Data assimilation and Numerical Weather Prediction

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1 Introduction

ITSC-18 again saw a very strong contribution from the NWP community, leading to a large working group on Data Assimilation and NWP, with 33 experts representing 16 operational NWP centres. Due to other commitments, the former co-chair Godelieve Deblonde (EC) stepped down at this meeting. The working group thanked Godelieve for her contributions and hard work for the NWP Working Group over the years. Andrew Collard (NCEP) replaced her as new co-chair.

Several presentations and posters at ITSC-18 captured a range of new research developments in NWP. Highlights included:

- First experiences with data from NPP, in particular ATMS.
- Developments in the assimilation of cloud information, including aspects of channel selection and radiative transfer.
- Further developments and progress in the assimilation of surface-sensitive channels over land or sea ice.
- First efforts in the direct assimilation of principal component scores.

Data denial experiments and other forecast impact diagnostics continue to highlight the substantial impact from the assimilation of satellite sounder data in NWP.

2 Polar orbiting constellation

Over the years, many observation impact experiments have demonstrated benefits from using MW and IR sounding data from three or more polar orbiting systems in NWP, compared to using data from just two orbits. An even spacing of orbits (early morning, morning and afternoon orbits) ensures the most homogeneous coverage, with benefits for forecast impact. With the recent cancellation of the polar orbiting satellite program of the US Department of Defense (DoD), such sounding capabilities in the early morning orbit are not secured in the future. The working group expressed its concern about this development. At the same time, the working group noted the promising developments and plans of other space agencies, in particular the Chinese FY-3 series, for which instruments from the first experimental satellites show encouraging data quality and availability. The working group sees potential in an

optimized coordination between space agencies in this respect, and therefore strongly recommends international cooperation to ensure a better harmonization of orbits.

Recommendation DA/NWP-1 to all relevant space agencies: The constellation of at least three orbits (early morning, morning, and afternoon), each with full sounding capabilities (IR and MW), should be maintained. The overpass times of operational satellites with sounding capability (IR and MW) should be coordinated between agencies to maximize coverage (including, e.g., China, India).

The cooperation between JAXA and NASA regarding GCOM-W and in particular AMSR-2 data was noted by the working group, and members reaffirmed their interest in obtaining the AMSR-2 data. It was not clear whether data access agreements are in place such that the data will be openly available to the wider user community via the JAXA/NASA partnership. The working group supports efforts already underway in this respect:

Recommendation DA/NWP-2 to JAXA and partner agencies: GCOM-W data should be made available to the international NWP user community in real time and in BUFR.

Action DA/NWP-1 on ITSC Co-chairs: To bring recommendations 1, 2, and 17 to the attention of CGMS.

3 Data timeliness

Timeliness of operational satellite data continues to be of great importance for the optimized use of the data in operational NWP. As shown at the meeting, data located towards the end of the assimilation period tends to have the largest impact in 4DVAR systems, and these data are most affected by data timeliness. Regional forecasting systems (often feeding warning applications) have even tighter cut-off times than global systems and rely on very swift data distribution.

The community greatly appreciates the joint efforts between EUMETSAT and NASA that led to the MetOp downlink station in Antarctica which greatly aids the timeliness for MetOp data and led to a significant increase in the data usage at many centres. The WG encourages that similar capabilities are established for other current and future operational satellites:

Recommendation DA/NWP-3 to NOAA/NESDIS: NOAA/NESDIS should consider establishing a similar capability with two complementary downlink stations for current and future polar orbiting satellites (e.g., NOAA, NPP, JPSS).

The working group also continues to support other low-cost initiatives to improve timeliness, such as the Regional ATOVS Retransmission Services (RARS), coordinated by WMO, which improves timeliness even further, down to less than 30 min. In particular, the WG welcomes the upcoming and planned extensions to IASI, MetOp-B, and NPP data. In the same context, the working group regrets that the Safety Net system (network of distributed downlink stations) has not been confirmed for the future JPSS. This makes it especially important to ensure that RARS capabilities are established and maintained also during the JPSS era.

Recommendation DA/NWP-4 to WMO: To support fast delivery initiatives (RARS) with extensions wherever possible (e.g., IASI, METOP-B, NPP). The working group believes that the system should continue to be low cost. Further extension of the RARS network towards global coverage is encouraged until the point is reached where further improvements are no longer cost effective.

4 Suomi NPP and cal/val of future instruments

ITSC-18 saw first results being presented from the new instruments of Suomi NPP, with encouraging results from initial monitoring and assimilation trials of ATMS data in NWP systems participating in the cal/val phase. CrIS data availability has been very limited so far for NWP centres, but initial results from instrument teams suggest that the instrument is functioning well.

European members of the NPP cal/val team (Met Office and ECMWF) noted that the provision of real-time data in BUFR during the cal/val phase was sub-optimal and did not meet the requirements of these cal/val team members. The expected data stream (dissemination via EUMETCast with collaboration between EUMETSAT and NDE) has not been routinely established at the time of ITSC-18, i.e. 5 months after launch. It is appreciated that some of the delays are a result of the restructuring of the NPP program, and community efforts to mitigate these issues are gratefully acknowledged. Working group members also appreciated the provision of simulated ATMS and CrIS data well before launch, which assisted many members in the preparation and testing of their systems as well as allowing the content of the distributed data files to be finalised. However, the final dissemination mechanism for real data appears to have been untested, and was disjoint from the successful simulation efforts, leading to substantial delays in the dissemination of the real data.

To improve the situation for future systems the working group made the following recommendation:

Recommendation DA/NWP-5 to Space Agencies: New operational data dissemination infrastructure should be tested at an early stage (well before launch) with simulated data.

The Working Group also notes that NWP is now an integral part of cal/val efforts, with many examples of how NWP can contribute to an early validation of level 1 data and the identification and correction of problems. To further aid and improve the calibration and validation of new data it is considered useful to distribute the data widely at an early stage, as this will ensure the maximum feedback from a large number of users. It is recognized that data quality and characteristics will be subject to change during the cal/val phase, and data availability might be intermittent.

Recommendation DA/NWP-6 to Space Agencies: There should be open access to new satellite data for all NWP centres to help with calibration and validation.

The WG notes that ATMS brings a number of novel aspects that will need to be investigated to optimize data usage in NWP while building on the AMSU-A/MHS heritage. Temperature sounding channels require footprint averaging to reduce noise, and several methods have been suggested to achieve this (3x3 averaging, FFT methods, Backus-Gilbert methods). Also, for AMSU-A, channels 1 & 2 are widely used for cloud detection. On ATMS these channels have a significantly larger footprint than the other sounding channels, and the implications deserve further attention. Given limited resources at many centres, it is recommended that results from such investigations are shared in the community to optimize data usage.

Recommendation DA/NWP-7 for NWP centres: Critically review options for remapping ATMS data (e.g., 3x3 averaging, FFT methods, Backus-Gilbert methods) with particular reference to quality control issues.

Action DA/NWP-2 on NWP Centres: Share results regarding remapping ATMS data with the NWP community via the NWP WG email list.

5 Noise estimates in BUFR for microwave sounder data

EUMETSAT is planning to disseminate instrument NEdT estimates in the BUFR level 1c products for METOP AMSU-A/MHS, information that is also now available for ATMS. The working group welcomes these plans as this additional information should be beneficial for the selection and use of the data. The addition of similar information in the NOAA satellite data is encouraged, and the move should also be harmonized for both global and RARS data as far as possible:

Recommendation DA/NWP-8 to NOAA and EUMETSAT: Consider harmonising the format and content of AMSU-A/MHS/AMSU-B files with respect to these noise estimates and also between RARS and global products.

The working group was not certain whether the above addition requires changes to the BUFR definitions currently used for AMSU-A/MHS/AMSU-B data, or whether the information could be appended to the existing sequences. In any case, the group recommends wide and early consultation and information regarding this or similar modifications or new definitions:

Recommendation DA/NWP-9 to Space Agencies and data providers: When designing new or modified BUFR formats, please circulate drafts to the NWP community via the NWP Working Group for feedback, prior to submission to WMO.

6 Data dissemination for hyperspectral infrared sounders

Channel selection

It was noted that as the use of hyperspectral infrared sounder data evolves, making further use of the cloud and surface information that is contained in the radiances, it might be necessary to revise the channel selected for dissemination to reflect this. For example, additional channels might be required to obtain information on the microphysical properties of clouds that may not have been considered initially. It might also be necessary to add channels where the current channel selection may be deficient. In all cases it is important for the NWP community to critically review any suggestions, as in many cases the number of channels that may be added to existing selections is limited.

Recommendation DA/NWP-10 to the NWP community: Studies for future channel selections for dissemination purposes should include aspects of cloud parameters, surface emissivities and skin temperature, and other identified deficiencies in the current selection (e.g., lower-level humidity).

Data compression

For future hyperspectral sounders (particularly geostationary imagers such as MTG-IRS) it will be challenging to losslessly disseminate all data. The working group encourages further study into lossless compression through the exploitation of temporal and spatial correlations. However, it is understood that the optimal approach may require spectral compression through principal component analysis where a small amount of information is lost with the discarded PCs. If this is the case the working group strongly recommends that a very conservative approach is followed and that the approach does not rely on studies (theoretical or otherwise) that indicate that the information can be retained with only a small number (less than one hundred) principal components.

Recommendation DA/NWP-11 to space agencies: To consider using temporal and spatial characteristics to achieve a lossless compression for such hyperspectral sounders.

Recommendation DA/NWP-12 to space agencies: If lossless compression does not achieve the required compression ratios, take a conservative approach in order to mitigate information loss (e.g., by retaining as many principal components as possible).

If hyperspectral infrared sounder data are disseminated as a set of principal component amplitudes, the data will most likely be assimilated at the NWP centres as either reconstructed radiances or remapped into a new set of PCs consistent with the forward model being used (see the talk by Matricardi et al. at this meeting). The use of reconstructed radiances for assimilation has been demonstrated at both ECMWF and the Met Office but questions remain concerning whether the principal component method for data compression will continue to provide all the information of the full channel set.

Three questions that arose from the working group discussion:

1) What is the effect of long term changes in the instrument performance and the atmospheric state (e.g., increasing CO_2) on the principal components being employed?
2) To what degree are the Jacobians of reconstructed radiances similar to those of the original channels or (as the reconstructed radiances are a linear combination of the full spectrum) can cloud contamination in high-peaking channels be an issue?
3) What is the best way to treat the observation errors for principal components and reconstructed radiances to ensure the greatest impact from these measurements?

Recommendation DA/NWP-13 to NWP centres and space agencies: To consider the implications from possible future use of PC compression for data dissemination, in particular in terms of

- **Required frequency of updates to the PC-set that might result from long-term trends of the evolution of the atmospheric state and the instrument.**
- **Differences in the observation errors and Jacobians of reconstructed radiances.**

As nearly ten years of AIRS data are now available, one possible way to quantify the stability of the principal component selection is to examine the time-series of the reconstruction scores from the NESDIS reconstructed radiances product (noting the times that the principal components were recalculated).

Action DA/NWP-3 on Tom King: To consider the investigation of time series of AIRS reconstruction scores to determine effects from long-term trends.

The working group also noted that many researchers currently working in NWP have had limited experience with the principal component analysis of hyperspectral infrared data. It was suggested that a central repository of resources on this subject be collated on the NWP working group web page.

Action DA/NWP-4 on Andrew Collard: To collect pertinent information relevant to the use of PC compression on a web-page under the NWP WG web-site.

7 Use of unapodised vs apodised radiances for hyperspectral IR sounders

It was noted that applying an apodisation function to Band 1 CrIS data resulted in an attenuation of the amplitude of the resonance in the interferogram that corresponds to the line

structure in the 15μm CO_2 band. While the apodisation is reversible if all channels are available, a loss of information in the assimilation process is possible if care is not taken to properly account for the resulting correlated observation errors.

It has therefore been suggested at this ITSC meeting that efforts be made to move towards the assimilation of unapodised radiances. Initially this will require the addition of the capability to model unapodised radiances to the fast radiative transfer models that are used in operational NWP (RTTOV and CRTM). It was recognised that other changes to the assimilation system may be required such as revised channel selections, observation errors and possibly moving from brightness temperatures to radiances. It is therefore also important to justify this additional effort by quantifying beforehand the expected impact on analyses of using the apodised versus unapodised data.

Recommendation DA/NWP-14 to NWP centres: To investigate the implications of using apodised vs unapodised radiances with particular reference to CrIS and MTG-IRS. This should consider the effect on the development of channel selection and radiative transfer models, balanced against the effect on information content.

8 Working group support to NWP community

The ITSC NWP working group is recognized as an ideal forum to exchange information and inform/update NWP users about new developments, aided by Wiki-pages and a dedicated email list.

Survey

For several meetings, the survey on the use of ATOVS data has been capturing the broad developments in the assimilation of sounder data in NWP. Ahead of this meeting, hyperspectral IR data were included in the survey, and the latest results are to be posted on the NWP working group web pages. Also, NWP centres were encouraged to share more detailed information on channel selection and observation error usage as part of this survey, and four centres provided such information. Further contributions are encouraged.

Action DA/NWP-5 on NWP centres: Continue to provide information on instrument channels assimilated and their observation error for inclusion on the NWP Working Group pages.

NWP WG web-site and email list

Several other activities were started at the last ITSC meeting to further foster information exchange, for instance in the area of regional data assimilation, where issues such as bias correction and background error specification may require solutions that differ from the practice for global systems. A website dedicated to this is now available (see https://groups.ssec.wisc.edu/groups/itwg/nwp/regional_data_assimilation). Further input is required to make the page a useful repository.

Also, the NWP Working Group email list could be used more effectively, and its increased use is encouraged, for instance for questions regarding data usage or to alert the community of data problems.

Action DA/NWP-6 on NWP centres: Send additions to the content on the NWP working group regional data assimilation page to Roger Randriamampianina (roger@met.hu).

Recommendation DA/NWP-15 to NWP WG members to use the NWP working group mailing list (itwg_nwp@metoffice.gov.uk) for questions or to alert other centres to data problems.

Monitoring statistics from NWP systems provide invaluable information about the performance of data assimilation systems and satellite instruments. The group noted that currently there are two websites where links to monitoring pages of NWP centres are collected, one maintained by the NWP working group, and one by the NWP SAF. To streamline these efforts, the group decided that one well-maintained page would be more beneficial, provided it gives a complete picture.

Action DA/NWP-7 on Robert Tubbs to e-mail the NWP working group with the NWP SAF monitoring web-site and to request further information on its use from NWP working group members.

Action DA/NWP-8 on Robert Tubbs to check that the links on the NWP working group monitoring web-site are consistent with those on the NWP SAF monitoring page, before the NWP working group monitoring web-site gets replaced with a link to the NWP SAF monitoring page.

Working group members whose centres are not yet included on the NWP SAF monitoring site are encouraged to email Robert Tubbs with the required links.

At the last ITSC meeting, an activity was started to collect evidence from existing Radio Frequency Interference (RFI) or research into potential impacts of RFI in NWP systems. A website has been set up (https://groups.ssec.wisc.edu/groups/itwg/nwp/rfi_and_nwp), including examples for Windsat, SMOS, and AMSR-E. We need to be able to document instances of RFI so that evidence can be presented to the relevant national authorities who may be able to remove offending illegal transmissions.

Action DA/NWP-9 on NWP working group members: If you have evidence of RFI, please send these to Niels Bormann (niels.bormann@ecmwf.int) for inclusion on the NWP working group RFI web page.

During ITSC, it was recognised that the information on this website should get greater visibility in the context of RFI issues usually discussed in the International working group, and efforts in this respect will be coordinated between Niels Bormann and Jean Pla.

SSMI/S

Investigations at various centres have highlighted problems with SSMI/S data resulting from a range of instrument issues. A means of sharing this experience, in particular in terms of bias correction and quality control between centres would be beneficial. Also, if there are established ways of identifying data that is known to be of poorer quality, it would be best if these were incorporated into reliable flagging of such problems in the disseminated data.

Action DA/NWP-10 on NWP WG co-chairs to set up an SSMI/S web-page with information on quality control and bias correction experiences, and to NWP working group members to contribute to this page.

Recommendation DA/NWP-16 for NRL: To review the quality flags provided in the BUFR data for SSMI/S to flag any known erroneous data.

Bias Correction Intercomparison

Following on from a suggestion at the last ITSC meeting, the group discussed the usefulness and scope of a bias correction intercomparison exercise, and it was reaffirmed that interest in this activity exists especially for regional data assimilation. Such an activity should compare the results of bias corrections, as well as providing information on the methods typically used. Further details about how this should be done and what should be compared still need to be formulated to allow an efficient inter-comparison exercise.

Action DA/NWP-11 on Roger Randriamampianina: To e-mail the NWP Working Group with a proposal for a bias correction inter-comparison exercise. This will cover both regional and global data assimilation models.

Action DA/NWP-12 on NWP centres: To consider Roger's proposals and to provide feedback and data as appropriate.

Updated channel characteristics

NWP systems or Simultaneous Nadir Overpass (SNO)-methods have been used to revise channel characteristics such as central pass-band frequencies for microwave instruments or spectral response functions for IR sounders. The group noted that it would be useful to collect this information at a central location, as such updates have been shown to reduce some air mass-dependent biases and therefore aid the assimilation of the affected data. The channel characteristics web-page of the Radiative Transfer Working Group seems a logical place for this, and Paul van Delst agreed to include such information.

Action DA/NWP-13 on ITSC members: If you have estimates of revised channel characteristics resulting from post-launch diagnostics, please email these to Paul van Delst (paul.vandelst@noaa.gov**).**

9 Invest resources in operational data assimilation to fully realise potential of new satellite data

New satellite programs can cost hundreds of millions of Euros/Dollars and yet it can take many years to learn to properly exploit the data in NWP. Additional investment in operational NWP (which while still expensive is only a few percent of the satellites themselves) therefore represents an efficient path for improving the cost/benefit ratio for satellite observations.

This additional investment should focus on improved computational resources (allowing more sophisticated models to be run and more resources for research); development of new assimilation techniques (many centres are still not running 4DVar thereby reducing the impact of observations with high temporal frequency) and improvement to the forecast models, as well as methods focussed on the particular observations themselves.

Investment in operational NWP is preferred as research conducted in this paradigm from the start is more easily transferred to operational status.

It is also noted that the larger the number of operational centres able to conduct cutting-edge research, the more likely that breakthroughs will be made in the use of satellite data.

Recommendation DA/NWP-17 to funding bodies of NWP centres and space agencies: Consider, as part of the cost of satellite programs, providing computational and

personnel resources *targeted at operational NWP centres* to optimise the public's return on investment from these expensive measurement systems.