Introduction to the parameterization of sub-grid processes

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- What is parameterization?
- Processes, importance and impact.
- Testing, validation, diagnostics
- Parameterization development strategy

Why parameterization

- Due to limited resolution, small scale processes are not resolved by large scale models and are sub-grid
- The effect of the sub-grid process on the large scale can only be represented statistically
- The procedure of expressing the effect of the sub-grid process on the resolved variables is called parameterization

What is parametrization and why is it needed

- The standard Reynolds decomposition and averaging, leads to co-variances that need “closure” or “parameterization”
- Radiation absorbed, scattered and emitted by molecules, aerosols and cloud droplets play an important role in the atmosphere and need parameterization
- Cloud microphysical processes need “parameterization”

- Parameterization schemes express the effect of sub-grid processes in resolved variables
- Model variables are U,V,T,q, (l,i,a,P_l,P_s)

Reynolds decomposition

e.g. equation for potential temperature:

$$\frac{\partial\Theta}{\partial t}\underbrace{+u\frac{\partial\Theta}{\partial x}+v\frac{\partial\Theta}{\partial y}+w\frac{\partial\Theta}{\partial x}}_{\text{advection}}=\underbrace{Q}_{\text{source}}+\underbrace{\lambda\left(\frac{\partial^2\Theta}{\partial x^2}+\frac{\partial^2\Theta}{\partial y^2}+\frac{\partial^2\Theta}{\partial z^2}\right)}_{\text{molecular diffusion}}$$

Reynolds decomposition:

$$U=u+u',\quad V=v+v',$$
$$W=w+w',\quad \Theta=\theta+\theta'.$$

Averaged (e.g. over grid box):

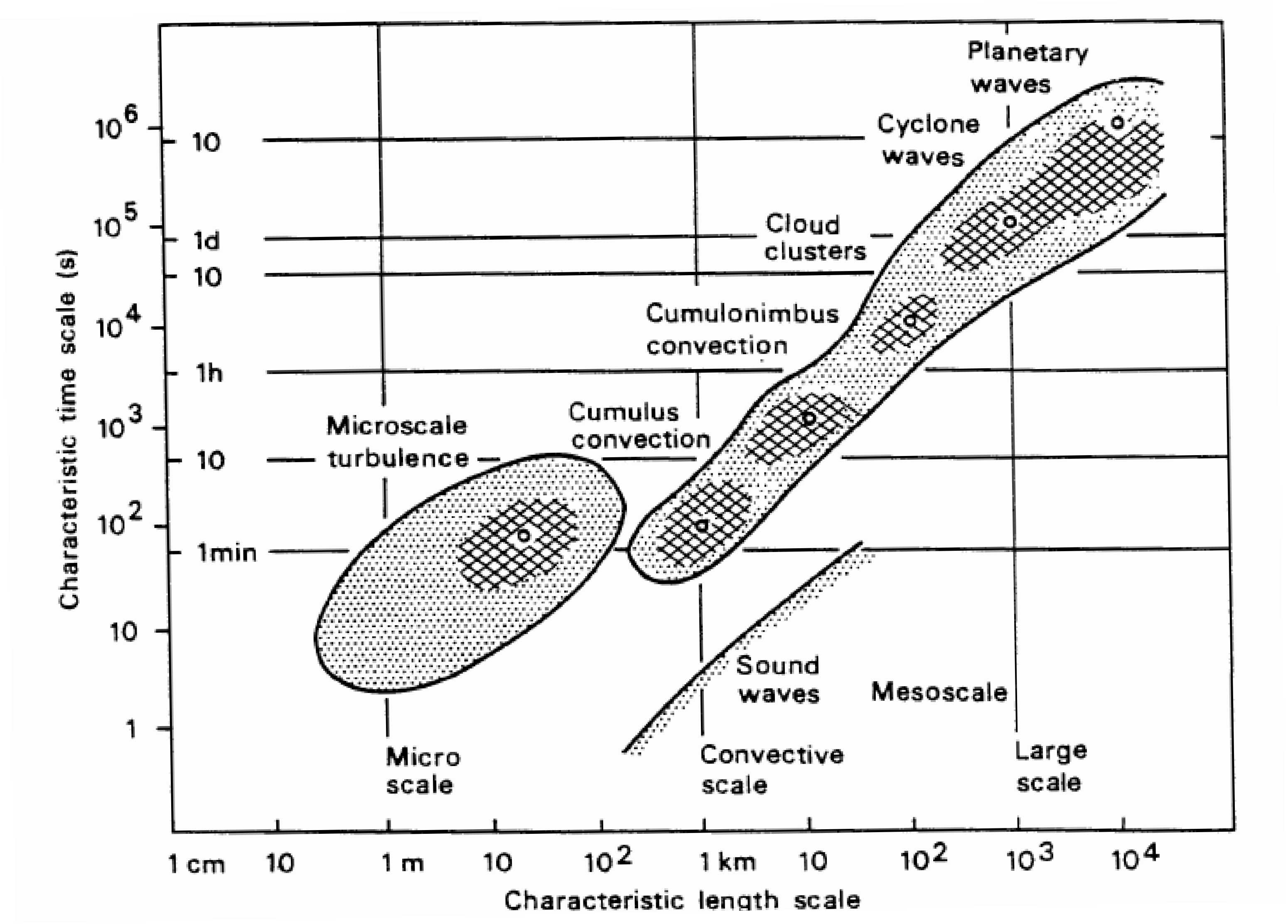
$$\frac{\partial\theta}{\partial t}+u\frac{\partial\theta}{\partial x}+v\frac{\partial\theta}{\partial y}+w\frac{\partial\theta}{\partial x}=$$

$$Q+\frac{\partial}{\partial x}\left(-\overline{u'\theta'}+\lambda\frac{\partial\theta}{\partial x}\right)+\frac{\partial}{\partial y}\left(-\overline{v'\theta'}+\lambda\frac{\partial\theta}{\partial y}\right)+\frac{\partial}{\partial z}\left(-\overline{w'\theta'}+\lambda\frac{\partial\theta}{\partial z}\right)$$

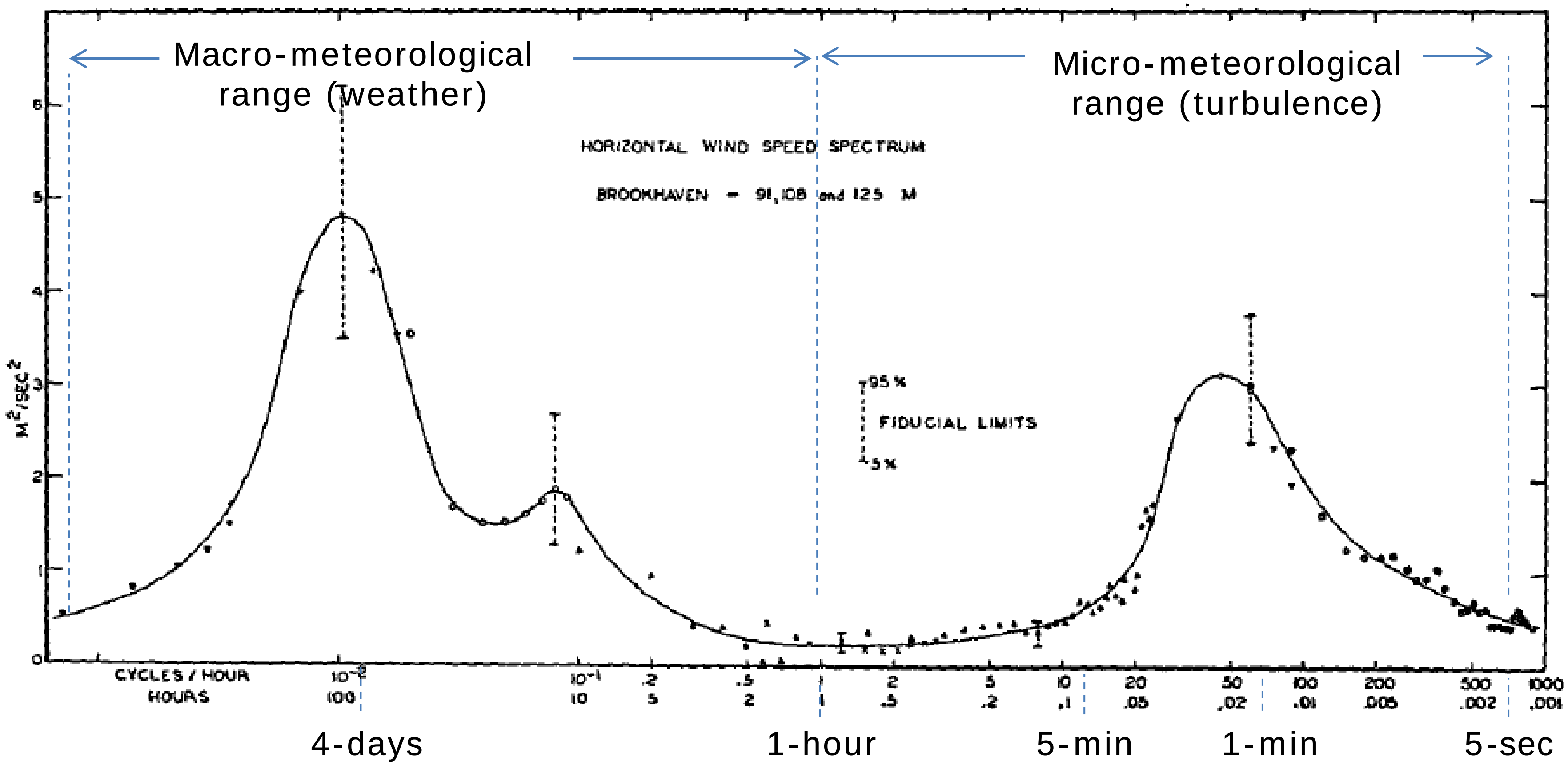
Q : source term (e.g. radiation absorption/emission or condensation)

$\overline{w'\theta'}$: sub-grid (Reynolds) transport term (e.g. due to turbulence, convection)

Space and time scales



Space and time scales



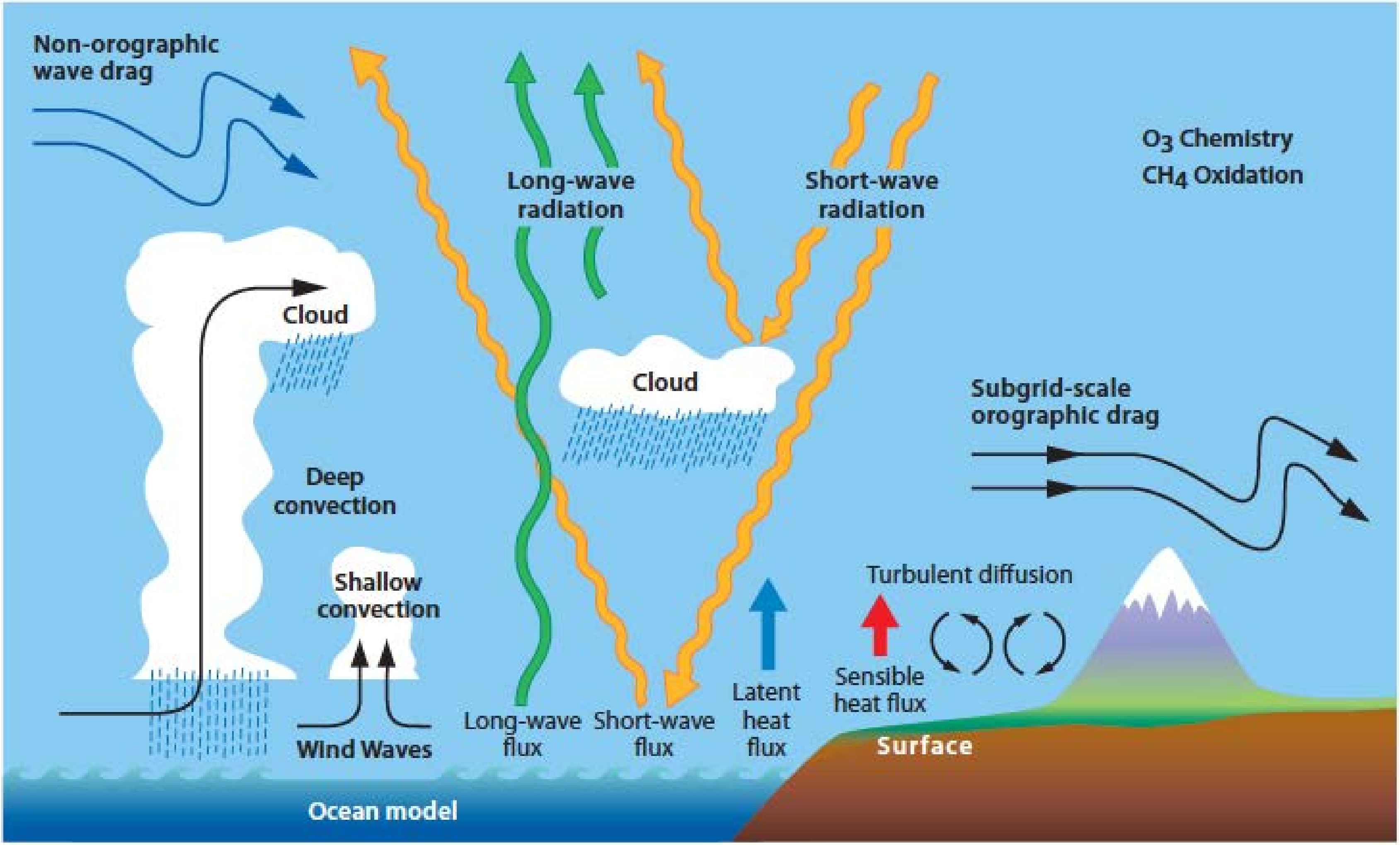
Horizontal wind speed spectrum at Brookhaven at z=100m (van der Hoven, 1957)

Numerical models of the atmosphere

	Vert. Scales	time range	Hor. scales
Climate models	100 km	400 m	100 years
Global weather prediction	15 km	200 m	10 days
Limited area weather pred.	5 km	200 m	2 days
Cloud resolving models	500 m	100 m	1 day
Large eddy models	50 m	50 m	5 hours

Different models need different level of parameterization

Parameterized processes in the ECMWF model



Applications and requirements

- **Applications of the ECMWF model**
  - Data assimilation T1279L137-outer and T95/T159/T255-inner loops: 12-hour 4DVAR.
  - Medium range forecasts at T1279/L137 (16 km): 10 days from 00 and 12 UTC.
  - Ensemble prediction system at T639L91 (32 km) for 10 days, and T319 (65 km) up to day 15; 2x(50+1) members.
  - Short range at T1279L137 (15 km): 3 days, 4 times per day for LAMs.
  - Seasonal forecasting at T255L91(80 km): 200 days ensembles coupled to ocean model.
  - Monthly forecasts (ocean coupled) at T319L91: Twice a week, 50+1 members.
  - Fully coupled ocean wave model.
  - Interim reanalysis (1979-current) is ongoing (T255L60, 4DVAR).

- **Basic requirements**
  - Accommodate different applications.
  - Parameterization needs to work over a wide range of spatial resolutions.
  - Time steps are long (from 10 to 40 minutes); Numerics needs to be efficient and robust.
  - Interactions between processes are important and should be considered in the design of the schemes.

Importance of physical processes

- **General**
    - Tendencies from sub-grid processes are substantial and contribute to the evolution of the atmosphere even in the short range.
    - Diabatic processes drive the general circulation.

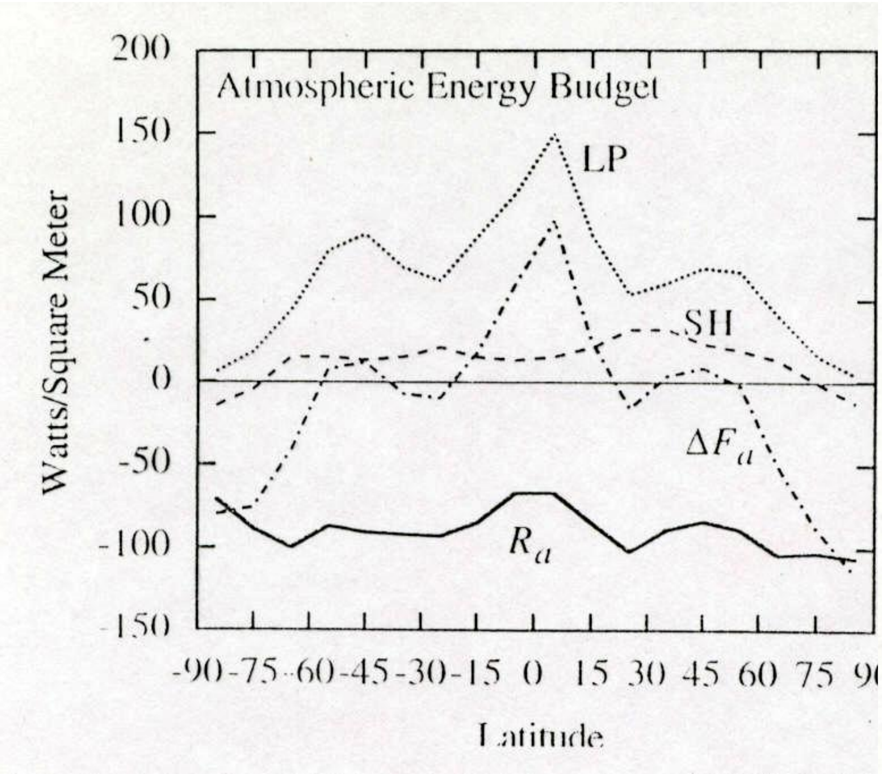
- **Synoptic development**
    - Diabatic heating and friction influence synoptic development.

- **Weather parameters**
    - Diurnal cycle
    - Clouds, precipitation, fog
    - Wind, gusts
    - T and q at 2m level.

- **Data assimilation**
    - Forward operators are needed for observations.

Global energy and water budgets

Energy



$$R_a + LP + SH = \Delta F_a$$

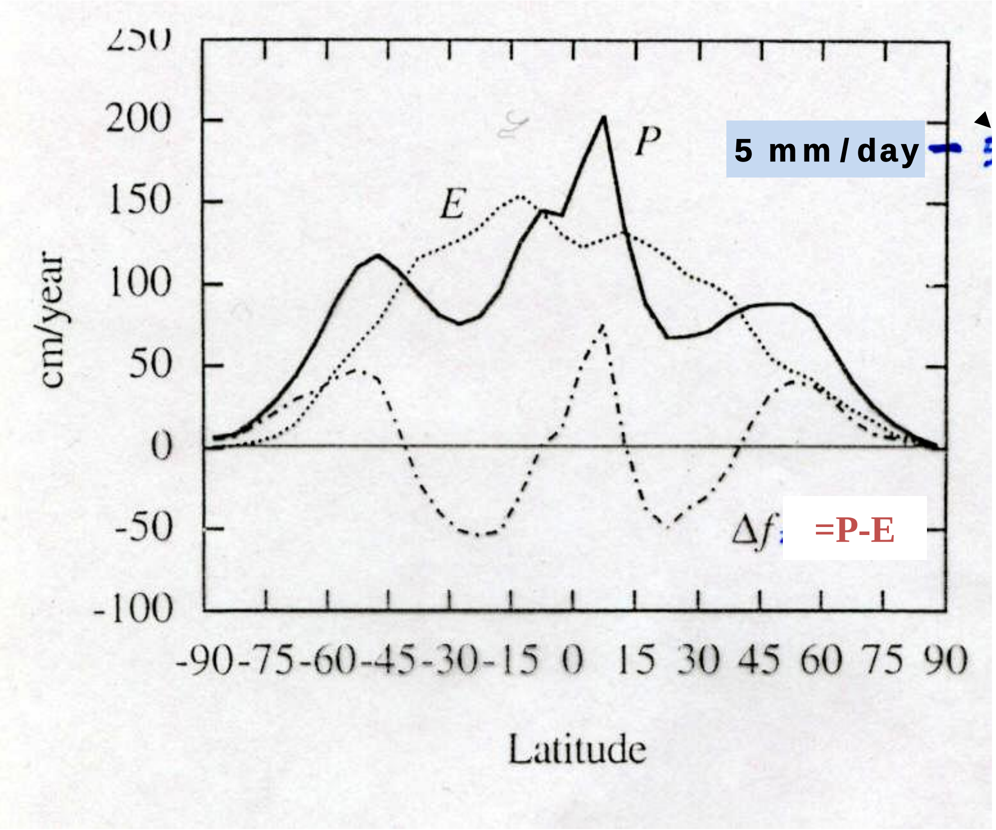
R_a Net atmospheric radiative heating

LP Heating due to latent heat release

SH Surface sensible heat flux

ΔF_a Horizontal energy flux divergence

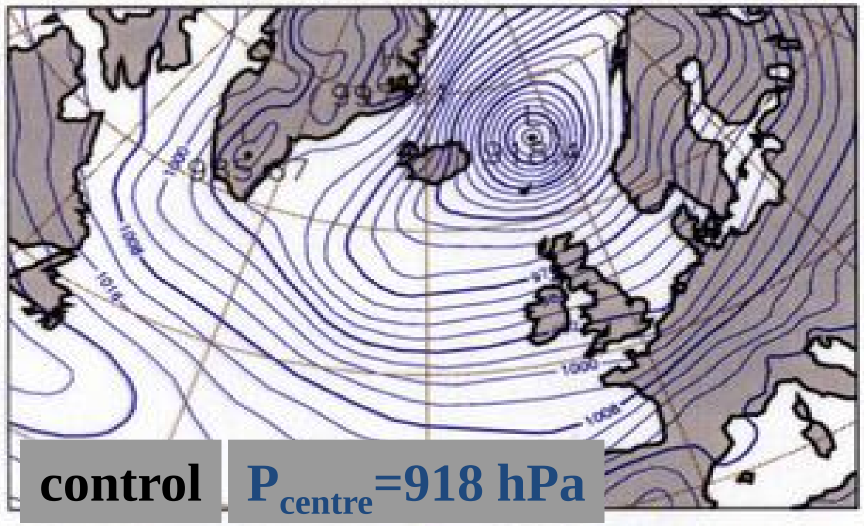
Moisture



Δf Runoff

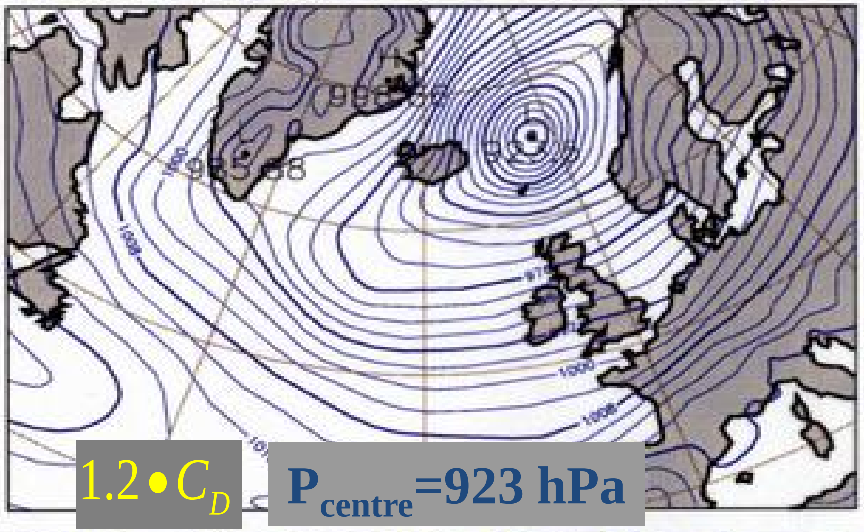
Sensitivity of cyclone central pressure to surface drag

Pressure (zp0v)930109 48h to 48h by 24



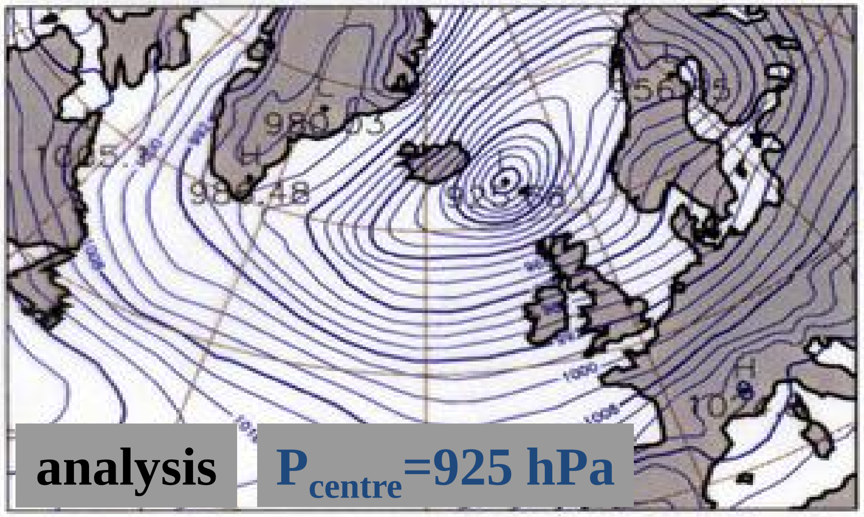
control P_{centre}=918 hPa

Pressure (zp4z)930109 48h to 48h by 24



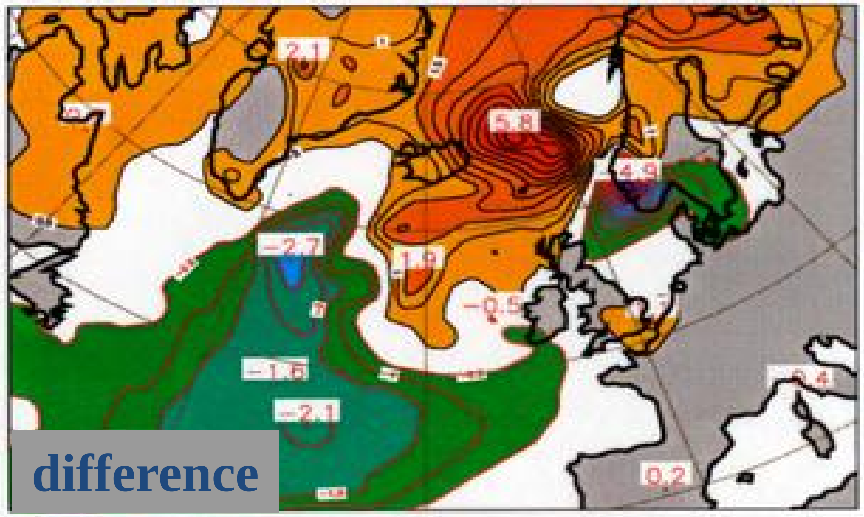
$1.2 \bullet C_D$ P_{centre}=923 hPa

Pressure (analysis)930109 48h to 48h by 24



analysis P_{centre}=925 hPa

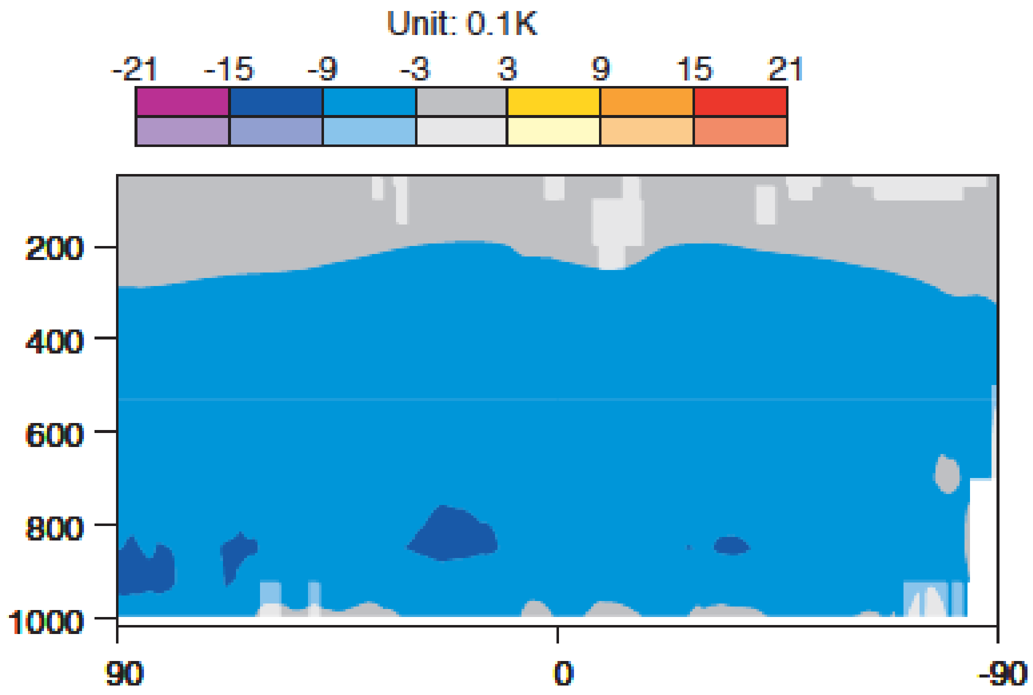
MSL Pres. Diff. 930109 48h to 48h by 24h zp4z - zp0v



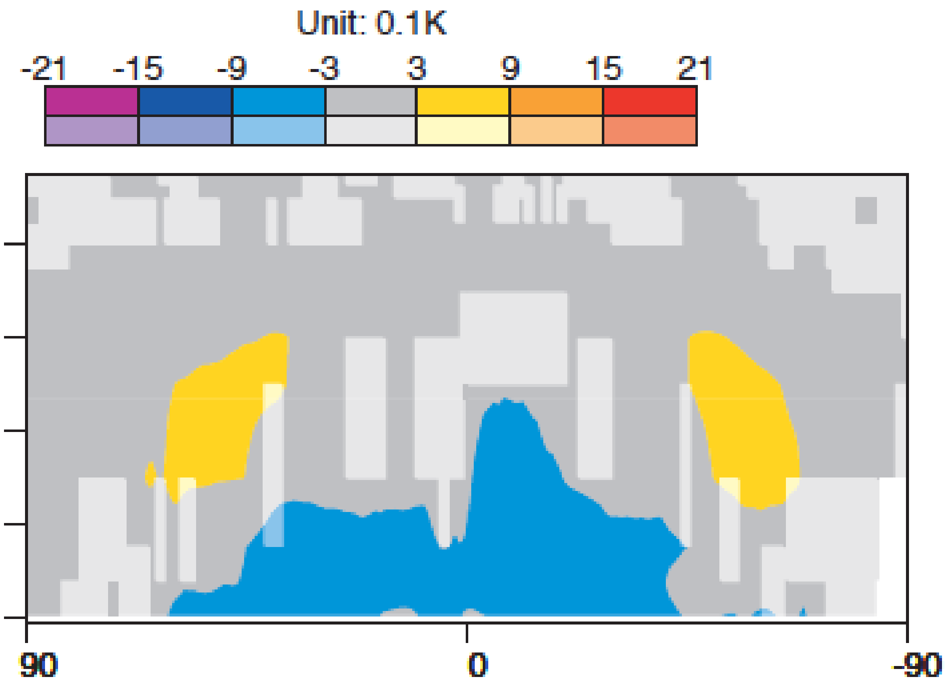
difference

T-tendencies over 12-hour data assimilation windows (K per 12 hours). Mean over DJF 2014.

Radiation

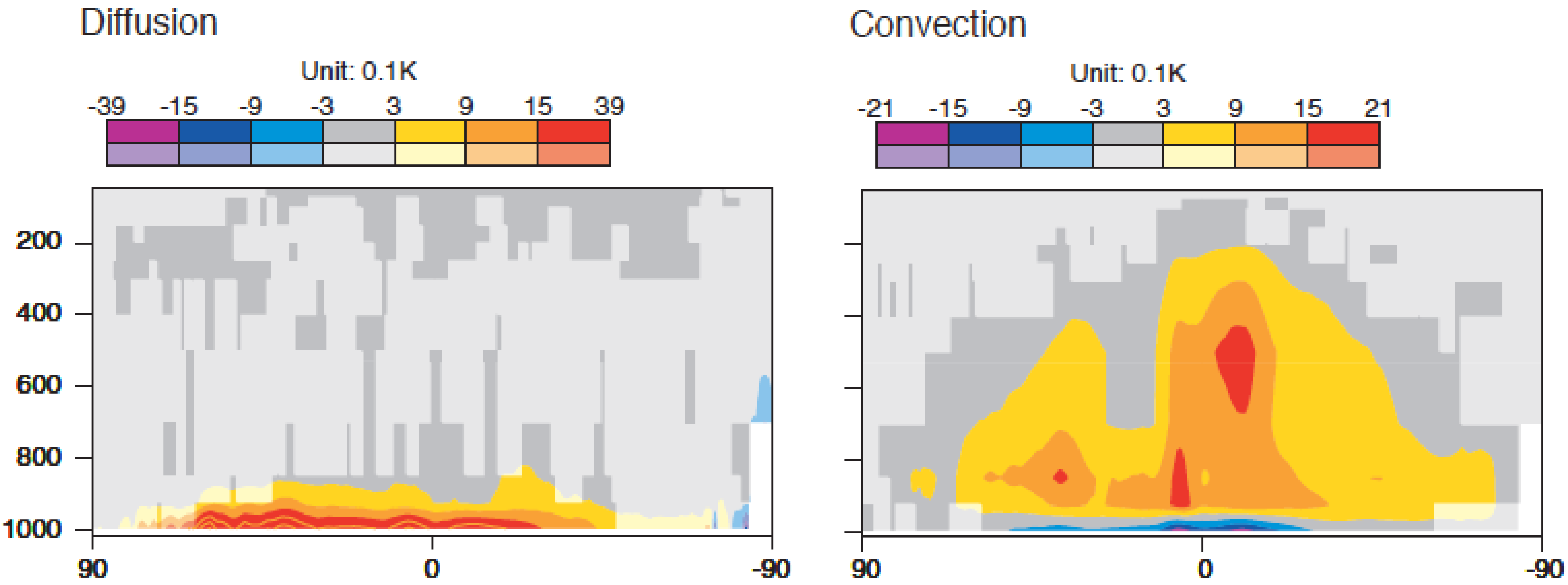


Cloud



Deep colours = 5% significant.
(Diagnostics Mark Rodwell)

T-tendencies over 12-hour interval data assimilation window (K per 12 hours). Mean over DJF 2014.



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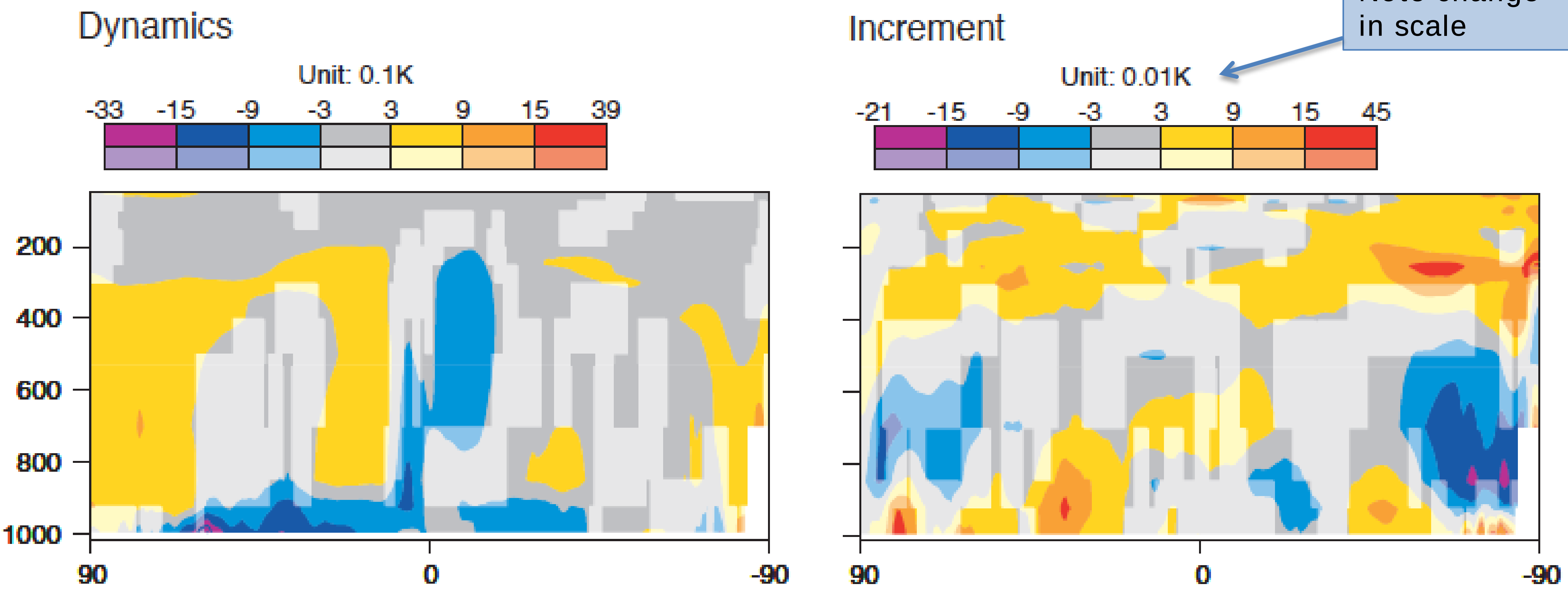


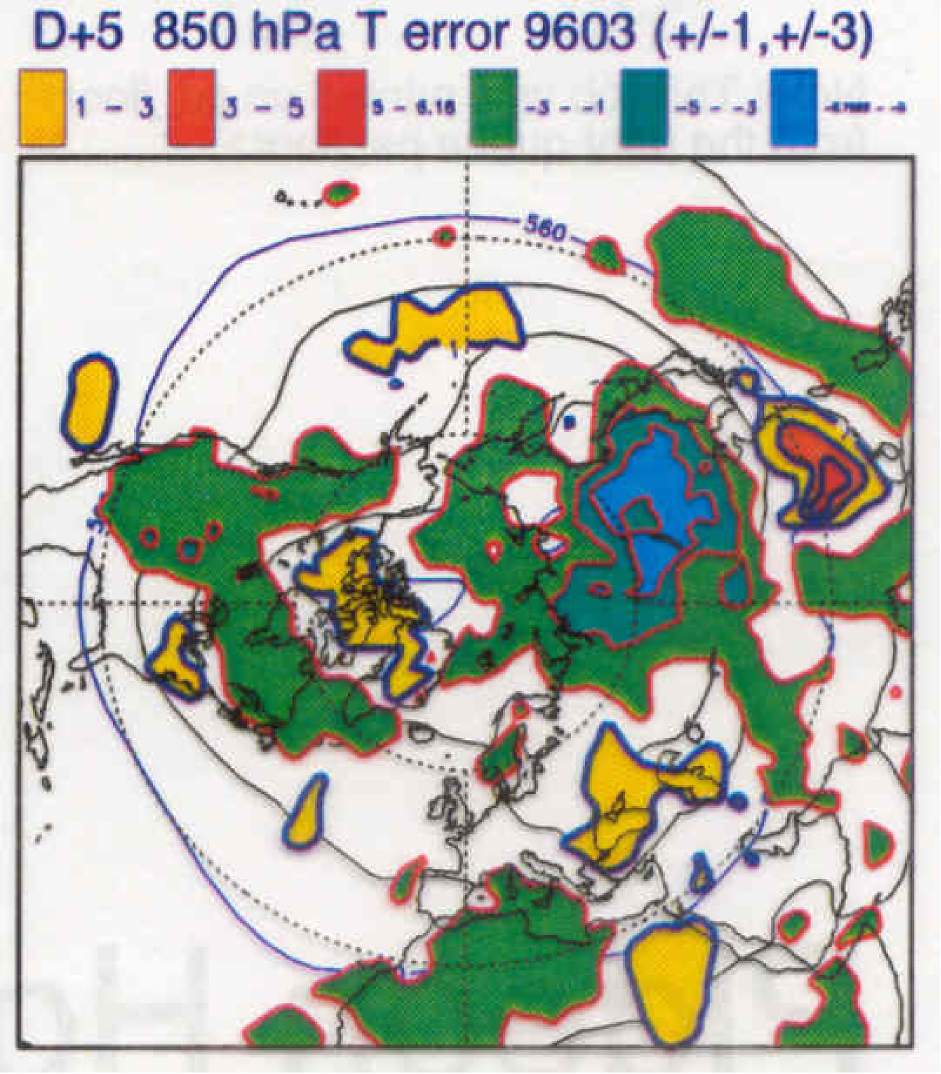
Note change in scale

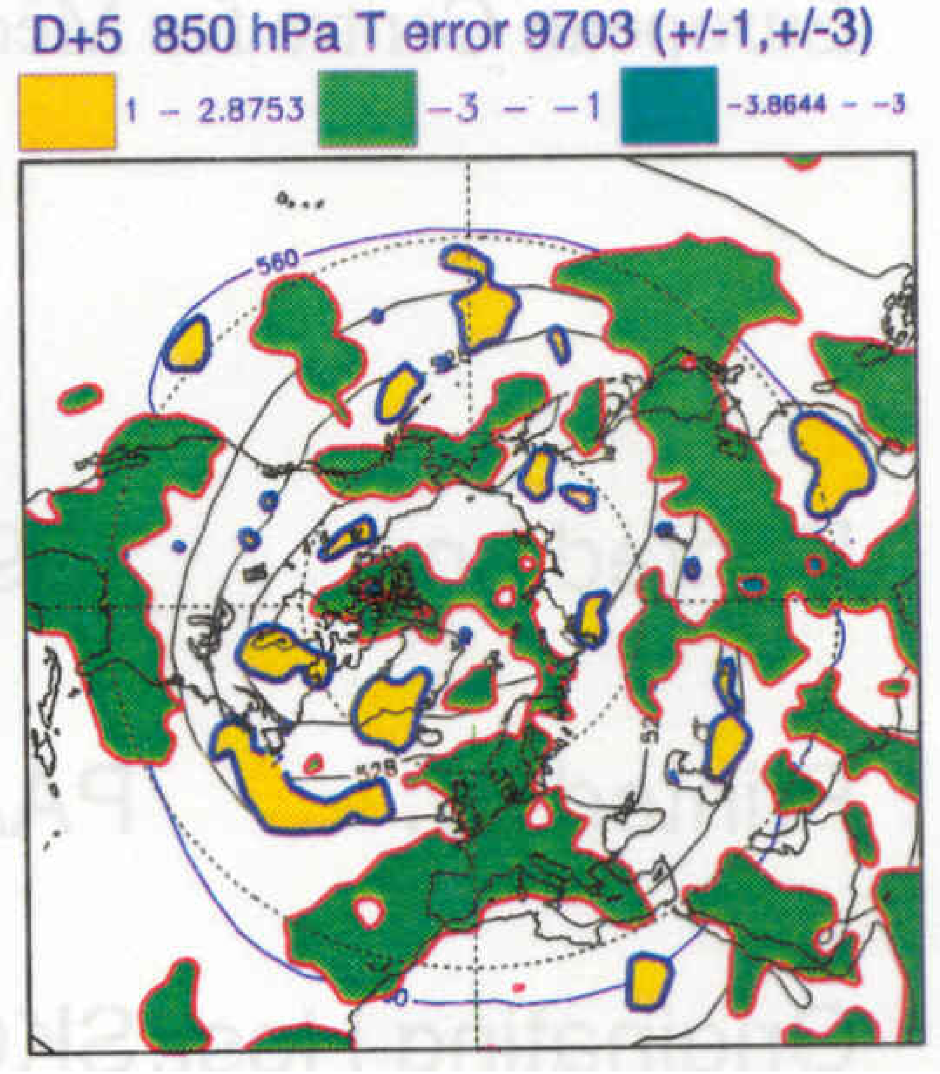
Deep colours = 5% significant.
(Diagnostics Mark Rodwell)

Validation and diagnostics

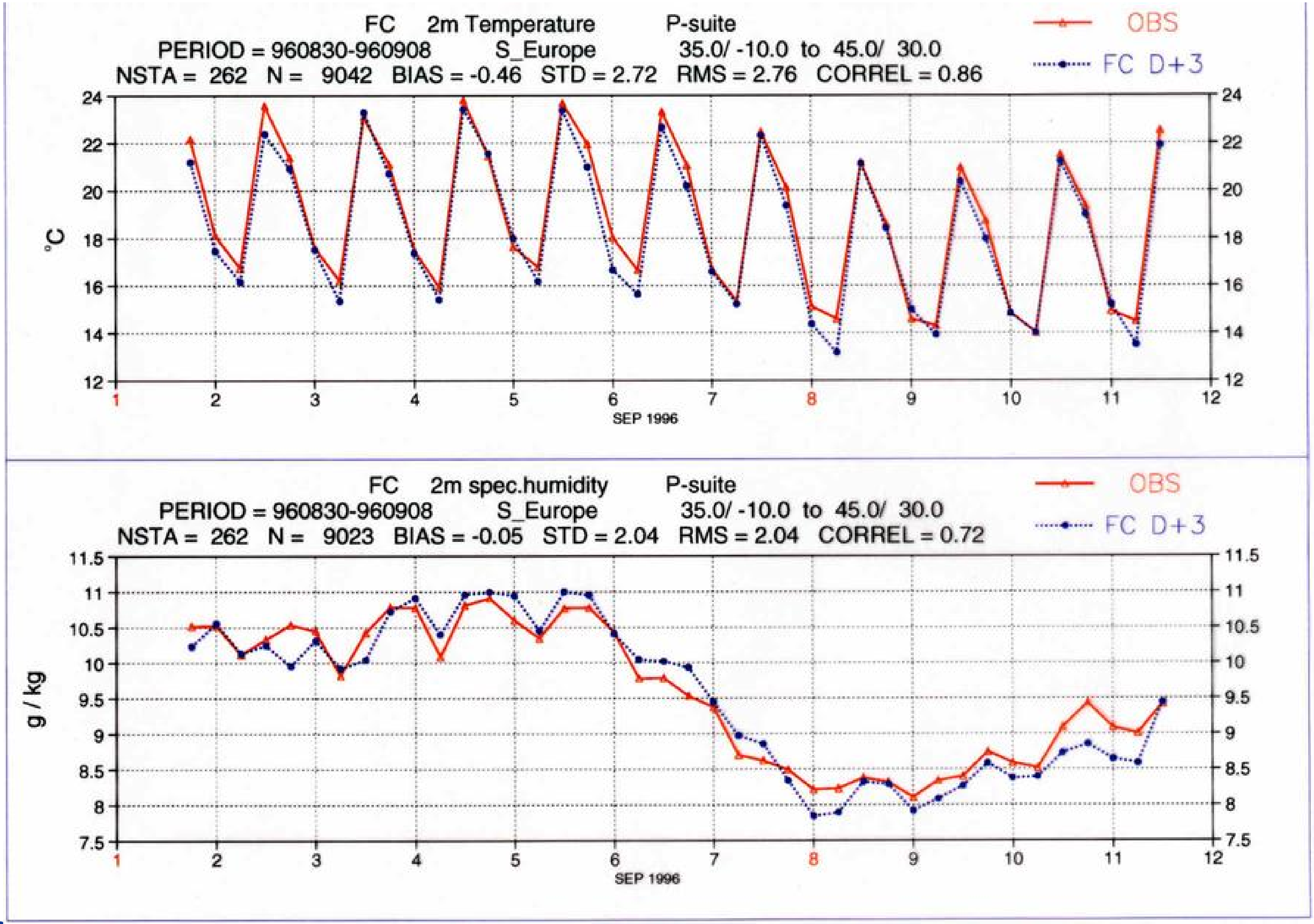
- **Compare with analysis**
  - daily verification
  - systematic errors e.g. from monthly averages
  - initial tendency diagnostics
- **Compare with operational data**
  - SYNOP’s
  - radio sondes
  - satellite
- **Climatological data**
  - CERES, ISCCP
  - ocean fluxes
- **Field experiments**
  - TOGA/COARE, PYREX, ARM, FIFE, …

Day-5 T850 errors

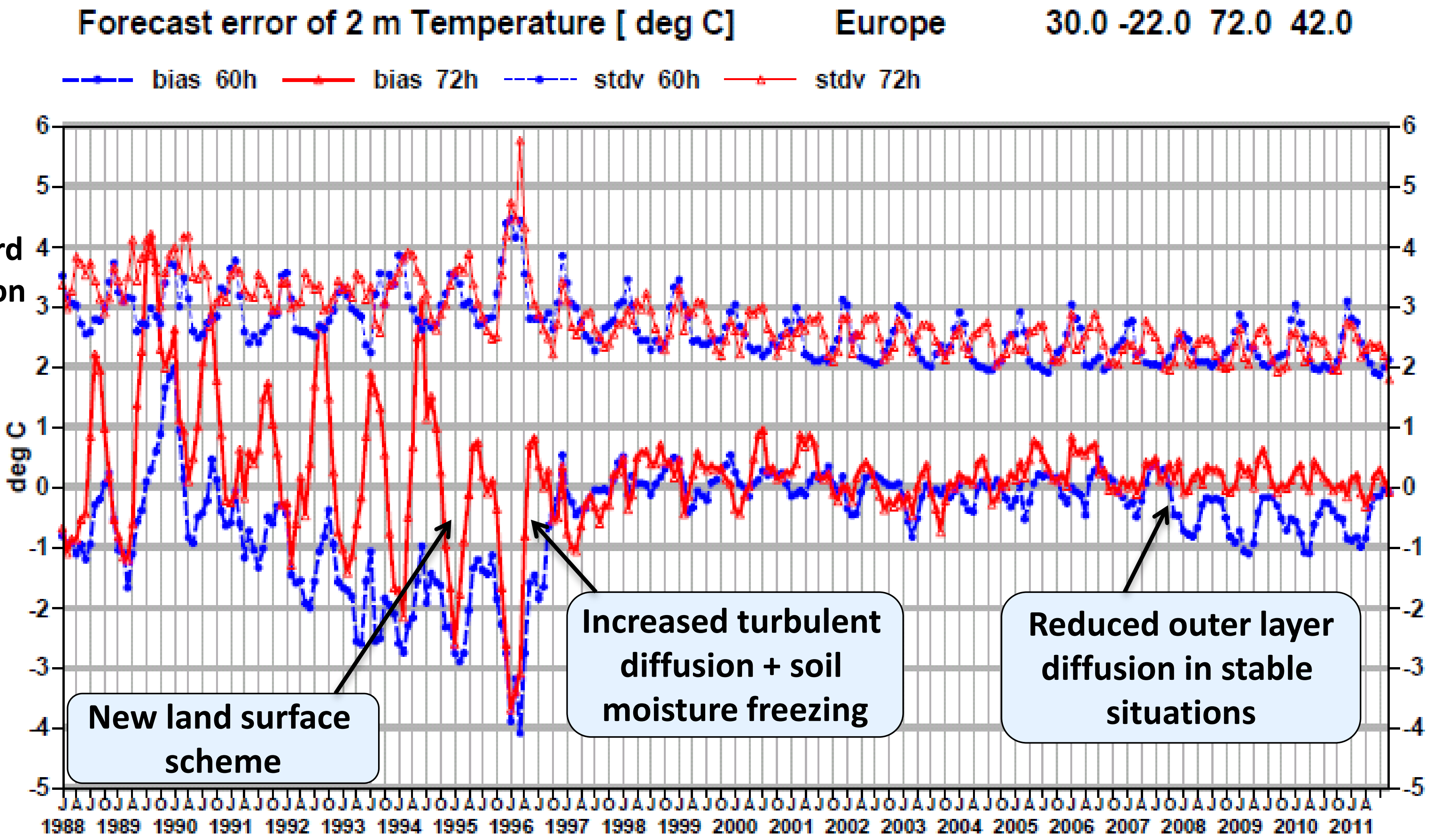




Diurnal cycle of T/q at SYNOP stations averaged over Southern Europe (D+3 forecasts versus obs)



History of temperature at screen level errors in ECMWF model (step 60/72)



Standard deviation

Mean error

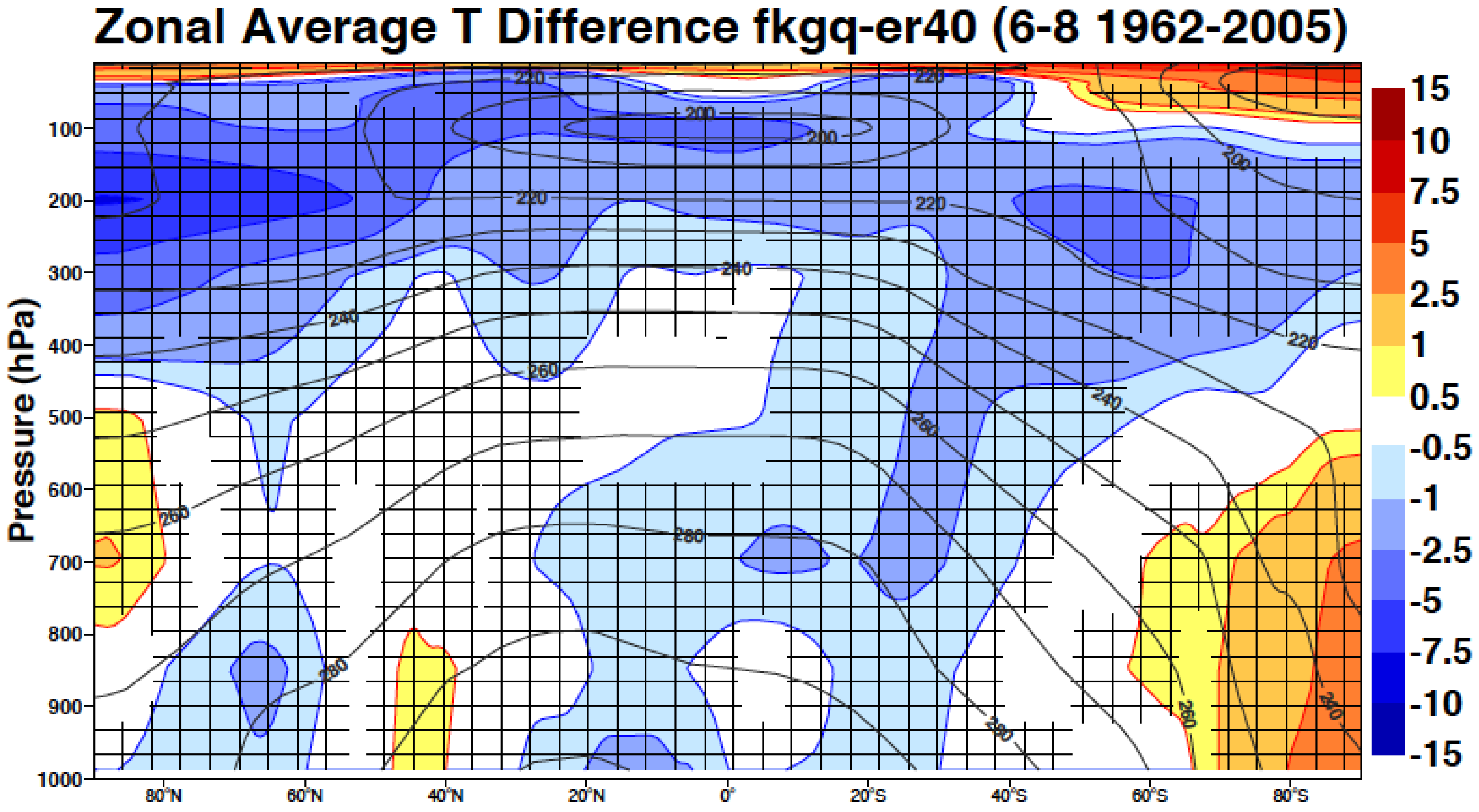
New land surface scheme

Increased turbulent diffusion + soil moisture freezing

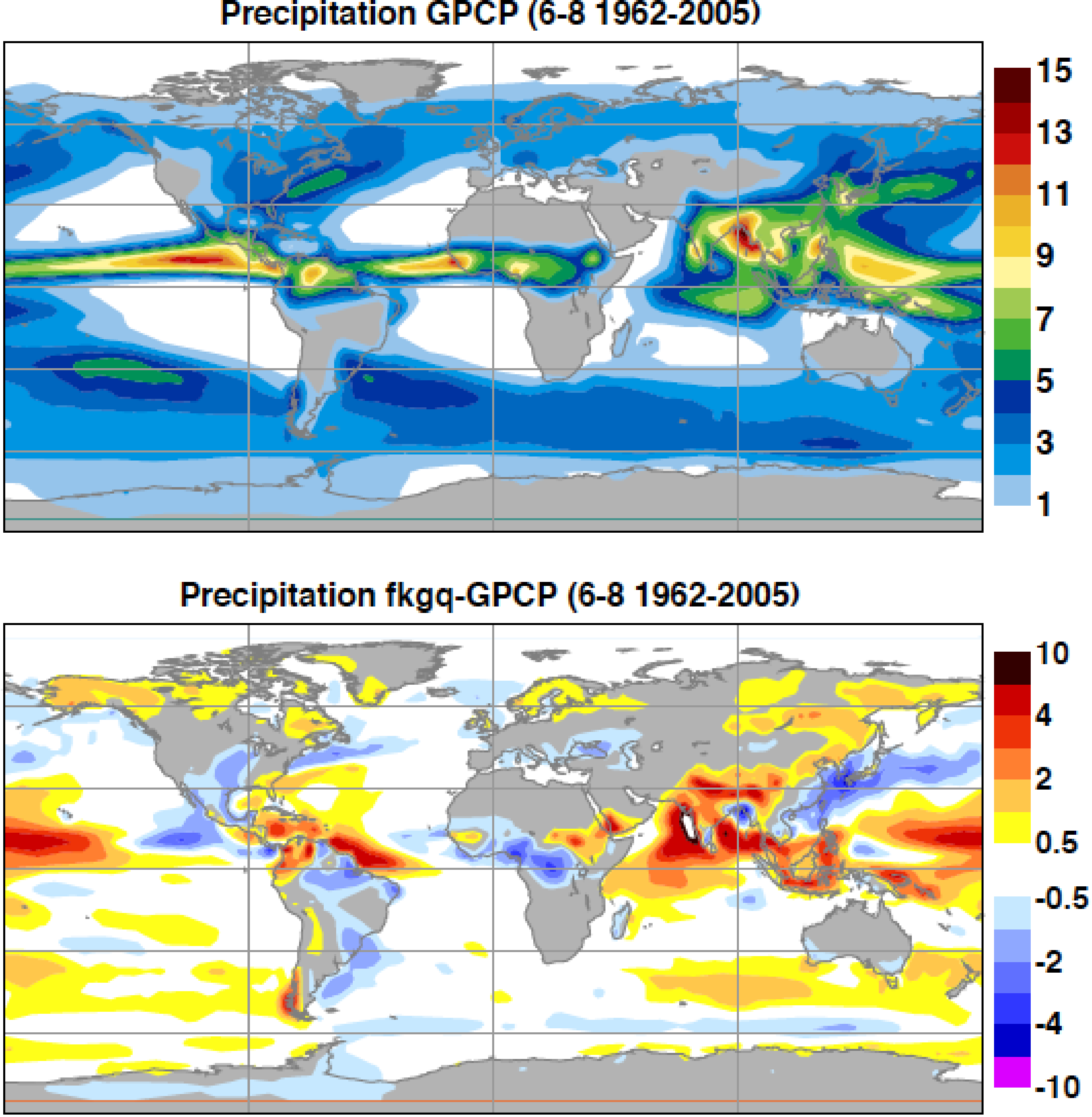
Reduced outer layer diffusion in stable situations

- Model temperature errors are influenced by many processes.
- Observations at process level are needed to disentangle their effect

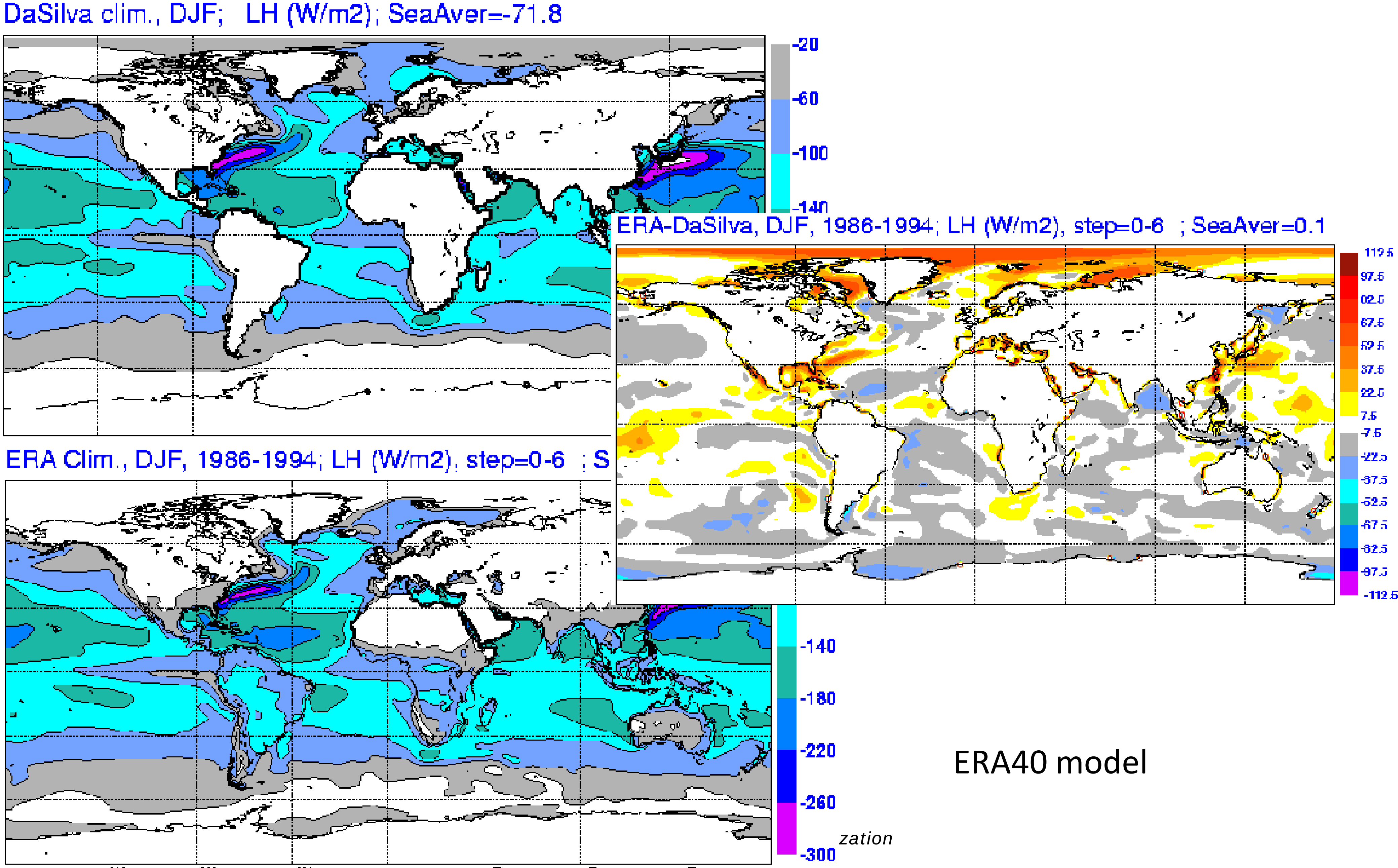
Zonal mean temperature bias of JJA model climate (37R3) versus ERA40



Precipitation in JJA model climate (37R3) versus GPCP



Lat. Heat Flux-DJF (ERA_40_Step_0_6 vs. DaSilva climatology)



DaSilva clim., DJF; LH (W/m2); SeaAver=-71.8

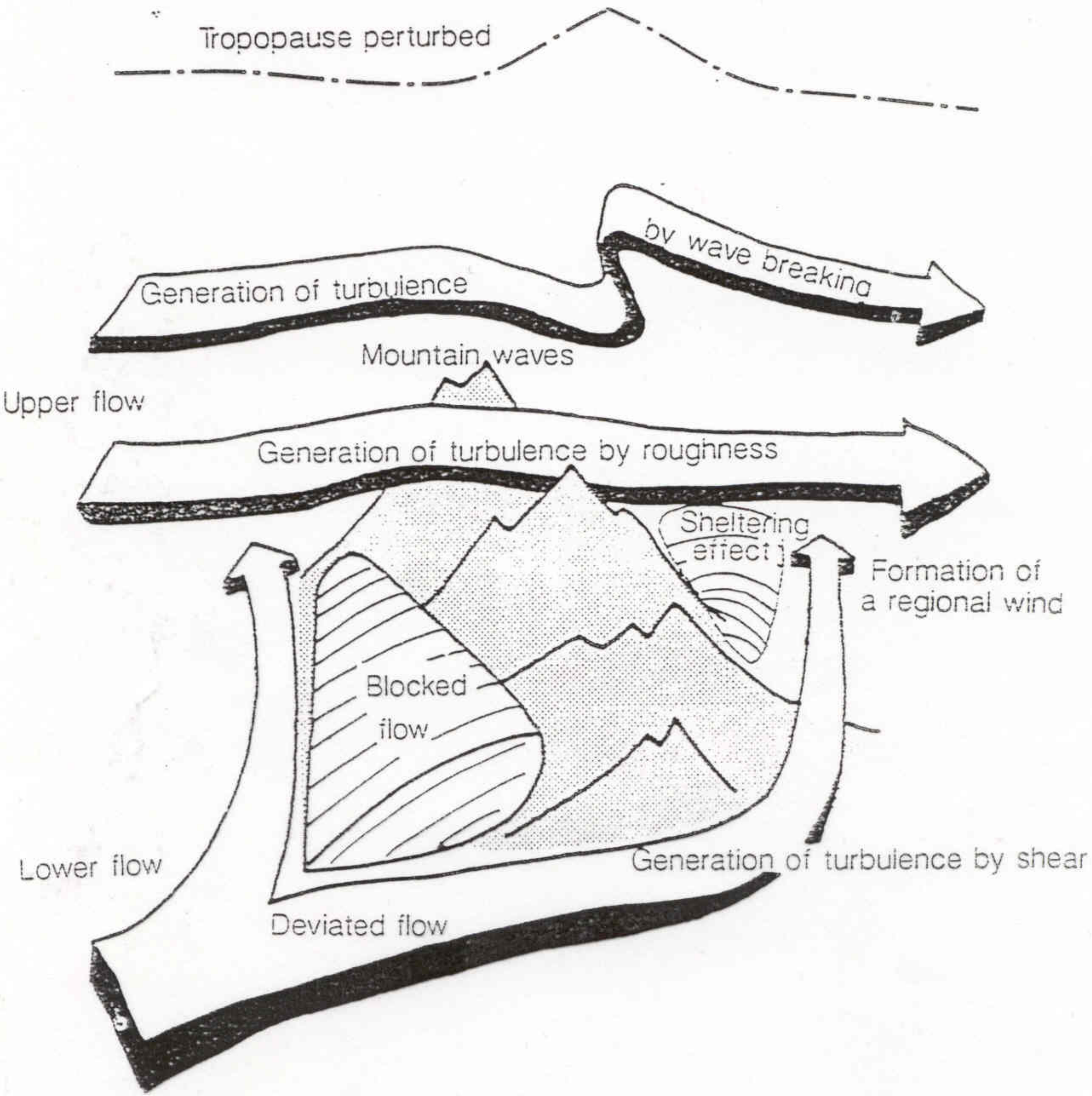
ERA-DaSilva, DJF, 1986-1994; LH (W/m2), step=0-6 ; SeaAver=0.1

ERA Clim., DJF, 1986-1994; LH (W/m2), step=0-6 ; S

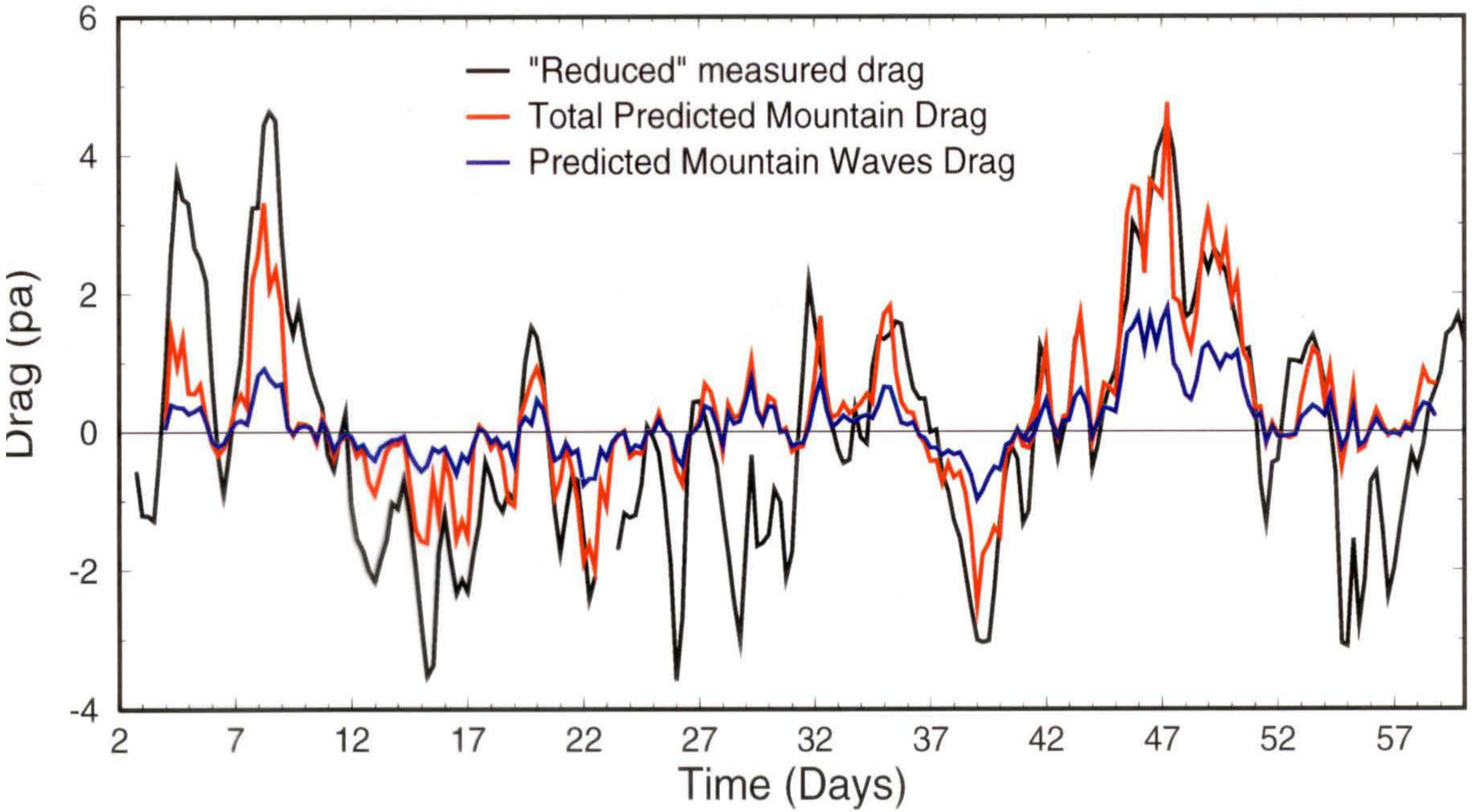
ERA40 model

zation

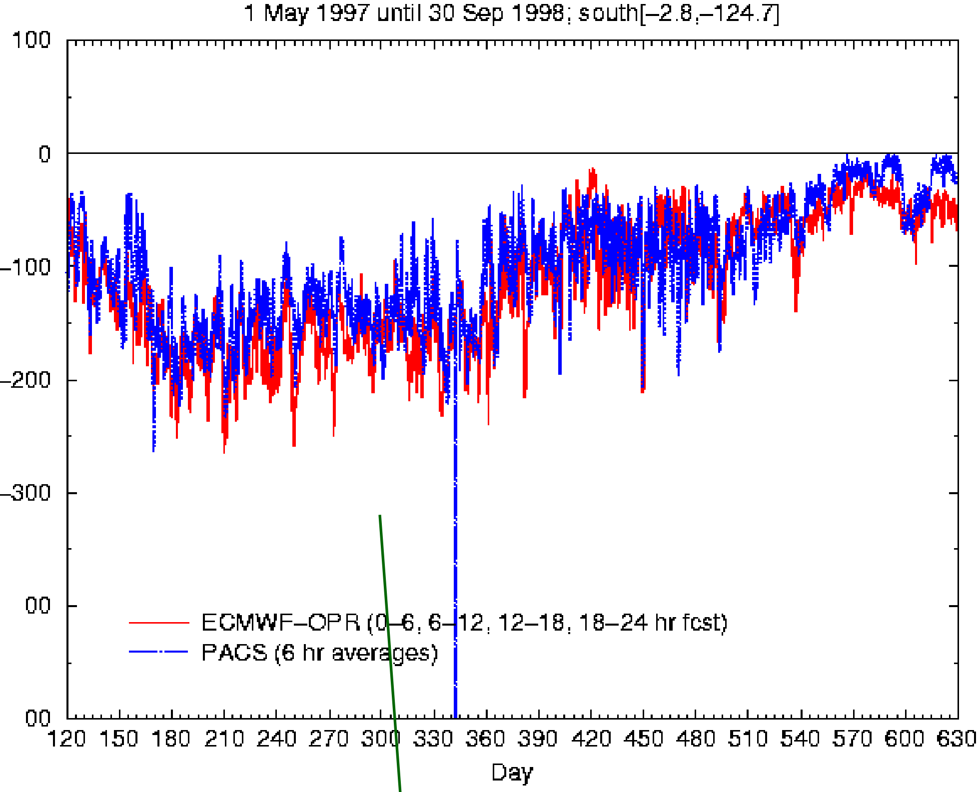
PYREX experiment

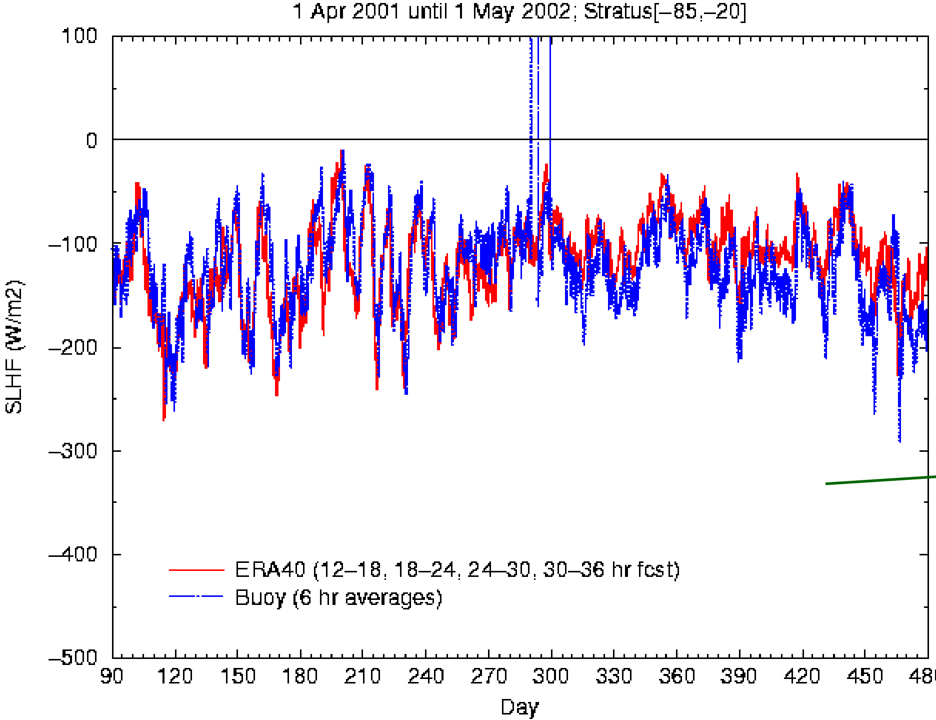


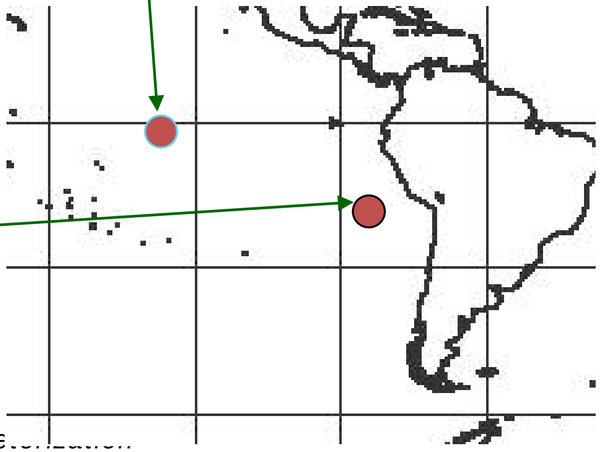
PYREX experiment: model results



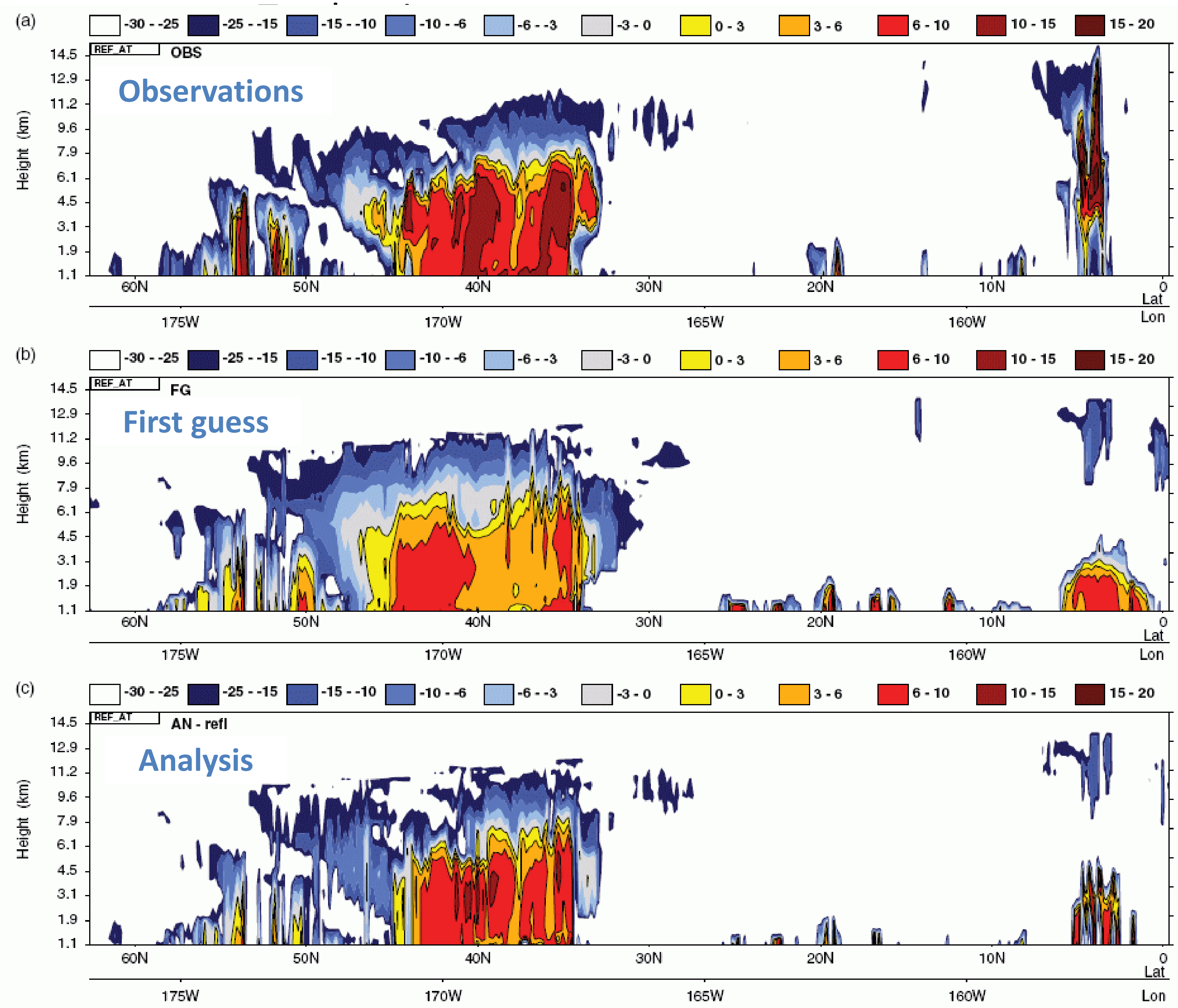
Latent heat flux: ERA-40 vs. IMET buoy

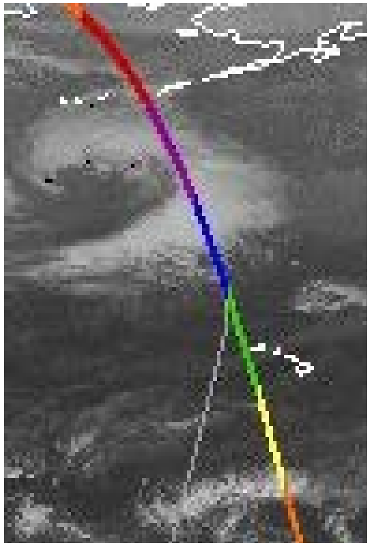






Data assimilation – 1D-Var of cloud radar reflectivity





20070123
over Pacific

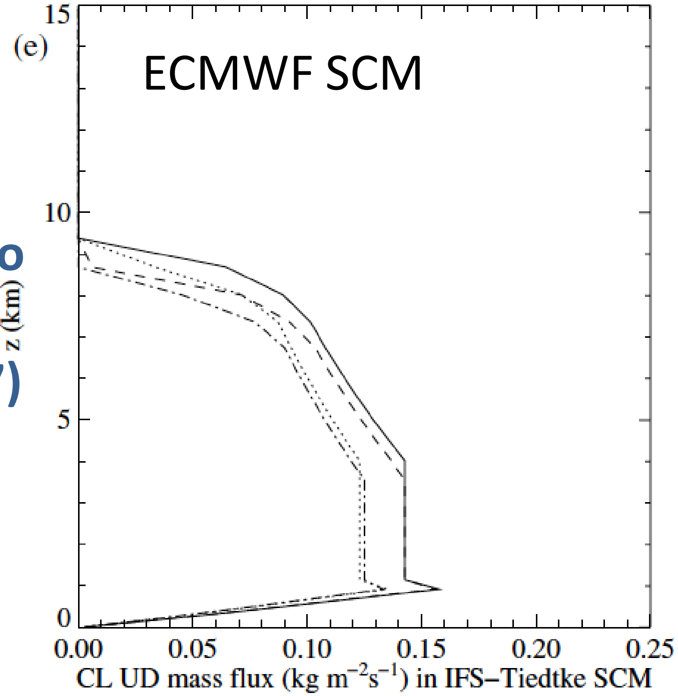
Observations:
CloudSat cloud radar reflectivity

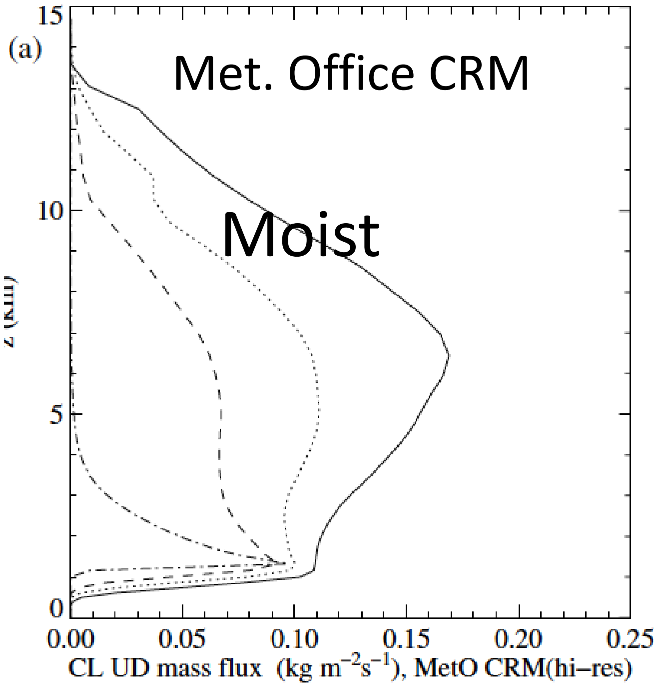
Parameterization development strategy

- **Invent empirical relations (e.g. based on theory, similarity arguments or physical insight)**

  To find parameters use:
  - Theory (e.g. radiation)
  - Field data (e.g. GATE/TOGA/COARE for convection; PYREX for orographic drag; HAPEX/SEBEX/FLUXNET for land surface; Kansas for turbulence; ASTEX/Cloudsat for clouds; BOREAS for forest albedo)
  - Cloud resolving models (e.g. for clouds and convection)
  - Meso scale models (e.g. for subgrid orography)
  - Large eddy simulation (turbulence)
- **Test in stand alone or single column mode**
- **Test in 3D mode with short range forecasts**
- **Test in long integrations (model climate)**
- **Consider interactions and optimize parameters**

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)





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

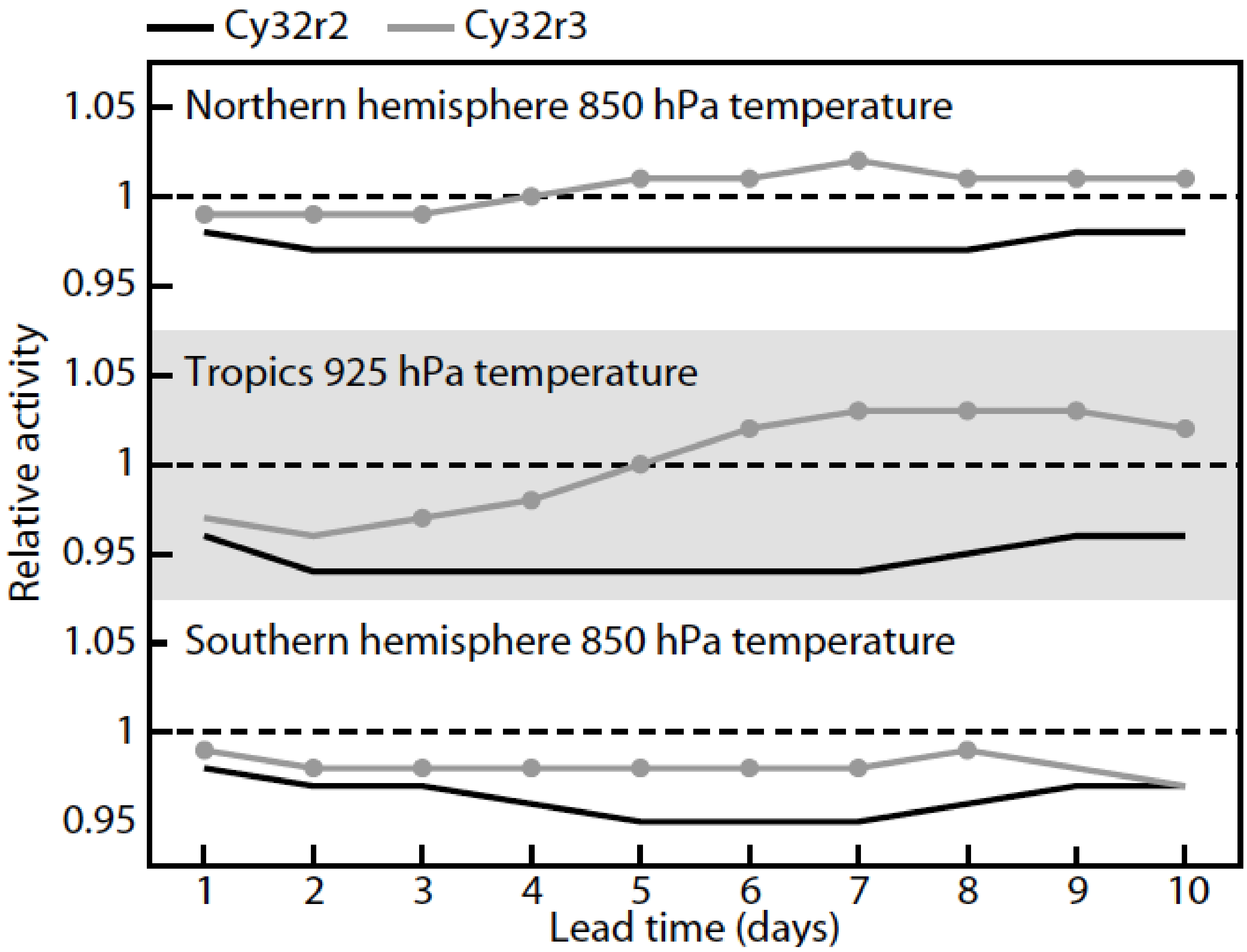
$$\frac{1}{M}\frac{\partial M}{\partial z} = \varepsilon - \delta \qquad \varepsilon = \underbrace{c_0}_{turb} F_\varepsilon + \underbrace{c_1 \frac{\bar{q}_s - \bar{q}}{\bar{q}}}_{org,deep,buoy>0} F_\varepsilon; \quad F_\varepsilon = \left(\frac{\bar{q}_s}{\bar{q}_{s,\mathrm{b}}}\right)^2$$

$$\tau = \frac{H}{\bar{w}_u^H}\alpha; \quad \alpha = 1 + \frac{264}{n}$$

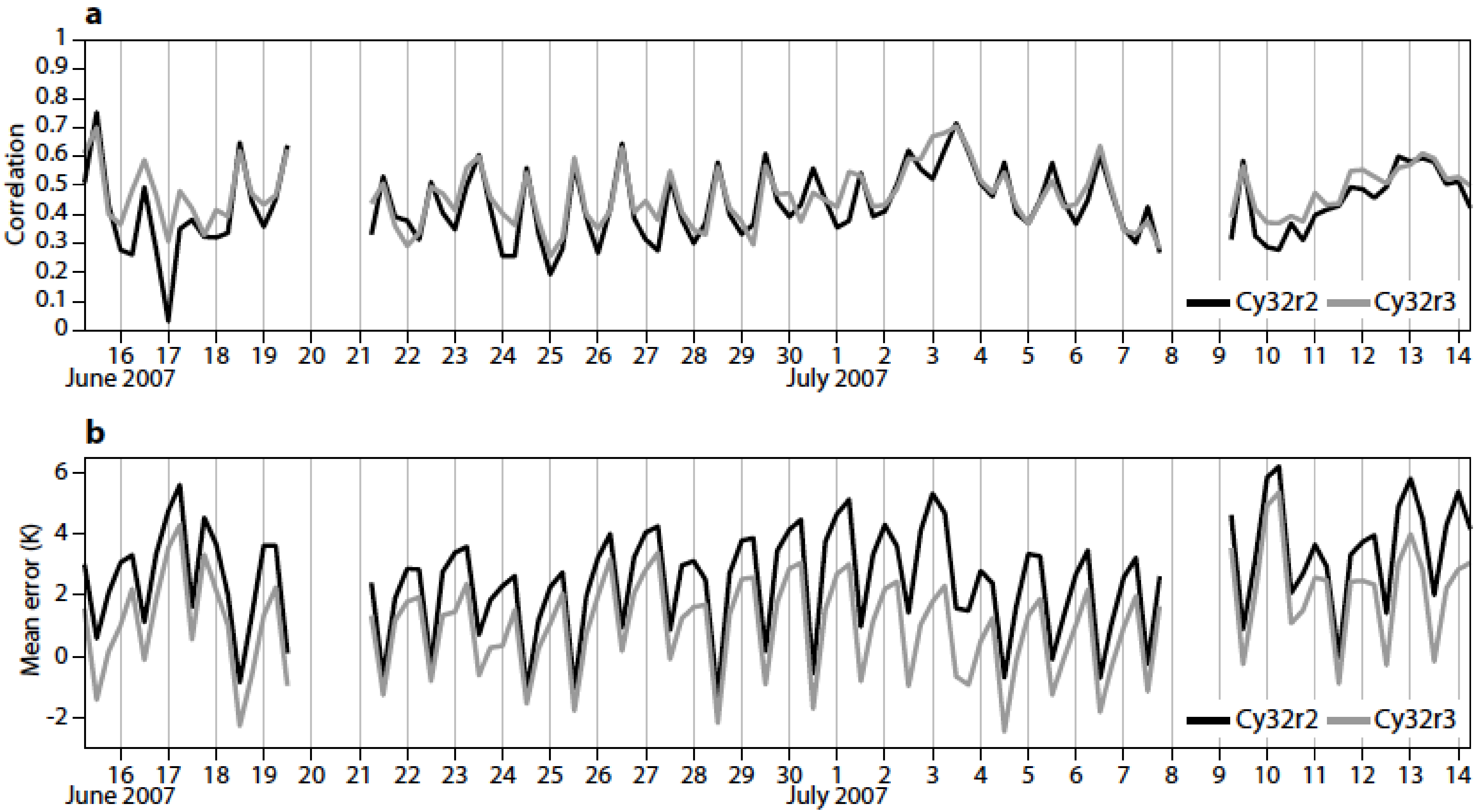
Model activity in T799 10-day forecasts

Relative activity is model activity divided by activity in analysis

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

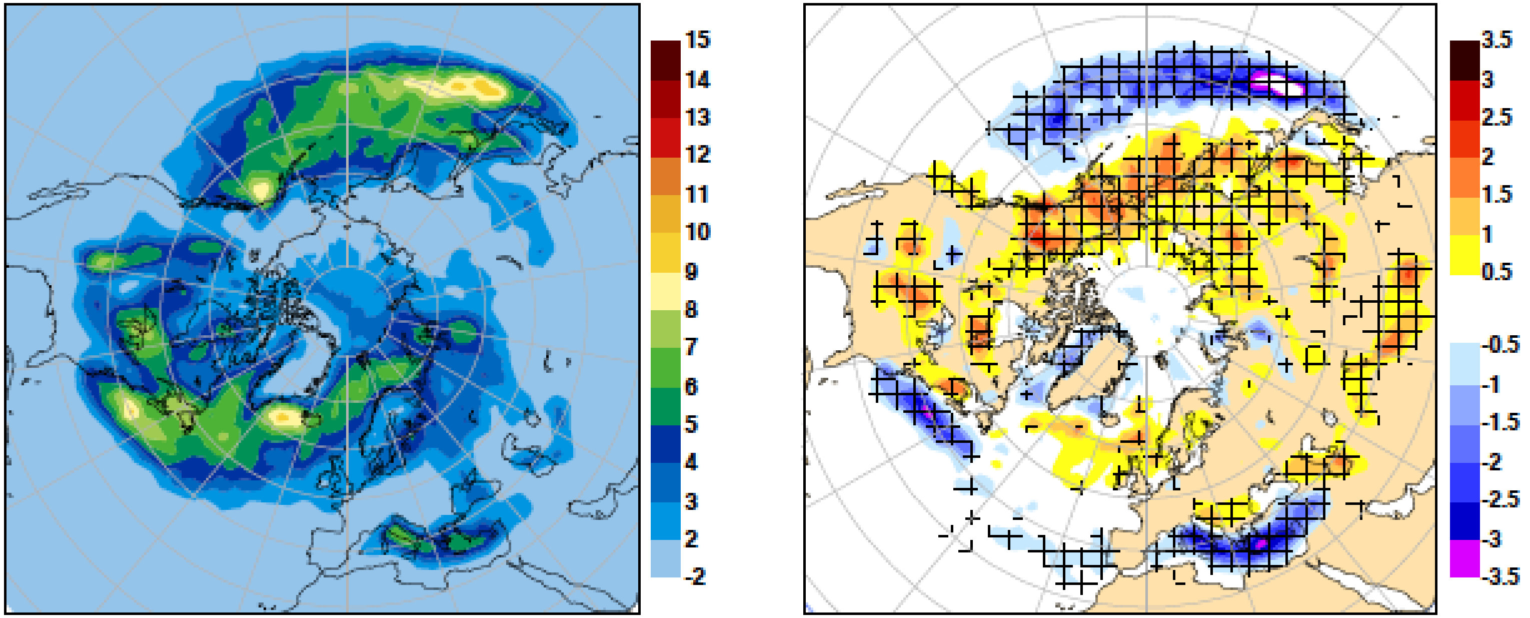


Verification of brightness temperature of daily 6,12,18,24 hr forecasts with Meteosat observations.



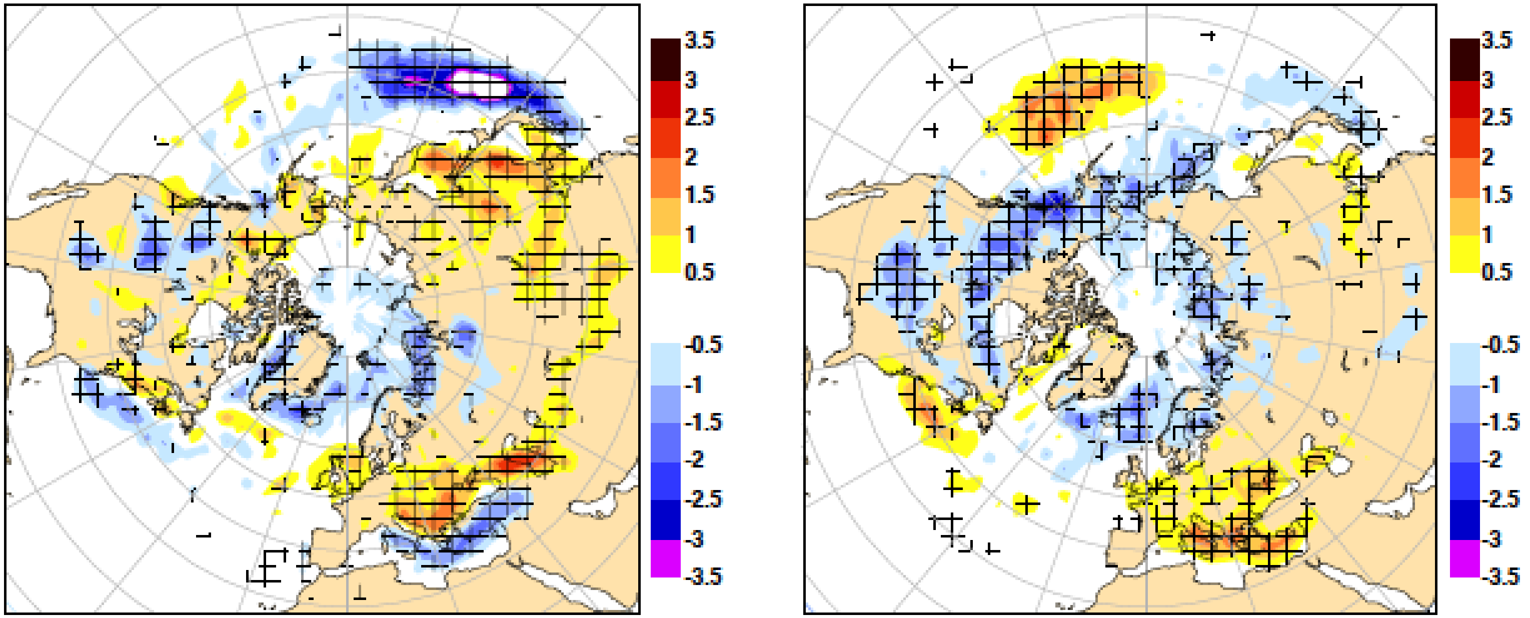
Storm frequency statistics (Bechtold et al. 2007)

T159 13-month integrations from 1962 to 2005



(a) Number of MSLP Minima (er40 DJFM 1962-2005)

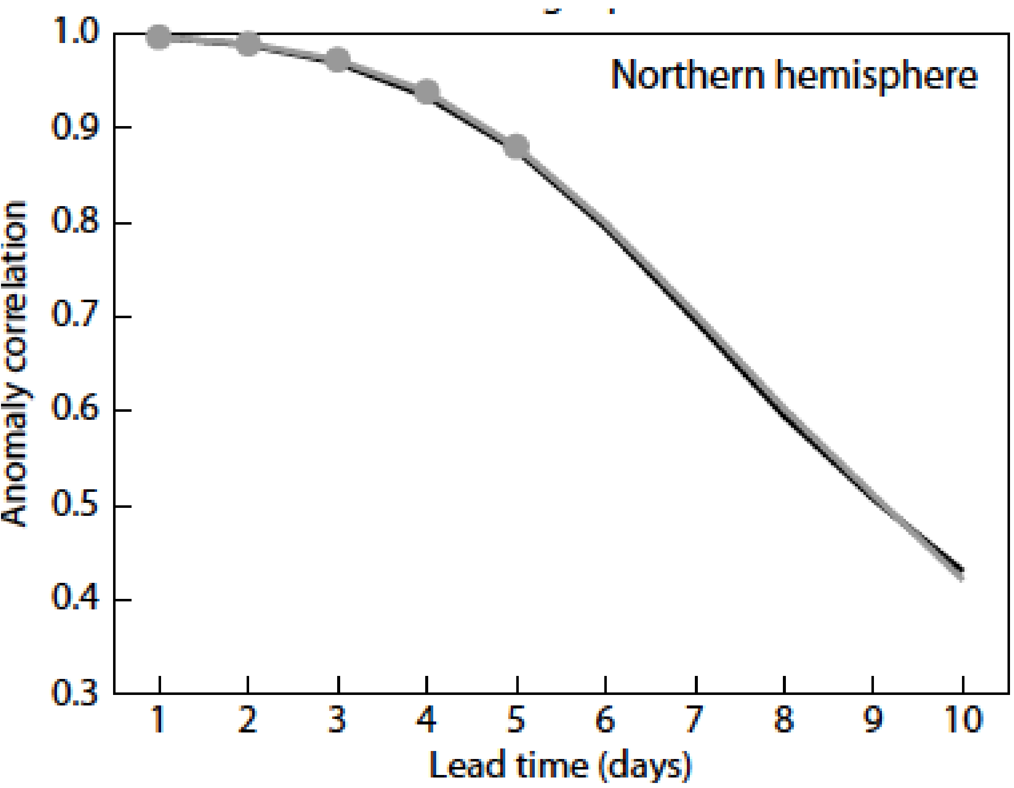
(b) Number of MSLP Minima (Cy32r2-er40 DJFM 1962-2005)

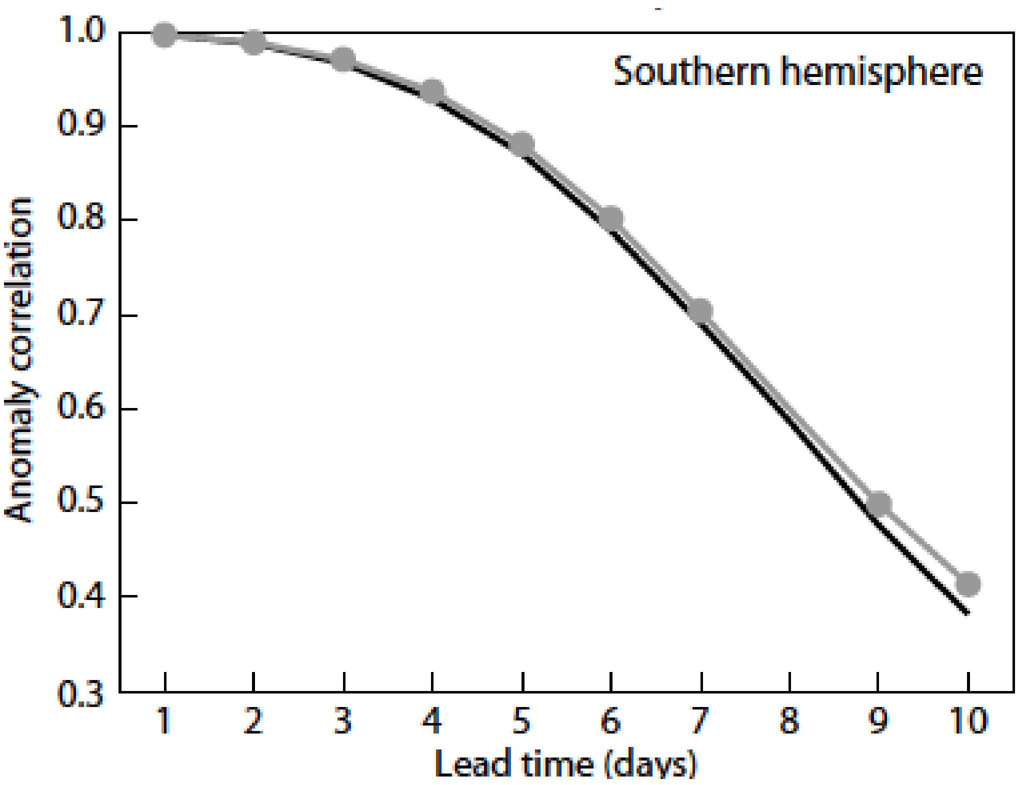


(c) Number of MSLP Minima (Cy32r3-er40 DJFM 1962-2005)

(d) Number of MSLP Minima (Cy32r3-Cy32r2 DJFM 1962-2005)

Anomaly correlation of 500hPa height in T799 10-day forecasts





Modest improvement in model performance in spite of increased activity

Concluding remarks

Enjoy the course

and

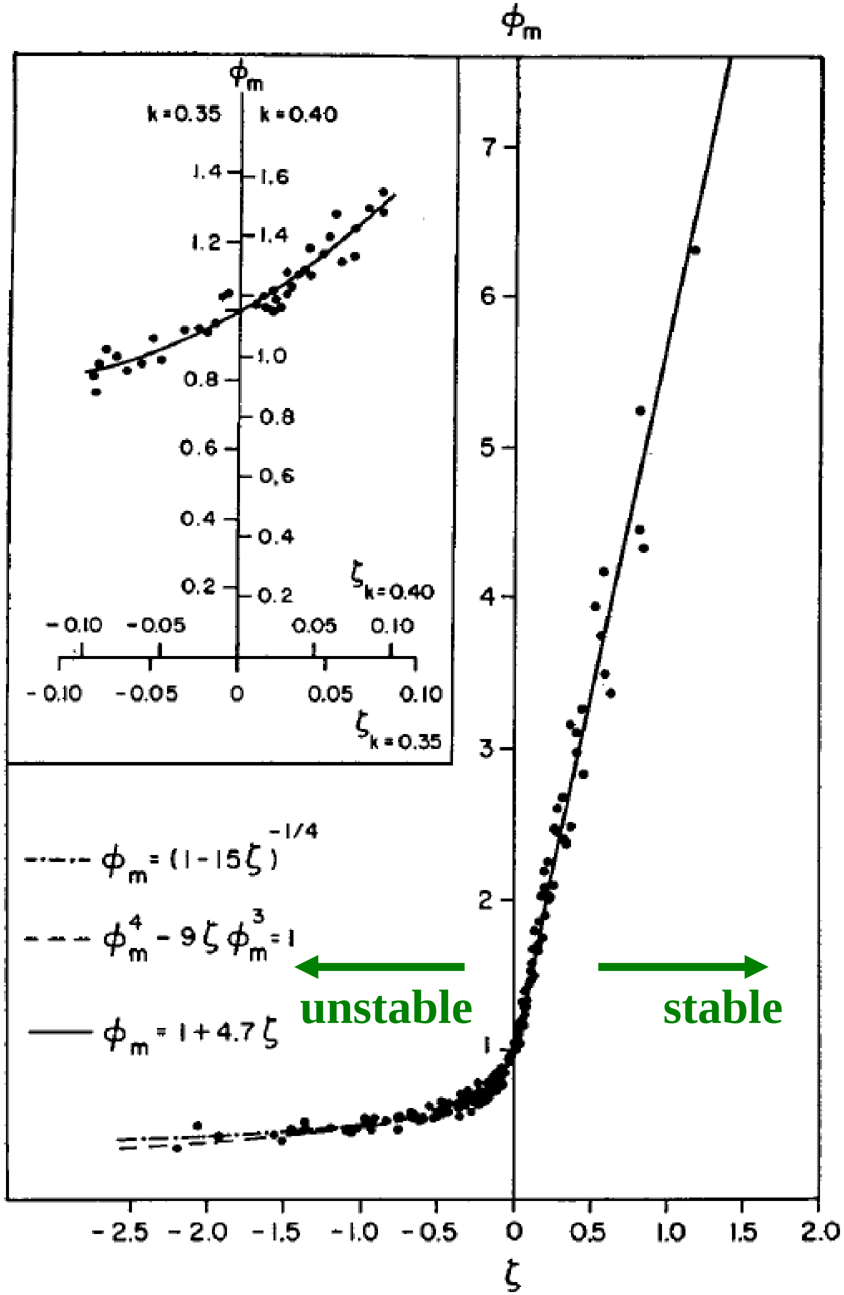
Do not hesitate to
ask questions

Measure turbulent diffusion coefficients

Parameterization should be simple:

- Clear scale separation
- Solid scaling relation between fluxes and profiles

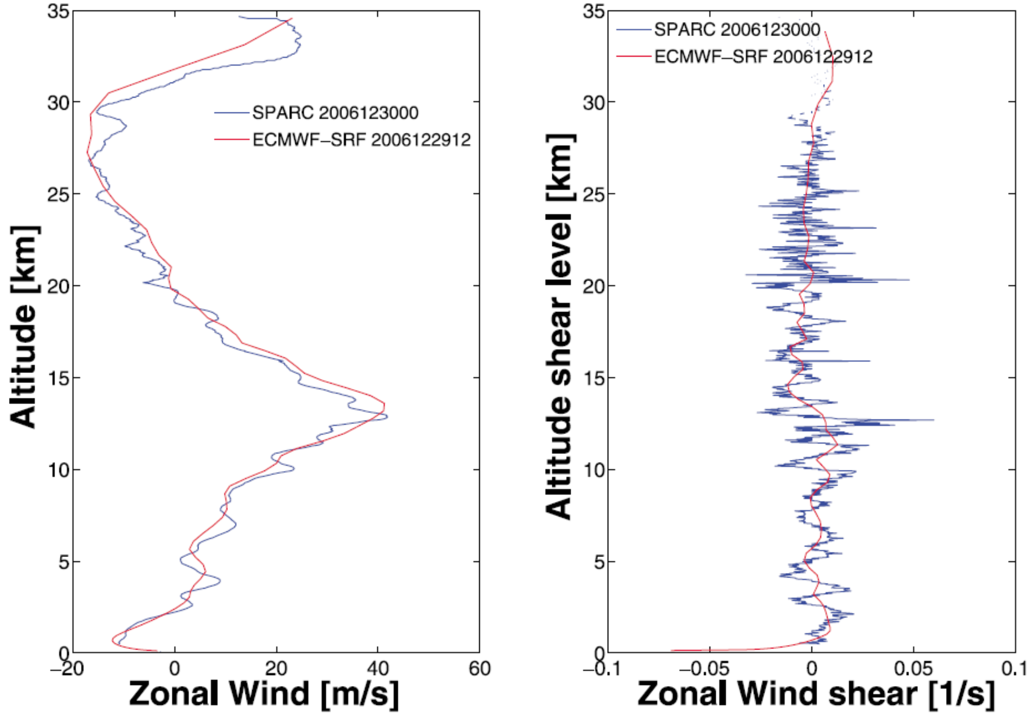
$$K_m = \frac{\kappa u_* z}{\phi_m(z/L)}$$



Businger et al. (1971)

But in practise

- The atmosphere has a lot of meso-scale variability, which is missing in the ECMWF model.
- Houchi et al. (2010) analyse a large volume of radio sonde data and conclude that the ECMWF model underestimates shear by a factor 2.5
- This might be the background of “long tail formulations”, which makes the uncertainty large



Houchi et al. (2010)

And how to handle the heterogeneous surface boundary condition ?

Concepts are well established:

- Use “effective roughness” (Mason, 1988); Grant and Mason, 1990; Wood and Mason, 1991)
- Turbulent Orographic Form Drag TOFD (Wood et al., 2001; Beljaars et al. 2004)
- The uncertainty in the coefficients that characterise the landscape and the sub-grid orography is large

Llanthony valley, S. Wales

Changes implemented in 40R1 building on Sandu et al., 2013

Turbulence closure for stable conditions: $K_{M,H} = \left|\frac{\partial U}{\partial Z}\right| l^2 f_{M,H}(R_i), \quad \frac{1}{l} = \frac{1}{kz} + \frac{1}{\lambda}$

Up to 38R2

- long tails near surface, short tails above PBL
- λ =150m
- non-resolved shear term, with a maximum at 850hPa

From 40R1

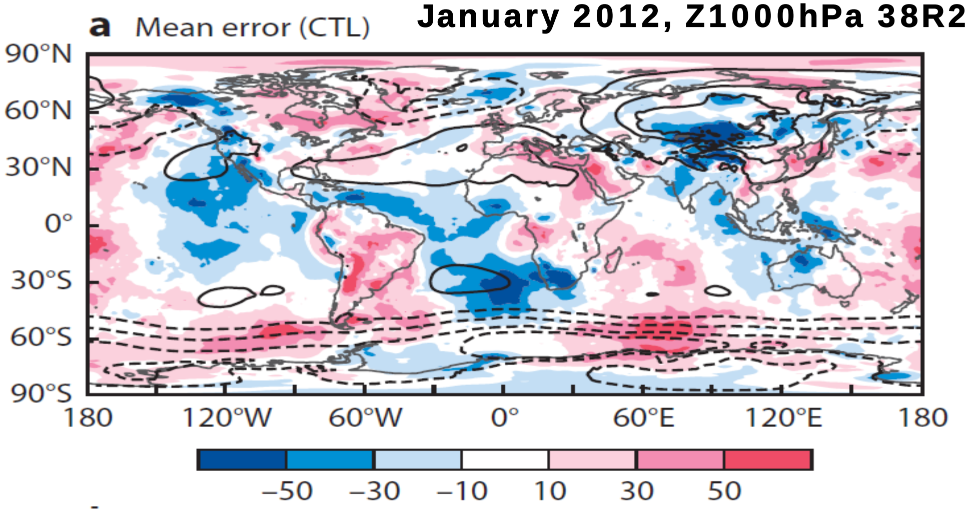
- long tails everywhere
- λ = 10% PBL height in stable boundary layers
- λ = 30 m in free shear layers

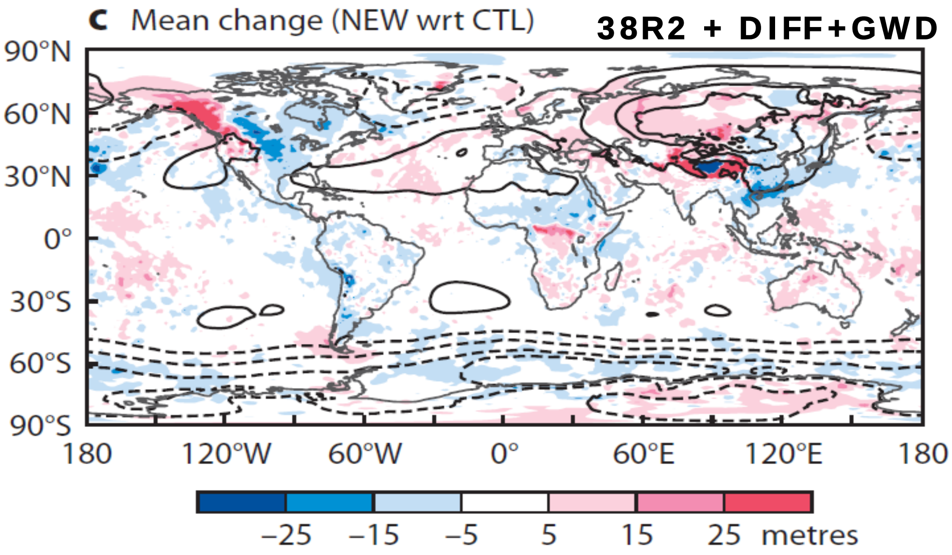
+

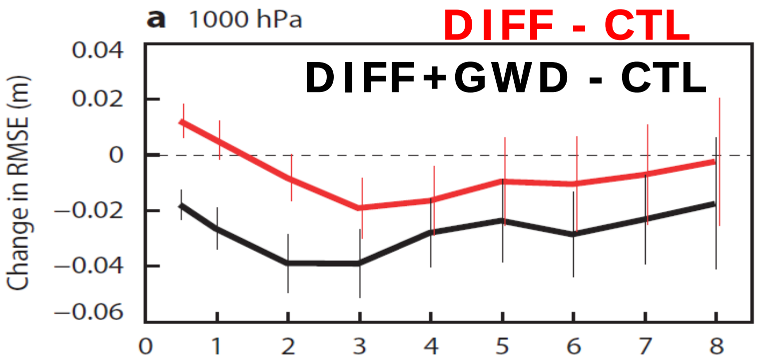
Increase in drag over orography

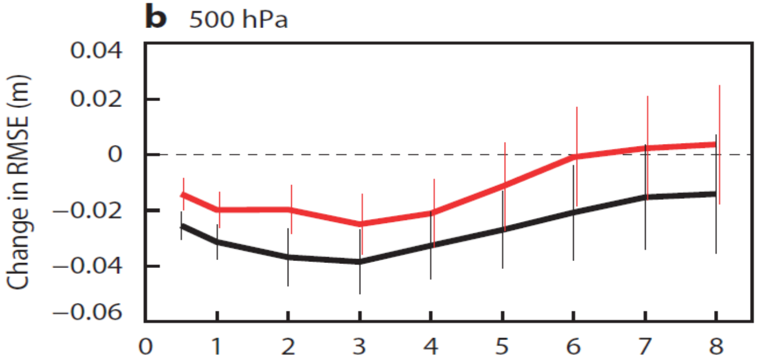
Consequence: net reduction in diffusion in stable boundary layers, not much change in free-shear layers, except at 850 hPa

Predictive skill since cycle 40r1







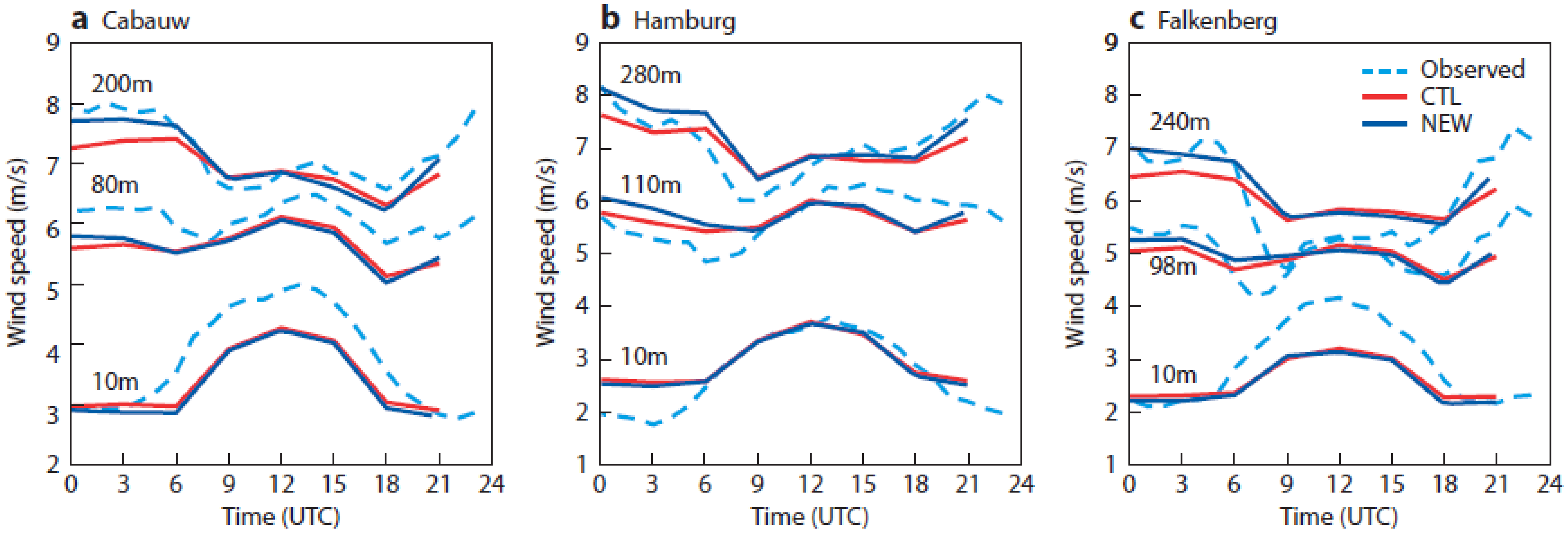


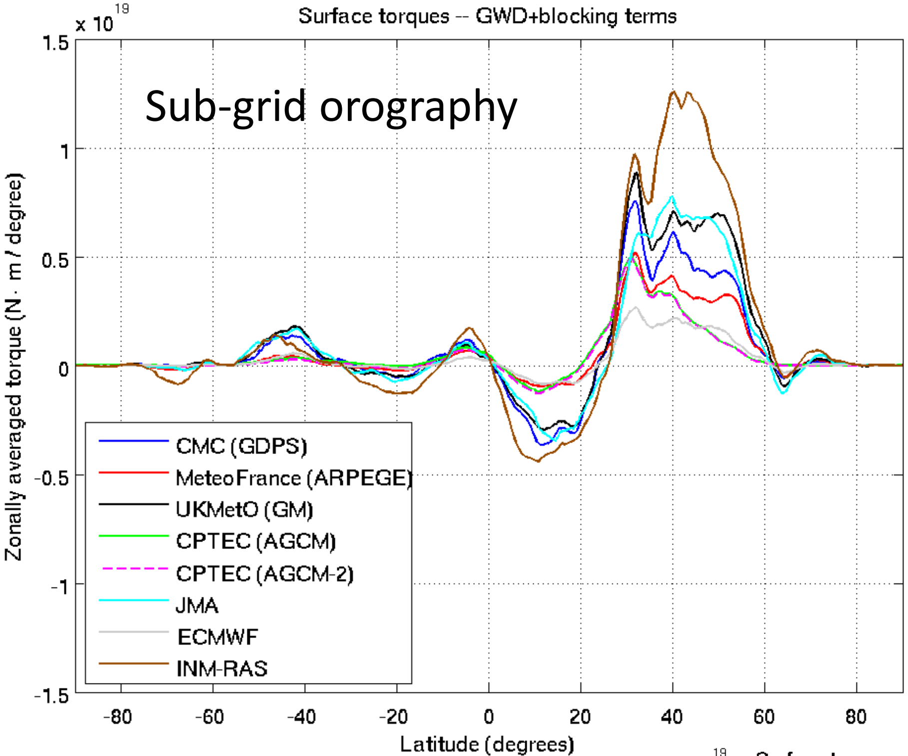
- Change to orographic drag affects planetary waves, anticyclones (e.g. too weak over EA)
- The improvement in averaged NH scores mostly located over E. Asia, NA

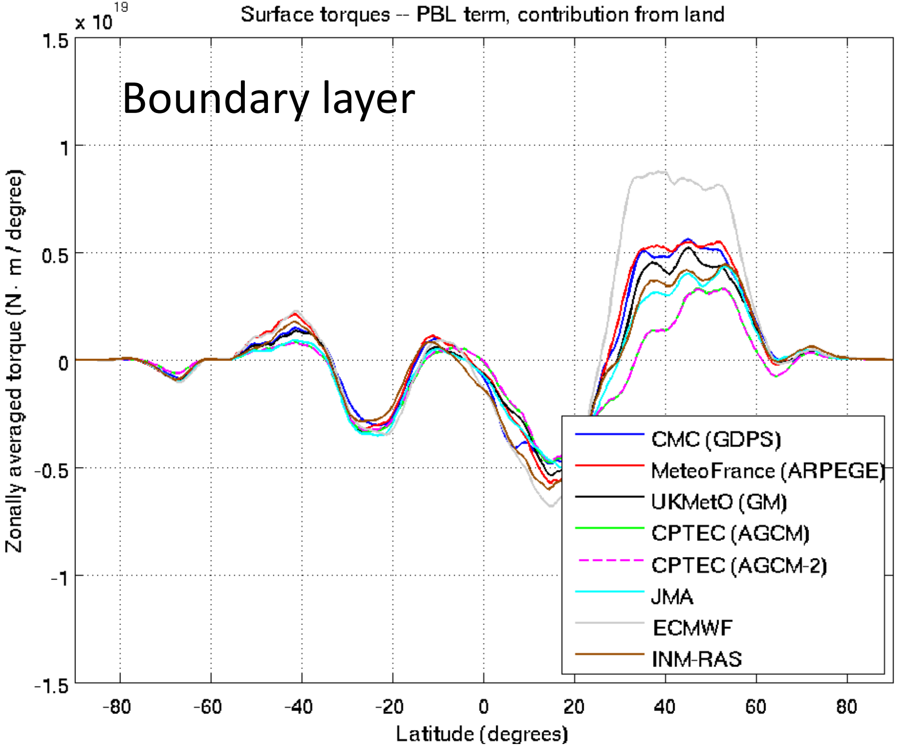
(I. Sandu; Newsletter, 138)

Impact of diffusion / sub-grid orography changes

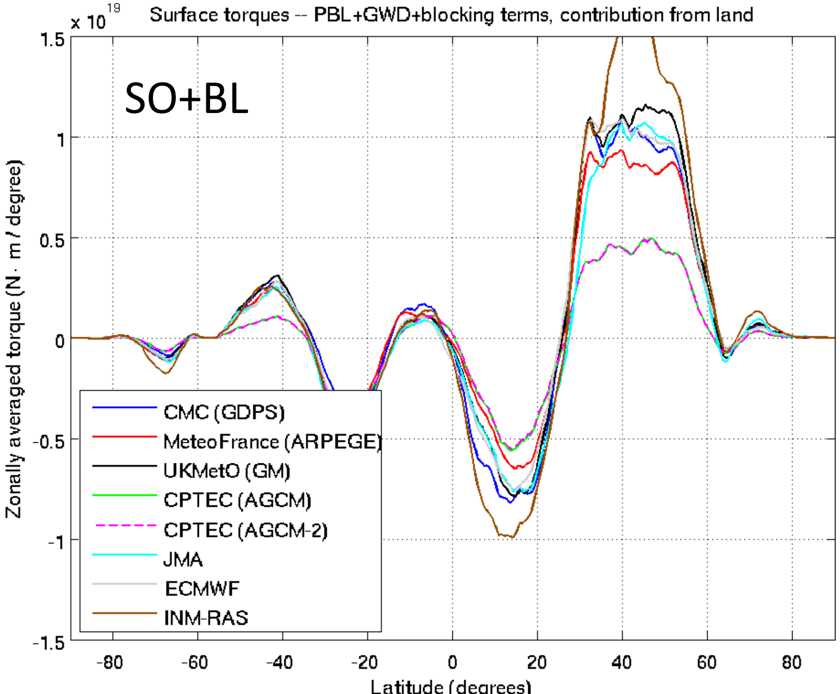
- Reduction of wind direction bias over Europe by 3° in winter, 1 ° in summer (out of 10 °)
- Improvement in low level jets
- Improvement of the large-scale performance of the model in winter N Hemisphere
- Deterioration of tropical wind scores (against own analysis, not against observations!)







WGNE/DRAG project (Ayrton Zadra)



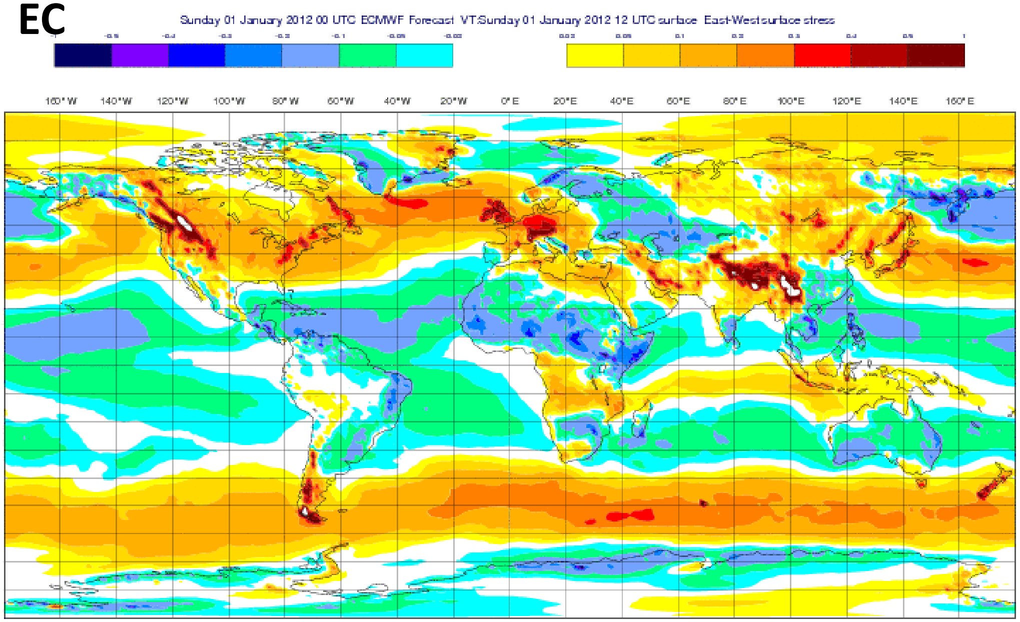
Comparison of surface torque over land from different models for January 2012

East-west surface stress averaged over 6-hr interval of daily forecasts in January 2012

6-12 UTC

18-24 UTC

EC



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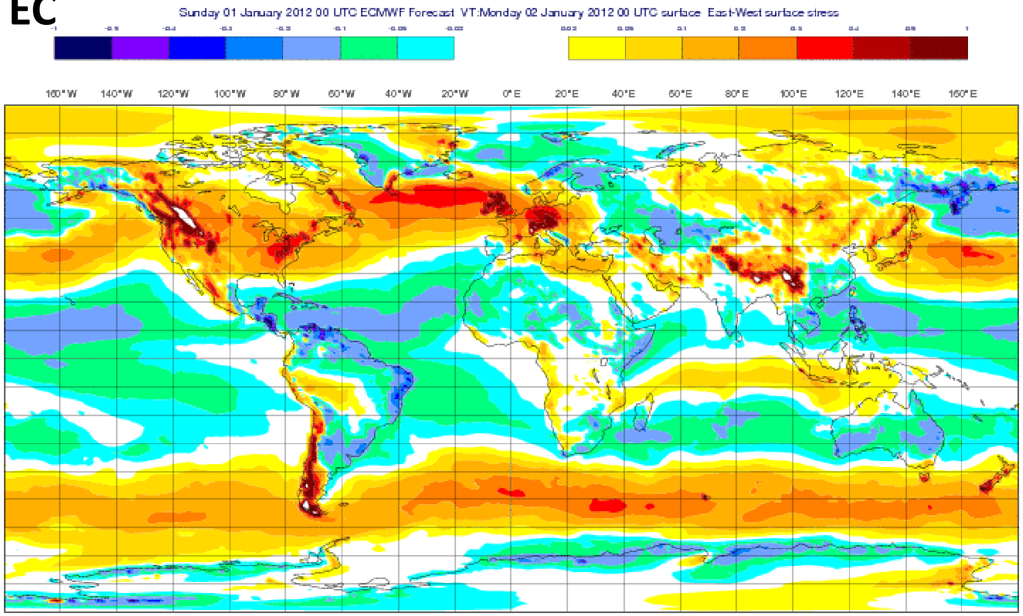

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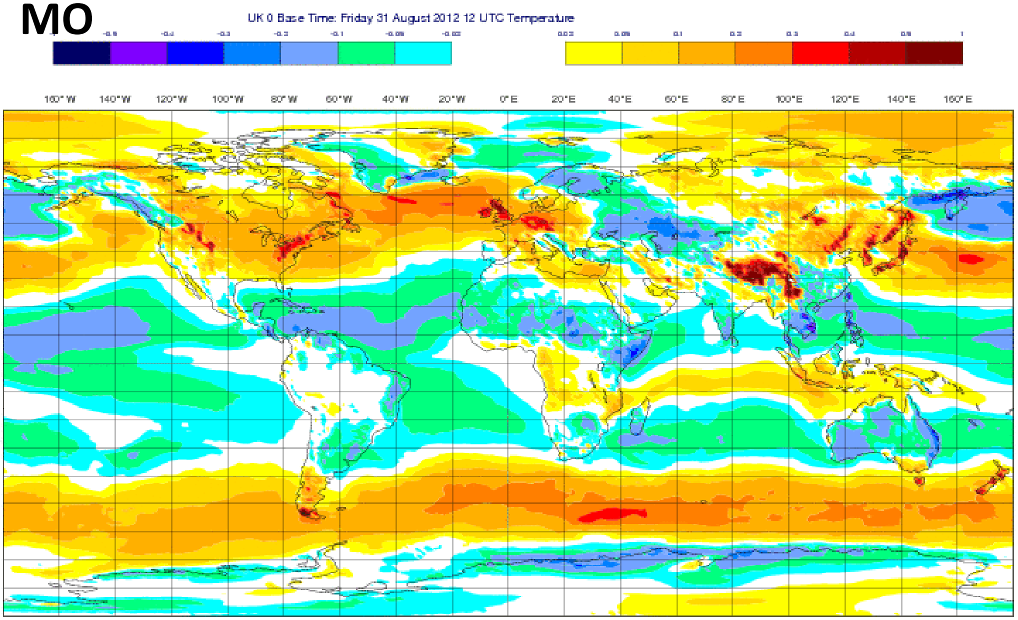

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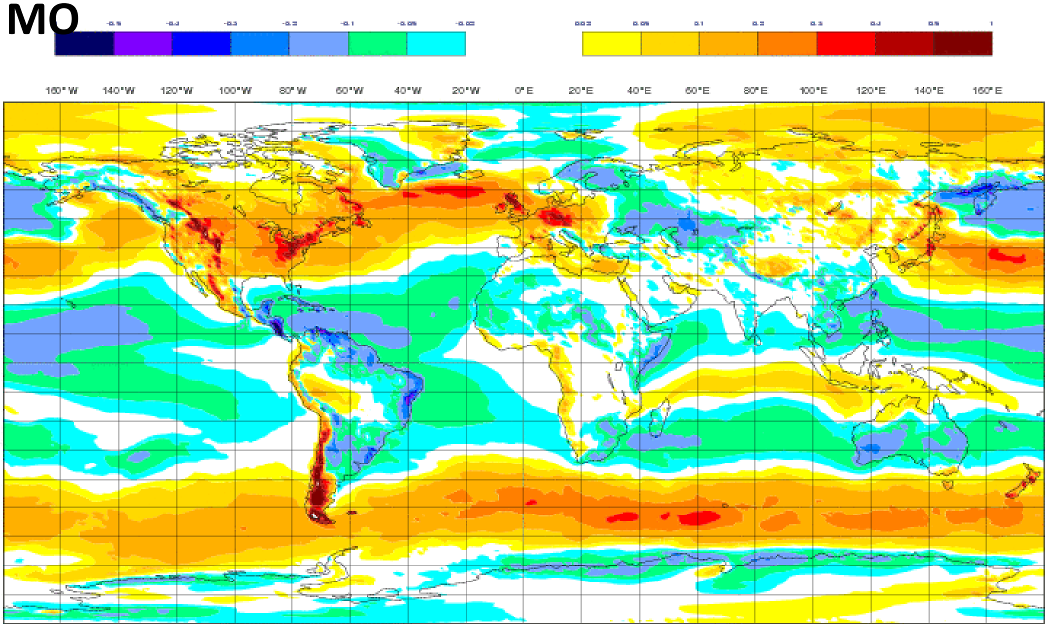

Concluding remarks

Enjoy the course

and

Do not hesitate to
ask questions