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ROLLING REVIEW OF REQUIREMENTS AND STATEMENTS OF GUIDANCE

STATEMENTS OF GUIDANCE

GLOBAL NUMERICAL WEATHER PREDICTION

(Submitted by Erik Andersson (ECMWF))

SUMMARY AND PURPOSE OF DOCUMENT

The document provides detailed information on the current status of the Statement of Guidance for Global Numerical Weather Prediction (GNWP).

ACTION PROPOSED

The Meeting is invited to note the information contained in this document when discussing how it organises its work and formulates its recommendations.

References: Current versions of the Statements of Guidance
http://www.wmo.int/pages/prog/www/OSY/GOS-RRR.html#SOG

Appendix: A. Statement of Guidance for GNWP

DISCUSSION

The Point of Contact (PoC) reviewed and updated the Statement of Guidance for Global Numerical Weather Prediction (GNWP) in March 2014. The new version proposed is taking into account recent changes in the global observing systems, and the increased importance of coupled assimilation with ocean and land surfaces. The PoC has involved experts on satellite data assimilation, conventional data and ocean analysis in preparing this update.

The new version is provided in the Appendix.

APPENDIX A

STATEMENT OF GUIDANCE FOR GLOBAL NUMERICAL WEATHER PREDICTION (NWP)

(Point of contact: Erik Andersson, ECMWF)
(Version approved by ET-EGOS-7, May 2012 and modifications by PoC March 2014)

Updates reflect: Recent changes in the global observing systems; and Increased importance of coupled assimilation with ocean and land surfaces

Global Numerical Weather Prediction (NWP) models are used to produce short- and medium-range weather forecasts (out to 15 days) of the state of the troposphere and lower stratosphere, with a horizontal resolution of typically 15-50 km and a vertical resolution of 10-30 m near the surface increasing to 500 m-1 km in the stratosphere. Forecasters use NWP model outputs as guidance to issue forecasts of important weather variables for their area of interest. There is a strong interest in using NWP model output to predict the risk for extreme or severe and damaging weather events. Statistical approaches based on forecast ensembles are used to predict the probability for weather events, especially at longer lead times. Such ensembles require good knowledge of the uncertainty in the NWP model and all input data including the observations. Global NWP models are also used to provide boundary conditions for regional NWP models.

NWP is an initial value problem where the accuracy of the forecasts primarily depends on how accurate the estimate of the complete atmospheric state is. Observations from surface-based, airborne and space-based platforms are all used to help define this initial state. Reliable error estimates of all observations are needed to estimate the accuracy of the initial state and to benefit optimally from observations in NWP. The observational requirements for global NWP are based on the need to provide an accurate analysis of the complete atmospheric state and the Earth’s surface at regular intervals (typically every 6-12 hours). Through a “data assimilation” system, new observations are used to update and improve an initial estimate of the atmospheric and surface states provided by an earlier short-range forecast. The uncertainty in the initial conditions is captured by ensemble Kalman filters or ensembles of data assimilations.

The key atmospheric model variables for which observations are needed are: 3-dimensional fields of wind, temperature and humidity, and the 2-dimensional field of surface pressure. Also important are surface boundary variables, particularly sea surface temperature, soil moisture and vegetation, ice and snow cover. Significant effort has gone into the use of observations of cloud and precipitation in NWP systems. In the latter part of the medium range, the upper layers of the ocean become increasingly important, and so relevant observations of the ocean are also needed.

Modern data assimilation systems are able to make effective use of both synoptic and asynoptic observations. Observations are most easily used when they are direct measurements of the model variables (temperature, wind, etc.), but the concept of observation operators has facilitated the effective use of indirect measurements (e.g. satellite radiances and the refraction of propagating radio wave), which are linked in a complex but known way to the model fields of temperature, humidity, etc. The use of four-dimensional data assimilation methods has facilitated the extraction of dynamical information from time series of observations and from frequent (e.g. hourly) and asynoptic data.

The highest benefit is derived from observations available in near real-time; NWP centres derive more benefit from observational data, particularly continuously generated asynoptic data (e.g. polar orbiting satellite data), the earlier they are received, with a goal of less than 30 minutes' delay for observations of geophysical quantities that vary rapidly in time. RARS has brought us closer to this goal. However most centres can derive some benefit from data that is up to 6 hours old.

In general, conventional observations have limited horizontal resolution and coverage, but high accuracy and vertical resolution. Satellite sounding data provide very good horizontal resolution and coverage but limited vertical resolution, and they are more difficult to interpret unambiguously and use effectively. Both conventional observations and satellite observations contribute significantly to the accuracy of NWP. Single *in situ* observations over the ocean or from remote land areas can occasionally be of vital importance. Also, a baseline network of *in situ* observations is currently necessary for calibrating the use of some satellite data. Observations are more important in some areas than in others; it is desirable to make more accurate analyses in areas where forecast errors grow rapidly, e.g. baroclinic zones and in areas of intense convection.

Recent developments on coupled forecasting systems indicate the benefits of coupling sea ice and atmosphere for the NWP forecasts. The timely initialization of the sea-ice and ocean data therefore needs to be considered. There is a trend towards merging the medium range with the extended range (30-60 days). It is likely that operational implementations of these systems will use the same ocean and sea initial conditions, and therefore the data needs are common for the two forecast ranges.

The following sections provide an assessment, for the main variables of interest, of how well the observational requirements are met by existing or planned observing systems.

3D wind field (horizontal component)

Wind profiles are available from radiosondes and pilot balloons over populated land areas and from aircraft (ascent/descent profiles), wind profilers and radars (VAD or radial winds) over some of these areas. In these areas, horizontal and temporal coverage is acceptable and vertical resolution is good. Over most of the Earth – ocean and sparsely-inhabited land – coverage is marginal or poor. Profile data are supplemented by single-level data from aircraft at flight level along main air traffic routes, and by single-level satellite winds (motion vectors from cloud or humidity tracers in geostationary imagery) over low and mid-latitudes (geostationary satellites) and over the polar regions (polar orbiting satellites). There is a gap in coverage between the polar and geostationary winds but new wind products are being developed by tracking features between geostationary and polar orbiting satellite or between two polar orbiters in similar orbits. In these areas, horizontal and temporal resolution is acceptable or good, but vertical coverage is marginal. There are very few *in situ* wind observations from the Polar Regions. In the lower stratosphere, only radiosondes provide wind information.

Accuracy is good/acceptable for *in situ* systems and acceptable/marginal for satellite winds.

Extension of AMDAR technology (principally for ascent/descent profiles but also for flight level information) offers the best short-term opportunity for increasing observations of wind, although large areas of the world would still remain uncovered. From satellites, Doppler wind lidar technology is being developed to provide 3D winds of acceptable coverage and vertical resolution, but thick cloud will provide limitations. The very small foot print of the high frequency lidar will give wind measurements in scattered cloud conditions. Advanced geostationary and polar-orbiting imager-sounders will offer some wind profile information in cloud-free areas through tracking of highly-resolved features in water vapour channels.

Surface pressure and surface wind

Over ocean, ships and buoys provide observations of good frequency. Accuracy is good for pressure and acceptable/marginal for wind. Coverage is marginal or absent over some areas in the tropics and the Arctic. Scatterometers on polar-orbiting satellites provide information on surface wind - with global coverage and acceptable horizontal and temporal resolution and accuracy. Scatterometers give information on both wind speed and direction, whereas non-polarimetric passive microwave imagers provide information on wind speed (only). Several NWP centres have noted the positive impact from scatterometer winds, in particular for the analysis and prediction of tropical cyclones and incipient frontal waves. Passive polarimetric radiometers have recently been demonstrated; in addition to wind speed, they offer directional information but of inferior quality to scatterometers at low wind speed. L-band microwave imagers have potential to provide wind speed information at very high wind speeds, where other techniques lose sensitivity, but the value of this is yet to be demonstrated in NWP.

Over land, surface stations measure pressure and wind with horizontal and temporal resolution which exceeds the requirements in some areas and is marginal in others. Measurement accuracy is generally good, though this can be difficult to use (particularly for wind) where surface terrain is not flat, because of the influence on the measurements of small scale circulations that global NWP models do not resolve (lack of representativity). Despite these problems, several NWP centres have recently successfully initiated the use of screen level wind measurements over land.

Surface pressure is not observed by present or planned satellite systems except for: some contribution from radio occultation data and measurements of differential atmospheric optical depth for a gas of known composition such as oxygen (e.g.the NASA's OCO-2 mission).

3D temperature field

Temperature profiles are available from radiosondes over populated land areas and from aircraft (ascent/descent profiles) over some of these areas. In these areas, horizontal and temporal resolution is acceptable and vertical resolution and accuracy are good. Over most of the Earth – ocean and sparsely-inhabited land – coverage of in situ data is marginal or absent. Profile data are supplemented by single-level data from aircraft along main air routes, where horizontal and temporal resolution and accuracy are acceptable or good.

Polar satellites provide information on temperature with global coverage, good horizontal resolution and high accuracy. Vertical resolution from passive microwave and first-generation infra-red filter radiometers is marginal. Second-generation, advanced infra-red systems have improved acceptable vertical resolution. Microwave measurements from AMSU-A provide considerable information, including in cloudy areas with moderate amounts of cloud water, and strong positive impacts have been demonstrated by all global NWP centres, to the extent that this is now the single most important source of observational information for global NWP, even in the northern hemisphere, given that at least 2-3 AMSU-A sounders with complementary orbits are available. Data from high resolution infra-red sounders (AIRS on EOS-Aqua, IASI on METOP and CrIS on S-NPP) have also shown strong positive impact, and similar data will become available from instruments on JPSS (CrIS)), Feng Yun-3 (HIRAS), Feng Yun-4 (GIIRS) and Meteosat 3rd Generation (IRS). Satellite sounding data are currently under-utilised over land, but progress in this area is being reported. Biasfree radio-occultation measurements now complement other systems through high accuracy and vertical resolution in the stratosphere and upper to mid troposphere with demonstrated significant NWP impact. Generally, both microwave and infrared radiance data containing information on lower-tropospheric temperature is under-utilized due to surface emissivity and land-surface temperature uncertainties.

3D humidity field

Tropospheric humidity profiles are available from radiosondes over populated land areas. In these areas, horizontal and temporal resolution is usually acceptable (but sometimes marginal, due to the high horizontal variability of the field), vertical resolution is good and accuracy is good or acceptable. Over most of the Earth – ocean and sparsely-inhabited land – coverage is marginal or absent. An increasing number of aircraft provide humidity measurements alongside wind and temperature measurements. Some of these data are not generally available. The recently introduced humidity sensors have high accuracy.

Polar-orbiting sounding instruments provide information on tropospheric humidity with global coverage, good horizontal resolution and acceptable accuracy. Vertical resolution from passive microwave and first-generation infra-red radiometers is marginal. Second-generation, advanced infra-red systems have improved acceptable vertical resolution. Microwave measurements from AMSU-B,MHS, SSMIS and MWHS have shown significant impacts. Data from high resolution infra-red sounders (AIRS on EOS-Aqua, IASI on METOP and CrIS on S-NPP) is used operationally, and similar data will be available from instruments on JPSS (CrIS)), Feng Yun-3 (HIRAS), Feng Yun-4 (GIIRS) and Meteosat 3rd Generation (IRS)Geostationary infra-red radiances, particularly in water vapour channels, are also helping to expand coverage in some regions by making frequent measurements and thus creating more opportunities for finding cloud-free areas. Satellite sounding humidity data are currently under-utilised over land, but progress in this area is anticipated in the near future. Radio-occultation measurements have potential to complement other systems by providing information on the humidity profile in the lower troposphere. Over ocean, coverage is supplemented by information on total column water vapour from microwave imagers. Over populated land areas, growth is expected in the availability of total column water vapour data from ground-based GPS measurements from national (geodetic) networks. At the moment these are generally available for Europe and USA. Also over land, total column water vapour information is available from near infra-red imagery (e.g. MODIS).

Sea surface temperature

Ships and buoys provide observations of sea surface temperature of good temporal frequency and accuracy. Coverage is marginal or absent over some areas of the Earth, but recent improvements in the *in situ* network have enhanced coverage considerably. Infra-red instruments on polar satellites provide information with global coverage, good horizontal resolution and accuracy, except in areas that are persistently cloud-covered. Here data from passive microwave instruments on research satellites has been shown to be complementary. Temporal coverage is adequate for short-medium range NWP but, for as the forecasting systems evolve the diurnal cycle is becoming increasingly important, for which present and planned geostationary satellites offer a capability.

Sea-ice

Sea-ice cover and type are observed by passive microwave instruments and scatterometers on polar satellite with good horizontal and temporal resolution and acceptable accuracy. Data interpretation can be difficult when ice is partially covered by melt ponds. Operational ice thickness monitoring will be required in the longer term, as demonstrated by CryoSAT. Inferred estimations of thin sea-ice thickness by SMOS are receiving increasing interest.

Ocean sub-surface variables, Sea Level and Surface Salinity

In the latter part of the medium-range (~7-15 days), the role of the sub-surface layers of the ocean becomes increasingly important, and hence observations of these variables become relevant. In this respect the requirements of global NWP are similar to those of seasonal and inter-annual forecasting (see SoG on Seasonal and Inter-annual Forecasting). However, the NWP and sub-seasonal forecasting have higher requirements on timelines and vertical sampling of the ocean mixed layer

Sea level from altimeter data is becoming more important as the resolution of the ocean component increases. The exploitation of altimeter sea level benefits from geoid information, such as thus derived from the gravity missions (GRACE and GOCE).

Surface salinity affects the mixed layer properties and can affect SST evolution. It is expected to become increasingly important as a proxy for accumulated precipitation. with the advent of coupled data assimilation systems.

Snow

Over land, surface SYNOP stations measure local snow depth with high accuracy and good temporal resolution. However many SYNOP messages omit snow depth observations when snow is not present on the ground and large regions and countries show extremely sparse SYNOP stations reporting snow depth. Additional national networks provide near-real time data to their country. Making available the national snow data to the NWP community would be very useful. This is the objective of the Global Cryosphere Watch programme “Snow Watch initiative to improve in-situ snow observations”. Visible and near infra-red satellite imagery provide information of good horizontal and temporal resolution and accuracy on snow cover extent (but not on snow mass) in the day-time in cloud-free areas. Microwave imagery offers the potential of more information on snow mass (at lower but still good resolution) but data interpretation is difficult. Snow cover over sea-ice also presents data interpretation problems.

Soil moisture

Low-frequency microwave imagery and scatterometer data are sensitive to surface wetness, with a penetration depth dependent on the wavelength of the radiation and surface type and soil moisture itself. An operational soil moisture product is now available from ASCAT onboard the Metop series. The data is of acceptable temporal and spatial resolution with marginal accuracy. Passive L-band microwave imagers on research satellites (e.g. SMOS, SMAP) also offer considerable potential. Some land surface stations report soil moisture routinely (e.g. SCAN network in US) but coverage is limited and far from homogeneous. The International Soil Moisture Network (ISMN) initiative coordinated by GEWEX collects national soil moisture networks but data latency can be variable (and non real-time). Near-real time soil moisture in-situ measurements with global coverage would offer great potential.

Surface air temperature and humidity

Over ocean, ships and buoys provide observations of acceptable frequency and acceptable accuracy (except ship temperatures during the daytime, which currently have poor accuracy). Coverage is marginal or absent over large areas of the Earth. Over land, surface stations measure with horizontal and temporal resolution which is good in some areas and marginal in others. Measurement accuracy is generally good, though this can be difficult to use where surface terrain is not flat, because of the influence on the measurements of local variability that global NWP models do not resolve (poor representativity). Despite these problems, several NWP centres have been using screen level humidity and temperature data with success in their land surface and atmospheric data assimilation systems. Satellite instruments do not observe these variables, or do so only to the extent that they are correlated with geophysical variables that significantly affect the measured radiation (i.e. skin temperature and atmospheric layer-mean temperature and humidity).

Land and lake-sea-ice surface skin temperature

Satellite infra-red and microwave imagers and sounders provide data containing information on these variables, although retrieval accuracy is affected by cloud detection problems and surface emissivity uncertainties, and interpretation is difficult because of the heterogeneous nature of the emitting surface for many surface types. The diurnal cycle of surface temperature is usually not well sampled except for sensors onboard geostationary satellites (e.g. SEVERI on MSG) that cannot provide global coverage. Otherwise, present and planned instruments offer data of good resolution and frequency.

Vegetation type and cover

Present-day operational satellite imagery from visible and near infra-red channels offers good resolution and frequency, and marginal accuracy. Research instruments, such as MODIS, offer considerably improved accuracy.

Clouds

Surface stations measure cloud cover and cloud base with a temporal resolution and accuracy that is acceptable but a horizontal resolution that is marginal in some areas and missing over most of the Earth.

Satellite instruments offer a wealth of information on cloud. Infra-red imagers and sounders can provide information on cloud cover and cloud-top height of good horizontal and temporal resolution and good/acceptable accuracy. Microwave imagers and sounders offer information on integrated cloud liquid water of good horizontal resolution and acceptable temporal resolution, with an accuracy that is probably acceptable (though validation is difficult).

At present the primary problem is not with the cloud observations themselves but with their assimilation, arising from representativeness problems and weaknesses in data assimilation methods and in the parameterisation of cloud hydrometeors and other aspects of the hydrological cycle within NWP models. Substantial improvements in these areas will be needed in order to make more use of the available observations over the next decade. Resolution increases and more flow-dependent data assimilation systems will to some degree help.

Current and planned visible and infra-red imagers offer some information on cloud drop-size at cloud top. Active optical (lidar) microwave (radar) instruments are required to give more information on the 3D distribution of cloud water and ice amounts and cloud-drop size. Some research instruments have been launched and more are planned. A sub-mm imager is planned for Metop second generation that will give detailed information on ice clouds (ICI).

Precipitation

Surface stations measure accumulated precipitation with a temporal resolution and accuracy that is acceptable. The horizontal resolution is poor in large parts of the world, and where coverage is good the data is often not available for international distribution. Ground-based radars measure instantaneous precipitation with good horizontal and temporal resolution and acceptable accuracy, but over a few land areas only. Significant effort to facilitate its global distribution is urgently required as is the provision of inter-calibrated rainfall products from radar networks

Microwave imagers and sounders offer information on precipitation of marginal horizontal and temporal resolution, mostly on the integrated liquid rainwater path, and acceptable/marginal accuracy (though validation is difficult). Geostationary infra-red imagers offer some information at much higher temporal resolution through the correlation of surface precipitation with properties of the cloud top, but accuracy is marginal due to the indirect nature of this relationship. Satellite-borne rain radars, together with plans for constellations of microwave imagers, offer the potential for improved observations.

Ozone

Ozone is being added as a new NWP model variable at several global centres. More accurate model ozone fields can improve the model radiation calculations and the assimilation of infra-red temperature sounding data. The accuracy of total column ozone obtained from satellite instruments is acceptable and has improved with the availability of high resolution infra-red sounders and more accurate solar backscatter instruments. However, to maintain realistic vertical distributions of ozone in NWP models, vertically resolved ozone information is needed, and could be useful even when available at lower horizontal and temporal resolution than retrieved from satellite instruments. A number of ozone sondes are launched once a week at widely spaced locations and their data are available to NWP centres. However, the timeliness of this data is normally not compliant with NWP near-real-time requirements, so that their usage is often limited to model validation. In addition, some of this data is not internationally distributed. Great potential is offered by microwave limb sounders (e.g. MLS) because they offer good vertical resolution and accuracy.

Wave height, direction and period

Ships and buoys provide observations of acceptable frequency and acceptable/marginal accuracy. Coverage is marginal or absent over large areas of the Earth.

Altimeters on polar satellites provide information on significant wave height with global coverage and good accuracy. However, horizontal and temporal coverage is marginal. Information on the 2D wave spectrum is provided by SAR instruments with good accuracy but marginal horizontal and temporal resolution.

3D aerosol

Assimilation of aerosols is generally immature in global NWP but is likely to increase in importance. Operational visible and near infra-red satellite imagery is used to provide estimates of total column amounts over the ocean with good horizontal resolution and acceptable temporal resolution but marginal accuracy. Advanced imagers such as MODIS have improved accuracy for total column amounts and provided information on aerosol particle size and type, and information over land. However, retrieved quantities are of column totals and means only. Data from radiometers measuring backscattered visible or ultra-violet radiation, such as OMI on Aura, can be used to obtain more accurate estimates of aerosol properties and total column amounts. Geostationary imagers are also useful to monitor the temporal evolution of high-aerosol events (e.g. dust storms). Lidar measurements will be required to provide vertically resolved information; research demonstrations are under way.

3D wind – vertical component

There is currently no present or planned capability. Research is required on indirect observation via sequences of geostationary infra-red imagery, or through Doppler enabled microwave sensors.

Additional observations for model evaluation

Data for model evaluation on the process level is important for NWP model development. Such data is becoming increasingly available from satellites, ground based observations and experimental campaigns. Here we mention just a few examples of widely used observations.

Top of the atmosphere longwave and shortwave radiation fluxes are very basic quantities for NWP and climate models and can be estimated, with varying degrees of accuracy, from several broadband or multi-spectral infra-red and visible satellite radiometers designed primarily for other purposes. Specialised instruments designed to measure accurately some component(s) of the Earth's radiation budget include CERES on TRMM, TERRA and Aqua, and GERB on MSG. Horizontal resolution is good. Accuracy is acceptable and depends on the accuracy of the absolute calibration and of the radiance to flux conversions.

Surface radiation fluxes are equally important, but more difficult to estimate. Surface short wave radiation is highly correlated with the top of the atmosphere and the satellite derived products have therefore acceptable accuracy (e.g. SRB). However, surface long wave fluxes are more difficult. Surface observations e.g. from the BSRN project fill an important gap and are also important for calibration due to their high accuracy.

Surface albedo can be estimated from shortwave broadband or multi-spectral radiometer measurements with good horizontal resolution. Clouds, aerosols and atmospheric gases affect the accuracy achievable, which is currently marginal or acceptable but should become good as progress is made in interpreting data from high-resolution, multi-spectral instruments.

Clouds and precipitation and there interaction with radiation are a substantial source of uncertainty in models. Examples of relevant data sets are the ISCCP satellite derived product for cloud cover, microwave imager derived liquid water path, microwave limb sounder derived ice water path and precipitation from microwave/infrared instruments and radar (TRMM). All these observations and derived products play an important role in model developments although there accuracy is limited. The requirements for accuracy increase as models improve. A relatively new source of information is from cloud lidar and cloud radar. They allow to measure the vertical structure of cloud properties and aerosols from space (Cloudsat/CALIPSO and EarthCare in future) or from the ground (e.g. ARM stations). Exploration of these data sources in the context of model development is an active area of research.

Research on land surface processes benefits increasingly from advanced data sets. Examples are: leaf area from e.g. MODIS, land surface temperature from infrared window channels and soil moisture from ASCAT and SMOS. However, surface turbulent fluxes can only be inferred from space by indirect methods. In the interpretation and evaluation of data, in-situ observations are crucial. Isolated tower observations projects have gradually evolved from campaigns, to long term monitoring and to networks (e.g. FLUXNET).

SUMMARY OF STATEMENT OF GUIDANCE FOR GLOBAL NWP

Global NWP centres:

- make use of the complementary strengths of *in situ* and satellite-based observations;
- have shown strong positive impact from advanced microwave sounding instruments (such as AMSU-A);
- have shown strong positive impact also from high spectral resolution sounders with improved vertical resolution (AIRS and IASI);
- have shown strong positive impact from radio occultation data in the upper troposphere and lower stratosphere in particular;
- use 4D data assimilation systems to benefit from more frequent measurements (e.g. from geostationary satellites, aircraft and automated surface stations) and from measurements of cloud, precipitation, ozone, etc.;
- benefit from the improved timeliness of key satellite data resulting from systems such as RARS
- would benefit from further increased coverage of aircraft data, particularly from ascent/descent profiles in the tropics;
- are beginning to see the benefits from global dissemination of high-resolution BUFR radiosonde measurements with detailed time-space information
- would benefit from more timely availability and wider distribution of some observations, in particular several types of in situ measurement and radar that are made but not currently disseminated globally, such as soil wetness, snow depth, precipitation from rain gauges and radar and ground-based GPS;
- would benefit from more ice thickness data and surface salinity.

The critical atmospheric variables that are not adequately measured by current or planned systems are (in order of priority):

- wind profiles at all levels outside the main populated areas;
- temperature and humidity profiles of adequate vertical resolution in cloudy areas, particularly over the poles and sparsely populated land areas;
- satellite based rainfall estimates;
- snow equivalent water content.