Working Group 1: Environmental Monitoring and Reanalysis Aspects

Chair: Sakari Uppala   Rapporteur: Dick Dee

Bias issues for GEMS applications

Data assimilation for GEMS is mainly concerned with providing unbiased analyses for monitoring purposes, rather than with improving forecast skill. This requires that the meteorological input (e.g. used to compute transport of constituents) does not contain large biases. Furthermore, model errors must be reduced (or at least accounted for in data assimilation) to achieve an adequate fit to the available observations. The ability to treat model errors during data assimilation is therefore especially important for GEMS applications.

Main sources of observational data are AQUA, Aura, METOP and ENVISAT for greenhouse and reactive gases, and Terra, AQUA, and ENVISAT for tropospheric aerosols. Observations with adequate spatial coverage prior to 2003 are difficult to find, with the exception of TOMS (total column ozone) and SAGE (stratospheric aerosol). Atmospheric Radiation Measurement (ARM) sites and aircraft field campaign data are extremely valuable for validation purposes.

Due to the timescales of the processes involved, data over long periods (i.e., spanning at least a year) are needed to be able to estimate biases. It is not clear how to separately identify model bias, other than by using independent high-quality data. Bias correction schemes currently used in operations may remove the useful signal for GEMS.

Conclusions and recommendations

- Further research and experimentation are needed to develop ways to address bias problems in GEMS applications
- In this early stage, existing adaptive bias correction schemes are not expected to be useful
- The weak-constraint 4D-Var approach being pursued at the Centre is very promising

Bias issues for reanalysis

The quality of a reanalysis is judged on a diverse set of criteria, including biases in the analyses, forecast performance, consistency in time, accurate climate signals, quality of the hydrological cycle, global diagnostics such as age of air, and regional features such as the polar mean circulation. To improve these and other quality aspects will ultimately depend on our ability to correct systematic errors in both models and observations.

Current plans for the Interim Reanalysis at the ECMWF include the use of variational bias correction of satellite data based on a minimal set of predictors for the radiance biases. The use of such an adaptive scheme has obvious practical benefits for a complex reanalysis production system. Preliminary experiments covering long time periods indicate that the method is stable and has a positive impact on the assimilation. The system appears to be well constrained by the available observations and by the information contained in the model equations. It remains to be seen how much fixed ‘anchoring’ information, e.g. as provided by the conventional observing network, is required to maintain the stability of an adaptive data assimilation system.

Other bias issues being addressed in the Interim Reanalysis are:

- Bias correction of surface pressure observations using a sequential updating scheme
- Use of homogenised radiosonde temperatures based on ERA-40 feedback information
- Bias correction of scatterometer winds

Bias issues that remain to be addressed include:

- Improving inter-satellite calibration
- Utilize improved CO2 and aerosol estimates in radiative transfer models
- Reduction of biases in cloud motion wind vectors
- Homogenisation of radiosonde winds (similar to temperatures)
- Improving VTPR response functions
- Improving the analysis of deep tropical cyclones

More aggressive blacklisting will be used for biased data that cannot be corrected (e.g. radiosonde humidity data).

Recommendations

With regard to the reanalysis effort in general:

- Define a stable subset of selected observations (e.g. certain radiosondes; recalibrated MSU channels) to be used for monitoring and validation
- Identify datasets suitable for anchoring adaptive bias correction schemes (e.g., certain conventional data; window channels on some sounders)
- Estimates of model and observation biases should be provided to the users as a reanalysis product

With regard to the Interim Reanalysis in particular:

- Continuously monitor changes with respect to ERA-40
- Perform experiments to better understand the biases present in the system:
    - Conventional data only, to continue in real time
    - Satellite data only, to continue in real time
    - Consider withholding one (of 3) AMSUA in the current period
    - Test the system on the pre-satellite period from 1948 onwards

Data reprocessing and data access

The complexity of a reanalysis project greatly depends on the evolution and diversity of the observing system. It is a monumental task to uncover observations from the past, to gain access to these data, to learn about their error characteristics, unify the different data formats, merge overlapping data sets, and deal with many other technical aspects. It is not always sufficiently appreciated that observational data sets are not simply fixed inputs to the system; rather, they are (or should be) continuously reexamined, reprocessed, and updated by the providers and various research centres around the world. These activities improve the coverage in space and time as well as the accuracy of the observing system, and will therefore have a large impact on the quality and usefulness of future reanalysis products.

Some examples of current efforts in this regard are:

- The development of improved filter functions for VTPR radiances
- Correction of radiosonde station heights, and homogenization of radiosonde temperature time series
- Reprocessing of wind data at EUMETSAT, JMA, and possibly NOAA

- o Ongoing work at NCAR on developing and improving their historical collection of conventional data

A fruitful spirit of collaboration is growing between the communities that collect, recover, and reprocess observations and the reanalysis centres. Open and complete access to observations and to reanalysis products is clearly beneficial to all and should therefore be promoted.

Recommendations:

- Investigate the possibility to remove discrepancies among different SSUs
- Further exploit ERA-40 feedback information to understand drifts and biases
- Further enhance collaboration between reanalysis and national climate centres
- Data providers and ECMWF should support version control of observational data sets, containing metadata to describe changes in processing algorithms
- Provide open, user-friendly, access to observations and departure data, following the approach at NCAR
- Develop and disseminate tools for access and visualisation in common with web-based monitoring

Operational support and monitoring issues

Operation of a numerical weather prediction system is naturally more concerned with the immediate present than with the past. Support for GEMS and reanalysis activities requires a broader view that incorporates the past as well as the present. It will be necessary to augment and improve procedures for collecting, archiving, and safeguarding observations, and to implement new monitoring facilities. The required resources for this additional technical support must not be underestimated.

Recommendations with regard to observation handling:

- Independent validation data (e.g. from ARM sites) should be continuously acquired, archived, and made available for verification
- Backfill gaps in received radiance (and other) data for a reasonable time lag (e.g. 1 year)
- Implement a lag-mode suite to process late-arriving data (e.g. ozone sondes, black carbon)
- Implement a periodic data inventory sweep to ensure that the operational and reanalysis archive is always ready for use
- Periodically compare data inventories with those at other centres

Recommendations with regard to monitoring procedures:

- Develop a stepwise plan to implement an integrated web-based monitoring system for NWP, wave modelling, reanalysis, and GEMS applications, involving both OD and RD
- Maintain long-term time series statistics on observation system performance and bias corrections
- Harmonize web interfaces to observing system monitoring among centres, to facilitate intercomparison of monitoring statistics
- Use and develop ECMWF’s `obstat` package to provide the needed functions for the many types of statistics in monitoring

- Develop new methods for monitoring the stability of adaptive bias correction schemes, based on carefully selected anchoring data
- Develop an expert system for detection of unexpected changes in the bias corrections, quality control, and other aspects of the observing system
- Provide additional resources for integrated monitoring of the observing system, including a full-time person dedicated to satellite monitoring

Working Group 2: Sources of systematic errors and independent validation datasets

Chair: Roger Saunders Rapporteur: Sean Healy

This working group was tasked with identifying the sources of systematic bias in observations, forward models and NWP models and assigning them a priority. It also reviewed the current status regarding validation datasets to identify biases.

Review of main sources of bias

The WG initially compiled a comprehensive list of possible sources of bias in the observed - background (O-B) departures. These are listed in the Annex. It was noted that screening (or QC) at each stage of the processing chain could influence the bias statistics of the final product.

The following subset is considered as the highest priority to be considered by the relevant centres.

Data providers:

- **Errors in sensor calibration:** The calibration must have clear specifications and it must have **traceability** to a reference standard.
- **Unmodelled instrument behaviour:** Space agencies should characterise anomalies using pre-launch and in-orbit data and apply corrections. NWP can provide a global view of such anomalies and should be used to help diagnose them. Documentation of the corrections applied to the data should be made available to users.
- **Radiosonde water vapour biases:** Operational centres should be encouraged to use the most accurate water vapour sensors available. New technology is now available to provide much improved upper tropospheric water vapour measurements.

It was noted a higher stability and accuracy is required for reanalysis and climate applications.

Forward modelling:

- **Spectroscopic database errors/missing lines:** Spectroscopists should continue their valuable work in refining databases and disseminate the information. RT modellers should endeavour to make more timely use of new databases.
- **Continuum effects (H_2O, O_2, CO_2, N_2):** Recommend researchers to continue laboratory experiments, measurement campaigns and theoretical calculations.
- **Line mixing:** Recommend that all RT modellers upgrade their models to take this effect into account.
- **Inadequate model assumptions (e.g. no solar reflection, non-LTE, poor vertical discretisation):** RT modellers should address these issues for simulating advanced IR sounder radiances to extend the use of these data.
- **Surface reflection/emission:** RT modellers should improve the modelling of surface properties for all frequencies to allow the use of satellite data over land surfaces.

Pre-processing:

- **Undetected residual contamination (e.g, cloud (IR), precipitation (microwave):** Satellite processing centres should improve screening and quality control of data.

NWP biases:

- **Water vapour absolute value and its variability:** The water vapour field is still in need of improvement. It was noted that there are few reliable water vapour observations to verify against.
- **Temperatures in the stratosphere and mesosphere:** Problems with the atmospheric circulation of the ECMWF model at these levels is one reason for the temperature biases.
- **Skin temperature (T_s) and surface emissivity (ϵ_s):** Reducing these would help enable increased satellite usage over land, but it is a large project, requiring collaboration between modelling, data assimilation and satellite experts.

Review of validation datasets

It was noted that the purpose of validation is to determine whether the error estimates made provide an accurate representation of the properties of the real data. It must be stressed that validation is **not** the process where the observation errors are estimated. If the validation exercise produces results which are not consistent with the original error model, then this model must investigated, revised where necessary, and the validation exercise must be repeated.

The data being used in a validation exercise should have a clear **traceability** to a recognised reference standard. This is considered essential if the measurements are to be used in climate or re-analysis applications, but in practice it may be less important for operational NWP. The importance of cross calibration with different datasets was noted.

Possible validation datasets

The group compiled a table of possible validation datasets and noted possible availability issues.

Variable type	Validation data sets	Availability	Priority
Radiances*	Cross calibration (e.g., HIRS/IASI or AIRS/IASI)	Poor	1
	NWP fields (temperature sounding channels)	Good	1
Temperature	Radiosondes/rocketsondes/dropsondes (not assimilated)	Good over N.Amer/Europe	1
	GPS RO measurements (10-30 km)	Fair	1
	Aircraft	Good in some regions mainly at cruising levels	2
Winds	ADM	Not yet	N/A
	Radar	Locally good	2
	Aircraft	As for Temp	2
	Wind profilers	Only U.S.	2
	Radiosondes/dropsondes	As for Temp	1
	MISR	Poor?	3
Water-vapour	Radiosondes/dropsondes	Campaign data	1
	Dial systems	Poor	2
	Aircraft/balloons	Poor	2
	Frost point hygrometers	Poor	3
	Near IR diode lasers	Poor	3
	Ground-based GPS	Locally good	1
	Microwave radiometers	Poor	1

	Mozaic	Poor	2
	Haloe	Fair	1
Ozone	Ozone sondes	Poor but NRT	1
	Brewer-Dobson network	Poor	2
	Mozaic	Poor	2
	Haloe	Fair	1
	Lidar	Poor	2
Clouds	Radar/lidar	Campaigns	2
	Cloudsat	Future satellite systems.	N/A
	Earthcare	Poor?	N/A
	MISR	Poor	3
	Radiometers	Good	2
	ISCCP	Good	1
	CLOUDNET		1
Precip.	Radar	All need to improve coverage and NRT issues.	1
	Gauges		1
	Disdrometers		1
Trace gases and aerosols.	Ground-based networks	Sparse and no NRT availability	1
	Aircraft (Few)		1

* **Note on radiances** : It was noted that NWP fields have proved useful for validating temperature channels but ideally this should be combined with a standard such as a baseline radiosonde network which has not been bias corrected. There are clear problems for the validation of UV, VIS and IR/MW channels affected by water vapour.

Transfer of expertise between data providers and operational/research centres

The group acknowledged the importance of close links between operational -centres, data providers and the research community.

The WG makes the following recommendations:

i) Fellowships (e.g. EUMETSAT), international workshops (e.g. ITWG, IWWG, IPWG) and visiting scientist programmes (e.g. SAFs) promoting interaction between operational centres, data providers and the research community should all be encouraged and supported

ii) Operational users should be involved in reviewing instrument specifications and any changes to them to avoid any surprises. User consultation must be a continuous process.

iii) NWP centres should be made aware of field campaigns and, where appropriate, be involved in defining them.

iv) Promote the establishment and maintenance of reference sites (e.g. ARM programme).

What biases should be fixed at source and what should be left to the user?

The WG recommended that in principle instrument related problems should be corrected by the data providers at source and the corrective measures should have a clear traceability. However, it is important that the NWP centres have an early involvement in the cal/val process and early delivery on pre-operational data is essential. The harmonisation of global and local (e.g. AAPP) processors is also important.

The WG noted that antenna corrections for microwave sensors is something of a ‘grey’ area. The data providers should ensure they produce a good antenna characterisation for users to develop a correction.

What biases should be corrected?

As noted in 2.3 above data providers should correct instrument biases and provide traceable uncertainty estimates. NWP centres will have to take a pragmatic view on whether to remove/correct model biases on a case by case basis. It may be necessary to correct a model bias to obtain better forecasts in the short term but in the long term attempts should be made to reduce the bias and improve the assimilation of the data. Any remaining biases should be continually monitored, and efforts made to progressively reduce them through improvements in the model and data assimilation.

WG 2 Annex

The following sources of biases were identified by the working group.

Data provider:

- Calibration (radars, radiometers, GPS).
- Change of orbit.
- Change of instrument characteristics when in space.
- Unmodelled behaviour (e.g., rotating lens)
- Measurement geometry.
- Geolocation (HIRS, SSMI).
- AMV cloud height assignment.
- Radiosonde water vapour.
- Ozonesonde at cold temperatures
- Station height and location (Synops, Ground GPS).
- Antenna corrections.
- Sun-satellite geometry.
- Inadequate co-registration (IASI/AVHRR).

Forward modelling:

- Spectroscopic database errors/missing lines.
- Inadequacies in line-by-line model.
- Unmodelled processes (trace gases, aerosols, non-LTE, ionospheric effects).
- Continuum effects (water-vapour,O_2 ,CO_2, N_2).
- Line mixing.
- Inadequate model assumptions/truncations (e.g., vertical discretisation, layer integration, solar reflection in the SWIR).
- Multiple scattering, 3D effects.
- Fast model parameterisation (e.g., choice of predictors).
- Surface reflection/emission.
- Valid range of modelling (e.g, range of viewing angles for ground GPS, radiometers).
- Choice of training sets (trace gases, aerosols, clouds)
- Uncertainties in dielectric properties (water, ice, aerosols).

- Viewing geometry (variable zenith angle with height).
- Representation errors (Inadequate representativeness of model parameters for required scales).
- Numerical errors.
- AMV unmodelled effects.
- Mapping from observation to model (e.g., RTTOV grid, horizontal interpolation).

Pre-processing:

- Observation residual contamination (e.g., undetected cloud (IR), precipitation (microwave)).
- Data selection and averaging.
- Remapping to a common field of view.
- Change of interferometer spectral response function with scene.

Level 2 Products:

- Incorrect a-priori (e.g., inadequate climatology for HIRS ozone).
- Biases in ancillary data.

NWP biases

- Water vapour (absolute value) and its variability.
- Temperatures in the stratosphere and mesosphere.
- Clouds.
- Stratospheric and mesospheric variability (e.g., errors in circulation for trace gas transport).
- Skin temperature (T_s) and surface emissivity (ε_s).
- Snow/sea-ice cover.

Working Group 3: Operational implementation of bias correction (including regional applications)

Chair: Stephen English Rapporteur: Thomas Auligné

Reference Network

Bias correction schemes need to be grounded by a reference. This is particularly important for adaptive schemes that may have a potential to drift. Therefore a network of observations approximating the "true" state of the atmosphere with well-defined uncertainties is required. The data must be compared to the NWP models, either passively to monitor any drift or actively to anchor the data assimilation system.

Recommendation to the NWP centres to identify a part of the global observing system (e.g. high quality Radio-sondes, GPS Radio-Occulation) as reference network which is actively assimilated but NOT bias corrected against an NWP system.

Recommendation to the NWP centres to request data from research sites (e.g. ARM) to be available in real time for passive monitoring in NWP system.

The reference network does not require a re-design of the global observing system.

Adaptivity

Automated systems (*vs.* manual) show a technical advantage in dealing with a growing number of satellite information.

The adaptivity has to be tuned to the sources of bias (RT, scan, air-mass, model error). The potential skill of separating different time-scales could be investigated. In practice, the implementation is application and centre related, depending on the risk (sudden instrument change *vs.* model drift).

Bias correction and quality control interact with each other. When using an adaptive bias correction, one should be aware of a potential feedback process.

Therefore there is no specific recommendation on using adaptive *vs.* static bias corrections.

Offline vs. Inline

If a highly adaptive scheme is required, a bias correction performed inside the meteorological data assimilation (inline) is better constrained than a separate (offline) scheme.

Recommendation to the NWP centres to conduct more research to determine the practical benefits.

Choice of bias model

The main challenge of a bias model is to discriminate, within the first-guess departures, the observation bias from the NWP systematic errors. Therefore physically based bias correction schemes (modelling the sources of bias) are recommended.

Regression schemes should not be used as a black box and coefficients should be exchanged between NWP centres for information purpose only. The possibility to exchange γ. parameters (*i.e.* radiative transfer absorption correction) and scan correction needs to be studied (ITSC XIII action).

No systematic method exists yet to automatically select appropriate predictors which will mostly account only for observation bias.

Recommendation to the NWP centres to study the actual impact of each predictor in regression schemes.

Account (or not) for NWP systematic errors

Observation bias correction and model error estimation consider two complementary problems based on the same information (*i.e.* the first-guess departures).

Correction of model error through bias correction can be considered in a pragmatic way, but feedback (*e.g.* uncorrected departures) to the model team should always be provided.

No strong recommendation concerning masking (e.g. to near radiosonde locations) prior to generating bias correction nor to tuning with respect the model first-guess or analysis

Recommendation to the NWP centres to conduct a common strategy when handling observation bias and model error adaptively.

Bias correction over various surface types

This is currently an unsolved problem with a number of strategies being pursued at NWP centres.

If using regression predictors that are sensitive to the surface (*eg*. Tskin, 1000-300 hPa thickness), even if the observation itself is insensitive to the surface, one might introduce gradients at boundaries between different surface types. 850 hPa is being used in place of 1000 hPa at some centres to make the predictor more robust when surface pressure is less than 1000 hPa.

Bias correction of cloudy radiances

This is acknowledged to be an important issue over the next five years that will require significant research.

Harmonisation of monitoring

Standard deviation of departures should be monitored before and after bias correction to account for any loss in the signal.

Recommendation to the NWP centres to monitor biases with respect to the scan angle.**Recommendation to the NWP centres** to develop automatic systems for detecting changes in observations, bias correction or NWP model (a technical description of the current MetOffice system will be circulated).

Uncontroversial warnings (*e.g.* sudden loss of a satellite) could be shared between automatic systems of different NWP centres.

In case of an identified problem, a more detailed monitoring should be made available. It should include graphics showing the outliers and the shape of the distribution (*e.g.* PDF)

Local Area Models specific issues

Capturing enough regime variability without accumulating for excessive long periods is currently an unsolved problem.

Recommendation to the NWP centres to investigate the use of adaptive inline schemes and computing bias correction from different seasons.

Recommendation to the NWP centres to test global scan biases for LAM usage