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# Infrared radiance simulation in an OSSE context


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## Introduction

One of the recurrent difficulties in the validation of data assimilation systems in atmospheric and oceanic sciences is that the real state of the ocean or the atmosphere is unknown. Observing System Simulation Experiments (OSSEs) are a way to assess the performance of an assimilation system using a known artificial "truth" referred to as the "Nature Run" (NR) and usually resulting from a free-run model integration or a reanalysis. Artificial observations can be simulated from the NR and assimilated by the assimilation system just like real observations. The performance of the assimilation system can then be assessed by comparing the analyses and forecasts directly with the NR, provided that issues related to differences in resolution between the NR and the analyses are properly handled. OSSEs are particularly useful to assess the performances of existing assimilation systems, for the design of new assimilation systems and to assess the impact on forecasts of future data types . In this poster, we describe the latest progress of Environment Canada (EC) OSSE capabilities with more emphasis on the simulation of infrared radiances. This system was first used as a baseline in the context of the preparation of the European Space Agency (ESA) PRocess Exploration through Measurements of Infrared and Millimeter-wave Emitted Radiation (PREMIER) space mission and also to evaluate the potential impact of the planned Canadian Polar Communication and Weather (PCW) satellite constellation. The focus is on the proper simulation of infrared radiance assimilation.

## Nature Run fields description

- 13 month free model run produced at the European Center for Medium range Weather Forecast (ECMWF) from 10 May 2005 to 31 May 2006 with the NWP model version of the CY31r1 cycle.
- T511 horizontal resolution
- 91 eta levels in the vertical (model top at 0.01 hPa)
- This NR is interpolated to EC operational model grid with similar resolution (80 levels, 35 km)
- Time-varying Sea Surface Temperature (SST) and ice provided as a lower boundary condition from the National Centers for Environmental Prediction (NCEP) for that same period.
- Observation types and distributions are those available 3 years after the date of the original NR fields to reflect a more up-to-date observing system: period from 10 May 2008 to 31 May 2009 (transposed to 2005-2006)

## Assimilation system description

- Use of a version of the EC assimilation code modified to allow for the analysis of chemical species (necessary in the context of the PREMIER mission).
- 3Dvar with First Guess at Appropriate Time (FGAT) analyses.
- Error statistics (observation and background error) same as used in EC operational Global Deterministic Prediction System (GDPS).
- 240x120 Gaussian analysis grid.
- The assimilation code and the Global Environmental Multiscale (GEM) forecast model share the same vertical coordinate: 80 eta levels with a top at 0.1 hPa
- Forecast model used is GEM-MACH, with use of the LINOZ linearized stratospheric ozone chemistry, a modified version of the operational model, on an 800x600 constant resolution horizontal grid

## Observations assimilated

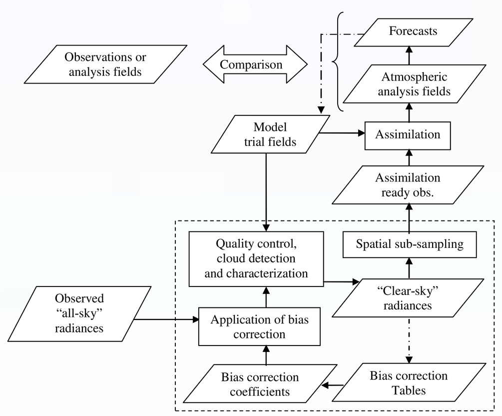
- Surface (SYNOP/SHIP/BUOYS/DRIFTER)
- Radiosondes
- Aircraft
- Satellite winds (geostationary imagers +MODIS)
- GPS radio occultations
- Scatterometers: Quickscat
- Microwave radiances:
  - AMSU-A from NOAA, AQUA and METOP (11 channels)
  - AMSU-B and MHS from NOAA and METOP platforms (4 channels)
  - SSMI and SSMI-S from DMSP platforms (7 channels)
- Infrared radiances:
  - AIRS from AQUA (85 channels)
  - IASI from METOP (62 channels)
  - Geostationary imagers (1 $H_2O$ channel)

## Simulation of observations

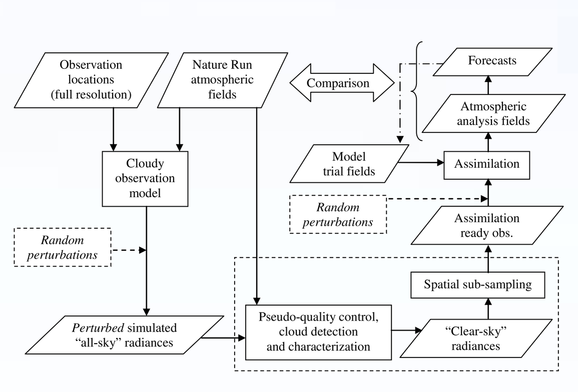
For observations other than IR radiances, the simulation procedure was quite simple: The position positions of observations were taken from real observations assimilated in 2008-2009. The observations were simulated from the NR fields using the same observation operators used during the assimilation. A random perturbation was applied just prior to assimilation.

### Simulation of IR radiances:

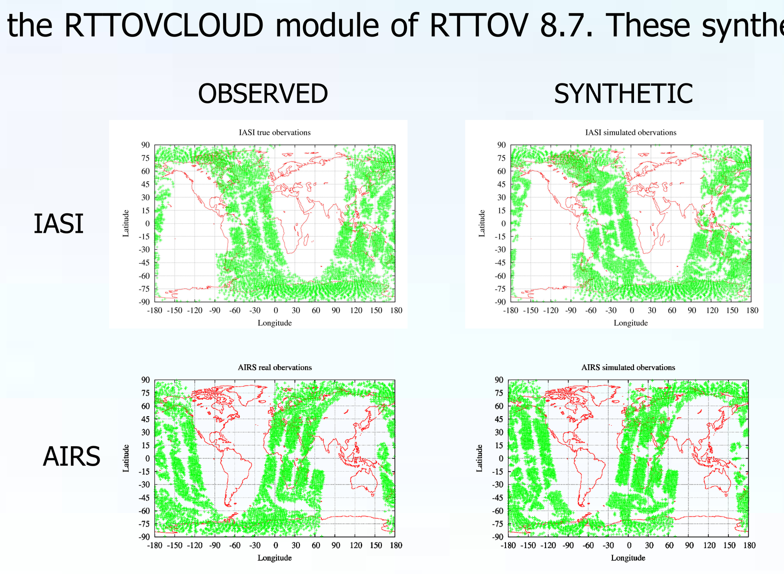
Because of their high sensitivity to clouds, it was not realistic to apply the same approach to IR radiances as cloud locations could be different between the NR and 2008-2009 real observations. Realistic cloud affected radiances were therefore simulated for all AIRS and IASI observation locations from NR fields using the RTTOVCLOUD module of RTTOV 8.7. These synthetic "all-sky" radiances were then subjected to a quality control procedure very similar to the one used with real observations.

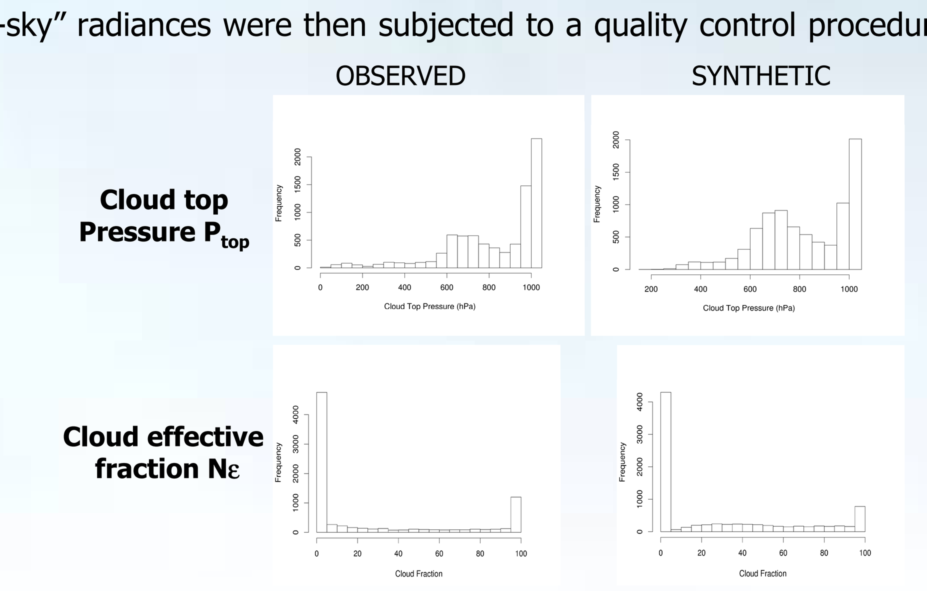



ASSIMILATION OF REAL RADIANCES




ASSIMILATION OF SYNTHETIC RADIANCES




## Perturbation of observations

Perturbation of synthetic observations is of utmost importance in an OSSE context. We use a Gaussian centered random perturbation of standard deviation $\sigma_{pert}$ : $N(0,\sigma_{pert})$. Following Errico et al., the values applied are proportional to the assigned observation error standard deviations whose inverse squares are used weights in the assimilation process:

$$\sigma_{pert}=\beta\sigma_{obs}$$

Tuning of the β factor was first performed observation family by observation family using the results obtained in a first reference experiment to target the observed O-A statistics with the pragmatic scaling rule:

$$\beta_{adj}=\beta_{ref}\frac{\left\langle \frac{2J_O(\mathbf{x_a})}{N}\right\rangle_{OBSERVED}}{\left\langle \frac{2J_O(\mathbf{x_a})}{N}\right\rangle_{REF}}=\frac{\chi^2_{OBSERVED}}{\chi^2_{REF}} \quad \text{with} \quad J_O(\mathbf{x})=\frac{1}{2}(\mathbf{H}(\mathbf{x})-\mathbf{y})^t\mathbf{R}^{-1}(\mathbf{H}(\mathbf{x})-\mathbf{y}) \qquad (1)$$

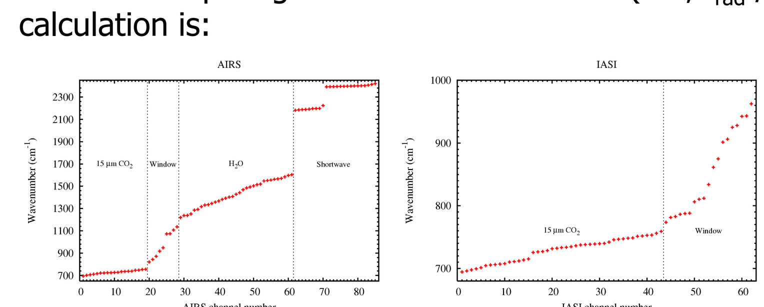
The resulting experiment will be referred to as **EXPADJ1**.

| Observation family | β |
|---|---|
| Upper air data | 0.92 |
| Aircraft | 0.56 |
| Wind profilers | 0.58 |
| Surface observations | 0.51 |
| Cloud drift winds (AMVs) | 0.28 |
| *GPS-RO* | *1.0* |
| *SBUV/2 and MLS ozone* | *0.6* |
| IASI METOP-2 | 0.77 |
| AIRS AQUA | 0.31 |
| AMSU-A AQUA | 0.44 |
| NOAA15 | 0.34 |
| NOAA16 | 0.34 |
| NOAA18 | 0.41 |

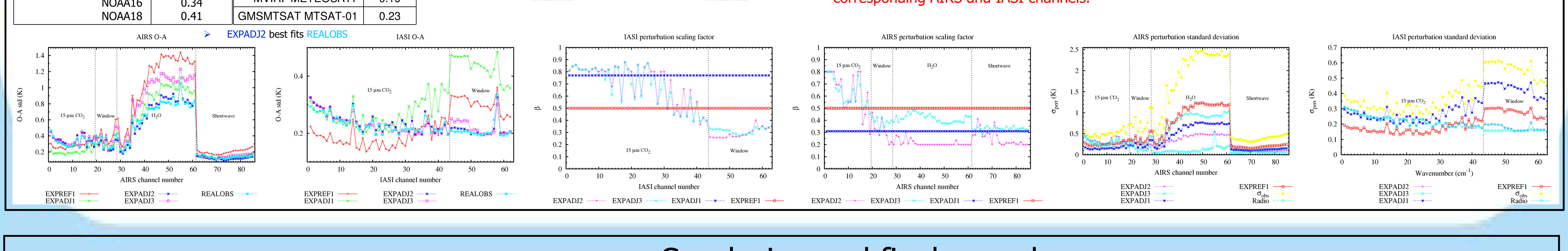
| EXPADJ1 scaling factors | |
|---|---|
| AMSU-B NOAA15 | 0.60 |
| NOAA16 | 1.25 |
| NOAA17 | 0.36 |
| MHS NOAA18 | 0.30 |
| SSMI DMSP13 | 0.32 |
| SSMIS DMSP16 | 0.21 |
| GOES GOES11 | 0.08 |
| SEVIRI METEOSAT9 | 0.21 |
| MVIRI METEOSAT7 | 0.19 |
| GMSMTSAT MTSAT-01 | 0.23 |

However, as shown in the table, some apparent discrepancies in terms of β between similar instruments such as AIRS and IASI are visible. Examination of the spectral dependence (see below) reveals part of the explanation. It turns out that the application of a perturbation using a β factor calculated channel by channel is necessary. Application of equation (1) channel by channel by itself was found to be inappropriate. Constraints on the values of β were therefore included. These consist of requiring that it be between $\max(0.2,\sigma_{rad}/\sigma_{obs})$ and $\max(0.8,\sigma_{rad}/\sigma_{obs})$ where $\sigma_{rad}$ is the radiometric noise standard deviation. The improved recipe for the calculation is:

$$\beta_{adj}^{'}=Max(Min(Max(\beta_{adj},0.2),0.8),\frac{\sigma_{rad}}{\sigma_{obs}})$$




Two variants were tried in the specification of $\chi^2_{OBSERVED}$ in (1): one using O-A (results applied to **EXPADJ2**) and the other using O-F (results applied to **EXPADJ3**). EXPADJ2 provides best results, following same approach as used for other data types (i.e. based on fitting (O-A)). It turns out (O-F) are well reproduced as well in comparison to real statistics. Following this, the adjustment factor is very similar for spectrally corresponding AIRS and IASI channels.




## Conclusion and final remarks

The EC OSSE capability was recently enhanced and used to estimate the impact of future planned space missions PREMIER and PCW. A realistic treatment (simulation, quality control and perturbation) of AIRS and IASI infrared radiances which included an estimation of cloud contamination was introduced in this context. As was done above, the perturbation strategy could be improved for AIRS and IASI instruments by using a channel by channel approach based on the adjustment to real O-A statistics. This strategy could also be applied to microwave sounders and conventional observations.

The principle of generating realistic observations and applying a realistic quality control should, in principle, be applied to other observations. For example, in the case of microwave radiances, realistic cloud- and precipitation- affected radiances could be generated using the RTTOVSCATT module from RTTOV with a realistic quality control being applied to those synthetic radiances. More ad hoc strategies could also be applied depending on the realism and cost of these radiance simulations. This OSSE framework gives a lot of possibilities to evaluate the impact of new observations in various ways and also the possibility to get a better understanding of the current EC operational assimilation system. Many other applications could be envisioned.