The use of surface-sensitive microwave radiances over land at ECMWF

Blazej Krzeminski[1] Niels Bormann[1]
Fatima Karbou[2] Peter Bauer[1]

[1]European Centre for Medium-Range Weather Forecasts
[2]Météo-France

2nd Workshop on Remote Sensing and Modeling of Surface Properties
Toulouse, 9–11 June 2009

Outline

- Current use of AMSU over land
- Dynamic retrievals of land surface emissivity
- Dynamic retrievals of skin temperature over land
- Kalman Filter emissivity estimation
- Impact of the emissivity / skin temperature retrievals
- Summary and outstanding issues

Current use of AMSU-A over land

Table 1: AMSU-A assimilated (●), monitored (○) and unused (–) channels over land, as of 04.06.2009

	channel number														
	1	2	3	4	5[1]	6[2]	7	8	9	10	11	12	13	14	15
NOAA-15	–	–	○	○	●	–	●	●	●	●	–	●	●	–	–
NOAA-16	–	–	–	–	–	–	–	–	●	●	●	●	●	●	–
NOAA-18	–	–	○	○	●	●	●	●	●	●	●	●	●	●	–
NOAA-19	–	–	○	○	●	●	–	●	●	●	●	●	●	●	–
AQUA	–	–	–	–	–	–	–	●	●	●	●	●	●	●	–
METOP-2	–	–	○	○	●	●	–	●	●	●	●	●	●	●	–

[1] channel 5 assimilated only over low orography (less than 1000m in tropics, less than 500m everywhere else)
[2] channel 6 assimilated only over low orography (less than 2000m in tropics, less than 1500m everywhere else)

Quality control:

- threshold check (± 0.7K) on channel 4 departures used to screen channels 5,6 and 7
- channel 5 and 6 observations rejected if $BT^{obs}_{24GHz} - BT^{obs}_{89GHz} > 3K$ (scattering index test)

Current use of AMSU-B/MHS over land

Table 2: AMSU-B assimilated (•) and unused (–) channels over land, as of 04.06.2009;

	channel number				
	1	2	3[1]	4[2]	5
NOAA-17	–	–	•	•	–
NOAA-18	–	–	•	•	–
NOAA-19	–	–	•	•	–
METOP-2	–	–	•	•	–

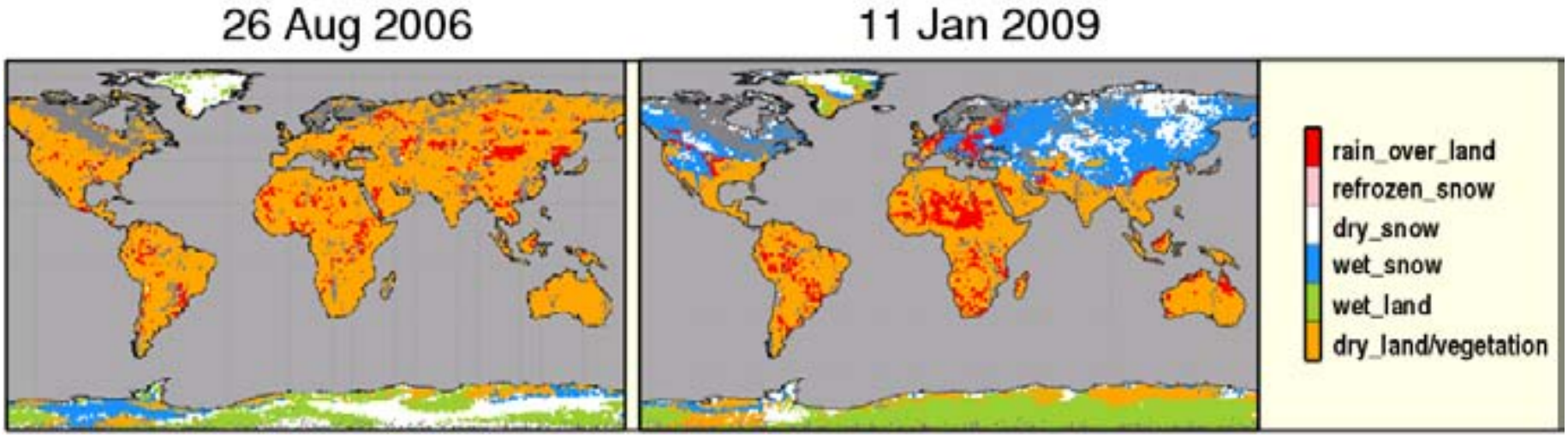
[1] channel 3 assimilated only over low orography (<1400m)
[2] channel 4 assimilated only over low orography (<1000m)

Quality control:

- threshold check ($\pm$5K) on channel 2 departures used to screen channels 3 and 4

Operational AMSU-A land emissivity

AMSU-A surface classification



Emissivity estimation for "dry land / vegetation" surface type:

$$\epsilon = -4.119{\cdot}10^{-2} - 9.0916{\cdot}10^{-3}{\cdot}BT_{23GHz} + 1.2172{\cdot}10^{-2}{\cdot}BT_{31GHz} + 4.8851{\cdot}10^{-4}{\cdot}BT_{50GHz}$$

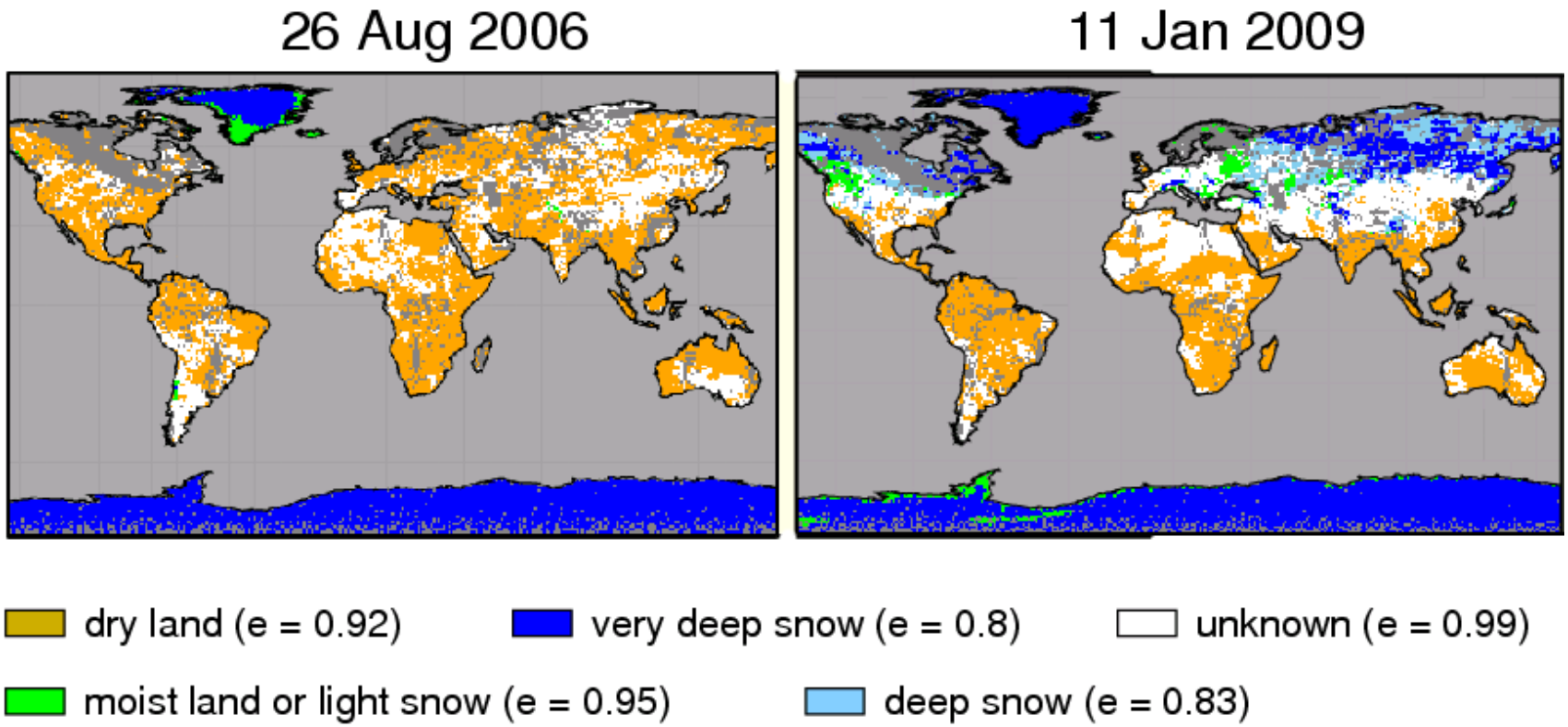
Emissivity estimation for other surface types:

$$\epsilon(\nu) = a + b{\cdot}log(\nu) \qquad \text{where a, b are specific for surface type}$$

G.Kelly, P.Bauer (2000): The use of AMSU-A surface channels to obtain surface emissivity over land, snow and ice for numerical weather prediction. In Proceedings of 11th International TOVS Study Conference, pp. 167–179, Budapest, Hungary

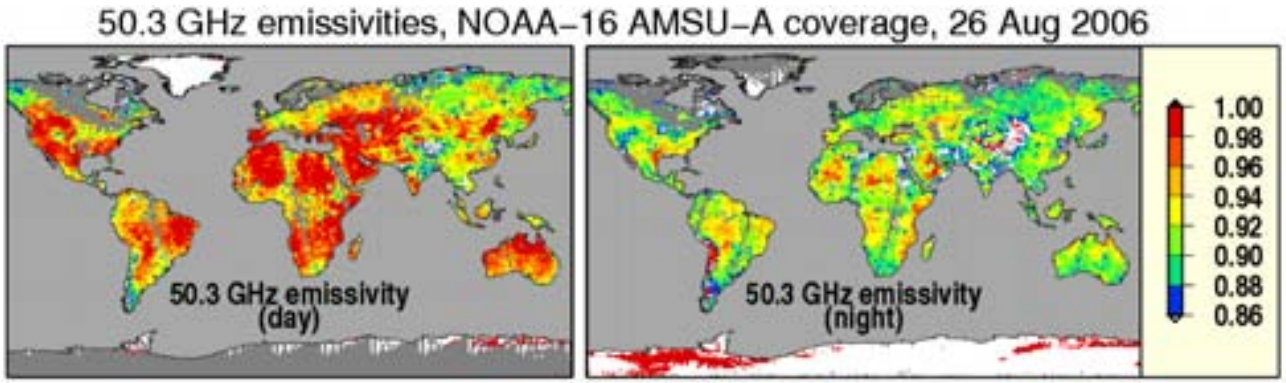
Operational AMSU-B land emissivity

AMSU-B surface type classification based on the IFS information about surface temperature, soil moisture and snow cover. Each surface type has assigned a constant emissivity value.



Shortcomings of the current scheme

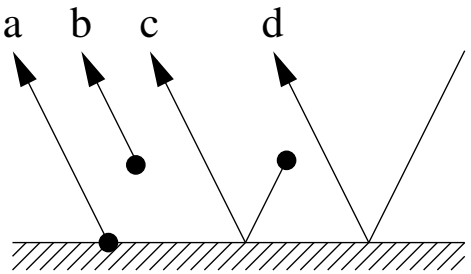
- Coarse surface classification
- Emissivity dependency on the viewing angle not modelled
- Large discrepancies between observed and simulated BTs for surface-sensitive channels
- Unrealistic diurnal variation of AMSU-A emissivity estimations:



New approach - emissivity / skin temperature retrievals

At microwave frequencies, brightness temperature observed by the satellite sensor can be expressed as:

$$T_{obs} = \underbrace{T_s \epsilon \Gamma}_{a} + \underbrace{T_{atm}^{\uparrow}}_{b} + \underbrace{(1-\epsilon) T_{atm}^{\downarrow} \Gamma}_{c} + \underbrace{(1-\epsilon) T_c \Gamma^2}_{d} \qquad (1)$$



$T_{atm}^{\uparrow}$ – net upwelling atmospheric radiance at TOA
$T_{atm}^{\downarrow}$ – net downwelling atmospheric radiance at the surface level
ϵ - surface emissivity, T_s - surface temperature, T_c - cosmic background temperature, Γ - surface-to-space atmospheric transmittance

assumption: specular surface reflection

Emissivity retrievals

By rearranging equation 1, emissivity can be calculated as

$$\epsilon = \frac{T_c\Gamma^2 + T_{atm}^{\downarrow}\Gamma + T_{atm}^{\uparrow} - T_{obs}}{(T_s - T_{atm}^{\downarrow})\Gamma}$$

ECMWF implementation (Karbou, 2007):

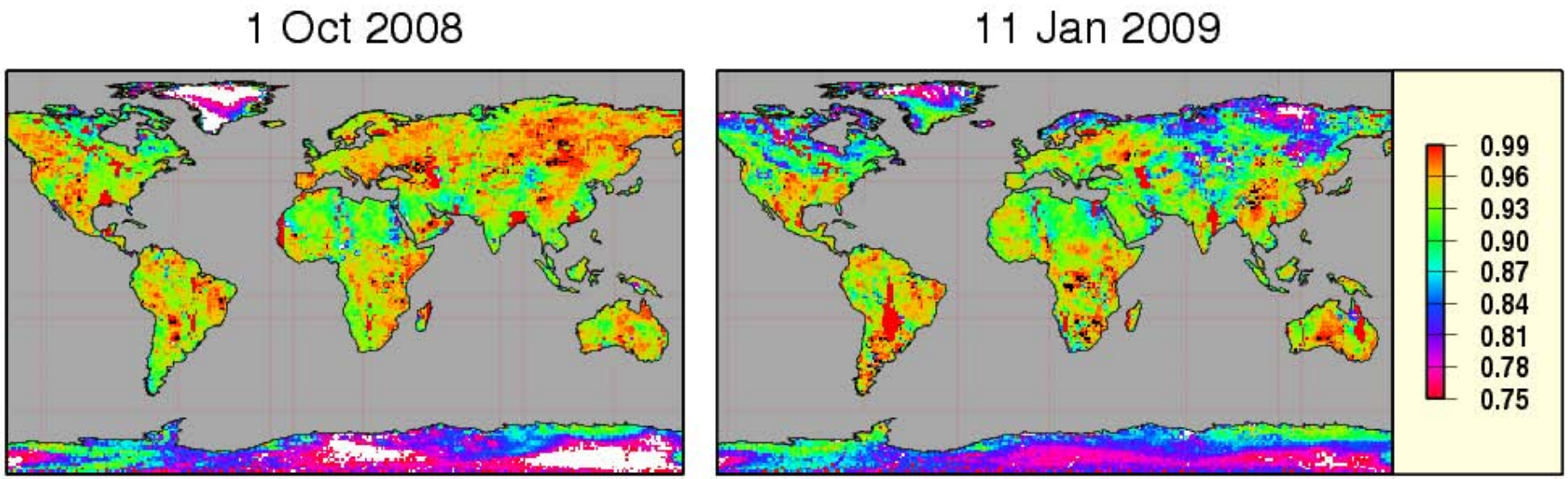
- $T_{atm}^{\uparrow}$, $T_{atm}^{\downarrow}$ and Γ calculated from ECMWF model background fields using RTTOV-9 (for clear-sky conditions only)
- T_s from the ECMWF TESSEL surface scheme
- Emissivity retrieved from window channel and used for sounding channels.
- AMSU-A channel 3 (50.3 GHz) and AMSU-B channel 1 (89 GHz) used for emissivity retrievals at ECMWF.

F.Karbou, N.Bormann, J-N Thepaut (2007): Towards the assimilation of satellite microwave observations over land: feasibility studies using SSMI/S, AMSU-A and AMSU-B. NWP SAF Programme Research Report.

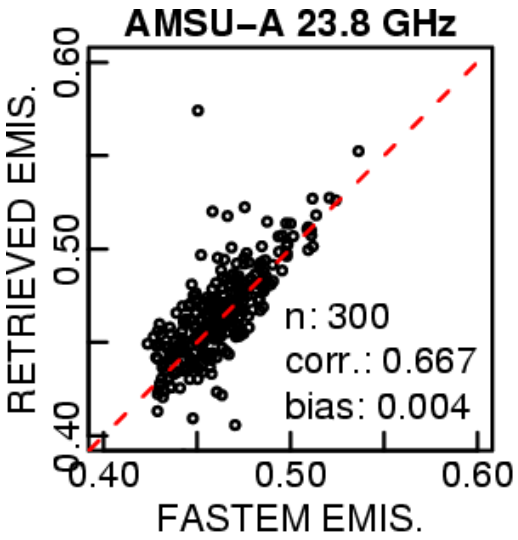
C.Prigent, F.Chevallier, F.Karbou, P.Bauer, G.Kelly (2005): AMSU-A land surface emissivity estimation for numerical weather prediction assimilation schemes. Journal of Applied Meteorology, 44:416–426

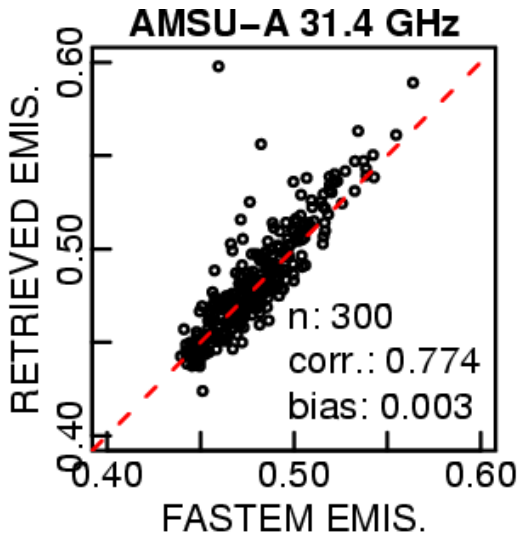
Emissivity retrievals

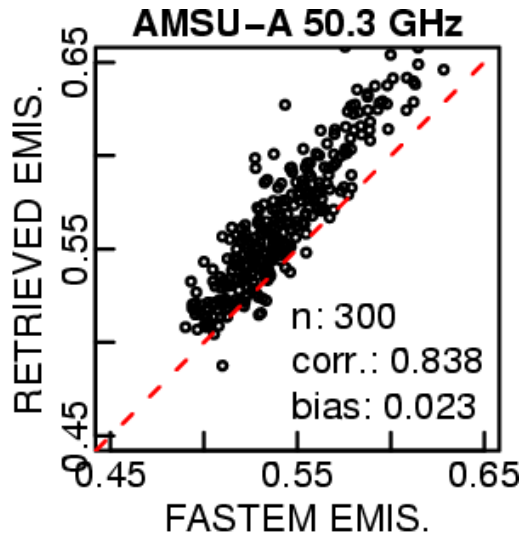
An example of 50.3 GHz (AMSU-A channel 3) dynamic emissivity retrievals for two different periods.

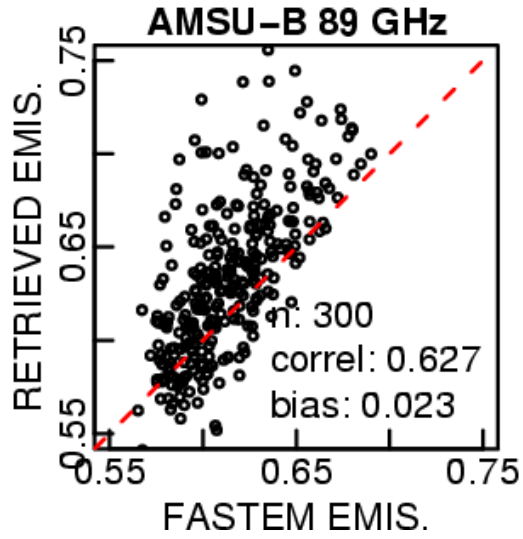


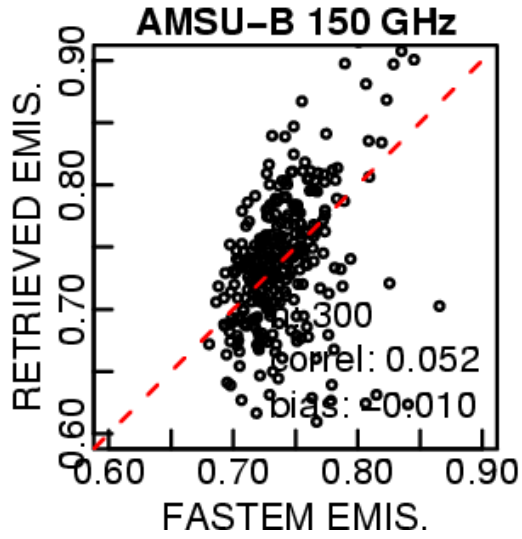
Emissivity retrievals vs. FASTEM-2 over ocean











Skin temperature retrievals

Skin temperature can be derived from eq. 1 as

$$T_s = \frac{(\epsilon - 1)\, T_c \Gamma^2 + (\epsilon - 1)\, T_{atm}^{\downarrow} \Gamma - T_{atm}^{\uparrow} + T_{obs}}{\epsilon \Gamma}$$

- $T_{atm}^{\uparrow}$, $T_{atm}^{\downarrow}$ and Γ calculated from ECMWF model fields
- Emissivity estimation must be provided as an input:
  - From emissivity atlas (dynamic emissivities averaged over several weeks) (Karbou, 2007)
  - From Kalman Filter emissivity estimation (see next slides)
- AMSU-A channel 2 (31.4 GHz) and AMSU-B channel 1 (89 GHz) used for skin temperature retrievals

F.Karbou, N.Bormann, J-N Thepaut (2007): Towards the assimilation of satellite microwave observations over land: feasibility studies using SSMI/S, AMSU-A and AMSU-B. NWP SAF Programme Research Report.

Kalman Filter emissivity estimation

Emissivity is parametrized as $\epsilon = \mathbf{Hx}$. An atlas of $\mathbf{x}$ vectors is updated using a Linear Kalman filter. Dynamic emissivity retrievals are used as "observations". For each "observation", $\mathbf{x}$ is updated at the respective atlas gridbox as follows:

- estimate a-priori emissivity model $\mathbf{x}$ (and its error) at time $\mathbf{t}$ assuming persistence, i.e that the emissivity is the same as it was at time $\mathbf{t-1}$:

$$\mathbf{x_t^a} = \mathbf{x_{t-1}}$$
$$\mathbf{P_t^a} = \mathbf{P_t} + \mathbf{Q}$$

- update the estimation with the "observation":

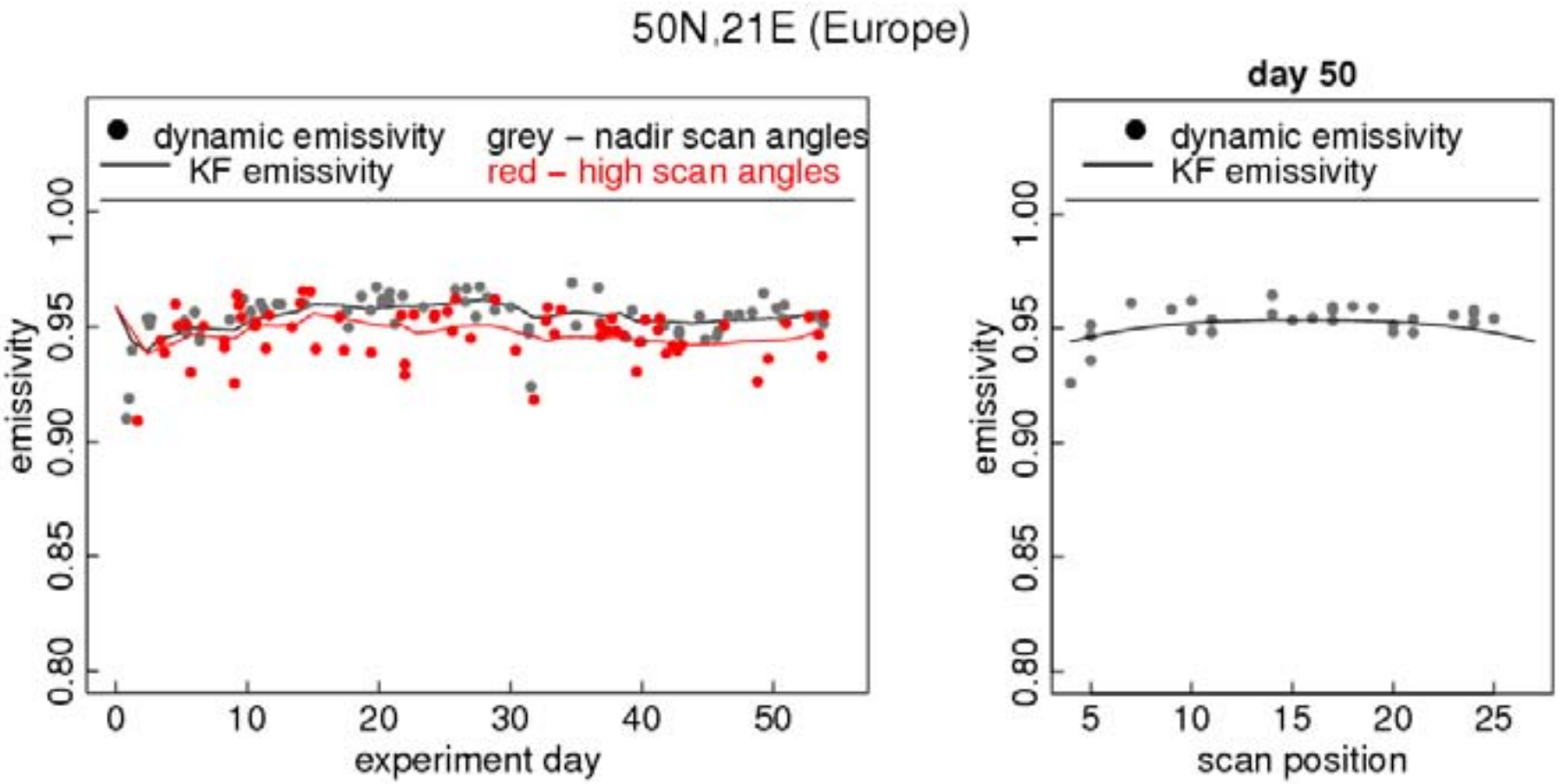
$$\mathbf{K_t} = \mathbf{P_t^a H^T}(\mathbf{H P_t^a H^T} + \mathbf{R})^{-1}$$
$$\mathbf{x_t} = \mathbf{x_t^a} + \mathbf{K_t}(\epsilon_t - \mathbf{H x_t^a})$$
$$\mathbf{P_t} = \mathbf{P_t^a} - \mathbf{K_t H P_t^a}$$

AMSU-A/B (cross-track scanning instrument): emissivity parametrized as a polynomial of the scan angle:

$$\epsilon = a + b\theta^2 + c\theta^4 = \begin{bmatrix}1 & \theta^2 & \theta^4\end{bmatrix} \cdot \begin{bmatrix}a & b & c\end{bmatrix}^T = \mathbf{Hx}$$

Kalman Filter emissivity estimation

Example: AMSU-A 50.3 GHz emissivities on a single $0.5^\circ \times 0.5^\circ$ gridbox:



Kalman Filter emissivity estimation

KF meant to reduce random errors in the emissivity estimations, from:

- instrument noise
- cloud/rain contamination of the observations
- random and diurnal errors in the model fields (T_s, profiles)

Systematic errors in the estimated emissivity can be a result of:

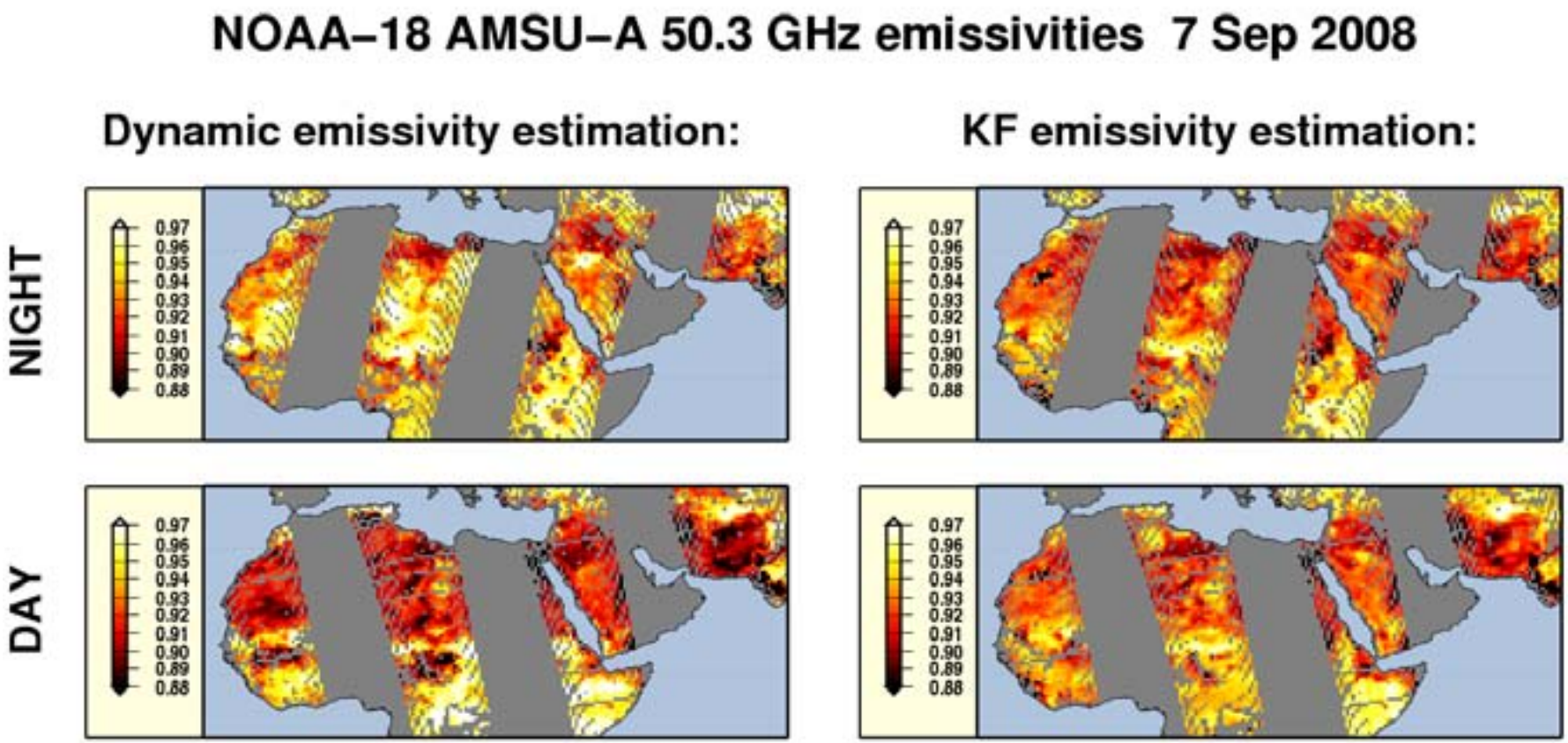
- assumption of the specular surface reflection (Karbou, 2005)
- bias in the ECMWF skin temperature (Trigo, 2003).
- emssivity retrieved from V channel, used for H channels.
- extrapolating window channel emissivity to other frequencies

To deal with them, bias correction of surface sensitive channels is applied over sea and land separately.

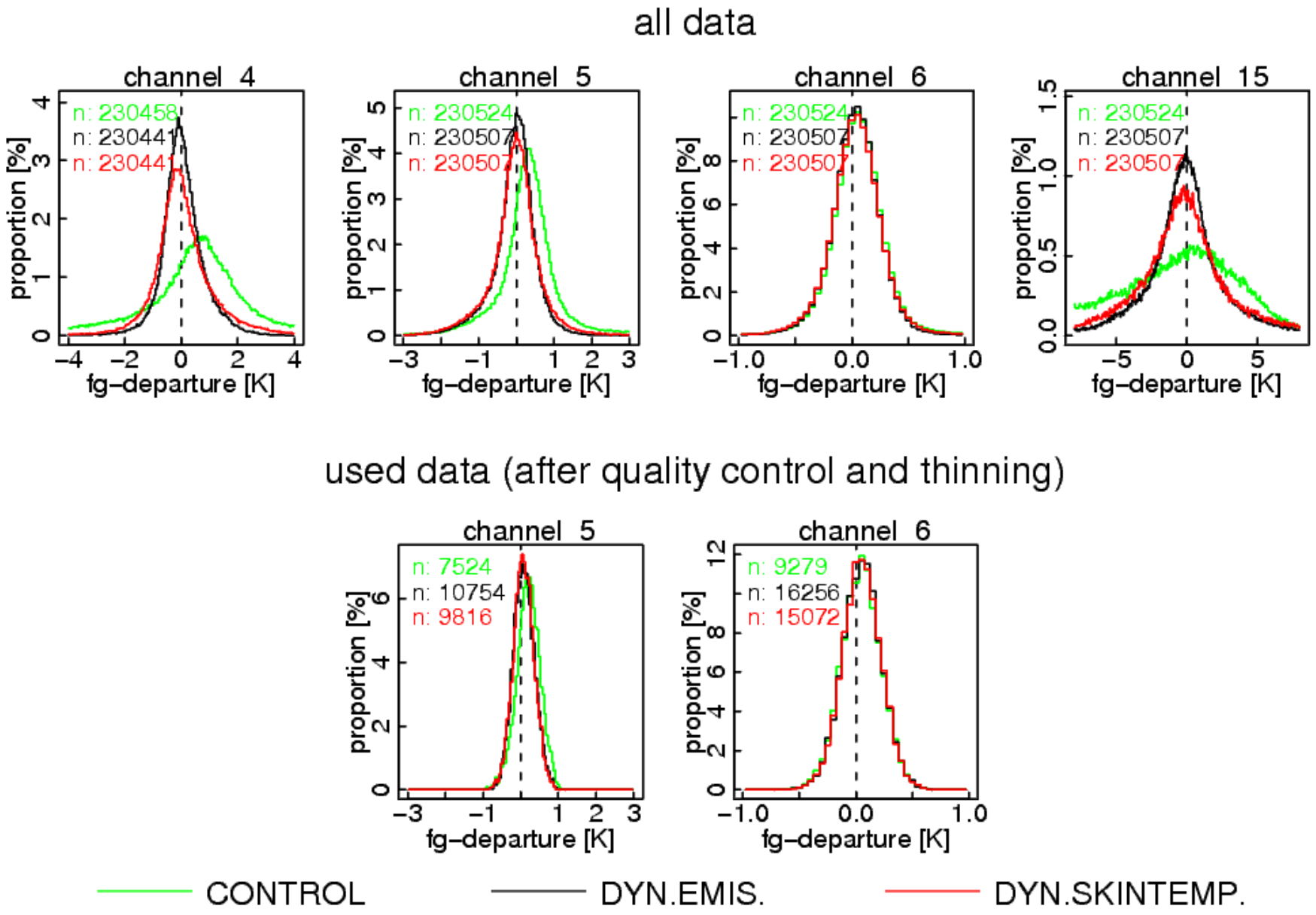
Karbou, F., and C. Prigent, 2005, Calculation of microwave land surface emissivity from satellite observations: validity of the specular approximation over snow-free surfaces, IEEE Geoscience and Remote Sensing Letters, vol. 2, no. 3, pp. 311-314

Trigo, I.F., and P. Viterbo, 2003: Clear-sky window channel radiances: A comparison between observations and the ECMWF model. J. App. Meteor., 42, 1463-1479.

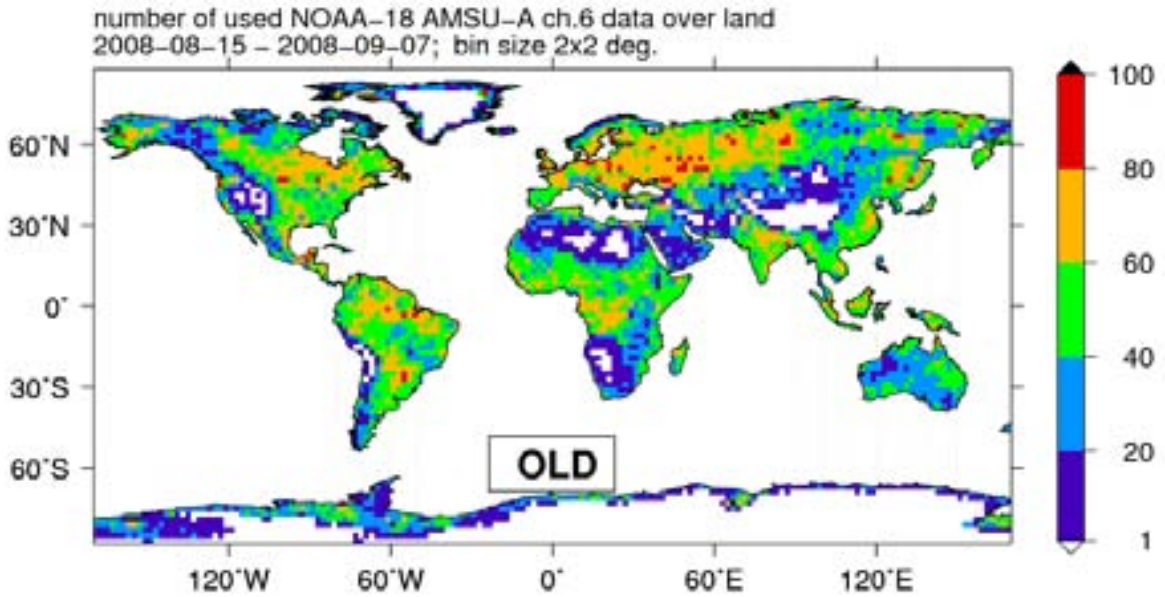
Kalman Filter emissivity estimation

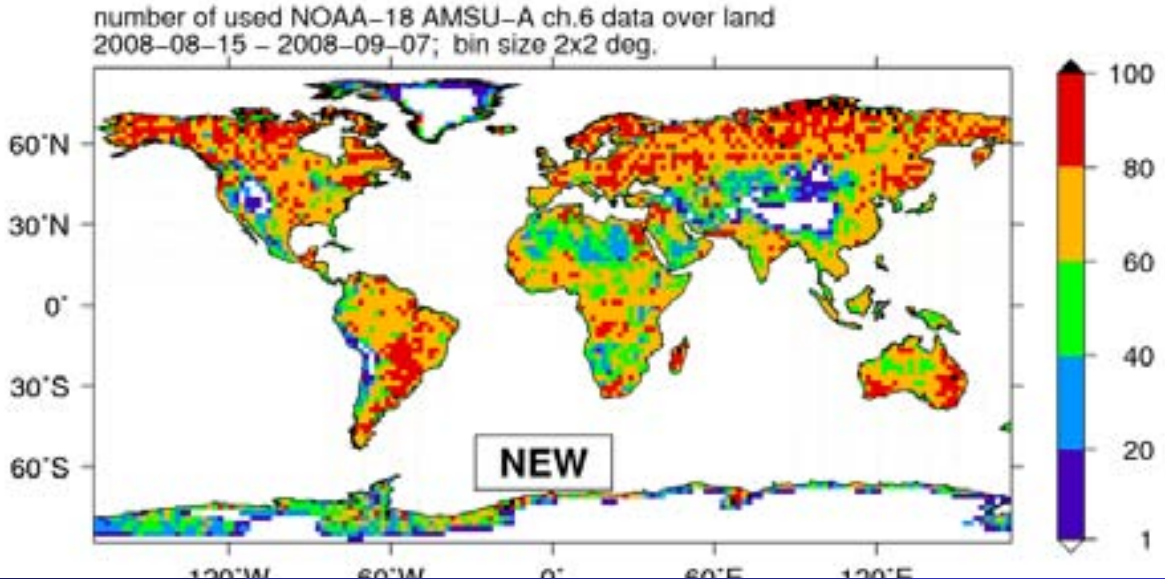


Impact on first guess departures (AMSU-A)

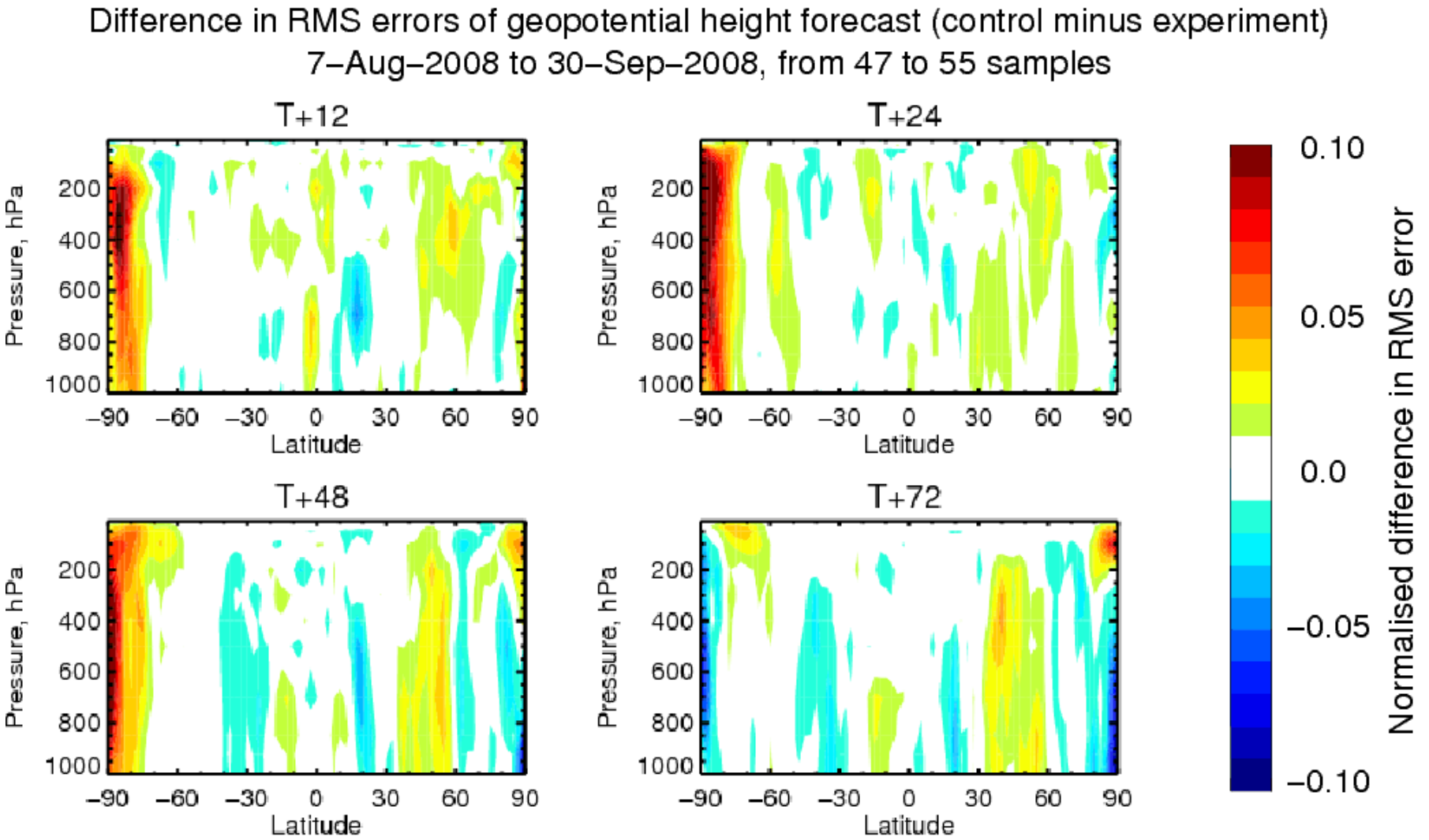


More data used over land

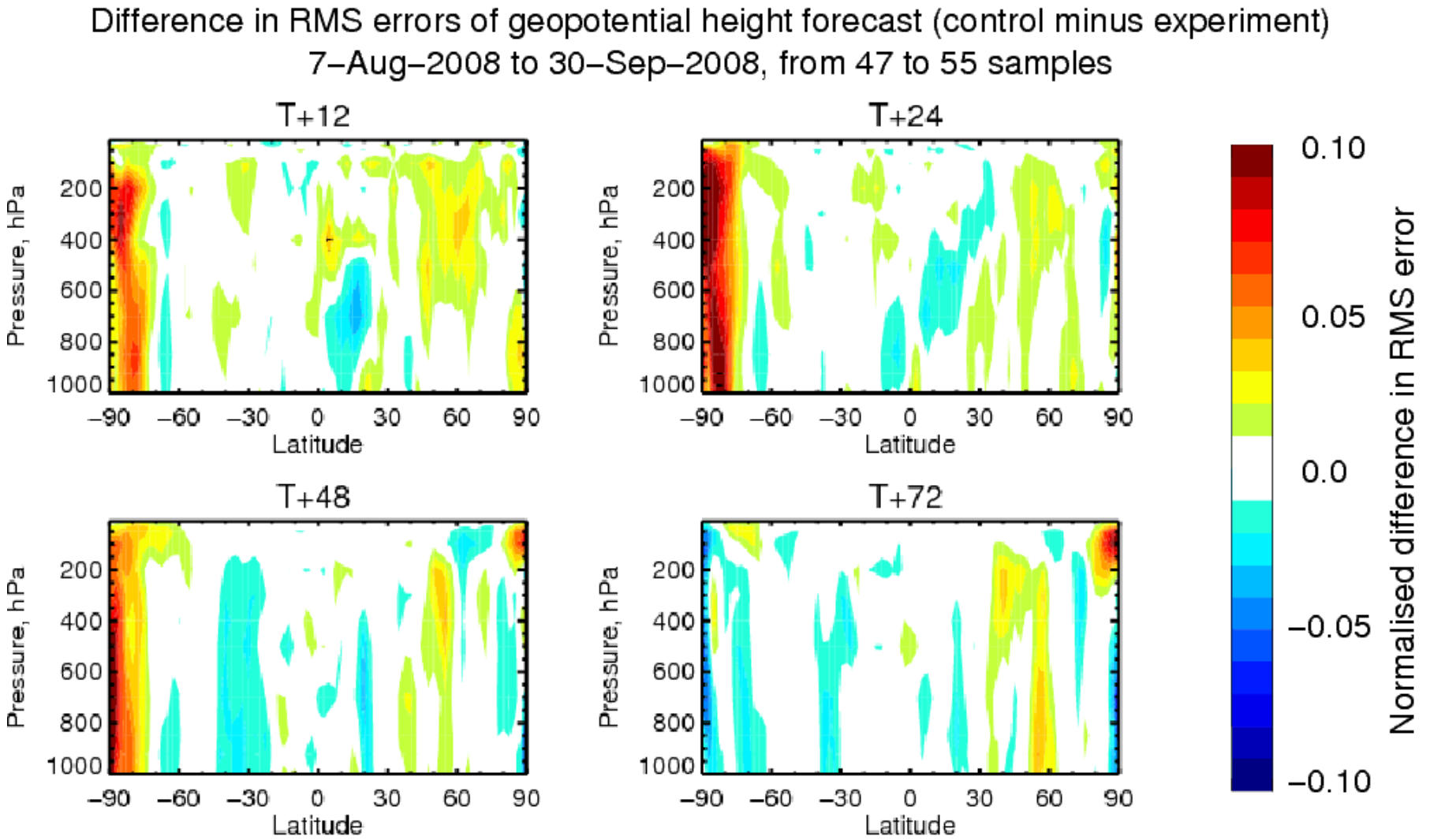




Impact of emissivity retrievals on the forecasts



Impact of skin temperature retrievals on the forecasts



Summary

- Emissivity / skin temperature retrievals $\Rightarrow$ simulated BTs for surface sensitive channels more consistent with the observations.
- More data used over land with the new emissivity scheme
- Impact on the forecast skill - neutral
- Kalman Filter emissivity atlas was implemented, skin temperature retrievals are investigated
- Dynamic emissivity retrievals will be used operationally in very near future

Plans

- Two AMSU-A instruments not used over land due to channel 4 failure – new QC channel needed.
- Investigate using only nighttime observations for Kalman Filter atlas.
- Fine tuning of the Kalman Filter.
- Investigate assimilation of additional channels over land (AMSU-A channel 4, maybe AMSU-B channel 5 ?)
- Address emissivity estimation over sea-ice (old scheme still used, +1K bias observed in channel 5 over sea-ice)