An optimal estimation based retrieval method adapted to SEVIRI infra-red measurements

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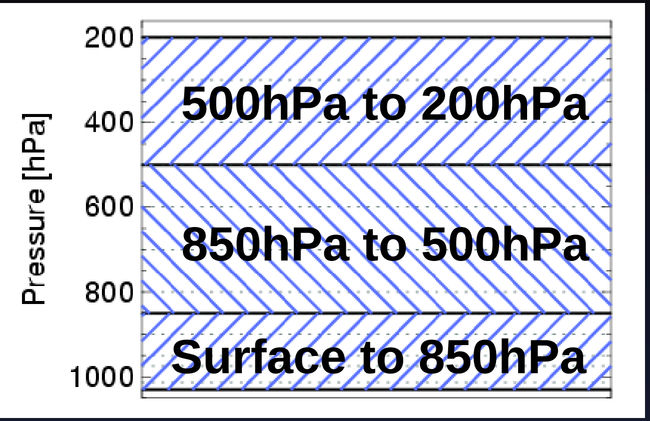
Workshop on Physical Retrieval of Clear Air Parameters from SEVIRI
(28-29 November 2007)

Overview

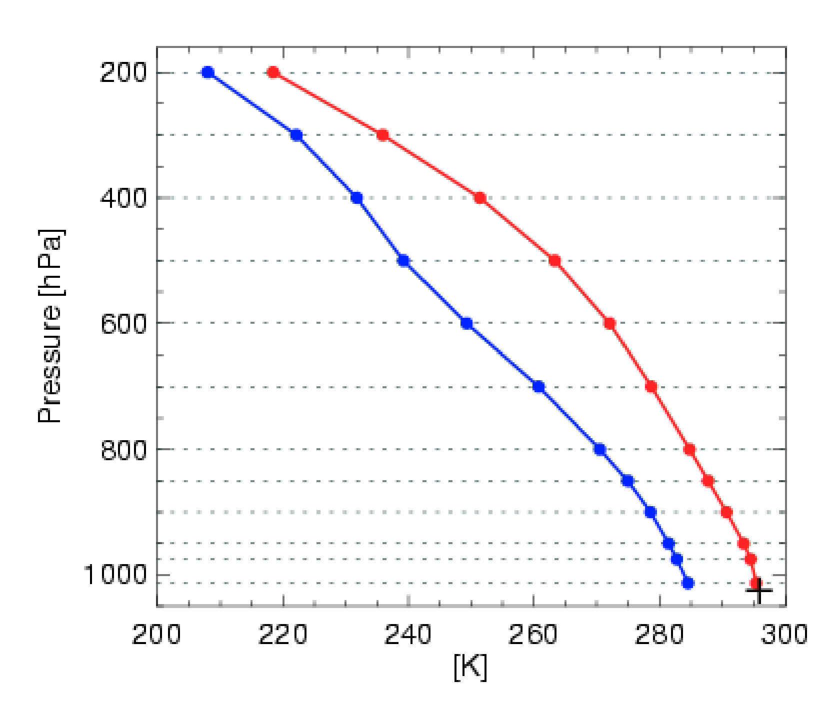


- Retrieval of layered and total integrated water vapour (IWV) and surface temperature (ST)
- SEVIRI infra-red (IR) observations (in clear-sky conditions only)
- Optimal estimation based
  - Gauss-Newton method / Incremental gradient decent
- A-priori information
  - Coming from climatology only (Radiosondes/NWP)
  - No NWP used as first guess!

State vector

- State vector (atmospheric model) configuration:
  - Surface temperature (Tsfc)
  - Temperature (T) and Dewpoint (D) at 12 fixed pressure levels (200, 300, 400, 500, 600, 700, 800, 850, 900, 950, 975 and 1013hPa)

$$\vec{x} = [T_{sfc}, T_1, \ldots, T_{12}, D_1, \ldots, D_{12}]$$



- Variations in observation can can be described by changes in the state vector

- Each state vector element affects the modeled observation

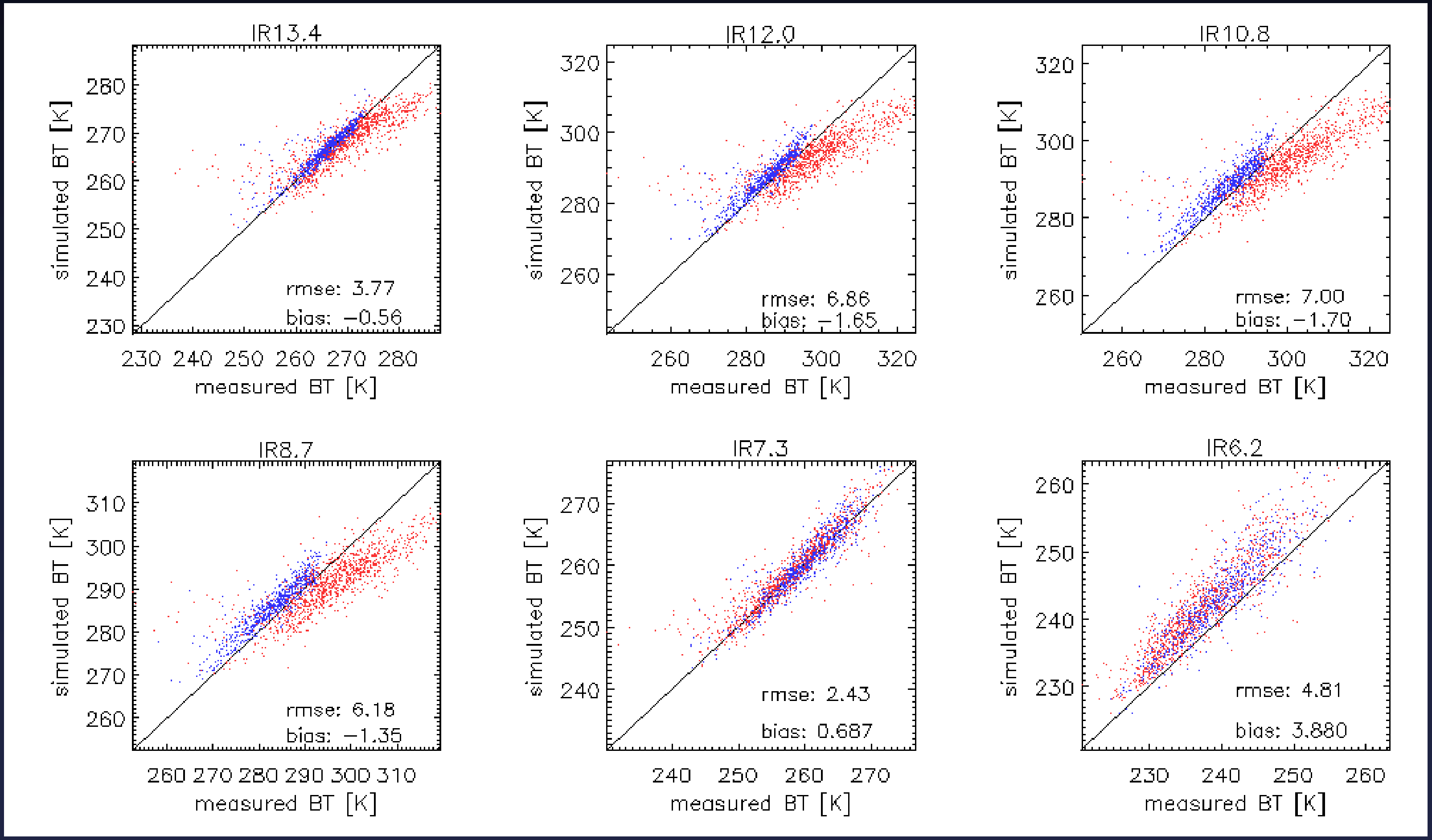
Observation operator

- Mapping state vector into observation space
- Interpolation to RTTOV-levels
- Adding standard profiles above 200hPa
- Calculation of gaseous optical depths (RTTOV-8)
- Sea surface emissivity taken from RTTOV IR emissivity model
  Land surface emissivity taken from mean emissivity maps (SSEC, Wisconsin)
- Radiative transfer calculation

$$\vec{x} \Rightarrow \text{forward model} \Rightarrow \vec{F}(\vec{x})$$

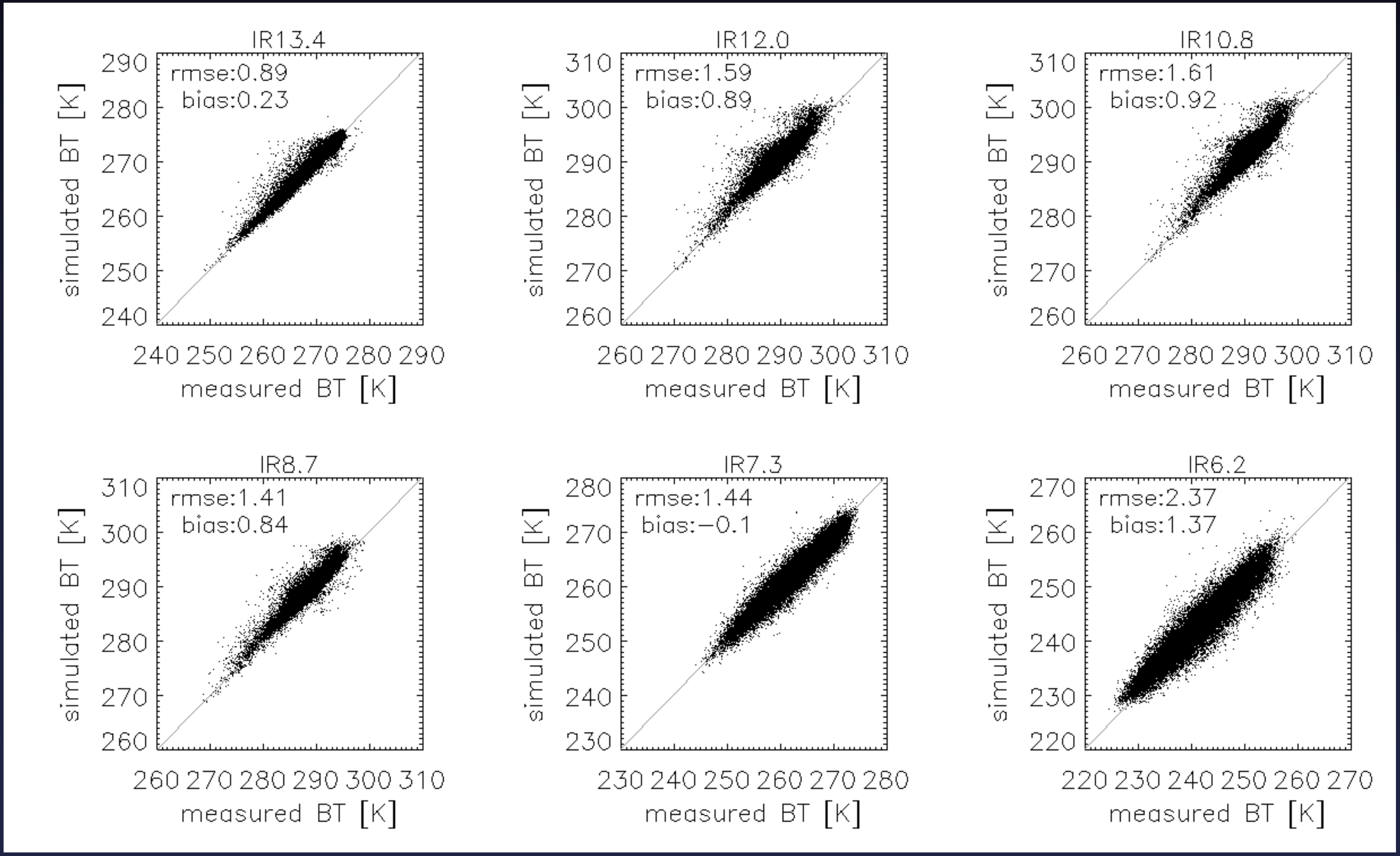
Observation operator performance

- Over land / Radiosonde data (00UTC, 12UTC)



Observation operator performance

- Over ocean / GFS data



Observations and correspoding errors

- SEVIRI IR channels / Observation vector
 (channels 3.9µm and 9.7µm blacklisted)

$$\vec{y} = [BT_{6.2}, BT_{7.3}, BT_{8.7}, BT_{10.8}, BT_{12.0}, BT_{13.4}]$$

- Observation error, ocean
 (channel noise, as in Schumann et al. (2002))

IR13.4	IR12.0	IR10.8	IR8.7	IR7.3	IR6.2
0.37K	0.15K	0.11K	0.10K	0.12K	0.21K

- Observation error, land

IR13.4	IR12.0	IR10.8	IR8.7	IR7.3	IR6.2
0.53K	0.65K	0.61K	0.60K	0.12K	0.21K

Observations and correspoding errors

- Observation error covariance matrix S_y:

$$S_y = \begin{bmatrix} \sigma_1^2 & c_{12}\sigma_1\sigma_2 & \cdots \\ c_{12}\sigma_1\sigma_2 & \sigma_2^2 & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix}$$

σ_i : measurement error of channel i (noise, spectral shift etc.)

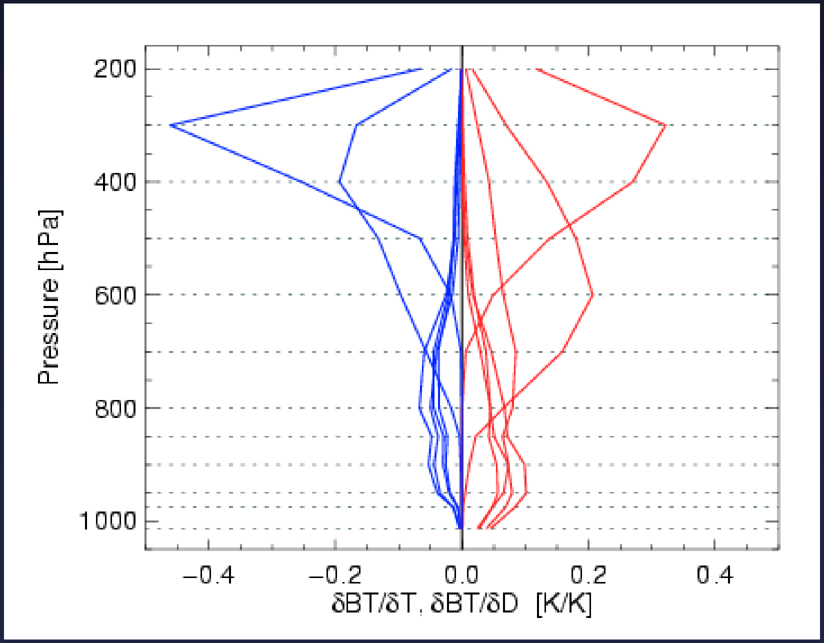
c_{ij} : correlation of errors of channels i and j

- Only diagonal elements not equal 0
  (Assuming observation errors between channels are uncorrelated)

Sensitivity functions / Jacobians

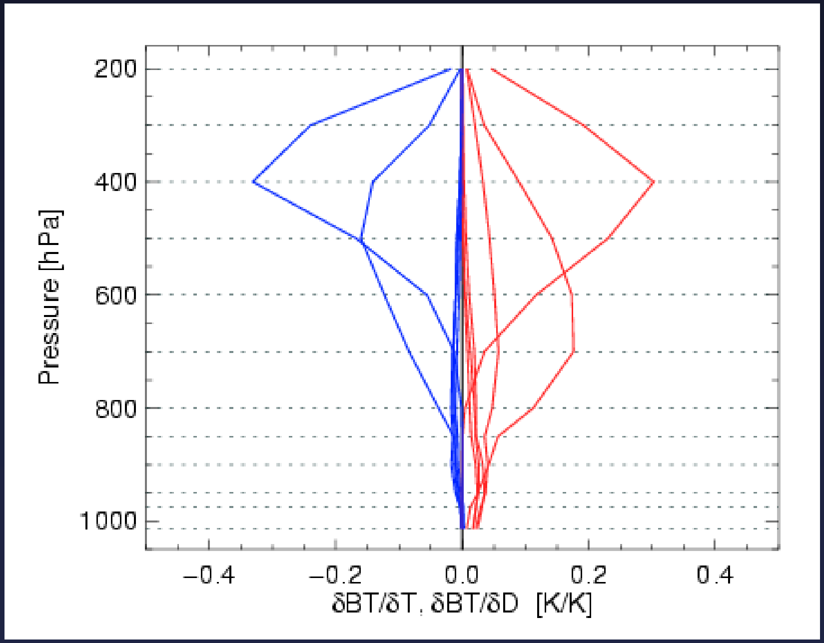
- Brute force for each state vector element
  - Advantage: no Jacobian interpolation needed
  - Disadvantage: relative slow

more water vapour



dBT/dTs = [0.14, 0.48, 0.61, 0.62, 0.00, 0.00]

less water vapour



dBT/dTs = [0.34, 0.80, 0.86, 0.79, 0.02, 0.000]

Minimization / Iteration

- Minimize χ^2

$$\chi^2 = \sum_i \frac{(y_i - F_i(\vec{x}))^2}{\sigma_i^2}$$

- Iterate to get the next guess (Gauss-Newton)

$$\vec{x}_{i+1} = \vec{x}_i + S_i \left(K_i^T S_y^{-1} \left(\vec{y} - \vec{F}(\vec{x}_i) \right) + S_a^{-1} \left(\vec{x}_a - \vec{x}_i \right) \right)$$

where: $$S_i = \left(K_i^T S_y^{-1} K_i + S_a^{-1} \right)^{-1}$$

- Iterate until χ^2 is below threshold

$$\chi^2 \le 15$$

A-priori information

- A-priori vector $\vec{x}_a$:

  Climatological mean of each single state vector element is used

- Background error covariance matrix S_a

$$S_a = \begin{bmatrix} \sigma_1^2 & c_{12}\sigma_1\sigma_2 & \cdots \\ c_{12}\sigma_1\sigma_2 & \sigma_2^2 & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix}$$

σ_i : error of prior knowledge about variable x_i
(standard deviation of climatological value)

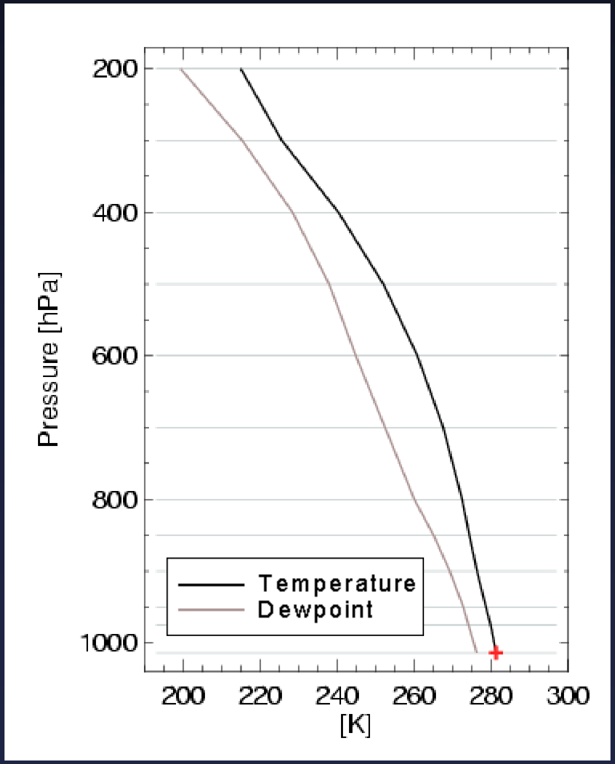
c_{ij} : correlation of errors of prior knowledge about variables x_i and x_j

- Calculated from a large ensemble of atmospheric profiles (Radiosondes / GFS)

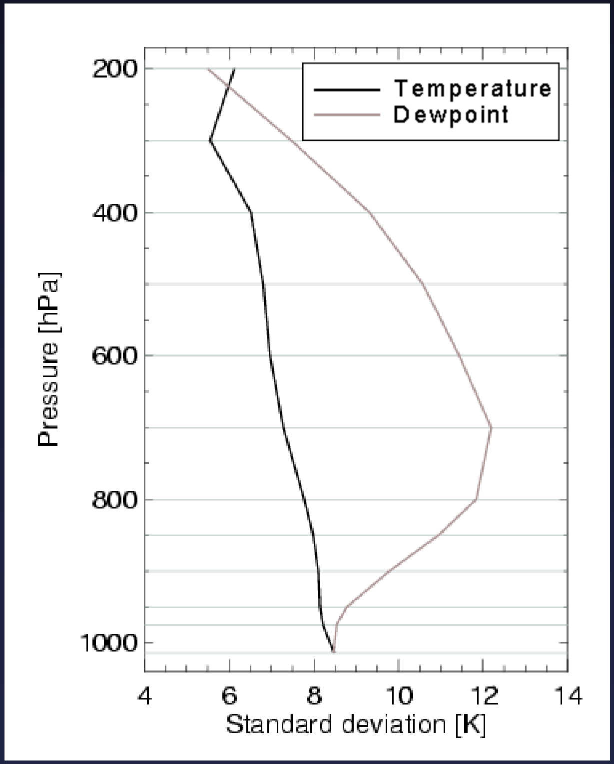
A-priori information / Strategy I

- Radiosonde measurements
  (data set dominated by european stations, with european climate)

Climatological mean



Standard deviations

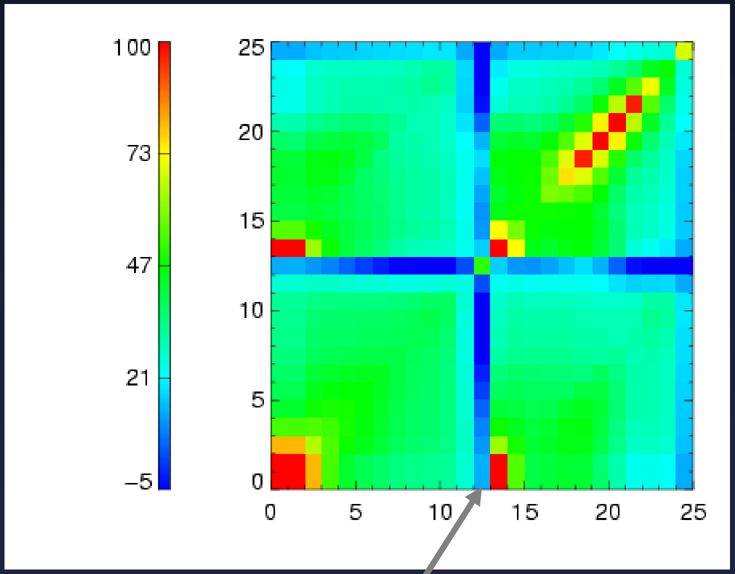


(Standard deviations show error when using climatological first guess)

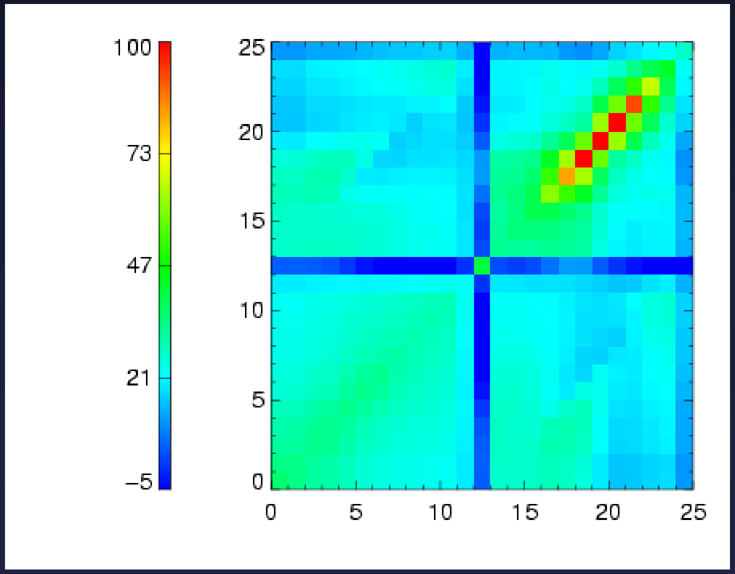
A-priori information / Strategy I

- Radiosonde measurements
  (data set dominated by european stations, with european climate)

Background error covariance - land (all)



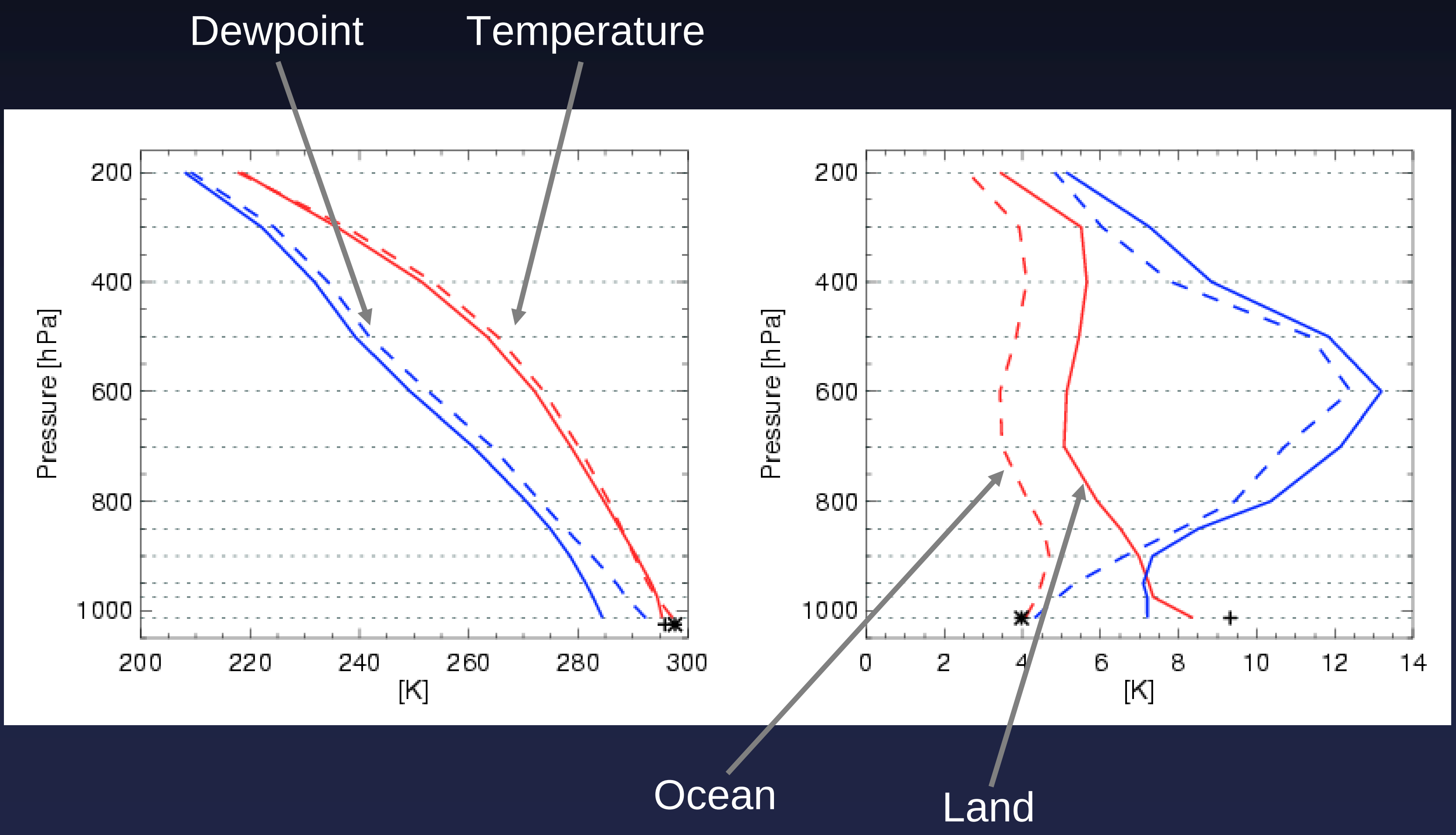
Background error covariance - ‘ocean’ (Tsfc >273K)



200hPa-Temperature

A-priori information / Strategy II

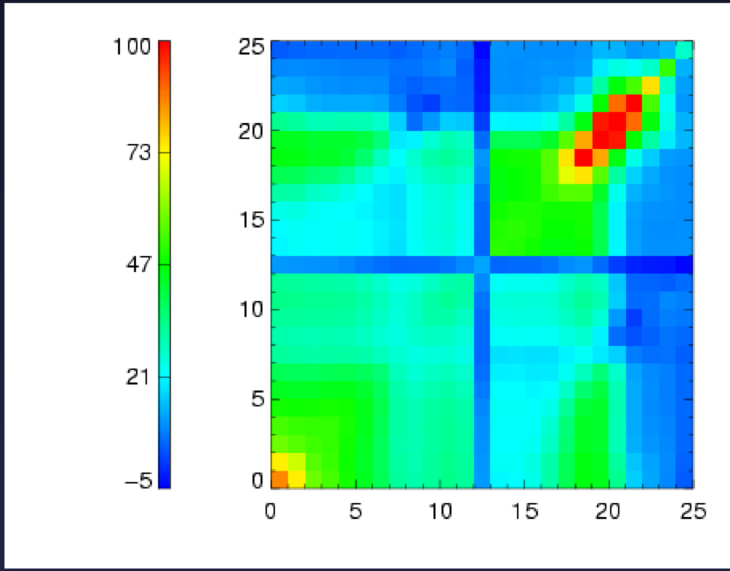
- GFS 12-hour forecast fields
  (give more comprehensive picture)



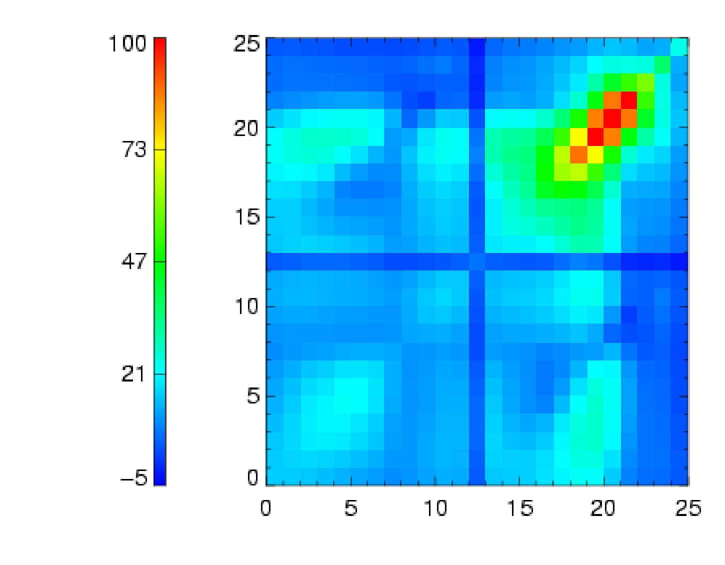
A-priori information / Strategy II

- GFS 12-hour forecast fields
  (give more comprehensive picture)

Background error covariance - land



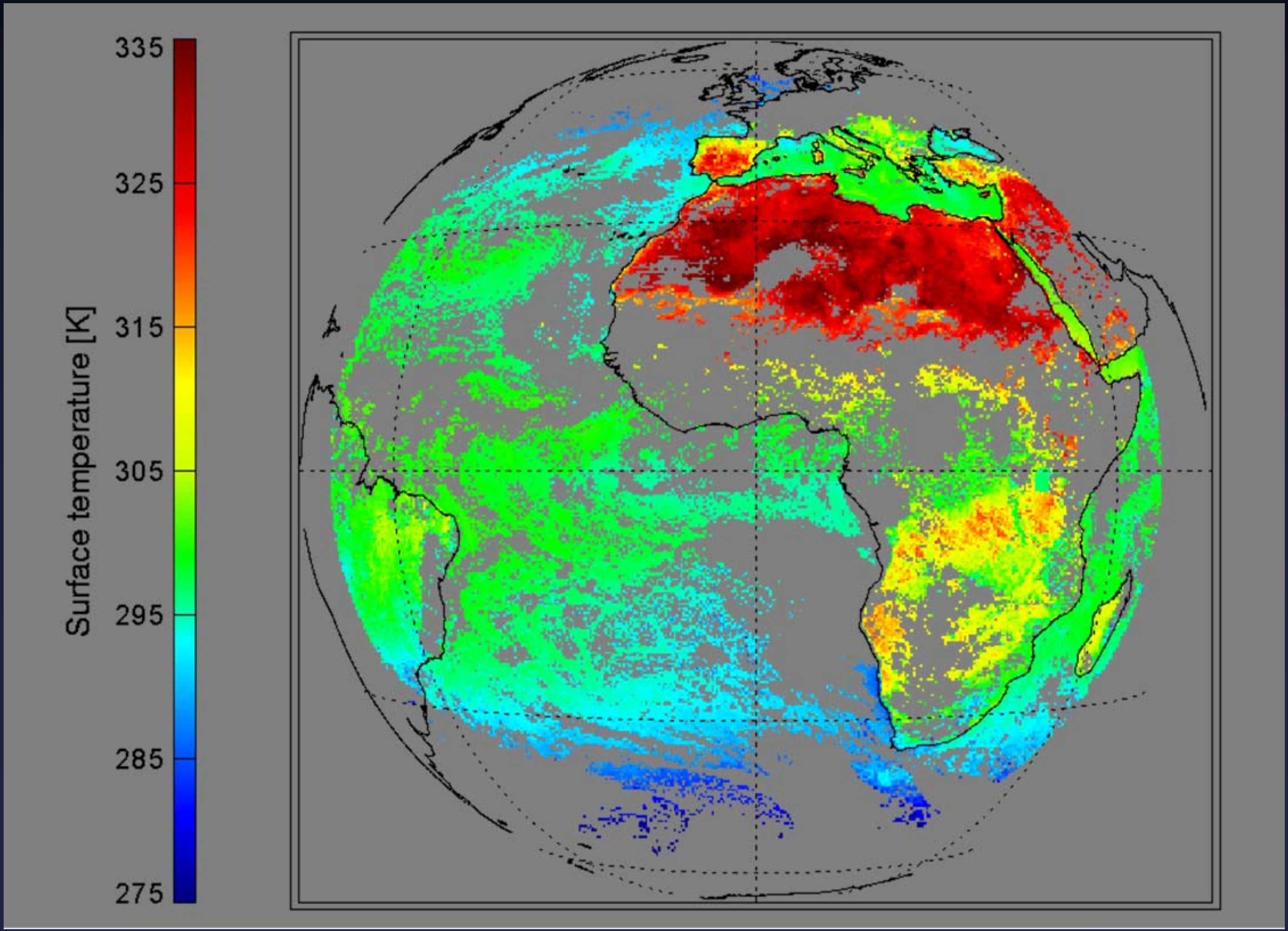
Background error covariance ocean



Together with a-priori profiles, this approach provides better background information

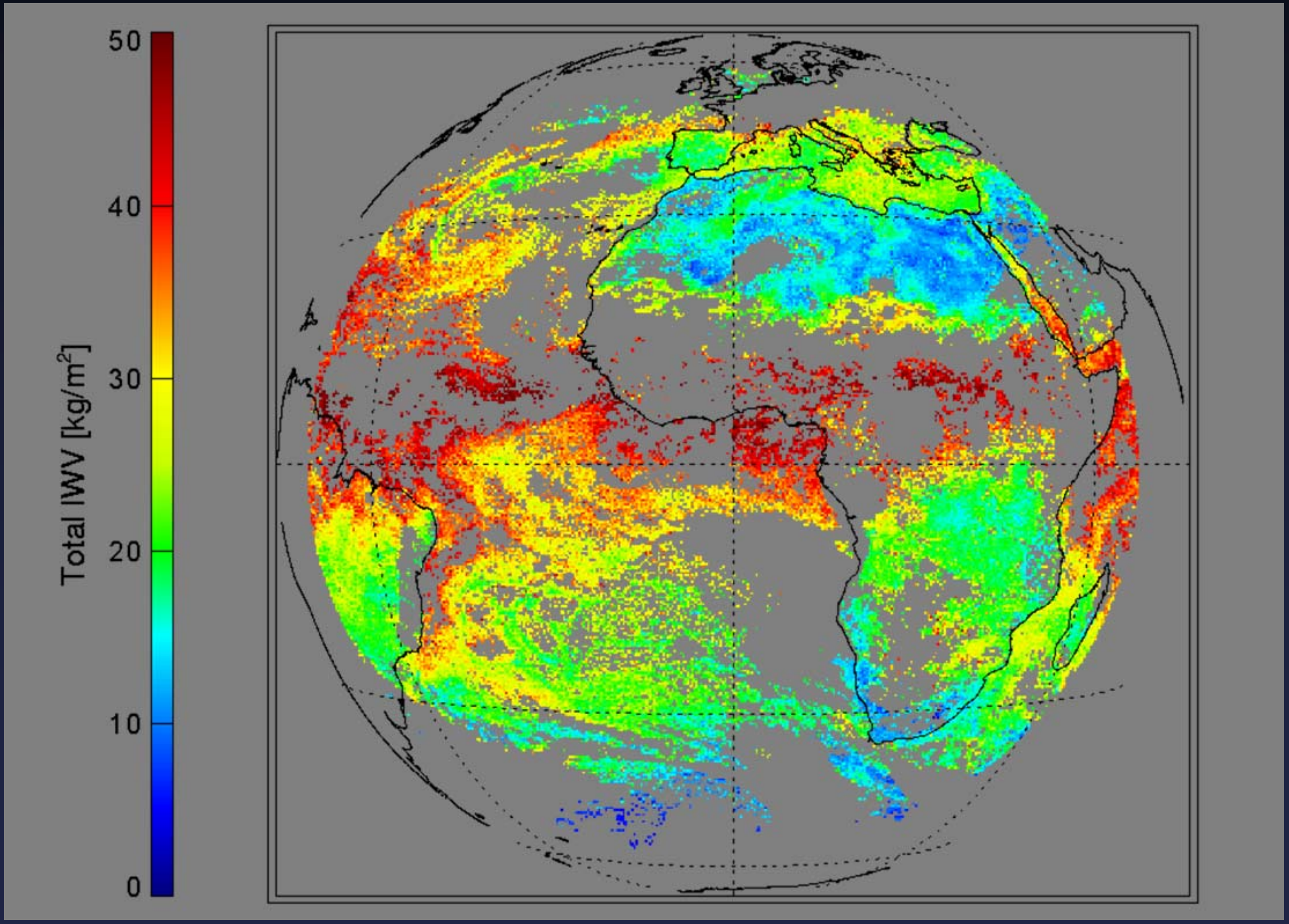
Retrieval example

- Surface temperature



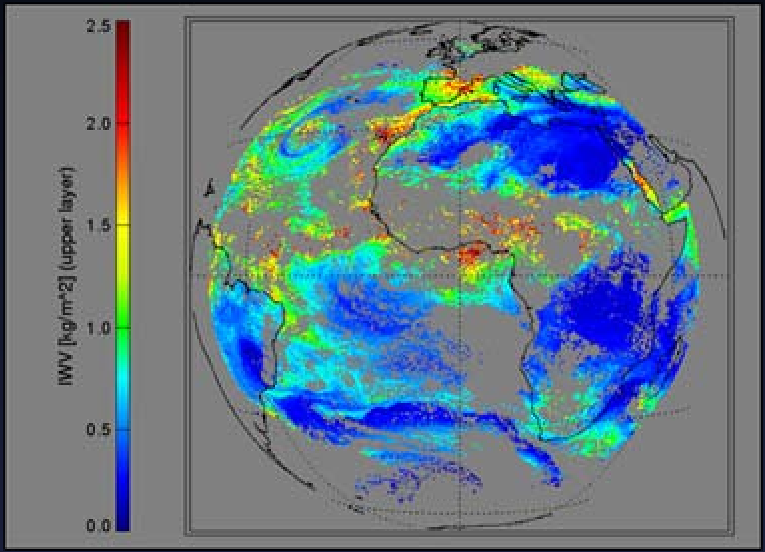
Retrieval example

- Integrated water vapour – Total column



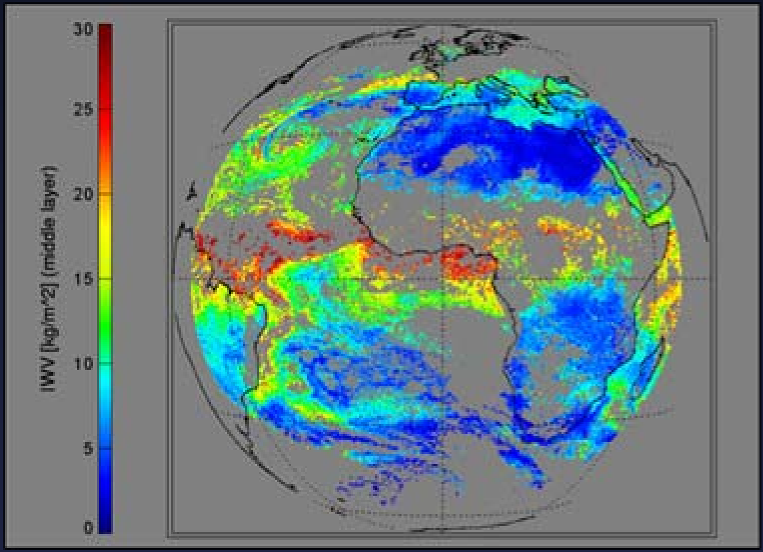
Retrieval example

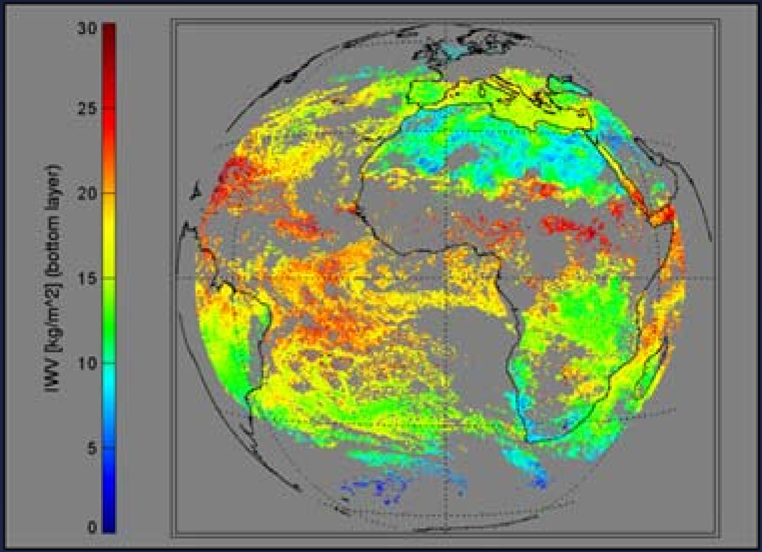
- Integrated water vapour – Layers



Upper layer

Middle layer



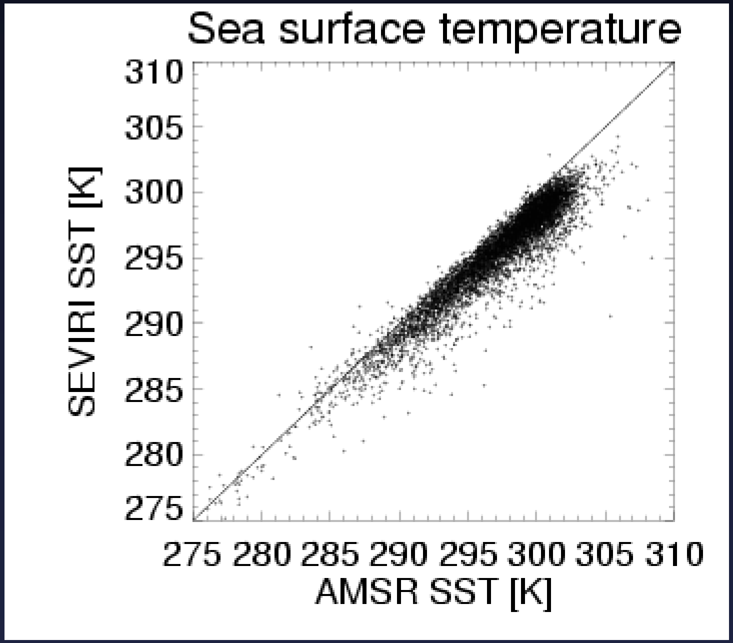


Bottom layer

Verification

- Over ocean: AMSR SST retrieval

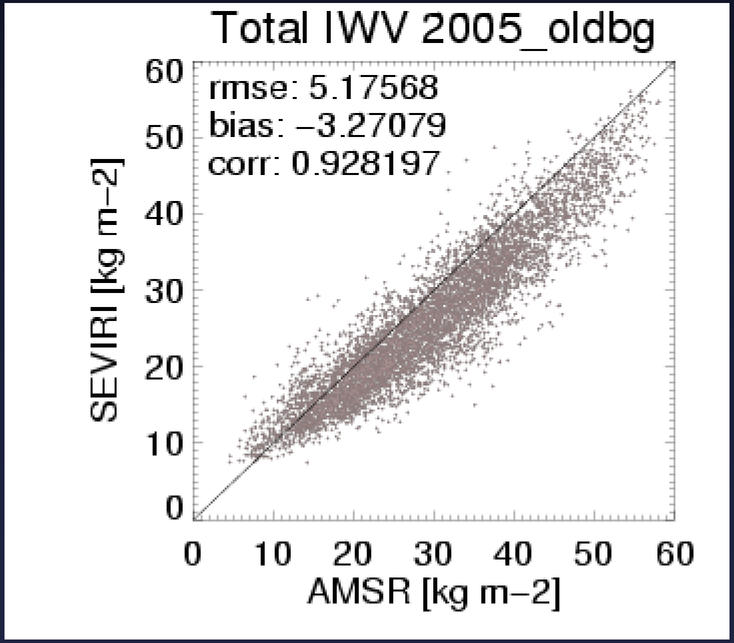
	RMSE	Bias
SST	2.2 K	-1.8 K



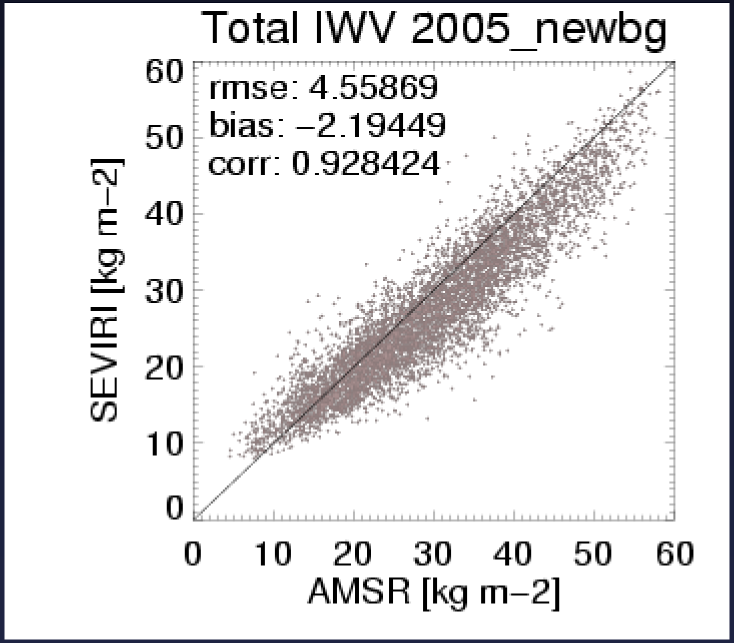
Verification

- Over ocean: AMSR IWV retrieval

With background info from radiosondes



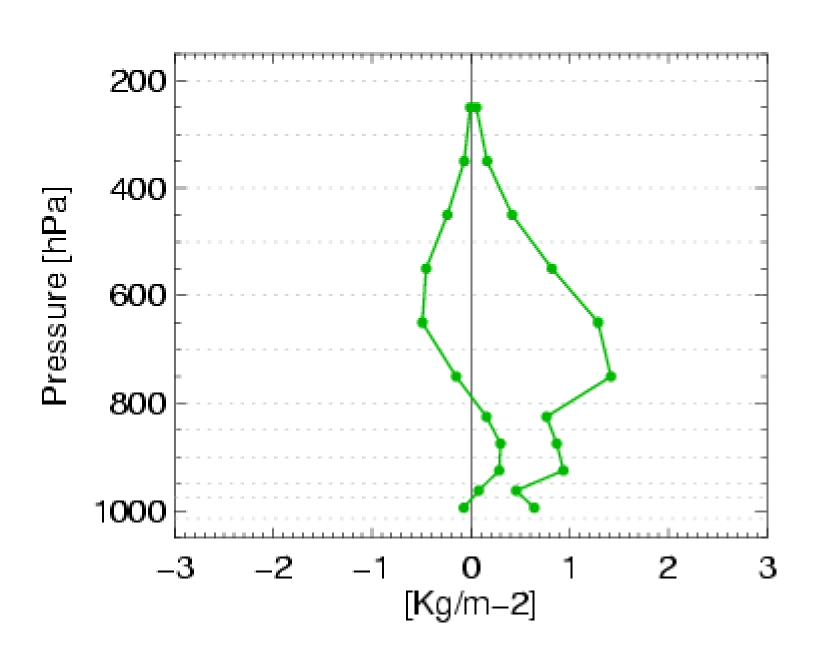
With background info from GFS



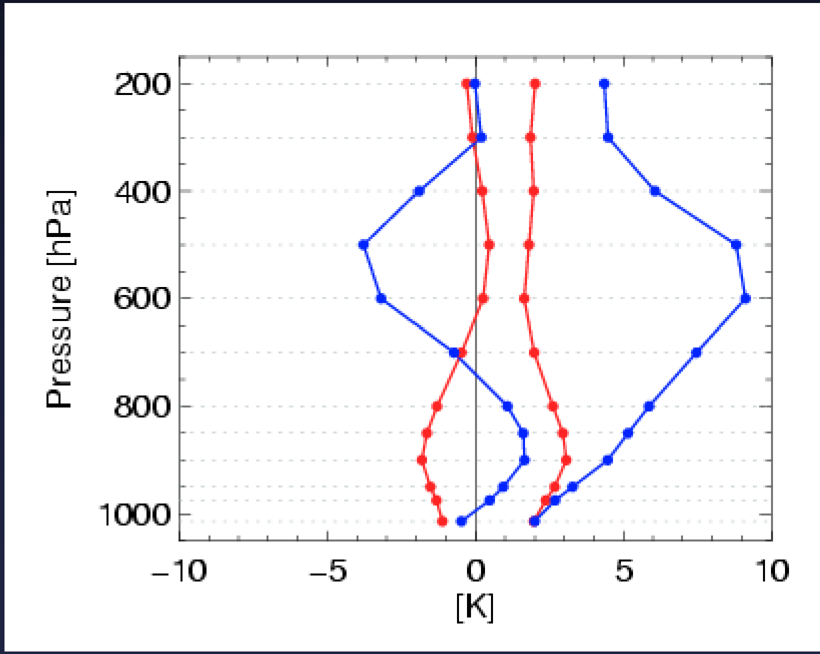
Verification

- Over ocean: GFS 12-hour forecast

Layered integrated water vapour



Temperature (red) and Dewpoint (blue)



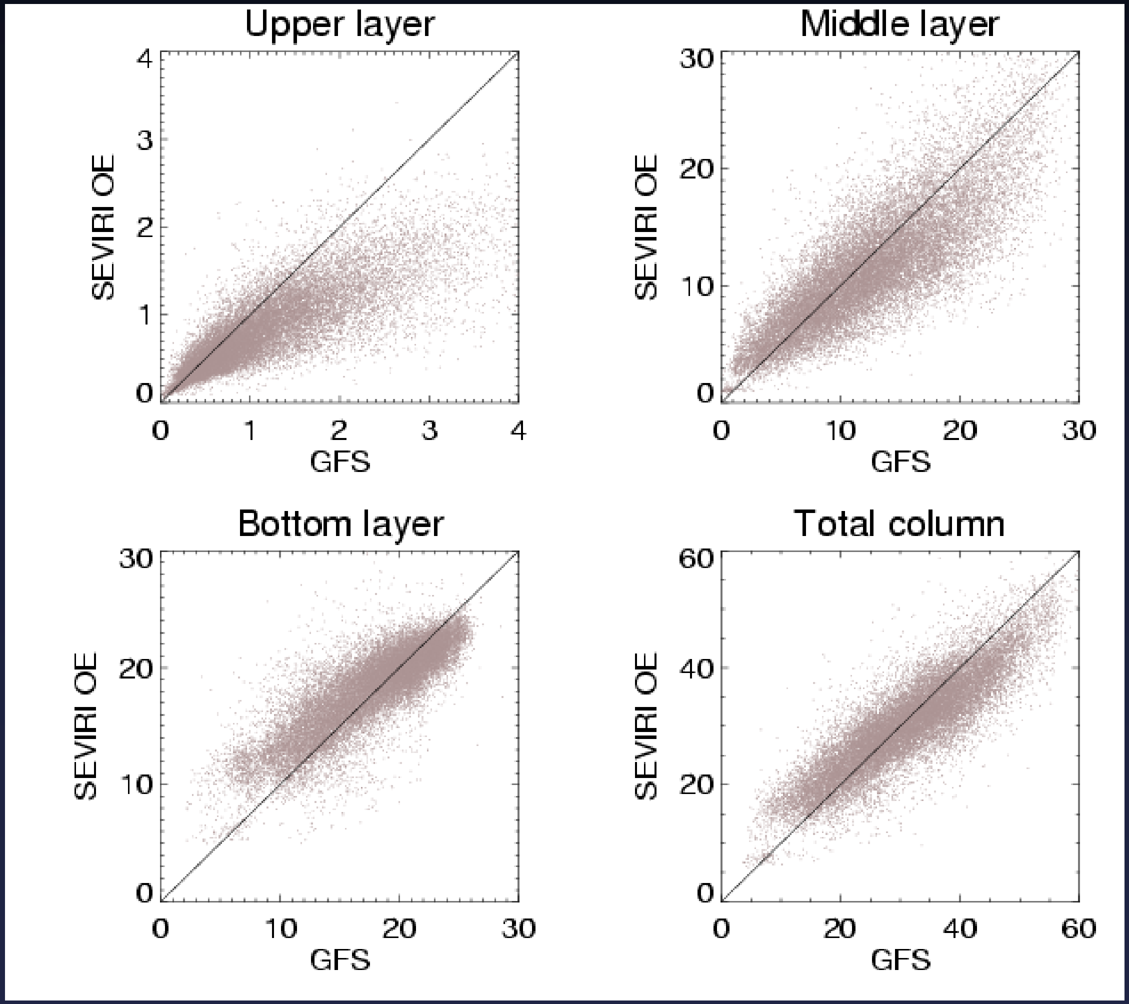
(Shown are RMSE and Bias)

Verification

- Over ocean: GFS 12-hour forecast

	RMSE	Bias
Upper L.	0.57	-0.3
Middle L.	3.5	-0.9
Bottom L.	2.6	0.6
Total Col.	5.1	-0.7

[Kg/m²]

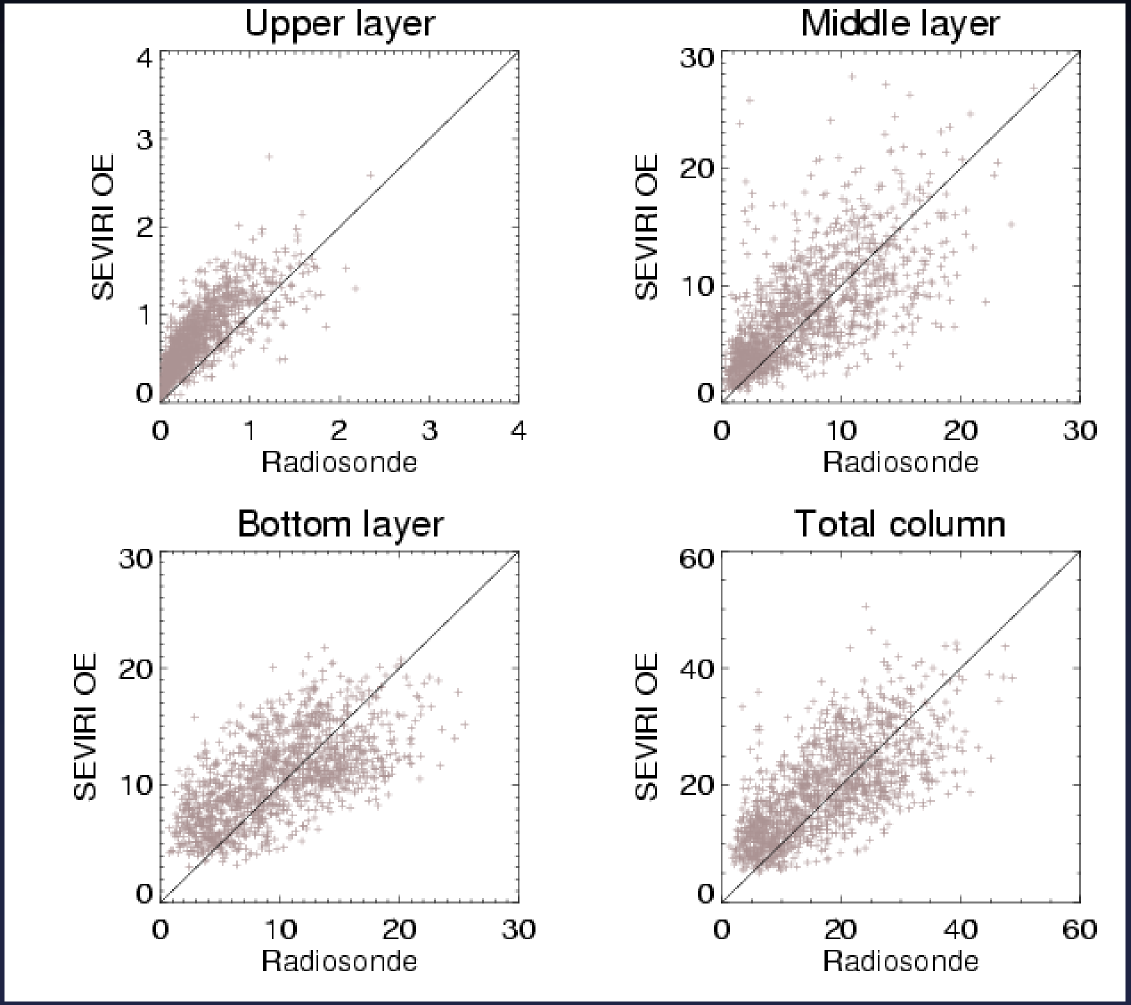


Verification

- Over land: Radiosondes

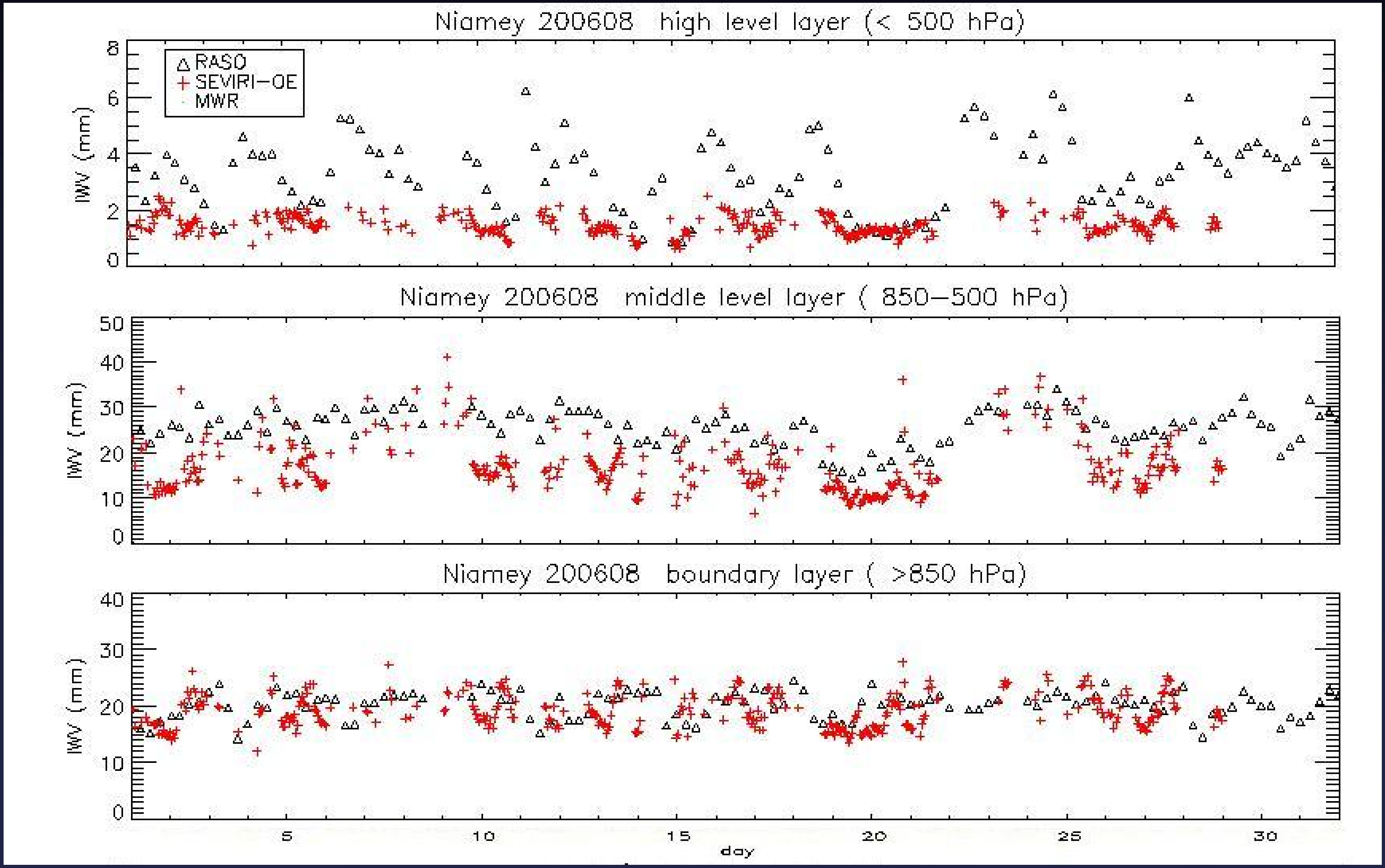
	RMSE	Bias
Upper L.	0.4	0.3
Middle L.	3.8	0.8
Bottom L.	3.9	0.8
Total Col.	7.2	1.9

[Kg/m²]



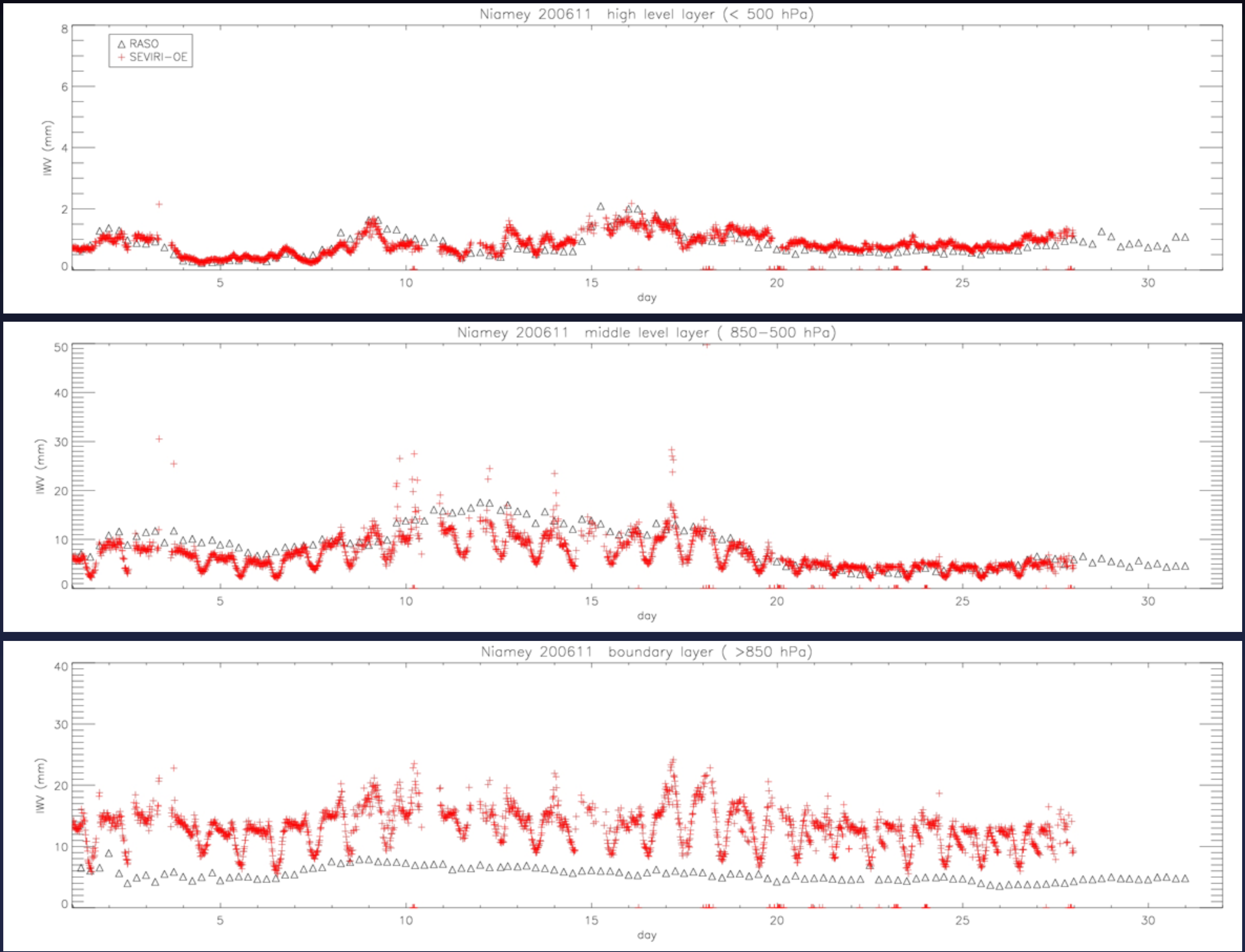
Verification

- Niamey measurement site: (08/2006)



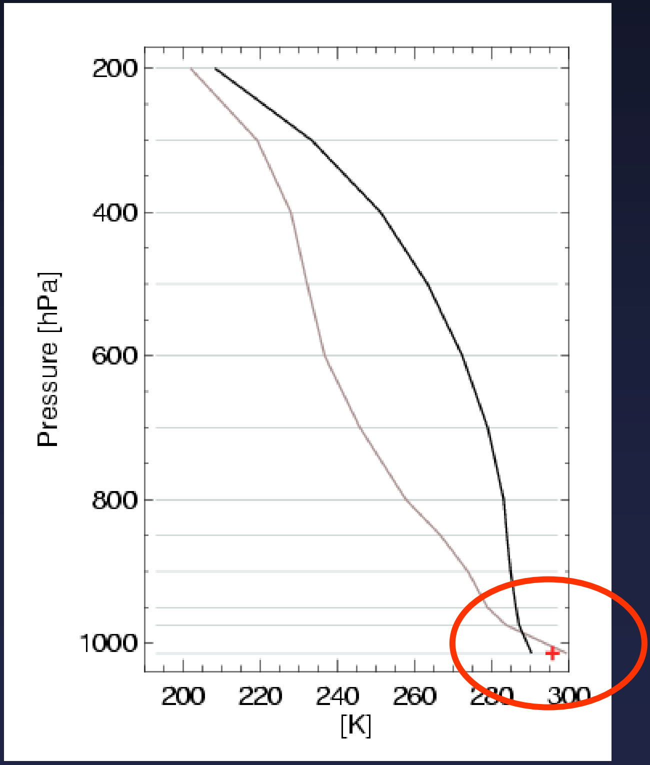
Verification

- Niamey measurement site: (11/2006)



General problems

- No suitable state vector found for about 10% of all cases
- Sometimes unphysical results: Dewpoint .gt. Temperature



Summary

- The retrieval can reproduce a realistic state vector in 90% of all cases
- Still problems over land.
  Emissivity data not accurate enough; fixed state vector levels (1013,….)
  (The derived upper layer WV matches radiosondes well in some cases)
- Works fairly well over ocean; comparison against AMSR retrievals show RMSE of about 4.5 kg/m² for the total column.
- SST shows good agreement with AMSR retrievals
- Comparison with GFS indicate also a useful retrieval of the water vapour in the 3 layers over ocean
- Results and the sensitivity of the retrieval are discussed within the climate monitoring context in Jörg’s talk.