Land Data Assimilation for operational weather forecasting

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- An overview of the Current Land Analysis and Climatologies
- Satellite estimates of soil moisture
- Recent Impact Trials
- Current & Future Developments
- Conclusions

Land Surface Requirements

Unified Model incorporates the JULES land surface exchange scheme. Consequently a range of satellite / in situ blended fields are required.

Climatologies: Leaf Area Index (AVHRR/MODIS)

Snow Free Albedo (MODIS)

Routine Analyses:

Snow Analysis (Northern Hemisphere – snow cover obs from NESDIS satellite vis & mw)

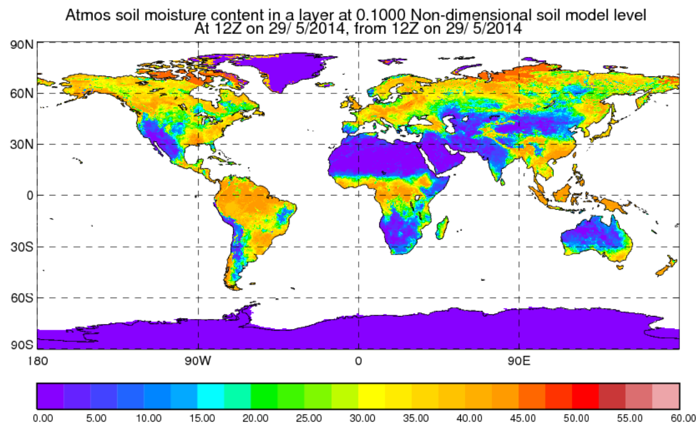
Soil moisture Content (satellite & in situ)

Soil Temperature (satellite & in situ)

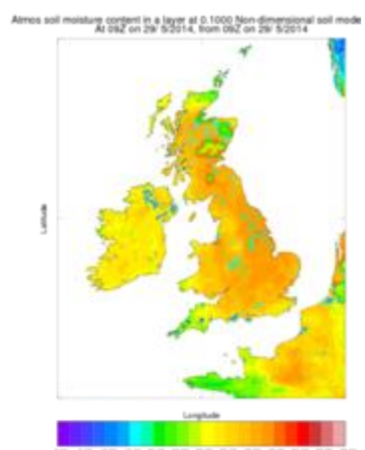
Priorities (ECMWF, Land Surface Workshop 2009): soil moisture, soil temperature, snow, albedo, Leaf Area Index

Global & Convective Scale Models

• land analysis is performed at the global resolution [every 6 hours]



And interpolated to the various regional models, conserving plan water stress (so-called equal beta method) [daily]



4 Soil levels down to depth of 2m

Progression of land analysis methods for soil moisture

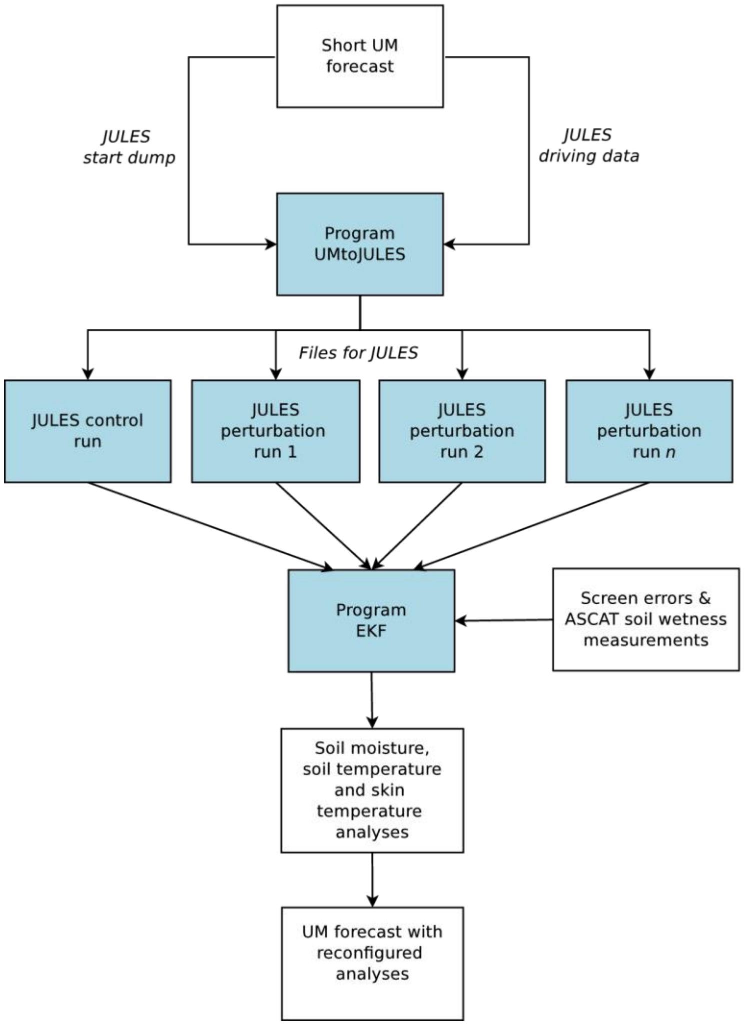
- Reset land to externally available climatologies
- As above but climatology created via offline land model driven by in situ observations (JULES + WATCH forcing data)
- Simplified Nudging scheme (simplified physics to diagnose error in soil moisture from model errors at screen level)
- Optimal Schemes: Kalman Filter based system. Main benefits
  - ability to use more satellite observations (passive and active microwave, Land Surface Temperature,…)
  - Take advantage of developments in atmospheric DA (observation error background error diagnosis,…)

Extended Kalman Filter scheme [EKF]

- Our main analysis tool providing analyses of soil moisture and soil temperature from surface to 2m depth
- Current driving observations are screen observations of humidity and temperature & remotely sensed soil moisture from the active ASCAT instrument on Metop A & B
- We aim to use realistic observation and background errors (based on comparisons with insitu soil moisture networks)
- Jacobians are computed from the JULES model via finite difference (as we have no access to an adjoint model of JULES)
- Horizontal error correlations are ignored.

Extended Kalman Filter scheme

- Jacobians are computed offline runs of *JULES* – the land surface exchange scheme within the Met Office Unified Model.
- To do this we run one unperturbed run of the land-surface model and one perturbed run per control variable (soil moisture on 4 levels + 1 skin temp + 4 soil temp = 9 perturbed runs).
- This potentially allows increments arising from satellite derived soil moisture to update in deeper levels as well as at the surface.
- The length of perturbation runs have been set to 3 hours.



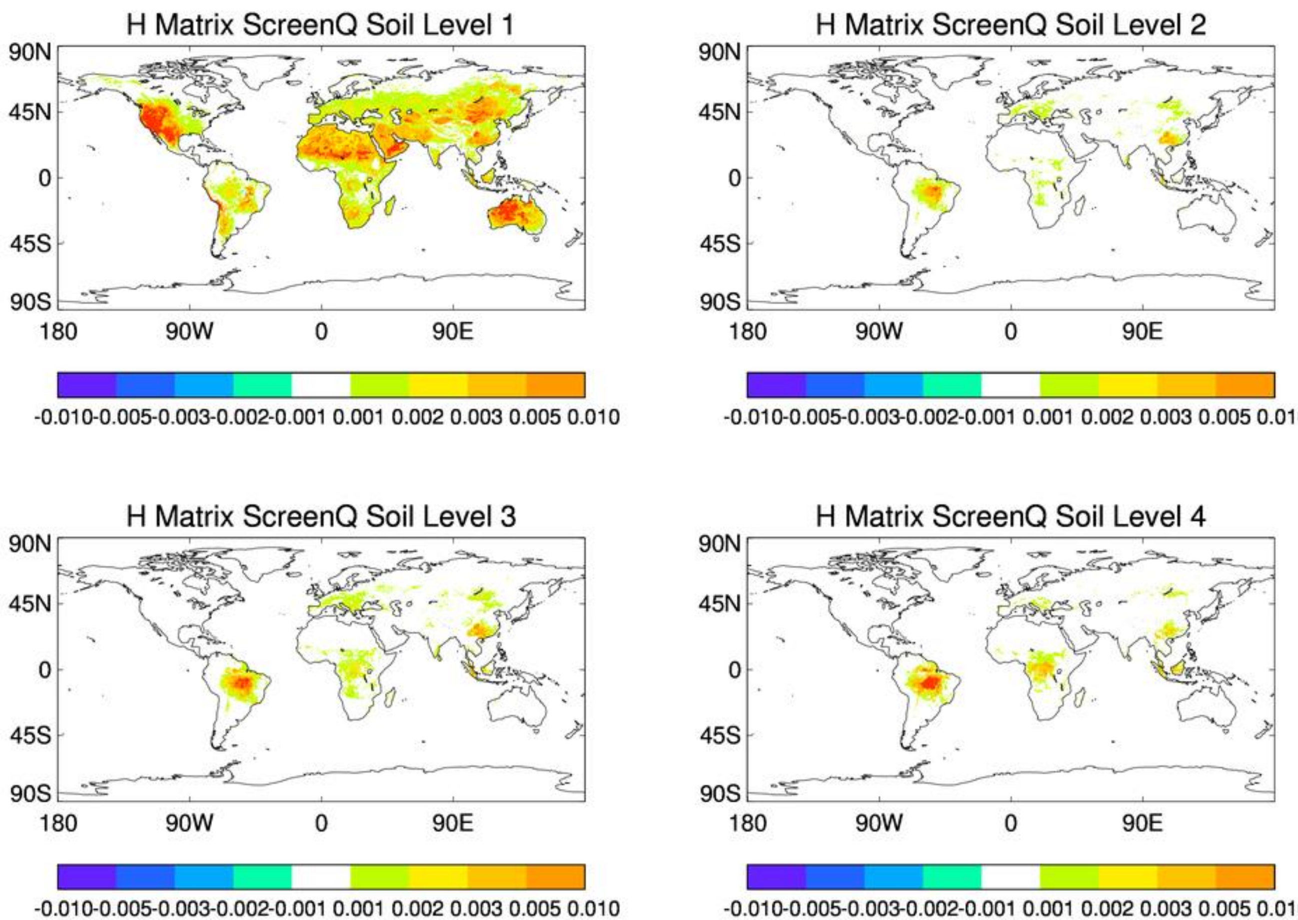
Jacobians – monthly means mid Aug- mid Sept

dscreenQ/dsm or soilmoisture sensitivity to Screen Humidity

Midday

Connection to deep layers via evapotranspitation

Too strong over bare soil at night?



Use of ASCAT soil wetness product (1)

- C-band Scatterometer. Principle of operation uses change in surface reflectivity through water effect on dielectric constant. N.B. there are other effects on the signal (surface roughness, vegetation interaction etc)

- Arrives in near real time from EUMETSAT with resolution of 12km [downscaled product also available at 1km from Hydrology SAF]

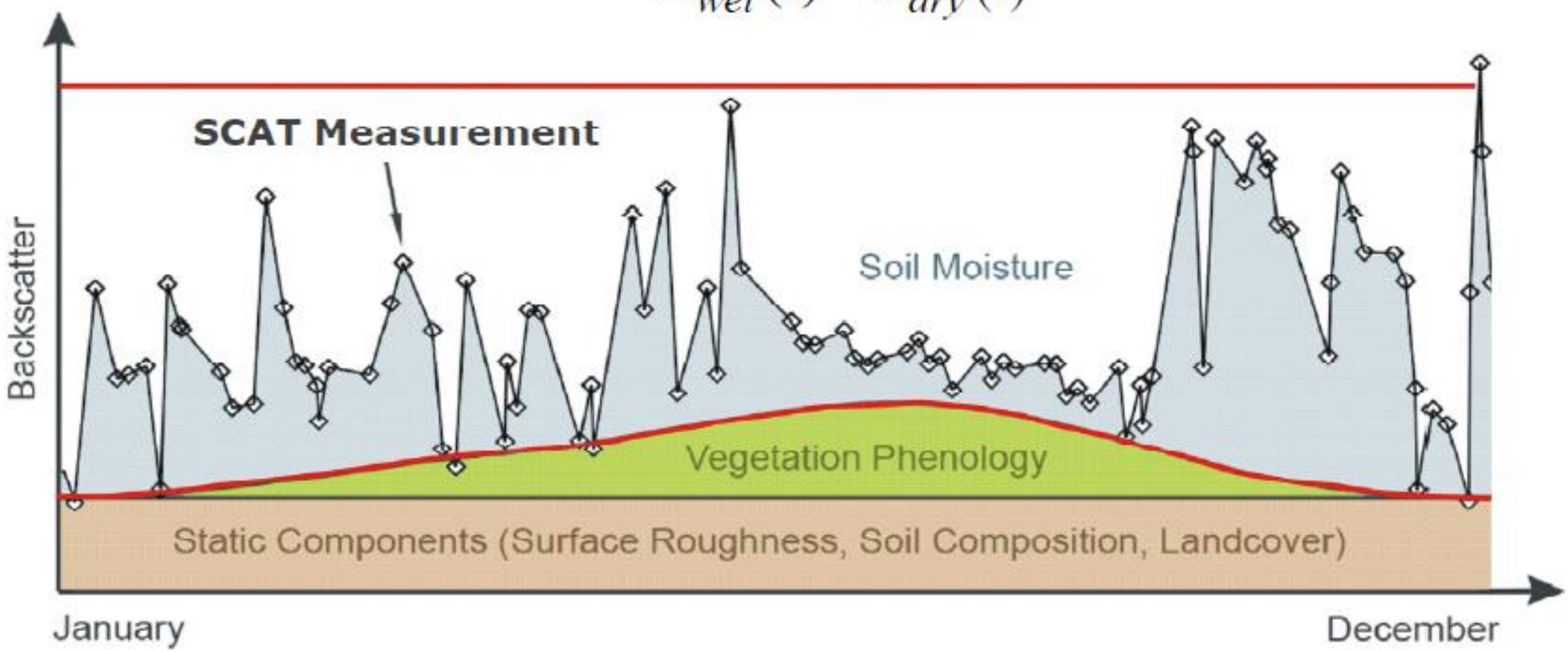
- Level 2 product: Conversion to Soil Wetness (0-100%) is performed at EUMETSAT

- Quality Control and conversion to soil moisture content applied prior to assimilation

Source: TUVienna

- Semi-empirical change detection Method
  - Accounts indirectly for surface roughness and land cover

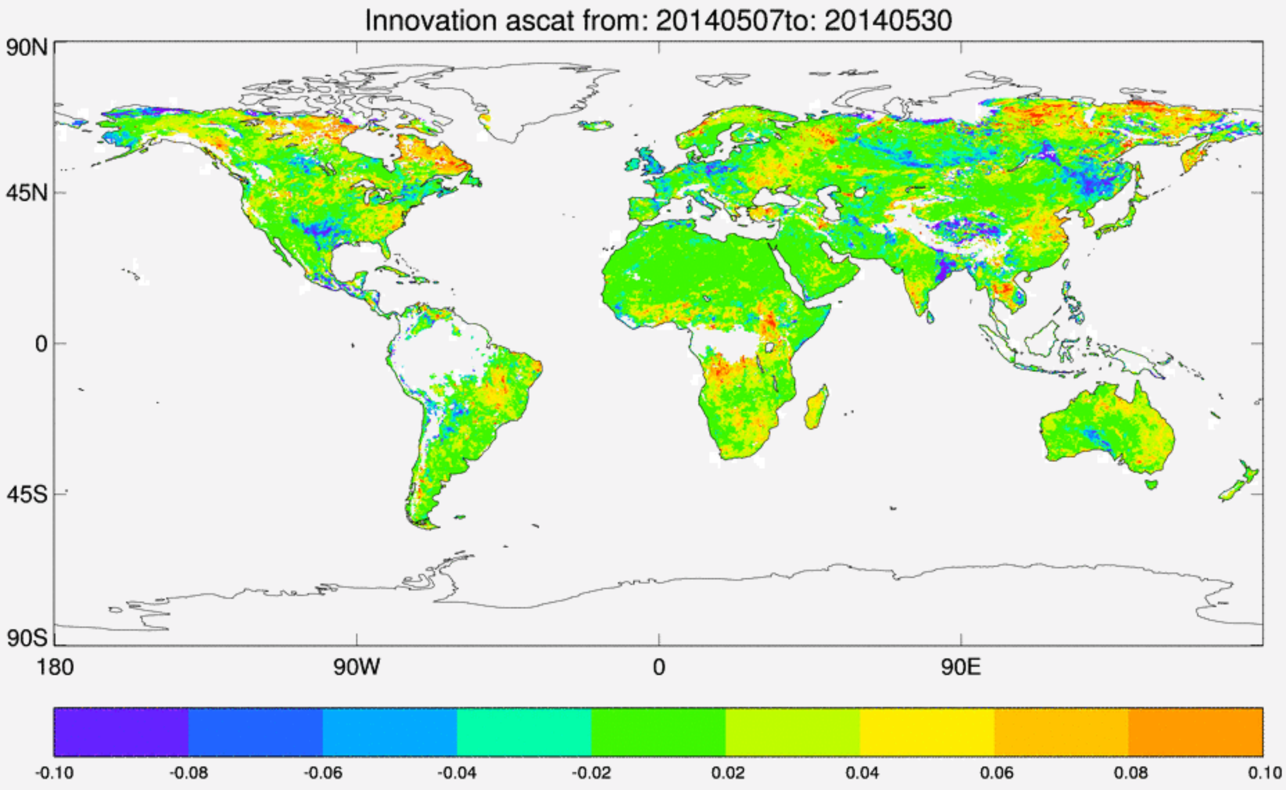
$$m_s(t) = \frac{\sigma^0(t) \quad \sigma^0_{dry}(t)}{\sigma^0_{wet}(t) - \sigma^0_{dry}(t)}$$



Use of ASCAT soil wetness (2)

Obs rejected over:

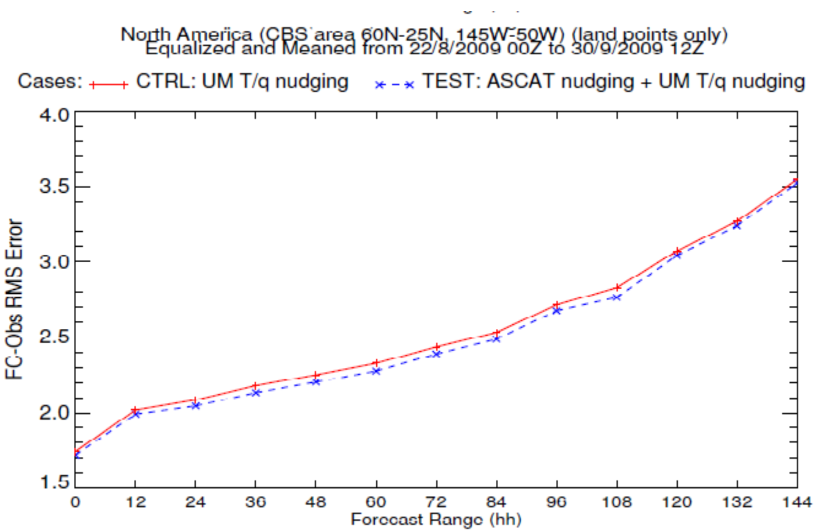
- **Significant vegetation**
- **Complex orography**
- **Snow and ice**



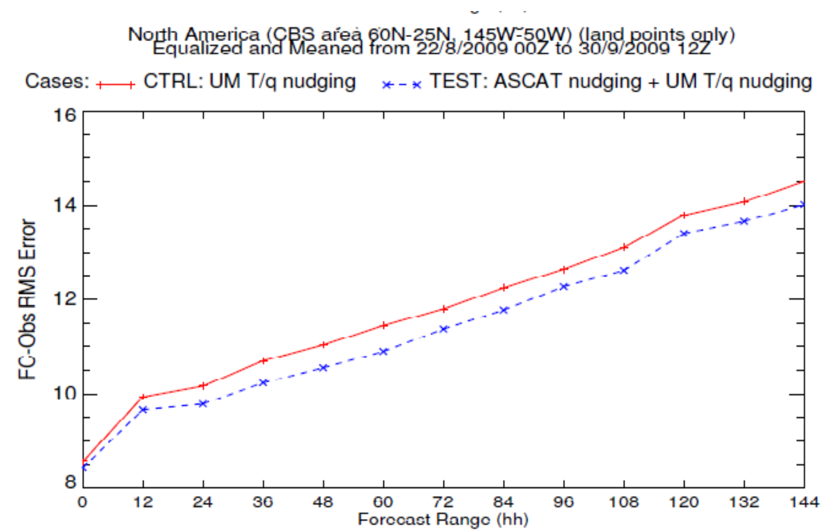
Use of ASCAT soil wetness (3) forecast impact.

positive benefit on forecasts of screen temperature and humidity for the tropics, north America and Australia. Impact on the global UM NWP index *neutral*

1.5 m Temp



1.5m Humidity



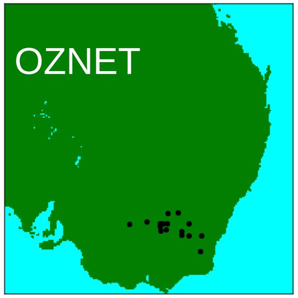
Source:Met Office NWP Tech Report #548 , available on line

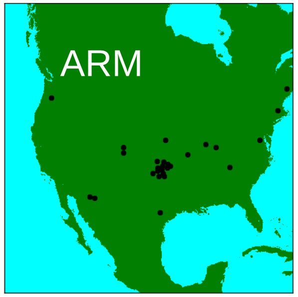
In addition to these forecast impacts we also examine the fit of the land analyses to independent observations and/ or satellite datasets of known quality

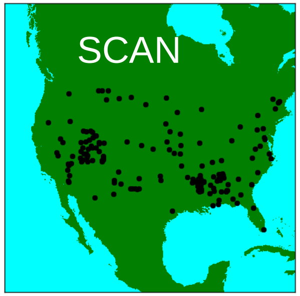
Determining Observation Errors – Triple Collocation

- Take three collocated estimates of the same parameter (e.g. soil moisture at level 1). If the estimates are *independent* then the errors can be determined from the variances
- Insitu data has been used for this work – extracted from networks shown (courtesy International Soil Moisture Network)
- SMOS data is level 2 retrievals with additional qc (avoiding significant vegetation, frozen soil)

The results here used data from summer 2012. Both satellite products have gone through updates in the previous year and this is reflected in an observed improvement compared with earlier results







parameter	Error m3/m3
ASCAT (version2)	0.035
SMOS (v501)	0.041
SCAN Station	0.036

Potential Improvements to the operational EKF

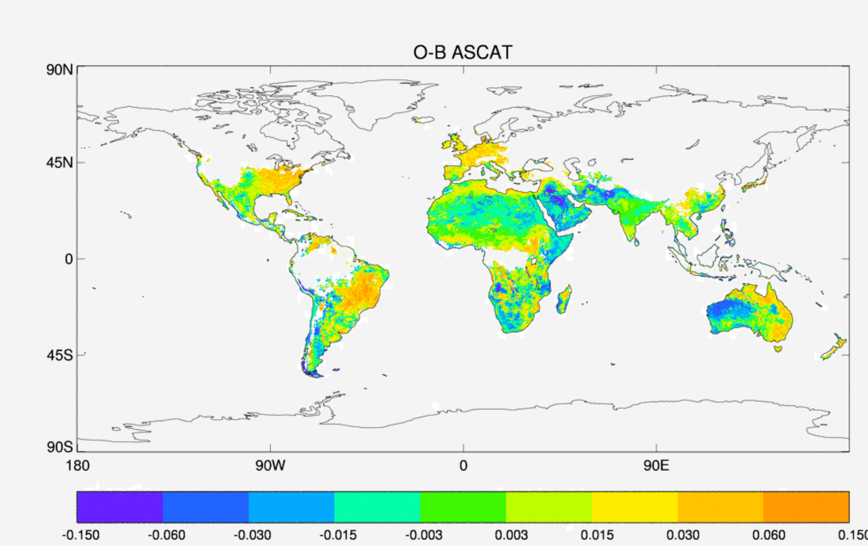
Met Office

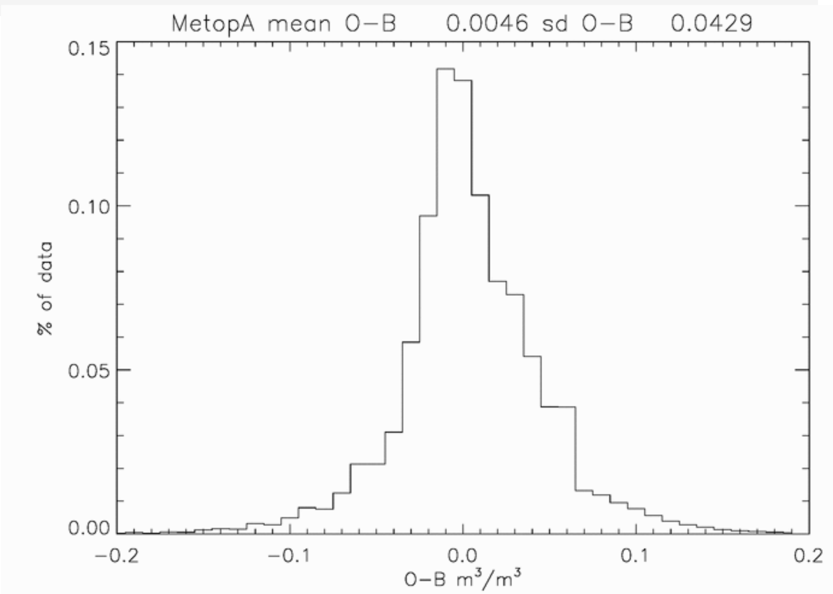
EKF operational for 14 months. The following developments have been tested to go live this year

1. Switch on second ASCAT instrument [MetopB products available since late 2012]
   - Principally robustness…
2. Review observation and Background errors.
3. EKF quality control. (legacy QC) Only use screen observations where the innovation signs are opposite.
   - O-B T +, O-B Q - (soil moisture too moist)
   - O-B T -, O-B Q + (soil moisture too dry)

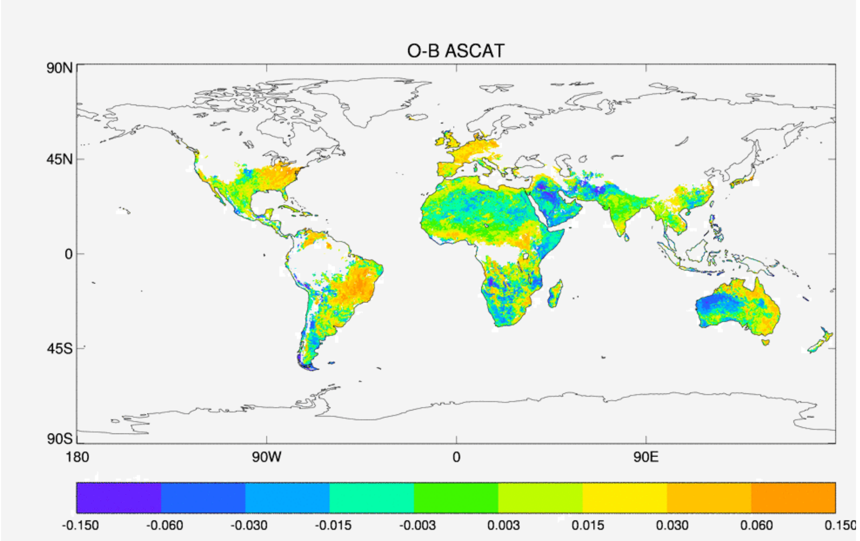
ASCAT instruments compared

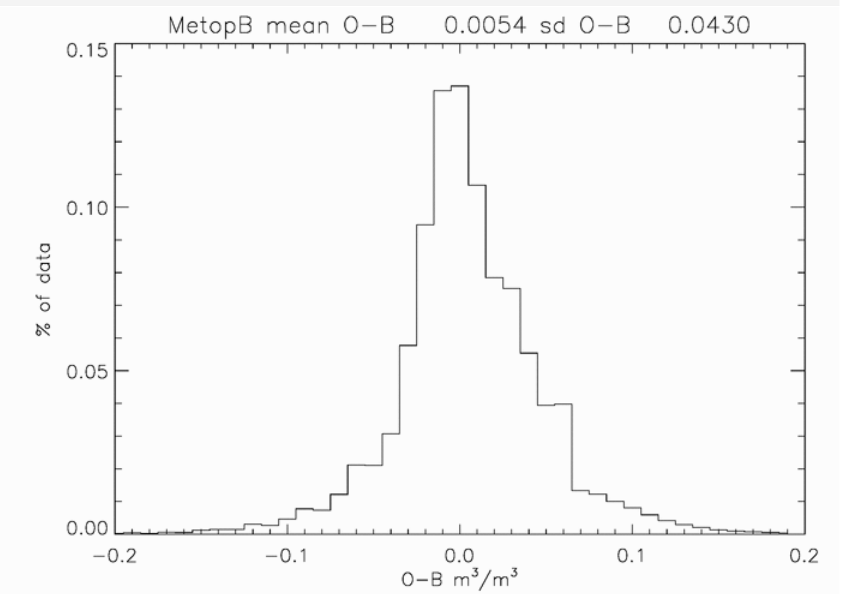
MetopA





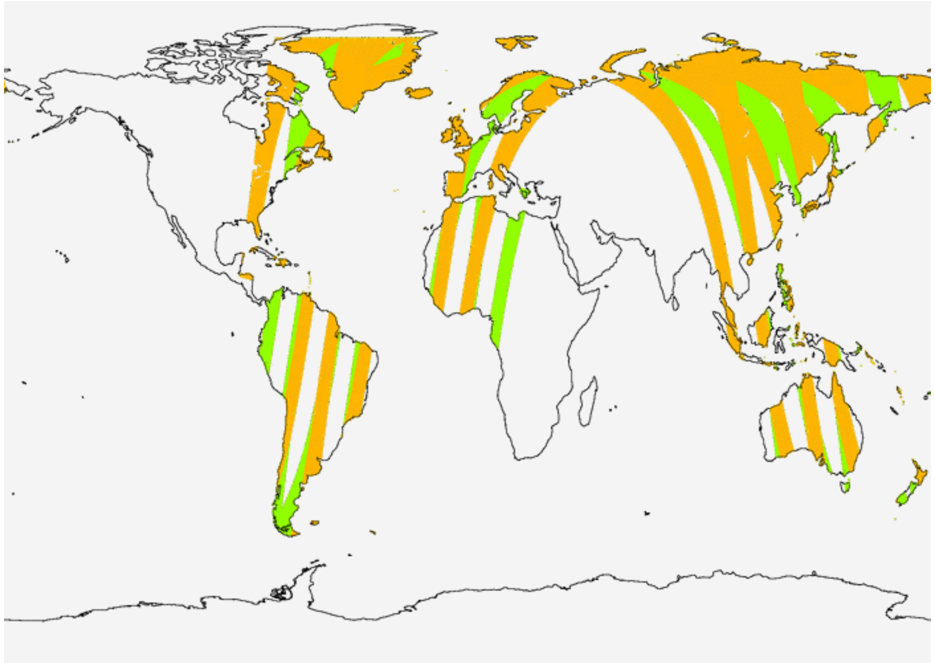
MetopB





Spatial extent of second satellite

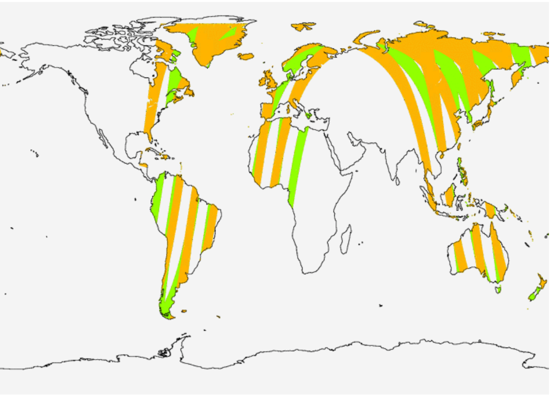
- Metop-B is on same orbit track 50 minutes behind Metop-A

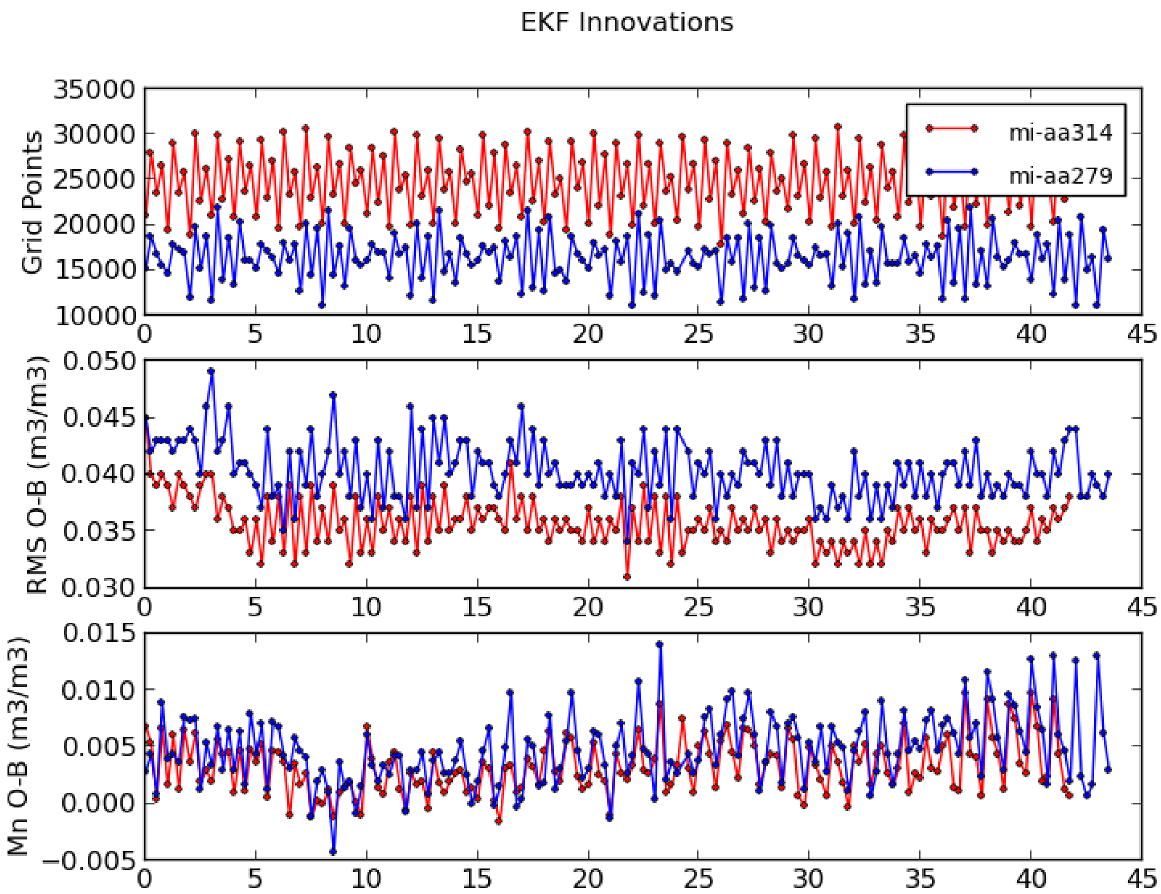


6 hours of data

Trial Results – Summer 2013

ASCAT Observation-Background



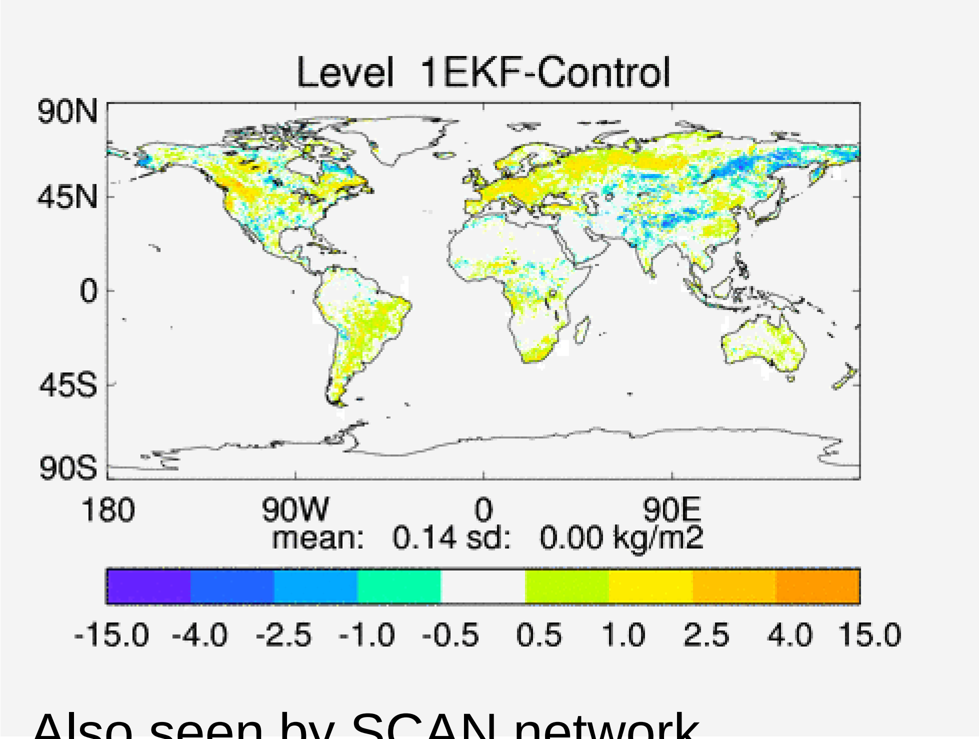


Red upgrade

Blue control

Analysis differences- Summer 2013

- Moister level 1 (10cm)

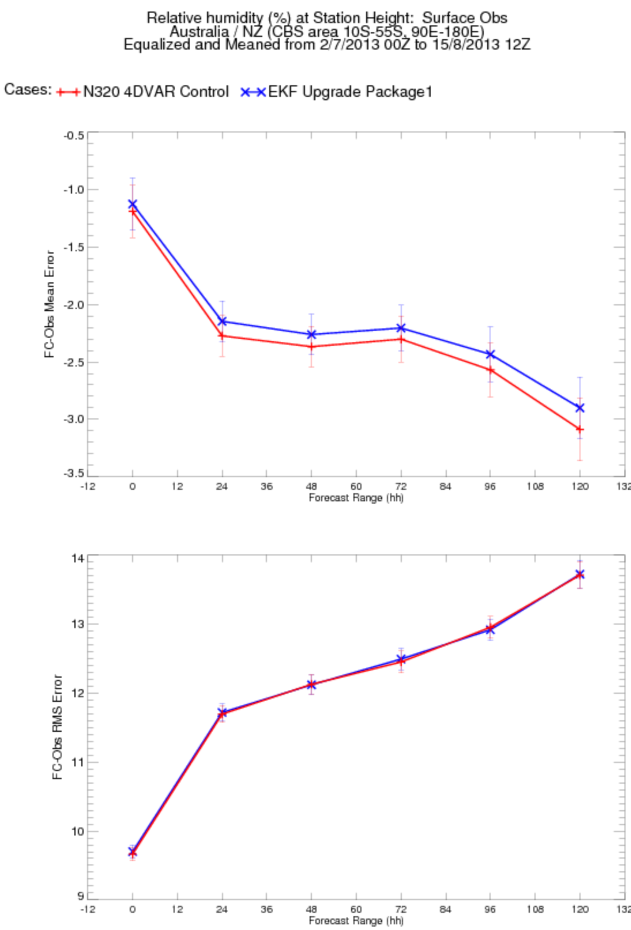


- Also seen by SCAN network

Experiment	Nstns passing QC	Correlation coefficient	Mean (station-model) m3/m3	SD (station-model) m3/m3
Control	61	0.55	-0.046	0.039
Upgrade	63	0.55	-0.053	0.039

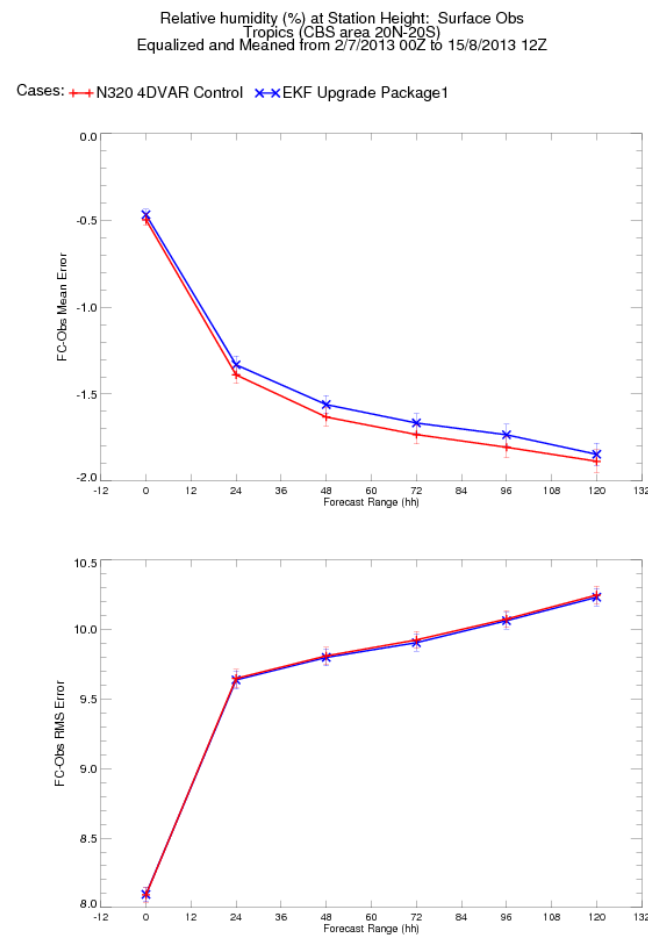
Forecast Impacts – Summer 2013

Australia



68% error bars calculated using $S/(n-1)^{1/2}$

Tropics



68% error bars calculated using $S/(n-1)^{1/2}$

Future Improvements (1) – Convective Scale

- Adapt EKF to run in Convective Scale UK model
- Initially 2 analyses per day
- Take advantage of additional screen observing networks over the UK domain. Also model specific background errors
- Need for high spatial resolution satellite soil moisture product -test bed for SAR products?

Future Improvements (2) – Additional Satellite Observations

- Test sensitivity of ASCAT impact to different methods of conversion to soil moisture content. [CDF matching & improved UM soil moisture climatology]
- Update Soil temperature through assimilation of Land Surface Temperature. Several mature sources:
  - Land SAF split window product from geostationary
  - Via operational sounding processing of the IASI&CRIS instruments at the Met Office
- Comparisons with Cardington IR radiometer suggest night time IASI retrieval errors are ~1.5K.

Conclusions

- Currently in operations a Kalman Filter is used to provide estimates of soil moisture and is driven by screen level observations and satellite estimates from the active microwave instrument on the Metop series of satellites.
- A series of improvements have been trialled in the last 6 months. In particular it appears that 2 ASCAT instruments are better than 1. [or it might be that the ASCAT weight is too low in the analysis]
- Next steps are to extend use of satellite data to Land surface temperature obs and modify the analysis technique for use in the UK convective scale model.

Extra Slides

Determining Observation and Background Errors – Cross check with Desroziers Diagnostic

- The triple collocations provide useful estimates of errors. However we have assumed a) independent errors and b) results from regional networks are representative globally

$$(\sigma^b)^2 = \frac{1}{n}\sum_{i=1}^{n}(a-b)(o-b)$$

- Use Desroziers Diagnostic as a crosscheck. For an optimal system (e.g. VAR, Kalman Filter) where o-b , o-a are the ob-background and ob-analysis differences. 24 hours of ASCAT monitoring statistics show the following for 2011. The diagnostics are computed within *observation space* - Since ASCAT is principally sensitive to top layer moisture – we can obtain estimate for background error at this level.

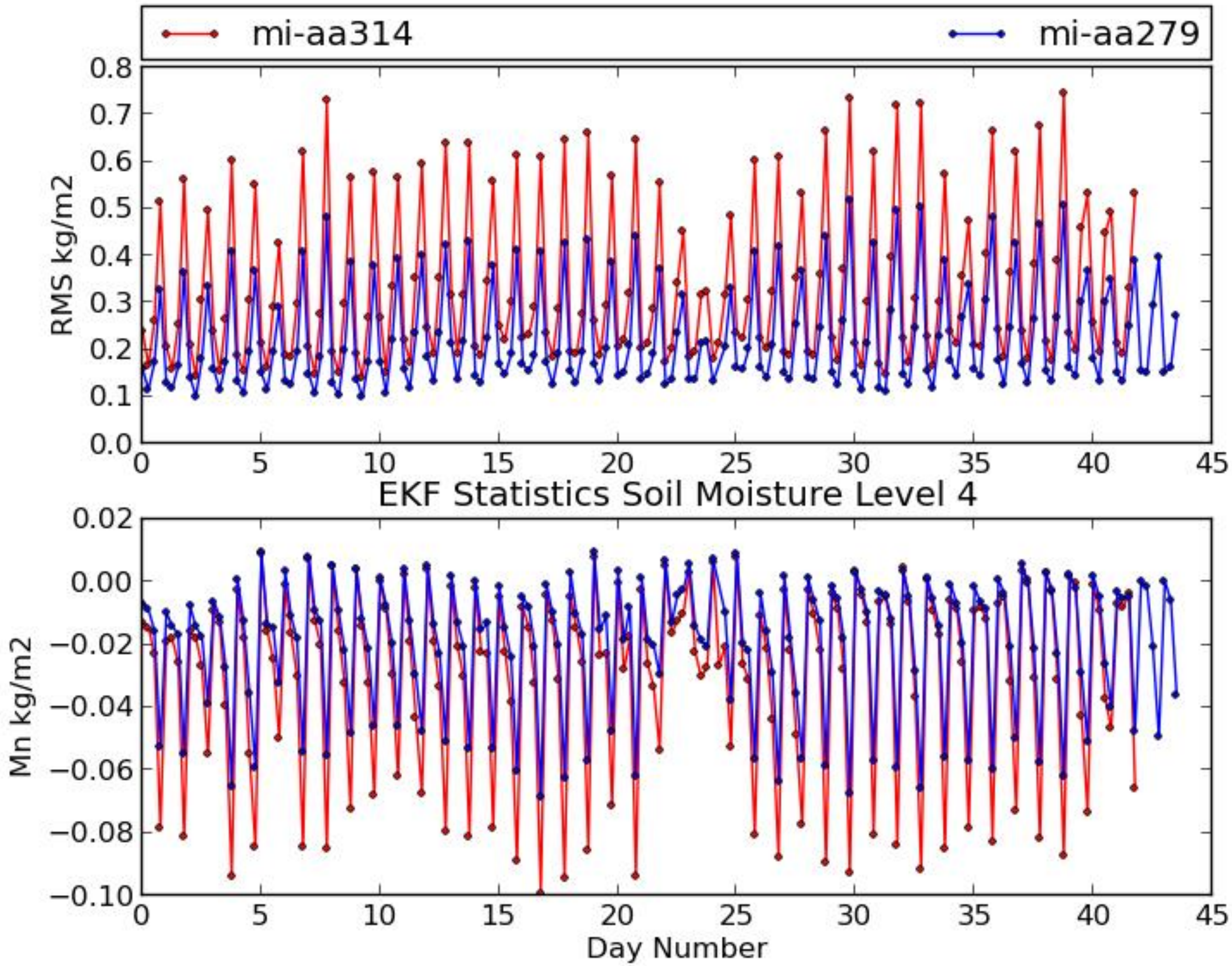
$$(\sigma^o)^2 = \frac{1}{n}\sum_{i=1}^{n}(o-a)(o-b)$$

$$\sigma^{ascat} = 0.041 m3/m3$$

$$\sigma^{b} = 0.031 m3/m3$$

- Very good agreement with triple collocations
- Future improvement: spatially dependent errors?

Summer 2013 increments



Red upgrade

Blue control

Background Errors for soil moisture

Met Office

Good estimate at the surface layer – based on *SMOS*, ASCAT and SCAN triple collocations. But difficult to determine for lower layers

Took 1 year of observations from each available network for 2011 and compared to NWP analyses. E.g. SCAN network:

Soil Level	Sensor depth	Nstns passing QC	Correlation coefficient	Mean (station-model) m3/m3	SD (station-model) m3/m3	Ratio SDleveli/SDlevel1
1	5 cm	33	0.61	-0.081	0.061	-
2	20cm	36	0.61	-0.082	0.051	0.84
3	50cm	30	0.62	-0.045	0.043	0.70

Other networks show similar stats – suggests that the errors at depth are lower. ~0.75 value of the surface value. Currently the operational EKF assumes smaller error.

How to compute H

H is an *m* x *n* matrix, where each row represents the sensitivity (*m*) or Jacobian for a particular observation type e.g. screen temperature. Each column (*n*) represents the sensitivity to a particular element of the analysis vector

$$\mathbf{H}_{m,n} = \frac{\partial H}{\partial \mathbf{x}} \approx \frac{H_m^p(\mathbf{x} + \Delta\mathbf{x}) - H_m^c(\mathbf{x})}{\Delta\mathbf{x}_n}$$

Where Δxn is a small perturbation applied to the *n*th element of the analysis vector (e.g. soil moisture at level 1) used to create the JULES initial state
C – control run
P – perturbed run

Soil Wetness to Soil Moisture conversion

$$w = \frac{\sigma - \sigma_{dry}}{\sigma_{wet} - \sigma_{dry}}$$

Conversion from wetness to volumetric soil moisture

$$\theta = \bar{\theta}_{um} + b(w - \bar{w})$$

Where the climatology of soil wetness is supplied and the climatology of UM soil moisture is computed from offline JULES runs – driven with appropriate data