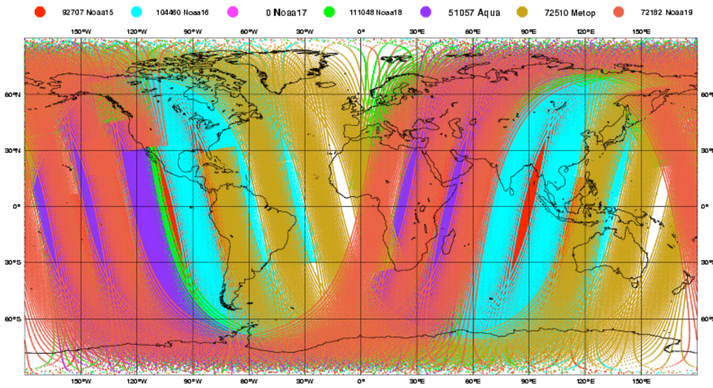
# Retrieval of water vapour atmospheric profiles from microwave observations

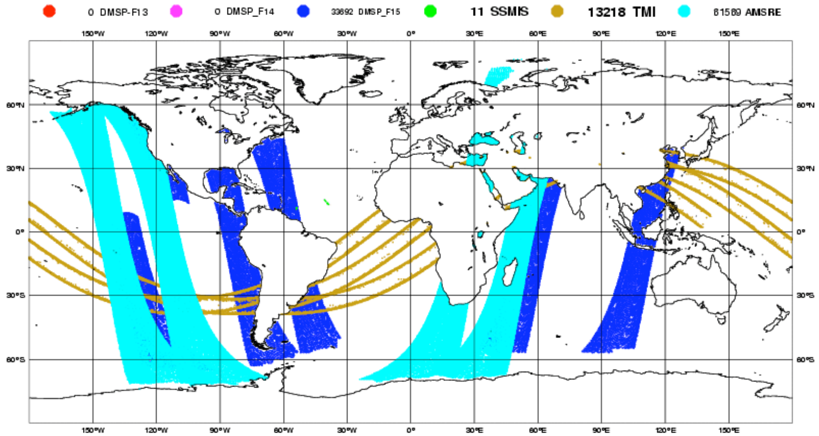
Filipe Aires, Frédéric Bernardo
Estellus
and Catherine Prigent
Lerma, Observatoire de Paris

# Example of 6-hourly satellite data coverage

## LEO Sounders

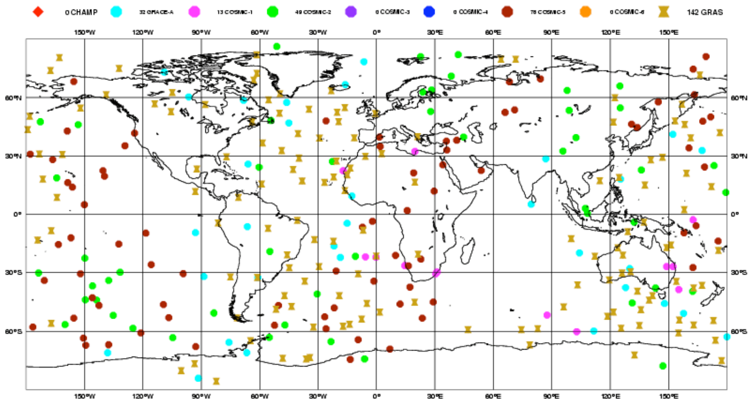



## LEO Imagers

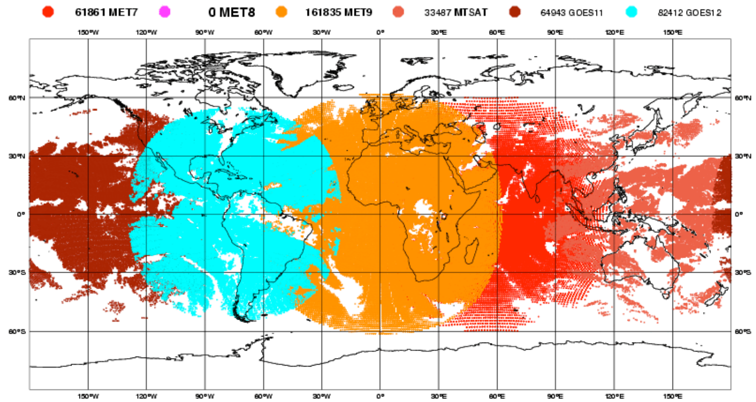



- AMSU-B/MHS on NOAA-17/19, Metop
- SSM/I on DMSP F-15, AMSR-E on Aqua

## GPS Radio Occultation



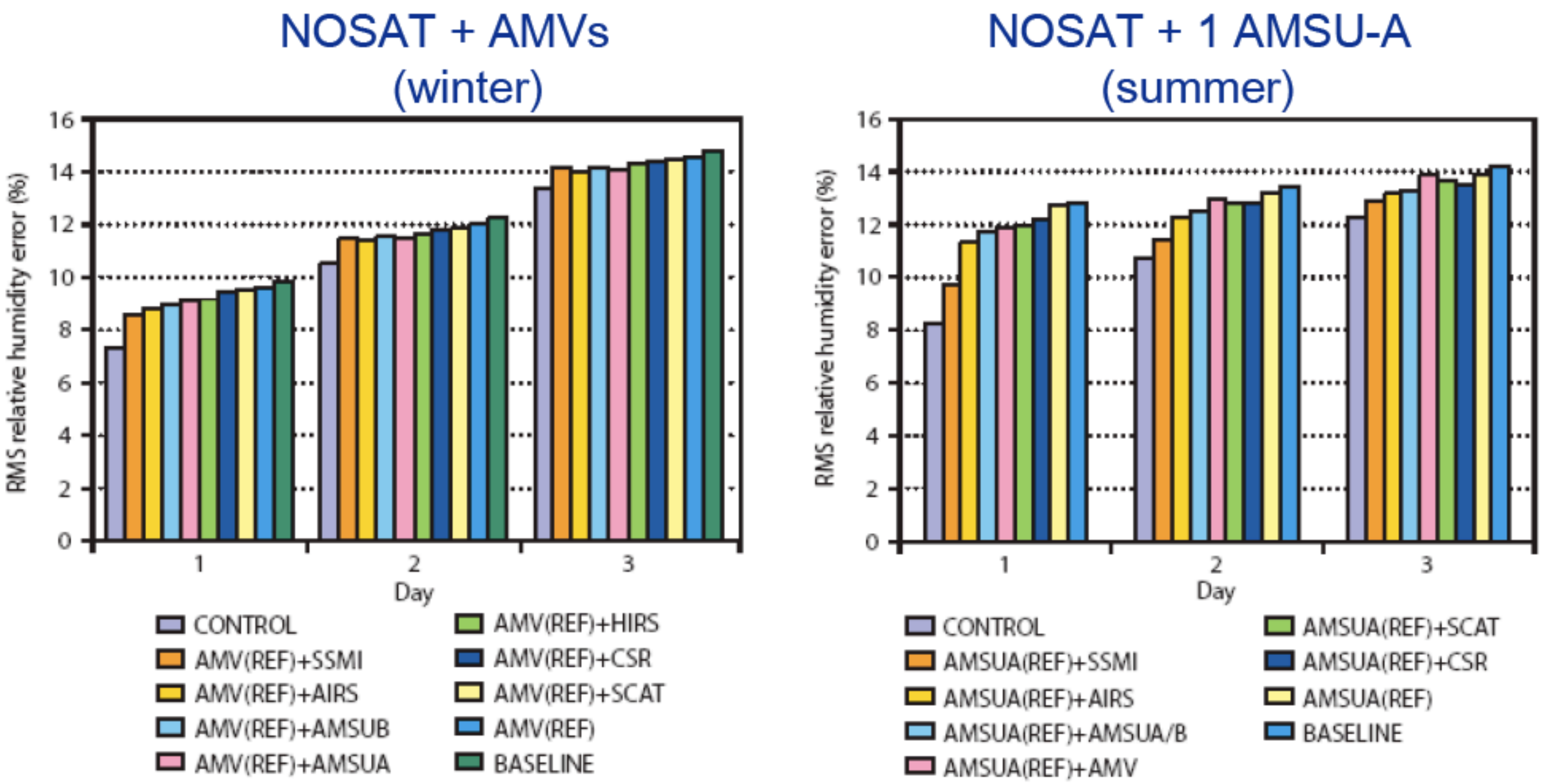

## GEO imagers




**9 April 2010 00 UTC**

# Individual impact of satellite data

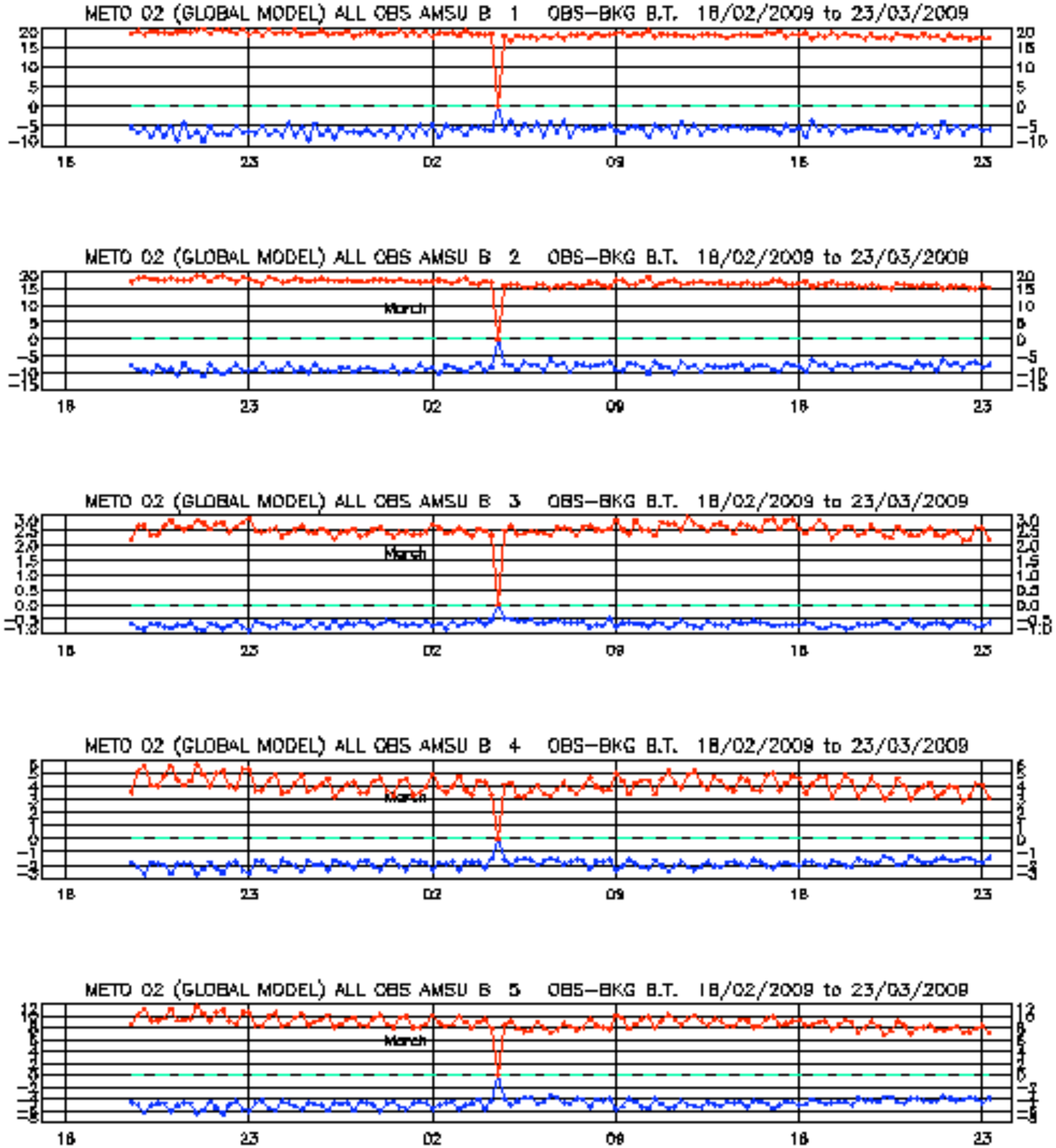
850 hPa *relative humidity* RMS error




ECMWF

## Monitoring of the Observed-Background at ECMWF

Much improvements can be done in water vapour channels in the operational centers




Mean

STD

# Introduction

- Bonne couverture spatiale en globale (mauvaise résolution temporelle)
- Information intéressante sur la WV

Mais :

- Des problèmes de calibration/validation
- Restitution au dessus des continents difficile à cause de la contribution de la surface (beaucoup de données rejetées à cause de cela, notamment pour la basse troposphère).

# Outline

- Total Column Water Vapour avec SSMI
  - First-guess
  - Emissivités de surface
- Sondage de la WV avec AMSU
- Sondage avec AMSU-B/HSB/MHS/Saphir (AQUA/METOP/Megha-Tropiques)
  - Telsem : outil pour First-Guess des émissivités MW
  - Calibration pour l'inversion
  - Outils de validation

Plate

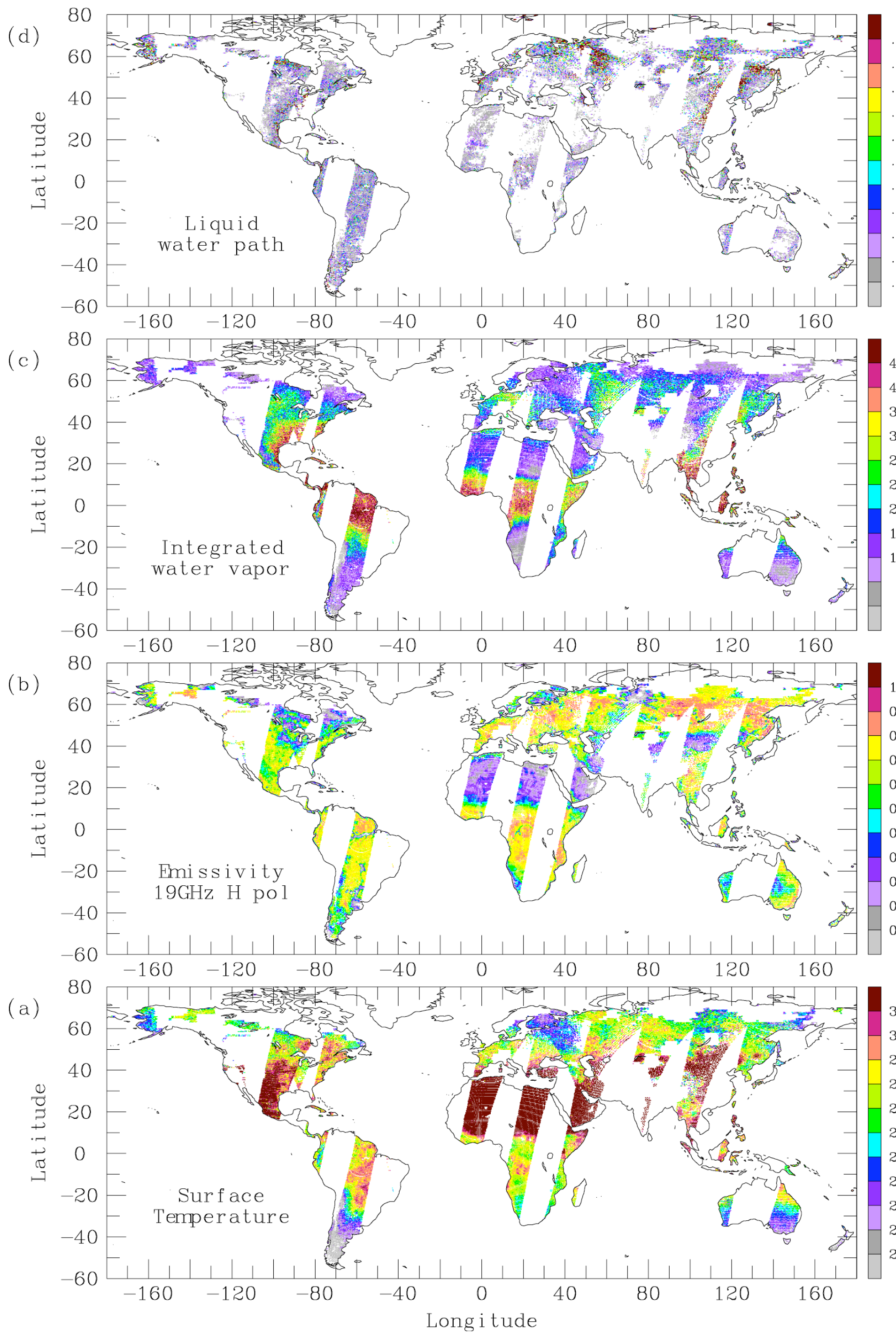
# Retrieval Results

Table 3. RMS Error Results for First Guess and Retrievals

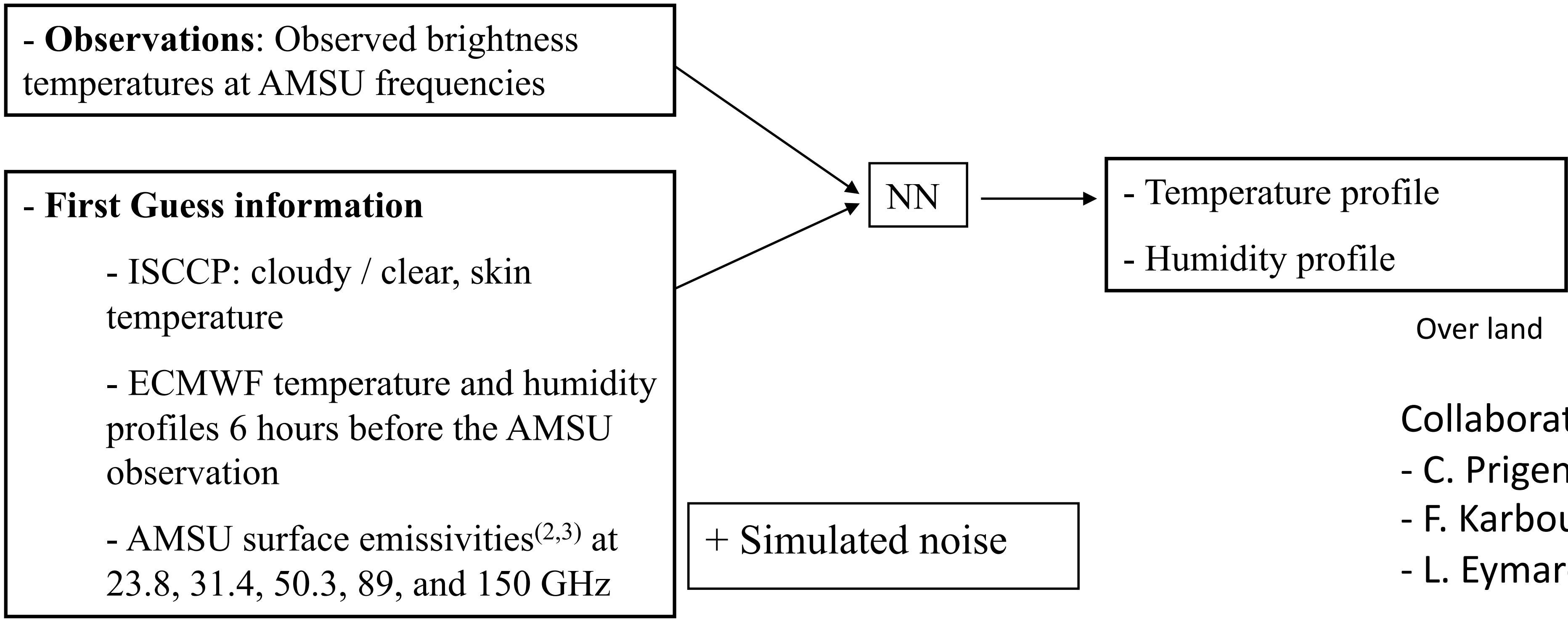
| | Observation or First Guess Errors | NN1 Clear Without First Guess | NN1 Clear With First Guess | NN2 Cloudy Without First Guess | NN2 Cloudy With First Guess |
|---|---|---|---|---|---|
| TbSSMI 19 GHz V (K) | 0.600 | ... | ... | ... | ... |
| TbSSMI 19 GHz H (K) | 0.600 | ... | ... | ... | ... |
| TbSSMI 22 GHz V (K) | 0.600 | ... | ... | ... | ... |
| TbSSMI 37 GHz V (K) | 0.600 | ... | ... | ... | ... |
| TbSSMI 37 GHz H (K) | 0.600 | ... | ... | ... | ... |
| TbSSMI 85 GHz V (K) | 0.600 | ... | ... | ... | ... |
| TbSSMI 85 GHz H (K) | 0.600 | ... | ... | ... | ... |
| Ta[a](K) | 3.000 | ... | ... | ... | ... |
| Tc[b](K) | 2.000 | ... | ... | ... | ... |
| Ts[b](K) | 4.000 | 3.470 | 1.340 | 3.310 | 1.570 |
| LWP[b](kg.m-2) | ... | ... | ... | 0.090 | 0.080 |
| WV[a](kg.m-2) | 40.00[c] | 5.330 | 3.830 | 6.860 | 4.900 |
| Em 19 GHz V | 0.016 | 0.012 | 0.004 | 0.012 | 0.006 |
| Em 19 GHz H | 0.018 | 0.011 | 0.004 | 0.012 | 0.006 |
| Em 22 GHz V | 0.018 | 0.013 | 0.005 | 0.013 | 0.006 |
| Em 37 GHz V | 0.015 | 0.012 | 0.004 | 0.012 | 0.006 |
| Em 37 GHz H | 0.018 | 0.011 | 0.005 | 0.013 | 0.006 |
| Em 85 GHz V | 0.020 | 0.015 | 0.006 | 0.016 | 0.009 |
| Em 85 GHz H | 0.023 | 0.016 | 0.008 | 0.018 | 0.010 |

[a] NCEP.
[b] ISCCP.
[c] In %.

Aires, Prigent and Rossow, JGR, 2001.
Prigent, Aires and Rossow, JAM, 2003.
Prigent, Aires and Rossow, JGR, 2003.



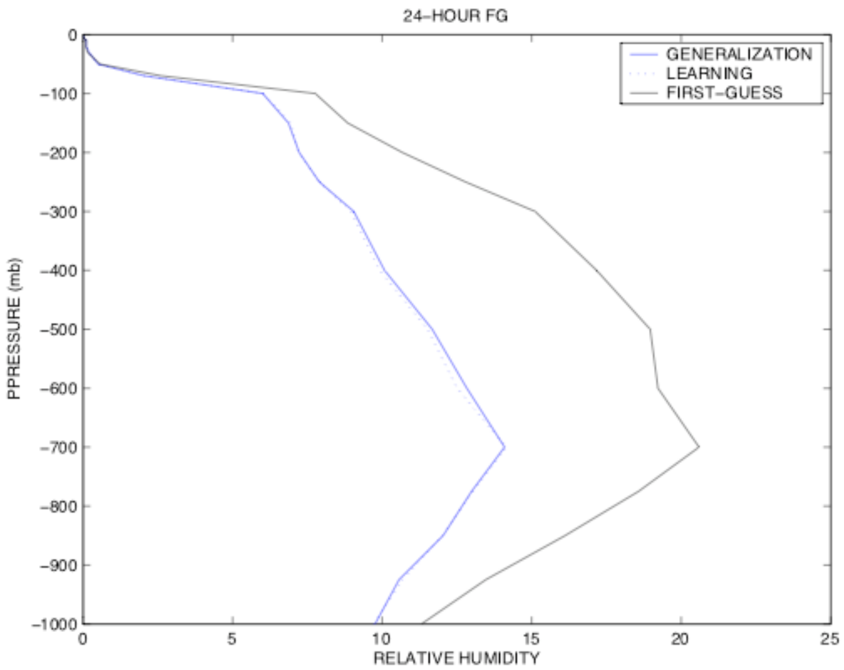
# Atmospheric Humidity and Temperature Profiles Over Land From AMSU-A and AMSU-B Observations[1]




Collaboration:
- C. Prigent
- F. Karbou
- L. Eymard

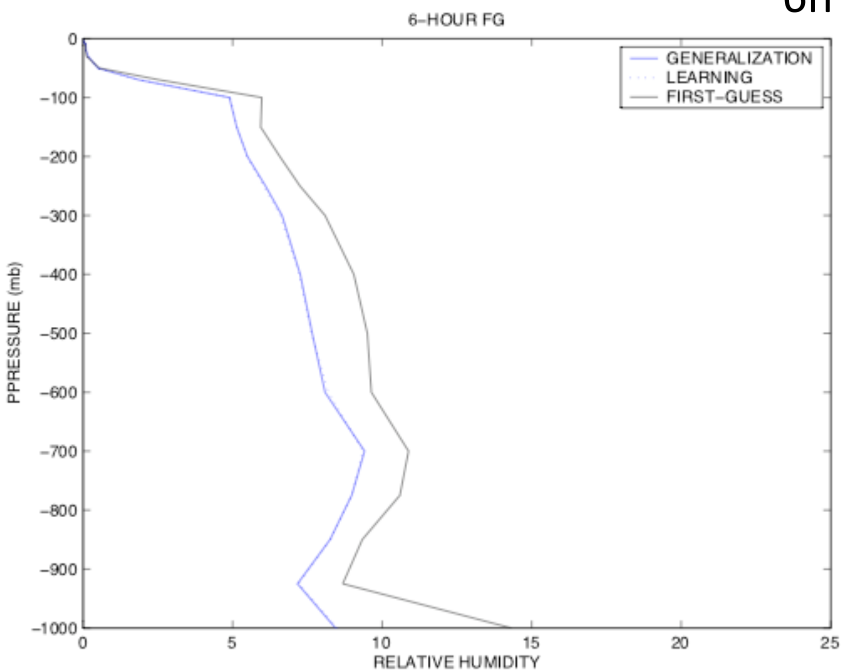
[1] Karbou, F., Aires, F., Prigent, C. Retrieval of temperature and water vapor atmospheric profiles over Africa using AMSU microwave observations. Journal of Geophysical Research, 110(D7), 2005.
[2] Prigent, Rossow, Matthews, Global maps of microwave land surface emissivities: Potential for land surface characterization, Radio Science, 33, 1998.
[3] Karbou, Prigent, Eymard, and Pardo, Microwave land emissivity calculations using AMSU-A and AMSU-B measurements, IEEE TGRS, 43(5), 2005.

# Impact FG for Specific Humidity Profile

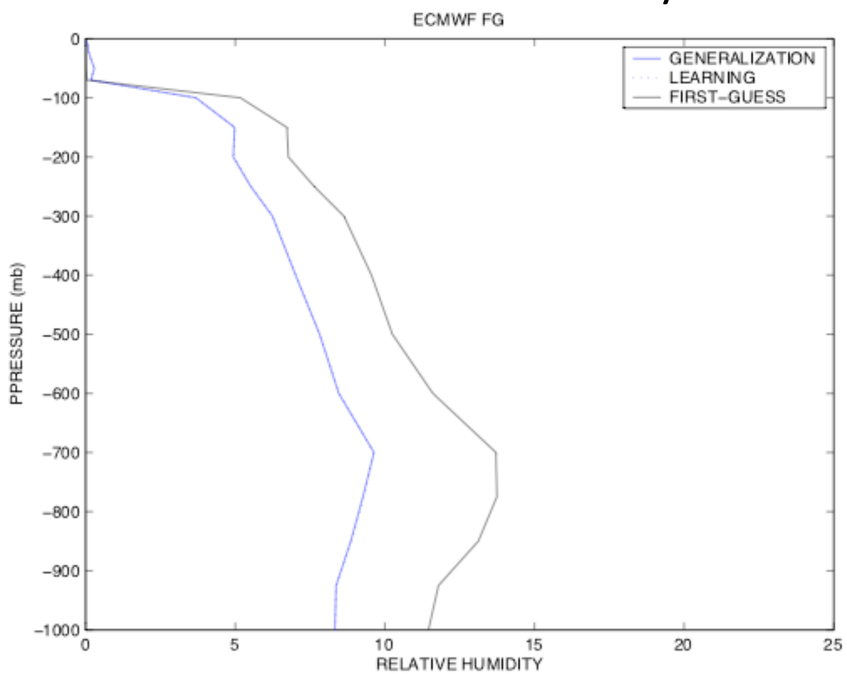



24h Forecast

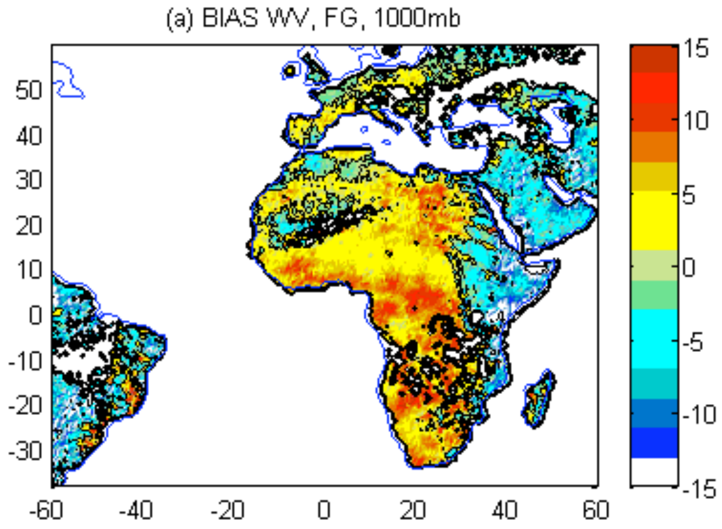
6h Forecast

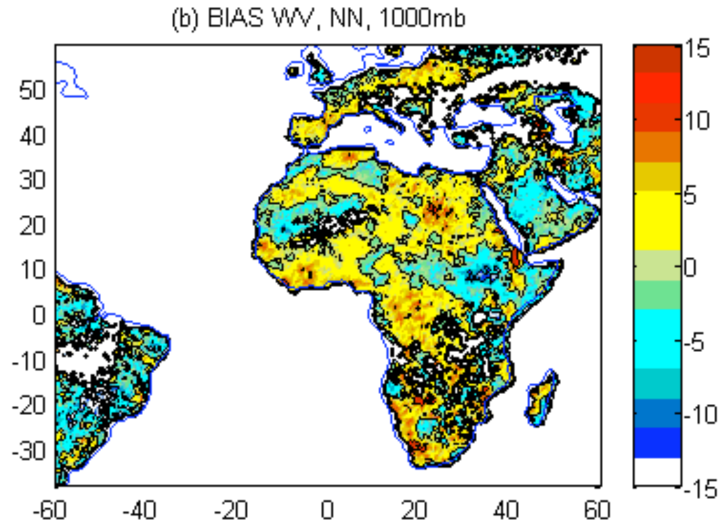


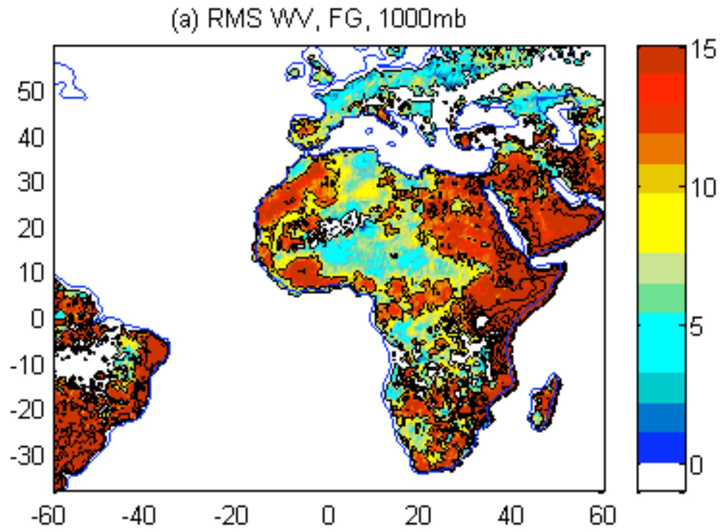

Analyse

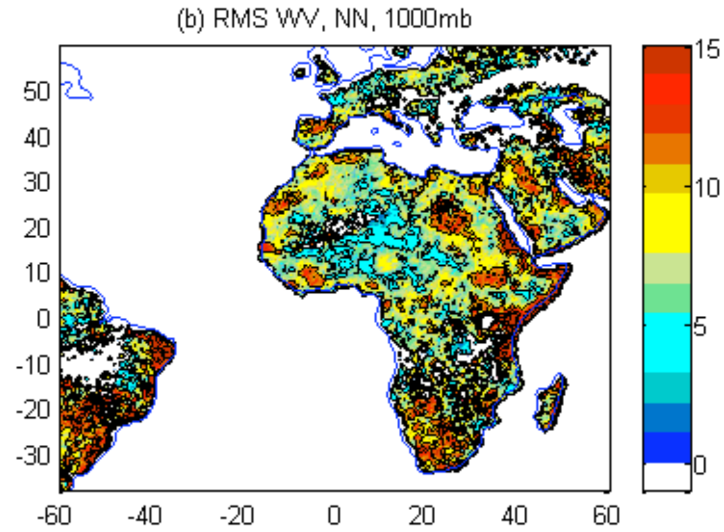


# Bias Statistics / FG and NN Retrieval

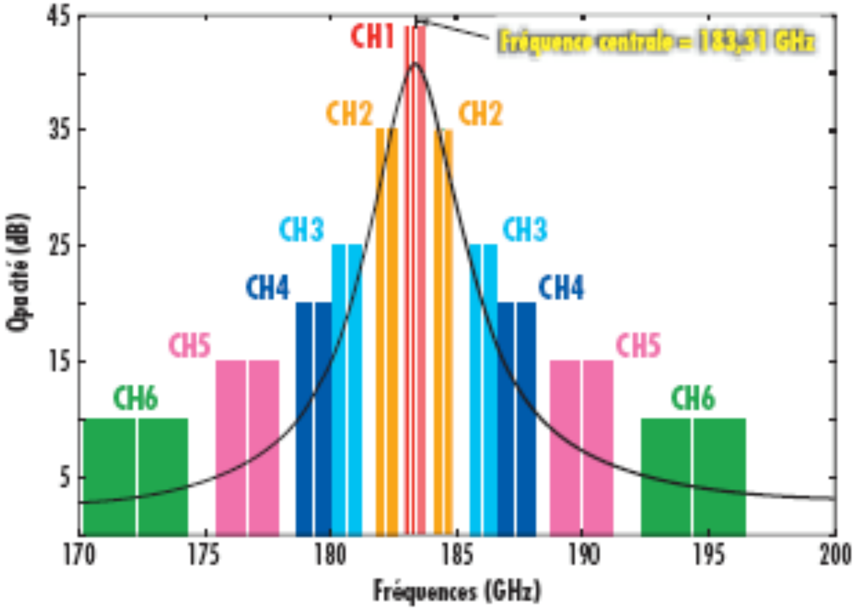


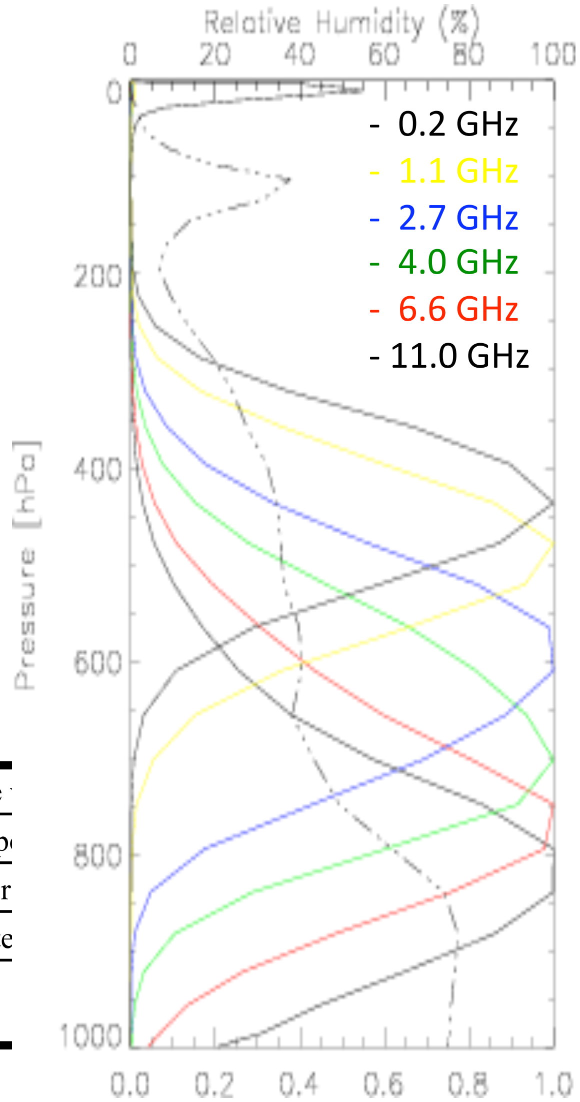



# Sondeur Atmosphérique du Profil d'Humidité Intertropicale par Radiométrie

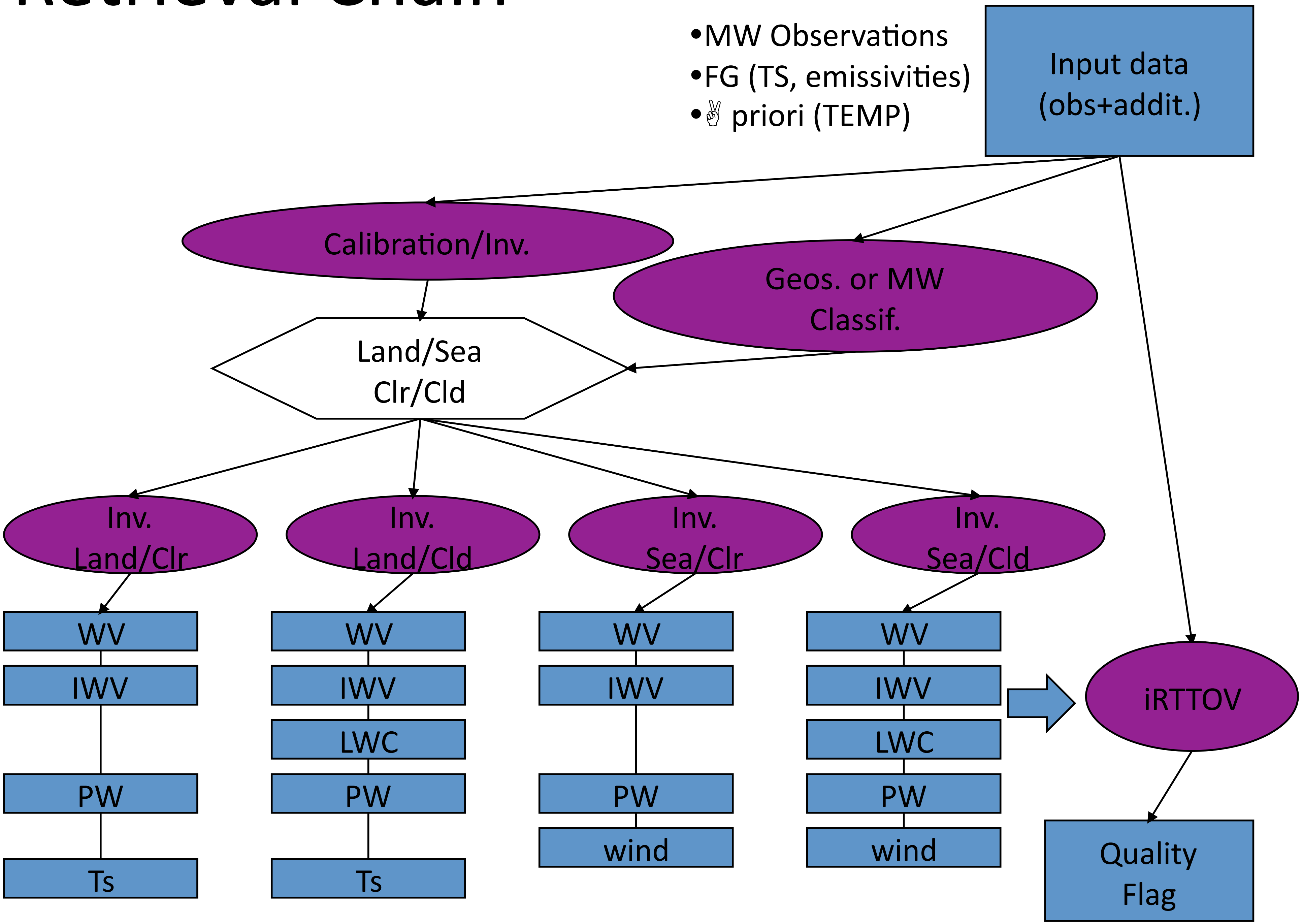



| | Frequencies | Polarization | Pixel size | Noise | Main use |
|---|---|---|---|---|---|
| Madras | 18.7 GHz ± 100MHz | V + H | 40 km | 0.46 / 0.53 | Ocean rain and surface |
| Madras | 23.8 GHz ± 200MHz | V | 40 km | 0.48 | Integrated water vap |
| Madras | 36.5 GHz ± 500MHz | V + H | 40 km | 0.44 / 0.49 | Cloud liquid water |
| Madras | 89 GHz ± 1350MHz | V + H | 10 km | 0.63 / 0.58 | Convective rain rate |
| Madras | 157 GHz ± 1350MHz | V + H | 6 km | 1.75 / 1.65 | Cloud top ice |
| Saphir | 183.31 ± 0.2 GHz | H | 10 km (at nadir) | 2.03 | vertical distribution of water vapour |
| Saphir | 183.31 ± 1.1 GHz | | | 1.53 | |
| Saphir | 183.31 ± 2.7 GHz | | | 1.37 | |
| Saphir | 183.31 ± 4.0 GHz | | | 1.25 | |
| Saphir | 183.31 ± 6.6 GHz | | | 1/06 | |
| Saphir | 183.31 ± 11 GHz | | | 0.99 | |



# Retrieval Chain

- MW Observations
- FG (TS, emissivities)
- ✌ priori (TEMP)



# A tool to Estimate Land Surface Emissivities at Microwave (TELSEM) frequencies

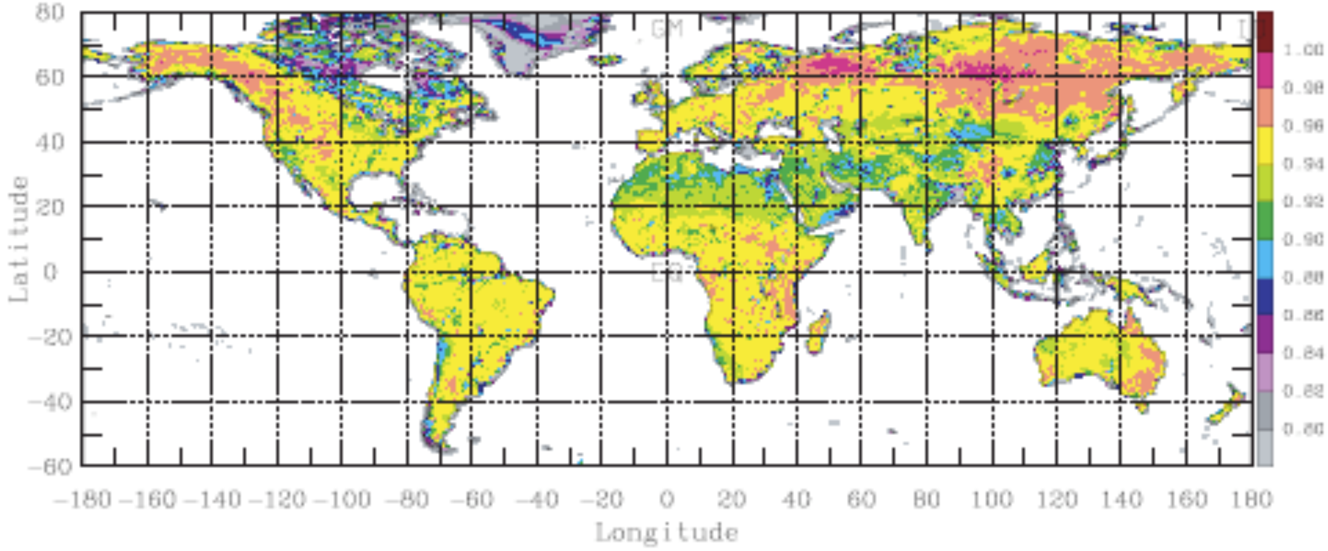



Figure 1. Example of emissivity calculation with TELSEM for September at 31.4 GHz, for 15° incidence angle and vertical polarization.

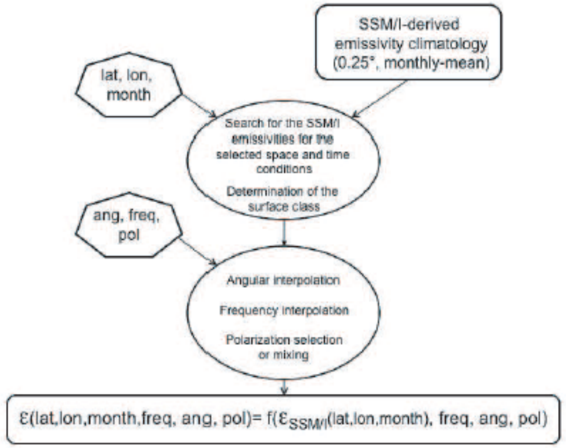



Figure 3. The different steps in TELSEM.

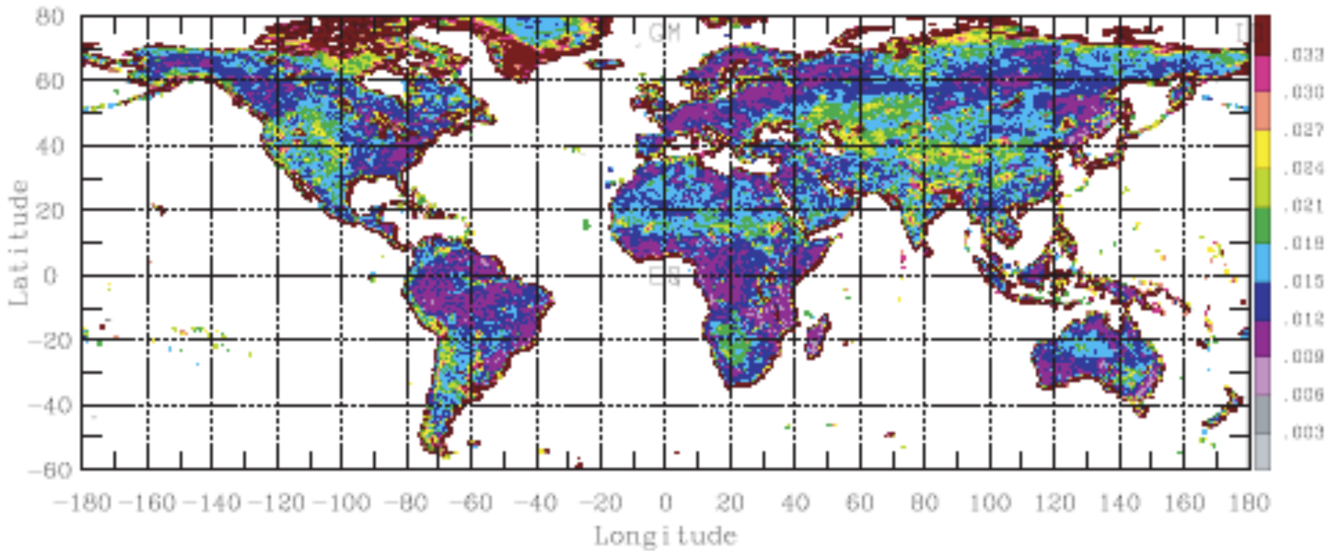
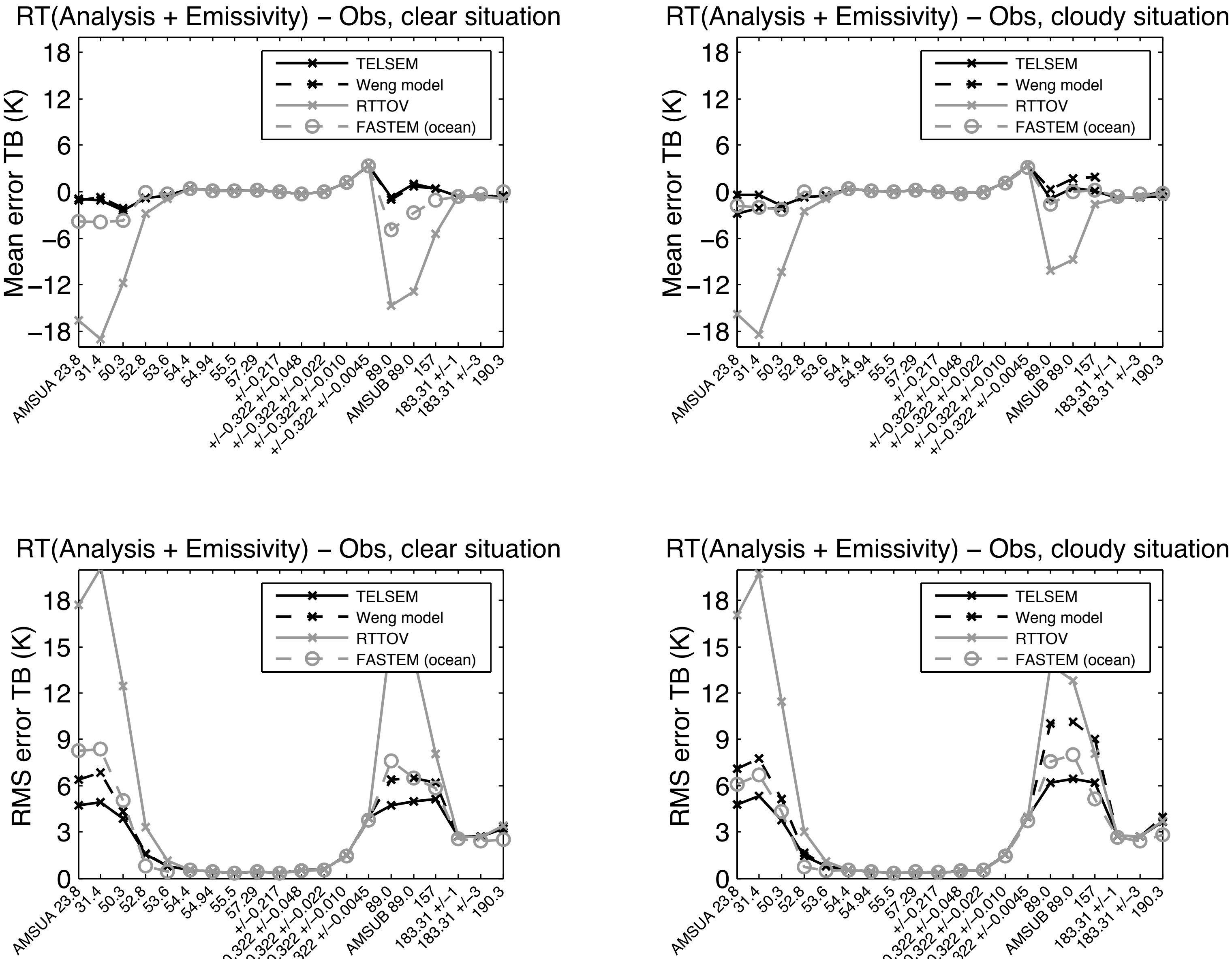



Figure 2. The emissivity uncertainty estimates for September, interpolated at 31.4 GHz, for the vertical polarization at 15° incidence angle.

- Prigent et al. 2008, IEEE TGRM
- Aires et al. 2010 (submitted QJRMS)


RT(Analysis + Emissivity) − Obs, clear situation
RT(Analysis + Emissivity) − Obs, cloudy situation
Mean error TB (K)
RMS error TB (K)
TELSEM
Weng model
RTTOV
FASTEM (ocean)
18
12
6
0
−6
−12
−18
15
9
3
AMSUA 23.8
31.4
50.3
52.8
53.6
54.4
54.94
55.5
57.29
+/−0.217
+/−0.322 +/−0.048
+/−0.322 +/−0.022
+/−0.322 +/−0.010
+/−0.322 +/−0.0045
89.0
AMSUB 89.0
157
183.31 +/−1
183.31 +/−3
190.3

# Calibration for retrieval: General idea

Any retrieval algorithm uses a Radiative Transfer Model (RTM):

- iterative inversion, 1D-var, assimilation: online utilisation
- statistical techniques (NN, Bayes.) : used for the construction of the learning database

→ If this RTM isn't correctly calibrated/corrected to get close to real observations, then the retrieval algorithm will suffer from some problems.

→ **We have developed a dedicated statistical calibration procedure that projects real observations onto the "RTM simulations" space**

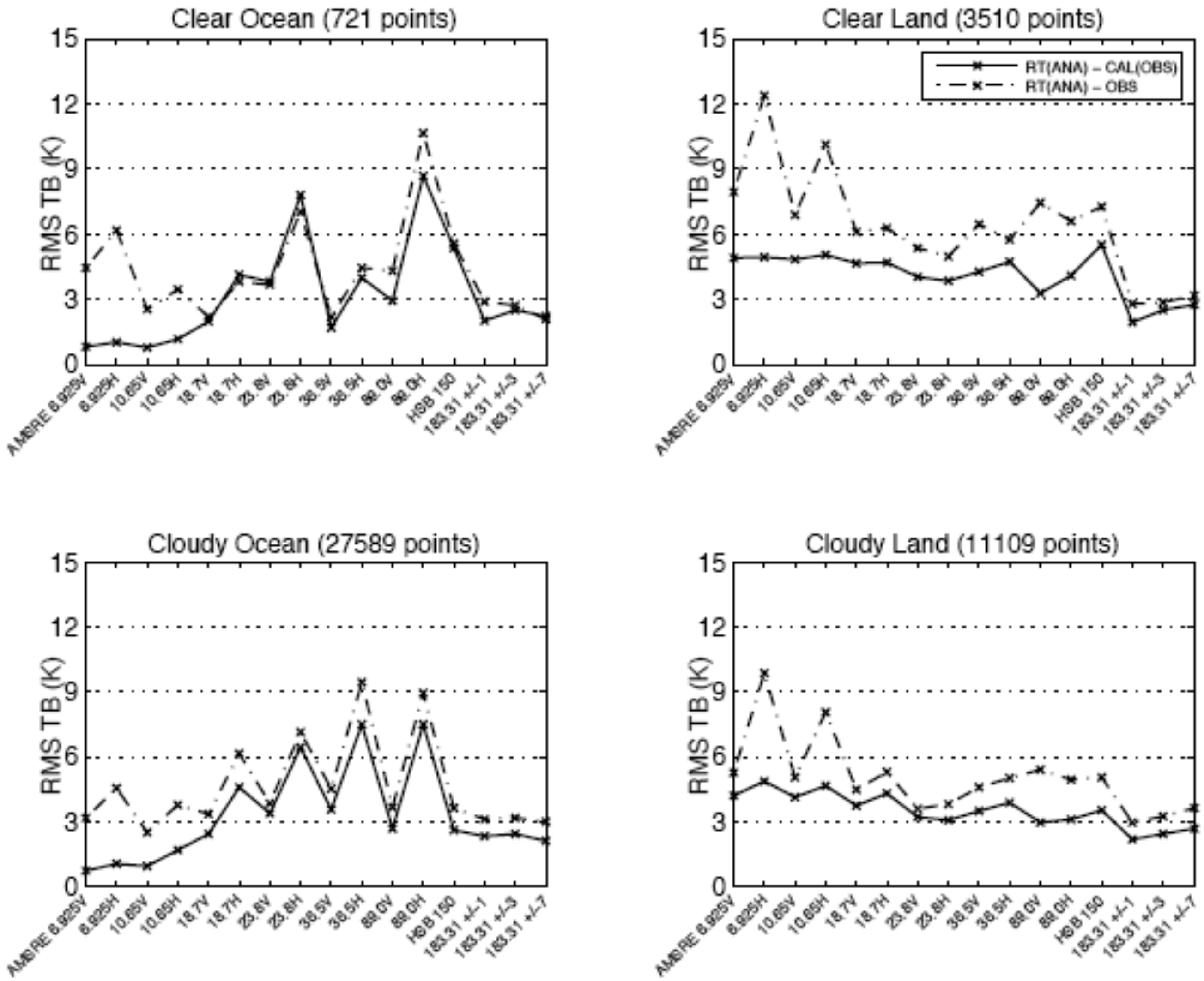



FIG. 2. Root Mean Square (RMS) differences between observed and calibrated data for AMSUR-E and HSB channels. Four cases are considered: cloud free (top) and cloudy without precipitation (down) situations; and for ocean (left) and land (right) scenes. The solid and dashed lines correspond to the RMS difference when using calibrated and non calibrated brightness temperatures, respectively.

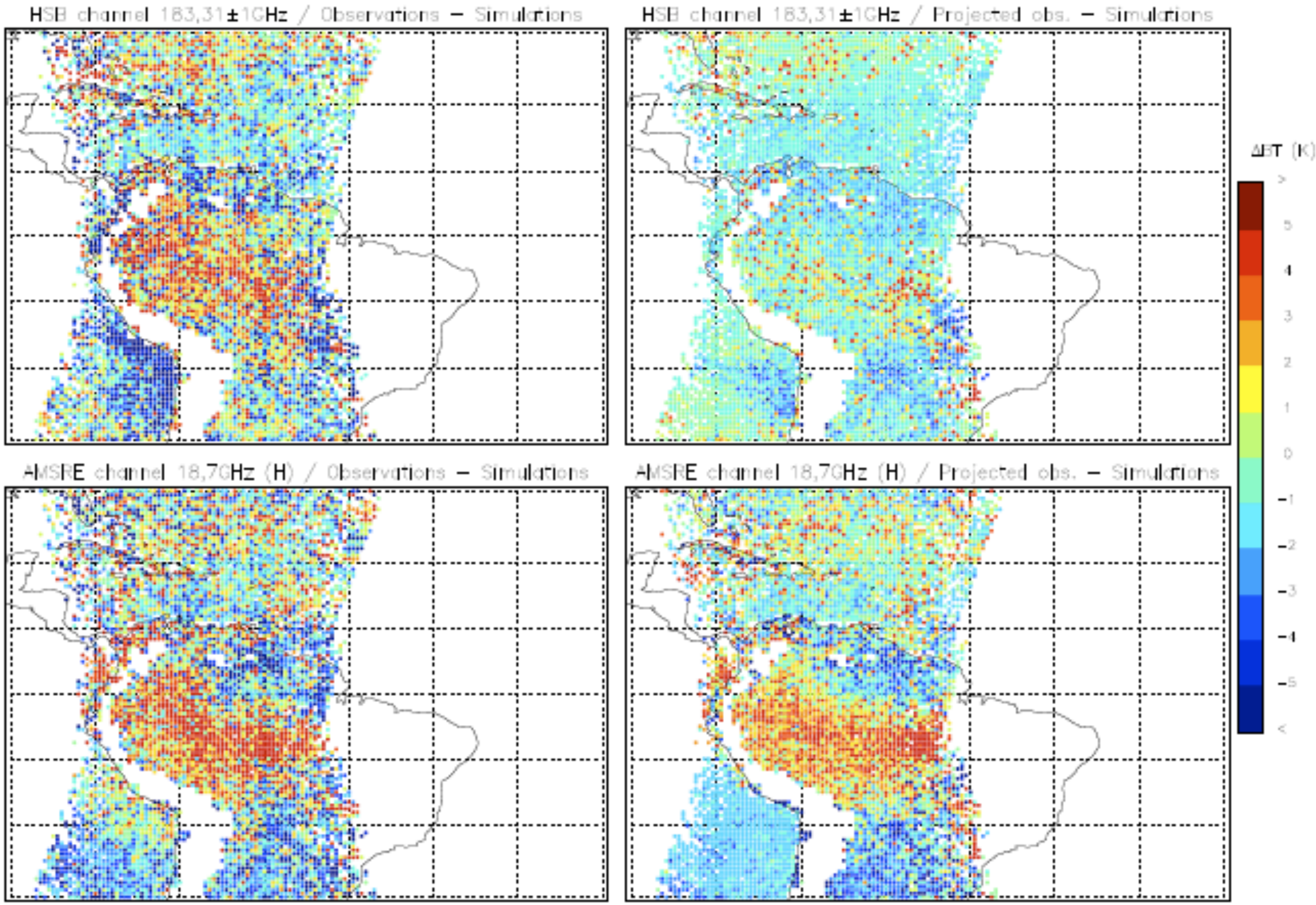



FIG. 3. Root Mean Square (RMS) error maps computed over two months for differences between RTTOV simulations and real AQUA observations (left) or calibrated AQUA observations (right): for a HSB channel at 183.31±1 GHz (top) and a AMSR-E channel at 18.7 GHz vertically polarized (bottom).

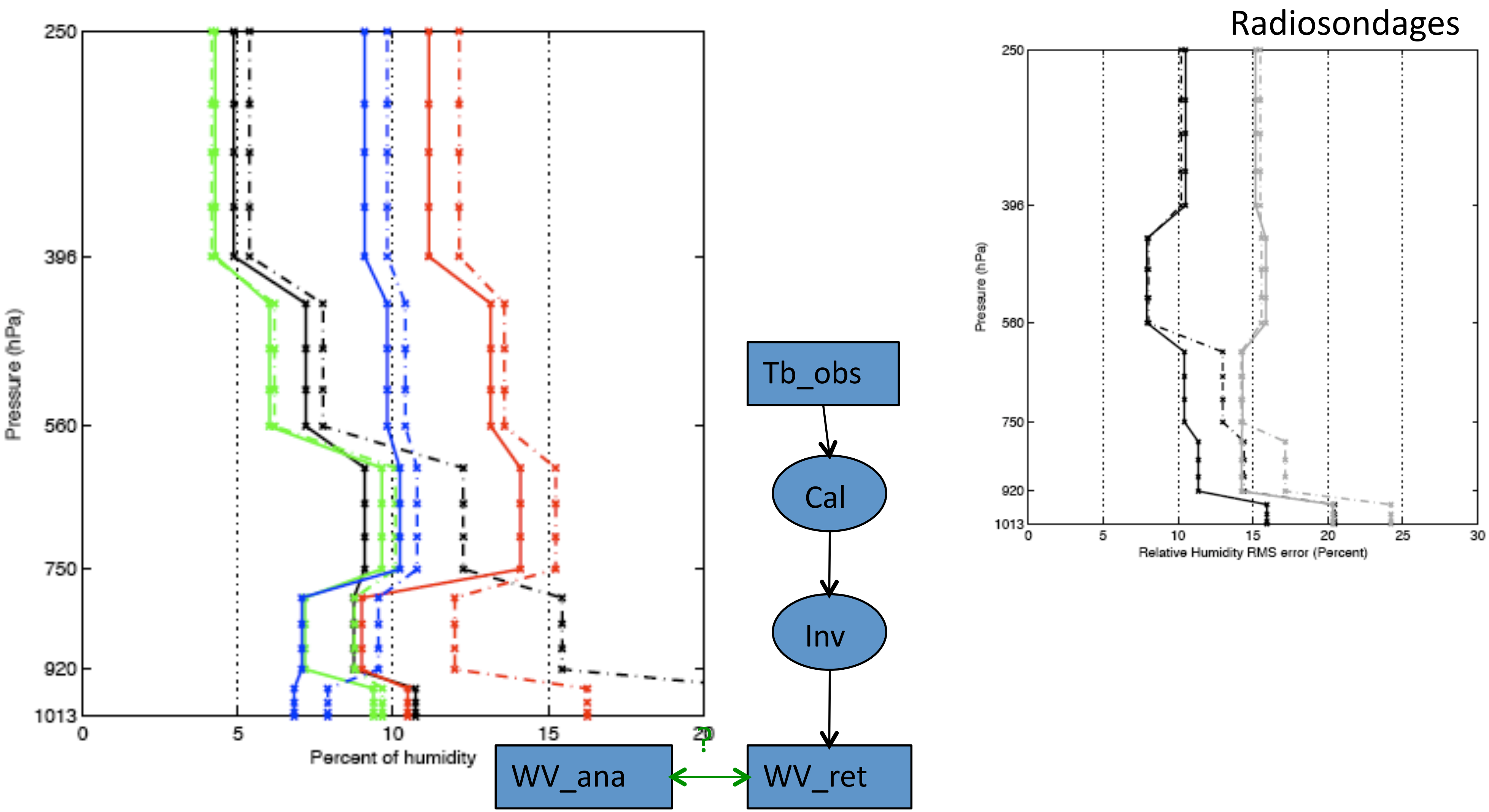
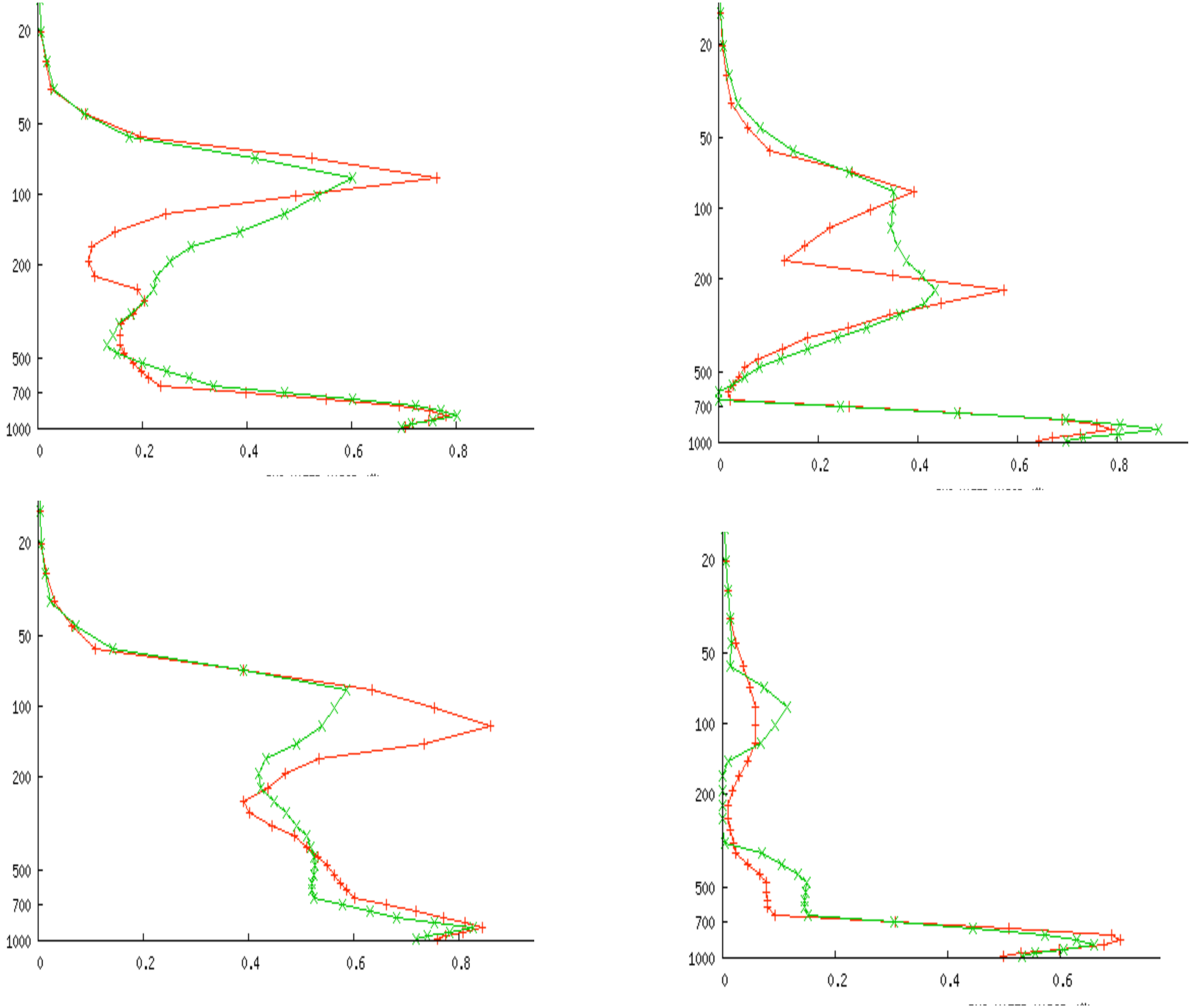



FIG. 5. Root Mean Square relative humidity departure of the ECMWF analysis and the retrieval from raw (doted) and calibrated (continuous line) AQUA observations: for Cloud Free/Land (black), Cloudy/Land (green), Cloud Free/Ocean (red) and Cloudy/Ocean (blue) configurations.

# Retrieval examples



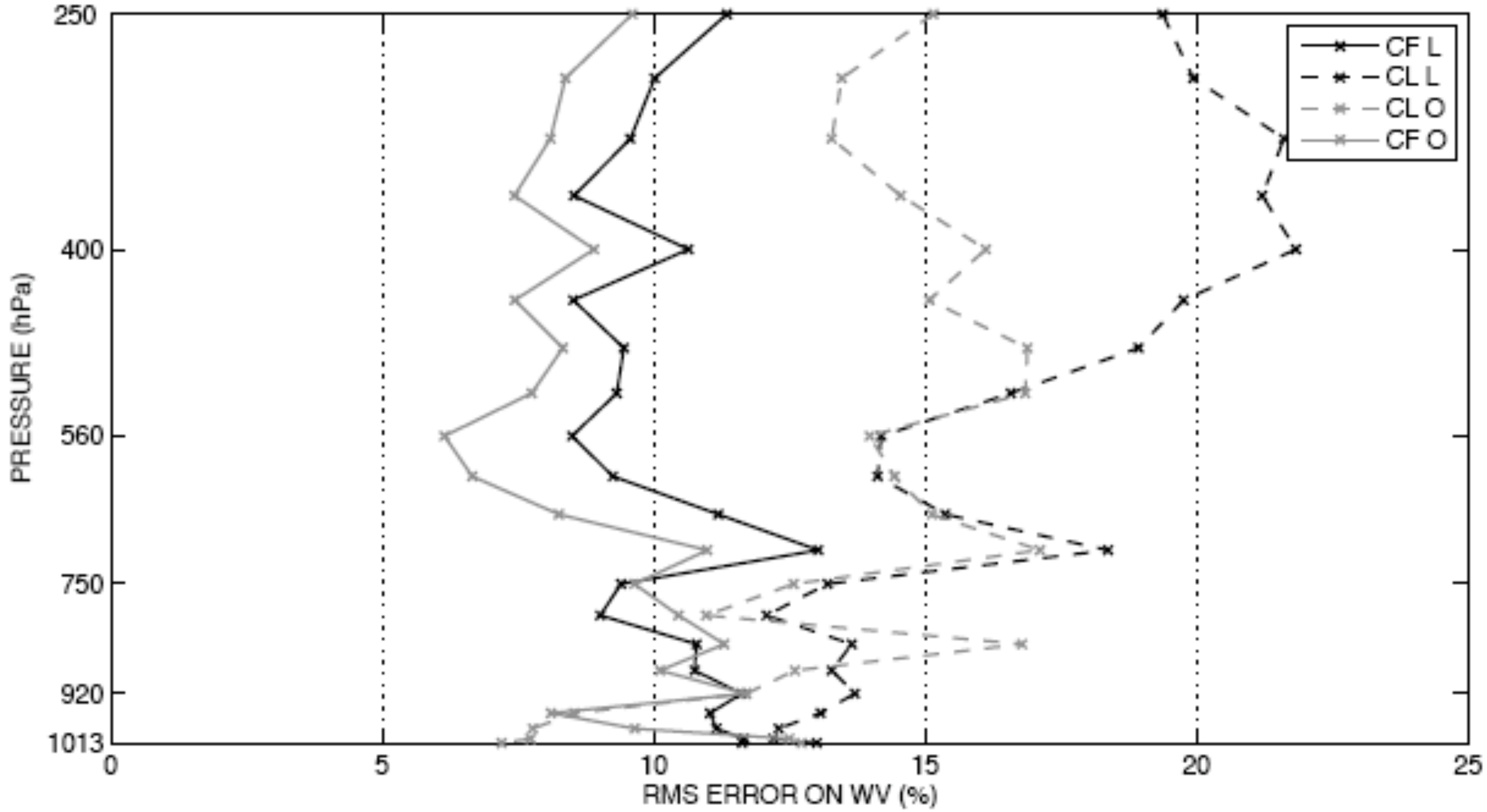
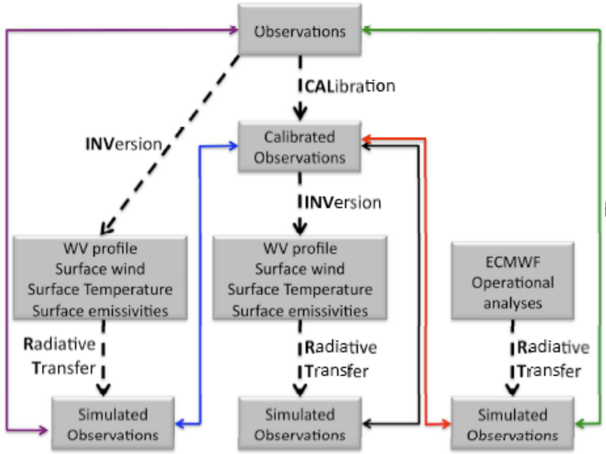
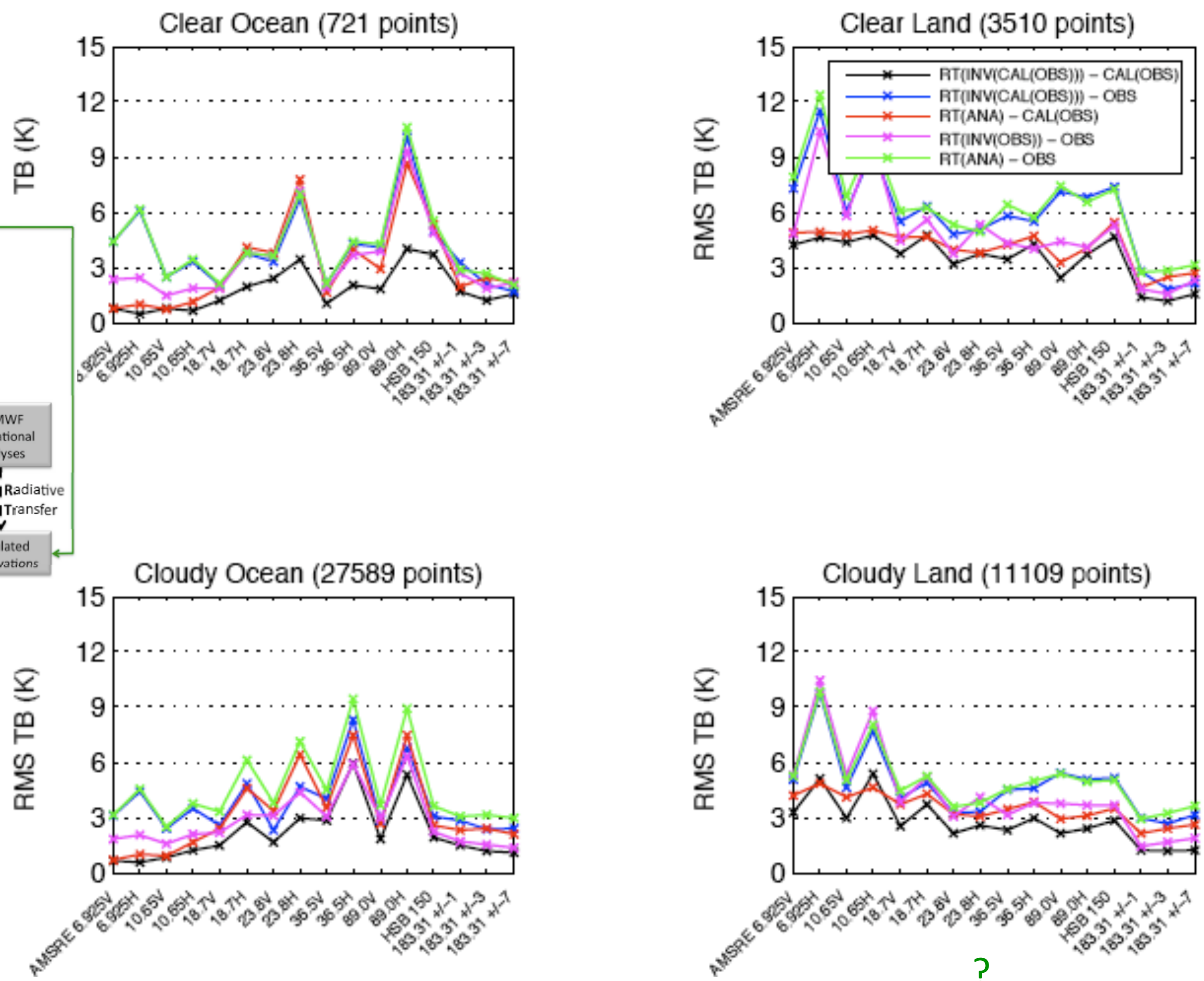
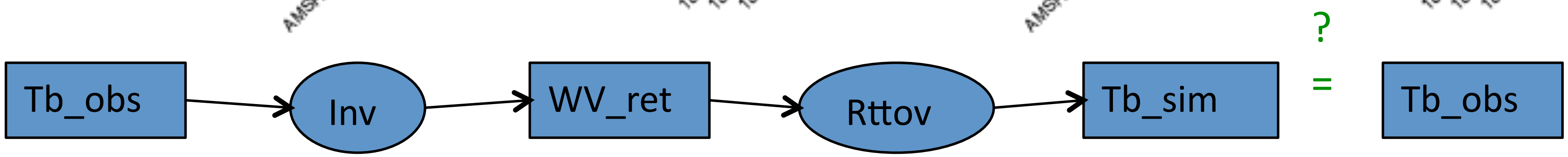



Figure 5. RMS relative error for the AMSR-E/HSB retrieval of relative humidity (in %). The statistics are given over the Tropical regions (±30°) for July 2002 and January 2003. Grey lines are for ocean surfaces (O) and black lines for land (L). Continuous lines are for Cloud Free (CF) scenes and dashed lines are for CLoudy (CL) situations.

# Validation on the TB-space



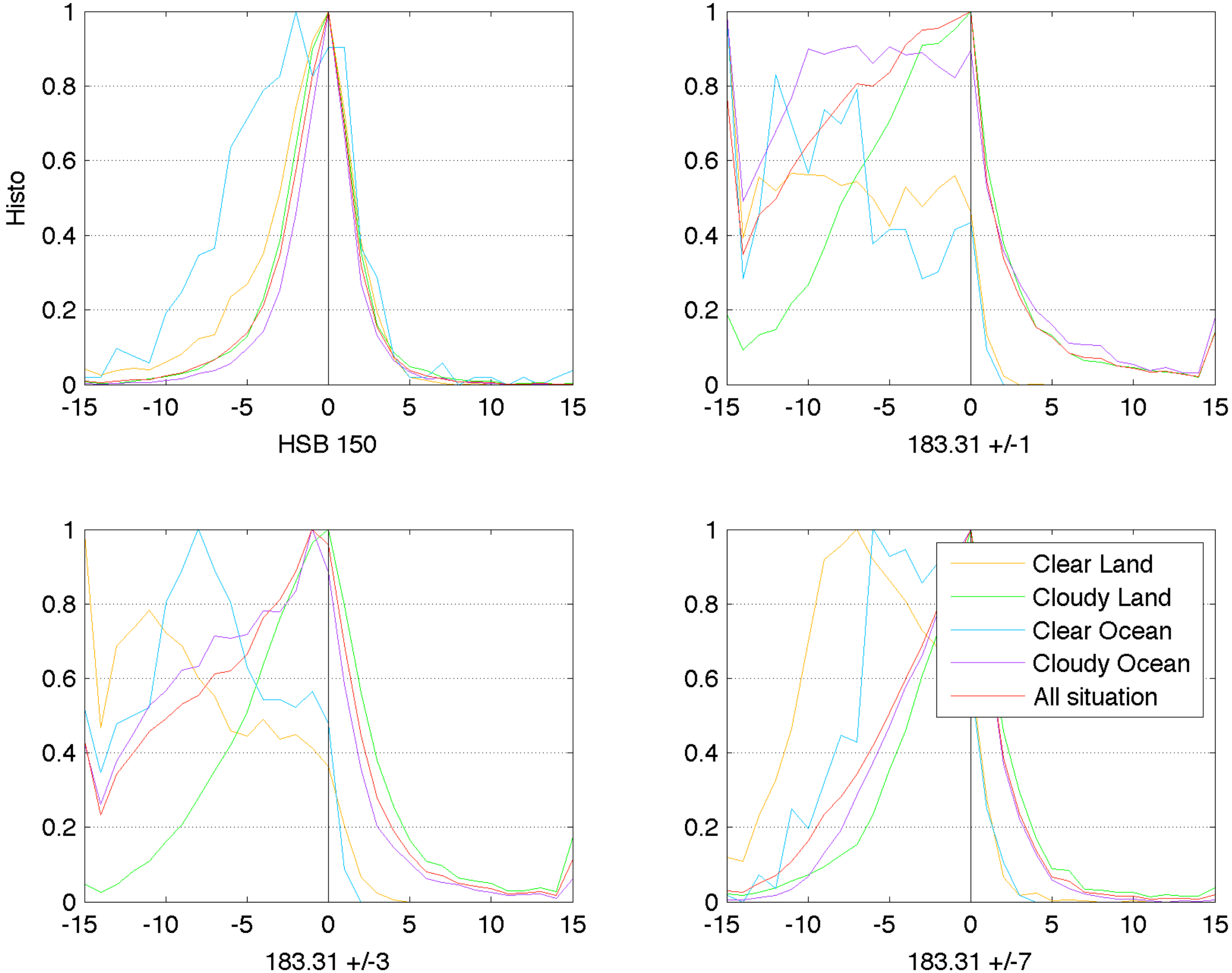



# Validation on the TB space (4/5)

TB_error_ret - TB_error_ana

HSB

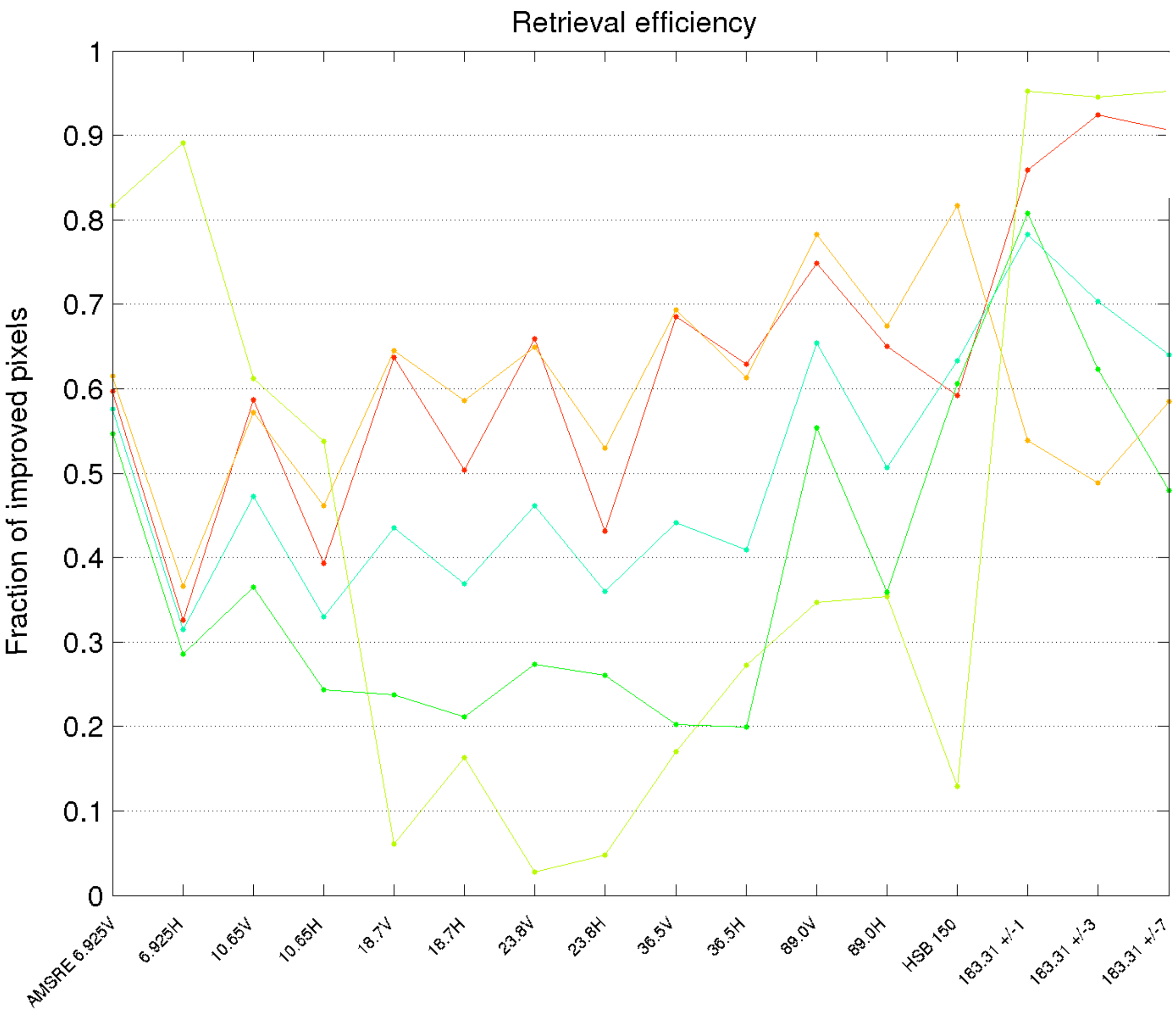



Clear Land
Cloudy Land
Clear Ocean
Cloudy Ocean
All situations

- Positive: degrade the analysis
- Negative: improve the analysis

Very important improvement on WV channels

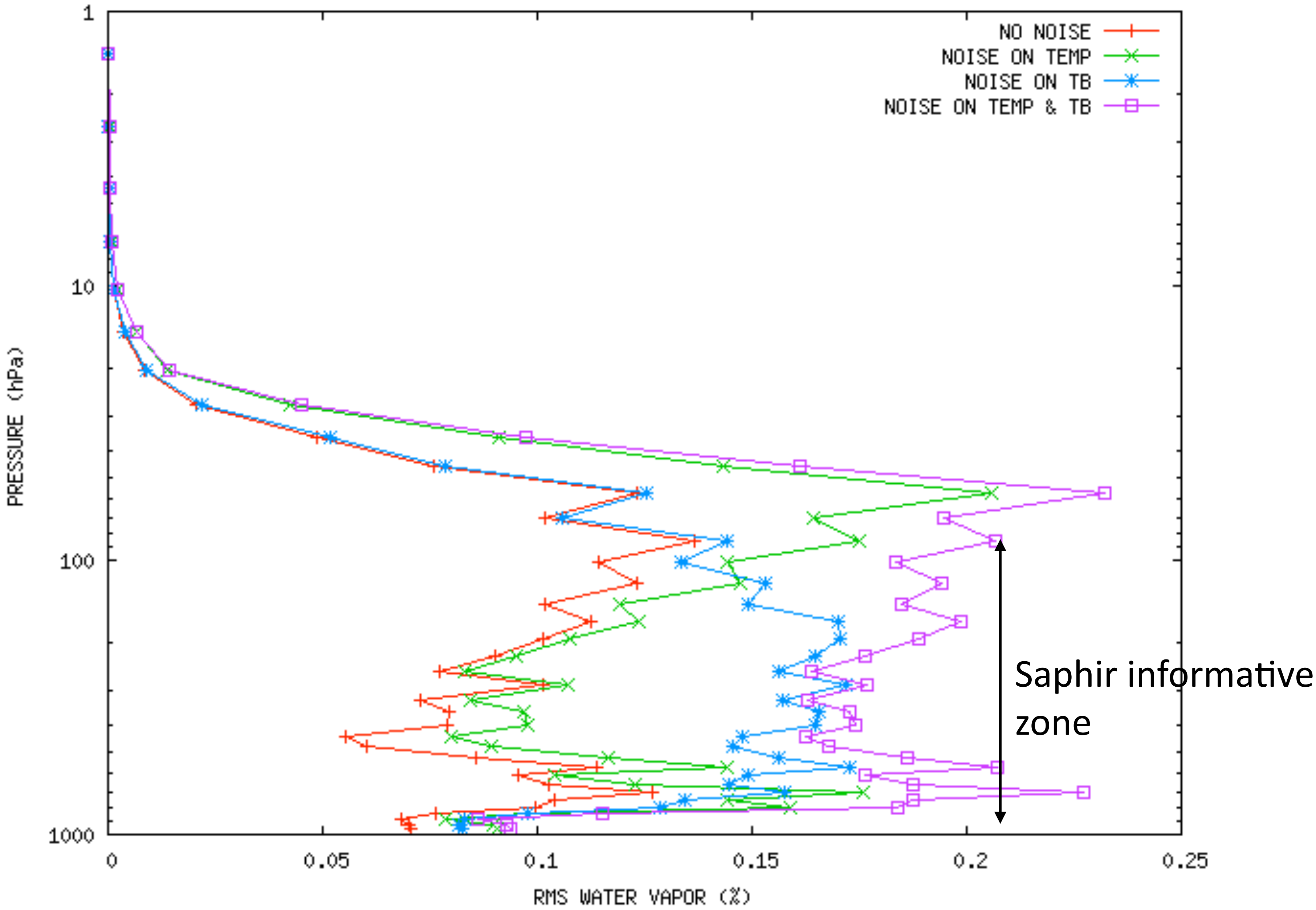
# Validation on the TB space (5/5)




Fraction of improved situations for each channel

Clear Land
Cloudy Land
Clear Ocean
Cloudy Ocean
All situations

# Sensitivity to uncertainties



# Optimization of retrieval layers

We don't perform retrieval in the high-layers and 6 undefined layers are considered in the low-atmosphere with variable size.

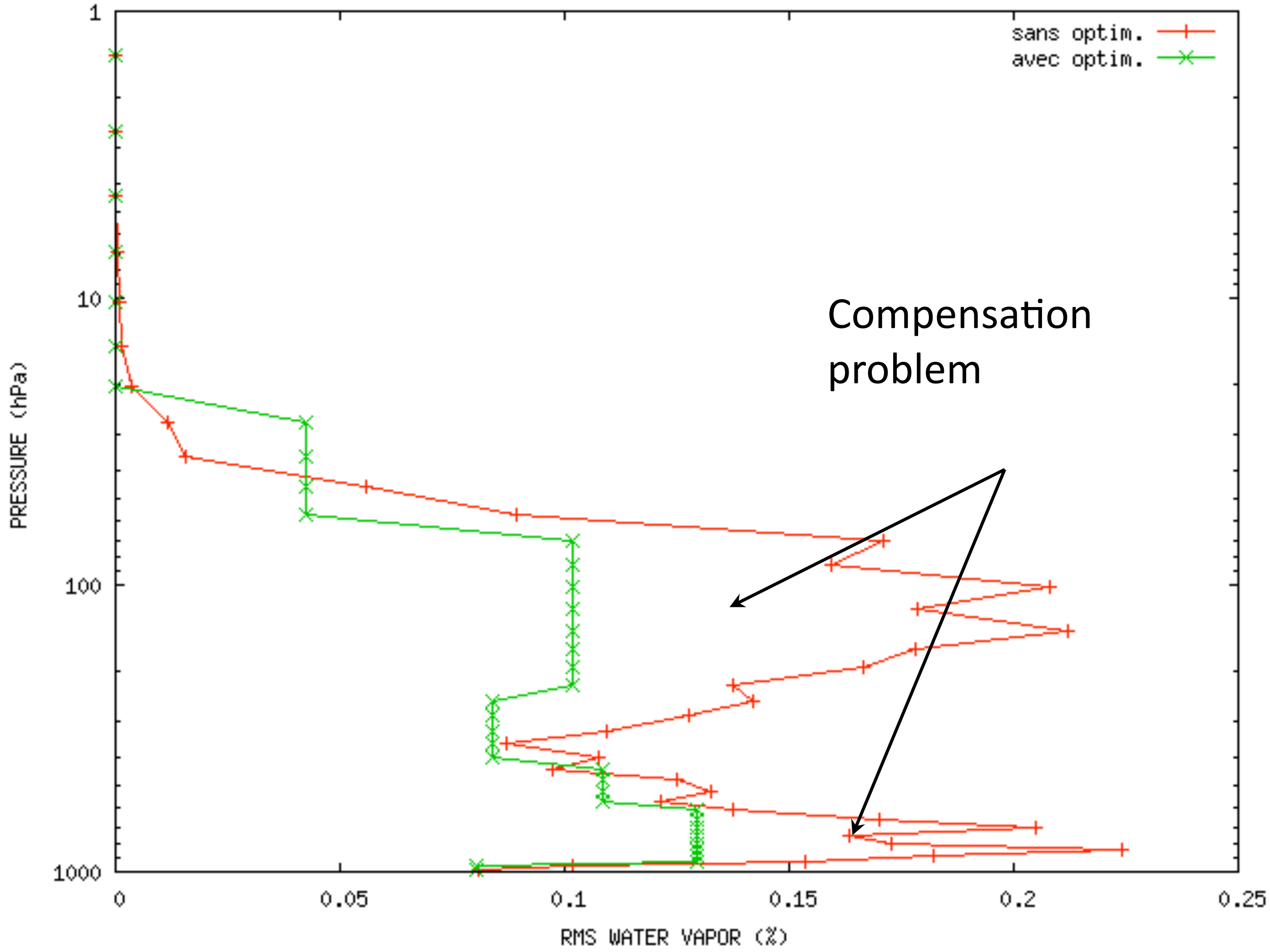
↓

Automatic optimization

↓

-10 layers

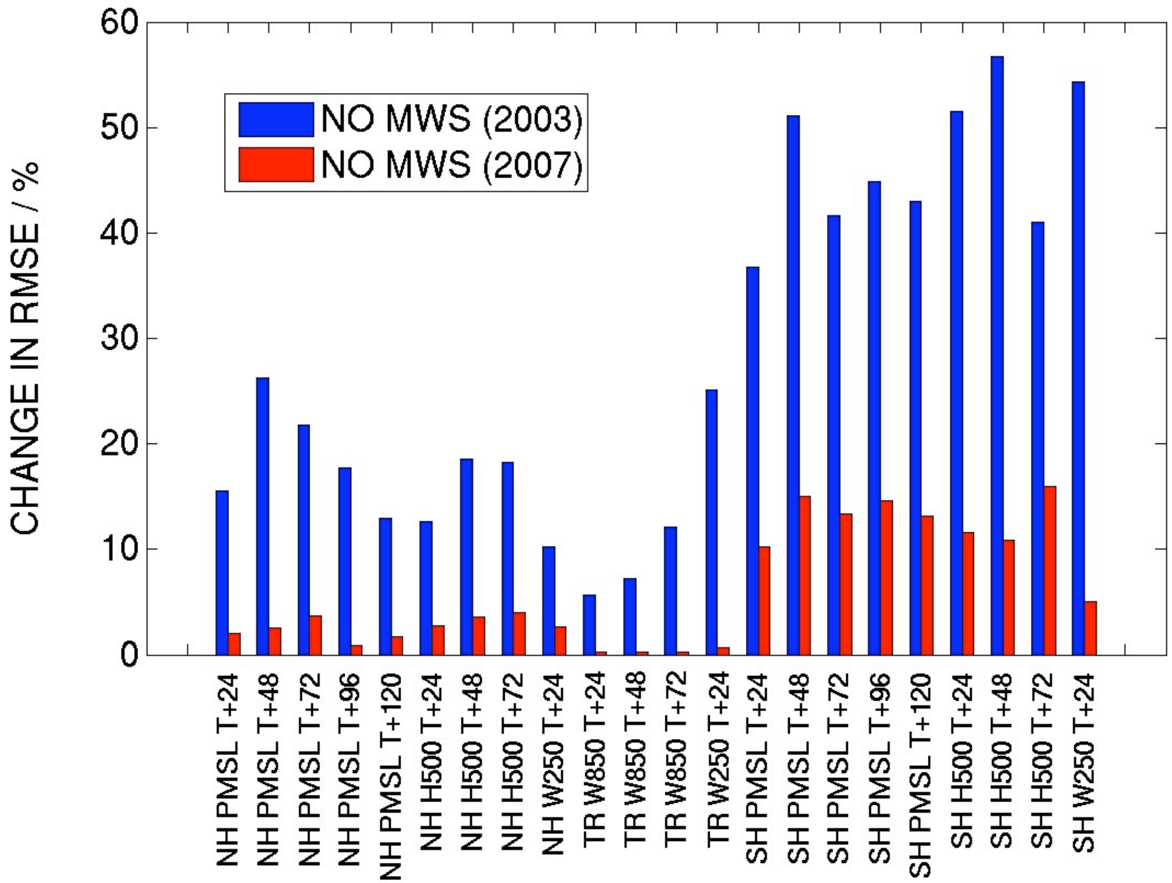
- 4 layers
- 8 layers
- 5 layers
- 4 layers
- 8 layers
- 4 layers



# Conclusions/Perspectives

- Restitution de la WV
- Possible de faire des restitutions au dessus des continents grâce aux outils développés ces 15 dernières années
- Problèmes de calibration (pour l'inversion, inter-instruments et pour les drifts instrumentaux)
- Validations difficiles
- Perspectives:
  - Analyse de la variabilité de la WV avec de potentiels post-traitements (interpolations temporelles et spatiales)
  - Amélioration des chaînes existantes, développement d'une climatologie
  - Synergie avec l'infrarouge (présentation Maxime Paul)

# Impact of microwave sounder data in NWP: Met Office OSEs




2003 OSEs:

- N-15,-16 and -17 AMSU
- N-16 & N-17 HIRS
- AMVs
- Scatterometer winds
- SSM/I ocean surface wind speed
- Conventional observations

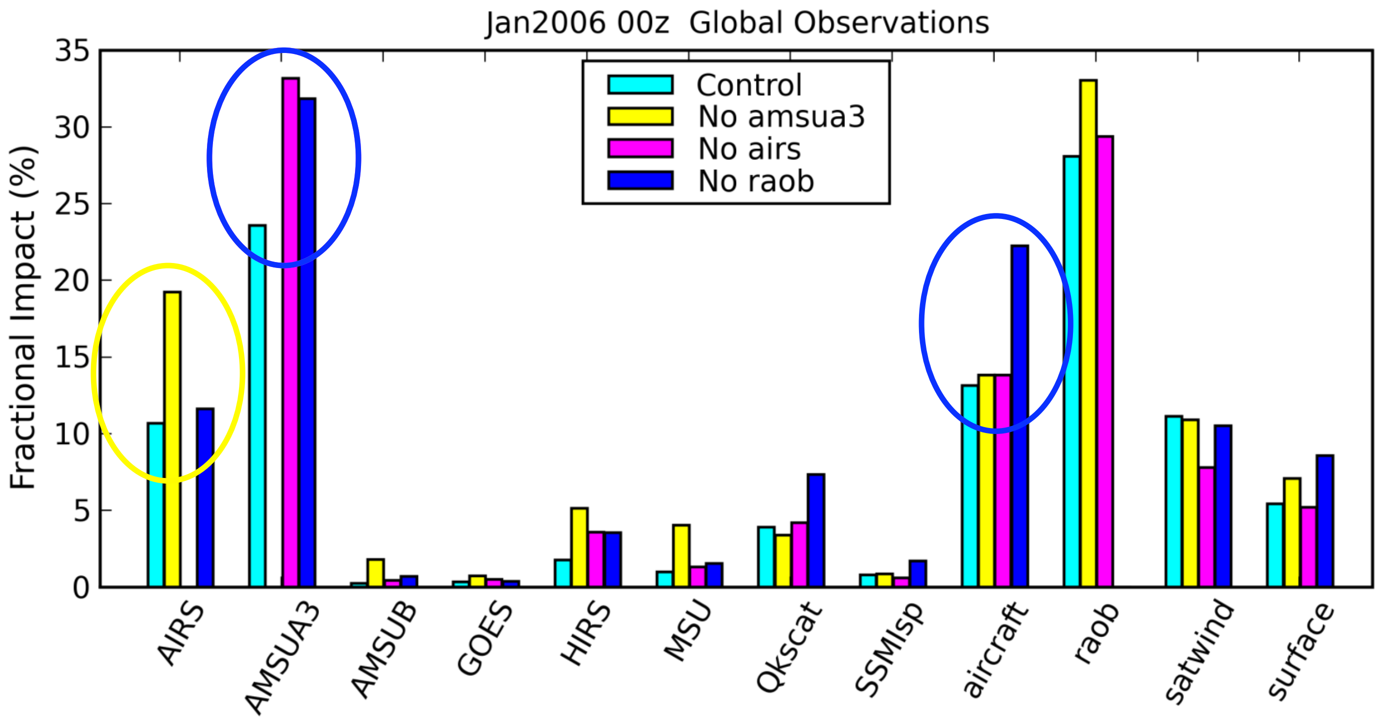
2007 OSEs:

- N-16, N-18, MetOp-2 AMSU
- SSMIS
- AIRS & IASI
- Scatterometer winds
- AMVs
- SSM/I ocean surface wind speed
- Conventional observations

(W. Bell)

Combined Use of ADJ and OSEs (Gelaro *et al.*, 2008)

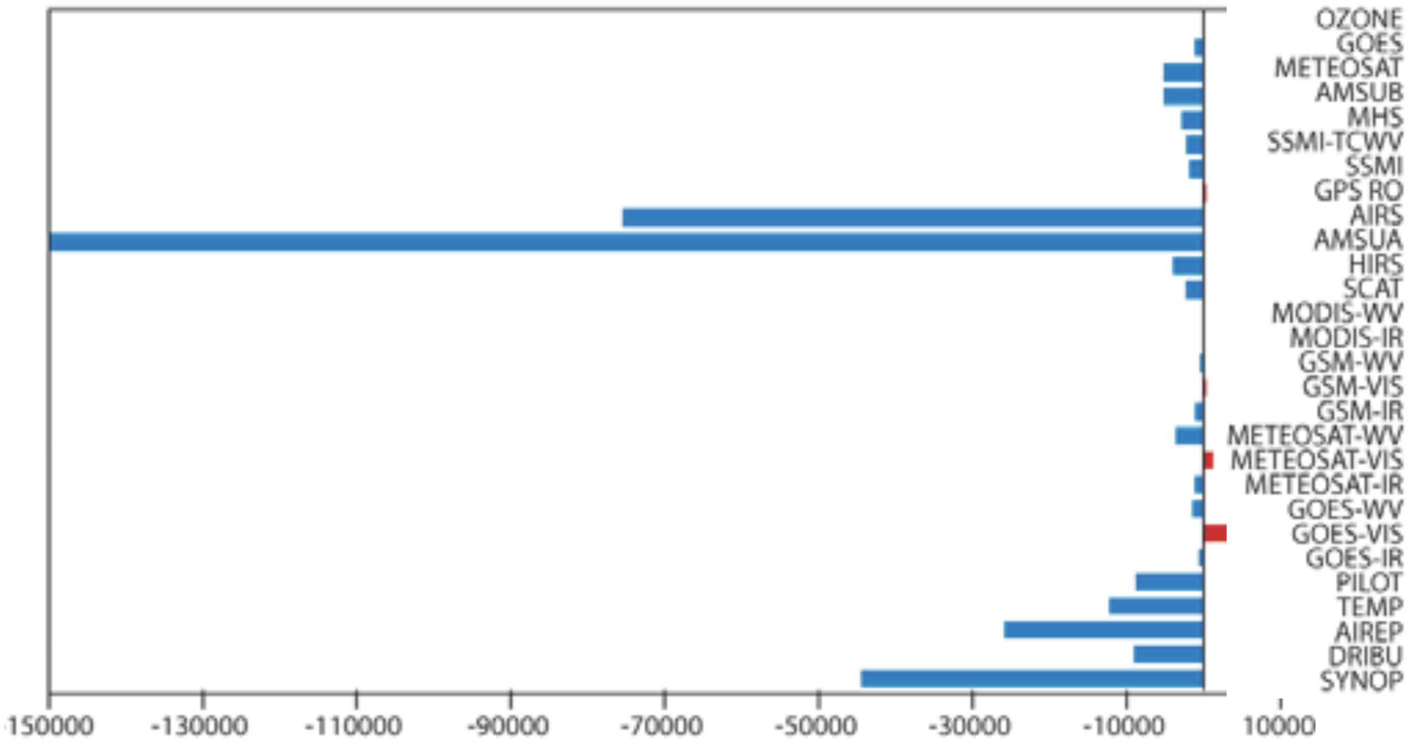
…ADJ applied to *various* OSE members to examine how the mix of observations influences their impacts




- Removal of AMSUA results in large increase in AIRS (and other) impacts
- Removal of AIRS results in significant increase in AMSUA impact
- Removal of raobs results in significant increase in AMSUA, aircraft and other impacts (but not AIRS)

**Forecast sensitivity to observation (FSO) as a diagnostic tool**

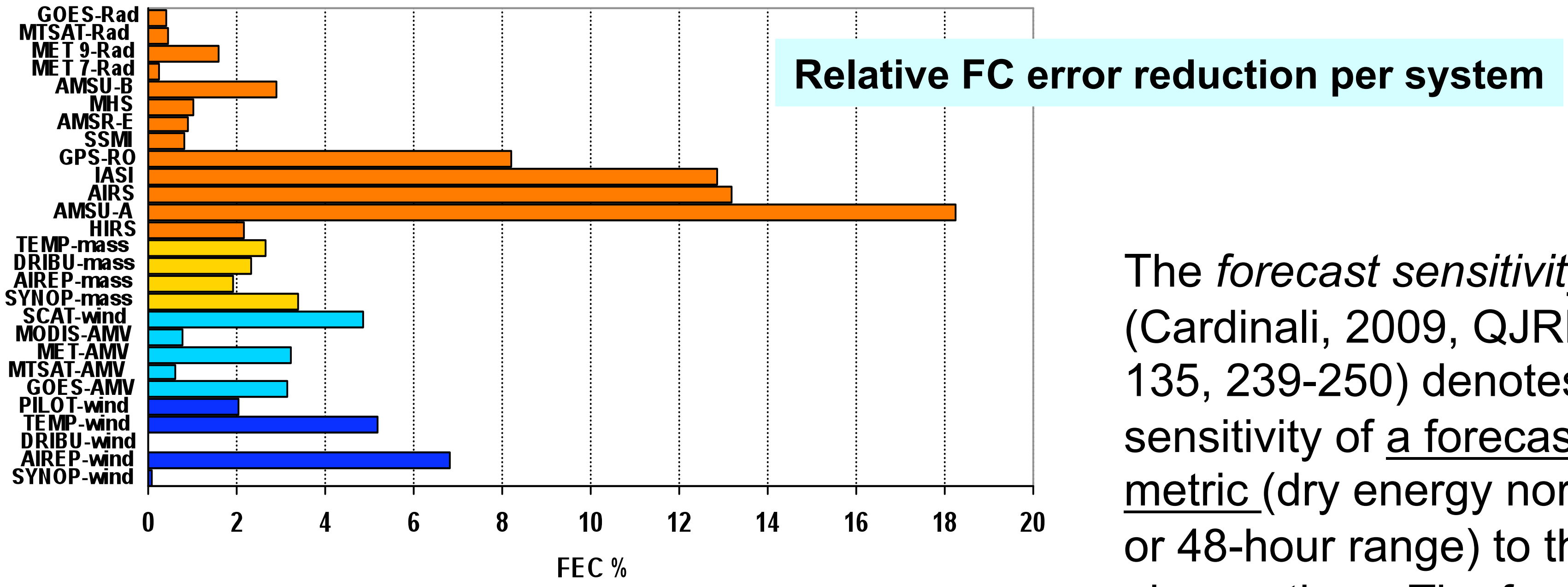
Carla Cardinali, October 2009

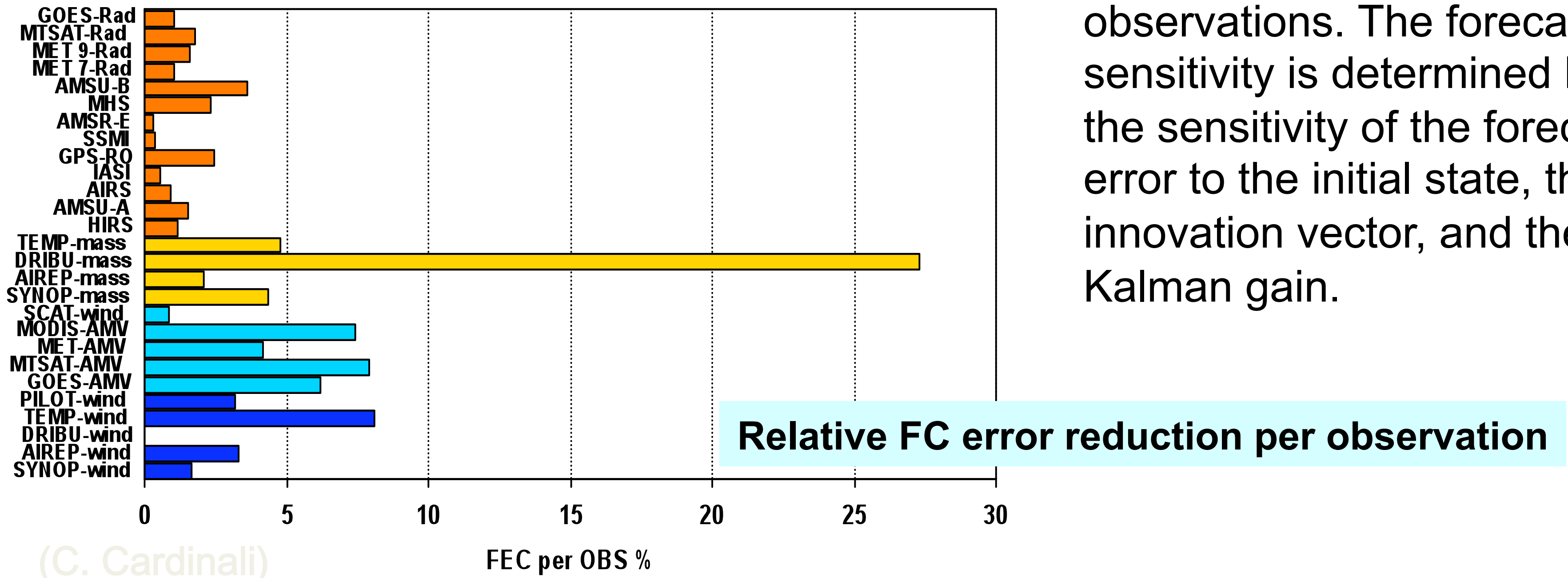



*24-hour forecast error contribution in J/kg of the components (types) of the observing system in winter 2007. Negative (positive) values correspond to a decrease (increase) in the energy norm of forecast error. FSO usesa third order sensitivity gradient.*

The impact of all types of observations on the short-range forecast has increased impressively. It has been shown that microwave satellite measurements (AMSU-A) are responsible for 18% of the forecast error reduction, infrared measurements (AIRS and IASI) for 12% and 10% of error reduction is due to radio occultation observations. Conventional observations (surface pressure, vertical profiler and aircraft) are as well decreasing the forecast error, being responsible for an average reduction of 6%.

# Advanced diagnostics

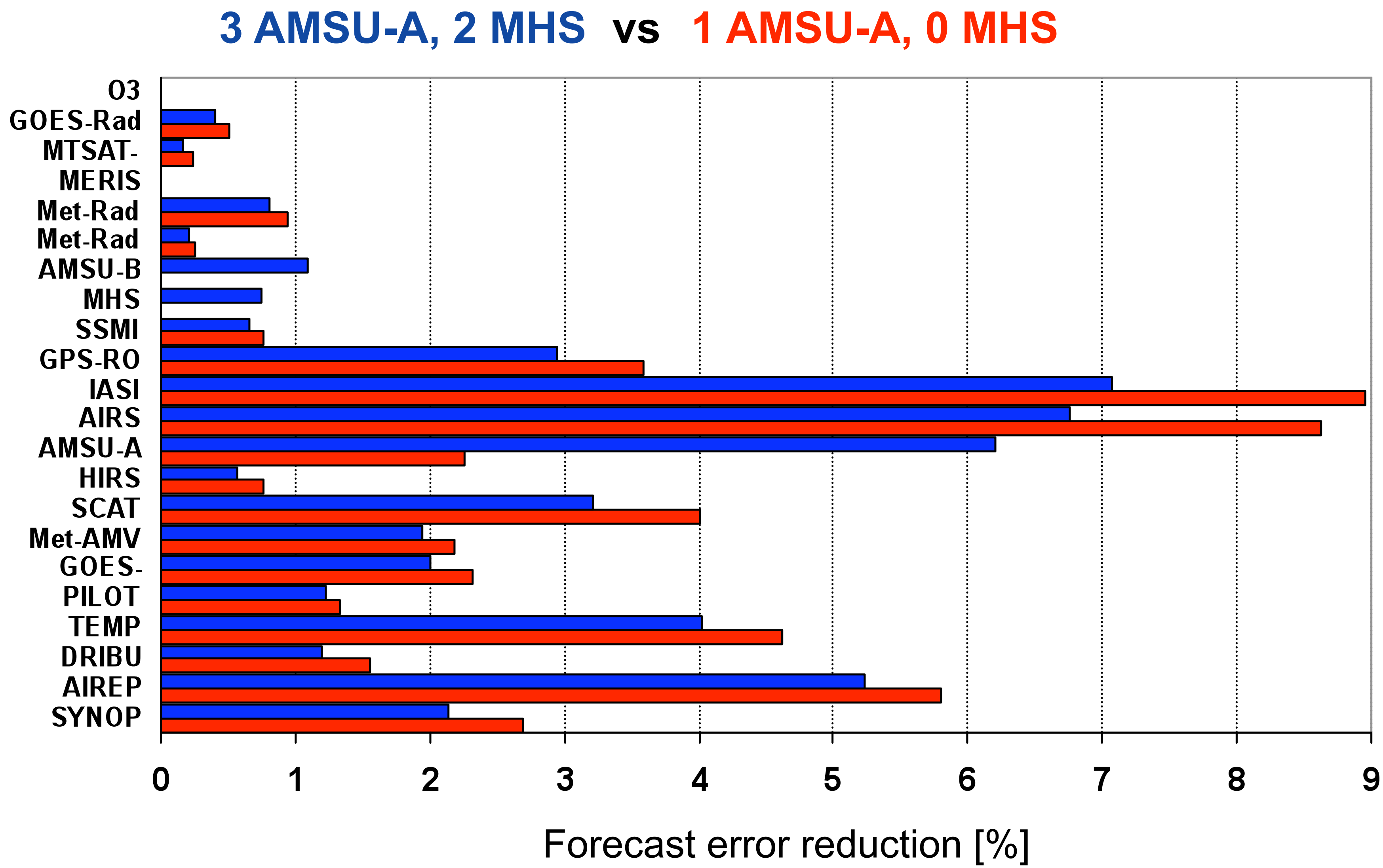



(C. Cardinali)

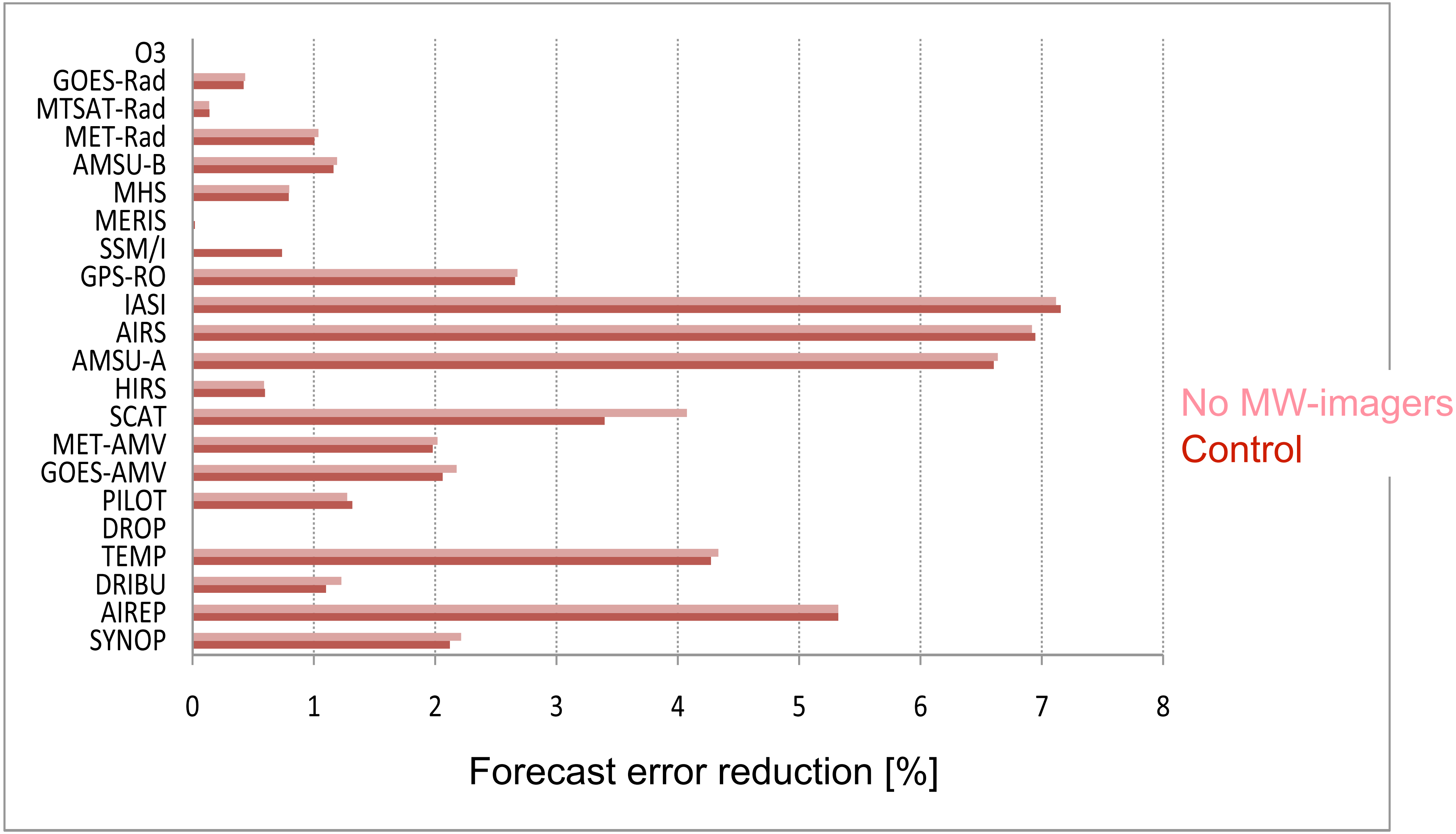
The *forecast sensitivity* (Cardinali, 2009, QJRMS, 135, 239-250) denotes the sensitivity of a forecast error metric (dry energy norm at 24 or 48-hour range) to the observations. The forecast sensitivity is determined by the sensitivity of the forecast error to the initial state, the innovation vector, and the Kalman gain.

# Advanced diagnostics – MW sounder denial




(C. Cardinali)

# Advanced diagnostics – MW imager denial




(C. Cardinali)