An Observing System Simulation Experiment to evaluate the future benefits of MTG-IRS data in a fine-scale weather forecast model

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Introduction

OSSE : Observing System Simulation Experiment

GOAL
software system to assess the value of an atmospheric observing system to operational mesoscale numerical forecasts

OSSE is useful for many applications, especially:

⇒ Evaluating current data assimilation and forecast systems;
⇒ Identifying observation need through sensitive experiments with synthetic observations.
⇒ Evaluating future observation system before deployment
Introduction

MTG-IRS : Meteosat Third Generation – IR Sounder

Scheduled for launch in 2018/2020?
GEO platform (36000 km)
Full disk coverage / 30 min
1738 channels
Spec. Res. = 0.625 cm\(^{-1}\)

<table>
<thead>
<tr>
<th>Mission Band</th>
<th>Frequency range (cm(^{-1}))</th>
<th>Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRS-1</td>
<td>700-770</td>
<td>CO(_2)</td>
</tr>
<tr>
<td>IRS-2</td>
<td>770-780</td>
<td>Surface, clouds</td>
</tr>
<tr>
<td>IRS-3</td>
<td>980-1070</td>
<td>O(_3)</td>
</tr>
<tr>
<td>IRS-4</td>
<td>1070-1210</td>
<td>Surface, clouds</td>
</tr>
<tr>
<td>IRS-6</td>
<td>1600-2000</td>
<td>H(_2)O</td>
</tr>
<tr>
<td>IRS-7</td>
<td>2000-2175</td>
<td>CO</td>
</tr>
</tbody>
</table>
Introduction

All observations are simulated from free-run forecast produced by a NWP model. These forecasts represent truth and are denoted the « nature run (NR) ». Simulated obs. must mimic as close as possible, error characteristics of obs. from the real system. Simulated obs. are assimilated into an assimilation system that is independent of the NR model. Performances in the forecast skill are evaluated.
Introduction

1. The Nature Run
2. The 3D-Var Data assimilation system
3. OSSE calibration (tuning of obs. error)
4. Simulation of observations
5. Potential impact of IRS : Assimilation experiments

Conclusion, limitations and future work
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Conclusion, limitations and future work
1. The Nature Run
Characteristics

**High Resolution ARPEGE/IFS Free-Run forecast**

Spectral resolution : T1200
~ 7 km over Europe
Vertical levels: L105
Initial conditions: 20/06/2013 – 0h
Model version : cy38op1
No data assimilation !

⇒ Simulated fields are available every hour for both pronostic and diagnostic model fields ( 3 periods of 3 months)
1. The Nature Run
Comparison with ARPEGE OPER

Maps of averaged temperature fields produced by the Nature Run vs the ARPEGE OPER forecast model over 1 month (July 2013)

Nature Run:

ARPEGE OPER forecast model:
1. The Nature Run
Comparison with ARPEGE OPER

Averaged temperature and humidity profiles produced by the Nature Run vs the ARPEGE OPER forecast model over 1 month (July 2013)
1. The Nature Run

Comments

⇒ This NR appears adequately realist with regard to the ARPEGE OPER model

Usage :
- Produce the initial first guess of the OSSE
- Provide coupling files for AROME OSSE boundary conditions
- Provide atmospheric states to simulate the full observing system (+ IRS)
- Verify the Forecast skills of the Limited Area model
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2. The 3D-Var data assimilation system Characteristics

3D-Var AROME/France forecast system
~ 2.5 km over France
Vertical levels: L60
Initial conditions: 15/07/2013 – 0h
Model version : cy38op1
3h-assimilation window
Coupling (1h) : Nature Run
Assimilation of the full atmospheric observing system (+ IRS) !
2. The 3D-Var data assimilation system

The operational observing system

Conventional:
- Radiosondes
- Aircraft
- Ship / Buoy
- Profilers
- VAD winds
- Surface station
- Reflectivities

Satellite:
- ATMS
- AMSU-A
- MHS / AMSU-B
- AMVs
- GPS-SOL
- IASI / CrIS / AIRS
- SEVIRI
- HIRS
After the forward model is applied to the grid point value of the NR (perfect obs.), a random contribution is added to the forward model output.

**Error sources**: Measurement, Forward model, Representativeness, Quality control errors …

For instance, observation errors are assumed uncorrelated (as in OPER)

**GOAL**:
The response in the real and simulated system are to appear similar : CALIBRATION
⇒ Verifies the simulated data impact by comparing it to real data impact.

Can we use the same stdev error (sigma O) in DAS-OSSE as defined in DAS-OPER ?
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3. OSSE calibration
Assignment of realistic errors for each obs. type

Configuration of assimilation experiments using simulated observations: sigma O scaling

<table>
<thead>
<tr>
<th></th>
<th>First Guess</th>
<th>Assim. OBS</th>
<th>Boundary condition</th>
<th>Stdev error</th>
</tr>
</thead>
<tbody>
<tr>
<td>REF_OPER</td>
<td>AROME OPER</td>
<td>Real</td>
<td>ARPEGE OPER</td>
<td>AROME OPER * fact_oper</td>
</tr>
<tr>
<td>EXP_sig0.8</td>
<td>ARPEGE NR</td>
<td>Simulation</td>
<td>ARPEGE NR</td>
<td>AROME OPER * fact_0.8</td>
</tr>
<tr>
<td>EXP_sig0.5</td>
<td>ARPEGE NR</td>
<td>Simulation</td>
<td>ARPEGE NR</td>
<td>AROME OPER * fact_0.5</td>
</tr>
<tr>
<td>EXP_sig0.2</td>
<td>ARPEGE NR</td>
<td>Simulation</td>
<td>ARPEGE NR</td>
<td>AROME OPER * fact_0.2</td>
</tr>
</tbody>
</table>

METHOD:
⇒ Analysis increments (not shown)
⇒ comparison of obs-guess & obs-analyse statistics
+ specified stdev modifications if needed

Note:
- conventional data
  fact_oper = 0.8
- satellite data
  fact_oper = 1.15
3. OSSE calibration
Ex: Radiosonde data

**TEMP**

**Stdev Observation - Guess**

**Stdev Observation - Analyse**

Level pressure (hPa)

Perturbation is too large.
Obs. impact is under-estimated.
3. OSSE calibration
Ex: Radiosonde data

TEMP

Stdev Observation - Guess

REF_OPER
EXP_sig0.8
EXP_sig0.5

Stdev Observation - Analyse

REF_OPER
EXP_sig0.8
EXP_sig0.5

Level pressure (hPa)

Perturbation is too small up to 300 hPa. Obs. impact is over-estimated.
3. OSSE calibration
Ex: Radiosonde data

TEMP

Stdev Observation - Guess

REF_OPER
EXP_sig0.8
EXP_sig0.5

Stdev Observation - Analyse

REF_OPER
EXP_sig0.8
EXP_sig0.5

Manual changes of the profile

Level pressure (hPa)
3. OSSE calibration
Ex: Radiance data

AIRS

Stdev Observation - Guess

REF_OPER
EXP_sig0.8
EXP_sig0.5
EXP_sig0.2

Stdev Observation - Analyse

REF_OPER
EXP_sig0.8
EXP_sig0.5
EXP_sig0.2

Channel index

RMS Errors (K)
3. OSSE calibration

Comment

No, we can NOT use the same stdev error (sigma O) in DAS-OSSE as defined in DAS-OPER since they produce too large perturbations.

Statistical properties of \texttt{EXP\_sig0.5} for the OSSE vs the real world assimilation show the best match for each observing system.

⇒ All specified \texttt{sigma O are reduced by 50\%}. Many of them were manually adapted to improve the fit.

This crucial evaluation was performed for the full observing system before to produce the final simulation …
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4. Simulation of observations

Full radiances observing system

Averaged Real Bt observations vs Simulated Bt observations (July 2013)

Channel Index

Brightness Temperature (K)
4. Simulation of observations
Ex: AMSU-A

Maps of AMSU-A channel 5 Bt: observations vs simulations (20 July 2013)
4. Simulation of observations
Preparations for IRS Bt assimilation

Out of the framework of the OSSE, we have conducted non-cycled assimilation experiments of real observations (IASI & SEVIRI) to model the **expected observation errors** for IRS radiances and the **optimal thinning distance**.

1) **Hollingsworth-Lönnberg**

Assumption: Observation errors are spatially uncorrelated and background errors are spatially correlated.

- Spatially uncorrelated variance: Observation error
- Spatially correlated variance: Background error

2) **Desroziers**

\[
\tilde{\mathbf{R}} = E[\mathbf{d}_a \mathbf{d}_b^T]
\]

\[
\mathbf{H} \mathbf{B} \mathbf{H}^T = E[\mathbf{d}_b \mathbf{d}_b^T] - E[\mathbf{d}_a \mathbf{d}_b^T]
\]

Assumption: Because data assimilation follow linear estimation theory, the weight given to the observations in the analysis is in agreement with true observation and background errors + diagnostic of correlation length for the thinning distance

3) **Adapted background error method**

*Bormann and Bauer, 2010*
4. Simulation of observations
Preparations for IRS Bt assimilation: Stdev error estimate

Estimate of observation error amplitude using IASI real data as proxy for IRS

DATA: IASI clear radiances
15 days (01/09-15/09)
Domain: AROME

⇒ IRS std dev error estimate: ~0.4K for T channels and ~0.5/1K for Q channels
4. Simulation of observations
Preparations for IRS Bt assimilation: Thinning distance

Error correlation length using real SEVIRI data as proxy for IRS

\[ R \text{ (obs error correlation function)} \]

\[ HBHt \text{ (bkgd error corr function in obs space)} \]

\[ Lo_{\text{Humidity}} \sim 25 \text{ km} \]

\[ Lb_{\text{Humidity}} \sim 50 \text{ km} \]

Result from the ensemble data assimilation:

\[ Lo = 50 \text{ km et } Lb = 45 \text{ km} \]

\[ \Rightarrow \text{IRS optimal thinning distance: } \sim 30/40 \text{ km} \]
4. Simulation of observations
Preparations for IRS Bt assimilation: Channel selection

Averaged IRS Bt simulated spectrum over the AROME domain

Window

641 Q channels

Ozone

113 T channels
4. Simulation of observations
Preparations for IRS Bt assimilation: Channel selection

Averaged IRS Bt simulated spectrum over the AROME domain

50 Q channels
4. Simulation of observations
IRS Bt simulations

Channel 1038

Brightness temperature

0UTC

6UTC

12UTC

18UTC

Brightness temperature

Brightness temperature

Brightness temperature
4. Simulation of observations
IRS monitoring

Time series of obs-Guess and obs-analyse stdev for 3 WV IRS channels
(Non cycled assimilation experiments)

![Graphs showing time series of observations and errors for three IRS channels.](image-url)
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5. Potential impact of IRS : Assimilation experiments

Configuration

- **REF** = Nature Run
- **CTL** = OSSE
  ~ AROME-OPER with the full simulated observing system
  + Boundary conditions from NR
- **IRS-80km** = CTL + IRS (80 km, 25 Q channels)
- **IRS-15chan** = CTL + IRS (80 km, 15 Q channels)

Additional experiments:

- **IRS-40km** = CTL + IRS (40 km, 25 Q channels)
- **IRS-20km** = CTL + IRS (20 km, 25 Q channels)
- **IRS-25chan** = CTL + IRS (80 km, 25 Q channels)
- **IRS-50chan** = CTL + IRS (80 km, 50 Q channels)
5. Potential impact of IRS
Relative analyse error stdev changes (%)
5. Potential impact of IRS
Relative analyse error stdev changes (%)

**SPECIFIC HUMIDITY**

- **GOOD**
- **BAD**

![Graph showing specific humidity changes with IRS-80km, IRS-40km, and CTL results.](image)

- IRS-80km
- IRS-40km
- CTL

1 day: 22 July 2013
(8 assimilation)
AROME domain
5. Potential impact of IRS
Relative analyse error stdev changes (%)

SPECIFIC HUMIDITY

GOOD

BAD

IRS-80km
IRS-40km
IRS-20km
CTL

-50%
-25%
-15%
5. Potential impact of IRS
Relative analyse error stdev changes (%)

GOOD   TEMPERATURE   BAD

GOOD   U-WIND   BAD

GOOD   V-WIND   BAD

1 day: 22 July 2013
(8 assimilation)
AROME domain

IRS-80km
IRS-40km
IRS-20km
CTL
5. Potential impact of IRS
Relative analyse error stdev changes (%)

SPECIFIC HUMIDITY

GOOD

BAD

IRS-15chan
IRS-25chan
IRS-50chan
CTL
5. Potential impact of IRS
Relative analyse error stdev changes (%)

IROME domain

IRS-15chan
IRS-25chan
IRS-50chan
CTL
Summary and conclusion

- An Observing System Simulation Experiment was implemented at Météo-France to evaluate the **future benefits of MTG-IRS data in a fine-scale AROME forecast model**

- The Nature Run was shown to appear adequately realist with regard to the ARPEGE operational forecast model

- The full observing system (conv+radiances) was simulated from the NR

- Observation errors (perturbation) were tuned to mimic as close as possible, error characteristics of obs. from the real system

- MTG-IRS data were simulated every 3h from the NR. The perturbation has been scaled using diagnosed obs. error from independent real obs assimilation exp. (IASI and SEVIRI)

- Several configurations (channel selection & thinning distances) were defined to evaluate the potential benefits of IRS on atmospheric analysis and forecast.

⇒ **IRS showed strong and systematic positive impacts on the analysis of humidity on top of the whole satellite operational dataset, including IASI & SEVIRI**

⇒ Negative impacts may occur if the density (channels, thinning) of IRS is inadequate …
Limitations and future work

- The Nature Run which define the « true » atmospheric state needs further investigations about the realism of mid-latitude cyclone statistics, cloud amount ...

⇒ Comparison with the ECMWF free-run model run

- An **optimal channel selection** for MTG-IRS data is also highly recommended to select the most informative channels and avoid redundancies and correlations (DFS …). The potential of using PC scores instead of L1 radiance data may also be considered.

- Further development of our OSSE should focus on the **impact of clouds** on simulated Bt and assimilation. This problem was not considered here.

- The use of **different radiative transfer models** for simulation and assimilation may help to understand the error associated to radiances observations.

- These results do not guarantee positive impact MTG-IRS in forecast. Longer time experiments are required for forecast impact.

- Simulated observations require **more realistic observational error**. Further calibration is required to gain the confidence in results.
Future work: observation error correlation

- Neglecting **spatial-error correlations** in the assimilation can lead to sub-optimal analyse if the observation are used too densely (Liu and Rabier, 2003)

- In this work, the perturbation added to radiances simulations was assumed to be uncorrelated.

- Recently, the a posteriori desroziers diagnostic for **inter-channel error correlation** was run on IRS simulated WV data within the framework of this OSSE.

**Result**: Significant inter-channel error correlation were found even if the perturbation added to the observation was not correlated …

\[ r > 0.7 \]
Thank you