Diagnosing the assimilation performance in observation space

Niels Bormann Carla Cardinali
Fernando Prates

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Monitoring the performance of the assimilation system and the short range forecast

- ECMWF 4D-Var system handles a large variety of space and surface-based observations. It combines observations and atmospheric state a priori information by using a linearized and non-linear forecast model

- Effective monitoring of a such a complex system with 10^8 degrees of freedom and 10^7 observations is a necessity. Not just a few indicators but a more complex set of measures to answer questions like is needed:
  - How much influent are the observations in the analysis?
  - How much influence is given to the a priori information?
  - How much does the estimate depend on one single influential observation?

- Observation Contribution to the forecast
  - Did observations improve the forecast?
  - How much is the observation impact on the forecast?

Enhanced "all-sky" system at ECMWF

- Direct assimilation of SSMI (F13 & F15) and AMSR-E radiances in 4DVAR:
  - Observations super-obbed to T255
  - Observation errors assumed to depend on cloudiness (symmetric model, see Alan's talk)
  - Observations assimilated over sea within ± 60º latitude
- Presented diagnostics based on T799 experiments for June/July 2009:
  - Separation between clear/cloudy based on threshold for liquid water path (0.05 kg/m^2)
  - LWP derived from observations and First Guess → 4 categories

Monitoring the performance of the assimilation system and the short range forecast

$$\mathbf{x}_a = \mathbf{K}\mathbf{y} + (\mathbf{I}_q - \mathbf{H}\mathbf{K})\mathbf{x}_b$$

$$\mathbf{K} = \mathbf{K}(\mathbf{B}, \mathbf{R}, \mathbf{H})$$

$$\mathbf{K}^T = \mathbf{K}^T(\mathbf{B}, \mathbf{R}, \mathbf{H})$$

B Model Accuracy
R Observation Accuracy
H Model

Analysis Observation Influence & DFS

$$\mathbf{K}^T$$

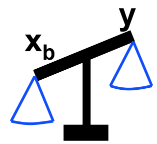
Cardinali et al 2004

Short-Range Forecast Error Observation Contribution

$$\|e\|_E \mathbf{K}^T(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

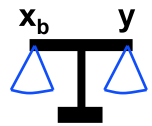
$$\|e\|_E \Rightarrow (x_t - x_0) \rightarrow Energy$$

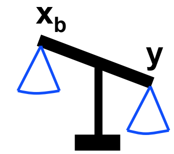
Cardinali 2009



Model space

Analysis Solution





Observation space

$$\mathbf{x}_a = \mathbf{K}\mathbf{y} + (\mathbf{I}_q - \mathbf{H}\mathbf{K})\mathbf{x}_b$$

$$\mathbf{K} = (\mathbf{B}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H})^{-1}\mathbf{H}^T\mathbf{R}^{-1}$$
$$= \mathbf{A}\mathbf{H}^T\mathbf{R}^{-1}$$

$$\hat{\mathbf{y}} = \mathbf{H}\mathbf{x}_a = \mathbf{H}\mathbf{K}\mathbf{y} + (\mathbf{I} - \mathbf{H}\mathbf{K})\mathbf{H}\mathbf{x}_b$$

K(qxp) gain matrix
H(pxq) Jacobian matrix

B(qxq)=Var(x_b)
R(pxp)=Var(y)

$$\frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} = \mathbf{K}^T$$

Forecast Sensitivity to the Observation

$$\frac{\partial \hat{\mathbf{y}}}{\partial \mathbf{y}} = \frac{\partial}{\partial \mathbf{y}}\mathbf{H}\mathbf{x}_a = \mathbf{K}^T\mathbf{H}^T$$

Analysis Sensitivity to the Observation

Forecast sensitivity to observation: Equations

from a Roger Daley idea

J is a measure of the forecast error e.g dry energy norm

$$\frac{\partial J}{\partial \mathbf{x}_a}$$

Forecast error sensitivity to the analysis
Rabier F, *et al*. 1996

$$\frac{\partial J}{\partial \mathbf{y}} = \frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} \frac{\partial J}{\partial \mathbf{x}_a}$$

$$\frac{\partial \mathbf{x}_a}{\partial \mathbf{y}} = \mathbf{K}^T = \mathbf{R}^{-1}\mathbf{H}(\mathbf{B}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H})^{-1}$$

$$\frac{\partial J}{\partial \mathbf{y}} = \mathbf{R}^{-1}\mathbf{H}\mathbf{A}\frac{\partial J}{\partial \mathbf{x}_a}$$

1) $\mathbf{A}^{-1}\mathbf{z} = \frac{\partial J}{\partial \mathbf{x}_a}$

2) $\frac{\partial J}{\partial \mathbf{y}} = \mathbf{R}^{-1}\mathbf{H}\mathbf{z}$

Krylov Subspace Method
Henk A. van der Vorst 2003

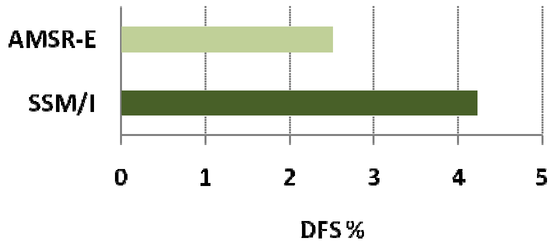
- **Compute the forecast impact or forecast error variation δJ**

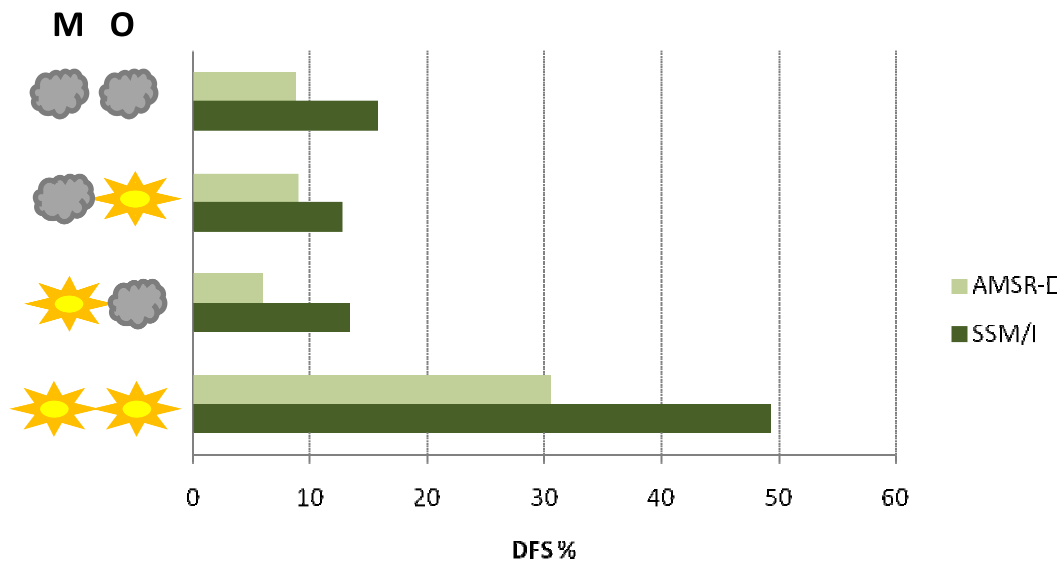
$$< \frac{\partial J}{\partial \mathbf{x}_a}, \delta \mathbf{x}_a > = < \frac{\partial J}{\partial \mathbf{x}_a}, \mathbf{x}_a - \mathbf{x}_b > = < \frac{\partial J}{\partial \mathbf{x}_a}, \mathbf{K}(\mathbf{y} - \mathbf{H}\mathbf{x}_b) > = < \mathbf{K}^T \frac{\partial J}{\partial \mathbf{x}_a}, (\mathbf{y} - \mathbf{H}\mathbf{x}_b) > = < \frac{\partial J}{\partial \mathbf{y}}, \delta \mathbf{y} >$$

$$\delta J = \frac{\partial J}{\partial \mathbf{y}}(\mathbf{y} - \mathbf{H}\mathbf{x}_b)$$

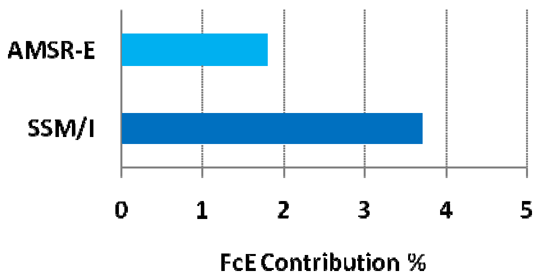
Analysis and 24h Forecast error Contribution of SSM/I and AMSR-E

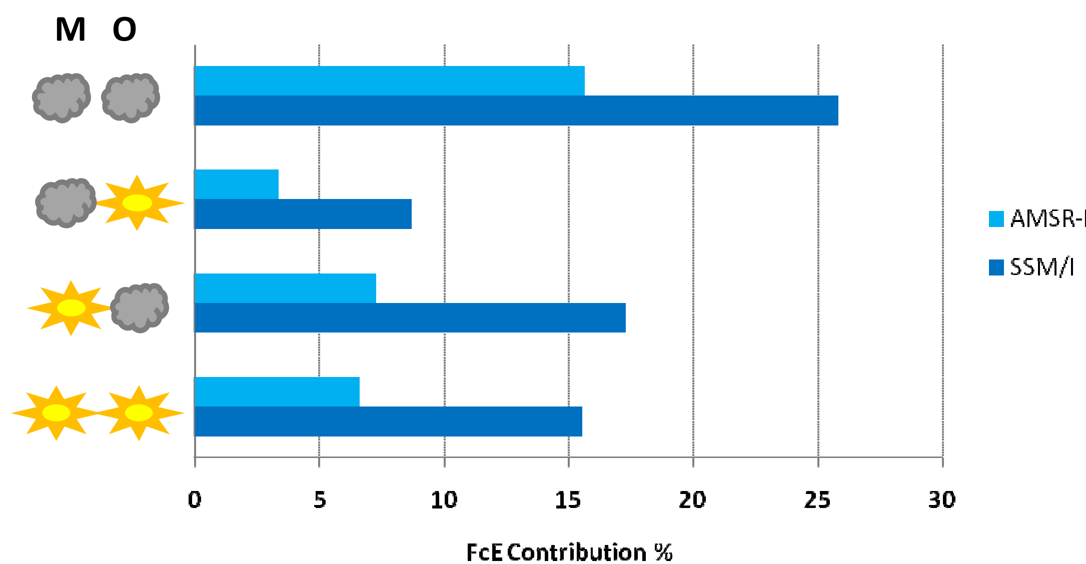
Max IASI 25%





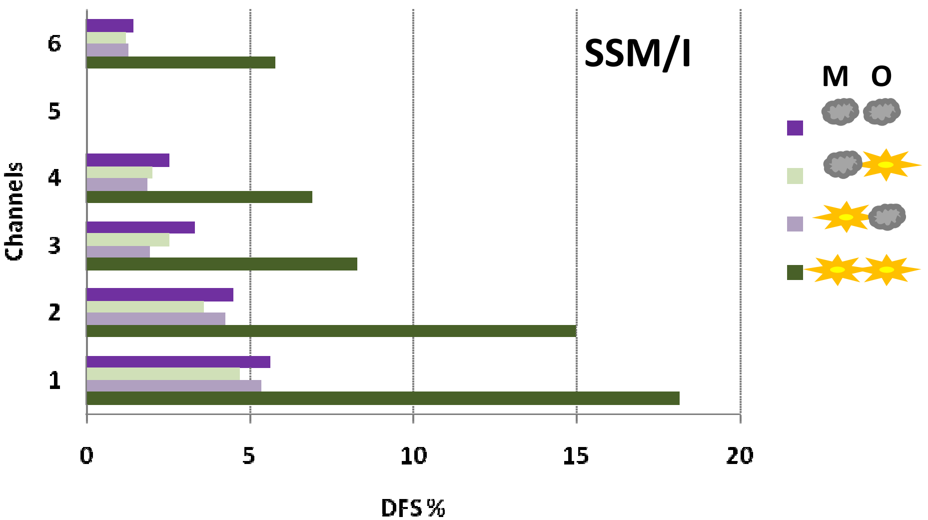
Max AMSU-A 15%

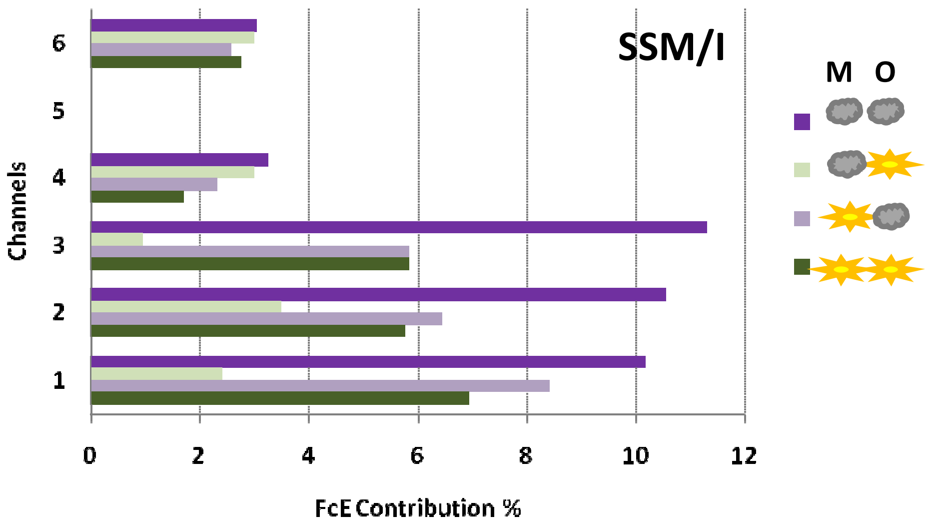


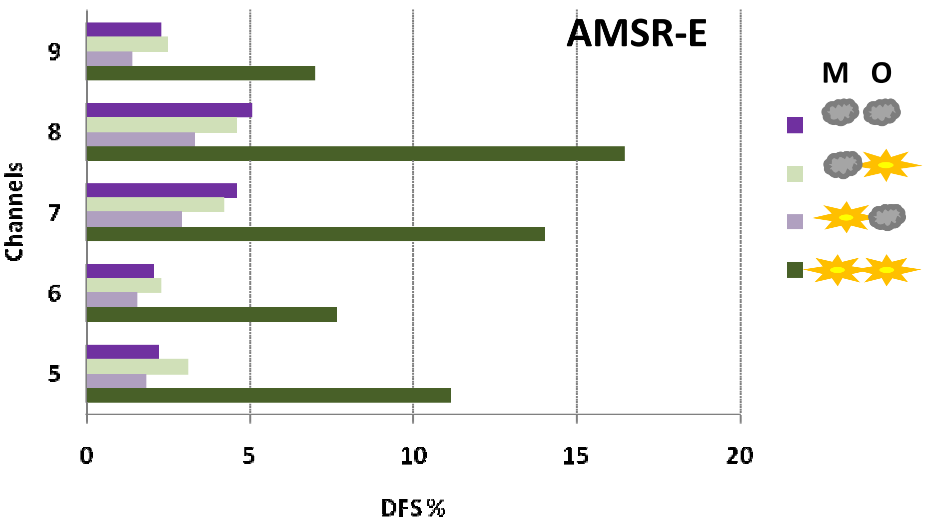


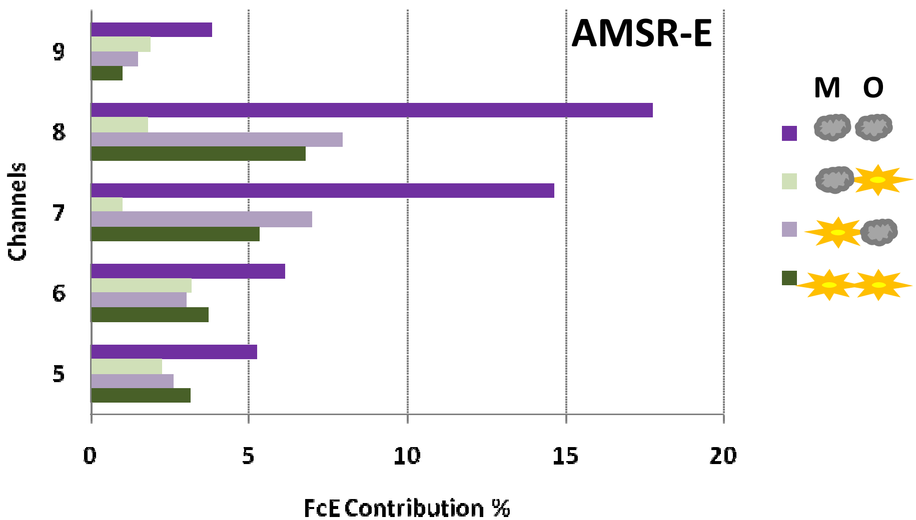
June 2009

Analysis and 24h FcE Contribution per Channels



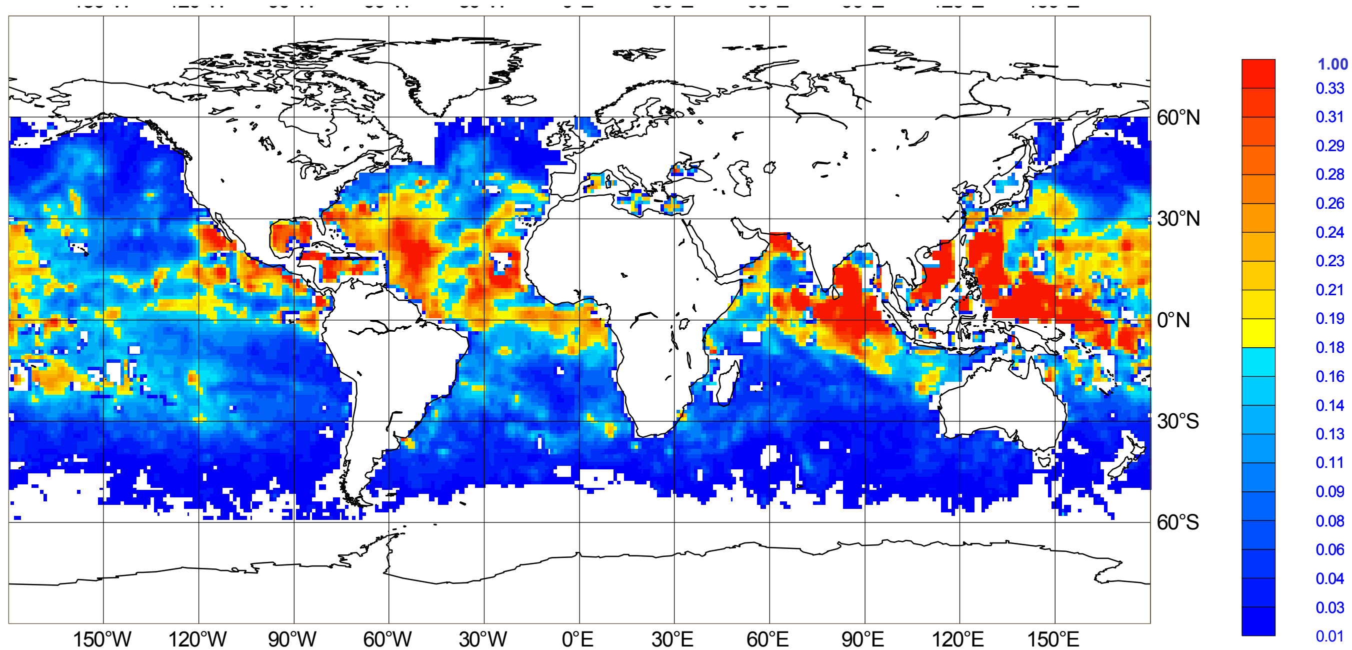




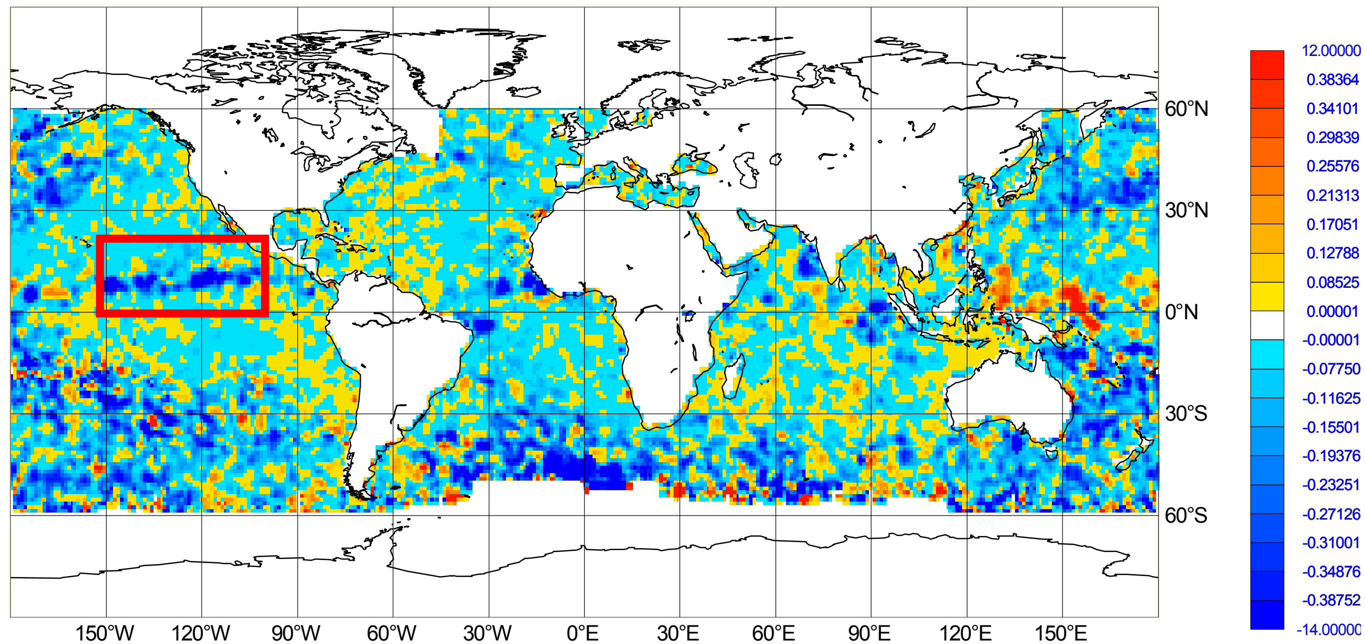


SSM/I Impact

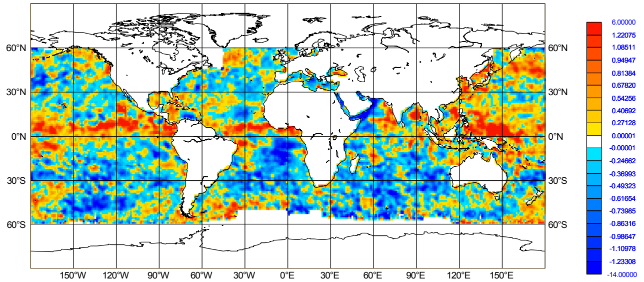
Observation Influence between 0 and 1

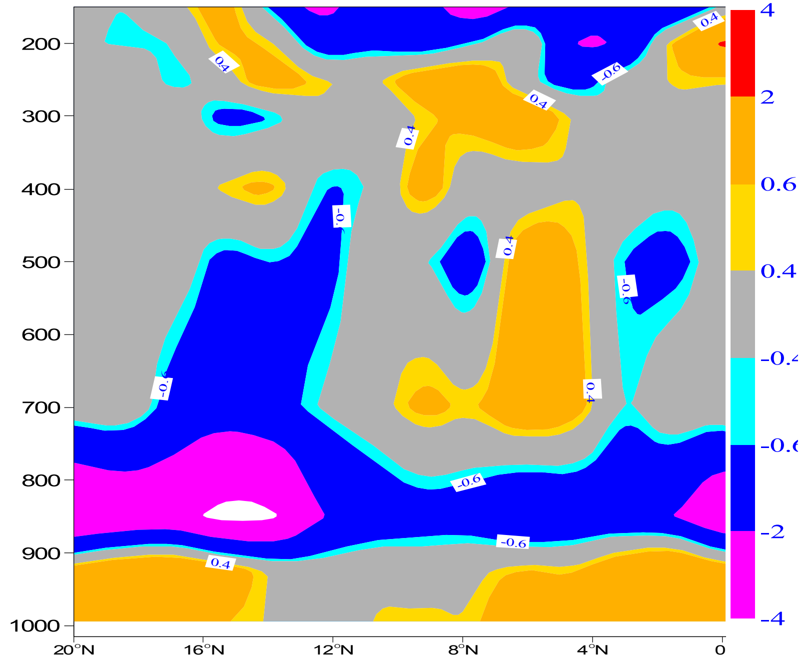


24 h Fc Error Contribution



June 2009
Observation Departure

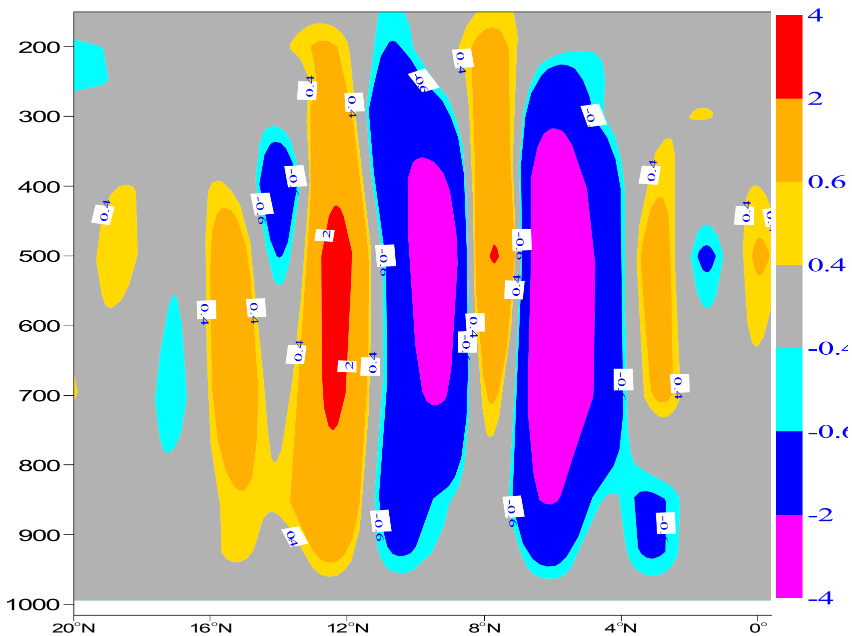




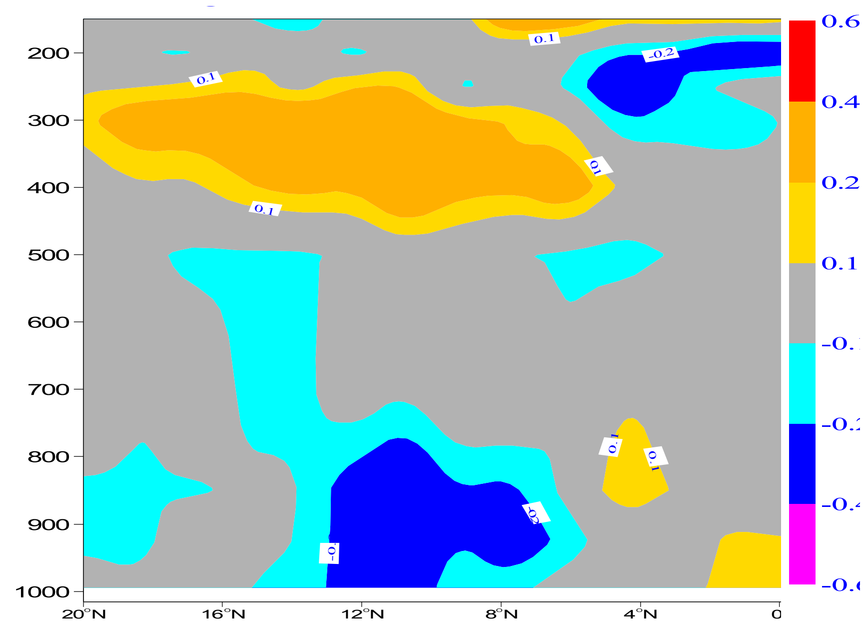
June 2009 Alan Geer OSE
SSM/I-NoSSM/I

Average RH %

Average
Vertical Velocity hPa



Average
V Component m/s

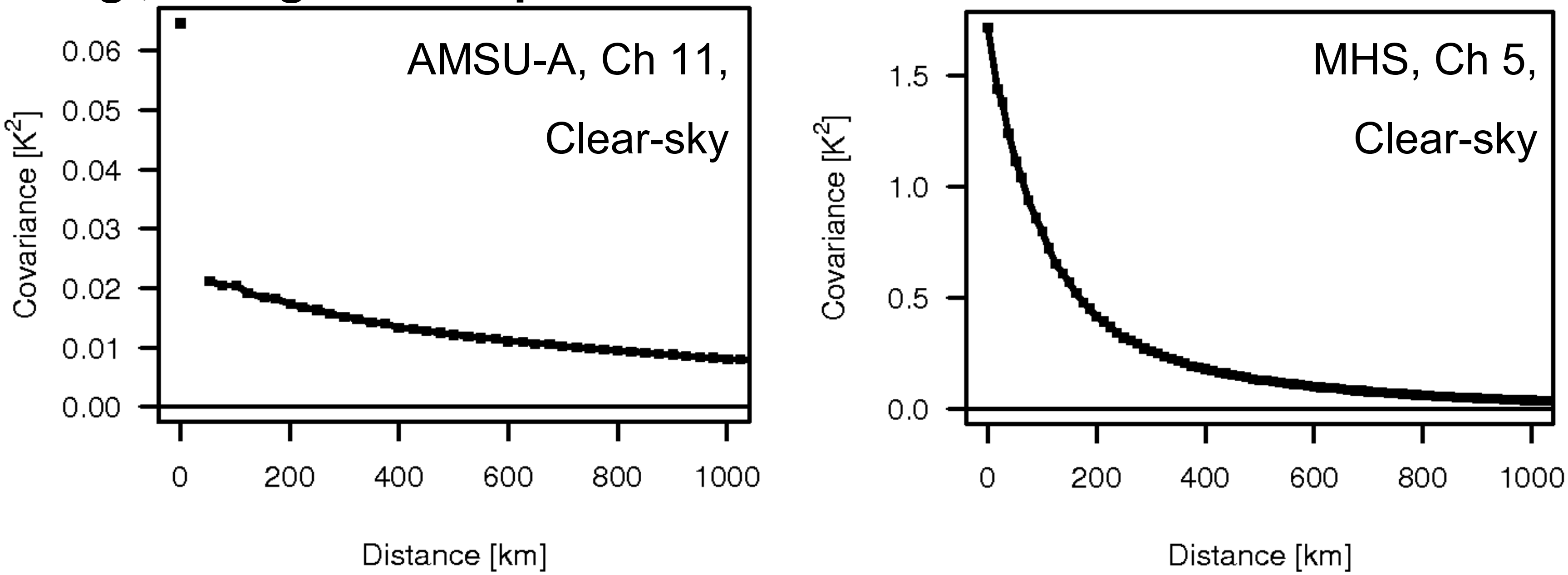


Diagnosing observation error covariances

- **Several methods to estimate observation error covariances from Obs-FG departures, e.g.:**
  - **Hollingsworth/Lönnberg**
  - **Background error method**
  - **Desroziers et al. (2005) diagnostic:** $\tilde{\mathbf{R}} = E\left[\mathbf{d}_a\, \mathbf{d}_b^T\right]$
    (with $\mathbf{d}_a$ and $\mathbf{d}_b$ the analysis and background departure, respectively)
- **All rely on (questionable) assumptions.**
- **Recently, results from these methods have been intercompared for clear-sky sounder radiances (Bormann and Bauer 2010, Bormann et al. 2010, QJ).**
  - **Here: Study extended to MW imager “allsky” radiances, but with Desroziers diagnostic only.**

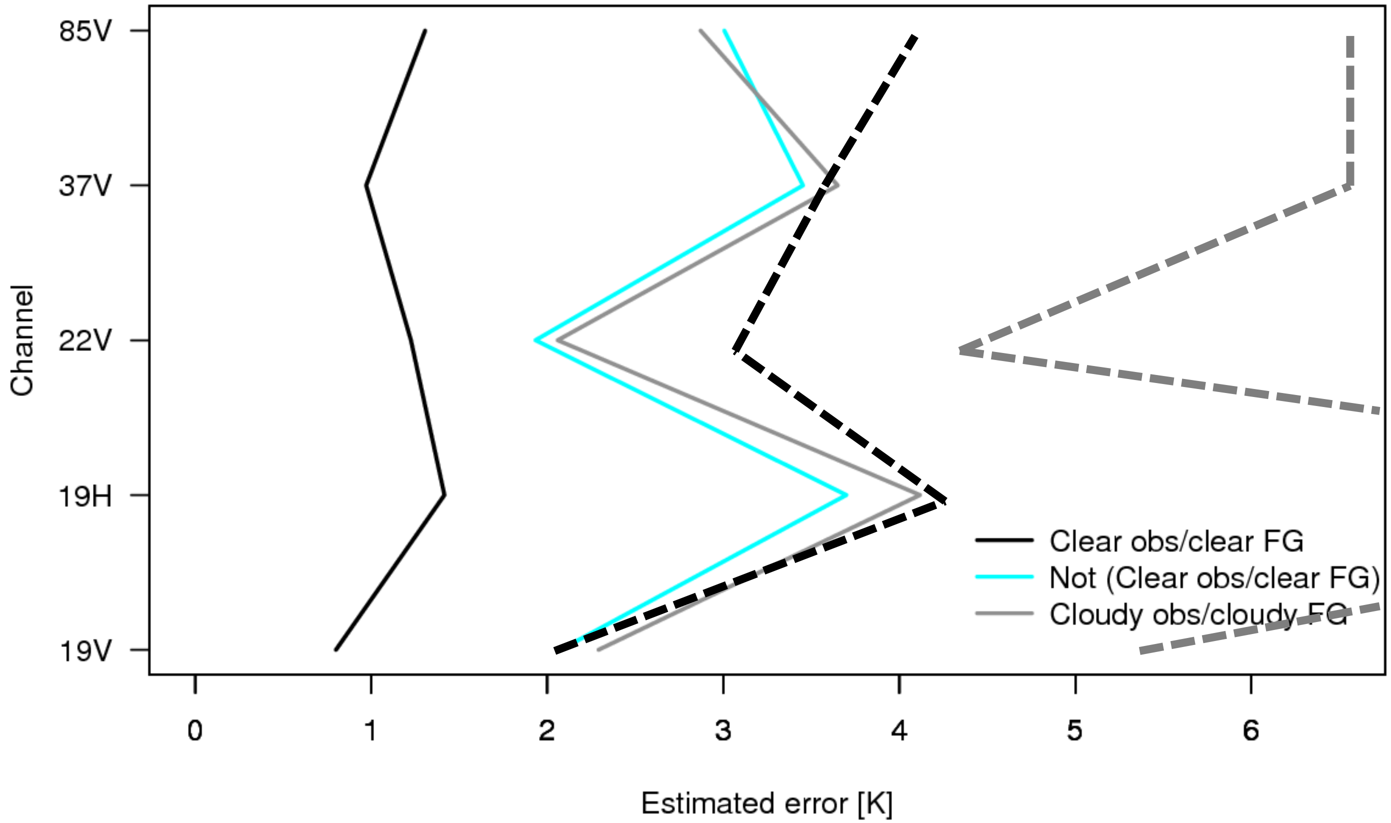
Diagnosing observation error covariances: Some caveats

- **Departure-based estimation of observation errors more difficult for humidity-sensitive radiances:**
  - **Background error relatively larger, with smaller spatial correlations.**
  - ⇒ **Background and observation error characteristics more difficult to separate.**
  - ⇒ **Behaviour of Desroziers diagnostic less clear.**
- **E.g., background departure covariances for AMSU-A and MHS:**



Observation errors from Desroziers

F-13 SSMI, July 2009:



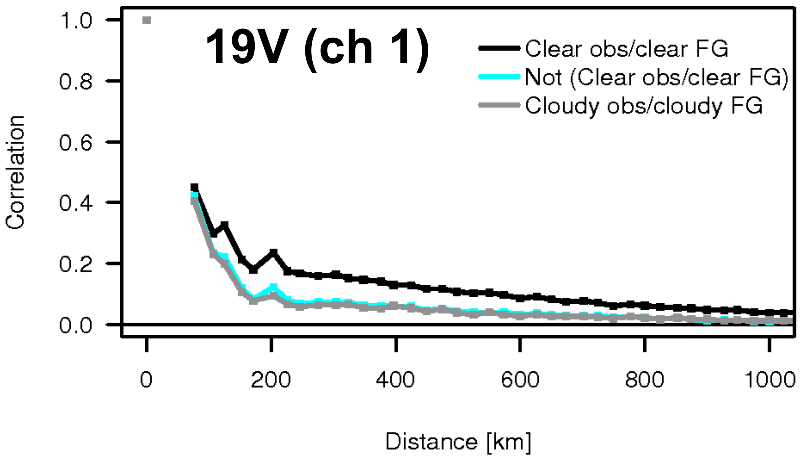
Mean assumed observation errors (dashed):

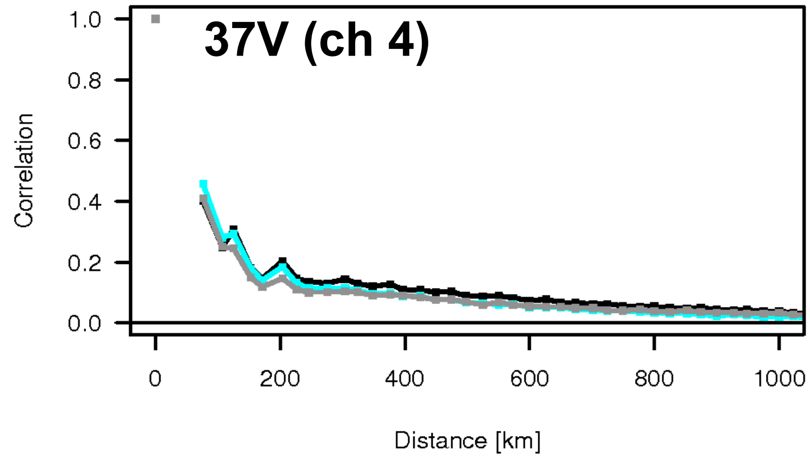
Clear obs/clear FG

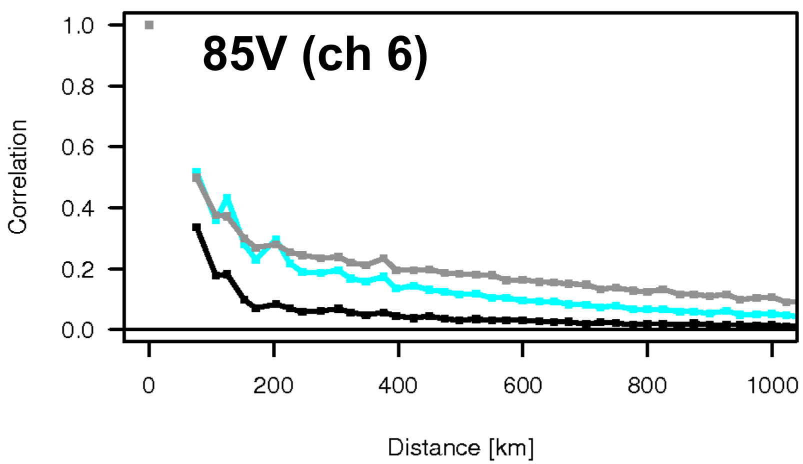
Cloudy obs/cloudy FG

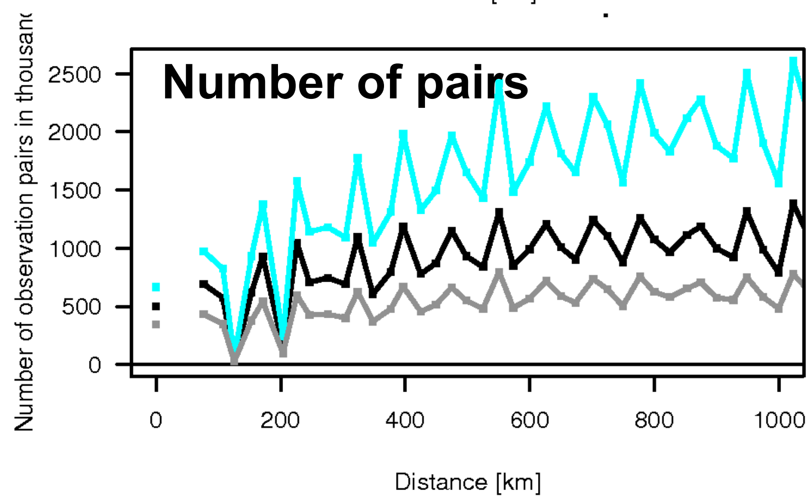
Spatial observation error correlations from Desroziers diagnostic

F-13 SSMI, July 2009:





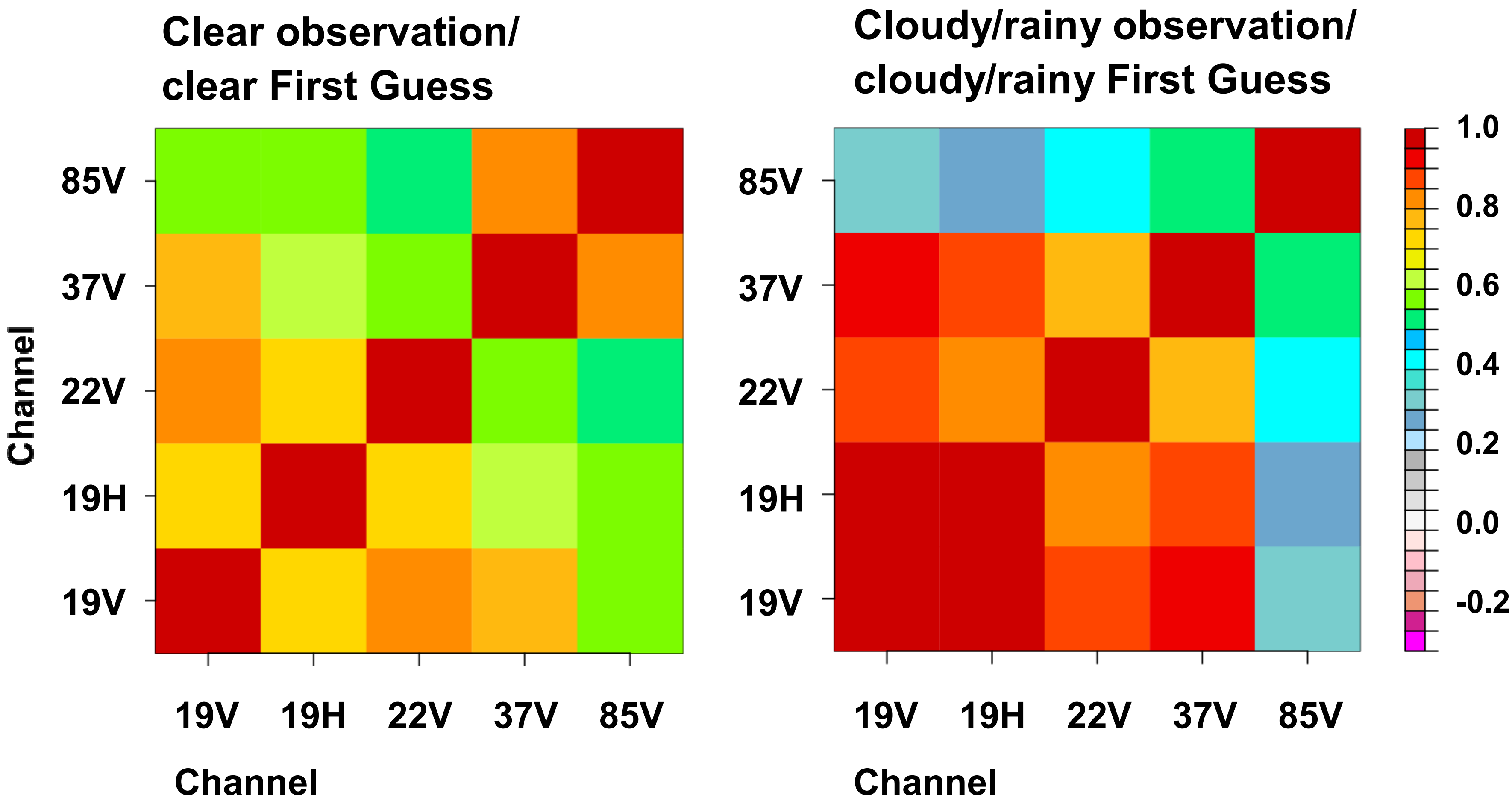




ECMWF

Inter-channel observation error correlations from Desroziers diagnostic

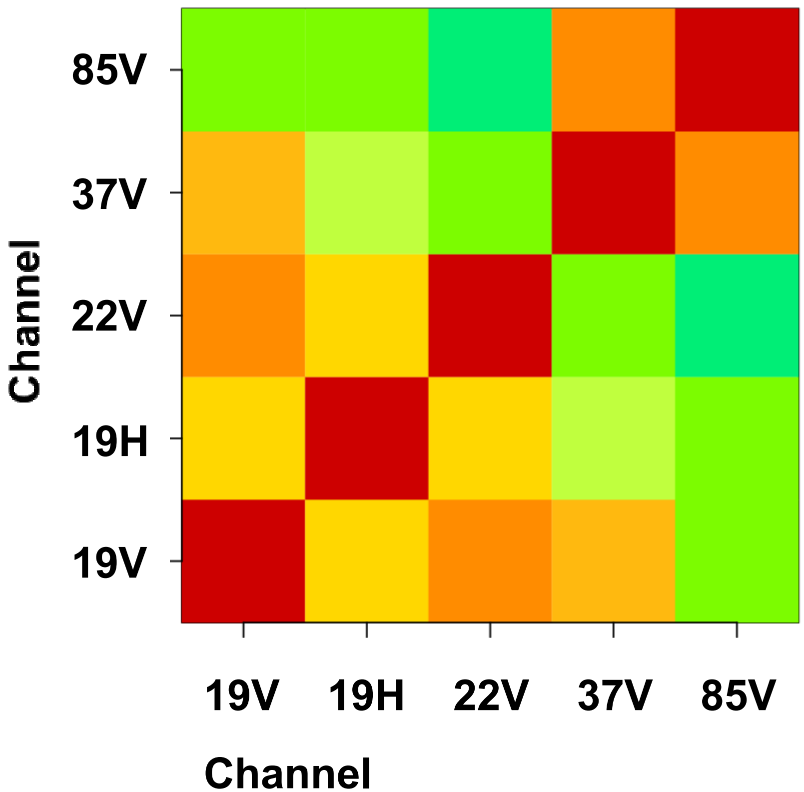
F-13 SSMI, July 2009:



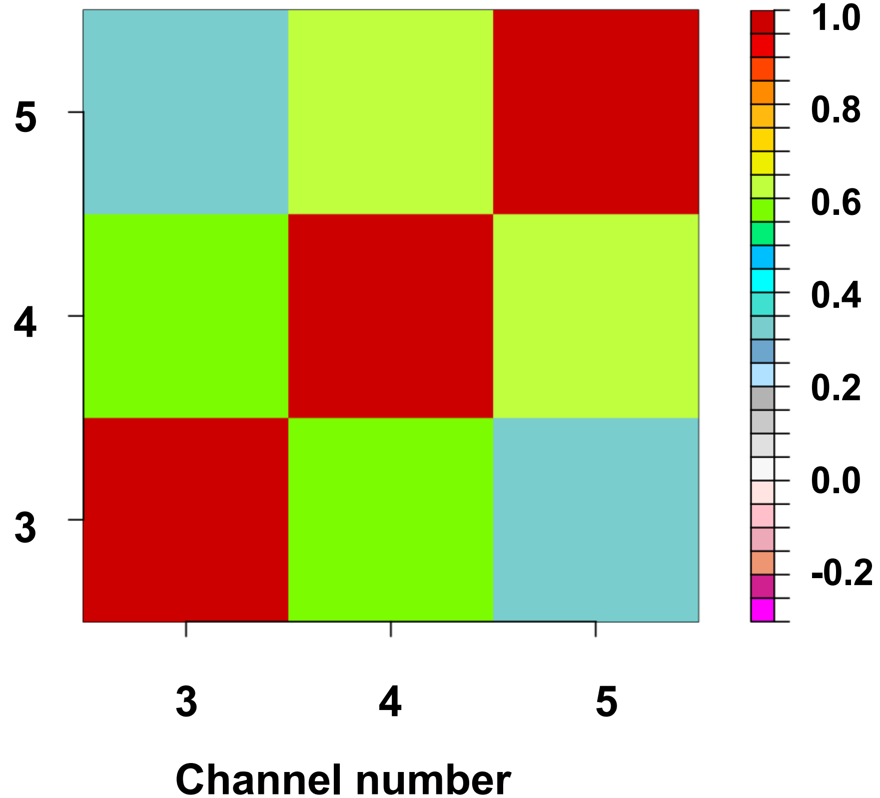
ECMWF

Inter-channel observation error correlations from Desroziers diagnostic

F-13 SSMI:
Clear observation/ clear First Guess



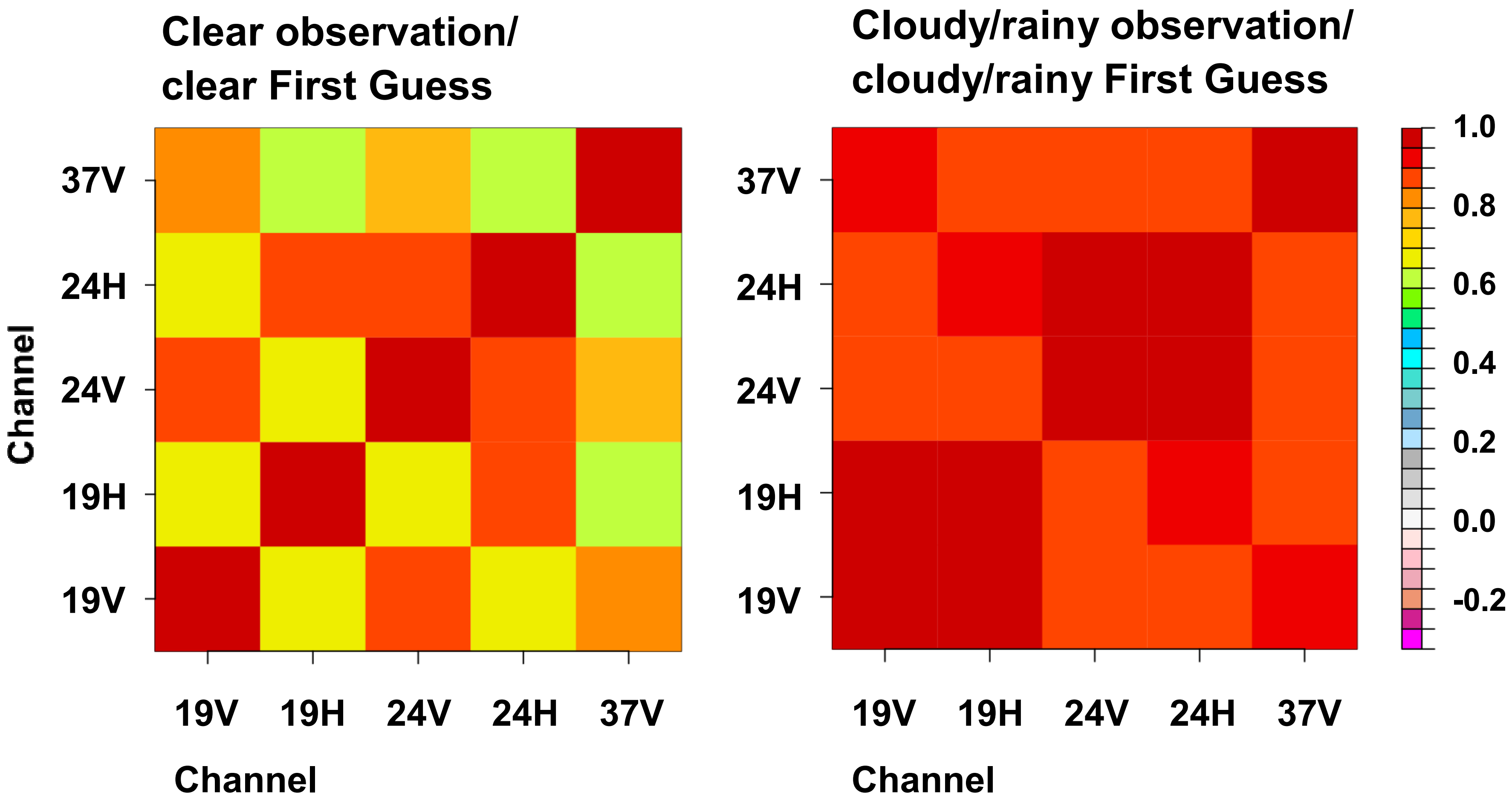
METOP-A MHS:
Clear-sky system



ECMWF

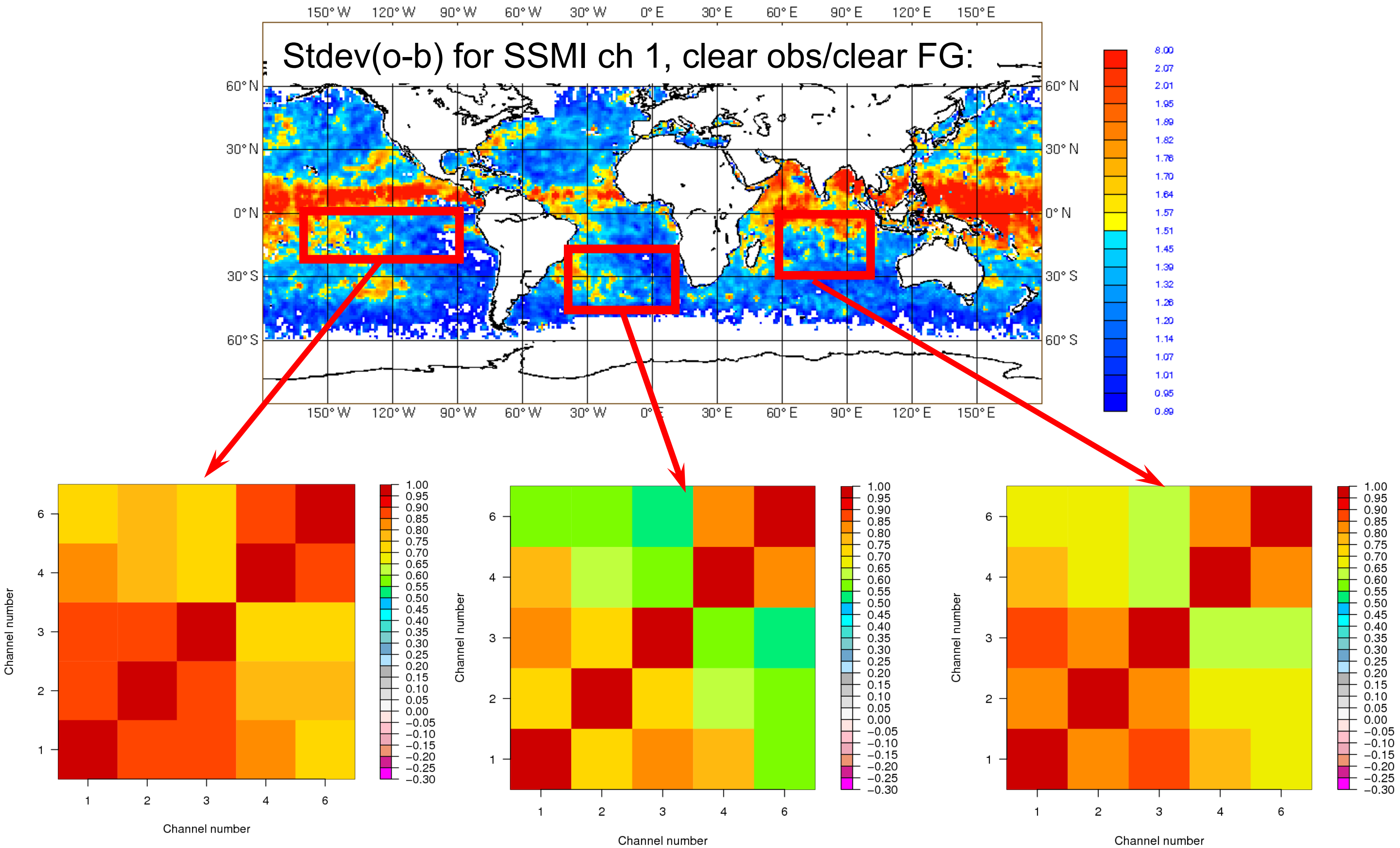
Inter-channel observation error correlations from Desroziers diagnostic

Aqua AMSR-E, July 2009:



ECMWF

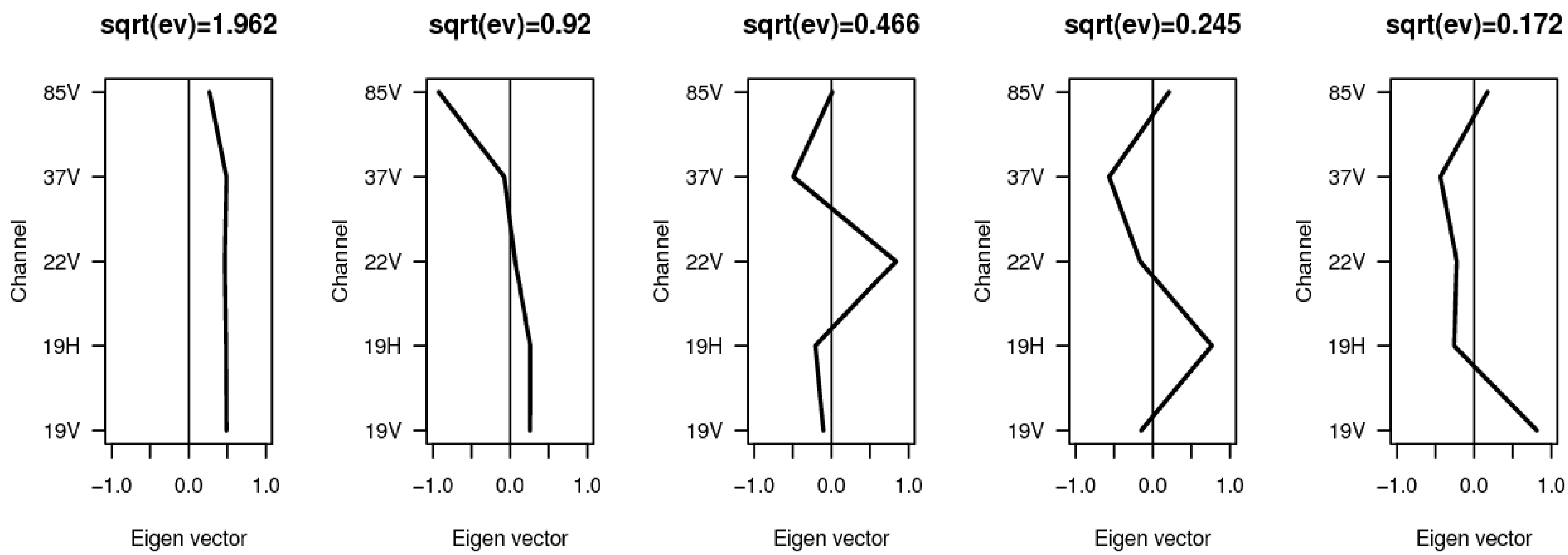
Situation-dependence of inter-channel observation error correlations?



Eigenvectors of inter-channel error correlation matrix

Sqrt(ev) gives the error inflation factor for each eigenvector structure relative to a diagonal correlation matrix.

F-13 SSMI, Cloudy observation/cloudy First Guess:



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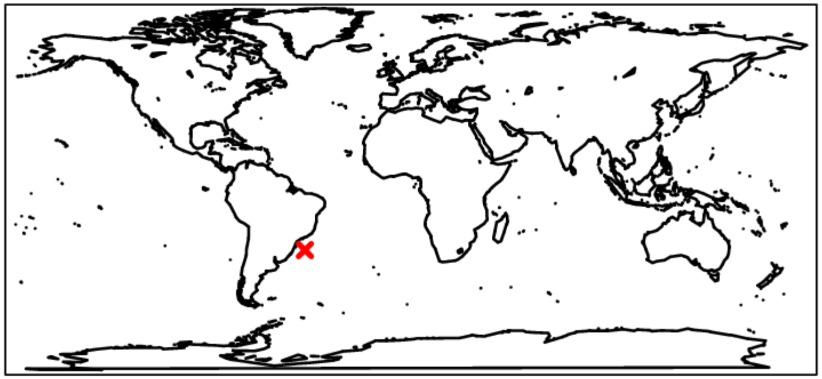
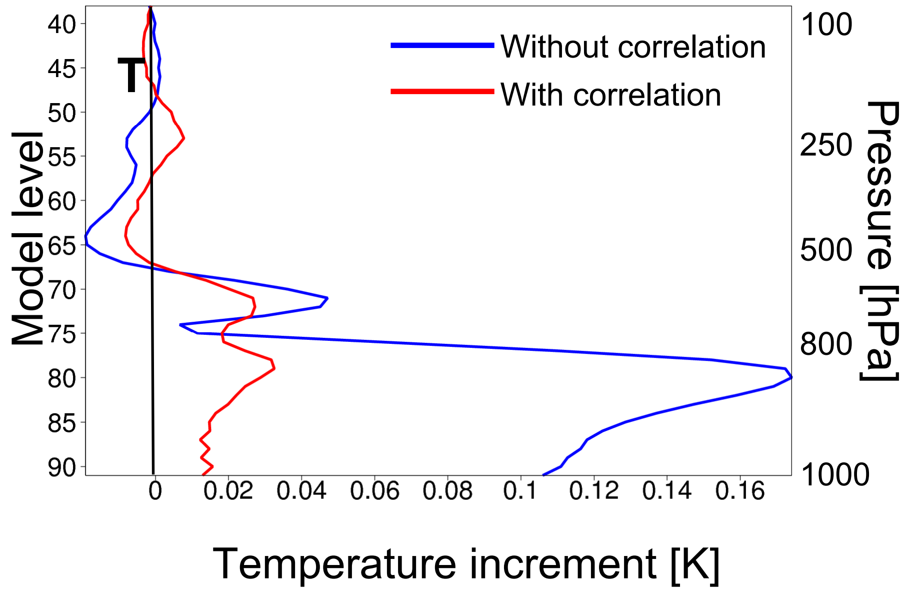
Assimilation experiments with a single SSMI FOV

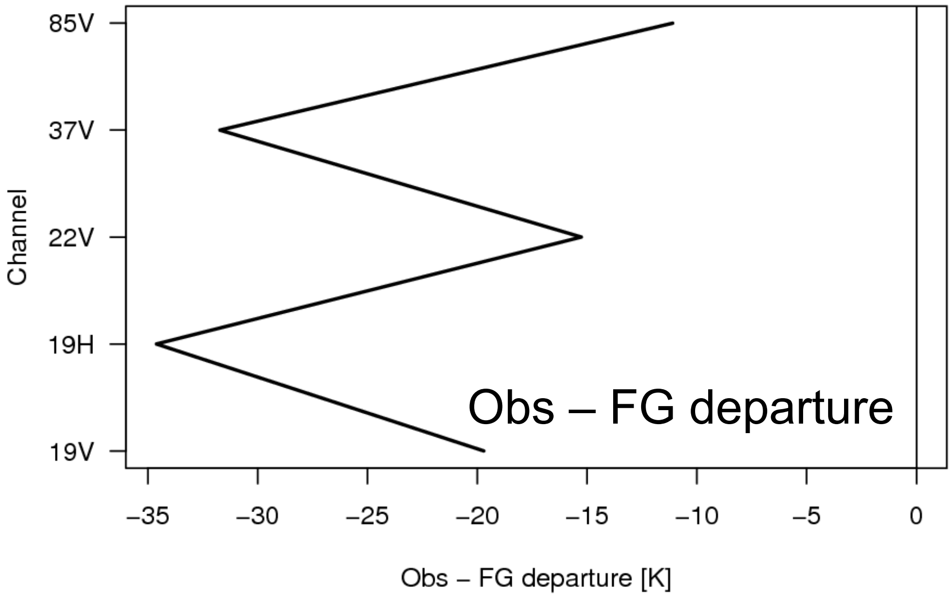
- Assimilate only a single SSMI FOV in 4DVAR – no other observations.
- Two experiments: With and without taking inter-channel observation error correlations into account; σ_O unchanged.
- Cases shown have cloudy observation and cloudy FG.

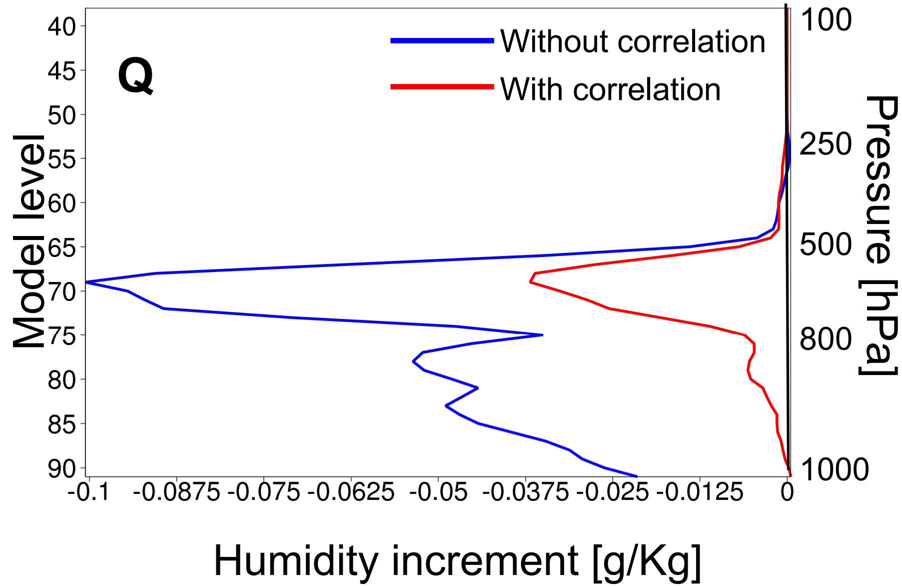
ECMWF

Single SSMI FOV assimilation experiments: Case 1

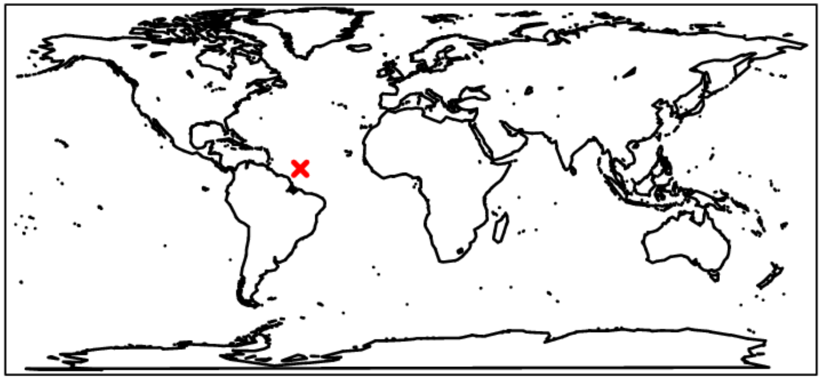


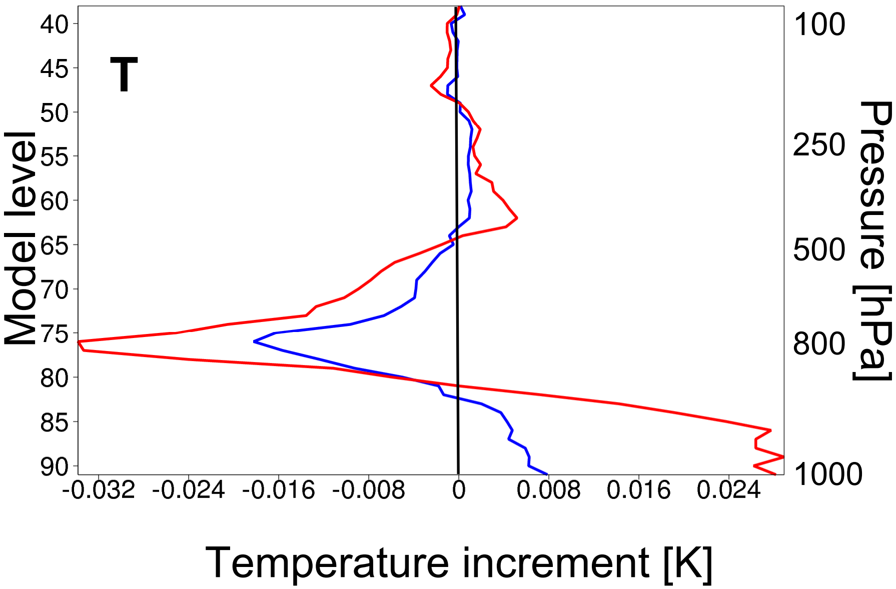


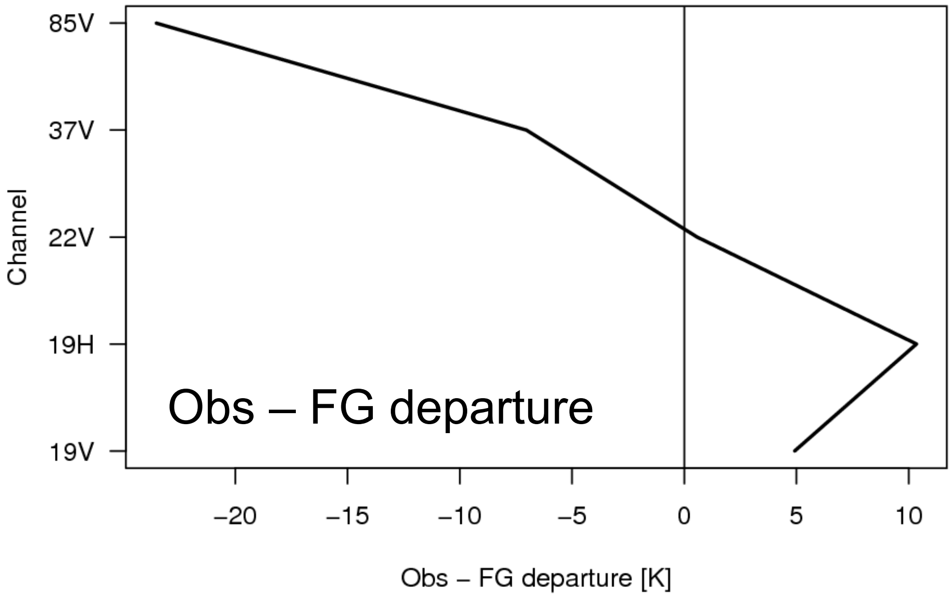


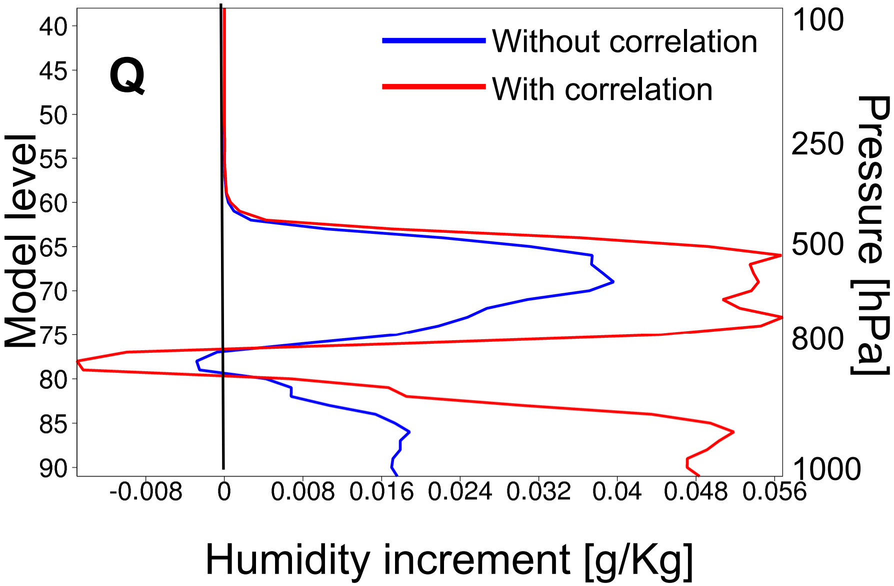


Single SSMI FOV assimilation experiments: Case 2









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Status

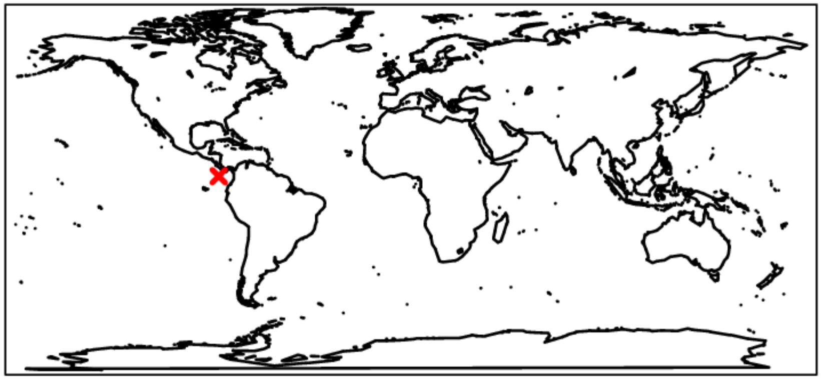
- Recent advanced diagnostic tools are used to monitor the assimilation system performance.
- The microwave “allsky” data are influential in the analysis and improve the forecast .
- Observation error correlation is investigated.
- Estimates for inter-channel and spatial observation error correlations are becoming available.
- Main indication of strong inter-channel and some spatial observation error correlations for humidity channels, esp. for MW imager radiances in cloudy/rainy regions.

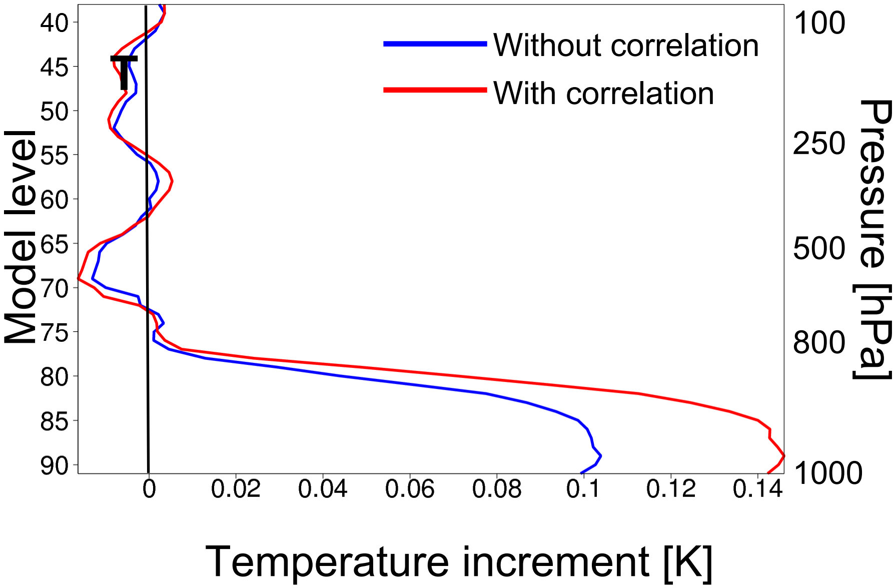
Recommendations

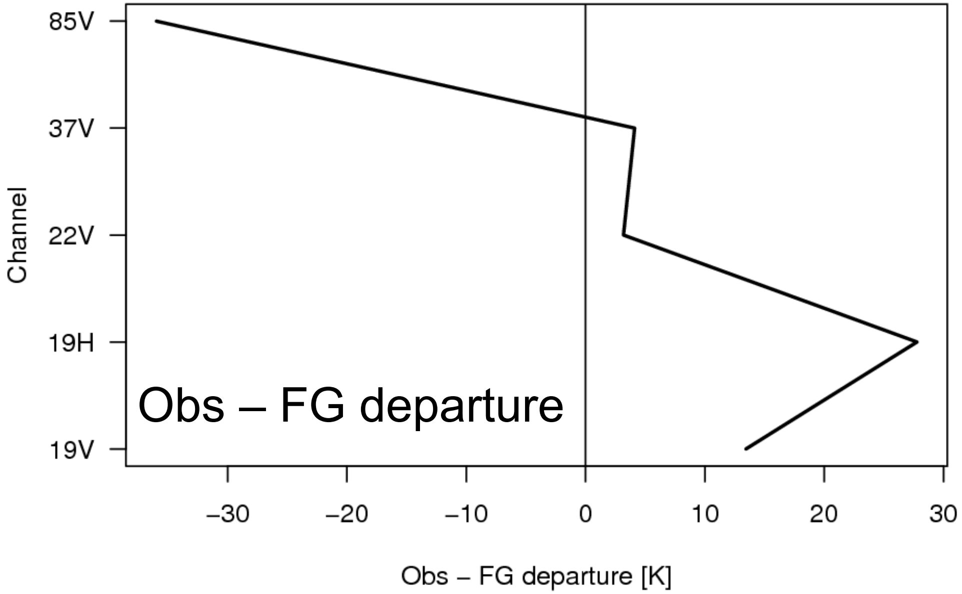
- **Need further characterisation/development of methods to estimate observation errors and their correlations in real NWP systems**

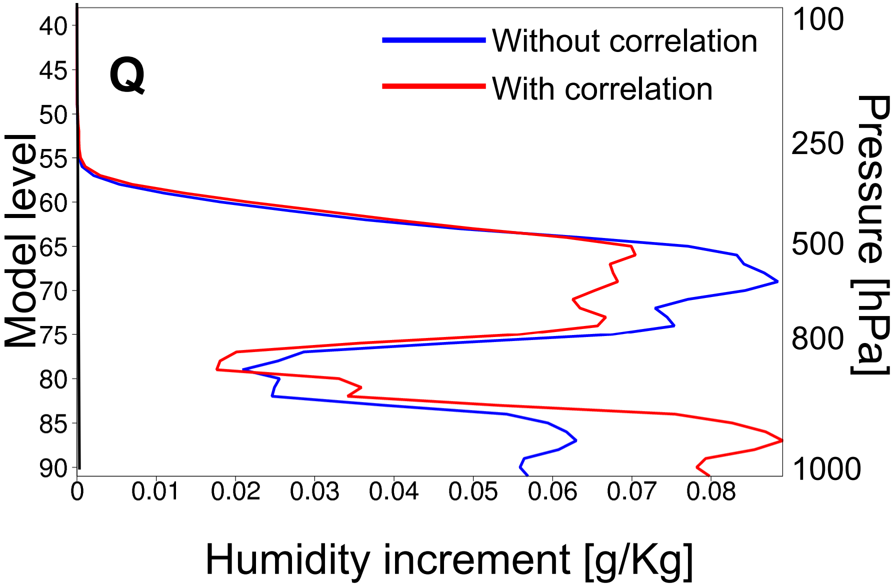
- **Need further research into refining assumed observation errors, e.g.:**
  - **Effect of taking observation error correlations into account in the assimilation.**
  - **Forecast model error contributes significantly to observation operator error for humidity-sensitive observations in strong-constraint 4DVAR. How to deal with this?**

Single SSMI FOV assimilation experiments: Case 3









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