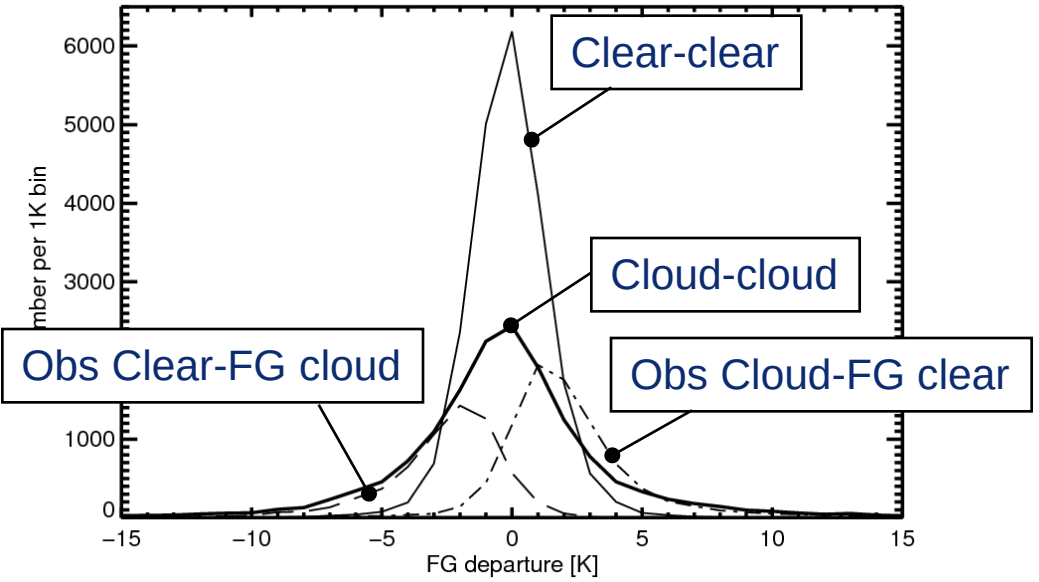
Direct assimilation of all-sky microwave radiances at ECMWF

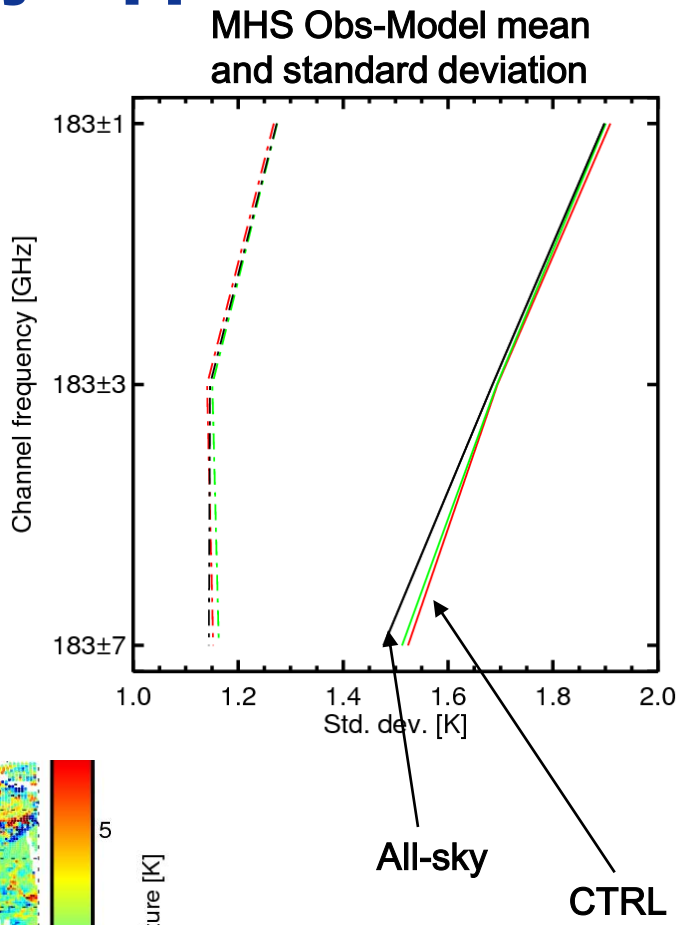
Peter Bauer, Alan Geer, Philippe Lopez, Deborah Salmond

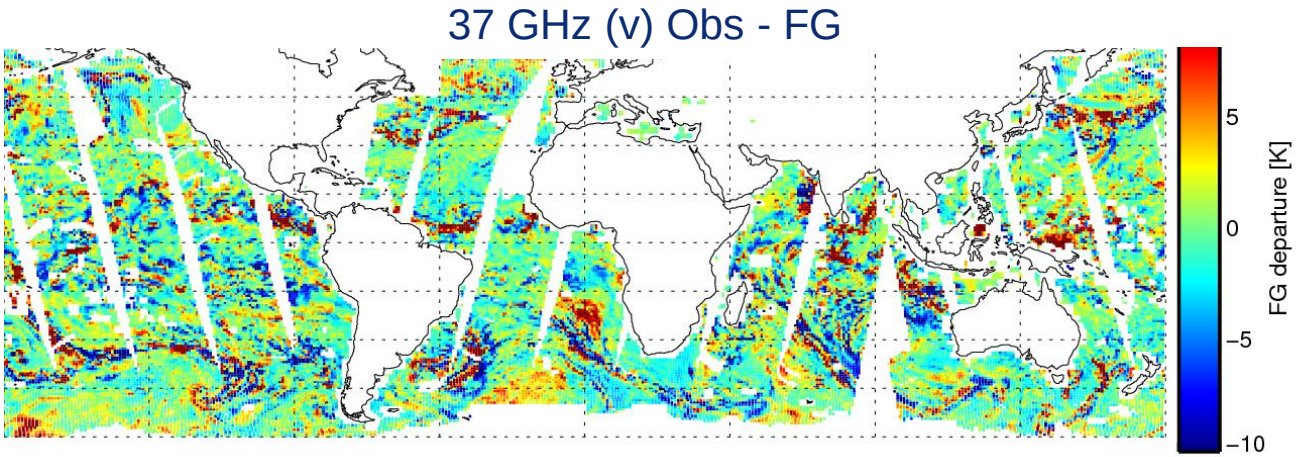
European Centre for Medium-Range Weather Forecasts

Reading, Berkshire, UK

Microwave imager ‘all-sky’ approach







In global Numerical Weather Prediction (NWP) systems, satellite observations provide 90-95% of the actively assimilated data. However, over 75% of satellite observations are discarded due to cloud contamination and unknown land, snow and sea-ice surface emissivity. Cloud-affected data is difficult to deal with because of the limited accuracy of moist physics parameterizations in numerical models and the need to model radiative transfer through clouds and precipitation.

Errico et al. (2007, JAS, 65, 3348-3350) summarise the most important issues related to the assimilation of cloud and precipitation observations. One prominent problem is the non-linearity (and non-continuity) of models, i.e. the sensitivity of the parameterizations to input parameter perturbations is strongly state dependent. This can cause data assimilation systems to produce erroneous analysis increments in model state variables affecting balance and stability.

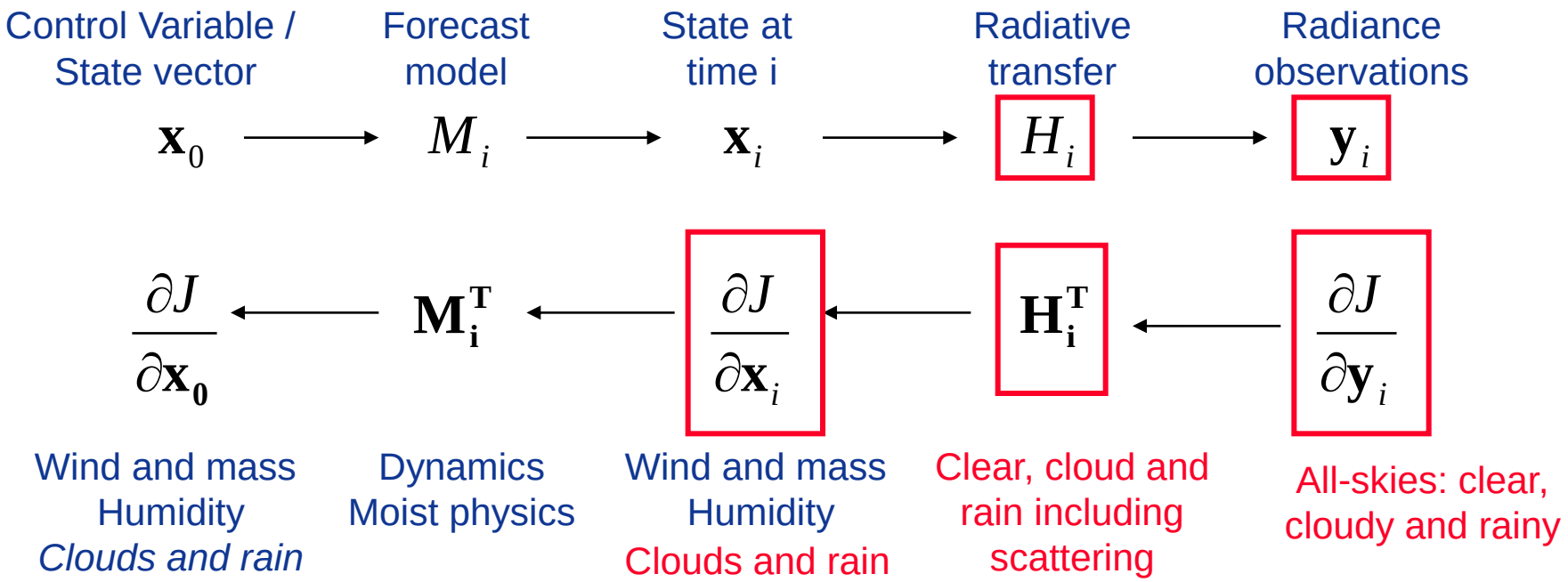
Moreau et al. (2003, QJRMS, 130, 827-852) and Bauer et al. (2006, QJRMS, 132, 2277-2306) have shown that for global models it is preferable to assimilate microwave radiances rather than rain rates because:

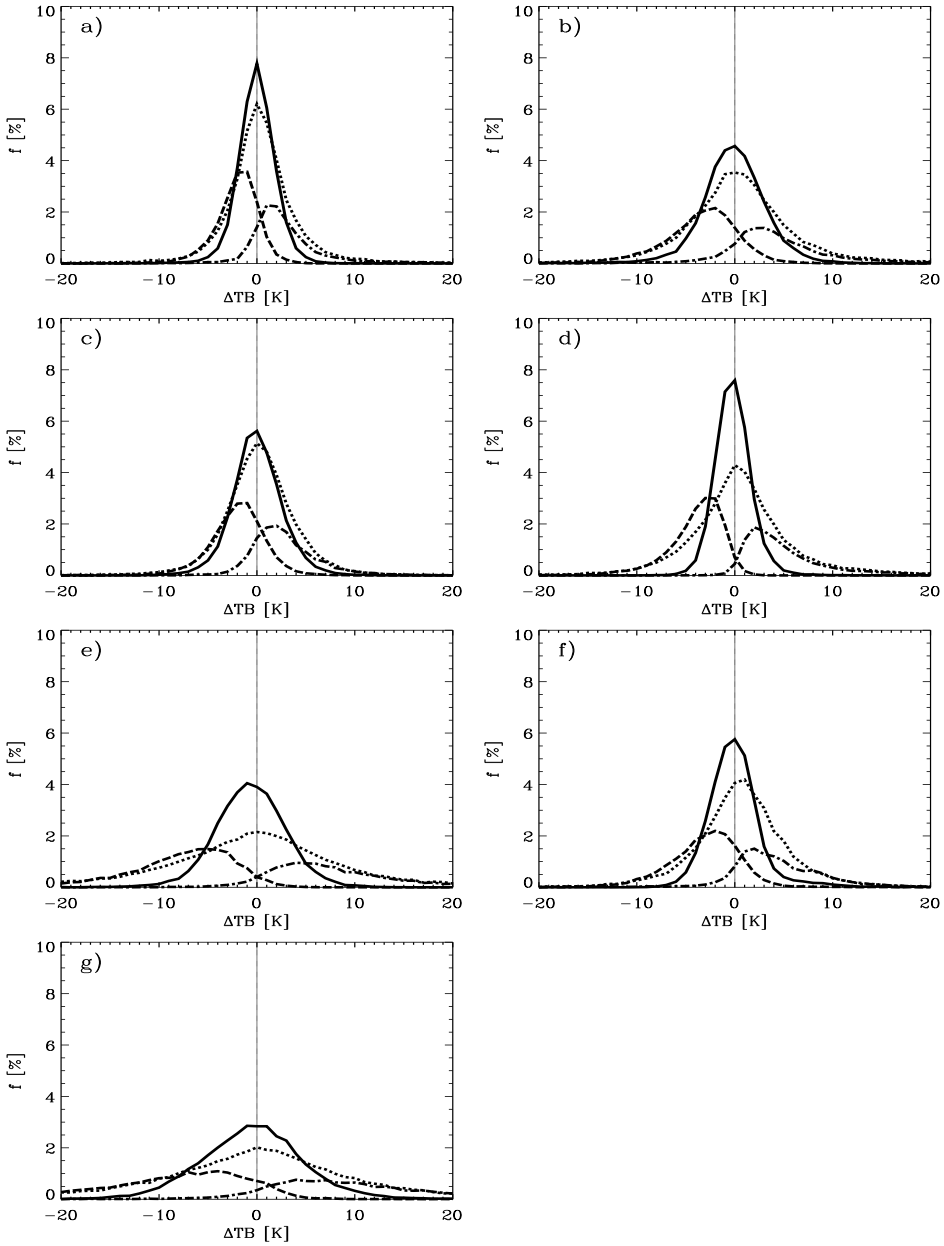
- the observation operator always produces non-zero gradients (in the absence of signal saturation) whether a scene contains clouds or not;
- an observation operator which combines moist physics and radiative transfer model behaves more continuously over its dynamic range than does moist physics alone;
- the statistics of observed-minus-modelled radiance departures have mostly Gaussian characteristics, and this also facilitates bias correction;
- observation operator errors can be derived from spatial departure covariance statistics.

Bauer et al. (2010, QJRMS, submitted) and Geer et al. (2010, QJRMS, submitted) describe improvements in the use of microwave satellite observations in the ECMWF forecasting system. Since March 2009, the operational system has assimilated all-sky microwave radiances directly into 4D-Var.

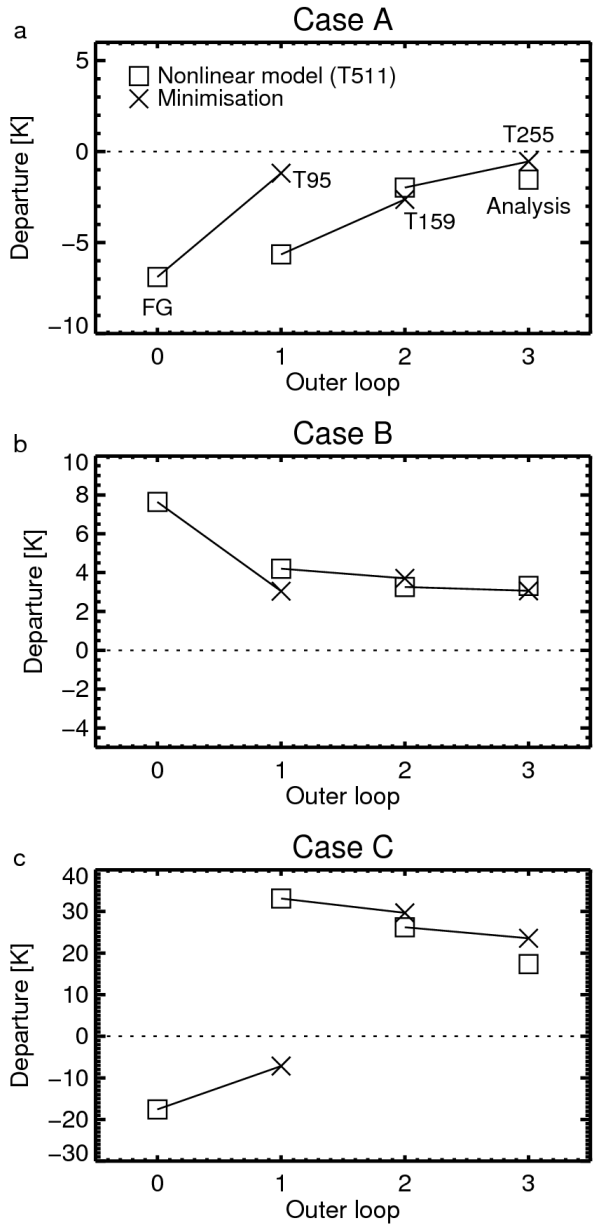
All-sky radiance assimilation:

- direct radiance assimilation over ocean only;
- no spatial interpolation – observations super-obbed to grid points, operators (moist physics and radiative transfer model) applied at grid-point locations;
- "all-sky" – all observations (clear, cloudy, rainy) assimilated through the same operator:
  - this gives balanced sampling,
  - and allows to create/dissipate/modify clouds similarly.





Histograms of SSM/I first-guess radiance departures for samples where both model and observations contain clouds (dotted) or only clear-sky (solid), where the observations contain clouds but the model is cloud-free (dash-dotted) and vice versa (dashed) for channels 19v (a), 19h (b), 22v (c), 37v (d), 37h (e), 85v (f), 85h (g). Data drawn from a 12-hour assimilation on 15 September 2007 00 UTC.



Linearity – single observation test:

- **A**: Convection in the inter-tropical convergence zone (ITCZ): model has too much rain compared to the observation.
- **B**: Mid-latitude cold front: model has too little moisture and cloud.
- **C**: Convection in the ITCZ: a near neighbour to case A, but chosen to illustrate a situation with poor minimisation quality.

SSM/I channel 19v first guess departures through the 4D-Var minimisation for single-observation test cases A, B and C using the all-sky approach. Squares indicate departures calculated using the nonlinear T511 forecast model in the `outer loop'; crosses indicate the departure at the end of each minimisations or `inner loop', calculated using the incremental method.

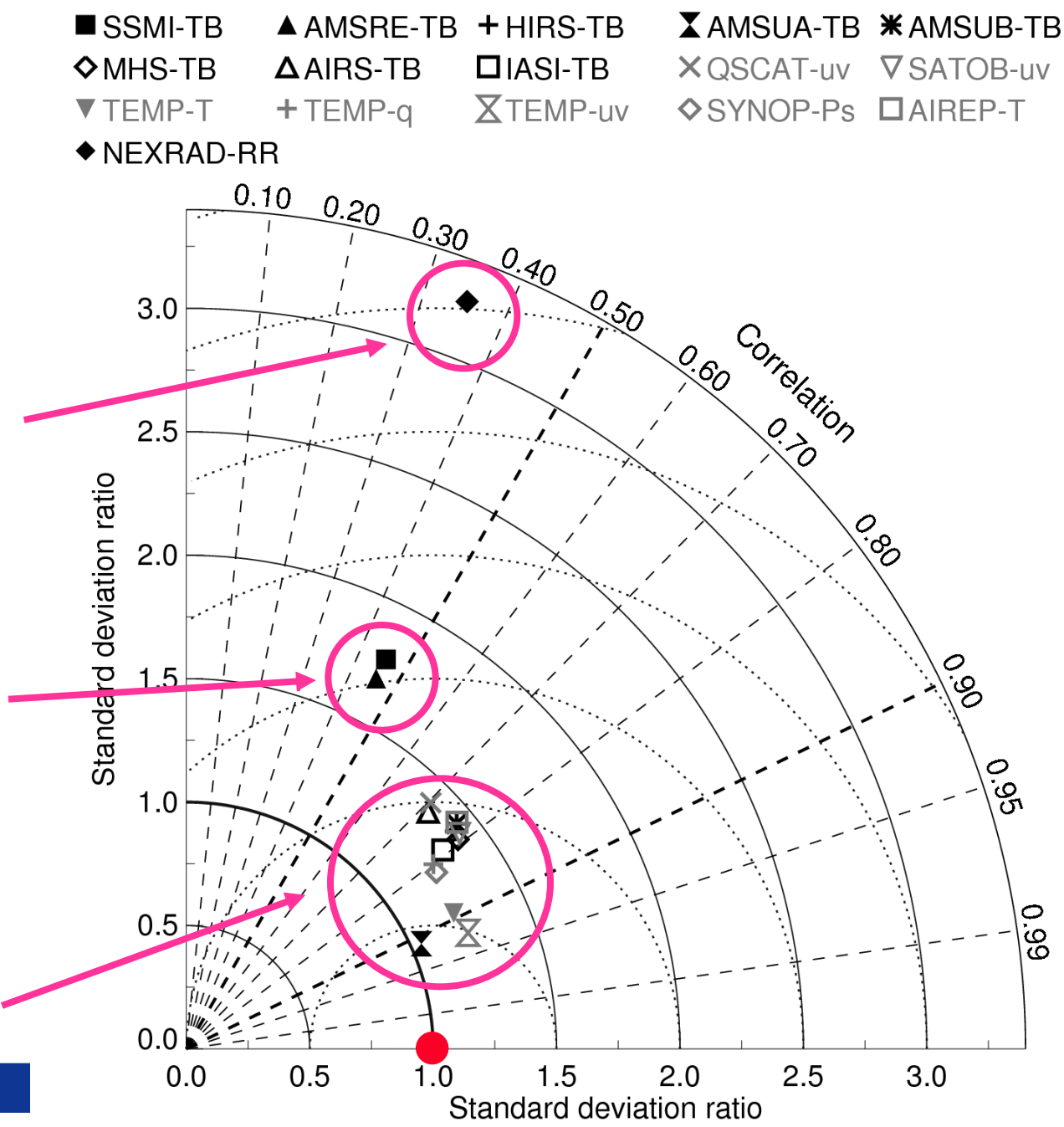
Linearity - full system

Non-linear vs. linear departures in first inner-loop

Rainfall radar (research only)

All-sky microwave imagers

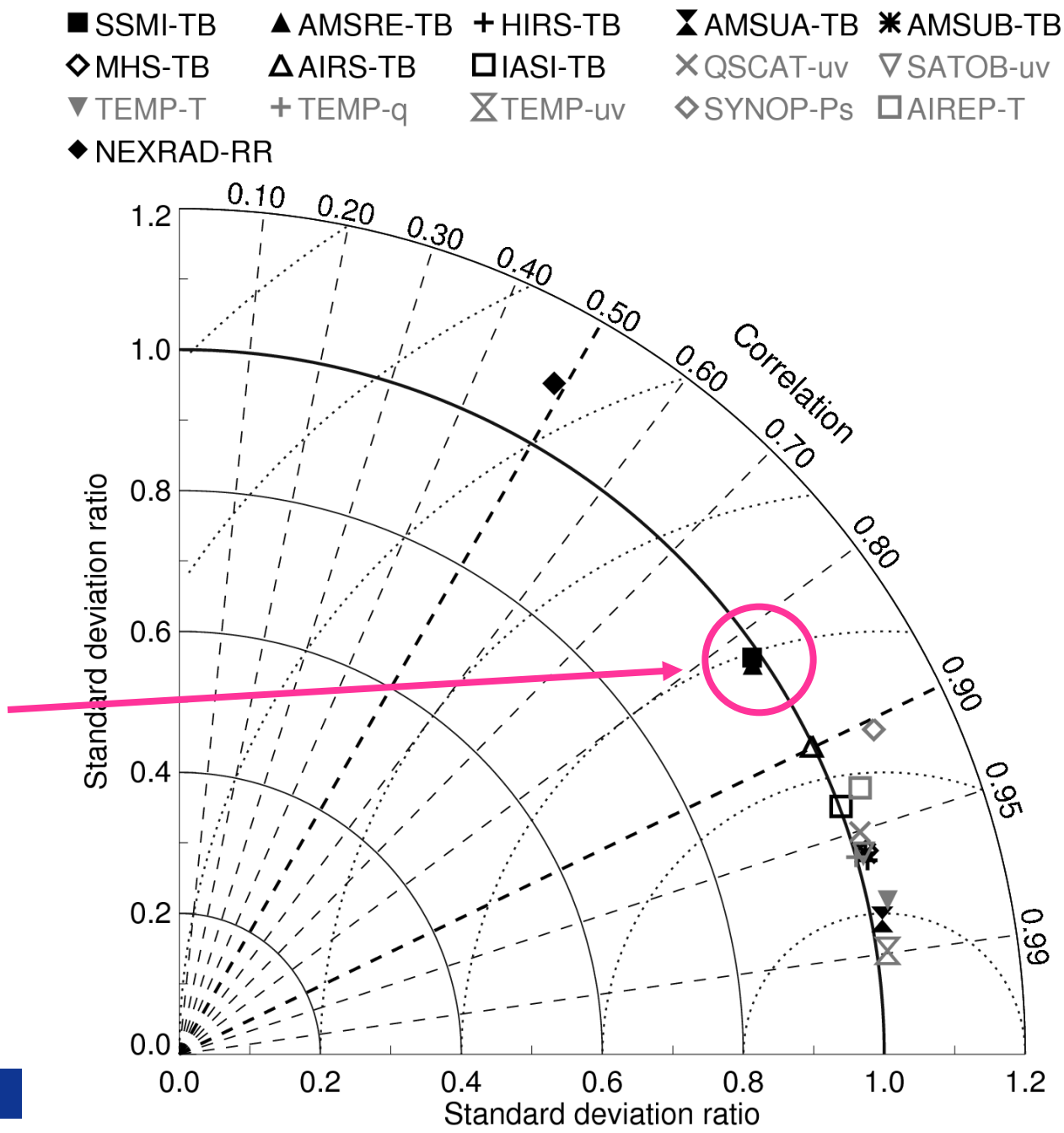
Clear-sky satellite and conventional



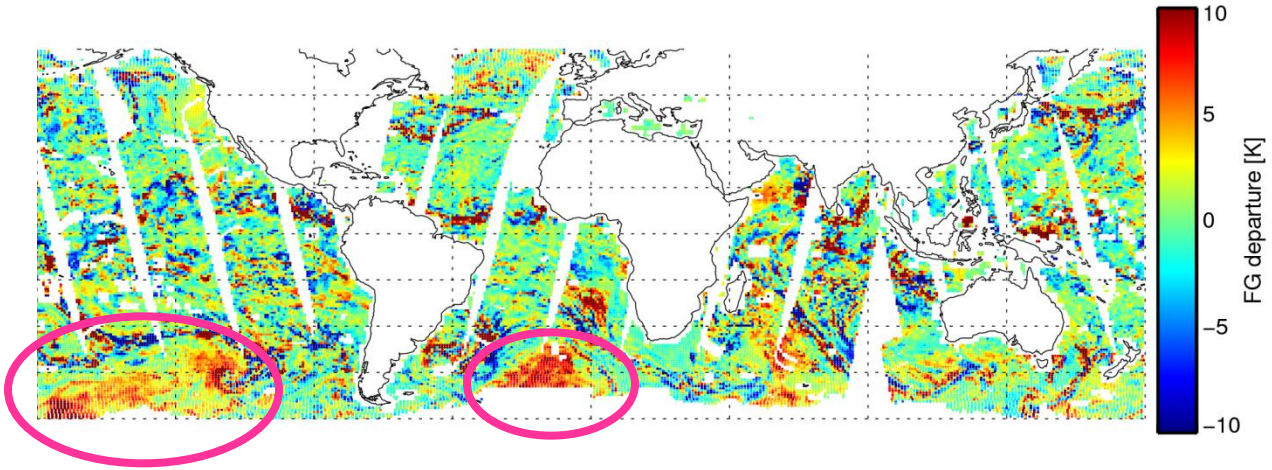
Linearity - full system

Non-linear vs. linear departures in last inner-loop

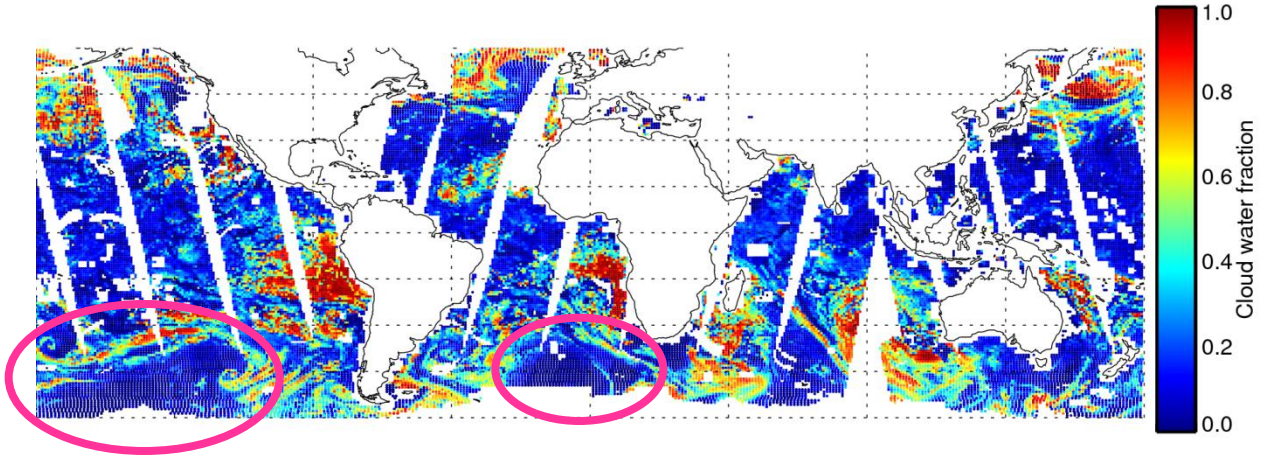
All-sky microwave imagers



NWP model biases – Example: cold sectors

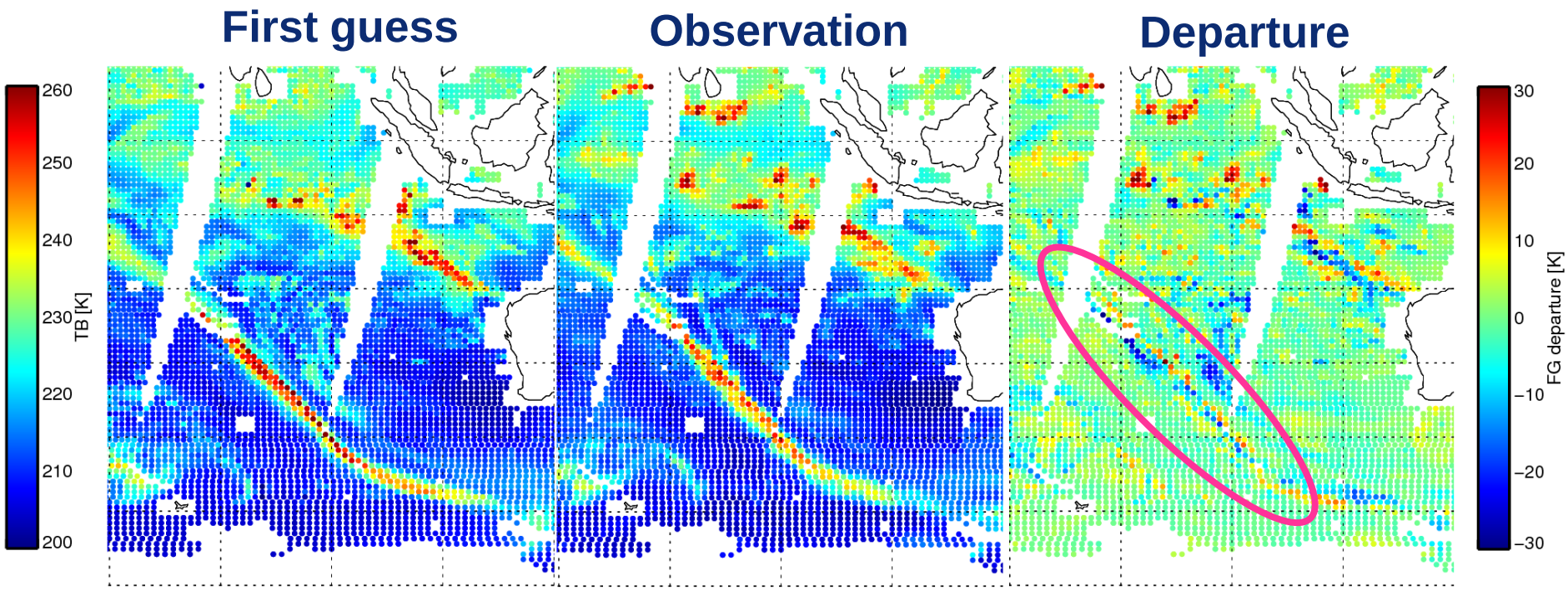


Mean SSM/I channel 37v first-guess departures (1st July 2009)

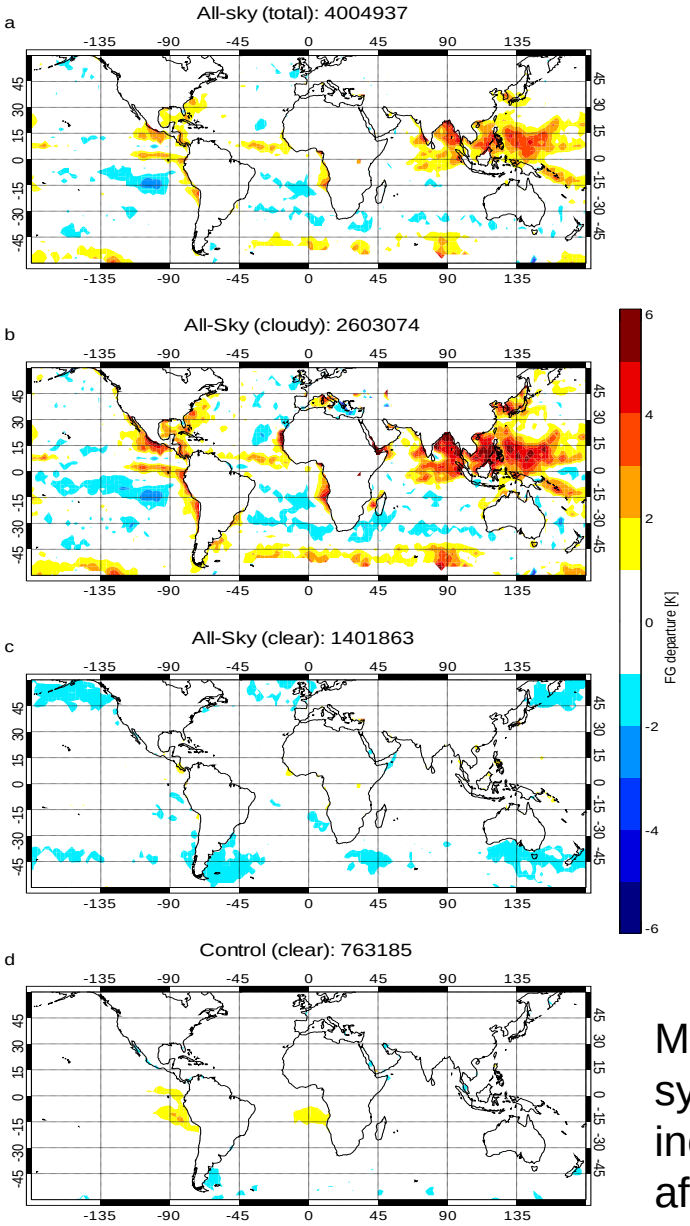


ECMWF model cloud liquid water fraction, (liquid + ice)/total

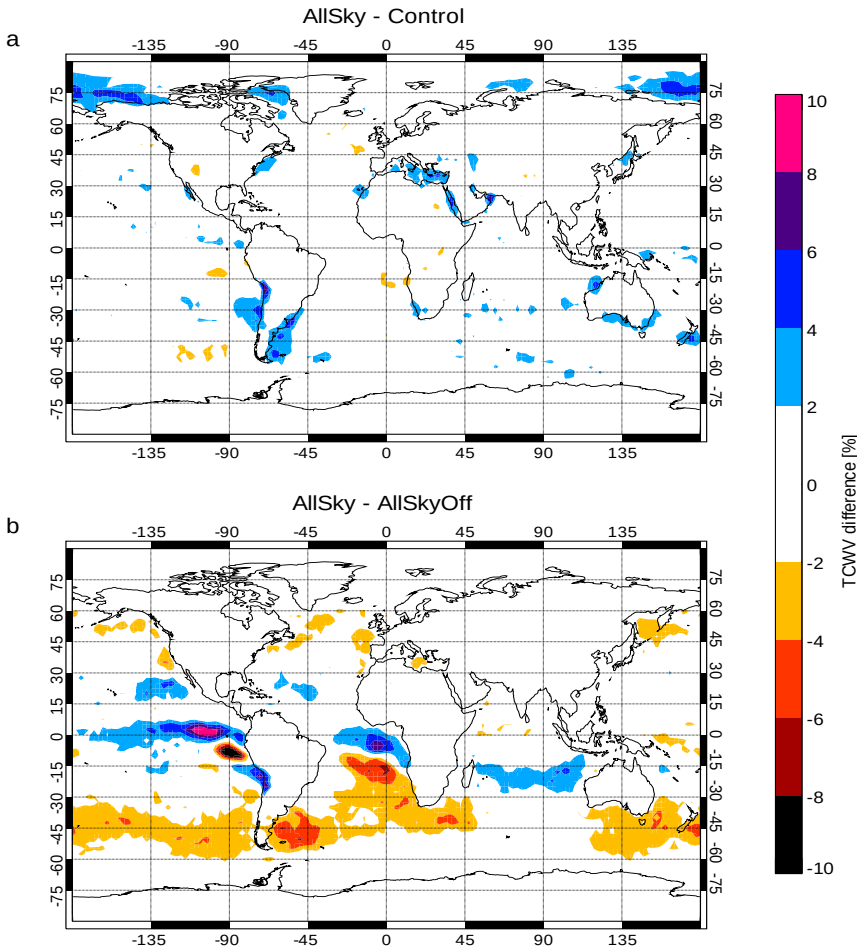
NWP model biases – Example: location/width of fronts



Mean SSM/I channel 37v radiance departures

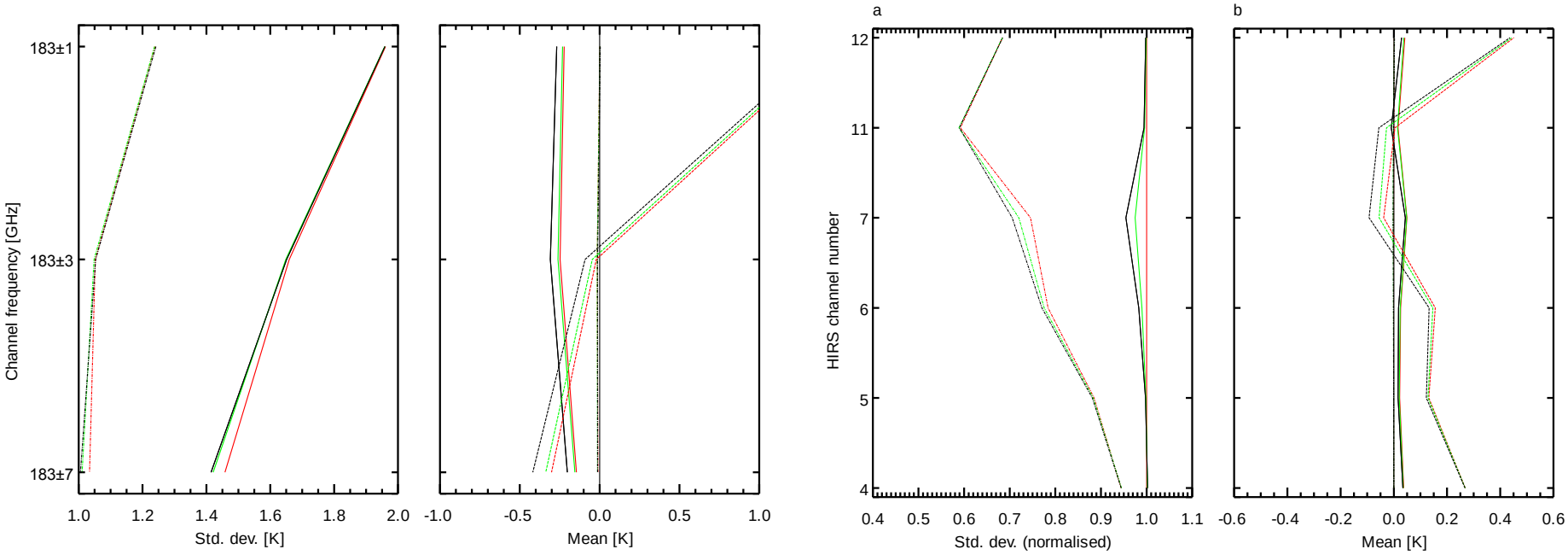


Mean TCWV increments



Mean SSM/I channel 37v first-guess departures highlight systematic model cloud deficiencies. The mean TCWV increments show that the moisture climate is similarly affected by 1D+4D-Var (Control) and the all-sky system.

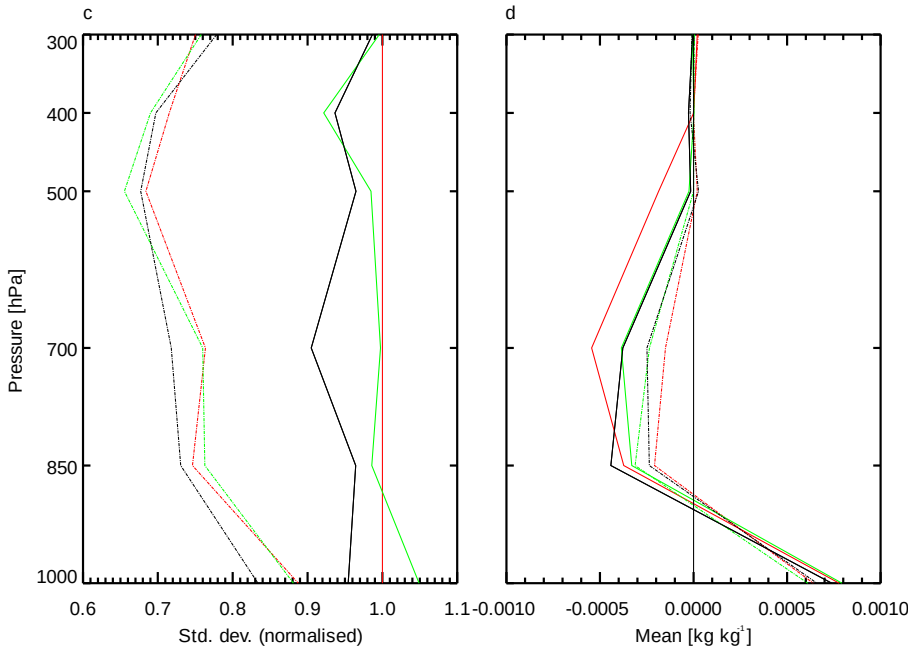
Impact verification - satellites

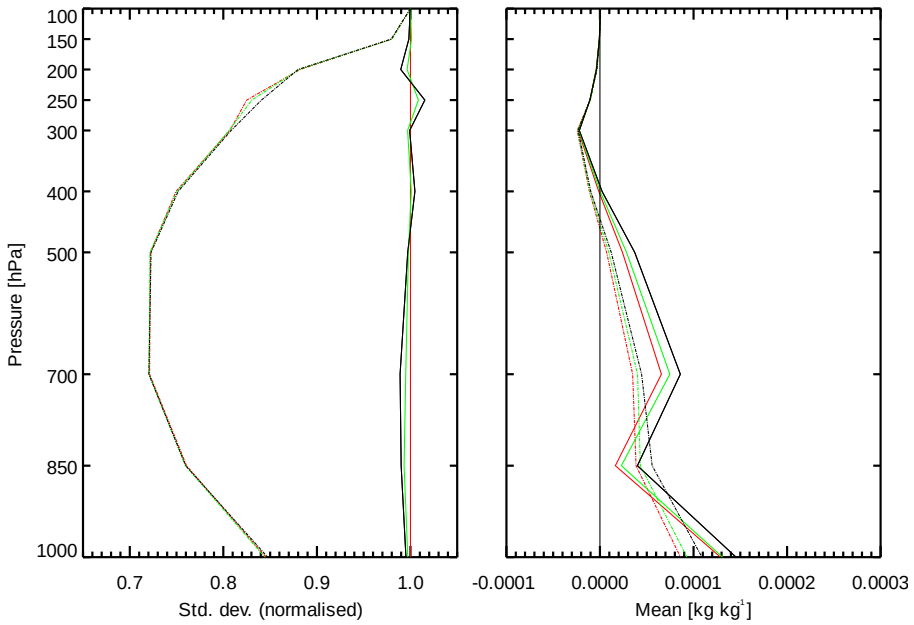


Verification of short-range forecasts (solid) and analyses (dashed) against MHS (left) and HIRS (right) radiance observations over period 1 July-31 October 2009:

- no microwave imagers
- 1st version of all-sky system
- revised version of all-sky system

Impact verification - sondes





Verification of short-range forecasts (solid) and analyses (dashed) against drop-sonde (left) and radio-sonde (right) observations over period 1 July-31 October 2009 (standard deviations have been normalized with 'no-imager values'):

- no microwave imagers
- 1st version of all-sky system
- revised version of all-sky system

Summary:
The all-sky microwave imager radiance assimilation system operated at ECMWF since March 2009 applies a unified observation operator to clear-sky, cloud and precipitation affected radiances. It mostly constrains moisture analyses and short-range forecasts over the oceans and improves the fit to other moisture-sensitive instruments such as HIRS, MHS, drop and radio-sondes. Despite initial concerns, operator linearity, Gaussian error statistics, and minimization performance were similar to a system with clear-sky observations. The main outstanding issues with clouds and precipitation are systematic NWP model biases and a better specification of model background error statistics in these conditions.

Operational implementations:
- June 2005 – Operational 1D+4D-Var of rainy/cloudy SSM/I
- June 2008 – Addition of AMSR-E and TMI to 1D+4D-Var
- March 2009 – All-sky direct 4D-Var of SSM/I and AMSR-E
- September 2009 - Direct assimilation of selected cloudy scenes from IR radiances (AIRS and IASI) – with cloud as a sink variable

Forthcoming changes:
- Autumn 2010 – All-sky upgrade: Complete revision of observation handling, errors, bias correction, and quality control, using a “symmetric total error” approach

In research:
- Extension to MHS and AMSU-A, infrared radiances; radar rain-rate assimilation.