Report from EUMETSAT Skills Development Short-term Placement

Hosting institution:

Joint Center for Satellite Data Assimilation (JCSDA):
NOAA/NESDIS College Park, MD, 7-11 October 2019
UCAR Boulder, CO, 14-18 October 2019
SSEC Madison, WI, 21-25 October 2019

Visitor:

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Introduction

This document summarizes the outcome of a visit to Joint Center for Satellite Data Assimilation, a US multi-agency research center to improve the use of satellite data, sponsored by European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) within the newly-established Skills development short-term placement program. The mission was executed between 5-27 October 2019 and included visits to their three cooperating institutions.

The general purpose of the stay was twofold: a) to review and discuss the current use of satellite products for regional data assimilation, with emphasis on hyperspectral sounders, and b) to start preparation for assimilation of Meteosat Third Generation (MTG) InfraRed Sounder (IRS) data by contributing to evaluation of data samples from hyperspectral Geostationary Interferometric Infrared Sounder (GIIRS) instrument flown on Feng-Yun 4 of Chinese Meteorological Administration (CMA), which included visualization, simulation of radiance with a radiative transfer model.

A series of work meetings was kindly organized by the hosts at all the three sites to discuss the current/future satellite observations and products, together with their application to forecasting/numerical weather prediction (NWP). The discussion were triggered also by author's seminars on current data assimilation activities in Slovenia and Regional Cooperation on Limited Area modelling in Central Europe (RC LACE), a consortium of 7 European countries (Austria, Slovenia, Croatia, Czech Republic, Slovakia, Hungary, Romania) were the author serves as area leader for data assimilation. Rather than summarizing individual meetings, we discuss the central issues that may help improving the current data assimilation systems in Slovenia and RC LACE consortium and may provide useful feedback to EUMETSAT with regards to its future observation missions.

Use of radiances in regional models

Use of radiances in NCEP's regional models

Radiance data assimilation for regional models was discussed within the National Centers for Environmental Prediction (NCEP) data assimilation group, based also on inputs from Slovenia/RC

LACE. At NCEP, regional data assimilation is realized through 3D-EnVar algorithm, with background-error covariance currently based on global NCEP ensemble members within their grid point statistical interpolation (GSI) system.

Usage of Advanced Baseline Imager (ABI) was compared to usage of MSG in RC LACE. Their 3 water-vapor channels are currently used. The impact on regional model was so far difficult to prove, but a positive impact on humidity is seen in global model over the northern hemisphere when combined with METEOSAT and Japanese Himawari. A nice discussion was related to use of water vapor information from geostationary imagers. The difficulty with variational assimilation techniques is that information from channels sensitive to water vapor often results in excessive corrections of temperature profiles through multivariate relationships enforced by background error covariances.

Apart from using clear-sky radiances (CSR), the partly cloudy scenes can be assimilated through the cloud-clearing process, realized through comparison of collocated sounder/imager data. Once the effect of cloud on measured radiances is diagnosed from imager pixels contained in a larger sounder footprint, it can be superposed to sounder data which is then used as cloud free. To account for errors related to cloud clearing, observation errors need to be inflated thus the impact on analysis is down-weighted. By doing so a positive impact on forecast could so far be demonstrated over sea, the same holds for using rainy microwave radiances on top of non-rainy ones.

Thinning and bias correction

A question of data averaging and thinning was opened but apparently the NCEPs regional setting for thinning stays the same as for global models (CSR with 30 km average in the first step, and thinning to 120 km). Bias correction is realized through variational bias correction (VarBC) and local cycling, which is the only option for NCEP as regional and global model levels differ significantly. As degrading impact with reduced thinning was demonstrated in RC LACE, is was suggested that reduced thinning might reduce the choice of cloud-free pixels and thus increase cloud contamination. For hourly systems, it was also suggested that the bias of geostationary radiances could be estimated over longer time frames, e.g. 3 hours. Some satellite channels are omitted from dynamic bias correction to serve as anchor observation (for instance, Advanced Technology Microwave Sounder (ATMS) channel 15 on Suomi NPP/NOAA20 is not corrected). No additional satellite observations are currently used for NCEPs regional model with respect to the global model.

Channel selection for LAMs

For limited-area models (LAMs), there is a question if the currently used channel selection for global models sufficiently represents the detailed vertical variability we might want to resolve. To investigate this issue, it was strongly suggested to try to assimilate as many channels as possible. On the other hand, the channel selection, once made for global NWP centers, affects the operational dissemination of data and thus limits the possibility of regional models to extend it. While the current techniques tend to optimize the description of vertical profiles with a reduced number of channels, the benefit from geostationary sounders is expected to arise (as already shown in first experiments with Chinese GIIRS) through better description of temporal evolution of moisture patterns. For that reason the temporal “information content” might be superior to the currently used vertical one. Another important thing is that optimal channel selection might depend on geographical variability, so the best result might be achieved by taking into account only the climate characteristics of the region. It was suggested to expect most impact on NWP from satellite data with at most 3-times coarser resolution compared to the resolution of the NWP model grid.

Current impact from a hyperspectral sounder in NWP

A nice demonstration of positive impact of GIIRS instrument was presented over China (Wei Han, formerly a member of CMA). It was emphasized that impact was seen especially when data was assimilated with high temporal resolution (e.g., every 30 minutes). Only a selection of 24 channels was used so far (out of 995). The selection method based on information content was discussed and it turns out that it is quite similar to methods used at Météo France or European Center for Medium-range Weather Forecast (ECMWF). Han also presented an interesting approach to increase the GIIRS coverage (targeted observations with increased resolution) and thus the analysis in the sensitive geographical areas determined by a flow-dependent analysis method (4D-Var).

A practical work was carried out to simulate GIIRS radiances for all the channels using RTTOV and coefficients provided by the CMA and to check their horizontal consistency. Figure 1 shows a brightness temperature simulation for the whole spectral range, for an arbitrary atmospheric profile. Further work was devoted into analysis of spatial maps for all channels for a specific date (Fig. 2). For this date we plan to check the observation-minus-first guess departures (OMG), with respect to corresponding model profiles ECMWF and CMA model. This work is ongoing.

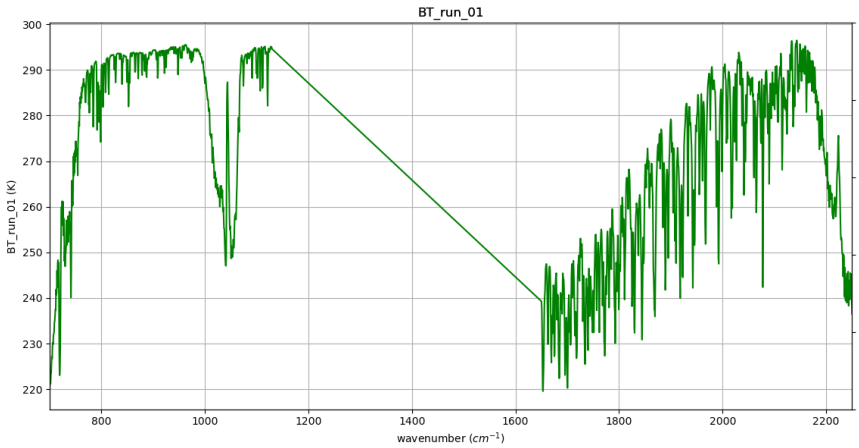

Figure 1: Brightness temperature (K) for all GIIRS channels, simulated by RTTOV-v12, using one of the standard atmospheric profiles. From left to right there are CO2, ozone and water vapor absorption bands which enable atmospheric profiling.

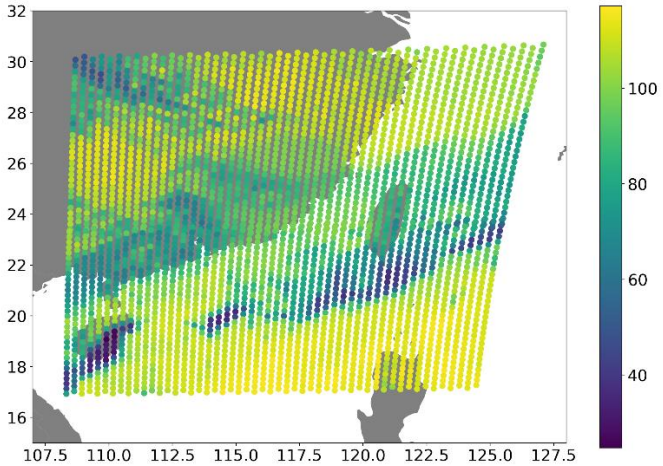

Figure 2: Simulated radiance for channel 200 (long-wave IR sensitive to water vapor) for 15 May 2019 7 UTC over China at highest horizontal resolution of GIIRS, available every 5 mins.

Assimilation of radiances versus retrievals

At several occasions throughout the visit the following question was raised: is it really more optimal to assimilate radiances rather than retrievals? In NWP, assimilation of radiances has been the preferred choice for years, mainly for the following reasons: 1) direct radiance (brightness temperature) assimilation using a radiative transfer model does not require any prior offline information from (another) NWP, 2) the observations are treated consistently with respect to what model can simulate in terms of physics and vertical resolution, 3) the bias correction is relatively straightforward and acts on raw data itself. On the other hand, retrieved profiles may benefit from combinations of different collocated sensors (e.g. imager/sounder) and especially, in the case of hyperspectral sounders, by using information from all channels which is difficult to achieve with raw radiances due to inability of assimilation algorithms to process this number of data and difficulties in dealing with heavily correlated observations. The possible approaches to bias correction in case of retrievals is currently a bit unclear. Based on this discussion it would be worth to conduct assimilation impact experiments also from retrieved IRS profiles (together with experiments using a selection and increased number of channels).

Data fusion

The data fusion technique to downscale sounder data with high-resolution imagers was presented at SSEC. Possible training combinations currently include Modis/AIRS, CriS/VIIRS or AVHRR/IASI. The method relies on K-d tree search algorithm to links several sounder FOVs which best match each of the imager pixels. This is then used to downscale the sounder channels to the resolution of imager. The method was presented to work very well for CO2 channels and slightly worse for water vapor channels. Although the technique is able provide more detailed information for the general forecasting, the question if such a downscaled product might add some value for data assimilation is currently somewhat unclear.

Use of other satellite-derived and complementary observations

Assimilation of GNSS-RO observations

Global Navigation Satellite Systems Radio Occultation (GNSS - RO) is an attractive observation for global NWP and currently also one of the most extensively validated by JCSDA. The coverage has been increasing in the last years as a number of commercial satellite missions started to provide such data. Several versions of obs. operators (2D, 3D) are already implemented in the new JCSDA's data assimilation platform (described in the next section). This data offers excellent vertical resolution and accurate measurements at higher elevations while the horizontal resolution is much lower. For this reason GNSS-RO is not usually used in the regional models. However, recent experience from NCEP's global model suggests that a positive impact from this data types mainly comes through constraining satellite bias correction – GNSS-RO is a highly unbiased measurement which can serve as anchor to improve VarBC for radiances. From that point of view studies within regional models over Europe would be useful, probably starting with observations from Metop satellites.

Atmospheric motion vectors

Several discussions were related to atmospheric motion vectors (AMV) and their use in NWP. A typical RMS difference between radiosondes and AMVs is 6 m/s, which is more than RMS difference between radiosondes, aircraft or NWP data. A major source of error for AMVs is height assignment, which in most relies on auxiliary NWP profiles, but also on errors in correlation

methods used for tracing. Another significant difficulty with high impact weather phenomena, often linked to high wind speeds, is that a large fraction of atmospheric winds is currently rejected because the model fails to provide a reasonable wind structure in the first guess. The most obvious example of this are tropical cyclones where a small displacement might lead to rejection of most observations. Despite the difficulties, wind information is essential and straight-forward to assimilate, and a significant impact on analysis is seen for global models. On regional scale, however, the data are typically too sparse to have a significant impact. Efforts are put into refining the tracing procedures to produce more AMVs, which was demonstrated for GOES on a hurricane case. New stereo techniques might allow for using more channels to retrieve wind, improve resolution and decouple the wind estimation from a-prior NWP information. Future hyperspectral sounders may allow for frequent and 3D wind retrievals.

Importance of aircraft data for DA and relevance for satellite-derived products

Aircraft observations were identified as observation type with highest impact in regional and global models (as seen in NOAA Rapid Refresh, GDAS/GFS or ALADIN/Harmonie-AROME) due to their accuracy as point measurements, relatively good coverage over continental US and Europe, and recently also because they can provide humidity information, which was shown to improve precipitation forecasts in some applications. Aircraft profiles also seem to provide a reasonable reference for evaluation of satellite products, e.g. L2 retrievals from sounders, and to constraint mid-level satellite bias correction, and are thus enhancing impact of satellite data.

Unification of data assimilation infrastructure in the United States

Joint effort for data assimilation integration (JEDI)

The majority of JCSDA core team is nowadays hosted by UCAR Community Programs in Boulder, Colorado. The group focuses on development of a new flexible and modular framework to apply data assimilation for satellite (and other) observations either in research or operational mode, the Joint Effort for Data Assimilation Integration (JEDI), which incorporates all the other developments of JCSDA. The system aims at providing the components of a data assimilation system along with flexible interfaces to different atmospheric/oceanographic numerical models. This includes a set of assimilation algorithms (OOPS), development and interface to Community Radiative Transfer Model (CRTM), a set of unified observation operators (from interpolation to more complex operators), and a generic framework to specify the background error covariances in a model-agnostic way. The framework also includes a large set of test configuration which enable inline benchmarking of the ongoing developments, but also demonstrations and learning on sample datasets and (inexpensive) model configurations. Another requirement is scalability and flexibility of the system to be run at various architectures, which is achieved by utilizing modern software container approaches. All this should help reducing redundant work at partner institutions and increase efficiency of research and transition to operations.

To gain some insight on the system usage and design, JEDI was used during my visit on a personal laptop by using a singularity container provided by JCSDA, which enabled testing CRTM and various other observation operators, and perform data assimilation step with a toy quasi-geostrophic model and later on also the future NOAA’s operational FV3 (finite volume, cubed-sphere dynamical core, using a very low C12 resolution), using the ensemble variational technique (EnVar). The JEDI system is expected to be open source and of interest for meteorological centers outside US, to increase efficiency of development and maintenance of DA systems.

Coupling of atmospheric and ocean models

Coupling between different kinds of environmental models will also be implemented within the unified JEDI system. Discussion with JCSDA Sea-ice Ocean and Coupled Assimilation (SOCA) team was focused on air-sea coupling in a regional model and possible inclusion of other couplings. In Slovenia, previous research highlighted an importance of DA system for ocean in a coupled system so that atmosphere can benefit from recent observations. It was suggested that a simple but frequent application of satellite sea-surface temperature (SST) products, although possibly not optimal for deep sea, should provide reasonable input for atmospheric processes such convection over the sea surface and along the coasts. Similar study was already been proposed as EUMETSAT-supported project within one of the past calls.

Forecast sensitivity to observations

JCSDA's Impact of Observing Systems (IOS) group investigates the impact of satellite and other observations on forecasts. The goal is to provide a relevant forecast metric and a platform to compare results of various cooperating and external institutions. Such a comparison enables detection of potential issues with any given observation set. Currently the system is tested on the past inter comparison periods. The main metric is Forecast Sensitivity to Observation Impact (FSOI), with two ways of computation: using the adjoint technique, suitable for systems with 4D-Var, and the ensemble technique, suitable for the ensemble or EnVar systems. Observed significant differences between those (in principle equivalent) methods are currently investigated.

Use of container infrastructure on parallel systems

One of the requirements for a unified and flexible data assimilation infrastructure is that it can be easily run across different platforms. JCSDA testes its JEDI systems in container environments, such as Docker, Singularity or Charliecloud. The main dilemma is where to implement Message Passing Interface (MPI), a software library which enables code parallelization. If the system implementation is used, several containers per application need to be run. By doing so a part of advantage of software containers is lost because the supervision system or the execution script cannot be included in the container. On the other hand, JCSDA's experience shows that the performance is degraded when MPI and a whole multi-node application remains in the container. These experiences are important for Slovenian Environment Agency as it plans to deploy more model installations to national high-performance computer (HPC) infrastructure and elsewhere in the near future.

Discussion on possible local applications and further collaboration

Possible short-terms improvements of assimilation system in Slovenia RC-LACE

Based on our discussions during the visit, the following short-term actions can be foreseen at Slovenian Environment Agency and within RC LACE community:
1) Upgrade the currently used RTTOV-10/11 to version 12. This upgrades the surface emissivity treatment over land (moves from static emissivity over land to using an emissivity atlas). It was emphasized that error in emissivity calculations might be spatially correlated which in turn causes correlation of errors in simulated radiances. One might try to utilize the uncertainty of emissivity value which comes together with the atlas.
2) Validation and operational assimilation of ATMS and CriS sensors from Suomi NPP/NOAA 20 as soon as possible.

3) Check how water vapor channels (SEVIRI/IASI) impact the humidity and temperature profile in the model. If variational technique prefers attributing the innovations to temperature profile, the strength of multivariate balance should be reduced.

Topics for future collaboration with JCSDA/NCEP/SSEC

1) Continued cooperation on evaluation of GIIRS data

A sample of 5-min GIIRS observations over parts of China was investigated by visualization of spatial maps for each channel. Model datasets (profiles) from ECMWF and CMA models are in preparation in order to study the innovations, either interactively (GUI) or in a batch mode. Further synthetic test profiles might be used to estimate the ability of the sounder to provide information on low-level features such as temperature inversions in the planetary boundary layer (PBL). On the other hand the high temporal availability of GIIRS should be investigated to estimate the trends in moisture patterns (e.g., during diurnal PBL evolution) and derivation of motion vectors. The lessons learned here are expected to be applicable to the future MTG/IRS sensor.

2) Assimilation of cloud-affected radiances

The usage of radiances in high-resolution models is limited by a poor coverage from polar orbiting satellites, horizontal correlation of representativeness and instrument error, and also because the domain is often cloudy during high-impact weather cases. Research and sharing experience on optimized satellite assimilation in partly cloudy or cloudy scenes is therefore very relevant for us, as well as propagation of satellite information to air mass variables (balance between temperature and humidity) during data assimilation process with the goal of retaining as much structure in humidity fields as possible.

3) Analysis of convective indices based on sounder data

A robust method to estimate CAPE based retrieved profiles from a sounder, combined with surface observations was presented at SSEC. Such products might be of interest for operational use at Slovenian Environment Agency, where preliminary study of L2 retrieved profiles from IASI was already carried out, but profiles were at that time considered too smooth to be useful over complex topography. Investigation on how to incorporate low-level inversions using surface measurements or ground-based profilers in such products would be of major importance.

4) Possible investigation of the JEDI system

A first hand-on experience with JEDI system of JCSDA proved that a system can easily be installed and run (trial experiments and unit tests) on different systems, including the author’s laptop. The OOPS part of the system is being gradually integrated in the export (operational) versions of the ALADIN model. As JCSDA plans to provide a public release of JEDI in the near future, Slovenia/RC LACE are interested to follow this development and possibly consider to couple it with the ALADIN model.

Acknowledgements

The author would like to thank the hosts at JCSDA (James Yoe, Katherine Shanahan, Robert Knutesson and director Thomas Auligne) and all their colleagues for interesting meetings and discussions.

The author would like to acknowledge EUMETSAT for supporting the mission which was very informative and will be very useful for his future work in regional data assimilation. The author is

ready to provide further feedback and discuss with EUMETSAT if needed and to further collaborate on data assimilation aspects of its future satellite missions.