Third WMO Workshop on the Impact of Various Observing Systems on NWP
Alpbach, Austria, 9-12 March 2004

WORKSHOP SUMMARY AND CONCLUSIONS

1. Introduction

The Fourteenth Congress (Geneva, May 2003) noted with satisfaction the challenging work being continued by CBS on the redesign of the GOS, which had already resulted in updated observational requirements of all WMO Programmes and a first assessment of the evolution of the surface- and space-based components of the GOS. This complex process involves experts and decision makers in observing technology, network design, data assimilation techniques and NWP, and eventually may require new joint funding mechanisms for the deployment of observing equipment and systems in remote and/or extraterritorial areas. It should be also underlined, that Member countries have a great interest in optimising their investment in observing systems with the view that advancing scientific knowledge and technology provide opportunities for increasing the availability of observational data while reducing the costs. In the light of the above CBS had continued to accomplish, as a matter of priority, several important actions through its Open Programme Area Groups (OPAGs) and, in particular OPAG on Integrated Observing Systems, by organizing and co-sponsoring expert meetings, workshops and studies focus on the redesign of the GOS.

This WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction organised by the CBS Expert Team on Observational Data Requirements and Redesign of the Global Observing System is considered as another important step forward in the process of redesign of the GOS. Special thanks should be extended to the Coordination Group for COSNA (CGC) chaired by Mr M. Lystad for their decision to provide the financial resources needed for this Workshop from the COSNA Trust Fund and Dr Helmut Rott from the University of Innsbruck for the help and coordination of the local organization of the Workshop in Alpbach.

Since previous Workshops that took place in Geneva (April 1997) and in Toulouse (March 2000), certain significant changes and developments have affected both surface-based and satellite-based subsystems of the GOS. That included new onboard instruments on operational satellites and launches of more R&D satellites. Intensive data assimilation studies (including impact studies) on these new data were carried out from 2002 onward. The conventional observing systems related to radiosonde and aircraft observations are also changing as demonstrated by regional programmes like EUCOS or NAOS. Targeting strategies started to be implemented in operational activities of some NMHSs and also envisaged in major research projects like THORPEX. More and more efforts are devoted to meso-scale observing and assimilation systems.

At this Third WMO Workshop the key recent results in all these areas were presented and discussed. The Workshop's agenda covered three major sections including Global Forecast Impact Studies, Regional Aspects of Impact Studies, Observation Targeting Studies and Observation Network Design Studies, where 30 lectures were presented. Almost 50 experts representing all major NWP and other centres active in the area of observing system impact studies, as well as representatives of the CGC Management Group and the WMO Secretariat attended the Workshop. The programme of the Workshop and the list of participants are given in Annexes I and II respectively.

The full text of papers presented at the Workshop as provided by the authors are reproduced in the second part of the Proceedings.

Section 2 of this report contains the assessment of impacts from various observing systems. Section 3 presents specific recommendations focused on implementation of evolving user's requirements as had developed under each section of the Workshop. Section 4 lists the overall conclusions and recommendations from the Workshop.

2. Assessment of impacts from various observing systems

2.1. Global impact of some global observing systems

An up-to-date summary of the impact from different observation types and parameters over the northern and southern hemisphere extra-tropics and tropics is presented in Table 1. The value given for each observation type resulted from all recent studies, in particular those presented at this Workshop. The results are expressed in terms of gain in large-scale forecast skill at short and medium-range (unit = hour). The gain is assessed by adding the observing system to all others used routinely in the assimilation. Since the number of observing systems routinely used varies considerably from centre to centre, this marginal gain may also vary considerably from one study to the other. The table also shows those variations of gain whenever they are supported by significant studies, otherwise general comments are provided. The table also contains notes with indication of whether the overall contribution to the skill of the NWP systems has increased/decreased as compared with assessments of the Workshop-2000. More and more satellite data are used by the more advanced data assimilation systems (but not necessarily by all operational assimilation systems). This explains an increase in the contributions from satellite sub-systems of the GOS to the performance and the skill of NWP systems. As a consequence, other components of the GOS, such as the radiosondes, now have less impact. Overall, the contributions from the satellite and radiosonde data towards the performance of the NWP systems in the northern hemisphere gave similar impact as presented in the synopsis of the results from the Workshop (see Table 1).

The table should be considered as a rough guide. It is implied that the magnitudes of the impact depend upon the model and assimilation scheme used, upon the impact variable and also the forecast range. The following specific remarks have also to be kept in mind when using the table.

- **a)** Some observing systems that are rated low individually (e.g.: several grey bullets in the table which correspond to "neutral to a few hours") may have a significant impact when acting together (modest but complementary contributions). Some of them have also a large impact on the very-short range forecast (e.g.: aircraft reports), which does not appear in this table.
- **b)** Some global observing systems (such as scatterometer data or surface wind observations in general) have an impact, which grows with the resolution: these data have a modest impact on the long waves but they are important for determining (e.g.) the exact position and characteristics of a cyclone.
- **c)** Very local observing systems cannot be rated globally and do not appear in the table (for example MODIS winds). They are mentioned in section 2.2.

Table 1

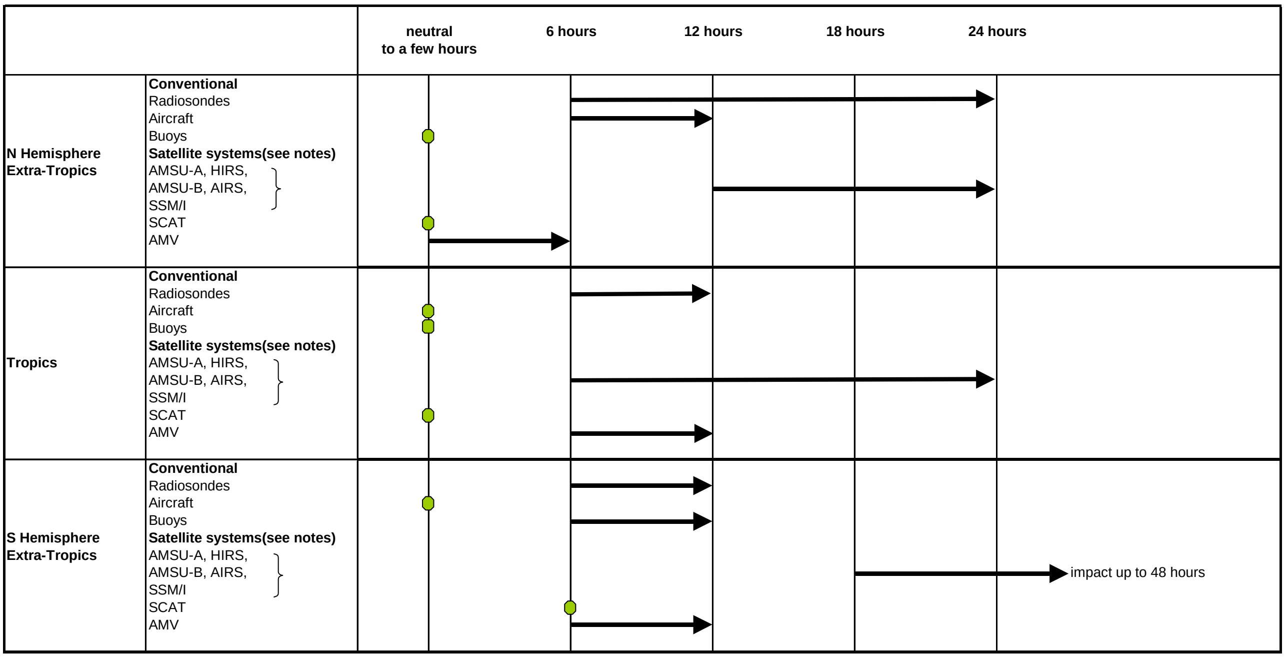

Table 1: Current contributions of some parts of the existing observing system to the large-scale forecast skill at short and medium-range

Notes:

1. SATELLITE SYSTEMS

AMSU-A................The dominant and more largely used sub-system
HIRS.......................Less important than AMSU-A, useful complement for humidity
AMSU-B................Not used yet in many centres: important for humidity over land
AIRS.......................Evaluation just starting (equivalent to one AMSU-A)
SSM/I......................Important impact on humidity fields (esp. tropics and SH)

2. OBSERVATION PARAMETER TYPE

Surf. Pressure Ps.....Important to anchor model Ps. (large model biases otherwise)
Surf. Wind..............Less important than Ps, useful complement (see SCAT)
Wind profiles.........The more important information to observe, esp. in the tropics

3. EVOLUTION OF THE RELATIVE IMPACT OF VARIOUS OBSERVATION TYPES

Compared to results obtained at previous workshops
(i) …..…………….The relative impact of satellite data has increased
(ii)……..…………Consequently, the relative impact of radiosonde data has decreased
(iii)………..………The impact of aircraft data has slightly increased

2.2. Impact of some regional observing systems

A significant number of studies presented at this Workshop deal with the impact of observations on regional and mesoscale NWP. These studies are able to evaluate the impact of systems, which are deployed only on a local basis: radars, profilers, GPS networks… This was not the case in the previous Workshops. One can now try to summarise the impact of observations on regional and mesoscale NWP (then the impact is often concentrated on very short range forecasting).

a) **High-density aircraft data** with also ascent and descent observing phases (such as the ACARs in the US) contribute to an important reduction of the RMS error in the forecast range 3 to 12h. When they are not available (during the night) profiler data are an interesting substitute, because they can report very frequently. When neither aircraft data nor profiler data is available for a region, it is important to have a dense radiosonde network reporting at least every 12h.
b) **MODIS winds** (AMV from polar orbiting satellites) show a positive impact, very significant to the north of 60N. This is obviously related to the lack of wind observations on the polar cap in all the other observing systems.

c) **Radiances and high-resolution winds from geostationary satellites** show also a positive impact, especially on the location and intensity of specific weather events.
d) **Precipitation data from radars** are now assimilated in various mesoscale systems. They do improve the location and intensity of precipitation forecasts at very short range; the improvement seems larger in sophisticated data assimilation systems.
e) **GPS observations** (Zenithal Total Delay or Precipitable Water) obtained from surface networks show occasionally some modest positive impact; this is encouraging for a system that is still in development.

3. Reports from the sessions

3.1 Session 1: Global Forecast Impact Studies (chaired by Lars Peter Riishojgaard and Jean-Noel Thepaut)

3.1.1 Overall impact of various components of the GOS

It is confirmed from all global data impact studies confirmed that satellite data, in particular ATOVS data, are the major source of information in NWP systems. The satellite data dominate in the SH, but in the NH large variability can still be found in the results depending on the NWP and data assimilation system used. There is also a large seasonal dependency. AMSU has much larger impact than HIRS (except for low level humidity fields).

The ability of global NWP systems to use satellite data has evolved remarkably over recent years, but several issues remain to be resolved, e.g. the best use of SSM/I data and the appropriate thinning of Automated Motion Vectors (AMV) data. Modeling capabilities must continue to grow and must be developed in step with the use of the data.

The approach for conducting and evaluating impact studies should be revisited. The overall impact of one component of the observing system can be established through denial studies (incremental approach) or through impact assessment by adding the observations to a baseline system.

It was noted that the overall impact on global model performance of some data types may be small but may be better reflected in individual cases and synoptic patterns. Weather parameter verification and synoptic studies are an essential part of the evaluation process.

Regarding guidelines for the evaluation of impact studies, there is a need for regional cases studies and time series verification.

3.1.2 Humidity analysis

A number of issues related to low tropospheric humidity have been identified. SSM/I provides information on horizontal distribution, but its vertical distribution is poorly defined. Adjoint studies show very large sensitivities in heat processes to errors in the humidity distributions. Analysing and modeling the low level humidity is not only an observational problem but also a modeling problem.

Stratospheric humidity fields are also important as demonstrated in bias and sensitivity studies. However, these features are poorly understood and most of the differences in assimilation systems are mainly based on differences in the model physics. Depicting the stratosphere is also both a modeling and an observation problem.

Only a few radiosondes penetrate deeply into the stratosphere. The value of these data has been established, but it remains an open issue how many of these are required for global NWP and what their global distribution should be. A problem is that NWP models assimilate humidity observations from satellites obtained only over cloud-free areas in dry air (clear skies). Under these circumstances, radiosondes provide the only measurements in cloudy systems. More effort should be made toward assimilating rain affected / cloudy radiances.

3.1.3 Tropical analyses

Lack of wind observations, in particular vertical wind profiles, hurts NWP results in the tropics. There may be a problem of predictability and additional observations may not help considerably, but if more observations would be available are to come in 10 years, or so, assimilation and models have to be ready. Thus, the workshop recommends a “small careful yes” in terms of for improving wind observations in the tropics, as long as modeling and assimilation techniques improve in parallel.

3.1.4 Observation targeting

Observation targeting is discussed in at the Workshop’s Session 3 (see section 3.3 of this summary). The targeted use of high-resolution satellite data could be of particular interest in the future. It will require the development of adequate corresponding data assimilation capabilities.

3.1.5 Timeliness

The requirements for early delivery and frequent updates of forecast guidance have evolved over recent years. NWP centres have significantly reduced their data cut-off times at the expense of available observations in their data assimilation processes. Timeliness requirements for observational data are becoming more stringent for NWP centres. HH + 20 to 90 minute data cut-off times are currently applied for many NWP short-range runs. Late data can only be assimilated in update runs with long data collection times (several hours). Within the next few years, a data processing and delivery time of approx 20 to 30 minutes is expected to be the operational requirement used in medium and short-range forecasts. Any minute gained is useful because observation arrival drives the rest of the forecast production chain. It is expected that NPOESS will be compliant, but further developments will be needed for METOP to meet these timeliness requirements.

3.1.6 Remarks concerning specific data types

3.1.6.1 AIRS

AIRS data are now assimilated either in research or operational mode at a number of centres; there is a modest impact despite poor treatment of data in clouds and a conservative data assimilation approach (we are still on the learning curve).

AIRS is a research instrument. As the distinction between research and operational instruments is fading away, the use of AIRS in an operational context is important. Research satellites are considered to be part of the GOS within the CBS; thus in this context they are really part of the NWP operational systems.

Future improvements will come from assimilating AIRS cloudy radiances. Furthermore it may be possible to infer atmospheric motions from AIRS radiances or AIRS retrieval fields; these could serve as a proxy to the MODIS wind products.

The preparation phase completed pre-launch for AIRS serves as a good example of collaboration between data producers and users.

3.1.6.2 AMSU

AMSU data are critical for successful NWP and the time spacing between satellites should be optimal (need for data from satellites in morning and afternoon orbits). NWP centres are concerned by the possible failure of NOAA-15. It is not known at this stage if SSMIS will serve as a replacement for the early morning AMSU. It was noted that the SSMIS is still an unfamiliar data set; no data have been released yet.

Interaction with NWP centres early after satellite launch and preferably during the cal/val phase is desirable. In this context, the excellent experience and interaction with NESDIS prior to the release of AIRS data was underlined cited in this context.

NWP centres are making efforts to make better use of cloud-affected radiances. Work is also underway to assimilate satellite data over land (and a better treatment of data at land-sea boundaries); this should be encouraged further (especially if the conventional network is would degraded further). The use of HIRS data over sea/ice/land boundaries is also a problem for HIRS.

3.1.6.3 AMVs

AMVs are a useful component of the GOS. NWP centres apply heavy thinning to the AMVs prior to their assimilation. The difference between the scales resolved in the data assimilation systems and those observed in the satellite data remains a problem. The QI information has been a valuable addition to the AMVs, and the CGMS efforts to unify the product have been of great help.

WMO and CGMS were very supportive in harmonizing the QI and the format for AMVs. This was acknowledged with appreciation by the workshop. However, it was noted that more interaction is still needed to achieve a better understanding of the processing and generation of these products. The International Winds Workshop (planned for June 2004) was seen as an important forum for communicating such information. The Workshop would encourage data providers were encouraged to make available more information regarding the AMVs estimates, e.g. with to attach the appropriate weighting function attached.

There still remains considerable room for improvement in the exploitation of high resolution winds in global NWP (super-obing?, adaptive sampling, accounting for AMVs representativeness, height assignment, etc. …). THORPEX may provide the opportunity for investigating adaptive sampling.

3.1.6.4 MODIS winds

MODIS winds are a unique source of wind observations at high northern and southern latitudes. Mostly positive results have been reported from impact studies with global NWP systems, but occasional negative impact has been reported from using the data over the southern hemisphere. Several NWP centres expressed an interest in using the data.

MODIS winds appear to have become an important part of the space observing system (operational use at ECMWF and GMAO, positive results seen by a number of centres). Improvements are currently being made in the MODIS wind production as it is being transferred to NESDIS.

The workshop recommended that an operational follow-on to MODIS polar winds be secured (this requires a water vapour channel on the operational imagers on NPOESS and METOP). In the longer term, direct use of radiances over the poles will also merit investigation (where surface emissivity over ice, spatial resolution, … need some study).

3.1.6.5 Scatterometer winds

Scatterometer data are being used operationally at ECMWF and other centres. They can be crucial for resolving synoptic features, e.g. for depicting tropical cyclones. It is important to capitalize on these research missions (ERS-2, QuikSCAT). It is also important to become familiar with other space-based surface wind observations as soon as possible; in this context, it was noted with dismay that data from the Windsat/Coriolis mission has not been made available to the NWP community to date.

3.1.6.6 Precipitation data

Satellite precipitation observations are or will be used operationally, with the precipitation radar from space (TRMM-PR) used for validation. Such an activity may help to reconcile the assimilation of observations in clear air and cloudy areas and should have high priority.

3.1.6.7 GPS radio-occultation measurements

Ongoing research in GPS radio-occultation measurements has been encouraging (from results obtained by the MetOffice and GMAO). The complementary effect from the use of data from different observing methods (limb and nadir) was pointed out. This raises the question whether this type of observation reduces the need for stratospheric radiosonde observations? It was noted that specific OSEs could be carried out done to answer this question, but any conclusion would be is premature at this stage (data coverage before COSMIC will remain marginal).

3.1.6.8 Space based Lidars

OSSEs have been completed that look realistic (they include systematic errors and have been verified against real observations) and show encouraging results. ECMWF evaluates ADM-AEOLUS data through ensemble analyses (to avoid the definition of the “truth” nature run).

3.1.6.9 Radiosondes

Radiosondes remain essential for global and regional NWP. However they are the only observations for which we do not know in detail precisely when and where the measurements are performed. There is a recommendation to include the time stamp, the sensor, and sensor sub-type information, etc… in the message (using the BUFR code). This is most important for limited area models. There is a general WMO strategy to move away from character code to binary code within eight years. The workshop reiterated the need for a timely distribution of radiosonde observations in BUFR with all significant points included in the message together with the time of observation and the position of each data point.

Impact studies have confirmed the positive contribution of the radiosondes to regional and global NWP. Further to this, studies to assess the relative value of the radiosondes for use in bias corrections in the Radiative Transfer (RT), a forward model should be considered.

3.1.6.10 Surface observations

Despite the overwhelming volume of satellite data, surface data (in particular surface pressure) over sea remain a requirement to anchor the pressure field. Surface data are important not only in global NWP, but also for regional NWP.

The impact of surface pressure and wind data was addressed in several OSEs. A large negative impact was found when surface pressure data were removed. There is no alternative equivalent source of observations available. Good quality surface pressure observations are of particular importance over the oceans. Surface pressure observations from ships only, in the presence of surface wind data, manage to recover much of the forecast skill lost when surface pressure observations are removed.

It was concluded from high-resolution (T511) experiments that surface observations over sea and land are still an very important component of the GOS. Their impact can be seen at all forecast ranges (very systematic during the first 72 hours) and in all seasons, with the largest impact in summer. Data from buoys and ships are of crucial importance synoptically.

3.1.6.11 Aircraft observations

Some new results on the impact of aircraft data were presented. It was generally acknowledged that these observations are a valuable contribution to the observing system. Observations at flight level and during ascent and descent are available at high temporal resolution. All NWP centres are now making use of the data and previously stated extensions of the data coverage into otherwise data sparse regions remain highly desirable (as reported in the Toulouse workshop 2000). It was noted that the AMDAR system is easily adaptable to observation targeting.

3.1.6.12 Ground based GPS

The use of Integrated Water Vapour information (or Zenithal Total Delay – ZTD) obtained from ground based GPS systems is currently being tested, mainly in regional models. The data processing needs to be standardized and the correction of data biases needs to be addressed. These data will also be of interest for use in global models. Global exchange of these data was recommended.

3.1.7 General template for running OSEs

It was noted that it would be highly desirable for a list of recommendations to be drafted that provide a guide for running and evaluating OSEs (same time periods under investigation among different centres). Coordination is needed to define how to evaluate the impact of a given instrument: guidance is needed on whether to run a denial experiment from the full observing system or to add a new instrument on top of an agreed upon basic system, how many days constitute a minimum number of days to run the OSE, etc…. A guidance document exists within ET-ODRRGOS that could serve as a starting point. This could be reviewed and updated by a subgroup of the workshop. It was mentioned that some degree of freedom should be left to the users because internal constraints often exist and because a large variety of impact studies allow cross-referencing of results.

3.1.8 OSSEs

The evaluation of new instruments, dropsonde capabilities, etc… could be done through OSSEs (note comments in section 3.1.6.8), but this requires a well-maintained and updated system (nature run, new real and synthetic observation types, etc…). This is also labour and computer intensive.

3.2 Session 2: Regional aspects of impact studies (chaired by Per Undén and Stan Benjamin)

3.2.1 Themes of the session

The major themes in this session were focused on the:

- need for more development work at regional scale
- regional OSEs which tend to rely more on case studies
- assimilation of data from research observing systems is growing and better understood
- need for improved regional and upstream observing systems, but also for considerable additional work on satellite data assimilation

3.2.2 Observing systems

3.2.2.1 Precipitation

Work on the assimilation of precipitation data has been undertaken at several centres:

- JMA - variational assimilation of 1h precipitation fields
- Meteo Swiss – latent heat nudging to 2 km radar reflectivity
- NCEP-Eta/EDAS – precipitation assimilation including latent heating/water vapour
- NOAA-FSL/RUC – radar reflectivity/lightning assimilation
- NCEP-GFS, ECMWF –- global assimilation systems using SSM/I, TRMM retrieved rain rate data

The overall impact is positive; it impact is seen primarily in the first several hours, with some impact out to 24 hours.

Concerns in this area are:

- Why is there no discernible impact at longer forecast projections? Projection onto dynamics – wind and temperature fields? Modeling of convective systems? Bottom line is either through precipitation observations or through improved observations of wind and temperature, there is a need for improved dynamics (wind and temperature) at the mesoscale to improve duration of accurate precipitation predictions.
- 4D-Var and 3D-Var can both add/remove precipitating systems (e.g., JMA 4D-Var, NCEP 3D-Var for global system). Nudging may help to build systems but not to forecast them; nudging does not clear out incorrectly forecast precipitating systems.
- Why is there an over-forecasting of light precipitation – is there a need for explicit physics?

The workshop recommended a continued effort to develop more advanced data assimilation methods. Research with 3D-Var and 4D-Var systems must be undertaken that can build both clear and precipitating systems from the background field. Research on developing appropriate divergent winds from precipitation assimilation must be started initiated.

- Collection of multi-station radar data sets with Quality Control (QC) applied in a timely manner, must be implemented is very important since precipitation assimilation is most important for short-range forecasts.
- This must be done in a timely manner since precipitation assimilation is most important for short-range forecasts.

- Ultimately, this will become an issue for global assimilation, to have timely sharing of global high-resolution radar data (both reflectivity and radial winds, where available).
- Improved quality and timeliness for microwave-based rain-rate data is important.

3.2.2.2 Satellite data

A summary of the major remarks on the impact are as follows-:.

- AMSU radiances – positive impact from all studies (HIRLAM, ALADIN, CMA-GRAPES, CIMSS)
- QuikSCAT – neutral impact (HIRLAM)
- GOES and METEOSAT AMVs – positive impact (NESDIS – EDAS/NCEP – ALADIN/Morocco)
- MSG radiances – ALADIN/France
- More impact is found from moisture channels in the warm season
- Clear positive impact from radiances/retrievals from GOES; MSG data is just becoming available

Issues raised include:

- Should there be more impact in regional / higher-resolution studies, especially from AMSU-B?
- There is a problem with bias correction for regional domains
- Can regional NWP take better advantage of high-resolution satellite data without thinning?
- One common problem with the global assimilation is the treatment of clouds
- Regional NWP tends to have larger percentage of land coverage. Therefore, slightly less emphasis on satellite data assimilation in past and more competing *in situ* data over land areas.

After discussion the following recommendations were made. More experimentation and development is needed regarding assimilation in regional NWP of (a) full resolution satellite data, (b) satellite radiances/products over land, and (c) cloudy radiances. Timeliness is important for regional assimilation. Data must be available within 30-60 min for regional NWP. Research on bias correction for regional applications is needed.

3.2.2.3 GPS ground-based precipitable water

Many groups discussed the use of GPS data (JMA, FSL/RUC, HIRLAM, MeteoSwiss) and reported positive impact in several studies. These were dependent on network and processing approach. Results with RUC show a strong positive impact. GPS Precipitable Water (PW) system is very mature in the US, with large spatial coverage; there has been a strong effort to date to improve quality, especially through identifying erroneous orbit data.

Issues that remain are:

- This is still an experimental system in some areas
- Common processing methods are needed. Processing techniques from regional centres should be leveraged (US, European, Asian/Japanese processing should be coordinated).
- Only an integrated quantity can benefit from combination with multi-channel satellite moisture assimilation (and assimilation of surface moisture observations). GPS PW can also, in turn, improve calibration of satellite moisture assimilation since GPS PW is relatively bias-free with adequate processing and also not absent in full cloud cover.
- Should there be requirement for total column PW report from radiosondes? (Since significant-level data is not always available)

Recommendations include:

- Encourage common processing between regional the processing centres concerned. Need to have improved processing to address, inter alia, the bias problem noted from European GPS ZTD (Zenithal Total Delay) data. US processing does not show bias problems.
- Encourage interaction between global NWP community and global geodetic community on common interest in gathering real-time GPS data, as positioning accuracy can be greatly increased from assimilation of accurate ground-based GPS data.
- Organize and formalize data distribution via GTS.

3.2.2.4 Aircraft

Impact Use of aircraft data (used in regional models) presented at the workshop includes assessed as follows:

- FSL/RUC showed strong impact on short-range (3-12h) wind and temperature forecasts
- HIRLAM showed weak positive impact
- South Africa showed weak positive impact, but acknowledged that this is the main source of any additional data
- Impact is clearly related to the distribution/density of the aircraft data, dependent on geographical regions, and a function of airline flight structures
- Expansion of aircraft/AMDAR observations to additional carriers (e.g. freight carriers to increase night time coverage) and other, especially data-sparse regions, (especially those that are data-sparse) will clearly aid accuracy of regional NWP.
- Stronger impact in US certainly related to higher volume in US, possibly also due to use of isentropic coordinate in RUC.

3.2.2.5 Profiler

Profiler experience has been reported from JMA, FSL/RUC, ALADIN, and HIRLAM. The major results are:

- Impact is positive but dependent on network size and vertical extent of profiler observations; OSEs need to use high-frequency assimilation (at least 3h, hourly is preferable) to take advantage of profiler observations.
- Profiler networks need monitoring. This occurs in US (manual monitoring, QC flags issued for BUFR data from US profilers). European wind profiler data has shown wind speed biases, for instance, and is not currently considered highly reliable for all stations. Bird migration contamination is a problem for profiler and radar wind data.
- In US, boundary profilers (915 MHz) are being implemented for air quality monitoring purposes.
- Advantages of wind profiler data include continuous hourly data, all weather, wind profiles, and full tropospheric profiles at 441 MHz (but these are more expensive).

Recommendations include:

- Use as fully as possible.
- Monitor quality, blacklisting desirable needed (in Europe,(already done in the US)
- Encourage implementation or expansion of profiler networks, where cost effective (i.e. more expensive than aircraft but also more continuous data and not dependent on airline operations).

3.2.2.6 Radiosondes

Regional radiosonde studies were reported by FSL/RUC and CIMSS/EDAS. They find that radiosondes are clearly important and even dominant for regional OSEs, especially with winds being especially important. Moisture observations are the dominant type for short-range forecasts. Radiosondes are still the most important observation tool for verification of basic tropospheric variables - mass and wind.

Recommendations, given importance of *in-situ* data for regional NWP, are to:

- Maintain at least the current network and actively counteract any further degradation, preferably with some optimization through relocating of some stations in certain areas to minimize overlap with aircraft hubs, wind profilers, etc.).
- Maintain current network of similar size, optimized with moving of current stations in some situations (minimize overlap with aircraft hubs, wind profilers).
- Recognize the need for Ensure 12-hourly radiosonde data observations over all global land areas. These data will be critical to improving regional NWP skill for these areas (including Africa – ref – Met Office and Meteo-France studies, South America, Russia).
- Consider adding full digital data for all radiosonde transmissions, including time and position. If full levels are not transmitted, need to add precipitable water.

3.2.3 Issues

What are key distinctions between regional and global OSEs studies?

- duration of forecast – focus on 3h to 3 days
- horizontal resolution – 2-40 km
- effect of lateral boundary conditions – more pronounced with smaller domains
- use of regional and experimental data sources
- larger area covered by land, hence more conventional observational coverage
- more resolved physics such as multi-species cloud microphysics, soon chemistry/aerosol will also be added
- regional data, often not available to global models, is used
- different priorities of observation systems
- chemistry, pollution applications, environmental monitoring
- sometimes model is non-hydrostatic for high resolution
- regional NWP will encounter various new issues a few years before the same issues will be faced by global NWP

Issues remain regarding precipitation verification and guidelines for regional OSEs and case studies.

3.2.4 Summary of recommendations / conclusions for regional observing systems

- There should be a global consolidation of GPS ground-based reporting: use of common accurate orbit data, elimination of bad erroneous orbit data
- There are several possibilities for additional profile observations over land
    - aircraft – to equip other fleets
        - major and lesser carriers, especially in Africa, South America, Asia, emphasis on high-resolution ascent/descent plus enroute at jet levels
        - capability for equipping fleets serving even more local routes – emphasis on mid and lower-tropospheric data
        - moisture sensors – WVSS-2, TAMDAR?

    - radiosondes
    - wind profilers
- *In-situ* observing systems when improved, will:
    - improve regional forecasts consistently
    - improve global forecasts intermittently
- Consideration needs to be given to what satellite data could better be used in regional scale models
    - full-density data, e.g., AMV thinning not needed
    - what are the requirements for future NWP
- Improved assimilation methods include:
    - 4D-Var
    - Ensemble methods
    - Dynamic background error covariance specification
    - Isentropic coordinate application – FSL/RUC, future NAVDAS

3.3 Session 3: Observation targeting studies and observation network design studies (chaired by S. Lord and J. Caughey)

3.3.1 Adaptive observing

Adaptive observing is a newly establishing concept.

- Such observations can be linked to severe weather events, as well as societally important events
- No single technique is best for computing where the sensitive areas are; this depends on the data assimilation system and other observation used
- Impact of such observations depends on data usage, background covariances, etc.

Research is ongoing

- There are positive, but not overwhelming, results
- There is a link between marginal resource expenditure and positive impacts
- There is a link to past and future field programmes (THORPEX)
- There is an opportunity to take advantage of data selection strategies from other platforms (e.g. satellite)
- Techniques involve approximations, short cuts, some lack of a strong theoretical basis
- There is a need for careful experimental design with controls
- Studies on adaptive removal of observations (removal instead of deployment) should be encouraged
- Verification should be relevant to the significant event and case studies must be accumulated (communicate to decision makers as well as scientific community).

Issues include:

- Can adaptive observations continue to provide positive impact in parallel to continually improving data assimilation systems and increasing observations (e.g. hurricane targeting)?
- Is it worth the cost?
- Is targeting with operational systems worthwhile?
- Interactive networks must address the economics of observing systems
- There is a large variety of weaknesses in all operational systems, including forecast models, assimilation techniques, forward models …
- Improved simulation systems, ongoing support, overall strategy for design, and implementation of advanced instruments are all required

- The needs for in situ and satellite observations must be integrated in a non-competitive, locally optimal way, especially in developing countries

3.3.2 Operationally Unsupported and New Observing Systems

3.3.2.1 AMDAR progress includes

- Rapid expansion increase in daily data volume
- On-going expansion to Africa, Asia, Canada, Saudi Arabia
- Planned expansion to regional carriers proceeding but has been problematic
- Desired expansion to new countries globally
- Progress in network planning and data management important in maximizing cost effectiveness
- Progress in network monitoring and feedback to airlines for remediation
- Development of a humidity sensor
  - WVSSII sensor tested in US in 2nd quarter 2004, others possible
  - TAMDAR beginning April 2004 on regional carriers in US, France, Australia
  - UK laser diode system installed on research aircraft
  - DWD planning to adapt Vaisala sensor
  - Russian Federation actively developing new sensor
- Turbulence (EDR) reporting is proceeding
- Icing program is proceeding

Future directions include

- Emphasis on broadening coverage and regional programs
- New sensors into operations
- Training, education, outreach
- Integration into GOS

Impact tests have shown

- In the US data distribution on week-ends is half that of week-days resulting in 7% worse forecasts on week-ends
- There is a 20% skill loss with no observations
- Ascent/descent data show
    - Positive impact in analyses and 48 h forecasts and 5 days over monthly mean 500 hPa height over North America and Europe (0.4 day at day 8)
    - Some biases with radiosondes
    - Consistency of results across NWP centres
    - 2-7% improvement in RUC analysis and 2-5% in 12 h forecasts at and below flight level, equal to or greater than increasing resolution from 40 km to 20 km (NCEP results?)
    - Off-time (or asynoptic ?) data is most valuable in mid and lower troposphere
    - Larger impact than profiler data and more economical (but smaller domain covered by profilers)

Issues remain regarding

- Optimal use of data for all NWP problems
- Winter vs summer and length of studies
- Multi-use of data (nowcasting, climate, air quality, etc)
- How to optimize issues for non-technical decision-makers?

3.3.2.2 AIRS experience indicates

- It is an accurate and stable instrument with greater vertical resolution and application to other gases and clouds
- 95% of the globe is cloud covered
- NWP impact is currently small but positive
- Cloud clearing increases the number of observed profiles which can be used
- It is providing risk reduction for other advanced sounders
- Real-time data provision is essential for development and testing
- Treatment of clouds remains a big issue
  - Cloud clearing requires research data sets, not operationally distributed one
  - Use of cloud contaminated radiances needs research (also this requires assumptions)
- Principal component analysis offers
  - Data compression
  - Quality control
  - Radiance reconstruction and noise reduction

3.3.3 Design of new networks, instruments or observing services

Issues include

- Shifting resources from well observed to poorly observed areas
  - Homogeneous coverage (space and time) desirable
  - Possible on global basis, not just regional (e.g. North Atlantic)
- Network management
  - Performance monitoring and feedback to providers
  - Encourage and plan for growth
  - Justification studies
    - OSEs
    - Pilot studies for new instruments & strategies: (e.g. AMDAR local carriers have shown feasibility of programme and willingness to participate)
- Designing a new network
  - Climate variability (from re-analysis) may be distorted by existing observational shortcomings
  - Design can be formulated as a variational problem based on reduction of natural variability
  - Russian radiosonde network provides an example
  - Local considerations and other applications may pertain
- Design of new instruments (e.g. MSG)
  - Active interaction with users for new capability and products is very desirable
  - Re-analysis of satellite data is critical to
    - Backfill products with latest algorithms
    - Re-calibrate instruments after real-time
    - Provide continuity of data across contemporaneous and successor instruments
    - Measure adequacy of pre-launch benchmarks and operational validation

4. Workshop conclusions and recommendations

During In the its final session, the workshop reviewed the draft recommendations for the evolution of the GOS from developed by the CBS OPAG-IOS Expert Team on Observational Data Requirements and the Redesign of the GOSlobal Observing System (ET_ODRRGOS). These recommendations together with an the first draft of implementation plan are given in Annex IV of the final report of ET on ODRRGOS Report from its the 6th session of the ET (held in Geneva, 3-7 November 2003). The recommendations from this 3rd WMO Workshop on the impact of various observing systems on NWP should be viewed considered in conjunction with the ET recommendations; the discussion focused mainly on complementary issues raised in the presentations and during the discussions.

4.1 Interaction between NWP centres, data providers and users

(i) Data assimilation and modeling capabilities have grown and are under constant development to make optimal use of current and future observing systems. NWP centres require

- early (advance) information about new data types ;
- early access to test data and observations during the cal/val phase to prepare for the operational use of the data
- information on the characteristics of the data and products (e.g. AMVs which may be representative of atmospheric layers rather than just at one level).

(ii) Research satellites provide valuable data for NWP, which should be made available in a timely fashion. Research satellite data provide NWP centres with an excellent opportunity to prepare for new satellite data streams, which will become part of the operational global observing system.

(iii) Effective learning of how to make use of new data types can best be achieved through operational use of any experimental data streams.

(iv) It was recognized that NWP centres will being doing have to do more work relevant to other environmental areas. This will require a wider data exchange and more cooperation on model developments (i.e. issues of environmental monitoring, atmospheric chemistry and transport processes will need to be addressed)

4.2 Observational data requirements

(i) It was recommended that polar wind observations be developed further and an operational follow-on to the MODIS winds be secured (this will require a water vapour channel on the operational imagers on NPOESS and METOP). Timeliness of data delivery can be addressed through direct data read-out. The number of stations with direct read-out capability should be increased. Such data should be made available directly to the processing centres.

(ii) The workshop reiterated the need for a timely distribution of radiosonde observations in BUFR with all observation points included in the message together with the time and the position of each data point; information on instrument calibration prior to launch and information on sensor type and sub-sensor type is also required.

(iii) For regional forecasting systems, a strong requirement was expressed for comprehensive and uniform coverage with at least 12 hour frequency of temperature, wind, and moisture profiles over continental areas and coastal regions. It was noted that the radiosonde network still plays an important role in meeting this requirement.

(iv) The extension of the coverage of vertical soundings into ocean areas (eg as pursued in the EUCOS programme) was supported and considered to be a valuable data source for general NWP.

(v) More T, U/V, Q profiles, but especially winds, are needed in the tropics. Rapid development of the AMDAR programme could be one solution.

(vi) Timeliness requirements for observational data are becoming more stringent for NWP centres. HH + 20 to 90-minute data cut-off times are applied at present for many NWP short-range runs. Within the next few years, a data processing and delivery time of approx 20 to 30 minutes is expected to be the an operational requirement.

(vii) Ground based GPS processing (ZTD and PW, priority for ZTD) should be standardized to provide more consistent data sets. Data should be exchanged globally. The coordination of geodetic data between the GPS processing centres is required.

(viii) There is a requirement for exchange of high-resolution radar data (both reflectivity and radial winds, where available) for use in regional models, and also in global models in future.

(ix) Workshop results on the usefulness of stratospheric observations should be consolidated and requirements for a stratospheric global observing system should be refined (need for radiosondes, radiances, wind data, humidity data, noting the availability and required density of existing data sources, including GPS sounders, MODIS winds and other satellite data).

4.3 Proposals for future studies

(i) The capability to make best use of high-resolution observations (space and time) should be developed. This includes

- assimilation experiments using hourly AMVs together with hourly radiance data
- optimal extraction of information content from AMV
- targeted use of high resolution satellite data (implies the development of corresponding assimilation capabilities).

(ii) The conduct and evaluation of impact studies should be revisited. The overall impact of one component of the observing system can be established through denial studies (incremental approach) or through impact assessment by adding the observations to a baseline system.

(iii) Guidelines for the evaluation of impact studies need to be revisited and the need for regional cases studies and time series verification should be included.

(iv) Impact studies have confirmed the positive contribution of the radiosondes to regional and global NWP. Studies to assess the relative value of the radiosondes for use in bias corrections in the RT forward model should be considered.

(v) The value of a properly tuned OSSE system was acknowledged (the huge initial investment was noted). Such a OSSE system would be a useful tool for the assessment of new observing systems in the shorter term, but less relevant for observing system to come on stream 10 to 15 years ahead. Complementary approaches e.g. use of simulated data in ensemble assimilation systems or studies of information content could be applied.