Introduction to parametrization development

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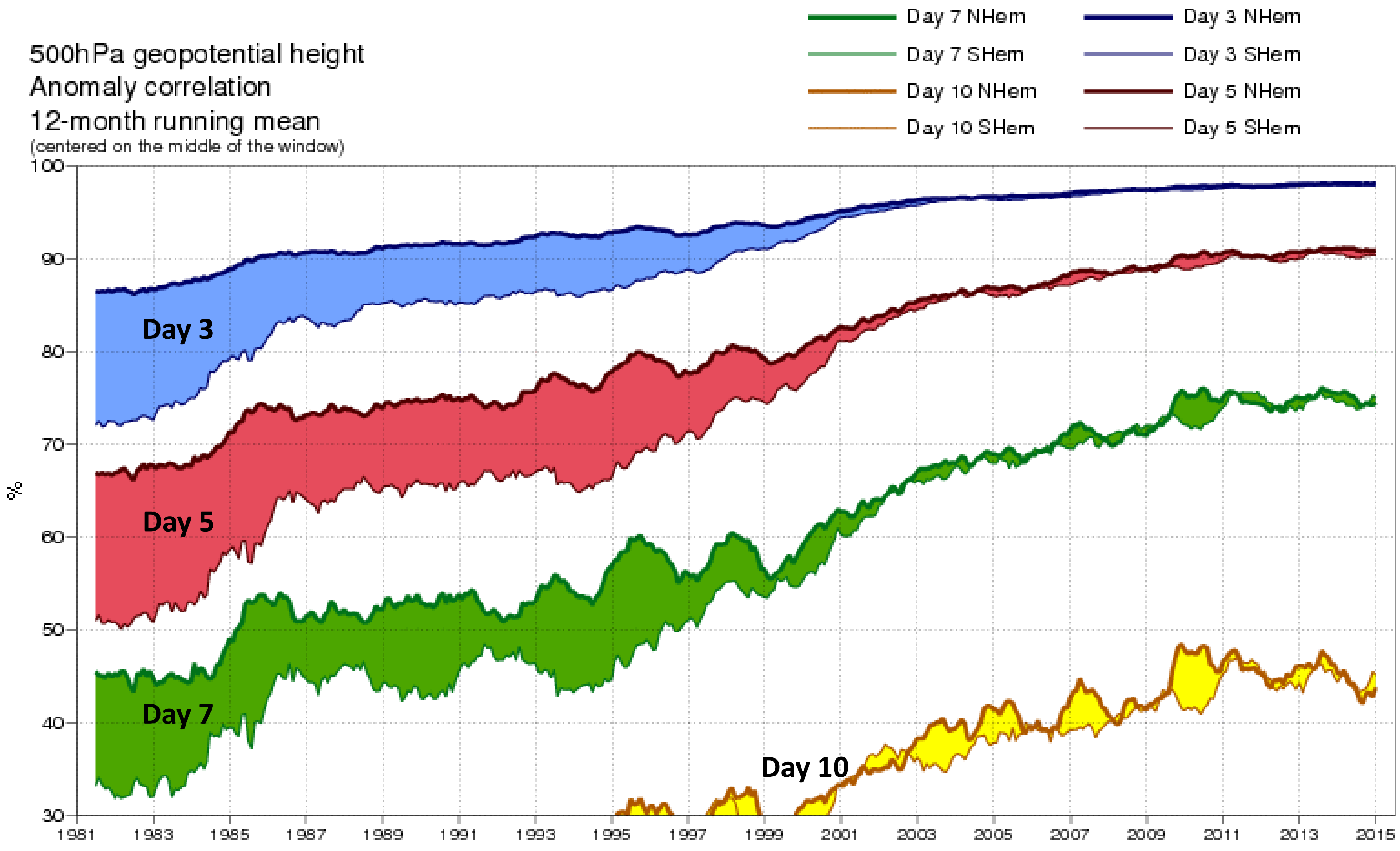
Thanks to: The ECMWF Physics Team and many others

Outline

- Introduction
- Physics related applications
- Does a sub-grid scheme have the correct dependency on environmental variables? Examples:
  - 2m temperature errors
  - Convection
- Interactions between schemes. Example:
  - Precipitation / evaporation feedback over land
- Future directions

Evolution of anomaly correlation of 500 hPa geopotential at ECMWF



Physics related model output

Parameters:

- Wind (profiles, 10m, 100m, gusts)
- Near surface temperature, dew point
- Land surface variables: soil moisture, snow, temperature, lake variables, runoff, turbulent fluxes, pot. evaporation
- Ocean fluxes
- Radiative fluxes (net, downward, diffuse, direct, PAR, UV)
- Precipitation (rain, snow, convective/large scale, super-cooled)
- Convective indices
- Clouds (ice, water, fraction)
- Boundary layer height

Examples of applications:

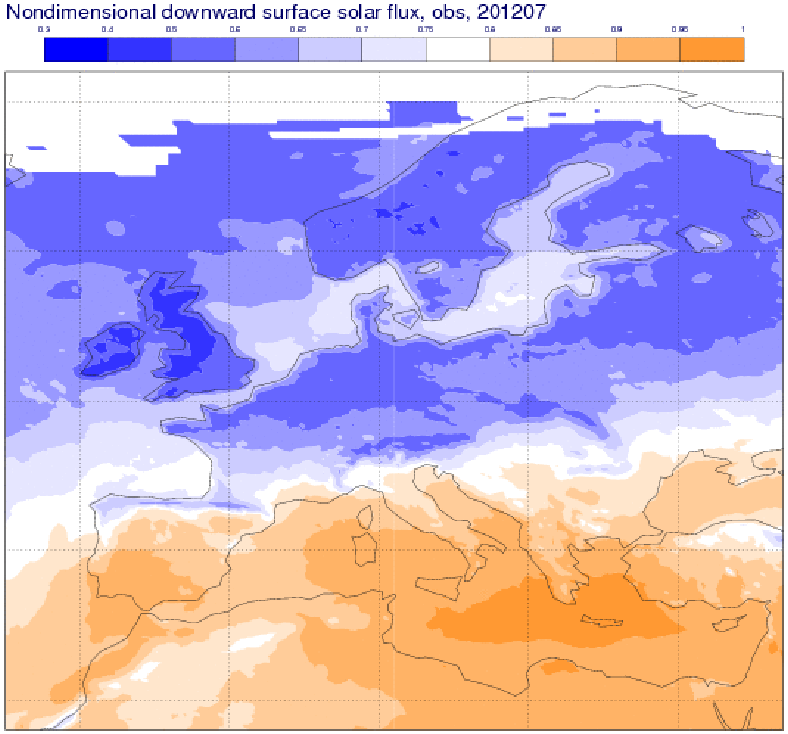
- Warnings, wind energy
- General forecasting, extremes
- Hydrology, agriculture, climatology
- Oceanography, climatology
- Warnings, agriculture, solar energy
- Warnings, general forecasting
- Warnings
- General forecasting, aviation
- Air pollution applications, tracer modelling

Day when precipitation score (1-SEEPS) drops below 0.45

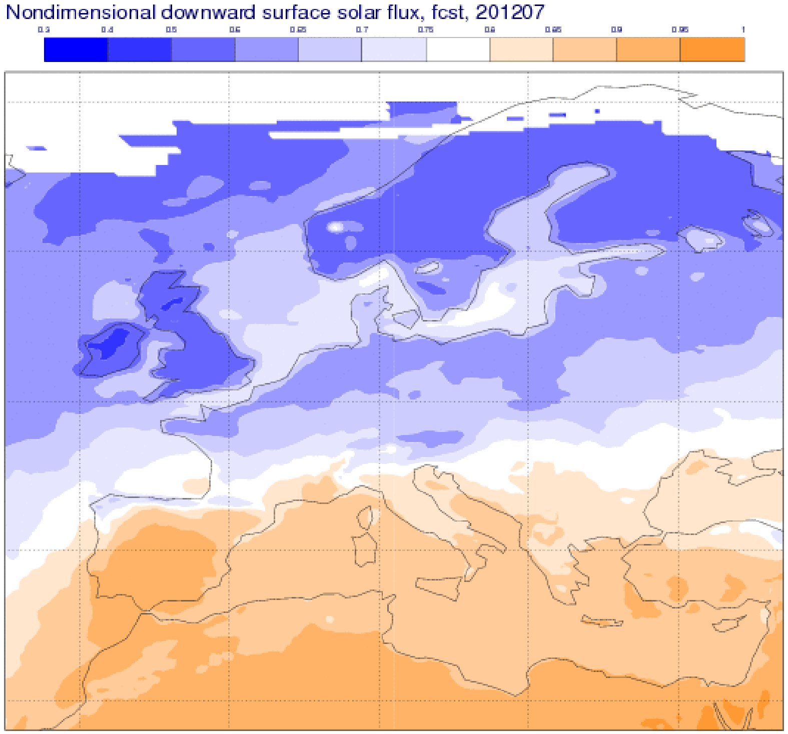
36r4 (09/11/2010):
- 5-species prognostic cloud scheme
- Refinement of all-sky radiance assim.
- Convection entrainment change
- SEKF for SM and OI for snow analysis

Cloud verification using Climate SAF product of solar downward radiation

Climate SAF JJA 2012



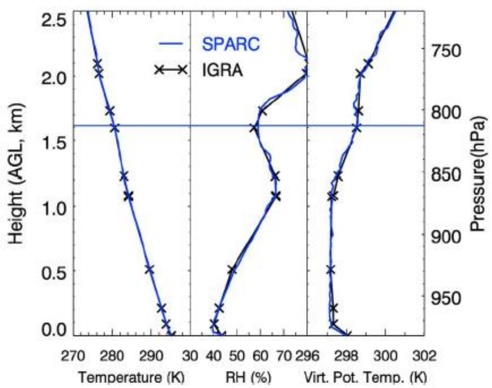
24-hour forecasts JJA 2012



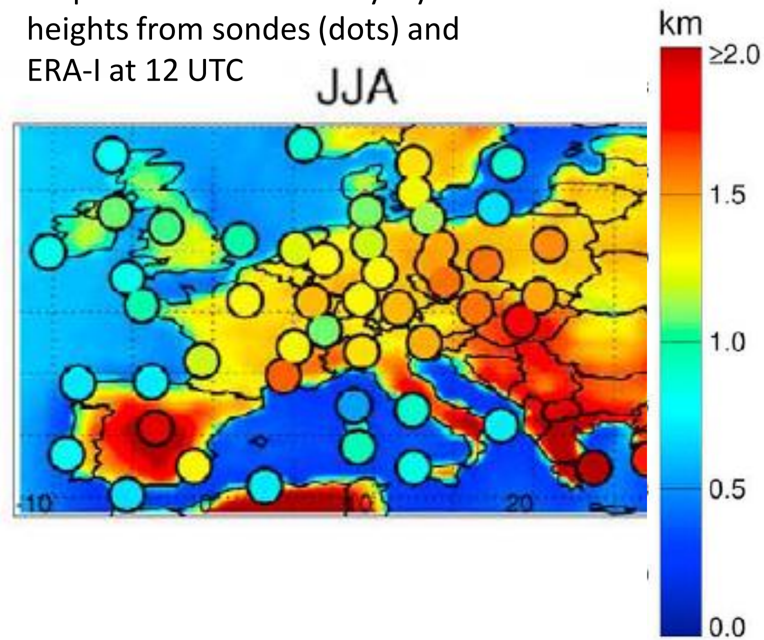
Downward solar radiation normalized with clear sky value

Boundary layer height

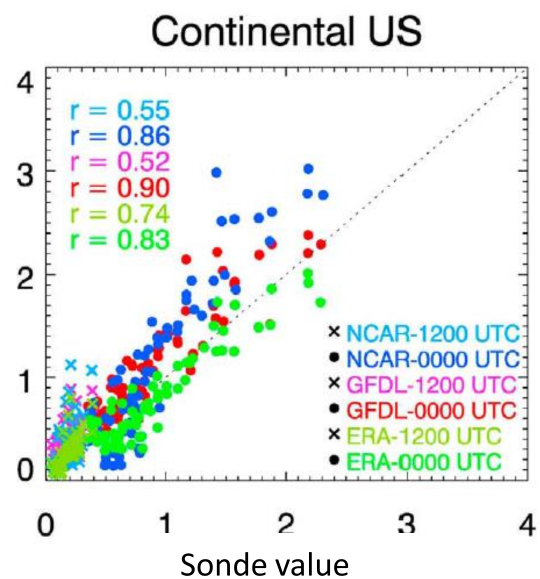
Boundary height diagnosed from sonde profiles and model level data using Ri-number criterion



Map of median boundary layer heights from sondes (dots) and ERA-I at 12 UTC



Climatological annual mean boundary layer height from different models and ERA-I



Seidel et al. (2012): Climatology of the planetary boundary layer over the continental United States and Europe, JGR, 117, D17106.

How to develop parametrization

Parametrizations express the tendencies due to subgrid processes in terms of resolved variables.

Develop scheme based on:
- Theory
- Observations
- Fine scale models

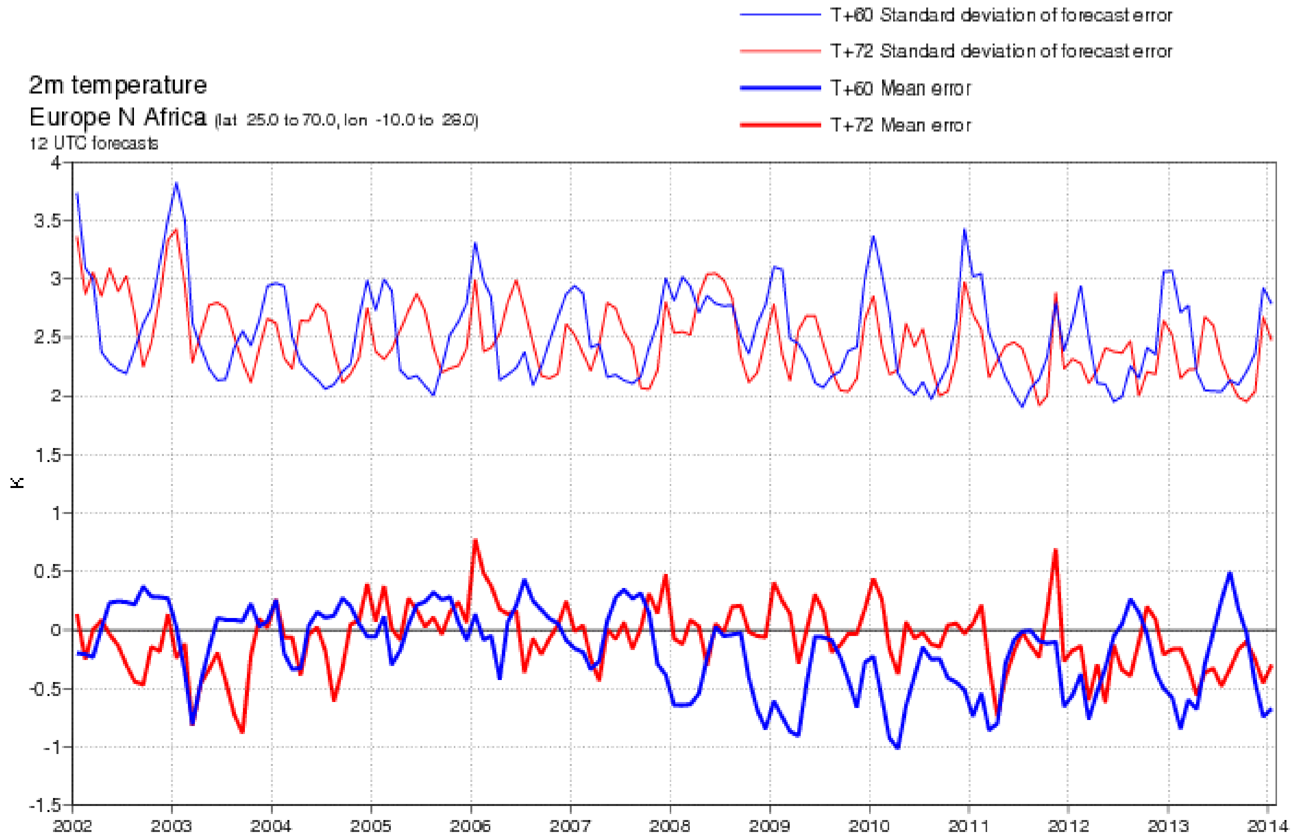
Dependencies are crucial, e.g. clouds depend on RH, turbulence on stability, etc.

Test extensively in:
- Single column
- Short range
- Climate
- Consider interactions between processes
- Consider feedbacks

Adjust parameters on the basis of final results (tuning / inverse modelling / variational optimization)

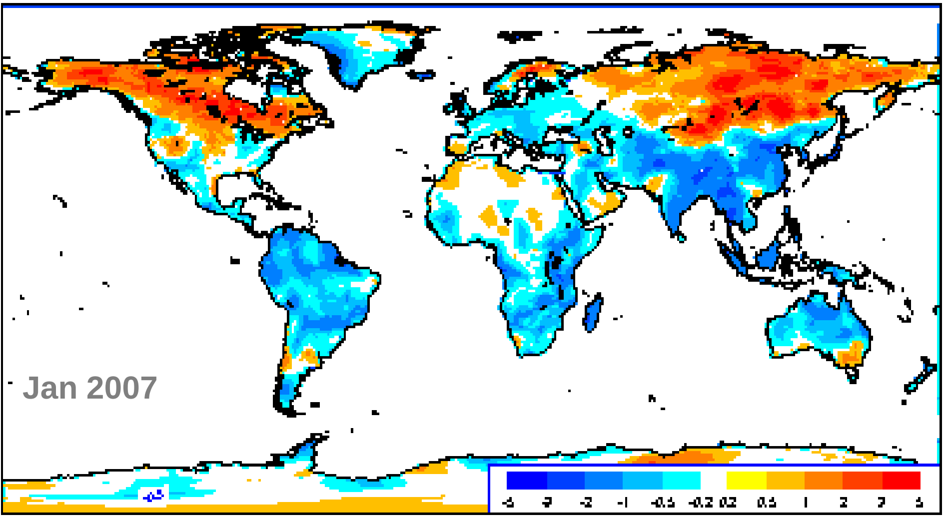
- Some of today's random errors will turn out to be systematic errors in future; we are just missing or misrepresent a dependency
- The model error representation in the ECMWF ensemble system introduces spread related to random model errors, and some of these are hidden systematic errors

Evolution of 0 and 12 UTC 2m temperature errors over Europe (Bias and RMS) : Are the errors systematic or random?

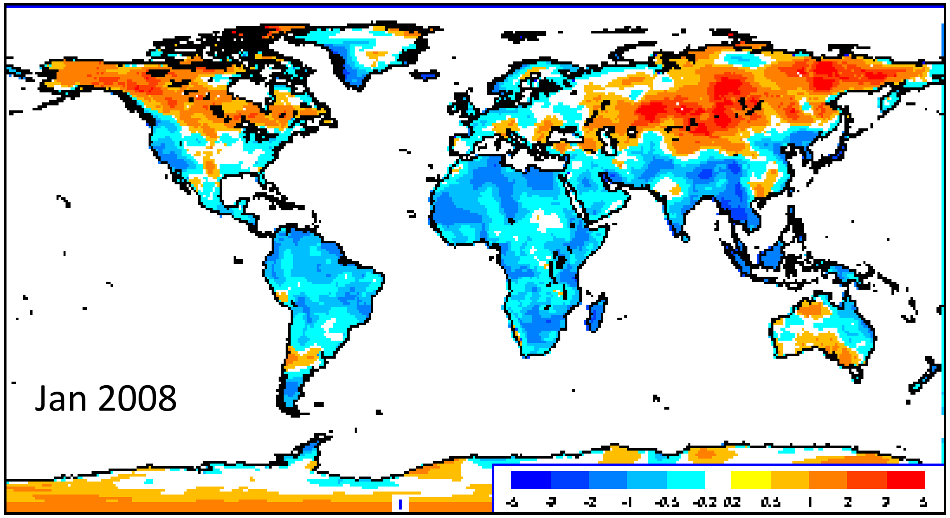


2m temperature errors averaged over daily 36-hr forecasts for January

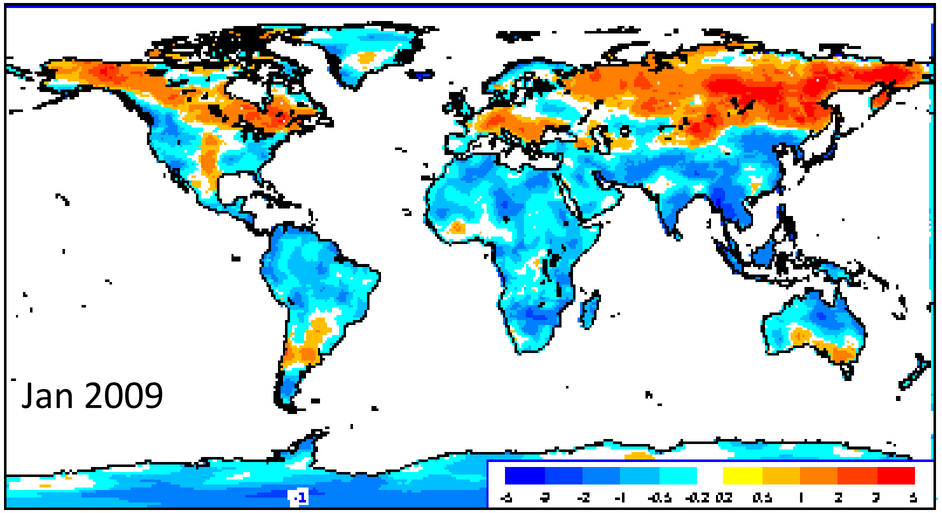
2T mean err exp[CY31R1(0001)+36-AN(0001)]; VT:20070102-20070201 12 UTC.



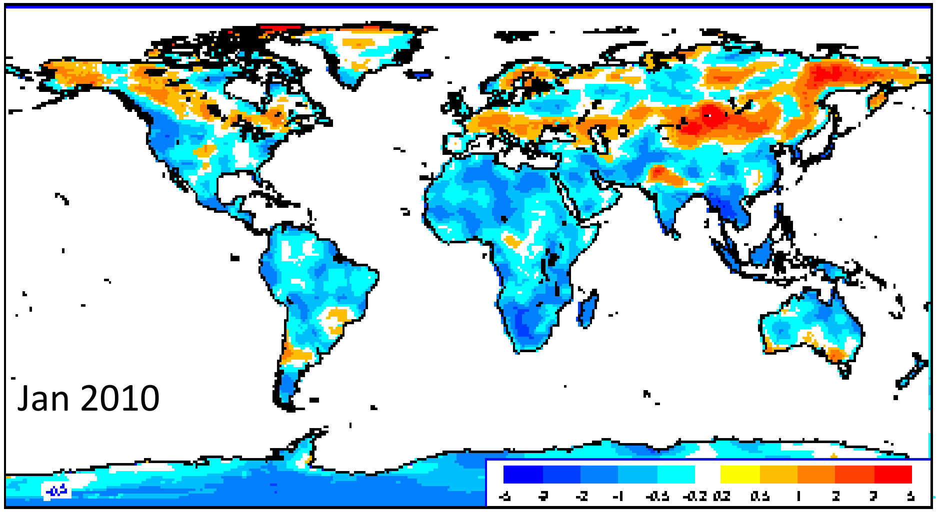
2T mean err exp[CY32R3(0001)+36-AN(0001)]; VT:20080102-20080201 12 UTC.



2T mean err exp[CY35R1(0001)+36-AN(0001)]; VT:20090102-20090201 12 UTC.



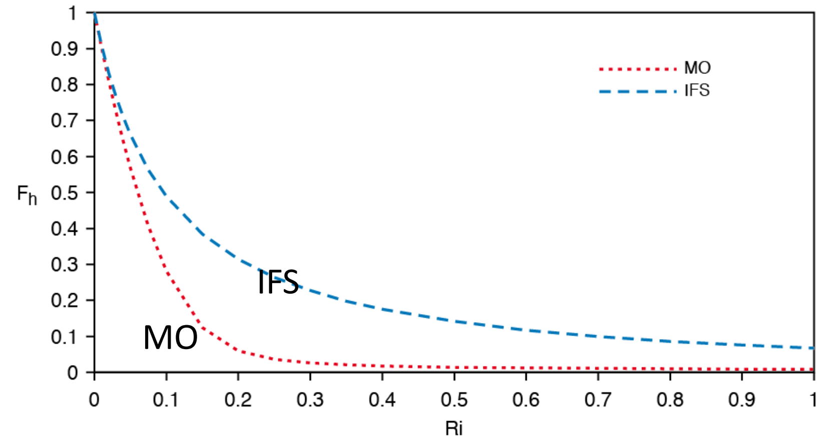
2T mean err exp[CY35R3(0001)+36-AN(0001)]; VT:20100102-20100201 12 UTC.



The example of turbulence closure

Turbulence closure has a solid basis in “Monin Obukhov” (MO) similarity. MO, “local scaling”, and observationally based stability functions lead to a very simple closure for diffusion coefficients in stable situations:

$$K_H = \left|\frac{\partial U}{\partial Z}\right| l^2 F_H(R_i) \qquad \frac{1}{l} = \frac{1}{kz} + \frac{1}{\lambda}$$



However, the observationally based MO functions are never used in large scale models, because they lead to:

- too cold nigh time temperatures
- too little surface drag.

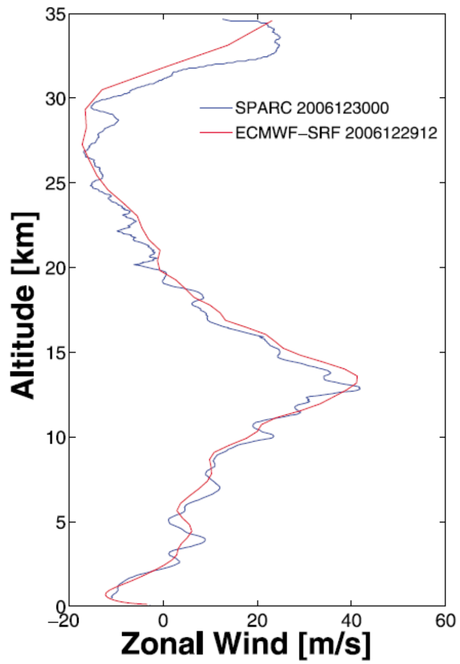
Why does MO not work? Are the observations wrong?

A possible explanation is that large scale models lack “meso-scale” variability (e.g. gravity waves, inertial waves).

Houchi et al. (2010) analysed a large volume of high resolution radio sondes and concluded that the IFS underestimates the magnitude of vertical shear by more than a factor 2.

Conclusion:

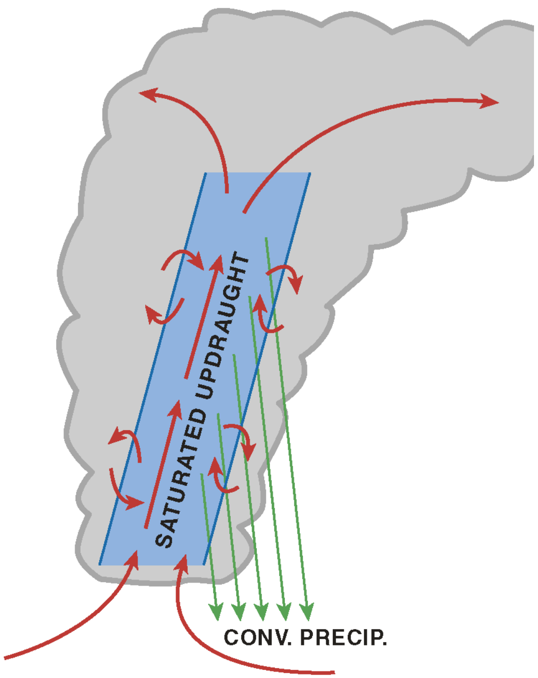
- The effect of meso-scale variability needs parametrization
- Such a parametrization should be resolution dependent



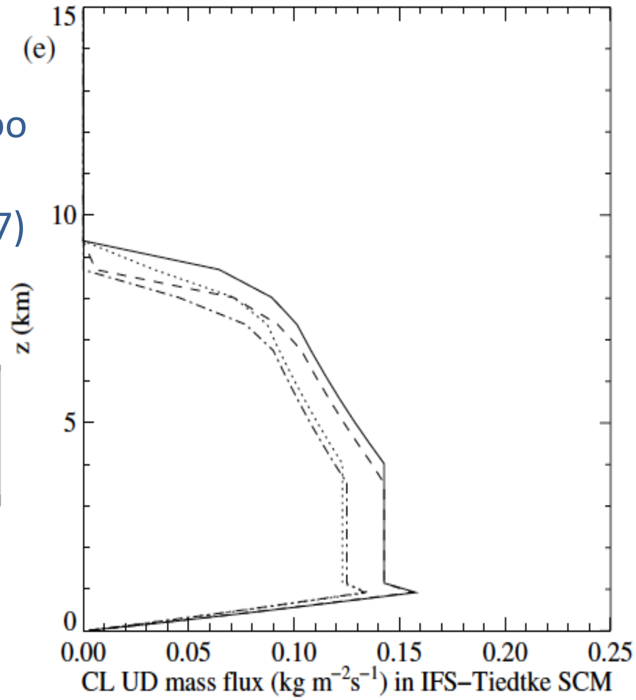
Houchi et al. (2010), JGR Atmos.., 115, D22

Dependence of convective mass flux and precipitation on environment moisture

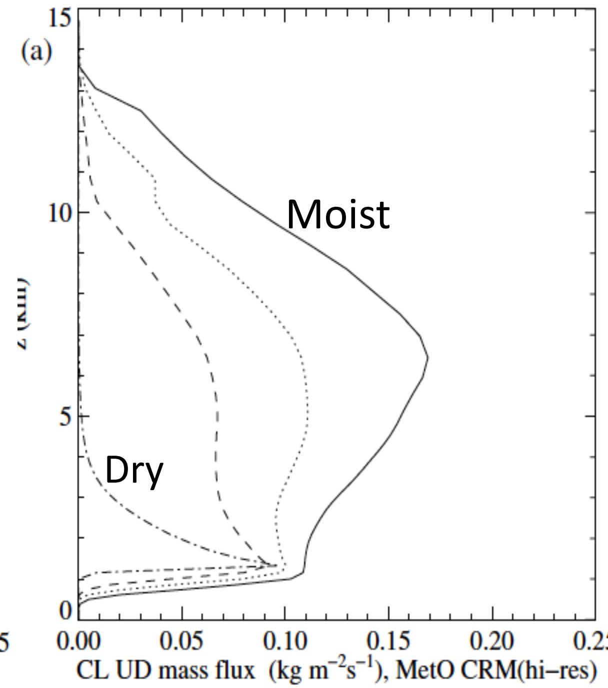
The GCSS inter-comparison of CRM's and SCM's showed that most parameterizations have too little sensitivity to environment moisture (Derbyshire et al. 2007)



ECMWF SCM



Met. Office CRM

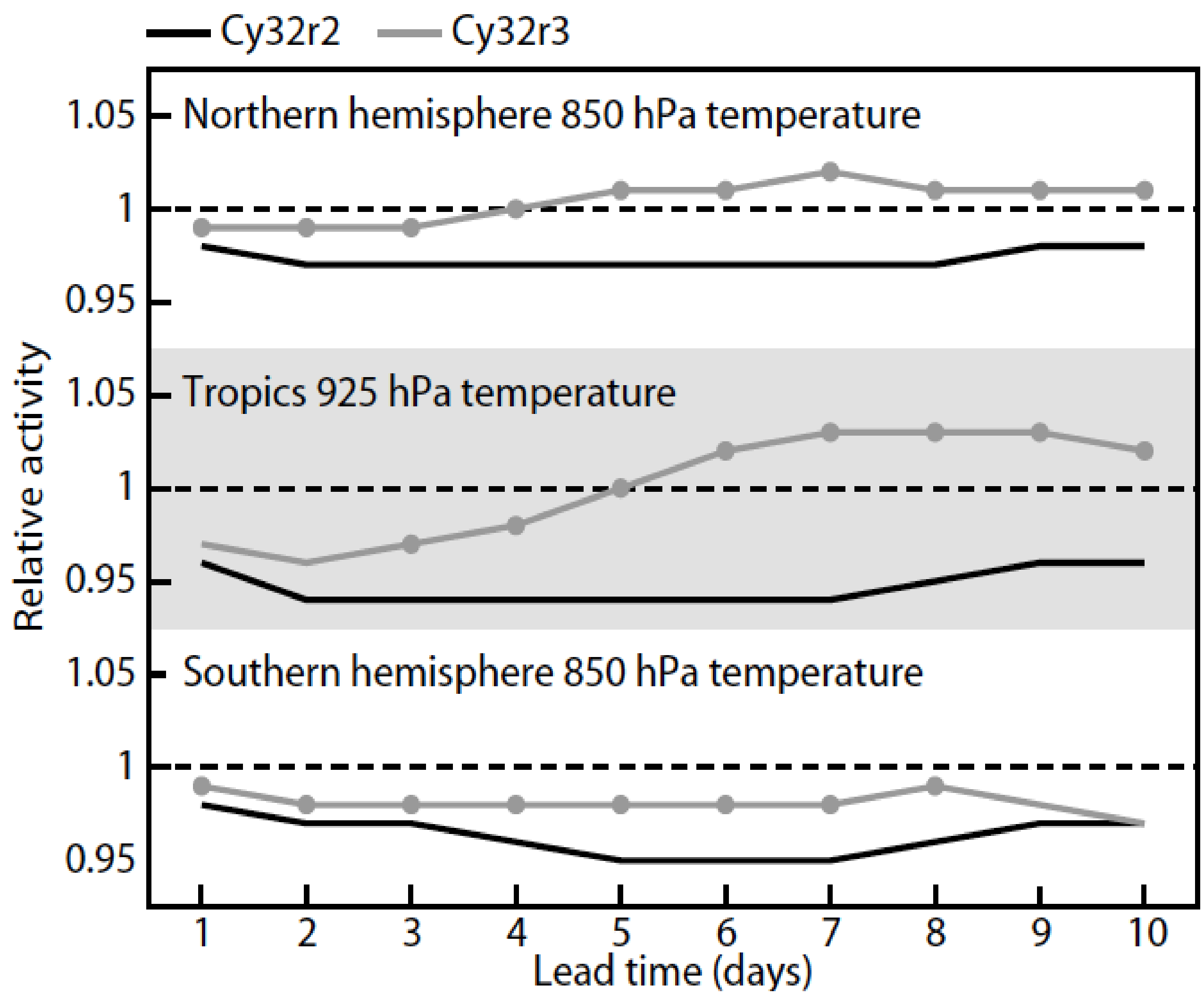


CY23R3 changes to convection parameterization (introduced Nov 2007) : stronger entrainment, also dependent on q, and variable CAPE reduction time scale (Bechtold et al. 2008).

Model activity in T799 10-day forecasts

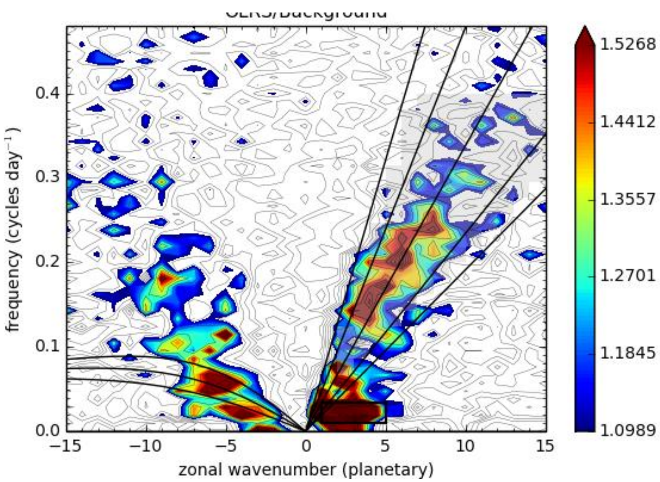
Relative activity is model activity divided by activity in analysis

Activity is standard deviation of anomaly from ERA-40 based climatology

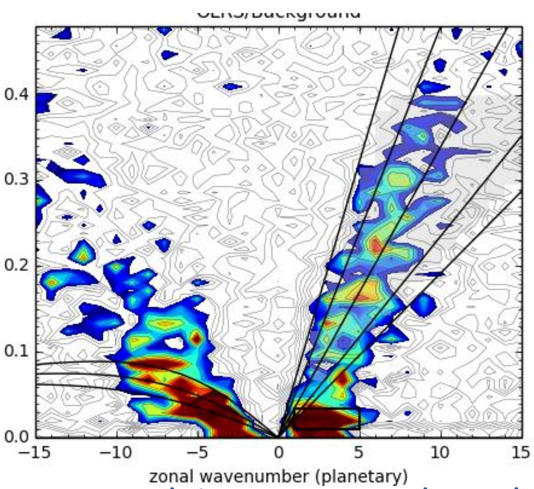


Convection: Tropical variability, OLR spectra, MJO

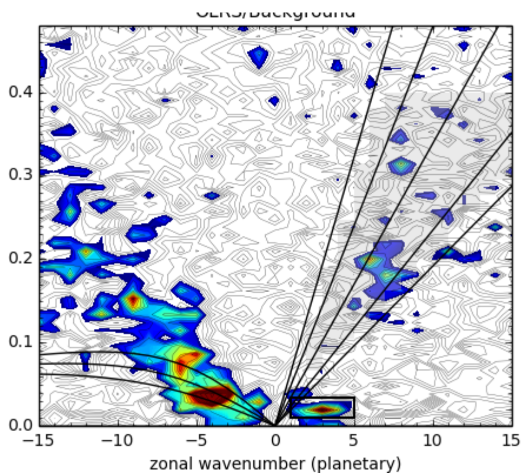
EC- Analysis 2008-2013



EC- Seas Fc Cy40r1=2014

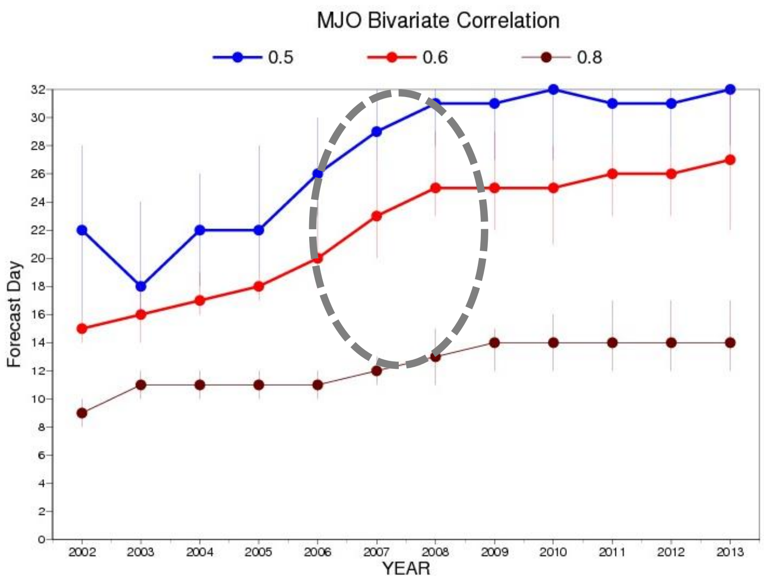


EC- Seas Fc ERAI-cycle=2006



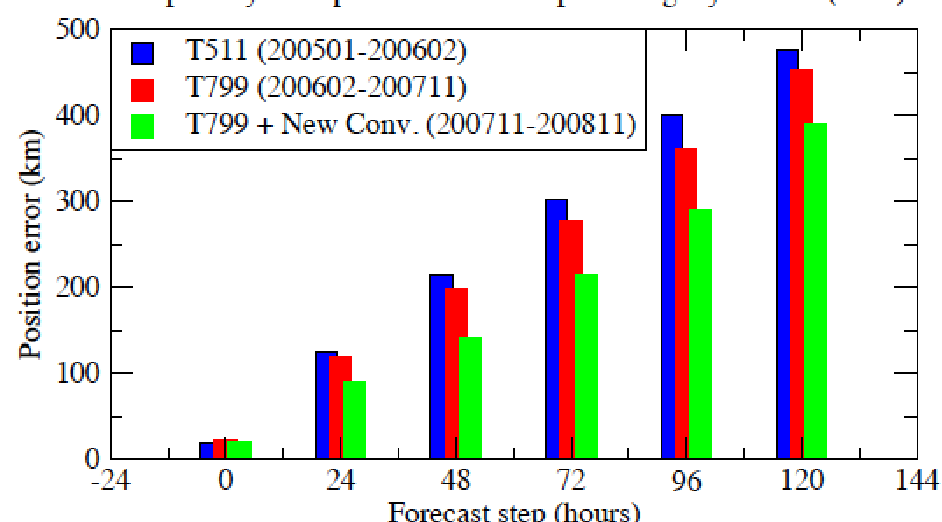
No Kelvin waves, and weak MJO before 2008

Gain of 6 days in MJO forecasts in 2007/8.
Average: 1-day/year since 2002

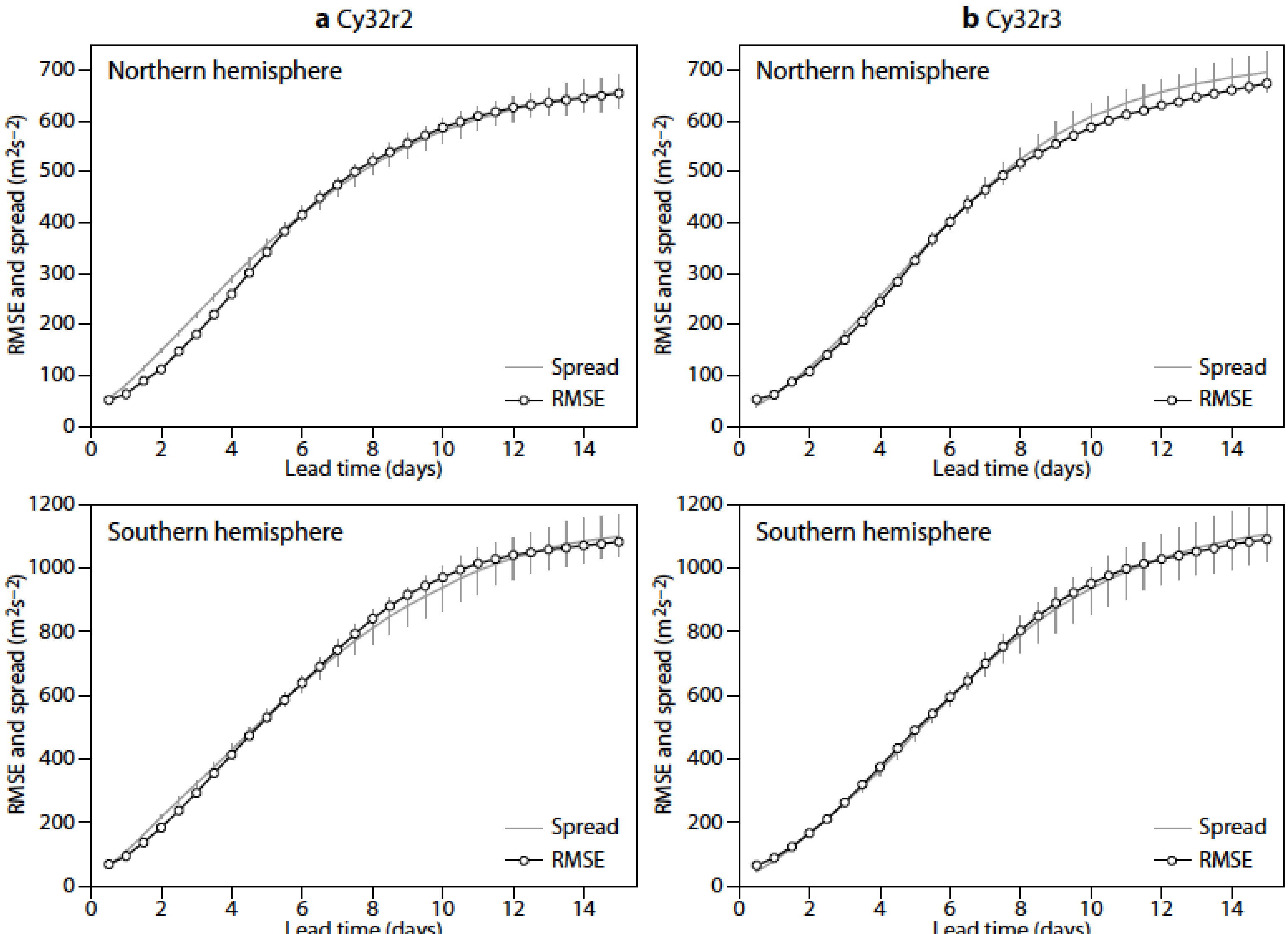


The Nov-2007 convection change improved TC's more than the resolution upgrade from T511 to T799 in Feb 2006.

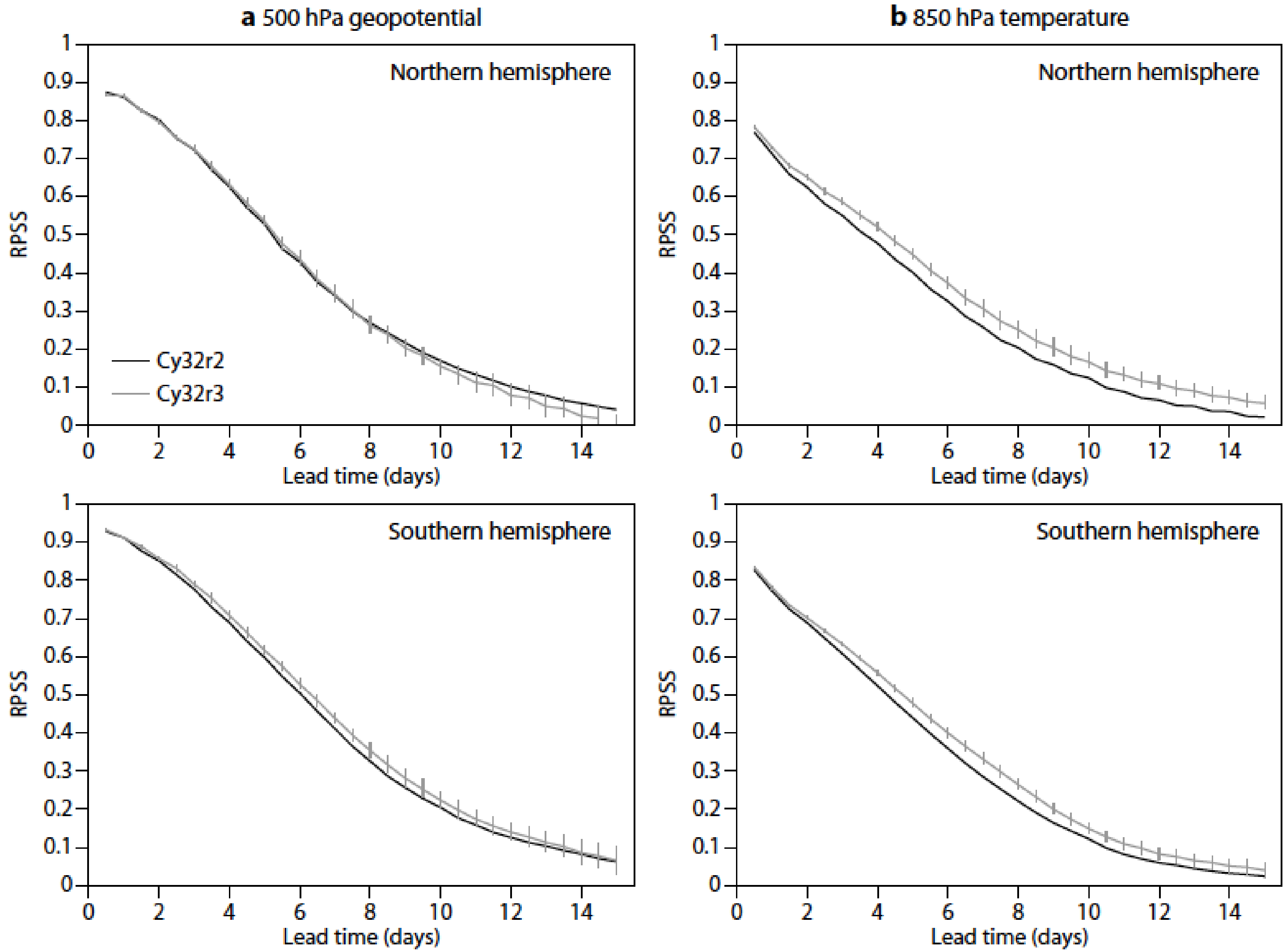
Tropical cyclone position errors: re-plot of fig. by Fiorino (2008)



In the ensemble prediction system the amplitude of the initial perturbations could be reduced by 30%



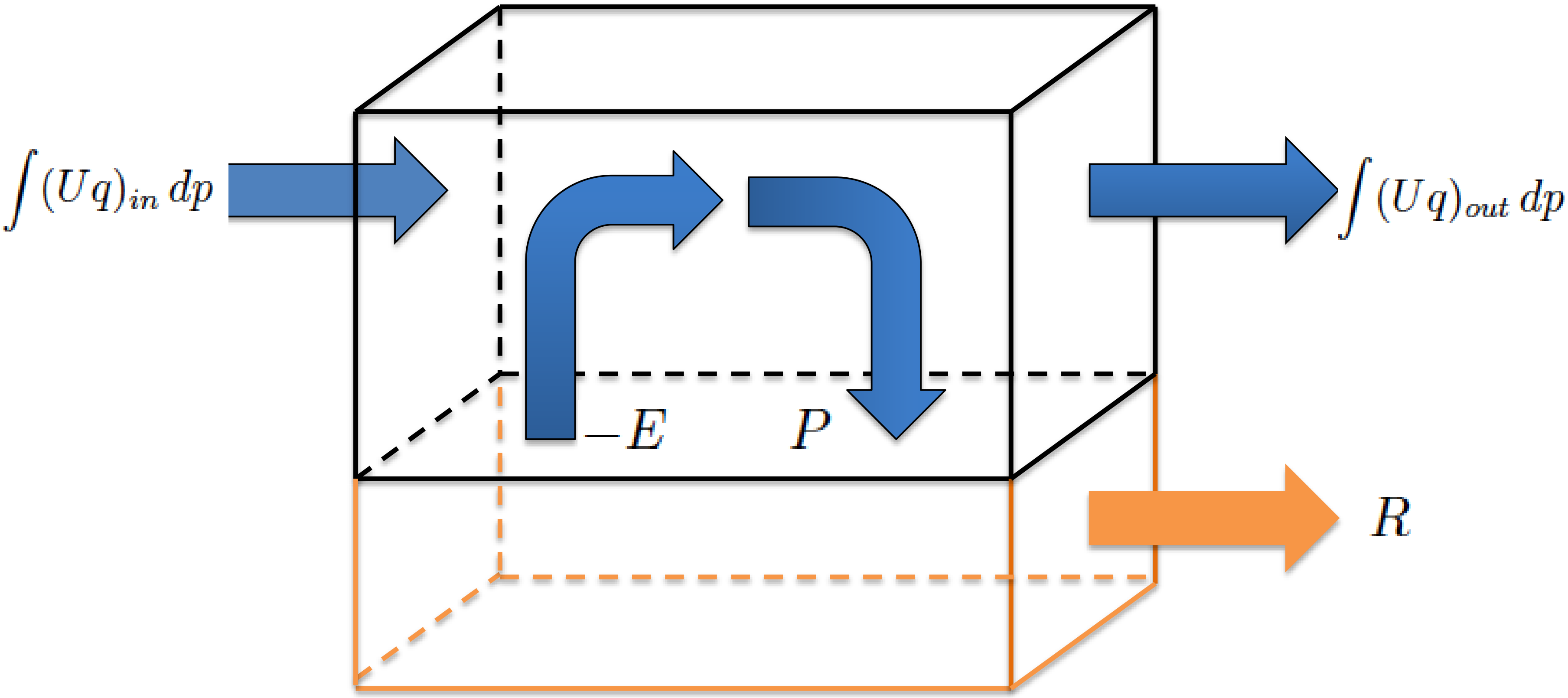
Verification of ensemble prediction system



Moisture budgets

Atmosphere:

$$\underbrace{\frac{\partial}{\partial t}\int q\,dp}_{\text{Change of total column water vapour (negligible for monthly time scale)}} + \underbrace{\frac{\partial}{\partial x}\int Uq\,dp + \frac{\partial}{\partial y}\int Vq\,dp}_{\text{Moisture divergence}} = \underbrace{-E}_{\text{Evap.}} \underbrace{-P}_{\text{Precip}}$$

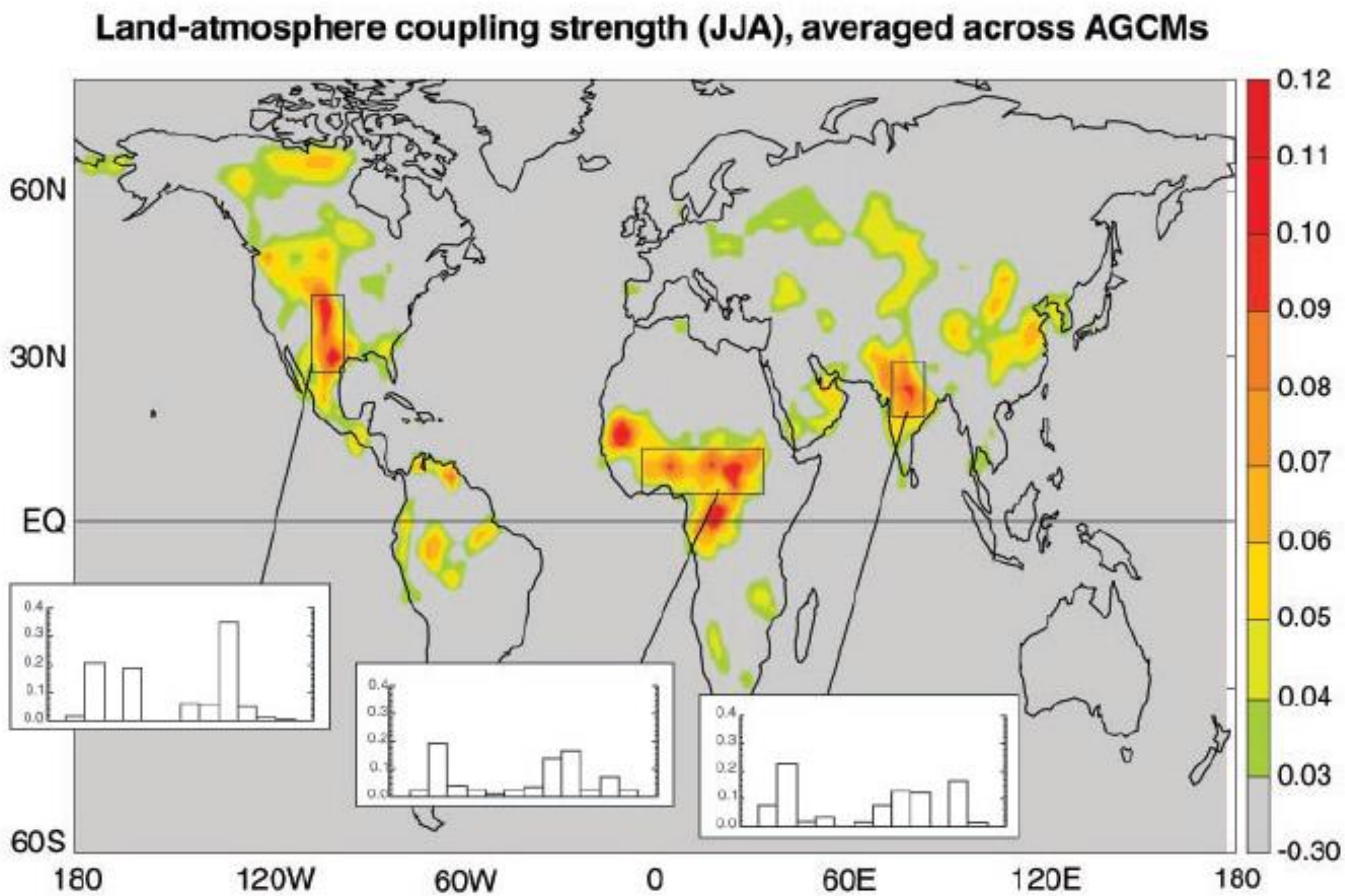


Soil:

$$\underbrace{\frac{\partial}{\partial t}\int \theta\,dz}_{\text{Change of soil moisture}} = \underbrace{E}_{\text{Evap.}} + \underbrace{P}_{\text{Precip.}} - \underbrace{R}_{\text{Runoff}}$$

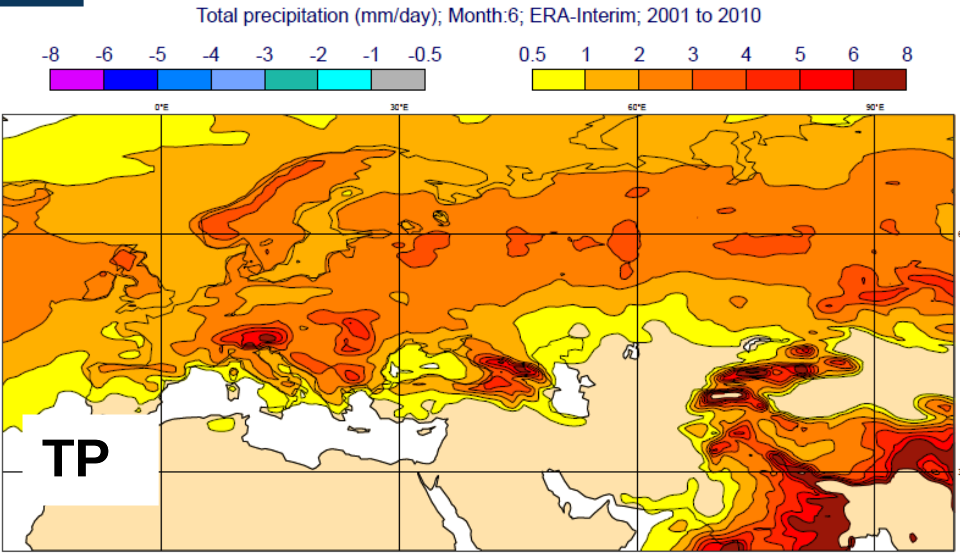
ECMWF

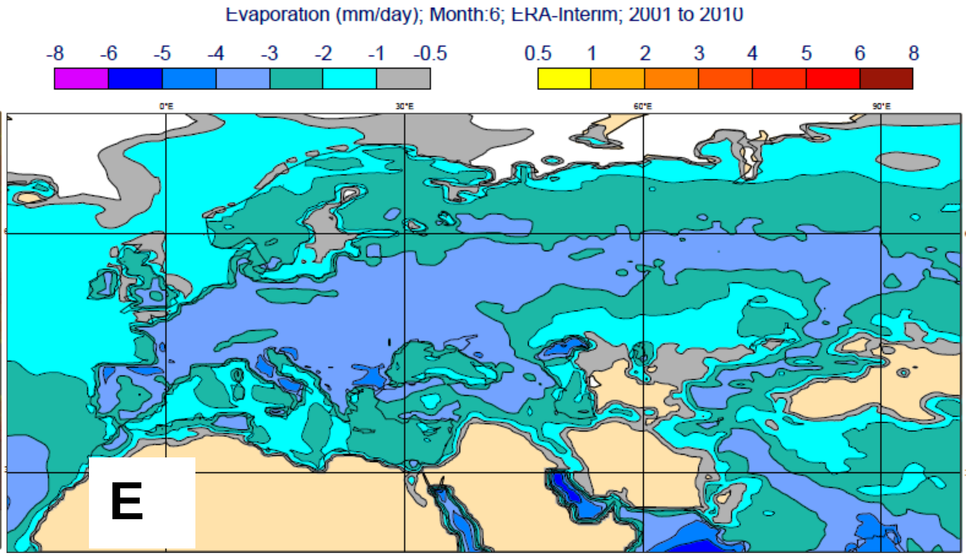
About interactions and feedbacks.
The example of atmosphere to land coupling through the water cycle

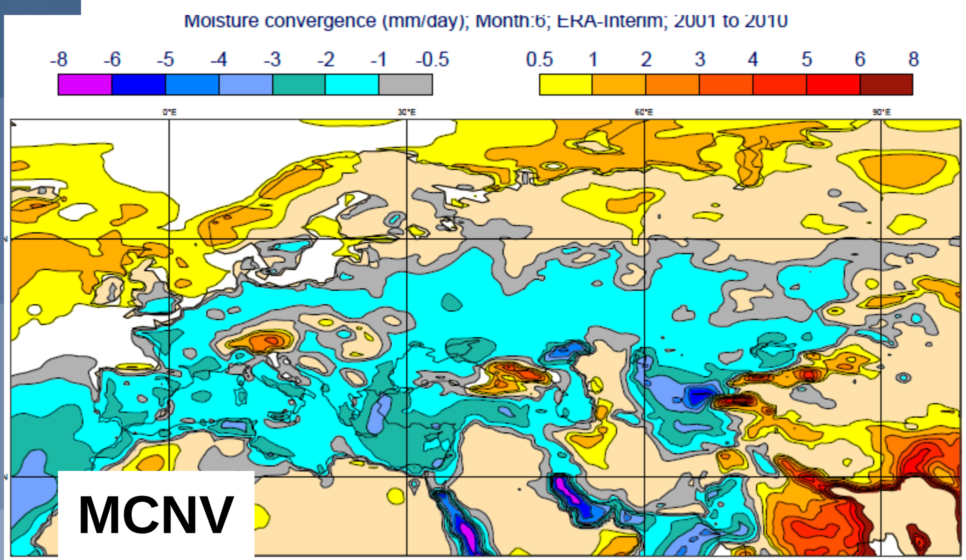


Koster et al. (2004): Regions of strong coupling between soil moisture and precipitation, Science, 305, 1138-1140.

Moisture budget terms from ERA-Interim (June)







June, ERA-I climatology
Average 2001-2010

- **TP:** Total precipitation
- **E:** Evaporation (up = negative)
- **MCNV:** Atmospheric moisture convergence

Long integrations

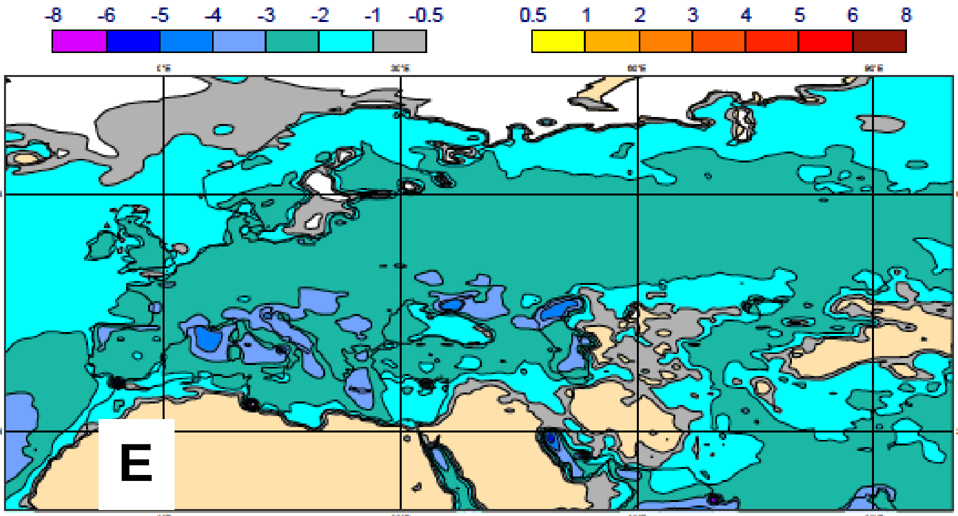
- Initial date: 20030401
- 4 member ensemble (only averages are presented, but individual members behave similarly)
- Length: 4 months
- Two experiments with soil moisture initial conditions (set according to local soil type):
  1. Field capacity everywhere (wet)
  2. Permanent wilting point everywhere (dry)

June

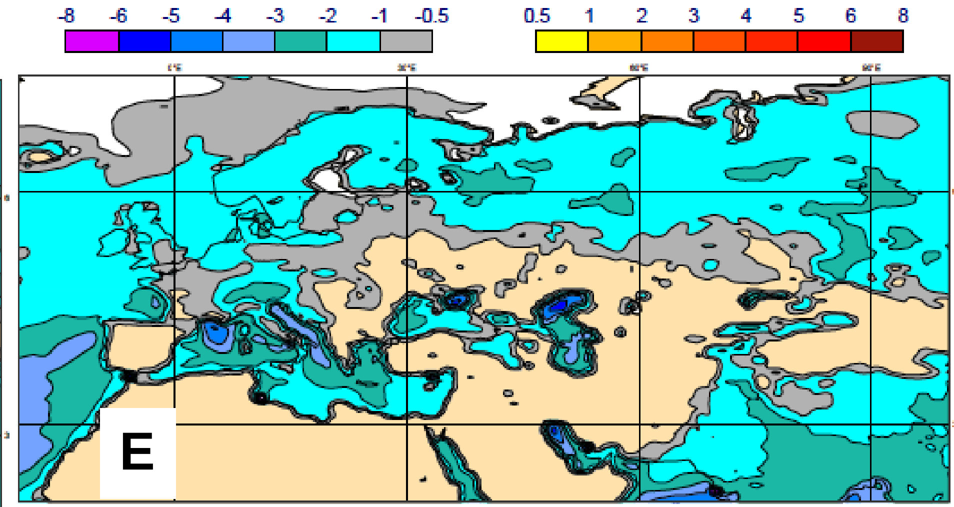
Wet

Dry

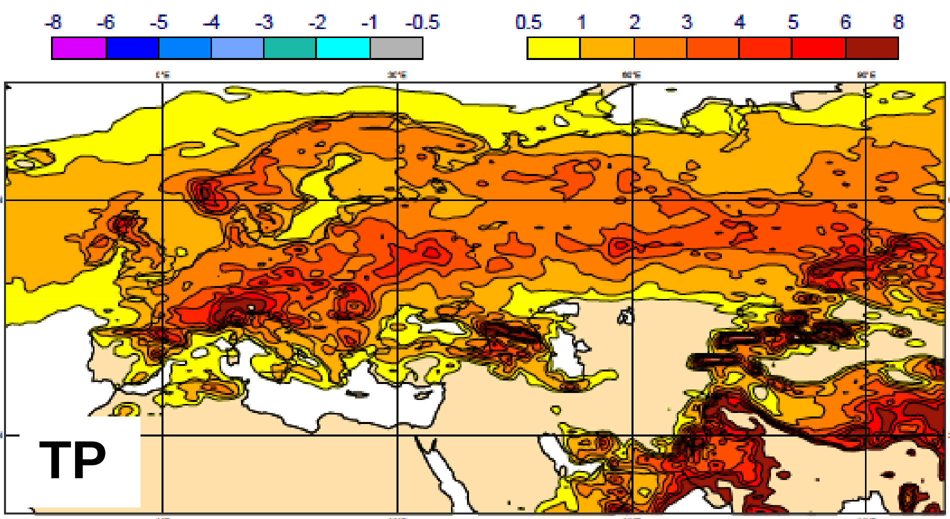
Evaporation (mm/day); Jun; Wet (gczp)



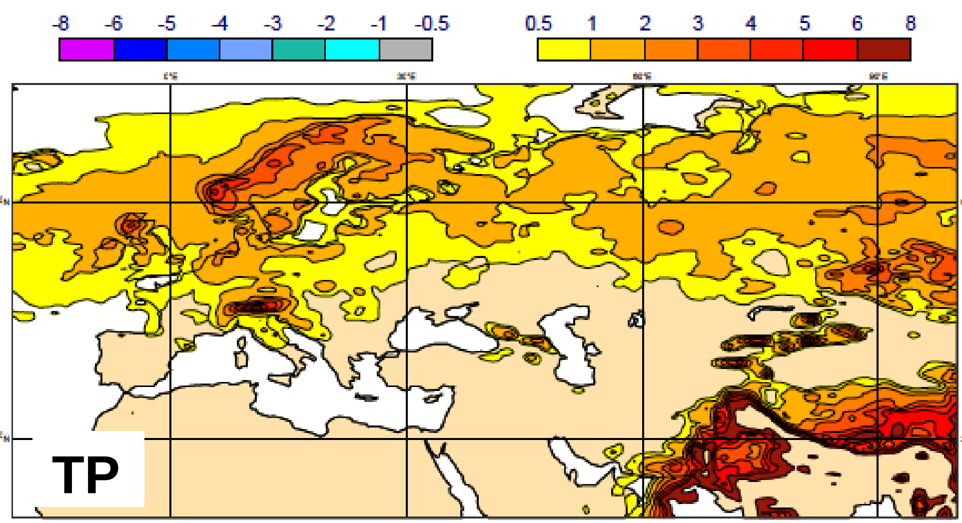
Evaporation (mm/day); Jun; Dry (gczo)



Total precipitation (mm/day); Jun; Wet (gczp)



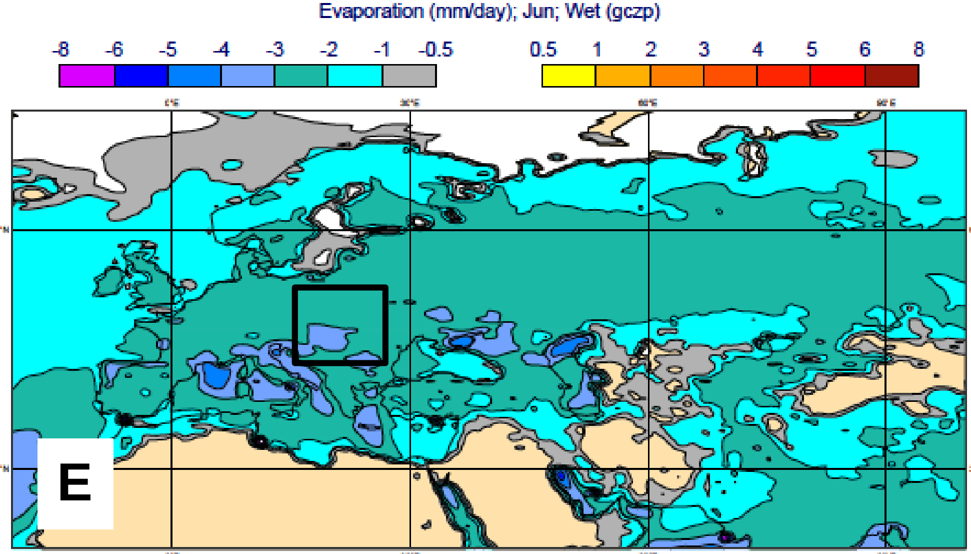
Total precipitation (mm/day); Jun; Dry (gczo)

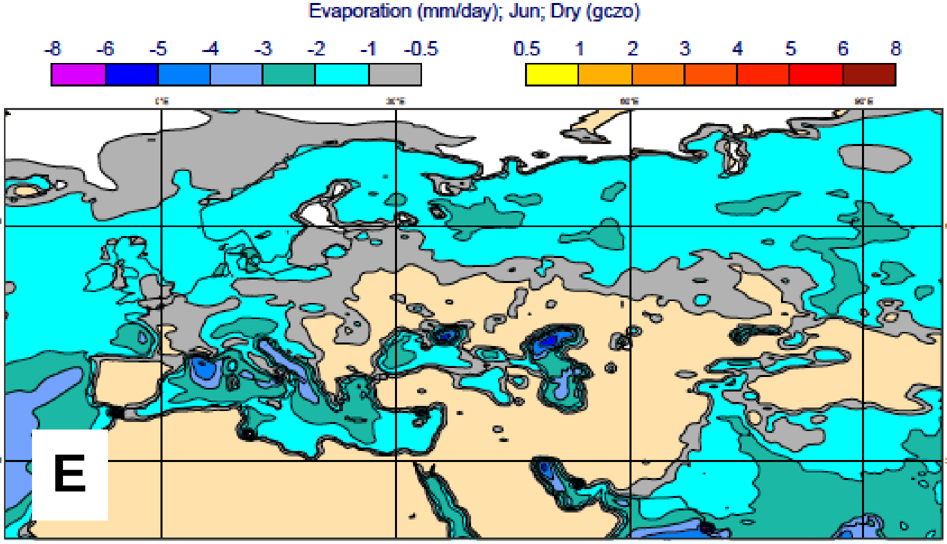


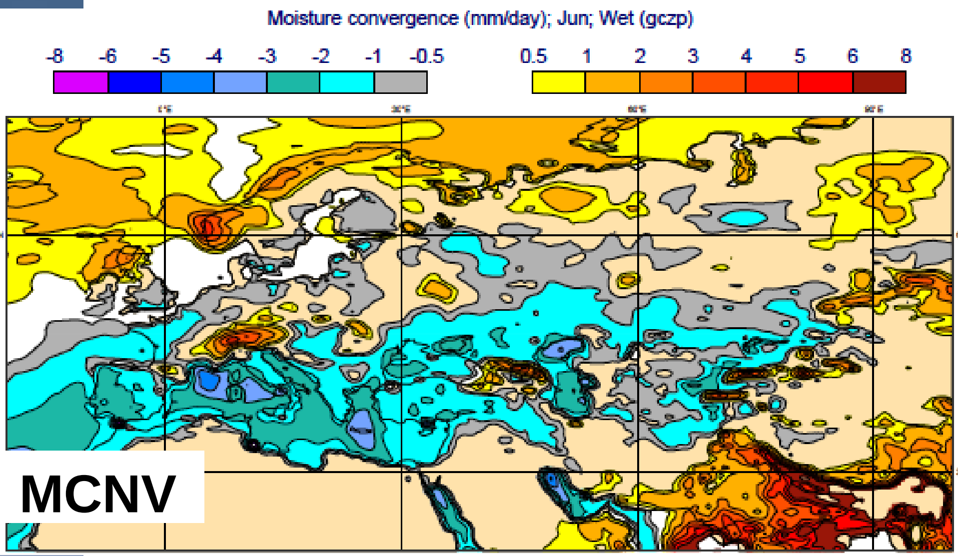
June

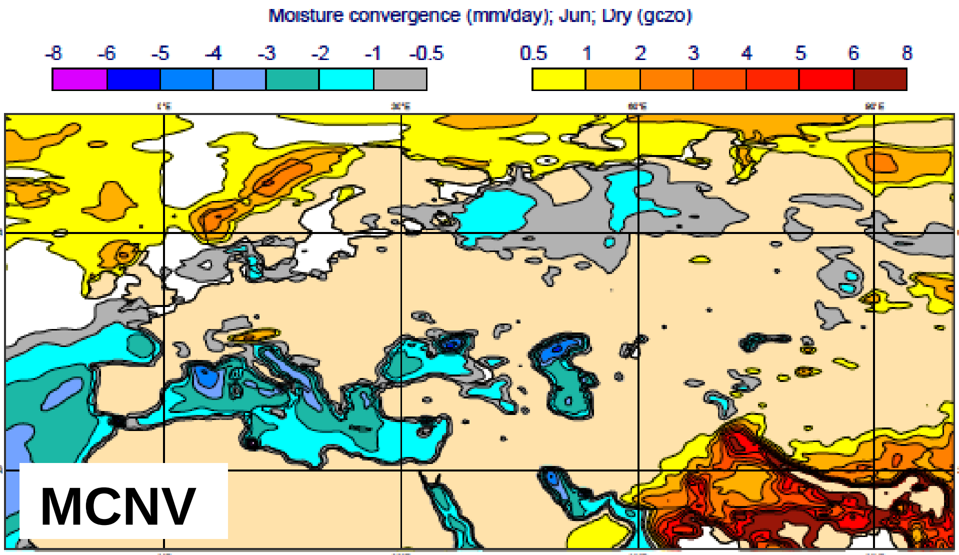
Wet

Dry


Evaporation (mm/day); Jun; Wet (gczp)
-8 -6 -5 -4 -3 -2 -1 -0.5 0.5 1 2 3 4 5 6 8
E

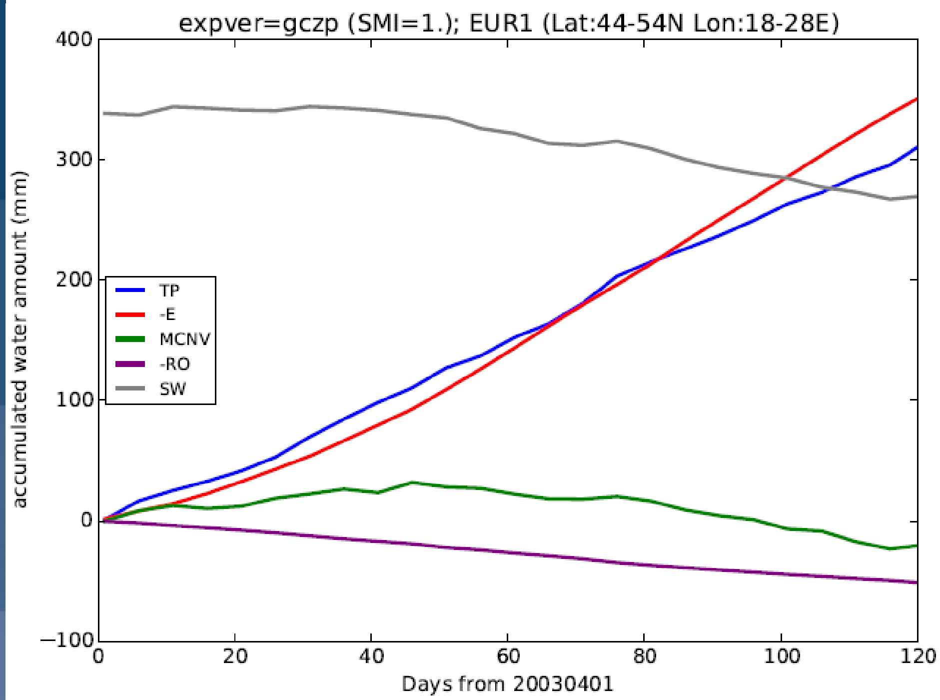

Evaporation (mm/day); Jun; Dry (gczo)
-8 -6 -5 -4 -3 -2 -1 -0.5 0.5 1 2 3 4 5 6 8
E


Moisture convergence (mm/day); Jun; Wet (gczp)
-8 -6 -5 -4 -3 -2 -1 -0.5 0.5 1 2 3 4 5 6 8
MCNV

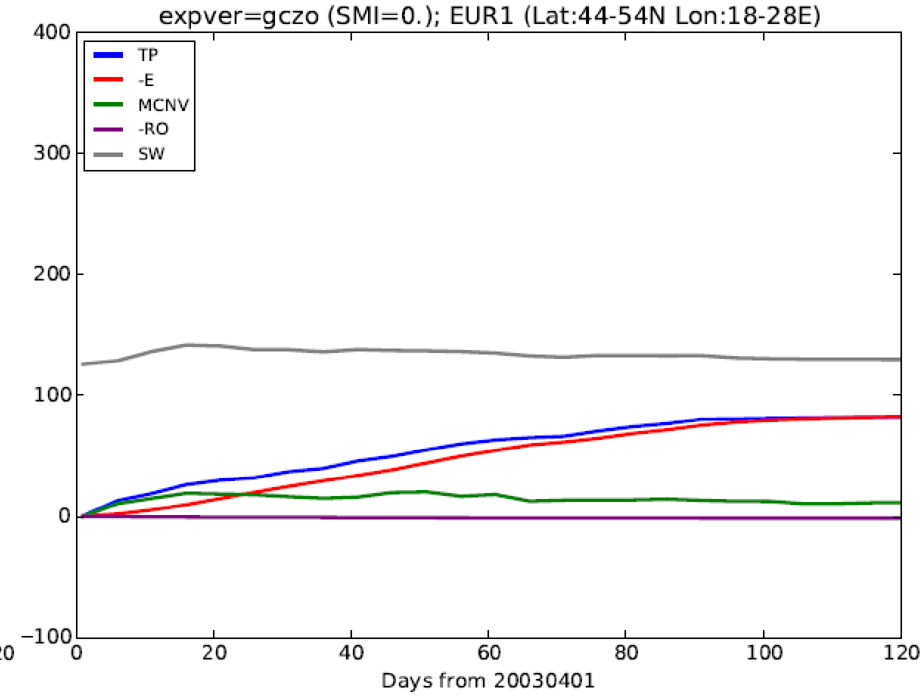

Moisture convergence (mm/day); Jun; Dry (gczo)
-8 -6 -5 -4 -3 -2 -1 -0.5 0.5 1 2 3 4 5 6 8
MCNV

SM and accumulated fluxes; area Europe 44º-54ºN / 18º-28ºE

Wet



Dry



Tentative conclusions:

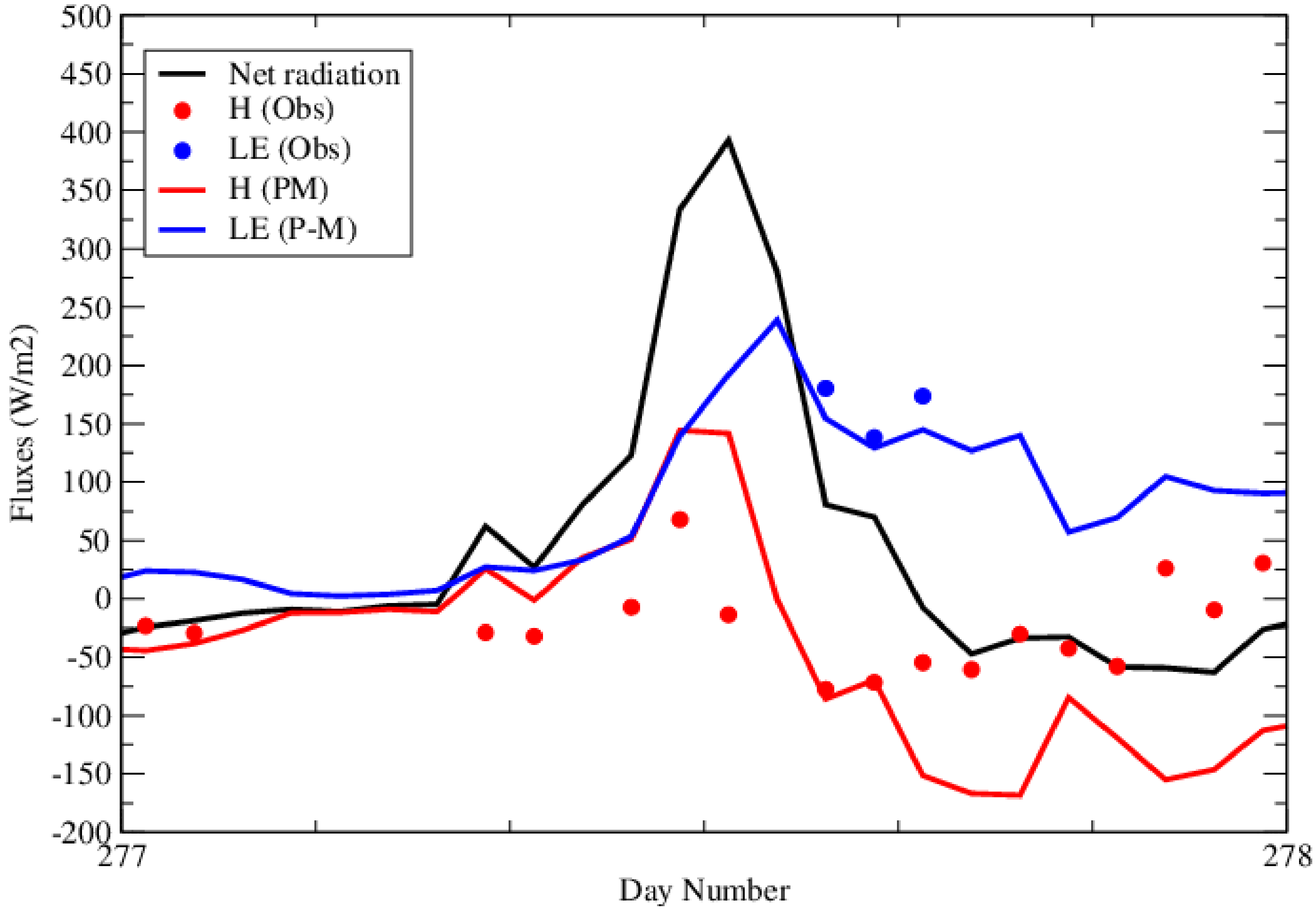
- **Precipitation over land in summer responds strongly to evaporation**
- **With such a strong coupling between precipitation and evaporation it is hard to create anomalies**

Questions:

- **Does evaporation respond correctly to soil moisture and atmospheric forcing?**
- **Does convection respond correctly to evaporation and boundary layer moisture?**

Meso-Gers experiment 4-Oct 1984 (flux station, South France)

$$\lambda E = \frac{-\Delta Q^{*} + \rho C_p (q_a - q_{sat})/r_a}{\Delta + \gamma^{*}(1 + r_s/r_a)}$$



Examples of future directions

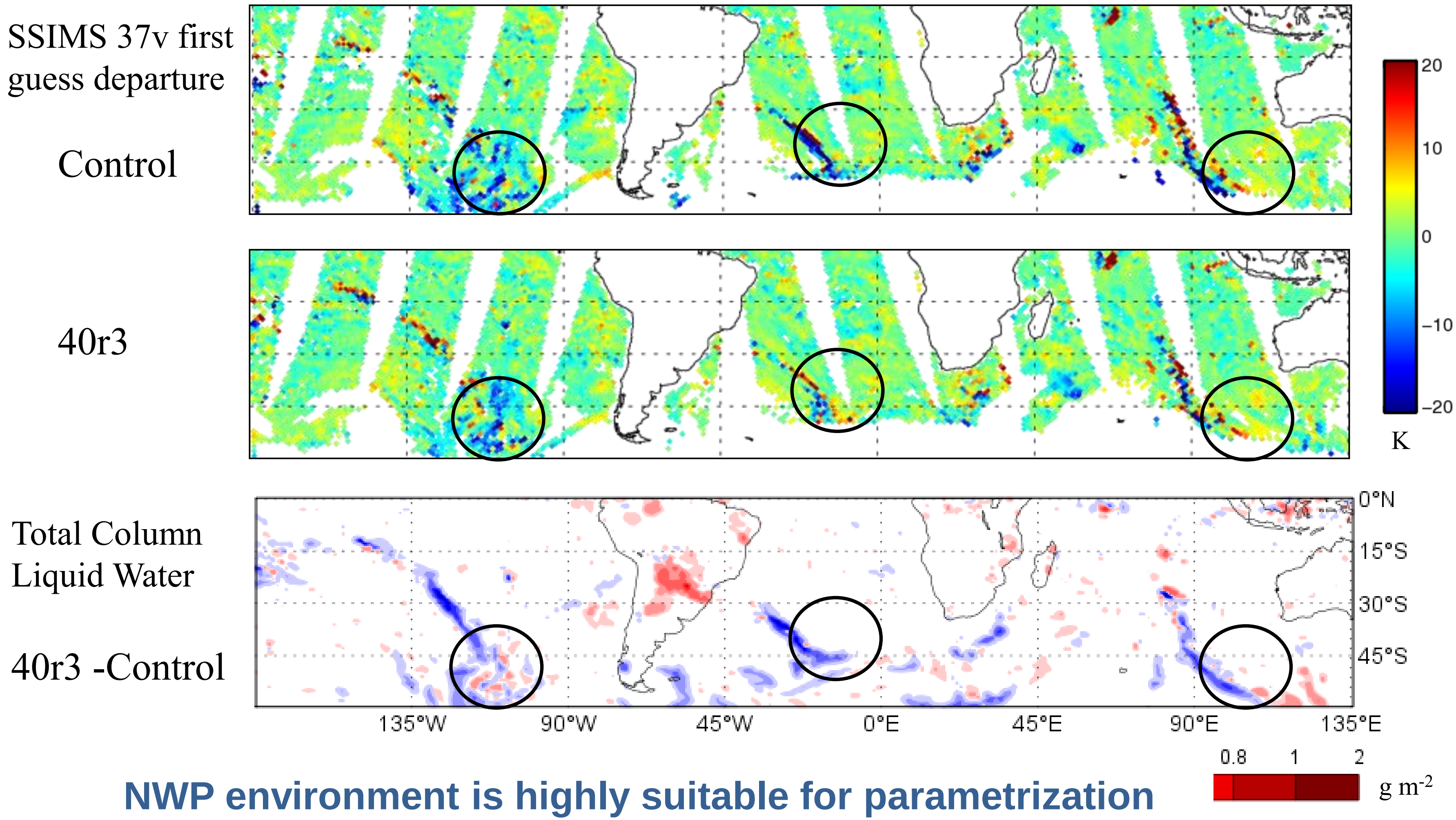
Use of observations

Inverse modelling

High resolution modelling

Future directions 1: Use observations to optimize parameters and explore dependencies on large scale variables

- First guess departures SSMIS 37v (channel 16) All sky radiances
- Example: Southern Hemisphere 12 UTC 19 Jul 2013
- Reduced errors in frontal regions with reduced liquid water path

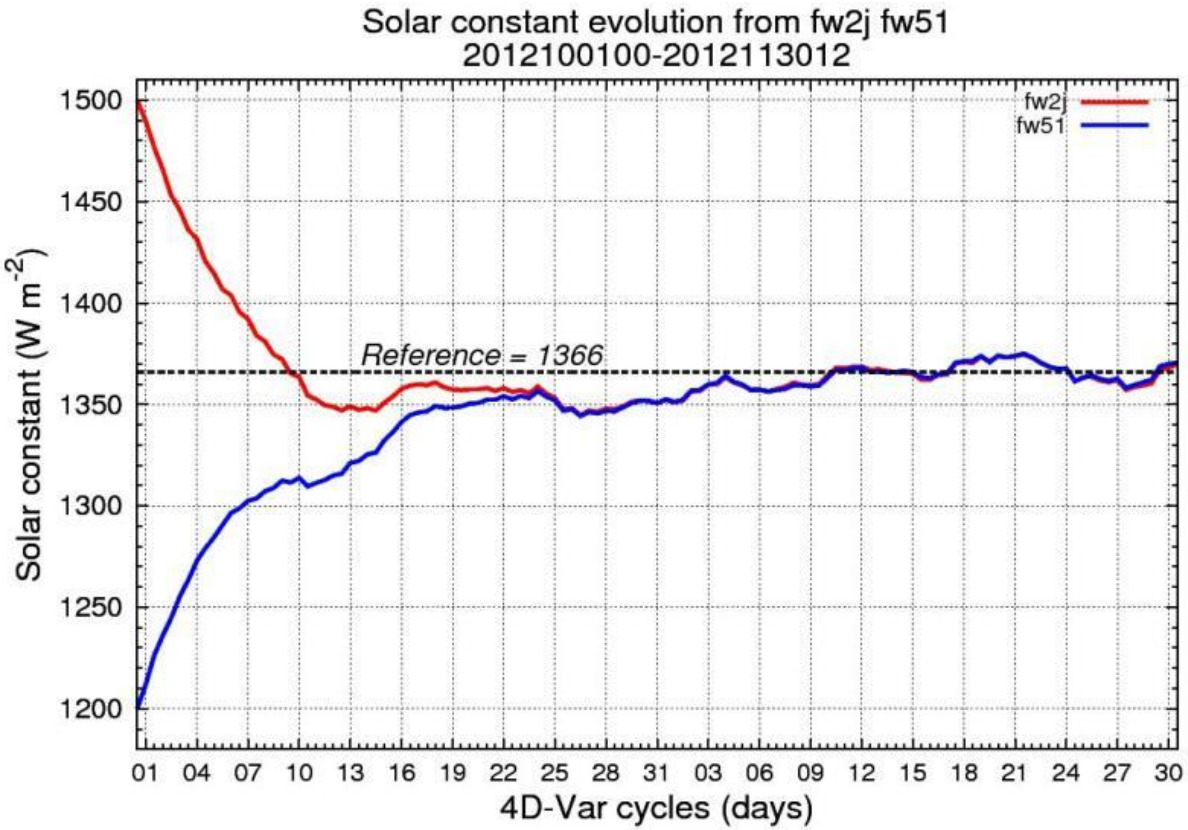


NWP environment is highly suitable for parametrization development

Fig: Alan Geer

Future directions 2: Optimize parameters using data assimilation techniques e.g. variational method

Proof of concept with solar constant:



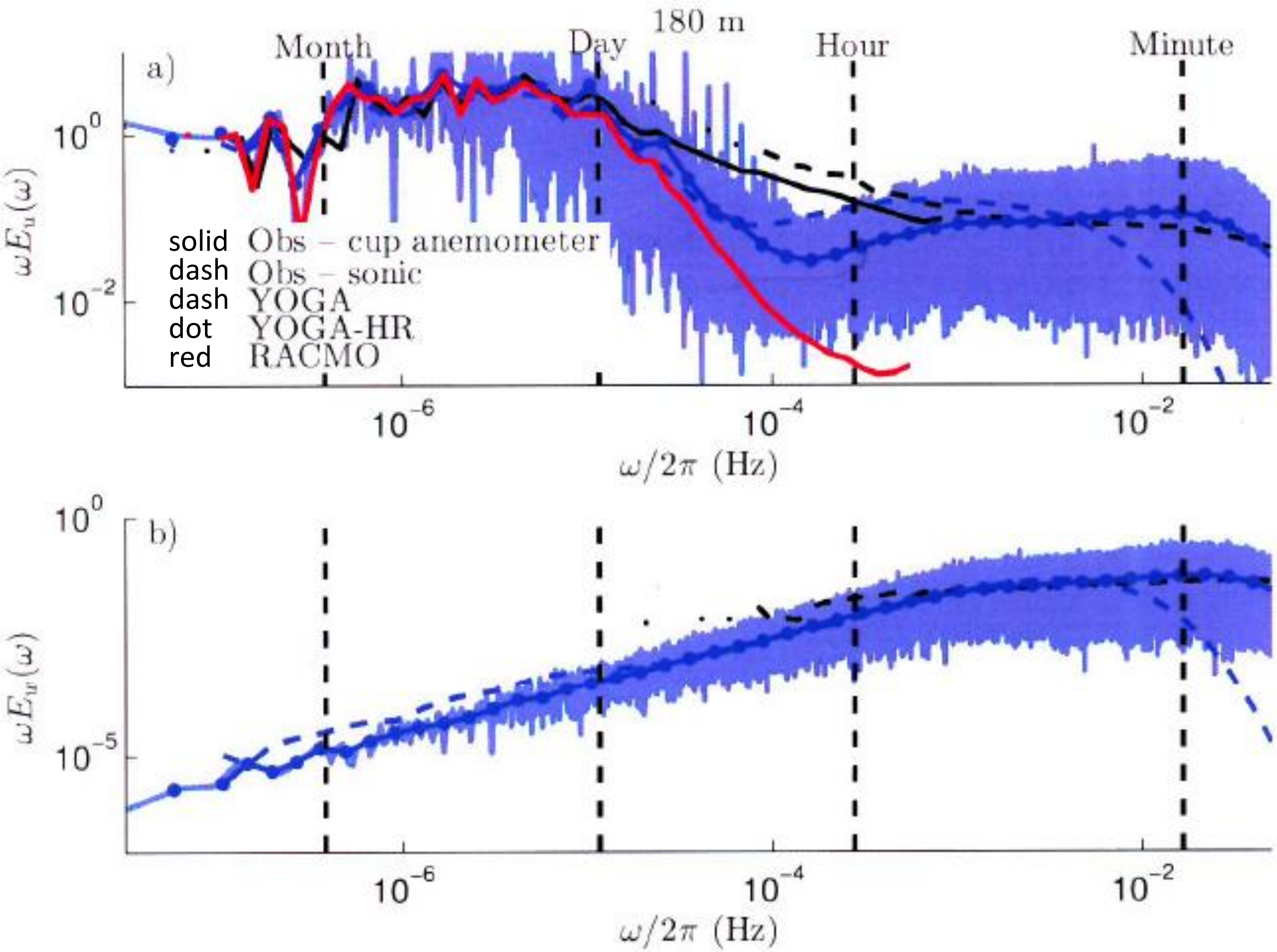
Using data assimilation is particularly relevant for large number of parameters, e.g. global fields of land surface parameters to characterise drag, thermal properties etc.

Fig: Philippe Lopez

Future directions 3: High resolution modelling over large areas

Horizontal wind

Vertical wind



Schalkwijk et al. (2015) : A year-long large-eddy simulation of the weather over Cabauw: an overview, Mon. Weather. Rev., 143, 828-844.

Embedding a LES in a large scale model is not sufficient to represent the energy in the meso-scale. LES simulations over large areas are needed. The meso-scale variability is missing in current parametrizations.

Summary

- **Correct dependence of sub-grid processes on large scale variables is crucial**

- **New and more quantitative knowledge about such dependencies will emerge in future and will reduce (what appears now as) random errors**

- **Good observations and advanced techniques to exploit such data are necessary to achieve improvement**

- **Interactions and feedbacks are crucial for predictability but need careful evaluation**

- **High resolution simulations will not only change the role of parameterization but can also be an important data source for the further development of parametrizations**