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Key results from 6th NWP Impact Workshop May 2016

The *6th WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction* (NWP) was held 10-13 May 2016 at the Shanghai Meteorological Service (SMS) Headquarters in Shanghai, China. The workshop was attended by roughly 80 participants from 14 countries, and it included experts on data assimilation and observation impact, experts on climate change and seasonal forecasting, representatives from space agencies and from private industry, as well as managers of observing networks.

In general, the major NWP centres tend to see less evidence of redundancy of observations or saturation of the impact than was reported at the previous WMO Impact Workshop in Sedona in 2012. In other words it was now reported that adding new observations to the assimilation would almost always lead to a positive impact on forecast skill. In terms of the most important observing systems contributing to forecast skill of global NWP models, little had changed since Sedona 2012. The top five system remain - in no particular order - Microwave sounders (AMSU-A, ATMS), hyperspectral IR sounders (AIRS, IASI, CrIS), radiosondes, aircraft data and atmospheric motion vectors (AMVs).

Compared to the status reported in 2012, significant progress was reported regarding data impact on limited area data assimilation systems, both for space-based and conventional data, including new data types provided by radars, lidars and ground-based GNSS systems.

A Final Report, which will include consensus statement regarding the impact of various observing systems as well as a number of formal recommendations, will be published by WMO later in 2016, and all presentations will be made available on the WMO website.

Action/Recommendation proposed: CGMS Members to take note of the work of the WMO and the NWP community on identifying the respective impacts on forecast skill of various observing systems, including space-based, and to formulate their requests (if any) for additional impact assessment work and transmit them to the WMO Secretariat.

(The following text is an excerpt of the initial draft of the Workshop Report and is provided to CGMS-44 for information only and is not to be shared publicly; it should be understood that the text, including the formal recommendations, may still change significantly in the final version to be adopted by the Workshop participants).

Introduction

The *6th WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction* (NWP) was held 10-13 May 2016 at the Shanghai Meteorological Service (SMS) Headquarters in Shanghai, China. The Workshop was hosted for the WMO Commission for Basic Systems by the China Meteorological Administration (CMA) and SMS, and additional financial support was provided by the World Weather Research Program and the Wold Climate Research Program. The WMO Inter Programme Expert Team on the Observation System Design Evolution (IPET-OSDE) had proposed topics for NWP impact studies relevant to the evolution of global observing systems (GOS) and participants were encouraged to present results on those topics in particular.

The workshop was attended by roughly 80 participants from 14 countries, and it included experts on data assimilation and observation impact, experts on climate change and seasonal forecasting, representatives from space agencies and from private industry, as well as managers of observing networks. The scientific organisation committee comprised Erik Andersson (Co-Chair, ECMWF), Yoshiaki Sato (Co-Chair, JMA), Carla Cardinali (ECMWF), John Eyre (Met Office, UK), Ron Gelaro (GMAO, NASA), Jianjie Wang (CMA), Jochen Dibbern (DWD), Thibaut Montmerle (Météo-France), Lars Peter Riishojgaard (WMO) and Wenjian Zhang (WMO). At the workshop the WMO Secretariat was represented by the Director of Observations and Information Systems, Dr Wenjiang Zhang and the WIGOS Project Manager, Dr. Lars Peter Riishojgaard.

The workshop was organized in three oral Sessions and one joint poster session:

1. Global forecast impact studies (chaired by J. Eyre and C. Cardinali),
2. Regional forecast impact studies (chaired by R. Gelaro and Jiangdong Gong (CMA)),
3. Sensitivity forecast impact studies (chaired by J. Dibbern and T. Montmerle), and
4. Poster session

There were roughly 15 presentations in each oral Session, for a total of 43 oral presentations and 41 poster presentations. Each oral session was followed by a dedicated discussion period. In order to lead off the discussions the Session Chairs presented their draft summary reports capturing the salient points, statements about observation impact and recommendations, taking into account also related material from the joint poster session. These summary reports were then discussed by all participants and subsequently amended by the Session Chairs. Overarching messages from the Workshop, tentative answers to the Science Questions, and any modifications to the Science Questions for the impact work in the future were all discussed during the wrap-up session on the final day. This report includes highlights from the presentations and it captures the main points agreed on during the workshop. Where appropriate, the conclusions are stated in terms of formal recommendations that are addressed either to WMO, to various observing system operators (both on the conventional and on the space-based side), or to the NWP community itself.

Session 1. Global forecast impact studies.

In general, the major NWP centres tend to see less evidence of redundancy of observations or saturation of the impact than was reported at the previous WMO Impact Workshop in Sedona in 2012 (henceforth referred to as Sedona 2012). In other words it was now reported that adding new observations to the assimilation would almost always lead to a positive impact on forecast skill. This could be due to either an improvement in quality of the observations or improved assimilation techniques. The Workshop was not in a position to make an unequivocal statement about the relative importance of these two factors (see also below regarding progress in assimilation).

In terms of the most important observing systems contributing to forecast skill of global NWP models, little had changed since Sedona 2012. The top five system remain - in no particular order - Microwave sounders (AMSU-A, ATMS), hyperspectral IR sounders (AIRS, IASI, CrIS), radiosondes, aircraft data and atmospheric motion vectors (AMVs). GNSS radio occultation (RO) data are also important, and the general sense was that if a larger number of soundings could be provided, this type of observation would become even more important. Among the notable changes with respect to Sedona 2012 was the emergence of ocean surface winds from scatterometers as a significant contributor to NWP skill.

Most of the reports shown at the Workshop included results given in terms of Forecast Sensitivity to Observation Impact (FSOI) statistics. However, also some classical data denial studies were reported, in particular from the Joint Center for Satellite Data Assimilation. Among the notable results:

- So-called secondary (or back-up) satellites within a given orbital plane have a very substantial impact on skill – their data are thus not redundant with those provided by the primary satellites;
- Removing the NOAA PM orbit coverage has a substantial negative impact on skill;
- Removing polar GNSS RO also has a substantial negative impact, but not as much as removing the PM coverage.

Scientific progress on assimilation was reported in a number of different areas. One area showing very significant improvement was the use of microwave radiances affected by cloud and precipitation, i.e. all-sky radiance assimilation. This has been made possible by much improved modelling of radiative transfer in these situations. The additional microwave data ingested in all-sky mode has been found to improve the wind analysis, which demonstrates the dynamical adjustment of the model to the new data.

Several new satellite data types have entered operational assimilation during the past four years, all with positive impacts. Among them are: Metop-B (in addition to Metop-A); CrIS and ATMS on Suomi-NPP; Megha-Tropiques/SAPHIR (MW sounder in low-inclination orbit); ISS Rapidscat (scatterometer in low-inclination orbit); FY-3C/MWHS-2 183 and 118 GHz channels; GCOM-W/AMSR-2; GPM-core/GMI; LEO-GEO AMVs;. In addition, assimilation experiments with both AMV and Clear Sky Radiances from the Korean geostationary COMS satellite are under way. The impact is currently still small, but work is in progress to improve it.

Generally positive impacts of surface-sensitive microwave channels over land and over sea-ice was noted, and the impact was found to be increased when using retrieved microwave emissivity. MWHS-1 data from FY-3B have been used over land and over snow surfaces with some positive impact. On the infrared side, it was pointed out that several sensors (e.g. IASI) are still under-utilized over snow-covered surfaces.

Several centres reported results obtained while using explicit modelling of observation error correlation. Due to technical limitations, observation errors had been assumed to be uncorrelated in most assimilation systems until relatively recently. Generally good impact for microwave and infrared radiances using inter-channel correlated observation errors. Studies regarding temporally correlated errors of ground-based GNSS data found negligible correlations beyond 1.5 hours. Further work on the modelling of correlated observation errors would be beneficial especially to high density and high volume data provided by nadir-looking satellites and by ground-based radars and further pursuit of such work was strongly encouraged.

> ***Recommendation 1***
> *All NWP centers are encouraged to include explicit models of observation error correlations, in particular for satellite and radar data.*

> ***Recommendation 2***
> *The constellation of scatterometers should be improved (better orbital spacing) in order to provide better space/time coverage. Generally the impact of adding observations in data void areas is significantly higher than the impact of adding additional data in areas where observations already exist.*

> ***Recommendation 3***
> *NWP centers rely on high-quality level 1 data. Space agencies are encouraged to make every effort to improve the quality of their level1 data, including via GSICS.*

In addition to the level 1 radiance products mentioned above, NWP centres also rely on high-quality level 2 processing undertaken by the space agencies, e.g. for AMVs and scatterometer surface winds. For the AMVs in particular, the space agencies were commended for the recent improvements in quality control and product quality, including improved height assignments.

> ***Recommendation 4***
> *Additional data impact studies for new AMV products (e.g. LEO-GEO winds, IR sounder winds, MISR winds) are strongly encouraged.*

The positive direct impact of GNSS-RO data on global NWP skill was confirmed, as well as the indirect impact of these data through their contribution to bias correction of radiance data from other satellite sensors. In similar fashion these data have the potential to also help improve the radiosonde bias correction. It was noted that the Taiwan-US COSMIC-1 constellation had entered a phase of decreased capabilities (fewer observations than previously due to fewer satellites still operating). The FORMOSAT-7/COSMIC-2 constellation as planned would consist of two components, namely COSMIC-2A: Six satellites in low inclination orbits, and COSMIC-2B: Six satellites in high inclination orbit. Only the first segment (COSMIC-2A), providing soundings primarily over the tropical regions is currently funded. The Workshop stressed the importance of also having GNSS RO data available over the extratropical regions.

An Observing System Simulation Experiment (OSSE) regarding the expected impact of a substantially enhanced future RO system demonstrated no saturation of impact (but a gradual decrease in incremental impact) even at ~100,000 profiles per day. OSSE work on future GNSS RO systems is still ongoing and will focus on issues such as data quality and vertical coverage in the future.

> ***Recommendation 5***
> *(first proposed by the IROWG and supported by this Workshop in slightly modified form)*
> *The deployment of an operational constellation of GNSS-RO satellites capable of providing at least 20,000 high quality soundings per day, at near-uniform global coverage and extending well into the lower troposphere is strongly recommended.*

Another OSSE study demonstrated a potential impact on tropical cyclone track forecasting of a geostationary hyperspectral IR sounder. Compared to an instrument - or even to a moderately sized constellation of instruments - flying in LEO, a GEO sounder can provide higher temporal resolution. Such GEO hyperspectral IR sounders are planned as FY-4A/GIIRS and MTG-S1/IRS. Furthermore a 183 GHz multi-spectral GEO radiometer concept is being studied, focusing on improving the analysis of humidity. So far this study has shown that it may be difficult to make significant improvements using the data from this proposed instrument concept. However, this was found to be far from unusual for new space-borne technologies, so the Workshop adopted the following recommendation:

> ***Recommendation 6***
> *The CGMS space agencies operating GEO satellites are encouraged to continue the development and deployment of hyperspectral IR GEO sounders. Further studies of GEO MW sounders and imagers and their potential impacts are encouraged.*

Regarding the impact of aerosol observations on NWP it was noted that case studies under the auspices of the WMO Commission for Atmospheric Science Working Group on Numerical Experiments (WGNE) were underway. Data assimilation for these observations continues to be a challenge due to the large uncertainties regarding the actual quantities being observed. It was noted that not enough high-quality data sets are available for assimilation and for validation of the assimilation products.

In general, the positive impact of aircraft observations, both flight-level and profile data, on skill continues to be very substantial. The quantity of profile observations made available and used for NWP has increased significantly with respect to the status in 2012. It was noted that ascent profiles tended to have slightly larger impact than data observed during aircraft descent. All NWP centres were encouraged to further increase the use of profile data from ascending and descending aircraft. Moisture observations from the Water Vapor Sensing System (WVSS) now operating on 135 US and 8 European AMDAR-equipped aircraft were shown to be of equal or better quality than radiosonde measurements. The largest impact on skill is over the CONUS region, where the impact is 50% larger than that of the twice-daily radiosondes. The assimilation of WVSS data in the NCEP Global Forecast System improved moisture forecasts out to 66 hours and had positive effects on the 12-36 hour precipitation forecasts at all thresholds.

> ***Recommendation 7***
> *WMO and the AMDAR Panel were strongly encouraged to investigate and publicize the benefits of aircraft humidity observations, since there is a risk that this capability may disappear unless a market for the sensing technology can be developed.*

During the workshop the scheduling of radiosonde launches was introduced as a topic of substantial interest to the WMO Commission for Basic Systems and the WMO community as a whole. Currently the radiosondes are launched simultaneously (primarily at 00 UTC and 12 UTC) by national weather services all over the world as part of their commitments to the WMO RBSN (Regional Basic Synoptic Network). However, both for climate applications and for certain local forecaster applications, some flexibility in the launch schedule may be desirable. In addition, alternative launch schedules might prove to be beneficial also to regional limited area NWP activities. No studies pertaining to this topic were presented, but the Workshop agreed on the following two recommendations for future work:

> ***Recommendation 8***
> *WMO to develop specific alternative scenarios for radiosonde launch schedules; NWP centres were encouraged to perform data impact experiments for such scenarios.*

> ***Recommendation 9***

Recent CMA field experiments with augmented launches has provided a useful dataset for that could be used by other NWP centres for impact experiments; CMA to consider whether the extra soundings could be made available to the international NWP community.

The Workshop took note of the current development in the space sector regarding commercial data providers proposing to put privately funded GNSS-RO constellations in space with an aim to sell these observations to national governments, and it was emphasized that unless the data are procured with a clear aim to continue respecting existing principles on international data sharing, these data will not be fully utilized, since their main application is in the area of global numerical weather prediction.

Recommendation 10
All data providers are encouraged to continue to share all observations internationally, especially those observations that are essential for numerical weather prediction, e.g. all GNSS-RO soundings.

During the Workshop, concerns about inconsistent use of terminology which might lead to misinterpretation of the results were expressed. Therefore, the following recommendation was agreed:

Recommendation 11
All NWP centres to use standard data assimilation terminology (e.g. Ide et al., 1998 and similar references) in their presentations; statistical significance to be included in all forecast skill charts.

Session 2. Regional forecast impact studies.

The general impression was that utilization of observational data in regional NWP - and therefore also the level of knowledge about observational data impact in regional NWP - had progressed very significantly since Sedona 2012. In the previous two impact workshop, many limited area NWP systems had shown only limited impact of local observations, and had in fact received much of their information from observations assimilated into the global systems providing the background and boundary conditions. During this workshop all presenters showed significant impact of local observations assimilated into the limited area model itself.

It was noted by several presenters that assimilating observations at increased temporal resolution tended to improve short to medium range forecast skill. This was assumed to be at least in part caused by a simple increase in the number of assimilated observations that are asynoptic in nature, e.g. satellite radiances, ground-based GPS, wind profiler data.

Radiosonde information above 100 hPa was found to be an important contributor to forecast accuracy in the stratosphere in both the NH and SH extratropics. While aircraft observations continue to have substantial positive impact on forecast skill, that is one of the reasons why these observations cannot be expected to fully replace the vertical profile information of wind, temperature and humidity provided by the radiosonde network.

A discernible positive impact of assimilating data from up to four scatterometers simultaneously was shown. With respect to the Sedona 2012 consensus, it was noted that all NWP centres now were showing positive impacts also on average forecast skill, and not only in selected cases of high impact weather as was the case previously. The Workshop attributed this primarily to improved assimilation techniques rather than to any increase in observation counts for these observations.

The addition of AMVs from MISR to the conventional suite of satellite winds was found to provide a modest additional positive impact on skill. This was nonetheless considered a significant result, since the spatial coverage of MISR AMVs is extremely limited compared to the existing AMV coverage.

A temporary reduction in the number of daily Russian radiosonde launches had led to a demonstrated significant degradation in medium-range forecast skill over Northeast Asia and the North Pacific. The Russian soundings (amounting to well over 10 % of total number of global radiosonde ascents, even after the temporary reduction) were found to be essential especially during the norther hemisphere winter season when the use of satellite observations is rendered difficult due to snow and/or sea ice on the surface. It was noted that WMO had reacted to this reduction and that the situation had since been rectified by Russia.

The data types currently being studied or tested for assimilation at the finest scales (meso- to convective-scale NWP) was broadly classified as follows:

a. Maturing data types
- Radar reflectivity, radial wind, and retrieved observations from radars such as RH profiles;
- MODE-S wind and temperature (flight radar based, many times more observations than AMDAR);
- Ground-based GNSS slant total delay, zenith total delay, retrieved precipitable water vapour;
- Space-based radar observations (e.g., GPM/DPR).

b. Emerging data types
- Ground-based MW radiometers, focus on brightness temperatures rather than retrievals;
- Temperature and water vapour from rotational Raman lidars (TRRL, WVRRL);
- Water vapour differential absorption lidar measurements;
- Radar refractivity.

c. Improved or enhanced usage of conventional data types
- Supplemental radiosonde launches;
- Surface mesoscale networks; e.g., China Automatic Weather Station (AWS) network.

It was noted that some regional NWP systems show significant impact from data that are not shared internationally (not disseminated via the GTS). Since the impact has been demonstrated and since regional model domains are set up largely irrespective of national borders, increased international distribution of these observations is encouraged.

> ***Recommendation 12***
> *WMO to articulate the requirement for international sharing of all observations used in NWP systems, e.g. via the new RBON (Regional Basic Observing Network) development; data providers (including NMHSs and space agencies) are encouraged to make these data available to all NWP centres.*

It was noted that the observational data requirements for convective-scale NWP are very challenging in terms of both accuracy and data latency. There is a need for higher vertical-resolution observations of temperature, wind and humidity in the boundary layer in order to help improve convective-scale forecast skill. A systematic set of OSSEs would be useful to help define the requirements for these observations. Passive measurement techniques alone are not likely to be able to satisfy these requirements, so active sensing techniques and assimilation in test mode of the data provided by them should be pursued.

> ***Recommendation 13***
> *NWP community to carry out impact studies regarding proposed observing systems for high-resolution sensing of the atmospheric boundary layer; WMO to document and record the requirements in its WIGOS databases.*

Convective scale NWP is now showing impact from assimilation of radar data, but there is still much potential for further exploitation of these data. At this point in time, the data assimilation effort is still mostly focusing on the use of fairly high level products, but it was noted that in line with previous successful efforts in assimilation of satellite data, direct assimilation of radar reflectivity should be the goal. Assimilation of radar reflectivity provides significant skill improvement up to about six hours in the NOAA RAP/HRRR system. Radar polarization information has proven to be useful for the quality control of radar data. Including the this information directly in the assimilation itself may provide additional benefits, but the experimental evidence for this is unclear at the present time. Further investigation is encouraged.

> ***Recommendation 14***
> *The radar data assimilation community is encouraged to gradually move toward assimilation of lower level products, in line with the methodologies first pioneered for satellite radiance assimilation.*

> ***Recommendation 15***
> *Further investigation into the use of radar polarization information is encouraged.*

It was pointed out that perhaps even more than is the case for other observing systems, attention to quality control is absolutely vital for any radar data assimilation effort due to the effect of clutter and various non-meteorological sources of back-scatter. The sheer volume of data provided by the radars poses significant logistic, technical and scientific challenges. Further investigation into various approaches for handling this issue is needed. It was noted that thinning removes mesoscale features, and therefore may not be desirable. Super-obing (horizontal averaging) will not remove the correlated error, and direct investigation into the modelling of correlated observation errors is therefore needed (strong support for ***Recommendation 1***).

Both the radar and the ground-based meso-network communities would benefit from increased organization, standardization of data formats and data quality control procedures, and from increased data sharing on an international basis. WMO has initiated such efforts but increased emphasis from all interested users and partners is strongly recommended.

> ***Recommendation 16***
> *WMO to continue and possibly strengthen its efforts on the development of protocols and formats for both national and international exchange of weather radar data.*

Strong support was expressed here also for ***Recommendation 13.*** The challenges of using 3D-VAR assimilation techniques for high-frequency assimilation due to spin-up issues and the need for specific additional tuning points to the need to exploit 4D-VAR techniques for mesoscale DA, which will also facilitate a more efficient use of high temporal frequency observations.

There has been much progress in the validation of the AWS mesoscale ground network over China, and experimental evidence showing the positive impact of these data on regional NWP.

MODE-S observations were found to give a small additional positive impact in the early part of the forecast range, beyond what was provided by the existing conventional data alone (reduced RMS errors in temperature and wind speed) in the DWD KENDA. GPS slant delay data provide a positive impact in the first 12 hours in DWD KENDA. Ground-based Microwave radiometers were shown to have a modest positive impact on the precipitation forecast (but not on the model dynamical fields) during the early part of the forecast range in the Météo-France AROME system. There was some indirect evidence that MWR data might have more impact if placed away from radiosonde sites; the likely explanation was that this would be due mostly to the general advantage of improved horizontal distribution of the observations rather than to any unique relationship between the measurements from radiosondes versus microwave radiometers.

Session 3. Sensitivity forecast impact studies

Drifting buoys were found to have a very substantial positive impact at the global level. A data impact study aimed at investigating the relative contributions from VOS (the WMO Voluntary Observing Ships) and the drifting buoys in the Atlantic showed that both are important, their relative contribution depending on weather situations and specific areas.

For some data assimilation systems using very short observation cut-off times, aircraft observations taken during ascent/descent are the most important data, together with soundings and geostationary satellite data. Over the Arctic regions, buoys and LEO satellite observations are essential, but additional in situ vertically resolved data (soundings) are needed.

> ***Recommendation 17***
> *WMO and the Global Cryosphere Watch (GCW) to investigate possibilities of obtaining additional soundings over the Arctic.*

Some radar wind profilers have shown good accuracy and with the use of efficient QC algorithms these now appear to have the potential to be as informative as radiosonde winds over the vertical region of their coverage.

The requirements for observations to support climate studies and climate monitoring were discussed during the workshop, and it was noted that the requirements differ significantly across different sub-disciplines that exist within the general area of climate. Long-term detection of climate depends less on extensive horizontal coverage and more on calibration and long-term stability of measurement accuracy. Process studies and detection of extreme events on the other hand lead to requirements that are more similar to the requirements for the weather-related WMO application areas. The development of OSSE methodologies to address specific climate-related observing network design issues was recognized as an emerging area, and further work in this area was encouraged.

> ***Recommendation 18***
> *Further investigation into the use of impact studies for the design of climate observing networks is encouraged.*

It was noted that for seasonal to decadal-range prediction performed with coupled models, additional observations would be needed, e.g. sub-surface ocean observations, more detailed sea ice observations (additional parameters needed), additional aerosol and gaseous atmospheric constituents (green house gases), solar irradiance measurements. No impact studies of this nature were presented at the Workshop, but it was recommended to do so in the future.

> ***Recommendation 19***
> *Longer range (seasonal to decadal range prediction) observation impact studies are encouraged.*

The quantitative influence of satellite observations on reanalysis has been growing during the last several years, but reanalyses are still heavily influenced by individual conventional data types (e.g. aircraft, synops). The relative ("per observation") impact of the conventional data is roughly twice the impact of the satellite data. It should be noted that since the concept of forecast skill does not apply to reanalysis data (unless a corresponding hindcasting effort is included), these results are stated in terms of the so-called DFS (Degrees of Freedom for Signal) diagnostics, which cannot be directly compared to the FSOI (Forecast Sensitivity to Observation Impact) diagnostics typically reported for forecast impact studies.

Concerning the FSOI diagnostics, it was noted that different methodologies are used for different data assimilation systems:

- FSOI using model adjoint
- EFSO using ensemble FSOI for EnKF
- Hybrid FSOI for 4DEnVar

These differ in their respective approaches to the backward propagation of sensitivities and in the ways in which the adjoint of the analysis gain matrix is computed. The ensemble-based FSOI diagnostics were found to be strongly dependent on technical details such as ensemble size, methods for localization and variance inflation, and it was therefore difficult to directly compare FSOI and EFSO diagnostics.

Different subjective norms were used as a basis for computing the sensitivities. Dry or moist total energy norms are based on evaluating the forecast error in model space and can therefore be sensitive to model biases. Normalized forecast departures with respect to observations are based on evaluating the forecast error in observation space. This methods leads to diagnostics that are more similar to DFS diagnostics.

> ***Recommendation 20***
> *Cost functions formulated in observation space should be used as a complement to the currently prevailing energy norms.*

The general sentiment expressed at the Workshop was that FSOI continues to be a very useful diagnostic with its well recognized and well publicized possibility to rank the NWP impact of the different data types and different network components with respect to the chosen norm. FSOI diagnostics can therefore be used by observing network operators to help them optimize the design of their networks, but the results must be interpreted carefully and they should preferably be complemented with OSEs (data denial/addition experiments) in select cases. Since the FSOI diagnostics are based on 24-hour forecast errors due to linearity assumptions, they may at times point to conclusions that differ from those drawn from data denial experiments. However, the consistency between the two methodologies was found to be reasonably good overall.

Since the FSOI diagnostics provide quantitative partitioning of contribution to error reduction between the various types of observations, they naturally lend themselves also to cost/benefit studies. One such study undertaken by the Met Office in the United Kingdom was presented at the Workshop. Among other things this study provided a rather striking illustration of the fact that while national observations can have quite unfavourable cost/benefit numbers when used and costed in isolation, the ratio becomes very favourable once the benefits of international data exchange are taken into account.

As also noted under Session 1, the recurring trend in all major studies presented was that the following five observing types provided the most significant contributions to error reduction for global NWP: Microwave sounders (AMSU-A, ATMS) hyper spectral IR sounders(AIRS, IASI, CrIS), radiosondes, aircraft data and satellite winds (AMVs). On a per observation basis, the impact was dominated by buoys, radiosondes and AMVs.

Intercomparisons between similar impact studies undertaken by different NWP centres are of great interest both for the NWP community and for the observing system operators. One such intercomparison was presented by the US Joint Center for Satellite Data Assimilation on behalf of a broad international group of NWP centres. The work toward developing a common framework for classification of observations, data formats etc. was commended.

> ***Recommendation 21***
> *Further coordination between impact studies undertaken by different NWP centres is strongly encouraged; this should extend also to issues such as common methodologies and diagnostics and common quantities used when presenting the results.*

It was also noted that the research and development regarding the use of FSOI-like diagnostics at the regional scale were necessary. Adjoint models could be used if available, although they may be less reliable at these scales. The use of ensembles looks promising. The development of new norms that would capture convection should be investigated.

> ***Recommendation 22***
> *Development of FSOI methodologies applicable to regional and convective scale is encouraged.*

Finally, concerning future work, strong support was expressed for the ocean observing networks for climate, and the NWP community was encouraged to further develop coupled modeling and assimilation efforts necessary to make use of the profile observations provided by e.g. the moored buoy arrays, and to undertake relevant sensitivity/impact studies as the methodologies mature.

> ***Recommendation 23***
> *NWP and modelling communities to continue to develop modeling and assimilation approaches relevant to surface flux measurements and sub-surface ocean observations and to undertake relevant data sensitivity and impact studies when possible*