Investigation of humidity variances and correlations towards the assimilation of WV radiances from MSG-SEVIRI and MTG-IRS into the DWD LETKF/VarEnKF

Chris Picking / APoD 2009

Dora Föhring, Ch. Köpken-Watts, A. Rhodin, R. Potthast

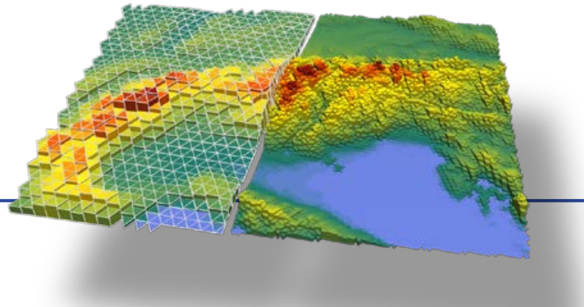
Eumetsat Fellow Day, Darmstadt, 9 March 2015

Overview

- Motivation
- The Local Ensemble Transform Kalman Filter (LETKF)
- The Ensemble Variational Data Assimilation (EnVar)
- The New Global ICON Model
- WV Assimilation
- WV Correlations & Comparison with 3dVar
- Outlook

Motivation

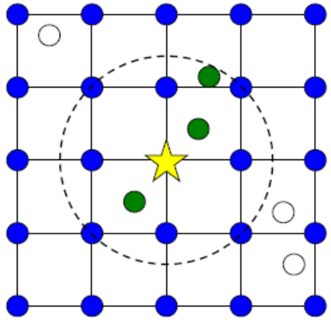
- Infrared geostationary radiances provide information about humidity structures.
- Humidity fields have previously been shown to give information about the wind field in 4D-Var (Peubey and McNally 2009, Lupu and McNally, 2012).
- The ICON model at DWD has been made operational as of January 20 2015.
- The current 3dVar data assimilation system will be replaced by a EnVar/LETKF system by the end of the year. (13 km deterministic, 40 km ensemble with 40 members)
- The aim is to adapt the EnVar system to read and process water vapour CSR.
- Evaluation of cross-correlations of humidity with wind and temperature give an insight into how far the EnVar can derive meaningful wind increments from humidity information.



LETKF

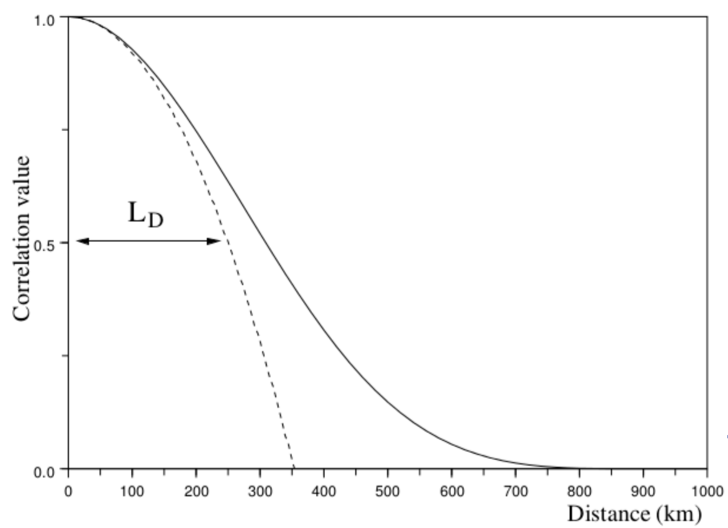
- LETKF - Localized Ensemble Transform Kalman Filter
- Implementation following Hunt et al. 2007
- Independent analysis is performed at each grid point → essentially perfectly parallel
- Multiple observations are treated simultaneously.
- Analysis done in the space of the ensemble perturbations.
- Analysis is given by a linear combination of forecast ensemble.
- Only observations within certain vicinity

  (localization radius) are taken into account.



Localization

- Within the localization radius observations (i.e. their inverse observational errors) are smoothly weighted by the (Gaussian like) Gaspari & Cohn function.
- Localization is required to suppress noise of the sample covariance matrix due to the limited ensemble size.
- Pseudo-Gaussian that goes to zero at som $L_D = c\sqrt{0.3}$ off length
- Characterized by the Daley length-scale



The Kalman Filter and the Local Ensemble Transform Kalman Filter

Kalman Filter

Model Forecast

$$\mathbf{x}_i^f = M\left(\mathbf{x}^a{}_{i-1}\right)$$

Forecast error:

$$\mathbf{P}_i^f = \mathbf{M}_{x_{i-1}^a}\mathbf{P}_{i-1}^a\mathbf{M}_{x_{i-1}^a} + \mathbf{Q}$$

$\mathbf{x}:[N]$ $\mathbf{P}:[N \times N]$

Observations

$$\mathbf{y}_i^o = H(\mathbf{x}) + \varepsilon_i^o$$

Observation operator

Observational error

Kalman gain

$$\mathrm{K}_i = \mathbf{P}_i^f\mathbf{H}^T\left[\mathbf{H}\mathbf{P}_i^f\mathbf{H}^T + \mathbf{R}\right]^{-1}$$

Analysis:

$$\mathbf{x}_i^a = \mathbf{x}_i^f + \mathbf{K}_i(\mathbf{y}_i^o - H(\mathbf{x}_i^f))$$

$$\mathbf{P}_i^a = \left[\mathbf{I} - \mathbf{K}_i\mathbf{H}\right]\mathbf{P}_i^f$$

Ensemble Kalman Filter

Ensemble Forecast

$$\mathbf{X}_i^f = \left[M\left(\mathbf{x}^{a(1)}{}_{i-1}\right)\ldots M\left(\mathbf{x}^{a(m)}{}_{i-1}\right)\right]$$

$$\equiv M\left(\mathbf{x}^a{}_{i-1}\right)$$

Number of ensemble members

Forecast error:

$$\delta\mathbf{X}_i^f = \left[\mathbf{x}_i^{a(1)} - \bar{\mathbf{x}}_i, \ldots, \mathbf{x}_i^{a(1)} - \mathbf{x}_i\right]$$

$$\mathbf{P}_i^f \approx \frac{\delta\mathbf{X}_i^f\left(\delta\mathbf{X}_i^f\right)^T}{m-1}$$

$$\mathbf{Y} = H\left(\mathbf{X}\right) = \left[\mathbf{y}_i^{a(1)}\ldots\mathbf{y}_i^{a(m)}\right]$$

$$\delta\mathbf{Y} = \left[\mathbf{y}_i^{a(1)} - \bar{\mathbf{y}}_i^a, \ldots, \mathbf{y}_i^{a(m)} - \bar{\mathbf{y}}_i^a\right]$$

Flow dependent!

$\mathbf{x}:[N \times m]$ $\mathbf{P}:[N \times m]$

LETKF vs 3dVar vs EnVar

- The EnVar is a hybrid variational analysis system which uses contributions from both the time invariant climatological and the flow dependent ensemble background error covariance matrix for a deterministic analysis.

Climatological P^f_clim used by 3dVar

- Derived by the NMC method (differences of forecast with different lead time).
- No flow dependent correlations.
- Cross-correlations between temperature and humidity are assumed to be zero.

Ensemble P^f_ens used by LETKF (and EnVar)

- Derived from differences of ensemble members
- Flow dependent correlations between all model variables

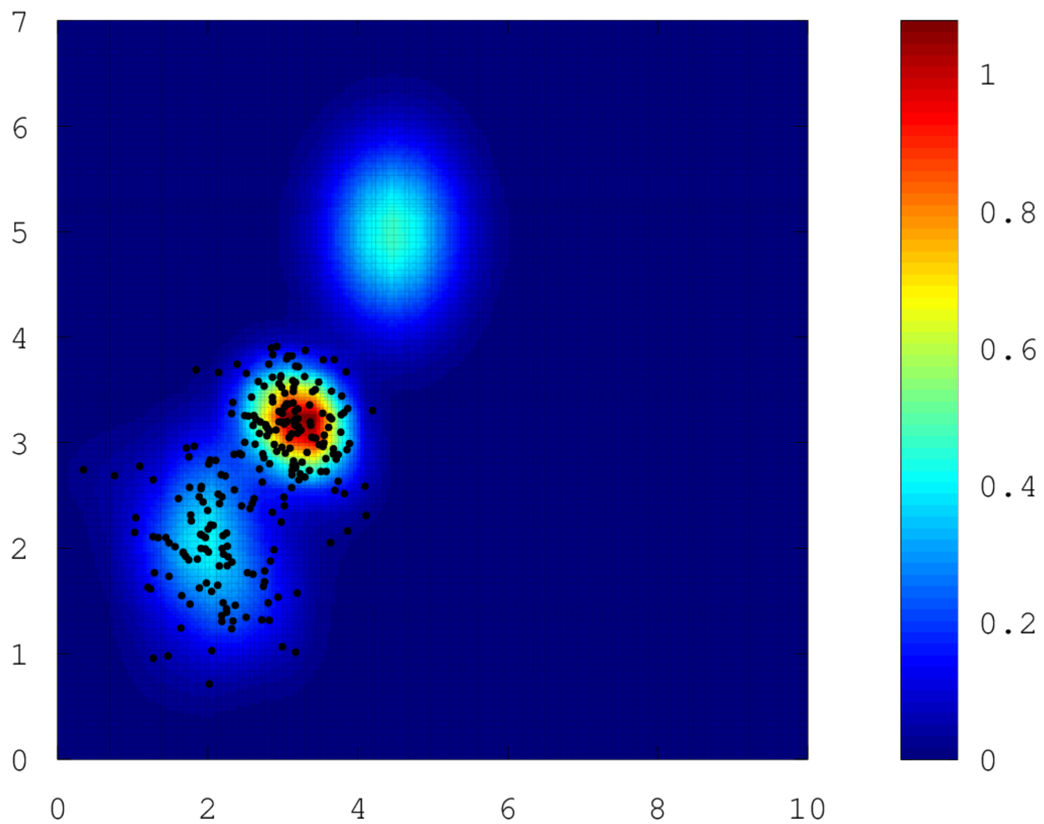
	3dVar	LETKF	EnVar
background error	climatological	flow dependent	combination of both
	P^f_clim	P^f_ens	0.5 * (P^f_clim + P^f_ens)
analysis	deterministic	ensemble	deterministic

LETKF: demonstration

Measurement

Analysis

Ensemble Prior

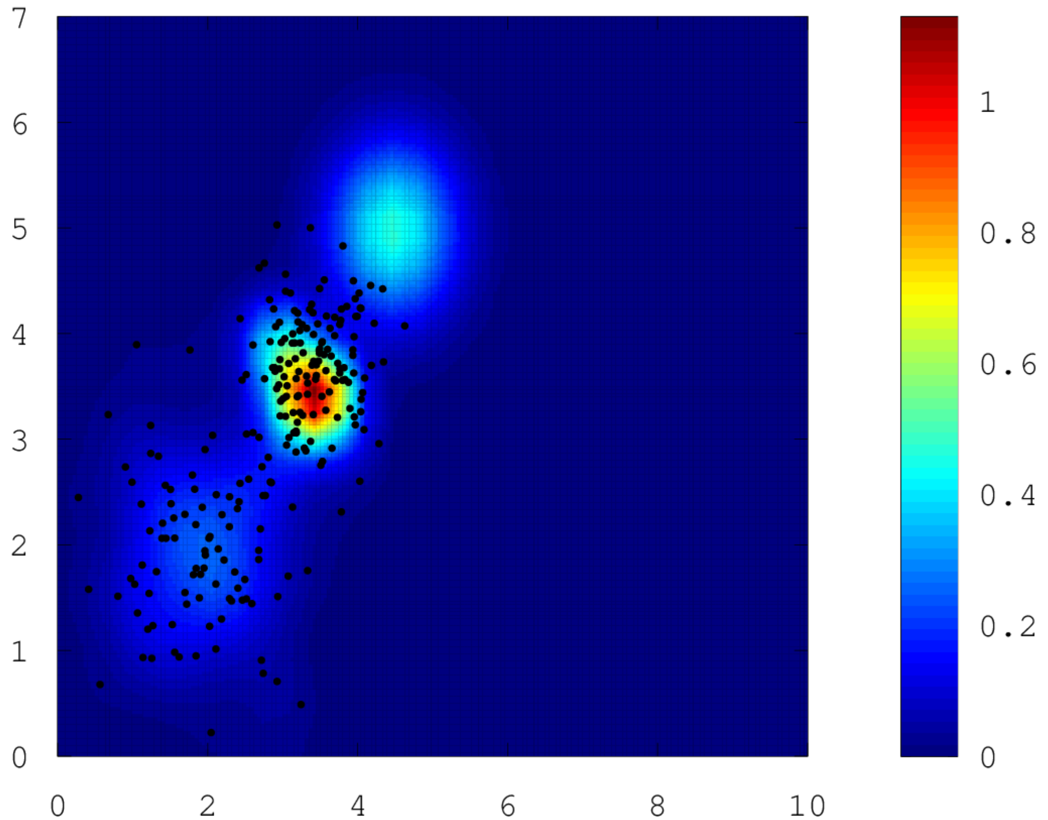


LETKF: demonstration

Measurement

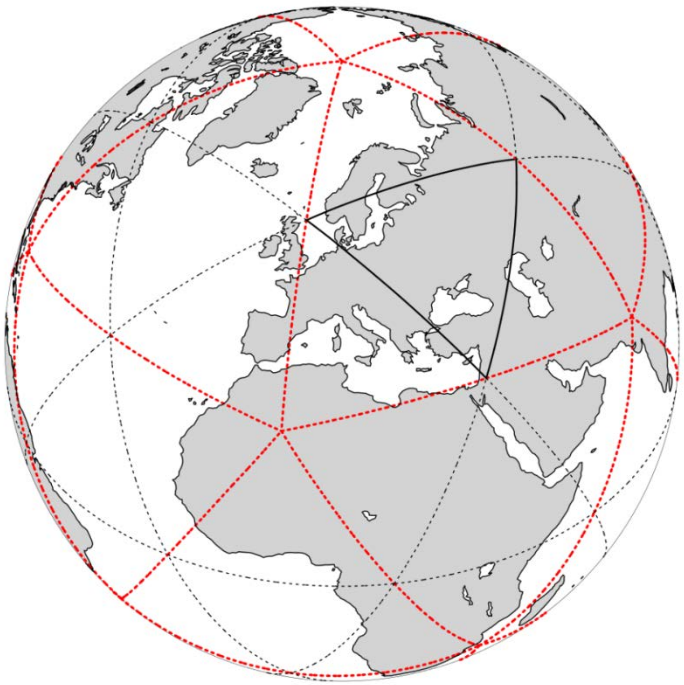
Analysis

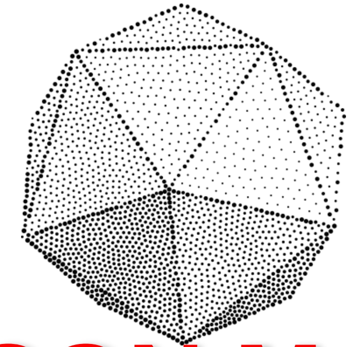
Ensemble Prior



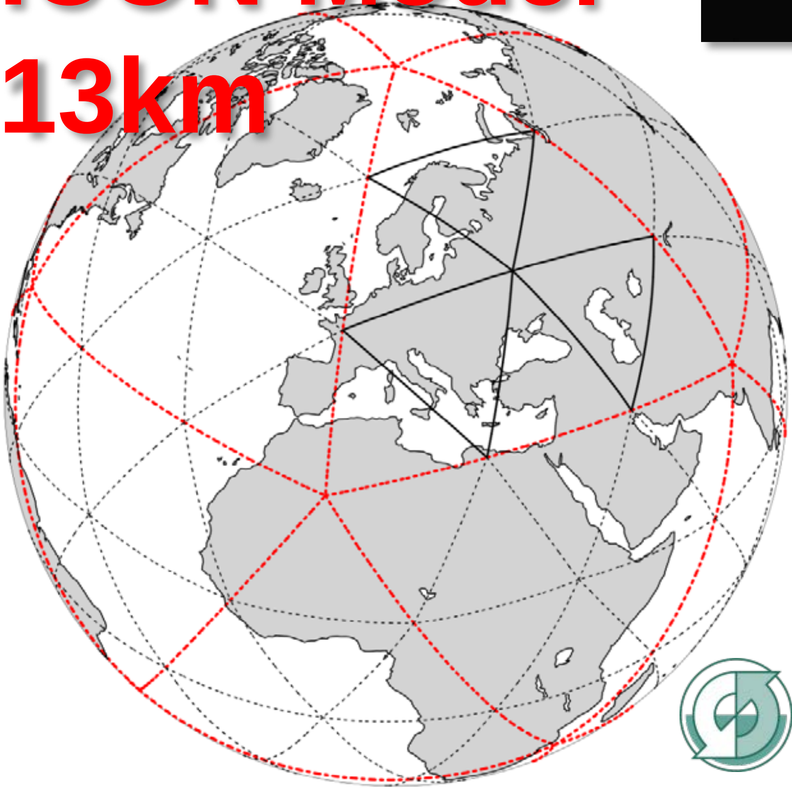
Increasing error on Prior

Global Modelling

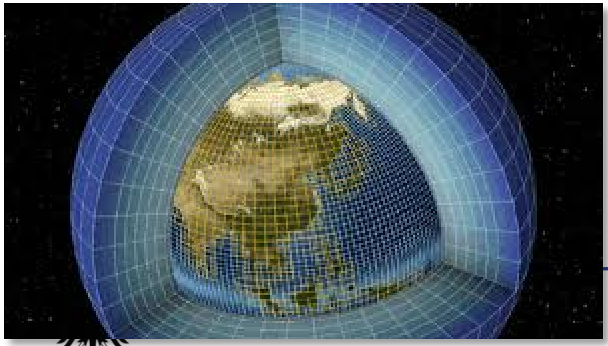




ICON Model 13km



ICOsahedral Nonhydrostatic



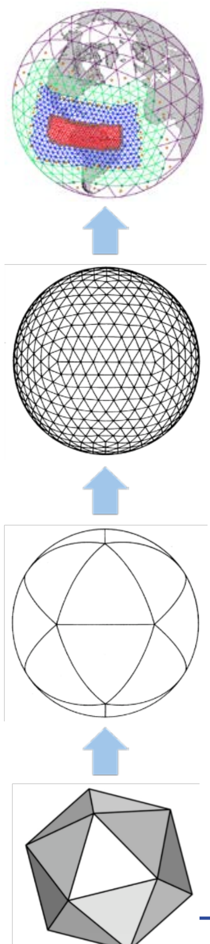
New Global Model ICON

- Operational since Jan 20, 2015

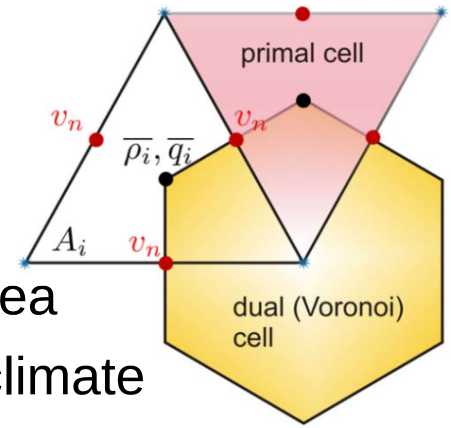
- Non-Hydrostatic
- 13km resolution globally
- 75km height
- 90 vertical levels

- Still a lot in the pipeline!!

ICON: NWP and climate model

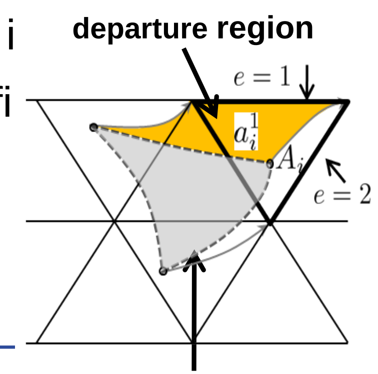


- Icosahedral grid on triangles (also hexagons)
- Non-hydrostatic (Gassmann, Herzog, 2008)
- Z-coordinate (terrain following)
- Two-way nesting (horiz. & vert.) and limited area
- Target resolution: 5-20km NWP, 100-200km climate
- LES option considered (100m-400m)



Numerics:

- C-type staggering
- Horizontally explicit, vertically implicit on sound wave (HEVI)
- Mahrer-type pressure discretization (Zängl 2012, MWR, i
- Flux-form semi-Lagrangian (FFSL) advection based on fi
  (Lauritzen et al 2011, Lauritzen 2010, Miura 2007)
- Mass-conserving, consistent, optionally monotone



ICON : 90 Level version

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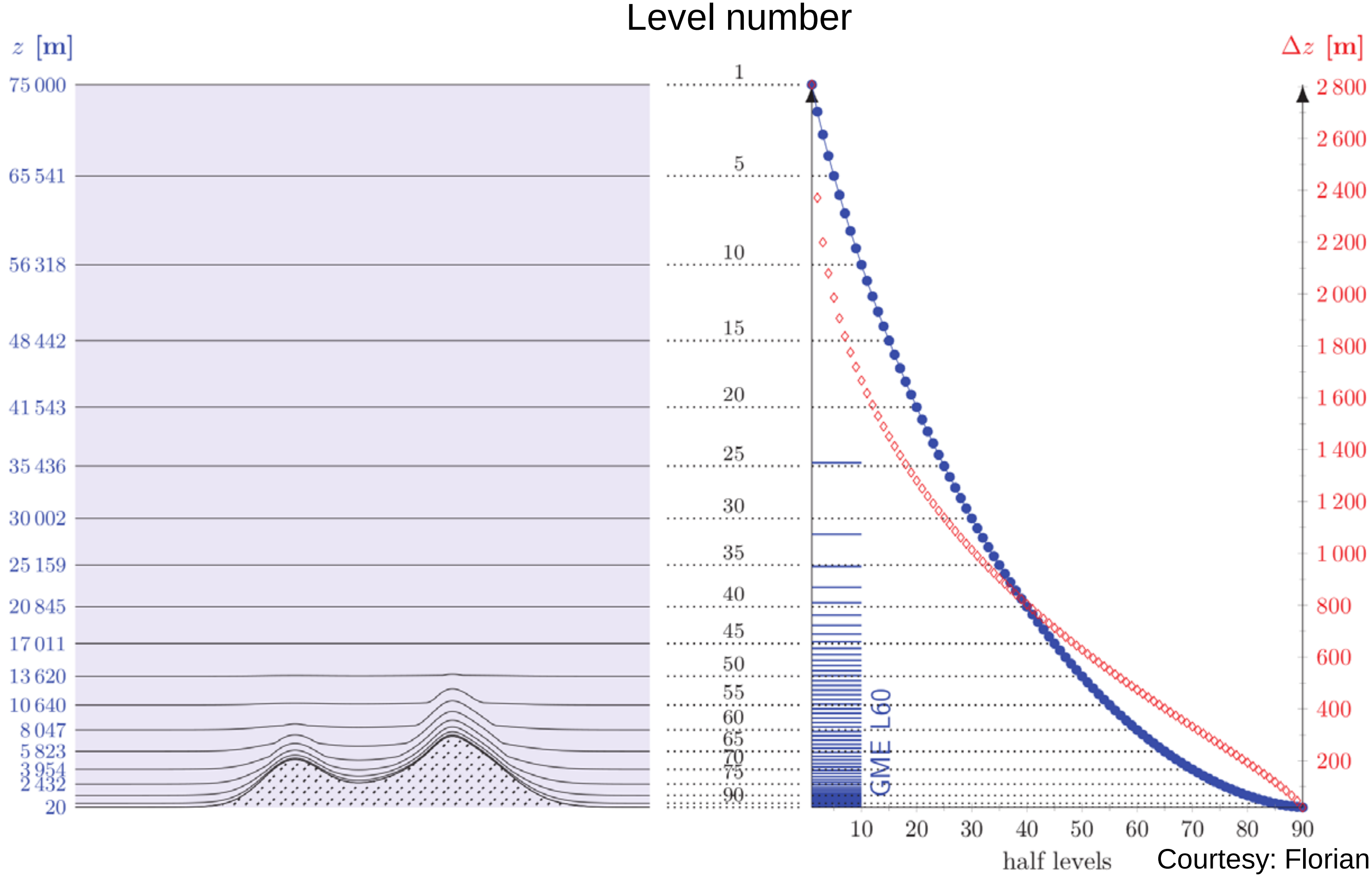
~2.6 Pa

~ 5 hPa



Courtesy: Florian Prill)

Considerably higher model top beneficial for use of radiances !

Summary of ICON Atmosphere Analysis Fields

- VN – Velocity normal to edges
- U – Zonal wind
- V – Meridional wind
- W – Vertical wind
- DEN – Density of moist air
- THETA V – Virtual potential temperature
- T – Temperature
- QV – Specific humidity
- QC – Cloud mixing ratio
- QI – Cloud ice mixing ratio
- QR – Rain mixing ratio
- QS – Snow mixing ratio
- TKE – Turbulent kinetic energy
- P – Pressure

Assimilated data:
Operational & tested for implementation

(I) All standard conventional data:

- RS, PILOT, AIREP, SYNOP, BUOY

(II) Satellite data:

- Radiances/IR : HIRS, IASI (METOP-A/B)
  CrIS
- Radiances/MW : AMSU-A (NOAA, METOP-A/B)
  ATMS
  MHS, ATMS, (FY-MWHS)
  AMSR-2, SSMIS
- RO (bending angles): GRAS (METOP-A/B)
  COSMIC, GRACE, TerraSar-X, C/NOFS
- AMVs - geo: GOES, METEOSAT, MTSAT (sea/land)
  - polar: Aqua/Terra, NOAA, METOP-A/B
- Scat (wind vectors): ASCAT (METOP-A/B), Rapidscat

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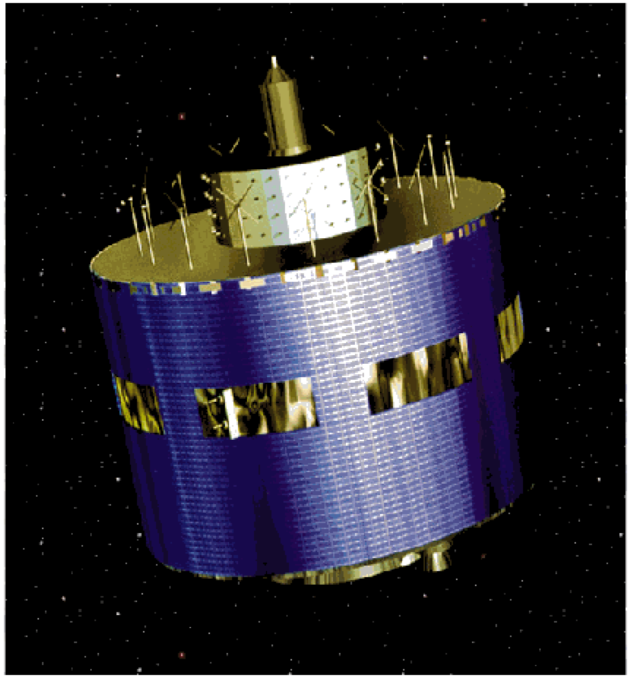
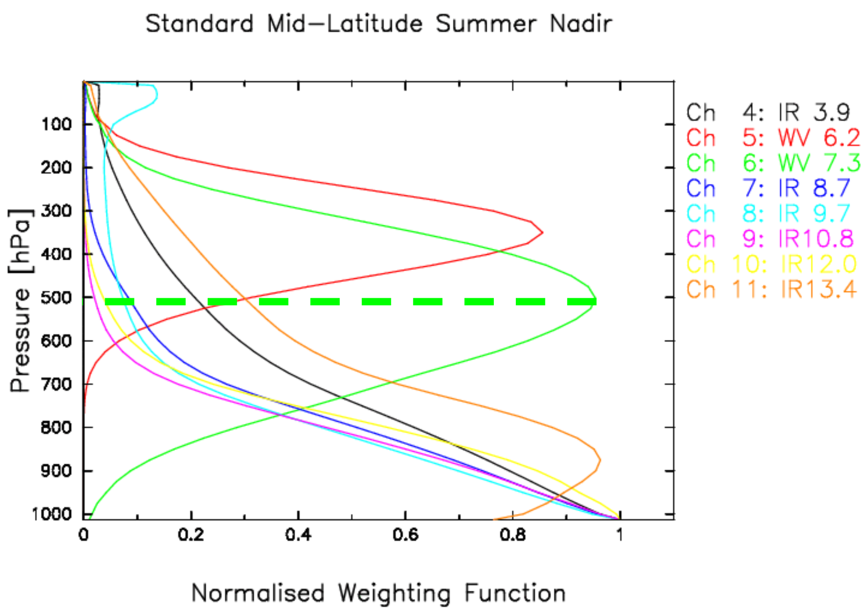
Water Vapour Channels – MSG SEVIRI

- Channel 01: VIS 0.6 μ
- Channel 02: VIS 0.8 μ
- Channel 03: NIR 1.6 μ
- Channel 04: MIR 3.9 μ
- Channel 05 WV 6.2 μ
- Channel 06: WV 7.3 μ
- Channel 07: IR 8.7 μ
- Channel 08: IR 9.7 μ (Ozone)
- Channel 09: IR 10.8 μ
- Channel 10: IR 12.0 μ
- Channel 11: IR 13.4 μ (CO_2)
- Channel 12: HRV (High Resolution Visible)



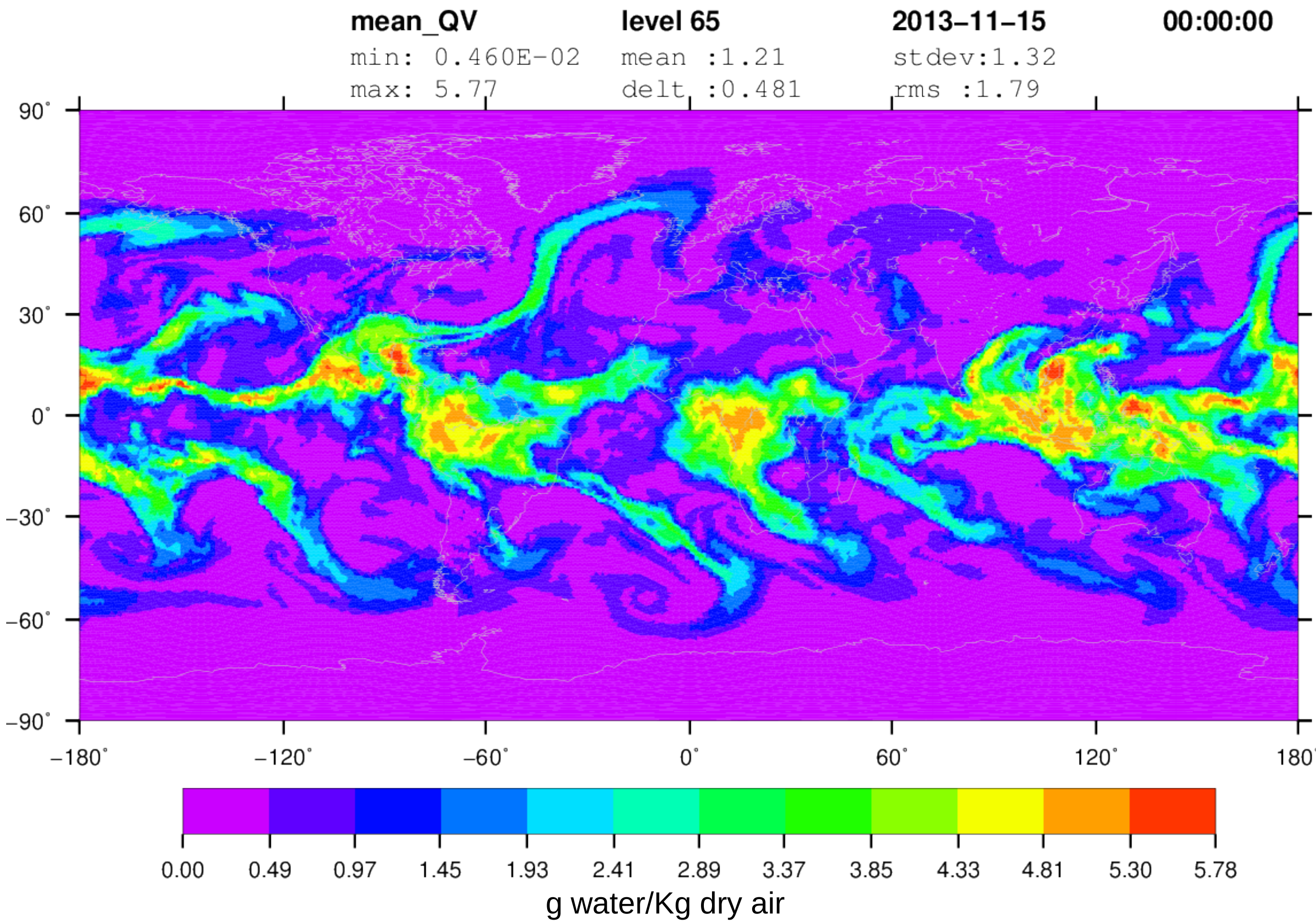
- Max signal in Ch 06 from approx. 500 hPa:

  → Corresponds to level 65 in the ICON model

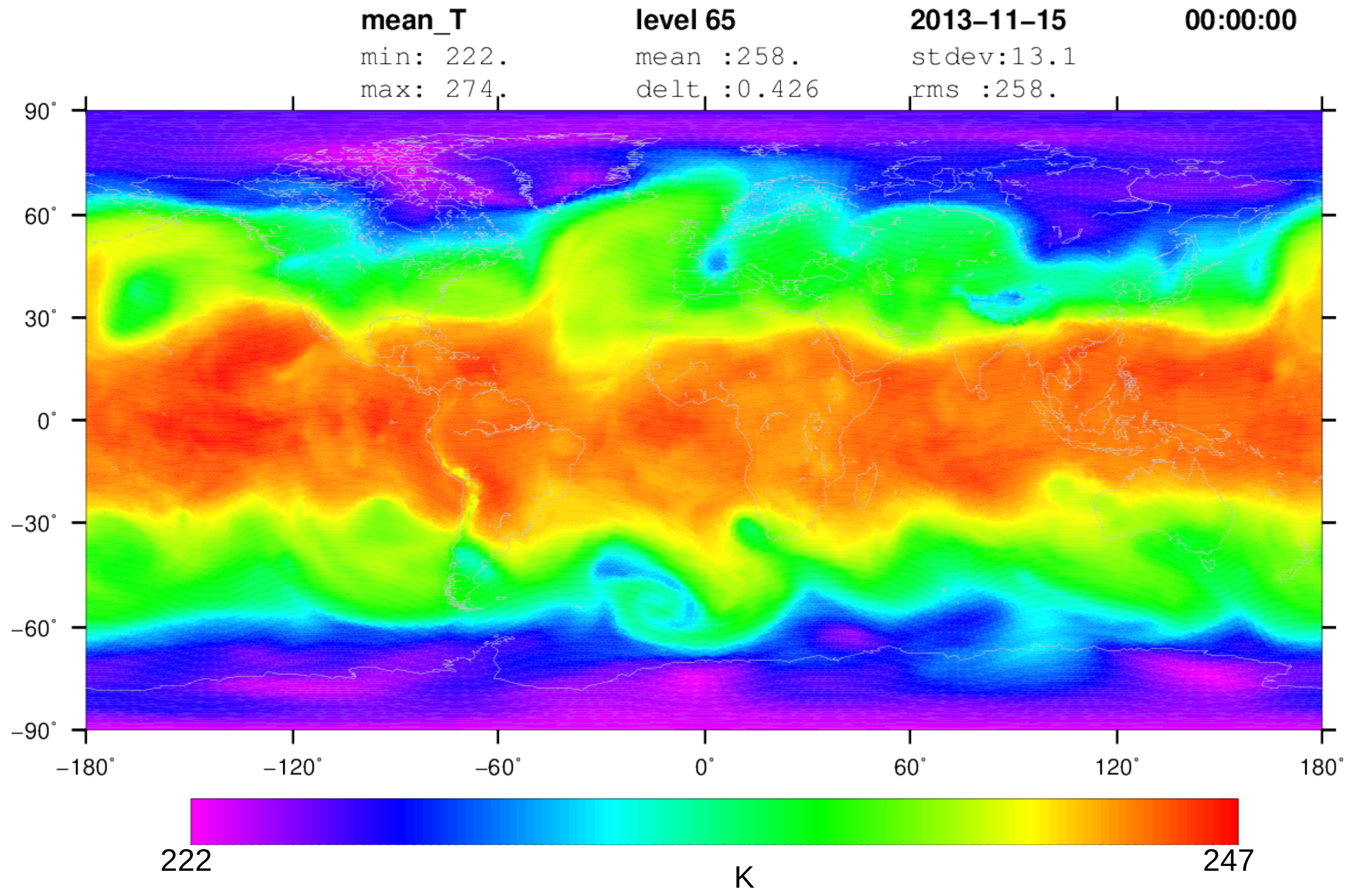


Weighting functions for the MSG SEVIRI thermal channels

Overview: Mean QV

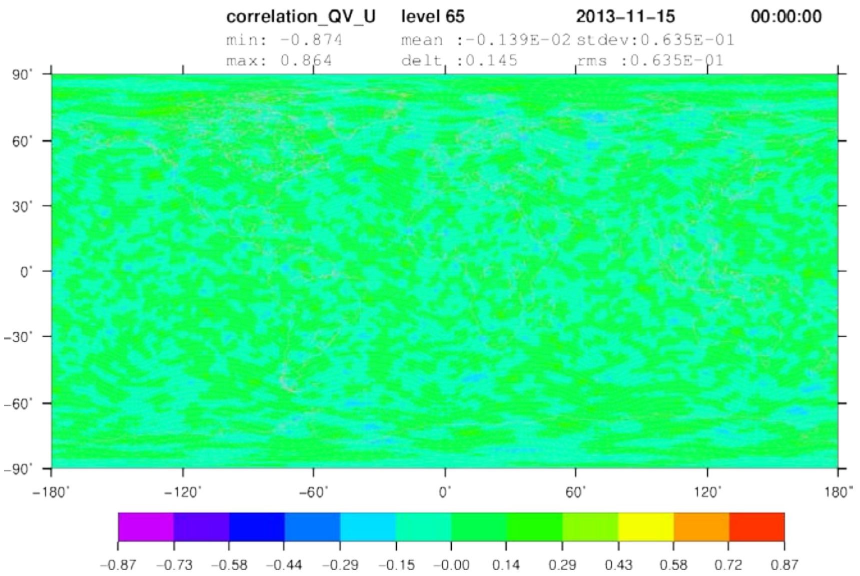


Overview: Mean T

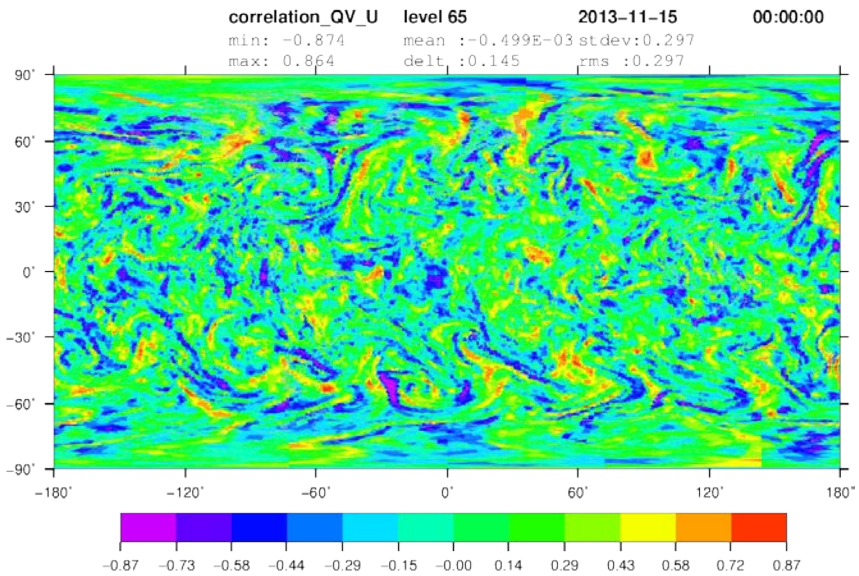


Correlations: Humidity - Wind

3dVar

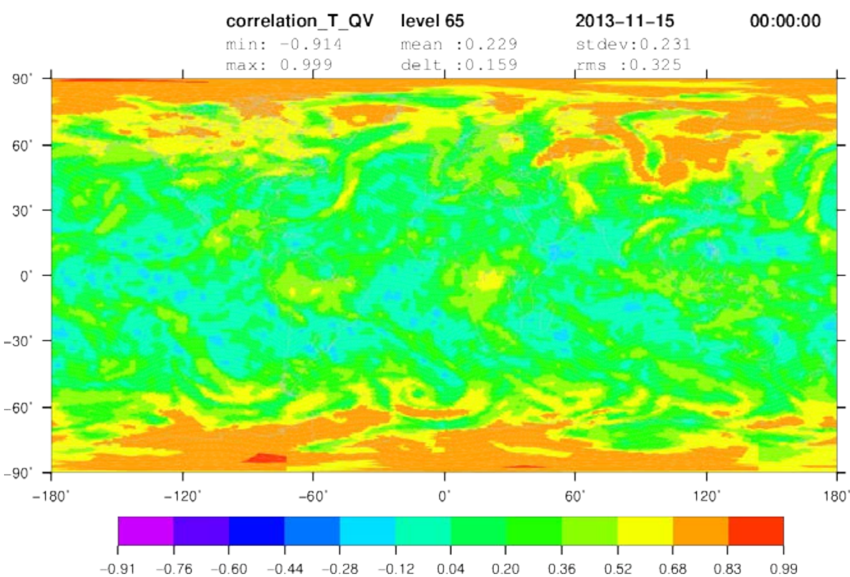


LETKF

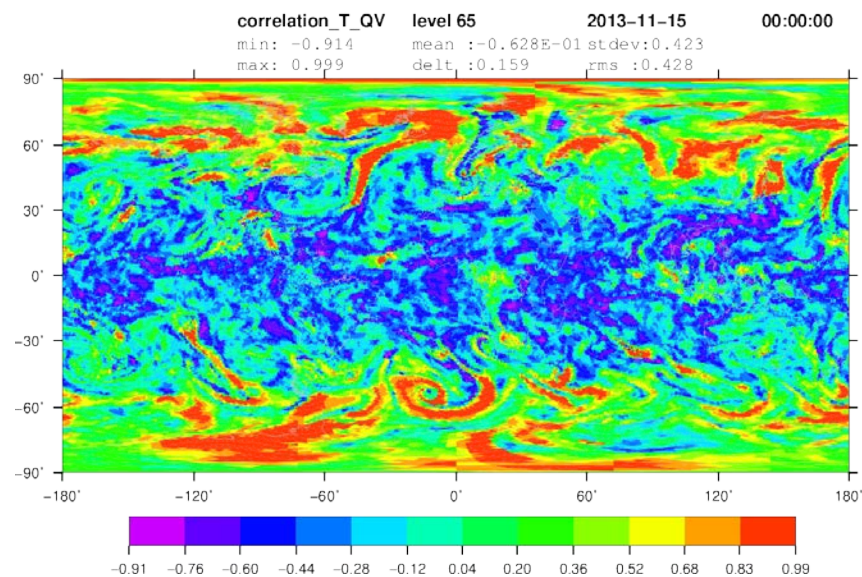


Correlations: Humidity-Temperature

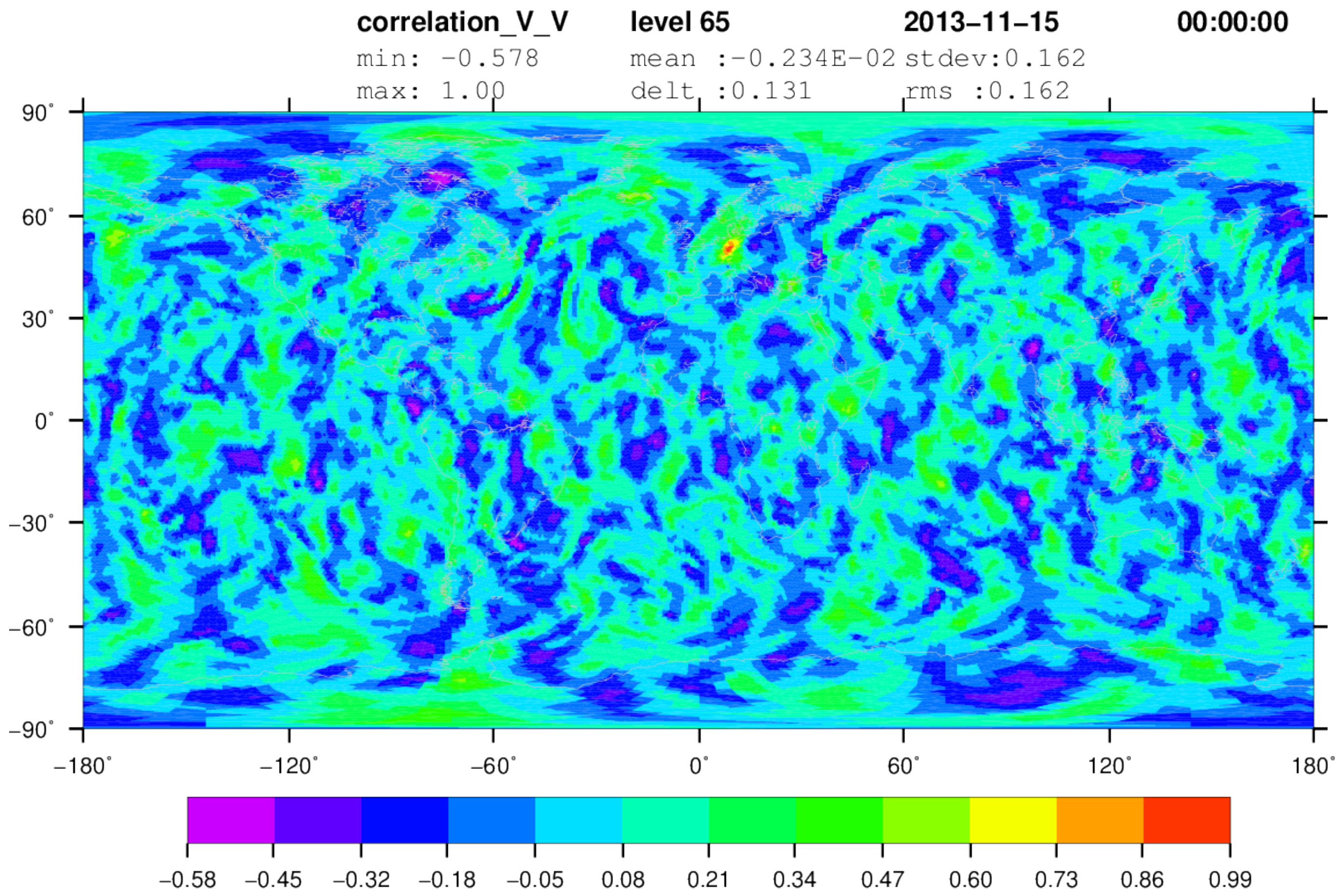
3dVar



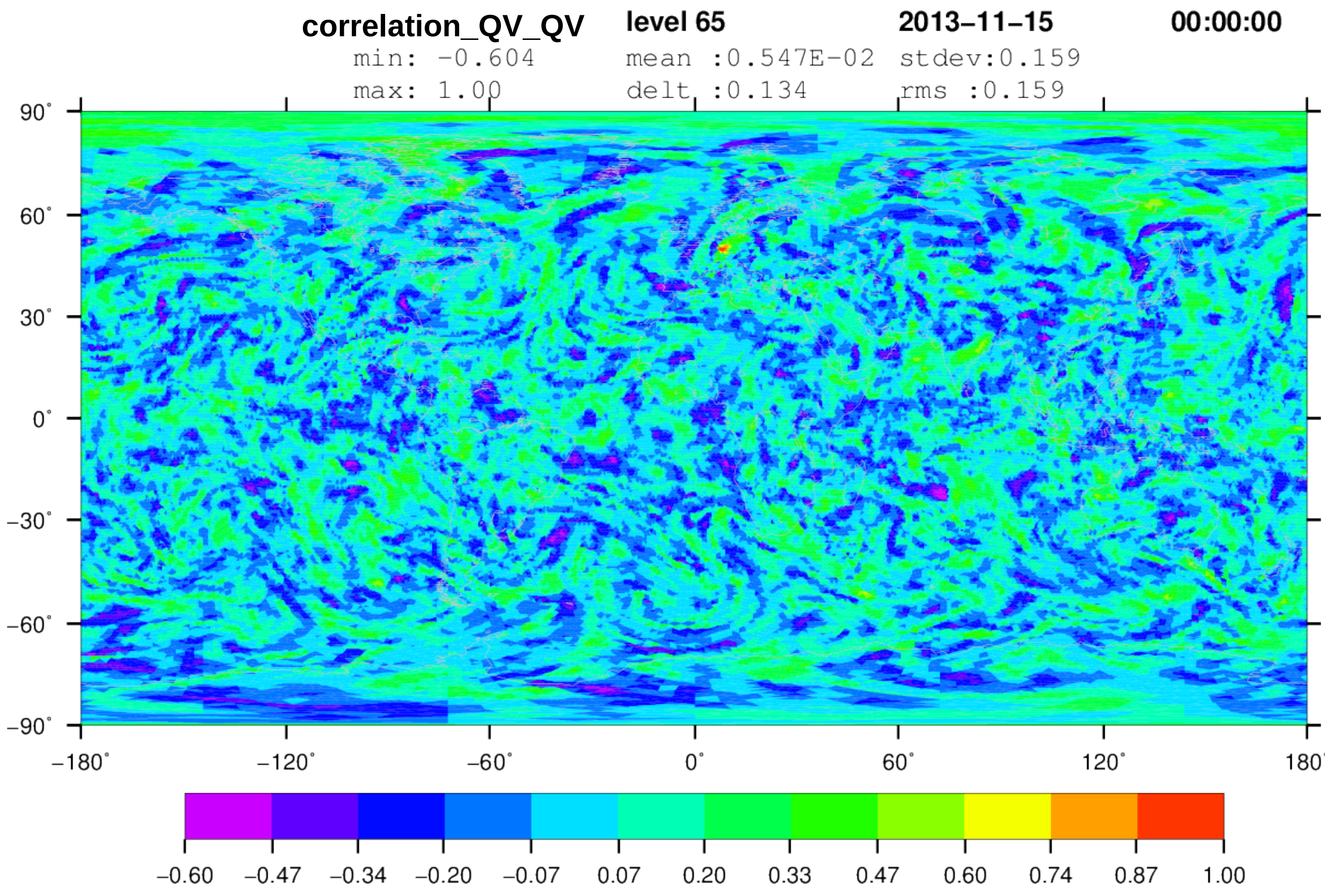
LETKF



Autocorrelations: V

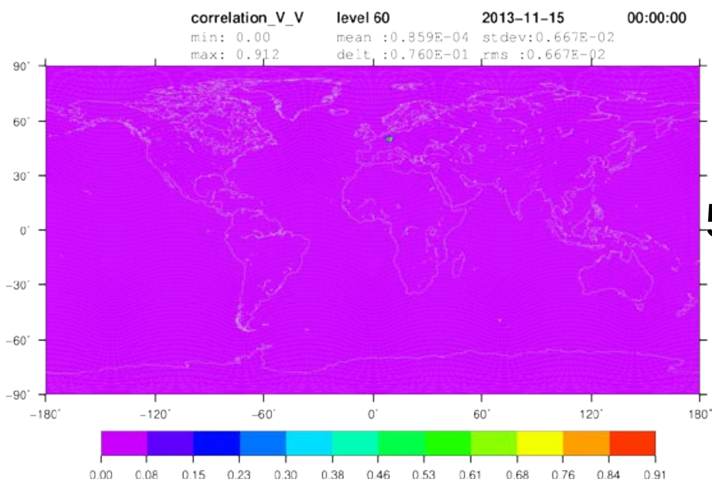


QV

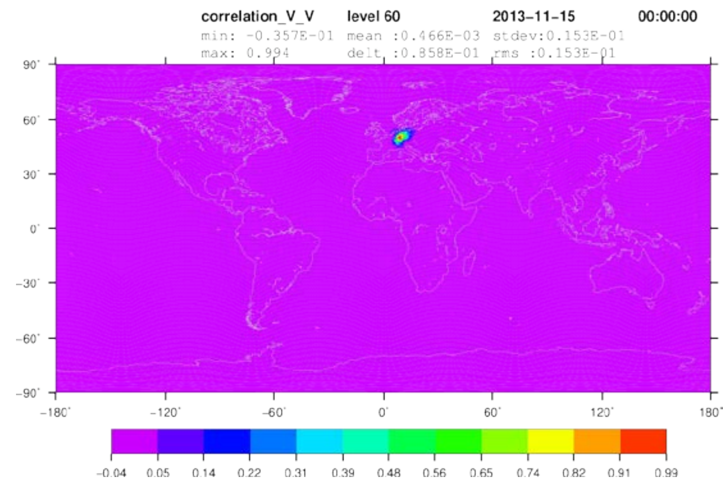


correlation_QV_QV
level 65
2013-11-15
00:00:00
min: -0.604
max: 1.00
mean :0.547E-02
delt :0.134
stdev:0.159
rms :0.159
90˚
60˚
30˚
0˚
-30˚
-60˚
-90˚
-180˚
-120˚
-60˚
0˚
60˚
120˚
180˚
-0.60
-0.47
-0.34
-0.20
-0.07
0.07
0.20
0.33
0.47
0.60
0.74
0.87
1.00

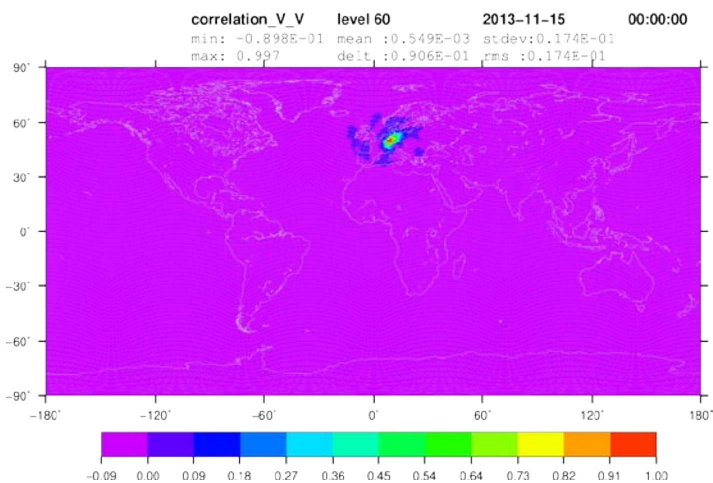
Localization



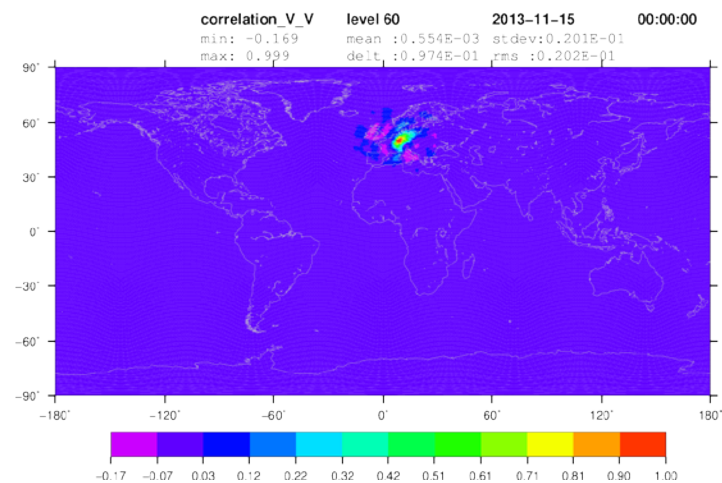
50km



200km



300km



500km

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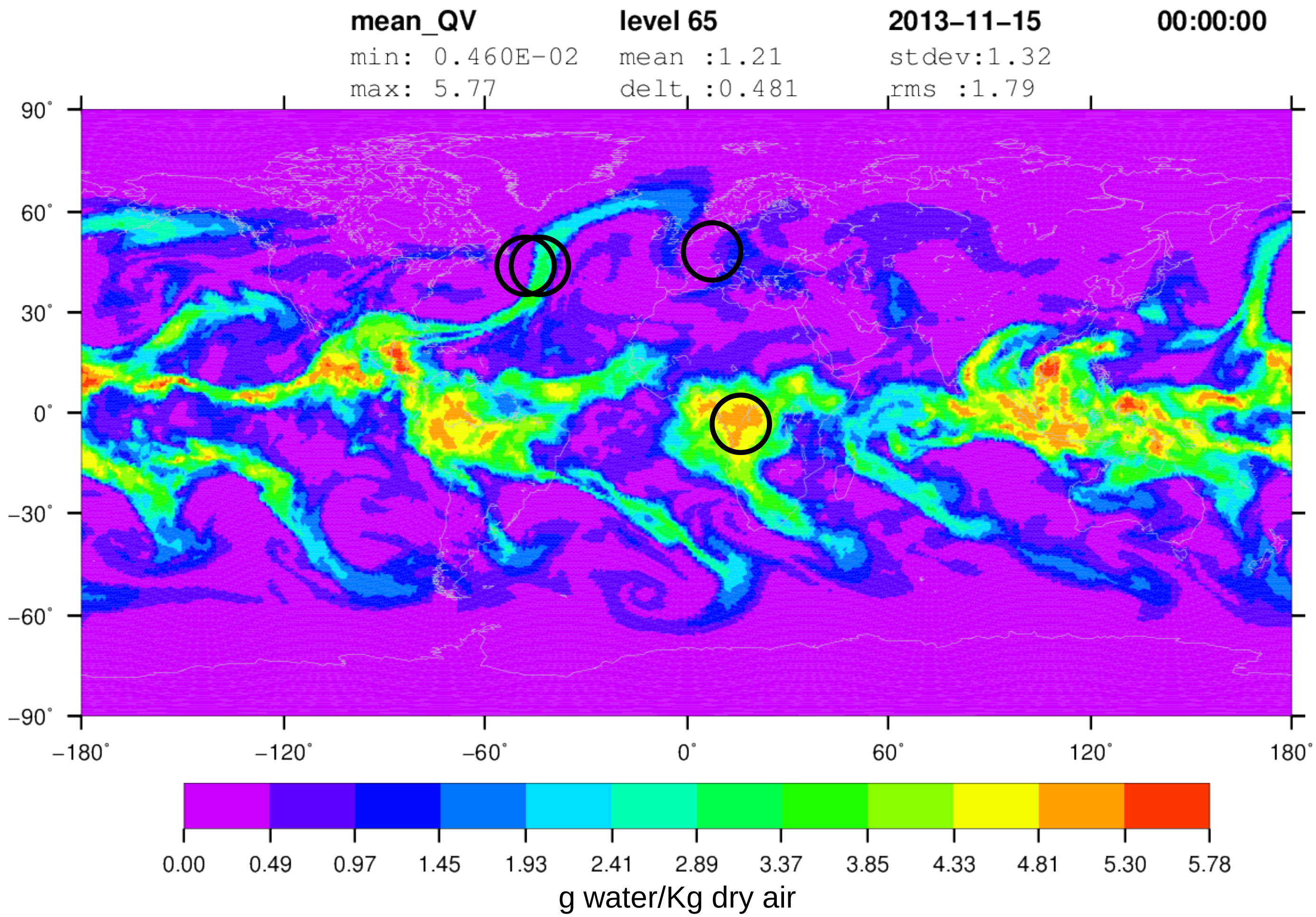
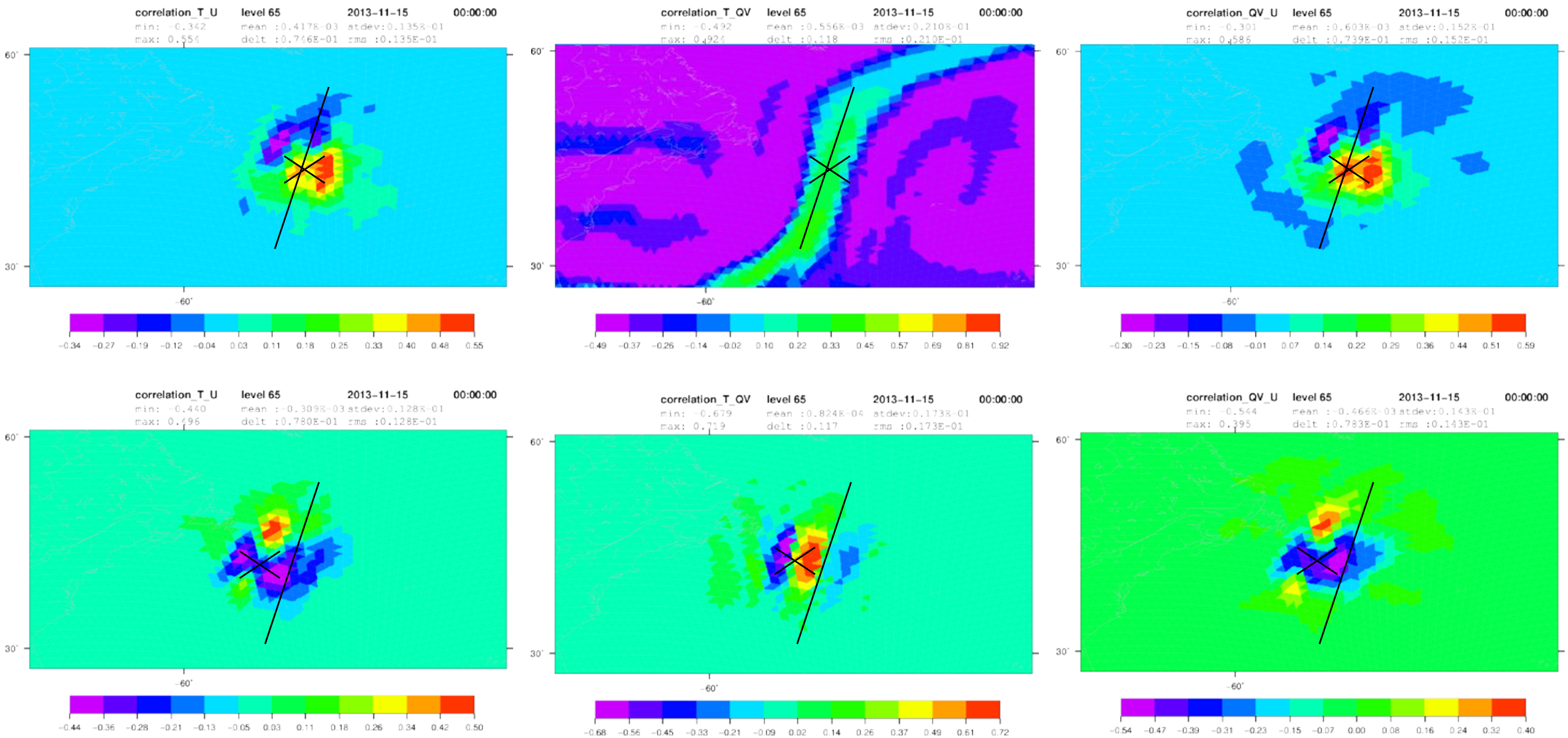
Overview: Mean QV



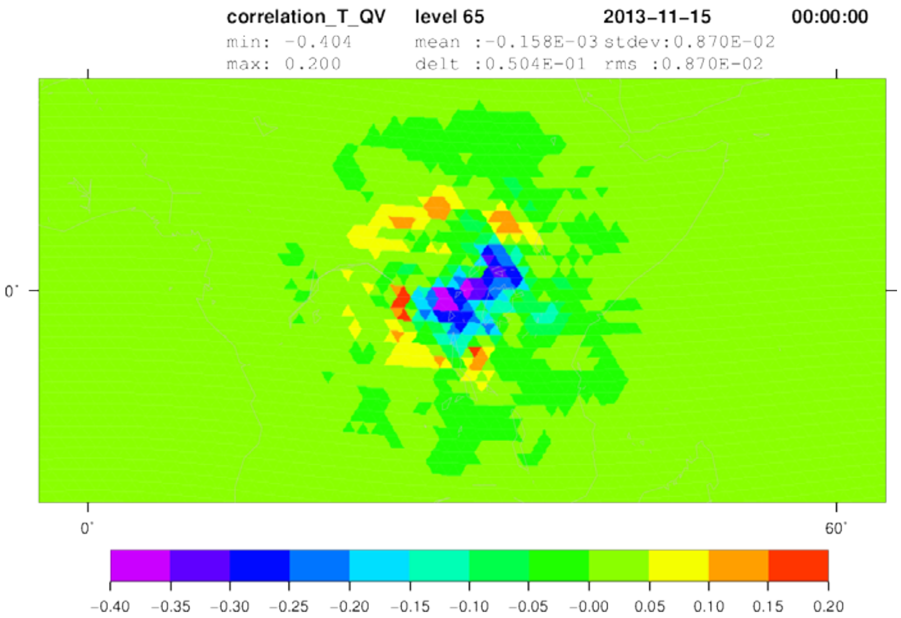
Correlations Across Fronts

T-U T-QV QV-U

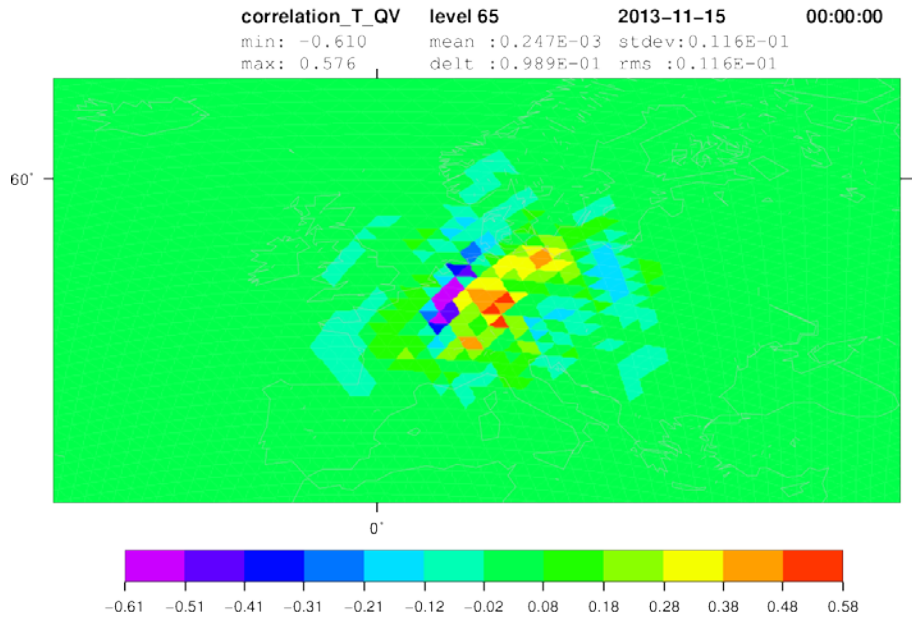


Correlations In Other Regions

Tropics



Extratropics



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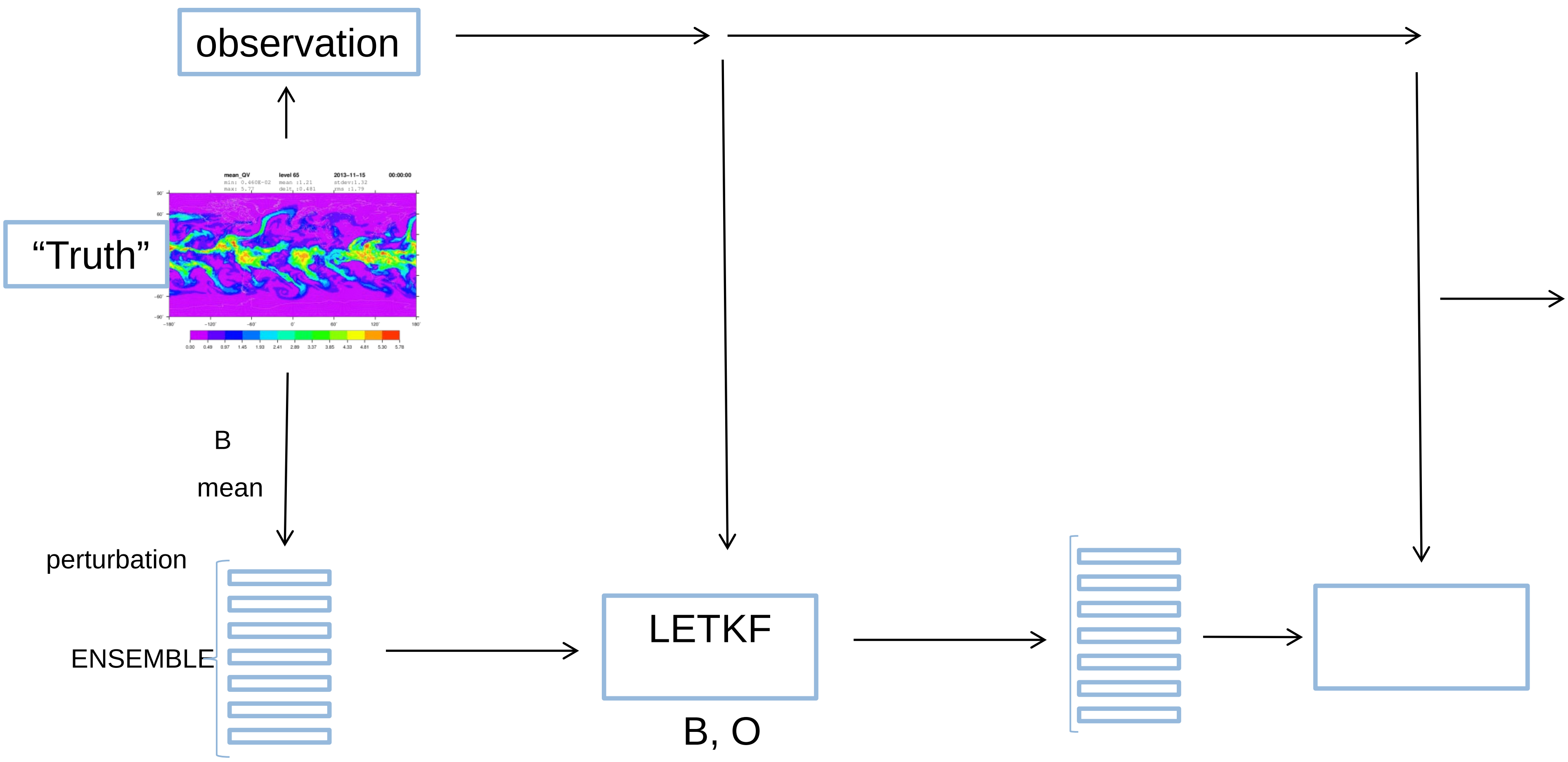
Outlook

- Passive Monitoring of data:
  - Compare model equivalent of assimilation: H(x)
  - Evaluate the fit of the model to the CSR data

- Assimilate artificial data:
  1. Artificial humidity data generated by a ‘truth run’
  2. Synthetic single layer 1 channel CSR computed from a ‘truth run’ for the relevant SEVIRI water vapour channels
  3. Equivalent brightness temperatures

- Assimilate real radiances

Assimilating Artificial Humidity Data



Outlook

- Additional investigation of the effect of the weighted B matrix on the results may be required.

- A statistical investigation of the relationships between the different parameters within a frontal system is also of interest.

Summary

- Humidity fields have previously been shown to give information about the wind field in 4D-Var.
- The aim of the project is to adapt the EnKF system to read and process water vapour CSR.
- The ICON global model has been newly made operational since January 20 2015 for both for operational NWP and climate prediction applications at the DWD.
- In contrast to the climatological B matrix in 3Dvar, there is strong correlation between temperature and relative humidity, and between humidity and wind within ICON, due to the flow dependent B matrix in LETKF.
- Future work will include testing whether the LETKF/EnVar is able to infer meaningful wind increments from the sequence of CSR data.
- Testing the assimilation of artificial humidity data generated by a ‘truth run’.
- Adapting the EnKF system to read and process water vapour CSR to test with real data.

Investigation of humidity variances and correlations towards the assimilation of WV radiances from MSG-SEVIRI and MTG-IRS into the DWD LETKF/VarEnKF

DF would like to thank EUMETSAT for funding!