higher salaries and more-competitive terms of employment.

2. Enterprises, airports, water managers, and ministries of transport and agriculture may undertake operation of stations in some places and in some seasons, meeting their own sectoral standards.

Assessment of Benefits of NMHS Operations/Modernization

Country-specific economic assessments of the benefits of NMHS modernization were undertaken within the scope of this study in the Southern Caucasus (Armenia, Azerbaijan, Georgia), South Eastern Europe (Albania, Serbia), Belarus, Kazakhstan, and Ukraine. Two approaches were used. In the first approach, sectoral user needs assessments showed that weather losses in ECA are in the range of 0.5 to 1.9 percent of GDP annually in the countries studied. In the second approach, benchmarking studies estimated vulnerability within ECA by leveraging global average data and assessing each studied country's position within global ranges, considering climate, agency capacity and exposure of the national economy. Results by this method estimated annual losses in the range of 0.3 to 1.2 percent of GDP. In any case, outcomes are comparable; the level of loss is high; and the benefits of mitigating it are considerable.

Studies indicated that ECA's NMHS services are already providing substantial benefits to national economies by mitigating the level of loss that would otherwise occur, at a rate exceeding the current costs of NMHS support. Enhanced support to NMHSs would be well justified: assessments indicated that the NMHS modernization programs considered could be expected to have benefits—in terms of avoided loss—four to six times the cost of the investment. Traditional cost-benefit analysis indicated that the economic rate of return (ERR) for modernization projects varied from 20 to 80 percent, and the simple pay-back period averaged 4.4 years. This finding persisted whether the analysis was formulated as a consideration of specific items to be bought, or of specific forecasting skills to be achieved (sector studies), or as a function of global averages in accuracy, cost, and benefit of agencies (benchmarking).

Deficient Financing of Weather/Climate Services

Why have these useful services at modest cost not been fully financed? It appears there are three main reasons for deficient financing. *First,* there is a lack of understanding of the value of NMS services. *Second,* decision-makers may believe that global providers can supply forecasts and that the national system is not truly necessary, when in fact the global system fully depends on inputs from NMSs. This is not apparent because NMS inputs are provided via the WMO and are not acknowledged by final users. *Third,* decision-makers may expect that NMSs should be able to finance basic operations by selling forecast services. While there are advanced NMSs in Europe that undertake commercial activities (Météo-France and the United Kingdom's Met Office, for example) they do not finance basic operations essentially from the income from commercial activities.

A second financing dilemma may be noted. It is broadly observed that NMSs that are allowed by national governments to undertake private contracts are more responsive to public sector users. However, revenue-seeking NMSs also have the incentive to withhold information from public dissemination. To take an important example, smallholding agriculture supports many families within ECA, and high-resolution, accurate, extended forecasts, to which most families do not have access at present, would promote their productivity. However, these families are not able to pay for this information, and therefore such forecasts, which are publicly available in other countries, may not be made available to smallholding farmers in ECA. National policy makers should consider the broader benefits that could be delivered by NMSs if the NMSs were not directed to self-finance. In parallel with undertaking urgent modernization of services, national policy makers should devise and adopt appropriate financial arrangements that would enable the services to meet public needs.

Conclusions and Recommendations

Support for NMHS service improvement should be based on:

- assessment of national climate, including average weather, variability of weather, natural hazards, observed climate change, and other aspects of climate;
- assessment of user needs, addressing households and key economic sectors, including smallholding agriculture—the source of livelihood for a significant share of the national population;
- assessment of NMHS status, including agency capacity, sustainability, and effectiveness in user orientation;
- assessment of the economic benefits of an upgrade to weather and climate services.

On the basis of these assessments, recommendations for agency modernization should be developed, incorporating a prioritized plan for improvement of data delivery to national users. Improvement priorities should include:

- initiatives in data processing, modeling and information dissemination;
- a slate of high-priority investments in modernization of the basic observation and IT infrastructure (communication and basic observation equipment);
- phased overall modernization, to include workforce training and recruitment, reinforcement of the main elements of NMHS infrastructure, institutional strengthening, and capacity building.

Planning for sustainable financing should take into account as appropriate the issue of incentives for delivery of high-quality forecasts to sectors unable to pay, among which, smallholding agriculture is of particular importance for its size and for its dependence on weather information. The economic benefits of NMHS modernization may be smaller in magnitude and in poverty relevance if incentives limit service to those able to pay.

CHAPTER 1

Motivation and Scope of the Study

Background

In most countries, weather and climate are forecast for the public by national meteorological services (NMSs); in the ECA region, NMSs are often organized as branches of national hydrometeorological services (NMHSs). In addition to routine weather forecasts used by households, NMSs often provide weather forecasts tailored to support agriculture, municipal services, disaster management, water resource planning and management, transport, environmental protection, public health, and other sectors (see Table 1.1 for a list of key economic applications). Among their higher-level goals, safety of life and property is their stated primary mandate, followed by reduction of the impact of natural disasters and support for national sustainable development. NMSs generally provide a limited menu of free services by mandate, such as short-term weather forecasts and emergency forecasts to the media and/or public and weather reports to specific government authorities. In recent years, a new service, information about the magnitude and direction of climate trends, has been identified as a matter of growing importance.

Some NMSs/NMHSs share the task of weather monitoring and forecasting with other agencies, while some are charged with additional tasks (such as environmental monitoring) in addition to hydrometeorology. With these variations, total global financing of weather services is not easy to break out. The global sum of NMS/NMHS budgets, US$4 billion, is a reasonable order-of-magnitude estimate of total national budget financing for weather/climate services. Per country, financing is usually on the order of .01 to .03 percent of GDP. Financing models fall broadly into two categories: a pure public-goods model with full financing from the national budget, and a model that incorporates some self-financing through paid contracts for specialized services.

Table 1.1. Economic Applications Served by National Meteorological Services

Average Rank Globally	As Ranked by the Services
1	Aviation
2	Agriculture
3	Disaster Management
4	Water Res. Planning &Management
5	Environmental Protection
6	Mass Media
7	Construction
8	Energy Generation and Supply
9	Marine Transportation
10	Tourism
11	Fisheries
12	Land Transportation
13	Food Production
14	Forestry
15	Insurance
16	Port and Harbor Management
17	Industry
18	Urban Planning
19	Communications
20	Sport
21	Health and Medical Services
22	Leisure
23	Offshore Operations
24	Legal Services
25	Animal Husbandry
26	Commerce
27	Manufacturing
28	Private Meteorological Service Sector
29	Banking and Financial
30	Retail Trade

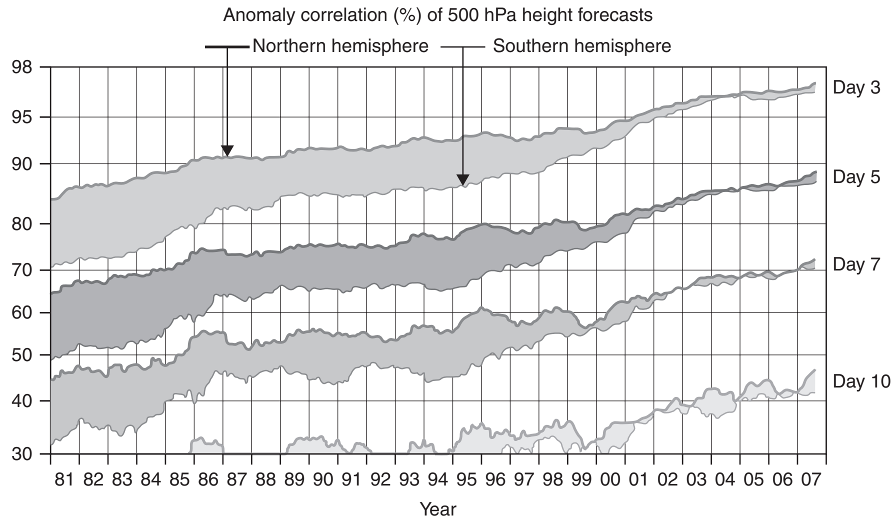
Source: WMO, "Responses to the Questionnaire on the Role and Operation of NMSs," Preliminary Analysis, 2001.

Globally, the skill[3] of weather forecasting has risen dramatically in the last few decades. Figure 1.1 shows the rising skill of weather forecasting at the European Center for Medium-range Weather Forecasting. The uppermost rising arc means that for three-day forecasts, the correlation between forecast pressure field and observed pressure field is approaching perfection. The third rising arc shows that seven-day forecasts today are almost as good as three-day forecasts were in the early 1980s. The lowest rising arc shows that ten-day forecasts, although still not very useful (values above 60 are considered useful), are improving yearly. The width of each arc shows the difference between the accuracy of forecasts in the Northern and Southern Hemispheres, which does not directly concern us here except that the narrowing gap shows the value of satellite data especially over oceans. Overall, the story of Figure 1.1 is one of dramatically rising skill in weather forecasting.

To understand the dramatic rise in skill, it is enough to note that improvement in weather forecasting has always tracked the development of instrumentation. From the time thermometers were invented, people have recorded weather as an application of new instruments, even before there were known uses for the time series being gathered. Later, scientific forecasting began (about 150 years ago) as an outgrowth of the age of popular science. Forecasting skill has grown since then, incorporating in turn telecommunications, radar, computers, artificial satellites, and supercomputing.

3. See Key Definitions section for the distinction between skill and accuracy.

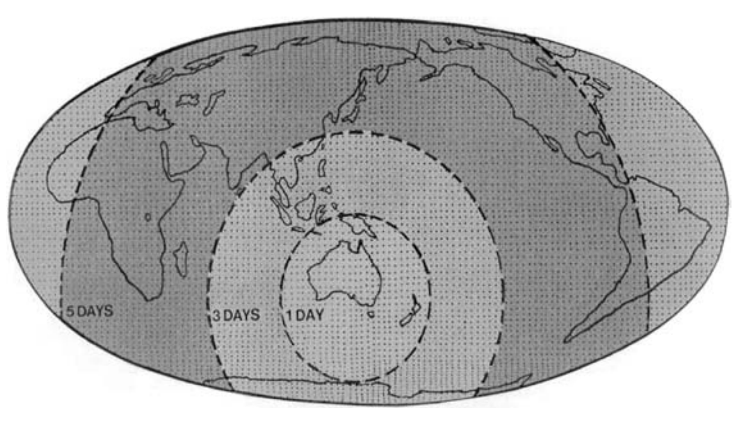
Figure 1.1. The Rising Accuracy of Weather Forecasts



Source: ECMWF, 2007. Used with permission.

Telecommunications systems (telecoms) were very important in facilitating international cooperation and data exchange, which were promoted even in the midst of the Cold War, a joint endeavor people could agree on. In that era, the World Weather Watch evolved, an international network coordinated by the World Meteorological Organization (WMO) of the United Nations that today continually and mutually reports meteorological data and forecasts among national meteorological services. The great importance of global data exchange and sharing is illustrated in Figure 1.2 (a figure developed by the NMS

Figure 1.2. Five-day Forecasts Require Almost Worldwide Data



Source: © Commonwealth of Australia. Used with permission.

of Australia on the basis of a study by the ECMWF). The widening shaded bands in this figure show the widening geographic scope of data needed to forecast local weather one, three, or five days in advance. In light of the dependence of each country's forecasters on mutual support, the WMO-coordinated network is today the only global cooperative endeavor operational 24 hours a day, seven days a week.

As of about 1970, weather forecasting had accumulated a set of computational tools that enabled useful forecasts a day or two in advance. Then came the advent of supercomputing. Weather forecasting has been a chief beneficiary of this new capacity. In fact, weather forecasting is the application for which many of the world's fastest supercomputers are built today. As supercomputers have improved, forecasting skill has leapt forward. An accurate five-day local forecast requires solution within a few hours of a numerical model ingesting data obtained within the past hour or two from nearly the entire globe—today, it has become possible to undertake exactly that, on a routine basis.

In the last few years, seasonal forecasting has begun to show useful skill. Success in forecasting and analyzing the effects of El Niño in the 1990s gave an impetus to ongoing investigations of similar phenomena in the same class, each potentially enabling months-early prediction of some phenomena—in some places, at some times of year—to colossal economic effect. Seasonal forecasting is not yet as skillful as forecasting in shorter time-frames, but its future promise is great (Livezey and Mayes 2006).

As forecasting skill has improved, economic sectors have continually developed the value of the new information. Global *aviation* is fully dependent on weather information for safety and load optimization. *Agriculture* makes use of many types of weather information, such as daily, extended, and seasonal forecasts of temperature, wind, and precipitation, to avert the need for re-sowing crops destroyed by frost, reapplying expensive chemicals blown away by winds, or re-sowing crops washed away by rain. *Water resource management* has a growing dependence on weather forecasting to drive hydrological forecasting. *Power generation and distribution* gain in optimality from every increment of growth in forecasting skill, whether forecasts of temperature or precipitation, whether they are hourly or seasonal. Environmental *air quality* regulations are more easily complied with when winds and atmospheric conditions are known. *Road transport* in winter is hindered by hazards that are mitigated more cost-effectively when they are better predicted. Better forecasting supports better *emergency preparation*, emergency warning systems, flood zoning, flood insurance, and water management under drought circumstances. *Forests* are better managed when "fire weather" is forecast. *Insurance* companies offer more services at lower cost where weather information is reliable and good forecasts are disseminated. *Construction* is dependent on site-specific climatological data, and when underway it makes use of wind forecasts and forecasts of extreme temperature conditions. *Oil and gas extraction* is more cost-effective when forecasts covering the fields are reliable. *Public health* is increasing its use of seasonal and long-time-scale climate forecasts to improve the effectiveness of public health interventions and to anticipate the impact of climate-sensitive diseases.

Putting some numbers to these qualitative remarks, Houston, Adams, and Weiher (2004) presents a summary of several dozen recent assessments of the value of specific investments in weather forecasting for economic applications in agriculture, aviation, energy, transportation, fisheries, households and recreation. Adams and Houston (2004) draws on ECSSD's 2000-02 set of flood studies, comparing estimates of annualized costs to GDP and summarizing impacts. The vulnerability of economies with underfunded agencies is shown in CESS (2007).

Summary valuation of the benefits of hydromet services to a national economy remains analytically challenging. A study by Dutton (2002) suggested that up to a third of the U.S. economy is comprised of industries that are influenced to some degree by weather hazards and that could benefit from good forecasts. However, Lazo and colleagues at UCAR later noted that sectors excluded by Dutton are actually significantly weather sensitive. Lazo and colleagues estimated the weather-related productivity variation of the U.S. economy at about 3.5 percent of GDP (Lazo and Larsen 2006; Harrod and others 2007).

Despite the difficulties of such analysis, several approaches to estimating the value of national weather agencies have been developed. As an introduction, some recent results follow (and see Chapter 5):

- An estimate in China undertaken 1994-1996 found a cost-benefit ratio of 1:35 to 1:40 for the budget of the Chinese meteorological service (Guocai and Wang 2003).
- An estimate of household value in the United States suggests a ratio of 1:4.4 for the budget of NOAA (Gunasekara 2003).
- A valuation of hydromet services found that an investment of about US$100 million (base costs) in hydromet information had a net annual benefit on the order of US$68–153 million over the first seven years (Tsirkunov and others 2004).
- An estimate in Mozambique suggested a cost-benefit ratio of 1:70 for investment in the national meteorological service. The explanation for this particularly high ratio is that the agency (once in possession of a rather strong network) lost most of its capacity during the country's 20-year conflict. Therefore, the investment being valued would in effect make the difference between a forecast versus no forecast. Moreover, in 2000, floods in Mozambique cost the country approximately half of its GDP; weather/climate information to enable efforts to prepare for those floods would have been extremely valuable.

A substantial share of the recent advances in global forecasting should be affordable by most middle- and lower-income countries; yet they are out of reach for ECA's underfunded NMHSs.

- *Bandwidth.* A global telecommunications system organized by the United Nations WMO shares global forecasts and data. Every agency participates to some extent. Yet, ECA's underfunded agencies are often unable to make full use of this resource for lack of bandwidth to download large files.
- *Satellite dishes.* A constellation of weather satellites has been launched over Europe that broadcasts images of storm systems, fire weather, coastal zone pollution, and other environmental data. The satellite consortia that own the satellites in some cases broadcast weather data for use at no cost or low cost. Even so, many ECA agencies do not have access to this data, lacking satellite dishes or processing capacity.
- *Local area modeling.* Global communities of experts have jointly devised open-source models for weather prediction that lend themselves to local weather forecasting at high resolutions and that can run on computers only slightly better than staff desktops. Although these desktop versions do not replace supercomputing

capacity and still require real data inputs, they make a large positive difference to the countries that run them. Many countries would benefit from training in use of these packages.

- *Forecasting workstations.* In some countries, satellite and radar data and models would be made available by neighbors, but agency staff do not have the workstations and software needed to display this data and make full use of it for forecasting. Adequate attention and resources should be available to ECA NMHSs for staff training to ensure proper use of these new data, instruments and techniques.

The priority and value of the low-cost upgrades just listed should not conceal the value of the more substantial national efforts needed to detail and update forecasts and provide the full spectrum of services needed by sectoral clients. A typical range of services draws on data from radars, surface weather stations, upper-air sounding stations, hydrological stations, and specialized networks—all communicating with national headquarters via effective telecoms—as well as well-trained staff, to produce excellent forecasts up to three days in advance and useful forecasts up to seven days in advance, with resolutions on the order of ten kilometers, in support of agriculture, hydrology, transport, and other sectors.

Principal Issues and Questions in ECA

Need for Modernization of Weather Forecasting

Twenty to thirty years ago, weather forecasting and overall provision of hydromet services in many ECA countries were at the leading edge of world capacity. However, the status of most weather services among the ECA countries has deteriorated considerably in the last two decades, mainly as a consequence of persistent under-financing. Performance has deteriorated in general, and some agencies are on the brink of collapse. Surface data collection stations have closed and the surface stations that remain open record a more limited set of parameters, on a less frequent basis, using instruments that are aging and failing. Communications equipment to convey station data to headquarters for analysis is often obsolete, unreliable, labor-intensive and expensive. Ongoing training is inadequate either to keep the skills of senior staff current, or to prepare an adequate number of incoming staff. The scope of the accumulated problem is so great that without massive modernization, networks in some ECA countries are on the way to becoming completely dysfunctional, leaving countries to depend on low-resolution forecasts prepared by others that miss significant local and rapid-onset hazards including floods, frosts and severe storms.

The link between weakening forecast capacity and increasing vulnerability was seen in Russia's system, where the percentage of hazardous weather phenomena that were unforecast increased from six percent at the beginning of 1990s to 23 percent ten years later. This situation prompted a decision to undertake modernization (in turn prompting this study). Elsewhere in ECA, it seems likely that lower-income countries, particularly those exposed to weather hazards by the importance of agriculture, have been disproportionately affected by the capacity decline of their national meteorological services.

As the region's NMHSs consider upgrading, they face the circumstance that in the last two decades worldwide meteorological practice has changed and become more knowledge-intensive and dependent on advanced technology. ECA's aging systems do not merely need replacement parts; they need completely new technologies if they are to support the development of competitive economies. For example, Doppler-capable radars (able to distinguish wind speed) are now used to warn urban areas of hard-to-predict convective storms. Upgraded IT and telecoms are indispensable for modeling, for overlay of radar mosaics with satellite data and other weather data types, for incorporation of real-time data into severe weather warnings, and for analysis of data from modern weather sensors. AMDAR (weather packages dropped by aircraft) is increasingly used for upper-atmosphere sounding, most useful in regions that are dense with airline flight paths. Under the aegis of the Global Earth Observation System of Systems (GEOSS), new data sets are being developed that will synthesize satellite and other data channels to develop new types of GIS analysis linking weather to health, land use and other social and economic applications.

Need for Data Exchange and Sharing

Data sharing also needs attention. Significant weather damage in ECA is caused by large-scale events that cross national borders. Damaging transboundary weather patterns of particular importance include Atlantic cyclones, Mediterranean cyclones, and intrusions of cold air from the far north. Rapidly-changing, dangerous events are best monitored in an environment of transboundary data sharing that goes beyond WMO requirements. (See Ogonesyan, 2004.) However, gaps in data sharing exist in ECA, for example, in the Caucasus and in South Eastern Europe, where the data-sharing arrangements of the former USSR and former Yugoslavia have been weakened—although not vitiated—by political changes.

Objective and Scope of the Study

This report aims to explore the scope for a deeper involvement in the meteorology sector in Europe and Central Asia. Because an optimal weather monitoring upgrade for one country depends on data available from the country's neighbors, investment poses questions best answered at a regional level. Which sectors are most weather-dependent? In what climate subregions is forecasting capacity most needed? What are the regionally significant capacity gaps? What are the economic returns of investment in these upgrades? How should upgrades be assessed in terms of cost and benefit from the national point of view?

Studies and working papers were commissioned from national and regional experts in the five key thematic areas presented below (see References).

Status of Weather Forecasting Capacity

Brief studies of national hydromet services were commissioned for nineteen ECA client countries in South Eastern Europe, the European CIS, the Caucasus and Central Asia.[4] The

4. Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Macedonia, Montenegro, and Serbia; Russian Federation; Belarus, Moldova and Ukraine; Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan; Armenia, Azerbaijan, and Georgia.

nineteen comprised essentially all ECA clients except the countries that have recently undertaken modernization (Turkey, Romania, Poland) or that were EU members when the study was initiated and thus had enhanced access to alternative financing sources. Study terms of reference focused on the national contributions to and interests in regional capacity issues, including: (i) intrinsic hazard of climate; (ii) exposure of the national economic structure to the weather hazard; (iii) the role of the hydromet service in national policy development; (iv) hardware, software and institutional constraints on effective forecasting to protect the economy; (v) availability of shared regional resources; (vi) financing of the hydromet service; and (vii) measures of the capacity of forecasting to limit risk to the economy.

Assessment of Economic Benefits of Hydromet Services

Studies of the economic benefits of hydromet services were commissioned in eight countries, building on an example from the Russian Federation. These studies were undertaken in the Caucasus, Serbia, Albania, Belarus, Ukraine, and Kazakhstan. Household surveys assessing public perception of economic benefits provided by hydromet services were undertaken in Azerbaijan and Serbia. Results have been used to facilitate modernization of national services and to assess opportunities to build regional cooperation, especially in support of lower-income countries.

Climate Change Projections

Climate change projections were commissioned for South Eastern Europe and the Caucasus on the basis of the A2 scenario and the Hadley Center's regional climate model. Regional experts were engaged to assess this output together with other available projections, discuss robustly forecast trends, and provide guidance on adaptation.

Household Surveys of Severe Weather Warnings

Public surveys of the effectiveness of severe weather warnings were conducted in Albania, Armenia, and Georgia, building on an example from the United Kingdom. Results were used to test the relative importance of better dissemination of emergency forecasts, versus more-accurate emergency forecasts.

Closing Gaps in the Regional Perspective

Other papers were commissioned addressing transboundary weather in Europe and Central Asia, sectoral benefits from weather forecast improvements, and the scope of ECA's cooperative institutions.

This study was coordinated and the development of its conclusions discussed with the hydromet directors concerned, representatives of the World Meteorological Organization, EU and CIS stakeholders, regional associations of hydromet directors, and other global stakeholders.

Organization of the Study

Chapter 2 addresses the question, "What are the needs of the key sectoral clients of the national hydromet services in the ECA region?" Chapter 3 addresses ECA's natural weather and climate issues, considering that they partly determine the capacities that must be developed: (i) ECA's vulnerability to transboundary weather events, (ii) its extreme weather, (iii) its variable weather, and (iv) climate change projected in ECA. Chapter 4 presents the workflow in forecasting, as a heuristic device to set out the main categories of capacity, and then presents key capacity gaps from the regional and national points of view. Finally, drawing on understanding developed to this point concerning ECA's key weather-dependent sectors, its natural weather issues, and its capacity gaps, Chapter 5 sets out ways to estimate the economic benefit of existing and upgraded forecasting capacity.

CHAPTER 2

Sectoral Beneficiaries of Weather Forecasting

Investments in weather forecast services have often been formulated as components of projects addressing the concerns of a single sectoral client of weather services—agriculture, or disaster management, or water resource management, for example. Only one project to date has been formulated to address a hydromet agency's full circuit of clients (Russian Hydromet Modernization Project, see Box 2.1). In either type of project, investment in weather forecasting can be more cost-effective and sustainable if the interests of all key sectoral clients are taken into account. Single-sector issues that influence the structuring of NMHS services to all clients include, among others: (i) the ability of smallholding farmers to benefit greatly from good forecasts but inability to pay (a global observation); (ii) the EU's environmental data regulations that broadly require data sharing (although exceptions may be carved out for meteorology); (iii) technical requirements for forecasts prepared for international aviation that are set by international treaty; (iv) lack of information sharing by enterprises or other Government agencies (such as agriculture, aviation, road transport, energy enterprises, water management or environment) of meteorological observations, and (v) global interest in data relevant to climate change. It would be valuable, therefore, to review the concerns of the sectors most affected by the skill and availability of forecasts.

To provide a cross-sectoral view of weather service issues and opportunities, this chapter presents the key weather-dependent sectors in ECA, summarizes the forecasting capacities most commonly needed by all sectors, suggests some prerequisites for achieving benefits from forecasts (such as relevant staff training and technological infrastructure; Adams and Houston 2004), and discusses global and regional institutions and mandates in certain sectors that frame weather service delivery. Sources of information include profiles of nineteen national services undertaken within the scope of this study, studies of economic

Box 2.1: Russian Hydromet Modernization Project

In 2005, the Bank approved the first-ever project with a stand-alone focus on a national NMHS. The Russian Hydromet Modernization Project was the first that undertook NMHS capacity development envisioned to upgrade service delivery to the entire NMHS sectoral clientele—rather than to emergency management or any other single sectoral client.

The main development objective of the project is to increase the accuracy of forecasts provided to the Russian people and economy by modernizing key elements of the technical base and strengthening RosHydromet's institutional arrangements. The total project cost is now estimated at US$133 million, but may be expanded by increased government co-financing.

The project has three main components. The first component aims at upgrade of RosHydromet's overall IT infrastructure (supercomputing, telecoms, archiving), not only to support the agency's forecasting skill but also to ensure delivery of tailored products across Russia's regions and sectors.The second component aims at upgrading the observation networks that are most important in supporting Russia's key weather-affected sectors, including storm mitigation in the most vulnerable river basins, municipal services in the largest cities, energy enterprises (which benefit from surface stations in the north), aviation (especially upper-air sounding over Siberia), environment and agriculture, which will be a principal beneficiary of upgrades in observing lead times and accuracy. Besides these, other sectors will benefit as well. A third component, institutional modernization, is designed to help RosHydromet to experiment with approaches to improving overall efficiency of operations, increasing sustainability, and improving the linkages between RosHydromet and users of its services.

benefits in eight services, recent literature on the economic benefits of investment in weather information for sectoral clients, and stakeholder interviews.

Agriculture, disaster management, water resource management, energy, transport and municipal services/construction are economic sectors within ECA particularly likely to benefit from improvements in weather forecasting capacity. In addition, in some countries important beneficiaries would also include oil and gas extraction, municipal services, forestry, insurance, and other clients.

Agriculture

Forecasting Needs

In every ECA country surveyed, the agriculture sector is a potential principal beneficiary of improved weather forecasting. This reflects the global finding that of all economic sectors, agriculture is the most dependent on weather conditions, and can be expected to benefit greatly from improved weather and climate forecasts (Weiher, Houston, and Adams 2007). The following examples are drawn from the ECA country studies of NMS services, and Table 2.1 presents valuations in other regions drawn from the literature.

- Climatology and ongoing soil moisture monitoring and phenology would help optimize routine crop selection (Moldova, Albania, Macedonia).
- Forecasts would enable timely sowing, plowing, irrigation and harvesting of crops. Tajikistan notes that 70,000 ha on average are re-sown annually because initial sowings are lost due to weather conditions (Tajikistan, Uzbekistan, Albania, Azerbaijan).

Table 2.1. Selected Valuations of Weather Forecasts to Agriculture

Short-Term Weather Information	Value of Weather Information
Precipitation, temperature, and wind forecasts	Imperfect forecast: $379,248/yr for cotton producers in Australia
Frost forecast	Imperfect forecast: $2,642/ha-yr for pear orchards
	Perfect forecast: $4,203/ha-yr for pear orchards
Precipitation forecast	Imperfect forecast:
	–$116 to +$276/ha-yr
	Perfect forecast: $0–$276/ha-yr Winter wheat production in Canada
Precipitation forecast	Imperfect forecast:
	–$4.5 to +$27/ha-yr
	Perfect forecast: $3–$55/ha-yr Alfalfa dry hay production in Canada
Precipitation and frost timing	Imperfect: 20% increase in profit for wheat producers in Australia
	Perfect: 15% of value of perfect forecasts is achieved by present forecasts
Frost forecast	Perfect forecast:
	$6,210/hectare/yr for apple orchards
	$3,781/hectare/yr for pear orchards
	$2,076/hectare/yr for peach orchards
Temperature forecasts	Imperfect: $0.38–$1.09/dollar of insurance premium
Improved satellite imager and sounder which improve short-term (3-hr) temperature forecasts	$9 million/year derived from improvements in frost mitigation
Improved satellite imager and sounder which improve evapotranspiration estimates	$33 million/year derived from improved irrigation efficiency
Precipitation and temperature forecasts	Imperfect forecast: $1040–$1156/ha-yr for lettuce irrigation timing in a humid U.S. climate
Precipitation, temperature, and evaporation forecasts	Perfect forecast: $105/ha/yr for alfalfa

Source: Houston, Adams, and Weiher (2004).

- Increased accuracy in forecasting would assist in timing of fertilizer application and pest and disease control, avoiding over-application that exacerbates environmental damage from chemical applications (Tajikistan, Montenegro, Uzbekistan, Albania).
- Forecasts would enable mitigation of frost damage (cited as a serious problem for agriculture by Ukraine Turkmenistan, Montenegro, Moldova, Armenia, Macedonia, Kazakhstan, Bosnia, and others). Means to mitigate the effects of sudden freezes are being developed globally, but cost-effective application depends on accurate forecasting.

- Forecasting could enable farmers to take preventive measures against hail, or against erosion caused by wind/precipitation events, or to mitigate drought (Armenia, Albania, Montenegro, Moldova, Macedonia, Tajikistan, Croatia, Ukraine, and Bosnia). Satellite data are indispensable for monitoring the state of crops (Belarus).
- Forecasting could be applied to optimize storage and transport of agricultural produce, reducing post-harvest losses (Montenegro).
- Forecasting could enhance pasture and animal production and fish catches (Montenegro). Rainfall affects availability of forage; animal health depends on management that takes into consideration temperature and wind (Dzama and Chimonyo 2007).

Capacity Requirements—Basic Forecasting

Agriculture benefits from high quality basic forecasts. Skillful forecasts of temperature, precipitation and wind conditions three to five days in advance are attainable and would greatly help farmers in the ECA region. To achieve this capacity, national hydrometeorological services would require local sensors to update and detail model outputs, and would benefit from radar for nowcasting (forecasts at zero to six hours). Regional and global capacity would be necessary inputs to medium-term forecasts: NMHSs would benefit from (i) membership in ECMWF and EUMetsat, (ii) adequate bandwidth and ground stations for access to satellite data and radar mosaics, (iii) membership in other regional institutions and consortia that provide forecasts and satellite data, (iv) participation in subregional protocols for radar sharing, and (v) deployment of telecoms capable of ensuring provision of local data to the WMO hubs to ensure that regional and global forecasters use locally accurate data.

The basic capacity required for agriculture is also needed by other sectors. However, the value to agriculture is detailed in this section to highlight the risk to small-scale farmers if the information products they need are restricted to paying clients.

Beyond basic forecasting, agriculture in ECA would benefit from agrometeorological (agromet) advice or extension, and drought monitoring. Kazakhstan experiences drought in one region or another every year, and other countries in the Caucasus and Central Asia as well as other ECA countries (including Moldova) have experienced dramatic drought damage within the past ten years. These capacities require agromet networks, including instruments to measure soil temperature and moisture and micro-climates, satellite data to facilitate agromet analyses and support drought monitoring, and models to draw out the implications of soil moisture, temperature and solar radiation data. These elements would enable the networks to present a continually revised estimate of the vulnerability of agricultural and other systems to periods of dry weather. In ECA, the agromet station networks have dramatically deteriorated, satellite data is often unavailable, and agencies have difficulty providing opportunities for training in agromet methods. While drought-prone Georgia once had 150 agromet stations, today that function has virtually ceased, replaced in small part by the use of satellite data. Bosnia's stations were destroyed in the war. Throughout ECA, there is a need for re-invigoration of agromet-observing programs, including up-to-date data on groundwater and glacier resources that are crucial for drought management and mitigation. National criteria for identification of drought conditions are inconsistent and should be reconciled with FAO criteria. In the drought-prone

Box 2.2: Public-Private Partnerships: NMS Commercial Services

There are several operational models for national hydromet services: agencies that provide only public services, agencies that mix public sector and commercial enterprise, and those that have created separate, independent commercial services. European weather services have over the past twenty years or so experimented with forms of commercialization; the U.S. weather service by contrast provides all of its products and services to the public at taxpayer expense. In Europe, the enthusiasm for the development of commercial services has been strongest in Scandinavia, UK, France and the Netherlands, and the development has encountered varying degrees of success, while DWD of Germany, which experimented with commercialization, has moved away from it towards a more focused public service mission.

It is difficult to assess how successful commercialization has been and how successful these efforts will remain in light of new European legislation, which takes the view that the reuse of public information is in the interests of all and should not carry a significant additional cost to the user. The provision of free services by some national agencies in fact has had a major impact on the value of basic services throughout the rest of the world. Many NMHSs, particularly in developing countries and least-developed countries, rely on access to free products and services from the U.S. weather service and other leading NMHSs to support their own national needs.

NMHSs are data monopolies that can enable the effective reuse of public information by individuals and the private sector. Without a clear separation of their public sector tasks from their commercial interests, it is easy to see how NMHSs may—inadvertently or otherwise—misuse their dominant position in the commercial market for weather, water and climate information. Commercial services are about exclusivity, confidentiality and competition; in contrast, public weather services are about the provision of information to everyone to make timely decisions to protect lives and livelihoods. The latter depends on the free and open exchange of data and information; profitability of the former depends on restricting information to paying customers. Are these activities mutually exclusive?

Operating within the competitive market also has an impact on the way NMSs view each other. Traditionally, they have been partners with even the least-capable providing a valuable contribution to the global network of observations, and the more-capable sharing and exchanging numerical weather prediction products. Increasingly, however, NMSs see each other as potential competitors and their information as proprietary.

Source: Based on Rogers (2005).

Caucasus, establishment of a subregional drought monitoring center has been recommended by the hydromets as more affordable than database development on a national basis.

Seasonal forecasts are in development, and their accuracy is improving. Projections of the human contribution to climate change are also improving. They are expected to become increasingly valuable supports to investment. However, these efforts need data support on a national basis. Stations collecting data required for interpretation of on-the-ground trends have been closed throughout ECA.

Prerequisites for Benefit: Rural Infrastructure, Advanced Forecast Products, and Agromet Extension

Several issues would potentially limit uptake of upgraded service to agriculture. (i) Some benefits depend on supporting infrastructure that is absent, such as irrigation. (ii) The small-scale farming sector uses only free forecasts (a global observation). As a result, there is likely to be a benefit only from services that are freely provided. Yet where NMHSs seek to sell their most advanced products to clients able to pay for the information, dissemination or provision of advanced forecasts to a very large number of small-scale farmers—by any means—would be strongly counter-indicated. (iii) Benefits also depend on farmer capacity to understand and use weather information. Agrometeorology was an area of specialized expertise on ECA's former state and collective farms that reportedly is now less available to small-scale farms in the region.

Millennium Development Goals

The MDGs would be promoted by improvement of weather forecasts delivered to the small-scale farm sector. Cost recovery arrangements that work well for other clients risk excluding or under-serving small-scale farmers, who have an important role in national as well as household food security. Cost recovery financing arrangements for NMHSs should be analyzed in order to assess the likely effect on access to this productivity support to small-scale farmers.

Disaster Management

Forecast Needs

Every country in ECA undergoes weather damage from severe events that could be mitigated with better forecasting (see, for example, Adams and Houston 2004). Forecasting enables emergency management teams to be put in place, mitigation measures to be prepared, and evacuations to be undertaken. According to UNISDR (2004), up to 35 percent of flood damage can be mitigated with advance flood warning; in the United States, as little as one hour of lead time can result in a ten percent reduction in flood damages (NOAA 2002). However, public surveys undertaken in ECA as a part of this study showed that forecasts of severe weather events in ECA's lower-income countries are likely to provide little lead time. In three of these countries, 25 to 50 percent of respondents found out about severe weather on the day it occurred, compared to six percent in the United Kingdom. During field work conducted within the scope of this review in the commune of Dajç in the Shkodra region of Albania, an inhabitant of the area that remembers the flood of 2003 stated, "We understood about the flood only in the moment when water entered in our houses" (CESS 2007). Weather events are different from country to country, and so these statistics do not necessarily refer to similar events, but available data suggests a strong need for accurate and effective warnings of severe weather events.

Capacity Requirements: Basic Forecasting, Nowcasting, and Transboundary Data

Management of severe weather emergencies first requires strong basic forecasting—the capacity to forecast temperature, precipitation and wind in the short and medium term (one to seven days) at high accuracy and spatial resolution. Beyond basic forecasting, disaster management has an incremental need for accurate "nowcasting"—forecasting over the period zero to six hours. Nowcasting makes use of radar, upper-air sounding, stream gauge data (ideally reporting automatically in real time), rapid national weather and hydrological modeling at high resolution, and effective telecoms linking the national network of weather stations to headquarters. Forecaster workstations are needed, to enable forecasters to assemble information, analyze it, and present tailored and updated forecasts rapidly.

Management of dangerous transboundary weather highlights a third need: transboundary data exchange from source regions of oncoming bad weather. Exchange of data requires both in-place agreements for data sharing, and telecoms capable of achieving it. Agreements that specify the conditions of data exchange can be very important, since NMHSs may be reluctant to initiate unusual transactions to notify a neighbor of oncoming bad weather for fear of sounding a false alarm and possibly precipitating an expensive mistake. To overcome that concern, it is best that objective criteria for bilateral sharing be set out in advance.

Finally, certain disaster management issues, such as forest fires and pollution, make the use of satellite data critically important.

Prerequisites for Benefit: User-tested Dissemination

Upgraded capacity to forecast severe weather will have no benefit if alerts are not effectively disseminated. In the surveys of severe weather warnings just noted, respondents considered the importance of better accuracy in alerts, longer lead times, available channels of dissemination, clearer visual formatting, and more-directive advice to accompany warnings (CESS, 2007). A few key findings follow:

- Most people receive warning of severe weather from commercial television if at all.
- Even where people do not think that weather forecasts are reliable, they still attend to them closely, are interested and respond to them.
- There is a strong demand for warnings that are more accurate and provide more lead time.
- There is strong interest in warnings supplemented by advice on how to handle the upcoming weather and its expected effects on transport.

Box 2.3: Public Private Partnerships: MesoWest/Western United States

The following agencies and enterprises undertake weather measurements for their own operations and comprise a MesoNet of mutual sharing that complements monitoring by regional weather forecast offices of the U.S. weather service. The MesoNet provides otherwise unavailable detail in weather information on remote areas.

- Altai Ski Area, Beaver Mountain Ski Resort, Brighton Ski Resort [and many other resorts].
- Bear River Wildlife Refuge, Salt Creek Wildlife Refuge and National Park Service.
- Transportation Departments of Idaho, Montana, Nevada, Utah, Washington.
- Kennecott Copper.
- Wildland fire agencies.
- Water agencies in California and Nevada.
- Several enterprises selling weather- related products and services.
- Universities, research institutions, and others.

Source: Horel and others (2002).

Box 2.4: Public-Private Partnerships: Honduras/Georgia

Community Monitoring of Severe Weather

In remote areas of hurricane-vulnerable Honduras, communities are working together to monitor escalation of severe weather conditions. On alert by the national weather agency, local emergency committees form, instructing the community to turn on radios and to monitor rainfall and river stages. Trained in interpretation of river levels and rainfall, the local emergency committee decrees stages of heightening alert, requiring more frequent monitoring, preparation for evacuation, and evacuation as needed.

One lesson is that advance preparation that incorporates security issues helps assuage the concerns of heads of households, generally men, who are often reluctant to abandon their homesteads; instead, they risk drowning. A second lesson is that setting triggers for evacuation helps address the concerns of village mayors who are reluctant to risk issuing false alarms.

These community initiatives, developed with support from the Government of the Netherlands, have already been successful in limiting damage from Central American hurricanes in recent hurricane seasons.

With financial support from the Government of Canada, an initiative is underway in Georgia to develop a community-monitoring approach as a means to mitigate vulnerability to climate change in ECA's remote areas.

In addition to provision of severe weather warnings, other disaster management services can be provided by NMSs: support for land use planning and zoning, support for development of national disaster strategies, and support for climate change adaptation among others.

Proposals for a Regional Multi-Hazard Center

Regional multi-hazard storm warning centers, in principle, would be cost-effective alternatives to national centers. Regional interest in this option was explored within the scope of this study. However, interest was not strong. A review of international experience found that there are few if any operational examples of multilateral cost sharing for severe storm prediction. There are institutions that approach such a role, for example, a center for medium-range warnings, and centers for disaster warnings that deliver alerts at no cost to neighboring countries. It appears that short-term forecasting tends to be seen as a national security issue. Regional cooperation is more readily welcomed as an option to build capacity for forecasts at the medium and longer terms. Europe may be moving toward a system in which alerts (at 3–5 day lead time) would be sent to NMSs by the regional forecasting center, ECMWF, and national centers would calculate the need for alerts at shorter lead time. To leverage this regional trend, national centers should develop the capacity to resolve ECMWF regional forecasts at 1–2 kilometer grid spacing.

Water Resource Management

Forecasting Needs

Weather forecasting is particularly useful for water resource management in river basins where dangerous flows form rapidly or where stream gauges are sparse. Linkage between weather models and hydrological models is at a stage of active development globally.

For example, several institutions have developed river forecast systems that use meteorological data to develop hydrological forecasts with greater lead time than hydrological data alone can provide. (Knowing about the water while it is still in the sky provides more lead time than measuring it when it is already in the river.) Meteorological information can also aid water resource management by providing historical weather data for hydrological studies requiring estimates of past flows. Moreover, forecasting of teleconnections is increasingly used in water resource management. For example, forecasting of El Niño and the Pacific Decadal Oscillation is used to predict stream flow in the Columbia River of the United States (Weiher, Houston, and Adams 2007). Lastly, long-term climate forecasts may eventually prove useful in assessing renewable fresh water resources, although the Intergovernmental Panel on Climate Change (IPCC) notes that in general, less is known about the impact of climate change on precipitation than about its impact on temperature (IPCC 2007). ECMWF has work underway to address that issue (see Box 3.1).

Capacity Requirements

The forecasting needs of water resource management include: (a) weather models that are linked to hydrological models; (b) a representative network of rain gauges and stream gauges that report data in real time; (c) digitization of historical weather and hydrological records; (d) seasonal forecasting; and (e) climate projection. Radar data is important to hydrology in that it provides a more representative sample of precipitation than rain gauges are able to provide. In Central Asia and the Caucasus, where snow and glacier melt is an important component of river flow, monitoring of snow accumulation and glaciers is needed to project water resources and water quality.

Prerequisites for Benefit

The benefits to water resource management from linking weather and hydrological forecasting depend, *inter alia,* on WRM infrastructure that is operational and staffed with skilled technicians (dams, reservoirs, power generation facilities and energy distribution networks), and availability of hydrological and water quality data from WRM agencies.

River Basin Management

The NMHS role may need to be carefully linked to mandates, such as the EU Water Framework Directive, that call for management of water resources at the river basin level. That Directive has on occasion been interpreted as calling for stand-alone forecasting by a river basin management agency. Stand-alone forecasting may appear to be an attractive alternative to dependence on the sometimes tottering NMHSs, but it is not an actual alternative. The global resources and forecasts on which river basin management agencies (and other national entities) could build their own forecasts ultimately depend on the expensive and underfunded data-gathering functions of the national NMHS (although dependence is intermediated and perhaps obscured by the international system).

Box 2.5: Public-Private Partnerships: Meteoagency (Russian Federation)

In the Russian Federation, cost recovery is intermediated by a not-for-profit enterprise, Meteoagency, established by RosHydromet. Meteoagency and its branches provide local forecast services at required skill levels to a range of clients. One of the main Meteoagency products is aviation forecasting provided on a negotiated basis to the airlines. Aviation cost recovery revenues are returned to RosHydromet. The measure of success of this model is that RosHydromet receives about 15 percent of its total funding (or roughly 50 percent of its commercial services) from this source.

Aviation

Forecast Needs, Capacity Requirements, and Prerequisites for Benefit

Aviation is an important client of hydromet services, because safe aviation requires accurate forecasting of the upper atmosphere over an entire national airspace, as well as accurate forecasts in the neighborhood of airports. Among the most useful data types, upper-air sounding[5] poses a particular issue, as it is one of the most expensive NMHS functions. Since the early 1990s, many upper-air sounding stations have been closed in ECA as a consequence of the underfunding of the agencies. The shortfall of upper-atmosphere sensing data is widely believed to have had a significantly negative effect on aviation safety in ECA. An alternative to weather balloon sensing exists (sounding by air traffic), but its coverage is limited.

Chicago Convention

Because international aviation is heavily dependent on weather monitoring, a public-private partnership designed to resolve the issue of financing the meteorological data requirements for aviation safety was forged about 50 years ago and secured by the global Chicago Convention. Since then, the system of airline fees the Convention set out has been a key source of NMS/NMHS financing; for example, these fees comprise 20 to 30 percent of revenue for the UK Met Office, for Météo-France and for Deutsche Wetterdienst. However, this arrangement is not achieving its set purpose in ECA today. In ECA countries, the immediate providers of forecasts are often privatized enterprises that receive airline cost recovery revenue. While some of these new enterprises pay the NMHSs for their forecast services—a model that can work effectively (see Box 2.5)—it appears that in many cases the privatized enterprises are retaining the lion's share of this large revenue stream. This is one of the reasons why NMS/NMHS networks and operations are underfunded and unsustainable, and why the upper air sounding stations that formerly provided crucial support to aviation safety are closing in many places.

Single European Sky

A new aviation policy, the Single European Sky, is being forged in Europe, which aims to minimize the distinct role of the many national agencies and promote the evolution of a

5. See Key Definitions section on Observing networks for explanation of upper-air sounding.

smaller number of aviation forecast providers, each of which would forecast on behalf of large areal blocks. Given the importance of aviation cost recovery to the budgets of every leading NMHS, it is unclear how this will unfold. However, it seems that the NMHSs that are already unable to finance national networks now face another struggle to secure access to aviation cost recovery revenue intended to secure financing for monitoring networks.

Other Sectoral Beneficiaries

Energy

Kobysheva (2007) summarizes many of the uses of climate data in the energy sector. Location and design of solar energy generation requires an estimate of expected long-term solar irradiance (for example, hourly sums of direct and diffuse solar radiation, angle of incidence of solar beams, monthly mean albedo[6]). Wind generation facilities are designed in terms of expected wind speed statistics: monthly wind speed, daily wind speed, probability of various wind speeds, vertical profile of wind speed, air density and intensity of turbulent wind flow. Hydroelectric plants are designed on the basis of expected flow regimes (such as monthly minimum, maximum, and mean), and must consider mean and maximum monthly precipitation, daily maximum total precipitation, and mean and maximum volume of snowmelt. Transmission line location and design take into consideration conditions of wind and icing. Pipelines also take climate into account. Projected power delivered by a thermal station depends on expected extremes of hot and cold. Nuclear power design takes into account the expected maximum and minimum air temperatures, expected snow cover and maximum wind speed, among other climatological data.

Furthermore, power generation is optimized on the basis of usage forecasts, which draw on weather forecasts, especially temperature forecasts for urban areas. Improved knowledge of future temperatures allows managers to more accurately predict peak loads and schedule generating plants to meet demand at lower costs (Weiher, Houston, and Adams 2007). The energy sector would benefit from improved routine weather forecasts and satellite data.

Municipal Management

Municipal management was an important beneficiary identified in the economic benefits study from the Russian Federation. Management of urban conditions such as snow and rain is more cost-effective if handled pro-actively. De-icing, for example, requires three times the volume of applied treatment if laid atop snow than if it is laid down before the snow falls. Management of snowplows and crews is also more cost-effective to the extent it is planned rather than reactive.

Alcoforado and Matzarakis (2007) recently reviewed the use of weather information in urban planning. Cities have climates that are different from those of the rural areas that surround them: cities are less sunny, yet hotter; the air is more still, but cities may occasionally channel very strong gusts; cities may be rainier but less snowy; cities are more polluted but less

6. Fraction of solar energy reflected from the earth's surface.

Box 2.6: "Storm Ready": Public-Private Partnership in Urban Severe Weather Management

The U.S. National Weather Service designates towns and communities "Storm Ready" if they meet criteria for disaster preparedness. These include designation of a 24 hour facility as a warning point that NOAA can communicate with, enhancement of links for reception of weather warnings, preparation of an emergency action plan, training of local people as storm spotters, and local monitoring of hydrological conditions, among other criteria. The "Storm Ready" designation by NOAA is linked to a significant reduction in flood insurance premiums in these communities.

frost-prone; and so on. Planning can enhance the positive and mitigate the negative aspects of urban climate. For example, if the urban heat island is uncomfortable, planners may cool the climate through the inclusion of lakes and parks, address the radiation balance through use of high-albedo paints (for example, white, smooth, flat), or opt for building materials that tend to mitigate temperature extremes. Building heights may be set to promote ventilation, or to limit gusts. An ongoing project in Lisbon has required planners to promote air circulation, considering both prevailing regional winds and the sea breeze, which need to reach the central city in order to mitigate the urban heat island and promote improved air quality. The country profile for Uzbekistan includes a remark that without knowledge of climatic parameters it is impossible to design a building so that it meets the requirements of a particular climate and provides comfortable housing.

Oil and Gas Extraction

Turkmenistan, Kazakhstan, Azerbaijan, and Russia have flagged the value of better forecasting to oil and gas extraction. For example, extraction of oil and gas from Siberia, which is extreme in both heat and cold, would benefit from better forecasting of temperatures for protection of infrastructure. Extraction from the Caspian would benefit from better marine forecasting to enable management of rigs in extreme winds and wave heights.

Insurance

The insurance sector, an emerging client of NMSs, is a large, capable stakeholder interested in reducing weather-related damages that are insured. Insurance companies seek verification of weather conditions that cause insured damage, as well as information on varied and changing levels of risk. To the extent that high-risk conditions often need a better highlight in ECA (facilities built in flood plains, facilities not adequately protected against likely weather events, under-used crop protection), gaps with respect to the information needs of the insurance industry are gaps that should be closed. However, it is important to avoid restriction of data on weather-related risk to paying insurance clients. Homeowners, farmers, and other insurance customers, as well as government agencies should have equal access to information on weather and disaster risk. Several weather insurance pilots are in preliminary stages in ECA.

Road, Rail, and Marine Transport

Road, rail and marine transport agencies and enterprises make use of forecasts and information about current conditions to promote safety (Mills 2007; Liljas 2007; Thornes 2007). Their concerns include, for example, slippery surfaces, obscured visibility and high winds (winds greater than 25 mph can inhibit the maneuverability and stability of high profile vehicles, and stronger winds can topple them, especially when they are traveling empty; National Research Council 2004). Icing of ships in ECA's northern water bodies is dangerous, especially to fishing boats, which lose stability as superstructures are iced, and can turn over and sink suddenly. Icing depends more on wind speed and ambient temperatures than on other conditions (Vilfand 2007). Marine weather forecasts provide support to the safety of marine transport and shipping. In addition, marine pollution dispersion models (for example, likely spread of oil slicks in the Baltic Sea or Black Sea) depend on wind forecasts. Railroads tend to decrease the overall vulnerability of economic activity to weather, but benefit from forecasting of weather events that may block rail lines, wash out road beds, or weaken tracks and bridges (Changnon 2006).

The NMHSs of ECA concur with the above weather-related concerns regarding transport. Among other NMHSs, Albania observes that strong winds, heavy rain, icy roads, fog and low air temperature seriously hamper road transport and shipping. Azerbaijan echoes a concern regarding marine transport. Kazakhstan emphasizes the value of weather warnings to assessing the risk of avalanches, which affects road transport. Georgia highlights the value of forecasts to assessments of road conditions in high mountain areas. Armenia points out the value of weather forecasts to optimizing snowplowing. Turkmenistan mentions road, rail and air transport as beneficiaries of forecasting. The NMHSs of ECA highlight a concern, however, that road transport agencies may not have the infrastructure or capacity to make use of improved forecasting.

Forestry

Forestry benefits from short-term weather forecasts of wind speed, temperature, precipitation and humidity, which enable accurate forecasts of forest fires and smoke transport (Weiher, Houston, and Adams 2007). Climate change projections will encourage forest managers to ensure robustness to the range of possible future growing conditions by considering species adapted to a range of climate conditions.

Health Sector

The health sector is making increasing use of weather alerts and advisories. Deaths from heat stroke increase during heat waves; deaths from hypothermia increase in cold snaps. Weather affects the distribution, seasonality and production of allergens, as well as concentrations of harmful air pollutants (Moreno and others 2007). Other connections are still being identified. The Japanese Meteorological Agency, among others, is developing the use of early warnings of extreme temperatures to predict the numbers affected by flu or heat stroke. Table 2.2 presents a selection of some effects of weather and climate on health outcomes, and the weather data that would support public health readiness. Within ECA, the NMHS of Macedonia has taken an active interest in this subject.

Table 2.2. Principal Health Impacts of Weather and Climate

	Principal Health Outcomes	Meteorological Data
Thermal extremes	Daily mortality; hospital admissions; clinic/emergency room attendance	Daily temperatures (min/max or mean) and humidity
Extreme weather events (floods, high winds, drought)	Attributed deaths, hospital admissions, infectious disease surveillance data; mental state; nutritional status	Meteorological event data; extent, timing and severity
Asthma and allergy	Changes in seasonal patterns of disease	Daily/weekly temperature and rainfall; pollen counts
Food- and water-borne disease	Relevant infectious diseases death and morbidity	Weekly/daily temperature; rainfall for water-borne disease, including *Cryptosporidium*
Vector-borne disease	Vector populations; disease notifications; temporal and geographical distributions	Weekly/daily temperature, humidity and rainfall

Source: Moreno and others (2007).

Findings and Recommendations

The following matrix is indicative of the link between economic goals and capacity required. It is not exhaustive, as new uses are continually being found for weather information.

In sectors from road transport to energy to health, operations can be made more cost-effective through the use of weather information. Inclusion of a forecasting component would, in many cases, support the rate of return on investments in infrastructure. The sustainability of forecasting upgrades can be promoted by design that takes into account the constraints placed on national meteorological services by their institutional environment.

- Re-invigoration of “routine” forecasting would benefit agriculture throughout ECA; upgrades to other forecasting needed by agriculture would greatly benefit other sectors as well.
- Economic benefit to farms would be enhanced by re-invigoration of agromet networks and agromet extension, which have experienced particular deterioration.
- Investments in forecasting undertaken to benefit sectors other than agriculture should scrutinize cost recovery arrangements to assess whether smallholder farmers are likely to be excluded from benefit, and how important the excluded information would be.
- Severe weather warnings disseminated in lower-income countries in ECA are not timely. Given their current infrastructural capacity, this is inevitable.
- Dissemination of severe weather warnings through official channels has not been found to be effective. TV and radio appear to be in many cases more-effective means of communication and are preferred by users.

Table 2.3. Economic Goals and Corresponding Requirements for Weather/Climate Service Capacity

Goal	Task	Capacity Required
Enable early warning	NMS to deliver high-resolution, highly accurate nowcasting results. Applicable measures of forecast accuracy exist.	Access to global models; local model capacity to forecast local and sudden-onset events to which country is prone; satellite data and strong national network of surface stations to record river flow, precipitation and soil moisture variability and update model output; upper-air sounding for the same purpose and to improve model quality; radar in urban areas to assess oncoming storms.
Protect food security (agriculture)	NMS to provide public extended forecasts to ten days on temperature, precipitation and wind; drought monitoring; frost forecasting. Applicable measures of accuracy in forecasting exist, including frost forecasting. Accuracy of drought monitoring is more difficult to measure.	Access to global models, local model capacity to forecast local and sudden-onset events to which country is prone; satellite data and strong national network of surface stations to update model output; upper-air sounding for the same purpose and to improve model quality. Access to skilled medium-range forecasts, soil moisture monitoring, and microclimate mapping of frost hazard.
Support urban environment	NMS to provide ample warning when possible of storm events, nowcasting of severe conditions. Accuracy of forecasting, effectiveness of dissemination and perceived usefulness can be measured.	Strong basic capacity as for early warnings and agriculture, with special emphasis on radar to support nowcasting.
Facilitate WRM and optimize hydropower	NMS to provide river basin authorities, water utility and hydro-construction managers with support for hydrological forecasting and real-time data. There exist applicable measures of accuracy of forecasting and timeliness of monitoring data.	Strong basic forecasting as described for early warnings and agriculture, very accurate precipitation forecasting in relevant watersheds, network of stream gauges, effective and reliable telecoms with stream gauges.
Use seasonal forecasts	NMS to prepare communication of these probabilistic outputs for affected users. NMS to model national effects of teleconnections such as North Atlantic Oscillation.	Digitized historical data, national detailed models of effect of relevant regional teleconnections, dialogue with broad range of sectoral users.
Mitigate transport losses	NMS to deliver forecasts adapted to aviation, and marine and road transport. There exist applicable measures of forecast accuracy, resolution, timeliness.	Strong basic forecasting as described for early warnings and agriculture; particularly strong need for upper-air sounding in support of aviation; specialized meteorological stations placed at key road locations; buoys and radar in coastal areas; marine models.

(*continued*)

Table 2.3. Economic Goals and Corresponding Requirements for Weather/Climate Service Capacity (*continued*)

Goal	Task	Capacity Required
Plan climate change adaptation	NMS to assess the range in which climate change may fall, and advise national economic sectors of climate assumptions that may be of weakening validity. There are no measures of accuracy, but there are global best practices.	Digitized historical data, an ensemble of high-resolution projections under various assumptions, dialogue with users to review the ways climatology is embedded in sectoral planning.
Facilitate tourism	NMS to provide public forecasts on the Web concerning recreational conditions relevant to national tourist industry. Accuracy of forecasting, effectiveness of dissemination and perceived usefulness can be measured.	Strong basic forecasting as described for early warning and agriculture, with additional capacity to address special snow, mountain, or marine conditions as relevant.
Promote health	NMS to provide alerts of weather associated with disease outbreaks, where nationally relevant. Accuracy of forecasting, effectiveness of dissemination to the sector, and perceived usefulness can be measured.	Strong basic forecasting as described for early warnings and agriculture, and dialogue with health community concerning weather-related health issues.
Promote competitiveness of industry and exports	NMS to provide specialized forecasts according to national needs. Accuracy of forecasting and user satisfaction can be measured.	Strong basic forecasting as described for early warnings and agriculture. Oil and gas production require marine forecasts in some ECA countries; in others, forecasts in remote regions. Energy distribution may require temperature forecasts at high temporal resolution in cities. Construction requires excellent wind forecasts. Dialogue with users required.

- As weather modeling improves, water resource management is a beneficiary, and will be able to make use of weather forecasts to generate more-timely hydrological forecasts.
- Aviation in ECA would benefit from improvements in upper-atmosphere sounding. Airline cost recovery is aimed to finance data networks that are important to aviation safety. In many countries of ECA, this public-private partnership is failing its purpose, and the revenue stream intended for basic networks is not being used for that purpose.

CHAPTER 3

Climate Risk

The sensitivity of a national economy to weather information depends partly on the country's climate. Is it storm-prone, drought-prone, or strongly influenced by weather patterns from un-monitored areas? This chapter highlights climate issues that help determine the forecasting capacity needed. Four issues are considered: transboundary weather patterns, harshness of climate, variability of climate, and climate change.

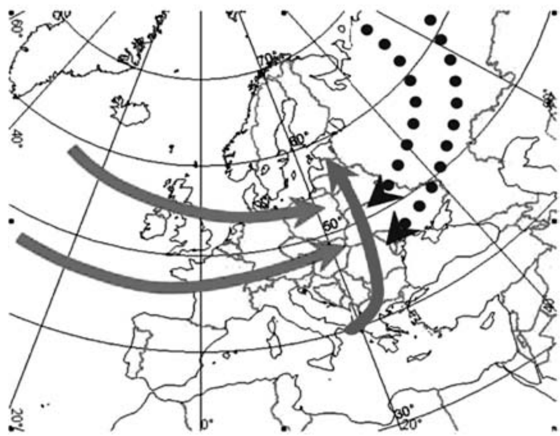
Transboundary Weather

The most important damaging transboundary weather patterns in ECA are (i) Atlantic cyclones that carry moisture west to east across Europe, (ii) Mediterranean cyclones that carry moisture northeast from the Mediterranean; and (iii) Siberian intrusions that carry cold, dry air from Siberia to south and west. Figure 3.1 and Table 3.1 show the particular importance of (a) data exchange within South Eastern Europe to monitoring Mediterranean storms, (b) subscription to data products from the EU to monitoring Atlantic storms, and (c) data exchange from northeast to southwest to monitoring frost and temperature swings. See also Ogonesyan (2004) for details on these and other transboundary weather patterns.

South Eastern Europe is subject to the strongest effects of the Mediterranean cyclones, which in some years cause catastrophic flooding during the winter months. Because they are often among the first European observing networks to record these storms, the SEE hydromet agencies would benefit from regional arrangements that support timely cooperation and enable updated nowcasts of events underway. Greece and Italy could be important partners.

The Caucasus is subject to many forms of severe weather. Because of its complicated topography and location in a meteorological transition region, the Caucasus has several

Figure 3.1. ECA's Principal Transboundary Damaging Weather Patterns



Eastward: Atlantic cyclones (precipitation).
Northward: Mediterranean or southern cyclones (heavy rain and strong wind).
Dotted: Cold air flowing from Siberia.
Source: Ogonesyan (2004).

risks that belong to it alone; consequently, it must rely heavily on its own networks to observe and forecast these risks. Forecast capacity to address local, sudden-onset phenomena is particularly important. Intra-Caucasus cooperation on short timeframes is needed to achieve good forecasting, because important threats arrive from several directions and are modified by Caucasus topography over short periods.

Central and Northern Continental Europe does not face severe transboundary events exacerbated by data gaps to the same extent as do SEE and the Caucasus. Atlantic events will have been first observed by agencies from Ireland and the United Kingdom, the Siberian events by Russia, and the southern events, by SEE and the ranks of agencies to the south. Although forecasting in northern Europe does not have such a heavy requirement for international cooperation on short timeframes as do SEE and the Caucasus, bilateral sharing remains important.

Central Asia falls between extremes of risk: it is not a source region of catastrophic weather systems, and can therefore rely to an extent on others for notice of transboundary bad weather. However, Central Asia's level of risk depends on information from neighboring networks.

Extreme Weather

Several measures of climate extremeness were considered. As apparent in Figure 3.2(a) [see endplates for color figures], precipitation extremes (in practice, heavy rain) are clustered in South Eastern Europe, the Caucasus and eastern Central Asia, with some hotspots in

Table 3.1. Damaging Atmospheric Processes, Short and Medium Range

Country	Main Atmospheric Processes	Main Weather Hazards Caused by Atmospheric Processes
Hungary, Poland, Czech Republic, Slovakia, Latvia, Lithuania, Estonia, Belarus, Moldova, Ukraine, Russia	Atlantic cyclones, Mediterranean cyclones, cold northern intrusions	Rainstorms, squalls, thunderstorms, hail, frosts, snowstorms, icing and frost mist, severe and intensive drops in temperature in winter, morning frosts
Albania, Bulgaria, Bosnia-Herzegovina, Greece, FYR Macedonia, Serbia, Montenegro, Slovenia, Turkey and Croatia	Mediterranean cyclones and cyclones that arise in passage of air across mountains	Hurricanes, strong winds, bora,* strong winds with snowfall and snow storms, (crivats), strong rainstorms, thunderstorms, fogs, devastating floods, local floods associated with rainstorms and snowmelt, heavy snowfall, droughts
Georgia, Azerbaijan, Armenia	Mediterranean cyclones, western spur of the Siberian anticyclone,* cyclones energized in mountain topography, and anticyclones over the Plateau of Armenia	Rainstorms, thunderstorms, hail, mud floods
Kazakhstan, Kyrgyz Republic, Tajikistan, Turkmenistan, Uzbekistan	Siberian anticyclone, western intrusions* (including Atlantic), southern cyclones (but not Mediterranean: arising from the Caspian Sea, from the Tejen and Murghab Rivers, the Amu Darya)	High and low temperatures, dust storms, mud floods, floods

*See A Few Words of Explanation.
Source: Ogonesyan (2004).

Transcarpathia. Cold extremes (endplate Figure 3.2(b)) stretch from Siberia to its south and west as far as Ukraine and Kazakhstan; heat extremes are found in ECA's deserts (endplate Figure 3.2(c)). Kazakhstan is extreme in both cold and heat. (See Hancock and Voynov 2005 for additional indices of climate extremeness.)

Variable Weather

The more intrinsically variable the weather is, the more valuable an accurate forecast can be. Endplate Figure 3.3 presents the natural variability of temperature and precipitation in Europe and Central Asia; red and yellow areas have greatest variability. The countries with the most variable temperatures over time horizons of 3–10 days are those in the northeast: Belarus, Russia, Ukraine, and Kazakhstan.

As for precipitation, the most-variable regions tend to be mountainous areas to the northeast of the regional seas, such as South Eastern Europe, the Caucasus, eastern Central Asia and hotspots in Transcarpathia. In the Caucasus, measured variability in precipitation incorporates flood and drought microclimates: coastal areas, the Armenian plateau, and the mountains of the Caucasus. Central Asia is variable because it is heavily mountainous, and northern Europe may be relatively strongly affected by the Atlantic storm systems. Least variable are the countries dominated by the Central Asian desert: Kazakhstan, Uzbekistan, and Turkmenistan.

Besides these measured hotspots, models indicate that Russia and Kazakhstan, although not strongly variable in precipitation, tend to be very highly variable in runoff, perhaps a consequence of temperature variability and resulting swings in evapotranspiration. Models also indicate Georgia as tending toward very strong runoff variability. See Hancock and Voynov (2005) for additional analyses.

Because the re-analysis considers historical data, and it is not clear whether the current state of the atmosphere is the same, the team considered measures of variability as assessed by another model as well (17-model-year run of a GFDL model of 1995). This essentially confirmed the same regional findings (Hancock and Voynov 2005).

Climate Change

In ECA as elsewhere in the industrialized world, economic development was undertaken in the 20th century according to projections incorporating an assumption that climate varied around a norm and that its statistics were stable; for example, that there existed such a thing as the unchanging probability of a flood of a given magnitude in a given place. But observations and models developed in the last few decades have highlighted ongoing and significant climate change, both anthropogenic and non-anthropogenic. A few measured climate trends over all ECA are illustrated in endplate Figure 3.4.

Projection of the non-anthropogenic component of climate change is not yet feasible. However, projections of the anthropogenic component of climate change over selected areas of ECA to the year 2080 were obtained: low resolution projections from NCAR[7] over the Caucasus and from MAGICC/SCENGEN calculations over South Eastern Europe, and higher-resolution projections of the A2 scenario over both subregions from the Hadley Center of the United Kingdom Meteorological Office (UKMO). These projections suggest that human influence is expected to comprise general warming, with increased precipitation in northern Europe and decreased precipitation in southern Europe over that period. The magnitude of the projected trend, as well as the boundary line between northern and southern precipitation trends, depends on the atmospheric model and economic scenario assumed. The high-resolution projections showed that the human-driven component of climate change is not expected to unfold smoothly on the ground; for example, within a region where precipitation rises overall, there are subregions where the projected trend is one of declining precipitation. It was not possible to obtain projections of non-anthropogenic climate change because some drivers and trends are still beyond the capacity of current atmospheric models. The scale of uncertainty is not known, but it is thought that

7. Community Climate System Model (CCSM).

long-term variability in cloudiness and atmospheric aerosols are important climate drivers (IPCC 2007).

To facilitate comparison of trends and projections, Figures 3.5 through 3.9 (see endplate for 3.5 to 3.7) present modeling results and observational data for South Eastern Europe.

Endplate Figure 3.5 presents trends in temperatures and soil wetness; specifically, the difference between average temperature and precipitation from the period 1968–96, and the period 1987–2006. Generally, the subregion has grown warmer, while the precipitation trends are more complex.

The next pair, endplate Figures 3.6(a) and 3.6(b), presents projections of temperature and precipitation to 2080 using six different atmospheric models. This shows the spread of conclusions that can arise from use of different atmospheric models (all projections used the same economic scenario); however, all show warming. There seems to be a greater steadiness of conclusions concerning temperature than of those concerning precipitation (IPCC remarks that in general there is less confidence in our understanding of forced changes in precipitation than of temperature).

Endplate Figure 3.7 presents projections of temperature and precipitation to 2080 using nine different economic scenarios (and only one atmospheric model—incidentally, the most alarming, for illustrative purposes). This shows the spread of conclusions arising from a range of economic assumptions; again, temperature projections are steadier than precipitation projections.

Endplate Figure 3.8 presents the downscaled projections to 2080 for a single economic scenario/atmospheric model combination. In this panel, the outlined square at the center of each figure covers the same area as a single grid block in Figure 3.6 or 3.7. While the corresponding grid block as an area of overall drying in the low-resolution projections, the high resolution projection shows that this comprises areas of positive and negative trends in precipitation.

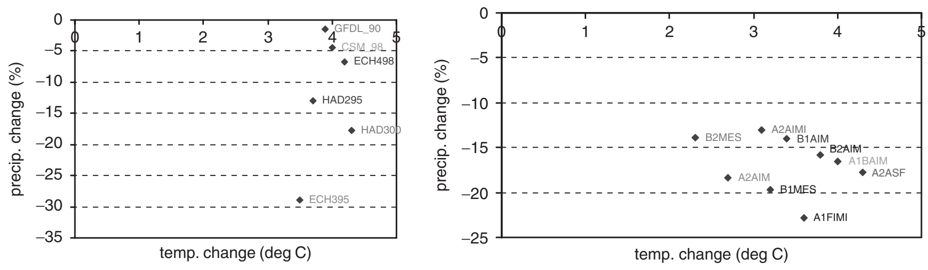
Figure 3.9 summarizes the scatter of projections over economic scenarios, and over GCMs, with respect to one grid block..

Despite uncertainties, climate change projections enable important analyses. Climate subregions that emerge from monitoring and models are not dissimilar from one another. The author of a study of climate change in the Caucasus undertaken in the scope of this review, comparing results from two different projections, remarks that the models project similar areal patterns of change, although the magnitude of change varies (see endplate Figure 3.10 and Hovsepyan and Melkonyan 2007). It seems that downscaled projections may lend clarity and detail to the climate subregions defined by monitoring data, better enabling leveraging of historical data.

Taken together, Figures 3.6 to 3.10 show that significant climate change can well follow, under reasonable assumptions, from trends underway now. At the same time, climate change may reasonably unfold within a wide range. Adaptation to a single deterministic forecast, or to trends forecast at low resolution, would be unwise. It is prudent to consider a wide range of projections and to assess their consistency with current trends, accepting that even after doing this considerable uncertainty may remain. Given the uncertainties about how climate change will unfold, it is recommended that the cost/loss characteristics of adaptation at different time frames be assessed for the sectors that will be strongly affected.

These analyses suggest important considerations in the development of strategies for adaptation to climate change. First, historical data (such as Figures 3.4 and 3.5) can highlight

Figure 3.9. (a) Projected Changes in Temperature and Precipitation at One Selected Grid Point, According to Six Models of the Atmosphere (Using Economic Scenario A2ASF). (b) Projected Changes in Temperature and Precipitation at One Selected Grid Point, According Nine Economic Scenarios (Using the HAD300 Atmospheric Model)



Source: Bruci (2007).

spatial variation in ongoing climate change, outlining climate "subregions" that trend together historically. Second, downscaled projection of the human-caused component of climate change (Figure 3.8) very usefully delineates climate subregions that emerge from models. Finally, an ensemble of scenarios (such as Figures 3.6 and 3.7) can provide a sense of the scatter among projections of the human-caused component of climate change. Figure 3.9 illustrates a lower bound on the range of possible projections. It suggests that temperature trends are robust under the assumptions of the models depicted, and that precipitation is likely to decrease in areas of South Eastern Europe, although the precipitation trend is less robust.

Within Europe, ECMWF is at work to address issues in regional downscaling (see Box 3.1). ECMWF's efforts are of great importance and should receive strong support. Adaptation

Box 3.1: Seamless Prediction of Weather and Climate: ECMWF

One of the key issues for climate adaptation decisions is the reliability of regional projections of climate change, especially for quantities such as precipitation. For example, since the current generation of climate models is known to have deficiencies in simulating aspects of regional climate variability over Europe, how trustworthy are predictions of wetter winters and drier summers in northern Europe?

The strategic framework of the World Climate Research Programme recognises that one key way to assess the reliability of climate projections is by using the same class of model in weather and seasonal prediction where validation data exists—a methodology known as "seamless prediction." ECMWF is at the forefront of research in developing this methodology. It is expected that the ECMWF forecast system will be able to play a direct role in guiding climate adaptation studies for European society.

Box 3.2: Potential Climate Change Adaptations in Albania

Agriculture (Temperature)

- Undertake measures to prevent soil erosion;
- Develop crops adapted to higher temperatures;
- Revive irrigation, introducing water-saving techniques including drip irrigation;
- Study agricultural pests and diseases that may emerge under projected climate conditions;
- Develop species and hybrids robust to expected pests;
- Strengthen extension services to farmers to facilitate adoption of needed changes.

Forestry (Temperature and Precipitation)

- Study adaptation of forests to species better adapted to projected conditions.

Energy (Precipitation and Water Availability)

- Adapt hydropower facilities to accommodate lower and/or variable flow rates.
- Noting that thermal power plants are affected by drought and variable-flow conditions that adversely affect the supply of cooling water, take anticipatory measures in constructing cooling water intakes for new power plants.
- Increase investment in solar and wind energy.
- Promote energy conservation.

recommendations for South Eastern Europe and the Caucasus, made in consideration of the range of projections shown here, are presented in Boxes 3.2 and 3.3.

It is recommended that ECA economies prepare for conditions of increasing climatic uncertainty, and that infrastructural technical specifications be devised for operation in a wider range of possible future climates. Hydrological modeling is needed, considering that even where hydrological models have been constructed, they tend to depend on climatology that is changing. ECA's water resource infrastructure will need to be reconsidered in light of ongoing changes to the hydrological regime. Outside the scope of these subregional mid-latitude recommendations, ECA's vulnerabilities also include the presence of indigenous communities at high latitudes and in permafrost areas affected by temperature trends.

ECA NMSs could provide enhanced and important support to regional and global efforts to project the effects of climate change, because the region's long history of weather observations means that it possesses a significant share of long-term climate records. Long-term weather/climate data is rare. Over the earth's oceans, indeed, there is little in the way of systematic, long-term, large-scale records prior to recent data from satellites and balloons. Over the earth's landmasses, however, ECA hydromet agencies have surveyed weather and its trends for periods up to 160 years, including coverage of the polar regions, deserts, permafrost, and a large share of the world's forests and its glaciated regions. Study of climate trends would benefit significantly from digitization of ECA's weather and hydrological data.

Likewise, IPCC (2007) notes that records of soil moisture and stream flow are often very short and not available from all regions, impeding analysis of changes in droughts. Precipitation records are of particular interest and importance: difficulties in the measurement of precipitation remain an area of concern in quantifying trends. Aerosols may

Box 3.3: Potential Climate Change Adaptations in Armenia

Water Resources

For the mitigation of climate change impact on the water resources of Armenia and adaptation of economy to the new natural conditions, the following measures should be carried out.

- Reconstruction of irrigation system in order to reduce losses of water, application of advanced water-saving methods of irrigation.
- Expansion of the water reserves of Lake Sevan (of great long-term benefit).
- Saving and rational use of water in all branches of economy.
- Improvement of water resource monitoring.
- Development of a national program for the use of water resources, considering the long-term demand of the national economy and possible climate change.

Agriculture

Climate warming will result in the expansion of plant-growing zones at 200–300 meters in elevation which, considering the forecast water deficit, raises the need to change the structure of sowing areas. The sowing areas of potato, cabbage and spring barley may be moved to 2600 meters, and crops of early maturing varieties will probably be displaced from the plan to the zone of 1400–1500 meters and higher. Early-maturing varieties of fruit–pear, apple, plum, etc.–that can be cultivated at elevations of 1400–2200 meters will also be moved from plain to foothills. Thus in the Ararat plain, plantations of grapes, peaches, and apricots, and the areas sown in heat-loving vegetable crops (tomatoes, peppers, eggplants, etc.) can be extended. In Armenia's internal arid regions up to elevations of 1600 meters, and in the northeast up to 1200 meters, the borders of the cultivation can also be extended. The upper border of winter-wheat cultivation will reach 2000 meters in the northeast, and in the internal regions, 2300 meters. In both regions, subtropical crops (pomegranates, figs, Japanese persimmons, nuts) can be successfully cultivated in the 400–900-meter zone; areas of valuable technical cultures such as geranium can also be extended. Tobacco, various fruits and vegetable crops can be cultivated in medium and high zones.

be very important in climate; IPCC cautions that the role of changes in aerosol in climate change in the twentieth century is not well established. Climate change associated with air pollution, specifically tropospheric ozone (O_3), black carbon (BC) aerosols, and methane (CH_4) together may be more significant than that caused by CO_2. Most aerosols have a cooling influence; soot has a warming influence. Increases in pollution as well as later decreases have been dramatic in ECA in this century (Baltensperger 2002), and these trends may have influenced climate strongly. Unfortunately, the net trend is not clear, the matter being out of the reach of current models (IPCC 2007). A Global Atmosphere Watch station has been recommended for Siberia (selected for its naturally pristine atmospheric conditions) to help close this data gap.

In recent years, the underfunded ECA agencies have struggled to sustain their globally important observational programs in remote areas, and have as a group made a great effort to sustain programs of observation important to resolution of the climate question, even while being pressed to take the shortest possible view and while their own funds were being severely cut. Yet many stations have closed. When the ECA gaps are addressed, it will greatly improve the global community's ability to adequately characterize the state of the global climate system and its variability, calibrate models, monitor the forcing of the climate system, whether natural or anthropogenic, support the attribution of the causes of climate change, support prediction of climate change, project global climate change information down to regional and local scales, characterize likely extreme events, and assess risk and vulnerability.

Findings and Recommendations

This chapter has aimed to briefly present four climate issues—transboundary weather, extreme weather, variable weather, and climate change—that help determine the sensitivity of ECA's national economies to weather information.

- Transboundary data sharing is needed for forecasting of dangerous transboundary weather patterns. South Eastern Europe and the Caucasus are particularly mutually dependent because dangerous weather can approach across regional seas. Agreements in some cases have been struck but require that technical analyses be undertaken to define the triggers for sharing as well as financing. Development partners should assist.
- Weather forecasting inputs to hydrological forecasting should be developed in the regions where precipitation is most variable: areas of South Eastern Europe, the Caucasus, mountainous regions in Central Asia, Belarus and Transcarpathia. Considering the variability of runoff, Kazakhstan could also benefit.
- Forecasting for temperature-sensitive economic applications is particularly important in an area centered in northeastern ECA and stretching from Russia to Kazakhstan to Ukraine.
- Projections of the human-caused component of climate change point to a reduction in precipitation in southern Europe and a rise in northern Europe. The boundary line between northern and southern trends varies from projection to projection; furthermore, downscaling highlights areas with counter-trends. The middle latitudes of Europe may face particular difficulty in assessing which trends and events are harbingers of the future and which are not.
- Adaptation to a single deterministic forecast, or to trends forecast at low resolution, would be unwise. It is prudent to consider a wide range of projections and to assess their consistency with current trends, accepting that even after doing this considerable uncertainty may remain.

CHAPTER 4

National and Regional Capacity of ECA NMHSs

As noted above, the study aimed to delineate the areas of strength and weakness of ECA's regional monitoring and forecasting system and the national economic applications most affected by weather. In sum, the first finding is that the regional system is deficient in data from measurements that are expensive to carry out, but that were often formerly available, such as upper air soundings and radar. Upper air sounding is important to every application and is a key to safe aviation. Radar is particularly important to disaster mitigation. The second finding is that the regional system is generally deficient in modern sensors and methods, such as automated data, up-to-date satellite data, local area modeling, and database management/archiving. Satellite data is of great importance in agricultural and environmental applications; modeling is important in every application from agriculture to hydrology and disaster mitigation; effective database management enhances every application and is a requirement for climate services. The third finding is that the regional system is also deficient due to weak telecom links. Station data is often unavailable to the region because of the weak links from remote stations to national centers, and sometimes because of weak links between national centers and regional hubs. This also affects disaster mitigation. These findings will be further detailed below.

Typical Steps in Operational Forecasting

Although ministerial subordination of national hydromet services varies widely (see Table 4.1), weather forecasting is carried out in a broadly similar way in every service.

1. National weather observations are made at the *network of weather stations* spaced across the country. WMO offers spacing recommendations related to the size of

Table 4.1. Ministerial Subordination of Selected ECA NMSs

Country	Selected NMSs—Ministerial Subordination
Albania	University of Tirana
Armenia	State non-commercial organization
Azerbaijan	Ministry of Ecology and Natural Resources
Belarus	Ministry of Natural Resources & Environment Protection
Bosnia and Herzegovina	Ministry of Civil Affairs
Bulgaria	Academy of Sciences
Croatia	Ministry of Science, Education and Sport
Georgia	Ministry of Environment Protection and Natural Resources
Germany	Ministry of Transport, Building and Urban Affairs
Kazakhstan	Ministry of Environment Protection
Macedonia	Ministry of Agriculture, Water Supply and Forestry
Moldova	Ministry of Ecology and Natural Resources
Russian Federation	Independent service reporting to Prime Minister
Ukraine	Ministry of Emergencies
United Kingdom	Ministry of Defense

typical weather systems (for example, WMO's recommendation for Europe is presented as the approximate size of the symbols used in endplate Figure 4.3). The network of weather stations gathers data at many stations at ground level, and at a few locations that obtain profiles of the atmosphere transmitted in weather balloon ascents. The surface network usually gathers data at least once every three hours; weather balloon launches usually occur once or twice per day.

2. *Telecom* networks assemble data from all of the observing stations, sometimes in stages of assembly, to local, subnational and then national centers.
3. *The NMS headquarters' data processing unit* quality-checks data and prepares it for upload to the global system. *The telecom* unit then transmits a share of national data to international regional hubs on the WMO-organized Global Telecommunication System (GTS).
4. *Regional hubs* transmit data onward to global data exchange hubs for outward redistribution of the entire collected set to all NMSs globally.
5. On the basis of global data, *some agencies* compute global forecasts. Among these, three World Meteorological Centers (U.S., Russian Federation and Australia) of the World Weather Watch compute global forecasts and freely distribute them. (Other countries may do the same.) The global forecasts are posted to the GTS for outward distribution.
6. National *telecom* unit downloads them for access by national agencies.
7. If the NMS has modeling capacity, then its *numerical weather prediction* team refines the global model to produce more highly resolved model output for the national area, at grid spacing down to 2 km and below. The national model may, in

the process, draw on fresh data from the *national weather station* network obtained by timely *telecoms*. However, only the most capable, recently-modernized ECA agencies have the latter capacity. Within ECA, this would be undertaken, for example, by Russia, Poland, Turkey, Romania, Bulgaria, and several countries of South Eastern Europe.

8. Model outputs would be updated by *forecasters*, who would take into account recent weather data because the processes listed above may have taken up to as much as twelve hours since the original data collection cycle. This step depends on the availability of data from *national weather station networks* that is updated over efficient *telecoms*, and in some circumstances on data shared by neighbors in unusual or dangerous weather. It draws on available satellite and radar data, and on archives of national weather patterns.
9. Finally, *forecasters* develop forecast products tailored for various user categories, including basic forecasts, storm alerts, and possibly forecasts for agriculture, water resource management, transport, forest fires, environment/air quality, energy, and all other users.

Typical Components of an NMS

The basic NMS units are often similar from one agency to the next: observational networks, telecoms, data processing and forecasting, metrological support and laboratories, research and development, and human resources. There may be other components, and/or territorial units. A brief review of typical NMS components follows.

Observational Networks

This component was historically seen as the NMS backbone. Staff of these networks have historically comprised a large share of agency personnel. Networks of observing stations carry out monitoring programs of many kinds: measurements of surface weather, river gauging, sensing of the upper atmosphere, measurement of the sun's radiation, and specialized programs to serve aviation, agriculture, and climate study, among others. The WMO specifies recommended station spacing for some observational networks.

Telecoms

Data from the national network, regional neighbors, and the rest of the world, are transmitted to NMS headquarters via telecommunications systems (telecoms), using a variety of channels that ranges from satellite communications to voice telephone calls. Reception of the national data from remote stations is one of the most difficult challenges in every weather service. Yet national weather stations in remote areas are important to meteorology for the same reasons they are remote: that is, rough or mountainous terrain, unusual land uses, coastlines and water bodies, can all strongly modify the air masses in transit over them. In addition to telecommunications with remote stations, data links with regional neighbors and to the UN WMO-organized Global Telecommunications System also pose chronic difficulties: the rising volume of available data requires rising bandwidth for NMSs to receive and use the available data and products (see Shaimardanov 2004 for a summary of the GTS).

Data Processing and Forecasting

When available data and global models are assembled and quality-checked, a section of the NMS/NMHS undertakes local weather modeling. In many countries, low-resolution global models are used as boundary conditions to constrain a model of local weather. Local modeling once required supercomputers, but is now coming within the reach of all ECA clients, as the model code has been re-developed for use with high-end desktops. Macedonia is running such a model, and Georgia is piloting an effort along these lines. On the basis of model output, forecasters can then prepare information tailored for different users. (As computing capacity strengthens, agencies would undertake multiple runs of local area models, to develop probabilistic information to accompany local forecasts.) NMS forecasters develop public forecasts and alerts of severe weather, with a varying boundary between their work and that of media and Ministries of Emergencies. Agencies may also provide agricultural forecasts, hydrological forecasts, dedicated support to aviation forecasting, seasonal outlooks, climate bulletins, marine and environmental forecasts, and other specialized products. Most ECA NMHSs have data archiving divisions that are responsible for preserving and making available past weather records for operational and future research use.

Metrological Support and Laboratories

The global system depends on input data that is standardized and calibrated. The "butterfly effect" influences forecasting daily: a single low-quality station data point incorporated in global forecasting can lead to an erroneous path forecast for a disaster on the other side of the world. NMSs' metrological divisions and laboratories ensure that various network instrumentation provide accurate and reliable observations, they are often responsible for sparing and maintenance, maintenance of national and global standards, and modify global methodologies for specific national circumstances.

Research and Development

Most ECA NMHSs have research and development units dealing with development of new methods and instruments of observations, and preparation of guidelines for network operations, data transmission, processing, forecasting and archiving. These units may also undertake studies of natural hazards and climatology including climate change, experimental meteorology, provision of services, and economic analysis. Some of these units are organized as separate research institutions affiliated with or under the umbrella of the NMHS, others as divisions of the NMHS.

Human Resources and Training

The key HR function faces considerable difficulty, as training funds are very scarce, and civil servant salaries at scales and distributions prescribed for the Government overall may be inadequate to retain a staff structure that requires familiarity with the leading edge of information technology, telecoms and modeling. Staffing is coasting downward slowly in many agencies, which are maintaining continuity of services by drawing on the training investments of a better-resourced era. Staff profiles tend to consist of a large percentage of highly trained staff approaching retirement without an adequate number of trained replacements in prospect. Profiles of national services (see References) delineate current training needs. The need for basic forecaster training appears often, as do agrometeorology, satellite meteorology, numerical modeling and instrument maintenance.

Other Components and Territorial Units

Finally, many but not all ECA NMSs are also national hydrological services (NMHSs, as we have been denoting them) that have corresponding networks, data processing and modeling, and forecasting, or that have monitoring and reporting on environmental quality. Globally, the variety is even greater. Finally, many NMSs have regional and/or territorial branches responsible for data collection and sometimes provision of weather services on their territories.

Priorities in NMHS Infrastructural Capacity

Every ECA NMHS faces somewhat different capacity challenges. For example, many but not all ECA agencies serve economies dominated by agriculture. Many but not all face damaging convective storms and locally developing river floods. A few ECA networks have undergone critical damage from civil unrest. Some have been the beneficiary of donations from many different national services and now require procurement of spares (sparing) from multiple sources. Some but not all are within the scope of freely available satellite data. However, it may be generally said that, with respect to their ability to carry out operational forecasting and other functions described above, most agencies in ECA have experienced a significant decline in public financing since the late 1980s, leading to an overall degradation of agency infrastructure. Capacity challenges in ECA fall into four categories: (i) IT and numerical weather prediction, (ii) monitoring networks and telecommunications, and (iii) sustainability, including staffing and financing issues.

Adequacy of IT and Numerical Weather Prediction

The main advances in weather and climate forecasting in recent decades have been driven by numerical weather prediction. Figure 4.1 compares the skill measured in daily forecasts from 1970 to 1998 with the skill that would have been achieved if the same data had been processed by the methods of the late 1990s. It shows that more than half of all improvement would have occurred before the first satellite was launched in 1957, if modern computers and models had been available fifty years ago. Analysis by ECMWF updates this finding: in the past 25 years, ECMWF has added 2.5 days of useful lead-time to its forecasts, of which ECMWF attributes one day to improvements in observational systems, and 1.5 days to data processing improvements.

The need for good models highlights three capacity issues common throughout ECA agencies: (i) uncertain access to global models for use as boundary conditions in local weather models, (ii) need for capacity-building to undertake local area modeling to produce highly-resolved outputs for national use, (iii) presentation of seasonal forecasting that needs to be adapted to national decision making.

Global Models. Access to global models is universal in principle, because such models are computed by several agencies and published over the GTS (see Shaimardanov 2004). Access is simplifying and improving from month to month. However, in practice, the bandwidth available to the NMHS is sometimes deficient, and the freely available products are sometimes not known.

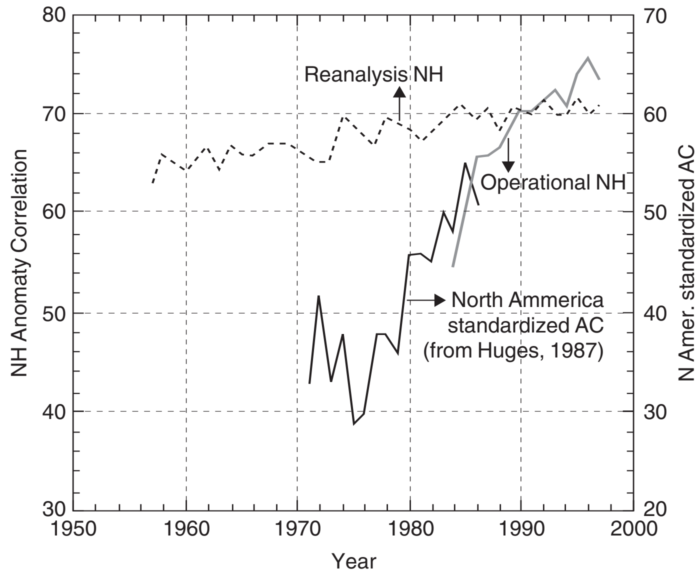
Local Models. Capacity for local area modeling varies. The current state of national modeling work in the nineteen ECA countries studied can be found in the profiles of national services (see References). As the profiles show, many countries are members of European modeling consortia. Many of these consortia unfortunately have geographic limits to their joint task; for example, there is no consortium that can address the modeling capacity gaps in the Caucasus and Central Asia. To remedy this, one of the recommendations of this report is that the countries that do not yet have access to modeling capacity should gain it, whether by forming new consortia, or taking on the task on a national basis. Advances in the last few years have made it possible to run local area models from high quality personal computers (comparable to staff desktops). Several ECA countries already have stand-alone capacity. By whichever means, ECA clients should undertake local modeling. ECMWF anticipates a future European configuration whereby global/regional models would be calculated at 10–20 km grid spacing, while national agencies would undertake nested models at higher resolutions.

Seasonal Forecasting. Most ECA NMHSs emphasize the value they would place on reliable seasonal forecasts. Yet it is not well understood that at present, usage of seasonal forecasts in Europe entails a significant risk of negative value for short-term users. Seasonal forecasts can be useful if their probabilistic nature is acknowledged and appreciated. Seasonal forecasting is most likely to benefit disciplined users making many independent decisions spread out over large areas (Livezey and Mayes 2006). However, depending on the cost of mitigation measures versus the losses to be mitigated (cost-loss ratio), smaller-scale and less-disciplined users risk losing the investment in mitigation measures on the occasions of wrong forecasts. The risk of negative value is significant in ECA, which is not strongly and directly affected by El Niño—the best understood of phenomena that drive successful seasonal modeling. In certain areas, seasonal forecasts may have enhanced accuracy and value. ECMWF and the Russian Federation's RosHydromet are developing methodologies to help clear this barrier.

Few ECA clients have undertaken extensive investigations of how the North Atlantic Oscillation (NAO) historically has affected them, or how it would be likely to affect them. Such investigations would enable rapid adoption of certain key types of seasonal forecast products.

Other IT Tasks. Other important IT capacity building investments include IT support for data quality control and forecasting workstations that systematize the task of overlaying

Figure 4.1. Re-analysis of Historical Data (Dashed Line) Compared to Forecasts Actually Delivered Over Past Decades (Solid Line) Shows that Much of the Gain in Forecast Accuracy is Due to Models and Computers



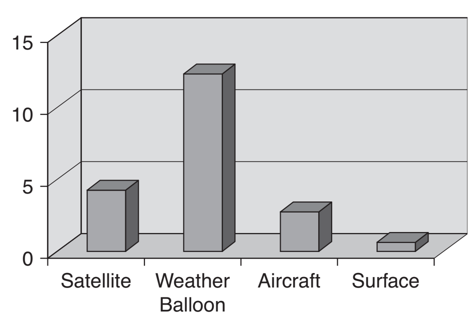
Source: Kalnay and others (1998).Used with permission of AMS.

and analyzing data sets from disparate sources, such as model output, radar, surface station data, satellite imagery, and other sources.

Adequacy of Monitoring Networks

Good model output depends on good data: as input, and for calibration and development of output. In Figure 4.2, an analysis by UKMO compares the impact of different data types on the accuracy of global weather forecasts. The figure shows that in the Northern Hemisphere (NH), the most important data input is upper-air sounding (weather balloon/ radiosonde data); second is satellite data; third is data from aircraft; and least important (for global modeling) is surface data. Good

Figure 4.2. An Analysis by the UK Met Office Compared the Impact of Withdrawing Different Types of Data on the Accuracy of Weather Forecast Models for the Northern Hemisphere. Weather Balloon Data is Most Important, Followed by Satellite, Aircraft and Surface Data



numerical models require an adequate monitoring network, delivering its data in a timely manner to the hydromet center.

National monitoring networks are needed to enable hydromet staff to prepare realistic forecasts. Even where good models are available, staff forecasters add critical value: (i) numerical models have chronic types of errors; (ii) model output is based on data that is several hours old by the time the model is ready; (iii) models have limited resolution (six to eight times grid spacing); and (iv) modeling usually is not suited to nowcasting of damaging weather events that develop locally and suddenly. Forecasters address these problems. Their work is most effective when they draw on digital satellite data, up-to-date surface station data, radar data, and data from neighboring NMSs.

Digital Satellite Data. A growing torrent of satellite data is being made freely available by providers. Many ECA NMHSs are not equipped to receive satellite data. Some NMHSs download imagery but do not have the infrastructure to download the underlying digital data.

Surface Meteorology Stations. The density of surface meteorology stations is crucially important for preparation of updated forecasts, with or without (as in most ECA countries) numerical weather prediction inputs. The most damaging weather events occur locally and suddenly; in particular, convective storms and flash flooding. In addition, meteorological station data provides ground truth for satellites, comprises basic climatological knowledge, is the source of the most readily interpreted harbingers of "on the ground" climate change, and helps in ensuring safety and avoiding economic losses (excedances of threshold values of temperature or wind may lead to limitation of construction, transportation and other activities). It is a data source of great interest to insurance providers.

Availability of data from ECA's national networks of surface stations and upper-atmosphere sounding stations was reviewed. The density of surface stations remained somewhat uncertain (because station lists sometimes but not always include stations that have missing instrument sets, or that have recently closed, and these uncertainties are of significant magnitude). However, some conclusions emerged. The station network is clearly sparse in some areas, and instrumentation is heavily depreciated. The network of upper air sounding stations is thinning and inadequate. Specialized networks such as agromet networks have become sparser as well. As for upper-air sounding (key to aviation safety and input to weather models), some ECA countries do not operate any such stations.

- The sparse network on the mountainous Balkan Peninsula is apparent, and is a cause for concern, as it limits the ability to issue forecasts that update global models with newer data. As such, it leaves the region under-protected to suddenly forming events that could influence every sector. The importance of Greece's stations is evident. It would be most helpful to the Balkan Peninsula to address the data gap along Albania's Adriatic coast.
- The sparse network in the Caucasus is a problem for the same reason. A more rapid cycle for sharing of available data within the Caucasus would be very helpful. Data from Turkey would help as well.

Box 4.1: Poland Flood Emergency Project

In 1997, Poland endured a massive flood that exceeded all of the country's recorded experience, affecting both of Poland's principal river basins. Fifty-five people died and dozens of cities and hundreds of villages were inundated. Total damage was estimated at US$3.4 billion (about 2.4 percent of Poland's 1997 GDP).

A Flood Emergency Project was undertaken with financing from IBRD and EBRD that included development of a monitoring, forecasting and warning system, flood prevention planning, and upgrading of flood prevention infrastructure. It also supported development of non-structural measures to limit damage, including regulations for economic use of risky areas, flood impact minimization plans prepared by local communities and groups, warning systems, and flood insurance, among other measures. The project is now complete.

The monitoring, forecasting and warning system, SMOK, included:

- A network of automated meteorological and hydrological measuring stations, densest in regions where flood waves form, comprising automated stations;
- A computing system able to automatically process the vast quantity of incoming data and produce quantitative forecasts;
- Upgrade of data processing and transmission systems at airports and forecasting offices so that these offices can acquire, visualize, convert and process data from various satellite, radar and other sources world-wide, as well as results of numerical models and forecasts from numerous sources;
- Development of a high-resolution weather forecasting model tuned to Poland, and procurement of a supercomputer able to recalculate the model several times per day;
- Upgrade of the data transmission channels that connect the offices and agencies of the NMHS;
- Development of a hardware/software platform that provides access to forecasts by users via telephone lines or the Internet;
- Procurement of equipment for hydrometry and geodesy;
- Lightning detection;
- Enhancement of Poland's weather radar system.

The system setup cost about US$62 million; operation and maintenance is estimated at about US$8 million annually.

- The mountains of Central Asia present a significant forecasting challenge. Air masses from the Atlantic and other seas to the west can appear to have exhausted their supply of moisture in traversing Central Asia from the Caspian to the east, but in rising to flow across the eastern mountains, air masses cool enough to deposit further moisture as precipitation, leading to rains and flash flooding in the Kyrgyz Republic, Tajikistan, and to an extent in Kazakhstan and Uzbekistan. Monitoring stations in these mountainous areas would be very helpful, but are closed at present. Vulnerability to rapidly changing events influences all the key weather-dependent sectors.

A broad move to replace manual observations with automatic observations is underway around the world. Human work is more accurate, but cannot comprise a continuous stream of data. Moreover, maintenance of a human presence in remote areas can be extremely expensive. However, there remain strong arguments for non-automatic stations. The switch to automation can amount to a structural shift from a labor-intensive enterprise built around robust and easy-to-maintain low technology, to a higher-technology, more-fragile enterprise, dependent on imported "black boxes" that often can be maintained only with vendor-supported training and sparing. Some variables are very expensive to measure without human intervention (sky cover, type of precipitation), and if these measurements justify some human presence, then savings from adopting automatic measurement of other variables is more limited. Security of remote meteorological stations is a problem everywhere. Finally, international standards note the importance of an ongoing program of manual observation alongside an automatic program, as a means of quality assurance. Thus, international civil aviation recommends against full automation; so does the WMO. If any of these considerations justifies an ongoing human presence, then savings from adoption of an automatic program is limited. Objective comparison of automatic/semi-automatic/manual technical solutions in these circumstances is not a straightforward task (Lynch and Allsopp 2006). In many ECA countries where labor costs are relatively low, massive one-time introduction of automatic sensors, which is under consideration by some NMHSs, may not be cost effective in a short- to mid-term perspective. A more careful, gradual introduction of automatic sensors and equipment in line with the NMHS' financial and technical capacity to maintain and properly use this equipment is recommended.

Meteorological Radar. Local and sudden-onset storms are often not forecast with adequate resolution and lead time by numerical models. Instead, detailing and updating of forecasts with the help of radar data is particularly helpful for early warning and minimizing damage. But meteorological radars still in operation are few, and are in any case out of date, few being Doppler-capable (able to sense wind speed). Several ECA countries operate no meteorological radar.

Box 4.2: Data Gaps in Measurement Networks

The importance of data gaps to forecasting can be seen from the consideration that the resolution of numerical models is limited by the resolution of data supplied. If input data is not spaced closely enough, models are more likely to wrongly interpolate between data points. The larger the gap, the more important these errors are. This consideration shows why the accuracy of the global models that form the basis for local forecasts depends on availability of data even from sparsely-populated regions.

Ways to overcome this limitation are always under development—use of probabilistic forecasts to represent the range of data that might have been, or use of simplifying assumptions over homogeneous areas such as oceans and seas, or use of satellite data, and so on. But the more variation in land use and topography occurs within a given unmonitored area, the less effective these alternatives are.

The errors introduced into forecasts are expected to spread outward around the missing data at increasing forecast lead times. Therefore, weak national sensor networks are thought to affect forecasting in their own country at short time horizons, and regional/global forecasting at longer time horizons.

Bilateral Data Sharing and Exchange. Data sharing and exchange are weak in the Caucasus and in South Eastern Europe, where there are many boundaries that lack any agreement on sharing beyond the system mediated by the WMO (a subset of stations is shared once per three hours). Even where agreements exist, some are not operationalized because the communications channels are not financed or the technical work needed to operationalize the agreements is not done (for example, what levels of wind or precipitation should initiate a transboundary data exchange that goes beyond normal WMO-mediated exchange). Particularly in sensitive situations, agencies are reluctant to precipitate expensive mistakes by neighbors. This concern can be allayed by formalizing the conditions for data sharing and exchange before such circumstances arise.

Telecoms

Data gathered at surface stations loses a significant share of its value if it is not transmitted to headquarters in time for incorporation in models and forecasts. This often occurs in ECA. Telecom requirements vary from country to country, depending on topography, availability of cell phone networks, and other circumstances. Of particular difficulty is communication with remote areas, often mountainous and underpopulated. The Arctic Region and the mountainous areas of the Caucasus and Central Asia pose particular challenges.

Sustainability of Operations

ECA NMHSs' hydromet staff are extremely capable, and have been able to maintain operations and in some cases improve the quality of forecasts to some extent in recent years. However, the appearance of normal operations is quite misleading. Lack of funding has led to: (i) deterioration of observation networks and reduction in observation programs, (ii) obsolescence of equipment and technology; (iii) development lag in monitoring equipment, forecasting and application software and methods; (iv) insufficient scientific and research support; (v) erosion of workforce quality and shortage of professional staff. Some agencies report that their observational network instrumentation is 100 percent depreciated and has been for several years. Some have reported that they have no trainees. One hydropower-dependent country has no telecom capacity for daily reporting of hydrological data from many of its posts; hydrological forecasts are prepared without the data. Even in the countries reviewed where hydromet services are relatively advanced, senior NMHS managers have no hesitation in acknowledging that the status of their services is poor and considerably deteriorated. All recognize the need for massive modernization of basic infrastructure and capacity improvement, and training of current and new hydromet staff.

The NMHSs' hardware and training problems cannot be resolved entirely by donors. A rule of thumb in hydromet services is that operations and maintenance of the network cost about 20 percent of the network's hardware cost annually. Therefore, large donations made in the absence of Government commitment to sustainably financing their operations may have to be abandoned by the NMHSs. National budget support is required, and to that end, the economic case for hydromet services must be made.

Status of Selected NMHSs in ECA

Country examples provided below, a sampling of Central Asia, the Caucasus, the European CIS, and South Eastern Europe, illustrate the status of NMHSs and a range of issues and national needs.

Turkmenistan

Turkmenistan has limited access to high-resolution numerical weather forecasting. Available forecasts do not present probabilistic information, and are missing key variables including relative humidity and wind speed, among many others. Availability of this additional data would enable the NMS to better serve agriculture, including the livestock subsector, as well as municipal services, and transport (road, rail, and aviation).

Turkmenistan's national networks of surface weather stations, hydrological posts and upper air sensing are all sparse by WMO spacing standards. (Although most of Turkmenistan's area is sparsely populated, this does not mean the weather stations can also be sparse. WMO station-spacing standards are set by the scale over which weather changes. If the network is too sparse, then developing weather patterns are likely to be missed or misinterpreted.) Moreover, existing equipment is deteriorating. It is obsolete, and as a result, spare parts are difficult or impossible to obtain. Most operating instrumentation has not been adequately calibrated in the past five to ten years.

Turkmenistan has no upper-atmosphere sensing stations at present. This compromises the safety of aviation in Ashgabat. Satellite images cannot replace weather balloons, because weather satellites at present yield atmospheric wind data only in favorable circumstances (such as clouds whose motion can be measured). Radar protection for Ashgabat should also be considered, to enhance gale warnings. Satellite data are needed by agriculture, Turkmenistan's energy sector, transportation (aviation, marine and road), water resource management and environmental monitoring.

National data archives should be re-established. It may be necessary to request support from the Moscow archives to complete data series, where local copies cannot be identified. Capacity building is required within the NMHS to update technical skills. It is also needed in the economic sectors that are to benefit to assure they are able to interpret hydromet data and make use of it.

Turkmenistan's NMHS is not financed on a sustainable basis, and if it were to receive infrastructural strengthening as a donation, it might have difficulty sustaining operations and maintenance of the new equipment from the present budget. What is needed above all is a case made to Government for a stronger commitment to financing this function. In the long run, the NMHS should develop an internal capacity to estimate the value of its forecasts to the economy, so that it can maintain a dialogue with policymakers concerning its optimal role in serving the national economy.

Tajikistan

It is difficult to list which is the foremost requirement for the NMHS of Tajikistan, considering that the economy is weather-sensitive, the climate highly variable, and current capacity run down to near collapse. Tajikistan does not have a capacity for local area modeling, which can partly help to close other gaps. If it did, its accuracy would still be unusually constrained by eastern ECA's lack of upper-air sounding, a gap that is likely to weaken global forecasting, which is the basis of local forecasting. It is not known whether this weakening really occurs since Tajikistan's network of weather stations was severely damaged in the conflict of 1992–98 and reliable weather time series are relatively unavailable. Tajikistan has been the recipient of donated equipment, but cannot provide enough funding to keep it operating, which not only constrains ongoing operations but also discourages further donations. If one capacity should be listed above all others as missing, it is the capacity to make a case to Government for the value of this function and for the services that cannot be provided at present resource levels.

Tajikistan's NMHS has one significant asset, and that is a staff that was trained very well, although long ago, and is able to improvise use of remaining pieces of equipment. However, senior staff are aging and nearing retirement, and have not as yet been able to persuade an adequate number of juniors to pick up Atlas' burden.

One may ask which sector of Tajikistan should be the beneficiary around which an initial upgrade could be formulated. Considering Tajikistan's disaster-proneness, dependence on rain-fed agriculture for food, dependence on irrigated agriculture for exports, fog-bound mountainous airports, and environmental sensitivity (as its glaciers and mountain areas comprise a key area of the upper watershed of the Aral Sea Basin), it is clear that prioritization would be contentious. It would be simpler to say that Tajikistan's NMHS is one of the priority ECA agencies for rehabilitation, heading for a catastrophic collapse in a vulnerable economy and climate. Proposed upgrades might be as follows.

The foremost perceived requirement of the NMHS is capacity building: new staff, and re-training of existing staff. Training is needed for station observers, and for other staff in new methods of forecasting, in use of satellite data, climate change, as well as in other areas where meteorology has changed dramatically in recent years.

The network of surface meteorology stations, hydroposts and environmental monitoring urgently needs rehabilitation, including associated metrological service and calibration laboratories. Station data from remote areas needs to be generated and delivered by reliable telecoms to NMHS headquarters. Tajikistan's hydrological network is of vital importance to its irrigated agriculture, dam regulation, and hydropower production and to overall forecasting of water resources for the Aral Sea Basin.

Tajikistan should obtain access to satellite data and to medium-range and long-range weather forecasts—at least, forecasts of the presence or absence of global teleconnections such as El Niño and the NAO that are associated with seasonal weather anomalies. Satellite imagery would be highly valuable to provide early warning of severe weather, and would enable enhanced services to agriculture, transport, energy, aviation and water resource management.

Upper-air sounding data (weather balloons) are needed for aviation; forecasting for Tajikistan's airports (situated as they are among the highest peaks in ECA) urgently requires weather balloon sounding to promote efficiency and safety. Upper-atmosphere sounding should also be a key input for upgrading the accuracy of forecasting to the benefit of other sectors.

Information technology, specifically modeling, archiving, telecoms, databases, forecasting, and bandwidth, is inadequate. Study of the state and dynamics of Tajikistan's glaciers is needed, as well as databases to support forecasting of avalanches and floods.

Archiving of data should be improved, and support should be requested from the Moscow archives to complete data series where local copies cannot be identified. The NMHS staff believes that the agency would benefit from enhanced collaboration with Voeikov Geophysical Observatory in St. Petersburg.

Kazakhstan

Kazakhstan is vulnerable to a range of weather hazards such as droughts, floods, strong winds, extreme heat and cold waves, hail, avalanches and others. The main weather-dependent sectors are mining, including oil and gas exploration (14.4 percent of GDP, 2005); agriculture, fishery and forestry (6.4 percent); transport (9.3 percent); construction (7.4 percent); and communal services (2 percent). Economic losses from natural hazards are not registered in most sectors; the only source of data is the Ministry of Emergencies, which estimates average annual losses from extreme weather events at about US$61 million for the period 2000-2005 (see also Chapter 5). National experts believe that actual losses are several times greater than this estimate, considering that the Ministry's data refer only to direct losses in large events.

The status of the NMHS (Kazakh Hydromet) has been evaluated by national experts as below the country's minimum needs. Kazakhstan does not have meteorological radars or specialized stations to receive satellite data. Numerical weather forecasting capacity is minimal and not used for operational needs; in addition, IT capacity is poor. More than 70 percent of all meteorological and hydrological equipment has exceeded its lifetime by considerable margins. The status of Kazakhstan's observation networks has greatly deteriorated since the mid-1980s. From 1983 to 1999, the number of meteorological stations declined from 373 to 244; the number of sites with hydrological measurements fell from 457 to 159; the number of upper air stations fell from 15 to 7. Most observations are still made manually by field-based staff. While manual observations are considered to be higher quality than automatic measurements, they are relatively expensive and not continuous in time. Most hydromet facilities in the field and in regional forecast centers are in urgent need of repair. Recruitment to assure a qualified workforce is a problem due to the service's low remuneration. Re-training of existing staff is also an issue due to lack of training funds. Operations of Kazakh Hydromet are funded by the national budget through the Ministry of Environmental Protection (75–80 percent of the service budget), together with collection of fees (20–25 percent of the NMHS budget) for services to customers in oil and gas, aviation, and land and sea transport. Primary expense categories have been staff salaries, operation and maintenance costs, and communal payments; capital investments until recently have been negligible.

Kazakh Hydromet has recognized the urgent need to modernize its infrastructure and to recruit and train its staff. Some hydrological and meteorological stations have been reopened in recent years and new automatic sensors are being introduced on a pilot basis. A *Development Program of Kazakh National Hydrometeorological Service for 2008–2010* was developed and has been submitted to the government for review and approval. The Program, tentatively costed at US$28 million, includes: (i) development and technical reconstruction of national observation networks, including initiation of a meteorological radar network; (ii) development of an IT and telecommunication network including modernization of forecast centers and a data collection and processing center; (iii) improvement of the quality of services and of emergency preparedness; and (iv) improvement of support for research and development and enhanced international cooperation.

Georgia

This mountainous country comprises a wide range of climate zones, has an intrinsically variable climate, and is exposed to various natural hazards. The most damaging weather events, responsible for considerable economic losses and loss of life, are avalanches and mud slides, strong rains and floods, droughts, strong winds, hail, and early frosts. Agriculture is heavily weather-dependent; transport, power production, irrigation and communal services are also vulnerable to weather conditions. Average annual economic losses are estimated by the local experts at more than US$50 million. The largest losses are caused by droughts, followed by floods and heavy rains (see Chapter 5). Several floods in 2005 were particularly destructive, with total losses of about US$25 million and several deaths.

In recent years, most meteostations have closed, as well as the majority of hydrological stations. Upper air observations have halted, and only one meteorological radar is in operation. Most specialized programs for agriculture, glacier surveillance, and other sectoral tasks are considerably reduced in scope or have ceased. Most instrumentation is fully depreciated, and calibration/metrological support is problematic. IT systems and telecoms are also weak, although reinforcement has been undertaken recently. At present, a new initiative for renewal is underway, but its scope not yet finalized. With the support of development partners, some stations are reopening. Staff have developed a working group to undertake local area modeling.

Ukraine

Ukraine, one of the largest countries in Europe, is exposed to almost all natural hazards typical of ECA. The most frequent dangerous weather events are: strong rains (45–75 events a year), snowstorms (20–40 events a year) and strong winds (11–22 events a year); floods and droughts are the most destructive but are less frequent. The main weather-dependent sectors are transport and communication (11.7 percent GDP in 2005), agriculture (9.2 percent), food processing (7.8 percent), mining (4.7 percent), energy (4.3 percent), and construction (3.9 percent). The Ministry of Emergencies recorded 214 weather-related emergencies of national and regional scale during 2000–2005; average annual economic losses from these events are about US$152 million (in year 2000 US$). Total economic losses from all types of dangerous and unfavorable weather events are estimated by local experts to be in the range of US$190–500 million (see also Chapter 5).

Since the early 1990s, Ukraine Hydrometeorological Service has suffered from systematic underfunding, which was two to three times below operational needs. Unlike in many other countries in CIS, reductions in the land-based observation network in Ukraine were minimal. UkrHydromet has made reductions in a number of observed parameters and in the frequency of observations. Yet the damage from massive underfunding is dramatic: all equipment is obsolete, over 90 percent of all instrumentation has exceeded its life time, and many facilities are in the urgent need of repair. A number of meteorological and hydrological stations will not be able to continue observations without urgent and massive replacement of instruments and facilities. UkrHydromet does not have Doppler radar; IT and telecommunication facilities are outdated; and modeling and forecasting capabilities are limited despite the presence of a qualified and experience workforce. Replacement and training of staff is problematic; senior professionals are approaching or beyond the retirement age.

UkrHydromet is designing a targeted five-year national program of technical and technological development of hydrometeorological services with tentative cost estimates of about US$82 million. The main directions of the proposed program include technical modernization of the meteorological radar network and its integration with the European network, re-equipment of aviation meteorological stations and upper air sounding, installation of automatic sensors, modernization of the hydrological network, improvement in telecommunication and IT systems including procurement of a supercomputer, and construction and repair of facilities. UkrHydromet expects to get funding for this program in 2009.

Albania

Albania is a country where meteorological and hydrological hazards have a great impact on the environment and economic activities. Floods, strong winds, droughts, heavy rains, and avalanches are frequent and destructive phenomena. Agriculture is one the most important sectors of the economy, contributing about a quarter of GDP and about 60 percent of employment in 2004. Agricultural productivity is dependent on weather conditions; yield fluctuations are 30 to 50 percent for corn, olives and fruits. The energy sector is also very important, accounting for about ten percent of GDP. Albania is heavily reliant on hydropower production. Weather conditions affect the amount and seasonality of flow in most rivers, which in turn affect electricity production and the timing of power generation. Transport and construction, each about ten percent of GDP, are weather-dependent, as is tourism.

The public weather forecasting agencies of Albania are weak (Smetanina and others 2006a). Equipment for telecommunication is not adequate. Real time data that could be critically helpful in cases of emergencies, for nowcasting, and for regular weather forecasting is collected by phone from a number of stations. Hydrological data cannot be collected in real time, a fact that increases the risks associated with floods. There are no upper-air stations or radar in the Albanian monitoring networks, constraining capacity for early warnings on severe storm development. Additional satellite data would be very helpful for weather forecasting and coastal zone management.

The Institute for Energy, Water and Environment (Albania's Permanent Representative to WMO) has developed a modernization program that includes the following main activities:

- Updating the monitoring technology for atmospheric phenomena and processes;
- Improving the on-line data collection system and updating the hydrometeorological data base;
- Establishing an early warning system;
- Increasing the lead time and accuracy of weather forecasts (short and mid-range);
- Implementing seasonal weather forecasting techniques;
- Increasing the range of specialized hydro-meteorological products and improving them with respect to user requirements;
- Improving public awareness of the impact of unfavorable hydrometeorological conditions.

Montenegro

Like the rest of South Eastern Europe, Montenegro has variable weather and limited opportunity to depend on upstream agencies to monitor storms that form in the Adriatic or Mediterranean. The economy is sensitive to weather information. Traditionally, Montenegro's economy has been linked to the sea, but now it includes an industrial plant and agriculture, each of which would be better able to optimize operations with better weather forecasting. Montenegro's NMHS has considerable capacity: it runs a local area model (a version of Eta), has an operating network of surface stations, and has been invited by its neighbors to make use of SEE calibration laboratories. The following priority upgrades might be considered.

A ground station for reception of satellite data would enable use of the vegetative index for crop, pasture and forest management, as well as for firefighting. Satellite data would enable detection and early warning of impending outbreaks of crop pests and diseases, and of changes in the crop-soil moisture status and their effects on agricultural production. Satellite data can also contribute to integrated pest and disease management and measures to reduce wind erosion, water erosion and combat desertification.

Radar capacity would be very helpful considering the storms and variable precipitation of South Eastern Europe, and Montenegro's "front line" location with respect to these patterns. Agriculture, transport (road, marine or aviation), water resource management, communications and construction would benefit from better nowcasting of storms. Observing and forecasting the state of the sea by radar would support the safety of marine activities and the protection of the coastal zone. More-detailed measurement of precipitation would support agrometeorology and optimal use of reservoirs and hydroelectric facilities.

As noted above, Montenegro undertakes a local area model to develop its weather forecasts. It would be helpful to link this model to hydrological forecasts, deriving flood forecasts from precipitation forecasts. Launches of an atmospheric sounder, such as a weather balloon, would support aviation in Montenegro and facilitate control of air pollution related to Montenegro's aluminum industry. The economy would benefit significantly if the agency were able to provide climate change analyses, agrometeorology forecasts, and rapid forecasts and warnings to ships at sea. Training in these areas would be useful, as would access to relevant data and a better dialogue with users.

Serbia

The status of the Serbian NMHS (Republic Hydrometeorological Service of Serbia—RHMS) is one of the most advanced among the 19 ECA countries reviewed in this report (Korshunov and others 2006). The meteorological observing system in Serbia operates as the integral part of the Global World Observing System. The network satisfies the standards of the WMO. The system includes 28 main meteorological stations with professional personnel and everyday reporting, 1 automatic station, about 70 climatological stations with monthly reports, about 400 precipitation stations with daily measurements and monthly reporting, one upper air sounding station, and 13 weather radars (most of which are used for hail suppression). The following types of weather forecasts are prepared by Serbian RHMS.

Table 4.2. Weather Forecasts Prepared by Serbian RHMS

Type of Weather Forecast	Valid Time	Frequency
Nowcasting	3 hours ahead	Several times a day
Very short forecast	2 to 12 hours ahead	Once, twice, or three times a day
Short-range	1 to 3 days ahead	Once/twice a day
Mid-range	7 to 10 days ahead	Once a week
Long-range	30 days ahead	Twice a month
Warnings	In the case of severe weather events	No regular frequency. When needed

The territory of Serbia is covered by 190 hydrologic gauging stations over five district centers. The personnel from these centers control the conditions of the structures and equipment at these stations, provide assistance to observers, perform hydrometric measurements and water quality tests, eliminate some smaller malfunctions of the instruments, etc. Data from 32 stations are sent to the headquarters by radio or telephone on a daily basis. Currently there are 25 automatic hydrologic stations in Serbia. Flood forecasting and warnings are considered to be among the most important and most efficient non-structural measures in flood damage mitigation. The government of Serbia makes annual operational plans for protection from floods, and the RHMS is obliged to distribute hydrological forecasts to all entities included in the system of flood protection. The Department for Hydrologic Forecasts collects and processes in real time information from 57 hydrological and 27 meteorological stations and 50 hydrological stations in Europe. Collected information and forecasts are distributed in real time to all interested organizations. The software PROGNOZA for data processing and distribution was developed to enable efficient, interactive and simple data access with graphical presentation. Forecasts for large rivers are made with lead times of several days using flow routing models, while rainfall-runoff models are used for smaller river basins. Early warnings are made based on radar observations and weather storm warnings. Besides flood protection, the hydrological forecasts enable optimal management of all water related activities. The information from significant water users and management systems is used for further analyses and forecast preparation.

Serbia has advanced telecommunication and IT systems. The core of its Data Receiving, Processing and Data Distribution System is based on COROBOR[8] and a database management system, and consists of two servers with automatic change-over. Serbia's meteorological archive has about 1,642,500 records of climatological data, about 3,100,000 records of hourly meteorological data and 4,380,000 records of precipitation data. Database management systems for standard climatological processing and data quality control include dBASE IV and V and CLIPPER. For visualization of numerical weather prediction products, RHMS uses its own graphics package called MICA (Meteorological Information, Charts and Animations), as well as MetView and MAGICS, and graphics systems from ECMWF, GRADS and NCAR (National Center for Atmospheric Research). Serbia uses the

8. COROBOR Systèmes is a French company that provides IT solutions for Meteorology and Aviation.

Table 4.3. Serbia: Current and Future Forecasting and Observing Systems—A Comparison

	Current	Future
Forecasting System		
Characteristic	From short to medium range	Very short range
Forecast period	>1 day, up to 8 or 10 days	From 0 to 12 hours up to 24 hours
Range	Synoptic	Meso
Information	Universal/general	Specialized for small regions or locations with details.
Observing System		
Time interval	From 3 to 12 hours	Less then 1 hour or online
Network density of synoptic stations	approx. 50 × 50 km	up to 10 × 10 km
Quantity of data	~1 MB/hour	~100 MB/hour
Data collection and processing data	Slow to fast (10 minutes up to several hours)	Fast to very fast (seconds to minutes)
Forecasting methods	NWP models, statistics interpretation (MOS, PP), Ensemble Prediction System	Extrapolation of super cell or 1 cell (convective storms), mesoscale NWP model, statistics.
Dissemination	Slow to fast	Fast to very fast

Meteosat Second Generation data with multi-spectral imagery of the Earth's surface and cloud systems from twelve spectral channels every 15 minutes. The resolution is 1 km for the visible channel and 3 km for the others.

The agency has well developed medium- and long-term modernization programs to be able to respond to the growing societal needs. The "medium-term modernization program of the RHMS for the period 2005–2008" is seeking about Euro 8.5 million to improve the observation system (automatic weather and hydrological stations, rain gauges, weather radars, lightning detection), upgrade telecoms and forecasting systems, train the staff, and undertake other activities. It is expected that modernization will lead to the improvements in observing system and forecast capacity shown in Table 4.3.

Findings and Recommendations

Broad findings and recommendations emerging from the above are as follows:

- *The main advances in weather and climate forecasting in recent decades are driven by numerical weather prediction.* This leads to the recommendation that NMSs be equipped to carry out numerical weather prediction or have access to output from others, and national monitoring networks able to verify models and highlight deficiencies.

- *The success of local numerical weather prediction depends on boundary conditions drawn from global models.* Data supplied to global modelers supports local accuracy, particularly upper-air sounding. This leads to the recommendation that upper-atmosphere data should be provided to modelers to enhance the local accuracy of global weather forecasts.
- *The success of forecasting also depends on forecaster updates and tailoring of model outputs.* This leads to the recommendation that NMSs must have trained forecasters, access to digital satellite data, surface station data, radar data near population centers, telecoms adequate to transmit real-time national data to the national center, and bilateral/transboundary data in dangerous weather conditions.
- *Specialized networks' priorities depend on national conditions.* Agrometeorology in agricultural countries, climate data, road, rail and marine weather networks, networks to serve oil and gas extraction, and links to hydrology are very important in some countries.
- *Capacity assessment must look beyond the present moment.* Depreciation of infrastructure should be addressed; staffing and training should reflect the country's future needs; financing should be scaled to meet the country's expectations of the agency.

Overall, it can be concluded that the status of this important public sector in the studied ECA countries is poor and deteriorating, lagging ever further behind world leaders. Urgent support is needed from national governments and the international community to keep this sector operational. Investments in the development of numerical forecasting capacity and in capabilities such as basic observational infrastructure, communication and IT technologies, training and recruiting of a refreshed workforce are highest priorities. Such investments are efficient, as they would help to avoid considerably greater economic losses than they would cost, and would save lives.

CHAPTER 5

Economic Benefits of NMHS Modernization

Lack of awareness of the value provided by NMSs limits the availability of public resources for these services. Quantitative assessment of the contribution of NMHSs to the national economy is therefore an important task for many NMHSs in the region.

The need for advocacy to secure funding for the hydrometeorological sector is not unique to economies in transition. Many governments, particularly those in developed countries, today want to see demonstrated results from resources allocated to NMSs/NMHSs. This situation is well recognized by the meteorological community. While over time the WMO has addressed a small number of weather-related socio-economic issues and has promoted interdisciplinary economic assessment, the larger meteorological community today is keenly interested in evaluating the socio-economic benefits of hydrometeorological information and services. The importance of this issue was emphasized at the recent WMO International Conference, "Secure and Sustainable Living: Social and Economic Benefits of Weather, Climate and Water Services" (Madrid, March 2007).

A number of approaches have been developed to estimate the economic benefits of meteorological services. These include the use of market prices to measure the benefits of specialized meteorological services when treated as private goods; normative or prescriptive decision-making models; descriptive behavioral response studies (including user surveys and regression models); contingent valuation models; and conjoint analysis. A brief overview is presented in Box 5.1.

Several studies have been undertaken in recent years to estimate the economic benefits of selected meteorological services and products (Nicholls 1996; Katz and Murphy 1997; Anaman and others 1998; Stern and Easterling 1999). Results have shown consistently that

Box 5.1: Assessment of the Economic Value of Meteorological Services

Market-based approaches. Market prices can be used as a measure of the marginal benefits to users of meteorological information, which have private good characteristics. An advantage of market prices is that they explicitly reveal the value users place on and are willing to pay for particular categories of meteorological information. The wide-scale applicability of market prices is limited by the public good characteristics of much of the meteorological information provided by NMS.

Normative or prescriptive decision-making models. The approach in these models is to view meteorological information as a factor in the decision-making process that can be used by decision-makers to reduce uncertainty. This approach is based on the Bayesian decision theory. The meteorological information acquired by decision-makers provides a basis for revising or updating the probabilities attached to each stage of meteorological event. Values of additional or new meteorological information are based on the expected payoff from the more informed decision as compared to the expected payoff without the information. In general, to estimate the economic value of meteorological information such as current improved forecasts using the perspective or normative decision-making approach requires: (i) information about the quality of current and improved forecasts and baseline "state of the atmosphere or nature" conditions; (ii) a model of how users incorporate forecasts into decisions (the process of maximizing expected net benefits); and (iii) a model of how economic outcomes (prices of goods and services, level of consumption and economic welfare) are determined by users' decisions and subsequent states of the atmosphere or nature.

Descriptive behavioral response methods. Descriptive behavioral response methods are based on the notion that the value of meteorological information depends on the influence it has on decision making by users engaged in meteorologically sensitive activities. Descriptive studies are divided into several groups, including "anecdotal" reports, case studies, and user surveys. Such "anecdotal" reports might provide stimulus for further studies. However, by themselves, they have limited use in determining the value of meteorological information. Case studies involve a more systematic study of the use of meteorological information than anecdotal reports. Sometimes, case studies are a useful way of representing a decision process in a simplified manner in order to develop tractable models. User surveys are essentially marketing studies and have limited use in helping to derive realistic estimates of the value of meteorological information.

Contingent valuation method. The contingent valuation method is a non-market valuation method used by some analysts in relation to public good meteorological information. There are two key implicit assumptions in contingent valuation studies. First, respondents are assumed to be able to assign values to the non-market goods concerned. The second assumption is that these values can be captured through the hypothetical markets of the contingent valuation method.

Conjoint analysis. Conjoint analysis is a method that has been used extensively in marketing and transportation research. It is similar to contingent valuation in that it also uses a hypothetical context in a survey format involving the users of meteorological information. The survey questions in conjoint analysis are designed as choices between and/or ranking of preferences for alternatives with multiple attributes. In other words, conjoint analysis requires survey respondents to rank or rate multiple alternatives where each alternative is characterized by multiple attributes.

Source: Gunasekera (2003).

the economic value of weather forecasts is significant (Box 5.2). Yet it remains difficult to systematically integrate assessments of value at a national or global level; most studies examine the economic impact of weather-related events on some part of an industry or sector.[9]

9. For example, Houston, Adams, and Weiher (2004) indicated that improvements in weather forecasts have the potential to improve agricultural GDP by 1–2%, transportation or aviation by 0.02–0.6%, and the energy sector by 0.75%.

Box 5.2: Economic Benefits of NMS Services (Selected Estimates)

According to the findings presented at the 1994 WMO Conference (WMO 1995), a rough approximation of the ratio of economic benefits to an NMS budget would typically be in the range of 5–10 to one. And given that the global budget for NMSs at that time was about US$4 billion, it was concluded that the global economic benefits were in the range US$20-40 billion.

In a statement at the opening of the international conference "Secure and Sustainable Living: Social and Economic Benefits of Weather, Climate and Water Resources (Madrid, March 2007), M. Jarraud, WMO Secretary-General, indicated that:

> [O]ne Euro spent on weather, climate and water-preparedness can prevent seven Euros from being spent in disaster-related economic costs, and this is indeed a very considerable return on investments. In addition, beyond disaster prevention alone, the modernization of meteorological and hydrological services can yield profit of even broader scope. Traditionally, the overall benefits accrued from investment made in the meteorological and hydrological infrastructures were estimated to be, in several countries, in order of 10 to 1. This ratio would of course differ from one eco-geographical zone to another, depending on the relative vulnerability of a specific locality, its socio-economic development and its susceptibility to weather and climate and parameters used in calculations.

According to the recent Report on Surveying and Evaluating Benefits of China's Meteorological Service (CMA) completed in 2006, the ratio of CMA's average annual costs to the overall yearly economic benefits of meteorological service is 1:69. Compared with the survey conducted by CMA in 1994, which adopted similar approaches and calculated the ratio between the input and benefit is in the range 1:35-40, it is assumed that the benefits of meteorological services have considerably increased as China has accelerated its economic development and social growth as well as the development of meteorological service.

Source: Xu (2007).

In 2003, the NMHS of Russia, Roshydromet, initiated the National Hydromet Modernization Project to assess the potential benefits of improving Roshydromet's services and products as part of making the case for large-scale modernization. In consideration of time and resource constraints, a sector-specific assessment approach was selected, i.e., to estimate and then generalize the direct weather-related losses for weather-dependent industries and sectors of the economy. This approach was developed by a joint World Bank—Roshydromet working group, with the participation of NOAA economists and in collaboration with WMO experts. Study results reported in 2004 indicated a likely reduction of 8.5 percent percent in weather-related losses as a result of forecasting improvements. Total returns to investment in the modernization project were estimated in the range of 400 to 800 percent over the period of project implementation. The results of the study were well received by the Russian Government, which decided to enhance the modernization package. From the original US$80 million, the package increased to about US$133 million.

Objective, Scope, and Approach of the Assessments

Following up on the experience gained in Russia, economic assessments were undertaken within the scope of this study to assist a sample of NMHSs within ECA to evaluate and quantify the benefits to national economies and to households. The study aimed to consider the benefits from existing weather forecasting services as well as the benefits that might be realized following service modernization. In the course of this work, the study aimed to identify the key economic benefits from enhanced services of the NMHSs of ECA, and to enable national decision makers to understand how to right-size the allocation of resources to NMHSs to ensure functioning at a level suited to national needs.

In the study's original plan, economic assessments were to be undertaken in selected low-income country NMHSs in the Southern Caucasus (Armenia, Azerbaijan, Georgia) and South Eastern Europe (Albania, Serbia). As the study unfolded, additional assessments were made in Belarus, Kazakhstan and Ukraine, in response to government requests and in order to evaluate the scope for regional cooperation. In the end, eight countries were studied. The heads of the respective NMHSs emphasized the importance of the study as a means to enhance dialogue with national planners.

Three independent approaches were developed and undertaken: (i) sector-specific assessments based on the approach applied in the Russian study were undertaken in all eight countries; (ii) a simplified benchmarking method was developed and undertaken in the same eight countries when it became apparent that available data was often inadequate or insufficient to carry out sectoral assessment; and (iii) a customized sociological telephone survey was developed on the basis of a contingent valuation (CV) approach to address economic benefits for the household sector, not considered in the first two methods. Given the limited availability of resources, the survey was conducted in only two countries—Azerbaijan and Serbia.[10]

The study assessments were commissioned and managed in close cooperation with the NMHSs under review. Each study built primarily on inputs from national hydromet and sectoral experts.

The above three approaches are reviewed in more detail in the next section.

Approaches to Economic Assessment

Sector-specific Assessment

As noted above, the sector-specific approach was developed during preparation of the National Hydromet Modernization Project in Russia in 2003–2004 and sought to estimate the economic benefits that would accrue from the improved quality of hydromet services following modernization. The method devised estimates of the economic benefit for each sector of the economy that incurs heavy losses from weather events (the "weather-dependent" sectors).

In the eight assessments undertaken within the scope of this study, national experts in each weather-dependent sector were surveyed (i) to estimate the current level of losses incurred in that industry or sector and (ii) to assess the marginal benefits likely to result from specified improvements in the lead time and accuracy of weather forecasts and warnings. Results were generalized and integrated to yield estimates of the current level of aggregate

10. The study focuses on values associated with benefits and damages to the material environment from weather events and forecasts, not human losses or injury.

economic benefits from hydromet services, and then of the incremental benefit that could accrue from a modernization project. This approach was a development of that undertaken in the Russian study, considering not only direct losses but also indirect (sample questionnaires are presented in Tsirkunov and others 2008). The potential effect of modernization was then expressed as an increment of the prevented losses from hazardous and unfavorable weather conditions that would come about from an improvement in the quality of forecasts and hazardous weather (HH) warnings, compared to expenditures for modernization of NMS plus the cost of the indicated preventive measures.

The eight assessments, undertaken within the modest scope of time and resources available to this study, yielded results that were found to be readily understandable to decision-makers. The method's dependence on economic experts facilitated the analysis of issues such as the effect of forecasting on indirect losses, for example, effects related to lost profits. Such results can be drawn upon to optimize the design of a modernization project, facilitate consideration of potential benefits related to specific improvements in general and specialized hydromet services, and permitting consideration of the present and future needs of specific users. Another advantage of this method is that the involvement of key stakeholders in the expert role facilitated interactions between the hydromet agency and its clients. These interactions established a connection between providers and users of weather information, and could lay the groundwork for new forms of public-private partnerships. Two concerns with this method were noted: it is sensitive to the selection of sectoral experts, and the data needed to estimate economic losses was frequently found lacking. Another significant limitation of this method is that it could not be used for estimating potential economic benefits for households.

Benchmarking Method

The need for a second assessment method was indicated when, in the course of the sector-specific assessments, it was noted that in many ECA countries, reliable historical data on weather-related losses was scanty or absent, and that sectoral experts sometimes had a fragmented capacity for economic valuation of those losses. To address these cases, a "benchmarking" technique was developed. The benchmarking method drew on data that could be readily obtained, such as official statistics, assessments of the intrinsic weather-dependence of the national economic structure, estimates of the meteorological vulnerability of the national territory, and surveys of the state of the NMHS (going to the quality of its information and hydromet service provision). Given an assessment of these circumstances, a reasonable scale for the likely benefits of modernization was assessed based on ranges found in the literature, as a function of GDP, and other macro characteristics.

Benchmarking is carried out in two stages. *In the first stage,* benchmark parameters are set to average values, scaled to national GDP.

- Average annual losses from adverse and dangerous weather conditions: 0.45 percent of GDP; range of annual losses: 0.1 to 1.0 percent of GDP. (There is no comprehensive and internally consistent global database on annual weather losses; estimates available in the literature vary from less than 0.1 percent to over 5 percent of GDP.)

- Average annual level of prevented weather losses: 40 percent of the losses that would have occurred had no measures been taken. (The range found in literature is 20 to 60 percent.)
- Weather dependence of the economy, that is, aggregate share of weather-dependent sectors in GDP: 50 percent.
- Share of agriculture in GDP: 15 percent.
- Meteorological vulnerability[11]: “average”.
- Status of hydrometeorological service provision: “satisfactory”.

In the second stage, the benchmarks are adjusted following rapid assessments of national climate, agency capacity, national economic structure, and so on. Adjusted benchmarks were then used to assess the marginal efficiency of the existing hydrometeorological service and of upgraded services following modernization.

One obvious constraint of the benchmarking method is that its parameters are established based on limited data. The single value used to characterize a country’s meteorological vulnerability and weather-dependence, for example, is not expected to capture all the complexity of the real situation. Another constraint is that this method assesses only the economic benefits of hydrometeorological services that were assessed in the existing literature from which the range of benefit estimates is drawn. The literature tends to emphasize direct losses, and so indirect losses (including losses of human lives, lost profits, etc.), which are under-represented in the literature, accordingly are not fully represented by this method. Similar to the sector-specific assessment, the benefits associated with the economic value of meteorological information for households are not assessed by this method. Nevertheless, the benchmarking method comprises an organized approach to developing order-of-magnitude assessments of the likely benefits of enhanced NMHS capacity, based on global averages. A detailed description of the benchmarking methodology, including its main assumptions and summarizing its limitations, is presented by Tsirkunov and others (2007).

Economic Value of Meteorological Information for Households: Sociological Survey

Survey Background and Objective. As indicated above, neither the sector-specific method nor the benchmarking method evaluates benefits accrued by households, although they are major beneficiaries of weather forecasting. These methods are not tuned to assignment of a money value to weather forecasts and warnings financed as a public good and provided free of charge to households. Assessment of the total economic value of weather information therefore requires use of a different technique, one applicable to assessment of public goods, to capture the value to households. To that end, a customized sociological survey, based on a contingent valuation approach, was used in Azerbaijan and Serbia to pilot efforts of their kind within ECA.

11. The meteorological vulnerability of the territory was assessed as a function of the extremeness of observed values for major meteorological variables, among which temperature (minimum and maximum), precipitation and wind, considered with characteristics of their statistical distributions.

The survey methodology took into account key examples of the application of contingent valuation methods to estimate the value of meteorological information, including the work of Chapmen (1992) and Lazo and Chestnut (2002) for the United States, Teske and Robinson (1994) for the United Kingdom, Anaman and Lellyet (1996) for Australia, and Brown (2002) for Canada. Most of those surveys focused on estimating the overall level of households' satisfaction with the performance of national weather services, or on the value of hypothetical changes in quality and quantity of non-market goods such as public weather information. The scope of study tasks varied from detailed studies of demand for various types of weather information products to optimizing aspects of particular weather service positioning. Willingness-to-pay (WTP) analysis is used to address specific objectives tailored to a given developed market of weather information services. With this in mind, the surveys undertaken within the scope of this study were developed to allow implementation in countries with different economic, social and cultural situations—with a prospect for subsequent comparison of the results.

The *main objective* of the survey developed is to estimate the economic value of weather information to households in a low- or middle-income country. The *scope* of the survey includes: (i) identification of the weather information needs of different households' users and the perceived importance and quality of this information; (ii) identification of the characteristics of different household users and how they use weather information; (iii) evaluation of the quality of performance of national weather service; and (iv) willingness to support the national weather service.

Methodological Framework. The survey instrument was formulated in a series of focus groups, a pilot study and an external review. Telephone polling was selected as a sociological survey methodology. The sample was randomized, quota-based, and representative for the population of national households. Zoning of survey samples was developed by a sociologist in consultation with experts from the NMHS.

As a somewhat "cover-all" indicator, willingness-to-pay (WTP) for weather and natural disaster information requires a multi-strand approach to assess potential demand for services. Three groups of indicators were developed:

- Respondents' interest in purchasing a publication containing only weather information for the month ahead.
- A question with reference to a broader aspect of demand for weather information, such as readiness to support (willingness to pay for) the country's weather service from respondents' own pockets.
- Respondents' keenness to have insurance to cover them against natural disasters.

The first two groups of indicators deal with different aspects of people's presumptive action to gain more information according to their personal interests and social and economic needs. The third group comprises selected market indicators, which enable correlation of causal and hypothetic strategies that people undertake based on their valuation of weather impacts.

The customized sociological survey used in this study has two kinds of limitations. The first one relates to the survey's similarity to the contingent valuation method, which is traditionally treated as evaluative and complementary. The second group of limitations relates to the nature of sociological survey methodologies. Based on the limitations of the applied approach, two important points should be noted: (i) its partial inconsistency with economic models of rational choice, and (ii) unavoidable biases, particular to a sociological survey method.[12]

Telephone polling of residents of Azerbaijan and Serbia was undertaken, using a survey questionnaire developed and tested in a pilot phase that confirmed its relevance, validity, stability, reliability and accuracy. More details on the methodology and further findings can be found in Konstantinovskiy, Kurakin, and Vakhshtayn (2006).

Results of Economic Assessment

All assessments indicated that significant economic benefits are received in the studied countries from the use of hydrometeorological information at the current level. Assessments also indicated that investment in the NMHS modernization would yield additional benefits, with relatively high potential returns on investment. The cost-benefit analysis, where undertaken, confirmed the financial feasibility of the proposed modernization initiatives considered. Some basic characteristics of the status of eight NMHSs where the economic assessment was undertaken are presented in Table 5.1.

Sector-Specific Assessment and Benchmarking Method: Results

Table 5.2 presents the main results of assessments by the sector-specific and benchmarking methods for the eight countries studied: Albania, Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Serbia, and Ukraine.

Sector-specific Assessments. None of the countries under review maintains systematic official accounting of economic losses suffered in connection with every type of hazardous and unfavorable weather event, except for Georgia, where the NMHS presented time series of economic losses by hazardous weather events, by sector, for the period of 1995–2004 (Table 5.3 presents data for 2000–2004). The Georgian data confirm that annual losses are highly variable and that the greatest part of the damage occurs in the agricultural sector. Data in Kazakhstan and Ukraine proved to be insufficient to undertake a complete sectoral assessment.

12. The contingent valuation method deals with "conceptual" biases that often cause specific problems. These problems (usually associated with CV external validity) are caused by the fact that people's answers are different from their real acts. These problems were analyzed in detail in Report of the NOAA Panel on Contingent Valuation (1993). The distinctive feature of the current survey is that people's behavior is not market driven since information provided by NMS is a public good. Hence, the validity of WTP declarations is mostly normative concept that makes it similar to referendum case (declarations are not the index of decision but the very decision itself). On the other hand, to apply CV-analogues model to other approaches we need to control conceptual biases in a way that reduces inconsistency with rational choice models. This task is a perspective one for further methodology improvement.

Table 5.1. Basic Characteristics of the Eight NMHSs Reviewed

Country	Average NMHS Funding: $, mln	Average NMHS Funding: % of GDP	Average NMHS Funding: $./k M²	Average NMHS Funding: $/per. Person	Revenues from Services as % of Total NMHS Funding	Number of Staff: Total	Number of Staff: Professionals/ University Degrees	Depreciation Level of Main Equipment	Number of Meteostations Total (and per 1000 KM²)
Azerbaijan	1.70	0.026	19.5	0.22	10	1700	118	65%	58 (1.3)
Albania	0.44	0.011	15.0	0.14	9	104	39	55%	15 (1.7)
Armenia	0.47	0.019	15.7	0.16	5	698	168	90%	48 (1.6)
Belarus	2.96	0.019	14.3	0.29	11	1450	573	60%	52 (0.23)
Georgia	0.47	0.014	6.71	0.10	3	780	432	80%	48 (0.7)
Kazakhstan	4.21	0.018	1.6	0.28	24	2437	446	60–80%	244 (0.09)
Serbia	5.15	0.050	58.5	0.64	3	699	166	80%	28 (0.32)
Ukraine	7.70	0.020	12.7	0.16	32	4765	1817	92%	187 (0.31)

Table 5.2. Main Parameters and Results of Assessment of Economic Benefits of NMHS Services and Proposed Modernization Programs (economic parameters are in US$ of 2000 constant prices)

	Albania	Azerbaijan	Armenia	Belarus	Georgia	Kazakhstan	Serbia	Ukraine
Average Annual GDP, $ million	4,229	7,061	2,579	15,011	3,620	23,991	9,763	38,305
Territory, thousand km^2	28,8	86,8	29,6	207,6	69,7	2,720	89,0	603,7
Population, million persons	3,1	7,8	3,0	10,3	4,9	15,1	8,1	47,1
Average annual NMS funding, $ million	0,44	1,70	0,47	2,96	0,47	4,21	5,15	7,70
Share of agriculture in GDP, %	24	12	30	10	25	7,0	17	9,2
Weather dependent sectors in GDP, %	65	51	69	43	62	45	44	46,2
Meteorological vulnerability (index)	“relatively high” (614)	“relatively high” (719)	“relatively high” (744)	“relatively high” (581)	“relatively high” (775)	“relatively high” (600)	“average” (445)	“relatively high” (627)
State of NMS	“poor”	“poor”	“poor”	“poor”	“poor”	“poor”	“satisfactory”	“poor”
Annual losses incurred, from benchmarking estimate (% of GDP)	1.00	0.50	1.25	0.38	0.99	0.32	0.44	0,40
Annual losses incurred—benchmarking estimate (in $ million)	42.2	35.5	32.2	57.5	35.8	77.9	42.6	152
Annual losses incurred (direct and indirect)—sector specific assessment, in $ million	32.1	54.5	50.1	72.3–83.1	53.6	—	95.0	187–496
Assessment of preventable annual losses, $ million, benchmarking	10.5	13.9	7.0	28.8	9.3	39.0	33.5	70,3
Assessment of economic efficiency of NMS resources at present (%), benchmarking	432	165	277	206	362	198	219	190
Incremental annual effect of improvement in NMS services—benchmarking assessment, $ million	2.5	3.8	1.6	8.6	2.2	11.5	5.5	20,1

Incremental annual effect of improvement in NMS services—sector-specific assessment, $ million	1.8–3.9	12.3	9.2	7.9–9.1	8.0	—	4.34	26–70
Estimated cost of modernization program, $ million	4.0	6.0	5.3	11.5	6.0	14.9	4.4	45,3
Investment efficiency, % (**across 7 years**), **benchmarking**	**440**	**430**	**210**	**530**	**260**	**540**	**880**	**310**
Investment efficiency, % (**across 7 years**), sector-specific assessment	**320–680**	**1440**	**1070**	**480–550**	**1050**	**—**	**690**	**410–1080**

Table 5.3. Damages Incurred by the Most Weather-dependent Sectors from Hydrometeorological Hazards and Unfavorable Weather Conditions in Georgia (million lari, current prices)

	Year				
HH and UWC	**2000**	**2001**	**2002**	**2003**	**2004**
1. DROUGHT	300.0	21.2	178.7	—	—
–agriculture	241.0	5.2	153.2	—	—
–irrigation	39.0	5.0	24.0	—	—
–energy	20.0	11.0	1.5	—	—
2. HAIL STORMS AND GUSTS	5.8	10.4	6.8	6.0	12.5
–agriculture	5.5	10.0	6.6	5.6	12.0
–communal services	0.2	0.2	0.1	0.3	0.2
–transport and communication	0.1	0.2	0.1	0.1	0.3
3. STRONG WINDS	1.0	1.0	2.5	—	2.5
–agriculture	0.5	0.8	1.4	—	1.9
–communal services	0.4	0.1	0.6	—	0.4
–transport and communication	0.1	0.1	0.5	—	0.2
4. FLOODS and FLOOD FLOWS	—	4.1	—	4.2	23.7
–agriculture	—	0.1	—	0.1	18.4
–communal services	—	0.2	—	0.3	0.8
–transport and communication	—	3.8	—	1.7	4.5
–irrigation	—	—	—	1.1	—
–energy	—	—	—	1.0	—
5. MUDFLOWS	0.5	—	0.5	0.2	19.2
–agriculture	—	—	0.1	—	8.2
–communal services	—	—	0.2	—	—
–transport and communication	0.5	—	0.2	0.2	—
–irrigation	—	—	—	—	10.0
–energy	—	—	—	—	1.0
6. AVALANCHES AND SNOW DRIFTS	3.0	3.5	1.5	2.1	4.8
–transport and communication	3.0	3.5	1.5	2.1	4.8
Sub-total damages from HH	310.3	40.2	190.0	12.5	62.7
–agriculture	247.0	16.1	161.3	5.7	40.5
–transport and communication	3.7	7.6	2.3	4.1	9.8
–energy	20.0	11.0	1.5	1.0	1.0
–communal services	0.6	0.5	0.9	0.6	1.4
–irrigation	39.0	5.0	24.0	1.1	10.0
Sub-total damages from UWC	144.2	32.0	83.1	6.0	65.2
–agriculture	143.0	29.3	77.7	4.4	60.5
–transport and communication	0.9	2.1	4.5	0.4	2.8
–communal services	0.3	0.6	0.9	1.2	1.9
Total damages from HH and UWC	**454.5**	**72.2**	**273.1**	**18.5**	**127.9**

To partly compensate for the insufficiency or complete absence of official information and expert judgments on economic losses related to weather hazards and unfavorable conditions in weather-dependent sectors, experts from national Ministries of Emergencies were invited to participate in the study in Albania, Belarus, Kazakhstan, and Ukraine. Their assessments of total economic losses made a critical contribution, but they appear to be an underestimate of total economic losses, because these Ministries' statistics do not take into account losses resulting from less-than-critical hydrometeorological phenomena, i.e., those that are not classified as emergencies; aside from this, the statistics do not cover all aspects of weather impact on the economy. Therefore, data from the Ministries of Emergencies was supplemented by loss estimates provided by sectoral experts or by the NMHS where possible.

Estimates of direct and indirect economic losses obtained by these assessments were highest in the countries where agriculture is most important (Albania, Armenia, Georgia), in the range 0.8 to 1.9 percent of GDP annually. However, losses were estimated as likely to be very substantial in the other studied countries as well: 0.5 to 1.0 percent of GDP annually.

Benchmarking. As noted above, benchmarking was undertaken to complement the sectoral studies. The assumptions used are presented in Table 5.2. Weather service delivery was rated by national experts of the eight studied countries as "poor" and meteorological vulnerability "relatively high," except that Serbia was rated "satisfactory" and "average" respectively. Weather sensitivity of the economy was highest in Albania, Armenia and Georgia, about 65 percent of GDP, in part because agriculture plays a particularly large role in these economies. Elsewhere about 40–50 percent of GDP was estimated as weather-sensitive. Making use of these parameters, benchmarking estimates suggested that economic losses from hazardous weather events would likely be lowest in Kazakhstan (0.32 percent of GDP annually) and highest in Armenia (1.25 percent of GDP). Although these estimates are of the same order of magnitude as the sector-based assessments, the benchmarking estimates are generally lower. This may be because sectoral assessments take into account both direct and indirect losses.

The economic efficiency of NMHS funding at the current level was calculated by comparing benchmark estimates of prevented losses to NMHS funding. The result is a conservative estimate of efficiency, because benchmarking tends to understate prevented losses, but even so, it suggests that the efficiency of NMHS funding is rather high, from about 150 per cent for Azerbaijan to about 425 per cent for Albania. That is, for each dollar spent on its NMHS, Azerbaijan averts US$1.50 of economic losses; for each dollar of support for the Albanian NMHS, Albania averts US$4.25 of losses, and so on (see Table 5.2).

As for the likely economic efficiency of future modernization, assessments suggest that the annual incremental benefit of modernization would be substantial. Estimates based on global benchmarks suggest that the economic efficiency of investment in a generic service modernization to a "satisfactory" level of service would range from 210 percent for Armenia to 880 percent for Serbia. Estimates based on sector-specific assessment suggest efficiency from 500 percent for Belarus and Albania to 1440 percent for Azerbaijan (Table 5.2).

Cost-benefit analyses undertaken to review specific proposed modernization plans were in the same range, suggesting benefit-to-cost ratios from 3.1 for Kazakhstan to 5.7 to Georgia (Table 5.4).

Table 5.4. Cost-Benefit Analysis of Proposed Modernization Programs (prices in US$ of 2000)

	Belarus	Georgia	Kazakhstan
Basic parameters			
Total losses, $ million	77.5	53.6	77.9
Annual incremental effect of improving status NMS and NMS delivery to "adequate", $ million	8.5	7.5	10.4
Potential Modernization costs, $ million	11.5	6.0	14.9
Years to implement	4	5	3
Maintenance, %	10	10	10
Discount rate, %	10	10	10
Main Results			
Total PV Benefits, $ million	51.6	43.1	67.5
Total PV Costs, $ million	15.6	7.5	22.0
NPV, $ million	36.0	35.6	45.5
B/C Ratio	3.3	5.7	3.1

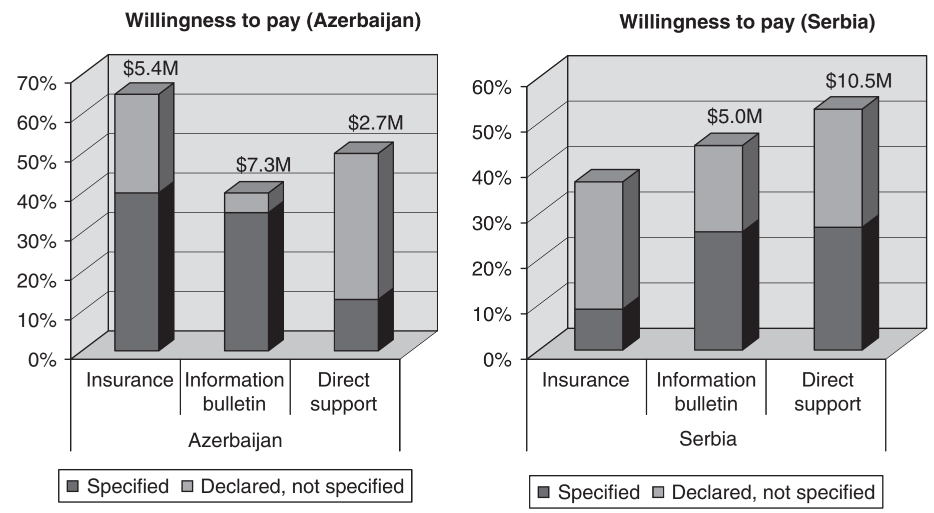
Economic Value of Meteorological Information for Households: Main Findings

The household surveys conducted in Azerbaijan and Serbia indicate that the public demand for weather information and weather hazard warnings is a function of some objective factors (such as exposure of the respondent's area to hazardous and adverse weather events, economic risks of the household, the impact of hydrometeorological hazards on the economy as a whole) and some subjective factors (general awareness of the population, communities' involvement in weather-dependent economic activities, relevance of hazardous weather events, meteorological vulnerability in general, and public perception of NMHS performance).

Figure 5.1 depicts factors affecting readiness to pay for weather information identified in the surveys in Serbia and Azerbaijan. Surveyed factors are ordered from the most concrete—willingness to buy insurance, to the least concrete—willingness to provide "financial support" to the national weather service. The diagram distinguishes between respondents who agreed to specify the sum they were ready to pay for weather information ("specified"), and respondents who were willing in principle to pay for information but declined to specify an amount ("declared, but not specified").[13]

13. Given the greater relevance and direct involvement of weather information in their everyday lives, households that "declared, but not specified" a sum that they were potentially ready to pay for weather information were shifted to the target "specified" group of those respondents, who are actually ready to pay. Hence, the estimate of the value of weather information as a public good was derived taking into account the aggregated group of households.

Figure 5.1. Willingness to Pay for Meteorological Information in Azerbaijan and Serbia



On the basis of the survey, a conservative assessment[14] of the value of the services that national NMHSs provide as a public good is US$2.7 million per year in Azerbaijan and US$10.5 million for Serbia. These amounts considerably exceed current public funding of the respective NMHSs. That assessment considers only respondents who specified the amounts they were willing to pay. However, if the additional respondents who did not specify amounts are assumed to be willing to make the same average contribution as those who did specify amounts, the indicated support in Azerbaijan would rise to a level of US$10.5 million, and indicated support in Serbia would rise to US$20 million.

The two household surveys identified considerable diversity in public perceptions related to hydrometeorological information and services. This diversity was associated with the various reasons for the public relevance of hydrometeorological service provision. A high level of relevance of weather information and potential risk was found to correspond to public willingness to support the NMHS. On the other hand, lack of perceived relevance among the public led to substitution forms of economic behavior, such as the high level of public interest in insurance products in Azerbaijan (see Box 5.3). Respondents' specified willingness to pay for insurance property coverage against weather hazards in Azerbaijan amounted to US$5.4 million/per year, more than double the corresponding estimate of household willingness to support the NMHS.

The findings of household surveys carried out in two pilot regions—Azerbaijan and Serbia—indicate that the proposed methodological approach can serve as a useful tool for

14. The implied value is mediated by actualized willingness to support NMS directly. Number of households in Azerbaijan: 1,744,000; mean of the monthly amount of WTP to support NMS: $1; number of households in Serbia: 2,401,326; mean of the monthly amount of WTP to support NMS: $1.35.

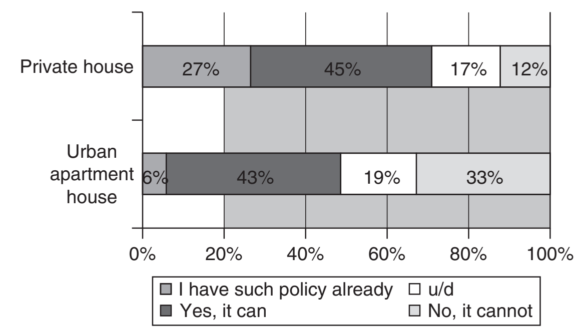
Box 5.3: Assessment of a Potential Market for Insurance Against Natural Disasters and Hydrometeorological Hazards

Assessment of a potential market for insurance against natural disasters and hydrometeorological hazards is of considerable interest as a separate area of research. This area may hold great promise in Azerbaijan, which is confirmed by the returns of this survey.

Main factors on which readiness to insure property against natural disasters depends are as follows:

- objective hydrometeorological vulnerability (rural and/or private house residents show more interest in such insurance—see Figure 5.2);
- standards of living (the overall proportion of high-income group of Azerbaijan citizens who are interested in property insurance against natural disasters reaches 85%);
- extent of relevance of hydrometeorological information (though this factor is not as important as those considered above).

Figure 5.2. Would Reliable Property Insurance Against Natural Disasters Be of Interest to You?



It should be noted that respondents differed even more in the nature of their interest than in the degree of interest in property insurance. Rural dwellers and respondents living in private houses have a *definite* interest in property insurance—they treat the insurance as a rational deal and a beneficial investment of funds, rather than a nominal “consideration” for abstract and extremely improbable risks.

The results of the survey show the prerequisites for the development of the insurance market in Azerbaijan and can be used as a starting point for more sophisticated research in this area.

assessment of economic value of hydrometeorogical information for households. However, this instrument may be sensitive to the sample design and the choice of polling technique.

Findings and Recommendations

It was shown in sector studies and data from Ministries of Emergencies that weather losses in ECA are in the range of 0.5 to 1.9 percent of GDP annually in the countries studied. This rate is comparable to the range of annual losses found in global literature, 0.1 to 5 percent of GDP annually. In a completely different approach, benchmarking studies estimated vulnerability within ECA by leveraging the global average, and assessing each studied country's position within the range, considering climate, agency capacity and exposure of the national economy. Results by this method forecast annual losses in the range of 0.3 to 1.2 percent of GDP, somewhat less than the level of losses when measured by sector studies, which included indirect losses as well as direct losses assessed by benchmarking. In any case, outcomes are comparable; the level of loss is high; and the benefits of mitigating it considerable.

Studies indicated that NMHS services are already providing substantial benefits to national economies by mitigating the level of loss that would otherwise occur, at a rate exceeding the current costs of NMS support.

Enhanced support to NMHSs would be well justified. The NMHS modernization programs reviewed in this study would be expected to have benefits—in terms of avoided loss—*four to six times the cost of the investment.* This finding persisted whether the analysis was formulated as a consideration of specific items to be bought, or of specific forecasting skills to be achieved (sector studies), or as a function of global averages in skill, cost and benefit of agencies (benchmarking).

Beyond these principal findings was another one that was less expected. Interactions with stakeholders identified a growing demand for ways to estimate the economic benefits associated with the use of hydromet services—methods of assessment that would be fast, relatively inexpensive and that would generate trustworthy estimates. A key problem is that existing, recognized methods of assessment are constrained by the lack of reliable statistics. In light of the survey of data availability and the broad experience with its constraints gained in the course of this study, the following actions are recommended.

- *Assemble studies of the impact of weather.* Review the results of existing studies and surveys in order to compile a comprehensive, consistent world-wide database on weather-related losses.
- *Fill gaps in studies of the impact of weather.* Conduct additional surveys in selected high-risk countries to expand the existing data set. Conduct additional surveys in selected countries on the impact of weather on selected sectors and industries that are vulnerable to weather and climate change.
- *Develop guidelines on the design of national databases on the impact of weather.* Provide technical assistance to pilot preparation, maintenance and utilization of these databases, engaging key stakeholders such as NMHSs, emergency agencies, ministries of agriculture and economic development, and others.
- *Assemble methodologies for assessing the value of weather information.* Make an inventory of methodologies for estimation of the value of hydromet information for weather-dependent sectors and industries.
- *Fill gaps in assessment of the value of an increment of weather information.* Organize and conduct a survey in selected countries, systematically sampling different levels of weather vulnerability, on the possible marginal impact of improved NMHSs on selected sectors and industries, and possibly on households as well.

Some participating countries have already embarked on preparation of large-scale NMHS modernization programs using economic assessments developed by the team as important

Box 5.4: Madrid Conference Statement and Action Plan

Action 11

Encourage the NMHSs and social science research community to develop knowledge and methodologies for quantifying the benefits of the services provided by NMHSs within the various socio-economic sectors. In particular:

- develop new economic assessment techniques including especially techniques of economic assessments for developing and least developed countries;
- develop WMO Guidelines on operational use of economic assessment techniques;
- train national staff on use and practical application of economic assessment of the benefits of services provided by NMHSs;
- present results of economic assessments to governments and donors/International Financial Institutions with the goal of modernizing the infrastructure of NMHSs and strengthening their service delivery capacity.

references: modernization programs are being designed or are at initial implementation stages in Belarus, Kazakhstan, Ukraine, Armenia, Azerbaijan, and Georgia. Modernization initiatives are under considerations in other ECA countries as well.

Results of economic assessments were presented and discussed with the WMO on a number of occasions. There is strong support from this leading UN specialized institution to encourage further developments in this area. Proposals developed by the project team were included in the Action Plan endorsed at the Madrid Conference (Box 5.4). The project team has also presented its preliminary findings to potential donors.

It is acknowledged that results presented from these studies of economic benefit of hydromet services are sensitive to the sample design, data availability and experts selected, and it is emphasized that the results presented here are based on limited data and should be viewed as tentative. But despite the pilot nature of the rapid assessment methods developed for this regional study, it seems that they have served as useful tools to assess the economic value of hydromet information for economic sectors and for households. They seem to comprise a robust indication of the high economic value of the hydrometeorological services and information, more likely an underestimate of its value than an overestimate. These "express" methods of economic assessment and their preliminary findings can be a useful tool for both the hydromet services in positioning themselves as important public sector functions, and for the national fiscal/economic authorities seeking to target scarce resources.

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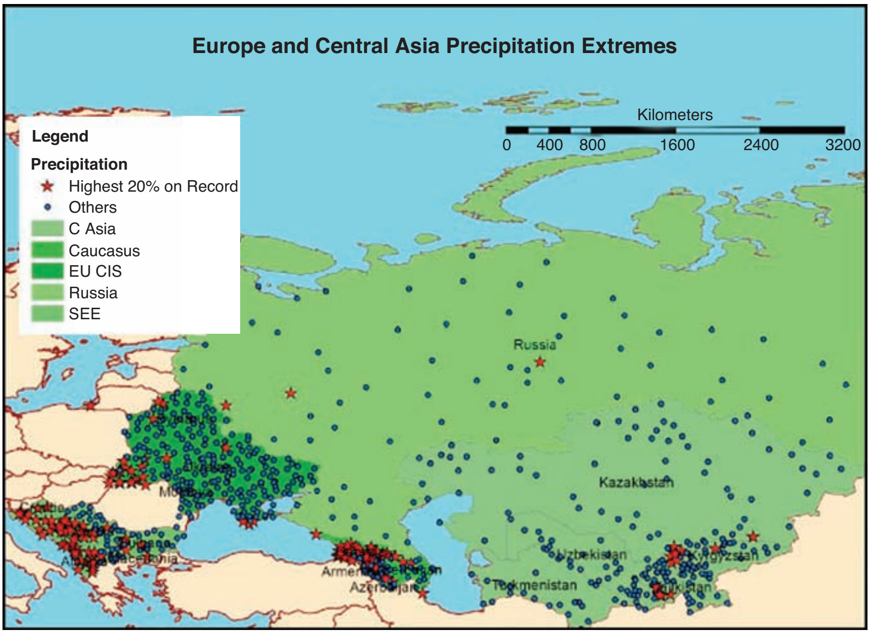
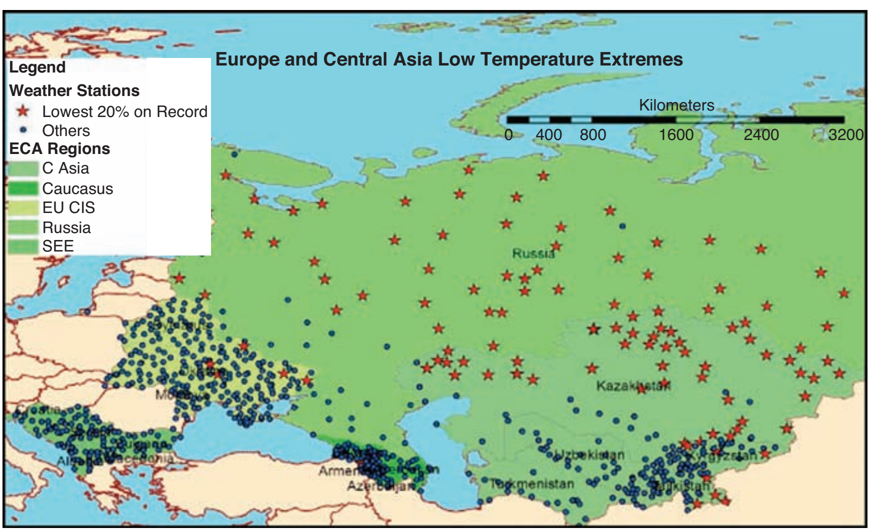
Figure 3.2(a). Precipitation Extremes



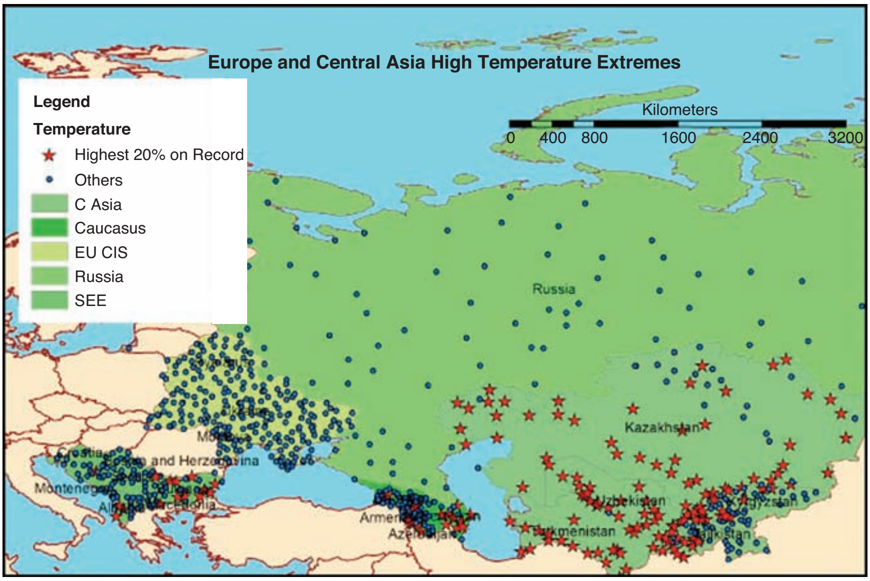
Note: Red flags: ECA's highest recorded precipitation.

Figure 3.2(b). Low Temperature Extremes



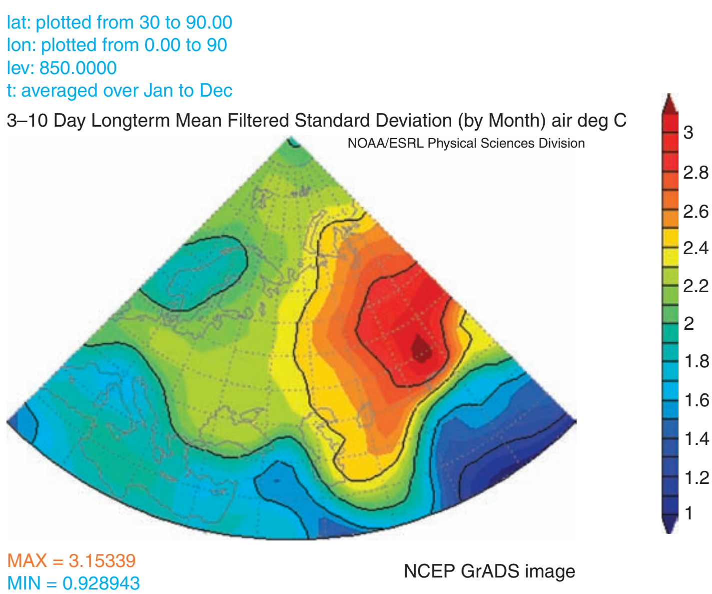
Note: Red flags show ECA's lowest recorded temperatures.

Figure 3.2(c). High Temperature Extremes



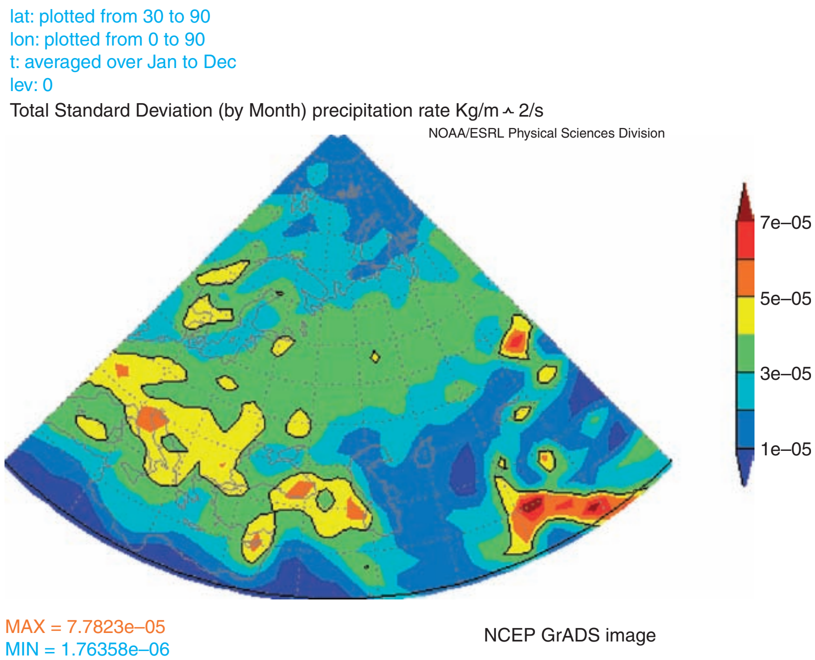
Note: Red flags show ECA's highest recorded temperatures.
Source: Country profile data.

Figure 3.3(a). Variable Temperature



Note: Red areas have the most variable temperatures (compared to averages over 3–10 days) according to historical data.

Figure 3.3(b). Variable Precipitation



Note: Red areas have the most variable precipitation (compared to monthly averages) according to historical data.

Source: http://www.cdc.noaa.gov/ncep_reanalysis/ (see Kalnay and others 1996).

Figure 3.4(a). Changes in Temperature in Europe and Central Asia, 1997–2006 Compared to 1968–96

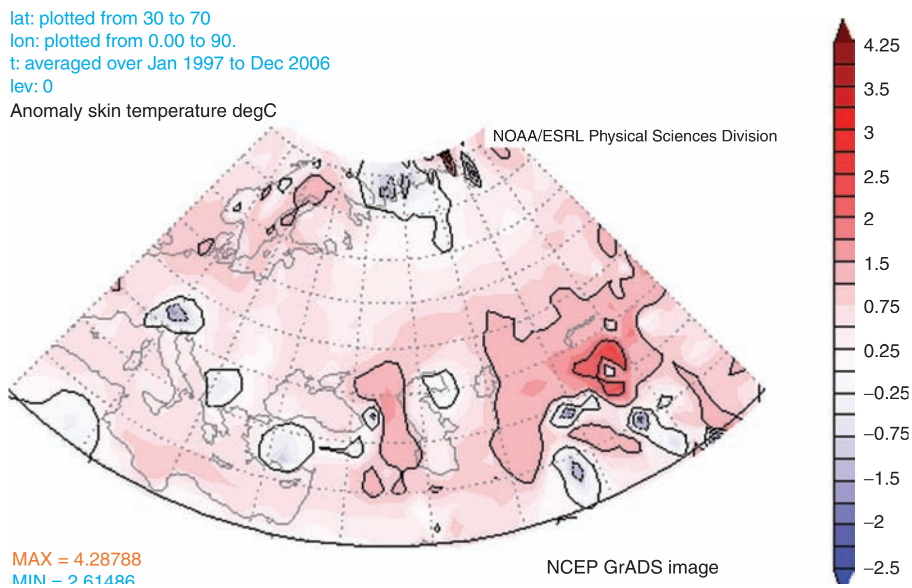
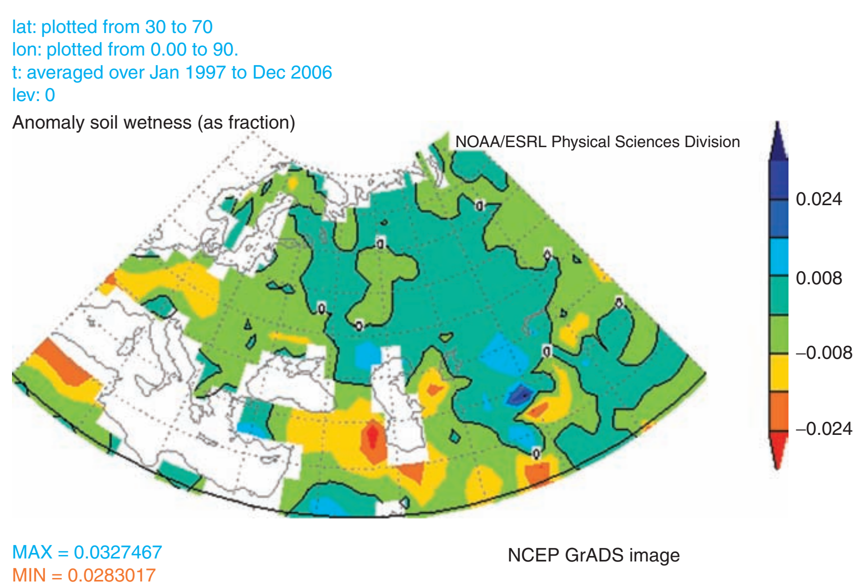


Figure 3.4(b). Changes in Soil Moisture Below Surface, 1997–2006 Compared to 1968–96



Source: http://www.cdc.noaa.gov/ncep_reanalysis/.

Figure 3.5(a). Land Temperature, 1987–2007 Compared to 1968–96 (change in degrees)

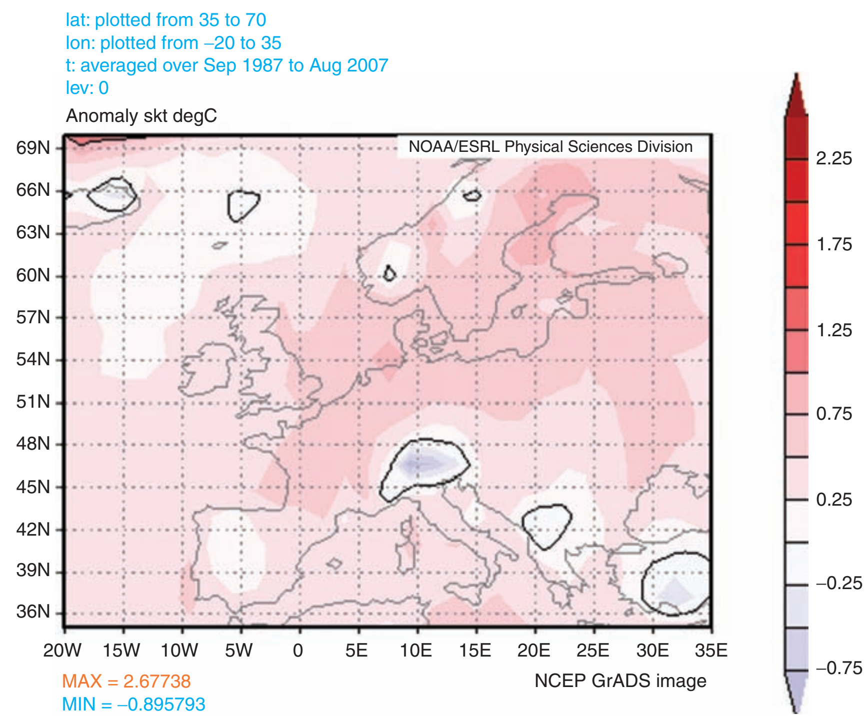
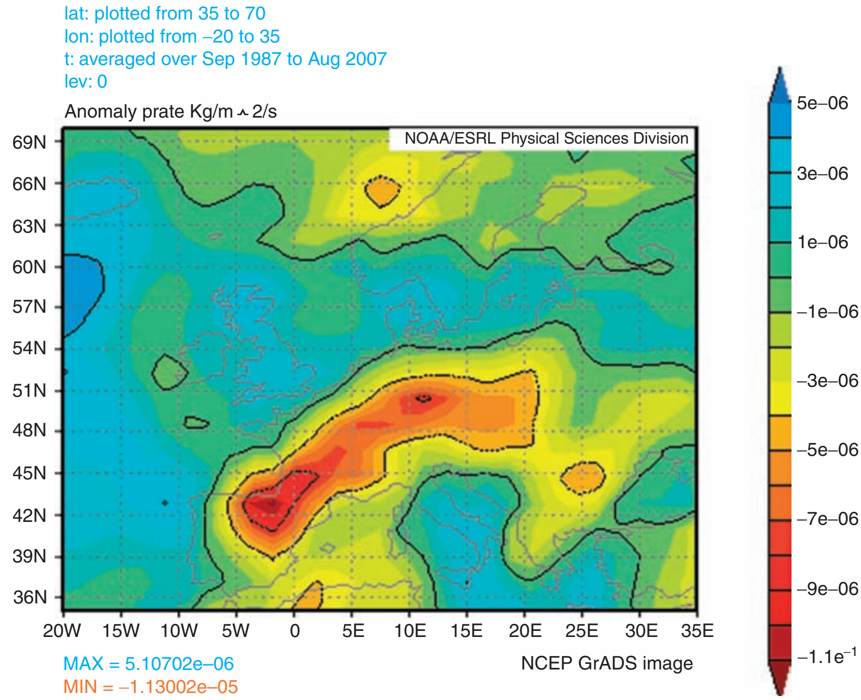
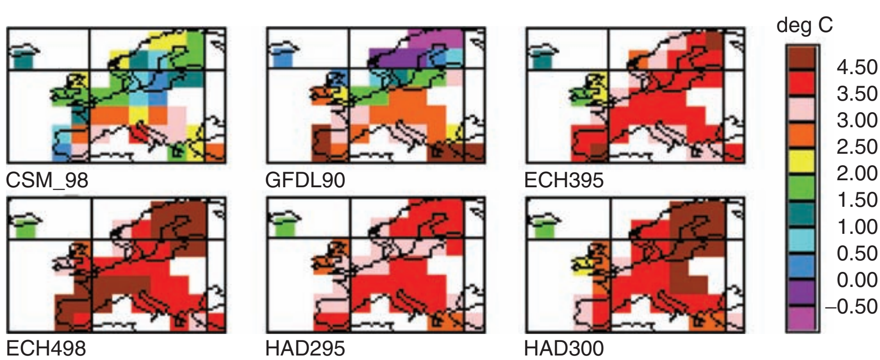


Figure 3.5(b). Precipitation Rate 1987–2007 Compared to 1968–96 (change in kg/m²/second)



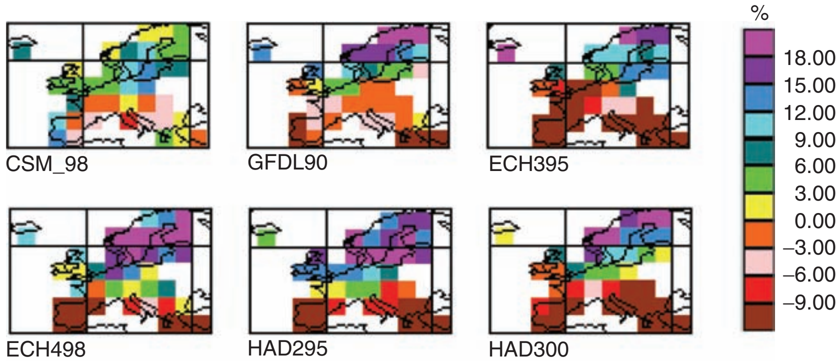
Source: NCEP Re-analysis, see Kalnay (1996).

Figure 3.6(a). Projected Change in Temperature over Europe by the 2080s, According to Six Different Models of the Atmosphere (assuming economic scenario A2ASF)



Source: Bruci (2007).

Figure 3.6(b). Projected Change in Precipitation over Europe Between Today and the 2080s, According to Six Different Circulation Models (assuming economic scenario A2ASF)



Source: Bruci (2007).

Figure 3.7 (a). Projected Change in Temperature over Europe by the 2080s, According to Nine Different Models of the Atmosphere (assuming HAD300 model of the atmosphere)

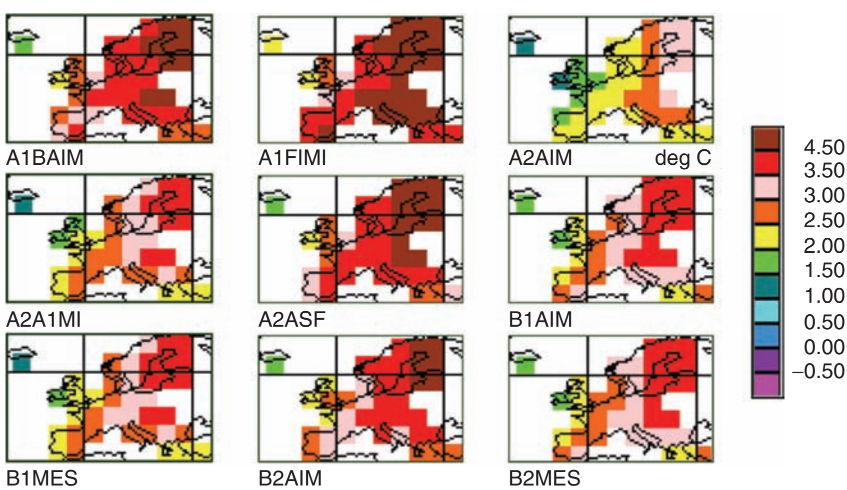
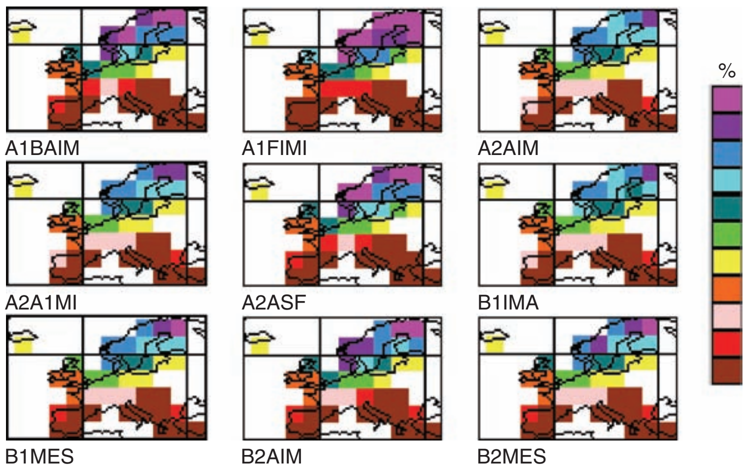
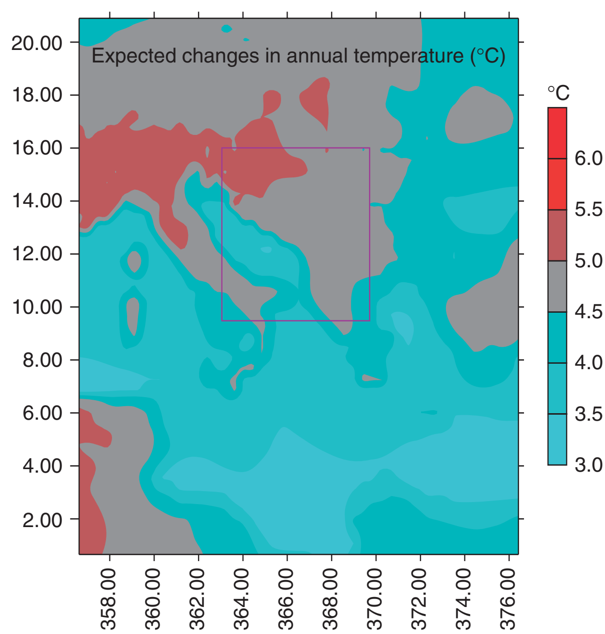


Figure 3.7 (b). Projected Change in Precipitation over Europe between Today and 2080s, According to Nine Different Models of the Atmosphere (assuming HAD300 model of the atmosphere)



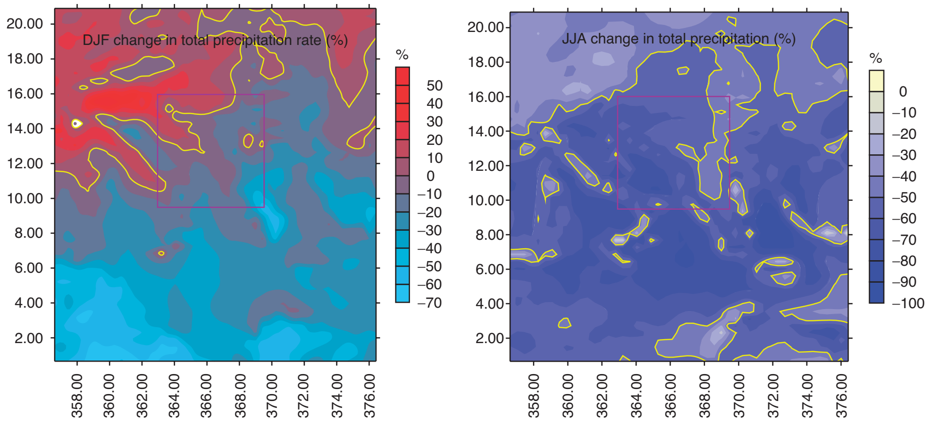
Source: Bruci (2007).

Figure 3.8(a). Projected Change in Temperature over South Eastern Europe, Assuming A2ASF/HAD300, Projected at 50 km Grid Spacing



Note: For comparison to low-resolution projections, the outlined inner block is the same size as one block in Figures 3.6 and 3.7.

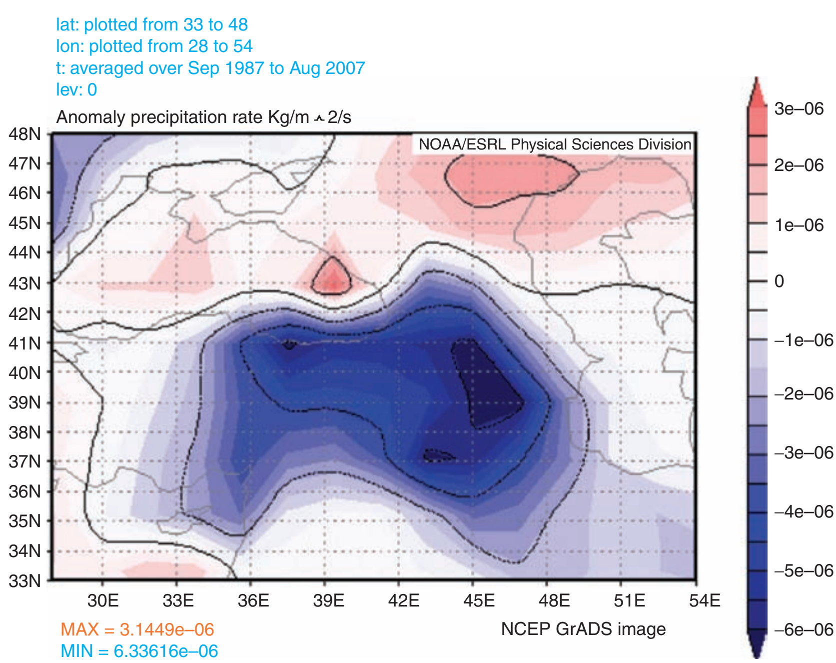
Figure 3.8(b, c). Projected Change in Winter/Summer Precipitation, Assuming A2ASF/HAD300, Projected at 50 km Grid Spacing



Note: Yellow highlight outlines boundary between areas of rising/falling precipitation trends. For comparison to low-resolution projections, the outlined inner block is same size as one block in Figures 3.6 and 3.7.

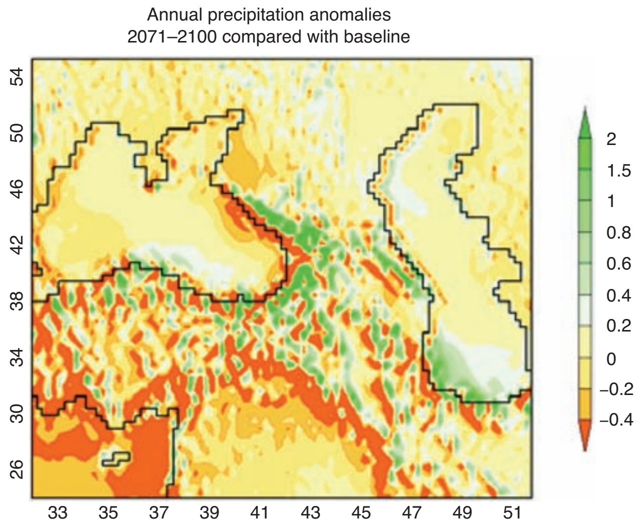
Source: Projection by Hadley Center, figure from Bruci (2007).

Figure 3.10(a). Observed Trend in Precipitation Rate, September 1987 to August 2007 Compared to 1968–96



Source: NCEP Re-analysis, see Kalnay (1996).

Figure 3.10(b). Modeled Trend in Precipitation Rate for the Period 2071–2100 Compared to 1961–90



Source: Hovsepyan and Melkonyan (2007).

Figure 4.3. Map of the Weather Stations that Report Surface Weather to the World Meteorological Organization for Global Sharing and Analysis

Note: Symbols are scaled to represent the recommended spacing for surface stations in Europe. Therefore, where topography "shows through," data shared with WMO may not sample weather patterns adequately. Only blue stations transmitted approximately the full expected reports in the monitored period.

Source: January 2006 SYNOP monitoring report.

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Worldwide, the accuracy and value of weather and climate services are rising, bringing great economic benefits. However, many national hydrometeorological services in Europe and Central Asia are in decline. As a result, these potential gains are often missed. Much more could be done to mitigate weather disasters, support the productivity of smallholding and commercial agriculture, conserve energy, and promote safe aviation and transport by road and rail. Although capacity deficiencies are serious, they could be remedied significantly by relatively modest—but sustained—investments.

Chapter 1 describes the worldwide growth in weather forecasting skill, presents principal issues and questions in Europe and Central Asia (ECA), and sets out the study's organization. Chapter 2 assesses the needs of the key sectoral clients of the national hydrometeorological services in the region. Chapter 3 addresses ECA's natural weather and climate issues: vulnerability to transboundary weather events, extreme weather, variable weather, and projected climate change. Chapter 4 presents the forecasting workflow, and then presents key regional and national capacity gaps. Chapter 5 discusses ways to estimate the economic benefit of existing and upgraded forecasting capacity.

This study is part of an ongoing Regional Working Paper Series sponsored by the Chief Economist's Office in the Europe and Central Asia Region of the World Bank.

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ISBN 978-0-8213-7585-3

SKU 17585