PCA assimilation techniques applied to MTG-IRS

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WORKSHOP
Assimilation of Hyper-spectral Geostationary Satellite Observation

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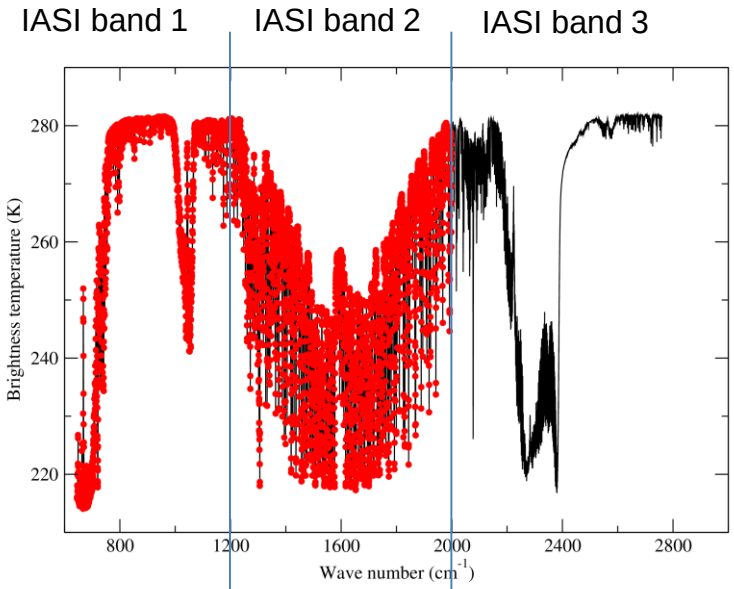
Motivations for developing a PC based assimilation system:

1) Assimilate directly into the 4D-Var system PC scores disseminated by data providers
2) Assimilate a subset of reconstructed radiances
3) Exploit the full information content of hyper-spectral sounders (e.g. IASI)

We currentlu use only 2% of the available IASI channels



Using Principal Component Analysis (PCA) we can encapsulate the vast majority of the information in *N* IASI channels in a smaller number of variables

The leading eigenvectors, *A*, of a covariance matrix describing the variations of the IASI's spectrum are used to calculate *m*<<*N* PC scores

PC scores (*p*):

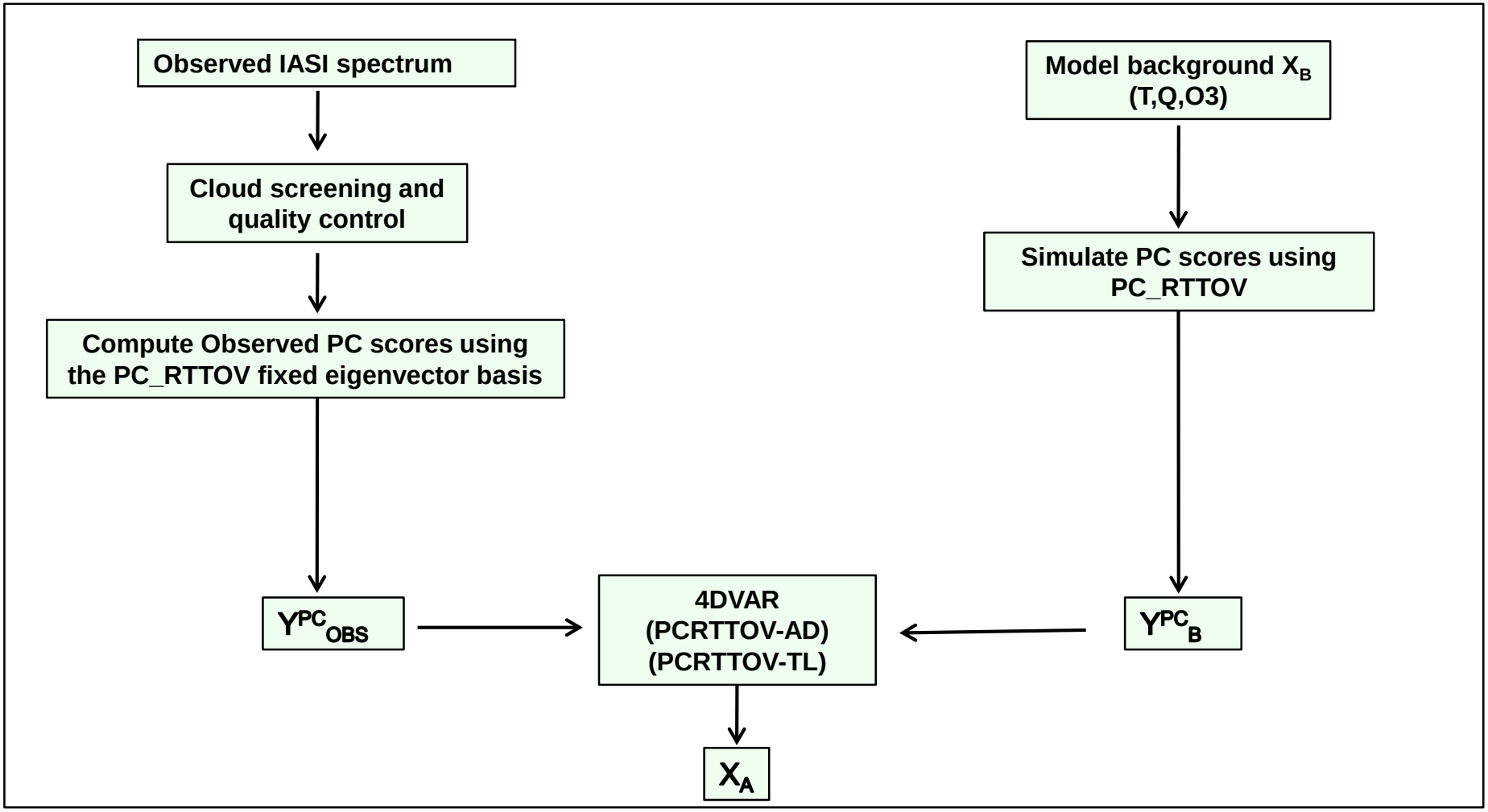
$\boldsymbol{p}=\boldsymbol{A}\,\boldsymbol{r}$

Reconstructed Radiances ($\tilde{r}$)

$\tilde{\boldsymbol{r}}=\boldsymbol{A}^{\mathrm{T}}\,\boldsymbol{p}$

We can select *m* reconstructed radiances to represent the same information contained in *m* PC scores

PC analysis system design



In 4DVAR we minimise the cost function J(X)

$$J(X)= [X-X_B]^T B^{-1} [X-X_B] + [Y^{PC}_{OBS} – Y^{PC}(X)]^T O^{-1} [Y^{PC}_{OBS} – Y^{PC}(X)]$$

Evolution of the 4D-Var PC score assimilation system

1) ***Prototype system (only conventional and IASI observations):*** assimilation of PC scores derived from channels in the short wave band of IASI

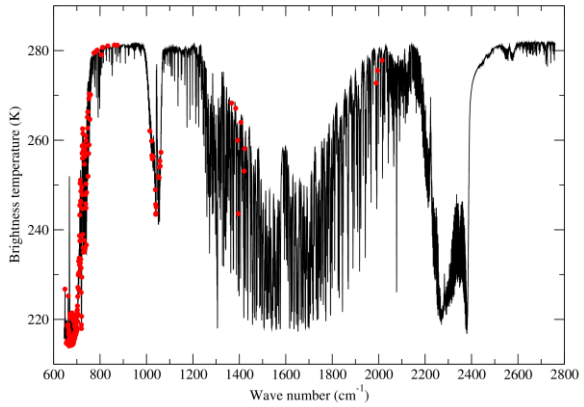
2) ***Full data assimilation system (all operational observations - satellite and conventional):***

   i) 191 long wave IASI channels used in operations (Matricardi and McNally 2013)

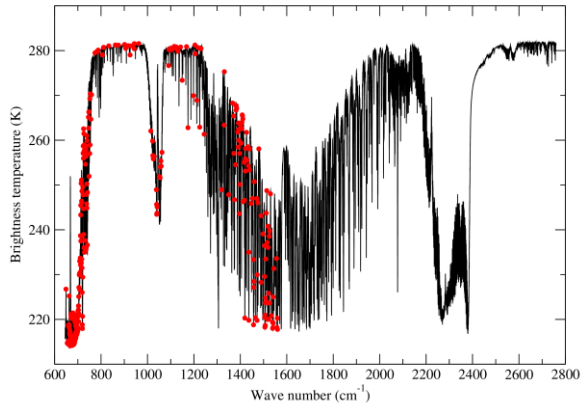
   ii) 305 IASI channels (Matricardi and McNally 2014, Matricardi and McNally 2015)

1) Full data assimilation system focused on maximising the spectral information of IASI using the full set of channels in IASI band 1 and 2

The 191 IASI channels used in operations

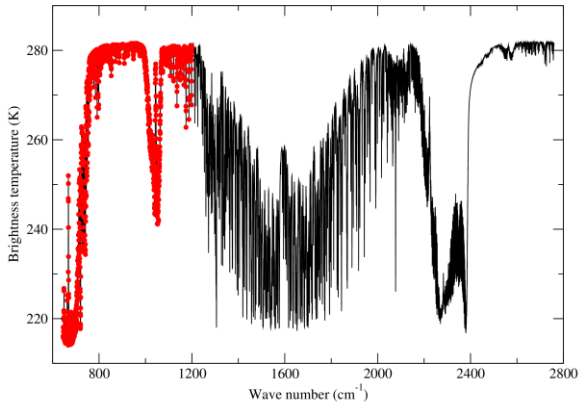


The 305 IASI channels (i.e. the 191 operational channels augmented with additional surface and water vapour sounding channels)



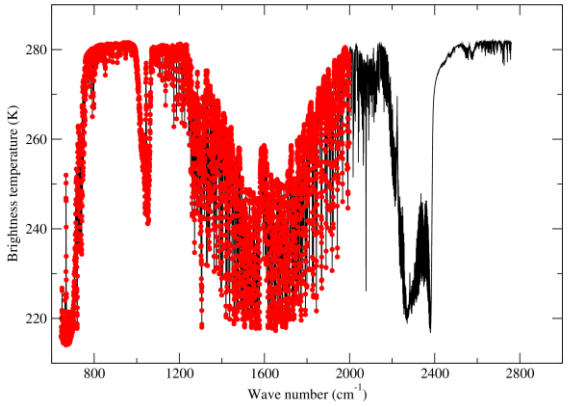
The 2221 IASI channels (26% of the total number)

In the assimilation, 2221 IASI channels are represented by 200 PC scores



The 5420 IASI channels (64% of the total number)

In the assimilation, 5421 IASI channels are represented by 400 PC scores



Assimilation of PC scores derived from 2221 and 5421 IASI channels

To asses the performance of the PC based assimilation system we have devised the following experiment design:

1) **BASE**: we use all operational observations (satellite and conventional) with the exception of IASI data.

2) **RAD** : identical to BASE but additionally assimilates radiances from the 191 channels used in the operational 4D-Var.

3) **PC_B1**: identical to BASE but additionally assimilates 200 PC scores derived from the radiances in 2221 IASI channels.

4) **PC_B1_B2** : identical to BASE but additionally assimilates 400 PC scores derived from the radiances in 5421 IASI channels.

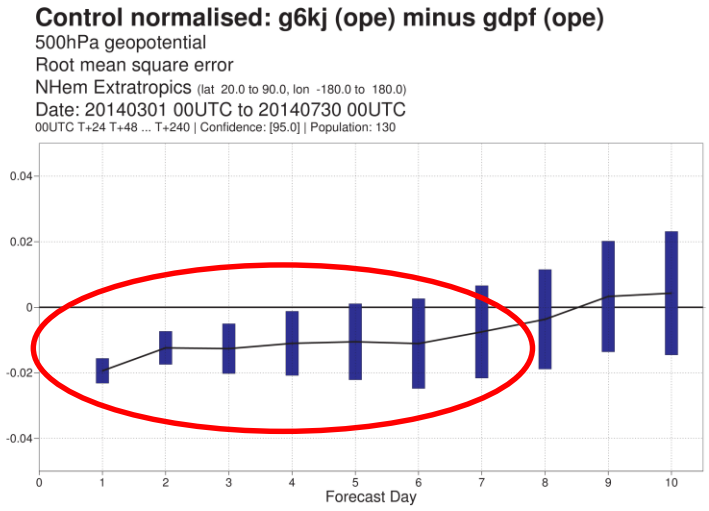
Experiments (cycle 40R2 – T511- 137 L) are currently covering the period 20 February 2014 - 13 August 2014.

NOTE: in all PC score experiments we assimilate only cloud-free scenes

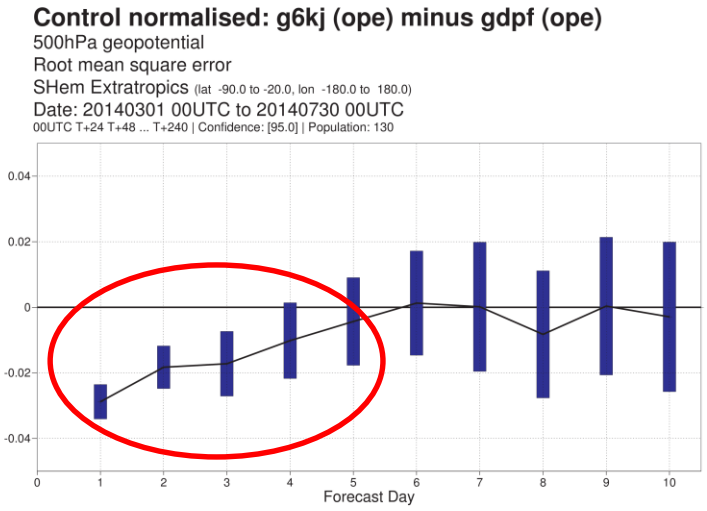
Clouds in PC space

Dealing with clouds in PC space is technically demanding within the context of a 4D-Var assimilation scheme and it would require an effort beyond the resources allocated to the study of PC assimilation in NWP.

The use of PC data is currently restricted to fully clear spectra and this is an important limitation to the use of the PC system in an operational environment



Restriction to clear spectra reduces the skill of the forecast



Assimilation of PC scores: specification of the observation errors

The Desroziers and Hollingsworth/Lönnberg methods have been used to ***diagnose*** the full observation error covariance matrix in PC space

The Desroziers and Hollingsworth methods give an ***approximate estimate on the errors*** because they are based on assumptions that are generally incorrect

Hollingswort/Lönnberg assumptions:

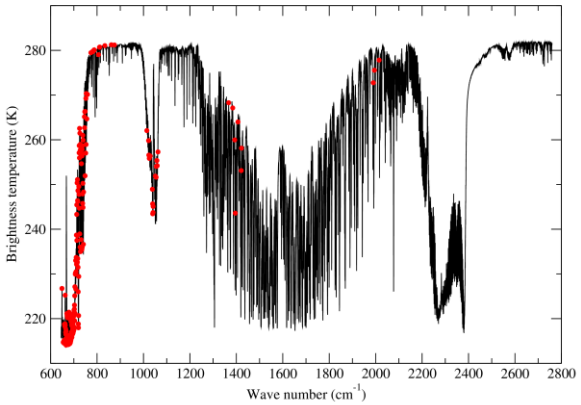
i) background errors are spatially uncorrelated
ii) observation errors are spatially uncorrelated
iii) background and observation errors are uncorrelated.

Desroziers assumptions:

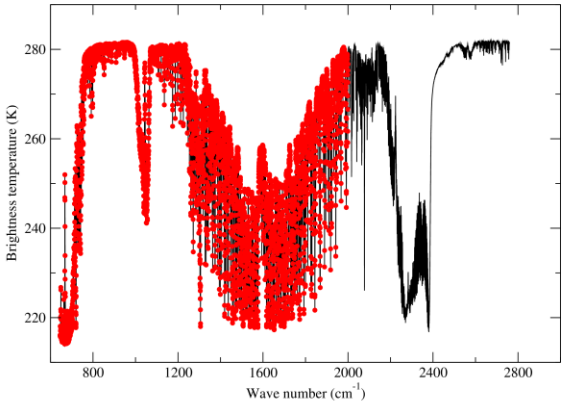
i) background and observation errors are uncorrelated
ii) the weights that are assigned to the observations in the analysis agree with the true background and observation error covariances.

The 4D-Var assimilation of PC scores derived from 2221 and 5421 IASI channels

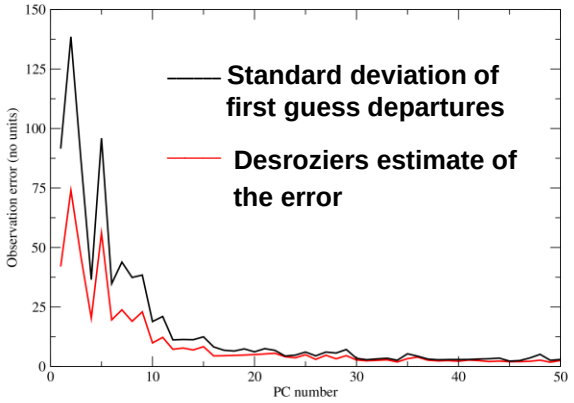
The 191 operational IASI channels (2.3 % of the total number)



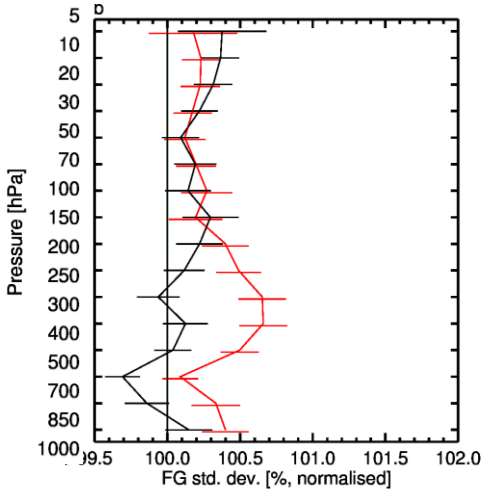
The full number (5421) of IASI channels in Band 1 and Band 2 (64% of the total number)



In both systems, observation errors are specified using full covariance error matrices derived utilising Desroziers's error diagnostics.



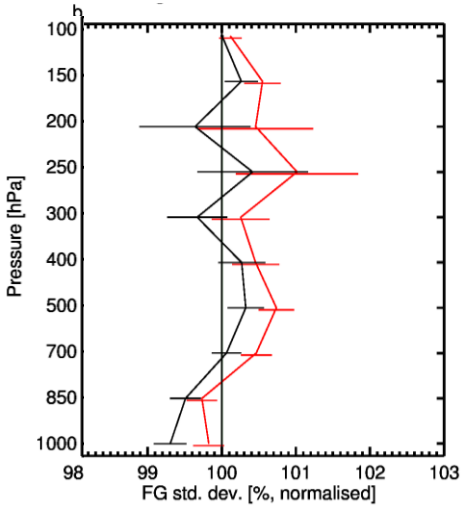
Verification against RADIOSONDES TEMPERATURE



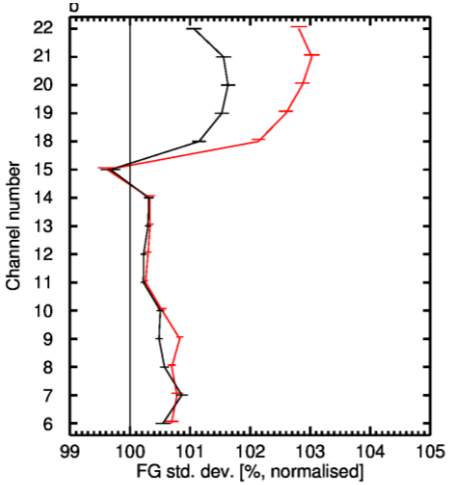
--- PC_B1_B2

--- PC_B1

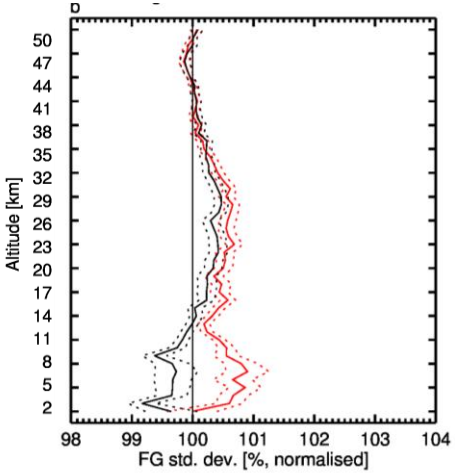
Verification against RADIOSONDES HUMIDITY



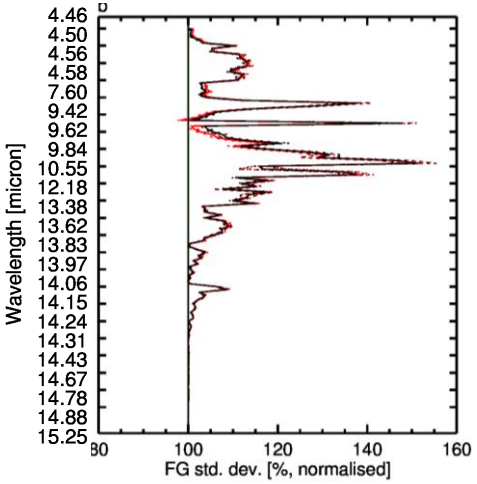
Verification against ATMS



Verification against GPSRO



Verification against AIRS



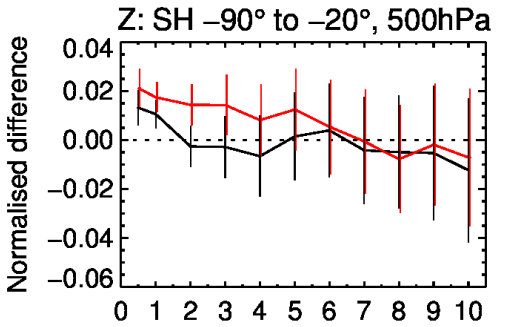
Forecast errors

Southern Hemisphere

Topics

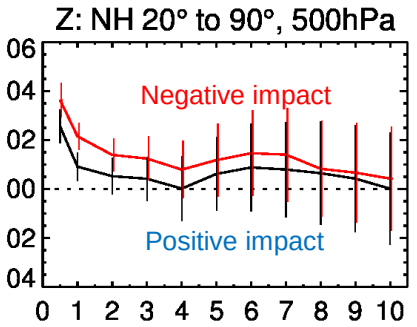
Northern Hemisphere

500hPa Geopotential

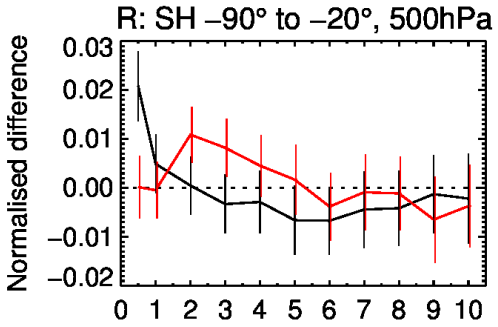


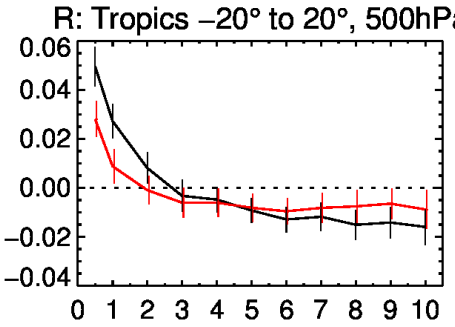
--- PC_B1_B2

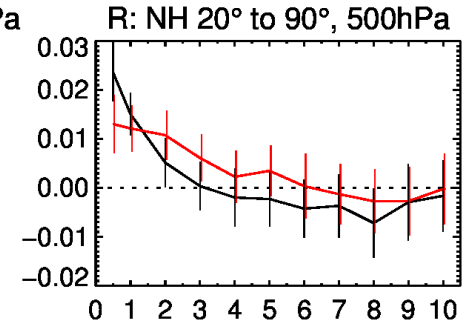
--- PC_B1



500hPa Relative humidity







The 4D-Var assimilation of 400 reconstructed radiances based on 400 PC scores

The benefits of the PC methodology can be reproduced via the assimilation of reconstructed radiances with the added benefits of being able to deal with cloudy scenes

The information contained in the 400 PC scores can be encapsulated in a subset of reconstructed radiances of the same size.

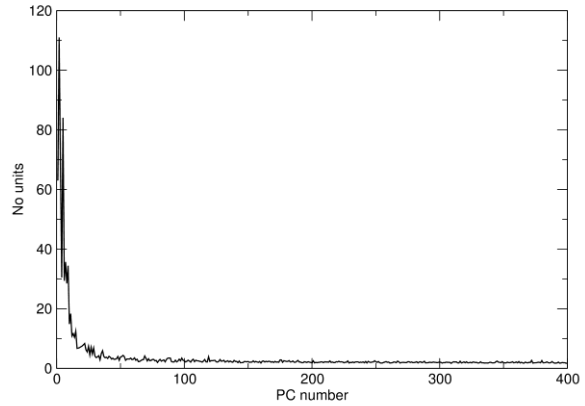
It can be shown that the cost function in PC space is identical to the cost function in reconstructed radiances space if:

1) The transformation of the observation error covariance matrix from PC space to reconstructed radiance space yields a non-singular matrix.

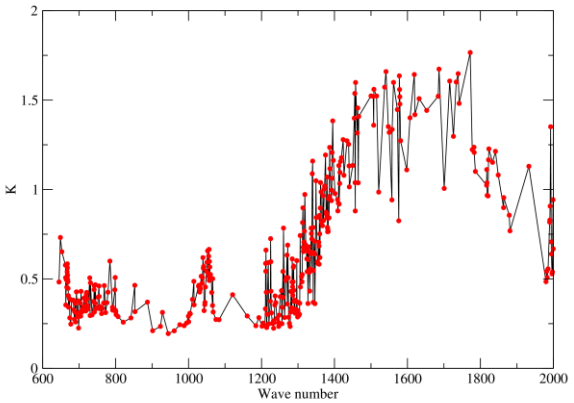
2) The simulation of the reconstructed radiances is based on the same forward operator used to simulate the PC scores (e.g. PC_RTTOV).

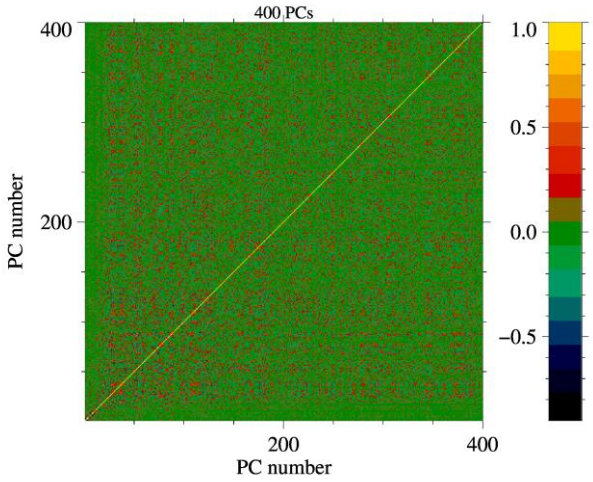
In all experiments we use a full error covariance matrix for IASI

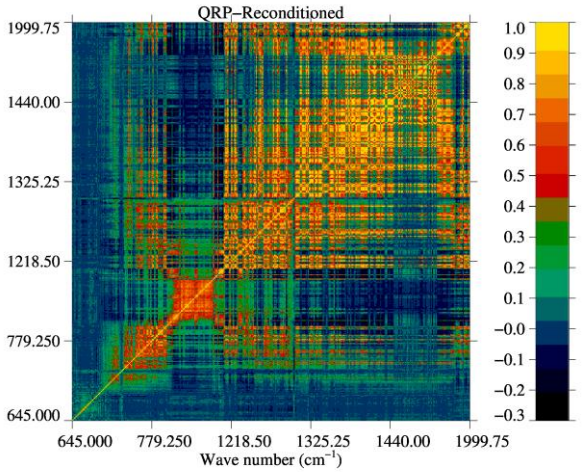
Desroziers's estimate of PC error



Reconstructed Radiances







Assimilation of PC scores and reconstructed radiances

To asses the performance of the PC based assimilation systems we have devised the following experiment design:

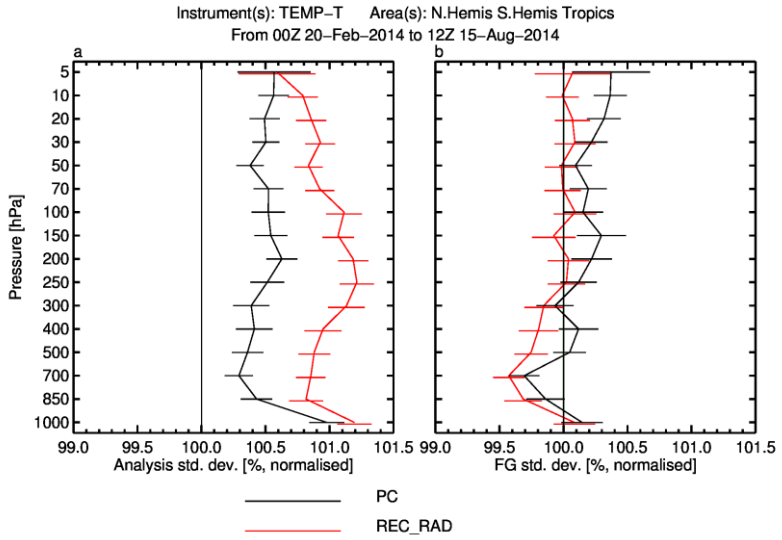
1) **BASE**: we use all operational observations (satellite and conventional) with the exception of IASI data.

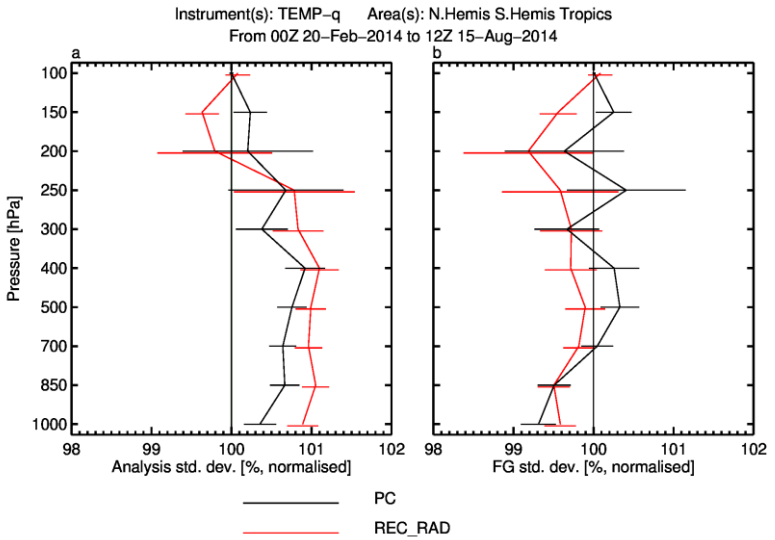
2) **RAD** : identical to BASE but additionally assimilates radiances from the 191 channels used in the operational 4D-Var

3) **PC_B1_B2** : identical to BASE but additionally assimilates 400 PC scores derived from the radiances in 5421 IASI channels.

4) **REC_RAD**: identical to BASE but additionally assimilates 400 reconstructed radiances

Experiments (cycle 40R2 – T511- 137 L) are currently covering the period 20 February 2014 - 13 August 2014.


Instrument(s): TEMP–T Area(s): N.Hemis S.Hemis Tropics
From 00Z 20–Feb–2014 to 12Z 15–Aug–2014
a
b
Pressure [hPa]
Analysis std. dev. [%, normalised]
FG std. dev. [%, normalised]
PC
REC_RAD


Instrument(s): TEMP–q Area(s): N.Hemis S.Hemis Tropics
From 00Z 20–Feb–2014 to 12Z 15–Aug–2014
a
b
Pressure [hPa]
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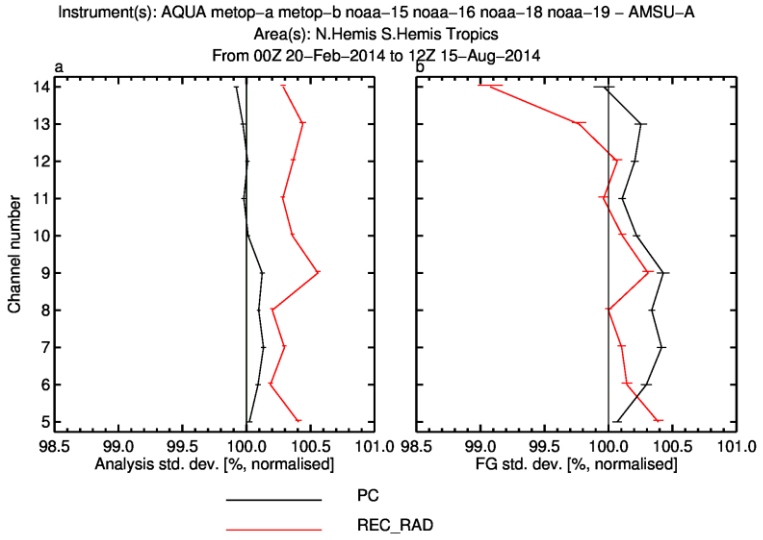
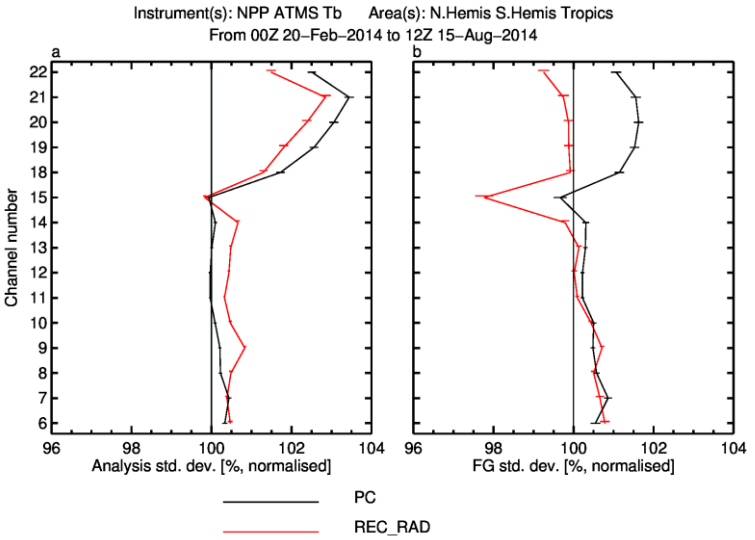
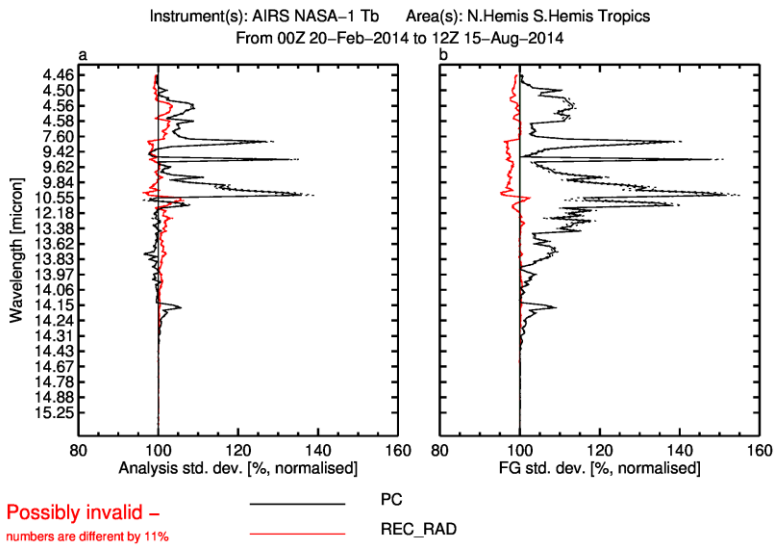
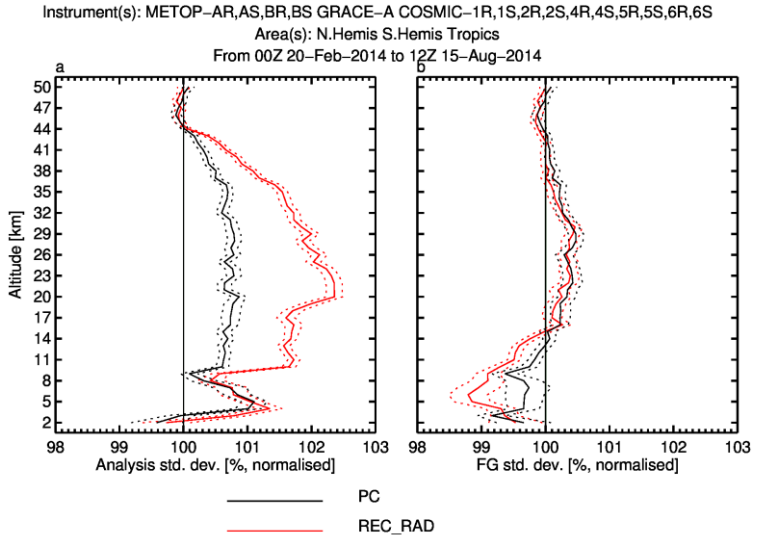
PC
REC_RAD


Instrument(s): AQUA metop–a metop–b noaa–15 noaa–16 noaa–18 noaa–19 – AMSU–A
Area(s): N.Hemis S.Hemis Tropics
From 00Z 20–Feb–2014 to 12Z 15–Aug–2014
a
b
Channel number
Analysis std. dev. [%, normalised]
FG std. dev. [%, normalised]
PC
REC_RAD


Instrument(s): NPP ATMS Tb Area(s): N.Hemis S.Hemis Tropics
From 00Z 20–Feb–2014 to 12Z 15–Aug–2014
a
b
Channel number
Analysis std. dev. [%, normalised]
FG std. dev. [%, normalised]
PC
REC_RAD


Instrument(s): AIRS NASA−1 Tb Area(s): N.Hemis S.Hemis Tropics
From 00Z 20−Feb−2014 to 12Z 15−Aug−2014
a
b
Wavelength [micron]
4.46
4.50
4.56
4.58
7.60
9.42
9.62
9.84
10.55
12.18
13.38
13.62
13.83
13.97
14.06
14.15
14.24
14.31
14.43
14.67
14.78
14.88
15.25
80
100
120
140
160
Analysis std. dev. [%, normalised]
FG std. dev. [%, normalised]
Possibly invalid −
numbers are different by 11%
PC
REC_RAD


Instrument(s): METOP−AR,AS,BR,BS GRACE−A COSMIC−1R,1S,2R,2S,4R,4S,5R,5S,6R,6S
Area(s): N.Hemis S.Hemis Tropics
From 00Z 20−Feb−2014 to 12Z 15−Aug−2014
a
b
Altitude [km]
50
47
44
41
38
35
32
29
26
23
20
17
14
11
8
5
2
98
99
100
101
102
103
Analysis std. dev. [%, normalised]
FG std. dev. [%, normalised]
PC
REC_RAD

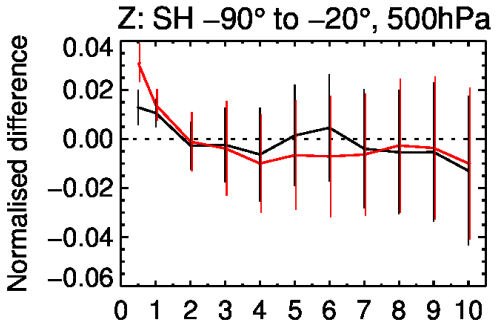
Forecast errors

Southern Hemisphere

Topics

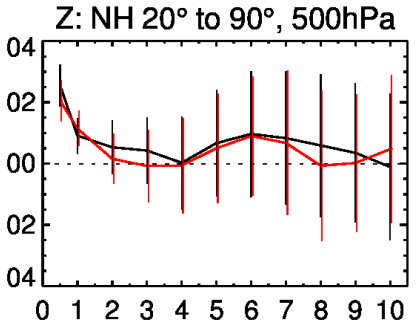
Northern Hemisphere

500hPa Geopotential

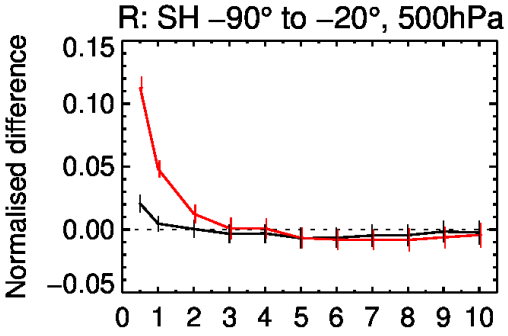


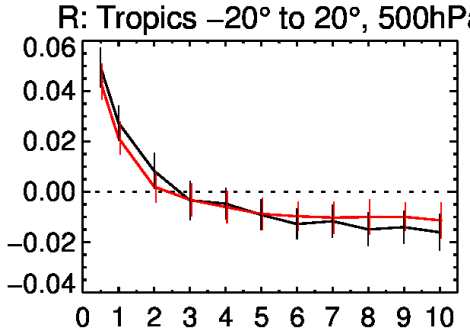
--- PC_B1_B2

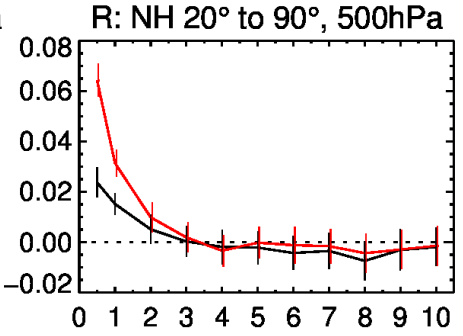
--- REC_RAD



500hPa Relative humic







Assimilation of reconstructed radiances (Forecast cycle 41R2)

To asses the performance of the PC based assimilation systems we have devised the following experiment design:

1) **BASE**: we use all operational observations (satellite and conventional) with the exception of IASI data.

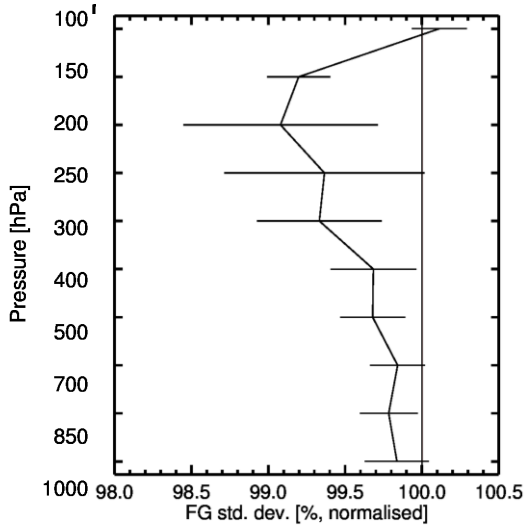
2) **RAD** : identical to BASE but additionally assimilates radiances from the 191 channels used in the operational 4D-Var

4) **REC_RAD**: identical to BASE but additionally assimilates 400 reconstructed radiances

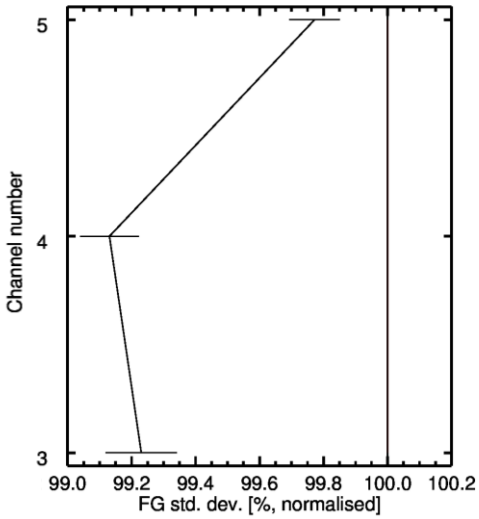
Experiments (cycle 41R2 – T637- 137 L) are currently covering the period 20 July 2015 - 20 December 2015.

Six months of 4D-Var assimilation trials show that the assimilation of 400 reconstructed radiances produces an improved humidity analisys compared to the operational system

Verification against RADIOSONDES

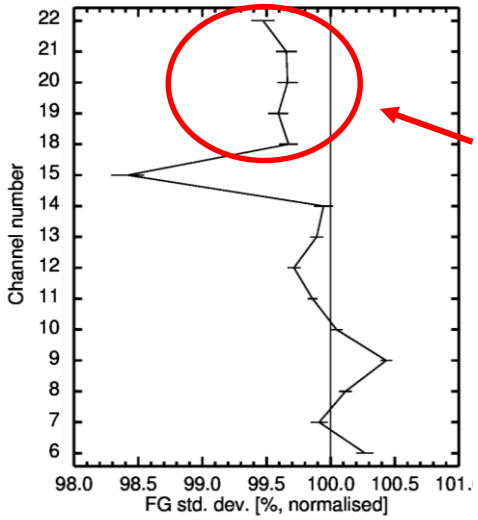


Verification against MWHS



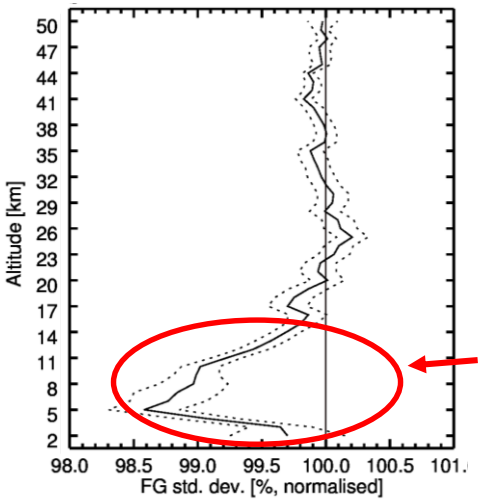
Values less than 100% indicate that the use of 400 reconstructed radiances produce a reduction of the standard deviation compared to the use of the operational 191channels

Verification against ATMS



Water vapour sounding channels

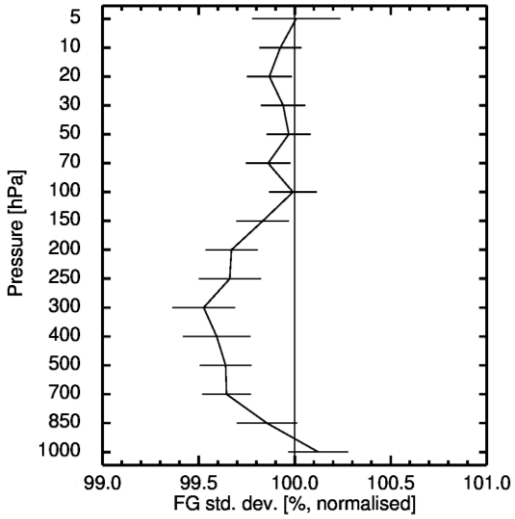
Verification against GPSRO



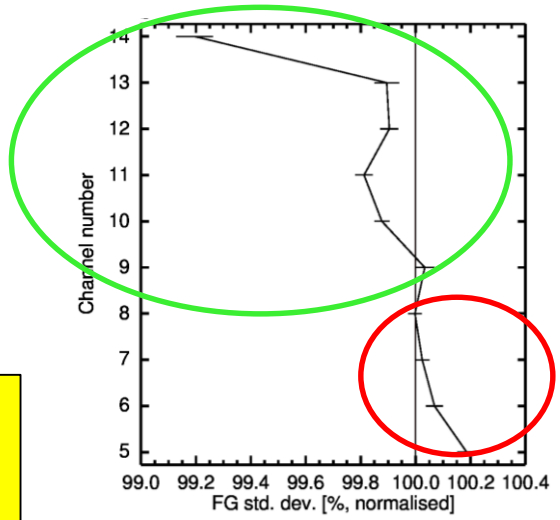
Water vapour information

Six months of 4D-Var assimilation trials show that the assimilation of 400 reconstructed radiances produces an improved temperature analisys in the stratosphere but there is evidence of a degradation of the temperature analysis in some regions of the troposphere

Verification against RADIOSONDES



Verification against AMSU

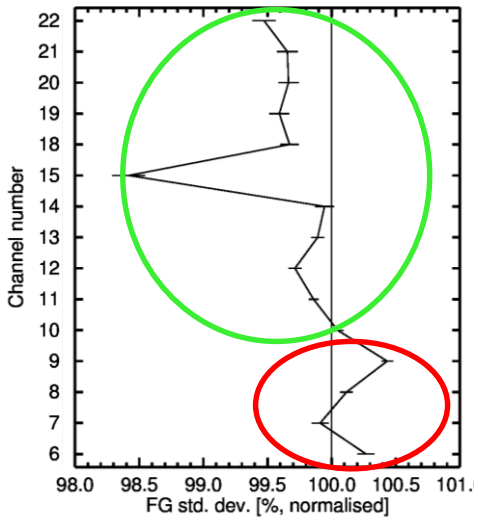


Stratosphere

Troposphere

Values less than 100% indicate that the use of 400 reconstructed radiances produce a reduction of the standard deviation compared to the use of the operational 191channels

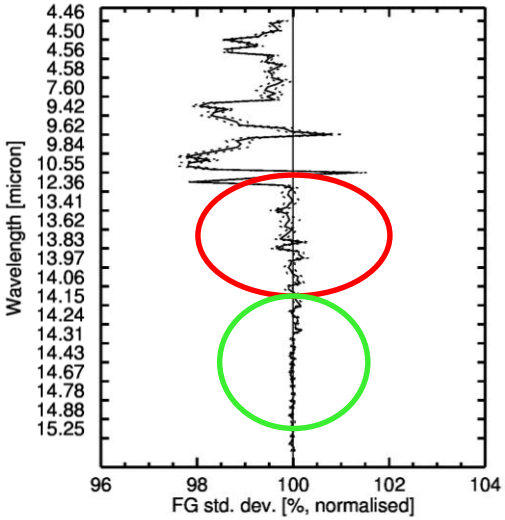
Verification against ATMS



Stratosphere

Troposphere

Verification against AIRS



Troposphere

Stratosphere

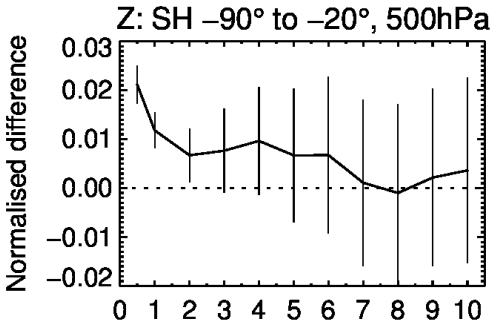
Forecast errors

Southern Hemisphere

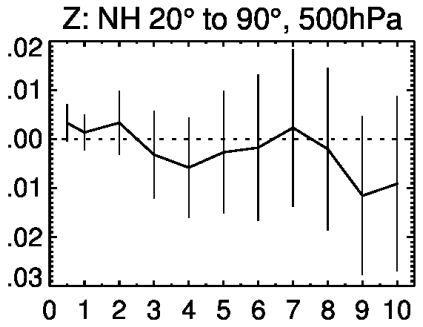
Topics

Northern Hemisphere

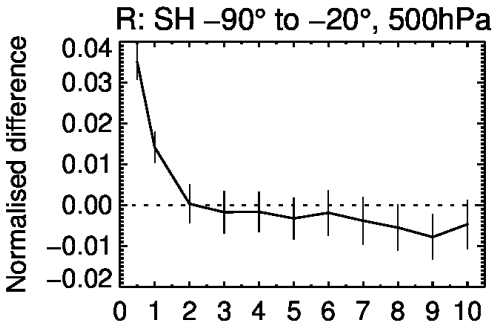
500hPa Geopotential

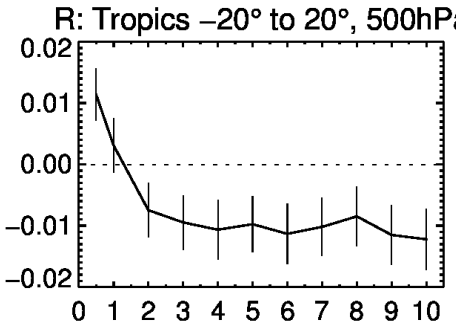


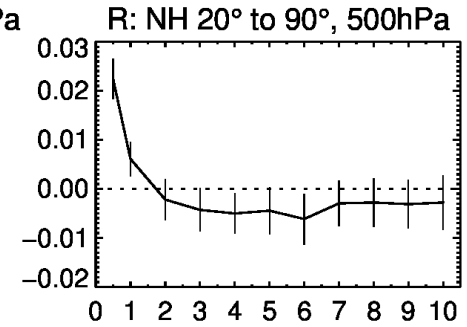
--- REC_RAD



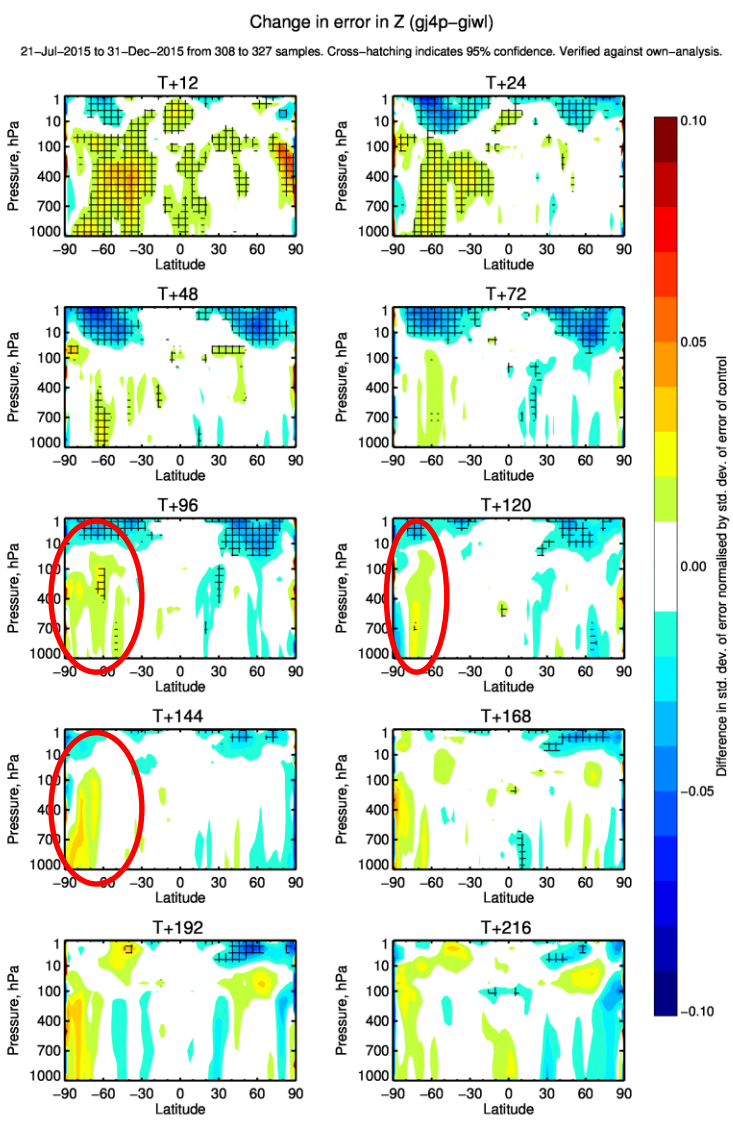
500hPa Relative humidity







Forecast errors: geopotential



Possible origin of the degraded temperature analysis in the troposphere

1) Imbalance between the temperature information from the long wave IASI temperature sounding channels and the temperature information from the mid wave IASI humidity sounding channels (i.e. the latter dominates).

2) Humidity background errors are too small

Possible strategies for improving the temperature analysis

1) Blacklist channels in the water vapour band.

2) Use a dufferent formulation of the humidity background errors (see Elias's talk)

Challenge

Improve the temperature analysis whilst preserving the improvements made in the humidity analysis

SUMMARY AND FUTURE WORK

- Latest results indicate that maximising the use of the available IASI spectrum produces improvements in the temperature and humidity analysis.
- The assimilation of IASI reconstructed radiances suggest that there are benefits compared to the assimilation of PC scores especially for the humidity analysis. There are, however, some issues with the temperature analysis in the troposphere.
- We will focus on the consolidation of the results obtained so far in view of a possible operational implementation of the reconstructed radiances.
- The PC methodology could be in principle extended to AIRS and CrIS data.
- The methodology could prove to be crucial for the full exploitation of the next generation of hyperspectral sounders (i.e. IASI-NG, MTG-IRS, GIIRS).