The Turbulent Kinetic Energy (TKE) scheme in the NWP models at Météo-France

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Thanks to : P. Marquet, Y. Bouteloup, F. Bouyssel, S. Malardel

Workshop on diurnal cycles and the stable boundary layer
7-10 November 2011 ECMWF, reading, UK

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Outline

1. The context 5 years ago
2. TKE scheme and the PBL parameterization
3. 3D validation in ARPEGE/ALADIN/AROME
4. Problems …
5. Conclusions and Perspectives

The context 5 years ago

- In ARPEGE/ALADIN. PBL parameterization : Louis (79) with a modified Ri for the shallow convection (Geleyn, 87) ➔ PBL is too dry partly due to an excess of mixing . Used until feb 2009

- Convergence for the physical parameterization between ARPEGE/ALADIN NWP and ARPEGE-Climat.

- AROME project= ALADIN NH + Méso-NH physics with LBC from ALADIN-MF now from ARPEGE

- The new physic for the PBL in ARPEGE/ALADIN NWP and in ARPEGE-Climat is based on a TKE scheme (Cuxart et al. 2000) and a shallow convection scheme (Bechtold et al. 2001)

- Advantages : **Better consistency between AROME and ARPEGE /ALADIN for the PBL** *and share the problems !*

- But more validations at various scales (500 km → 2.5 km), time-step (1800s – 60s), global budget, 1D comparison (Sodankyla, Cabauw etc …), 1D case GABLS,ARM-Cu, ASTEX, etc …

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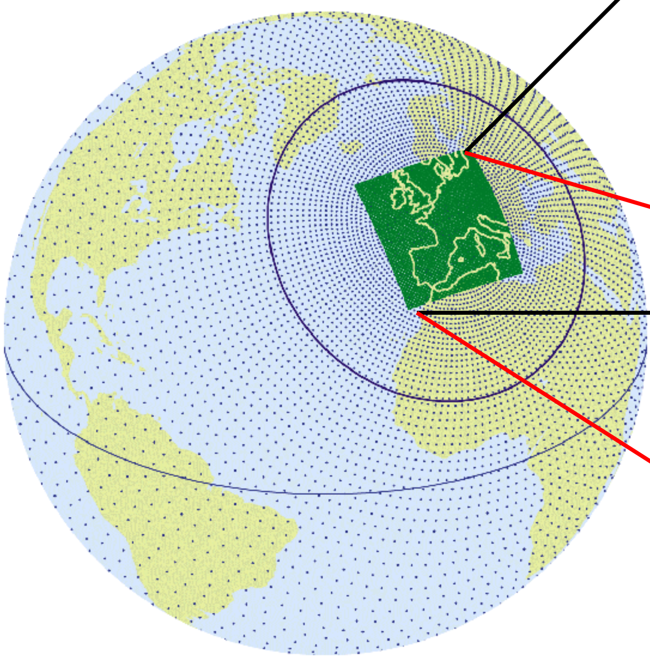
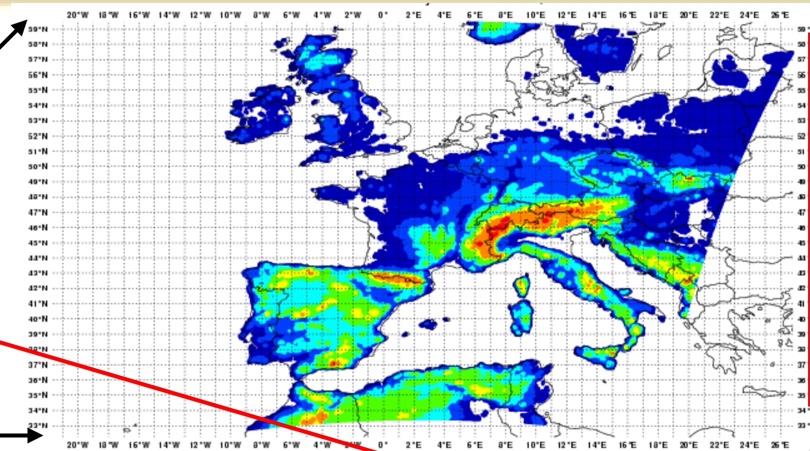
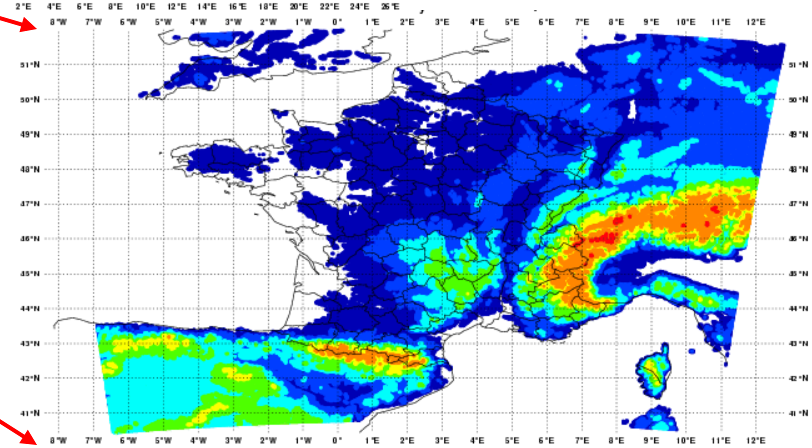
Operational Weather forecasting at Météo-France:
ARPEGE/ALADIN and AROME





ALADIN :
54h h forecasts
every 6h
dx=7.8 km,
70levels,
time-step=450s (SL)
3DVar Data
Assimilation system



Cloud Resolving Model AROME
30 h forecasts every 6h
dx=2.5 km, 60 Levels, time-step=1mn (SL)
3DVar Data Assimilation system (RUC3h)

Global ARPEGE-IFS
4-day forecasts every 6 hours dx=10 km on France, 55km on Australia dt=10mn
Stretching factor c=2.4 and turning of the pole over the zone of interest
Stretched vertical grid with 70 levels
4DVar Inc Data Assimilation system
(T107 25iter and T323 30iter dx=60km)

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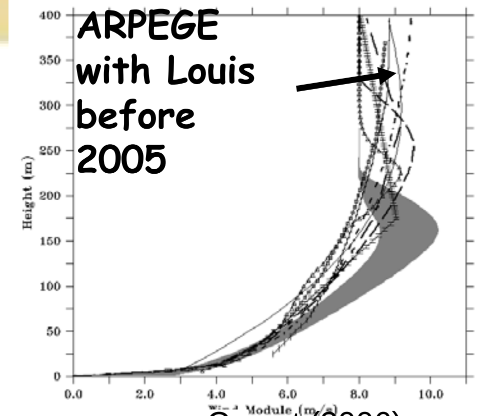
PBL parametrization (before Feb. 2009) used in ARPEGE/ALADIN



Cuxart (2006)

How to compute the subgrid flux ? $\overline{w'\psi'}$

- with a diffusion scheme: $\overline{w'\psi'} = -K\dfrac{\partial\psi}{\partial z}$

-with a mass flux scheme : $\overline{w'\psi'} = -M\left(\psi - \psi_{updraft}\right)$
(used only for deep convection in the 90's)

Louis (79) propose to compute K as follows: $K_\psi = l_m \cdot l_\psi \left|\dfrac{\partial\vec{U}}{\partial z}\right| F_\psi(R_i)$

And to "simulate" the mixing done by the shallow convection, a enhanced Ri is used following Geleyn 87 :

$$R_i = \frac{g}{c_p T}\,\frac{\partial s/\partial z + L\min\left(0, \partial\left(q - q_s\right)/\partial z\right)}{\left|\partial\vec{u}/\partial z\right|^2}$$

But the PBL was too dry partly due to an excess of mixing with an underestimation of the stratocumulus and low cloud

Turbulence and shallow convection (used since Feb 2009 in ARPEGE/ALADIN)

EDMF concept : Siebesma and Teixeira, (2000) and Hourdin et al., (2002) and Soares et al., 2004

$$\overline{w'\psi'} = -K\frac{\partial \psi}{\partial z} - M\left(\psi - \psi_{updraft}\right)$$

TKE Scheme CBR(2000), BL(89)

- Shallow convection from Bechtold et al (2001) for ARPEGE/ALADIN (KFB) And Pergaud et al 2009 for AROME

$$K_u = \alpha_u \cdot l \cdot \sqrt{\overline{e_T}} \qquad K_{\theta/q} = \alpha_\theta \cdot K_M \cdot \phi_3$$

$$\frac{\partial e_T}{\partial t} = advec + P_d + P_\theta - \frac{1}{\rho}\cdot\frac{\partial \overline{\rho w' e_T'}}{\partial z} - c_\varepsilon \cdot \frac{\overline{e}_T^{3/2}}{l_\varepsilon}$$

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TKE scheme in ARPEGE/ALADIN

- The TKE is computed on the « half-level » , the levels of the exchange coefficients for momentum (Km) and temperature (Kt)
- The top-PBL entrainment is parametrized following the ideas of Grenier and Bretherton (2001)
- The moist fluxes are computed with θ_{vl} and the Betts variables θ_l and q_T
- The sub-grid variance of cloud water is computed with a “mixture”of a symmetric (Gaussian) and asymmetric (Exponential) for the Cumulus and the strato-cumulus respectively (Bougeault 82 and Bechtold 95)
- **Since April 2010 (T538L60→ T798L70 with 14 levels below 1500m):**
  - The top entrainment was switch off
  - TKE is advected with the semi-lagrangian scheme. TKE is interpolated on the full-level after the physic for the advection and then go back to the half-level for the physic → small impact and only positive for the wind gust diagnostic

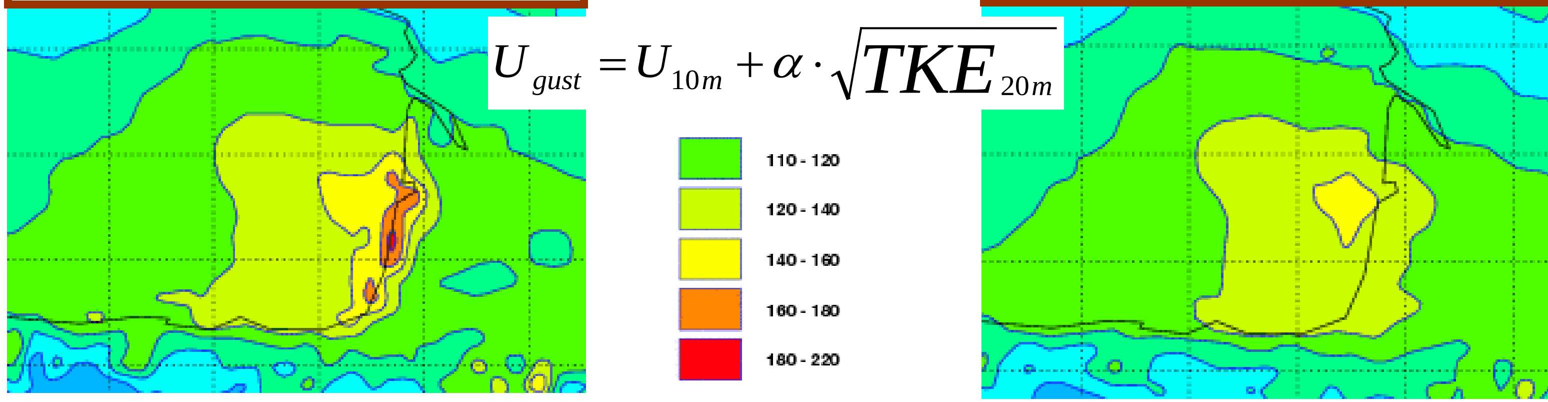
Impact of the TKE advection

Wind gust computed with a TKE not advected

24/01/2009

Wind gust computed with a advected TKE

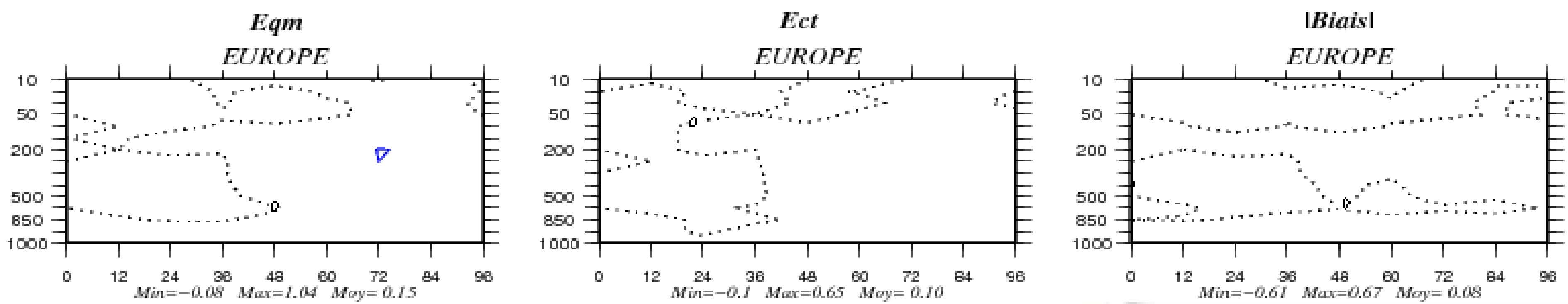
$$U_{gust} = U_{10m} + \alpha \cdot \sqrt{TKE_{20m}}$$



GEOPOTENTIEL:P7570.r 00/TP(Ref)–P7577.r 00/TP(Exp)

(1. m)

10 simulations (500 hPa) de 96 h du 20090601 au 20090614



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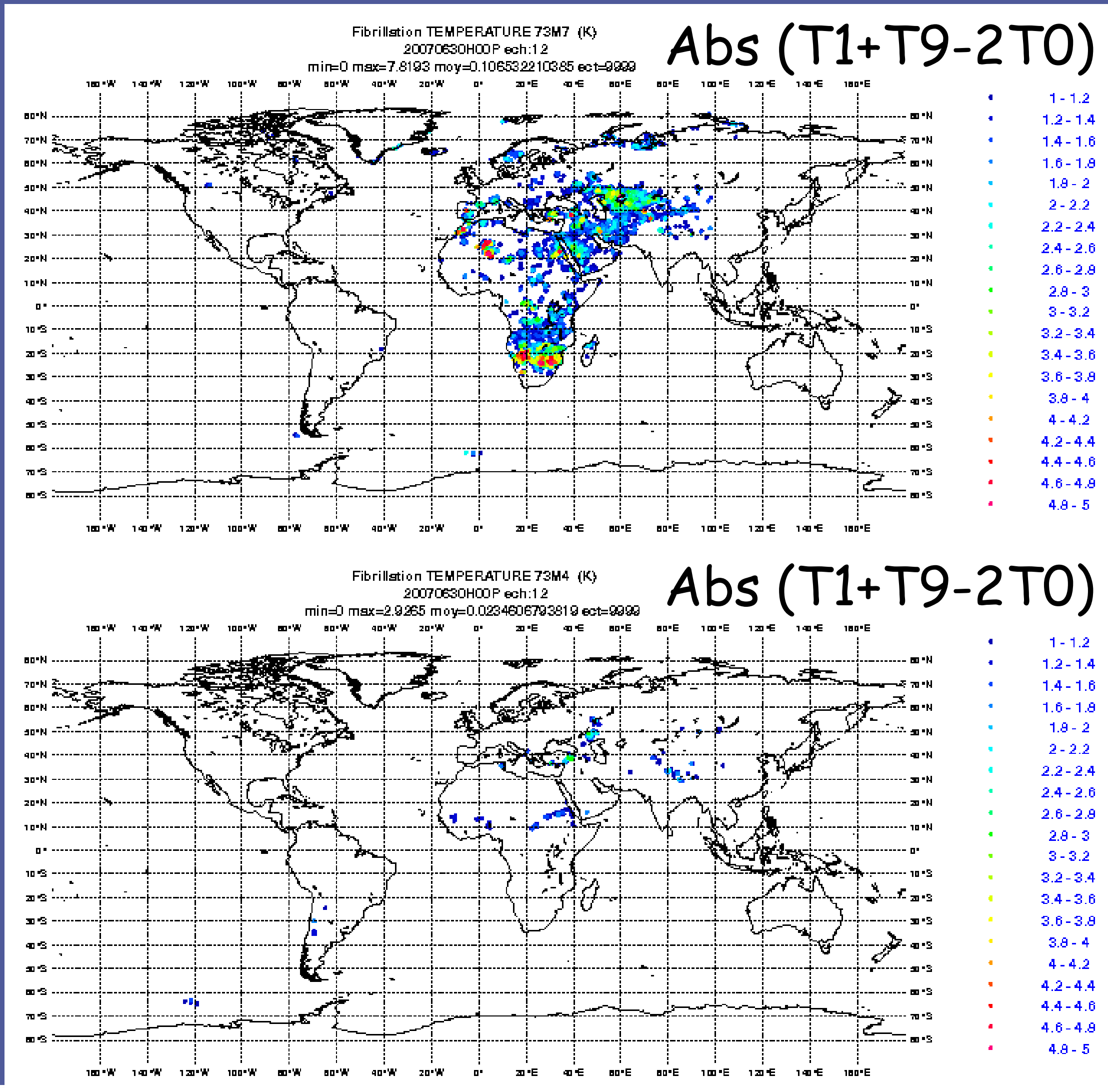
Stability: T538c2.4 dt=900s (15km over France)
Temperature at Level 60 (1st level above the surface)



Louis's scheme with antifibrillation (XMULAF=-1.85)
max=7.8°C Mean=0.1

TKE without antifibrillation scheme
max=2.9°C mean=0.02
Less noisy and less dependant of the time step

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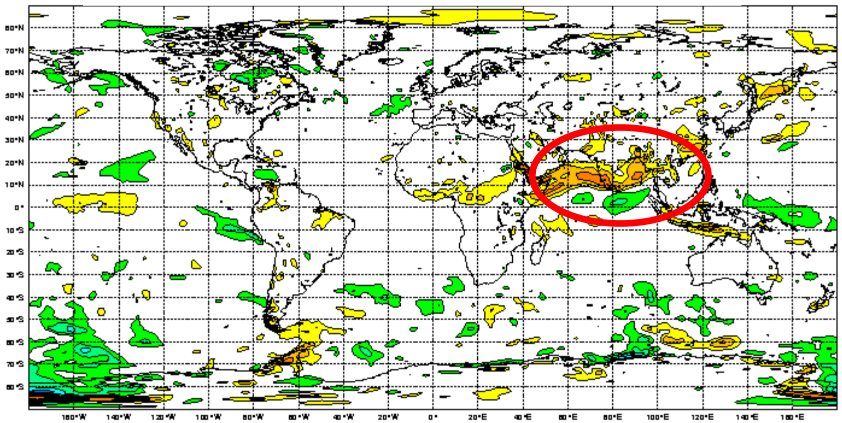
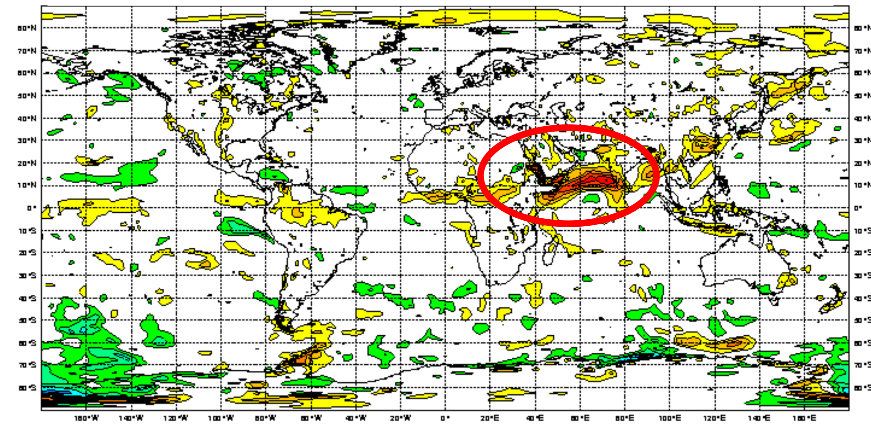
But in the tropics ....

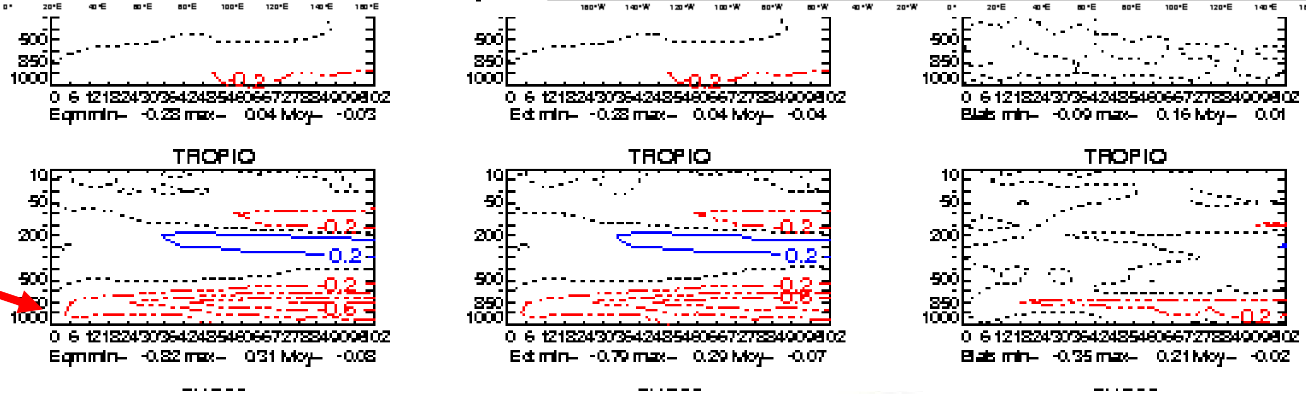
Wind anomaly 850hPa vs ECMWF analysis

ARPEGE (with Louis)



ARPEGE withTKE+KFB





Wind
Pb in the tropics

For the wind problem …

1. Increase the wind mixing with new values for the TKE scheme
2. Modify the mixing length with the shallow convection scheme and additional term for the thermal production

$$K_u = \alpha_u \cdot l \cdot \sqrt{\overline{e_T}} \qquad K_\theta = \alpha_\theta \cdot l \cdot \sqrt{\overline{e_T}} \cdot \phi_\theta$$

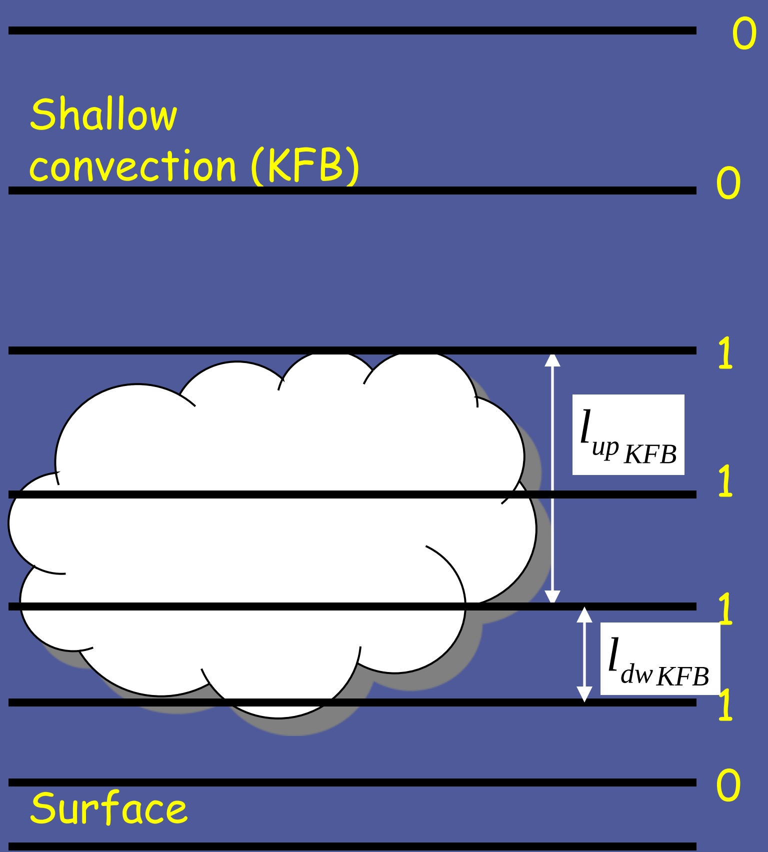
$$\alpha_u = 0.0667 \rightarrow 0.126 \qquad \alpha_\theta = 0.16675 \rightarrow 0.142$$

$$\frac{\partial \overline{e}_T}{\partial t} = P_d + P_\theta - \frac{\partial \overline{w^{'} e_T}}{\partial z} - c_\varepsilon \frac{\overline{e}_T^{3/2}}{l_\varepsilon} \qquad C_\varepsilon = 0.7 \rightarrow 0.85$$

$$\frac{1}{\rho} \frac{\partial}{\partial z} \left(\rho \cdot C_e \cdot l \cdot \sqrt{\overline{e_T}} \cdot \frac{\partial e_T}{\partial z} \right)$$

$$C_E = 0.4 \rightarrow 0.34$$

Link between shallow convection and TKE



$$l_{up\_cvpp} = Max(l_{up\,bl89}, l_{up\,KFB})$$

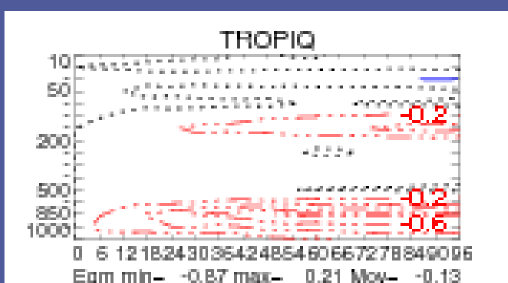
$$l_{dw\_cvpp} = Max(l_{dw\,bl89}, l_{dw\,KFB})$$

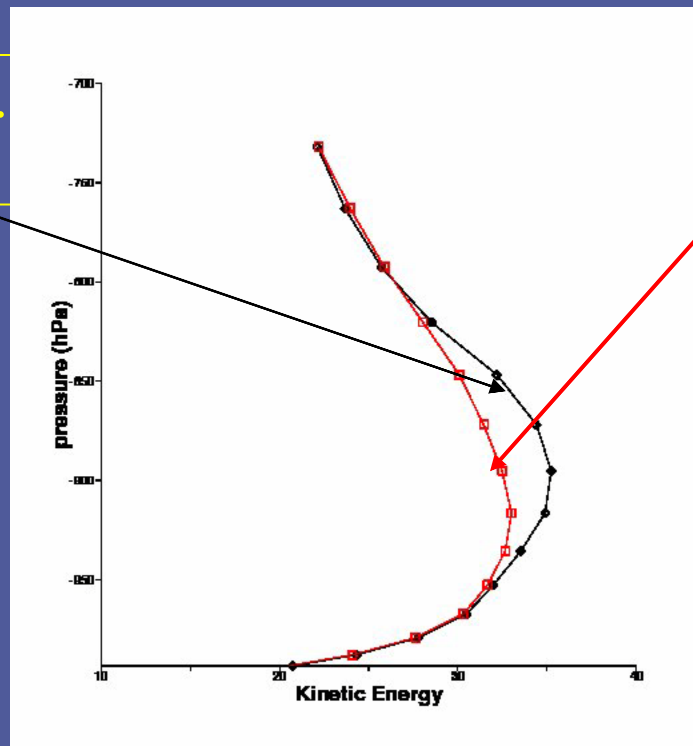
$$\left(-\frac{g}{\theta_v}\overline{w'\theta_v'}\right)_{shallow} \longrightarrow \frac{\partial \overline{e}_T}{\partial t}$$

Enhance the mixing

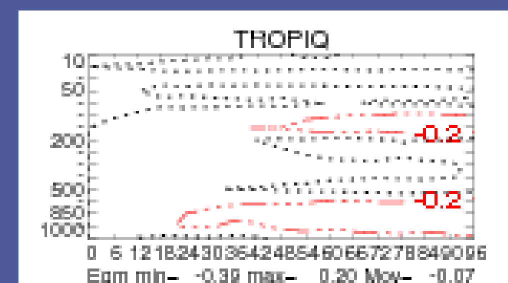
Impact of the thermal production from KFB for the TKE and the modified mixing length. Diff of RMS error for wind

without thermal prod.. from shallow





With thermal prod. from shallow + modified L



Zonal mean over the tropical area of the Kinetic energy (J/kg)

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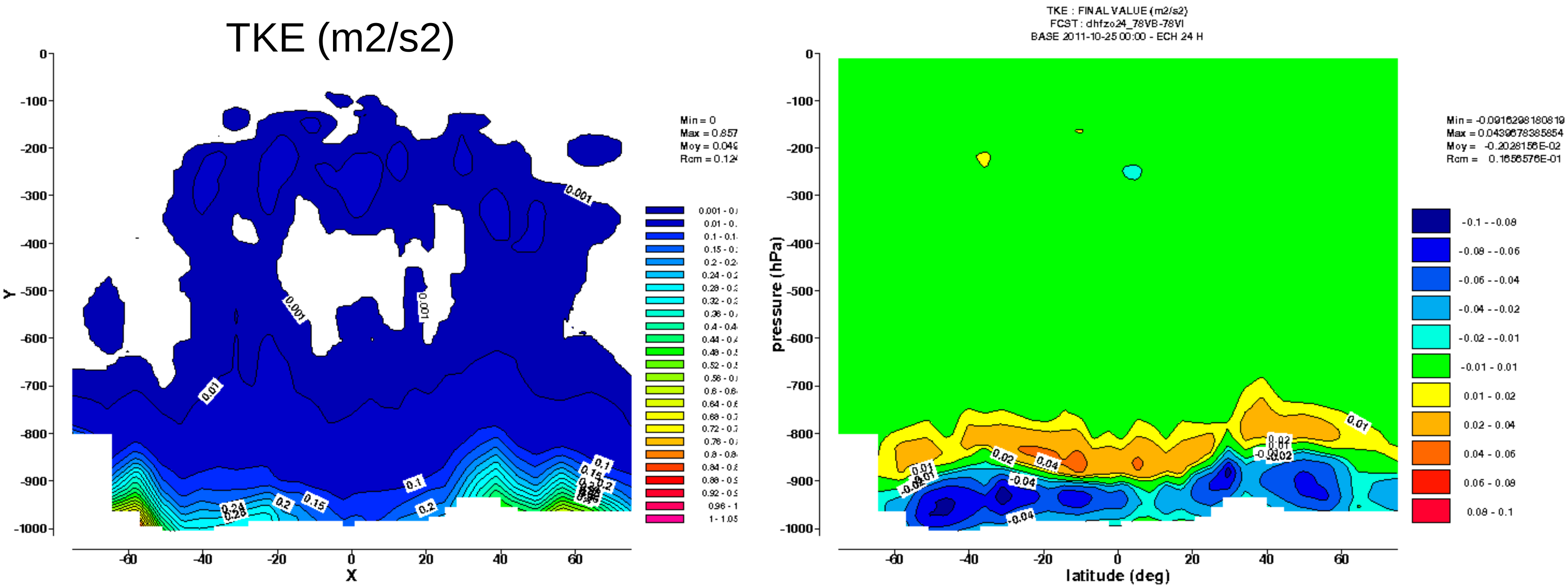
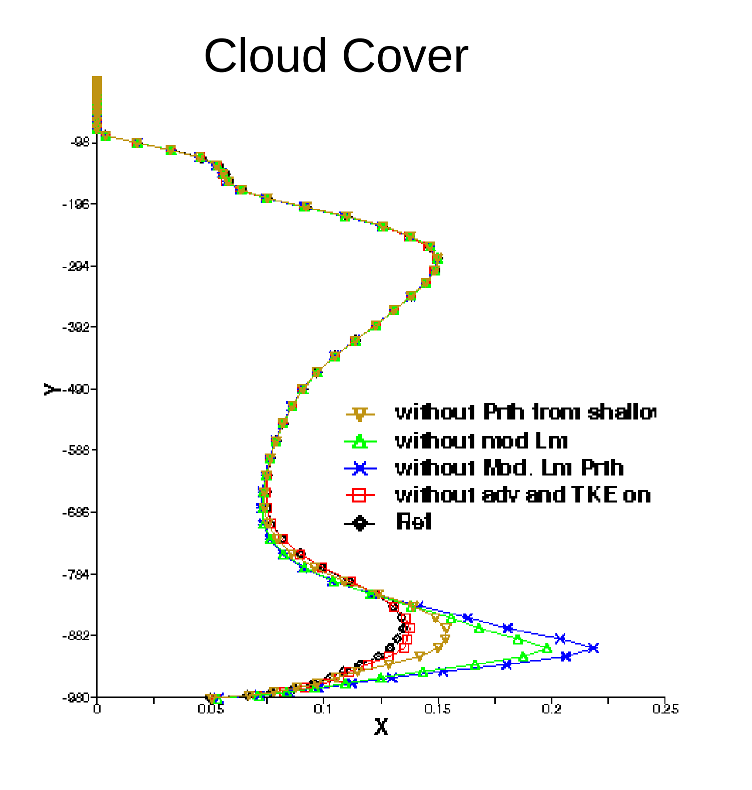
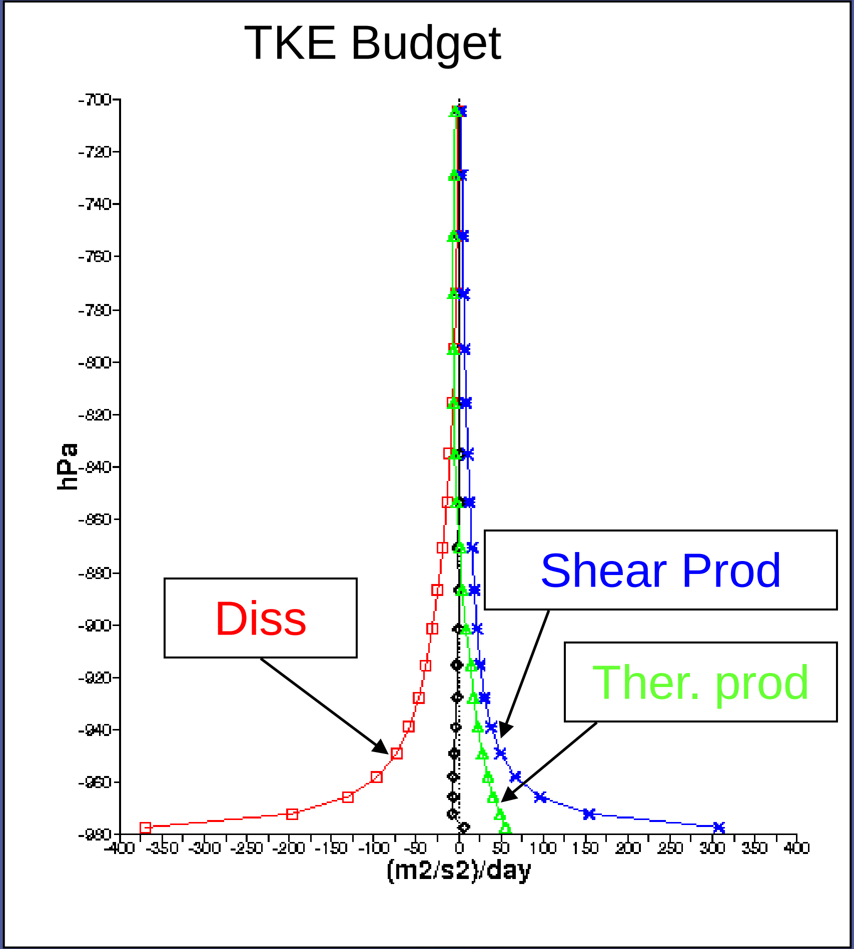
Impact of the thermal production from KFB for the TKE and the modified mixing length.



More TKE with Lm increased → more mixing

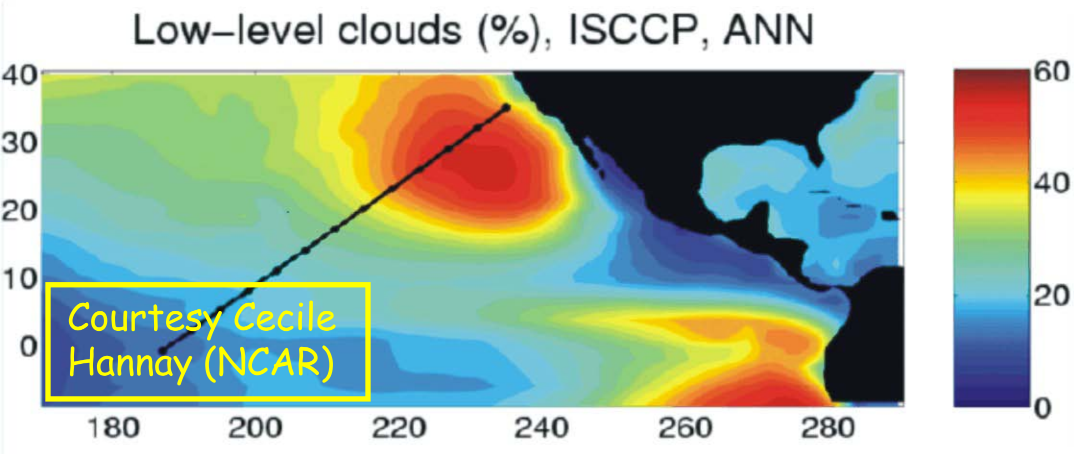
Impact of the thermal production from KFB for the TKE and the modified mixing length.



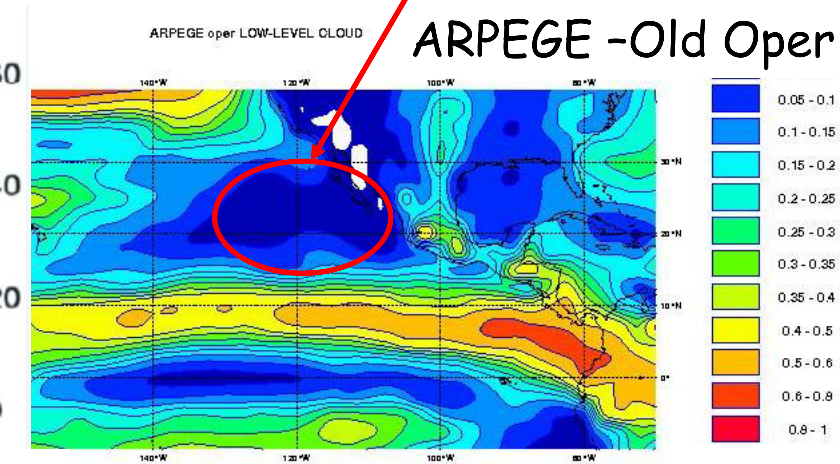


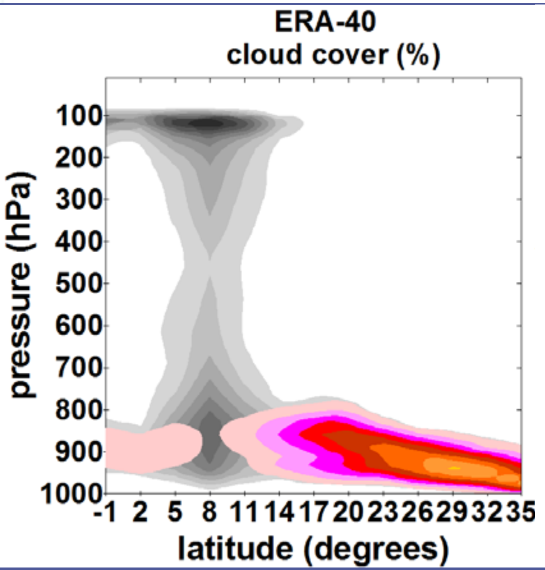
3D NWP validation
GPCI : Gewex Pacific Cross-section Intercomparison

Less than 10%

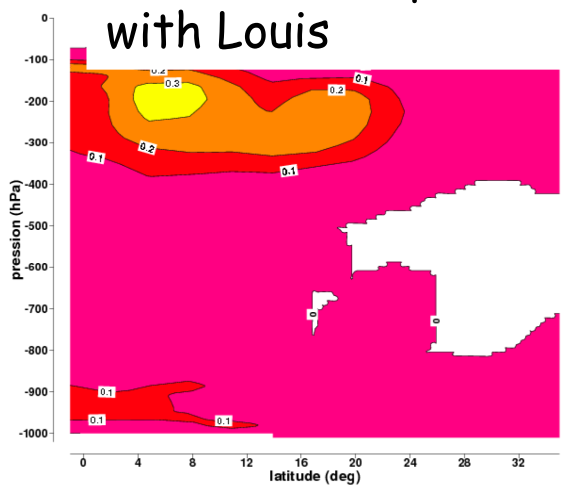


ARPEGE –Old Oper

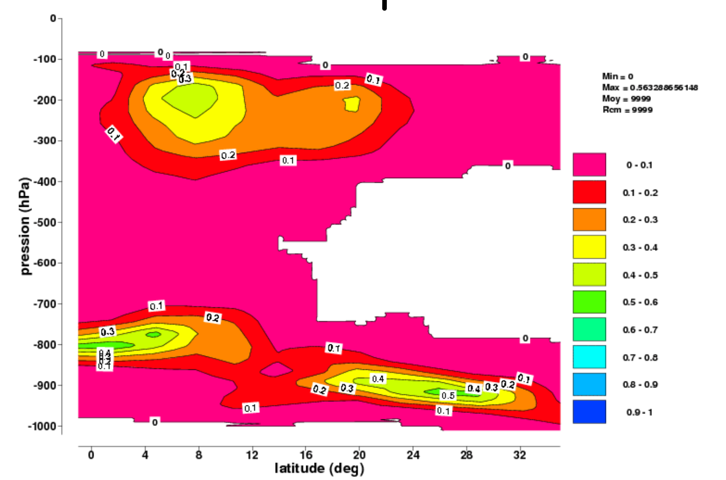




ARPEGE old oper with Louis



ARPEGE –Oper



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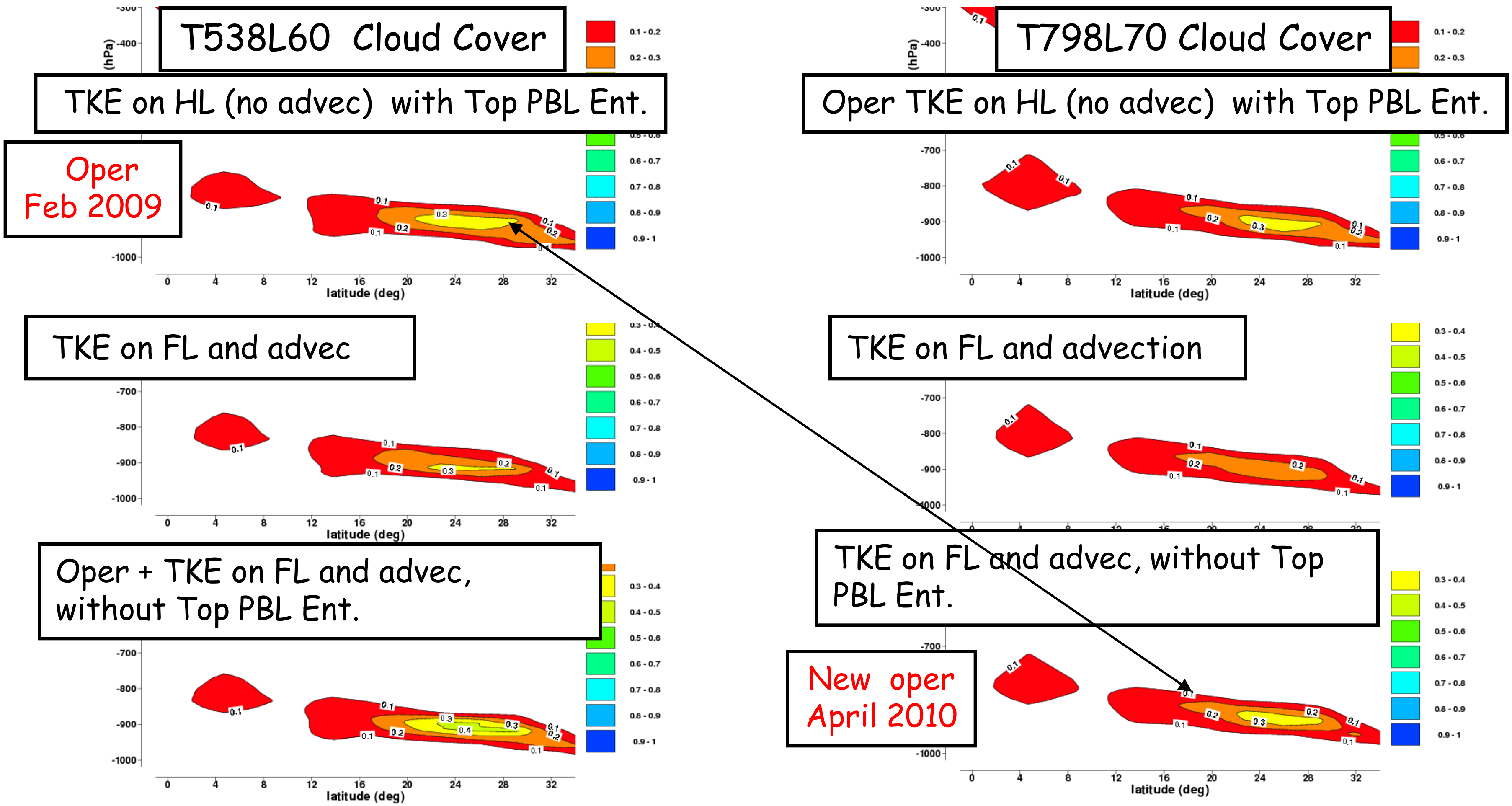
Physics modifications impact on the *Gewex Pacific Cross-section Intercomparison (July 2009)*



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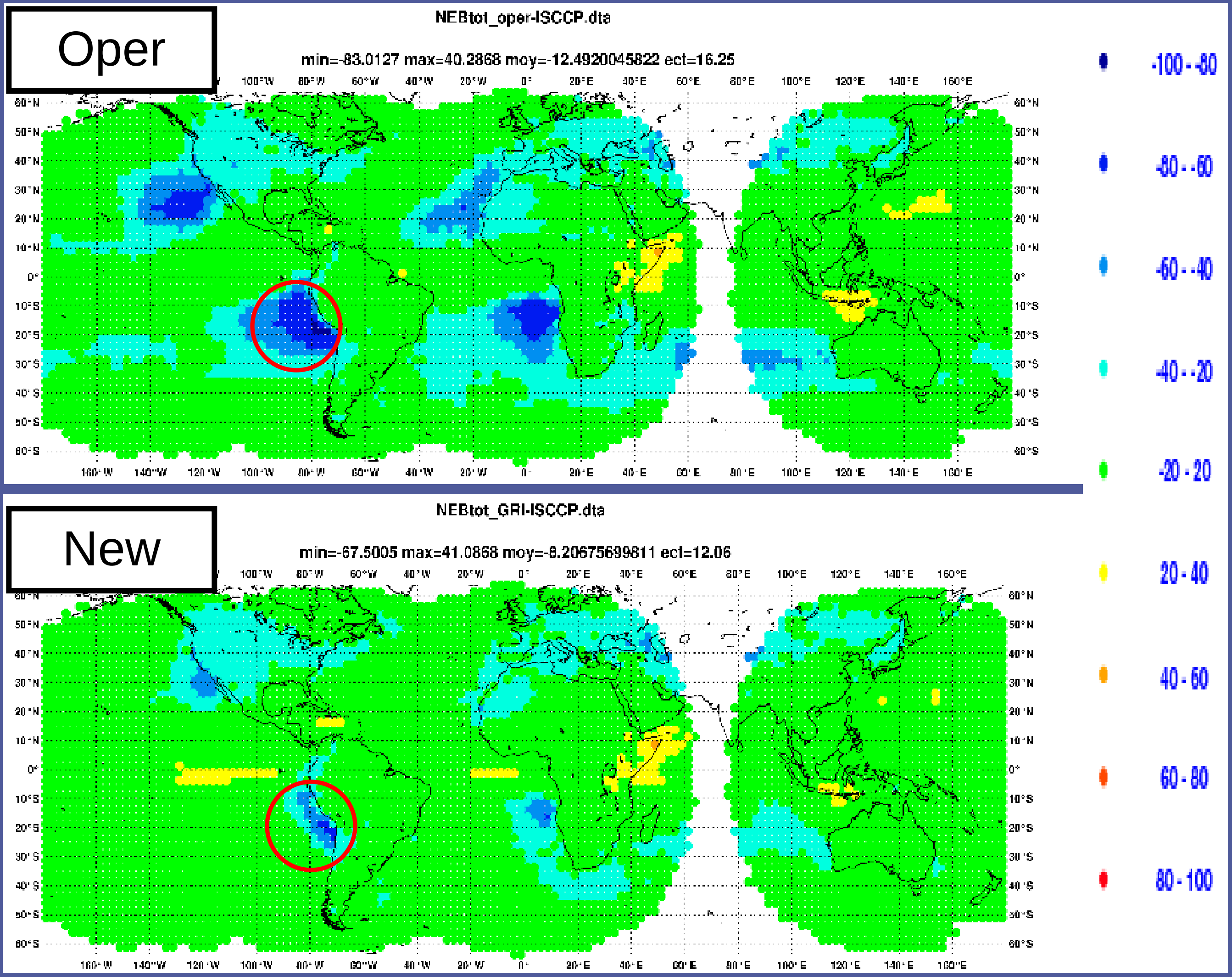
3D NWP validation
Total Cloud Cover bias Model - ISCCP



T224C2.4L60
DJF + JJA

better estimation of stratocumulus on the eastern border of anticyclone

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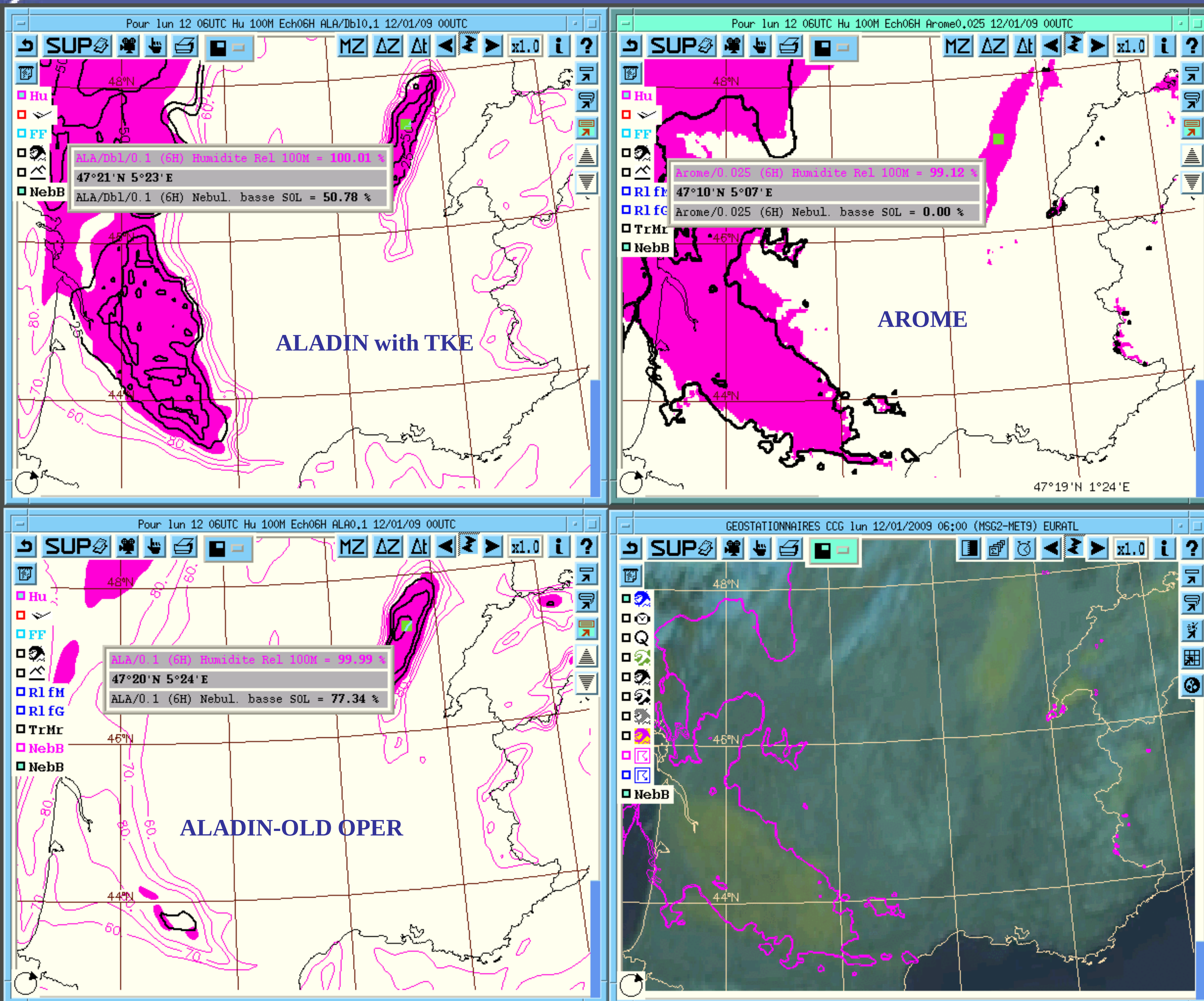
Fog over Garonne Valley 12/01/2009

Hu=pink at 100m Black line=cloud cover



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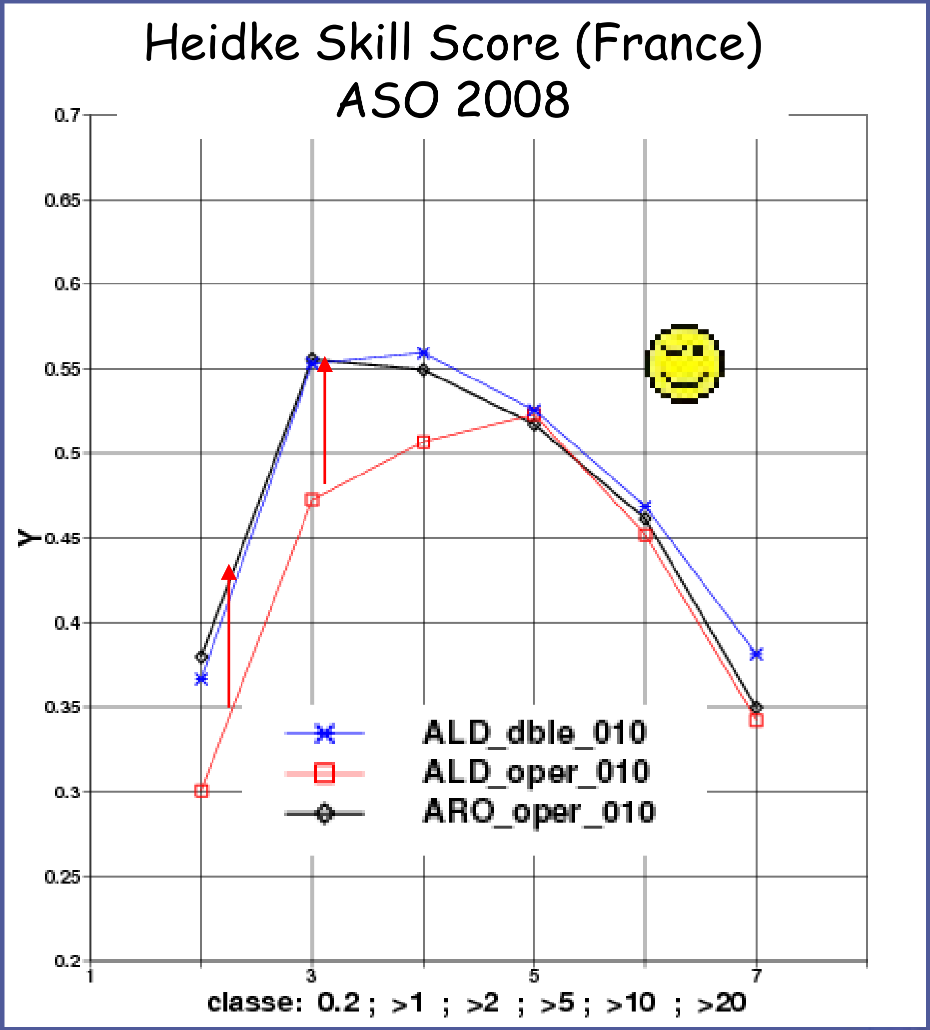
It was necessary to modify the deep convection scheme due to the new PBL parameterization



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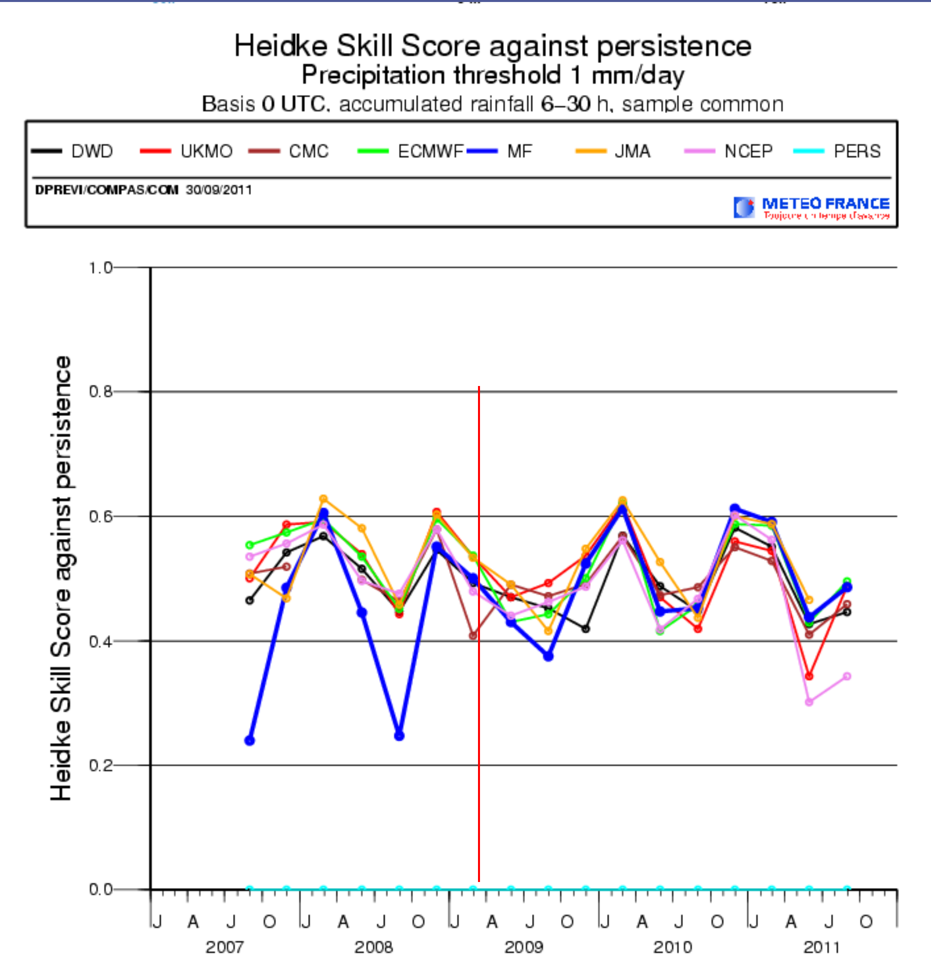

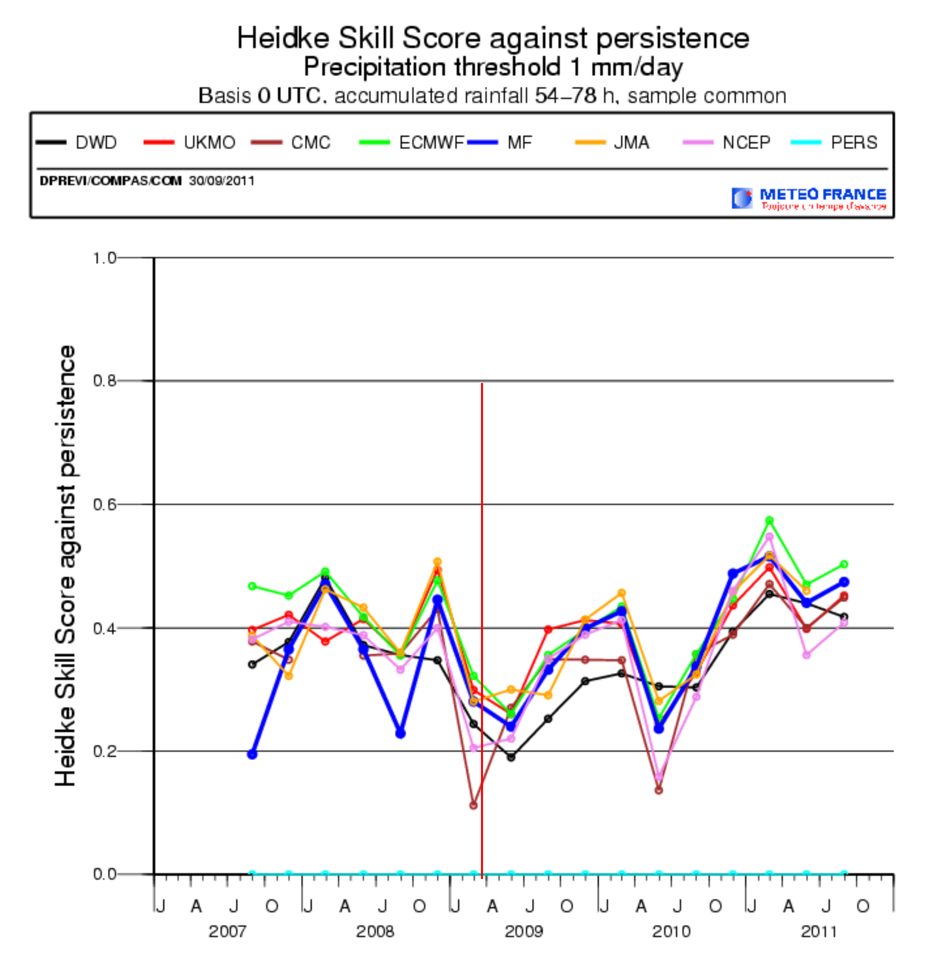

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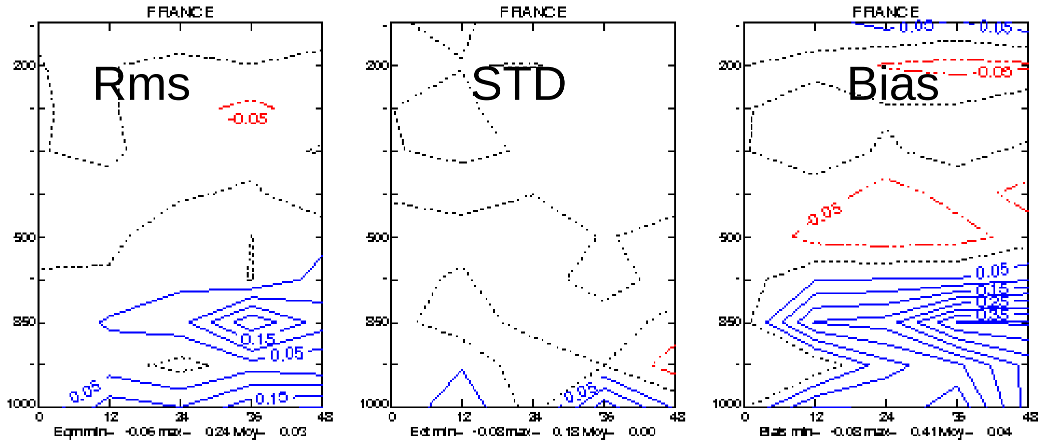
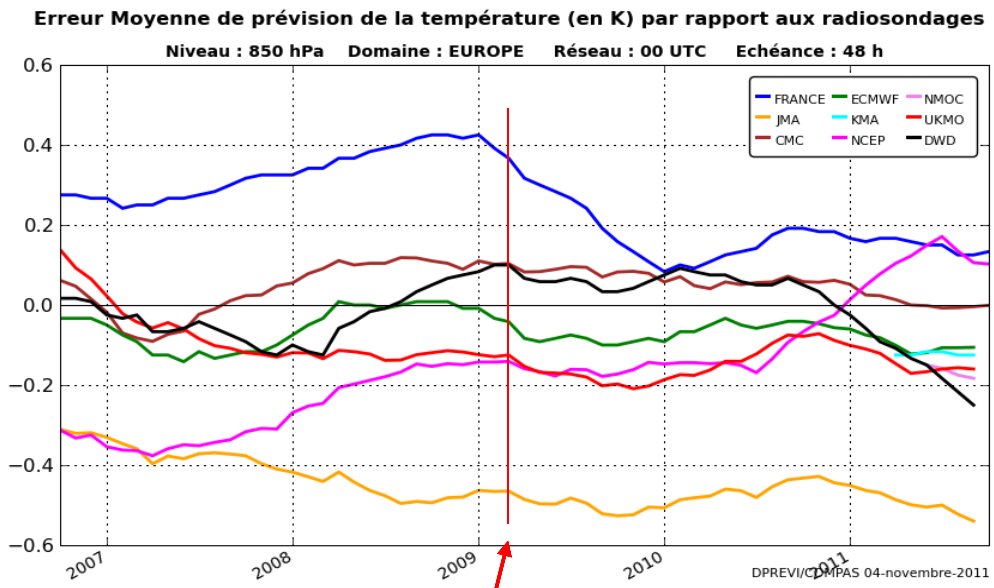
Impact of the new PBL parameterization (TKE+KFB) on Temperature



June 2007
Improvement:blue



Annual mean bias
T850hPa vs Rs
Europe 48h

New PBL parameterization

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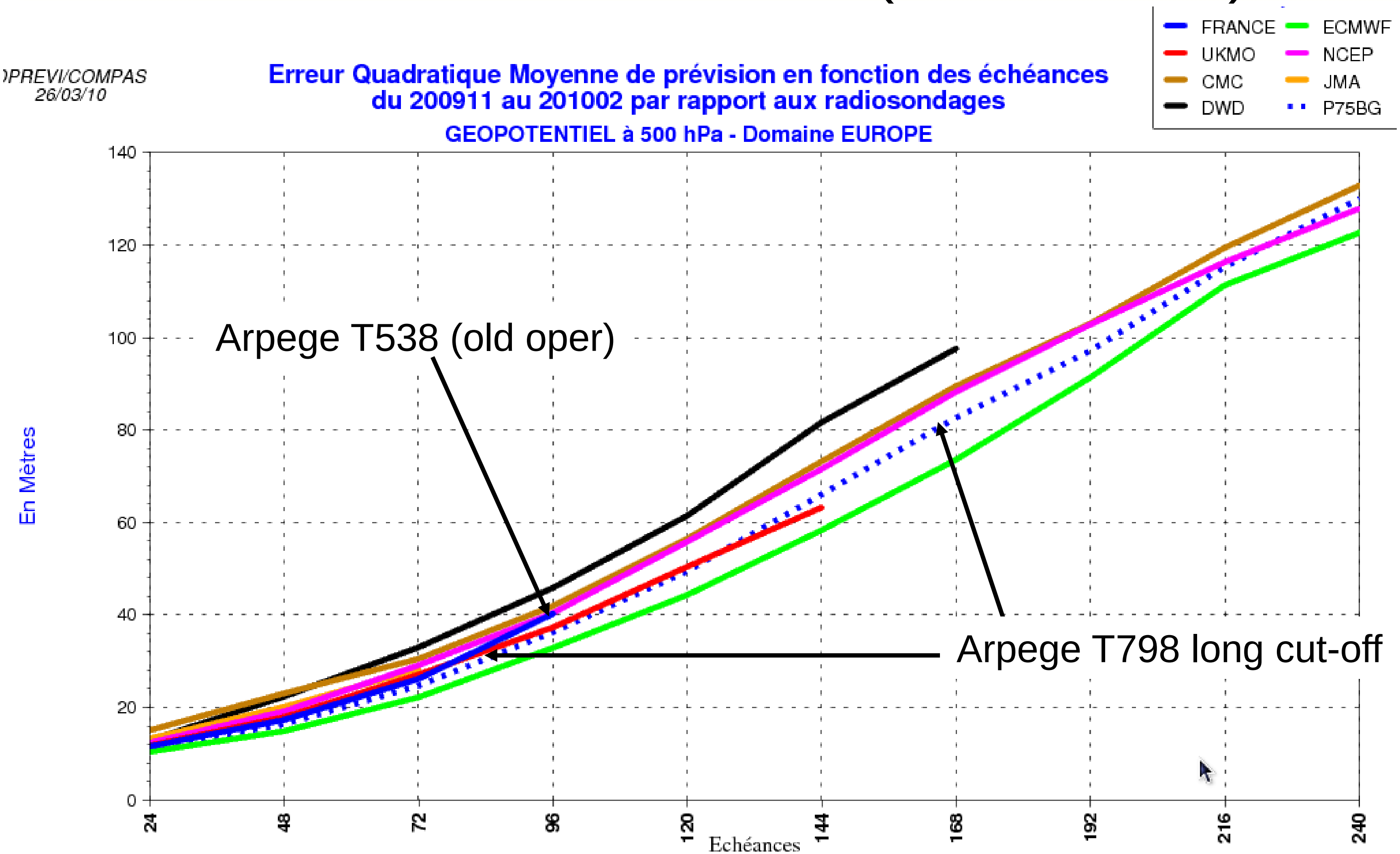
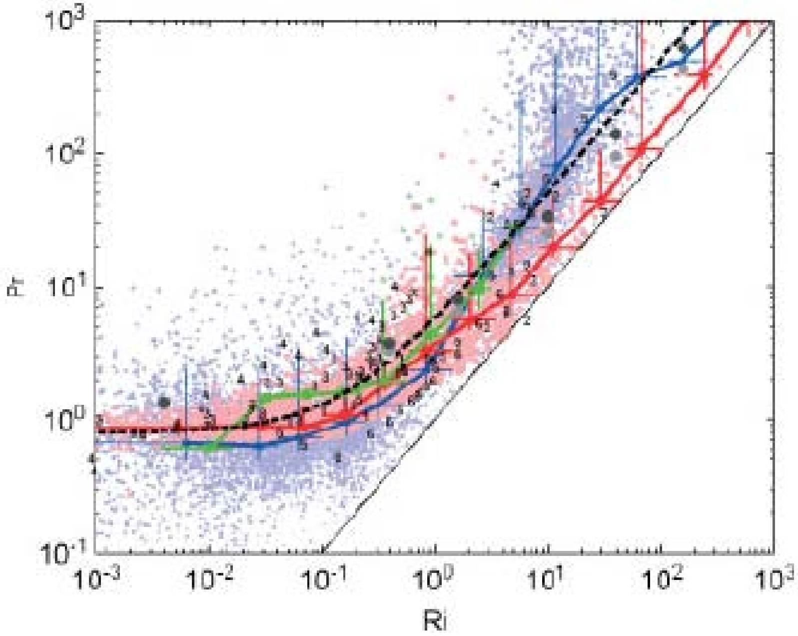
10 days forecast
Nov.2009 → Feb.2010 (120 forecast)

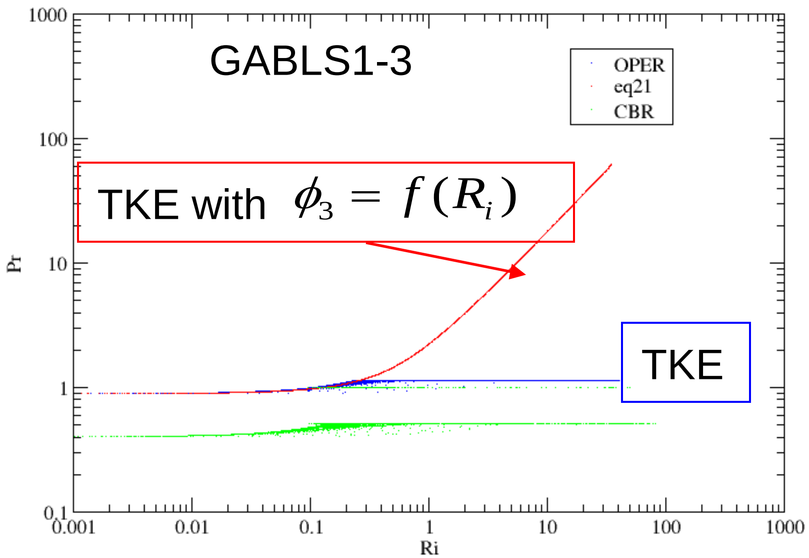


Some weaknesses …

1. We still have warm bias → interaction with the surface and the snow scheme
2. Following Galperin et al 2007 and Zilitinkevich et al 2008 turbulence survives for Ri>>1. It is not the case with TKE …



From Zilitinkevich et al 2008



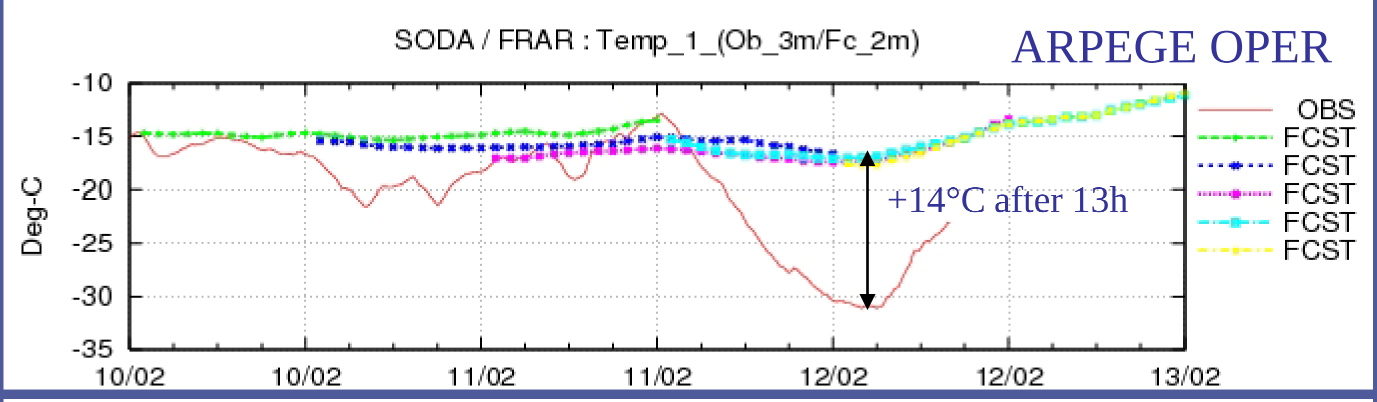
$$\Pr = \frac{K_m}{K_h} = \frac{1}{\alpha_\theta \phi_3}$$

with $\alpha_\theta = 1.13$

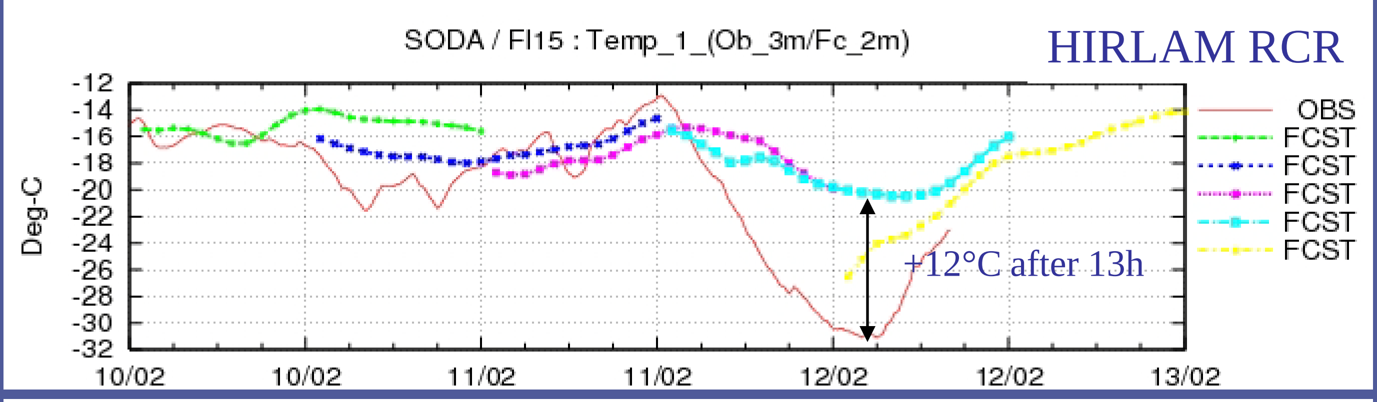
$0.78 < \phi_3 < 2.2$

Sodankyla T2m 20100211 starting at 12UTC

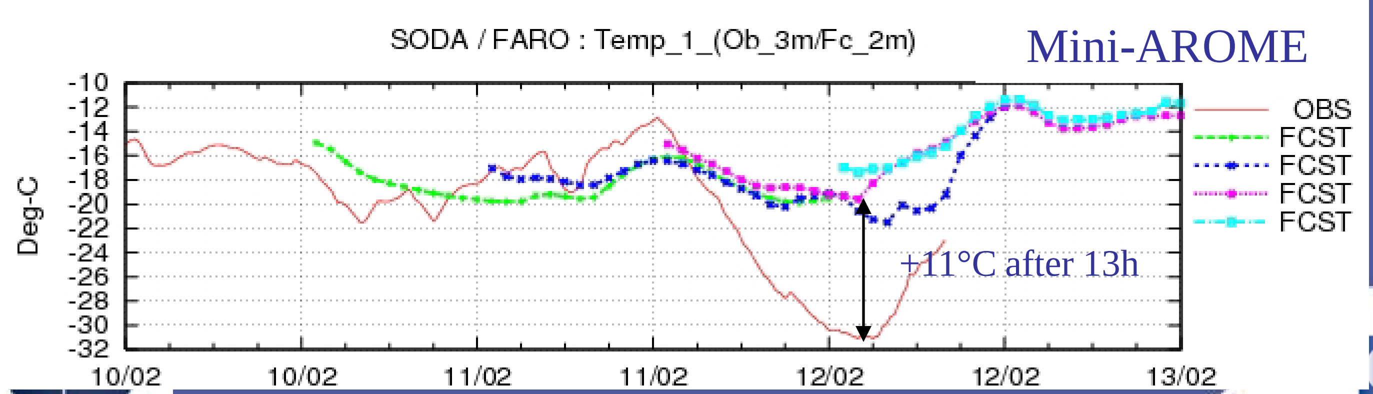
From http://fminwp.fmi.fi/mastverif/mastverif.html



ARPEGE: too warm →surface analysis has rejected the T2m obs at 00UTC the 12th Feb. (yellow curve)



HIRLAM RCR : also too warm but less than ARPEGE → the surface analysis is able to capture the cooling (yellow curve)



Mini-AROME : 30x30 pts dynamical adaptation from ARPEGE with SURFEX (snow scheme D95) → no specific analysis.

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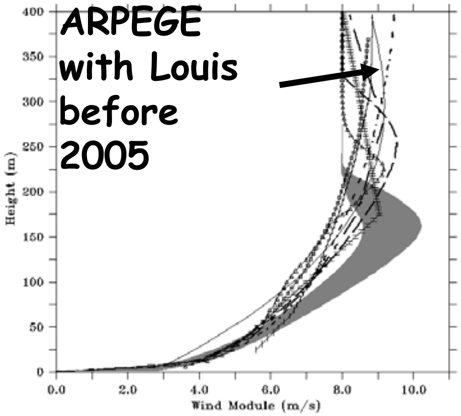
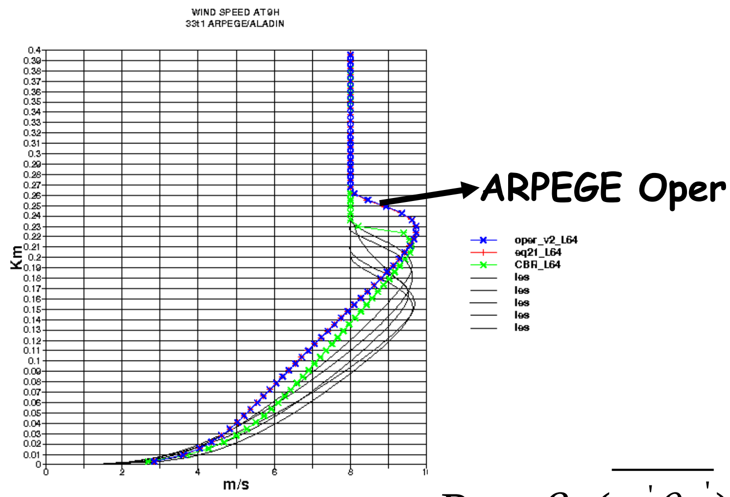
Impact of Phi3=f(Ri)



Cuxart (2006)

GABLS1



$$\overline{(w'\theta_l')} = -\alpha_\theta \alpha_u l \sqrt{\overline{e_T}} \cdot \frac{\partial \overline{\theta_l}}{\partial z} \cdot \phi_3$$

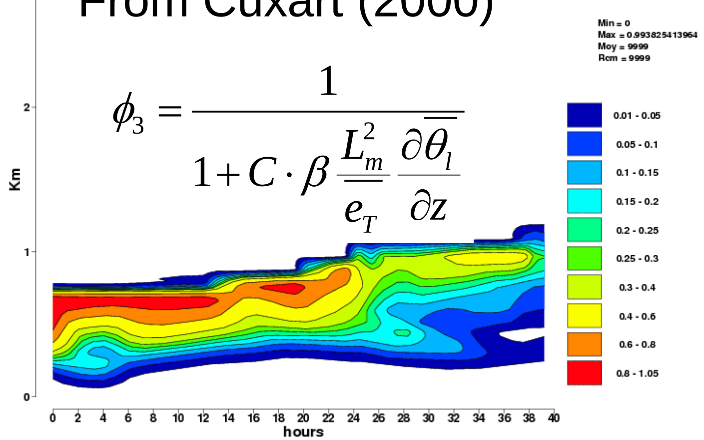
$$\overline{(w'q_t')} = -\alpha_\theta \alpha_u l \sqrt{\overline{e_T}} \cdot \frac{\partial q_t}{\partial z} \cdot \phi_3$$

$$P_\theta = \beta \cdot \overline{(w'\theta_{vl}')} = \beta \cdot E_q \overline{(w'q_t')} + \beta \cdot E_\theta \overline{(w'\theta_l')}$$

Cloud Cover ASTEX Lagrangian (Euclipse)

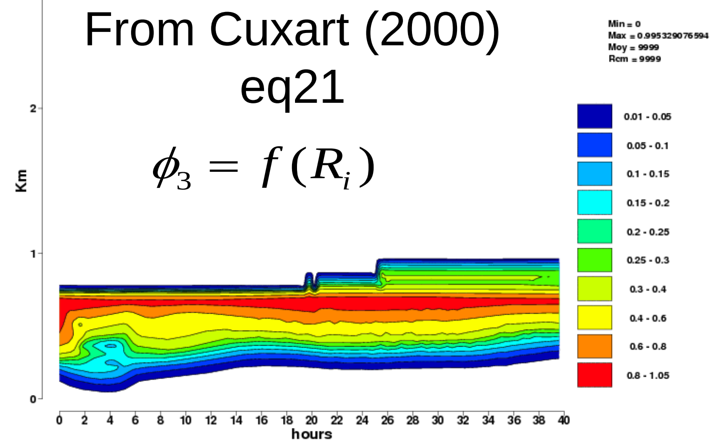
From Cuxart (2000)

$$\phi_3 = \frac{1}{1 + C \cdot \beta \frac{L_m^2}{\overline{e_T}} \frac{\partial \overline{\theta_l}}{\partial z}}$$



From Cuxart (2000)
eq21

$$\phi_3 = f(R_i)$$



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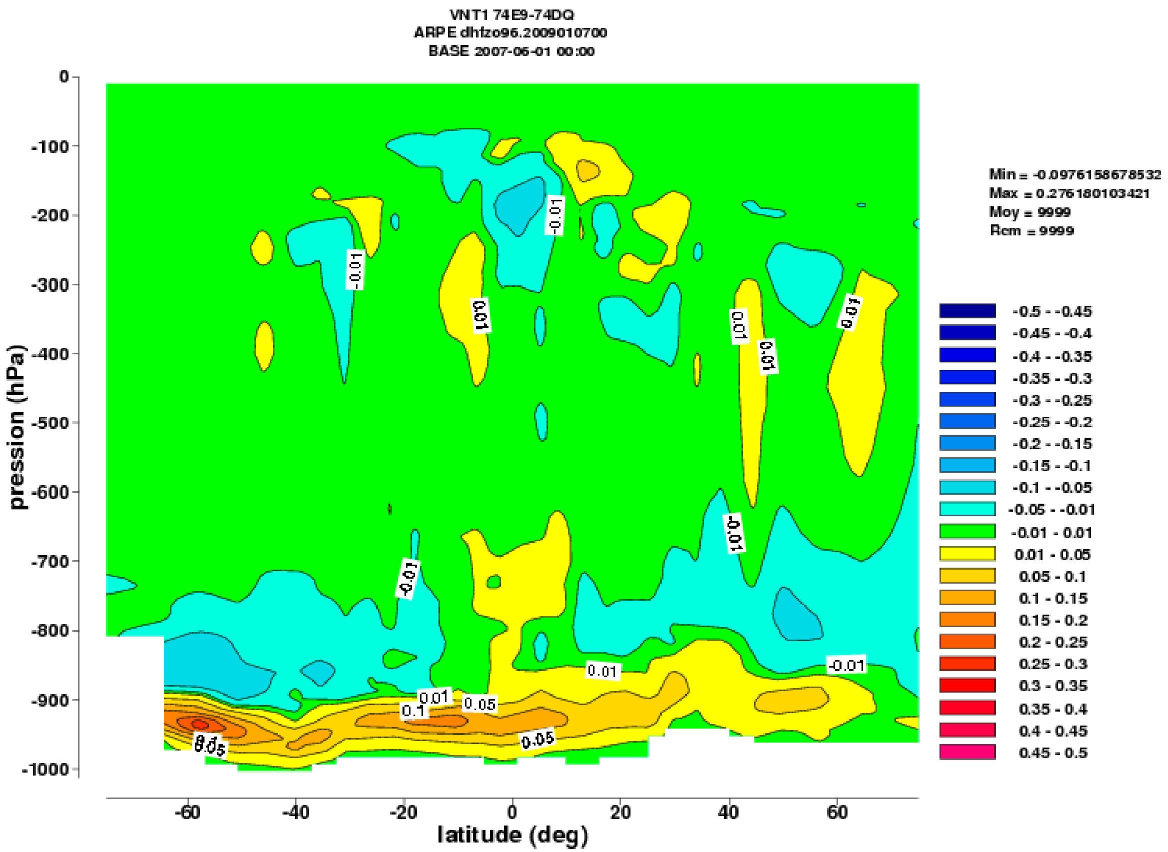
Impact of Phi3=f(Ri) in ARPEGE 3D

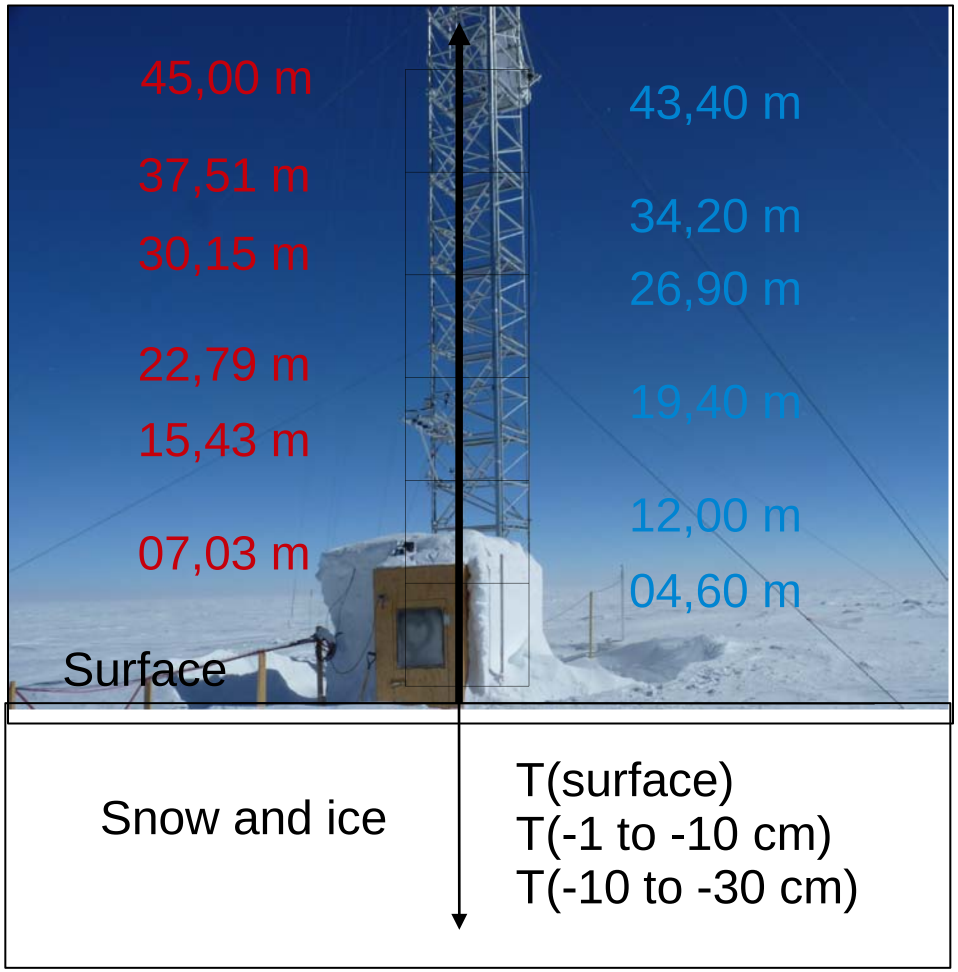


Phi3=f(Ri) increases the humidity in the PBL → more low cloud

Conclusions

- The new subgrid vertical mixing (TKE + KFB), implemented in ARPEGE/ALADIN (Feb 2009):
    - positive impact on the temperature and the relative humidity in the PBL, improves the low level jet in stable case
    - Better representation for the low-level clouds (fog) and the transition between strato-cumulus to deep convection along the GPCI transect
    - requires new tunings for the deep convections scheme → improves the precipitation distribution and QPF
- 1D experiment are very useful even if the final tuning requires to going back and forth between 1D and 3D
- Problems: warm bias during winter over snow, critical Ri ?
- Try to use the Total Turbulent Energy (Mauritsen et al 2007)

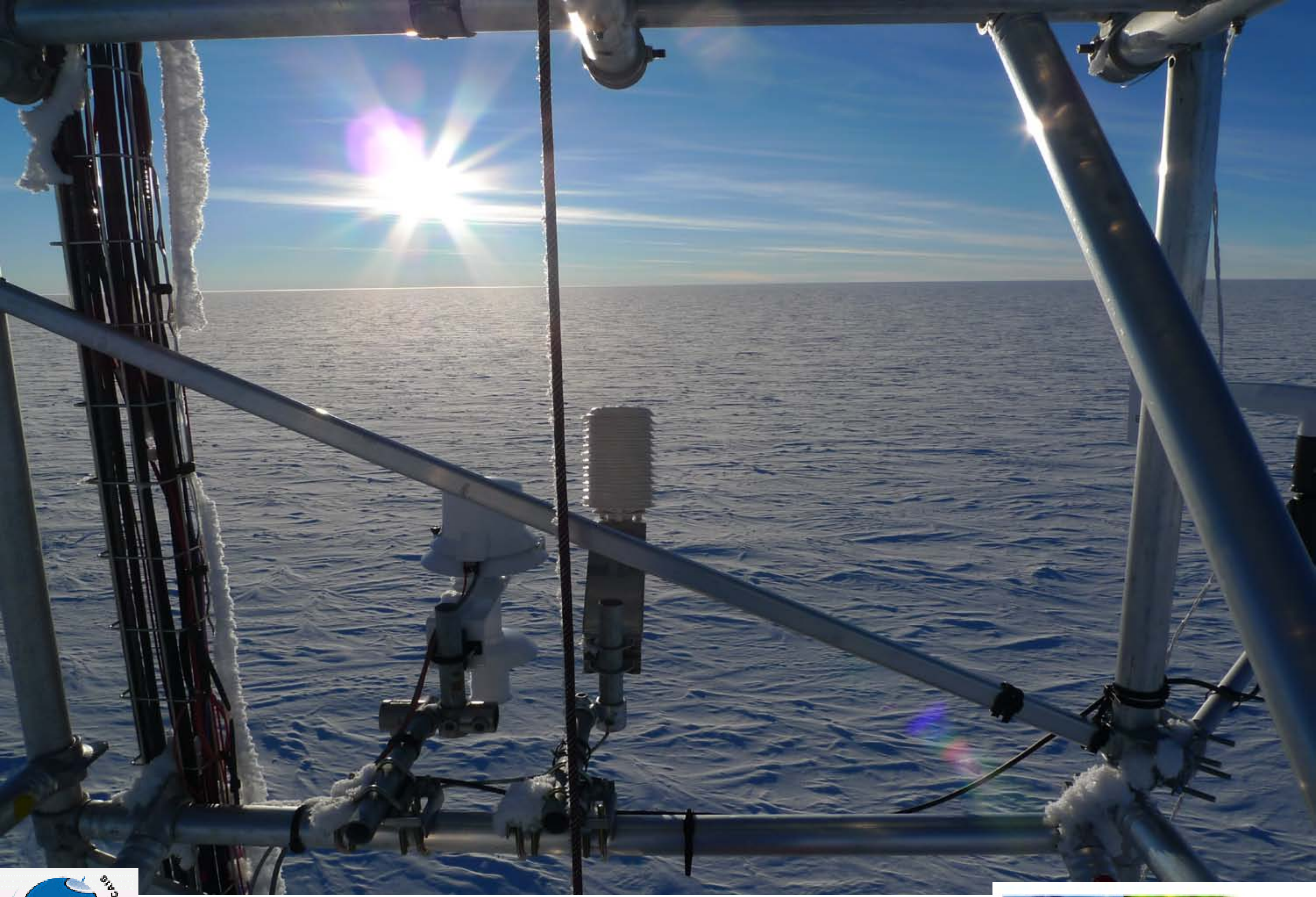
Dome C / Concordia : a very convenient site to study snow-atmosphere interactions : GABLS (3 + n) ?



« American » Tower

- High frequency parameters (10 Hz) from 6 ultra-sonic anemometers : 3D Wind components and sonic temperature
- Low frequency parameters (30 min) : air temperature (ventilated and not ventilated), relative humidity, wind speed and direction (**Young**)
- 1 minute solar radiation components
- Sub and surface temperatures

Thanks to O. Traullé (MF), Gert König Langlo (AWI for PMR, Bremerhaven, De) Christian Lanconelli (ISAC, Bologna, It), Andrea Pellegrini (ENEA, Roma, It), Eric Fossat (LUAN, Nice, Fr), Christophe Genthon (LGGE, Grenoble, Fr)



Boundary layer observation from a 45m tower (LGGE)
for stand-alone simulations and models evaluation

Laboratoire de Glaciologie et Géophysique de l'Environnement

Characteristics of the coupled simulation

E. Brun et al (2011) Journal of Glaciology (vol52)

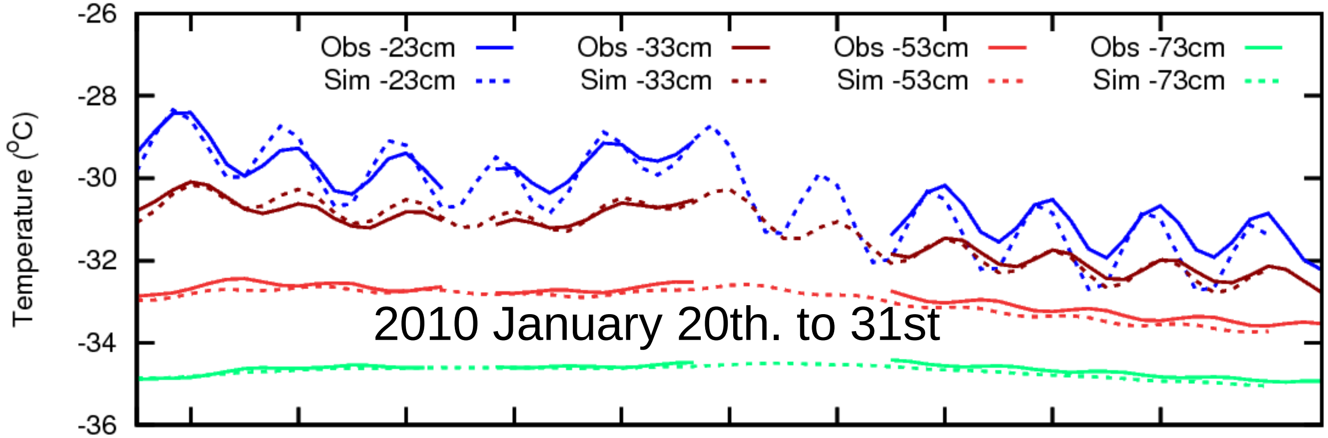
- AROME : regional model for Numerical Weather Prediction
  - 2.5km , non-hydrostatic, domain 625 x 625 km² centered around Dome C
  - 60 vertical levels ➔ bottom 3 levels : 8.5 , 27 and 51 m
  - Turbulent Kinetic Energy as a prognostic variable ➔ turbulent fluxes
  - boundary conditions and daily initial states from ARPEGE
  - ARPEGE: global model stretched over Antartica, 4D-Var
  - ARPEGE/IFS library : Météo-France, ECMWF, ALADIN/HIRLAM, Meso-NH

- Fully coupling between snowcover and the atmosphere thanks to SURFEX (externalized land surface model)

- Cycling of the snow cover throughout the 11-day simulation

Simulation of the propagation of the diurnal heat waves inside the snowcover

E. Brun et al (2011) Journal of Glaciology (vol52)



Observed snow temperature profile from Laurent Arnaud