Fourth WMO Workshop on the Impact of Various Observing Systems on NWP
Geneva, Switzerland, 19-21 May 2008

SUMMARY AND CONCLUSIONS

1. INTRODUCTION

The Extraordinary Session of the Commission for Basic Systems (Seoul, Republic of Korea, November 2006) requested its Open Programme Area Group on Integrated Observing Systems (OPAG-IOS) to interact more closely on observational issues with the Commission on Atmospheric Sciences (CAS) and encouraged Numerical Weather Prediction (NWP) Centres to keep stimulating the studies of observation targeting strategies in coordination with the THORPEX ad hoc working groups and requested the OPAG-IOS and the WMO Secretariat to organize the Fourth Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction.

The fourteenth congress (Cg-XIV) (Geneva, Switzerland, May 2007) noted with satisfaction that the major activities of CBS in the domain of observations were concentrated, among others, on the evolution of the Global Observing System (GOS) and scientific evaluation of Observing System Experiments (OSE) and Observing System Simulation Experiments (OSSE). It appreciated and supported proposals of CBS in the context of the operations and development of the future composite GOS which aimed to contribute markedly to alleviating deficiencies in the surface and upper-air data coverage. Congress reaffirmed that sustainable operation of the GOS has a vital role and highest priority for WMO in providing observational data to meet the requirements of weather forecasts and warnings, climate monitoring and other strategic tasks of the Organization; and that GOS through coordinated efforts of Members should continue its fundamental mission in providing timely, reliable and consistent meteorological data to meet the requirements of various users worldwide and ensure its essential role in the planning and implementation of an integrated WMO global observation system concept. The Congress also encouraged members to keep supporting the studies of observation targeting strategies based on the THORPEX, AMMA and IPY results; and, based on the guidance given in the Implementation Plan for Evolution of Space and Surface-based Sub-systems of the GOS, to pursue, especially in developing countries a wider use of observing systems (satellite, AMDAR and AWSs) that were less dependent on infrastructure, expertise and funding.

The fourth session of the WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction, organized under the auspices of the CBS OPAG-IOS Expert Team on the Evolution of the GOS (ET-EGOS) by the Organizing Committee headed by Drs John Eyre, Ko Koizumi and Jean Pailleux, is considered as another important step forward in the process of a design of the future GOS.

At the three previous workshops, which were held in Geneva (April 1997), Toulouse (March 2000) and Alpbach (March 2004), the global and regional results of Observing System Experiments were presented and significant conclusions were drawn concerning the contributions of the various observing system components to the large scale forecast skill at short and medium range. Since then, significant developments have taken place in the GOS, such as the launching of satellites equipped with newer instruments, for example METOP in 2006 and the COSMIC constellation providing radio-occultation soundings. In particular, global data assimilation systems are being used with these data as well as data derived from high vertical resolution infra-red sounders (AIRS, IASI). Microwave data are increasingly being assimilated operationally and mesoscale assimilation systems can use local observations such as radar reflectivities, radar Doppler winds and data from surface GPS stations. Design studies on satellite missions planned for the present and next decades are currently being conducted. In order to further contribute to these studies, a Joint Observing System Simulation Experiment (Joint OSSE) initiative was launched in 2006 in North America and Europe. Conventional observing systems are also being adapted through regional programmes like the EUMETNET

Composite Observing System (EUCOS), in particular, radiosonde, aircraft and buoy observations. Targeting strategies are being used or considered for increased use through, for example, the THORPEX Programme and the EUCOS/PREVIEW Data Targeting System (DTS).

During this workshop, major NWP Centres presented recent results in the above-mentioned areas in three different sessions dealing with the: (a) Global Forecast Impact Studies; (b) Regional Aspects of Impact Studies; and (c) Sensitivity, Impact Assessment Techniques and Observation Network Design Studies. Forty-four experts representing all major NWPs and other centres active in the area of observing system impact studies, as well as representatives of 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 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 a synthetic summary of the assessment of impacts from various observing systems. Section 3 presents some specific results on the use and impact of various observing systems which led to discussions in the Workshop. Section 3 presents also specific recommendations focused on implementation of evolving user's requirements as had developed under each section of the Workshop. Section 4 lists the major overall conclusions and recommendations from the Workshop.

2. ASSESSMENT OF IMPACTS FROM VARIOUS OBSERVING SYSTEMS

2.1. 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 medium-range and (to a smaller extent) at short range (unit = hour). The gain is assessed by adding the observing system to all others used routinely in the assimilation. For some systems, the impact cannot be measured through an objective score and it can be identified only on case studies. This is obviously due to the increasing diversity of observing systems used operationally: this improves the overall skill of the system but makes it more and more difficult to evaluate the positive impact increment with respect to all the other systems used in NWP. Notes are attached to table 1 with indication of whether the overall contribution to the skill of the NWP systems has increased / decreased as compared with assessments of the Workshop-2004. As an important tendency of the period 2004-2008 has been the appearance of new observing systems (especially from satellites), the individual impact of most individual observing systems has decreased compared to 2004, but the total impact of the combined observing systems has improved, and the GOS is now more robust because of the variety and quality of instruments available.

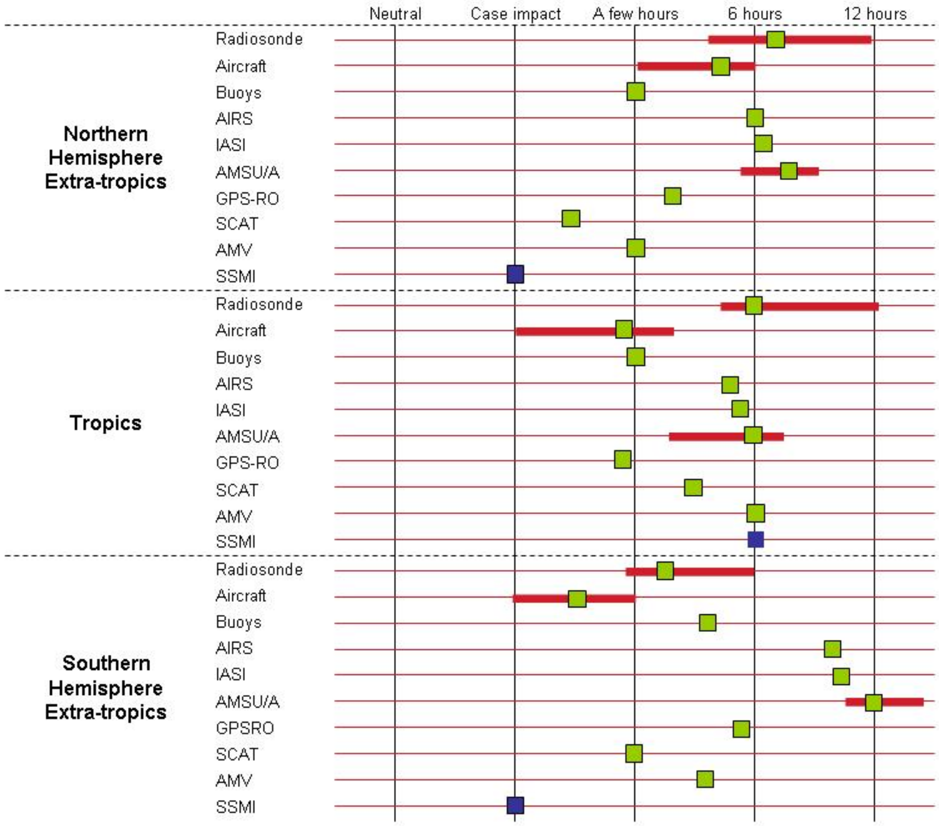

Table 1: Current contributions to some parts of the existing observing system to the large-scale forecast skill at short and medium-range. The green colour means the impact is mainly on the mass and wind field. The blue colour means the impact is mainly on humidity field. The contribution is primarily measured on large-scale upper-air fields. The read horizontal bars give an indication of the spread of results among the different impact studies so far available (for several observing systems the quantity of impact studies is too small and the spread is not quantified).

Notes:

- The table estimates the impact of the total ensemble system appearing on each line. For example the line "AMSU / A" corresponds to the 3 or 4 instruments available on current polar orbiting satellites. It is then compared to one single AIRS or one single IASI instrument, and scores more. One single AMSU/A has been quantified to a slightly smaller value than one AIRS;

- Compared to the situation in 2004, AMSU / A does not dominate any more; AMSU / B is used as well; the new infra-red sounders contribute to the impact with a magnitude similar to micro-wave sounders;

- Micro-wave instruments like SSM / I, SSM / IS and AMSU / B are also very important for large-scale humidity fields, especially in the tropics. Each of them can be rated similarly to SSM / I appearing in table 1;

- MODIS winds are very important for polar caps, and their impact spread quickly to mid-latitude: the impact is always found significant and positive in the southern hemisphere (and in the northern hemisphere, most of the time);

- Global wind profiles remain the more important information to observe, at least relatively to the current GOS where the temperature profiles can be indirectly observed by satellite sounders or GPS radio-occultation (no change with respect to the previous workshop, four years ago); and

- Surface pressure observations are important to anchor the model surface pressure; surface wind observations are less important, but are a very useful complement (provided mainly by scatterometers).

The previous evaluation is mainly based on a synthesis of all known OSEs, including the more recent ones presented at the Workshop. It generally puts more weight on medium-range than on short-range forecasts. Another assessment technique is now used in some NWP Centres. It evaluates the sensitivity of the 24h forecast to each observation through adjoint computations. The use of such an assessment technique is not systematic enough to be summarized in a table. However, some results are documented in the Workshop proceedings (see for example the paper by Gauthier et al.). They confirm the important impact of the radiosonde network and of the satellite sounders (microwave and infra-red).

2.2. Impact of some regional observing systems

- Radiosondes are relatively more important for regional models than for global models; isolated profiles of wind and temperature (from radiosondes, AMDAR…) are crucial for NWP;

- Radiances from geostationary satellites are used in several regional systems with a small positive impact: there is still a lot of potential to improve the use of this type of data;

- Wind profilers have shown neutral impact on average: slightly positive in some impact studies, slightly negative in others. In the workshop of 2004, there were very few results; the impact was marginal but positive. Quality control and screening procedures in data assimilation is an issue which affects the results and should be further studied; and

- Radar data and GPS surface observations have demonstrated their positive impacts on regional assimilation systems, and on some occasions also on global systems.

3. REPORTS FROM THE SESSIONS

3.1 Session 1: Global Forecast Impact Studies (chaired by Lars Peter Riishojgaard and John Eyre)

3.1.1 Summary of results presented in the talks

Here are reported the major results from the global impact studies presented at the workshop.

The summary of OSE and OSSE activities presented by ECMWF includes the impact studies funded by EUCOS and EUMETSAT. These sets of OSEs provide the most comprehensive assessment of the main observing systems to date. A wealth of detailed information can be extracted: (see the extended abstract by E. Andersson et al.) in the proceedings attached to this report. All components of the observing system are giving positive contributions to some aspects of the global analyses and forecasts. The potential for improving the use and the impact of some sub-systems (such as IASI) is still large. Early impacts from Metop data have been positive, and access to Metop data soon after the launch was crucial for early operational use. A short presentation focused on the wind lidar satellite mission ADM-Aeolus showed the type of work needed to prepare the assimilation of a completely new type of observations. It was noted that when radiosonde and aircraft temperature and wind data are used together, they contribute more than the sum of their separate contributions.

At Deutscher WetterDienst (DWD), the operational OI system uses pseudo-TEMPS extracted from the ECMWF analyses every day at 00 UTC - this is a means for them to benefit from the advanced satellite data assimilation at ECMWF. In tests without pseudo-TEMPS, ATOVS data have a large positive impact in both OI and 3DVAR. The 3DVAR system is much better than OI, both with and without ATOVS data. The impact of Metop has been tested, too, and found to be beneficial in southern hemisphere and Europe, but not much in northern hemisphere. GPS Radio-occultations (RO) has demonstrated large impact at 72h, 500 hPa, in the southern hemisphere, and much smaller impact in the northern hemisphere. These OSEs have been run with respect to a conventional-only baseline. The impact was found to be half as big as that of AMSU-A. Atmospheric Motion Vectors (AMVs) have positive impact everywhere, but especially in the tropics at 200 hPa. MODIS winds can now be used in the main run at DWD, as well as in the delayed cut off assimilation. In the northern hemisphere, their impact is small to neutral; it is relatively larger in the southern hemisphere. ASCAT showed relatively neutral impact, apart from one particular case, which was quite dramatic (a low pressure west of Ireland was positioned and deepened correctly by ASCAT).

In global impact studies carried out at Météo-France, GPS-RO data from COSMIC, CHAMP and GRACE showed nice positive impact for geo-potential, temperature and wind. The data are used for both rising and setting occultations, down to 1 km over the Polar Regions, but only down to 6 km in the tropics. A positive impact of IASI was also shown, although the amount of infra-red channels is still limited. The variational technique (called VarBC) to correct the bias in the observation seems very efficient and improves the use and impact of most observing systems. For micro-wave sounders, Météo-France use the radiance observations to retrieve emissivity at the observation point, by inverting the radiative transfer in surface channels (AMSU-A channel 3) and using it in the sounding channels. This improves the distribution of used data over land, e.g. for AMSUA channel 7. This has been studied especially on the African area of the AMMA experiment. A small positive impact of the extra AMMA sondes was detected when verified against satellite sounding channels in the area, and verified against surface data too. Additional bias correction for the radiosondes in this AMMA area, developed at ECMWF, has been applied and has been found to enhance the positive impact of sonde data. For the THORPEX-IPY / CONCORDIASI project in the Antarctic there will be 600 dropsondes released in 2009 from drifting stratospheric balloons. These data and even the flight-level balloon data will be distributed over the GTS.

Data impact experiments carried out in Washington (JCSDA and NCEP/EMC) were presented (see the extended abstract by Lord and Riishojgaard in the proceedings attached to this report). The COSMIC GPS-RO data were put into operations in 2007. It showed positive impact at 500 hPa (geopotential) in both hemispheres, larger in the southern hemisphere. About 1000 COSMIC profiles per day are used. QuikScat impact was tested over four months, with emphasis on tropical cyclones, and with no visible impact in averaged 1000 hPa scores. Then a marginal positive impact in the southern hemisphere was obtained from QuikScat and Windsat used together. Windsat on its own did not show positive impact. A result was found in which MODIS winds degrade the northern hemisphere scores, but was very beneficial in the southern hemisphere. For IASI they will rely on the EUMETSAT channel selection. Initial tests with IASI showed some small positive impact at day 6-7 in the southern hemisphere. IASI is not used operationally yet at NCEP, but will be implemented as soon as possible. A positive impact was also found from SSMI/S data, and it was shown that this positive impact can be enhanced by improving the cloud detection and processing.

A detailed presentation of the joint OSSE project and its status was given. NCEP and JCSDA are collaborating on this project with American, European and Asian partners, and ECMWF has provided the Nature Run. The conventional observations are currently simulated from the Nature Run. Work has started on simulating the radiances and Doppler wind lidar data. There is no secured funding for the core of the OSSE project which could guarantee its existence for several years.

A Met Office presentation was dedicated to the conventional observing systems (at global scale as well as regional scale). The results from the EUCOS study confirm generally the ones found by ECMWF. Radiosonde data are shown to be still very important on the northern hemisphere; major reductions in sonde networks (down to GUAN baseline) can come with substantial degradations in NWP performance. A "subjective targeting" has been evaluated over the USA: the experiment consists first in removing most of the existing radiosonde sites over North America, down to 17 stations, none in the verification area where the forecast impact is checked. Then each day, depending on the meteorological flow, 10 radiosonde observations are picked up in the "sensitive upstream" area. "Upstream data" were shown to be very valuable in this context. Like many other studies presented at the workshop, these targeting experiments demonstrate the benefits of additional profile observations in otherwise data sparse areas. Benefits for global NWP have also been shown through assimilation of more surface level observations.

Another Met Office presentation was dedicated to the use and impact of satellite data. It confirmed a positive impact from most of Metop instruments (shown by ECMWF). It showed the importance of a rapid dissemination in real-time of satellite data from polar orbiting satellites, through specific retransmission systems (RARS, EARS, etc.). In Alpbach, four years ago, it was shown that microwave sounders on three well-spaced polar satellites is close to optimal, and this result is now consolidated. Concerning infra-red sounders, a good early impact from IASI data (clear radiances only) was demonstrated, and strong improvements from the assimilation of cloudy AIRS radiances were shown, with implications for future impacts of other advanced infra-red sounder data. Concerning scatterometer data, it was shown that ASCAT has the highest quality in terms of 10m wind departures "observation – background", then come Windsat, QuikScat, and ERS scatterometers, which all show smaller departures to the background than buoy and ship wind data. The impact of Windsat is equivalent to the impact of ASCAT, and will become operational soon. Adding ASCAT on top of QuikScat shows a significant positive impact (2 satellites with scatterometer data improve significantly on 1). Concerning GPS-RO observations, 6 COSMIC satellites are currently used at the Met Office, soon the GRACE and CHAMP satellites will be added, and a continuous improvement of the forecast was shown when introducing 4, then 6, and finally 8 satellites (impact saturation does not appear to be reached with 8 satellites).

The results presented by the Canadian Meteorological Service (MSC) were concentrated on observations assimilated over North America and North Pacific. They were performed at two different resolutions (100 and 33 km) and two different assimilation schemes: 3-D and 4-DVAR. It was shown that the low-resolution 4-DVAR has the same quality as the high-resolution 3-DVAR. The impact of Pacific aircraft data (mainly the zone covered by the routes from USA to Hawaii) quickly spread and drifted eastward. Clear impact of satellite data originating in the area to the South-East of this zone was shown for the USA.

The global results coming out from the JMA presentation highlighted the fact that the satellite data coverage is much improved in the early analysis (2h20' cut-off time) by the Asia-Pacific Regional ATOVS Retransmission Service (AP-RARS), point also mentioned in a Met Office presentation. The impact of AP-RARS is not large but the EARS one is very clear and positive (result consistent with the data volumes). MTSAT-1R clear-sky radiances improve the prediction of cyclone tracks, as well as BUFR-format AMV, especially when a strict screening based on their quality index is performed.

Although the Australian results presented by BoM / CAWCR had mainly regional implications (see section 3.2), it was shown that remote radiosonde observations still show benefits (which are not yet outweighed by the availability of satellite data), and that an increased benefit can be obtained from AMVs by improved processing.

The Chinese (CMA – CAMS) study which was presented does not show the impact of any satellite system as such, but it shows how important a retuning of one parameter (observation error standard deviation) can be for assimilating ATOVS data in the GRAPES Chinese system (3-DVAR assimilation).

3.1.2 Discussion items

From the studies carried out in several global centres, it is clear that all components of the GOS are contributing to some aspects of the performance of NWP. For example, this is true for satellite instruments. The "domination" of microwave sounders (noted in Alpbach in 2004) is not true any more. Nowadays global NWP is dependent on a satellite-based observing system which is a combination of microwave sounders, infra-red sounders, GPS radio-occultation receivers and AMVs, none of these systems being negligible with respect to the others. This is valid for the upper-air analysis; for the surface analysis (pressure, surface winds), the scatterometer data are an important observing system to take into account. The biggest gap at global scale is the need for wind profiles, which explains the interest for the future data of ESA mission ADM-Aeolus.

The current state of the art in global NWP is far from making full use of satellite data. One example is the small percentage of data which is used operationally from AIRS and IASI sounders. Many research and development tasks are carried out in various groups to improve the use of satellite instruments: studies on the surface emissivity and other soil properties, on the bias evaluation, on the data screening, or on the processing of AMV. All these studies are likely to progressively improve the quantitative assessment of the satellite data impact, as it was evaluated in this workshop.

For polar orbiting satellite instruments, the quick availability of data in real-time NWP (including the latest orbit) is important. This was stressed in the discussion, following the results presented by several speakers. This relies on ad hoc telecommunication systems allowing the quick re-transmission of some data, as soon as they "reach the ground" (EARS, RARS).

It may be difficult to draw any concrete action from the result showing that the impact of radiosonde wind and temperature fields is "more than additive" (EUCOS terrestrial study), i.e., that the total impact is greater than the individual impact of temperature and wind data (evaluated separately). It is clear that both fields are needed globally with a good accuracy for the operational analyses, but we do not necessarily need wind and temperature observations at the same point. Also, when a study is carried out in a data sparse context, the first isolated wind and temperature profiles not only act synergetically to improve the forecast but their impact is very big: see Rabier et al. in the workshop proceedings (part dedicated to AMMA) and also Klink et al. (part dedicated to the impact of ASAP). Also, putting aside the humidity field, it is clear that radiosonde and AMDAR have a similar role, a similar impact, and can be interchanged. It is generally easier to increase the AMDAR data coverage than the radiosonde data coverage. Therefore, all the AMDAR opportunities should be used to improve the wind and temperature data coverage, especially in data-poor areas like the intertropical regions. This means to get new wind and temperature profiles at some airports by equipping some aircrafts travelling regularly to these airports, and also to get the data from cruise levels in these regions (which are otherwise data-poor regions). Following the same logic, in Europe, several radiosonde sites, close to busy airports, are likely to be discontinued in the future EUCOS optimisation process.

So far, most of the OSEs have been concentrated on the impact of observations on short or medium ranges forecast (say until day 10). However, the “second week” of forecast range should not be forgotten in terms of observation requirements. It was reminded that the THORPEX programme concentrates on forecast improvements up to day 14, with obvious links with monthly forecasts in terms of numerical tools and observation requirements. This means that in the future some attention should also be given to the impact of analysed surface fields, such as soil moisture, or to the stratospheric fields which are likely to influence the tropospheric weather more at 7-14 day ranges than at short range. For doing this, the current OSE methodology may not be sufficient, as forecasts are currently more dependent on ensemble prediction techniques at ranges of one week or more.

The stratospheric observation requirement is an issue which is not answered completely by the studies presented at the workshop. It is clear that the current rapid increase of the use of GPS-RO is a new factor which contributes to improve very significantly the stratospheric analyses (also the upper tropospheric ones). GPS-RO data are improving directly the stratospheric profiles in temperature (and the wind profiles indirectly outside the tropics). It is clear that the existence of some GPS-RO missions in the future has to be guaranteed for operational use. What is the optimum number of satellites? This question will be addressed for example in the context of the OSSE project, together with the future availability of ADM-Aeolus winds. Then the old question “how many radiosonde sites must observe the stratosphere globally” will have to be addressed again in this new context (without forgetting the GCOS requirements).

3.2 Session 2: Regional aspects of impact studies (chaired by Warren Tennant and Harald Schyberg)

3.2.1 Summary of results presented in the talks

In this section, some of the findings in the regional studies that were presented in the workshop are reviewed. The Met Office reported on experiments with their regional system demonstrating a significant positive impact from radar VAD wind assimilation. They also have performed experiments with moisture related observations such as MOPS derived cloud data and visibility data, demonstrating some positive impact. The Met Office also obtained a small positive effect of ground based GPS data on several parameters.

Regional experiments performed at the Japanese Met Agency (JMA) demonstrated positive impact of radar Doppler winds and retrieved radar precipitation data in their 4-DVAR assimilation. The importance of the thinning strategy for radial winds was pointed out. Positive effects of ground based GPS data on precipitation forecasts were also demonstrated.

The Australian Bureau of Meteorology (BoM) showed results from a regional study of the impacts of the various available radiosondes around the Australian continent. The Canadian Meteorological Service (MSC) presented some studies showing that the availability of some radiosondes at high latitudes is very important in terms of forecast impact, presumably because of the strong air mass variations and of the relatively poorer availability of any other types of observed information in the polar areas.

Several impact studies have been performed in the HIRLAM community regionally with, for instance, MODIS winds, GPS surface data and radar radial winds. Positive impact was found in many, but not in all cases. Regional studies of the various components of the terrestrial part of the observing system were conducted in the framework of EUCOS OSEs, and these show that the relative importance of radiosondes tends to be higher than in global studies, perhaps because the HIRLAM assimilation system does not make use of satellite data as extensively as done in the global systems. The HIRLAM results showed positive impact of ASAPs, although there might be significance issues, as the impact comes from a small number of specific cases, e.g., one Scandinavian storm. No significant impact from adding humidity data and from adding wind profiler data could be demonstrated.

Several impact studies have been performed within the ALADIN community. Results using SEVIRI radiances were positive. Results indicate that the best effect is obtained when also 2m temperatures are assimilated. Results from radial wind assimilation in the AROME setup (2.5km of horizontal resolution) were also presented. It showed the ability of the system to represent the spatial distribution of convergent structures connected to the convective systems. Experiments with reflectivity assimilation are also ongoing. The importance of a proper determination of the background error covariance matrix (especially the vertical correlation), rather than interpolating from matrices on coarser resolution was demonstrated. The ALADIN EUCOS terrestrial studies showed a clear positive impact of both aircraft and radiosonde temperature and wind observations on all the meteorological fields except humidity fields. This positive impact was very significant up to 24 hours range. A positive impact of radiosonde humidity observations was also shown on precipitation forecasts at all ranges, and also on surface pressure forecasts (in the winter period of the study, not the summer period).

An extensive experiment with extra radiosonde launches has been undertaken at the Korean Met Agency (KMA). Positive impact, in particular in convective rainfall events, was demonstrated in their WRF system. The sensitivity of the results to cloud microphysics was also discussed.

South African Weather Service (SAWS) presented a comprehensive demonstration of the positive effect of AMDAR and radiosondes in their regional implementation of the Unified Model. The results support the general idea to prioritize the wind and temperature profile requirements in data sparse areas.

Several impact studies carried out with the COSMO regional system were presented. A positive impact from assimilating precipitation data from the radar network with latent heat nudging was noted up to about 8 hours forecast range. Case studies with ATOVS and SEVIRI radiances used in a 1-D-Var + nudging procedure were presented, showing a slight positive impact. VAD wind assimilation gave mainly neutral results. Assimilation experiments with screen level data have also been undertaken, different setups showing neutral to clearly positive impact. New E-AMDAR humidity measurements have been monitored to assess the possibilities of building up such an observation system in the future. A clear detrimental effect of degrading the radiosonde network over Europe was demonstrated.

Finally, regional studies with the WRF system have been undertaken on Antarctic and Asian domains. In particular, a good effect of COSMIC radio occultation data was found in the troposphere, but revealing model upper boundary problems higher up. Positive impact of AIRS and MODIS data was also demonstrated in the Antarctic domain. On a Korean domain a positive impact of radar, mainly from radial velocities, was shown.

3.2.2 Discussion items

This is an account of some of the main discussion points following the presentations in this session dedicated to regional aspects.

Concern was raised about the variability in the design of regional OSEs and also how sensitive the results were to changes in this design. For example, significant differences between 3-DVAR and 4-DVAR, and the specification of the B-matrix were presented. Notwithstanding, regional

OSE studies are valuable and groups performing such studies were encouraged to place more emphasis on verification relating to the application of their system, for example, air quality or heavy rainfall, as these applications justify the need of high-resolution regional systems. Although it is not possible to standardise verification methods, such scores should be aligned with these application needs and aim to facilitate exchange of results with other centres.

There is a number of observing systems unique to regional NWP, but the group wished to highlight the real-time distribution of such data. Sharing of Doppler Radar wind data should be the start, as these were shown to have positive impacts in a number of systems. Centres producing Radar data need to agree on data pre-processing and transmission standards on the GTS. This should include a channel for users to provide feedback to data producers on the quality and impact of this data in their NWP systems. As a second priority, just after radar data, the GPS surface networks should be exchanged: they have shown their value for regional NWP but also for global NWP models. Although there are problems with observation quality in certain cases, we were also reminded that models have inherent biases, and this will impact negatively on the efficiency of data assimilation. Other improvements in regional observing systems include a new AMDAR humidity instrument that will be tested later in 2008 and will be available for E-AMDAR in due course.

Regional NWP models are currently less dependent on satellite radiances than global NWP models. The main reason is the forecast domain of regional NWP which is often covered mostly by land, and the satellite sounder channels sensitive to the lower troposphere cannot be assimilated properly over land in the current data assimilation systems. Some studies for surface emissivity modelling over land are already available. They are highly required for regional NWP to fully exploit the satellite observations.

There are some links from impact study work to various other programmes, such as the IPY. To enable the community to assess the impact of IPY data, it is important to know which observations types are exchanged in real-time. It is also important to consider which systems will potentially remain in place after IPY. There are also good links to the THORPEX Data Assimilation Working Group and communication is ongoing for example through the intercomparison exercise set up for the THORPEX T-PARC experiment (see section 3.3).

3.3 Session 3: Sensitivity, impact assessment techniques, observation network design studies (chaired by P. Gauthier and J. Caughey)

3.3.1 Summary of results presented in the talks

In this section, the different numerical tools and techniques which can be used to evaluate the impact of observations on NWP, i.e., the OSE methodology (which is the standard one), but also several other techniques are discussed. This section also deals with the benefits which can be drawn from the above tools for network studies on conventional observations and for planning satellite missions. As many of these tools and studies are very dependent on the assimilation system, it is important to intercompare different assimilation systems and to come up with strategies involving several of them.

Several centres (ECMWF, Navy / NRL and GMAO) are now able to run in a quasi-routine mode, diagnostics on the Forecast Impact of Observations (FIO) based on the adjoint of the data assimilation mathematical operators and of the forecast model. The FIO evaluates the impact of any observation subset (down to a single observation datum) on a selected measure of short-range forecast error (at least one particular aspect or norm attached to this short-range forecast). It can be used, displayed and exchanged in a similar way to the DFS (Degrees of Freedom for Signal) which assesses the relative weight of the different observations in the analysis. It was shown (ECMWF) that OSEs and FIO (adjoint techniques) often give the same general message about the impact of one particular observing system. However, the techniques are complementary: with the FIO one can look at the impact of any single observation or of any small ensemble of observations on one parameter measuring the forecast quality; with the traditional OSE it is almost the opposite, as one can measure the impact of one perturbation only (addition or denial of a particular observing system in the assimilation) on all the aspects of the output forecast (any field, any statistical score). Although the new technique requires an adjoint model (not available in all the NWP centres), and is directly applied only to short-range forecasts, the exchange of these FIO diagnostics should be encouraged.

The ECMWF results showed that FIO information can be used to pinpoint and explain why observations can have a negative impact. For instance, it was found in one example that wind profilers over North America had a negative impact that could be explained by problems with the instrument when the local wind variability is much higher than the climatological mean. Negative impact of low-level U-component of AMV winds was noted in some sub-tropical areas and attributed to inaccurate height assignment. Overall, the sensitivities with respect to observations measured through adjoint-based methods yields a consistent signal with that obtained from OSEs.

NASA / GMAO results obtained on the observation impact evaluated with the adjoint-based method were also shown. It was pointed out that only slightly more than 50% of the observations have a positive impact but this is consistent with the statistical nature of the assimilation problem. However, a good observation type should yield an overall positive impact. Examples from GMAO's assimilation system showed problems associated with some of the water vapour channels that become more apparent if a localized error norm is used to estimate the forecast error. Adjoint-based methods differ from OSEs in that, by removing observation types, the latter alter the background against which observation impact is measured. The observation impact applied to two OSEs, gave a striking example showing that the removal of AMSU-A radiances significantly enhances the impact of AIRS radiances. On the other hand, the removal of AMVs wind observations decreases the impact of AIRS radiances. This shows again that sensitivities with respect to observations provide a complementary tool to OSEs.

Results obtained at Navy / NRL were presented where observation impact is used on a routine basis to monitor NRL's assimilation and forecast system. The interpretation of observation impact can help to improve the selection and use of observations for numerical weather prediction. Negative forecast impact may suggest quality control issues, while large impacts from small numbers of observations may suggest regions where more observations should be added. An example was shown for a case where observation impact helped to detect problems with AMV wind processing. This was confirmed in OSEs that showed that restricting the use of AMVs in areas on the fringe of the coverage has a positive impact on the forecast. An NRL website has been developed to display observation impact results (currently for 00 UTC data), see: http://www.nrlmry.navy.mil/obsens/.

The EUMETNET composite observing system, EUCOS, over Europe, which includes ASAP, AMDAR, BUOYS, RAOBs and SYNOP, was presented to the workshop. The main effort is directed towards the future design and coordination of the evolution of ground based EUMETNET observing systems. A studies programme has been put in place to provide guidance on the evolution of EUCOS. Impact studies and new approaches are required to plan for changes in the observing network that would take into account the changes in data assimilation at the regional and global scales. The value of the ground based segment needs to be evaluated in relation to the rapidly developing satellite component. The components of EUCOS have developed strongly in recent years (particularly the AMDAR data coverage) and data assimilation systems are now able to assimilate data with high time resolution. Scientific evidence is required to get the approval of EUMETNET council for further network changes and modifications. The presentation showed that it is possible to design changes to an operational radiosonde network, basing the decisions on scientific analyses coming out from impact studies. More specifically, the results stressed the importance of isolated radiosondes such as Atlantic ASAPs and indicated the possibility to evolve the European continental network towards a better synergy (or less redundancy) between radiosonde and aircraft data.

In Europe, an experiment consisting in deploying targeted observations of radiosondes and AMDAR was presented also by EUCOS and is ongoing until the end of 2008. The main targeting tool (called DTS: Data Targeting System) consists in a web tool developed at ECMWF and used by the Met Office for the decision process (to deploy or not to deploy an extra observation).

A presentation by MGO (Russian Federation) discussed the situation of the current upper-air network in Siberia. The network now comprises 22 stations but only 19 are reporting regularly. The objective of this study was to configure an 'optimal' network design based on information content, in view of making proposals in Russia to upgrade the current network. In practice, several RAOBs stations have been added in Siberia but most are now in the Southern part which deviates from the optimal configuration. This is considered to be insufficient to provide the accuracy needed for winds and temperature. A case study was also presented on the RA-I African network. Missing data areas with respect to operational RAOB station list for RA-I are very significant. Only 46 from nominal 262 sites carried out measurements in January-April, 2004. A scenario for existing operational RAOB network has been proposed to extend from 46 to 59 stations by recovering measurements at 13 stations, which provide a substantial reduction of error fields for all meteorological variables in missing data areas. The studies performed by MGO showed that in Siberia and Africa, it was possible to plan improvements to the upper-air network through simple network studies based on the estimation theory.

EUMETSAT has an operational mandate to plan for the future operational meteorological satellites and related services. The EUMETSAT presentation emphasized the importance of preparing for new instruments so that observations can be used shortly after launch to maximise the cost benefit ratio of the missions. The OSEs / OSSEs and impact studies help to demonstrate the usefulness of the data by measuring the impact or expected impact of observations from satellite measurements. Regarding METEOSAT Third Generation (MTG), the priorities of the infra-red hyperspectral sounder will be to focus on the time evolution of vertically resolved water vapour structures. It will provide atmospheric dynamic variables with high vertical resolution (e.g., water vapour flux, wind profile, transport of pollutant gases). As for the post-EPS, the highest priority has been given to high-resolution infra-red sounder, microwave sounding, scatterometry and VIS / IR imaging. An OSE has been carried out to measure the impact of 'losing' METOP on current NWP systems. This experiment was useful to confirm the choice in priority for a future EPS. The following more general issues were also raised in the EUMETSAT presentation:

- A need is felt for a framework in order to organize better design studies (OSSEs or simpler studies) when a new satellite mission or instrument is emerging, and also to guide the studies assessing the potential impact during the development phase;

- The full utilization of a new satellite instrument requires a rather long learning process; this type of effort for a better use of satellite data should be carried out independently of the operational ground segment, as it involves different scientific and technical tasks; and

- The satellite community is expecting impact studies which help the choice of the compromise they have to make between "diversity of observed parameters" and "data coverage quality". As an example, a train of satellites (like Aqua-Train) gives a high priority to the availability of various parameters at the same observation point and at the same time (and a low priority to the improvement of the data coverage).

The assessment of the impact of observations depends on the characteristics and components of the assimilation method (e.g., error statistics), the nature and volume of assimilated observations, and the NWP model. To make firm statements about the value of observations, it becomes important to examine if different centres get similar conclusions when the systems are configured to be as close as possible. To address this question, the THORPEX Data Assimilation and Observing Strategies Working group (THORPEX DAOS-WG) is conducting intercomparison experiments using a common method to evaluate the observation impact.

A number of centres took part in a first intercomparison exercise for January 2007, using a common set of observations assimilated by all the centres, and using the same adjoint-based technique. As mentioned before, results were presented to the workshop by the NRL, NASA-GMAO and ECMWF. ECMWF is using a 12-h 4DVAR while NRL and GMAO use 3DVAR with a 6-h assimilation window. The results agree on several elements: AMSU-A radiances and aircraft data are found to have an important impact for example. However, significant differences still persist. The AMVs have more impact at NRL than ECMWF and GMAO while ECMWF's 4-DVAR provides a larger impact for surface and ship data and QuikScat surface winds may have a negative impact. (For additional details, see the paper by Gauthier et al. in these workshop proceedings). The conclusion to be drawn is to acknowledge that the value of observations does depend on the assimilation and forecast system and on other elements (e.g., flow regimes). The observation impact intercomparison experiment will be pursued and interested groups were invited to contact the THORPEX DAOS-WG. The objective will also be to use these tools to evaluate the value of observations deployed during the 2008-2009 THORPEX Pacific-Asia Regional Campaign (or T-PARC). Various observing strategies will be used to deploy observations during the different stages of the lifecycle of Tropical cyclones from genesis, to landfall and the recurvature phase, the Extra-Tropical transition and finally, when they move north in the extra-Tropics. It will be interesting to compare different methods to evaluate the impact of observations some being based on adjoint models while ensemble based methods are also proposed. This exercise is important to assess the robustness of the impact evaluation itself.

3.3.2 Discussion items

With respect to the traditional OSEs, the measurement of the impact through an adjoint technique appears as a new and promising technique which should be recommended.

The FIO computed by an adjoint technique will also be very useful to assess some data targeting strategies like the ones which are currently tested within the EUCOS / PREVIEW DTS Project. It will take time before an optimal targeting strategy can be worked out. Whether it is better to add extra targeted observations every now and then, or to target intensively some particular weather episodes for several days in a row, is still an open question. To answer such a question, studies like the current DTS project are needed, but also studies using existing data, especially satellite data. The discussion on the verification and validation of targeting strategies led also to the following points: (i) the verification and validation must not be limited to the averaged scores measuring the overall impact of targeted data; (ii) some tests must be made to check if targeted data are more valuable than non-targeted data; and (iii) targeting of special meteorological events (cases of high impact) must continue to be supported.

In order to improve the conventional upper-air observing network in the different WMO Regions, the discussion recognized the need for a simple statistical tool, maybe limited to the handling of a radiosonde network at the regional scale, which could provide simple guidelines on the priorities for (re)activating upper-air stations, or for closing existing ones. The mathematical tool could follow the method presented by MGO at the workshop: see paper by Oleg Pokrovsky in the proceedings attached to this report. It should however provide an estimate of the more/less informative radiosonde sites with respect to a background which is as realistic as possible in the context of NWP. Statistics on the background error coming from an advanced NWP centre (which assimilates many satellite data) could provide this proper reference. One can foresee simple and flexible software which could be used for different WMO Regions, implemented on a PC and portable, introducing every now and then updated background information from a NWP centre. However, the utility, the efficiency and the complexity of the design of such a tool was not completely assessed in the workshop; this has to be done before deciding the development. If developed, such a tool should be designed in a way that can be used to optimize not only the upper-air observing stations but also, if possible, the Regional Basic Synoptic Networks (RBSN) as a whole. Still, the priority should be put on the upper-air design (radiosonde) to start.

The discussion about the standardization of the OSE methodology and experimentation recognized the fact that guidelines for OSE already exist in different WMO documents (including the preceding workshops similar to this one). In addition, it was noted that there are two different families of OSEs: (i) The "OSEs of opportunities", which are carried out regularly by NWP centres for their own purposes, most of the time for validating the addition of an extra observing system to their operational data assimilation system; and (ii) The "coordinated OSEs" (like the EUCOS ones in this workshop), where the standardization on the data, the period used, the verification techniques, etc. are pushed very far. Then one should aim at a better exchange of the information, between the different centres, but one should not try to push much further the OSE coordination.

Concerning OSSEs and future observing systems, an improved coordination is still felt desirable by the people planning future satellite missions. An OSSE framework has been built in the US with the help of ECMWF. It can be used for several purposes, but the main concern is to fund the effort in the long term. Although no precise recommendation could be formulated by the workshop, it seems such a coordinated framework would require the joint support of several satellite agencies and NWP centres. Firstly, it is essential to establish a calibrated baseline OSSE, and this must be a centralized effort. Thereafter, the work on a range of OSSE activities can be distributed, and a variety of funding sources can be pursued.

4. WORKSHOP CONCLUSIONS AND RECOMMENDATIONS

The discussions on the workshop presentations and results took also into account the reports from the preceding workshops and the latest comments made by ET-EGOS-4 (Geneva, Switzerland, 7-11 July 2008). They led to the following conclusions and recommendations.

Almost all centres were able to identify positive impacts on forecast skill of practically all parts of the observing system. This is a testament both to the quality of the Global Observing System and to the increasing level of maturity of the models and assimilation systems used to ingest the information for numerical weather prediction. A tremendous activity is now evident in regional NWP using variational assimilation systems to explore new data types. The methodology has converged, and rapid progress is being made in many countries

Several studies seemed to indicate that the impact of simultaneous use of mass (temperature) and wind observations exceeded the sum of the individual impacts in experiments where the two types of information were used separately, especially in the tropical regions. This will have implications for the requirements of the observing system of the future as far as the balance between observations pertaining to the different model variables is concerned.

4.1. Interaction between NWP centres, data providers and data users

a) Some regional observation data sets appear to be more and more useful for regional NWP and will soon be useful also for global NWP. It is recommended to implement a global exchange of these data sets, starting by: (i) Radar data radial wind and reflectivities as the highest priority; and (ii) GPS surface networks as second priority; and

b) For polar orbiting satellite instruments, the quick availability of data in real-time, NWP is important for operational NWP (global and regional). It is then recommended to develop and maintain ad hoc telecommunication means allowing the quick re-transmission of some data (like the existing systems EARS and AP-RARS).

4.2. Observational data requirements

a) Because of the lack of profile-type observations in the polar latitudes, every effort should be made to maintain the existing radiosonde sites, and / or find new systems to observe the vertical structure of the atmosphere (wind, temperature, humidity) in the polar areas. The IPY year is an opportunity to have new systems deployed (e.g., drifting balloons and unmanned aerial vehicles). An exhaustive list of these IPY-specific observations should be made available to all NWP users, and the extension of some of these systems beyond the IPY should be considered;

b) One of the highest priorities in terms of observation requirements is to add more profile observations in many data-poor areas. Thus, all the AMDAR opportunities should be used to improve the wind and temperature data coverage, especially in data-poor areas like the inter-tropical regions or Central and South Africa. This implies collecting new wind and temperature profiles at certain airports by equipping some aircraft flying regularly to these airports, and also to get the data from cruise levels in these regions (which are otherwise data-poor regions); and

c) Remote radiosonde stations are still of exceptional value (as shown with isolated islands, ASAP observations and AMMA radiosonde observations). They are essential and should not be closed although they are the most expensive. We have not yet reached the point of satellite utilisation that makes it possible to close down such stations.

4.3. Proposals for future studies

a) The use of the adjoint technique to compute a FIO is highly recommended to complement OSEs and DFS, to all the centres which can afford it (the adjoint of a forecast model is needed). A somewhat systematic exchange of results between some centres (as is currently done for monitoring of observation availability and quality) is also desirable;

b) For studying rapidly and objectively the optimization of stations of the Regional Basic Synoptic Network (RBSNs) in the WMO Regions (especially radiosondes to start with), it is recommended to study the design of a simple mathematical tool, in the form of a portable software, based on the optimal estimation theory. If assessed feasible and potentially useful, the design could be pursued along the lines of Oleg Pokrovsky, in the present proceedings, but using appropriate NWP background statistics rather than climatology, and taking into account the cost of each individual station);

c) More attention should be given to the forecasts at ranges from 7 to 14 days, in some future impact studies. In this context, some studies should address the requirements in surface variables such as soil moisture, SST and sea-ice and also the observation requirements in the stratosphere. Ensemble prediction systems could be a helpful tool for these future studies;

d) Concerning the stratosphere, the requirements for conventional observations will have to be studied again in the new context where GPS-RO has started to play a major role, and when ADM-AEOLUS wind data are likely to be available within few years. The current Joint OSSE project provides a test-bed for studies to answer the general question of observation requirements in the stratosphere; and

e) Studies related to surface emissivity over land are highly required for regional NWP in order to fully exploit the satellite observations. Some are already available, but the efforts should be increased.

REFERENCES:

Pailleux, Jean (Ed.), 1997 : Impact of Various Observing Systems on Numerical Weather Prediction. Proceedings of the CGC/WMO Workshop, Geneva, Switzerland, 7-9 April 1997, WMO Technical Report No. 18, WMO/TD No. 868.

Pailleux, Jean, and Böttger, Horst (Ed.), 2000: Proceedings of the Second CGC/WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction, Toulouse, France, 6-8 March 2000, WMO Technical Report No. 19, WMO/TD No. 1034.

Böttger, Horst, Paul Menzel and Jean Pailleux (Ed.), 2004: Proceedings of the Third WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction. Alpbach, Austria, 9-12 March 2004, WMO TD No. 1228.