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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METEO FRANCE
Toujours un temps d'avance

EUMETSAT

cnrs INSU
Observer & comprendre

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

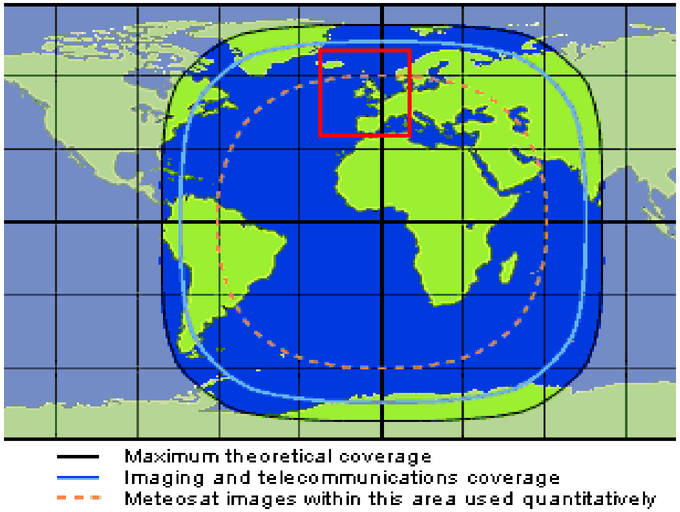
Scheduled for launch in 2018/2020 ?

GEO platform (36000 km)

Full disk coverage / 30 min

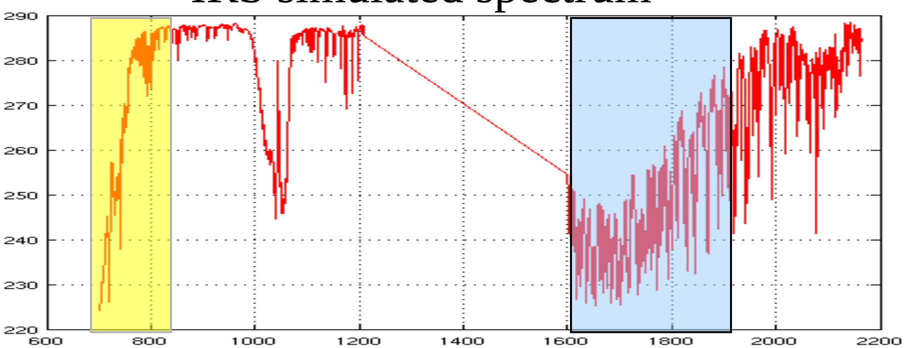
1738 channels

Spec. Res. = 0.625 cm^{-1}



Mission Band	Frequency range (cm^{-1})	Contribution
IRS-1	**700-770**	**CO_2**
IRS-2	770-780	Surface,clouds
IRS-3	980-1070	O_3
IRS-4	1070-1210	Surface,clouds
IRS-6	**1600-2000**	**H_2O**
IRS-7	2000-2175	CO

IRS simulated spectrum



Introduction

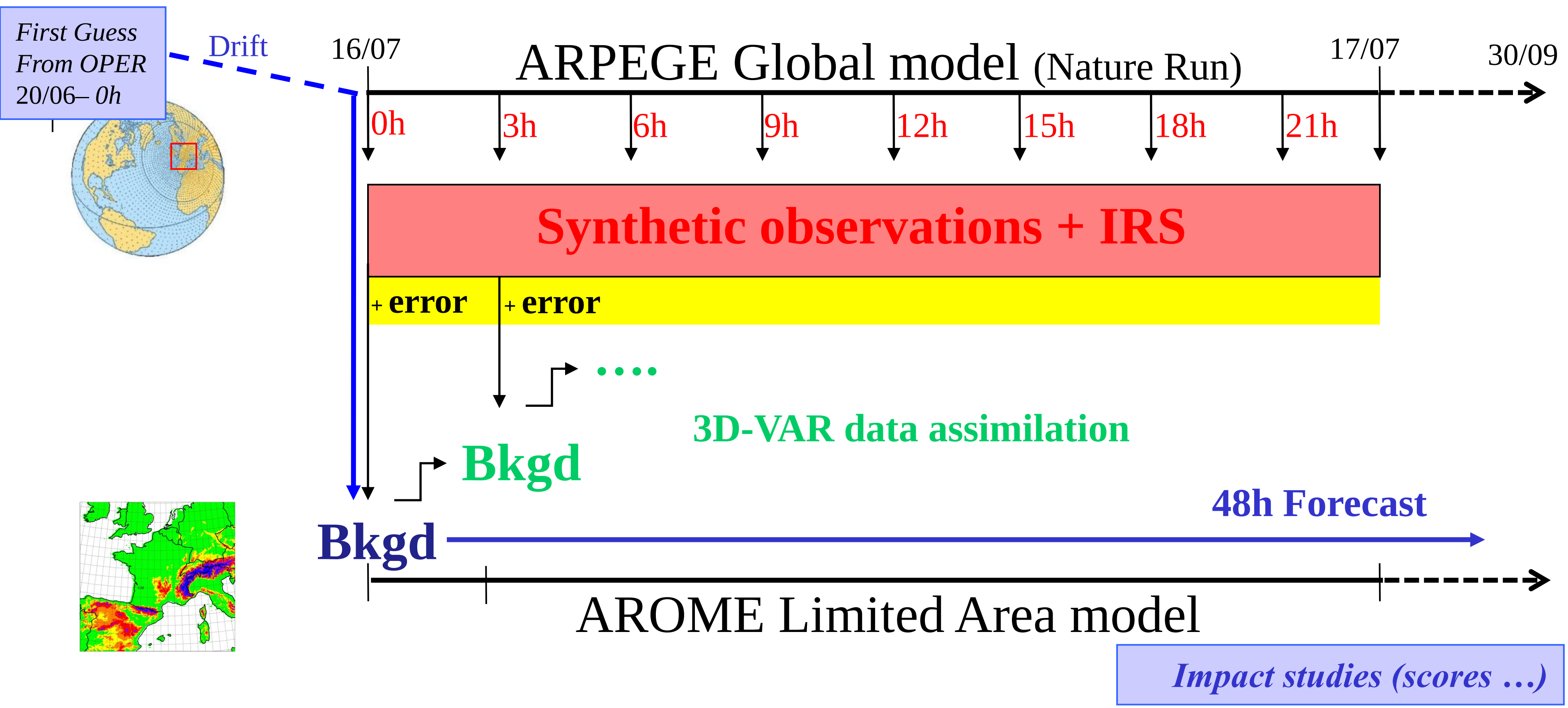
All observations are simulated from free-run forecast produced by a NWP model

These forecasts represent truth and are denoted the « nature run (NR) »

Simulated obs. must mimic as close as possible, error characterics 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



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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

Content

1. The Nature Run Characteristics

High Resolution ARPEGE/IFS Free-Run forecast

Spectral resolution : T1200

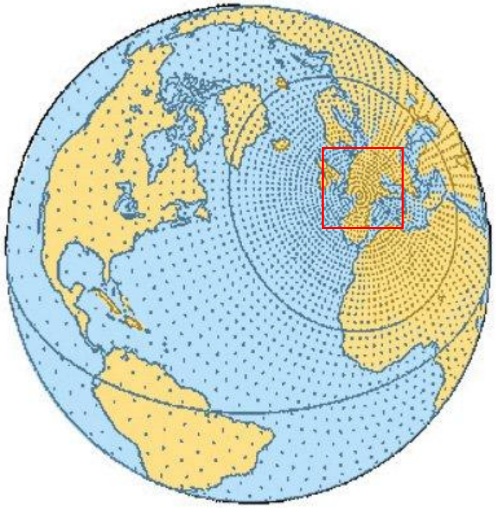
~ 7 km over Europe

Vertical levels: L105

Initial conditions: 20/06/2013 – 0h

Model version : cy38op1

No data assimilation !



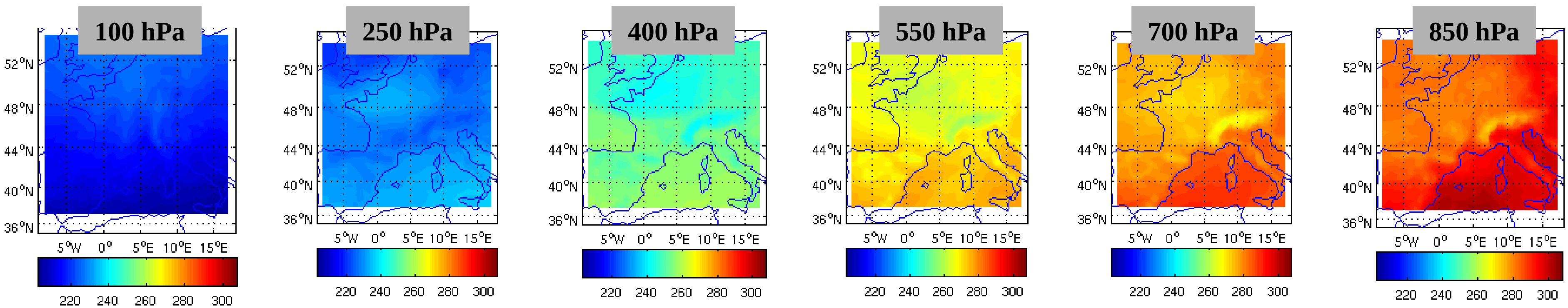
The ARPEGE domain

⇒ Simulated fields are available every hour for both pronostic and diagnostic model fields (3 periods of 3 months)

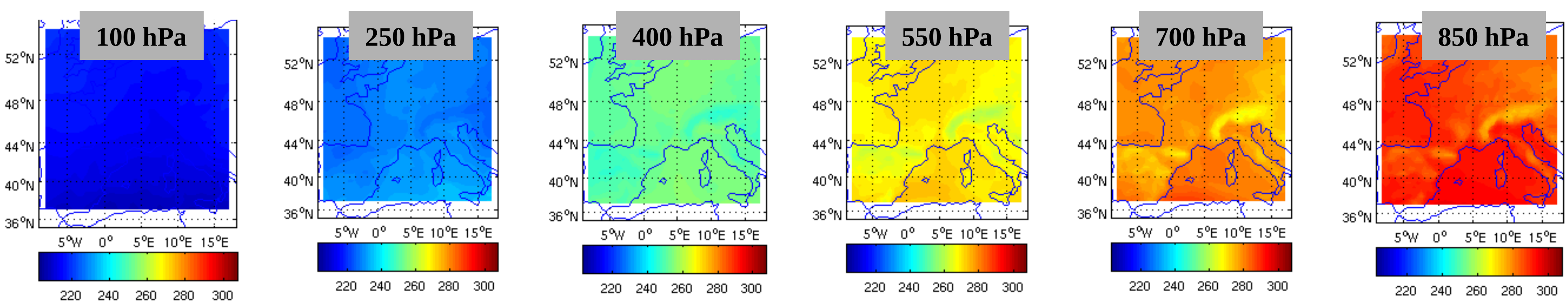
1. The Nature Run
Comparison with ARPEGE OPER

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

Nature Run :

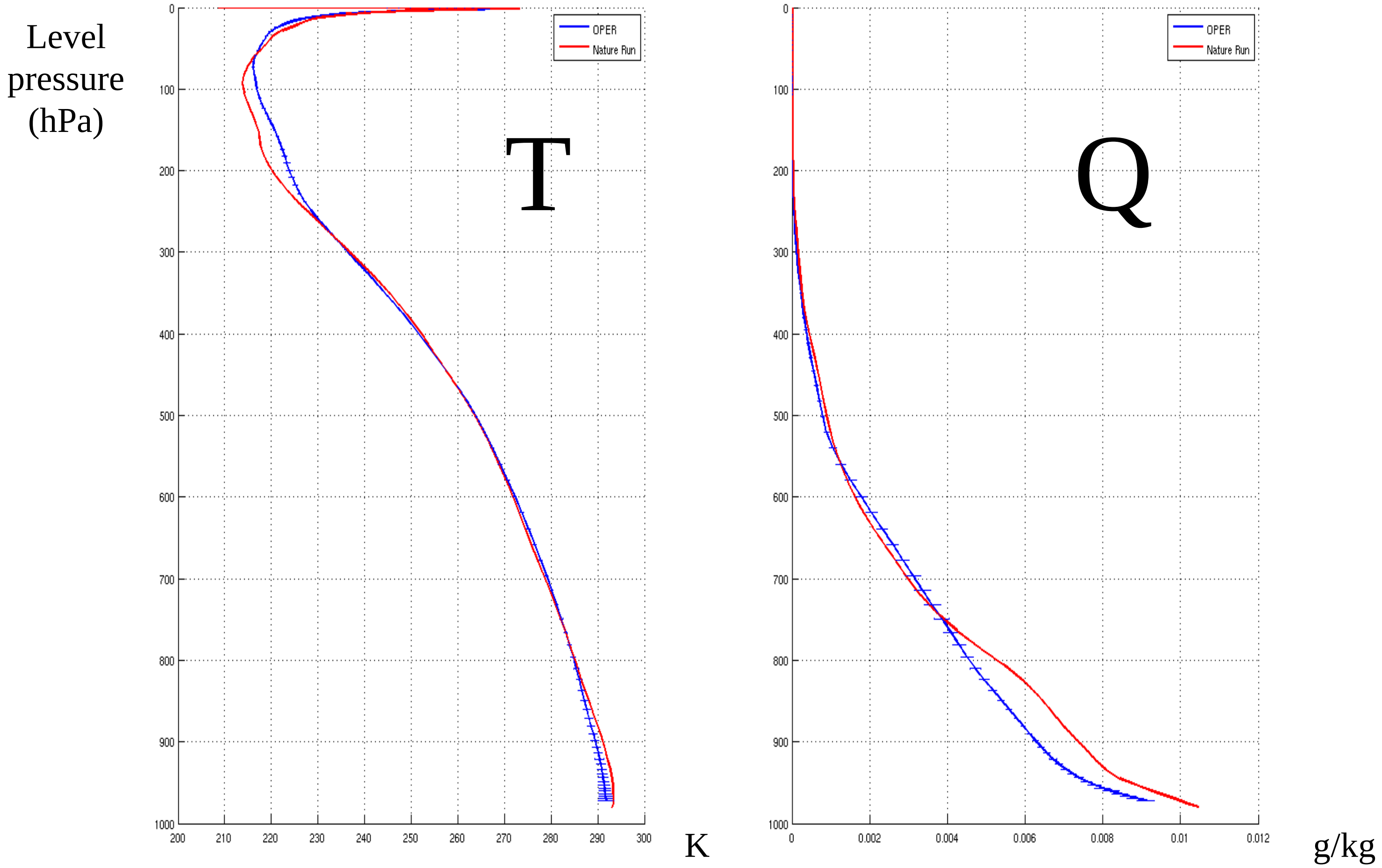


ARPEGE OPER forecast model :



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

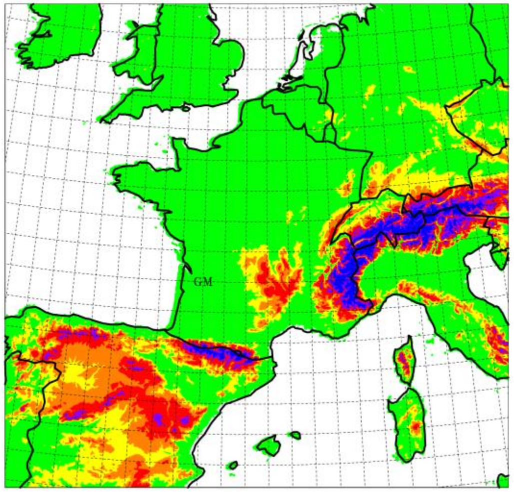
Initial conditions: 15/07/2013 – 0h

Model version : cy38op1

3h-assimilation window

Coupling (1h) : Nature Run

Assimilation of the full atmospheric observing system (+ IRS) !

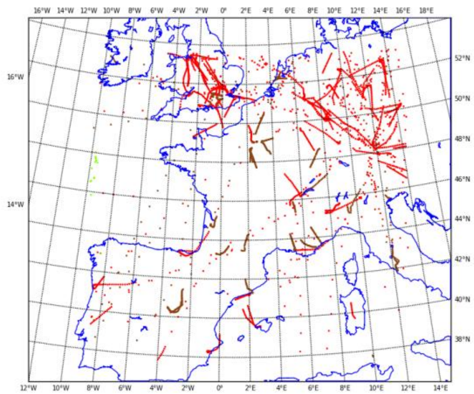


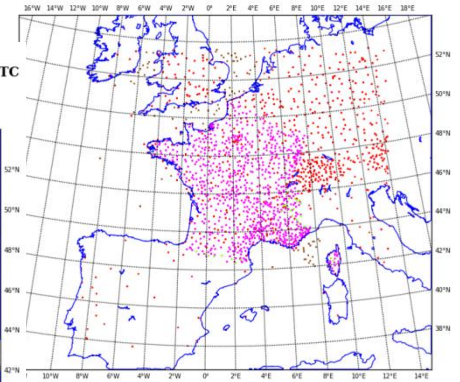
The AROME domain

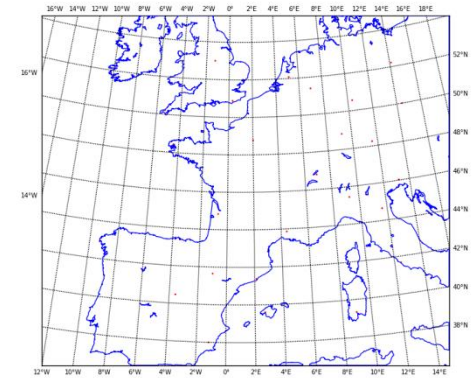
2. The 3D-Var data assimilation system
The operational observing system

Conventional :

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

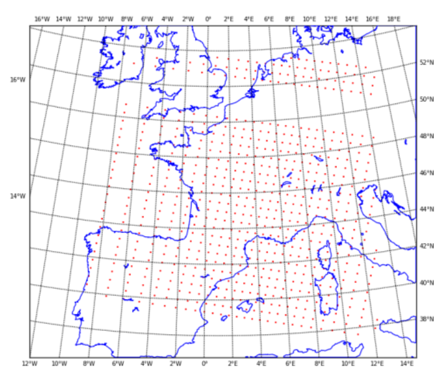


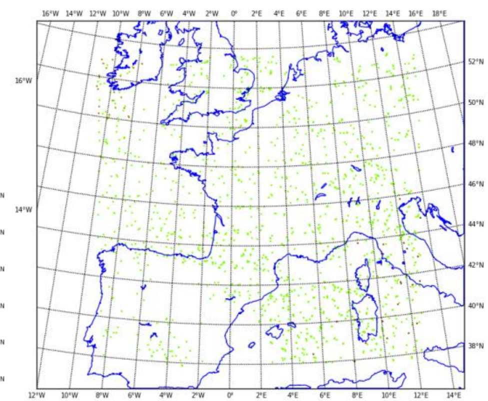


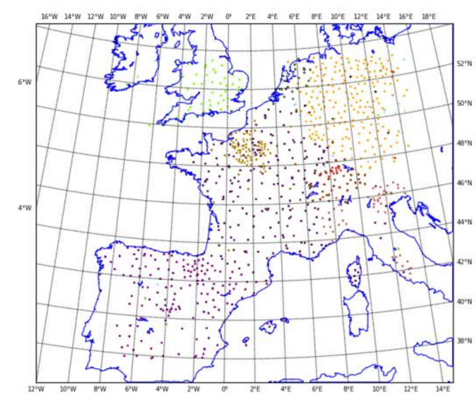


Satellite :

- ATMS
- AMSU-A
- MHS / AMSU-B
- AMVs
- GPS-SOL
- IASI / CrIS / AIRS
- SEVIRI
- HIRS







2. The 3D-Var data assimilation system
Simulation of realistic observations

Nature Run (T,Q,u,v,P …) → Forward model → Perfect observations + ERROR

Forward model: 3D-linear interpolation (+ RTTOV)

After the foreward model is applied to the grid point value of the NR (perfect obs.), a random contribution is added to the forward model output.

<u>Error sources</u> : 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 ?

Content

3. OSSE calibration
Assignment of realistic errors for each obs. type

Configuration of assimilation experiments using simulated observations :
sigma O scaling

	First Guess	Assim. OBS	Boundary condition	Stdev error
REF_OPER	**AROME OPER**	Real	**ARPEGE OPER**	AROME OPER * fact_oper
EXP_sig0.8	ARPEGE NR	Simulation	ARPEGE NR	AROME OPER * fact_0.8
EXP_sig0.5	ARPEGE NR	Simulation	ARPEGE NR	AROME OPER * fact_0.5
EXP_sig0.2	ARPEGE NR	Simulation	ARPEGE NR	AROME OPER * fact_0.2

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

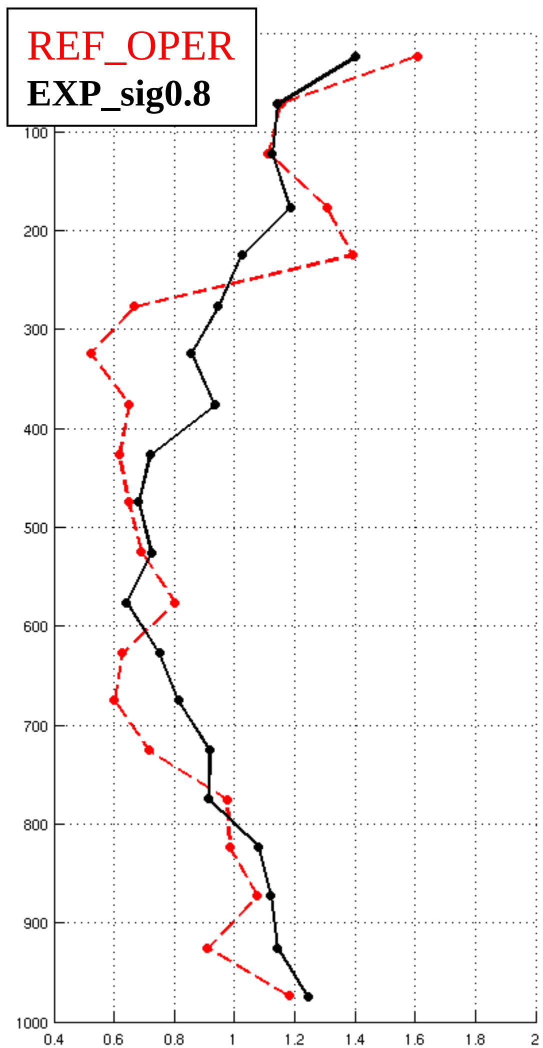
13 days : July 2013
(104 assimilation)
~ 2000 obs/levels
AROME domain

3. OSSE calibration
Ex : Radiosonde data

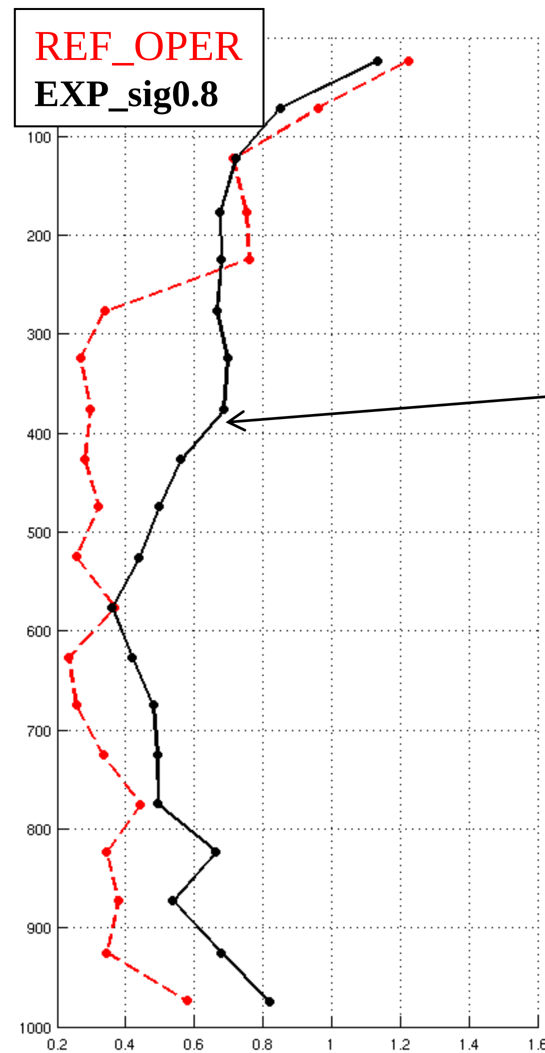
TEMP

Level
pressure
(hPa)

Stdev Observation - Guess



Stdev Observation - Analyse



Perturbation is too
large.
Obs. impact is
under-estimated

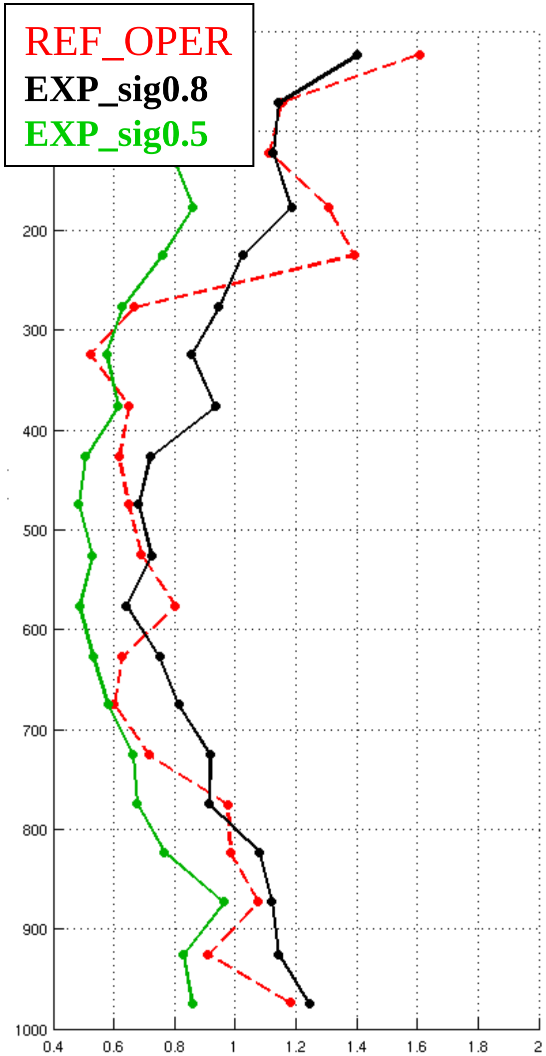
3. OSSE calibration
Ex : Radiosonde data

13 days : July 2013
(104 assimilation)
~ 2000 obs/levels
AROME domain

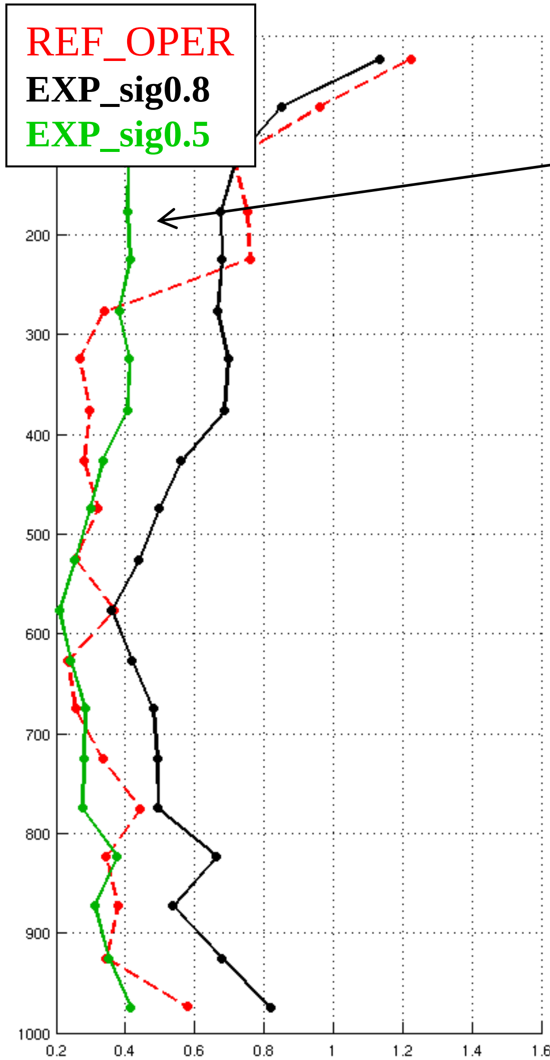
TEMP

Level pressure (hPa)

Stdev Observation - Guess



Stdev Observation - Analyse



Perturbation is too small up to 300 hPa.
Obs. impact is over-estimated

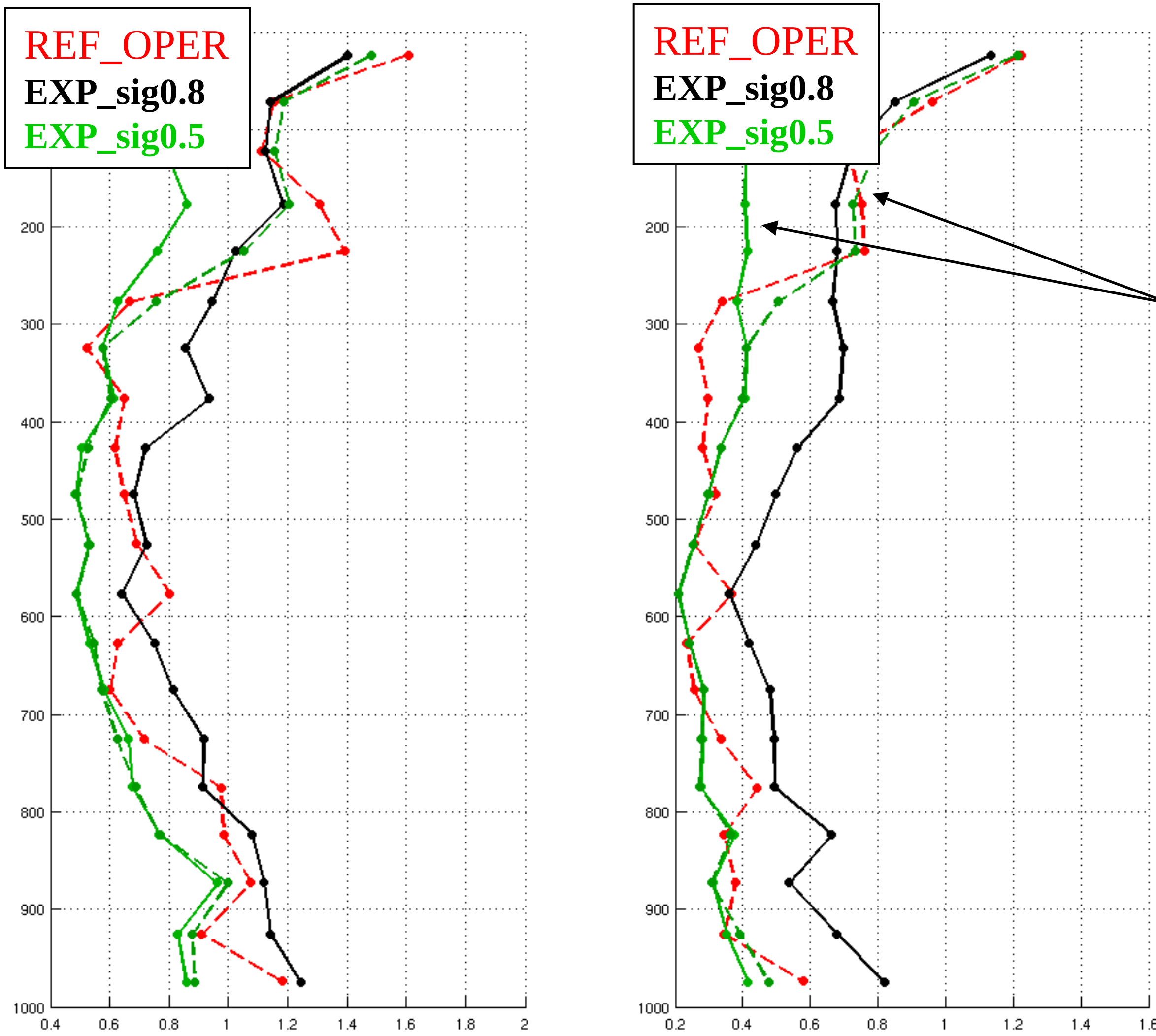
13 days : July 2013
(104 assimilation)
~ 2000 obs/levels
AROME domain

3. OSSE calibration
Ex : Radiosonde data

TEMP

Stdev Observation - Guess

Stdev Observation - Analyse



Level pressure (hPa)

Manual changes of the profile

3. OSSE calibration

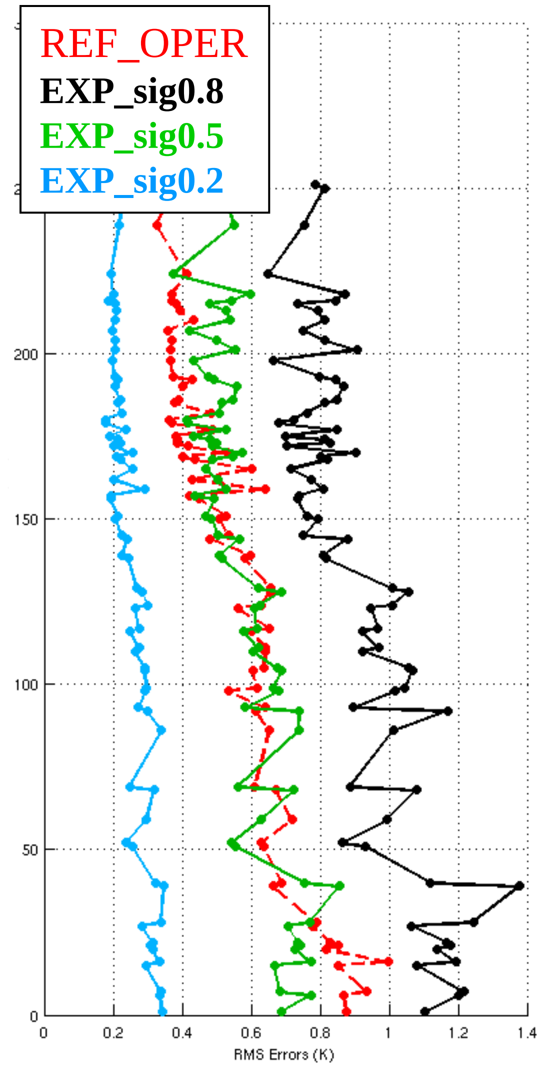
Ex : Radiance data

13 days : July 2013
(104 assimilation)
AROME domain

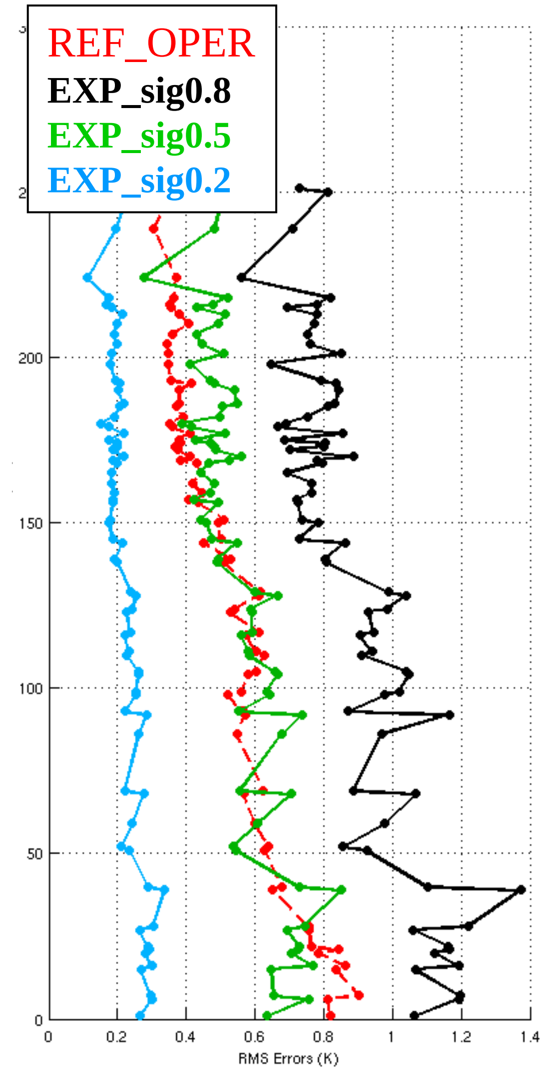
AIRS

Channel index

Stdev Observation - Guess



Stdev Observation - Analyse



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 **EXP_sig0.5** for the OSSE vs the real world assimilation show the best match for each observing system.

⇒ All specified **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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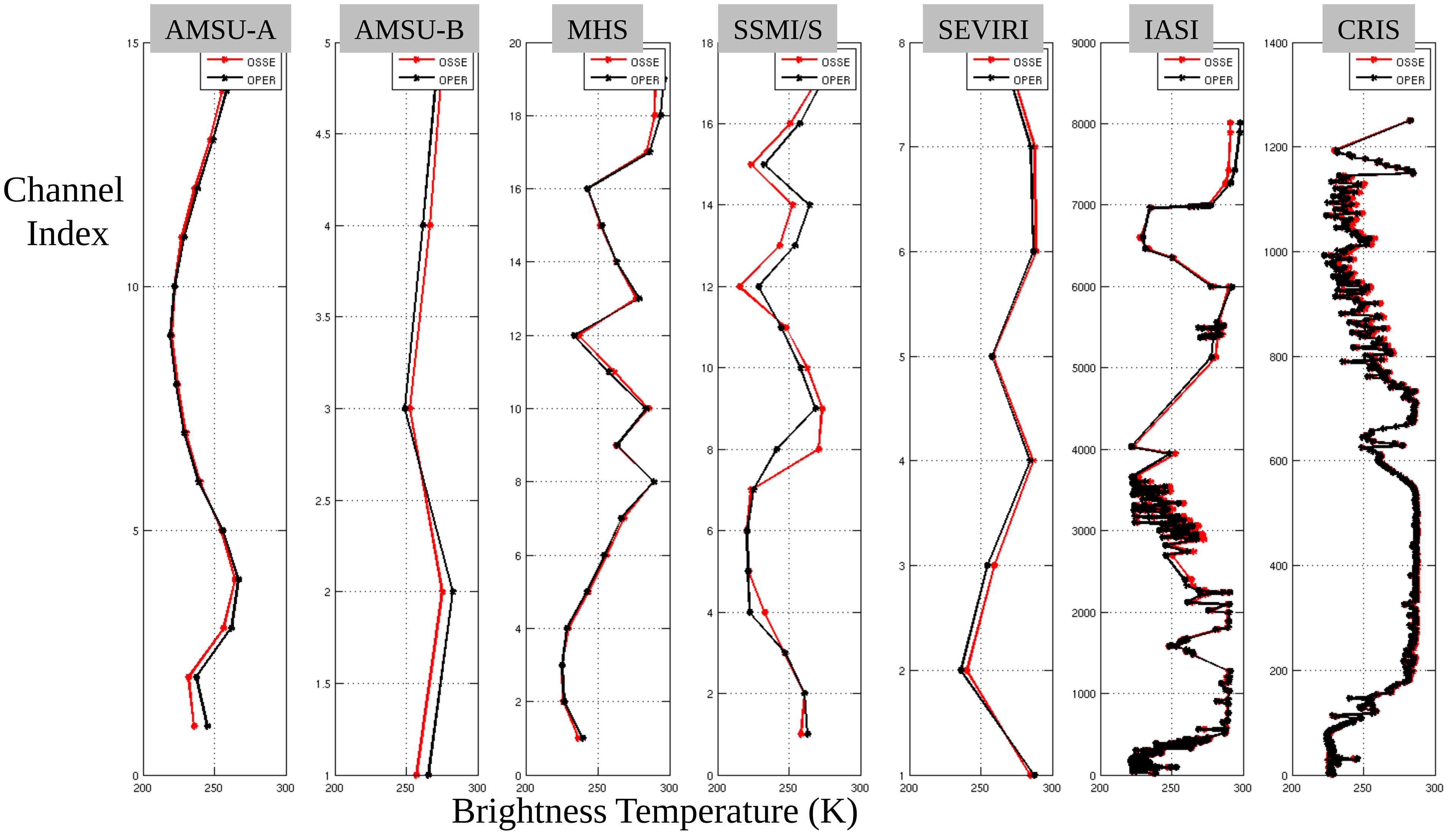
4. **Simulation of observations**
5. Potential impact of IRS : Assimilation experiments

Conclusion, limitations and future work

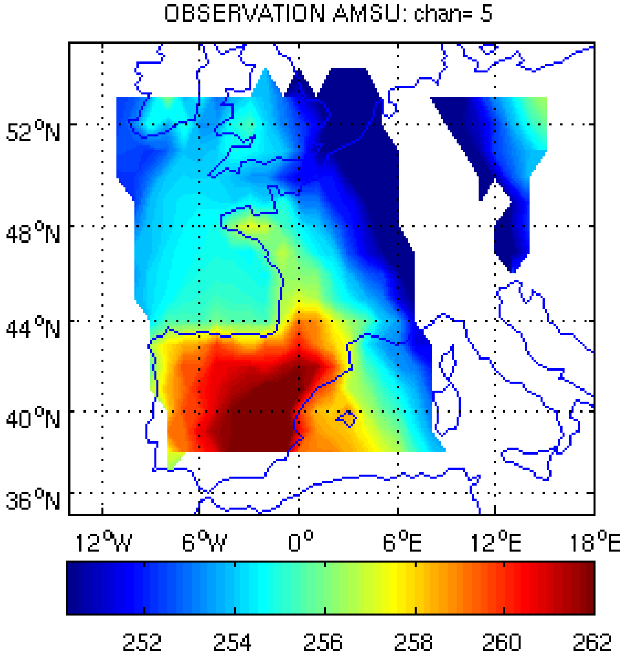
4. Simulation of observations
Full radiances observing system

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

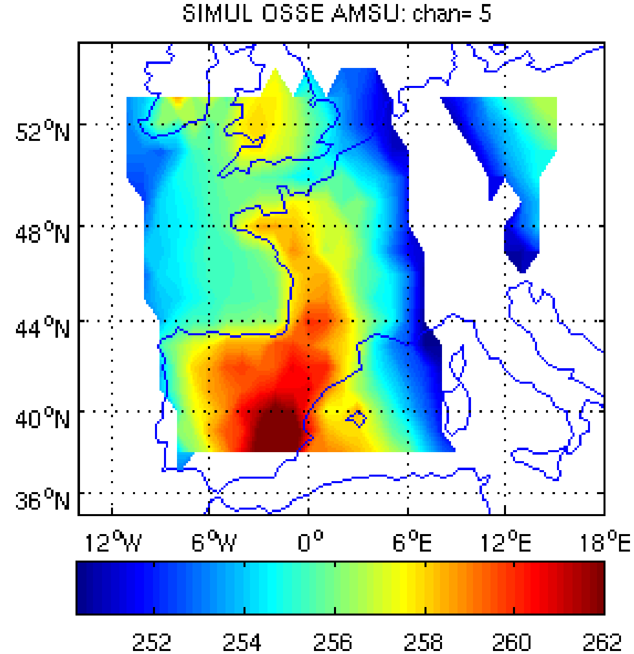


4. Simulation of observations
Ex : AMSU-A

Maps of AMSU-A channel 5 Bt : observations vs simulations (20 July 2013)



Brightness temperature

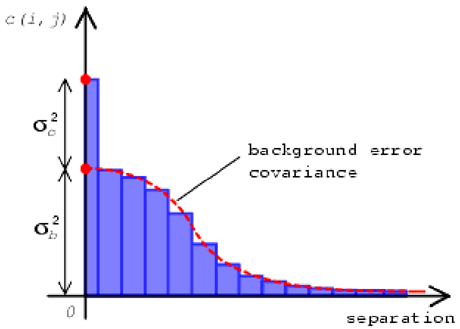


Brightness temperature

4. Simulation of observations
Preparations for IRS Bt assimilation

Out of the framework of the OSSE, we have conduced 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

$$\tilde{\mathbf{R}} = E\left[\mathbf{d}_a\,\mathbf{d}_b^T\right]$$

$$\mathbf{H}\tilde{\mathbf{B}}\mathbf{H}^T = E\left[\mathbf{d}_b\,\mathbf{d}_b^T\right] - E\left[\mathbf{d}_a\,\mathbf{d}_b^T\right]$$

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

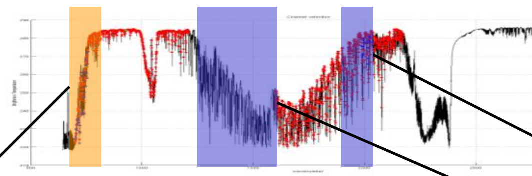
Bormann and Bauer ,2010

4. Simulation of observations

Preparations for IRS Bt assimilation : Stdev error estimate

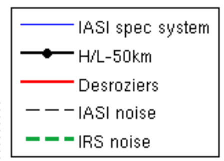
Estimate of observation error amplitude using IASI real data as proxy for IRS

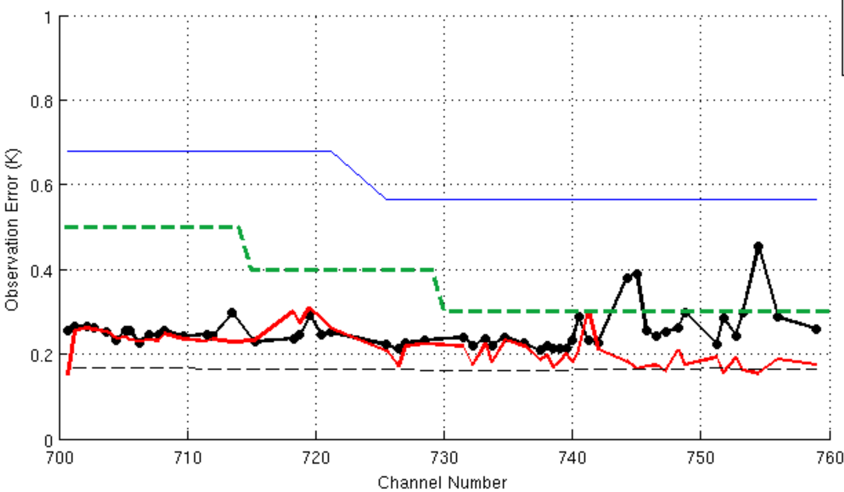
DATA: IASI clear radiances
15 days (01/09-15/09)
Domain: AROME

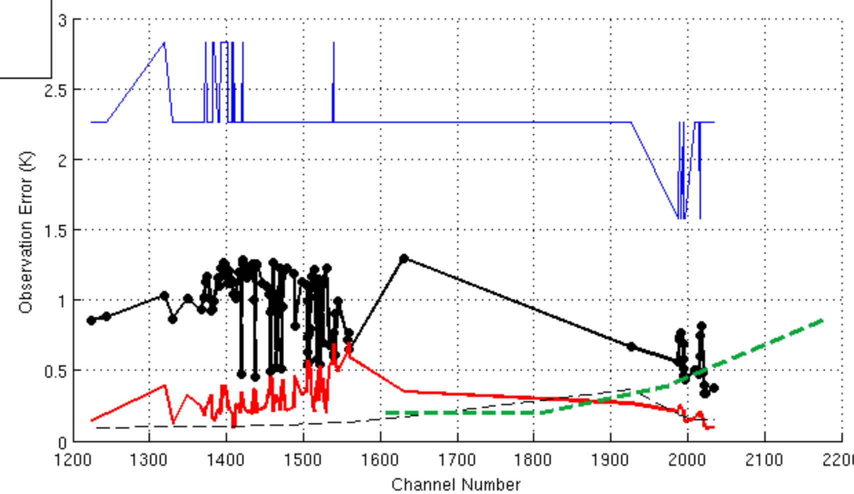


55 T channels

96 + 20 Q channels







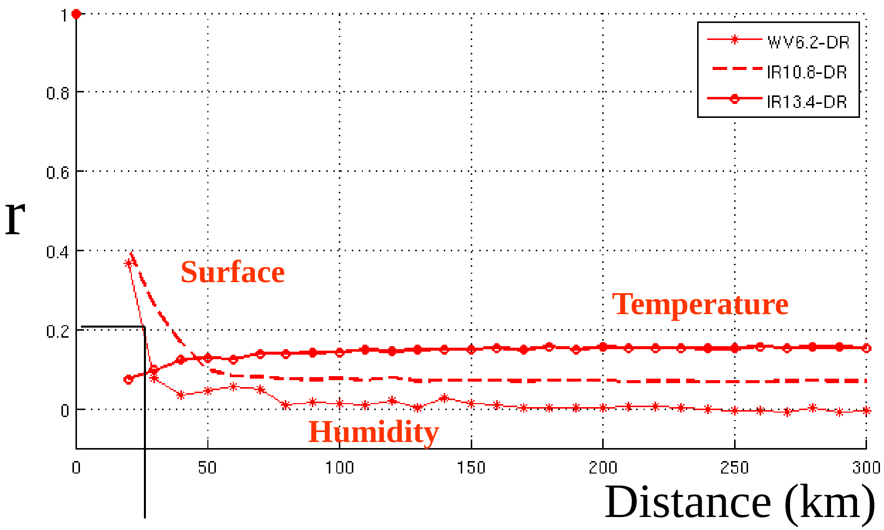
⇒ IRS stdev error estimate : ~0.4K for T channels and ~0.5/1K for Q channels

4. Simulation of observations

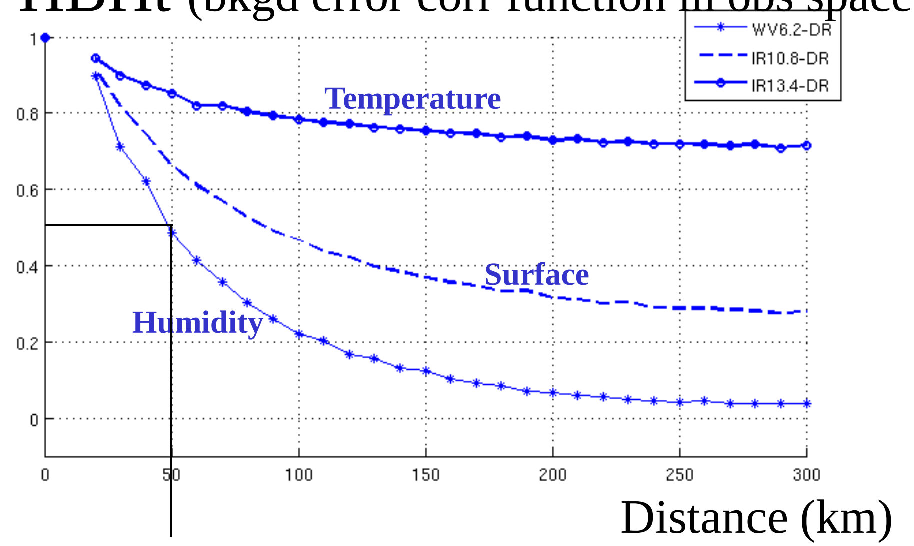
Preparations for IRS Bt assimilation : Thinning distance

Error correlation length using real SEVIRI data as proxy for IRS

R (obs error correlation function)



HBHt (bkgd error corr function in obs space)



Lo $_{\text{Humidity}}$ ~ 25 km

Lb $_{\text{Humidity}}$ ~ 50 km

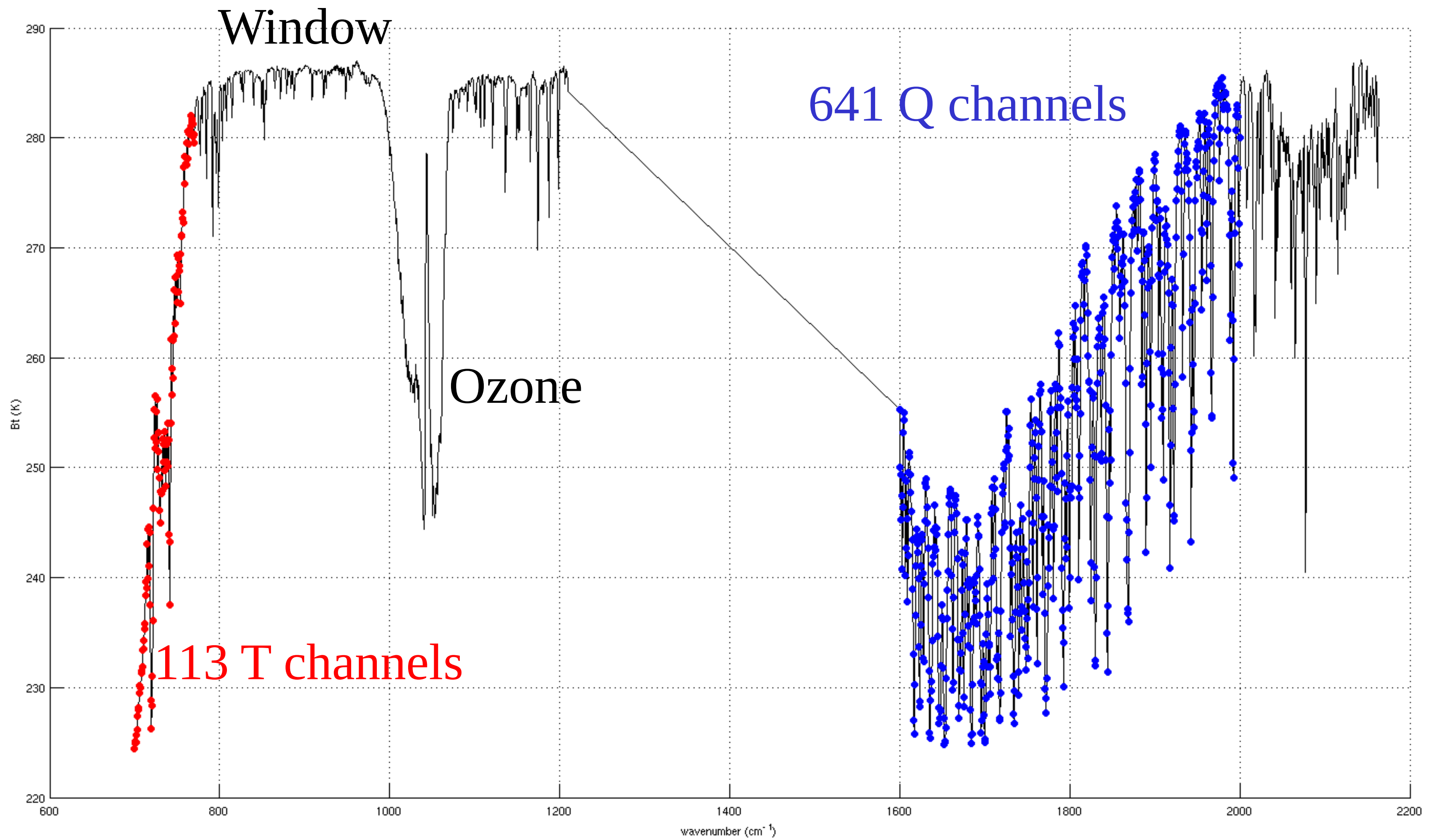
Result from the ensemble data assimilation :

Lo = 50 km et Lb = 45 km

⇒ IRS optimal thinning distance : ~ 30/40 km

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

Averaged IRS Bt simulated spectrum over the AROME domain



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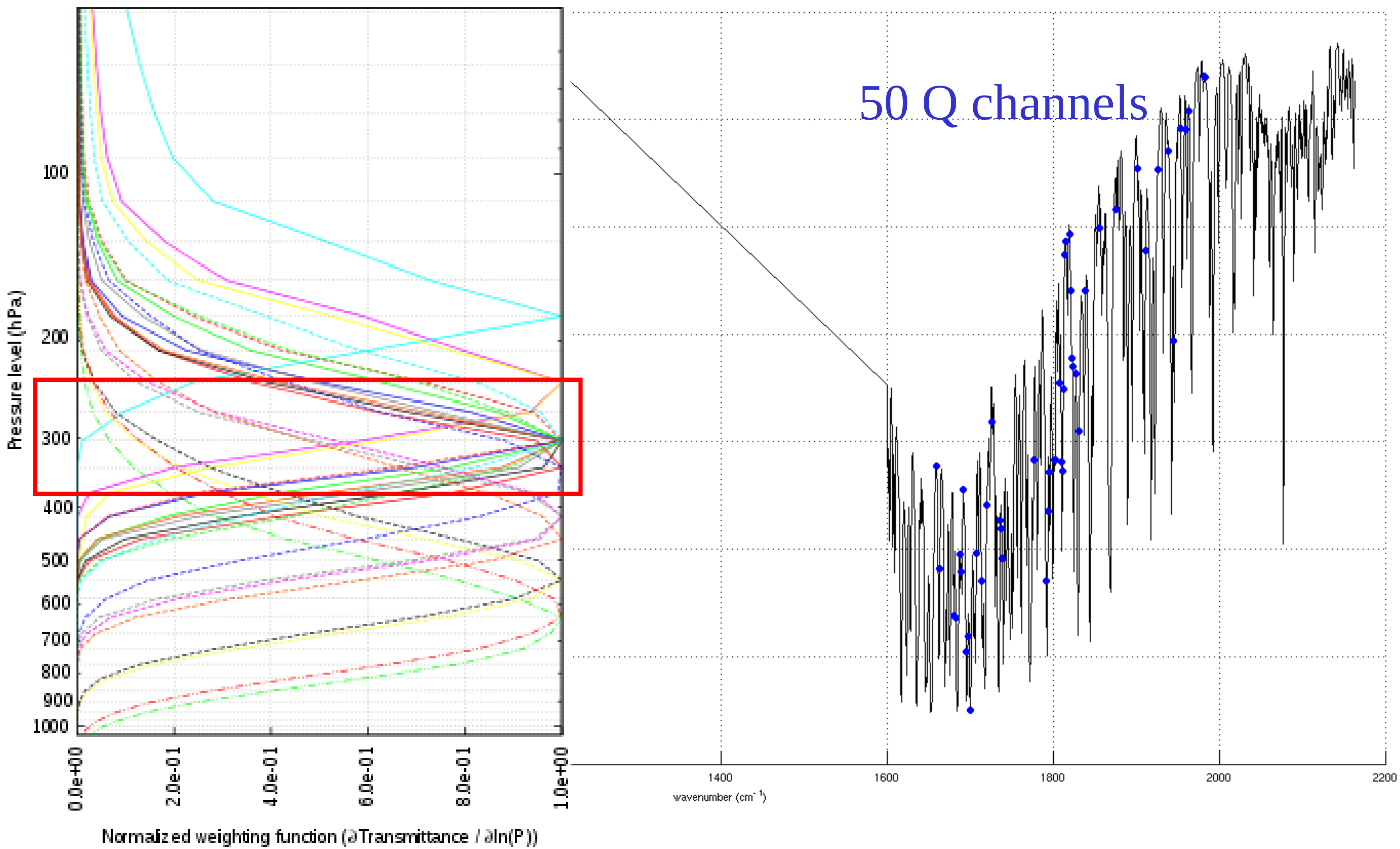
Preparations for IRS Bt assimilation : Channel selection

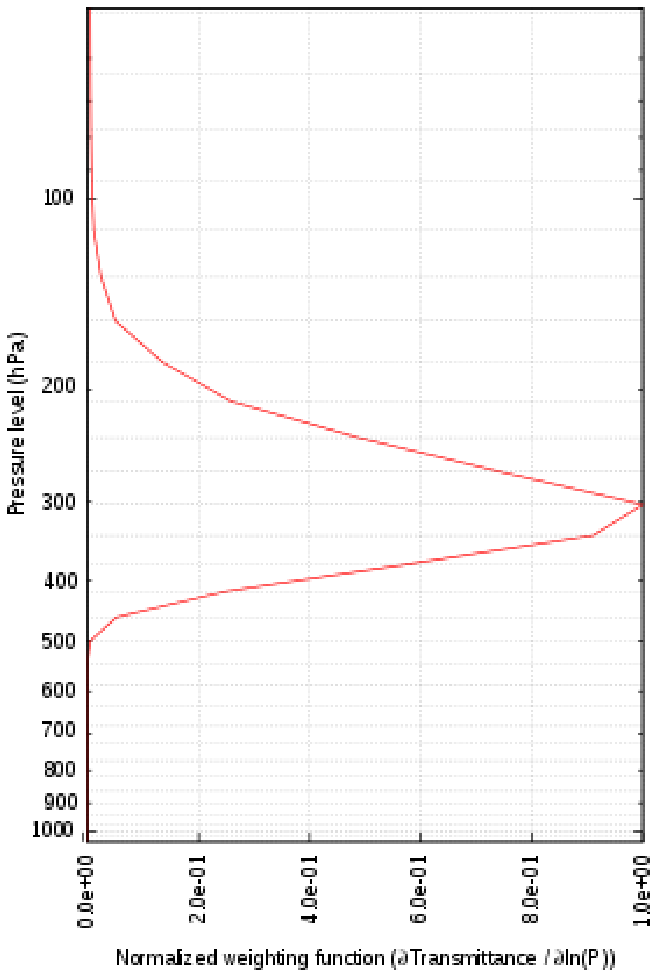
Averaged IRS Bt simulated spectrum over the AROME domain

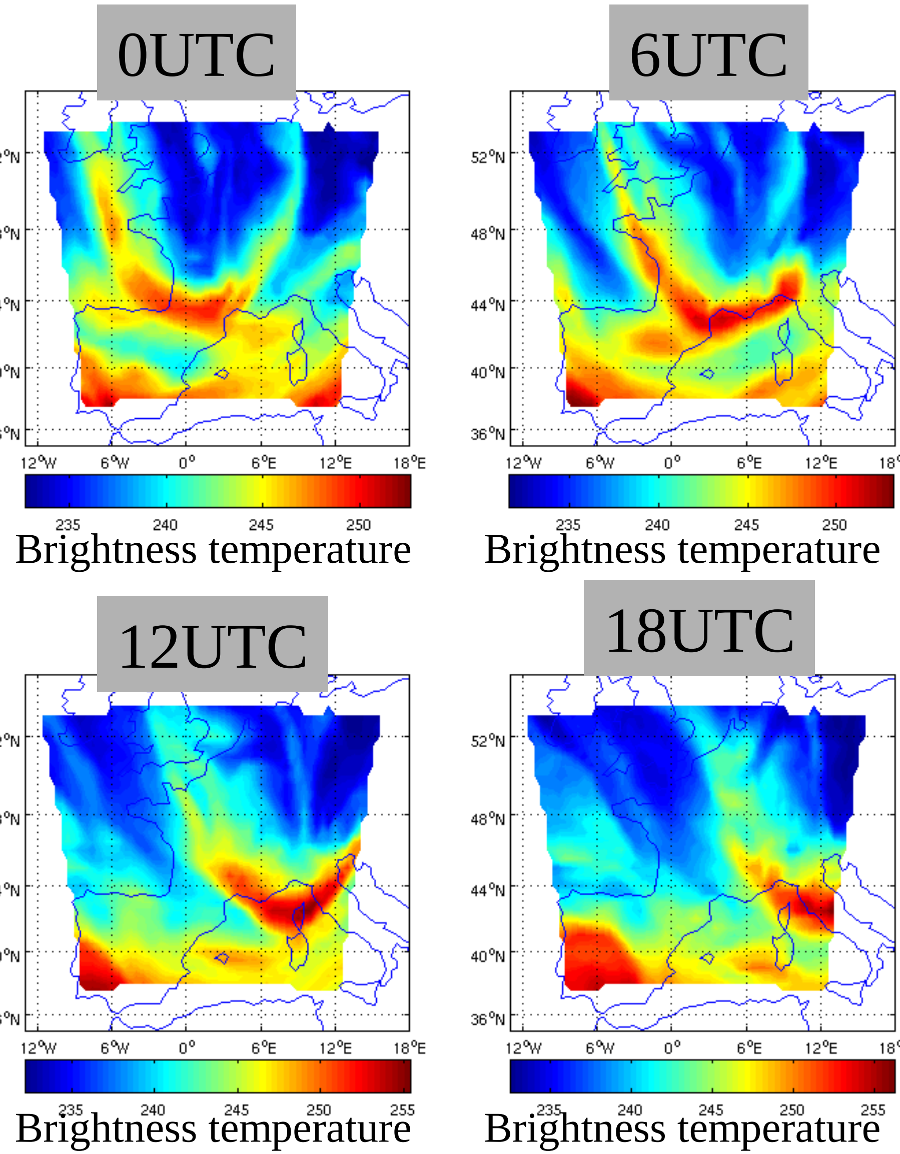


4. Simulation of observations

IRS Bt simulations

Channel 1038





4. Simulation of observations
IRS monitoring

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

obs-guess
obs-analyse
Specified sigma 0

Stdev
Error (K)

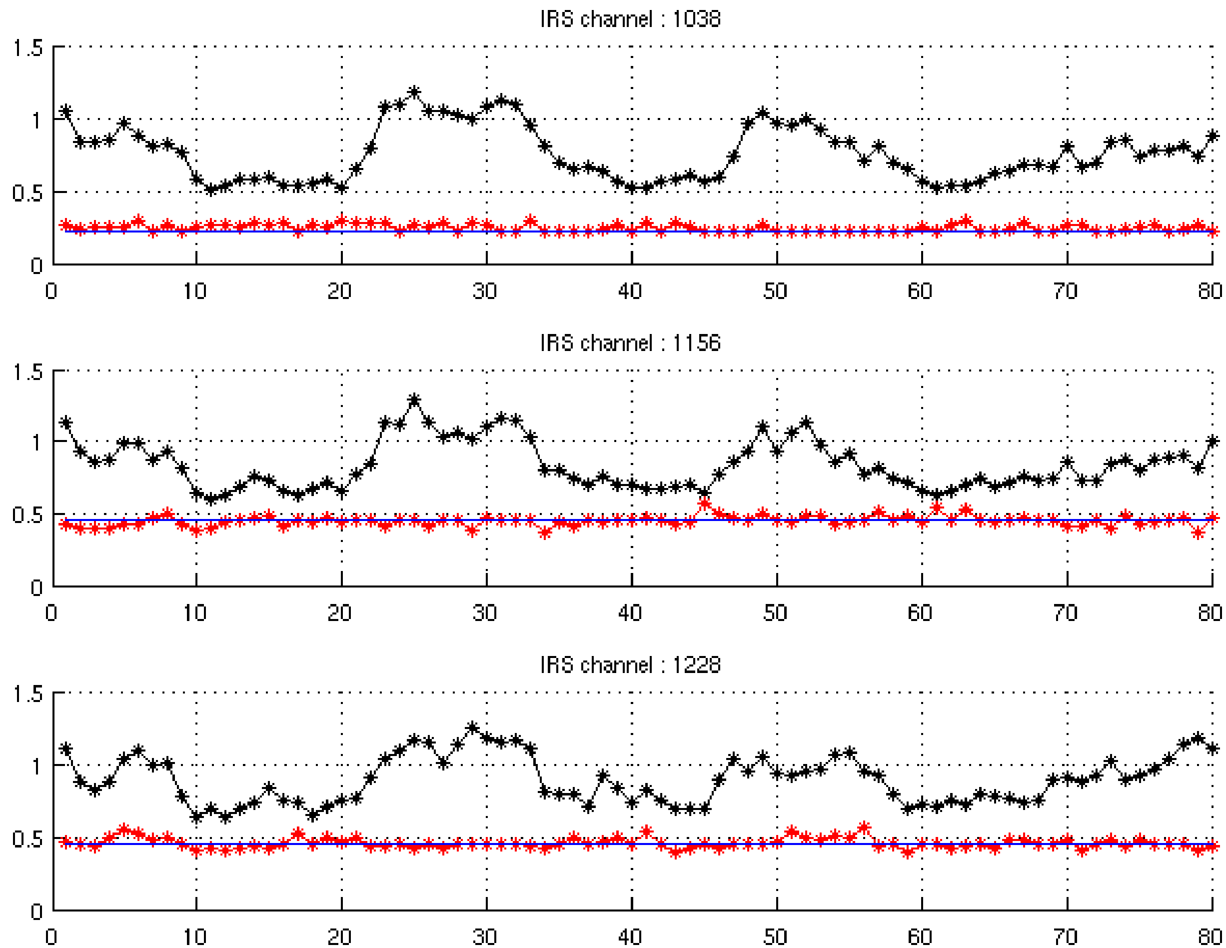
Time (every 3h)

Stdev
error

Time

Stdev
error

Time



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5. **Potential impact of IRS : Assimilation experiments**

Conclusion, limitations and future work

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)

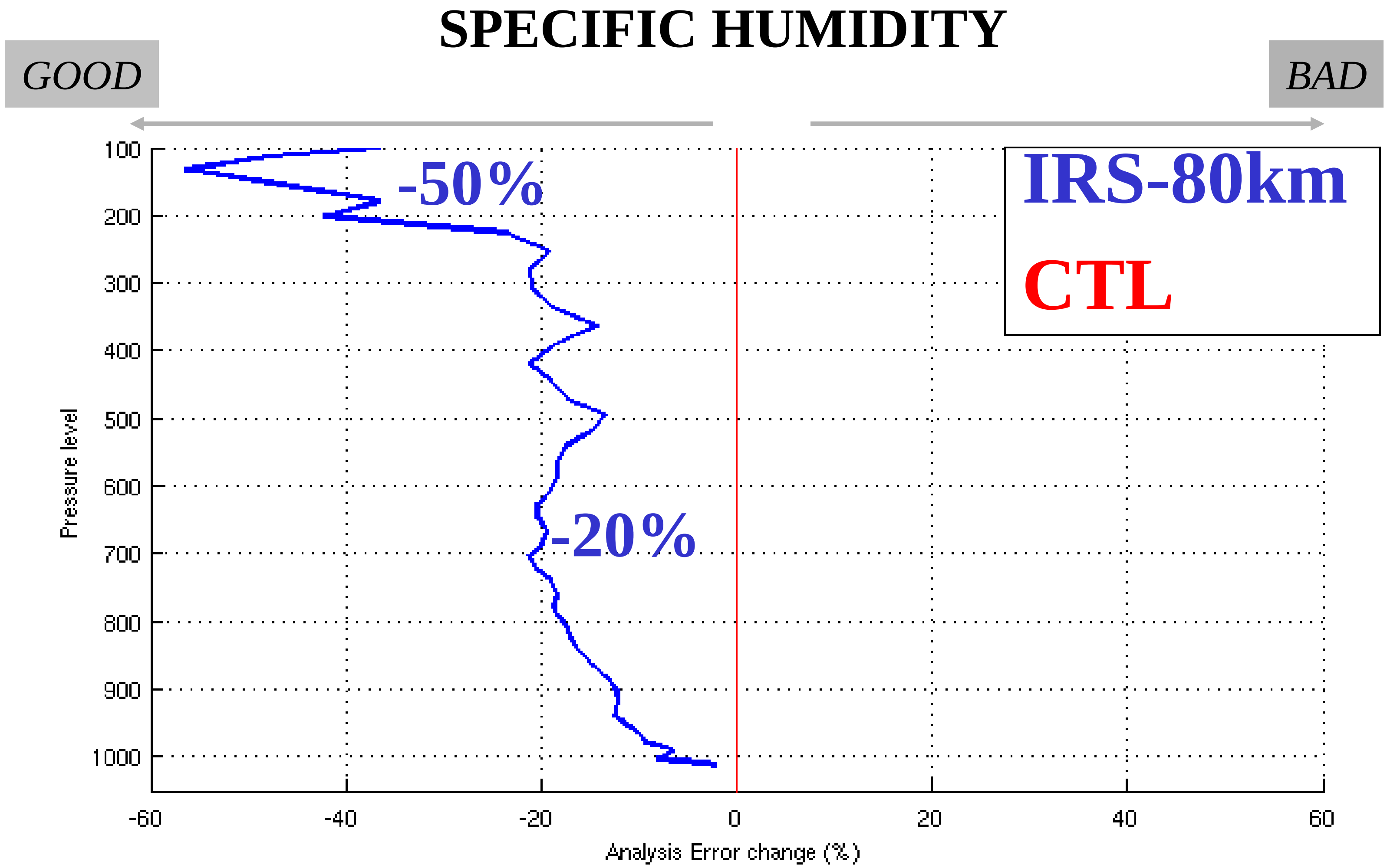
Additional experiments :

- **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**)

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

5. Potential impact of IRS
Relative analyse error stdev changes (%)



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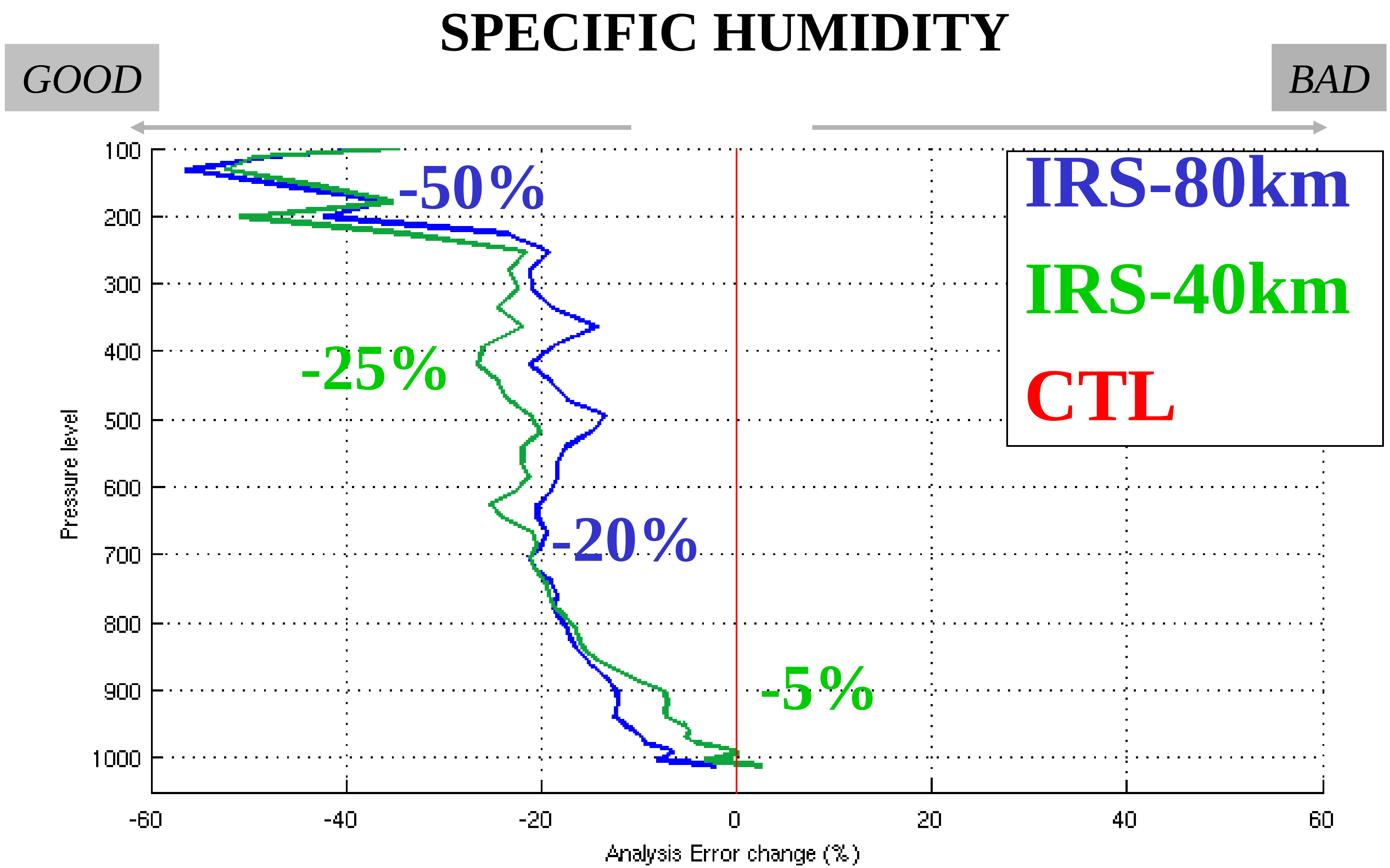
Relative analyse error stdev changes (%)



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1 day : 22 July 2013
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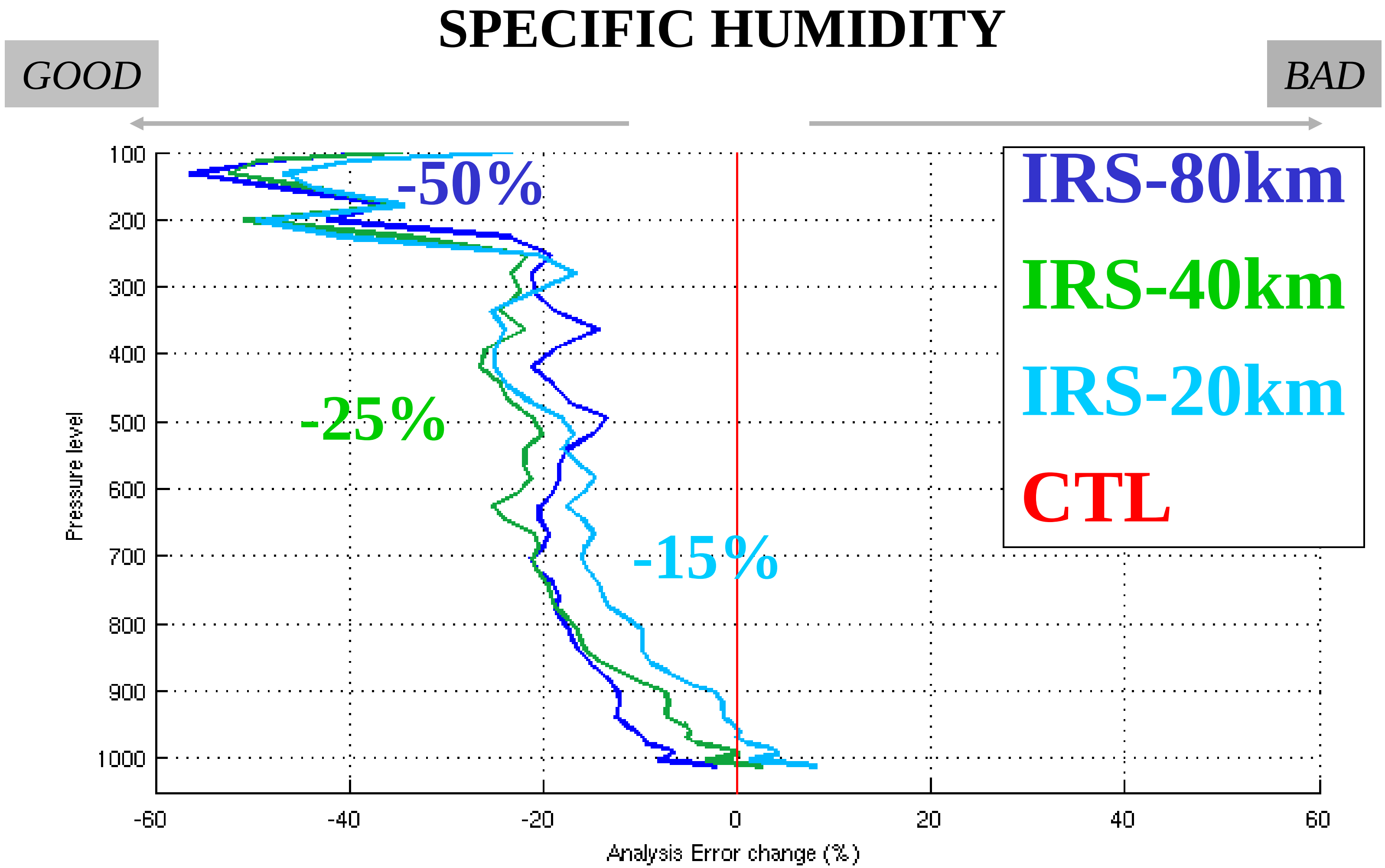
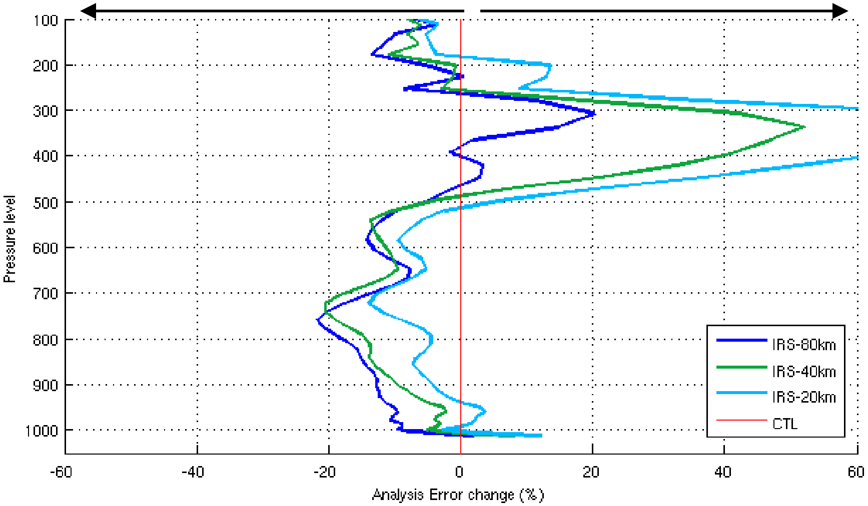
AROME domain



5. Potential impact of IRS
Relative analyse error stdev changes (%)

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

GOOD **TEMPERATURE** *BAD*



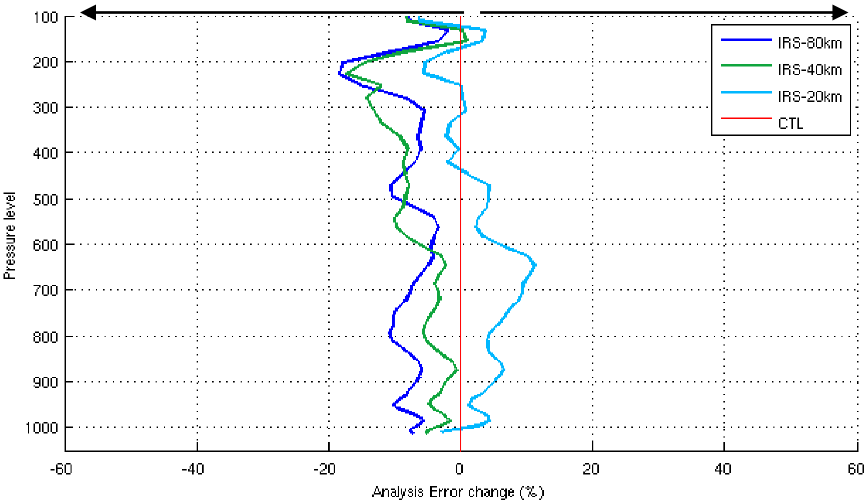
IRS-80km

IRS-40km

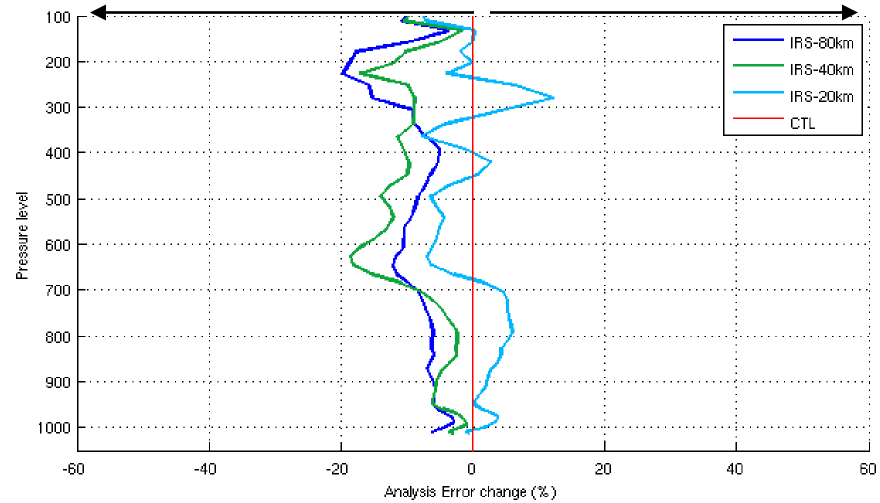
IRS-20km

CTL

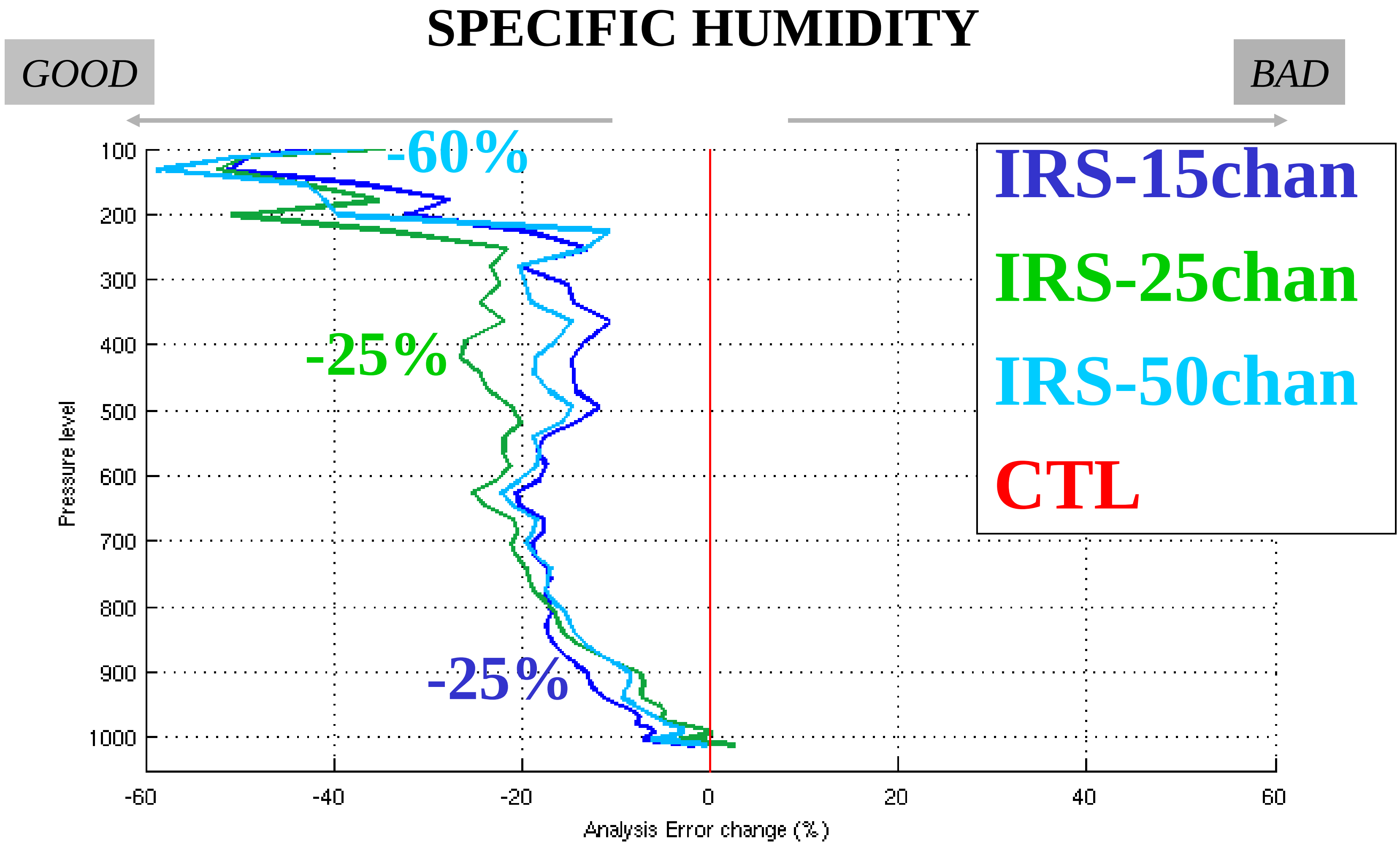
GOOD **U-WIND** *BAD*



GOOD **V-WIND** *BAD*

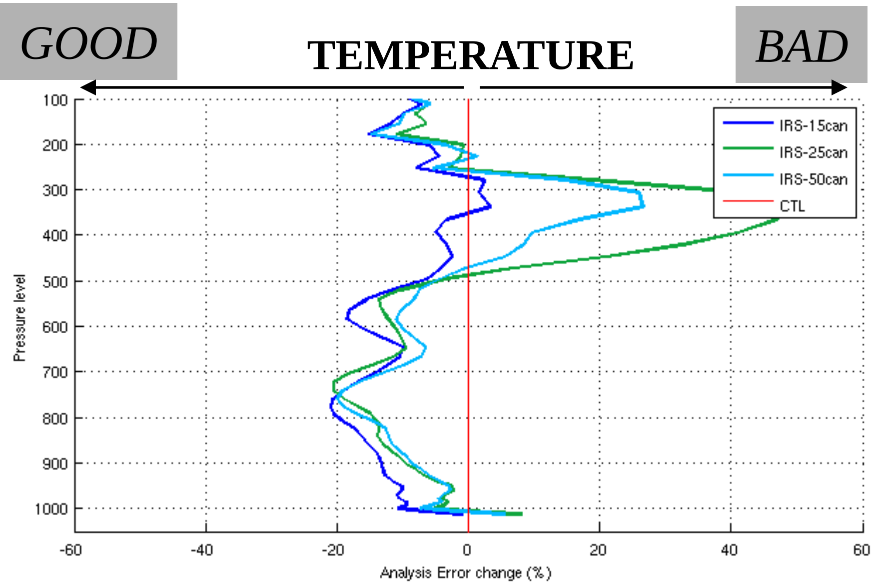


5. Potential impact of IRS
Relative analyse error stdev changes (%)



5. Potential impact of IRS
Relative analyse error stdev changes (%)

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

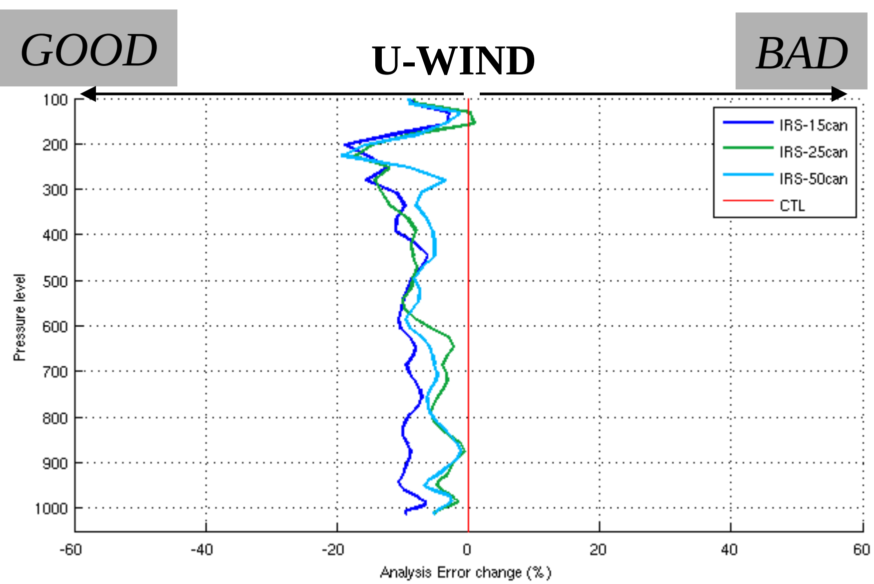


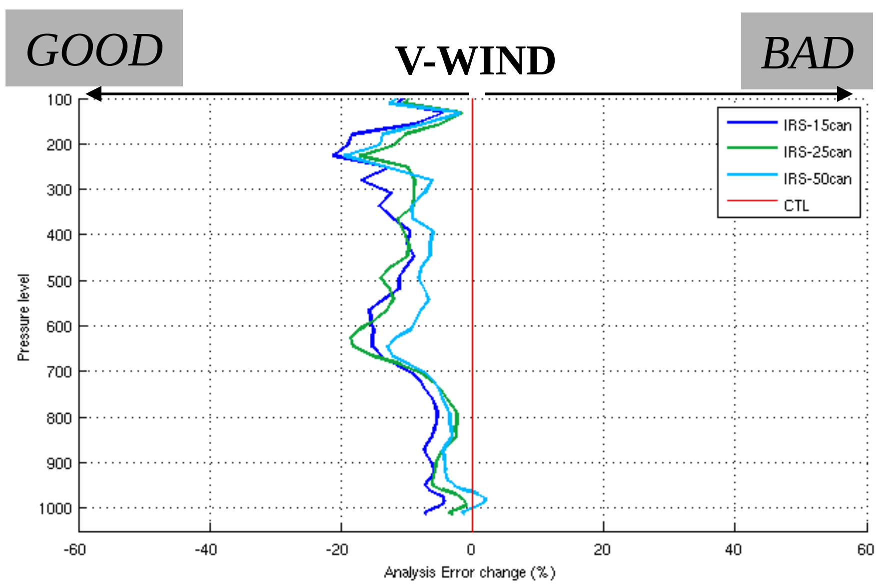
IRS-15chan

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 higthly recommanded to select the most informative channels and avoid redondancies 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

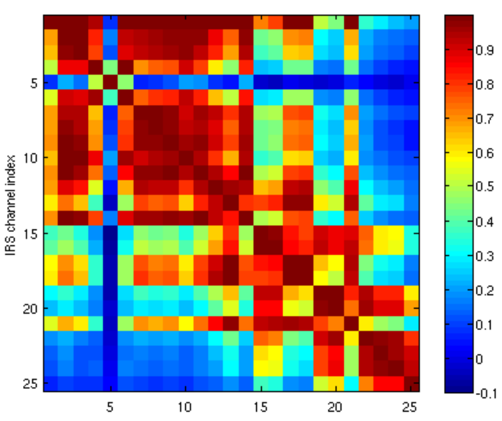
- Neglecting **spatial-error correlations** in the assimilation can lead to sub-optimal analyse if the observation are used too densely (Liu and Rabier, 2003)

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

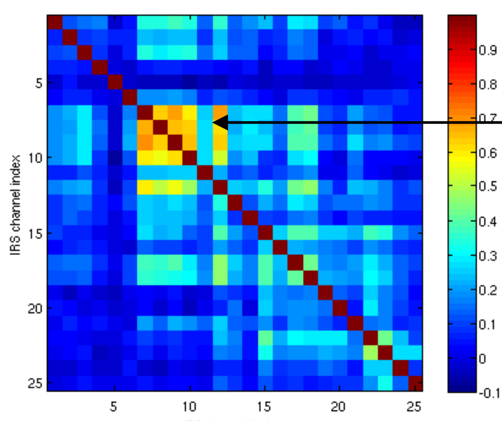
- Recently, the a posteriori desroziers diagnostic for **inter-channel error correlation** was run on IRS simulated WV data within the framework of this OSSE.

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

B corr matrix

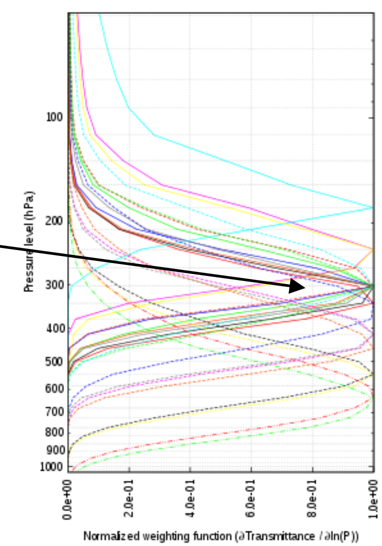


R corr matrix



r > 0.7

?



Thank you