Physics & Diagnostics

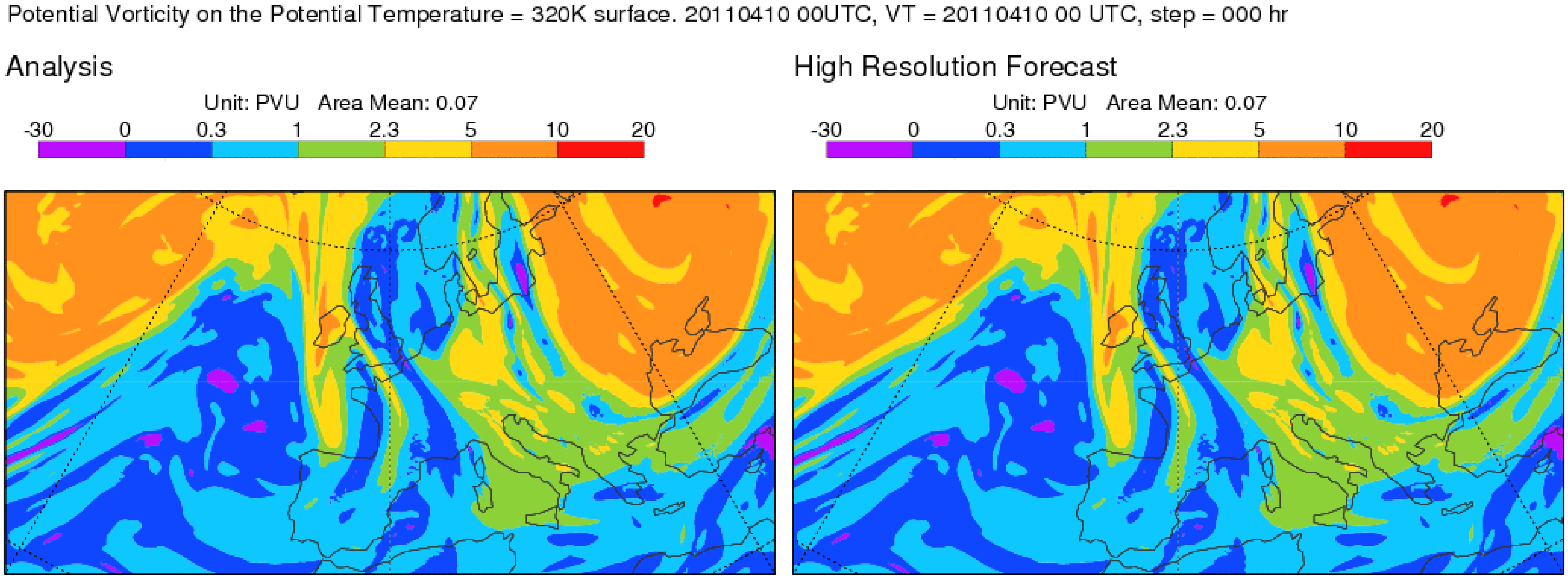
Mark Rodwell

Meteorological Training Course
Parameterization of Diabatic & Subgrid Processes

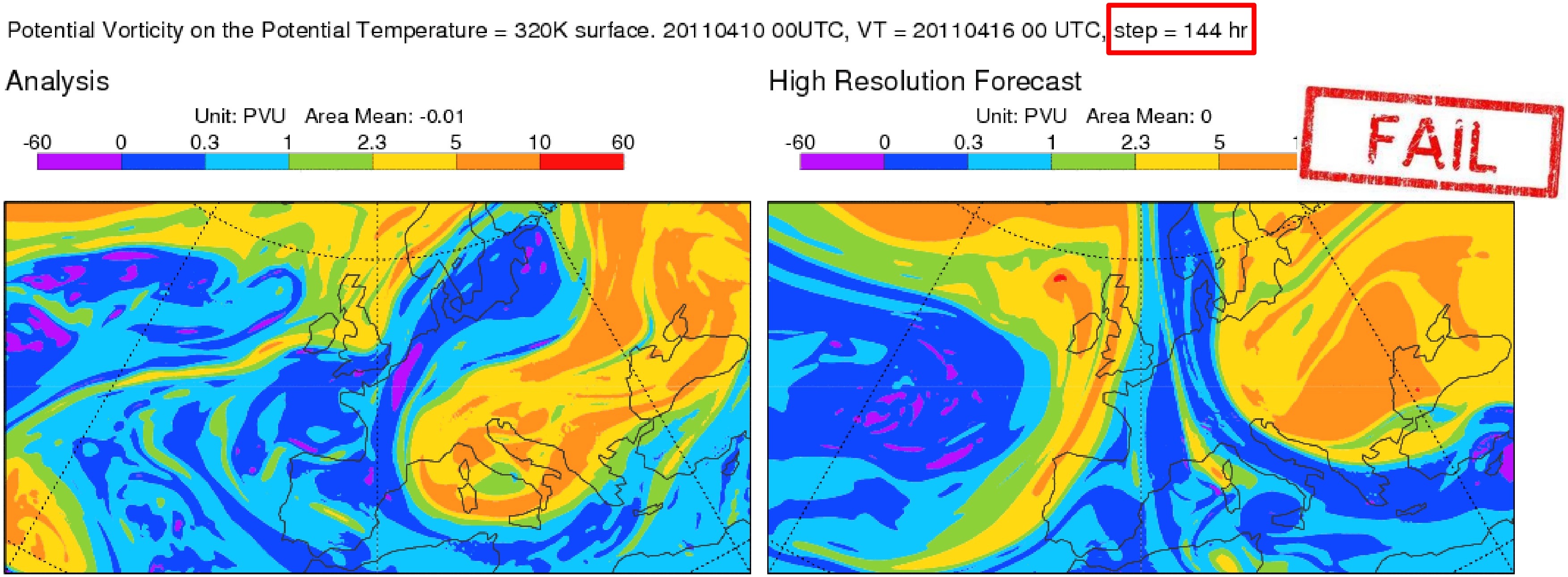
ECMWF

15 May 2015

Single high-resolution forecast (initial conditions)

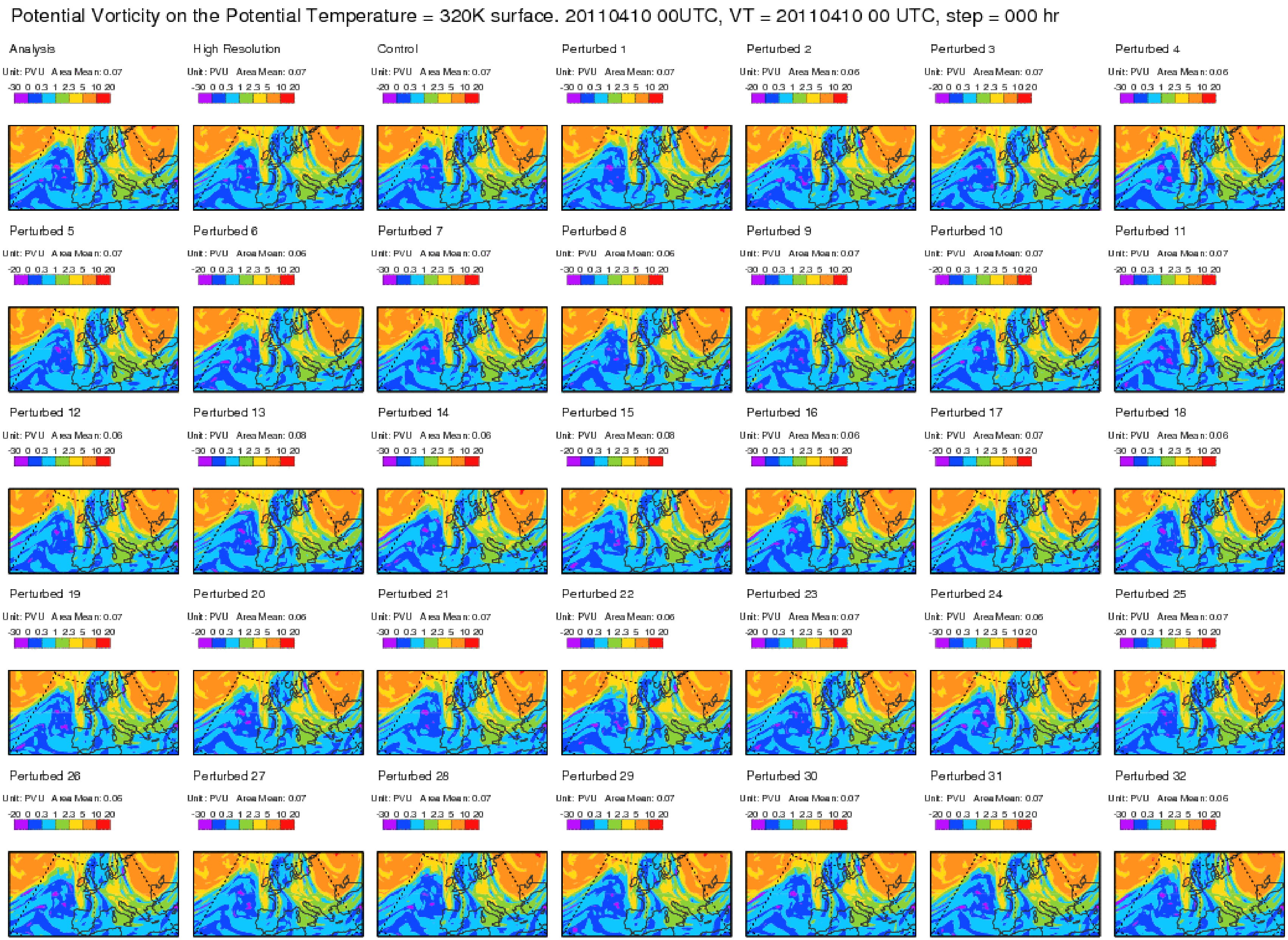


Single HRES forecast (flow evolution to day-6)



It is difficult, by day-6, to disentangle model error from the natural growth of initial condition uncertainty (chaos)

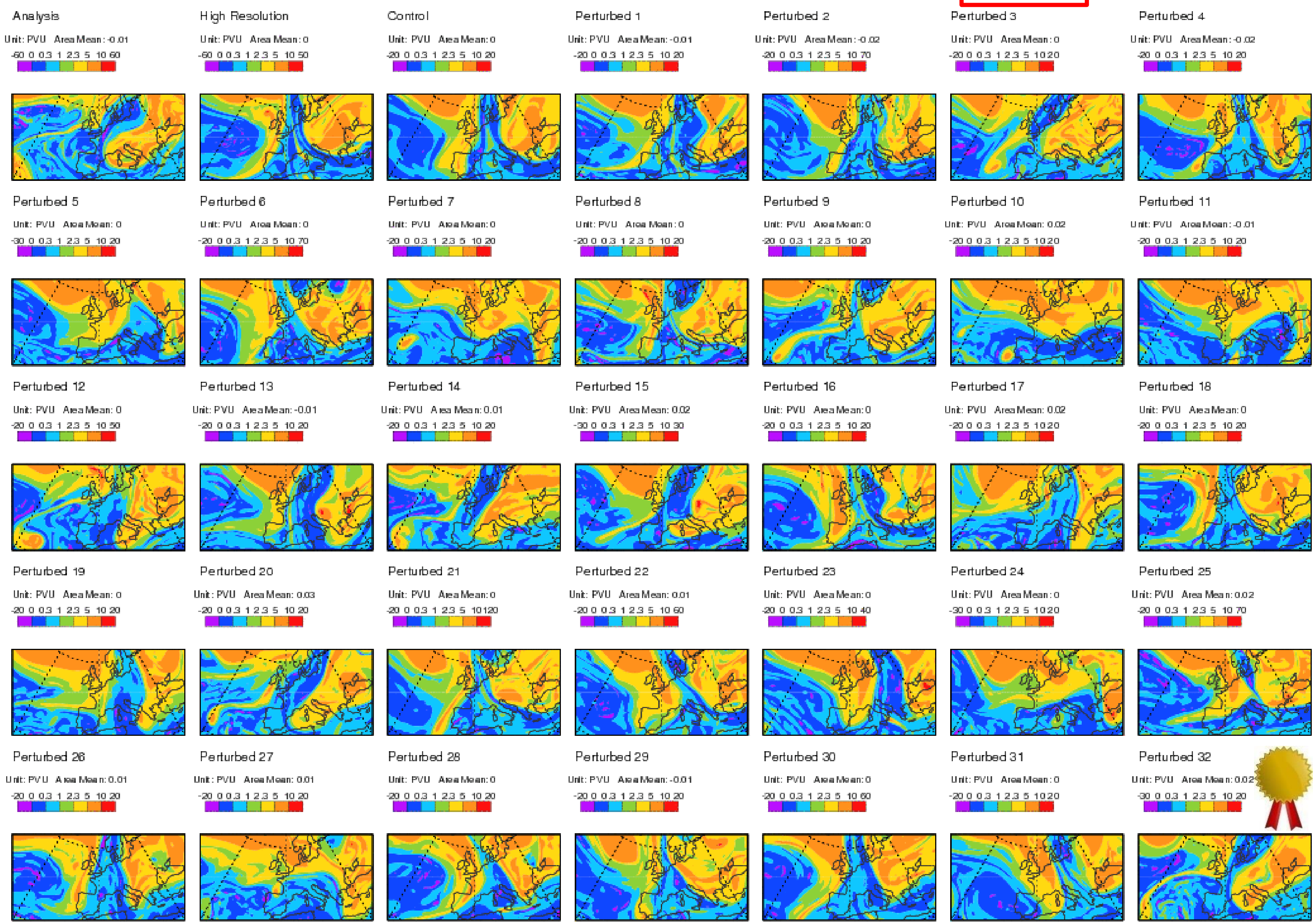
Ensemble forecasting (initial conditions)



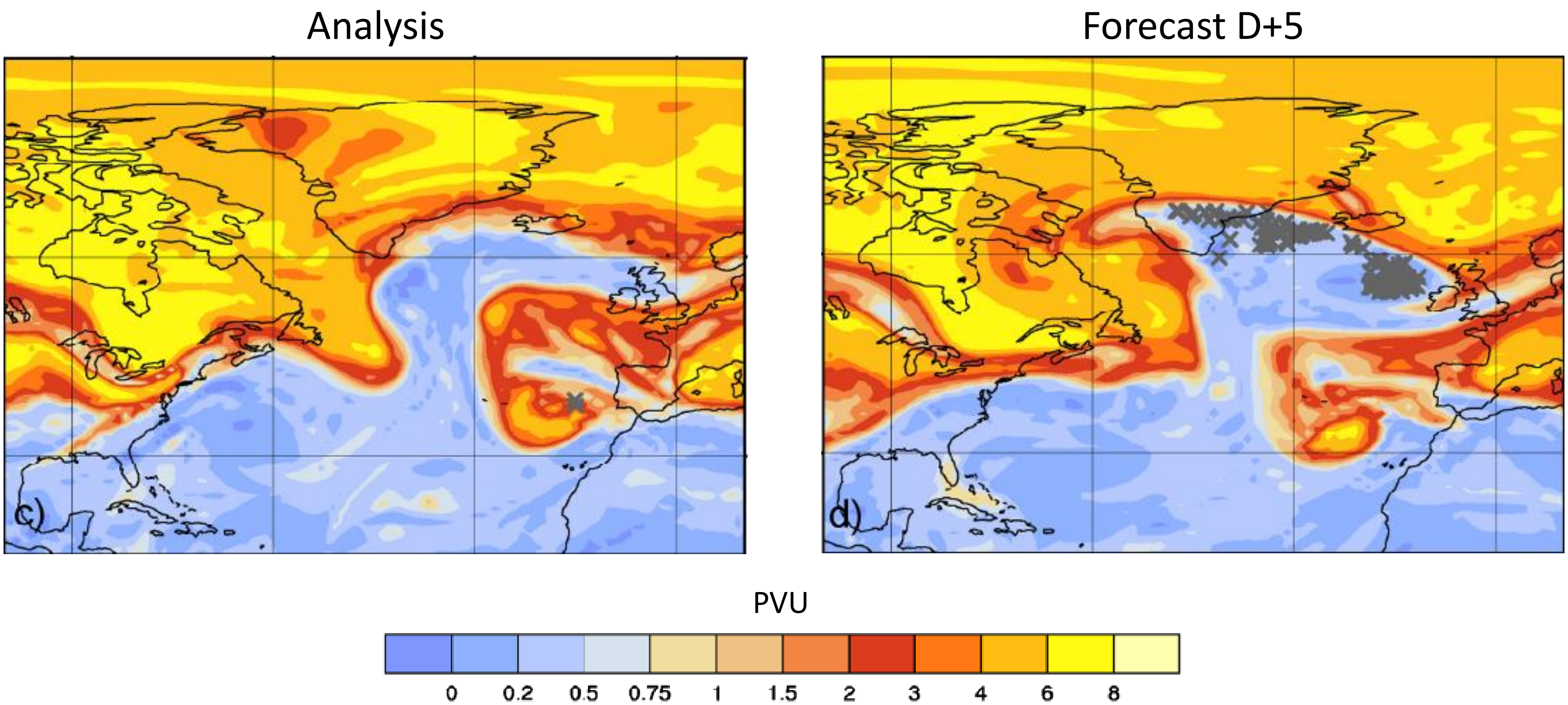
Ensemble forecasting (flow evolution to day-6)

Diagnostics

Potential Vorticity on the Potential Temperature = 320K surface. 20110410 00UTC, VT = 20110416 00 UTC, step = 144 hr



PV_{315K} and Warm Conveyor Belt intersections (=X)



The Warm Conveyor Belts are the trajectories of rapidly ascending air parcels

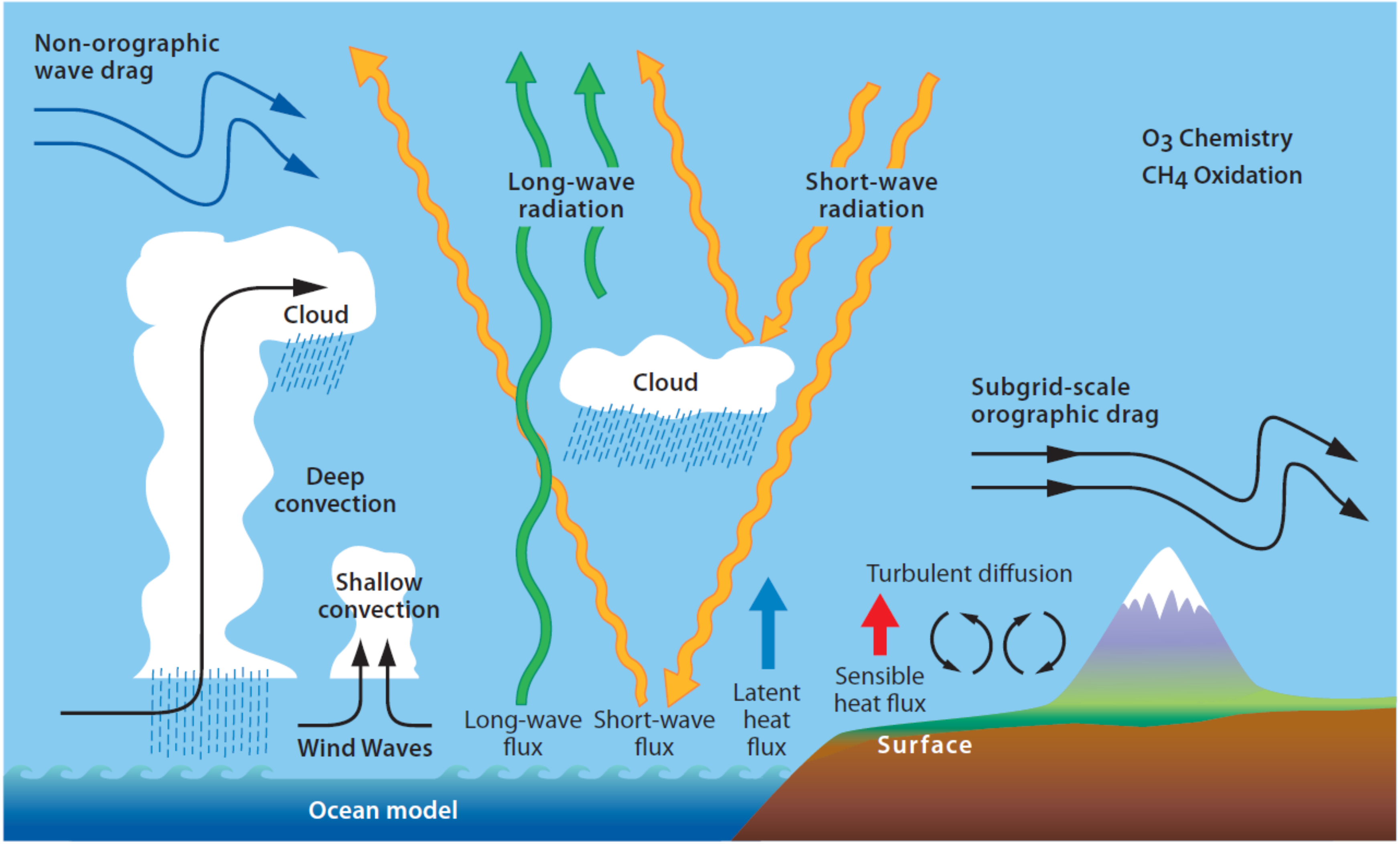
In this case, these are more extensive in the forecast, indicative of stronger latent heating, and deposit more anticyclonic vorticity aloft – affecting the evolution of the upper-level wave

Validity time 20110121, 12UTC

Figure from Erica Madonna

Initial tendency diagnostics

The complexity of present-day model physics

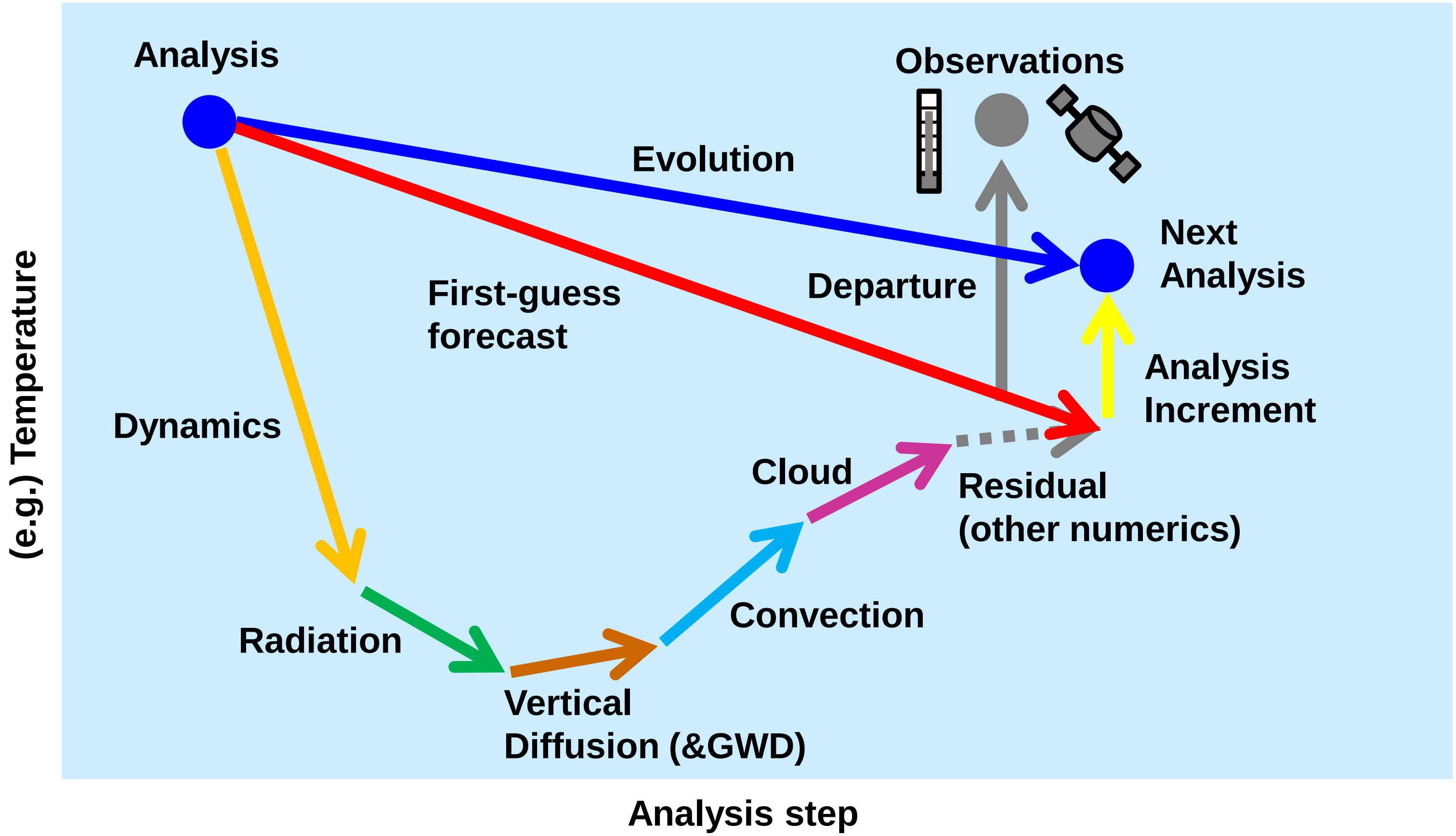


The complexity of today's models, with numerous interactions between physical processes and the resolved flow (including teleconnections), can make it very difficult to isolate the offending process(es). Single column and LES models can help, but these do not take into account the evolution of the resolved flow.

Figure from Peter Bechtold

Diagnosis of analysis & deterministic model error

Schematic of the data assimilation process – a diagnostic perspective



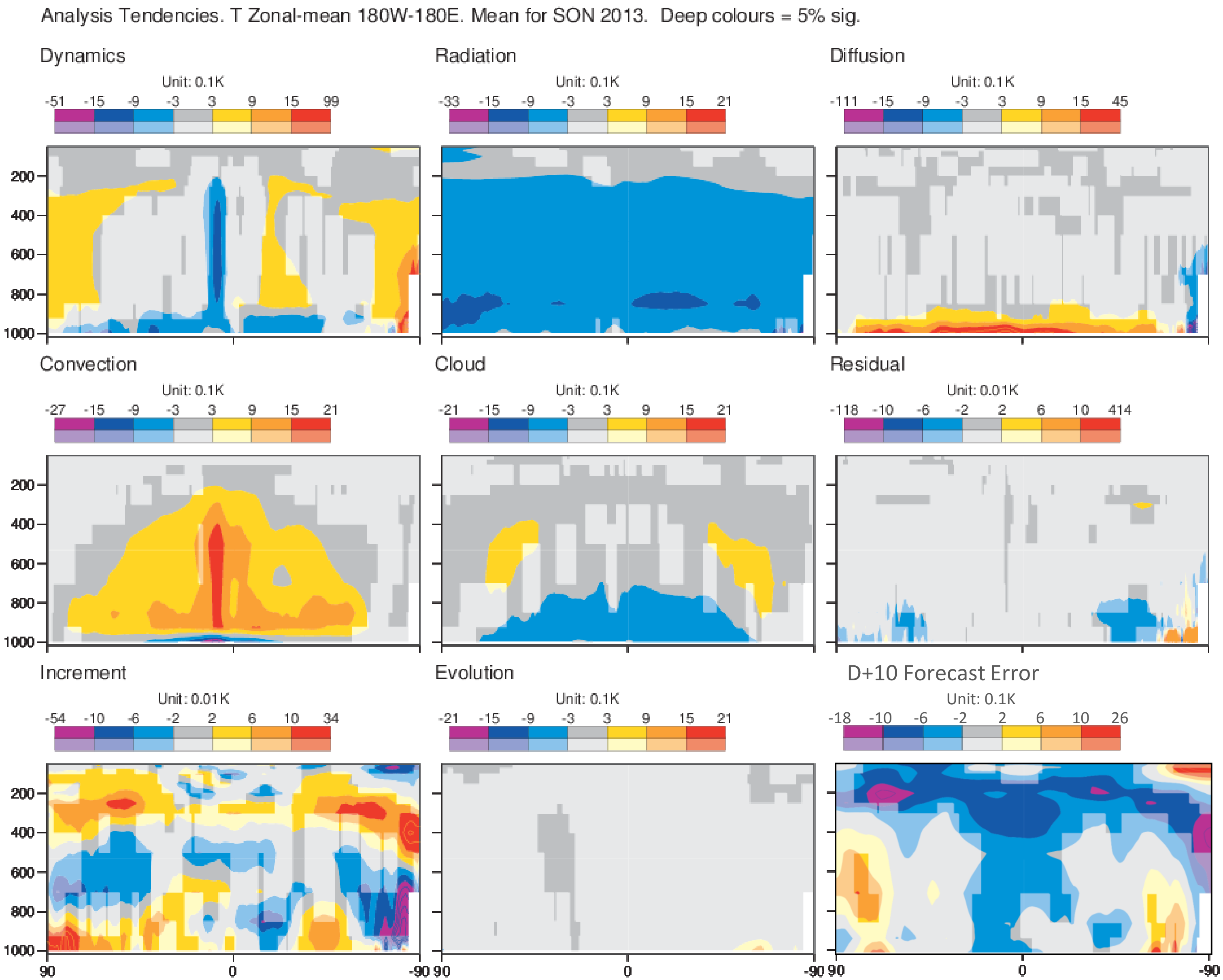
Analysis increment corrects first-guess error, and draws next analysis closer to observations.

First-guess = sum of all processes.

Relationship between increment and individual process tendencies can help identify key errors.

“Initial Tendency” approach discussed by Klinker & Sardeshmukh (1992). Refined by Rodwell & Palmer (2007)

Initial temperature tendencies and D+10 error



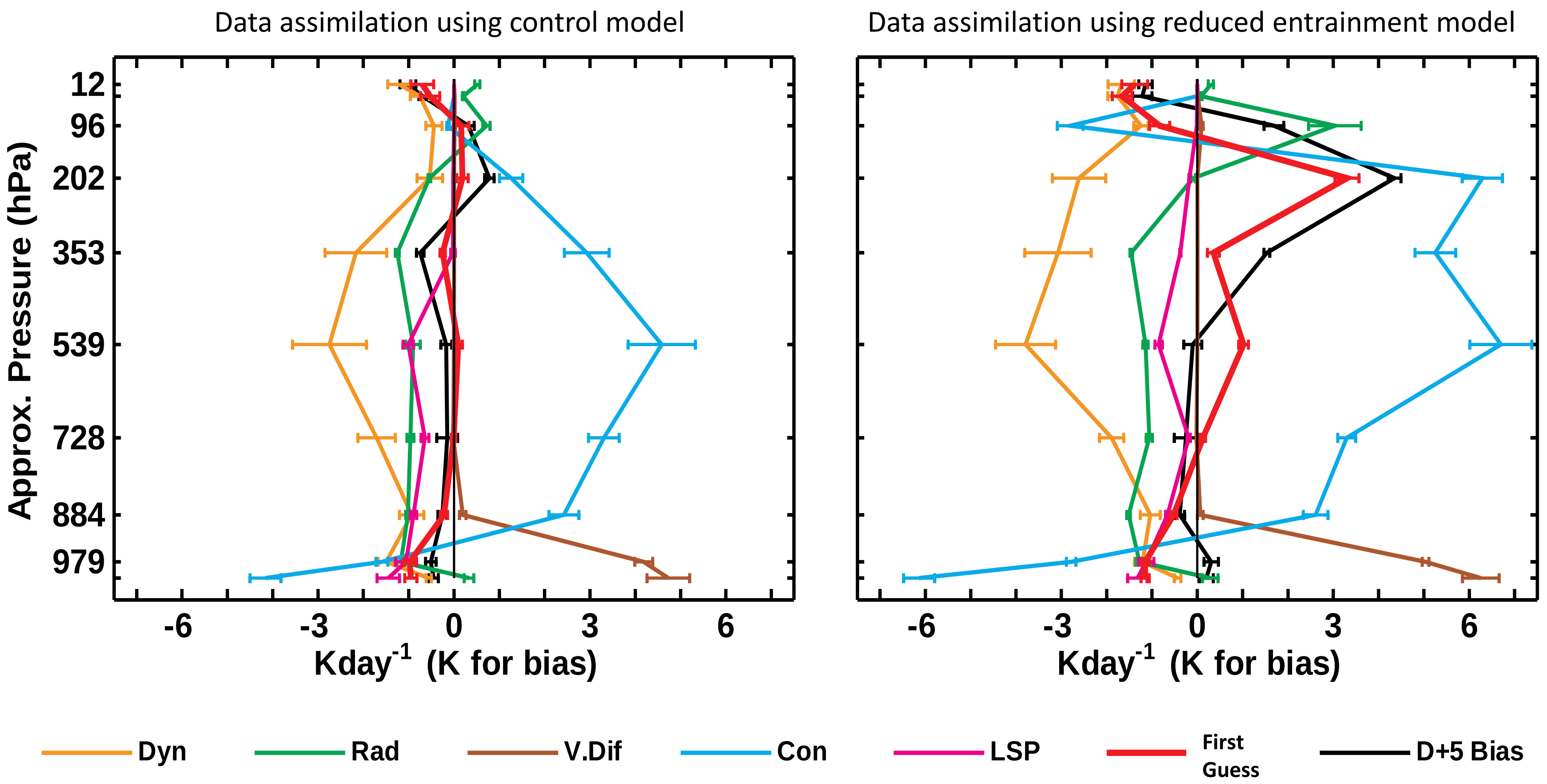
Strong upper-tropospheric increments (where radiation is not balanced by dynamics)

Error grows x10 by D+10 (due to poorly constrained humidities?)

Note that increment and residual plotted with smaller contour interval. D+10 error also has different interval.

1st example: Method questions 12K warming

Temperature tendency profiles over the Amazon (300-320ºE, 20ºS-0ºN)

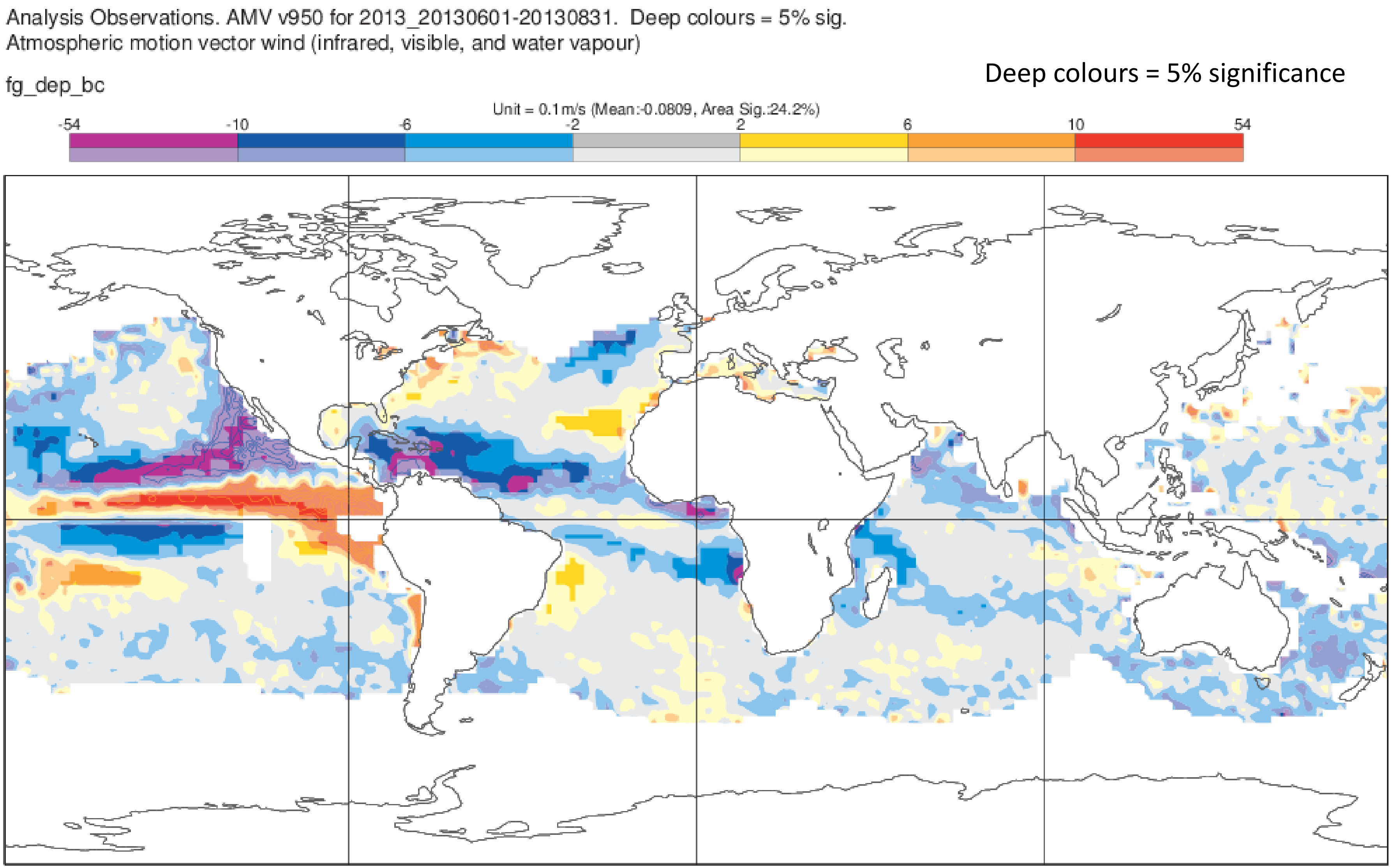


Mean first guess tendency, red, (the sum of all processes) is 'quite small': A reference value for the realism of the model's physics

Greatly increased time-mean first-guess tendency: Perturbation leads to poorer physics. Reject this perturbation from climate ensemble?

Rodwell and Palmer (2007). 6hr tendencies. 31 days (January 2005) X 4 forecasts per day. 70% conf.int. T159, L60,1800s.

2013 JJA Mean FG Departure AMV v950

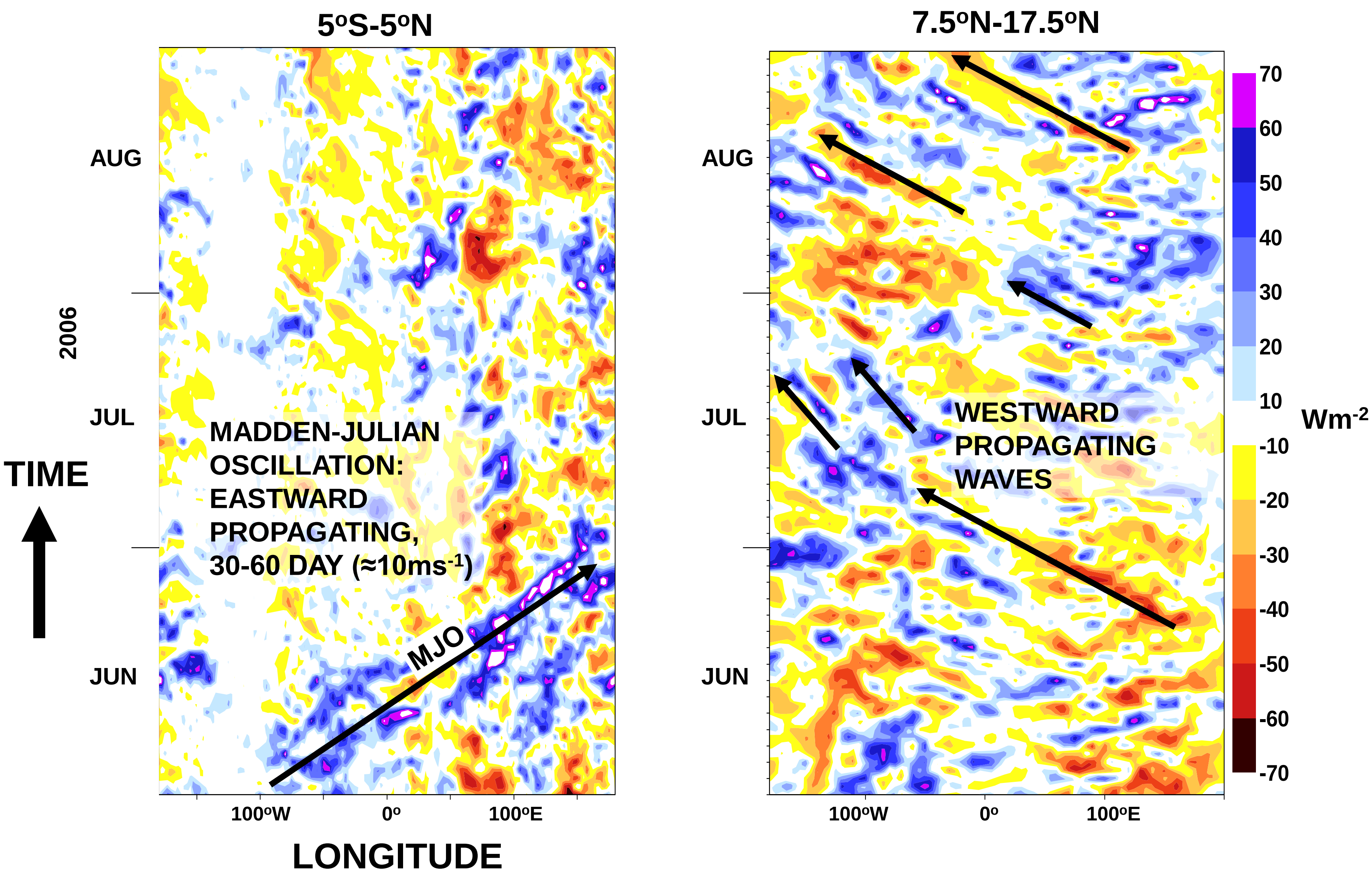


Deep colours = 5% significance

Sometimes the increments (or departures) may reflect observation issues

Waves, physical interactions and flow instabilities

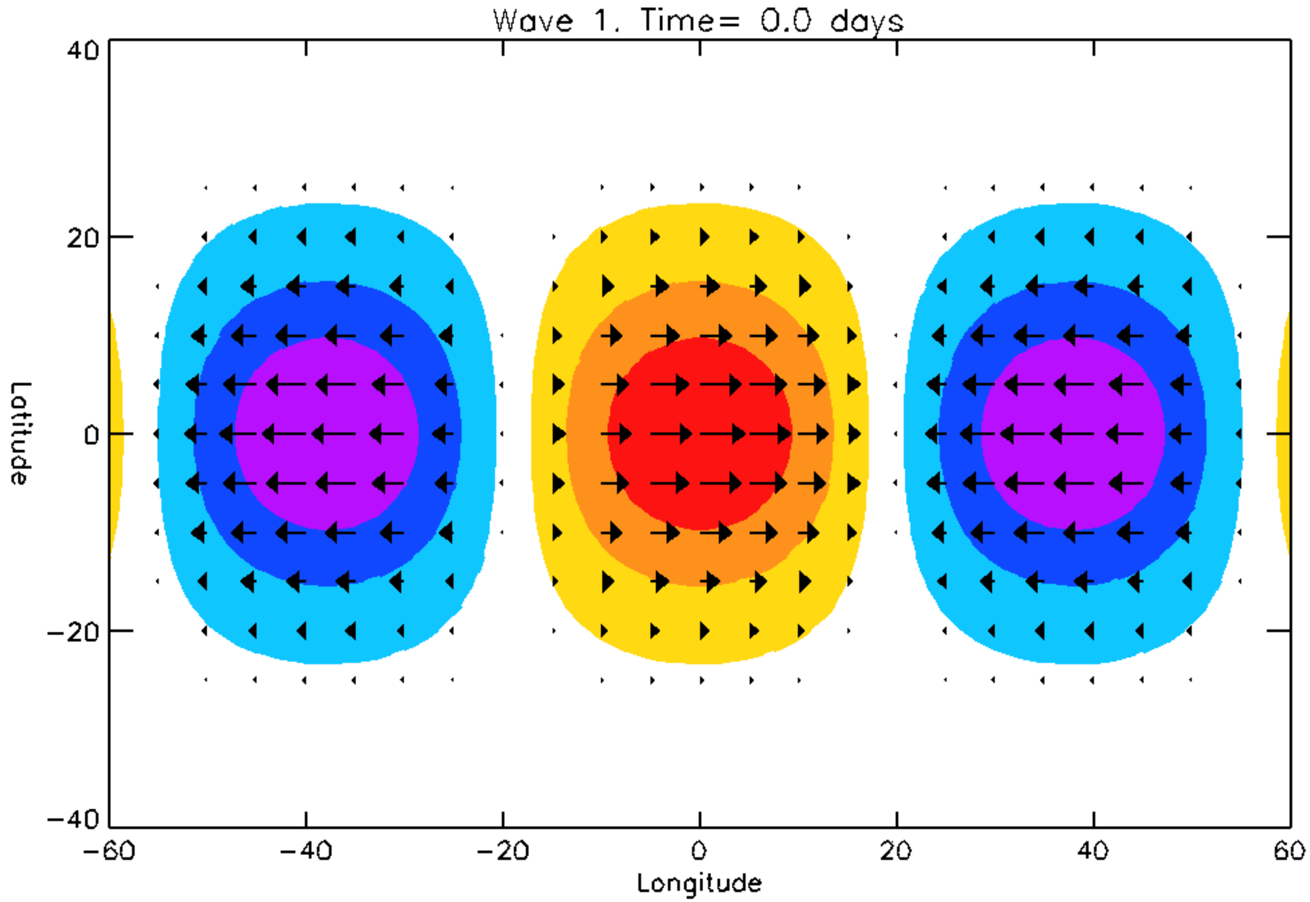
Tropical Waves: Outgoing Long-wave Radiation



Data from NOAA

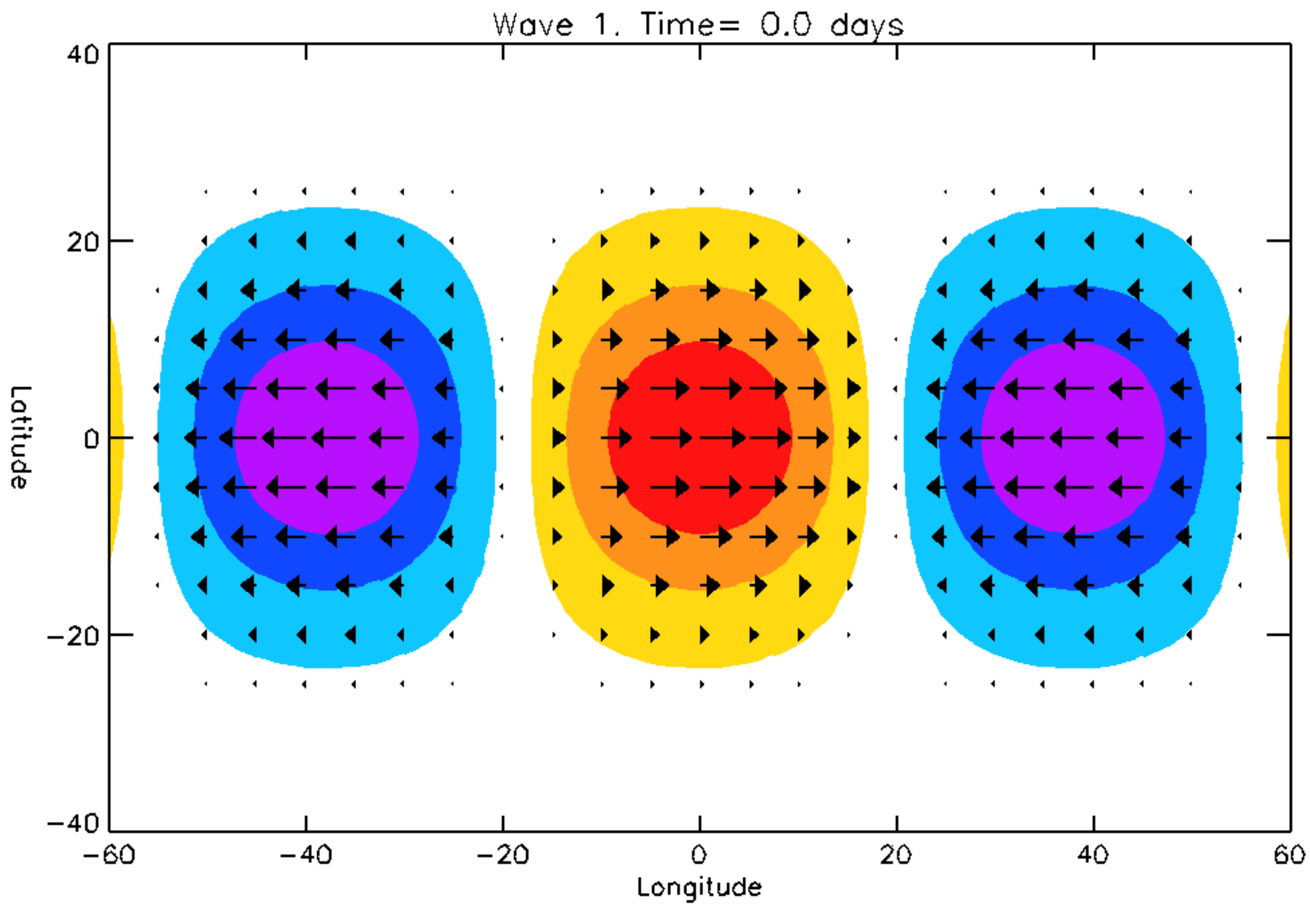
Wave Spotting: The movie

Movie of dynamical waves in the tropics (free solutions of the shallow water equations)



Colours show height perturbation (red positive, blue negative), arrows show lower-level winds
Frequency (ω) is the local rate of change of phase
Zonal wavenumber (k) is the number of waves that would fit around a latitude circle
We are interested in the meridional structure and the phase-speed ω/ k

Wave Spotting: The movie



Col winds

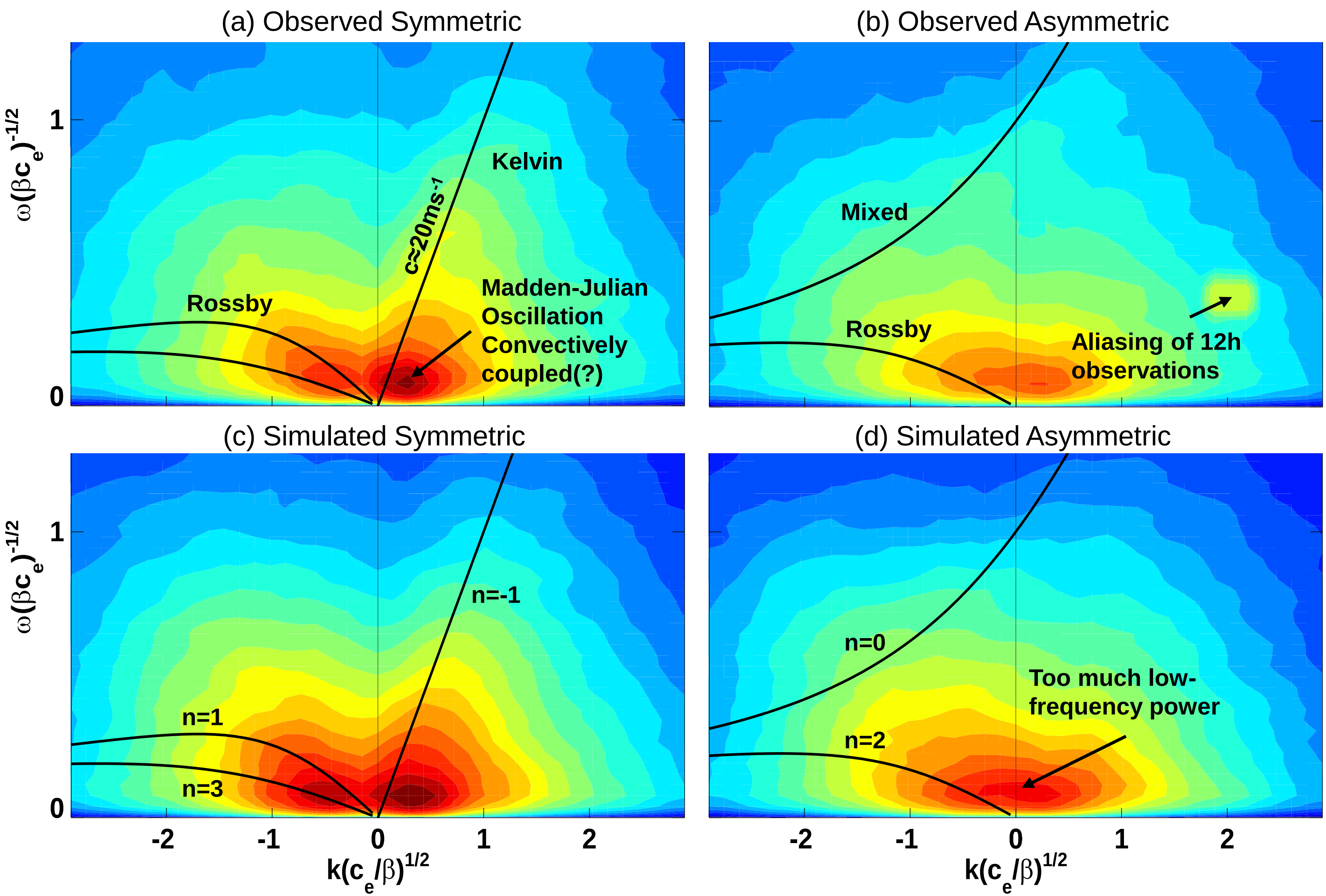
Frequency (ω) is the local rate of change of phase

Zonal wavenumber (k) is the number of waves that would fit around a latitude circle

We are interested in the meridional structure and the phase-speed ω/ k

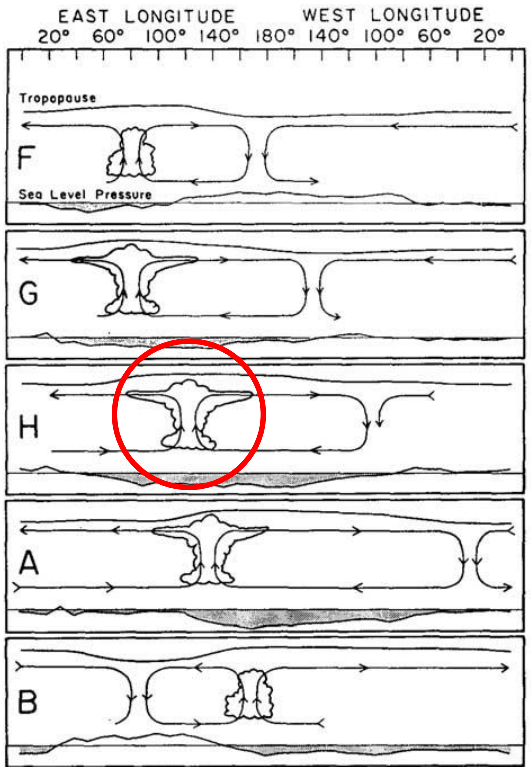
Movie of equatorial waves based on shallow-water equations (shortened version 1m 30s)

Wave Power OLR DJF 1990-05 NOAA & 32R3

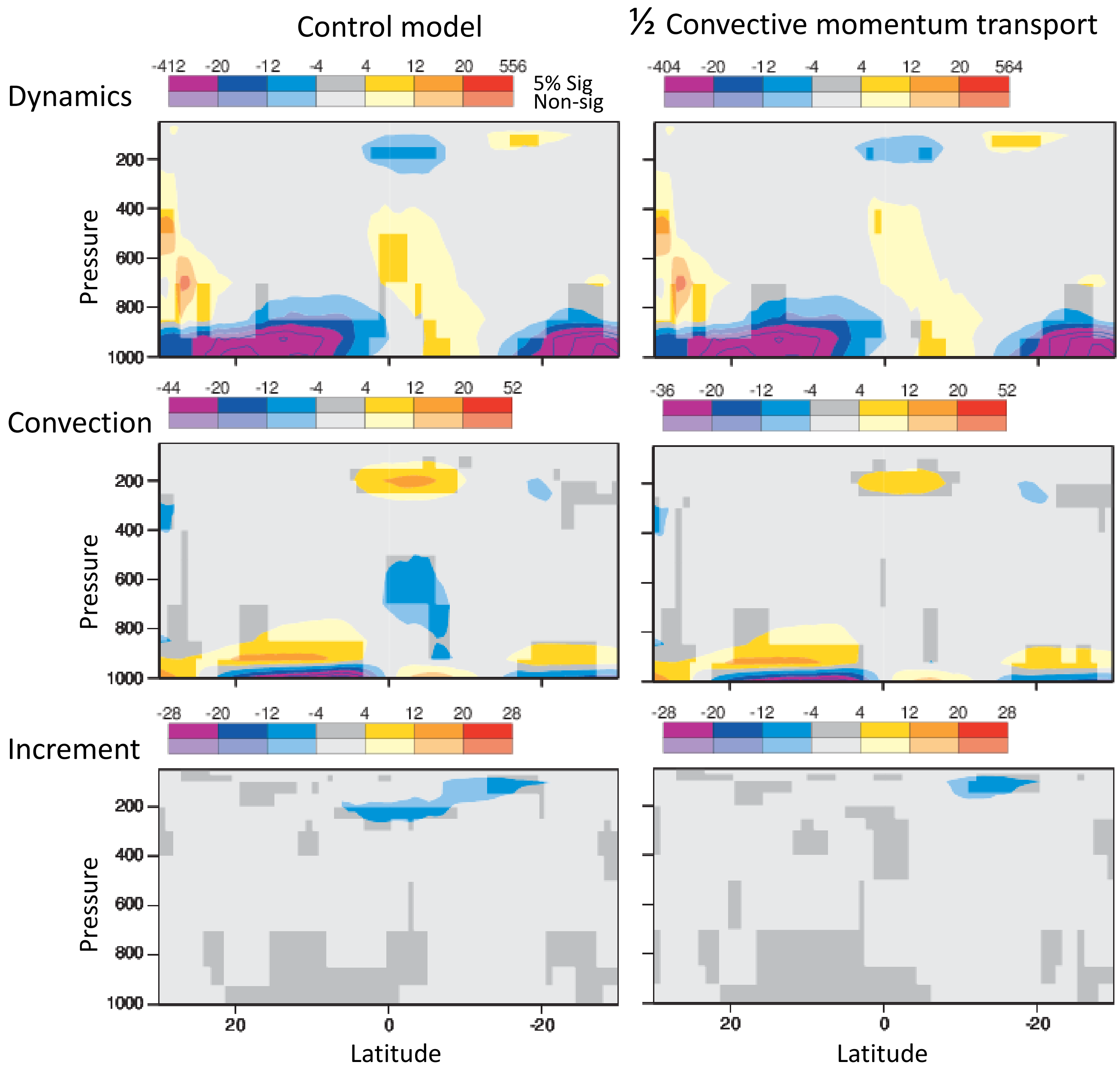


Agreement with shallow-water theory if OLR is “slave” to the free waves, linearity etc.

Mean zonal wind tendency (60-180ºE) during MJO



From Madden and Julian (1972)

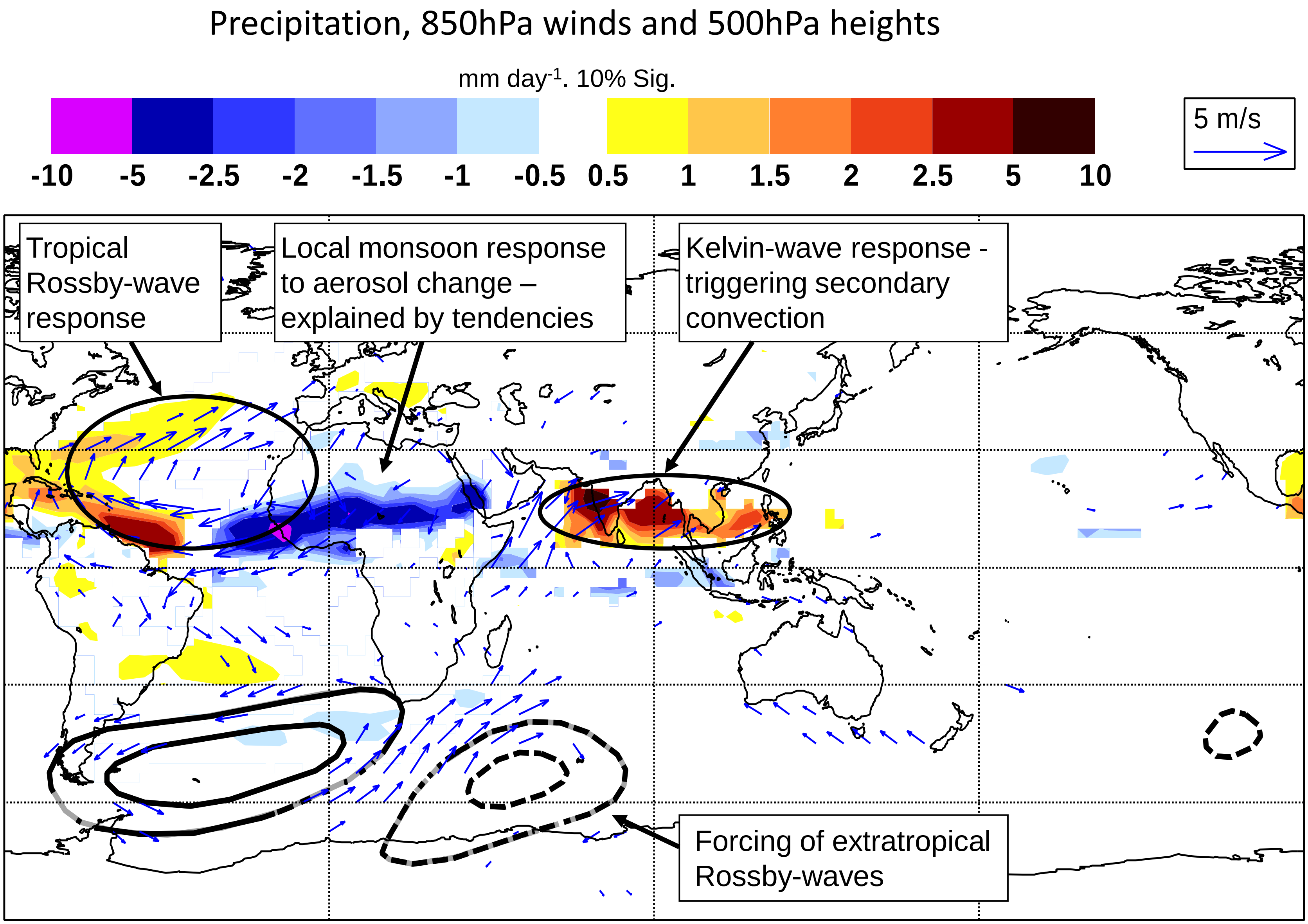


Period : 20130201-27 (MJO convection active over warm-pool)

Better balance with dynamics when convective momentum transport is halved

Work with Peter Bechtold, Anton Beljaars , Jian Ling, Philippe Lopez, Frederic Vitart & Chidong Zhang

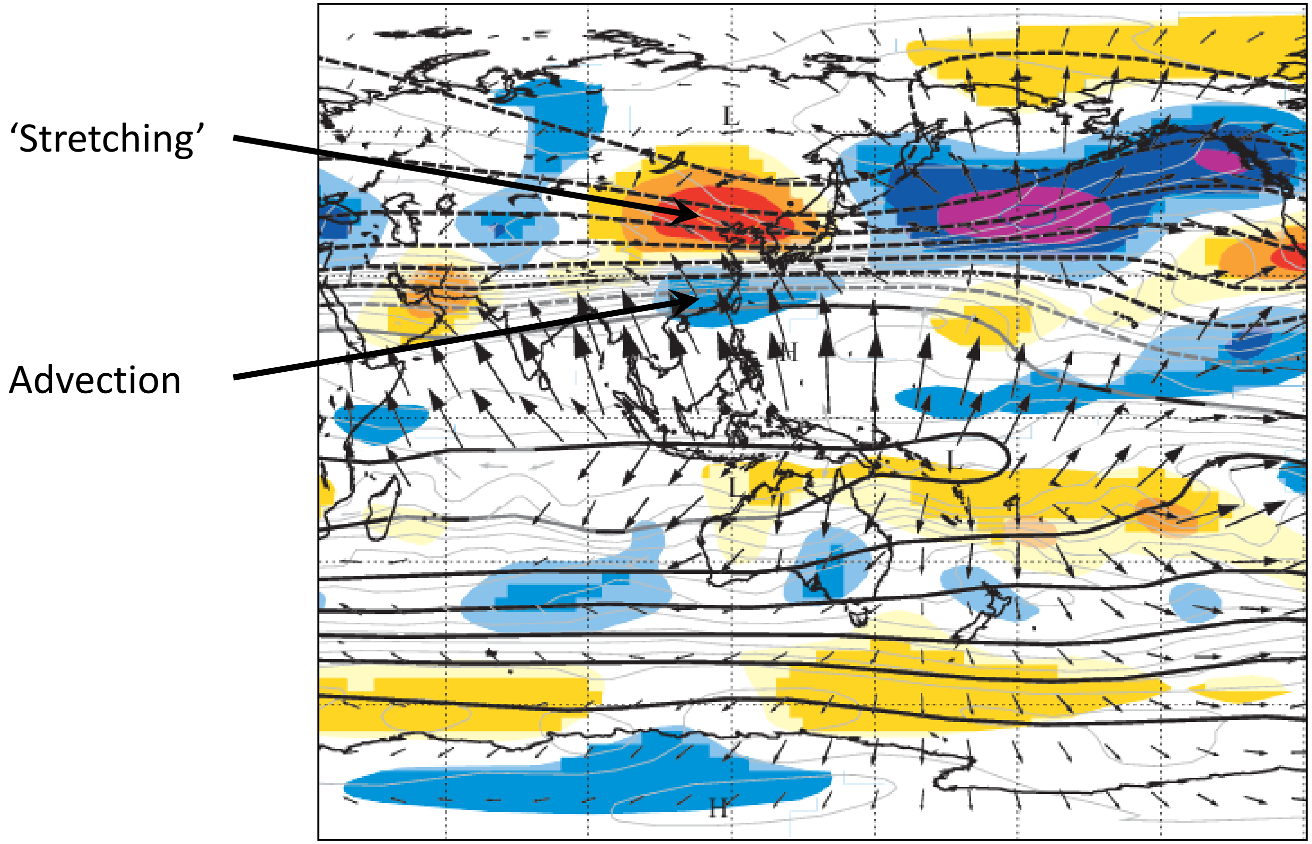
Model climate response to Sahara aerosol change



Rodwell and Jung (2008). JJA season response to (primarily) a reduction in aerosol over the Sahara

'Stretching' and vorticity advection from Tropics

Rossby Wave Source: shading unit = 10^{-11} s^{-2} . Streamfunction: contour interval = $2x10^7$ m^2s^{-1}. Divergent wind vectors

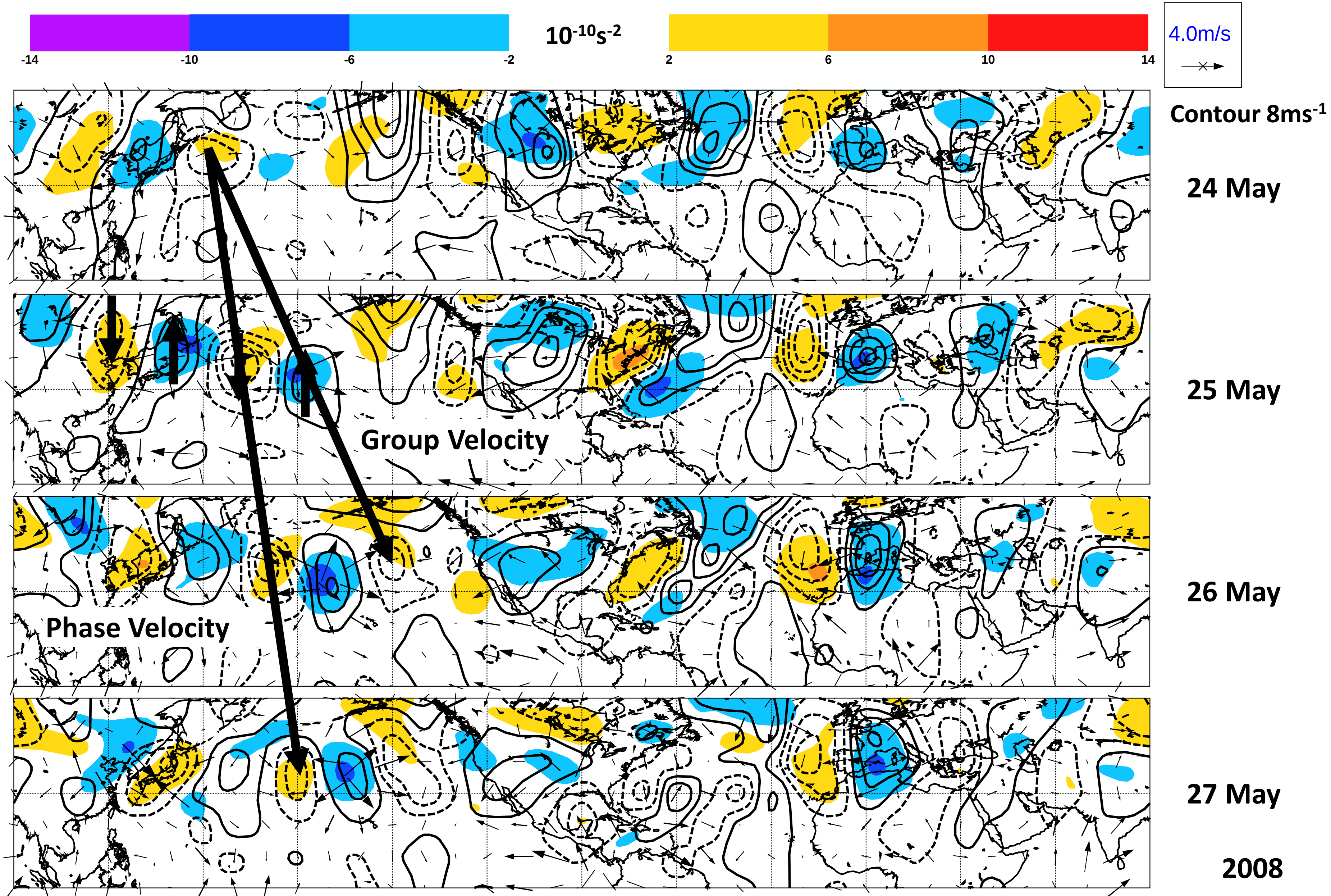


Mean errors in stretching and advection account for ⅓ to ½ of RMSE of vorticity forcing at day-1

Reducing in this mean error should improve prediction of stormtracks

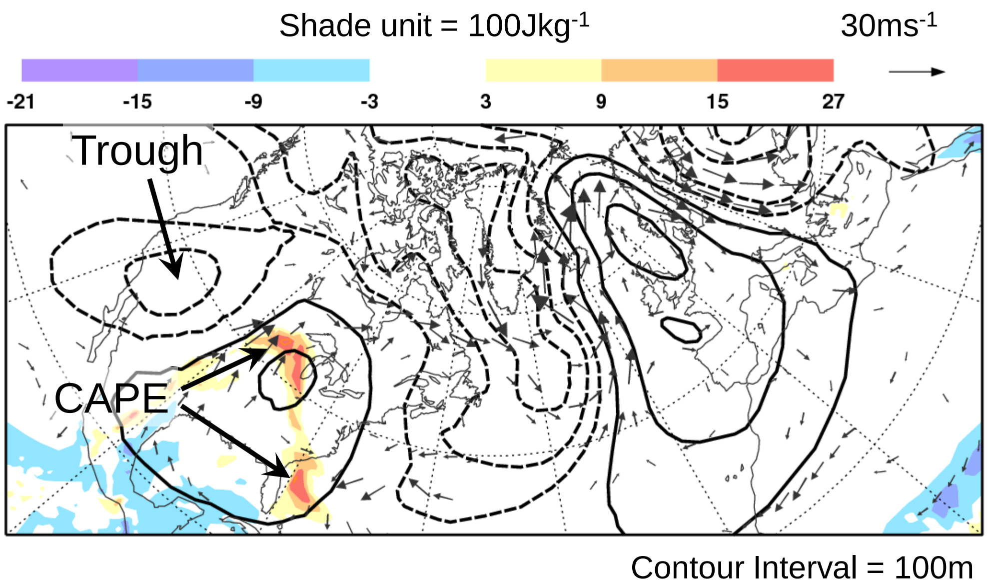
All integrated 100-300hPa, DJF 2012/13

Extra-tropical waves. 300–100 hPa v_ψ, $\underline{v}_\chi$ & RWS

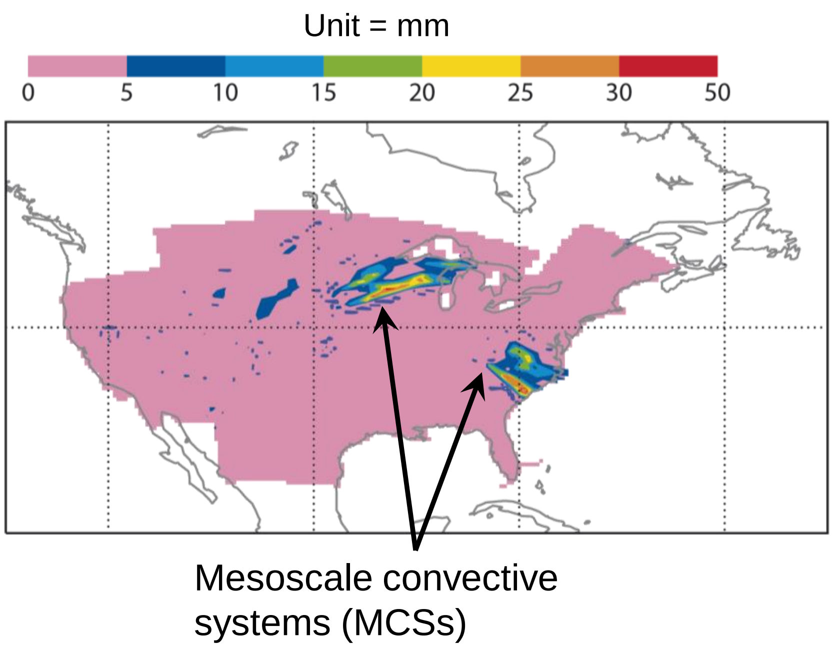


10 April Rockies trough with CAPE & MCS ahead

Z500 and CAPE anomaly



12-hr Radar-observed precipitation

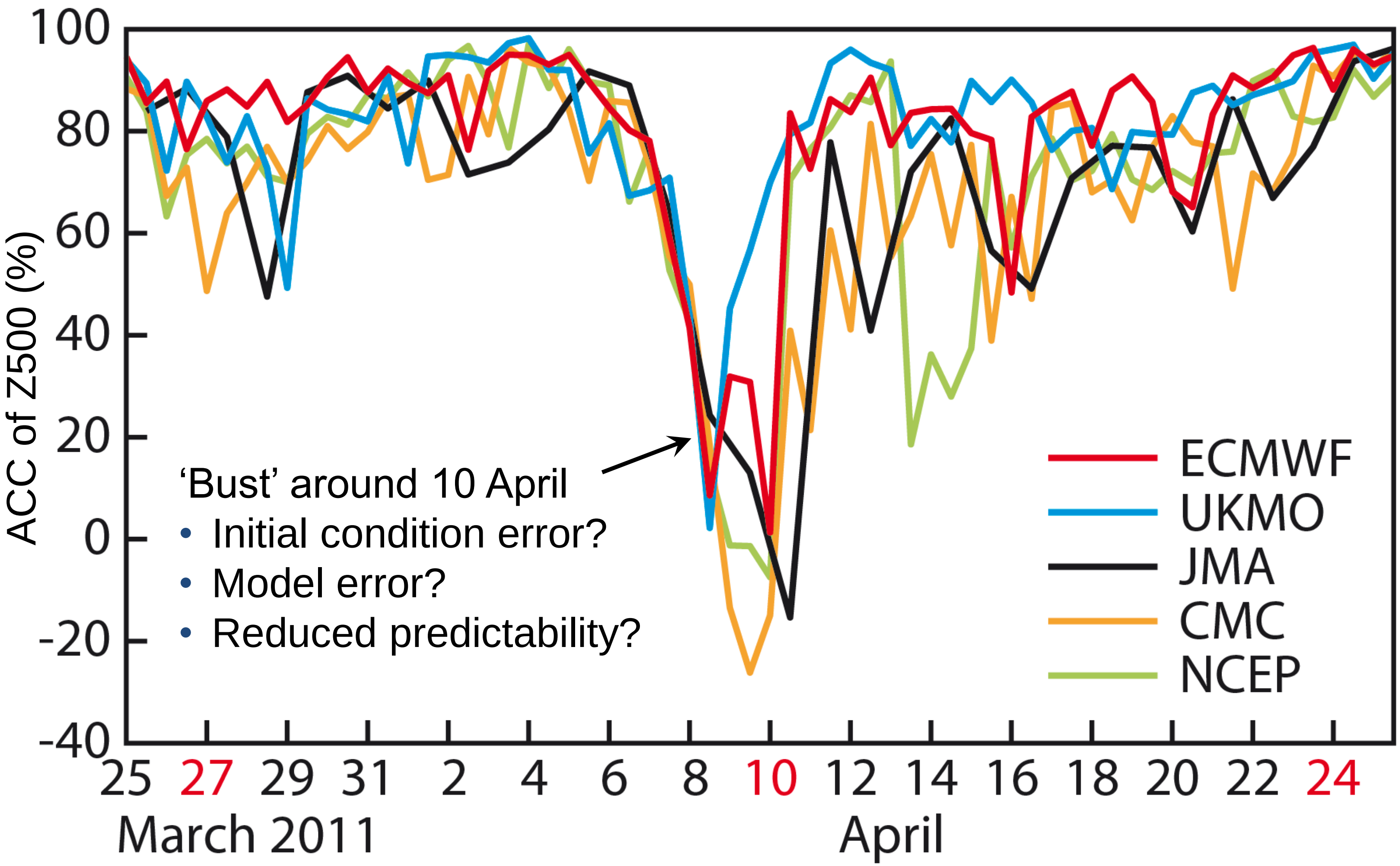


Rodwell et al. (2013)

Anomalous trough over Rockies with warm moist advection and MCSs ahead
MCSs over northern North America can disrupt the upper-level Jet Stream

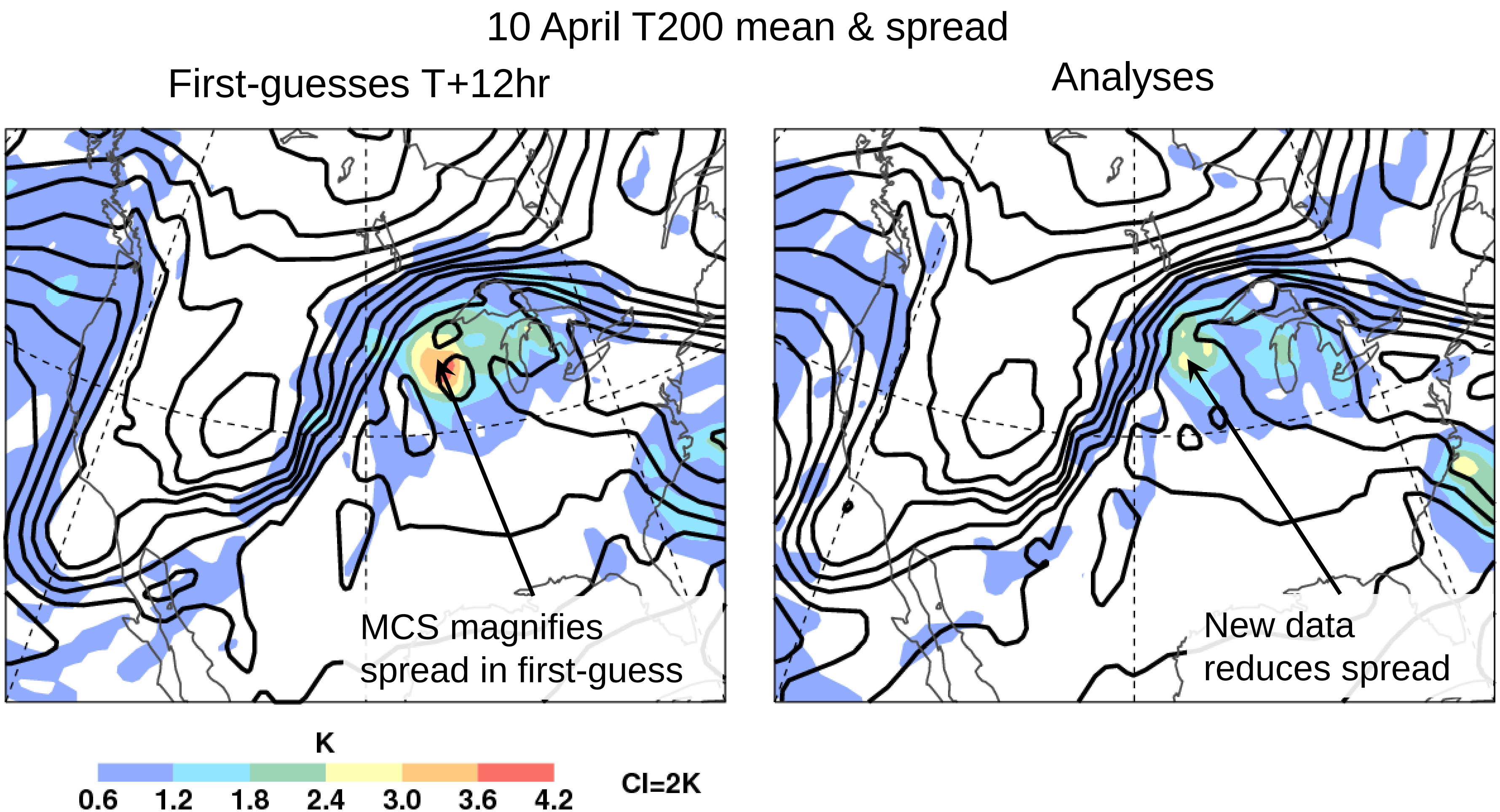
Z500 at 0UTC, CAPE at 6UTC (T+6), 12hr 'NEXRAD' Radar precipitation accumulated to 9 UTC

Skill of single forecasts (Europe, leadtime = 6 days)



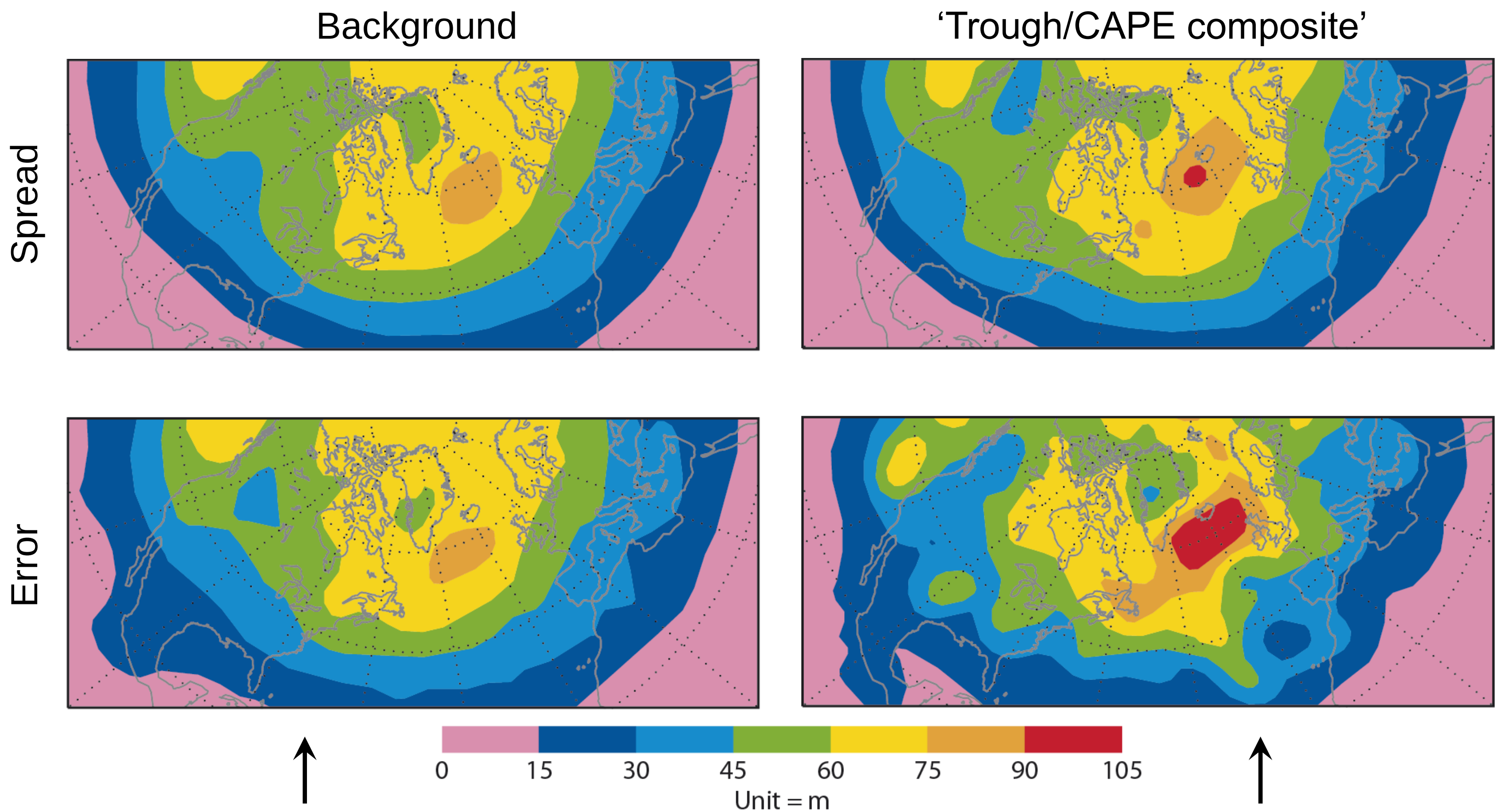
Score is the spatial Anomaly Correlation Coefficient (ACC)x100 for 500 hPa geopotential height (Z500) over Europe (12.5ºW –42.5ºE, 35ºN–75ºN). The date shown is the forecast start date

Ensemble of data assimilations, EDA



The ensemble of first-guess forecasts develops spread over the first 12 hours associated with uncertainties in the prediction of a mesoscale convective system. The incorporation of new observations by the ensemble of data assimilations results in a contraction of the spread. Key question: Is the final analysis spread too large or too small to correctly reflect the predictability of the subsequent flow? Data: Temperature at 200 hPa from 10-member EDA, valid at 6UTC.

Composite ensemble spread & error (Z500 at day 6)



Error ≈ spread (system 'reliable' in the mean). *e.g.* stormtrack

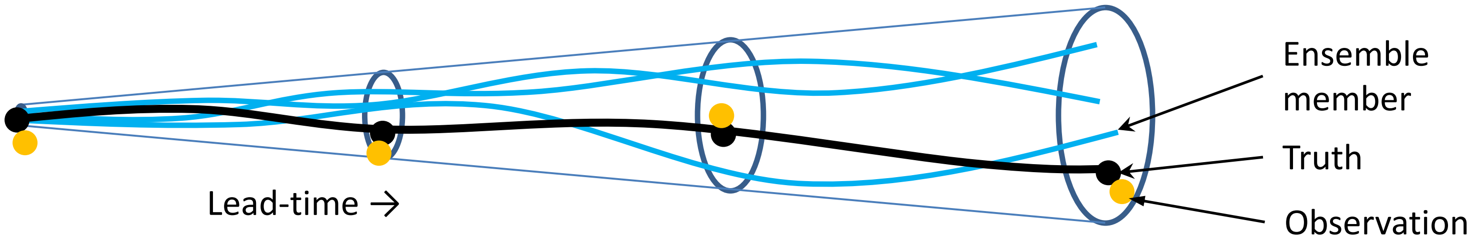
30% increased error. Spread not fully predicting the reduced predictability?

Composite over all 84 events 10 November 2010 – 20 March 2012 (0 or 12UTC) with a strong trough over the Rockies and positive CAPE ahead. 'Error' is RMSE of ensemble-mean (dominated by random component), 'Spread' is ensemble standard deviation, scaled for finite ensemble

EDA reliability budget

The goal of probabilistic forecasting

Reliability at all ranges requires good representation of error growth (sensitive to Stochastic Physics)



Ensemble-mean error^2 ≈ Ensemble variance

Not clear how well we know the truth, so think in terms of observations

For forecast i, write:

$Error_i$	≡ Ensemble-mean minus observation
$EnsVar_i$	≡ Ensemble variance
$ObsUnc_i$	≡ Estimated standard-deviation of observation error
Bias	≡ Mean Error (over all forecasts)

Averaged over sufficient number of forecasts

$$Error^2 = Bias^2 + EnsVar + ObsUnc^2 + Residual$$

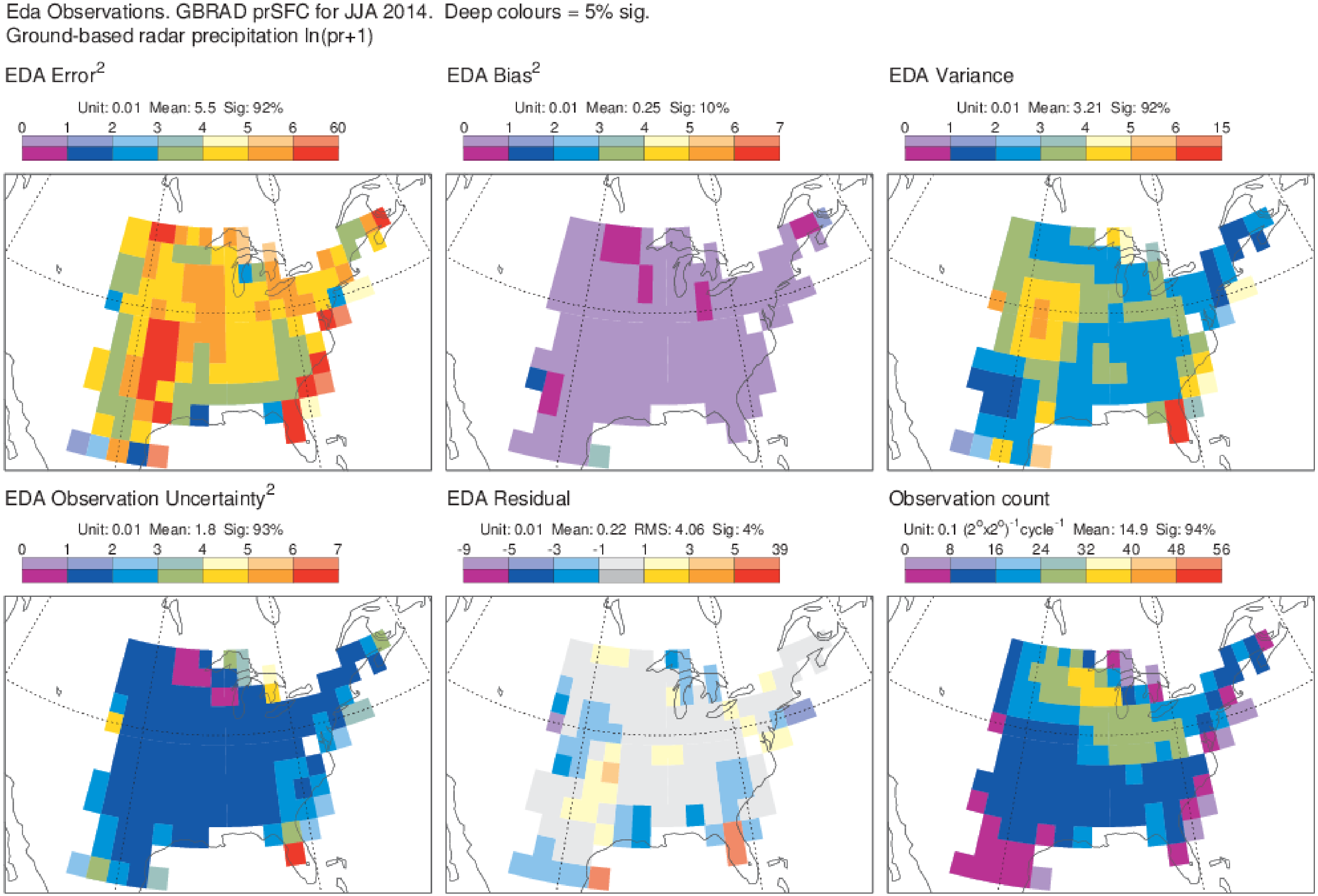
Where the residual is a measure of the lack of reliability

At short lead-times (EDA background forecasts)

Before waves propagate information, so a *local* assessment of Stochastic Physics (and ObsUnc)

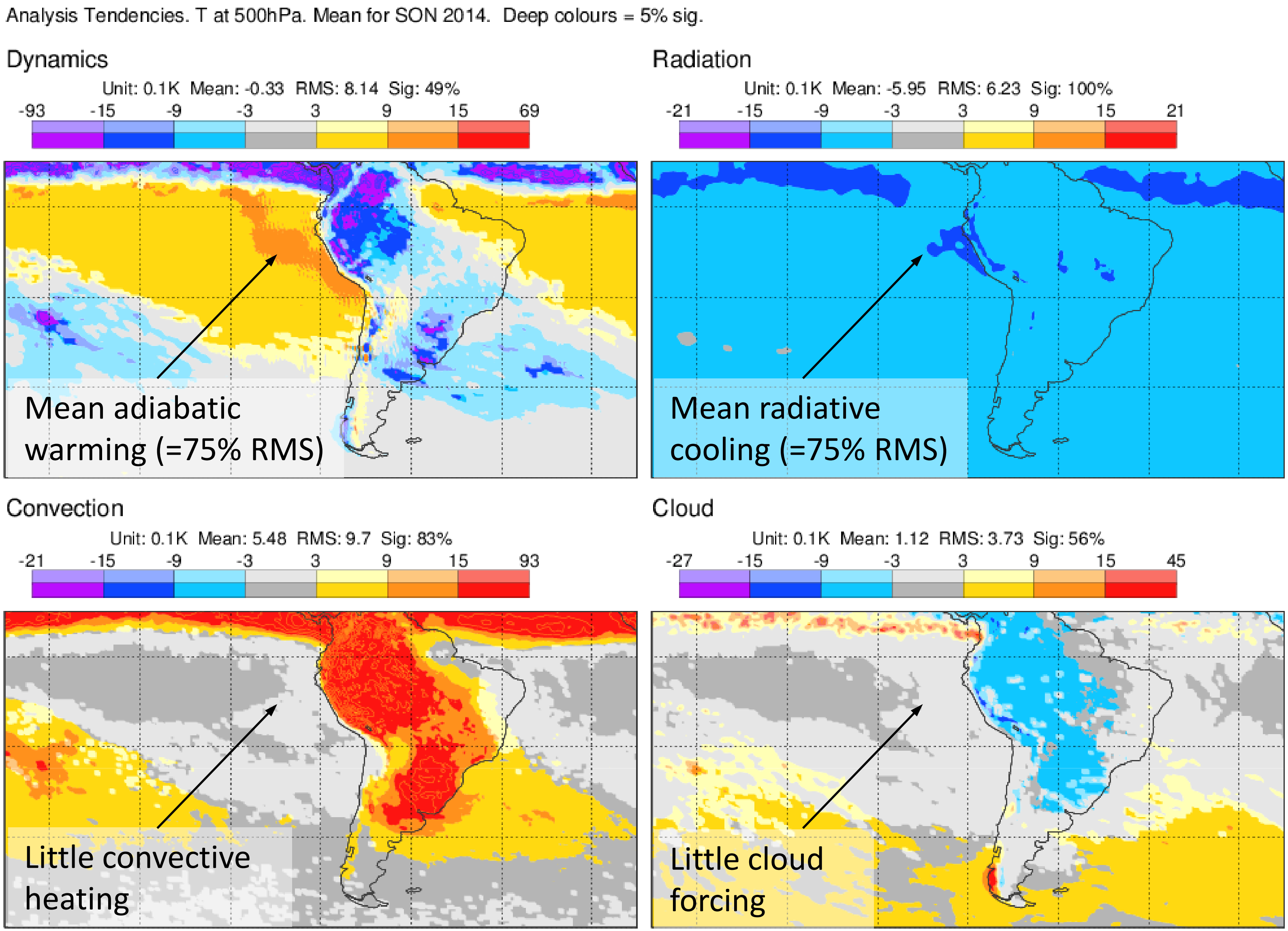
$Error^2$, EnsVar , $ObsUnc^2$ have similar magnitudes, so assessment of all aspects

EDA reliability budget: Radar precipitation rate



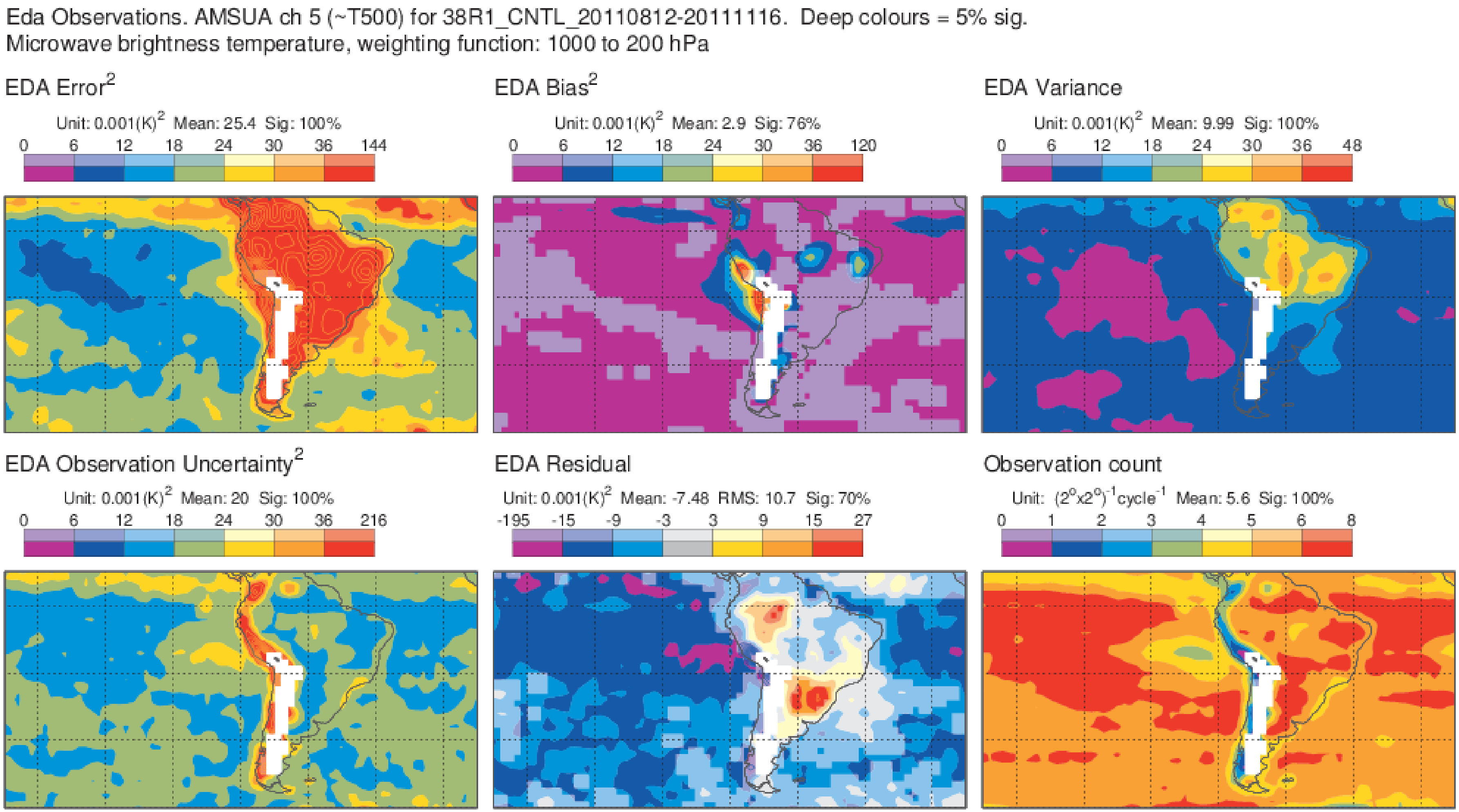
Error^2 largely accounted-for by EDA variance and Observation Uncertainty^2: Consistent with reliability

Time-mean initial process tendencies (T500)



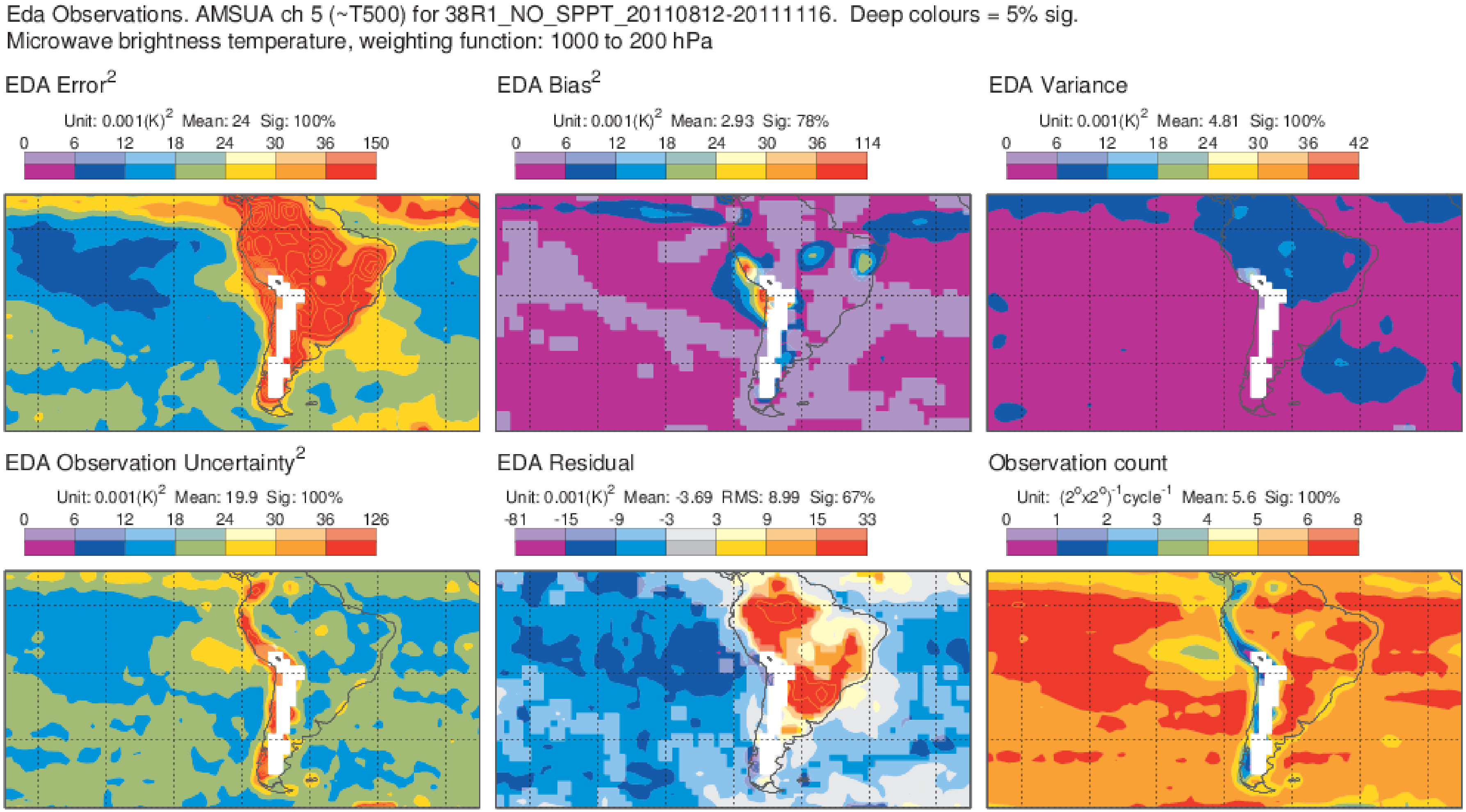
Is physics in subtropical anticyclones as uncertain as Stochastic Physics treats it?

EDA reliability budget: Satellite microwave (~T500)



Reference experiment (2 members) reproduces negative residuals within subtropical anticyclones

Reliability budget: ~T500 (no Stochastic Physics)



- Improved reliability within subtropical anticyclones, but convective regions worse
- Key result: EDA reliability budget *is* sensitive to *local* changes in Stochastic Physics
- Note that Obs Error assignment also likely to be an issue in this budget (better in new IFS cycle)

Summary

- Forecast error
  - Model error or initial uncertainty?
- Initial tendencies
  - Local assessment of a model physics (and dynamics)
  - Can help identify root-causes of errors
- Waves, physical interactions, and flow instabilities
  - MJO
  - Forecast busts
- EDA reliability budget
  - Local assessment of reliability
  - Need for meteorologically-aware Stochastic Physics