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Infrared Cloudy Radiances Assimilation Experiments at Environment Canada

ITSC-17
Monterey, California

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Outline

- Assimilation of clear infrared radiances from AIRS and IASI
- Simplified cloudy radiative transfer modeling
- Modifications necessary to go from 3D-Var to 4D-Var assimilation mode
- Quality control criteria
- 4D-Var experiments:
  - Description
  - Statistics in observation space
  - Validation of forecasts against Radiosondes
  - Validation of forecasts against Analyses
- Conclusions, perspectives

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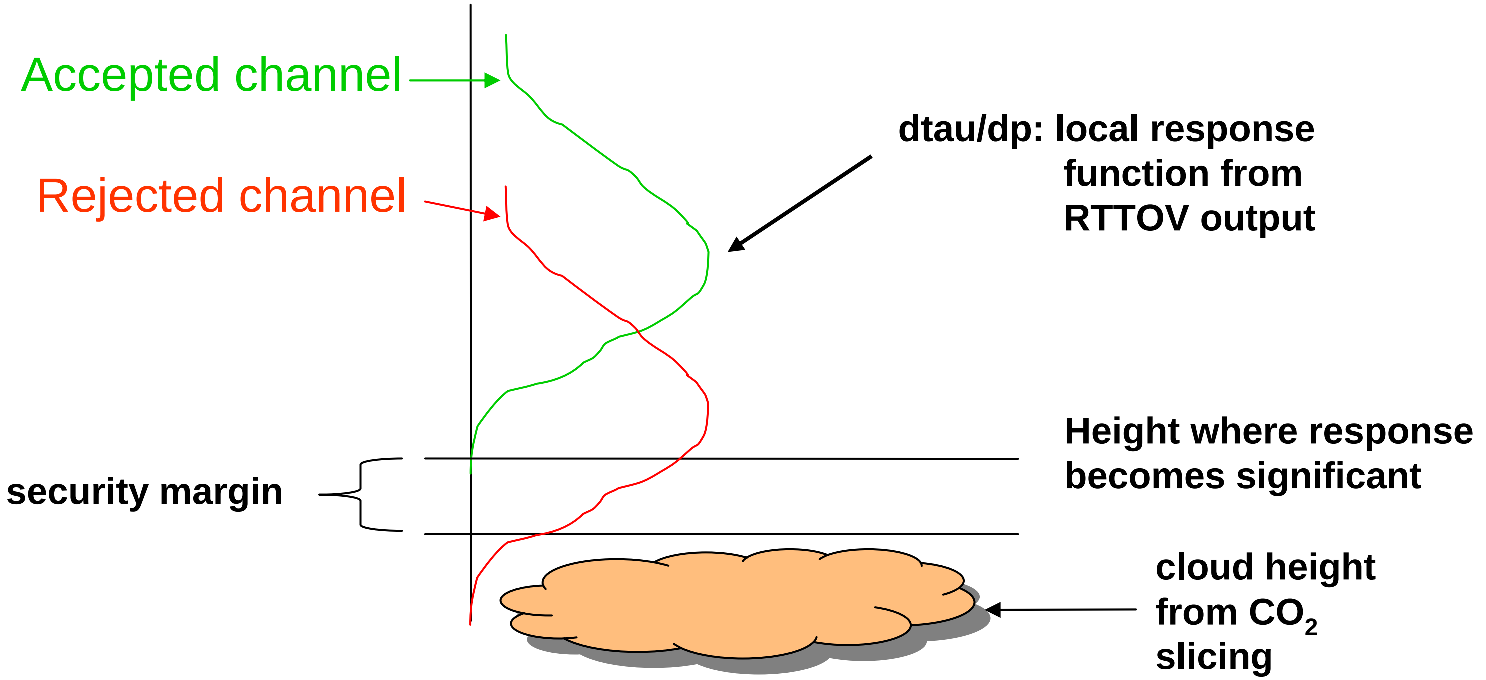
AIRS and IASI clear assimilation setup

- Assimilation of cloud unaffected radiances:



Simplified cloudy radiance modeling with effective cloud parameters 1

- Simplified description of the cloud radiative effect for a cloud located at P_c (cloud top pressure) with cloud emissivity spectrum $N\varepsilon(\nu)$:

$$I_{cld}(\nu) = N\varepsilon(\nu) I_{ovc}(\nu) + (1 - N\varepsilon(\nu)) I_{clr}(\nu)$$

$I_{cld}(\nu)$: Cloudy radiance

$N\varepsilon(\nu)$: cloud effective emissivity

$I_{ovc}(\nu, \mathrm{P_c})$: Cloudy overcast radiance

$I_{clr}(\nu)$: Clear radiance

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Simplified cloudy radiance modeling with effective cloud parameters 2

- Cloud emissivity model:

$$N\varepsilon(\nu) = 1 - \exp\left[-k_{cld}(\nu, r_e, D_e)\delta\right]$$

r_e : effective radius for liquid phase (set to 12 μm)

D_e : effective diameter for ice phase (set to 55 μm)

δ : effective cloud water path

• Up to date optical properties of liquid and solid (ice) water are used

• Scattering is accounted for approximately

•It is implicitly assumed that the cloud covers the whole field of view

- First guess and background values determined from CO_2 slicing for δ (via retrieved $N\varepsilon$) and P_c

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From 3D-Var to 4-Dvar assimilation

- Minimization of the cost function more difficult in 4D-Var mode than it was in 3D-Var mode

→Need for a preconditioning with the diagonal of the hessian Matrix for cloud parameters

$$z \longrightarrow Z = C(z - z_b)$$

Where z is a cloud parameter

with $$C = \sqrt{\frac{1}{\sigma_c^2} + \sum_{\text{channels } i} \left(\frac{1}{\sigma_{oi}} \frac{\partial H_i}{\partial z} \right)^2}$$ Instead of $$C = \frac{1}{\sigma_c}$$

σ_c represents the error associated with the cloud parameter z
σ_{oi} represents the observation error of channel i
H is the radiative transfer operator

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Various other improvements modifications

- Modification of the value of the effective diameter (from 25 μm to 55 μm) for ice to reduce observed biases
- Improvement in the CO_2 slicing algorithm (work of O. Pancrati and L. Garand see presentation by Louis later)
- Use of the MPI version (new) of the assimilation code
- Application of a flat bias correction (instead of aBT+B) calculated using only clear radiances

Quality control criteria for cloud-affected radiances

- Assimilation of cloudy radiances above sea only
- No assimilation of AIRS shortwave channels
- For cloud top pressures between 250hPa and 900 hPa
- Restriction to near overcast situations ($N\varepsilon > 0.9$)
- Exclusion of situations with temperature inversion leading to an ambiguous solution for the CO_2 slicing algorithm
- Restriction to situation where the solution of the CO_2 slicing is well defined ($\sigma_{Pc} < 50$ hPa, $\sigma_{N\varepsilon} < 0.1$)
- To limit the impact of uncertainty on cloud phase:

$$\left| \left(\varepsilon_{ice} - \varepsilon_{liquid}\right) \frac{\partial T_B}{\partial \varepsilon} \frac{1}{\sigma_{obs}} \right| \leq \frac{1}{4}$$

Description of the 4D-Var experiments 1/2

- 4Dvar assimilation experiments
- From 12/15/2008 to 01/08/2009
- **Control experiment** assimilation of:
  - Conventional data (radiosondes, etc…)
  - Quickscat winds
  - AMSU-A and AMSU-B microwave radiances from NOAAxx and AQUA platforms
  - SSM-I and SSM-I-S microwave radiances from DMSP-xx platforms
  - ***GEORAD radiances***
  - AIRS infrared radiances (87 channels)
  - ***IASI infrared radiances (128 channels)***
  - GPS radio-occultation (refractivity profiles)
  - ***Humidity from planes***
- **Test experiment**: same but with assimilation of AIRS and IASI in cloudy mode

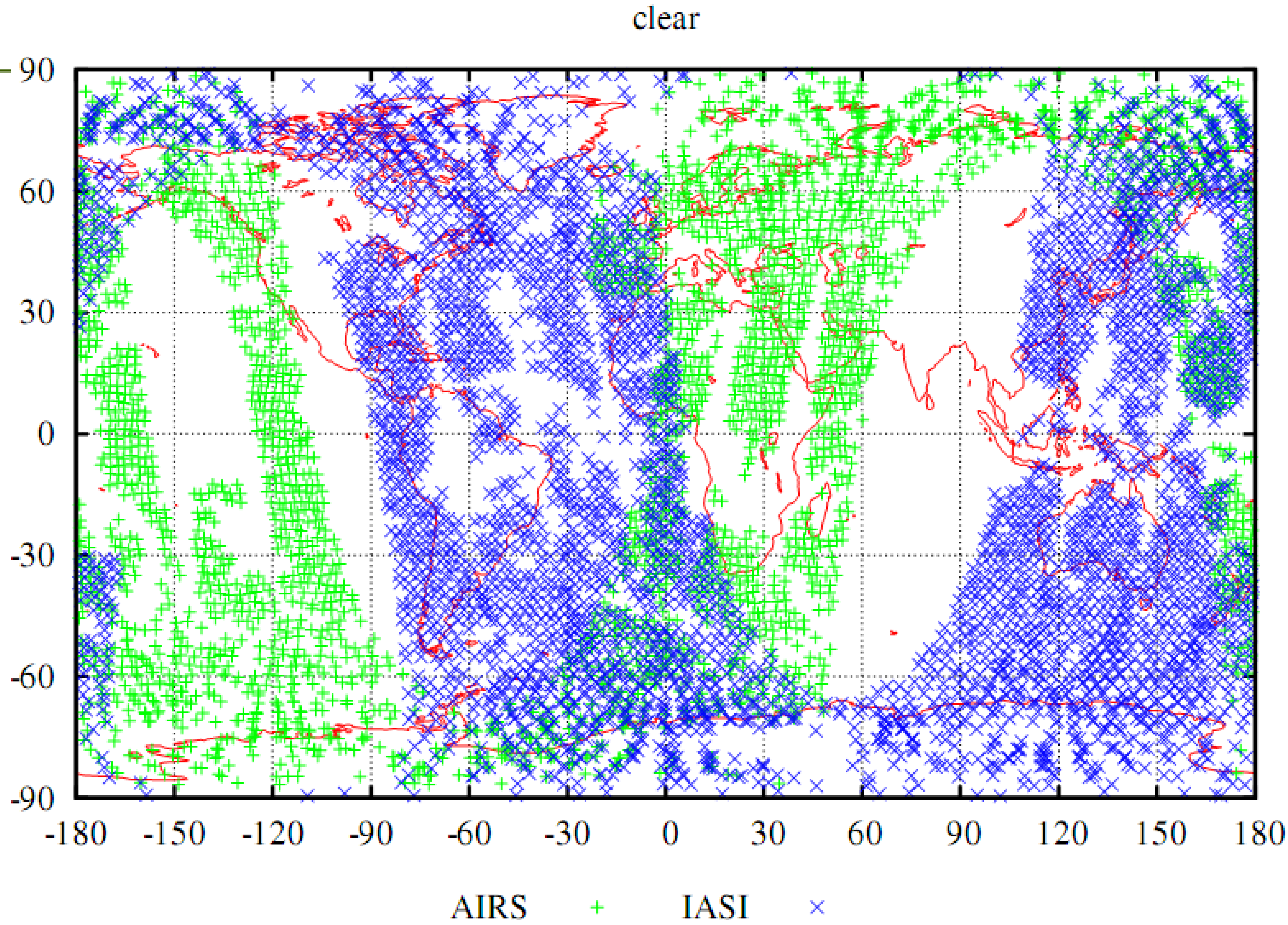
Description of the 4D-Var experiments 2/2

- Background error for cloud parameters are estimated to be equivalent to an error of 2K for a window channel

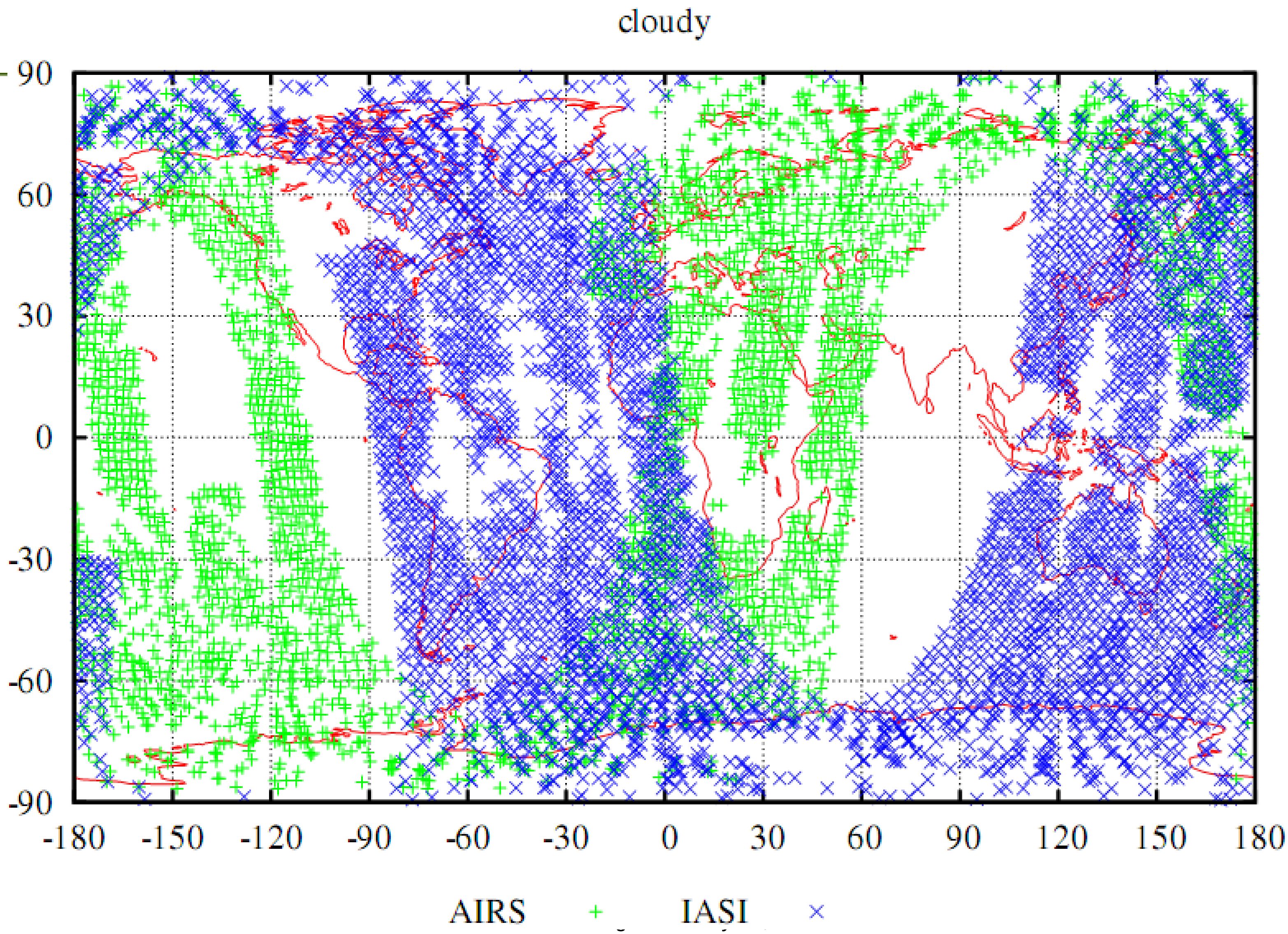
Description of the model

- GEM global model
- 800x600 grid
- 80 vertical hybrid levels with a top at 0.1 hPa

Location of extra observations



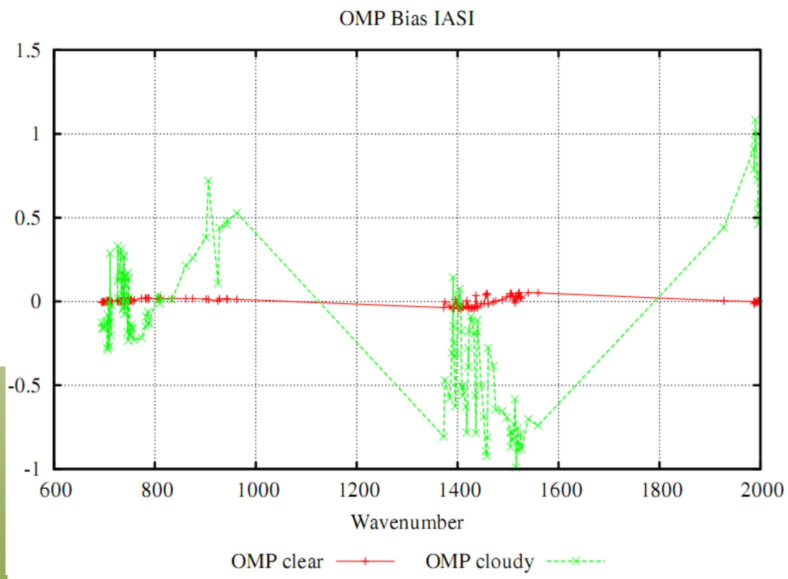
Location of extra observations

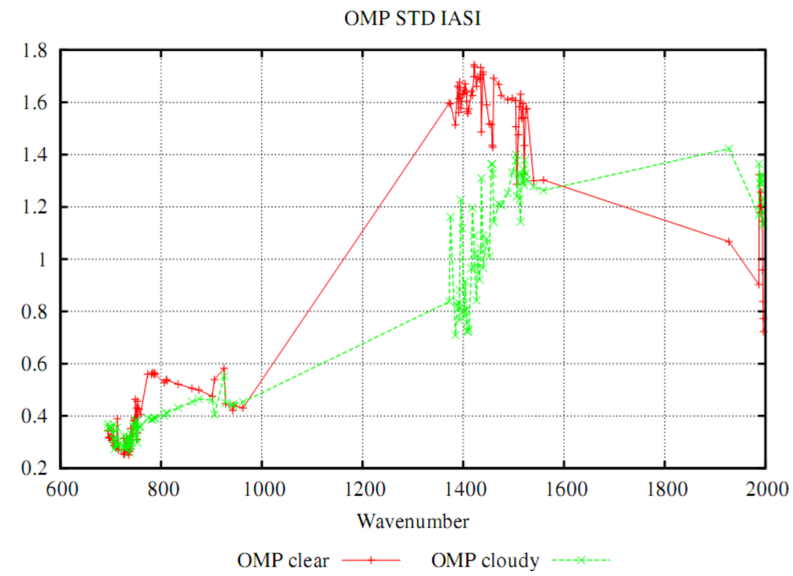


Statistics in observation space 1

First guess departures for IASI

Less than 5% extra radiances





Residual bias for cloudy radiances not negligible
Cloudy standard deviation lower for water vapor sensitive channels
Very similar standard deviation for temperature channels

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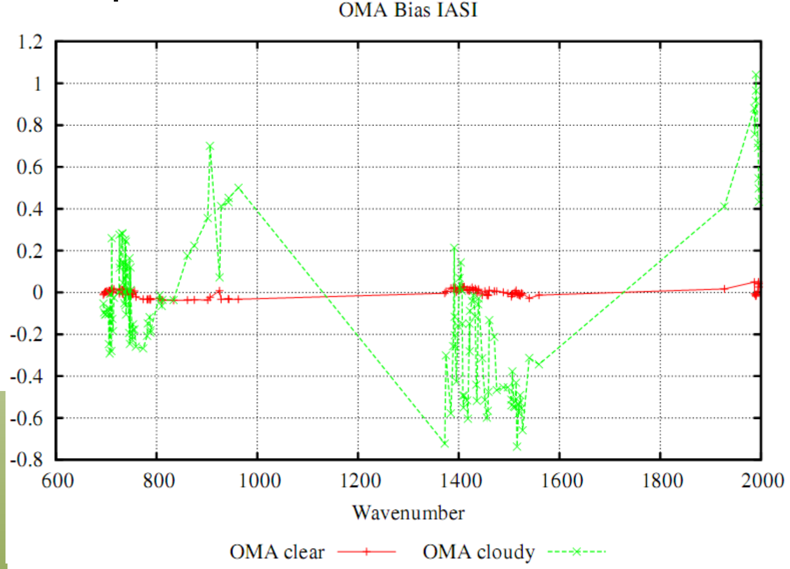
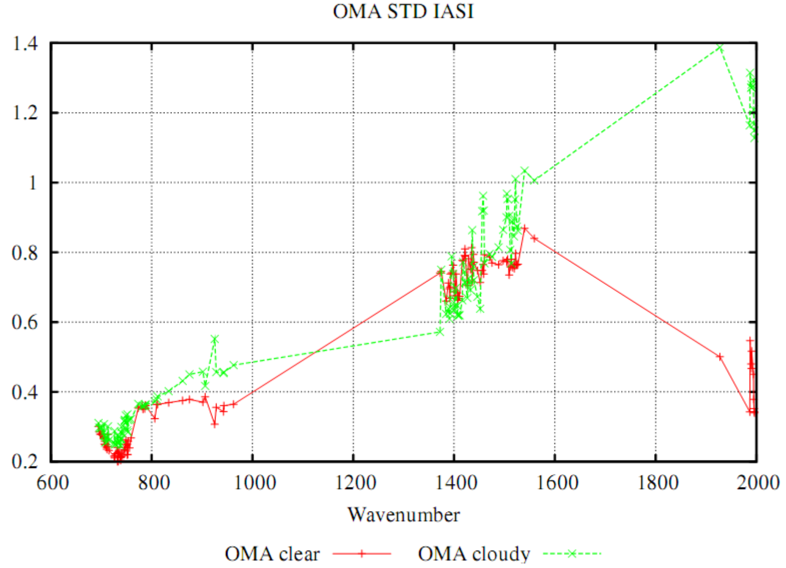
Statistics in observation space 2

departures after assimilation for IASI





Persistant residual bias for cloudy radiances
Similar standard deviation after assimilation except for channels close to 2000 cm^{-1}

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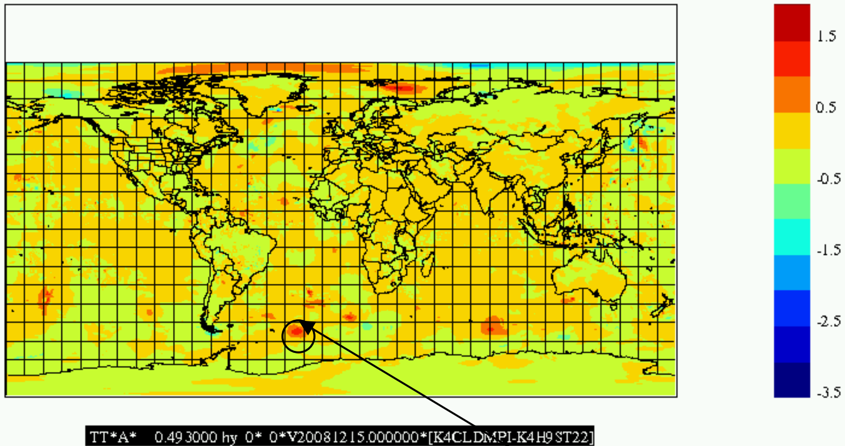
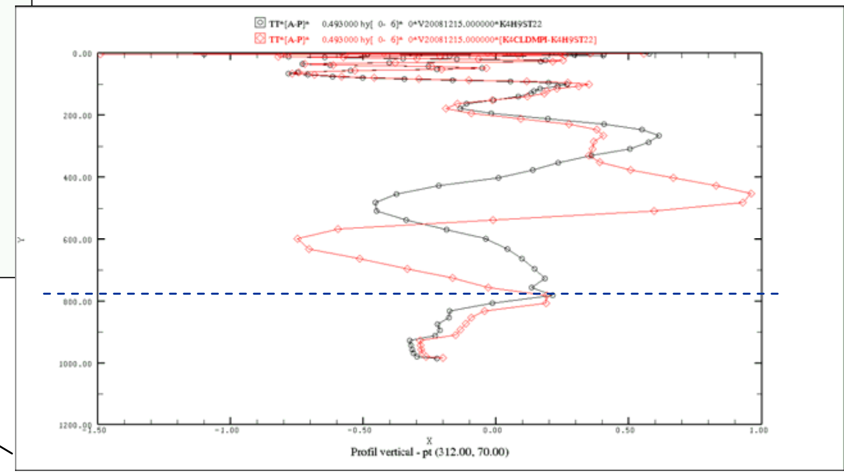
Example of analysis increments

500 hPa Temperature increment differences



From first analysis

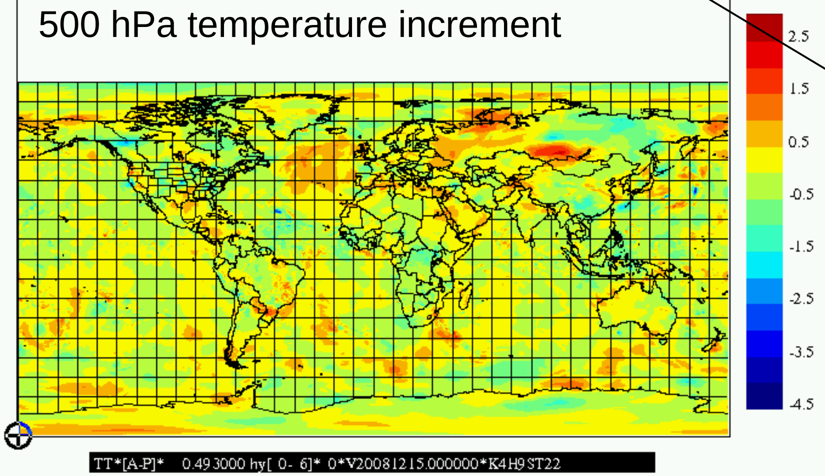


Clear increment

Cloudy increment

TT*[A-P]* 0.493000 hy[0- 6]* 0*V20081215.000000*[K4CLDMPI-K4H9ST22]

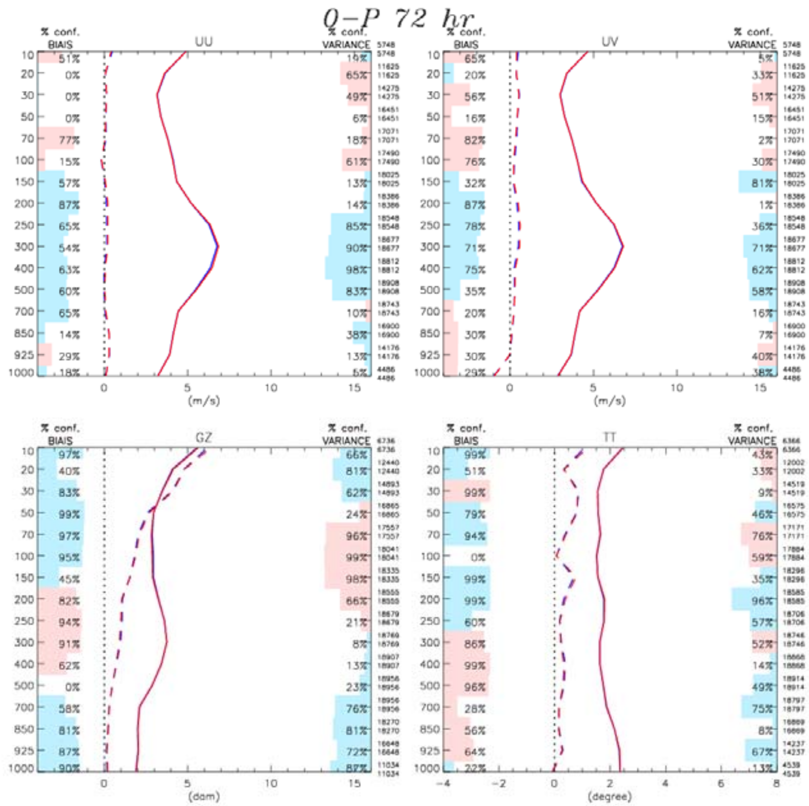
500 hPa temperature increment



Validation against radiosondes 1

- Validation of forecasts against radiosondes: World 72 h

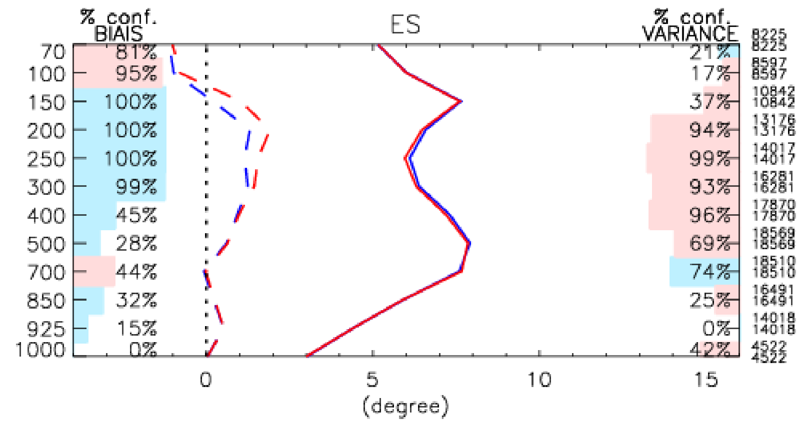
Wind



Geopotential height

Temperature

Dew point depression



38 cases

Legend:

Control is better

Test is better

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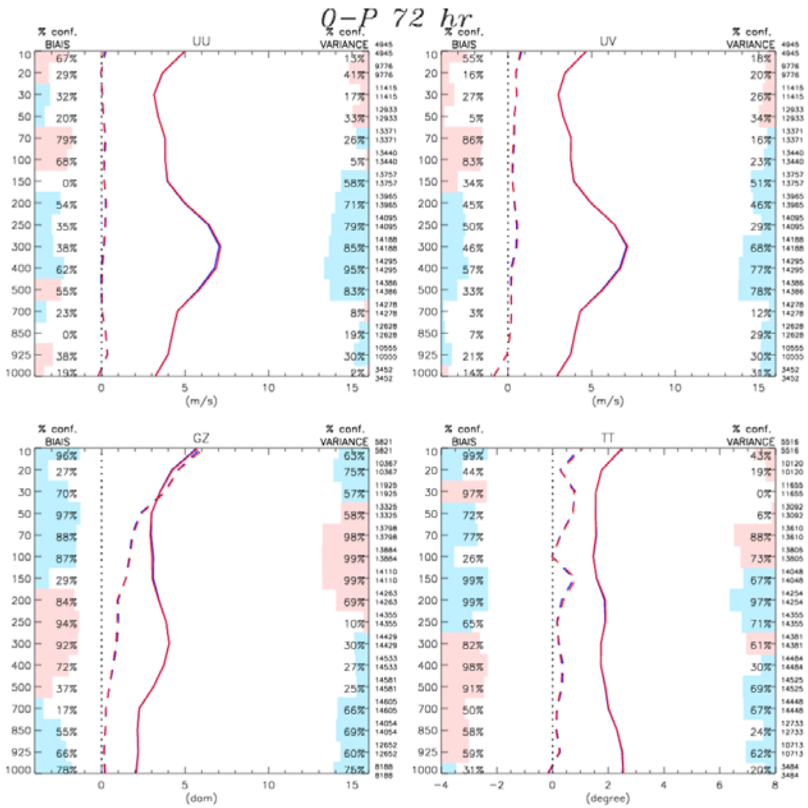
Validation against radiosondes 2

- Validation of forecasts against radiosondes: Northern Hemisphere 72 h

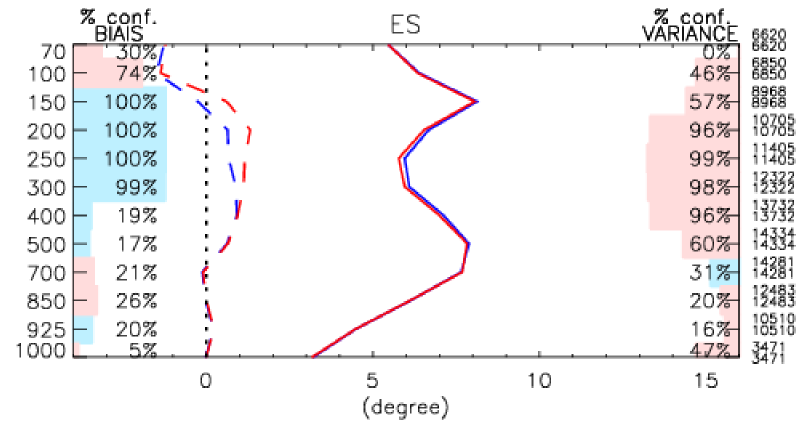
Wind



Geopotential height

Temperature

Dew point depression



38 cases

Legend:

Control is better

Test is better

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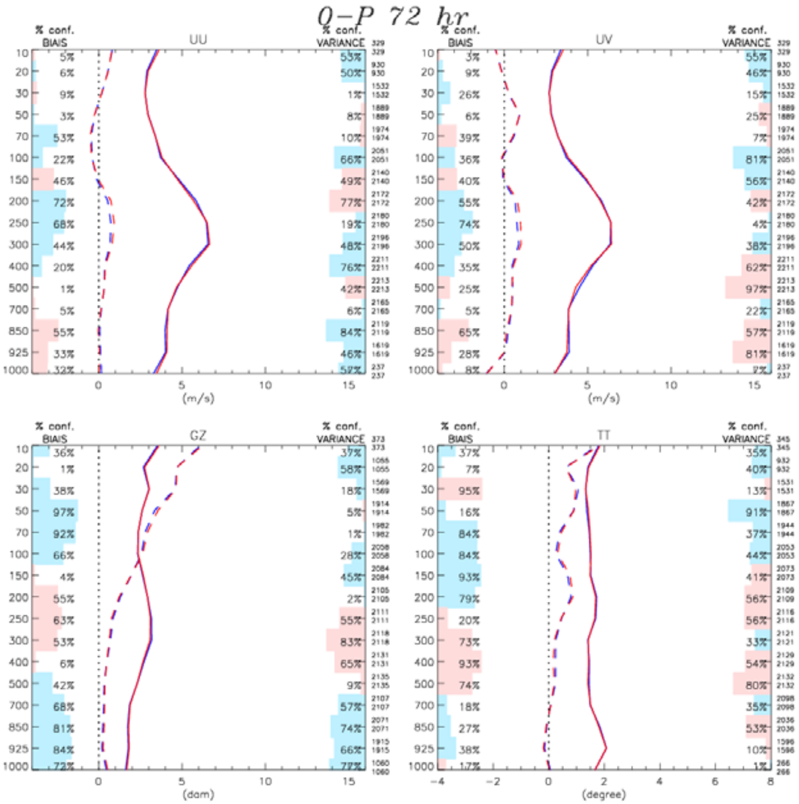
Validation against radiosondes 3

- Validation of forecasts against radiosondes: Southern Hemisphere 72 h

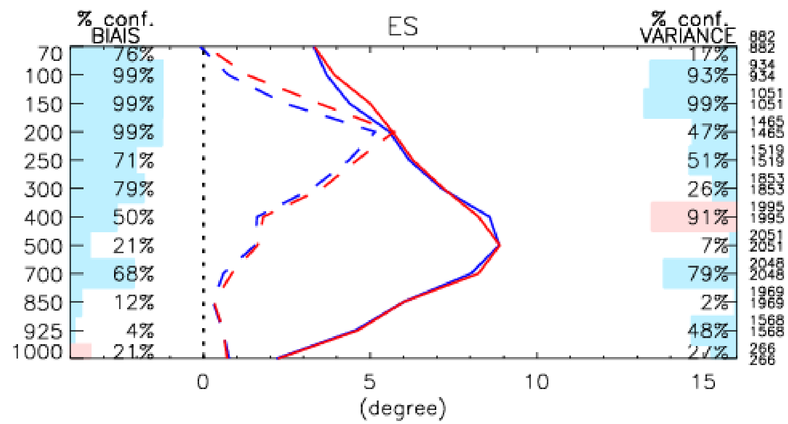
Wind



Geopotential height

Temperature

Dew point depression



38 cases

Legend:

Control is better

Test is better

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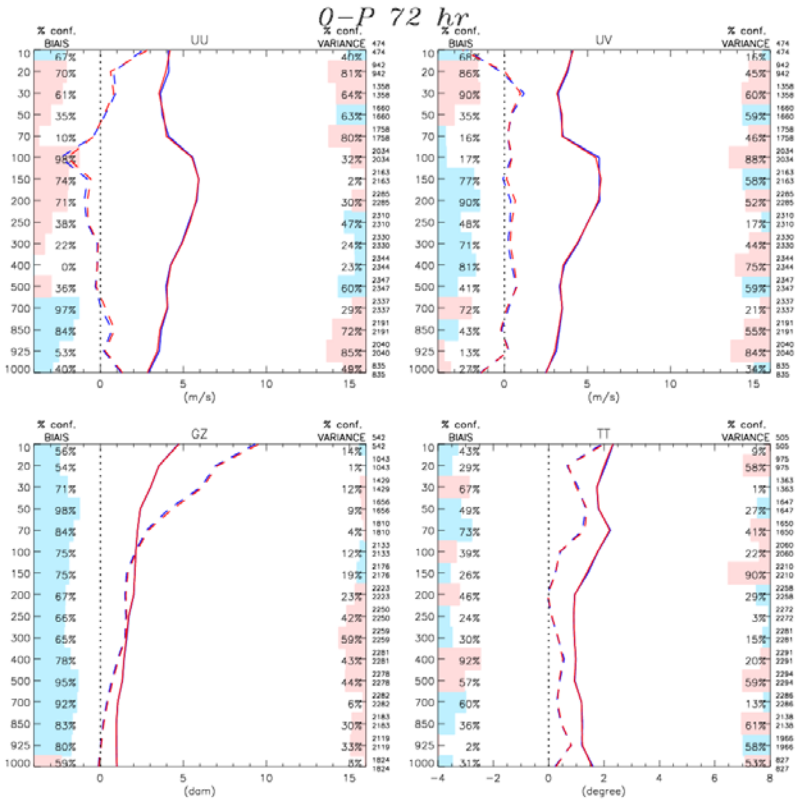
Validation against radiosondes 4

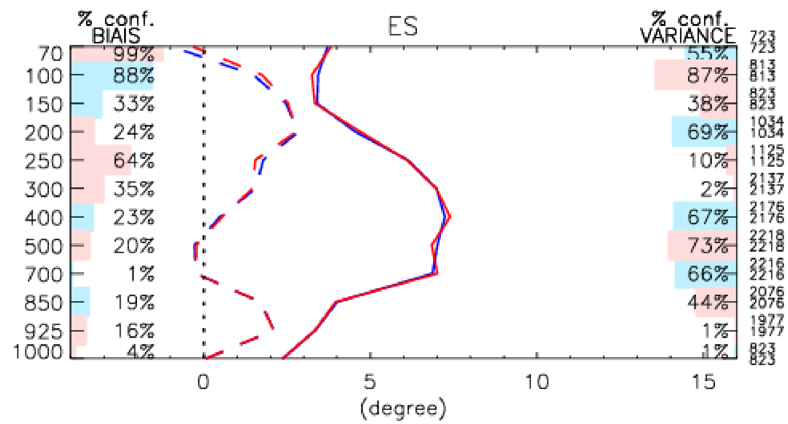
- Validation of forecasts against radiosondes: Tropics 72 h

Wind



Geopotential height Temperature

Dew point depression



38 cases

Legend:

Control is better

Test is better

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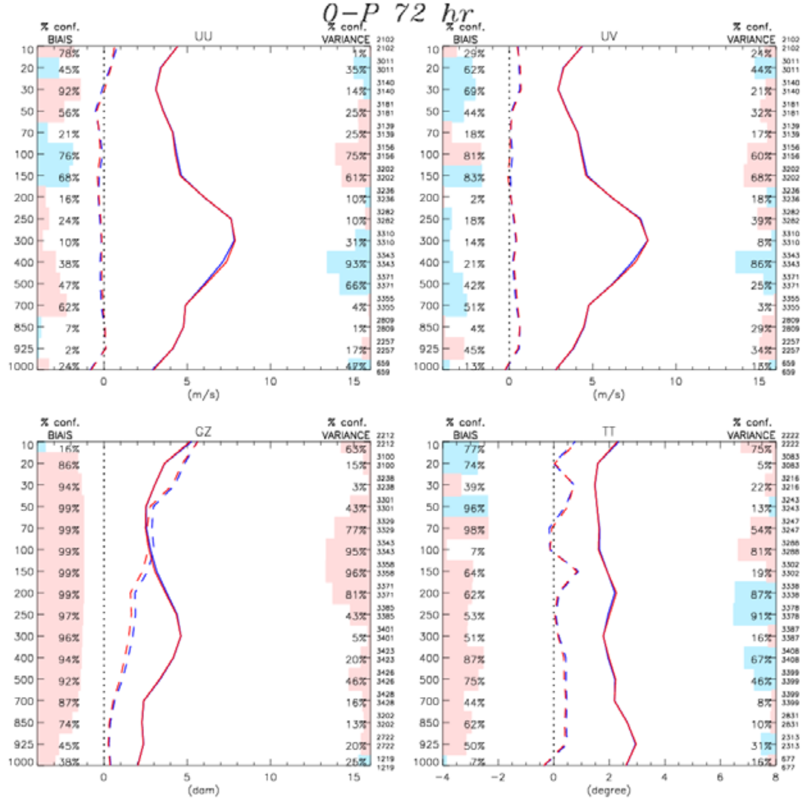
Validation against radiosondes 5

- Validation of forecasts against radiosondes: North America 72 h

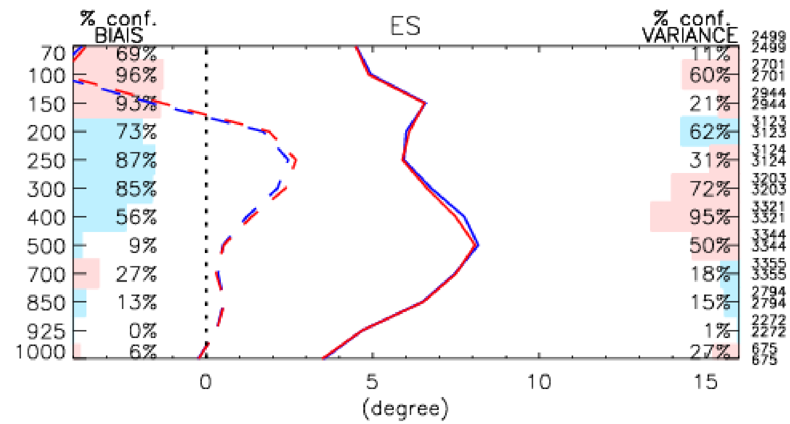
Wind



Geopotential height

Temperature

Dew point depression



38 cases

Legend:

Control is better

Test is better

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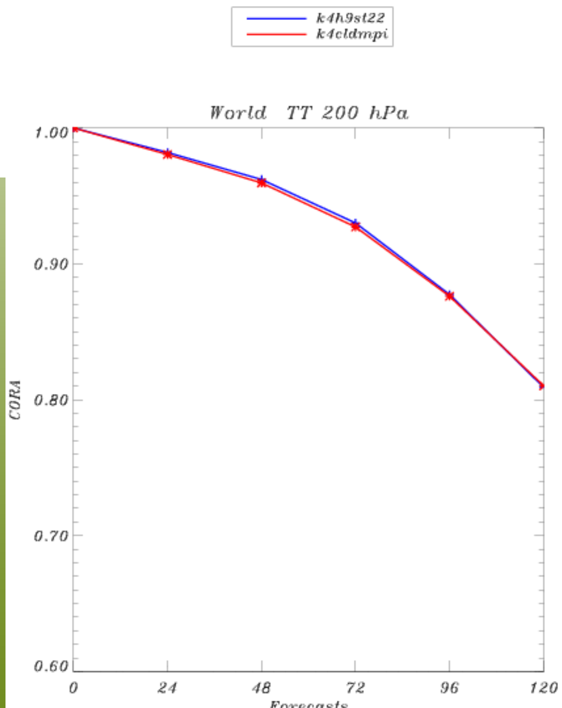
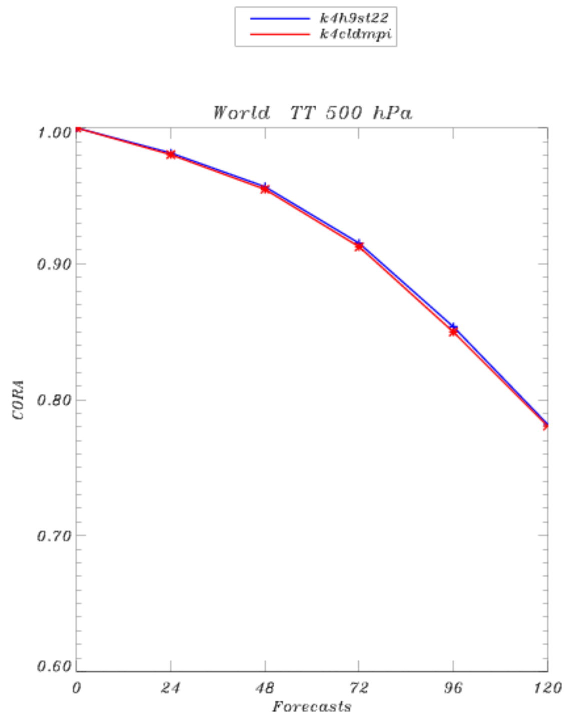
Validation against Analyses 1

Global temperature correlation of anomaly score

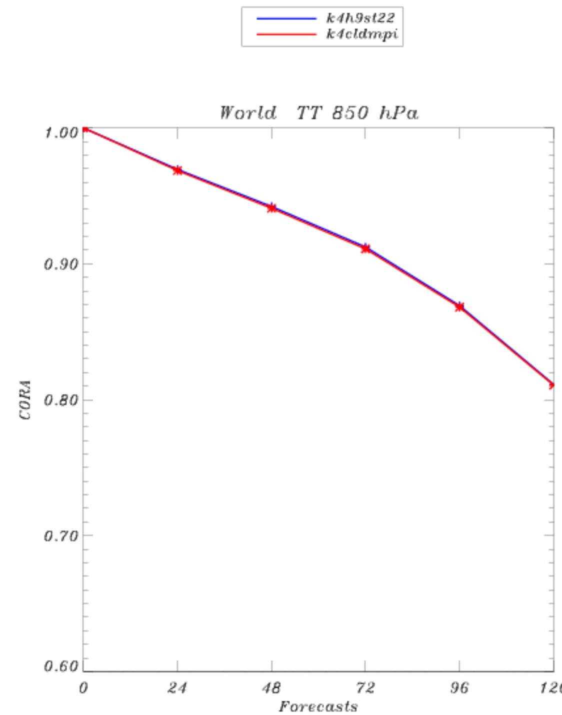
200 hPa



500 hPa



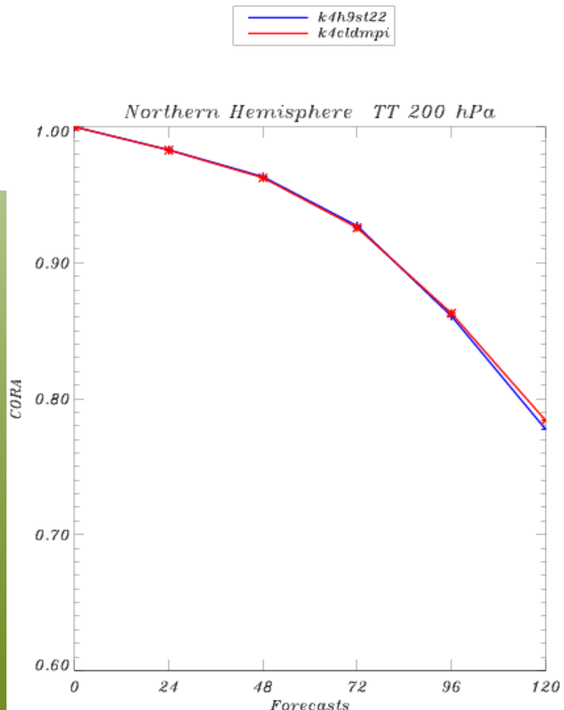
850 hPa



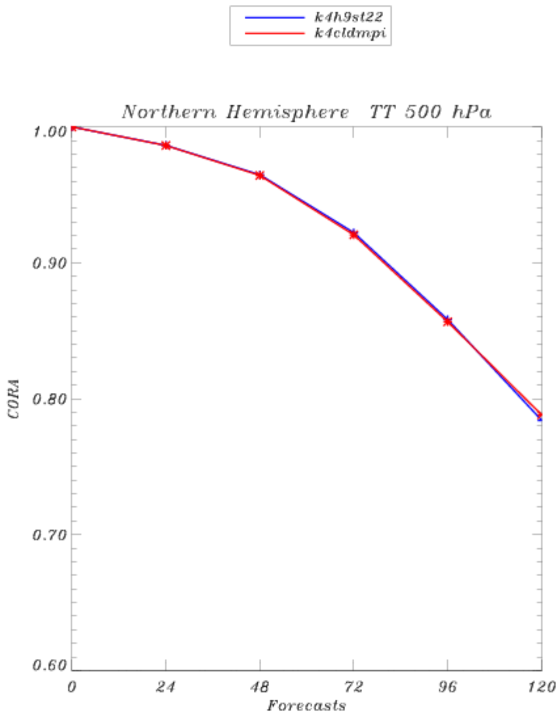
Validation against Analyses 2

Northern hemisphere temperature correlation of anomaly score

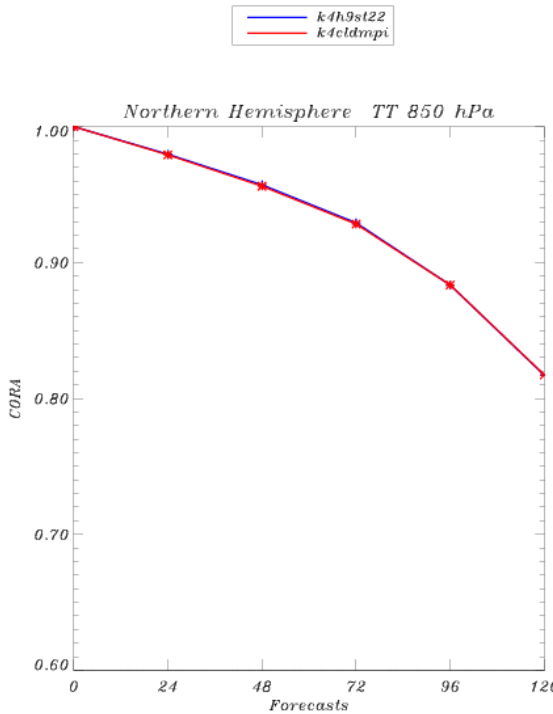
200 hPa



500 hPa



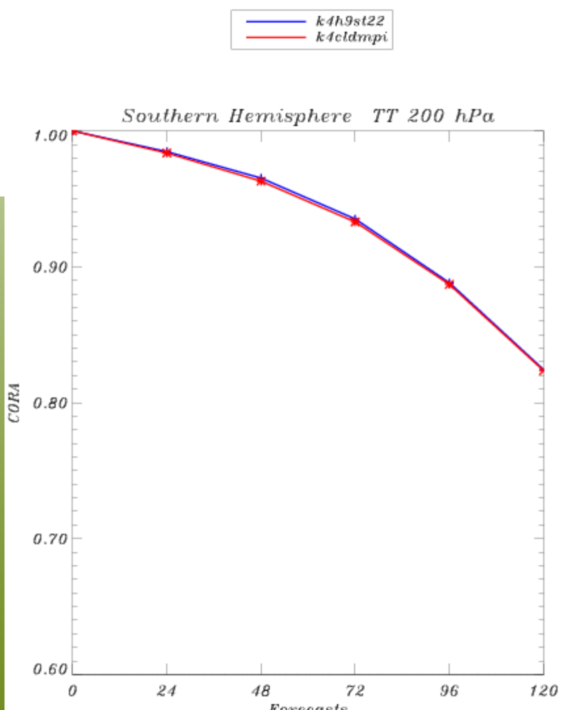
850 hPa



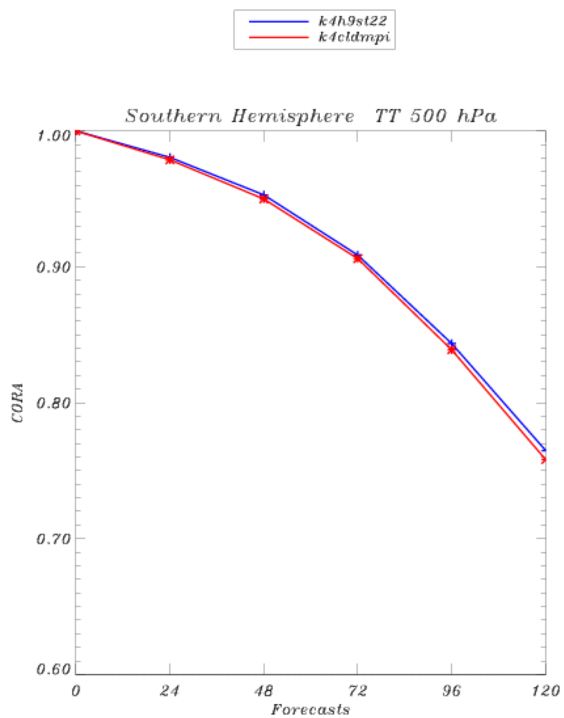
Validation against Analyses 3

Southern hemisphere temperature correlation of anomaly score

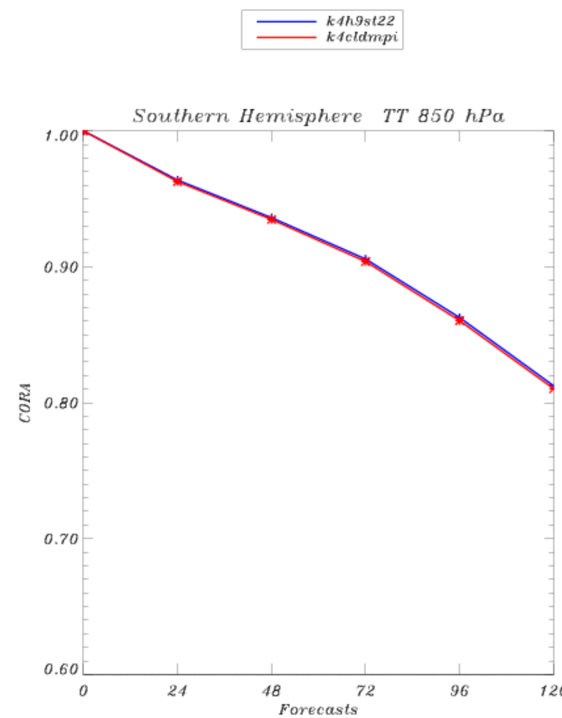
200 hPa



500 hPa



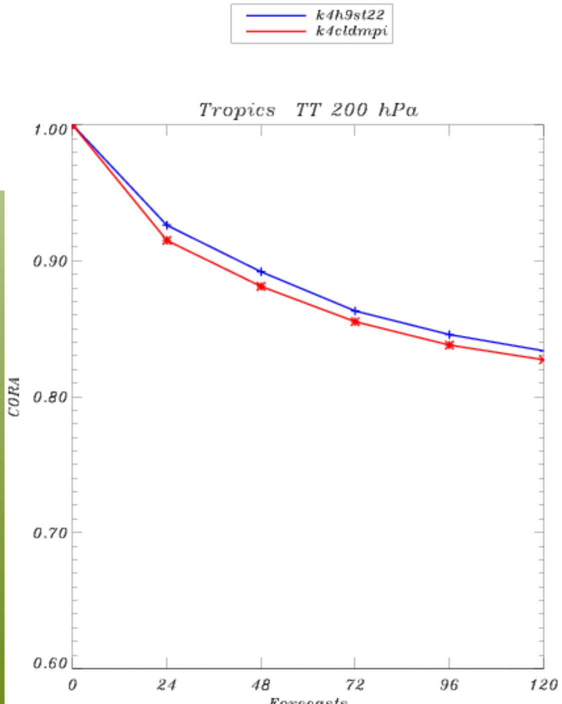
850 hPa



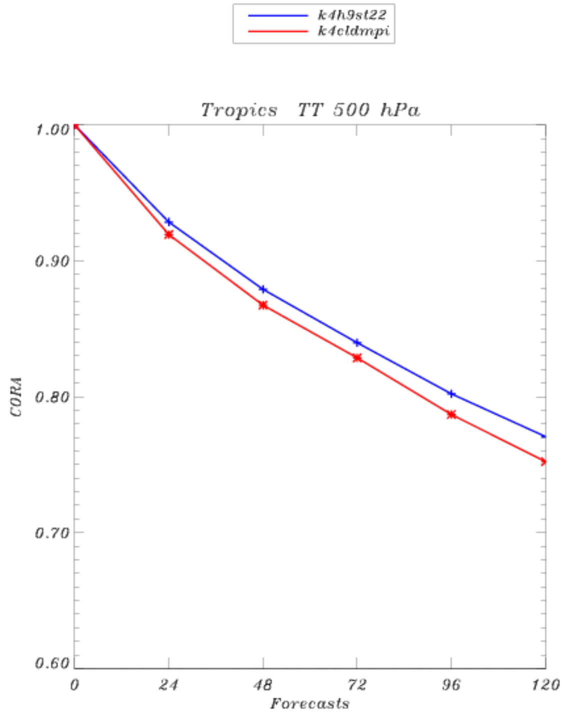
Validation against Analyses 4

Tropics temperature correlation of anomaly score

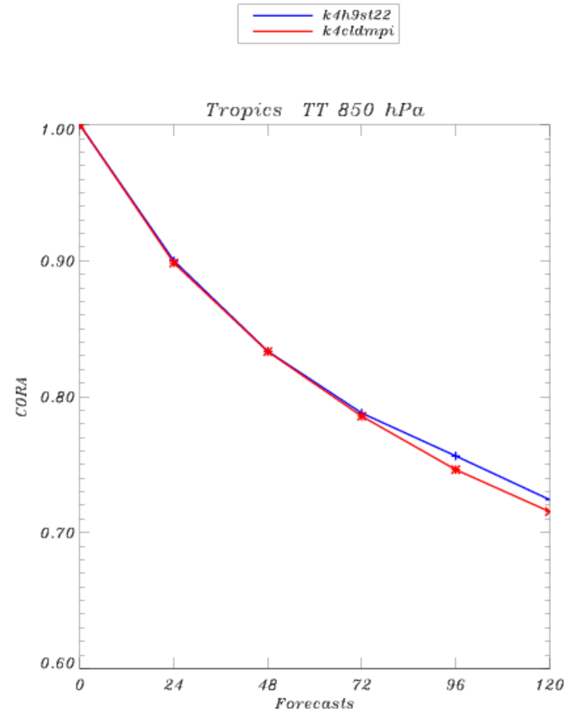
200 hPa



500 hPa



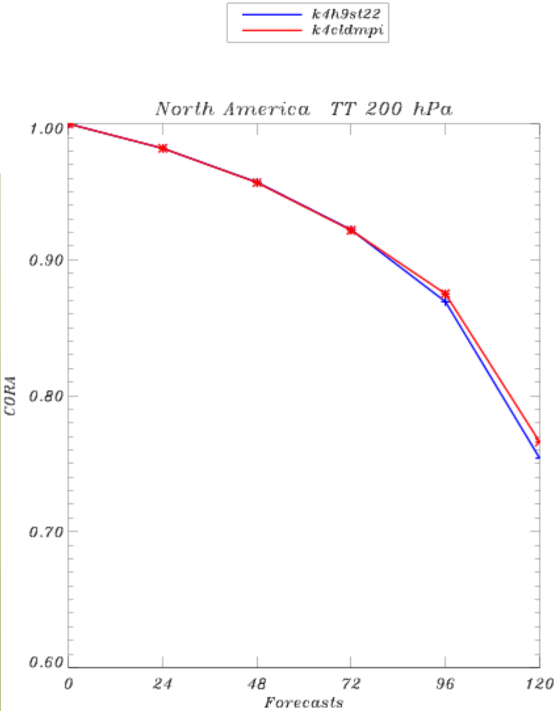
850 hPa

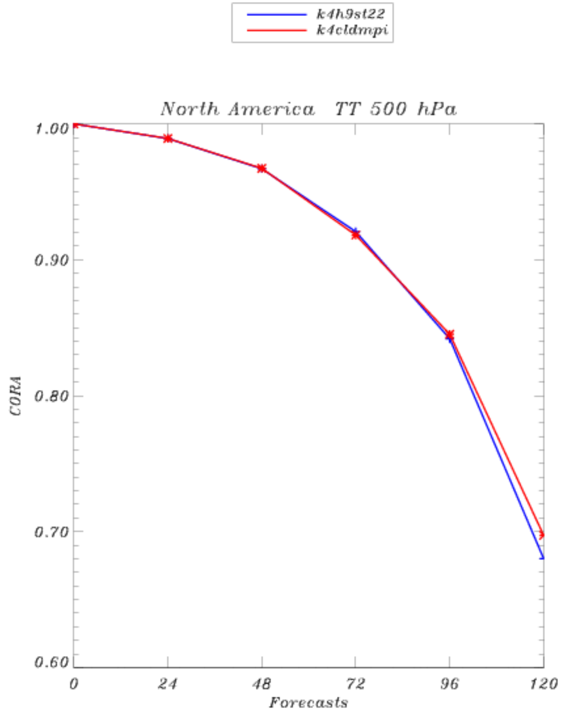


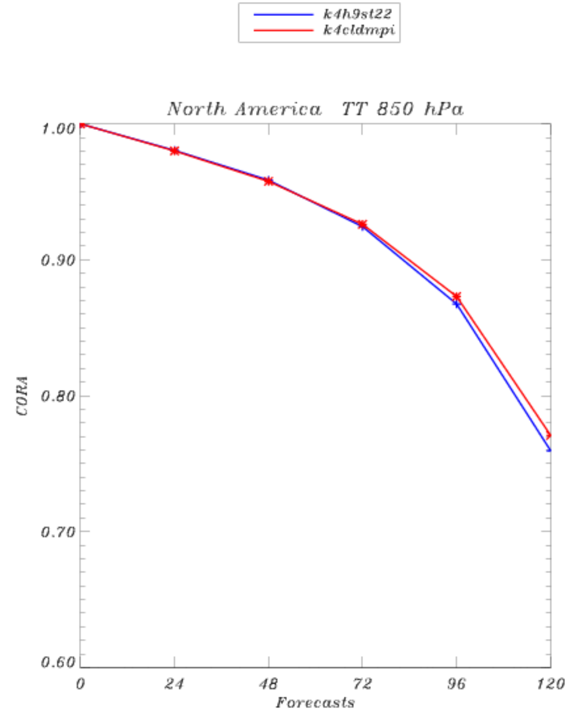
Validation against Analyses 5

North America temperature correlation of anomaly score

200 hPa | 500 hPa | 850 hPa

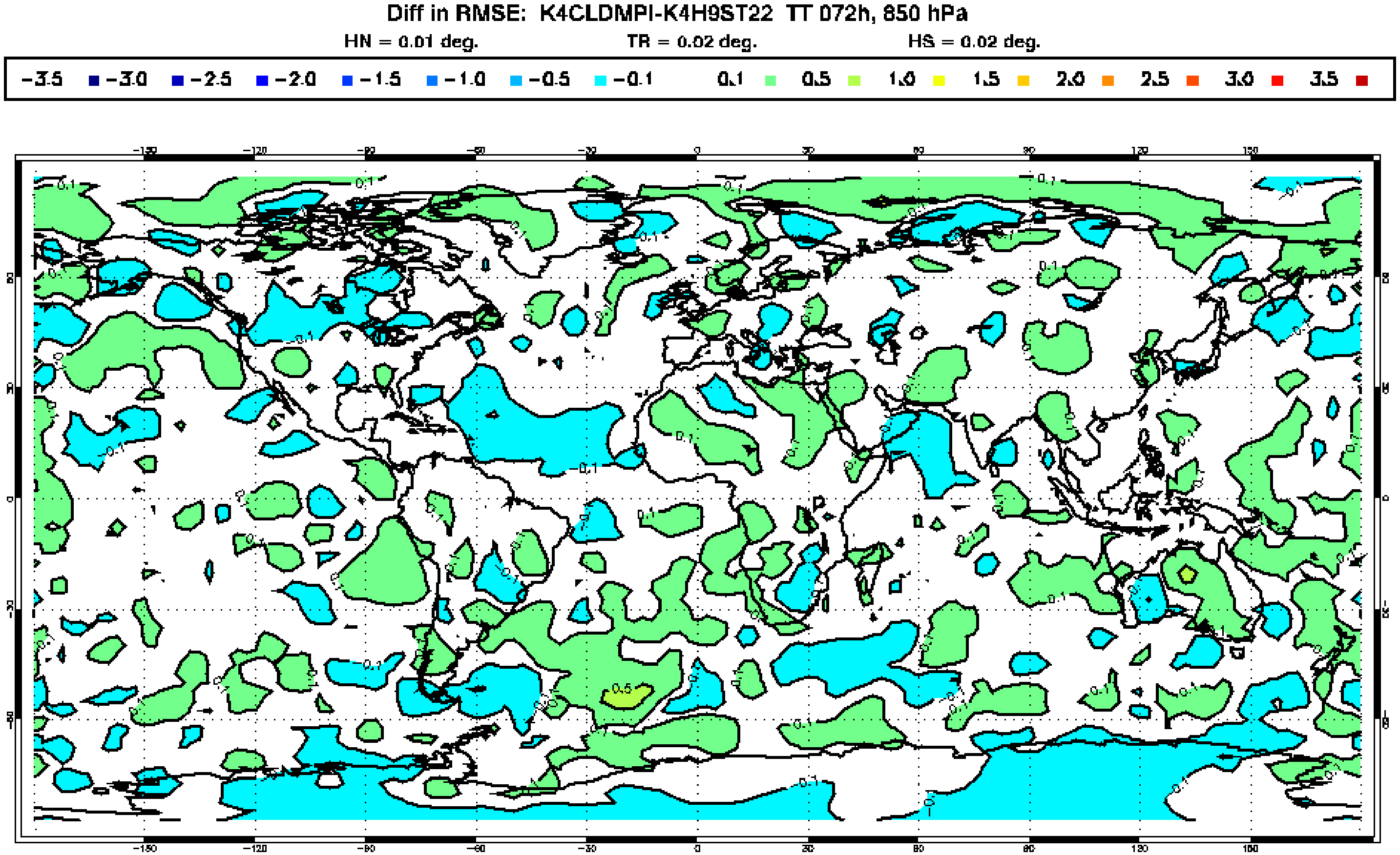






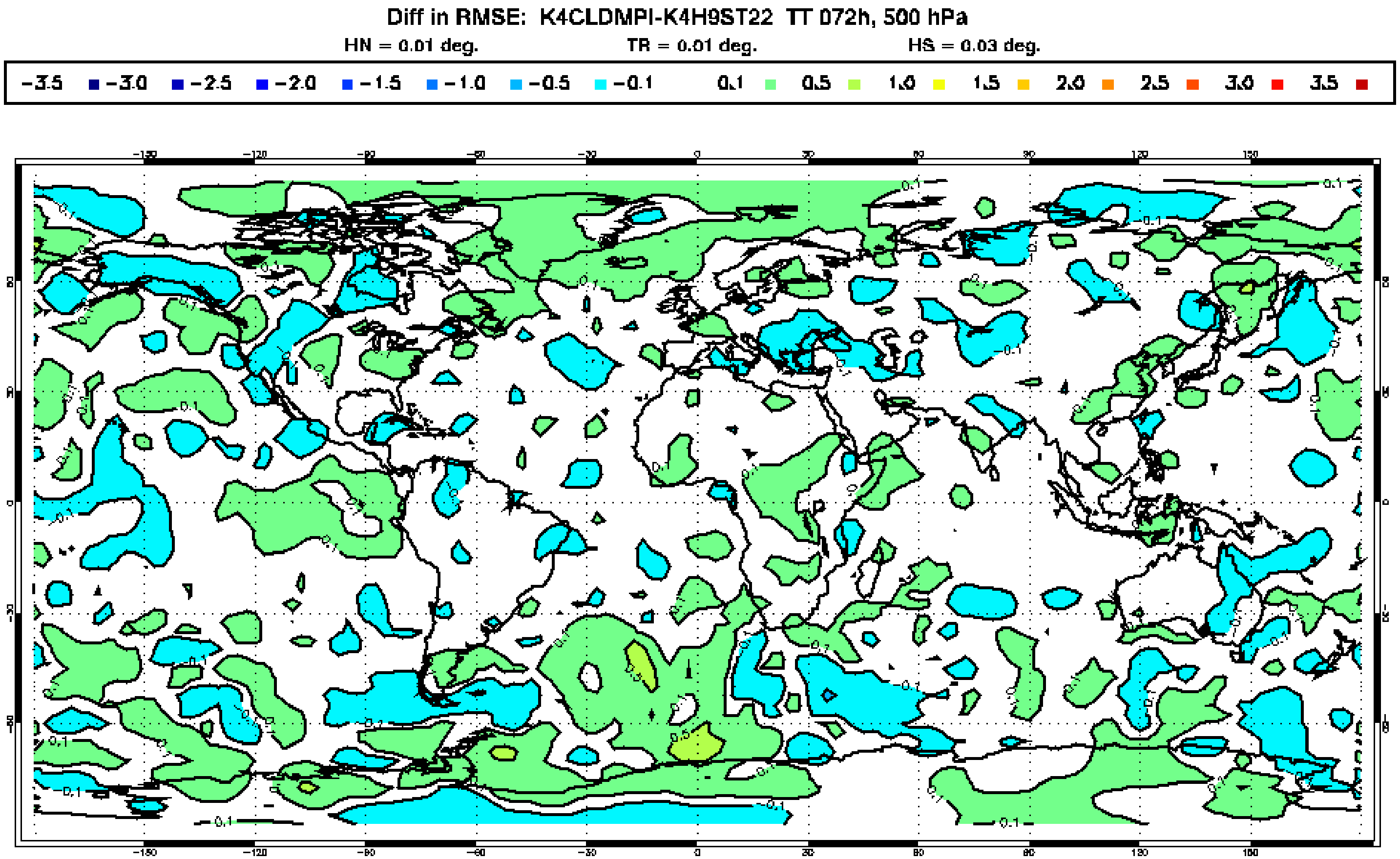
Validation against Analyses 6

850 hPa Temperature RMS error (72 H forecast-analysis) difference.
Experiment-Control. negative is good



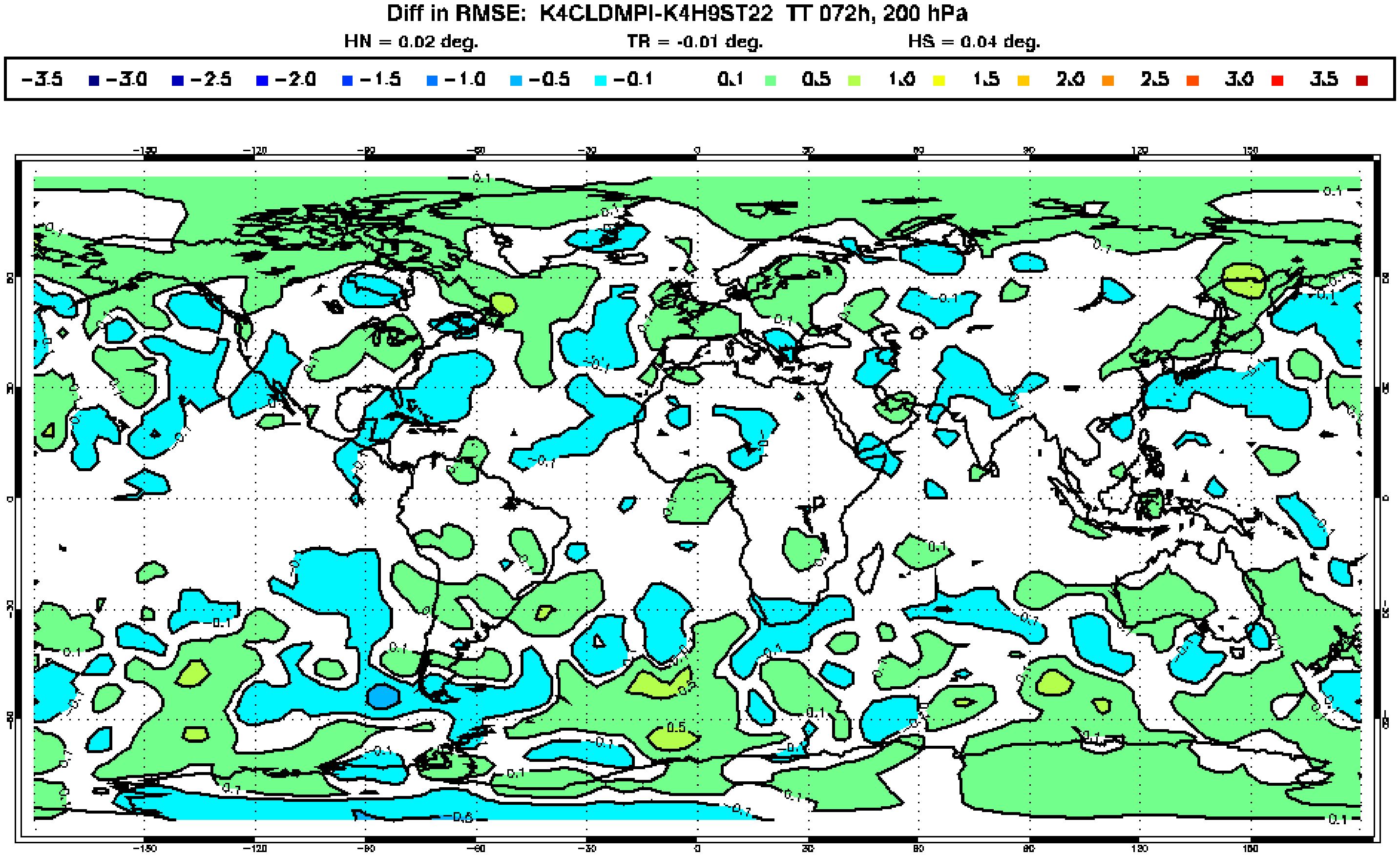
Validation against Analyses 7

500 hPa Temperature RMS error (72 H forecast-analysis) difference.
Experiment-Control. negative is good



Validation against Analyses 8

200 hPa Temperature RMS error (72 H forecast-analysis) difference.
Experiment-Control. negative is good



Conclusions

- EC assimilation system is now extended to assimilate cloudy radiances in 4D-Var mode
- The assimilation is robust and the additional computational cost is modest
- The system takes into account the spectral variation of cloud optical properties
- Results of first 4D-Var assimilation experiments (3 weeks) indicate a mix of slightly positive and negative impacts

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Perspectives

- Perform longer assimilation experiments
- Refining of the quality control criteria (for example eliminate IASI channel around 2000 cm^{-1})
- Use of subgrid information from AVHRR could be useful for IASI to select single layer clouds
- A specific bias correction could be necessary for cloudy radiances. Alternatively, correct for known negative bias of CO_2 slicing height retrievals which is consistent with the cold O-A bias observed for H_2O channels.
- Augment the yield of the data by allowing lower $N\varepsilon$