Recent developments in the assimilation of satellite data at Météo-France

Florence Rabier

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CNRM-GAME,
Météo-France and CNRS

METEO FRANCE
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Outline

Model and use of observations

Use of AIRS and IASI

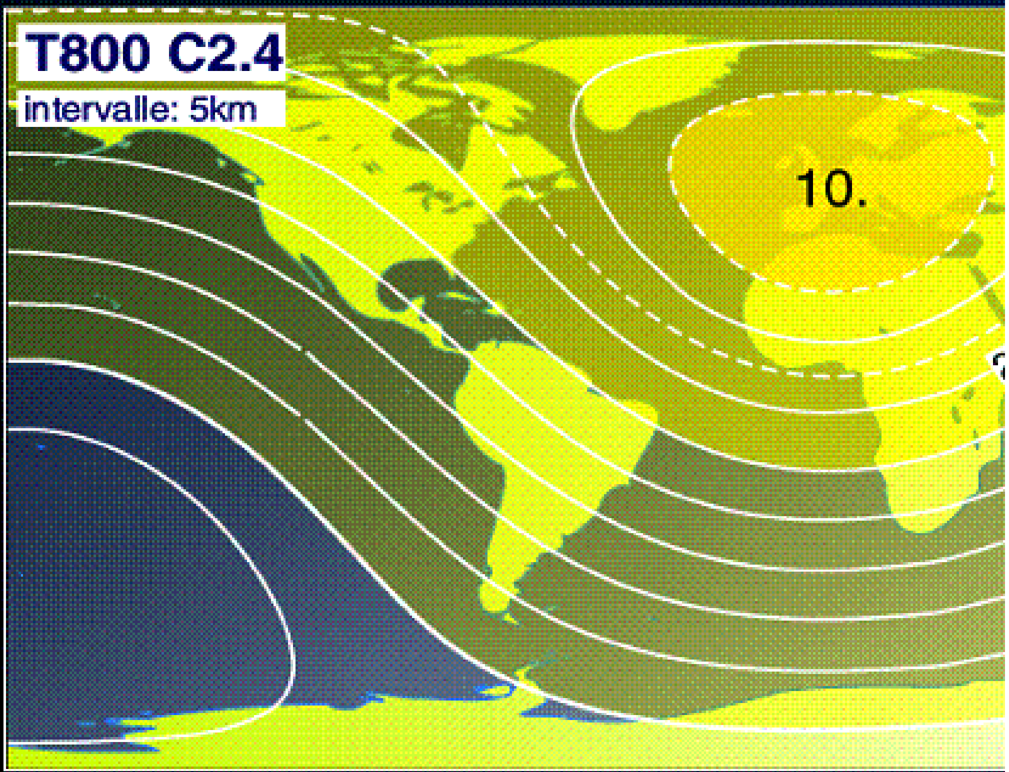
Preparation for SSMIS

Use of microwave data over land and sea-ice

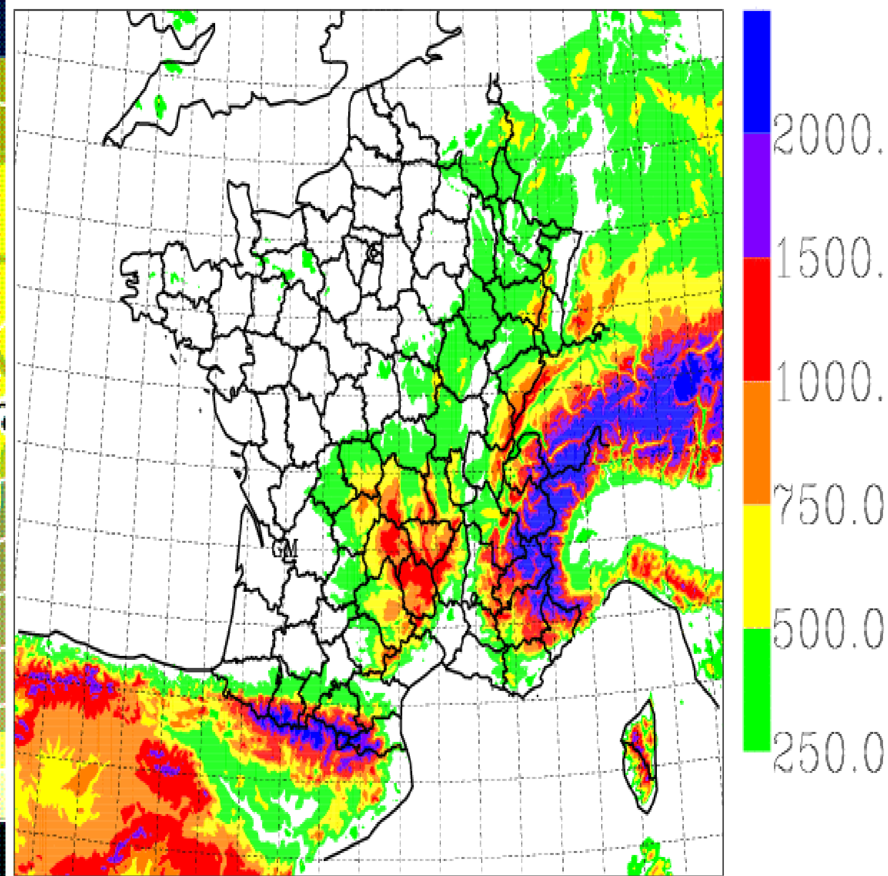
The Concordiasi project

The operational models: ARPEGE and AROME

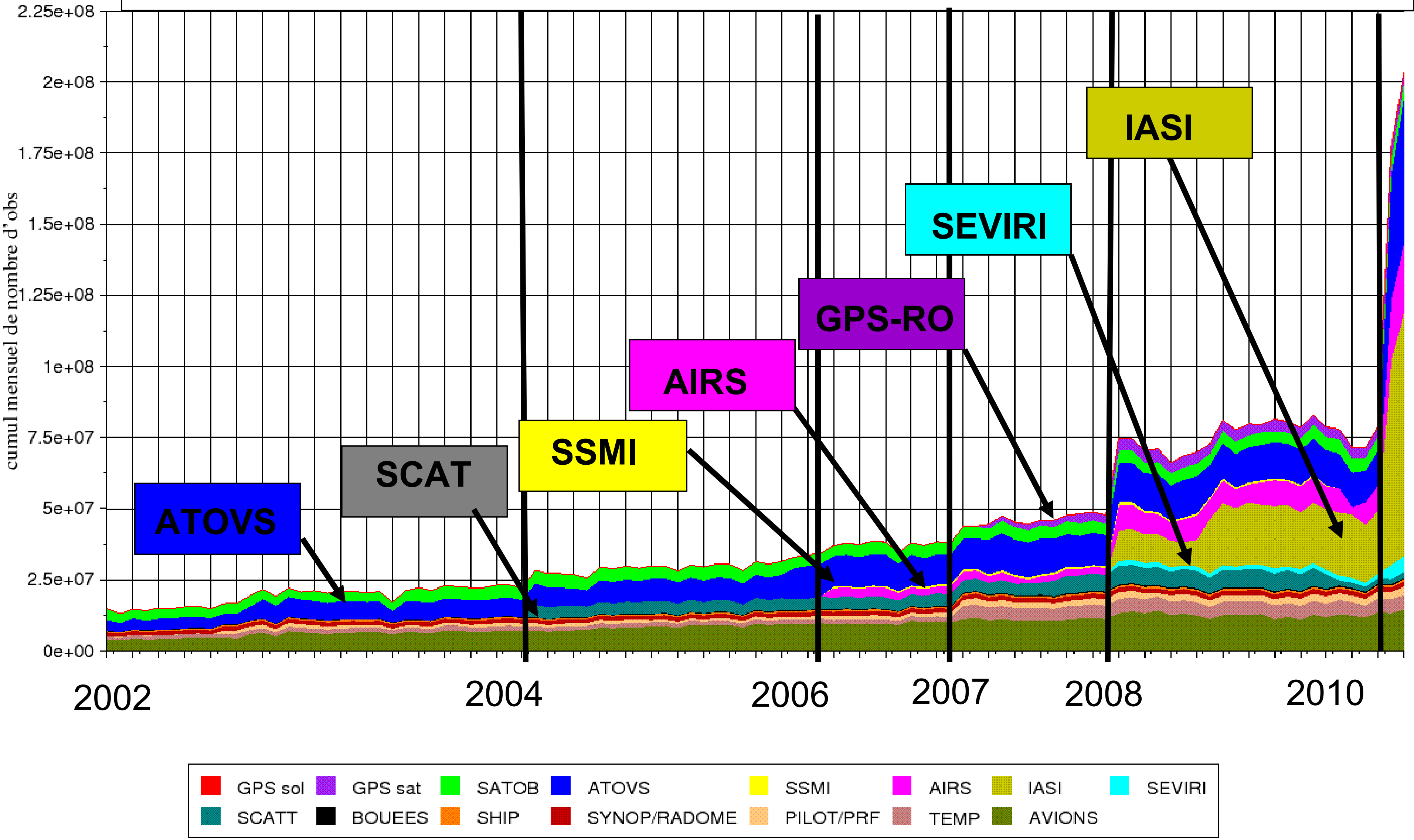
ARPEGE



AROME



Monthly number of observations used in the global model



Use of AIRS and IASI

IASI

- **"long wave" temperature and water vapour** channels
- **Clear conditions** (1 flag/channel, McNally & Watts, 2003)

	Number of channels used
Open sea	**77** channels
Land	**59** channels
Sea ice	**41** channels

AIRS

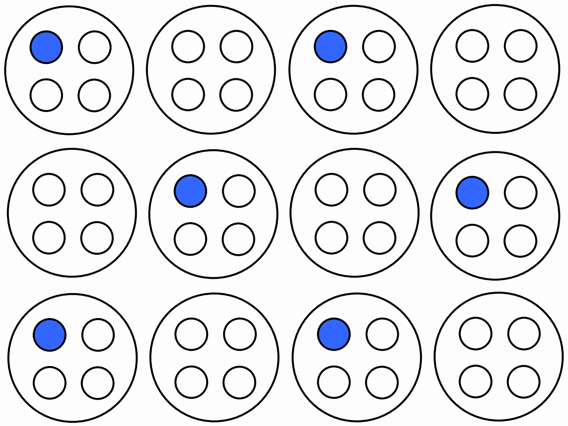
- **"long wave" temperature** channels
- **Clear and cloudy** conditions
- **Over open sea**

		Number of assimilated channels
Clear		**54** channels
Cloudy		**54** channels

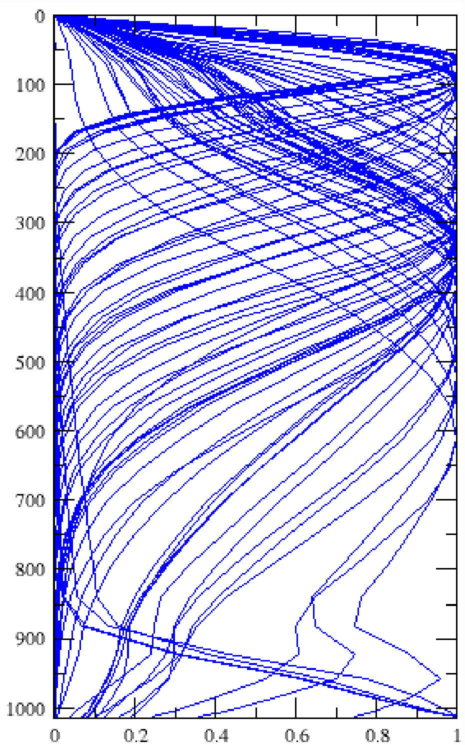
IASI pixel and channel selection

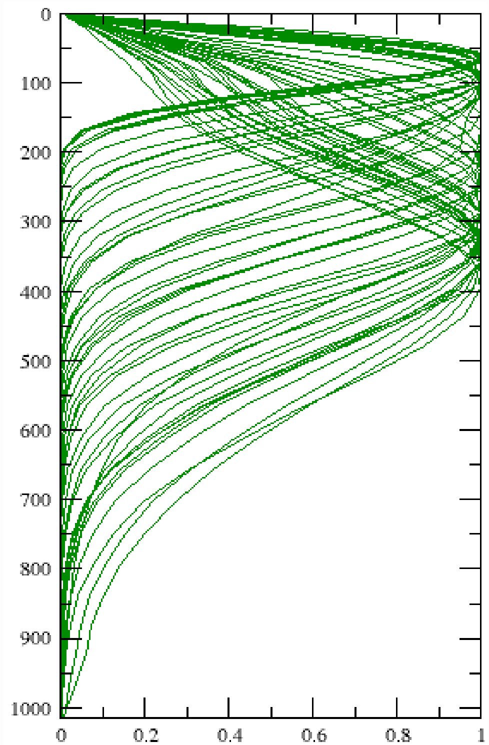
Pre-selection:

- Only data from detector #1
- Pattern depending on scanline→



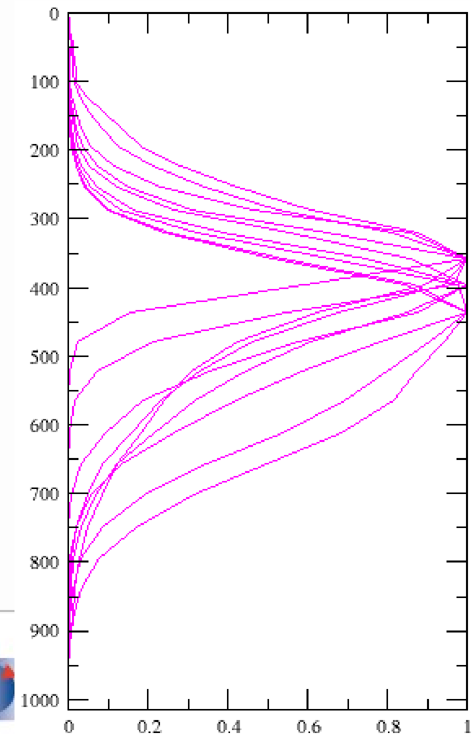
Geographical thinning: 1 prof. / 125km





9 WV channels

LW - T
68 over sea
50 over land



Method used for the assimilation of AIRS cloudy radiances affected by mid- to low-level clouds

Cloud parameters determined with CO2slicing (120 channels)

Minimisation of $F_{k,p}$

$$F_{k,p} = \frac{(R_{clr}^{k} - R_{obs}^{k})}{(R_{clr}^{K_{ref}} - R_{obs}^{K_{ref}})} - \frac{(R_{clr}^{k} - R_{cld}^{k,p})}{(R_{clr}^{K_{ref}} - R_{cld}^{k_{ref},p})}$$

Robs: observed radiance
Rclr: clear radiance simulated from the model
Rcld: radiance with opaque cloud at pressure level p
k= channel of the C02 band
Ref= reference channel (surface)
= 917.31 cm-1 (AIRS)

Cloud top pressure: emissivity

Effective cloud

$$p_c = \frac{\sum p_{c,k} w_k^{2}}{\sum w_k^{2}}$$

$P_{c,k}$: pressure level minimizing $F_{k,p}$
W_k: derivative of $F_{k,p}$ wrt pressure

$$N_{\varepsilon} = \frac{(R_{clr}^{k_{ref}} - R_{obs}^{k_{ref}})}{R_{clr}^{k_{ref}} - R_{cld}^{k_{ref}}}$$

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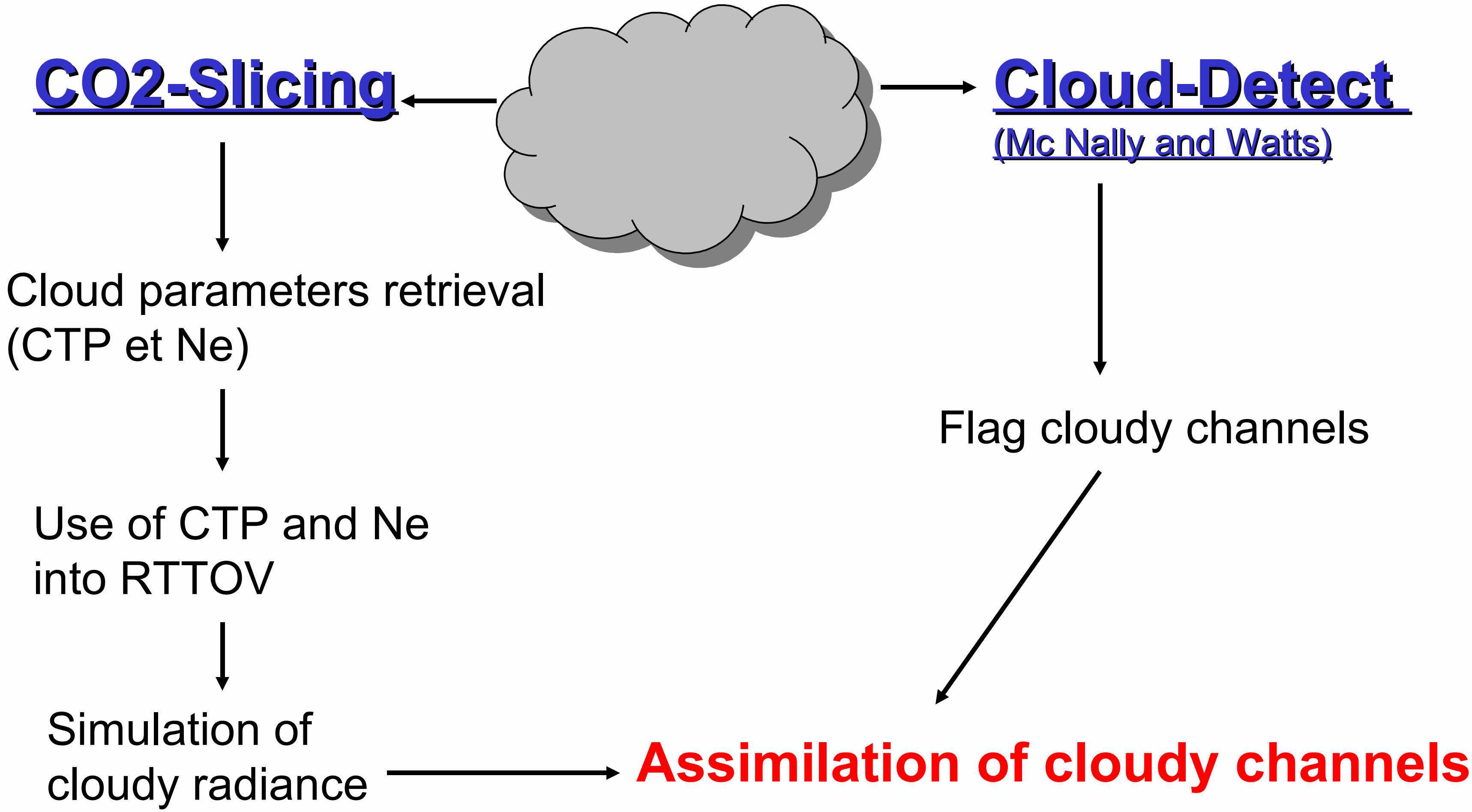
Method

Pangaud et al, 2009

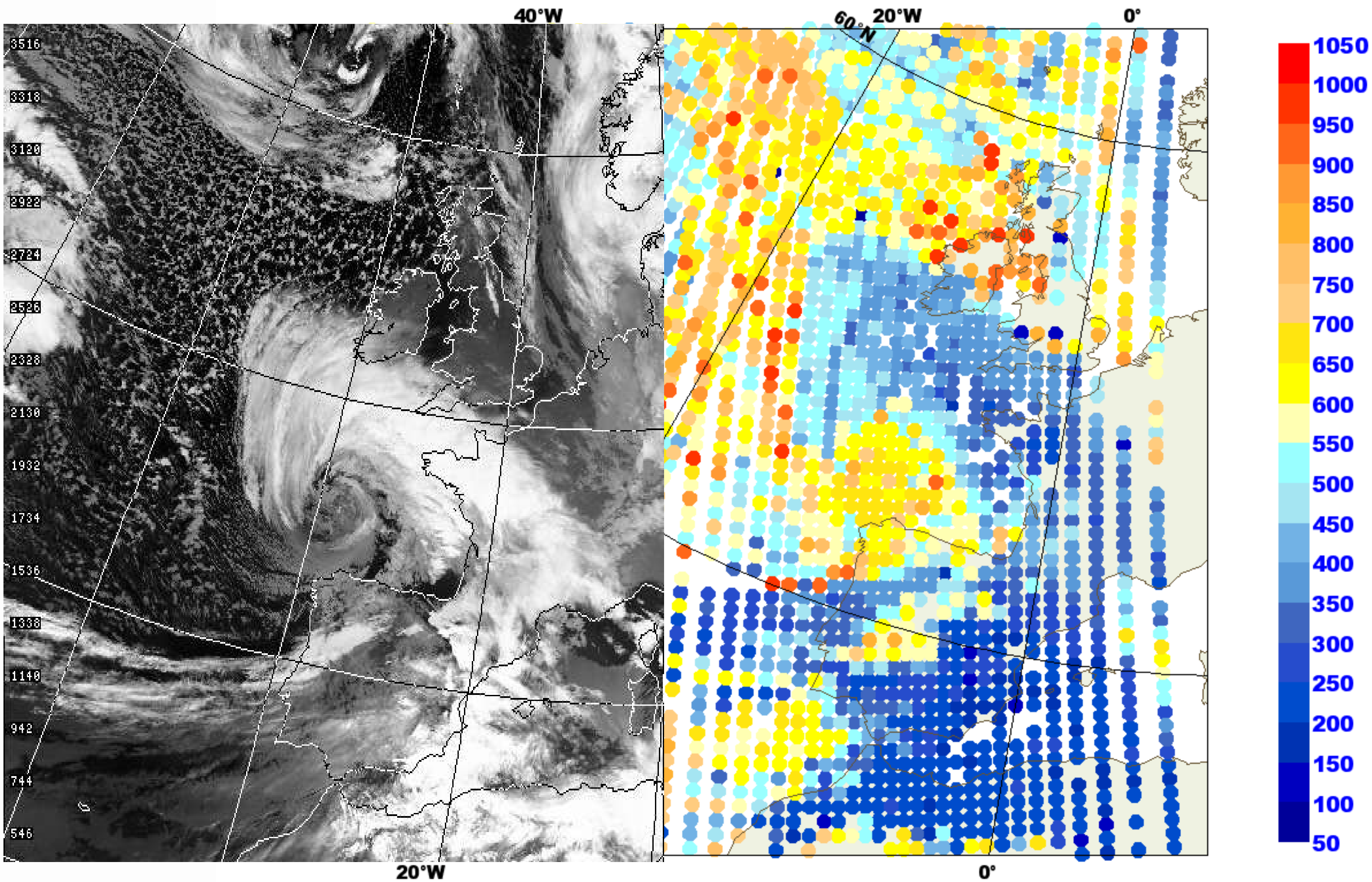


- 600hPa<CTP<950hPa
- AIRS: sigma_o(cloudy) = sigma_o(clear) = 1K

Operational since February 2009

IASI cloudy radiances :Preliminary results

KLAUS: Cloud top pressure for 24 January 2009, 00 UTC



AVHRR channel 5, 23 january 2009
21H41UTC

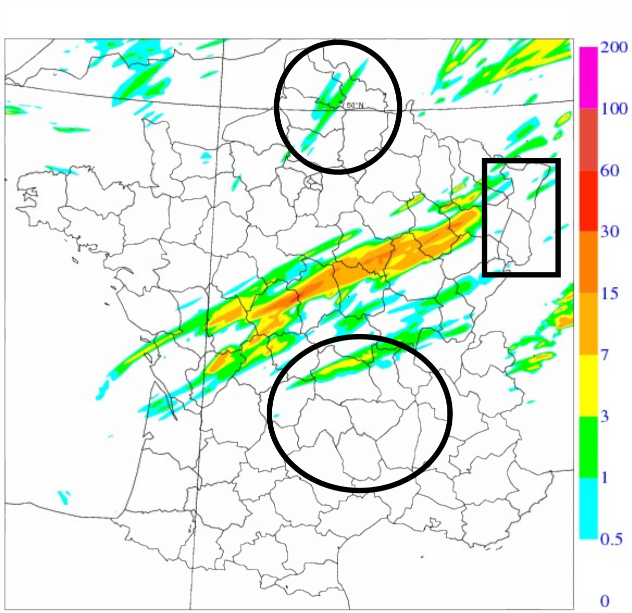
N. Fourrié

IASI in AROME

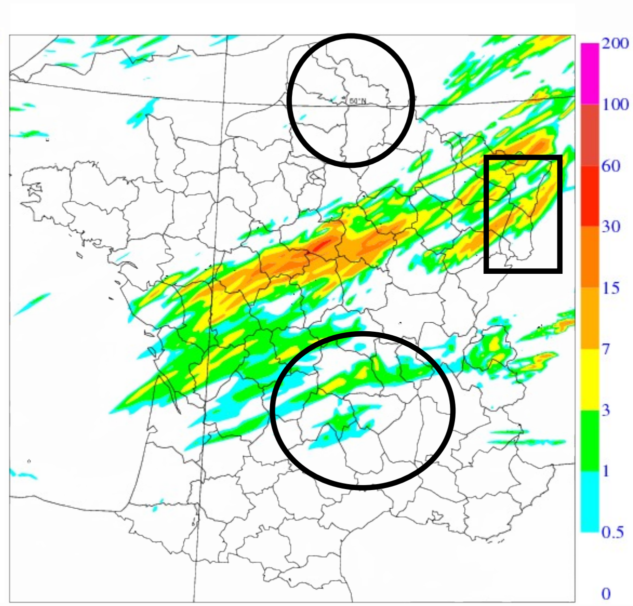
Impact on precipitation prediction

example of 12h precipitation between 00 and 12UTC on 21 May 2009

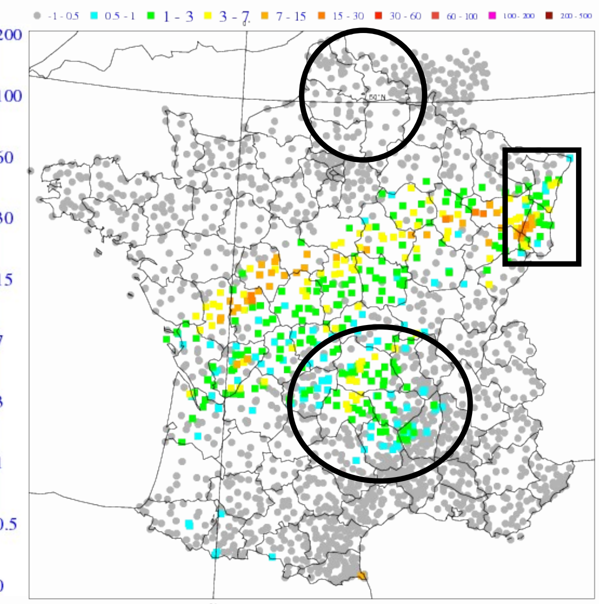
12h forecast range



Reference: no IASI



Use of IASI at 125km



Verif.: Rain gauges

Guidard et al, 2010

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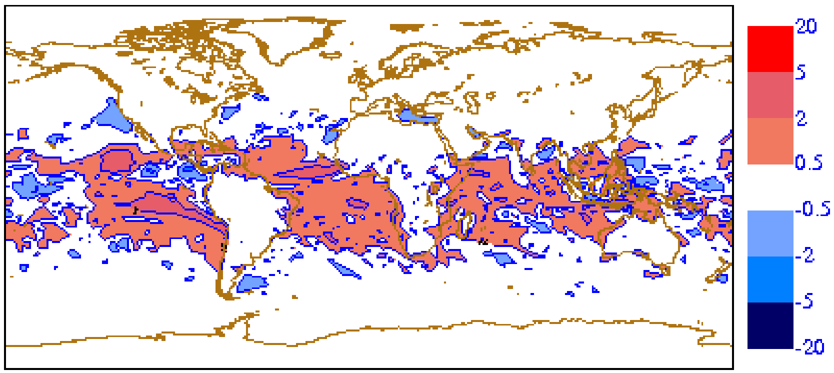
Experimental assimilation of SSMI/S

Exp: with SSMI/S imager

Ctr: without SSMI/S

Exp-Ctr TCWV analysis difference
Mean= 0.239 $kg.m^{-2}$ (+1%)



Moistening of model/analysis

Δ(TCWV) (Exp-Ctr)/Ctr	All points	Land points	Sea points
Globe	+1.0%	+0.8%	+1.1%
NH	-0.3%	+0.3%	-0.5%
Tropics	+1.6%	+1.0%	+1.8%
SH	+0.5%	+0.8%	+0.5%

E. Gérard

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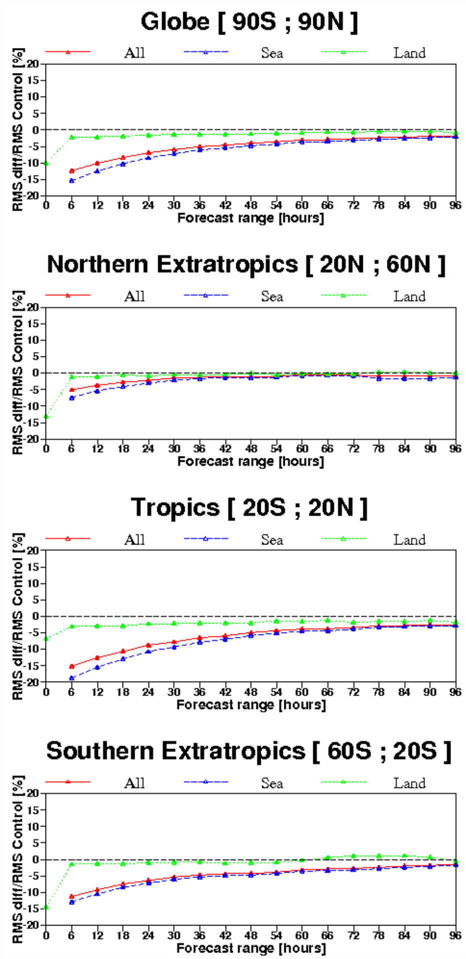
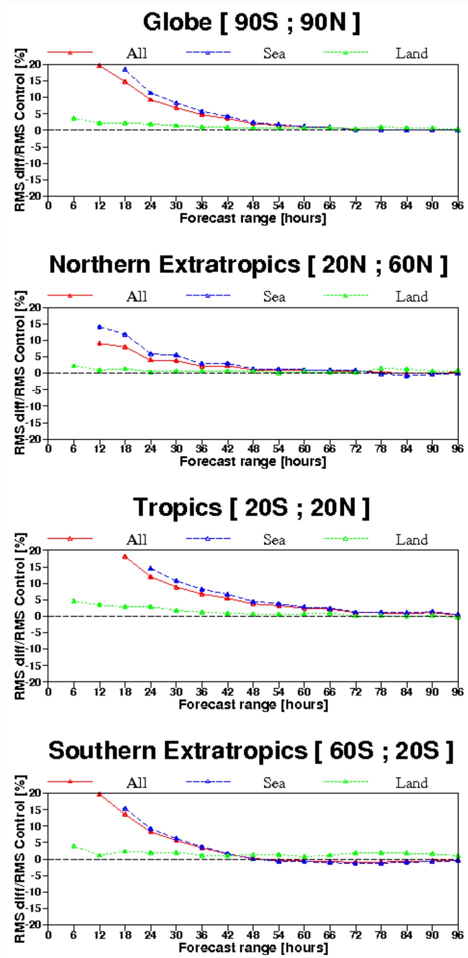
TCWV forecast normalised RMS reduction

wrt ECMWF analysis



wrt own analysis



+ Improvement of forecast scores,

especially in the Tropics

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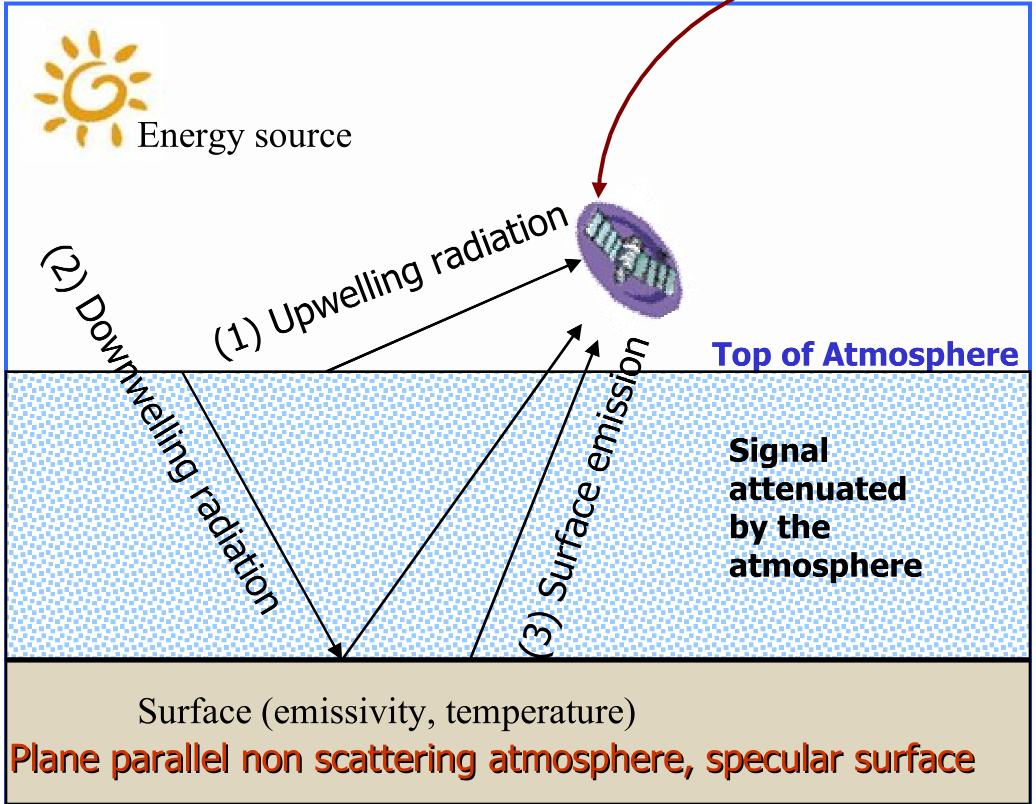
Assimilation of AMSU-A & AMSU-B over land and sea-ice

Since July 2008, a "dynamical retrieval method" is used in ARPEGE to estimate the land surface emissivity at microwave frequencies

• Instantaneous emissivity retrieval at one surface surface channel (Ch1=89 GHz for AMSU-B and Ch3=50 GHz for AMSU-A)

• The emissivity is then assigned to sounding channels (with no frequency dependency)

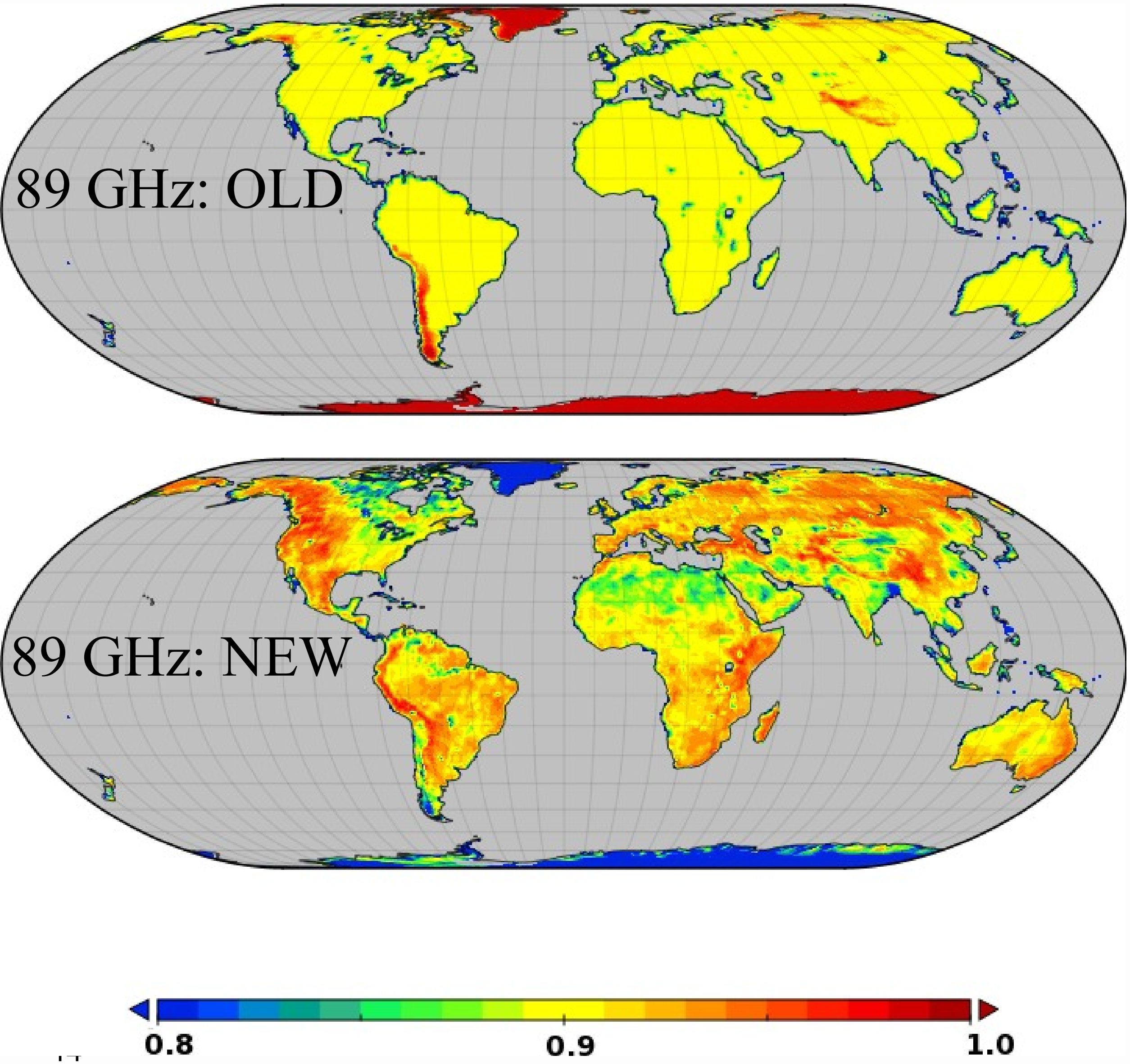
$$T(p,\upsilon) = \varepsilon(p,\upsilon).Ts.\tau + (1-\varepsilon(p,\upsilon)).\tau.T(\upsilon,\downarrow) + T(\upsilon,\uparrow)$$



$$\varepsilon(p,\upsilon) = \frac{T(p,\upsilon) - T(\upsilon,\uparrow) - T(\upsilon,\downarrow)\times\tau}{\tau\times(Ts - T(\upsilon,\downarrow))}$$

Karbou et al. 2006

Land emissivity at AMSU-B frequencies



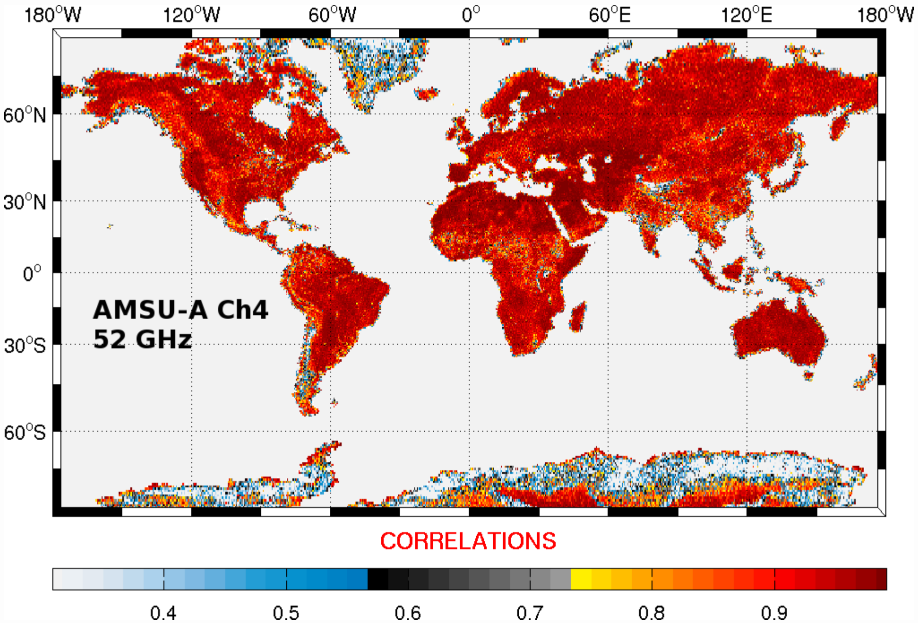
Land surface emissivity : regression version of models ➔ eased the assimilation of sounding channels

Since July 2008, operational implementation of a new land surface emissivity parameterization

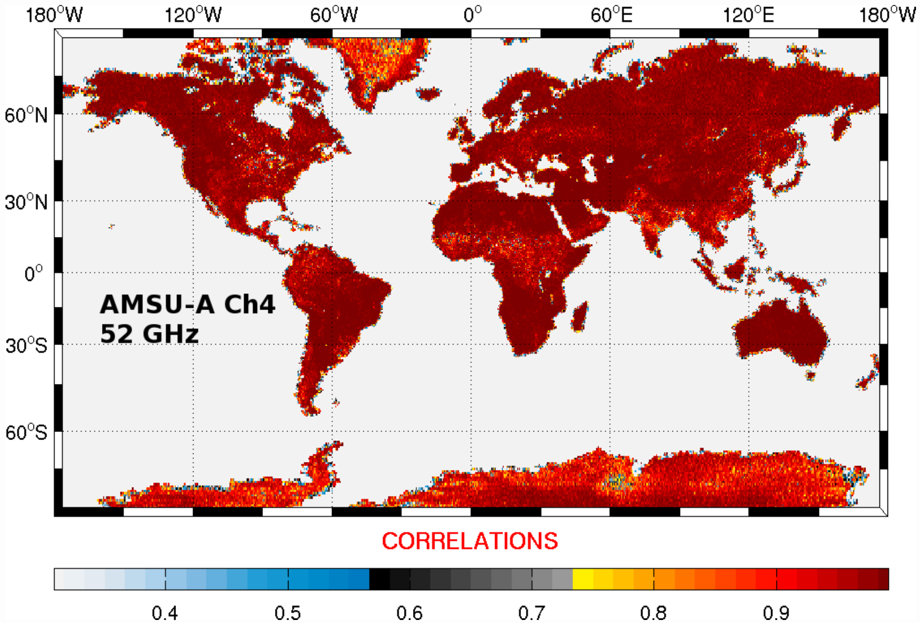
Land emissivity at AMSU frequencies

elations between Obs and RTTOV Sim., AMSU-A ch4, August 2006

CTL



CTL + dynamical emis.



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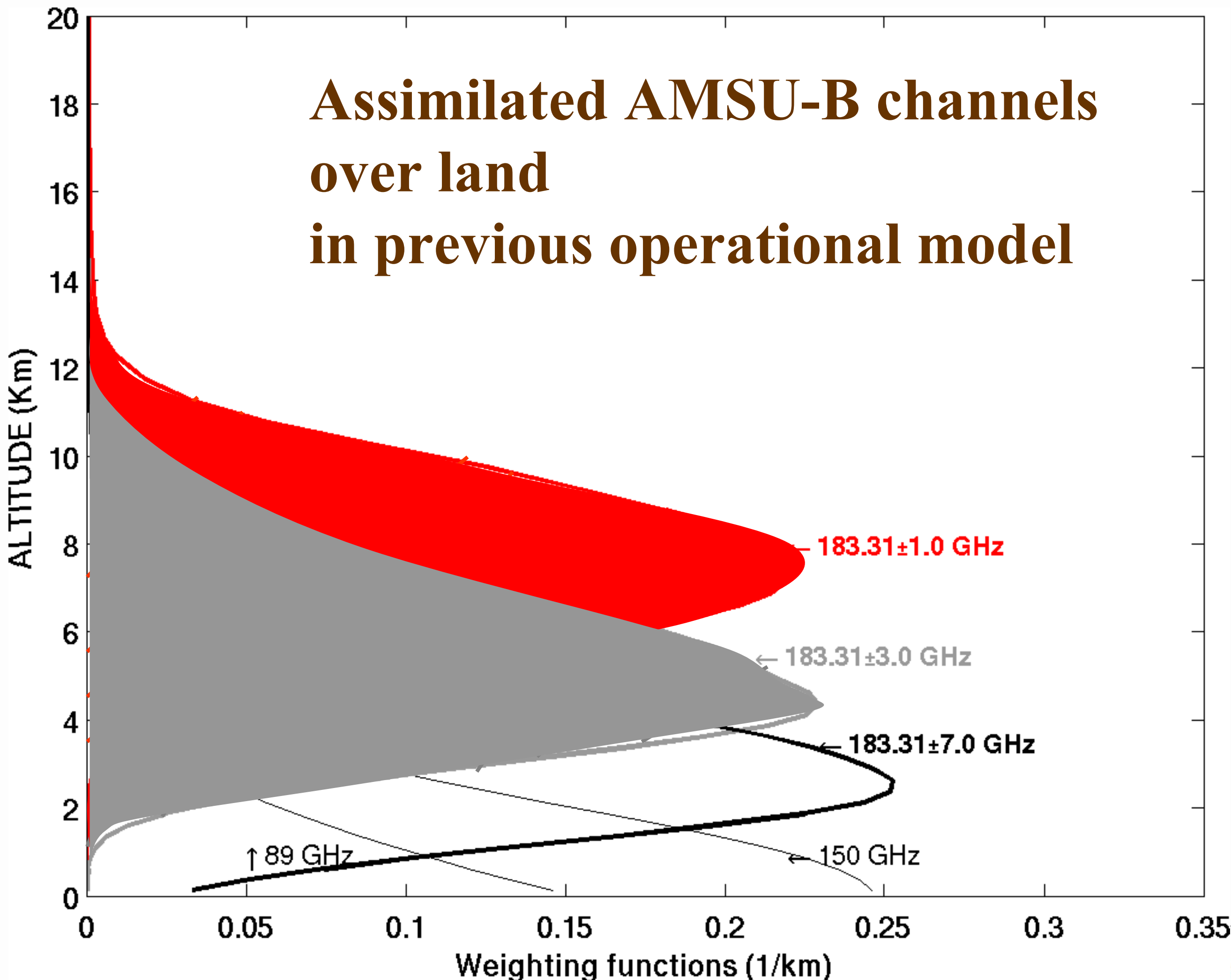
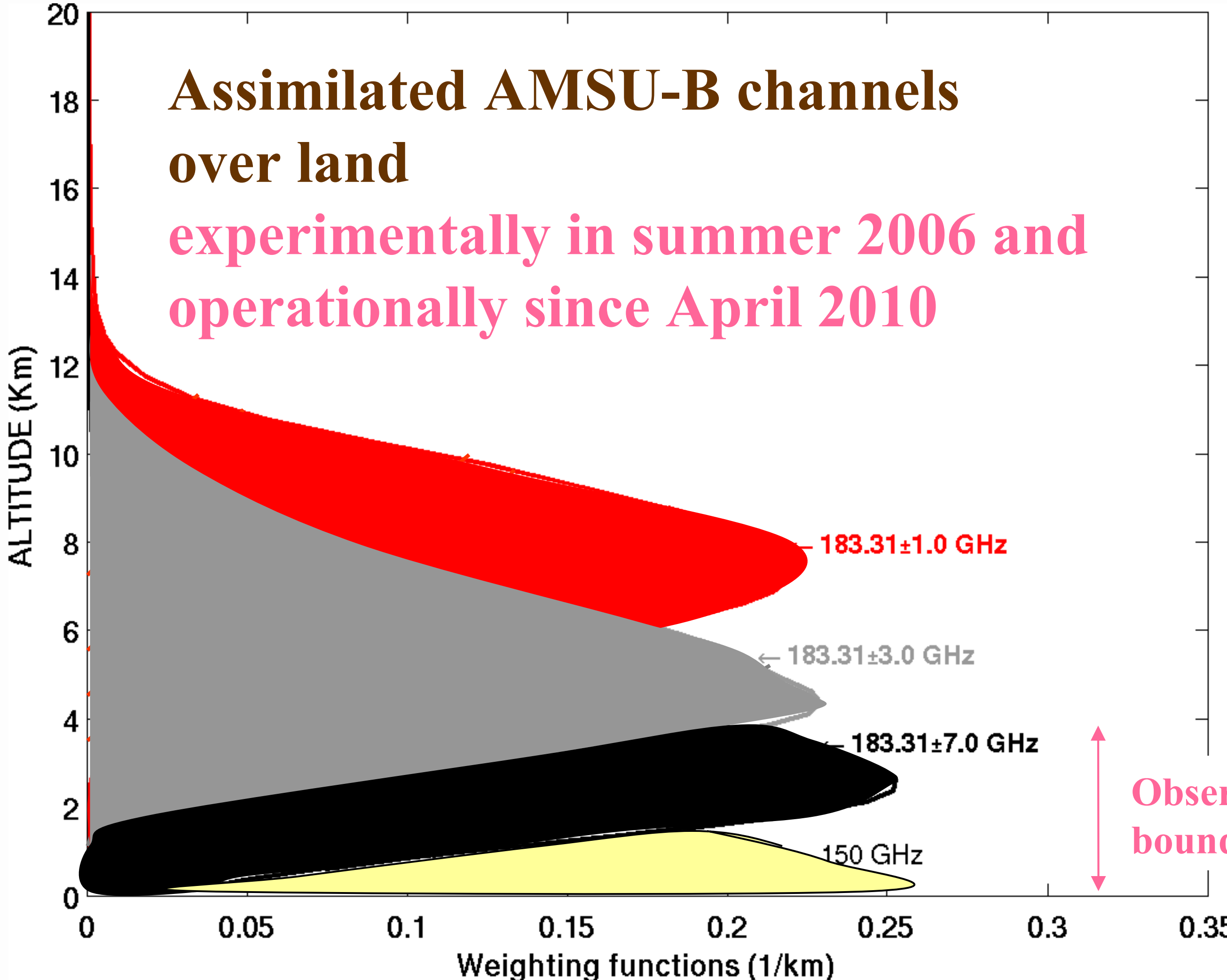
Assimilation of surface sensitive channels over land



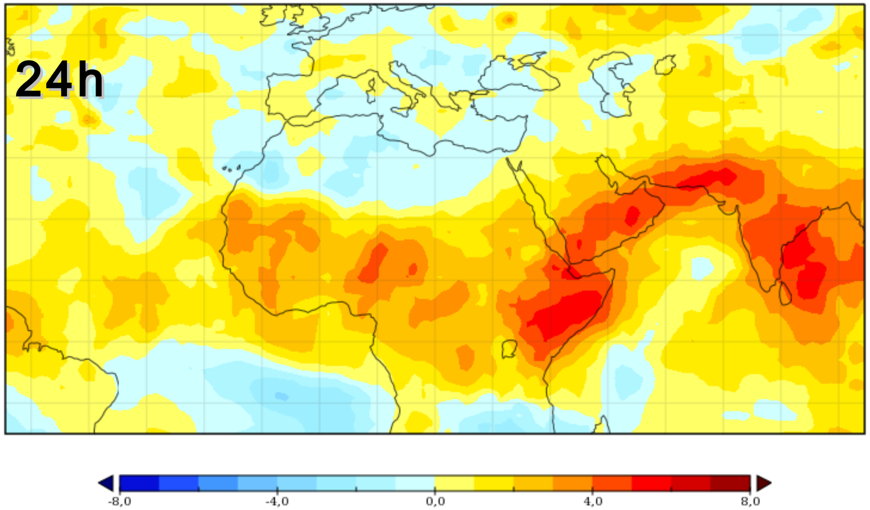
Assimilation of surface sensitive channels over land



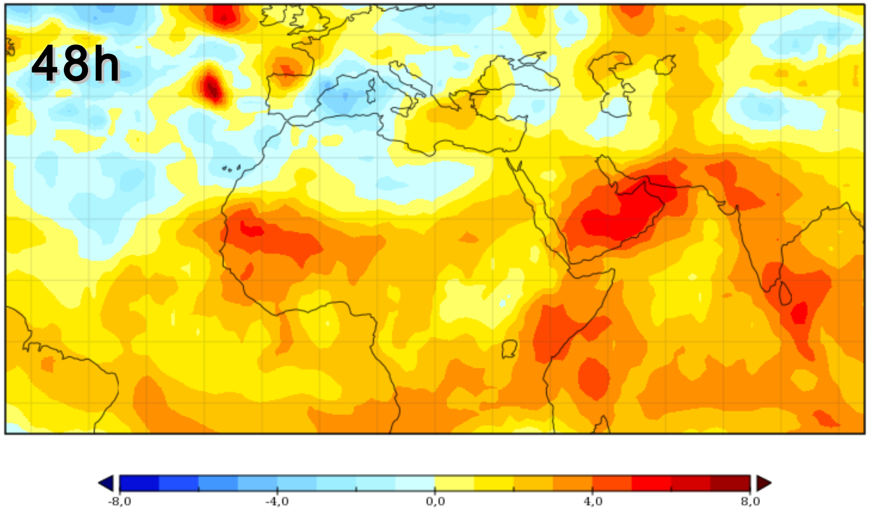
Observations of the boundary layer over land

Assimilation of surface sensitive channels over land: Effect on forecasts

Differences of geopotential forecast errors with respect to analyses (CTL-EXP), 200hPa, 1month



Smaller errors in EXP



Smaller errors in EXP

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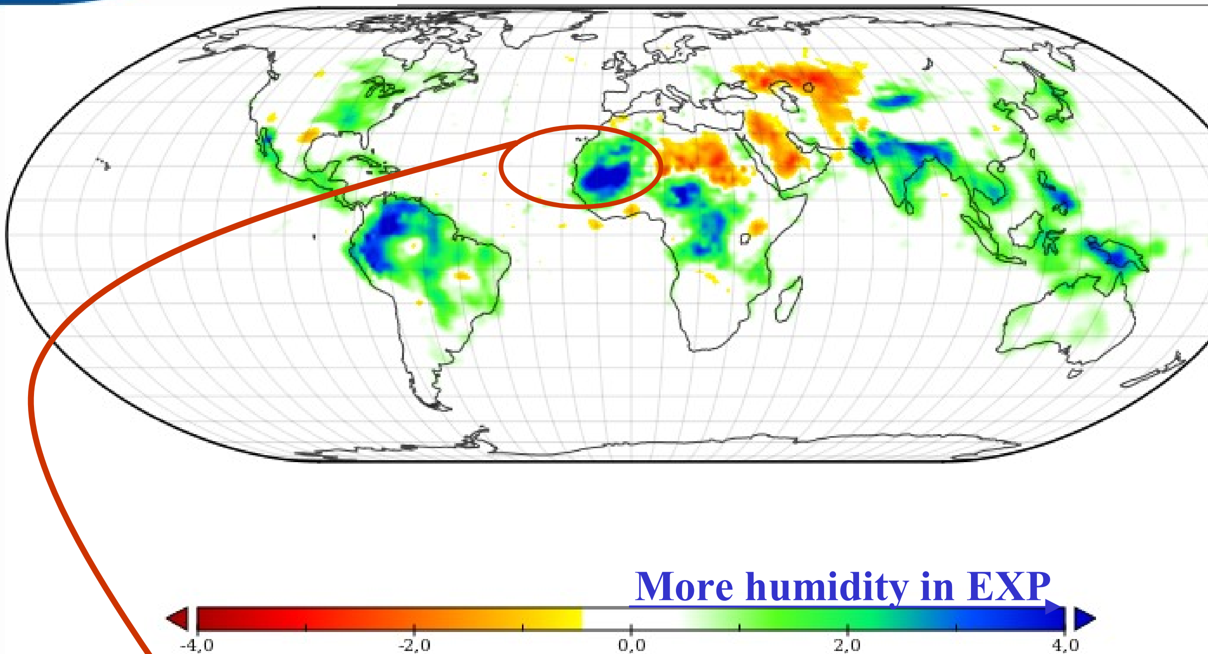
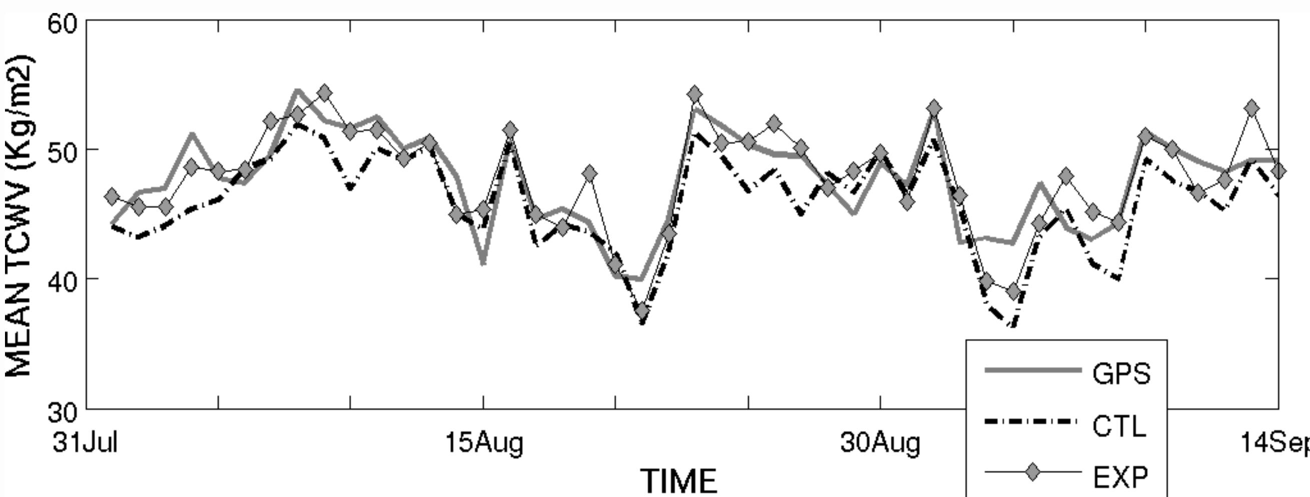
Assimilation of surface sensitive channels over land: Effect on analyses



TCWV (EXP-CTL)

Evaluation against GPS measurements

TCWV daily time series, Ouagadougou



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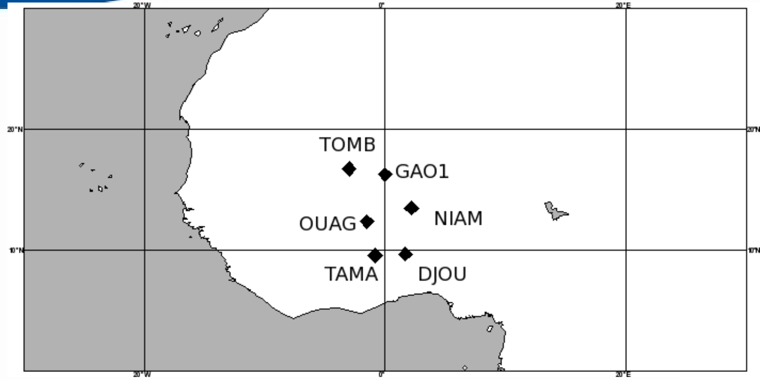
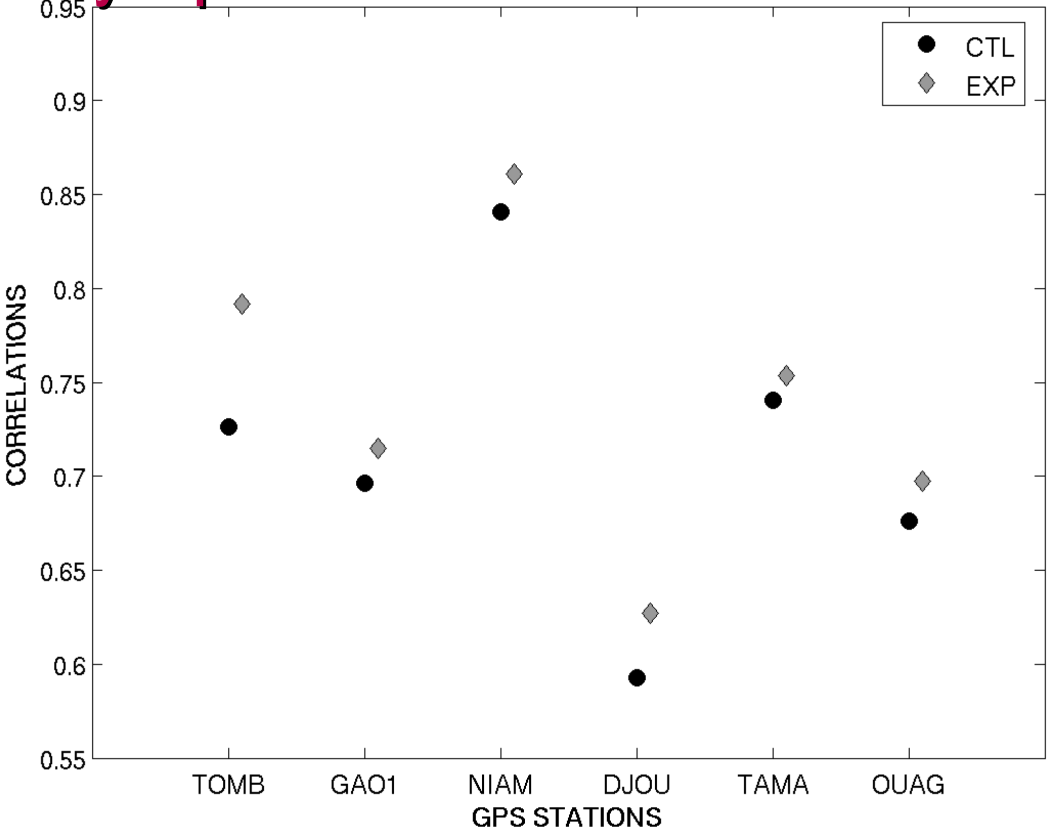
Assimilation of surface sensitive channels over land: Effect on analyses



Correlations with GPS, 45 days, synoptic times



AMSU over land: Conclusions

- A good representation of land surface emissivity motivated assimilation studies to assimilate low level humidity observations (usually blacklisted)
- The assimilation of these channels:
  - Positive impact in scores wrt radiosondes, analyses
  - Large impact on humidity analysis (& temp., wind) over the Tropics: low to mid-levels
  - TCWV Change evaluated against independent GPS measurements

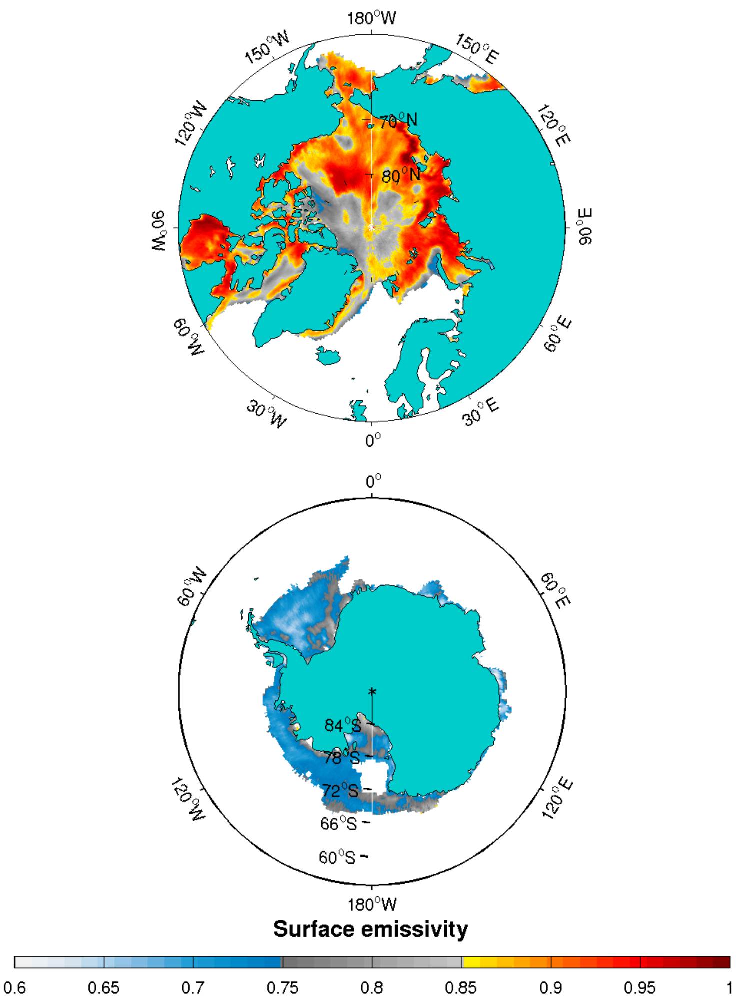
Assimilation of AMSU surface sensitive observations: operational at Météo-France since 6th April 2010.

Karbou et al. 2010a-b

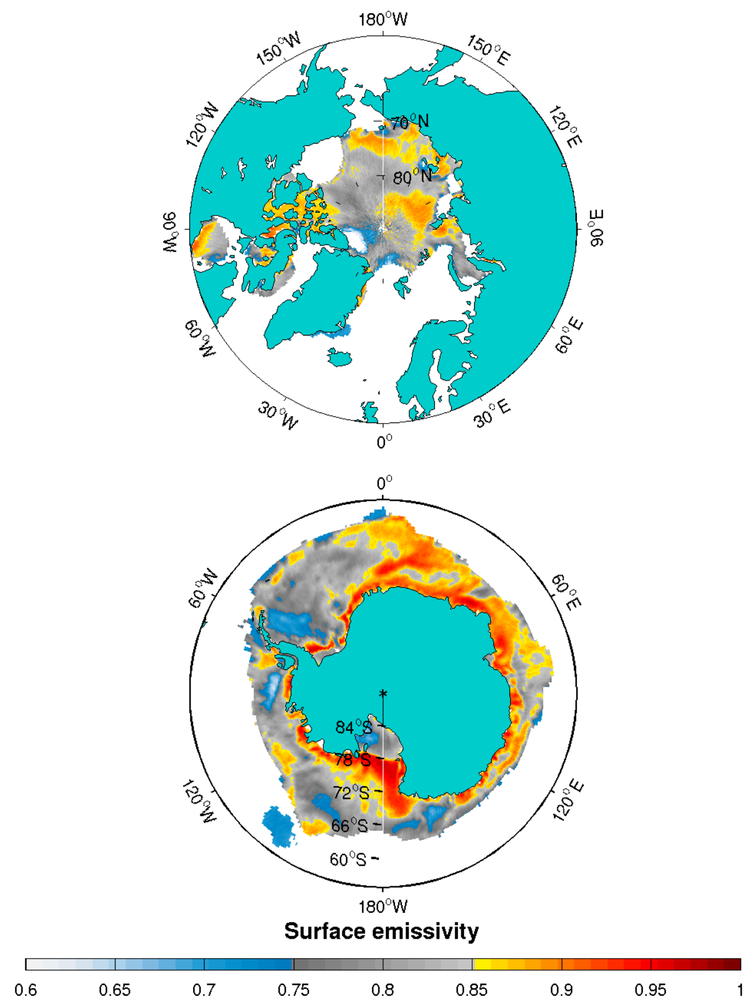
Emissivity for AMSU-A & AMSU-B over sea-ice

Surface emissivity at 89 GHz

January

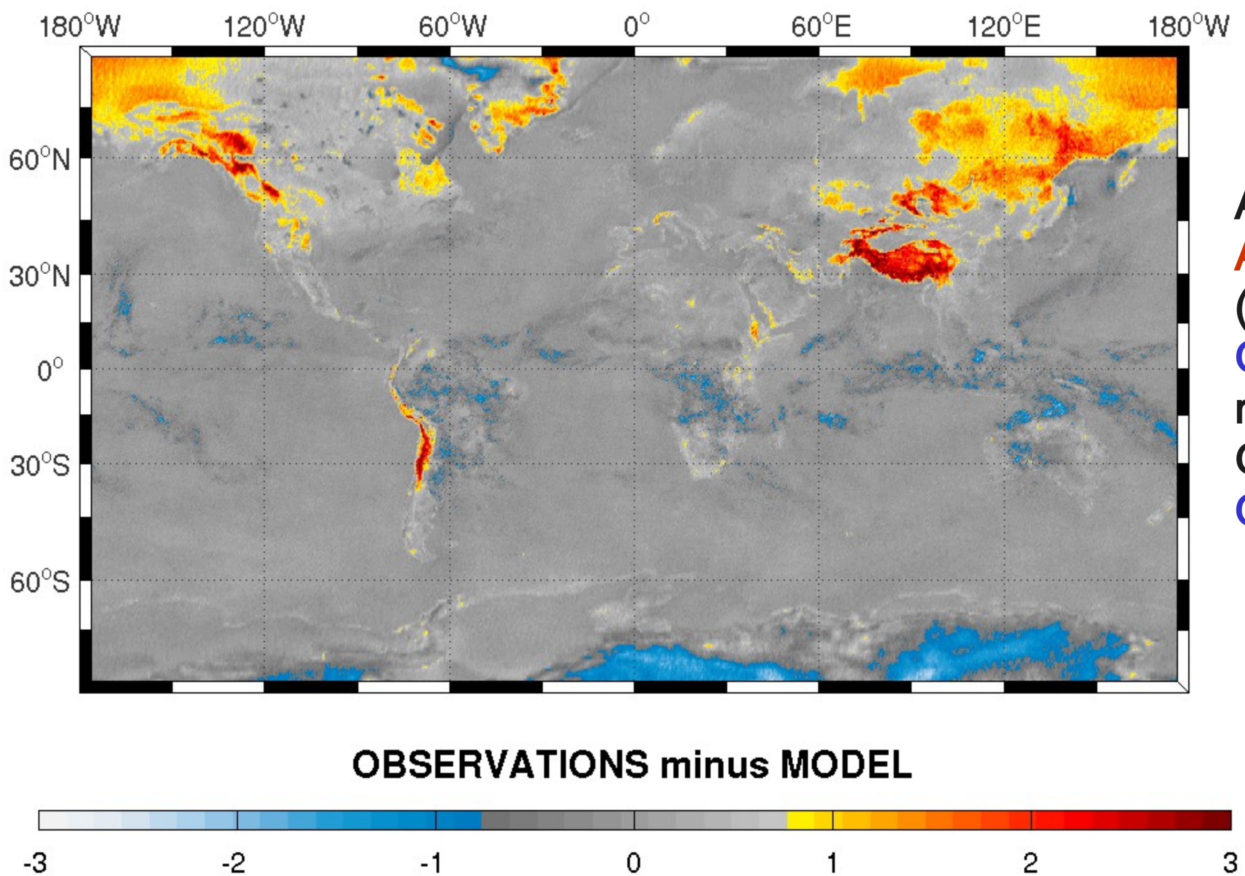


July 2009



Assimilation of AMSU-A & AMSU-B over sea-ice

For AMSU-A: we can safely use the 50 GHz emissivity for temperature sounding (52-60 Ghz) over sea ice;
Over snow, the specular assumption can introduce biases



AMSU-A channel 5 (53 GHz)
All observations
(One week of data)
Over land & sea-ice: retrieved emissivity at 50 GHz
Over sea: FASTEM model

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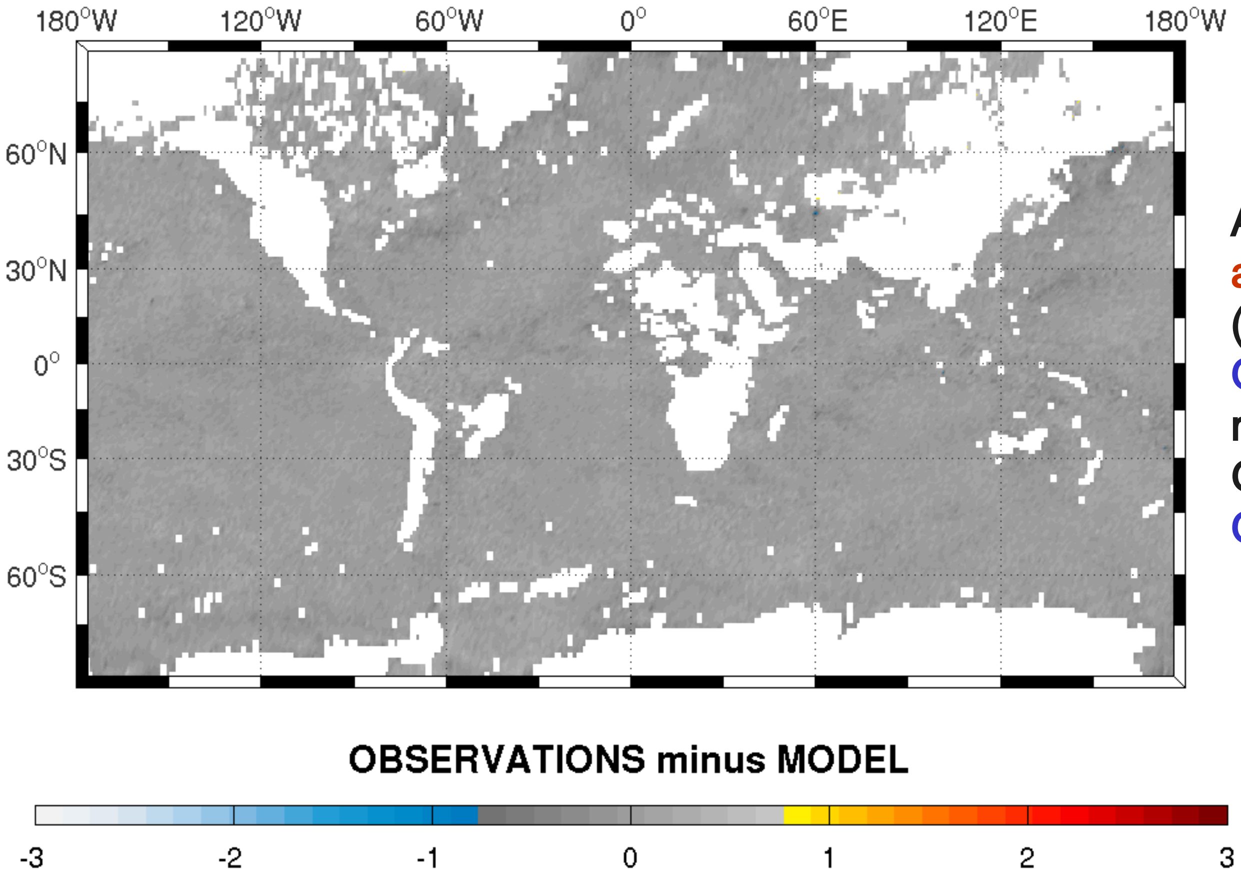

AMSU-A channel 5 (53 GHz) assimilated observations (One week of data)
Over land & sea-ice: retrieved emissivity at 50 GHz
Over sea: FASTEM model

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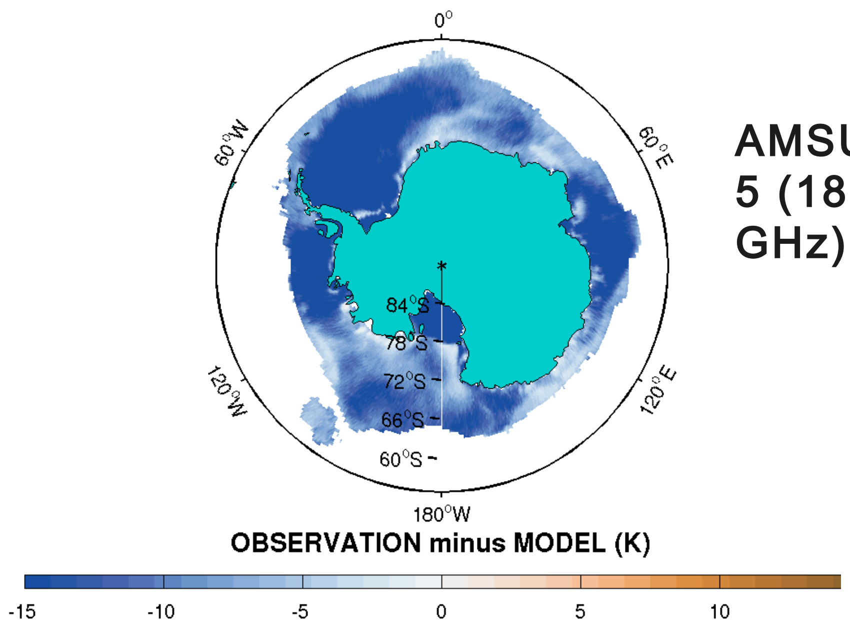
Assimilation of AMSU-A & AMSU-B over sea-ice

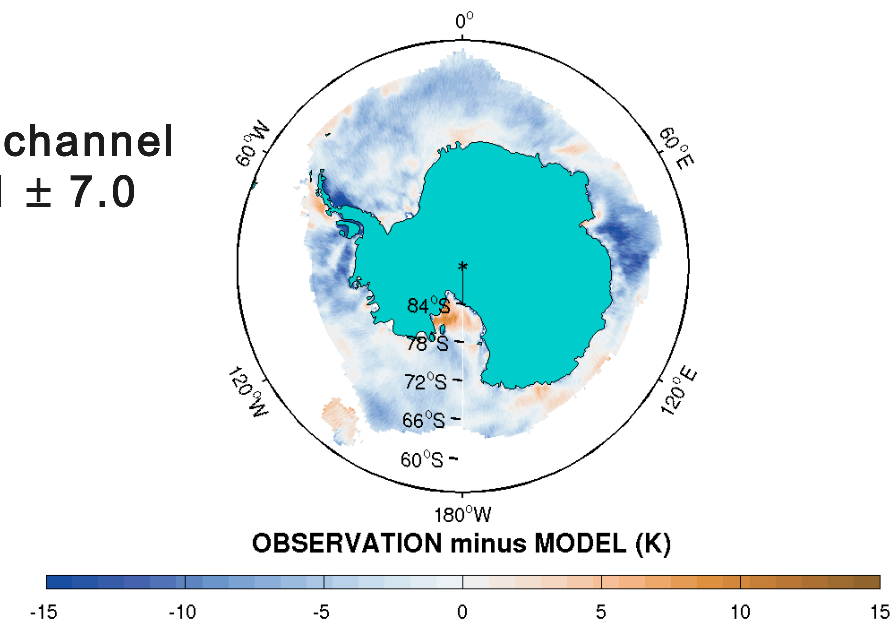
For AMSU-B in particular, can we still use the 89 GHz emissivities for sounding channels without any frequency dependence parameterization ?

Current system (0.99)



AMSU-B channel 5 (183.31 ± 7.0 GHz)

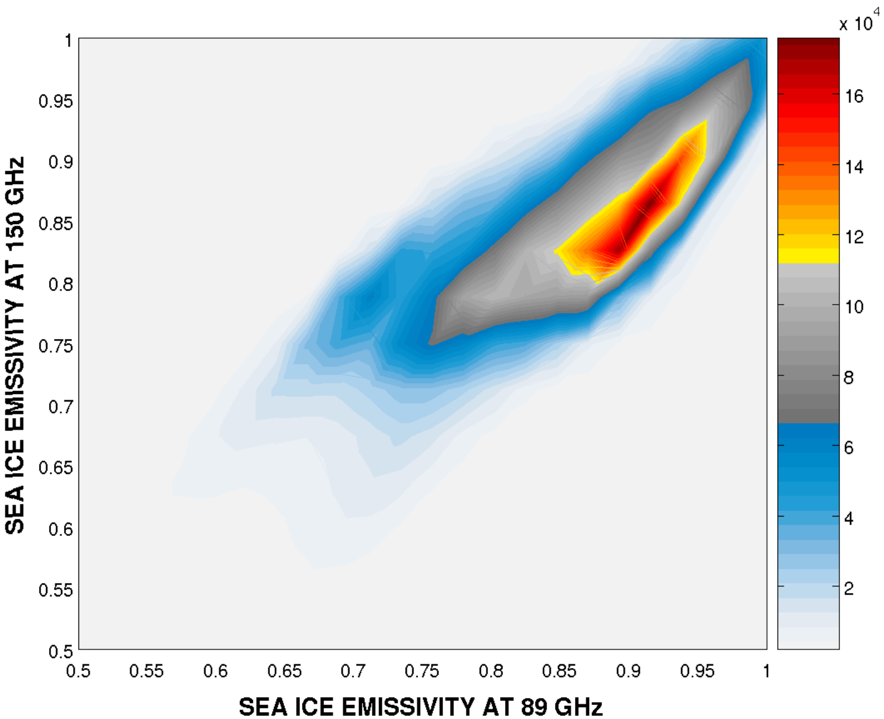
89 GHz emissivity without frequency parameterization



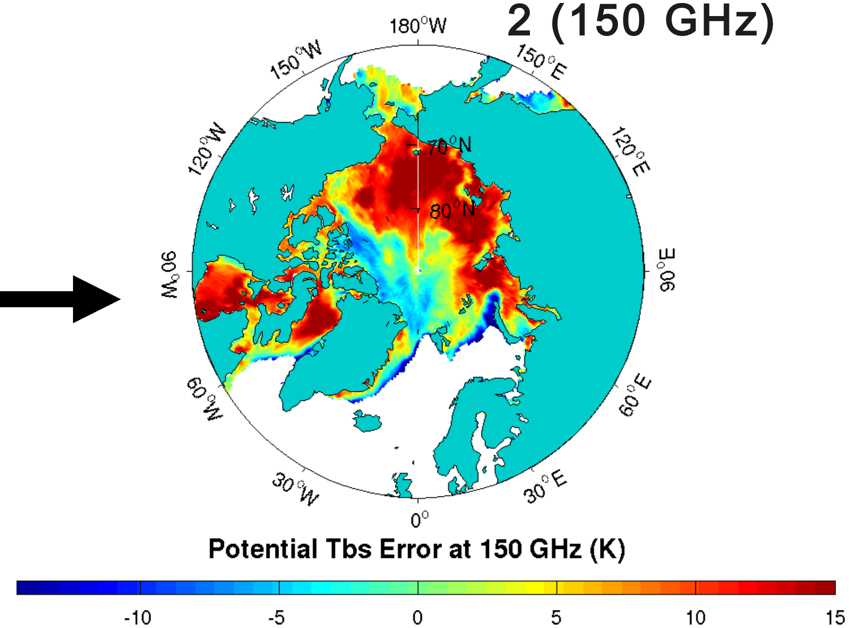
Assimilation of AMSU-A & AMSU-B over sea-ice

For AMSU-B in particular, can we still use the 89 GHz emissivities for sounding channels without any frequency dependence parameterization ?

January 2009



AMSU-B channel 2 (150 GHz)



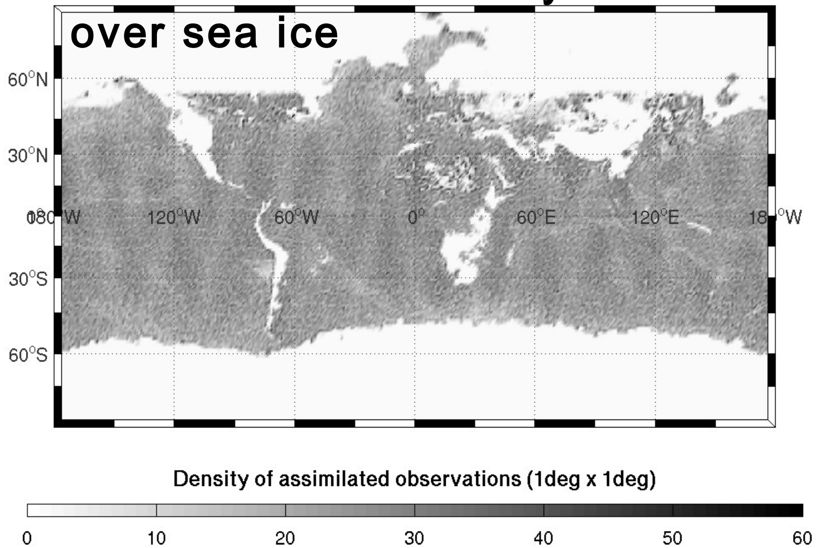
Data impact results

Usage of AMSU-B channel 5 (183.31 ± 7.0 GHz) in ARPEGE

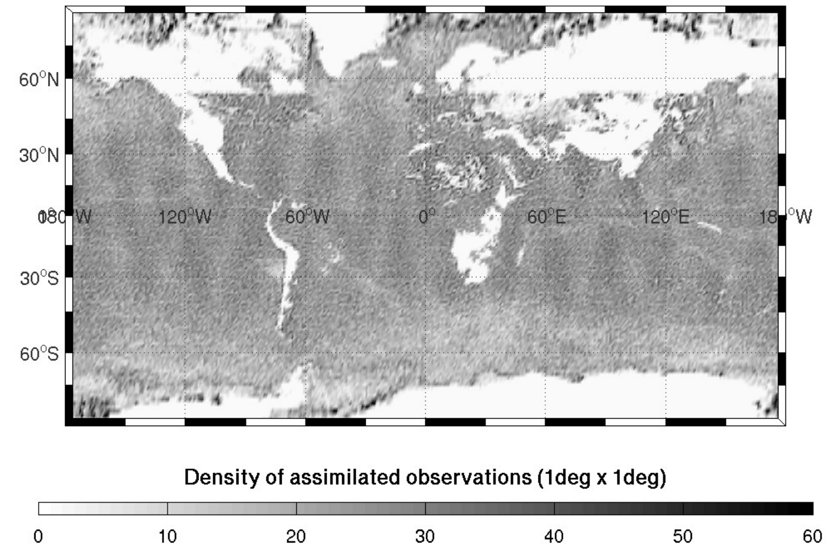
Use of frequency parameterization for sea ice: to describe the emissivity change from 89 GHz to 183.31 GHz Emissivity (~183 GHz) = Emissivity at 89 GHz + f (Tb 89, Tb150, Ts)

Data impact studies for evaluation:

- Period: 15/12/2009 to 04/02/2010
- CTL: the current operational system
- EXP: CTL + emissivity model over sea ice + assimilation of AMSU-A/-B over sea ice



CTL



EXP

Data impact results

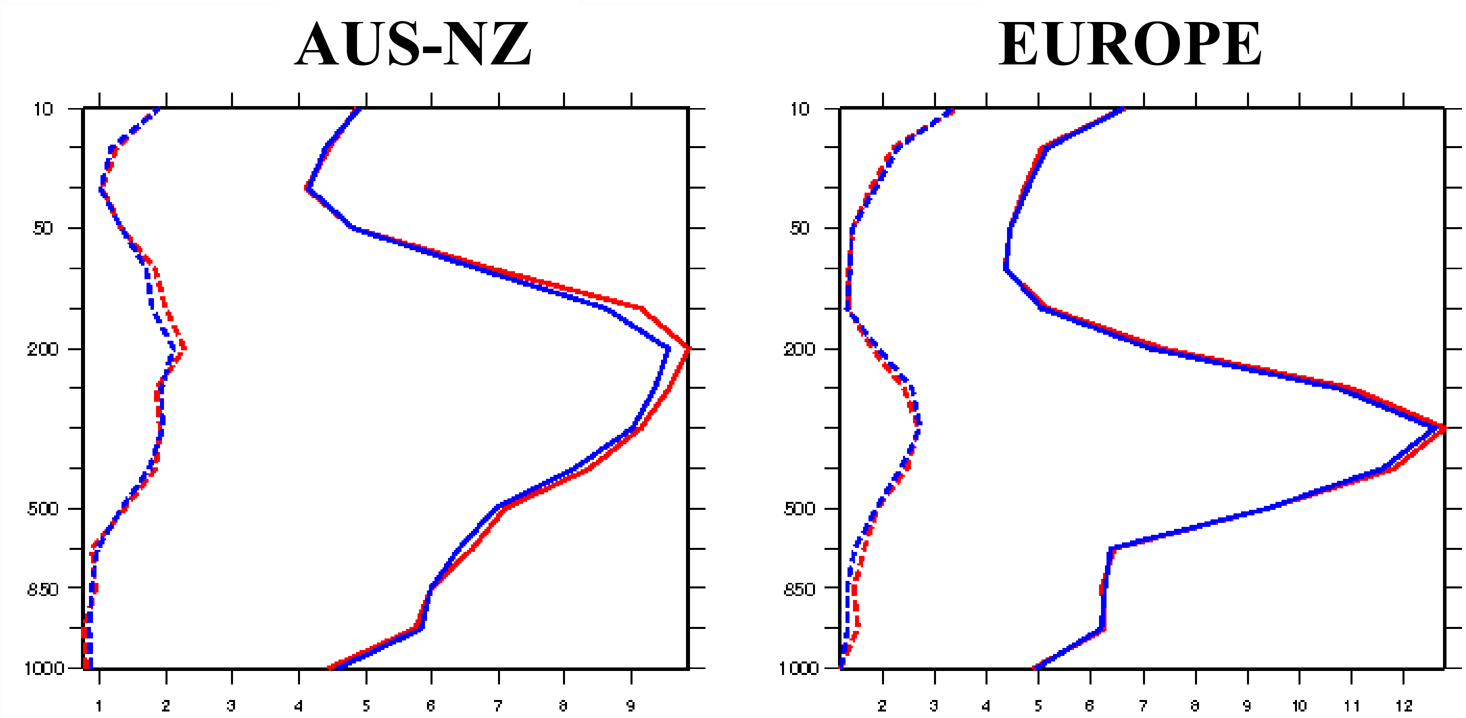
Forecast errors wrt Radiosondes

Wind speed (m/s), 96 hr

20 samples, from 20081229 to 20090117

CTL --- BIAS
__ RMSE

EXP --- BIAS
__RMSE



AMSU over sea-ice: Summary

Objective: extend the use of AMSU observations over sea ice

Method to calculate the sea ice emissivity to be used to assimilate humidity and temperature observations

Beneficial for ARPEGE: data usage, RTTOV performances, fit to all available observations, quality of analyses/forecasts

In experimental suite in 2010

Karbou and Rabier, 2010

Concordiasi: an international project

Participating Institutes:

- CNES, CNRS/INSU, IPEV, LMD, LGGE, Météo-France, PNRA, Alfred Wegener Institute
- NSF, Purdue University, UCAR, University of Colorado, University of Wyoming
- ECMWF

Collaborating institutes:

- NWP centres (Met Office, Australia…), NASA/GMAO, UCLA, ….

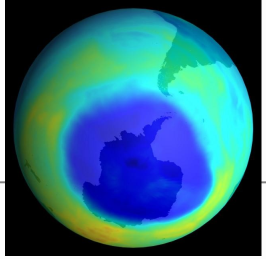
Part of the THORPEX-IPY cluster

- **Overview of Concordiasi: “The Concordiasi project in Antarctica”**

  Rabier et al, Bulletin of the American Meteorological Society, January 2010.

- **Website** www.cnrm.meteo.fr/concordiasi/

Motivation



Reducing uncertainties in diverse – but complementary - fields in Antarctic science

- Better use of satellite data, including IASI on board MetOp for analyses, forecasts and reanalyses
- Progress on the understanding of interactions between ozone depletion, stratospheric clouds and dynamics

Experimental design

- Surface-based: radiosoundings at Concordia (and Dumont d'Urville) + 45-m instrumented tower, snowfall and accumulation observations at Concordia
- Stratospheric superpressure balloons with meteorological sensors, ozone sensors, particle counters, GPS receivers, driftsondes carrying dropsondes
- Modelling: global and fine-scale models, chemical-transport models

Concordia
and Dumont d'Urville
Additional
Regular
radiosoundings

Concordia

Frequent
radiosoundings
and instrumented tower

Antarctic area

Stratospheric
super–pressure balloons

Flight level instruments
- meteorological sensors
- ozone sensors
- particle counter
- GPS receivers

Dropsondes

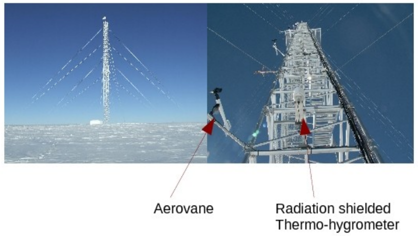
2008	2009	2010	2011

Preliminary Data Assimilation studies
Instrument preparation

IASI retrievals at Concordia
Boundary layer studies
Instrument preparation

Targeting dropsondes

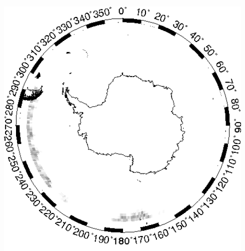
IASI retrievals at dropsonde locations
Evaluation of chemical transport models
Scientific studies based on stratospheric data
Data Assimilation studies using balloon data
Validation of satellite data assimilation using dropsonde data

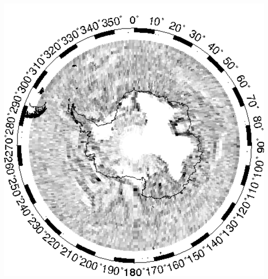


Enhanced assimilation of satellite data

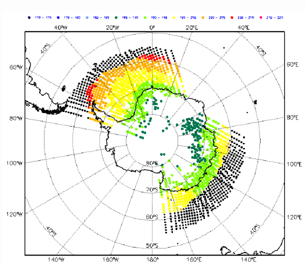
To improve the assimilation of satellite observations in Météo-France global meteorological model ARPEGE

Assimilation experiment over sea-ice and land with more satellite data infrared & microwave





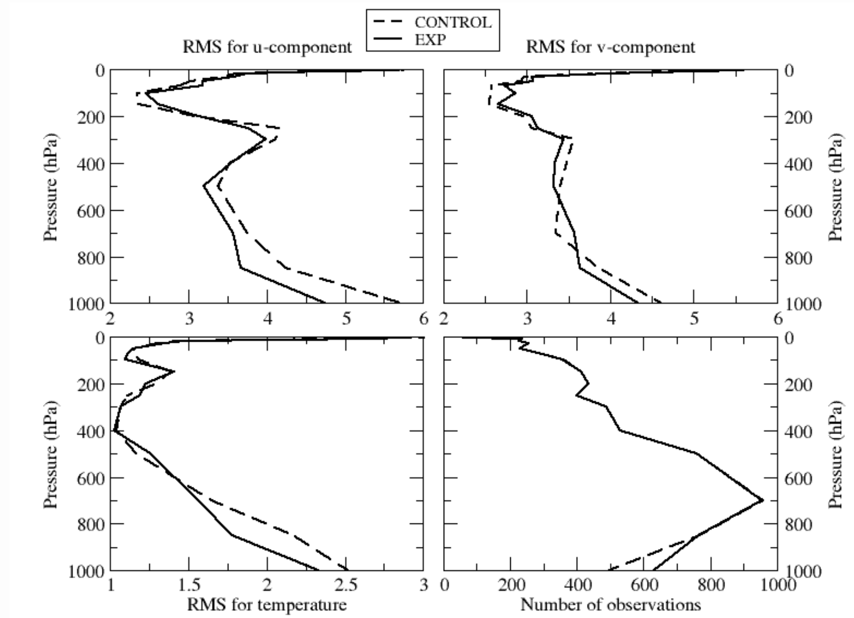
AMSU-B, channel 3: before (left) after modification (right)



Black : without additional data

Color : additional IR data

Additional data (IR and MW)

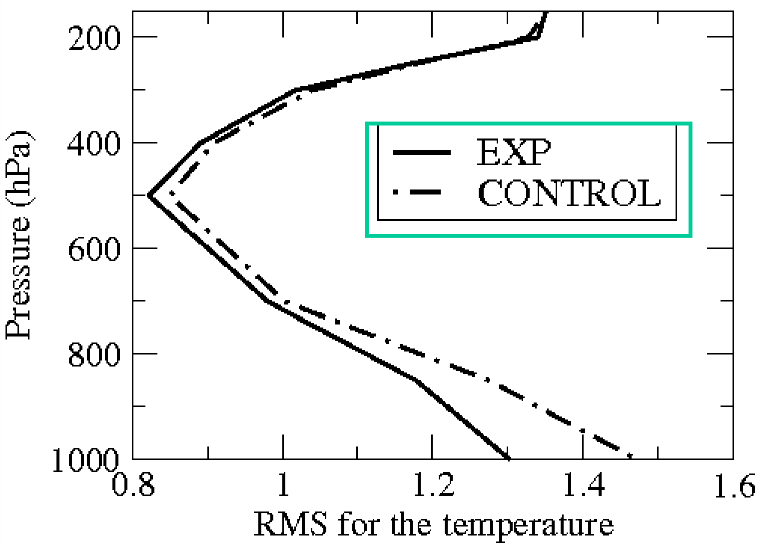


Comparison (RMS) to Radiosoundings for area : 65°S – South Pole

Number of obs between 300 and 900

Predictability studies, effects on lower latitudes

Improving assimilation over polar areas can also improve forecasts at lower latitudes



Assimilation experiment with more satellite data over sea-ice and Antarctica:

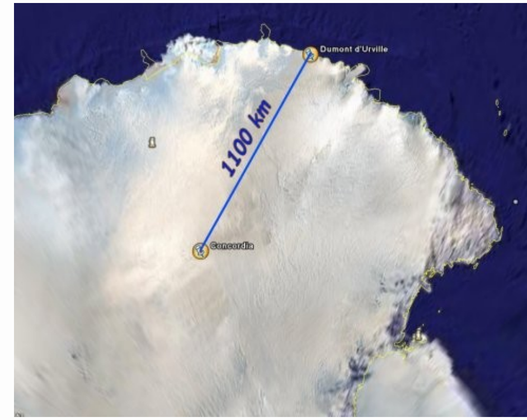
Obs – model for a period of 20 days during austral winter 2007

Obs : AIREP (airborne data) between 20°S and 50°S

CONCORDIASI

Data at Concordia

An exceptional location to validate satellite data assimilation



Time Period : from the 15 September 2008 to 30 November 2008
and 19 November 2009 to 13 December 2009

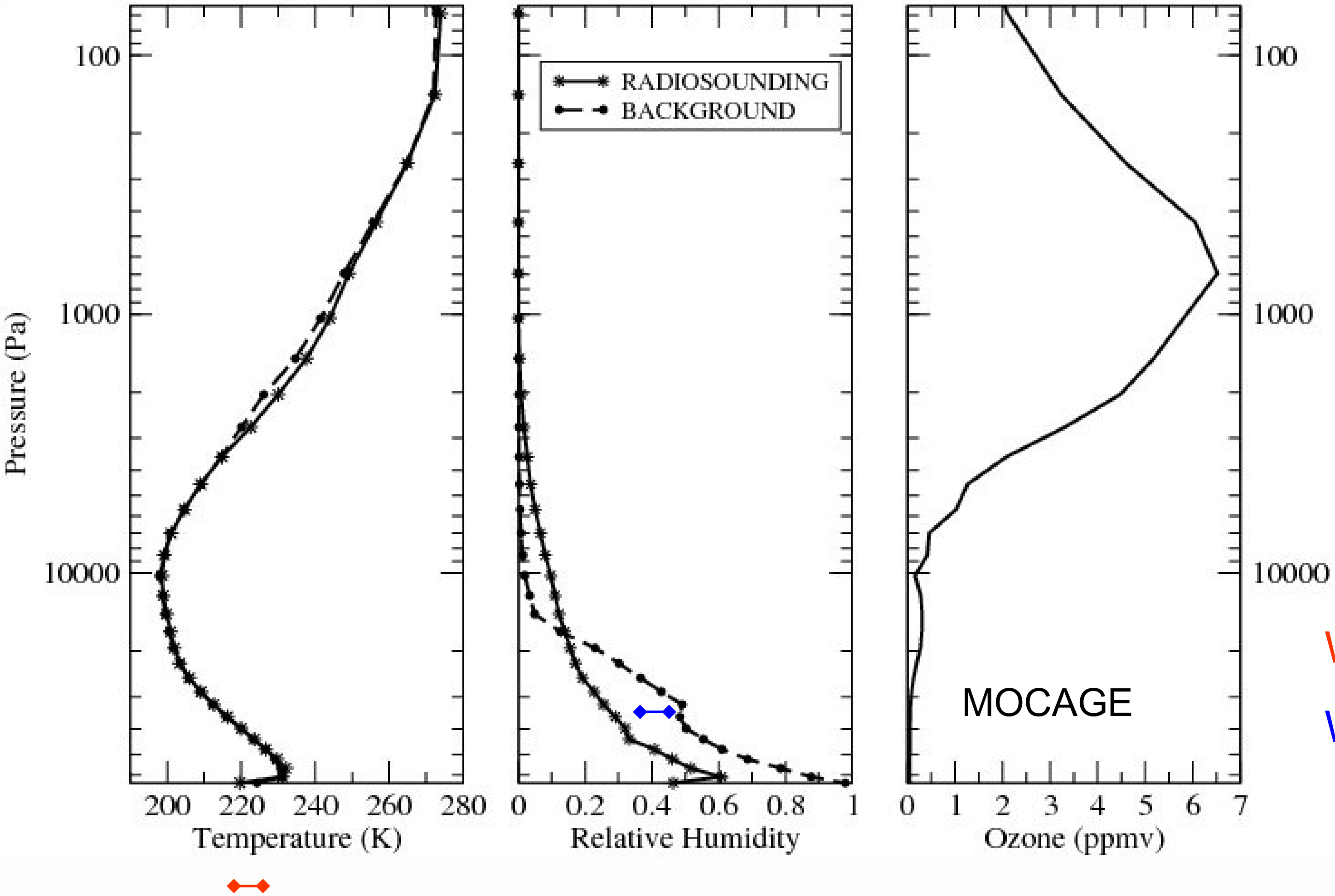
Observations:

- **2008** : Radiosounding at **DomeC** (75°S ; 123°E) in order to have 2 observations per day, at **0UTC** and 12UTC. Complementary launch at the same time of IASI overpass.
- **2009** : As 2008 + Surface measurements (vertical profile of the snow temperature) at the time of the sounding.

Meteorological conditions :

Out of 120 cases in 2008: **62% clear sky**
Out of 17 cases in 2009: **59% clear sky**

Statistics model/observations at Concordia



70 profiles

at 00UTC

From

15/09/2008

to

30/112008

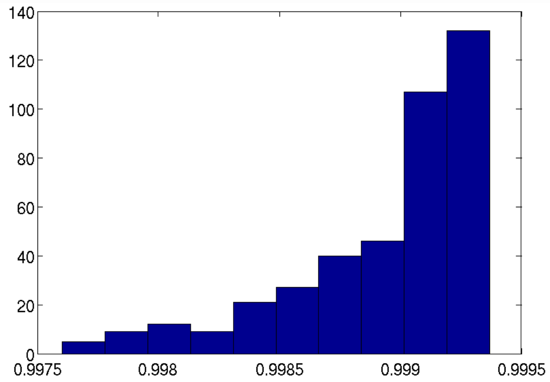
Warm bias in Ts

Wet bias

+ field campaign in 2009 with additional measurements

Impact of surface parameters for retrievals over the plateau

Retrieval from a window channel of IASI sensor



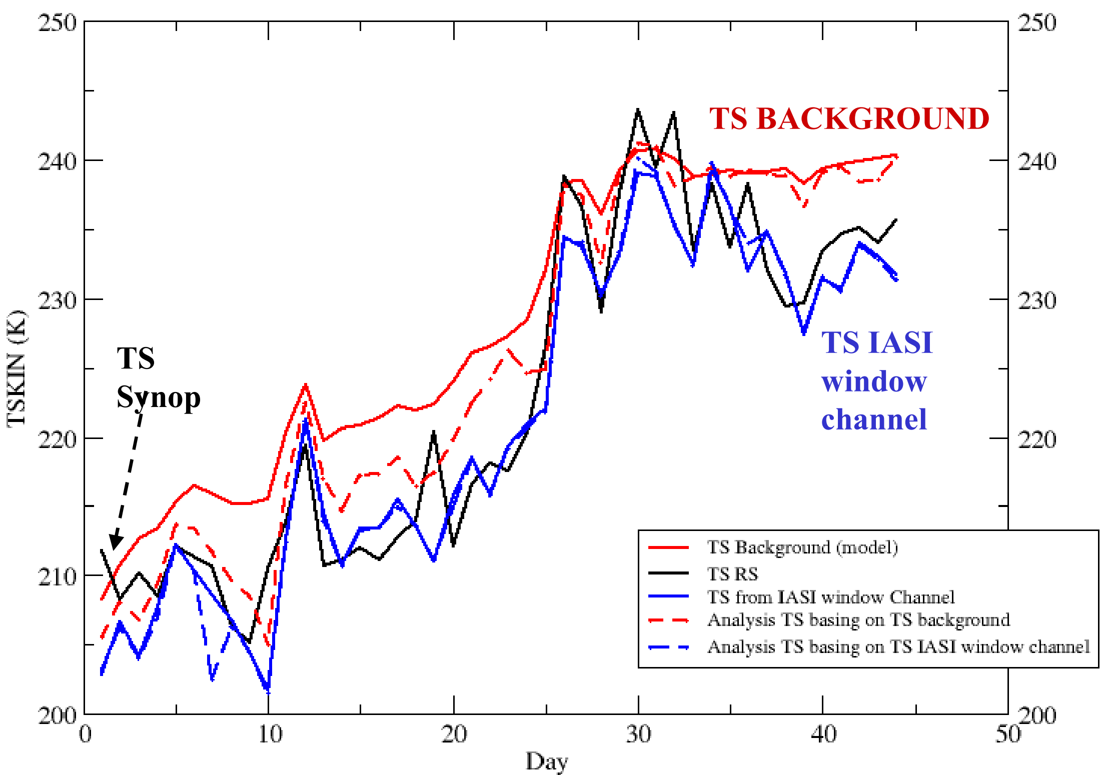
1) Choose of a window channel with a high transmittance: channel 1194 (943,25cm^{-1}) - Mean τ: 0.9989

2) Retrieval of skin temperature (Tskin) from this channel using RTTOV model – Radiative Transfer Equation, with a surface emissivity fixed at 0.99

→Time evolution of the Tskin, over 44 cases, from 1st October to 29 November 2008

→ TS from IASI channel close to TS from Synop

→ Use of 1D-VAR cloud detection

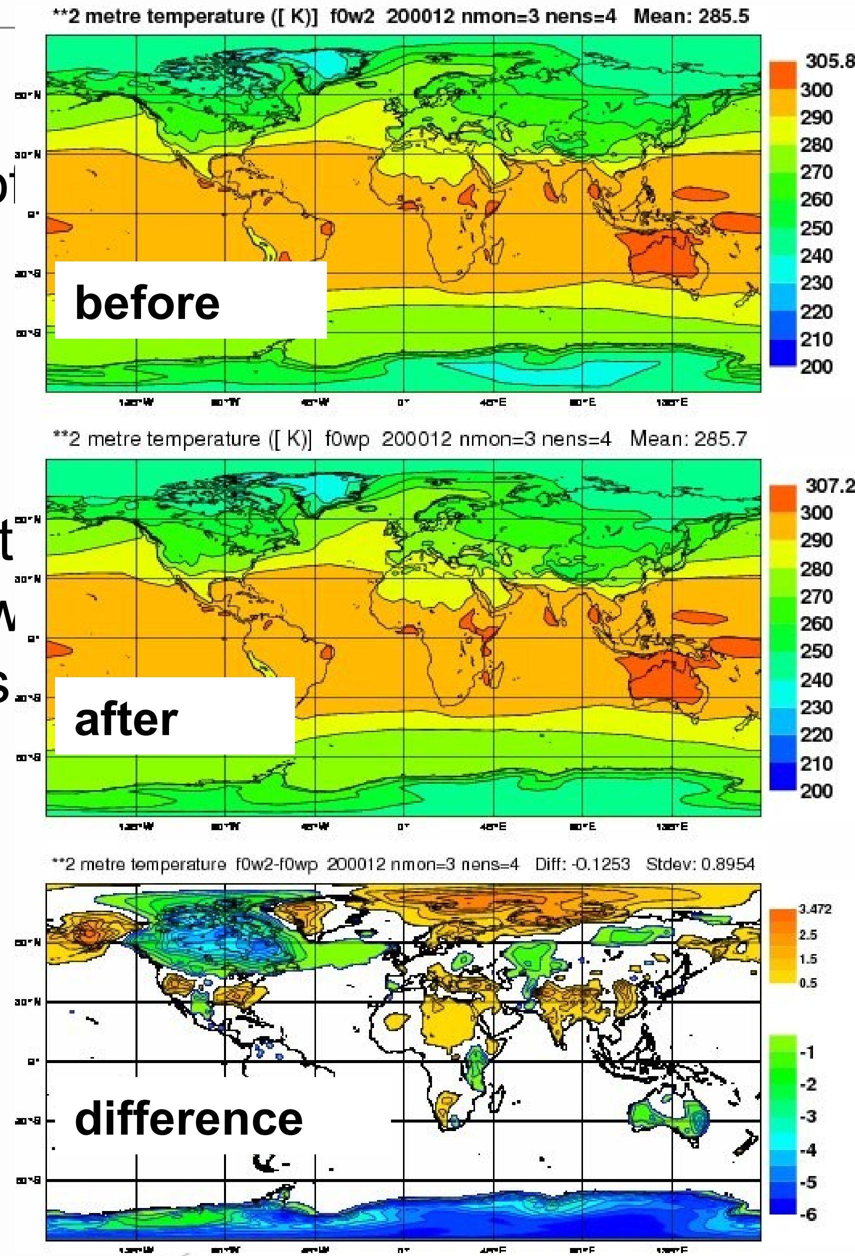


Model improvement

Statistics at Concordia and diagnostic of model performance (C.Genthon, LGGE)

Improvement in the ECMWF model
Based on interaction with polar scientist
Change in albedo over permanent snow effective in 2008. Decreased warm bias.
(G. Balsamo, ECMWF)

Work performed on snow modelling
(E. Brun, CNRM)



Next step: launching stratospheric balloons from Mc Murdo

Launch site:

- Flattened area,
- 2 Jamesways with power, and some heating

METEO FRANCE
Toujours un temps d'avance

Balloon system characteristics

18 superpressure balloons from CNES

All with meteorological sensors
at gondola level (temperature, pressure)

12 with driftsondes from NCAR
(500 dropsondes in each)

6 with innovative instruments:
ozone sensors, particle counters, GPS receivers

METEO FRANCE
Toujours un temps d'avance

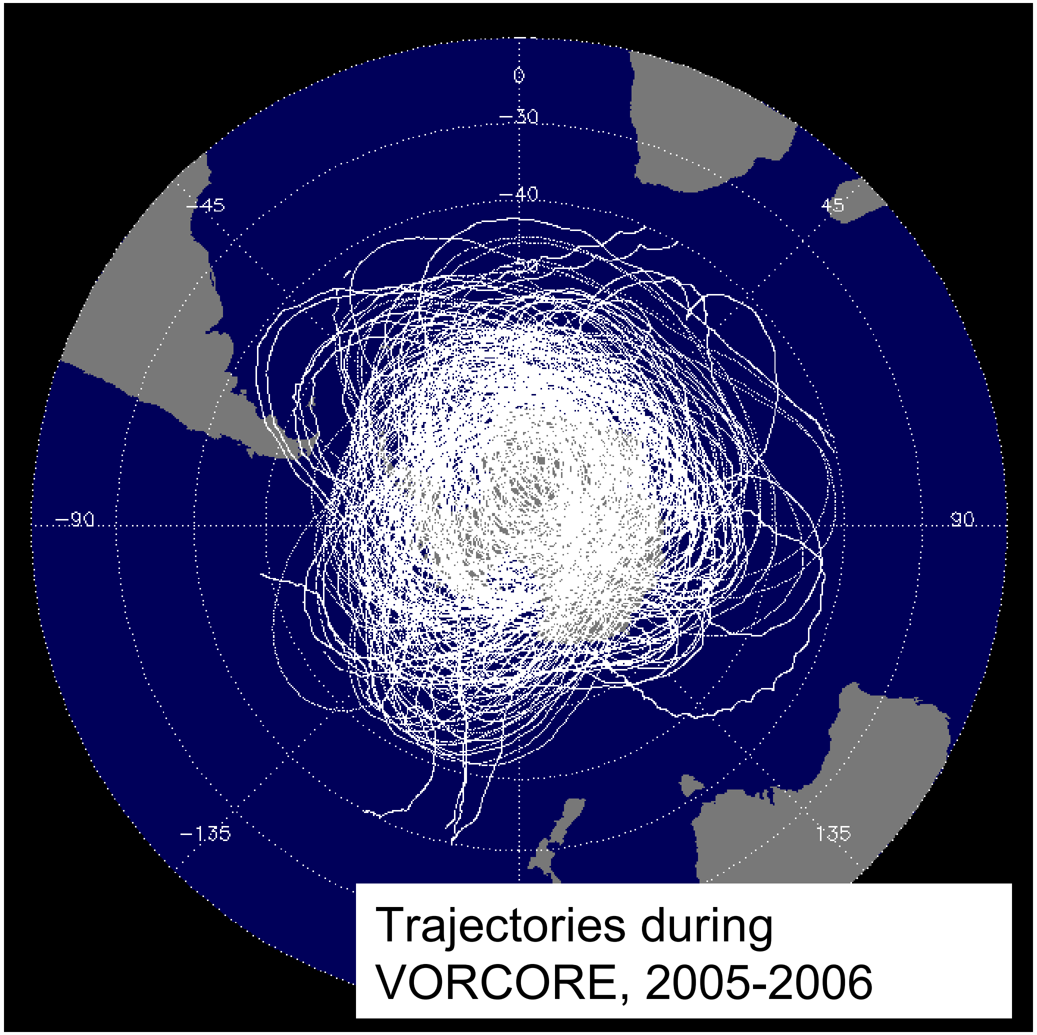
Lagrangian structures of the flow and data assimilation

Trajectories will be used to better understand the control exterted by the vortex on the motion of air parcels

(R. Mechoso, UCLA)

Use of the Concordiasi flight-level observations directly in the assimilation

(A. Tangborn, GMAO)



Trajectories during VORCORE, 2005-2006

CONCORDIASI

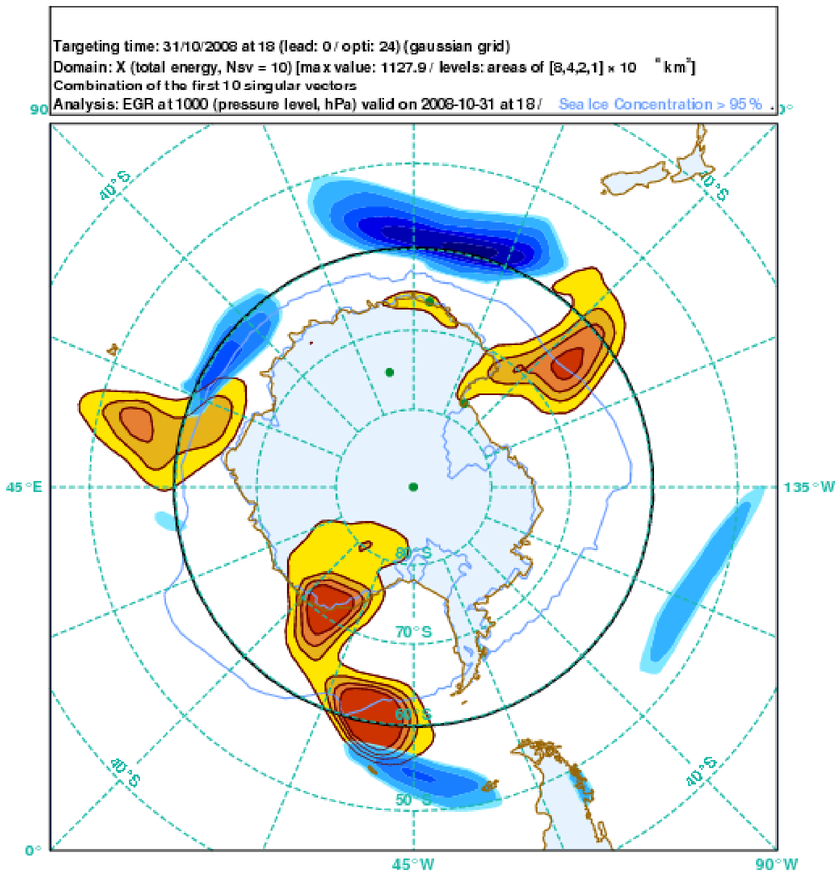
Dropsondes to calibrate the assimilation and for predictability studies

Most of the sondes will be dropped when coinciding MetOp overpasses

(calibration of IASI retrievals, validation of AVHRR winds..)

Part of the dropsondes will be deployed in sensitive areas

Localized singular vectors will be computed At ECMWF



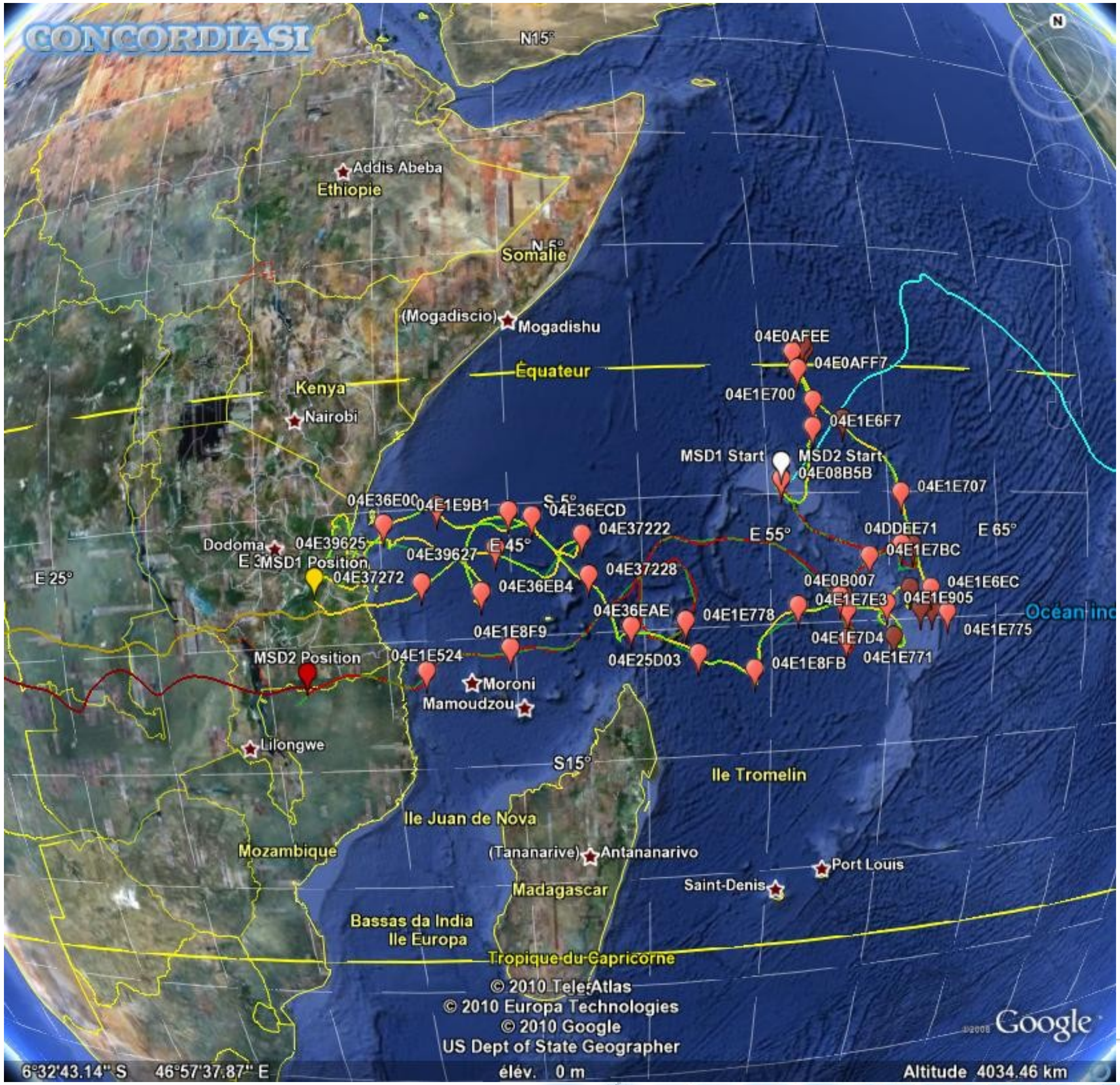
Test campaign in the Tropics

Pre-Concordiasi

February-March 2010

2 Driftsondes

1 additional stratospheric balloon: Ozone sensor from LMD, particle counter from UW



Data on the website http://www.cnrm.meteo.fr/concordiasi-dataset/

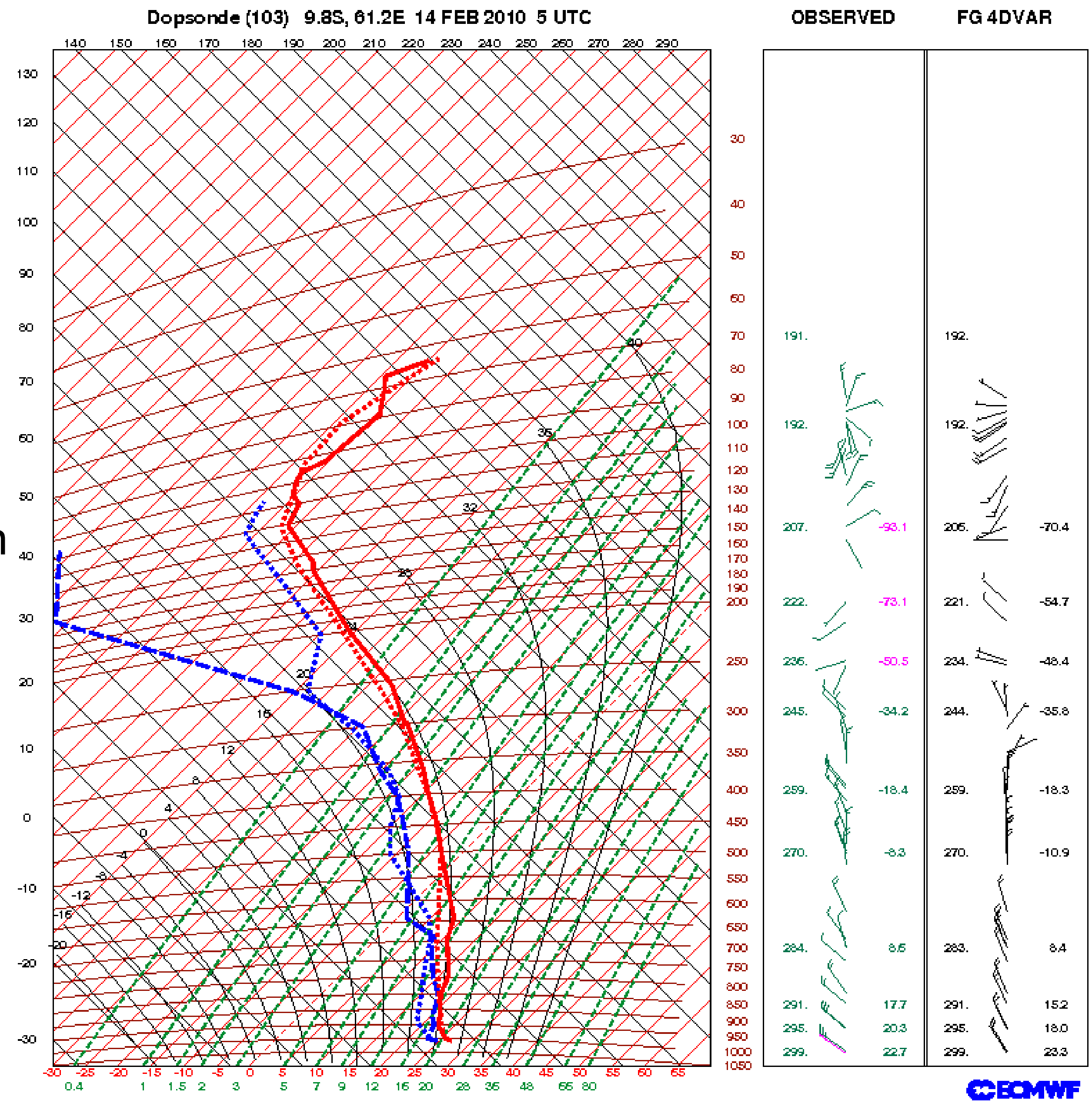
Non-protected access: data from GTS

(needs simple registration to access data)

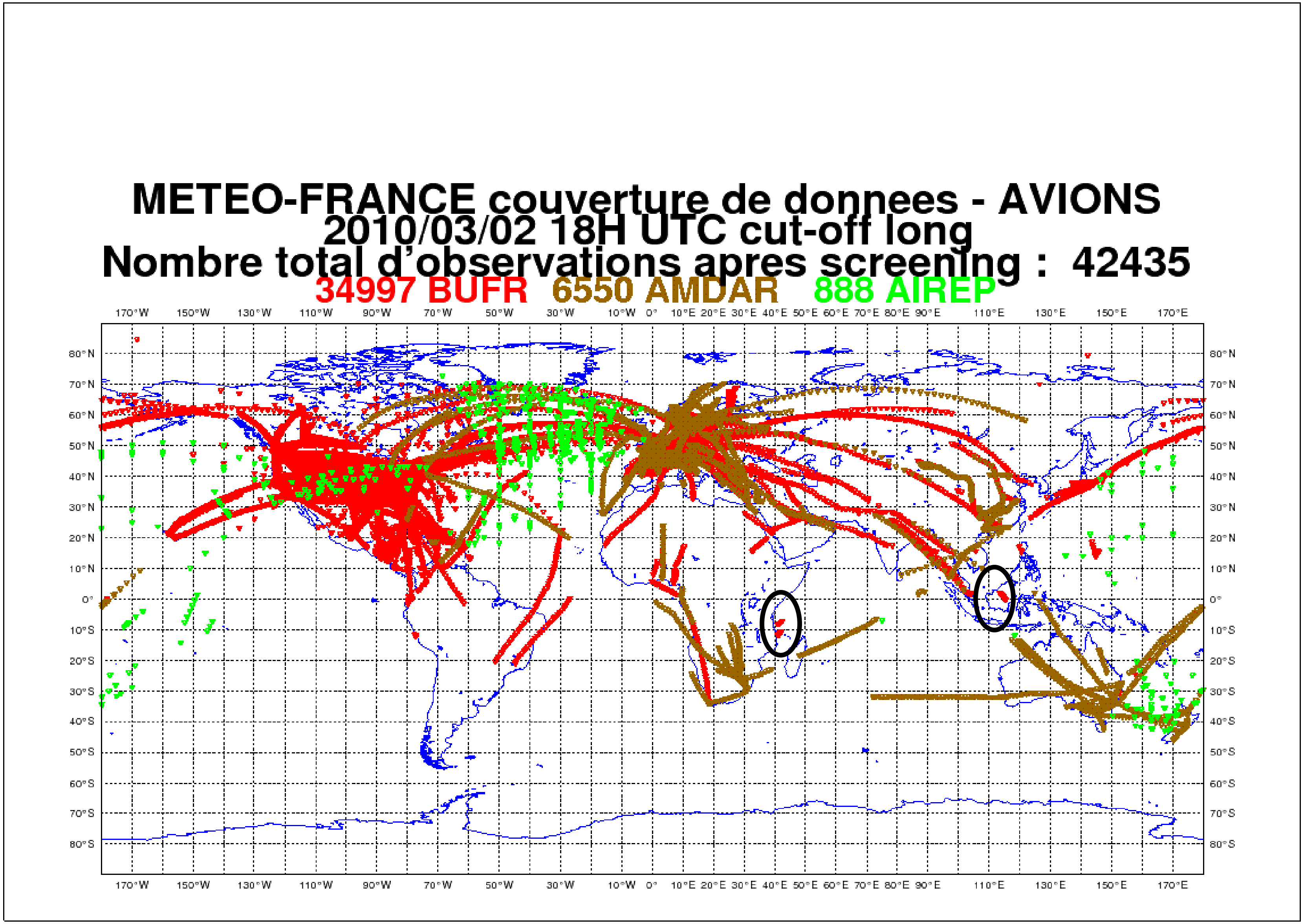
Protected access: high-resolution soundings, both from driftsondes and Concordia.

Example of Comparison with the ECMWF model

Only major problem is Humidity above 300 hPa



Gondola information assimilated



Ozone depletion, polar stratospheric clouds and stratospheric dynamics

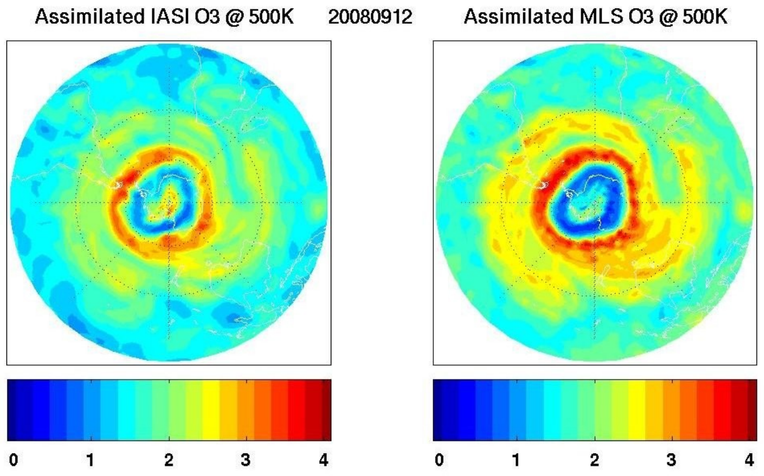
Interannual variability of ozone depletion depends on the activity of stratospheric waves and the presence of polar stratospheric clouds

Documentation of ozone loss along trajectories with meteorological (P, T, Wind), chemical (Ozone) and microphysical observations.

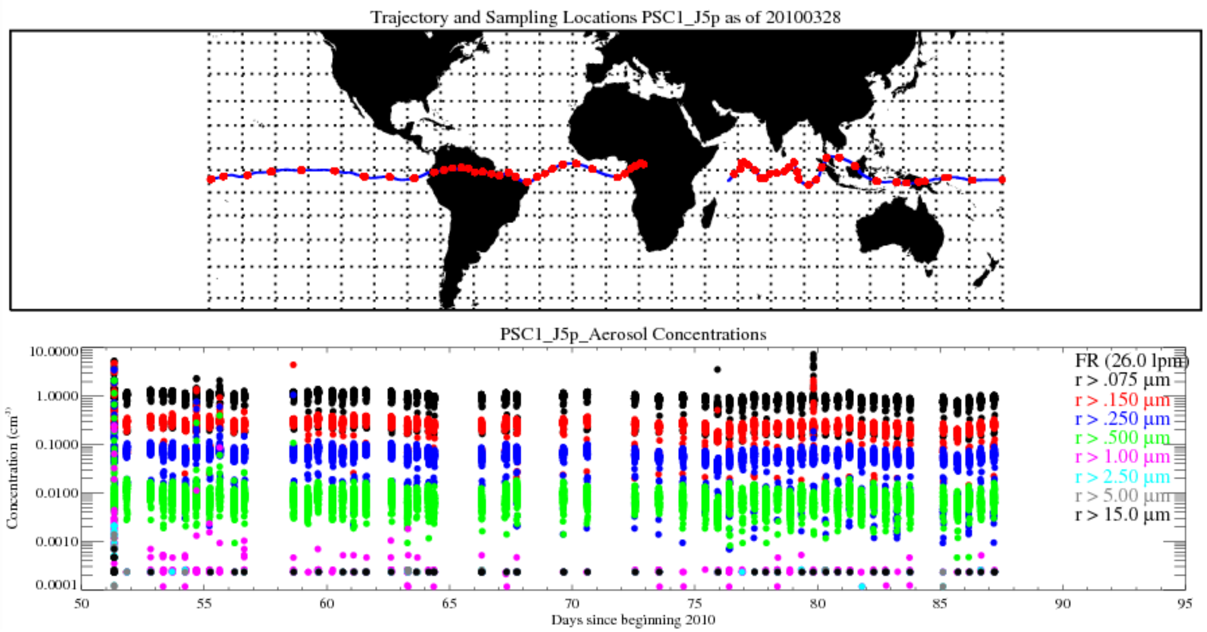
(A. Hertzog, T. Desher, L. Avallone)

Validation of Chemical-Transport model and Stratospheric ozone assimilation.

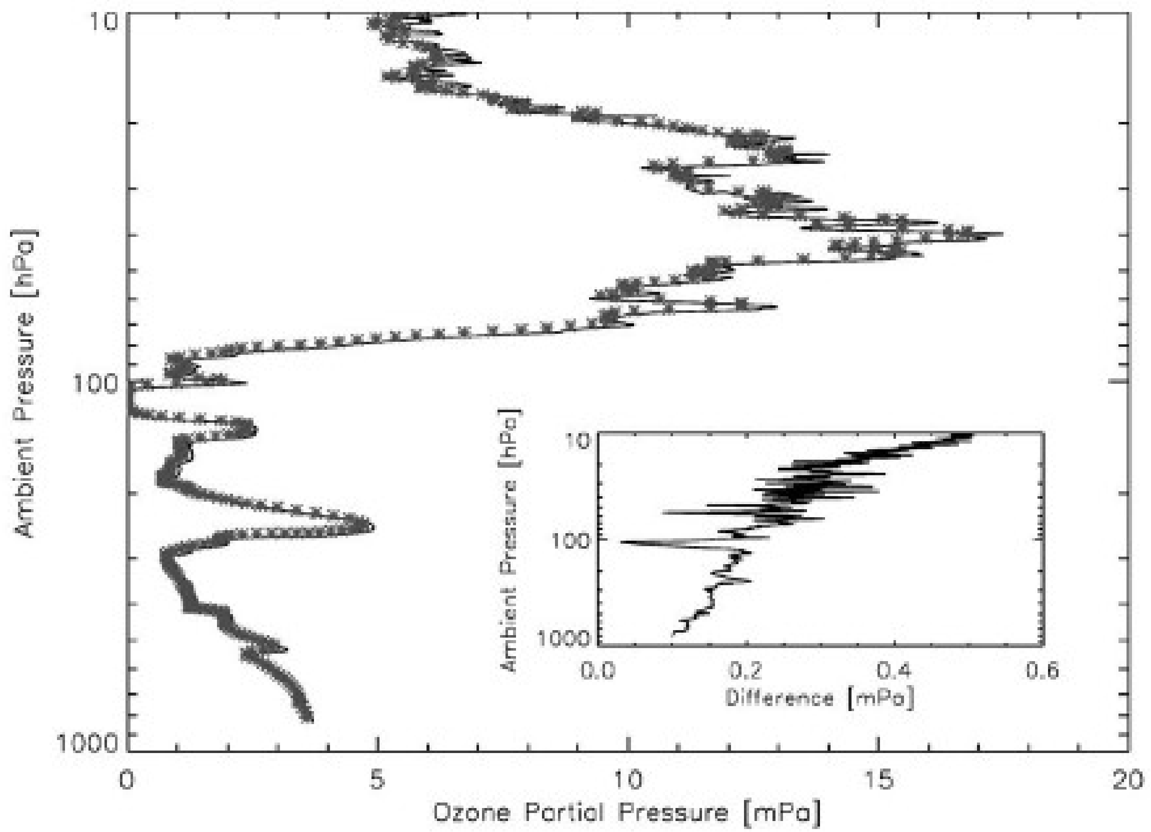
(L. El Amraoui)



Particle counter (T. Deshler, U. Wyoming)



UCOZ Instrument Performance (L. Avallone, U. Colorado)



Accuracy: 7 – 10 %

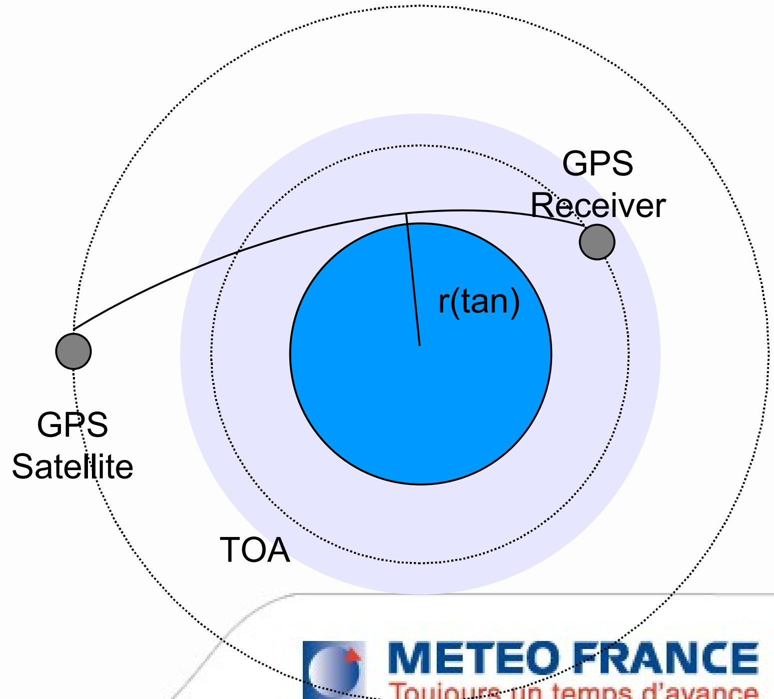
Precision: 0.7 ppb @ 10 sec

GPS radio-occultation (from J. Haase, Purdue University)

GPS radio occultation is used to obtain high-resolution atmospheric profiles of refractivity

Radio signals pass through the atmosphere from GPS satellite to GPS receiver

- As it travels, the signal encounters atmospheric layers of varying density
- The density changes cause the signal to refract and delay slightly
- A doppler shift is associated with the overall delay seen in the signal and can be converted into an atmospheric refractivity value at a geometrically determined tangent point to the Earth



Background

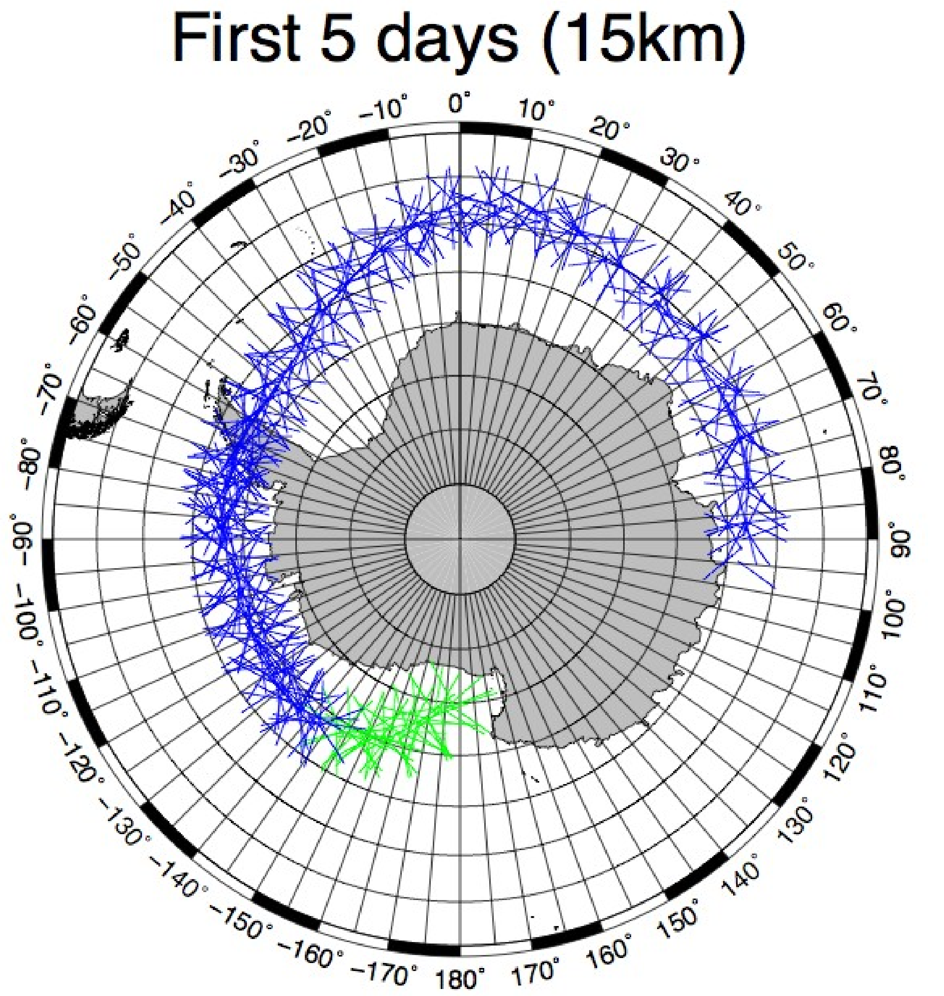
Refractivity (N) is related to temperature (T) , pressure (P) and water vapor partial pressure (Pw)

$N = 77.6\ {}^{K}/_{mbar} * P/T + 70.4\ {}^{K}/_{mbar} * Pw/T + 3.73*10^5\ {}^{K^2}/_{mbar} * Pw/T^2$

Two of the twenty balloons launched will be equipped with high-accuracy, duel-frequency GPS receivers

The system will be compared with dropsondes on closely spaced flights, and will help in the calibration of the IASI satellite

Occultation simulation



Occultations observed during the first 5 days of the 110 day flight (day 1 shown in green)

- An average of 115 occultations per day, 58 of which are setting
- Larger tangent drifts than originally expected, most likely due to GPS satellite orbital geometry

Next steps...

- Distinguish between poleward and equatorward occultations
- Increase balloon height to 19 km
- Look at the azimuthal angles of occultations

Outlook

Concordiasi 2008 and 2009 field campaigns: data have started to be used in studies over the plateau.

Balloon test campaign successful: promising for the 2010 field campaign from McMurdo

Use of meteorological data in real-time in NWP models

Use of additional in-situ data to calibrate/validate the assimilation of satellite data, and to better understand ozone depletion

CONCORDIASI

Questions ?

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