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WMO Integrated Global Observing System

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(Sedona, Arizona, USA, 22-25 May 2012)

World Meteorological Organization
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Fifth WMO Workshop on the Impact of Various Observing Systems on NWP
(Sedona, Arizona, USA, 22 - 25 May 2012) - Workshop Report

(Edited by : Erik Andersson and Yoshiaki Sato)

1. Introduction

The 5th WMO workshop on the impact of various observing systems on numerical weather prediction (NWP) was held 22-25 May 2012 in Sedona, Arizona (United States). The Workshop was hosted for WMO by the Joint Center for Satellite Data Assimilation, and additional financial support was provided by THORPEX, NASA, and NOAA (GOES-R Program Office). The WMO Expert Team on the Evolution of the Global Observing System (ET-EGOS) had proposed topics for NWP impact studies (Appendix I) 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 59 experts on data assimilation and observation impact, representatives from space agencies and managers of observing networks from 13 countries. The scientific organisation committee comprised Erik Andersson (Chair, ECMWF), Carla Cardinali (ECMWF), John Eyre (Met Office, UK), Ron Gelaro (GMAO, NASA), Miroslav Ondras (WMO), Florence Rabier (Météo-France), Lars Peter Riishojgaard (JCSDA) and Yoshiaki Sato (JMA). At the workshop the WMO Secretariat was represented by the Director of Observations and Information Systems, Dr Wenjiang Zhang.

The workshop was organised in three Sessions:

1) Global forecast impact studies,
2) Regional forecast impact studies, and
3) Scientific questions.

There were 10-12 presentations in each Session, followed by discussion. The Session Chairs provided summary reports capturing the salient points, statements about observation impact and recommendations. These reports were reviewed and agreed by the workshop during its final day. The current workshop report is a draft version subject to review by all Workshop participants and final review by the organizing committee.

Session 1. Global forecast impact studies.

Several of the global numerical weather prediction (NWP) centres presented detailed assessments of the impact on forecast skill of the main meteorological observing systems.

The traditional technique to assess the impact of observations is to conduct observing system experiments (OSEs) where the forecast impact of perturbations in the assimilated observational data set is measured against the forecast performance of an unperturbed (control) assimilation. In recent years several new techniques that augment the OSE results have been developed and they are now widely adopted, notably adjoint based tools such as Forecast Sensitivity to Observations (FSO), Degrees of Freedom for Signal (DFS) and others.

The use of four-dimensional data assimilation schemes (4D-Var, Ensemble Kalman filters and hybrid systems), which are now operational in most operational NWP centres, has significantly improved the use of observations, particularly so for single-level and asynoptic observations and also for radiances and other observations that are indirectly linked to the model variables through complex observation operators.

There is broad consensus amongst the global NWP centres that the same observation types tend to be the highest-ranked contributors to forecast skill: AMSU-A (microwave temperature sounder), AIRS/IASI (hyper-spectral infrared temperature and humidity sounders), radiosondes, aircraft observations and atmospheric motion vectors (AMVs) from geostationary and polar orbiting satellites, although not necessarily uniformly in this order. Radio occultation data based on the global positioning system (GPSRO) also has a substantial impact but the GPSRO data volumes are currently declining as the COSMIC RO system is approaching the end of its lifetime. The workshop discussed the results presented and recommended an expansion of the GPSRO numbers to at least 10,000 profiles per day from operational systems.

In terms of NWP impact there is now no single, dominating satellite sensor; there are several sensors that contribute to forecast skill. There is thus more complementarity between satellite sensors than was seen in previous years (Geneva 2008) when the impact of AMSU-A was very dominant. The OSE results indicate that the current global observing system is more resilient in the sense that when one sensor or sensor-type is withheld from the assimilation, others compensate, at least partially. This resilience is however threatened by a possible decline in the overall capability of the operational polar orbiting satellite systems in the coming years. The lack of commitment for the early morning orbit is a cause for concern.

It was noted that the impact of any one data type depends on the mix of other data types assimilated in any particular NWP system; for instance, NWP centres that use less radiance data typically show relatively higher impacts of atmospheric motion vectors (AMVs). Globally, satellite data tend to dominate, although conventional data still have a substantial global impact and tend to be dominant in the northern hemisphere. For a discussion of regional impacts, see Session 2 below.

Since the Geneva 2008 workshop there has been good progress on the use of humidity observations. There is now increased evidence that humidity observations have a beneficial impact on forecast skill. It is, however, not clear whether their impact is measured appropriately with the methods used at present. The use of event-driven metrics has been suggested, e.g. measures based on the intensity and timing of rainfall events. It was noted that the potential impact of humidity-related observations may not yet be fully realized because of uncertainties in the analysis, the presence of model errors, and the relatively crude representation of physics in linear and adjoint models. There has also been good progress with all-sky assimilation of cloud and rain-affected microwave radiances, as well as the use of infrared radiances in overcast conditions.

Improved modelling of microwave and infrared emissivity has led to progress in the use of radiances over land. It has been found that radiance data over land can have major beneficial impact on humidity over tropical areas, where in situ profiling data is largely absent. Experiments using the additional radiosonde data available during the African Monsoon Multidisciplinary

Analyses (AMMA) campaign over Western Africa have demonstrated the importance of in situ profile observations in this area. The forecast impact tends to be short-lived (24 hours or so) because of current model deficiencies in the diurnal cycle of the boundary layer. However, there was also evidence that the AMMA data can have downstream impact at longer forecast ranges. Bias correction for radiosonde humidity data is particularly important in this tropical region.

FSO calculations at multiple NWP centres have shown that conventional observations and GPSRO have the largest forecast impact on a per-observation basis. The influence of buoy surface pressure observations is particularly large on a per-observation basis and their OSE impact extends from the surface throughout the troposphere in mid-latitudes.

For the radiosonde and AMDAR observing systems there is generally more impact from winds (u and v components combined) than from temperature. The combined impact of wind and temperature observations is larger than the sum of the respective impacts of wind and temperature data when assimilated separately. Their main impact is in the troposphere at 200 hPa and below.

The ConcordIASI campaign in the Antarctic has demonstrated that, over polar areas, hyper-spectral data can have a large impact but the data is difficult to use at lower levels because of clouds and the difficulties with cloud detection (to be improved, research is continuing). The use of GPSRO data has shown good impact in Polar Regions. There is potential of using more microwave observations over snow and sea-ice but further work on improving the specification of surface emissivity is needed.

GPSRO has become a critical part of the global observing systems, directly as a valuable source of vertically resolved temperature and humidity information, and indirectly through the absolute anchoring of the temperature analysis at upper levels. The anchoring is very effective in determining the bias correction for radiances and other observation types that require calibration. In a parallel development, the Global Space-based Inter-Calibration System (GSICS) has shown that the hyper-spectral sounders (AIRS, IASI, and the recently launched CrIS) also can be used as reference radiance data for the calibration of other components of the global observing system (GOS) because of their accurate and stable calibration.

The importance of scatterometer data has been demonstrated at previous workshops in this series for their ability to position accurately cyclone centres and frontal zones at the ocean surface. In terms of the metrics commonly used in global NWP the impact of scatterometers is, however, relatively modest. This is because their impact is generally confined to the near-surface wind field. The importance of the scatterometer data is nevertheless very evident for shipping, predicting wind energy and wave height, and other applications. There is evidence that two scatterometers on well-separated orbits are required for adequate coverage of the low-level wind field over the oceans.

During the discussions, the workshop participants cautioned against the use of self-verification (using the analysis of the perturbation experiment) for OSEs in the short range, or more generally for OSEs that make dramatic changes to the routine observing system. The issue of analysis uncertainty in the verification is even more pertinent for humidity data. The recommendation was instead to use the analysis from the control run, which uses the most data. It was also recommended to verify OSE forecasts against observations or independent analyses where possible.

Session 2. Regional forecast impact studies.

A substantial body of results was presented demonstrating beneficial impacts on regional NWP from various components of the Global Observing System. Current regional NWP systems use 3D or 4D data assimilation techniques at high horizontal resolution (2 to 10 km) with short data cut-off times. In regional NWP, it was found that the observing systems providing the highest forecast skill impacts are different from that in global NWP; there are also substantial differences between the respective results reported by different regional NWP centres.

Beneficial impact of data assimilation was shown also in convective-scale NWP models, demonstrating an improvement over the observation impact achieved by simply “down-scaling” lower-resolution analyses. Advances in convective-scale NWP increase the need for observations at high space/time resolution, and for more timely availability of observations.

New observation impact diagnostics (FSO, DFS and reduction of error variance) provide effective means of summarizing the contributions of different observing systems also in regional applications.

In regional NWP, impacts were demonstrated from:

- radiosondes,
- conventional surface observations and ground based GPS
- aircraft observations (AMDAR, regional AMDAR systems and MODE-S),
- radar (precipitation, winds and reflectivities),
- radiances (AMSU-A, MHS, AIRS/IASI and geostationary imagers),
- high-resolution AMVs, clouds (geostationary imagery),
- ships and buoys, profilers
- GPS radio occultation

Compared with the 4th WMO NWP Impact Workshop (Geneva 2008), substantial progress was reported on the assimilation of radiances as well as the assimilation of radar reflectivities and Doppler winds in regional NWP.

Progress has been made on addressing model spin-up, but this remains a significant problem limiting the benefit and impact of assimilated observations in terms of precipitation forecast skill.

Several presentations focused on the importance of in-situ profiling observations for regional NWP. Significant benefit is obtained from radiosonde ascents together with wind and temperature profiles from ascending or descending aircraft available in most parts of Europe and North America, and some parts of Asia, Australia and elsewhere. Based on these results, the workshop recommended augmentation of the profiling network by extending coverage of ascending and descending aircraft observations to regional airports. The impact of radiosonde data is expected to increase further once the reporting of the complete time and position information as well as high vertical resolution have been widely adopted and utilized in assimilation.

The importance of aircraft data in regional NWP was evident from several presentations. In the European area, the limited potential of aircraft observations to substitute for radiosonde data has been demonstrated with some significant caveats:

- aircraft ascent/descent data are generally not available at local night time,
- aircraft data provide only limited humidity information at present,
- the spatial and temporal coverage provided by aircraft data is driven by the operational and commercial needs of the aviation industry rather than by NWP requirements,
- replacing radiosonde launches with aircraft ascent/descent data should be considered only after careful design studies, e.g. as done by EUCOS (report in preparation).

The results of recent impact studies provide strong support for exchange of more observations between regions, and between countries within regions: e.g. ground-based GPS data, radar data, hourly surface observations and MODE-S data at airports.

The workshop encouraged future studies of impact per observing system or per observation linked to their cost. The workshop recommended observation impact studies specifically addressing the observation needs for forecasting high-impact weather phenomena, e.g. severe convection, flooding, winter storms and tropical cyclones.

More work is needed on defining appropriate impact metrics for regional NWP including precipitation and other surface weather elements.

Session 3. Scientific questions

The remit of ET-EGOS extends to all the observing systems coordinated under WIGOS. There is a large number of application areas for which NWP-type observation impact studies may be relevant. What can be achieved in terms of network design studies for WIGOS?

- There is a strong requirement for observing system impact assessments coming from both the WMO members (NMHSs), the space agencies and other managers of observing networks.
- The NWP community has a range of well-established tools to carry out observation impact assessments.
- There is some hesitation amongst the scientists about getting too closely involved in policy decisions, especially regarding elimination of observations.
- There is a general recognition that additional metrics are needed beyond the traditional objective scores such as anomaly correlation, root-mean square error and total energy in the case of FSO (forecast sensitivity to observations). Metrics that are more closely related to high-impact weather and service delivery should be developed and explored.
- The European EUCOS programme is a useful model for coordination and optimisation of regional observation networks; the adoption of a similar approach to address specific issues is recommended for other regions and application areas.

It is essential to keep a visionary outlook, appropriate for the long-term evolution of the GOS and the realisation of the Vision for the GOS in 2025. The observation impact work should not be driven exclusively by the current political and budgetary situation.

Despite very significant advances in the assimilation of radiance data during the last decade, there remain substantial variations in analysis accuracy over different regions of the globe, as measured by differences between the analysis products of operational NWP forecast centres. For example, the uncertainty in wind and height analyses over the southern oceans and North Pacific Ocean is significantly larger than over Europe and North America. In addition analysis uncertainty is considerably larger over polar regions and developing nations in Africa, Asia, and South America. The reduction of these disparities in analysis accuracy should be considered as an objective for design of the future global observing system.

It is considered particularly important to retain radiosonde stations in remote regions and along coastlines, especially where there are few aircraft ascents and descents. At the workshop, the use of the observation influence (measured for example by the DFS, degrees of freedom for signal, on average per observation type) to evaluate the analysis impact of the observations has been demonstrated. Maps of observation influence can help inform this type of network design decision.

More work is needed to document analysis uncertainty, taking advantage of newly developed ensemble techniques and comparing ensembles of analyses between various centres.

The relative lack of in-situ observations in the African region remains a concern. Is an expanded AMDAR programme a viable way of counteracting the decline in the number of radiosondes, especially in Region I? Every effort should be made in equipping inter-continental and regional aircraft with AMDAR capability. Also a better and more extensive use of AMVs over Africa is recommended.

Study of observation impact on the forecasting of tropical cyclone and other severe weather events deserves particular attention. This is not only a resolution issue in assimilation and forecasts. Too few cases were shown at the current workshop to enable definitive statements to be made; high-impact episodic events such as tropical cyclones require studies extending over several seasons in order to build up statistically robust results and to draw relevant and unequivocal conclusions. Additional metrics beyond track errors are needed to measure the observation impact in terms of tropical cyclone damage and intensity and for severe weather events in general, e.g. related to intensity (wind), precipitation and risk of flooding.

The limitation of the current assimilation systems to resolve extreme phenomena such as tropical cyclones has been also noted. In particular, the state of background-error covariance modeling needs to be advanced in order for the assimilation systems to successfully use the information from all observations assimilated including targeted dropsondes and observations in strongly convective environments.

Current global observing systems are heavily skewed towards mass observations over wind measurements, especially for the satellite components. And yet many studies presented at the Workshop pointed to a higher than average impact of wind observations, both on a component and on a “per-observation” basis. There is a need to invest in enhanced wind observations in the tropics and over the oceans especially. The collection of aircraft observations at flight level over ocean areas should be increased, but this will not in itself provide the required coverage. Ascents and descents from regional aircraft should be further explored. From the classical atmospheric dynamics view, wind becomes increasingly important at smaller horizontal scales and larger vertical scales. This is also true in data assimilation, with the additional consideration that accurate analysis of strongly ageostrophic flows (associated with jet entrance and exit regions, and convective clusters for example) requires wind profile observations also in mid and high latitudes. Development of satellite-based wind profiling systems remains a priority for the future global observing system.

The THORPEX-DAOS working group, together with several leaders in the field, recently delivered a comprehensive report on observation targeting. It was concluded that the impact of assimilating targeted aircraft observations in the mid-latitudes has been small, but positive on average. While the scientific principle of improving forecasts with targeted observations has been validated, the goal of adding sufficient observations over the entire target subspace has proven to be logistically difficult to achieve. Targeted observations have, however, been demonstrated to be effective for tropical cyclone forecasting, through the use of dropsondes and rapid-scan satellite winds. The targeted use of off-time (06 UTC and 18 UTC) radiosonde data has been shown to improved mid-latitude forecasts.

In response to the Report, the workshop recommended that targeting continue to be investigated on the data assimilation side, e.g. via the state-dependent use of satellite observations in sensitive areas.

APPENDIX I – Proposed topics for NWP impact studies relevant to the evolution of global observing systems, updated to reflect the status at the time of the workshop

The WMO Expert Team on the Evolution of the Global Observing System (ET-EGOS) has proposed topics for NWP impact studies relevant to the evolution of global observing systems. The list of proposed OSEs and OSSEs has been distributed widely as it formed part of the invitation to the workshop. Status and progress with respect to each of the topics was reviewed and noted at the final day of the workshop. The green colour means the condition of achievements is good and that relevant results are now available, yellow means that work is ongoing and needs to continue whereas pink indicates little or no activity was reported at the workshop.

Short name: Full name	**Science question**
	Surface-based
S1MarinePs: Surface pressure over ocean	What density of surface pressure observations over ocean is needed to complement high-density surface wind observations from satellites? Suggestions: (a) network density reduction OSE in N.Atlantic, (b) southern oceans OSSE.
S2Strat: In situ observations of the stratosphere	What network of in situ observations is needed in the stratosphere to complement current satellite observations (including radio occultation)? What about the tropics?
S3AMDAR: Coverage of AMDAR	What is the impact of current AMDAR observations? What are the priorities for expansion of the network?
S4ASAP: Coverage of ASAP	What is the impact of current coverage of profiles from the Automated Shipboard Aerological Programme (ASAP)? How might coverage be optimised for a given level of resources?
S5Radar: Radar observations	What are the impacts of current radar observations, including radial winds and reflectivities?
	Space-based
S6RO: Radio occultation saturation	At what level, in terms of profiles per day, does the impact of radio occultation observations start to saturate?
S7SatLand: Satellite radiances over land	What is the impact of new developments in the assimilation of radiance data over land?
S8Sounders: Impact of multiple satellite sounders	What benefits are found when data from more than one passive sounder are available from satellite in complementary orbits, e.g. multiple AMSU-As, AIRS + IASI ?
S9AMVs: AMVs	What impacts are currently found from AMVs?

General	
S10Thinning: Data density and data thinning	What impacts/benefits are found from data density/thinning strategies from various observation types?
S11PBL: Observations of the PBL for regional / high-resolution NWP	What should be the focus of improvements for observations of the PBL in support of regional/high-resolution NWP? Which variables and what space-time resolution?
S12UA: EUCOS-like upper air OSEs	Can EUCOS-like upper air studies be performed for other regions?
S13AdjEns: Regional application and adjoint and ensemble methods	What insights can be gained from more tailored use of adjoint- and ensemble-based measures of observation impact, for example, in the tropics or at the meso-scale where metrics other than global energy may be appropriate?
S14ExtRange: Impact of observations on extended range forecasts	Which observations are particularly important for the 7-14 day forecast range?
S15Targeting: Targeted observations	What do experiments on targeted observations tell us about observing system design?
S16aAMMA, **S16bIPY**: AMMA and IPY legacy	What impacts/benefits could be expected by sustained components of the AMMA and IPY special observing systems?

APPENDIX II – Final Programme of the Fifth WMO Workshop on the Impact of Various Observing Systems on NWP

FIFTH WMO WORKSHOP ON THE IMPACT OF VARIOUS OBSERVING SYSTEMS ON NWP

Sedona, Arizona, (USA)
22-25 May 2012

Final Programme

Tuesday 22 May 2012

08:00	Continental breakfast and registration
09:00	Welcome and opening remarks

Session 1: Global forecast impact studies

Co-chairs: Florence Rabier and Ron Gelaro

09:30	Rolf Langland, Naval Research Laboratory	Uncertainty in operational atmospheric analyses and re-analyses
09:55	James Jung, NOAA	Observing System Experiments using the NCEP Global Data Assimilation System
10:20	Break	
10:50	John Eyre, Met Office	Impact studies with satellite observations at the Met Office
11:15	Erik Andersson, ECMWF	Impact of satellite and conventional observations on the performance of the ECMWF data assimilation system by Observing System Experiments
11:40	Alexander Cress, DWD	Global impact studies at the German Weather Service and Regional impact studies at the German Weather Service (DWD)
12:05	Nancy Baker, NRL	The Impact of Satellite Atmospheric Motion Vectors in the U.S. Navy Global Data Assimilation System
12:30	Lunch	
13:30	Yong-Sang Kim, KMA	The new NWP system at KMA and some preliminary results of sensitivity test to observational data
13:55	Yan Liu, China Meteorological Administration	Use and impact of GPS radio occultation data in GRAPES
14:20	Patrick Moll, Météo-France	Data impact studies in the global NWP model at Meteo-France
14:45	Break	
15:15	Florence Rabier, Météo-France	Impact of observations in the Southern Polar area during the Concordiasi field experiment
15:40	Lidia Cucurull, NOAA	Assessing the benefits of assimilating GPS RO profiles into Global Numerical Weather Prediction Models
16:05	Sean Healy, ECMWF	GNSS radio occultation measurements: Current status and future perspectives
16:30	Yoichiro Ota, NCEP	Observation impact estimates using the NCEP GFS/EnKF
16:55	Discussion session 1	
18:00	Cash bar	

Wednesday 23 May 2012

Session 2: Regional forecast impact studies

Co-chairs: John Eyre and Yoshiako Sato

09:00	Stan Benjamin, NOAA	Impact of upper-air and near-surface observations on short-range forecasts from an hourly assimilation cycle (RUC and Rapid Refresh)
09:25	Yoshiaki Sato, Japan Meteorological Agency	Global and regional impact studies at JMA
09:50	Dale Barker, Met Office Presented by Gareth Dow	Marginal benefit of higher resolution analysis and mesoscale observing networks in the UK Met Office operational convective scale model
10:15	Xiang-Yu Huang, UCAR	Monitoring the observation impact with Taiwan Central Weather Bureau operational analysis/forecast system
10:40	Break	
11:10	Gergely Bölöni, Hungarian Meteorological Service presented by Andras Horanyi	Regional aspects of a European upper-air network redesign study: results obtained with the ALADIN limited-area model at the Hungarian Meteorological Service
11:35	Siebren de Haan, KNMI	Operational use of high resolution observations for very short term numerical forecasting
12:00	Roger Randriamampianina, Hungarian Meteorological Service	Impact of different observation types in the HIRLAM/ALADIN-LACE regional weather forecasting models
12:25	Lunch	
13:25	Jean-François Mahfouf, Météo-France/ CRNS, CNRM/GAME, GMAP	Evaluation of data impact in the mesoscale AROME 3D-Var system at Météo-France
13:50	Chris Tingwell, Centre for Australian Weather and Climate Research	Observing system impact studies in ACCESS
14:15	Ralph Petersen, University of Wisconsin	Impact of AMDAR aircraft observations
14:40	José Antonio Aravéquia, INPE/CPTEC	The role of assimilating satellite data over South America using LETKF
15:05	Break	
15:35	Discussion session 2	

Session 3: Specific scientific areas (including network design)

Co-chairs: Carla Cardinali and Lars-Peter Riishojgaard

16:35	Sharan Majumdar, Rosenstiel School of Marine and Atmospheric Science, University of Miami	Targeted observations for improving Numerical Weather Prediction: An overview
17:00	Brett Hoover, University of Wisconsin	Observation target regisions for improving NWP tropical cyclone motion forecasts: Comparison of objective sensitivity-targeting techniques

17:25 Adjourn

Thursday 24 May 2012

Session 3: Specific scientific areas (continued)

08:30	Martin Weissmann, Ludwig-Maximilians Universität	The impact of T-PARC special observations on typhoon track and mid-latitutde forecasts
08:55	Richard Marriott, Met Office	Adjoint-based impact studies of surface-based observation types at the Met Office
09:20	Sangwon Joo, Korea Meteorological Administration	Satellite impact to short-range global forecast using the adjoint-based sensitivity method
09:45	Toshiuki Ishibashi, Japan Meteorological Agency	Estimation of linear observation impact and its applications
10:10	Break	
10:40	Cristina Lupu, ECMWF	Use of DFS to estimate observation impact in numerical weather prediction. Comparison of observation impact derived from OSEs and DFS results
11:05	Ron Gelaro, NOAA/GMAO	The Impact of Satellite Atmospheric Motion Vectors in the GMAO GEOS-5 Global Data Assimilation System
11:30	Carla Cardinali, ECMWF	Monitoring the observations performance in the forecast
11:55	Ronald M. Errico, NASA	The use of observation impact estimates to validate an OSSE
12:20	Johannes Schmetz, EUMETSAT	On the role of NWP impact studies to support the evolution and development of current and future satellite programmes
12:45	Lunch	
13:45	Yves Rochon, Environment Canada	Observation system simulation experiments for the PREMIER mission
14:10	Louis Garand, Environment Canada	Assimilation impact from satellite wind observations filling the gap at high latitudes
14:35	Junghong Wang, National Center for Atmospheric Research (NCAR)	Opportunities and challenges in designing a reference upper-air network in support of NWP
15:00	Stefan Klink, DWD Presented by Sabine Hafner	Update on observation impact studies coordinated by EUCOS and plans for future studies
15:25	Break	
15:55	Jaime Daniels, NOAA	Satellite winds
16:20	Discussion session 3	

17:20 Adjourn

Friday 25 May 2012

Session 4: Workshop discussions and conclusions

08:30	Discussion and recommendations (Session 1)
09:30	Break
10:00	Discussion and recommendations (Session 2)
11:00	Discussion and recommendations (Session 3)
12:00	Closure of the workshop

APPENDIX III – Resume of presentations

Please refer also to the actual presentation slides available at http://www.wmo.int/pages/prog/www/OSY/Reports/NWP-5_Sedona2012.html

Session 1: Global forecast impact studies

Rolf Langland (NRL) analyzed uncertainty in operational atmospheric analysis. Availability of radiosonde and aircraft data reduces uncertainty in upper-air analyses of temperature and wind. The uncertainty is relatively small over land and large over ocean and Polar Regions. It was questioned why the uncertainty over oceanic regions is much larger than over land, despite the assimilation of large amounts of radiance data.

James Jung (NOAA) presented the results of comprehensive observation denial experiments using NCEP's global data assimilation system. As past studies suggested, satellite data has the greatest impact over the Southern Hemisphere. The negative impact from withholding a single instrument is much smaller than the impact from entire suite of instruments. Tropical wind statistics show that most types of observations have a positive impact. Hurricane statistics showed radiosondes and AMSU-A having the greatest individual impact on hurricane track forecasts.

John Eyre (Met Office, UK) presented a summary of their recent observation impact activities. Good progress on assimilation of IR sounder radiances was reported. Assimilation of cloud affected infrared radiances show large positive impact. Bias of IASI radiances over land is much reduced with its newly developed emissivity retrievals. The dangers of any observation-free zone in data assimilation were also reported. Temperature bias at mesosphere is much reduced by raising the top of GPSRO bending assimilation from 40 to 60 km. GPS-ZTD assimilation shows the significant impact on forecasts of surface variables. Forecast sensitivity to observations (FSO) analyses showed that the most important observation platform is METOP. AMV denial study shows the positive impacts of AMV.

Erik Andersson (ECMWF) presented a summary of their recent observation impact studies. With data denial study of both radiosonde and aircraft, the relative impacts of these data on the analysis in terms of bias and forecasts skill were evaluated. It was shown that GPSRO currently provides a more efficient anchor for satellite radiance bias correction than radiosonde data in the operational system. Stratospheric radiosonde observations are especially important for Tropical wind forecast performance. In upper air network redesign study for Europe, 250 km thinning show some clear degradation of forecast capability, whereas 100 km does not. Extra Atlantic buoy observations have clear positive impact. ASAP (Automated Shipboard Atmospheric Profiling) have measurable positive impact in the short range.

Alexander Cress (DWD) presented a summary of their global and regional impact studies. A comprehensive set of data denial experiments for radiosonde and aircraft had been conducted and it shows the importance of these data and also that the wind information is more important than temperature. Polar orbiting satellite data denial study show the importance of Metop-A. GPS-RO assimilation shows strong impact especially in the stratosphere. AMV and Scatterometer denial study also shows a positive impact. DWD also conducted AMDAR humidity sensor evaluation and the new sensor showed much better quality than old one. The regional impact study show positive impact of radar rain rates in forecasts up to 6 hours and a positive impact of GPS ZTD. VAD wind shows small positive impact but need a careful selection because the data quality is very mixed.

Nancy Baker (NRL) presented results from a study that was designed to evaluate the impact of AMV in the NRL system, and to address the question why the NRL system obtains greater benefit from AMV than other NWP centers. The OSE (control vs. AMV denial) study results showed that the assimilation of AMVs reduces the forecast errors for winds and heights. The tropical cyclone track errors were also reduced when AMVs are assimilated, although the sample size was small for the test period. When AMVs are denied, the adjoint-based observation impact increases for most observing platforms, with microwave and infrared sounder radiances providing the largest compensating. This study was performed in collaboration with NASA GMAO (*cf.* the presentation by Gelaro). Together, the results suggest that the greater impact from AMV in the NRL system is due to (1) large number of assimilated winds; (2) assimilation of super-obs, which gives slightly better forecast skill; (3) less use of satellite sounder radiances at NRL than in many other centers.

Yong-Sang Kim (KMA) presented their system upgrade and recent impact studies. The KMA system is upgraded to use the Unified Model (developed by the Met Office) from 2010. For the regional system, interpolation of global analysis and regional data assimilation cycling are compared and the better result was obtained by cycling. KMA also conducted the COMS satellite AMV data impact study and the result show better impact on the typhoon case forecast. Preliminary FSO analysis is also conducted and the top most data is ATOVS followed by TEMP, SYNOP, IASI, BUOY and aircraft.

Yan Liu (CMA) introduced their data assimilation and forecast systems and presented GPSRO refractivity assimilation impact study and its significant positive impact especially over Southern Hemisphere.

Florence Rabier (MétéoFrance) presented summary of observation impact results. Although 86% of assimilated data amount is satellite data, Degree of Freedom of Signal (DFS) shows 33% is from the ground-based observation. Therefore, the relative importance of ground-based observations is larger (per observation) than the satellite based one. By using dynamical land emissivity parameterization, low level radiance data can be assimilated and was shown to provide a positive impact. There was evidence that AMMA (African Monsoon Multidisciplinary Analyses) radiosonde data assimilation leads to better forecast after three days over Europe. World ground based GNSS data exchange is desired. MétéoFrance also presented summary of Impact of observations in the Southern Polar area during the Concordiasi field experiment. Large impact of satellite data are confirmed for AMSU-A, IASI and AIRS, GPS-RO. In some systems, large impact of AMSU-B/MHS over sea-ice, and large impact of MODIS winds are found. Both Concordiasi dropsonde and gondola information have a positive impact on forecast performance and the dropsondes have a larger impact at high latitudes.

Lidia Cucurull (NCEP) presented summary of GPSRO impact and its use in NWP. All NWP centres have found significant positive impact with the use of the data and most of the centres use the data without bias correction. GPSRO works as anchor to temperature bias correction and it is proven that GPSRO is one of the key observing systems for global NWP.

Sean Healy (ECMWF) outlined the main characteristics of GPSRO. GPSRO can constrain large surface pressure biases in analyses where conventional surface observations have been denied, but the results are sensitive to biases in other parameters. Continuity of GPSRO observation numbers is a major concern given the current decline of COSMIC. In a study to access the optimum number of GPSRO observations it was found that assimilation schemes can derive impact from 10,000 globally distributed soundings or more without reaching saturation.

Yoichiro Ota (NCEP) demonstrated the ensemble based sensitivity study with GFS. The preliminary results from a short study show the most sensitive data is aircraft data, followed by AMSU-A and radiosonde. All the observation types contribute to reduce the short range forecast error on average. It is remarked that the study period was one week which is considered insufficient. Longer continuous investigation is recommended.

Session 2: Regional forecast impact study

Stan Benjsamin (NOAA) showed the comprehensive impact studies with RUC and Rapid Refresh system. Data denial experiments were conducted for the various types of observations. The results show the most important data is aircraft data followed by radiosonde data. The results from the Rapid Refresh experiments also show the contribution of ground-based GPS and surface observation. VAD wind contribution was also shown but a negative impact was found in the night time. The cause might be bird migration contamination.

Yoshiaki Sato (JMA) presented a summary of their Global and regional impact studies. The global OSE showed positive impact of the more homogeneous data usage of AMSU-A, positive impact from the humidity data over land area such as MHS and ground-based GPS assimilation. The regional OSE showed positive impact from the remotely sensed data but the impact is hardly confirmed after 10-hours of forecast. Preliminary OSEs for SHIP and BUOY data are conducted and a 200 km thinning did not show the forecast degradation while 500 km thinning showed a clear degradation.

Gareth Dow (Met Office, UK) presented results obtained with the Met Office regional NWP system. Consistent benefit for all elements from full higher-resolution analysis relative to downscaled analysis has been confirmed. Impact from using extra observation was also investigated. Although extra observations did not always show positive impact on UK's NWP index, the benefit from radar rain rate for summer precipitation forecast and the benefit from MOPS cloud for cloud cover forecast was shown.

Xiang-Yu Huang (NCAR) summarized FSO diagnostics in WRF data assimilation as well as FSO results from the Taiwan Central Weather Bureau. The highest FSO data type is GeoAMV data, followed by TEMP, SYNOP, and GPSRO. It is noted that satellite radiance data is not assimilated in the TCWB system. The FSO monitoring showed the FSO was different among each analysis time in UTC. The negative impact of TEMP on 06/18UTC was reported, but it might come from sampling error. The highest FSO per observation was obtained with GPSRO in this study.

Gergely Bölöni (OMSZ, presented by Andras Horanyi, ECMWF) reviewed EUCOS upper-air network redesign study results. The scenario 1 is a baseline; scenario 2 is operational observation usage (control); scenario 3a is 100 km thinning of radiosondes; scenario 3b is 100 km radiosonde thinning at 06,12,18 UTC; scenario 4/5 is 250 km / 500 km thinning of both radiosonde and aircraft data. The results showed the forecast degradation in scenario 1,3a, 4, 5 but Scenario 3b is neutral compared to control in summer and positive in winter in some components. At 00 UTC, available aircraft data is few over Europe and it might make the importance of radiosonde data higher at that time (local night time).

Siebren de Haan (KNMI) introduced some new observations and its impact in a very high-resolution NWP system. Since ATC radar interrogates all the aircraft for their identity, flight level, airspeed/direction and Mach number, wind data are obtained from this system (Mode-S). The Mode-S wind data show similar quality as AMDAR data. KNMI also showed the positive impact from GPS ZTD and radar radial winds. Enhanced exchange of radar data with the surrounding countries was requested. The requested radar data type is raw data.

Roger Randriamampianina (OMSZ) showed the summary of DFS analysis result in some countries contributing to the EUCOS impact study. The results showed that the regional NWP system is more sensitive to the wind and humidity observation than the other parameters. Aircraft, radiosonde and SEVIRI radiance have the largest impacts. However the result is different between the regions. Satellite radiance data is more important for higher latitude regional models.

Jean-François Mahfouf (MétéoFrance) showed the DFS analysis result of the regional model. Most important observations for the model are surface data, radar and aircraft. However, the aircraft data is not available for 00 UTC (local night time) and radiosonde data is especially important for the time. Radar data availability is variable. By spectral decomposition, only GPS and radar data contribution for scales below 200 km is confirmed.

Chris Tingwell (CAWCR) showed the positive impact of GPSRO and IASI data in the Bureau of Meteorology global "ACCESS" NWP system and the positive impact of hourly AMVs in regional NWP. Upper air observation data denial impact studies were also described: radiosonde and AMDAR data denial demonstrated that these data contribute significantly to forecast skill in regional NWP for lead times up to 1.5 days, with radiosondes having more impact than AMDARs in the Australian region. Early results for the impact of radar rain-rate latent heating nudging, plus 3DVAR assimilation, on high resolution precipitation forecasts suggest value is added to the forecast for the first six hours, mainly by suppressing incorrect precipitation and enhancing weaker precipitation. Cloud nudging may help with deeper convection.

Ralph Petersen (University of Wisconsin) summarized the AMDAR data impact, quality and benefits. The AMDAR data impact was shown based on the result of some NWP centres' impact studies. And it is stressed that the AMDAR data is the most economical data compared to the other observations. And it is also presented that the AMDAR data is not only used by the NWP but by the forecasters.

José Antonio Aravéquia (INPE/CPTEC) introduced their LETKF data assimilation system and the comparison of the satellite image data for the more proper use for the satellite data.

Session 3. Specific Scientific Areas

Sharan Majumdar (University of Miami) presented an overview on observation targeting; the work was supported by the DAOS–THORPEX working group, see (http://www.wmo.ch/pages/prog/arep/wwrp/new/documents/THORPEX_No_15.pdf).
The primary conclusions are that for the extratopical campaigns evaluated in the OSEs context, the value of targeted data is small but positive on average with forecast benefit differing from model to model. A targeting limitation is also related to the range of aircraft available and the specific region to target. The targeting evaluation from the adjoint-based-technique suggests that large numbers of observations with relatively small individual impact provide a larger cumulative benefit than small numbers of targeting observations. Observation targeting on tropical cyclones suggests a statistically improvement of track forecasts. In general, targeted satellite data shows promise but more experimentation is envisaged to quantify their impact. From the recommendation, the improvement of scientific basis for quantitatively predicting forecast error variance reduction is suggested as well as the improved understanding and quantification of the socio-economic value of observations.

Brett Hoover (University of Wisconsin) presented an overview on objective targeting techniques for forecast skill improvement of tropical cyclone (TC). The NWP of tropical cyclone requires a way to estimate the potential forecast impact of additional observations and the dependency of the forecast steering and intensity of tropical cyclone to initial condition error. Errors that project onto ADSSVs (Adjoint-Derived Sensitivity Steering Vector) are not related to the sensitivity of TC steering with respect to initial state perturbations, but rather to the sensitivity of some measure related to TC track changes. Similarly, the energy SVs do not compute the sensitivity of TC steering with respect to the initial state perturbations, but rather the sensitivity of some measure related to TC track changes. The main effect which has the dominant impact on the metrics used by both ADSSV and SV techniques is the displacement of the TC vortex at the final time. Regarding the ETKF objective targeting technique which often generates a downstream sensitivity, it can be in part explained by the TC's ability to generate significant downstream uncertainty. A refinement of targeting techniques presented is suggested to more specifically represent the TC steering process.

Martin Weissman (Ludwig Maximilians Universität) presented a summary on the T-PARC campaign impact studies which includes two typhoons Sinlakuan and Jangmi over three weeks. The models that had been inter-compared are JMA, KMA WRF, NCEP and ECMWF. Models with 3D-Var (KMA WRF and NCEP GFS) both showed a very beneficial impact of dropsondes, while the impact in systems with 4D-VAR and more satellite observations was smaller. For JMA, no improvement was noticed, probably due to an inadequate treatment of dropsondes within the typhoon. For ECMWF, the mean track improvement is only significant from 72 to 120 hours lead time. Sensitivity studies with the ECMWF model showed that observations near the storm had the highest impact, while observations in remote regions pointed out by singular vectors, observations within the typhoon and observations at a later stage during ET (extra tropical transition) had little impact. In addition, airborne Doppler wind lidar observations during typhoon Sinlaku were documented to have a comparably high impact in the ECMWF and NOGAPS system.

Richard Marriott (Met Office, UK) presented an overview of the UKMO FSO system. The results show that the observation-type with the most beneficial impact is AMSU-A followed by radiosonde, IASI and aircraft. In particular, the observation impact of conventional and surface-based observation types was examined. 36% of overall observation impact on the Met Office 24-h forecast error is due to radiosonde, aircraft and SYNOP. AMDAR winds were found to give twice the impact of temperature observations and the impact is fairly uniform over the globe in spite of the heterogeneous distribution of the measurement locations. Flight-level AMDAR impacts show some degree of information saturation in the Met Office's global model, over Europe and North America, whereas it was suggested that observation frequency be increased over Africa, South America and oceanic regions with the exception of the North Atlantic. The increase of AMDAR observation profiles is also suggested over Africa and South America. A study on the benefit of ASAP observations (supported by EUCOS) shows that the ASAP impact per observation is high but that there are few of them. More use of shipping routes in the Tropics and Southern Hemisphere is envisaged.

Sangwon Joo (KMA) presented the relative importance of satellite data in terms of forecast error reduction (FSO) in the recent Met Office global NWP system. About 64% of the short-range forecast-error reduction is due to satellite observations and the remaining 36% to conventional observations. The observation impact of satellite is mainly led by LEOs, including Metop and NOAA. LEOs contribute about 58% of the total observation impact. Metop-A has the largest impact of any satellite platform (38%), followed by NOAA and Aqua. IASI is the most valuable sensor on Metop-A and the dominant role of Metop-A compared with the NOAA series satellites is mainly due to the additional instruments IASI, ASCAT and GRAS. Meteosat shows the strongest impact among the GEO satellites, mainly due to the large volume of data assimilated. GPSRO has the largest observation impact per measurement among the satellite instruments. The impact of the daytime IASI data over land is evaluated and a new channel selection is proposed to make use of more information from IASI data without any changes in the current data assimilation system. The additional use of daytime 8-10 μm IASI channels over land can improve the NWP forecast at the Met Office. 10-13 μm IASI channels can be assimilated after removing negative background departure in desert locations.

Toshiuki Ishibashi (JMA)**:** Diagnoses of the JMA global 4D-Var performance by using FSO technique shows that almost all observation data types contribute on average to reduce the global forecast error. The results also imply that it is possible to derive more information from radiance data by improving their usage as well as improvements on the observation operator. The covariance matrix optimization methods and the observation impact estimation (FSO) show that the JMA GDAS assimilation system has too large observation error (R) and too small background error (B) covariance matrices.

Cristina Lupu (ECMWF) presented a North America observation impact as derived from the DFS and OSEs. North America is divided in three areas: Canadian Arctic, Southern Canada and Continental United States. Over Canada and continental US the analyses are controlled by RAOB and Aircraft data. Over Canada and US the DFS of ascent/descent Aircraft reports alone account for 40% of the impact of all Aircraft data in North America. Relatively low DFS of RAOB over US is explained by its collocation with profiling Aircraft data. AMSU-A and AMVs MODIS winds compensate most over Canada Arctic when RAOB and profiles are denied whilst AMSU-A and Aircraft data compensate over Canada. Less significant data compensation for the loss of RAOB and profiles occurs over continental US mainly because in this region Aircraft data is as informative as RAOB data. In general, the 12 hour forecast impact (assessed by the 500 hPa geopotential height) from the OSEs agree well with the observation impacts deduced from the DFS.
Regarding the benefit of assimilating cloud affected SEVIRI radiances at ECMWF, in the context of no-satellite baseline experiment, CSR (Clear Sky radiances) plus OV (Over Cast radiances) have a positive impact on wind analyses through the troposphere, with better performance than CSR alone in the Southern Hemisphere. The largest forecast error reduction (FSO) comes from the combined CSR and OV observations.

Ron Gelaro (NOAA/GMAO) presented the assimilation of NRL AMVs observations into the GMAO GEOS□5 data assimilation system. Compared to the control run with GMAO (NCEP) AMVs, the assimilation of NRL AMVs provides substantially increased beneficial impact (FSO), and also appears to improve forecast skill overall (OSE). All results indicate that the larger volume (versus 'superobing') of the NRL AMVs is primarily responsible for their larger impact, but there is evidence that superobing is also beneficial. Observation mix plays a significant role in modulating the impact of any one data type: the smaller impact of the NRL AMVs in the GMAO system (compared with their impact in the NRL system) is likely due to the larger number of satellite radiances in the GMAO system. Additional experiments might include assimilating NRL AMVs while reducing the number of radiances.

Carla Cardinali (ECMWF) DFS and observation Forecast Error Contribution (FEC or FSO) are compared to highlight poor short□range forecast performance. In particular, some poor performance of Pilot – Radiosonde at significant levels□ is found and the degradation is believed to be due to the way the wind which is rapidly varying with the altitude is assimilated in the ECMWF system. The wind component above 400 hPa will therefore be assimilated after some vertical average of the point measurements. The poorer Temp (radiosonde) performance above 200 hPa is instead likely due to biases in the model. The use of the observation influence is also suggested to design alternative network or to optimize the existing observation network. The radiosonde observation influence is shown as illustrative example.

Ron Errico (NASA) A variety of statistics that can be computed in both real assimilation and OSSE contexts are evaluated and compared to evaluate the OSSEs robustness. All these statistics measure the difference or error and therefore generally depend on explicit or implicit modelling, instrument, and representativeness errors but also on the chaotic effects of model dynamics and physics. In general, it is fairly easy to match Observation minus Forecast statistics in the real assimilation and in the OSSE. It is instead harder to match the analysis increment statistics and the hardest is to match the forecast error metrics. The resent OSSE framework validates reasonably well.

Johannes Schmetz (EUMETSAT) presented the role of NWP impact studies to support the evolution and development of current and future satellite programmes. Informed decisions on future operational meteorological satellites and related services must be based on careful analyses. Important constraints to be observed are: i) the continuity and robustness services and ii) the evolution of services based on new requirements. An established way to demonstrate usefulness/benefit of a specific observing system is through impact studies (OSE and FSO) with a NWP system and the need of OSSEs remains for new instruments. The presentation suggests enhancing within the framework of WMO the provision of information that shows and regularly updates the impact of current (satellite) observing systems on NWP. Some important details (e.g. metric used) should be included and in general guidance should be included on how to read the impact results. An overview of Meteosat Third Generation (MTG) and EPS-Second Generation (next Metop series) missions is also illustrated. .

Yves Rochon (Environment Canada) presented the result of OSSEs for the PREMIER mission. The PREMIER mission is composed of infrared limb sounder (IRLS) and millimeter wave limb sounder (MLS). Joint OSSE data are used for this research. Positive impact was found in temperature analysis for IRLS and to half for MLS.

Louis Garand (Environment Canada)**:** A comprehensive OSSE setup was developed which proves that the Highly Elliptical Orbit (HEO) AMVs adds substantial information in NWP systems. In the OSE context, the real AMVs have modest but consistent positive impact up to day 4 at all latitudes in the OPE system. In the OSSE, adding PCW AMVs has a significant positive impact up to day 3, not only in region of PCW data (50-90 N) but also in the midlatitudes (20-50 N). Validation versus the Nature Run or own analysis is consistent after day 2. In general there is a gain of predictability of the order of 1-3h at day 3 in region 20-90 N.

Junghong Wang (NCAR) presented the GRUAN network for ground-based reference observations for climate in the free atmosphere established in the frame of GCOS. It counts 15 stations and it is envisaged to be a network of 30-40 sites across the globe. GRUAN is a new approach to long-term reference observations of upper air essential climate variables but also the reference quality of GRUAN data makes them useful for verifying NWP model outputs, and for validating and correcting other data being assimilated into NWP models. GRUAN data can also be directly assimilated into NWP models.

Sabine Hafner (DWD) provided an update on observation impact studies coordinated by EUCOS and plans for future studies. In particular, EIG (Economic Interest Grouping) EUMETNET is grouping 29 European National Meteorological Services that provides a framework to organize co-operative programmes between its Members in the various fields on basic meteorological activities. These activities include observing systems, data processing, basic forecasting products, research and development and training. The program components of EUCOS are E-AMDAR, E-ASAP, E-SURFMAR, E-WINPROF, the Territorial Segment (upper air and SYNOP stations). The program includes operations monitoring, observation targeting and volcanic ash monitoring. The future priorities for the Observation Programme consist on radar activities, standardization of surface weather stations and improvement of vertical profile measurements which are of highest importance for the Members. On the results of the large variety of impact studies performed it is worth to mention that the removed radiosonde sites collocated with 3-hourly visited E-AMDAR airports show almost no degradation in forecast skill. On the contrary, the thinning of upper-air observations to 250 km or 500 km spacing show a significant degradation of forecast skill for most parameters and for both summer and winter periods. With the results, EUCOS defines the combined radiosonde and E-AMDAR network with 90 radiosondes and 60 airports.

Jaime Daniels (NOAA) presented the summary of the International Winds Working Group on the coordinated study on Atmospheric Motion Vector (AMV) impact on NWP and other satellite wind highlights. The IWWG is a well established, and active working group focused and poised to address issues related to satellite winds to be achieved through collaborative projects. Coordinated OSEs study of AMV impact on NWP demonstrated a consistent level of positive forecast impact from AMVs across all NWP centers. In addition to the classic denial study, the FSO further indicates significant relative importance of the AMVs in the global observing system context. The future work of IWWG will focus on NWP model and data assimilation improvements together with new approaches for deriving atmospheric winds.

APPENDIX IV – Acronyms

AIRS: Atmospheric Infrared Sounder
AMDAR: Aircraft Meteorological Data Relay
AMMA: African Monsoon Multidisciplinary Analyses
AMSU: Advanced Microwave Sounding Unit
AMV: Atmospheric Motion Vector
ASAP: Automated Shipboard Atmospheric Profiling
ASCAT: Advanced Scatterometer
ATC: Air Traffic Control
CAWCR: Centre for Australian Weather and Climate Research
CIMSS: Cooperative Institute for Meteorological Satellite Studies
CMA: China Meteorological Administration
COMS: Communication, Ocean and Meteorological Satellite
COSMIC: Constellation Observing System for Meteorology, Ionosphere & Climate
CPTEC: Centro de Previsão de Tempo e Estudos Climáticos
CSR: Clear Sky Radiance
DA: Data Assimilation
DFS: Degree of Freedom of Signal
DWD: Deutscher Wetterdienst
DWL: Doppler Wind Lider
E-AMDAR: EUMETNET Aircraft Meteorological Data Relay
E-ASAP: EUMETNET Automated Shipboard Aerological Programme
E-GVAP: GNSS water vapour programme
E-SURFMAR: EUMETNET Surface Marine Programme
E-WINPROF: EUMETNET Wind Profilers
ECMWF: European Centre for Medium-Range Weather Forecasts
ET-EGOS: Expert Team on Evolution of Global Observing System
ETKF: Ensemble Transform Kalman Filter
EUCOS: EUMETNET Composite Observing System
FEC: Forecast Error Contribution
EPS-SG: EUMETSAT's Polar System – Second Generation
ERA: European Reanalysis
EUMETNET: Network of European National Meteorological Services
EUMETSAT: European Organisation for the Exploitation of Meteorological Satellites
FSO: Forecast Sensitivity to Observation
GCOS: Global Climate Observing System
GeoAMV: Atmospheric Motion Vector from Geostationary satellite
GFS: Global Forecast System
GMAO: Global Modeling and Assimilation Office
GNSS: Global Navigation Satellite Systems
GOS: Global Observing System
GPS: Global Positioning System
GRUAN: GCOS Reference Upper Air Network
IASI: Infrared Atmospheric Sounding Interferometer
INPE: Instituto Nacional de Pesquisas Espaciais
IPY: International Polar Year
IR: Infrared
IRLS: Infrared Limb Sounder
IRS: Infrared Sounder
IWWG: International Wind Working Group
JCSDA: Joint Center for Satellite Data Assimilation
JMA: Japan Meteorological Agency
KMA: Korean Meteorological Administration
KNMI: Koninklijk Nederlands Meteorologisch Instituut
LETKF: Local Ensemble Transform Kalman Filter
Metop: Meteorological Operational

MHS: Microwave Humidity Sounder
MLS: Milimater wave Limb Sounder
MODIS: Moderate Resolution Imaging Spectroradiometer
MOPS: Moisture Observation Pre-processing System
MTG: Meteosat Third Generation
MW: Microwave
NASA: National Aeronautics and Space Administration
NCAR: National Center for Atmospheric Research
NCEP: National Centers for Environmental Prediction
NMHS: National Meteorological and Hydrological Service
NOAA: National Oceanic and Atmospheric Administration
NRL: Naval Research Laboratory
NWP: Numerical Weather Prediction
O-B: Observation minus Background
OMSZ: Országos Meteorológiai Szolgálat
OPERA: Operational Programme for the Exchange of Weather Radar Information
OSE: Observation System Experiment
OSSE: Observation System Simulation Experiment
OV: Overcast
PCW: Polar Communication and Weather mission
RO: Radio Occultation
RUC: Rapid Update Cycle
SEVIRI: Spinning Enhanced Visible Infra-Red Imager
SV: Singular Vector
TAMDAR: Tropospheric Airborne Meteorological Data Reporting
TC: Tropical Cyclone
TCWB: Taiwan Central Weather Bureau
THORPEX: The Observing System Research and Predictability Experiment
T-PARC: THORPEX Pacific Asian Regional Campaign
UKMO: United Kingdom Meteorological Office
VAD: Velocity Azimuth Display
WIGOS: WMO Integrate Global Observing System
WRF: Weather Research and Forecasting Model
ZTD: Zenith Total Delay