Seamless prediction of weather and climate: an opportunity and a challenge for physical parameterizations development

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Physical processes in present and future large-scale models
ECMWF Annual Seminar, 2015

Outline

- Introduction

- Multi-environments validation of a new convection scheme for NWP and Climate models

- Some successes in using same physical schemes in NWP and Climate models

- And some challenges …

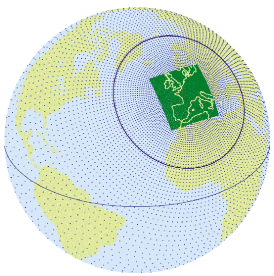
Introduction

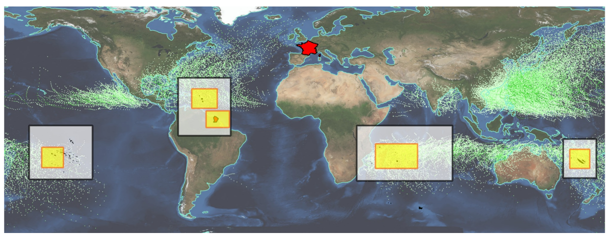
A wide range of spatial and temporal scales simulated (Météo-France)

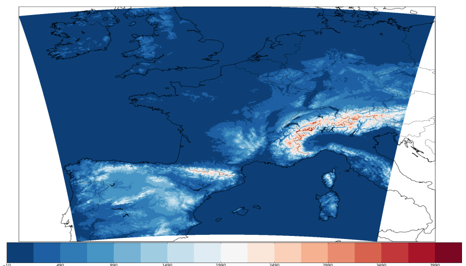
- NWP systems based on IFS/ARPEGE software developed in collaboration with ECMWF and ALADIN, HIRLAM NWP Consortia
- CNRM-CM Earth System Model developed in collaboration with CERFACS

BULLX B700 DLC

1) NWP:







Global ARPEGE
T1198c2.2L105 7.5-36 km
4DVar : 135 km and 50 km

LAM ALADIN
8 km, L70, *3DVar (3h)*

LAM AROME
1.3 km, L90, *3DVar (1h)*

Global ensembles ARPEGE:
EDA : 25 members, 40 km
EPS : 35 members, 10-60 km

New systems (2015/2016): **AROME-Nowcasting** 1.3 km
AROME Overseas 2.5 km
AROME-EPS 2.5 km

2) Climate models:

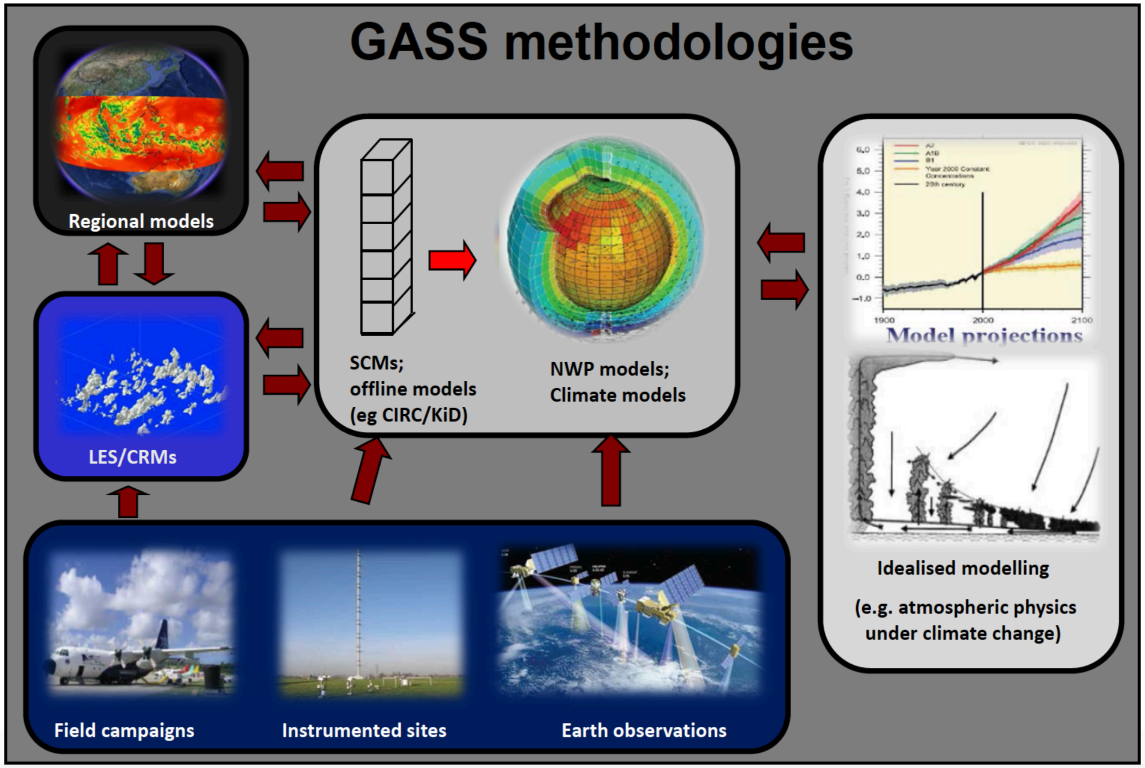
Global ARPEGE: likely resolutions for CMIP6: T149 (135 km) and T359 (55 km)
but also stretched configuration: T719C2.5 (12-70 km), T159C2.5 (50-300 km)
LAM ALADIN: 12km - 50km
LAM AROME: 2km

Physical schemes needed for all these configurations!

Development of physical parameterizations

Working with many model types

bringing together expertise in observations, modelling and understanding through intercomparison projects



A lot of work needed to improve and develop better physically based parameterizations!

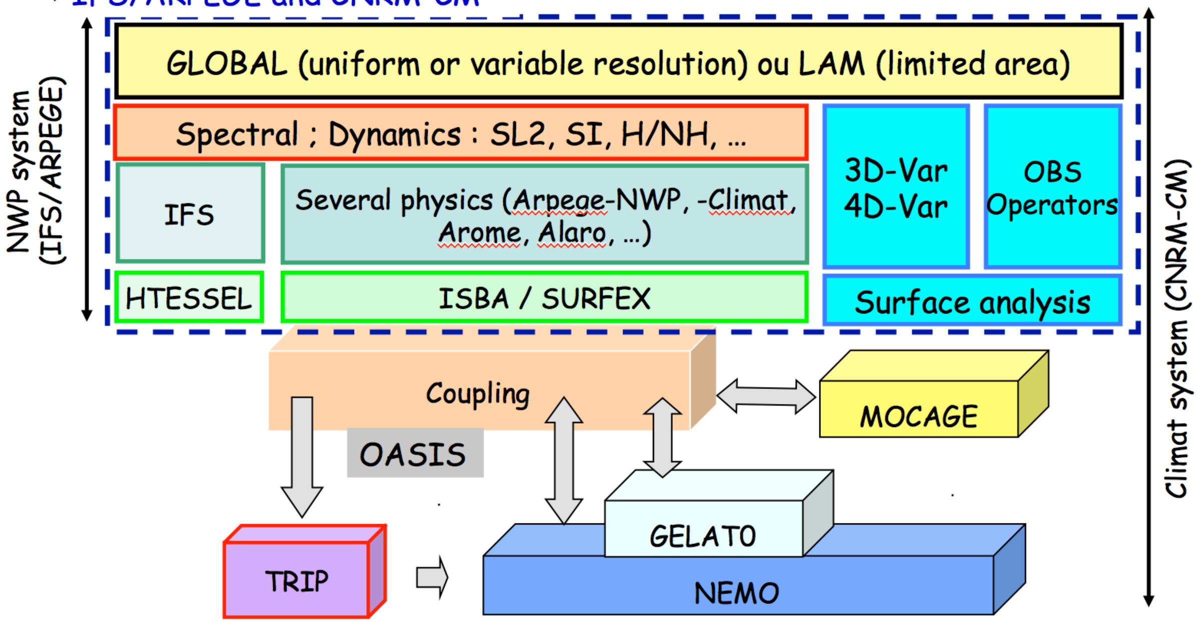
Towards seamless prediction

Motivations :

- Other Earth components contain sources of weather predictability (ocean, sea-ice, long lived anomalies in soil moisture)
- Sub-seasonal to Seasonal (WWRP/WCRP) project (teleconnections, MJO, monsoons, etc.)
- Support agencies require analyses and predictions over a wide range of temporal scales ("from minutes to months") of new components (AQ, GH, flooding)

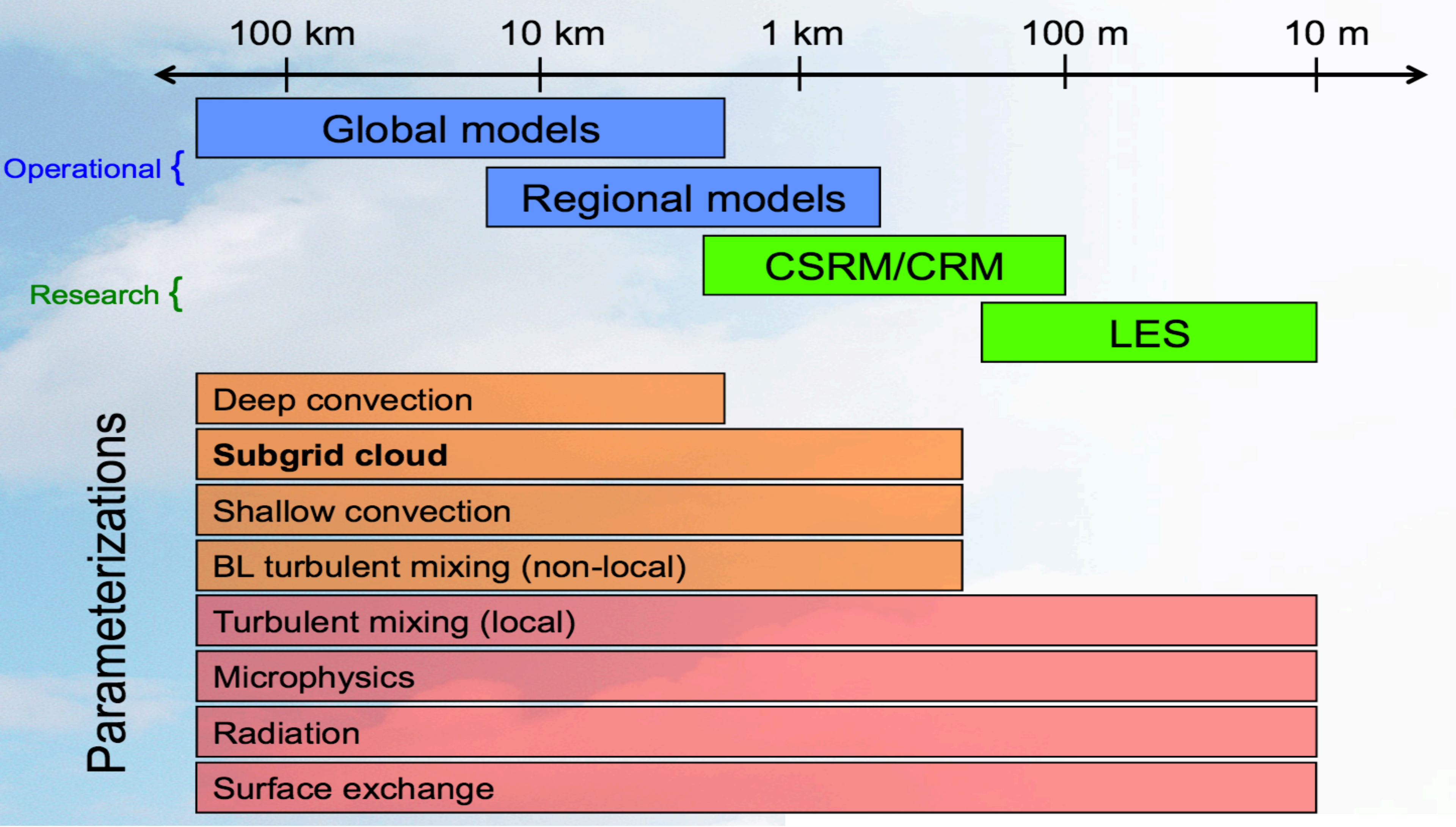
WWOSC 2014 End of Conference Statement:
"Today's weather forecasts and climate predictions are likely to evolve towards seamless weather–climate–impacts forecasting."

✓IFS/ARPEGE and CNRM-CM



All these will contribute to bridge the gap between weather and climate!

On the importance of model resolution



Towards common physics for weather & climate models at Météo-France

Brief history:

NWP convective scale model
(physics from research model MesoNH)

1990 2000 2010

One physics for global, regional NWP & Climat models

Some divergence between NWP and Climat physics

Motivations for developing common physics for hydrostatic scales (NWP and Climate):

- Better physically based physical parameterizations
- Physical parameterizations adapted to a wide range of spatial/temporal scales
- Gather expertise and coordinate efforts from various communities (NWP, Climat observation, process study) around the improvement of physical schemes

(National research project DEPHY (CNRS/INSU) with LMD, LGGE, LA research labs)

Guidelines:

- Share same physical parameterizations with convective scale physics, when possible (surface, radiation, turbulence and PBL thermals)
- Keep two distinct microphysics schemes (for hydrostatic and convective scale physics)
- Develop a new convection scheme ("PCMT")

Physical packages

	Targeted physics for hydrostatic scales (ARPEGE NWP and Climat)	Operational physics of convective scale model (AROME)
Surface	SURFEX (Masson et al., 13): surface modelling platform	
Radiation	RRTM (Mlawer, 97) + SW6* (Fouquart 80, Morcrette 01)	
Turbulence	1.5 order scheme prognostic TKE (Cuxart et al., 00)	
Mixing length	Non local, buoyancy based (Bougeault-Lacarrère, 89)	
PBL thermals	PMMC09 (Pergaud et al., 09)	
Clouds	PDF based: (Smith, 90) **or** (Bougeault, 82)	
Microphysics	Bulk scheme with 4 prog. var. (Lopez, 02)	Bulk scheme** 5 prog. var. (Pinty and Jabouille, 98)
Convection	New scheme PCMT (5 prog. var) (Piriou et al., 07) and (Gueremy, 11)	x
Subgrid orographic effects (GWD, blocking, etc.)	Catry-Geleyn (08)	x

* Plans to use SRTM (IFS scheme)

** On going researches on prognostic hail and 2-moments microphysical scheme “LIMA”

Multi-environments validation of a new convection scheme for NWP and Climat models

CNRS dépasser les frontières

METEO FRANCE

New convection scheme « PCMT »

"PCMT": Prognostic Condensates Microphysics and Transport

- 5 prognostic equations for convective hydrometeors (cloud droplets, ice crystals, rain, snow) and vertical velocity
- Grid-scale equations from the convection scheme separate microphysical processes and transport processes (Piriou et al., 2007)
- Same microphysics (Lopez, 2002) used for resolved and convective precipitations (called twice)
- Triggering condition, mass flux, entrainment based on buoyancy. CAPE relaxation time for closure (Gueremy, 2011)

Piriou J.-M., J.-L. Redelsperger, J.-F. Geleyn, J.-P. Lafore and F. Guichard, 2007: An approach for convective parameterization with memory, in separating microphysics and transport in grid-scale equations , J. Atmos. Sci., Volume 64, Issue 11, pp. 4127–4139

Gueremy, J. F., 2011: A continuous buoyancy based convection scheme: one- and three-dimensional validation. Tellus A, 63: 687–706.

Multi-environnements validation

A hierarchy of configurations used to characterize (and better understand?) the development of model errors :

Strongly constrained → Weakly constrained

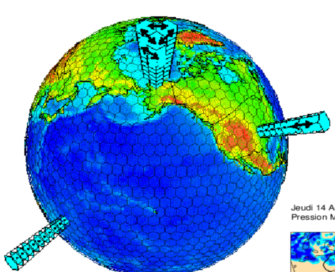
1D model
Pros: obs, LES, Initial conditions and forcings prescribed
Cons: local, few cases, no coupling with dynamics

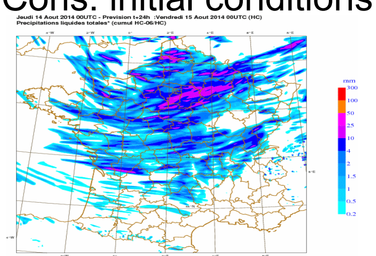
NWP
(short, medium range)
Pros: obs, analysis, forecaster evaluation, Synoptic scales well simulated, Evaluation of fast physical processes
Cons: initial conditions

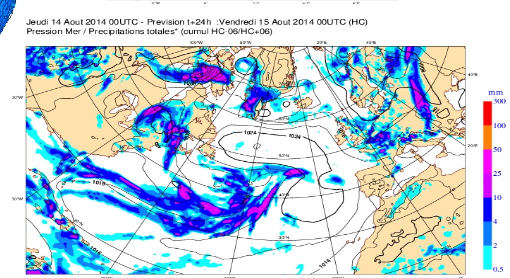
Seasonal
Pros: obs, analysis
Cons: ocean initial conditions, interactions between physics and dynamics

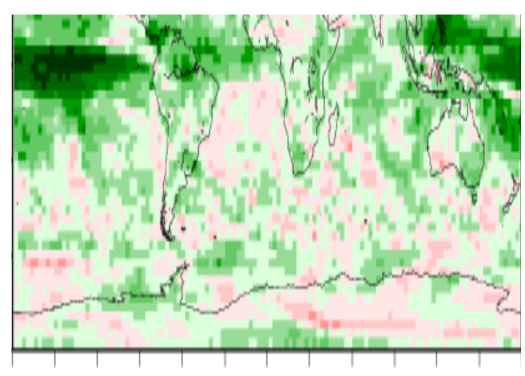
AMIP
Pros: obs, reanalysis
Cons: interactions between physics and dynamics

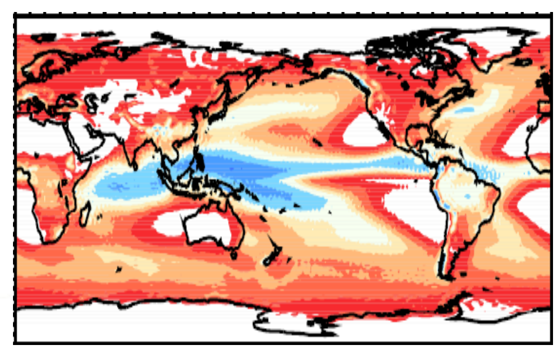
CMIP
Pros: obs, reanalysis
Cons: interactions between physics and dynamics (including ocean)







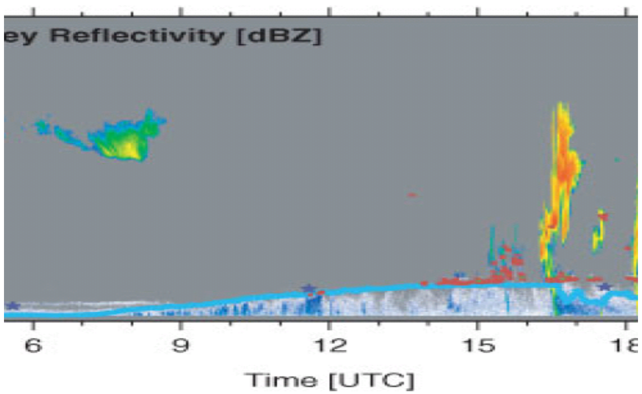




1D model evaluation

Evaluation of several 1D cases: ARM, BOMEX, EUROCS, LBA, AMMA, ...

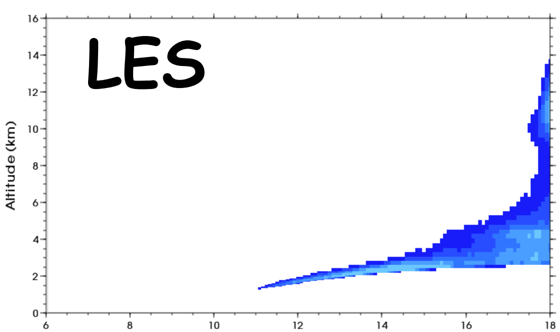
EMBRACE FP7 project : Diurnal cycle of convection over the Sahel derived from the AMMA campaign (10th of July 2006 over Niamey)

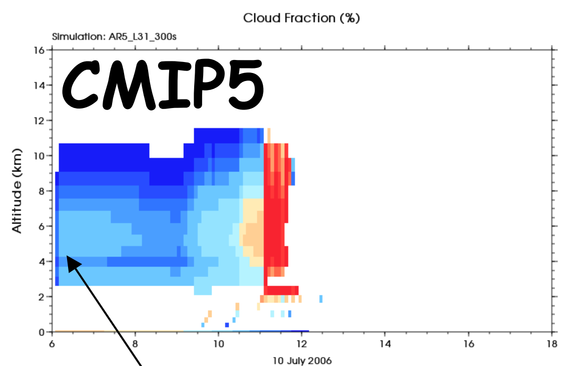


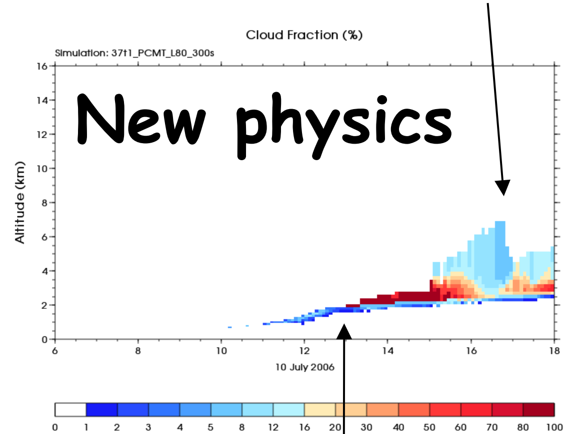
- Well documented case: Lothon et al. 2012
- Convection in a semi-arid environment
- Transition between shallow and deep convection
- Deep convection starts around 16h30

Deep convection underestimated

Cloud fraction







LES simulations
Couvreux et al. 2012

Triggering from the start of the simulation

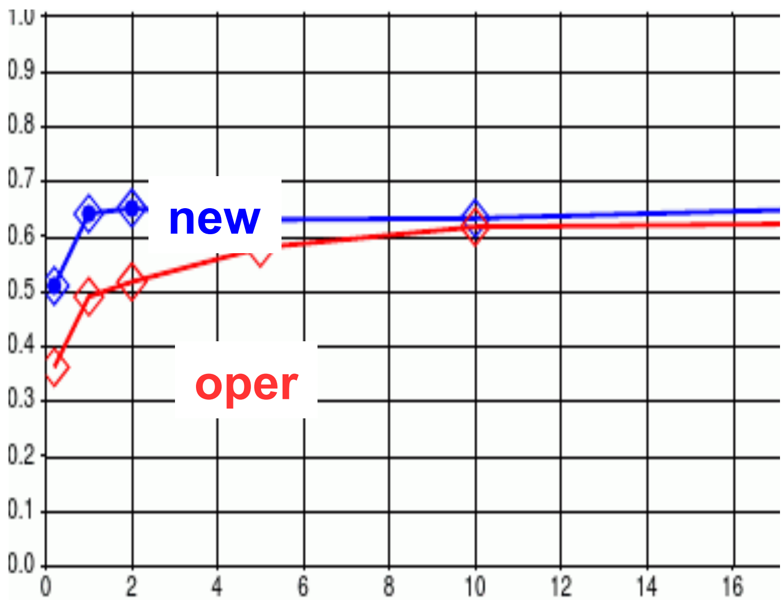
Better representation of BL and shallow convection development

NWP evaluation

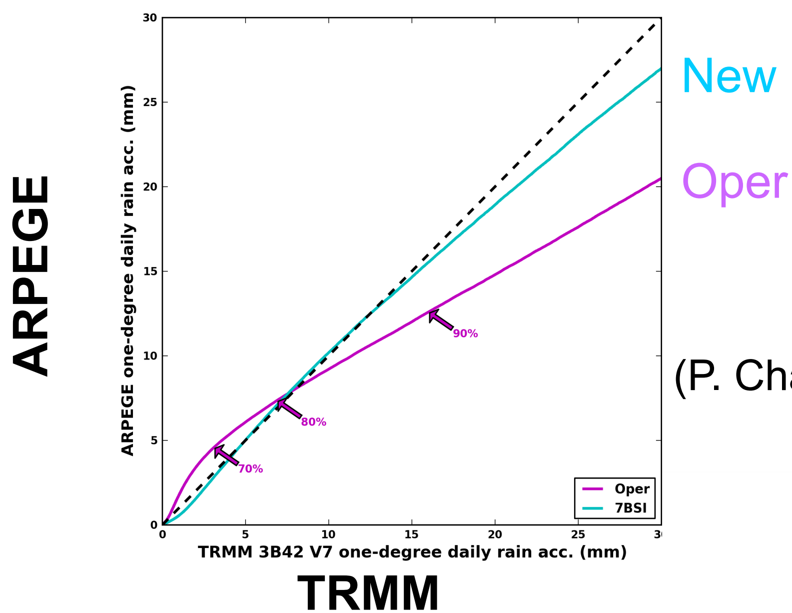
Evaluation based on global forecasts starting from operational analysis and with full assimilation (4DVar and EDA):

- Objectives scores on upper-air and surface parameters against observations and analyses
- Diagnostic based on analysis increments, initial tendencies, etc.
- Comparison to ground-based observatories, to satellite observations, etc.
- Subjective evaluation by forecasters: focused on synoptic and high impact weather

<u>24h Precipitation score against rain-gauges over France:</u>
BSS score (50km tolerance)
July-August 2013



<u>Forecast versus observed 24h precipitation distributions comparison</u>
(intertropical zone ; 1° by 1° ;
TRMM 3B42 V7 ; July/August 2013)



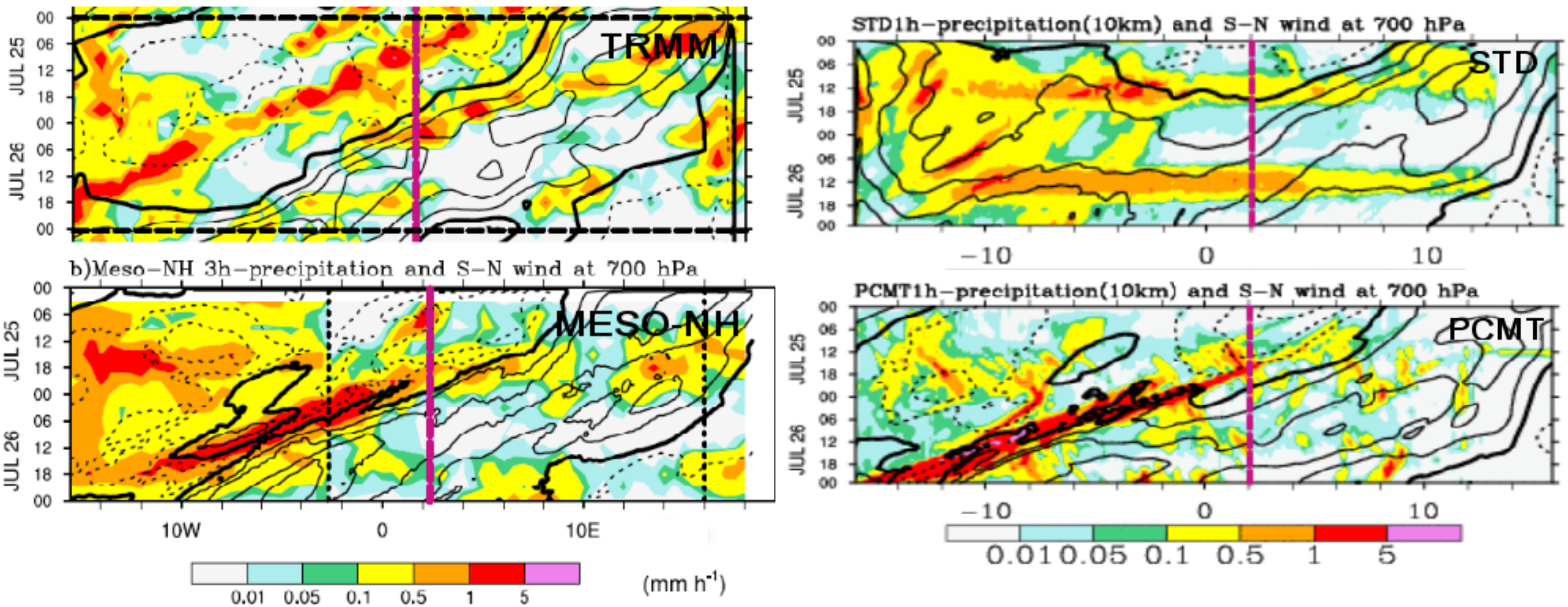
(P. Chambon)

Evaluation on West Africa

Explicit simulations vs Parameterized simulations at different horizontal resolution from 300km to 10km on the same regional domain with the same initial and lateral conditions on observed case studies.

Hovmöller diagramm of the AMMA case (25-26 July 2009)

Two successive MCS located ahead and in phase with the trough of an African Easterly Wave (AEW).



Precipitation (mm h−1; colored areas) and meridional wind (contours: 2 m s−1 intervals; solid and dashed lines represent southerly and northerly wind respectively) are averaged between 8°N and 15°N.

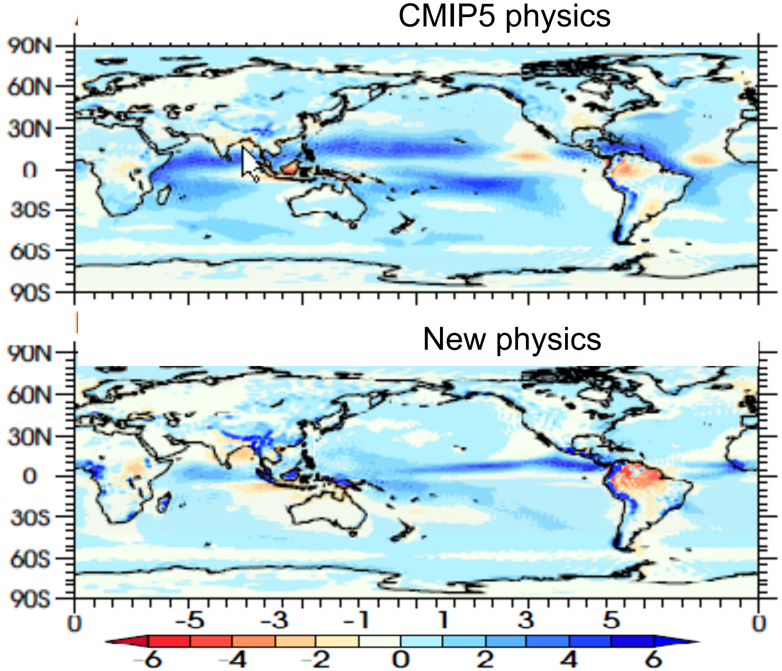
(D. Pollack, N. Ascensio, F. Beucher)

Climat evaluation

Wide range of configurations (regional/global, nudging/forced/coupled) and diagnostics :

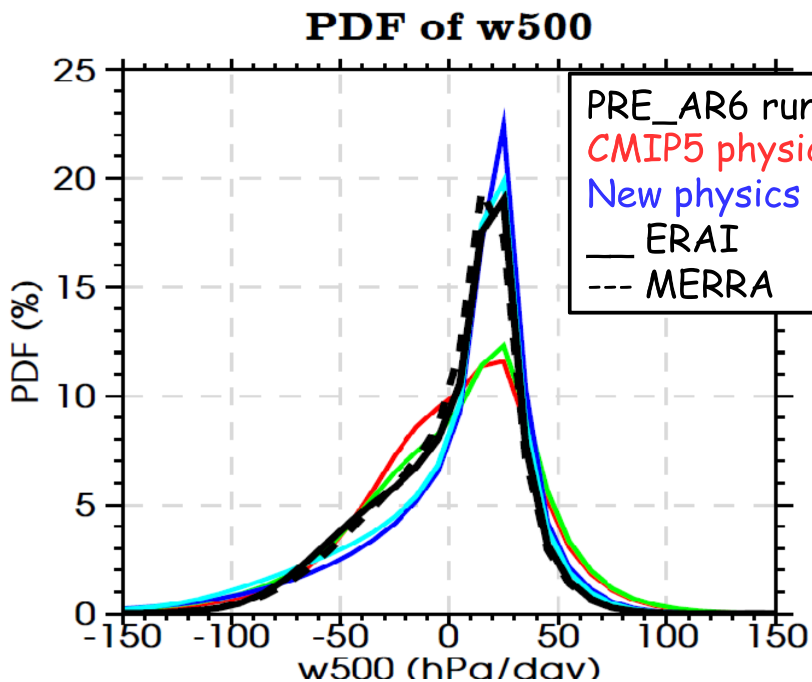
T127 AMIP simulations [1979-2012]

Annual precipitation biases vs GPCP



- Partially reduced double ITCZ
- Overestimation of convective RR (East Pacific,Himalaya, ...)
- Underestimation over Amazonia

Circulation over tropical oceans [30°S-30°N]

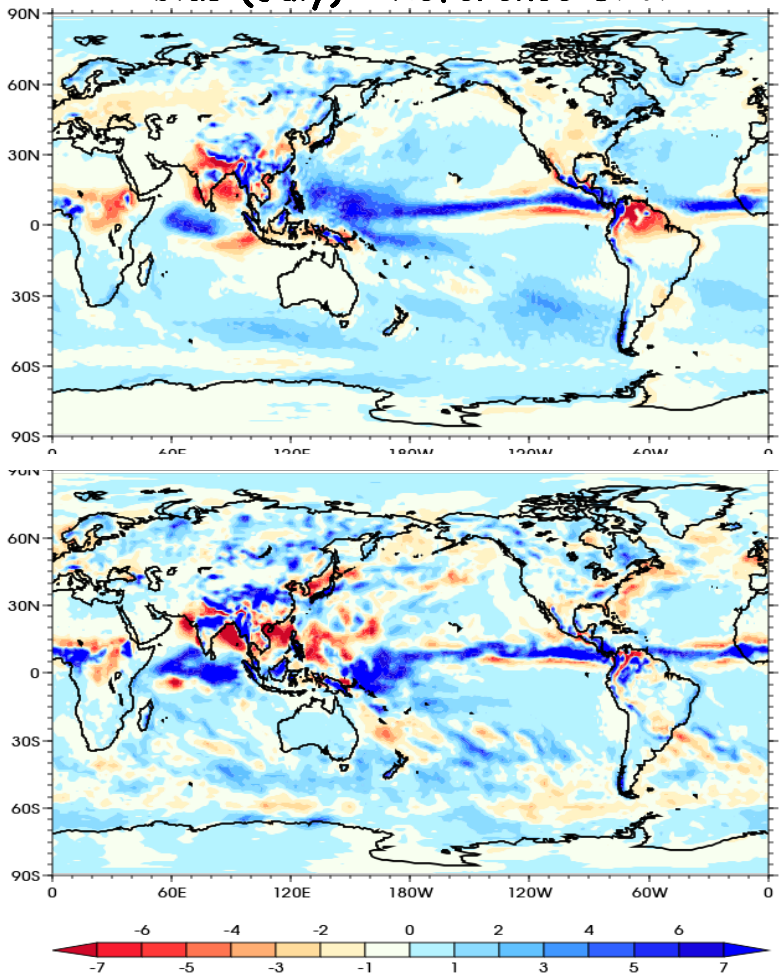


- Improvement of dynamical regimes
- Overestimation of strong ascendant regimes
- Underestimation of weak ascendant regimes

Transpose-AMIP method

A methodology where climat models are used as NWP ones, designed for tackling with climate models biases related to fast processes (Xie et al. 2012, Williams et al. 2013, Ma et al. 2014).

New physics precipitation bias (July) – Reference GPCP



- Importance of surface state initialization with informations consistent with the surface scheme for continental biases (not shown)

- TA method seems relevant for many biases of the CNRM climate model

- Decomposition of rainfall biases between thermodynamic and dynamics contributions --> insight in their origins, identification of different processes in AMIP and TA configurations.

- Analysis of terms contributing to the budget equations in both frameworks (Amip and TA). What are the predominant terms in a short-term forecast and in a long-term/ climate simulations ?

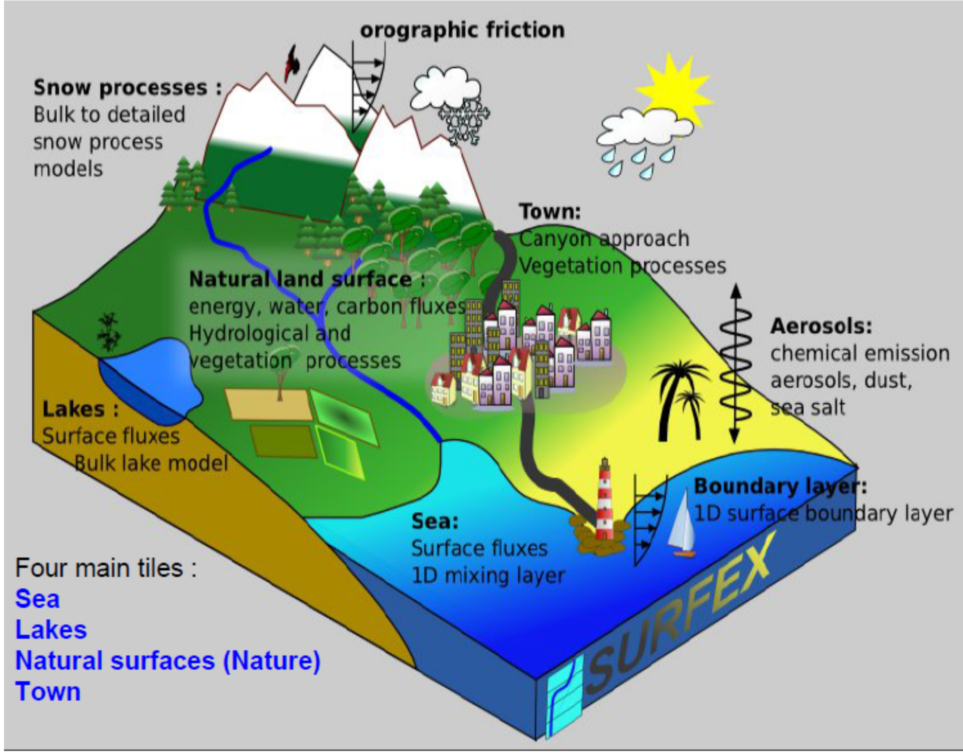
(A. Ahmat Younous, R. Roehrig, I. Beau)

Some successes (surface, radiation, PBL turbulence)

Surface

"SURFEX", an "externalized" surface model, is progressively used.

Same physiography and surface schemes are currently used all systems : ECOCLIMAP database, ISBA soil/ vegetation/ hydrology, D95 snow scheme, ECUME sea surface fluxes, except Town Energy Model used only in convective scale model



New surface parameterizations developed simultaneously for LAM and global NWP and Climat systems : Explicit soil diffusion scheme (ISBA-DIF), Explicit snow scheme (ISBA-ES), Multi-Energy balance (MEB), Carbon options (ISBA-A-gs)

(Masson et al., 2013)

Radiation

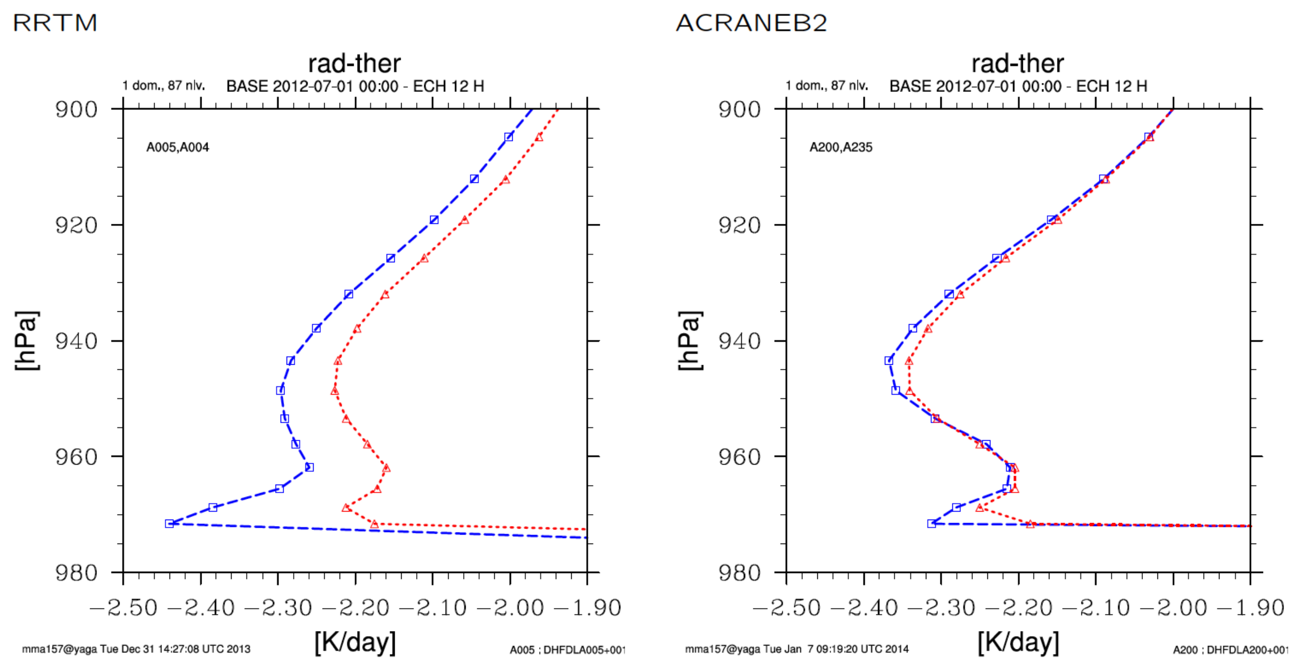
Same radiation schemes used in all NWP, Climate and research models. The code originates from IFS : RRTM (Mlawer et al.), SW6 (Fouquart and Morcrette)

Full radiation computations are expensive: done every 15 min in Arome, every 1h/3h in Arpege NWP and GCM.

Alternative approach (Masek et al., 2015):

slowly evolving gaseous transmissions are updated on the timescale of hours, while quickly varying cloud optical properties are recomputed at every time-step

DDH thermal heating rates, 12 h integration, summer case with front passage



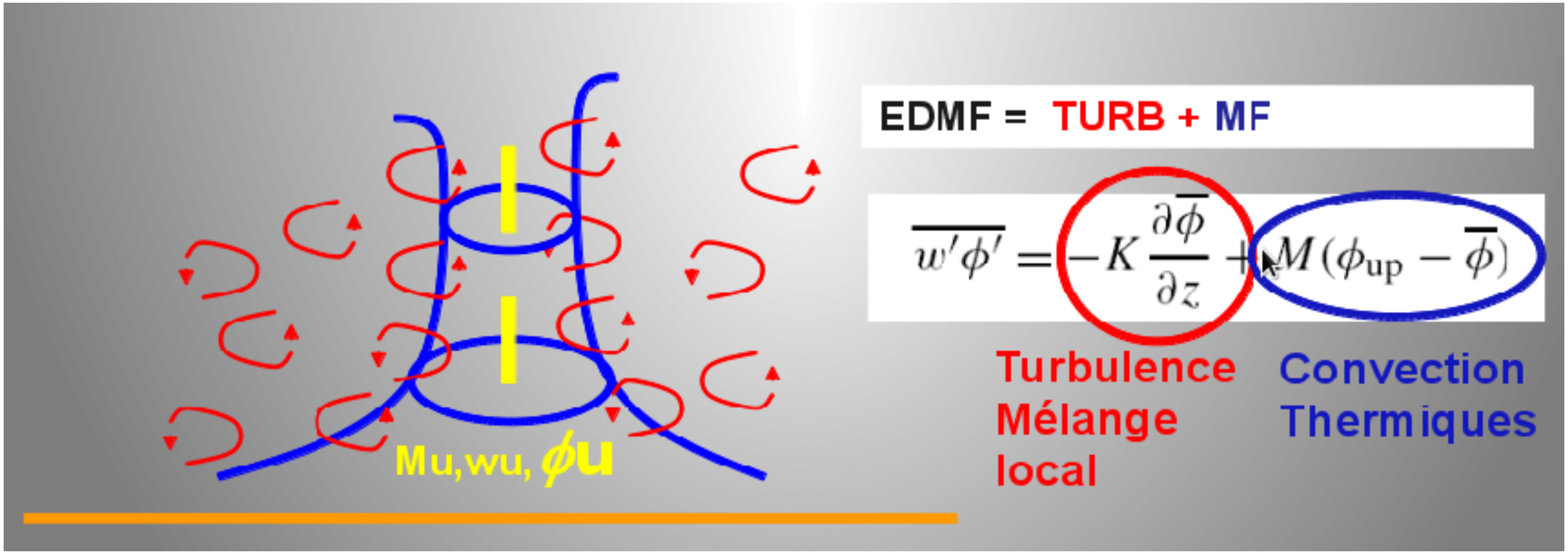
no intermittency
1 h intermittency **including** clouds

no intermittency
1 h/3 h intermittency **excluding** clouds

EDMF : Eddy Diffusivity & Mass Flux model

Scale separation for modeling turbulence:

- **Small scale turbulence: Eddy diffusivity formulation**
- **Non local turbulence (thermals): Mass flux formulation**



(Chatfield and Brost 1987, Siebesma and Teixera 2000, Hourdin et al. 2002, Soarez et al 2004, Siebesma et al. 2007, Rio and Hourdin 2008, Pergaud et al. 2009, etc.)

Convergence on turbulence scheme and EDMF framework

All NWP models use now « EDMF » framework:

$$\overline{w'\phi'} = -K\frac{\partial\bar{\phi}}{\partial z} + \frac{M_u}{\rho}\left(\phi_u - \bar{\phi}\right) \quad \text{with} \quad K = cL_{BL89}\sqrt{e}$$

Prognostic TKE Scheme: Cuxart et al. (2000), Bougeault & Lacarrere (89)

Shallow convection from Bechtold et al. (2001) for ARPEGE Pergaud et al. (2009) for AROME

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

and

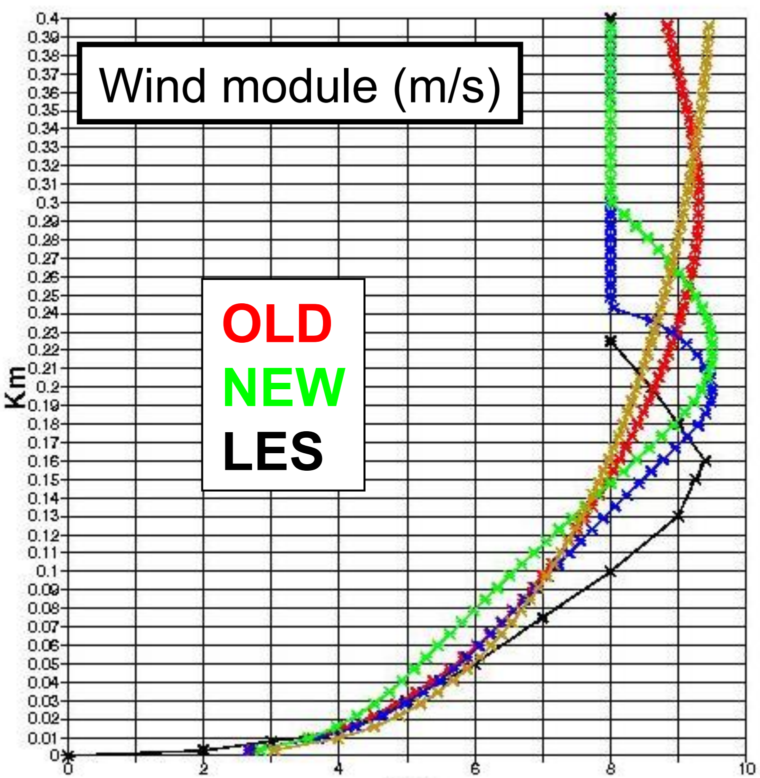
$$L_{BL89} = \left[\frac{\left(l_{up}\right)^{-\frac{2}{3}} + \left(l_{down}\right)^{-\frac{2}{3}}}{2}\right]^{-\frac{3}{2}}$$

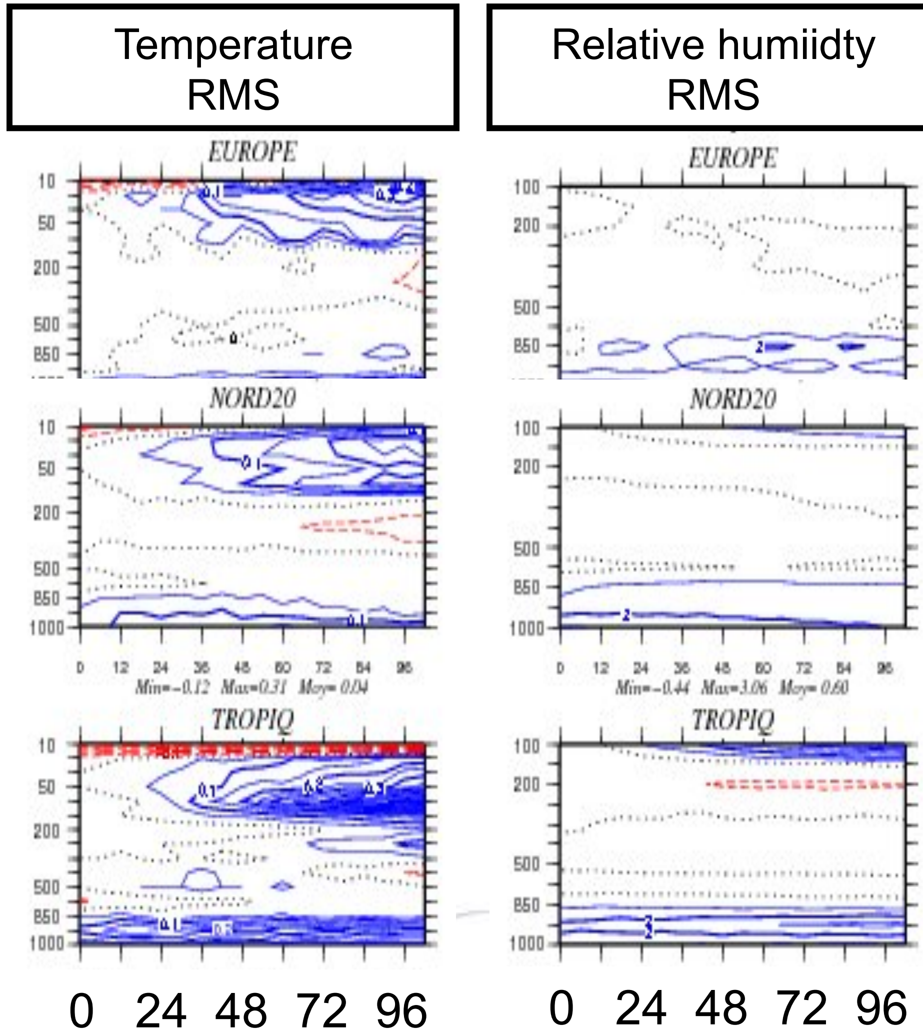
Where l_{up} and l_{down} are computed using dry buoyancy following Bougeault and Lacarrère (1989)

Convergence on turbulence scheme and EDMF concept

GABLS I
Cuxart et al, 2006 BLM

Radiosoundings scores : NEW-OLD
ARPEGE-NWP (Sept-Dec 2009)





(Bazile et al., 2011)

Evaluation of AROME thermal scheme in ARPEGE

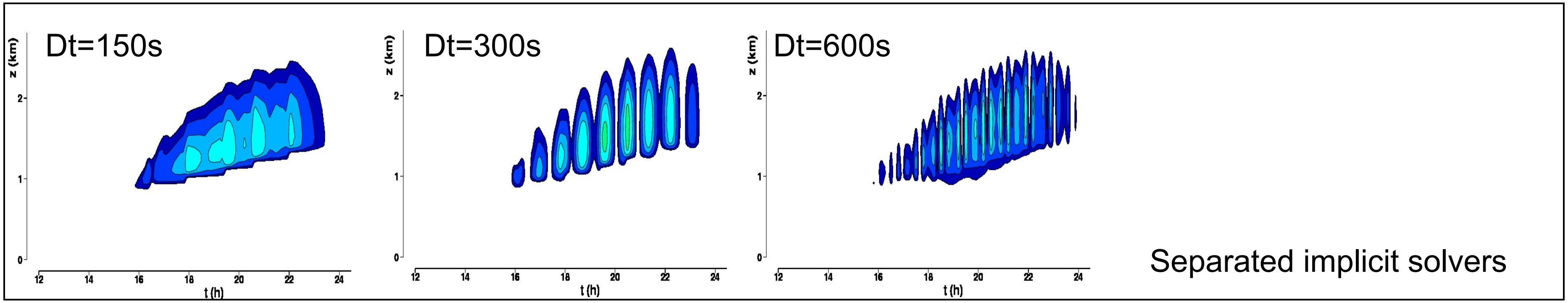
Motivations of evaluating "Pergaud et al, 2009" (PMMC09) scheme in Arpege :

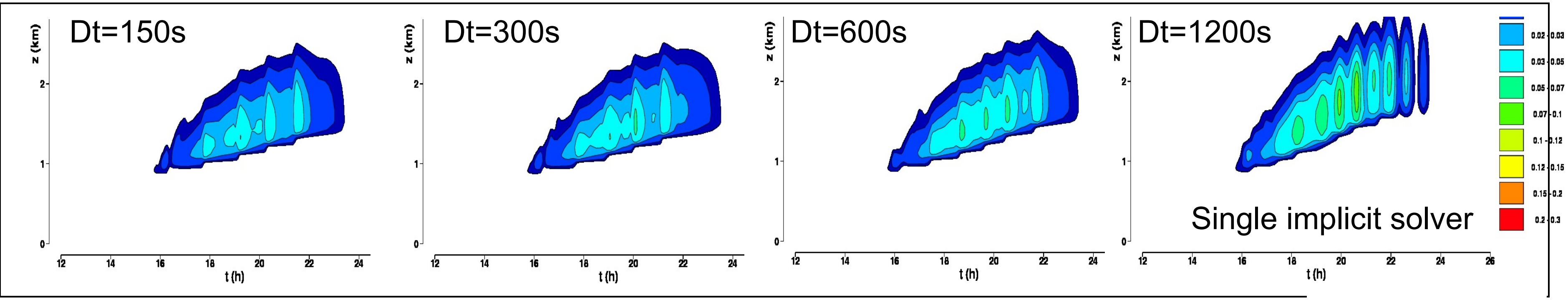
- Improve representation of thermals (dry thermals, improved closure, momentum mixing)
- Extend validation of the scheme on the globe
- Convergence of PBL schemes with Arome

Algorithmic adaptation for long time step: Unique implicit solver for mass flux and diffusion terms :

$$\left(\frac{\partial \psi}{\partial t}\right)_{edmf} = \frac{1}{\rho}\frac{\partial}{\partial z}\left(-k\frac{\partial \psi}{\partial z} + M\left(\psi_u - \overline{\psi}\right)\right)$$

ARM Cumulus 1D case (cloud water content)

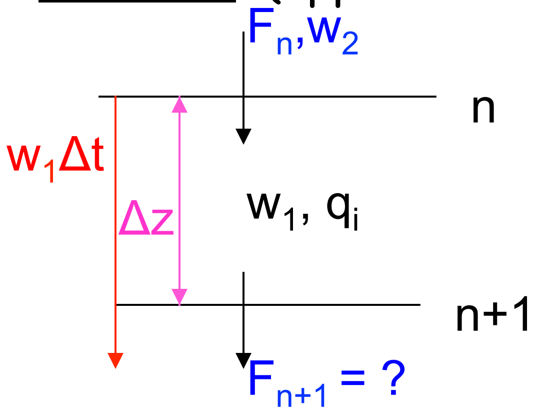




(Bouteloup)

Statistical sedimentation scheme

AROME : (applied on cloud dropplets, snow, rain and graupel)



$$P_1 = \min\left(1, \frac{w_1 \Delta t}{\Delta z}\right)$$ (Proportion of layer n leaving the layer in dt)

$$P_2 = \max\left(0, 1 - \frac{\Delta z}{w_2 \Delta t}\right)$$ (Proportion of F_n crossing the layer in dt)

$$w_2 = F_n . \frac{\Delta t}{\rho \, \Delta z}$$

$$F_{n+1} = \frac{P_1 . \rho . q_i . \Delta z}{\Delta t} + P_2 . F_n$$

ARPEGE : longer time steps -> need to take into account microphysics process during sedimentation (applied on rain and snow)

$$F_{n+1} = \left(1 - \frac{S^i_n}{q_i + (\Delta t / \rho . \Delta z) F_n + S^o_n}\right) \times \left(\frac{P_1 . \rho . q_i . \Delta z}{\Delta t} + P_2 . F_n + \frac{P_3 \, \rho . \Delta z . S^o_n}{\Delta t}\right)$$

$P_3 = (P1+P3)/2$ (Proportion of q_i produced in layer n during dt which leaves the layer during dt)

S^i_n = sinks of q_i (evaporation for rain, evaporation + melting for snow)

S^o_n = sources of q_i (autoconv., collection and melting for rain, autoconv. + collection for snow)

Developed for long time step (typically 15 min), but also beneficial in Arome (50s)

(Geleyn at al. 2008, Bouteloup et al. 2010)

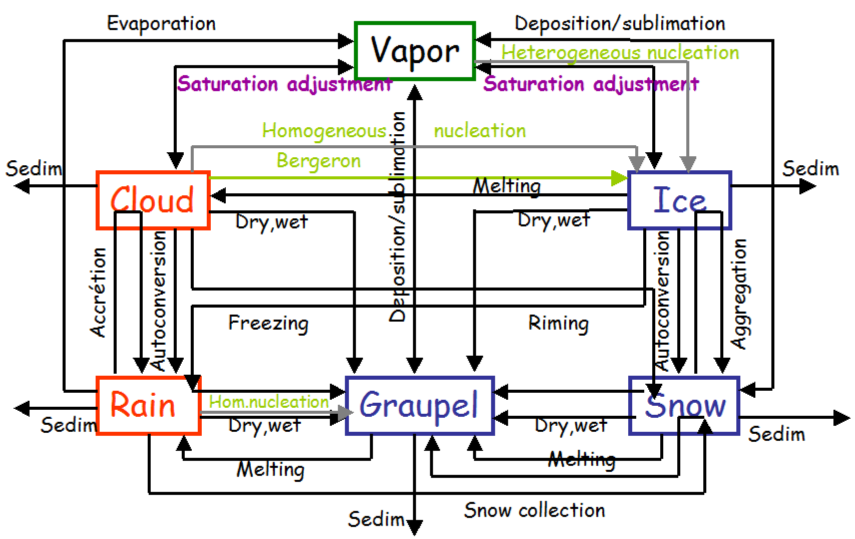
Some challenges in the development of seamless physical parameterizations

Appropriate level of complexity

Example with microphysical scheme :

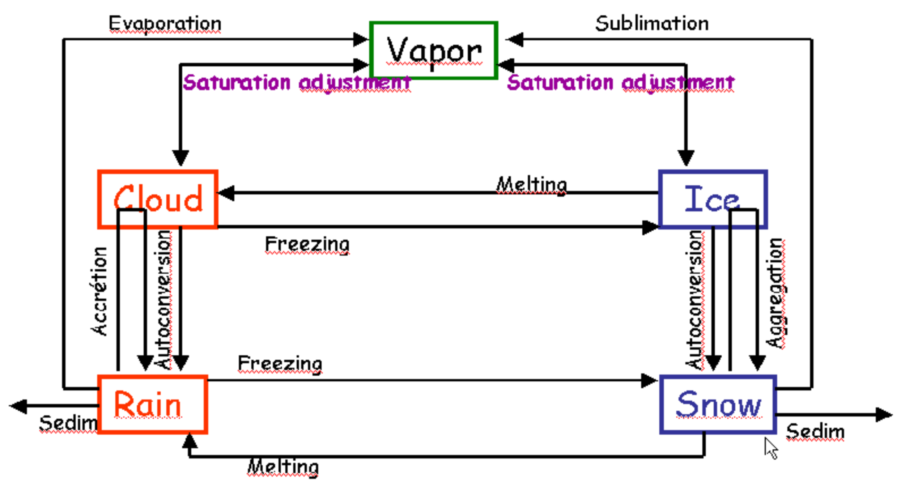
✓ appropriate level of complexity in CSRM and large scale model (Dx>10km)?

✓ difficulty to build microphysical scheme suitable for a wide range of time steps (from few seconds to tens of minutes).



AROME (ICE3)

(Caniaux, 1993 – Pinty and Jabouille, 1998)



ARPEGE

(Lopez, 2002 – Bouteloup et al., 2005)

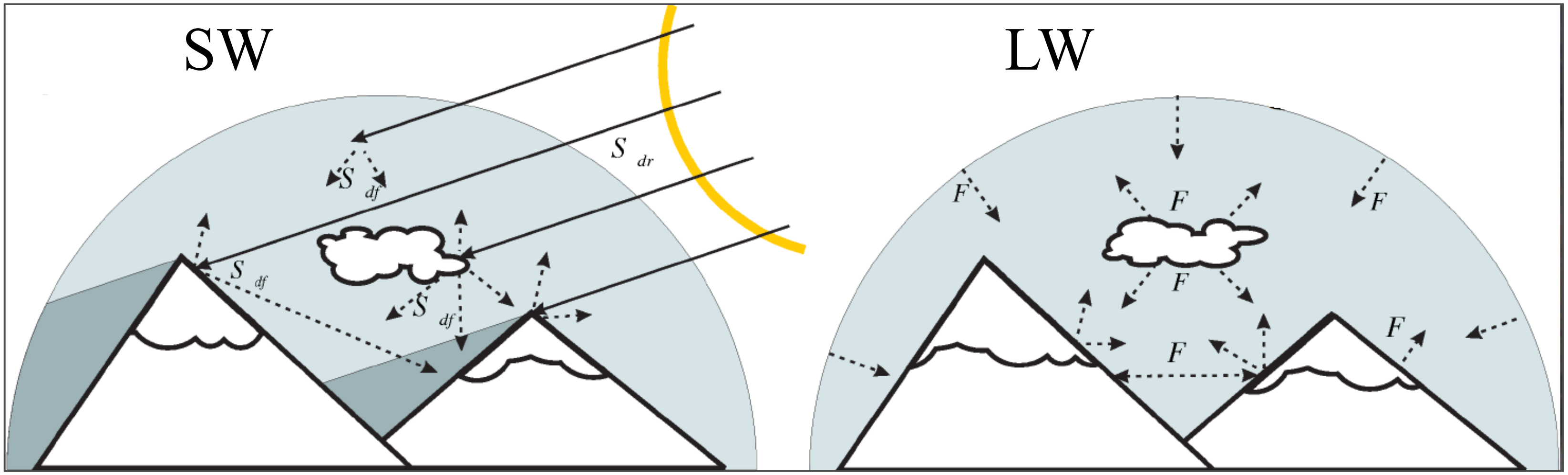
- Global NWP: One-moment prognostic scheme probably good enough for the next years.
- Convective-scale NWP: Two-moment schemes are expensive, but should be the better choice
- Data assimilation: Assimilation of cloudy pixels or convective-scale DA: more detailed microphysics schemes.

Towards hectometric resolutions for NWP

New processes to parameterize.

For instance, R&D needed on 2D/3D physical parameterizations:

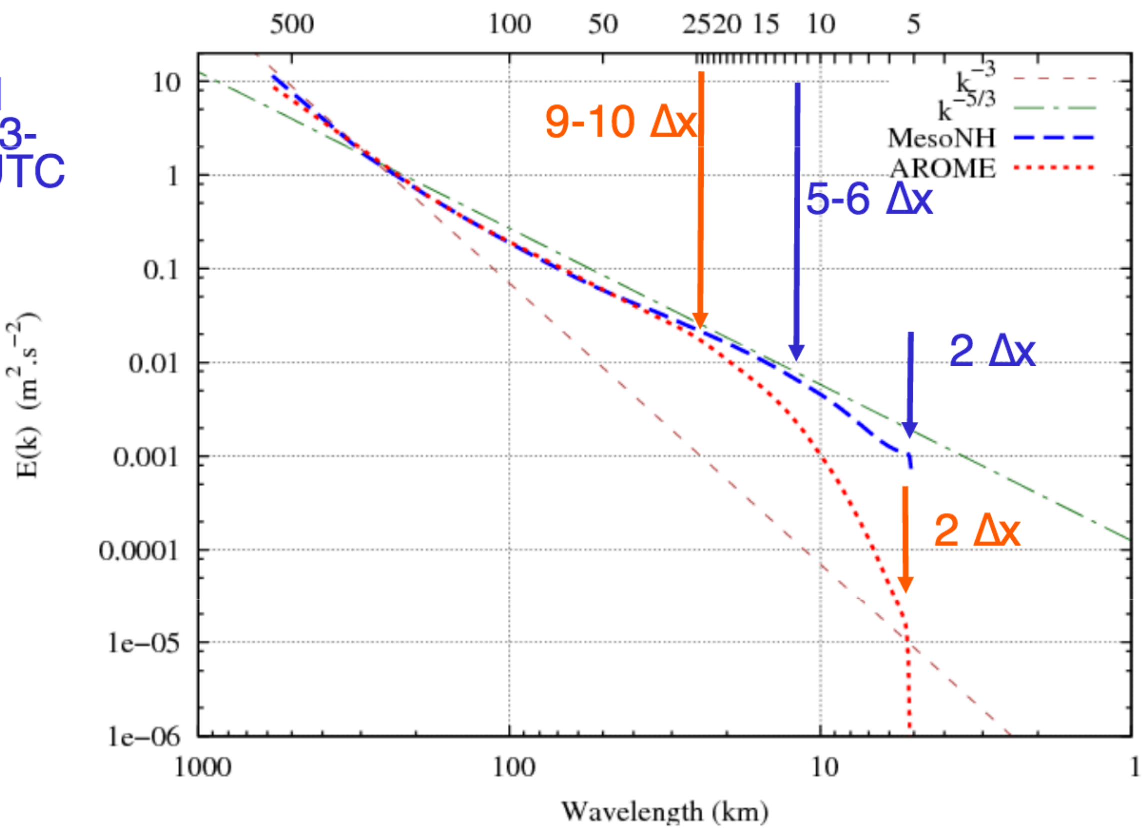
- ✓ Turbulence (over orography, for convection)
- ✓ Atmospheric radiative effects
- ✓ Orographic radiative effects (slope, shadows, etc.)



Effective resolution

Comparisons of 2 simulations with different dynamical cores but same physics and boundary conditions at 2.5km (explicit convection)

KE spectra (U,V) averaged over the free troposphere (3-9km) between 13 and 17 UTC

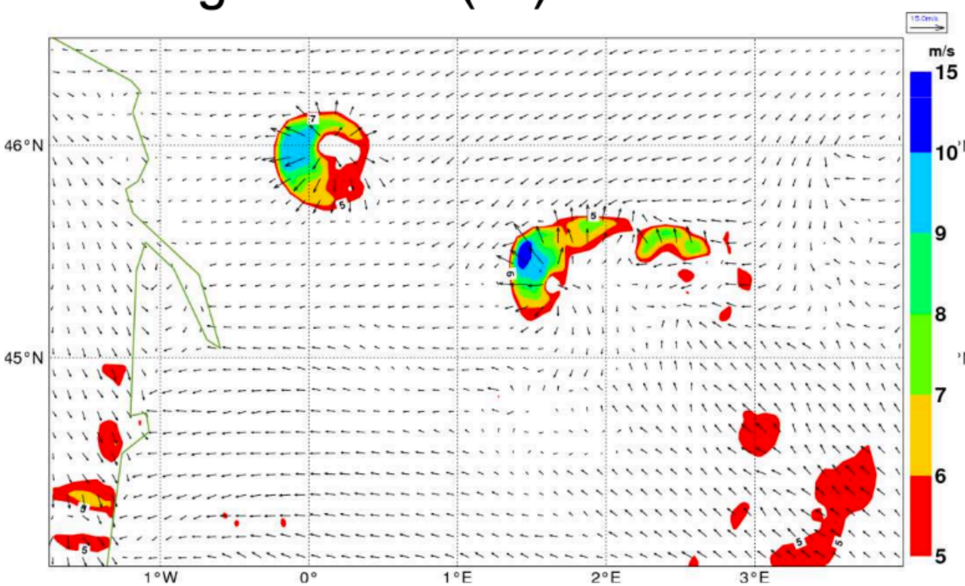


(Ricard et al., 2013)

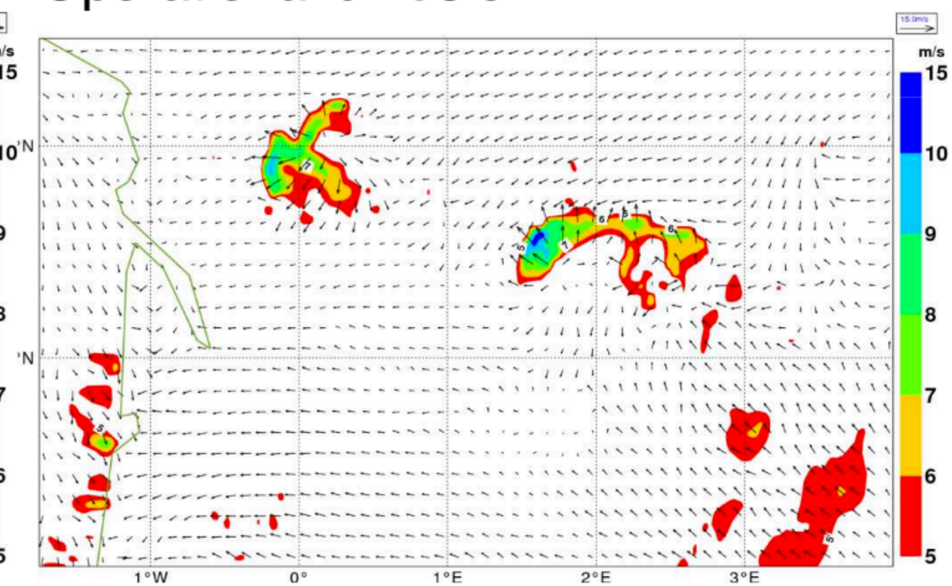
Effective resolution

Sensitivity of convective scale models to numerical diffusion: example of Arome at 2.5km resolution

Strong diffusion (x4):



Operational diffusion:



Wind at 17 m (intensity and vectors, m/s), 15 UTC

Strong outflow under the convective cells: « fireworks »

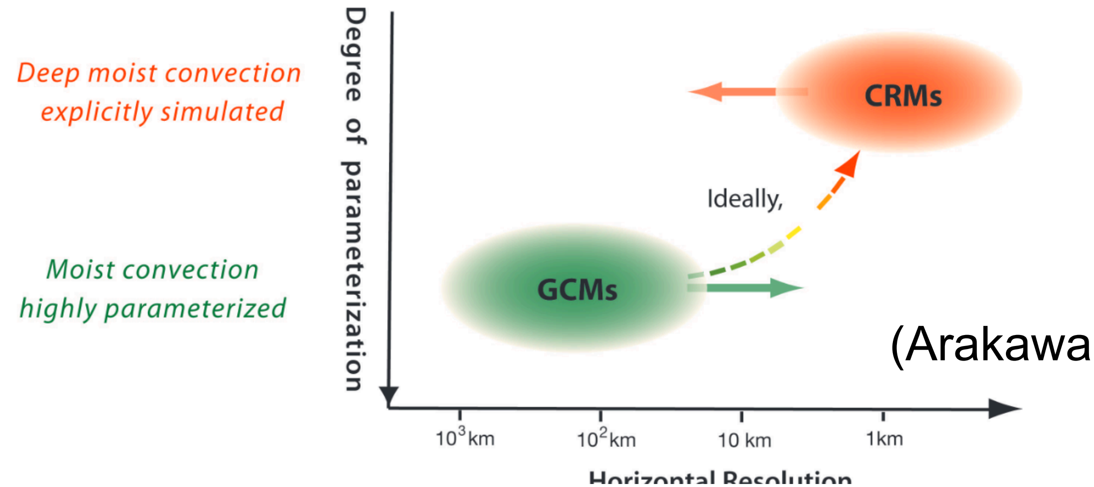
Not the case with operational tunings

(Ricard et al., 2013)

Grey zones (subgrid ≅ resolved)

1) For deep convection (~5km) : explicit deep convection in Arome

2) Forturbulence, ie dry and moist thermals (~500m)



(Arakawa)

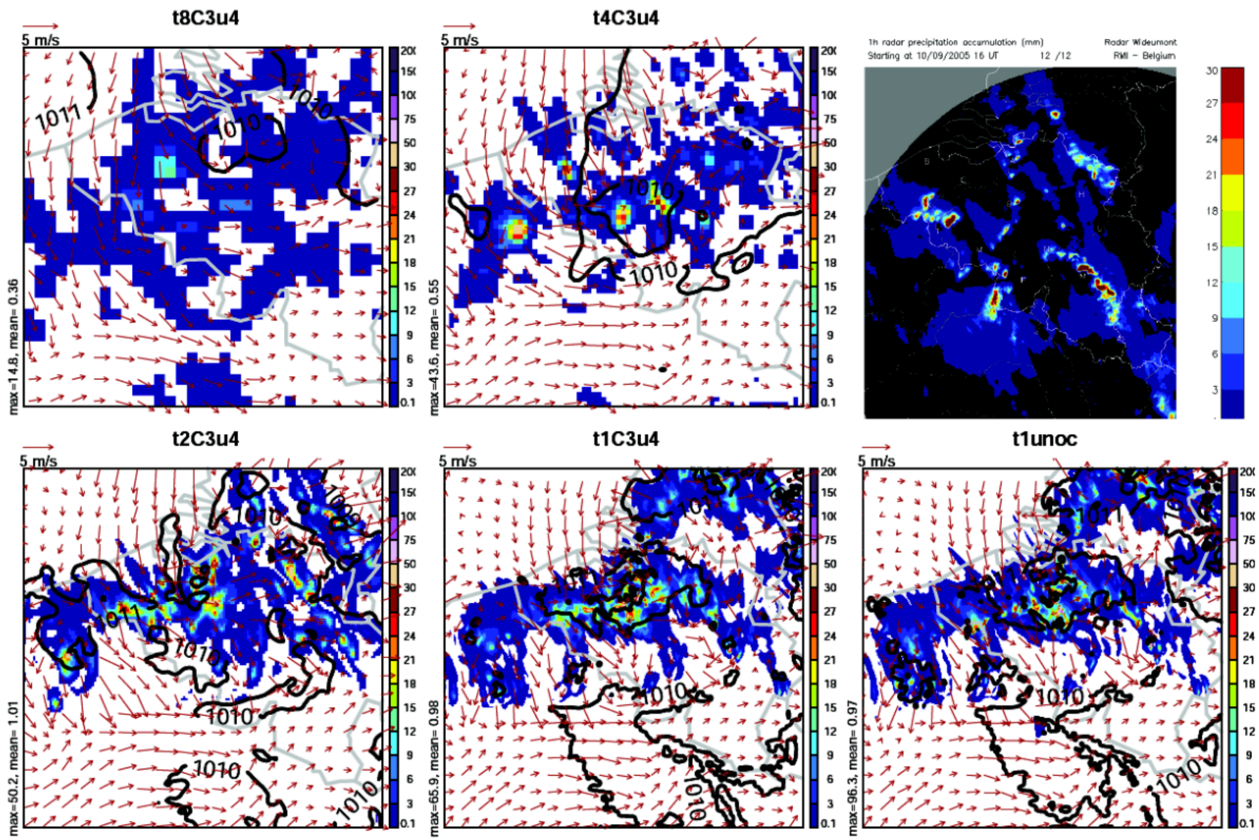
Conceptual problem of representing motions on scales which are neither resolvable nor parameterisable using current assumptions:

- Convective quasi-equilibrium (assume convection is entirely diagnostic)
- Statistical Equilibrium (average over many “features” per grid-box)
- Segmentally-constant / homogeneous / “top-hat” updrafts & downdrafts
- Instantaneous ascent
- Small updraft area fraction
- Local compensating subsidence

Active area of research: *Gerard and Geleyn (2005), Gerard (2007), Plant and Craig (2008), Moeng et al. (2010), Grandpeix and Lafore (2010), Arakawa et al. (2011), Grell and Freitas (2013), Arakawa and Wu (2013), Keane et al. (2014), Bechtold et al. (2014), Rochetin et al. (2014), Moeng*

Grey zone (deep convection)

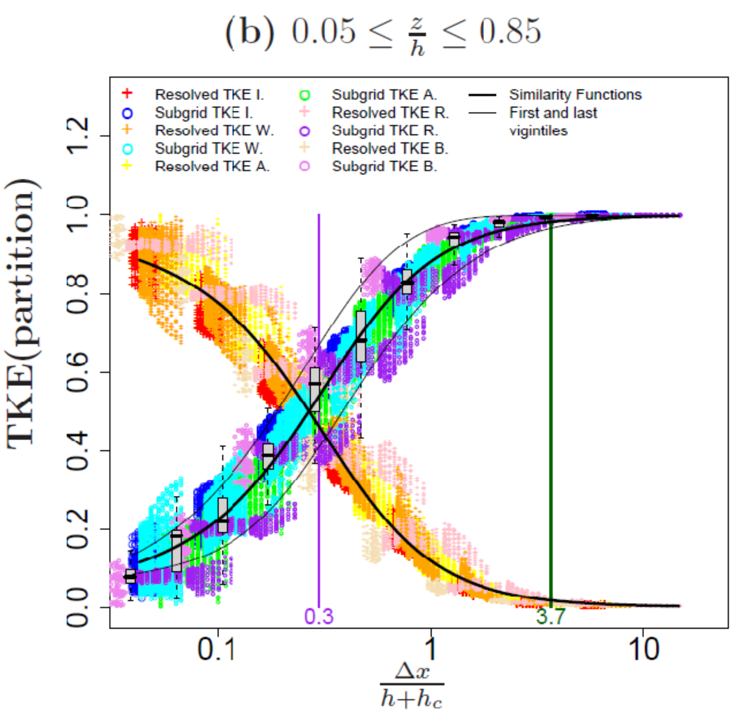
Multi-scale behavior of the prognostic
deep convection in the ALARO model with the 3MT scheme

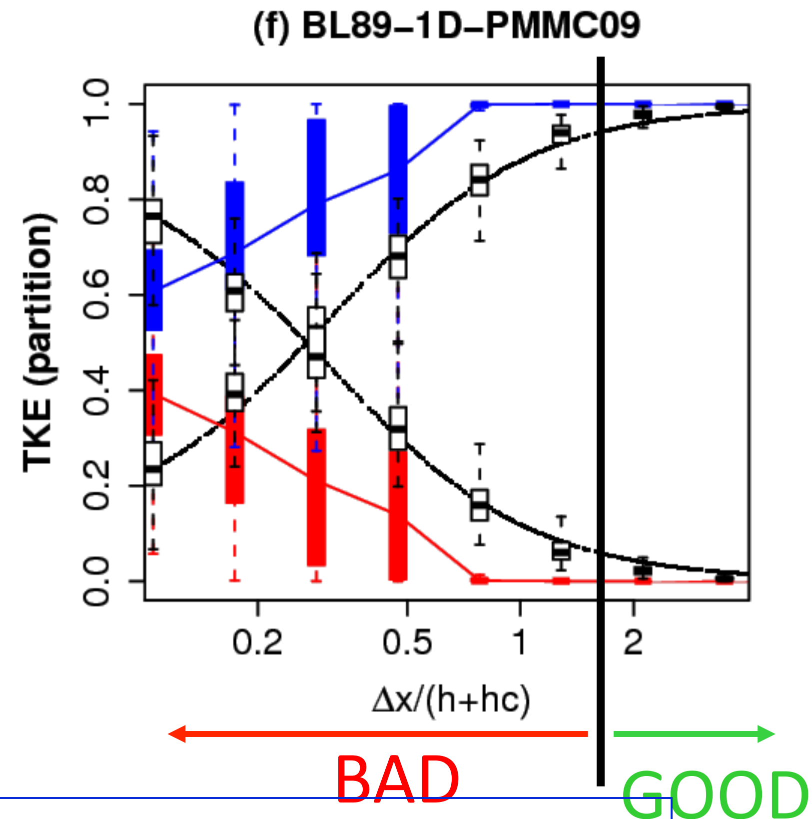


Courtesy L. Gerard: Gerard and Geleyn (2005), Gerard (2007), Gerard et al. (2009)

8, 4, 2, 1 km

Grey zone (turbulence)

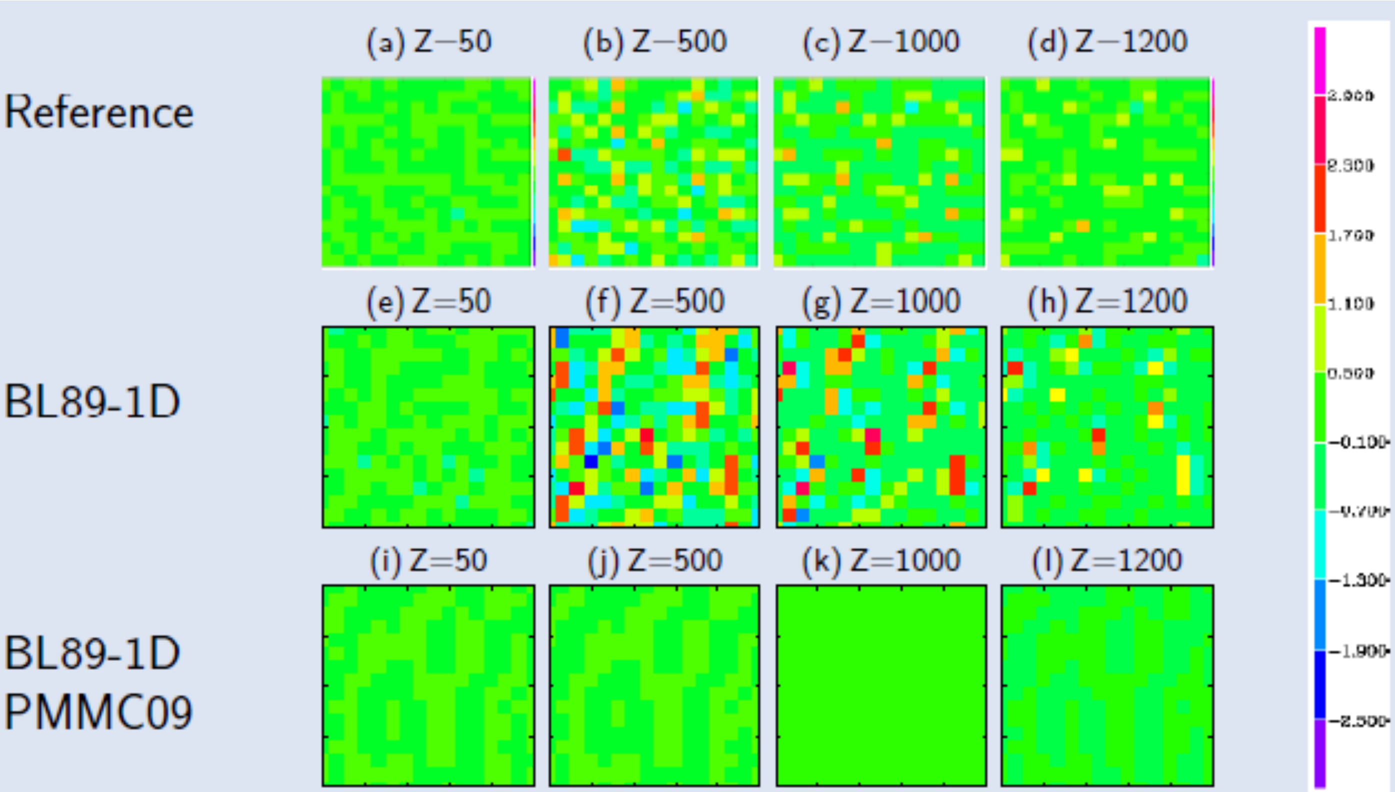




- Adaptation of the Mass-Flux scheme equations for the grey zone
- Dependence of the closure on the resolution

(Honnert et al., 2011, 2012)

Grey zone (turbulence)



Without the mass-flux scheme

Too strong resolved movements.

Too large structures.

With the mass-flux scheme

Deficit of variability.

The representation of the sub-grid thermals has the most significant impact.

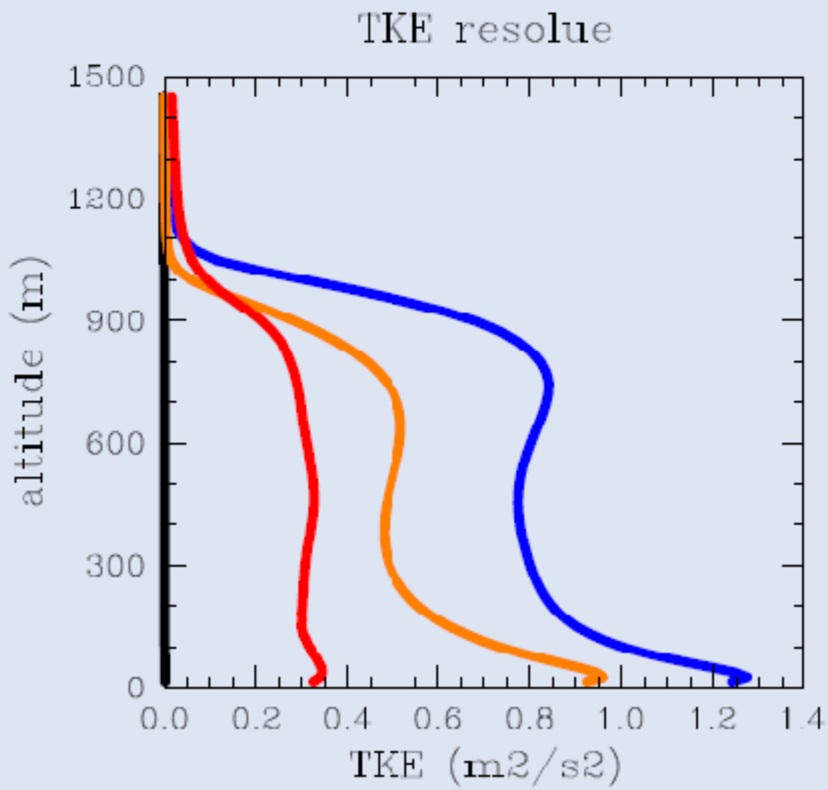
(Honnert)

$$\frac{\partial M_u \phi_u}{\partial z} = \tilde{E}\phi_e - \tilde{D}\phi_u + \alpha(F_u - \overline{F})$$

Similar to the meso-scale equation but ...

- α sub-grid thermal fraction, α not negligeable
  $\rightarrow \phi_e \neq \overline{\phi}$, ϕ_e average value of ϕ over the environment
- $\overline{w}$ not negligeable $\rightarrow M_u = \alpha(w_u - \overline{w})$
- $\tilde{E}$ et $\tilde{D}$ include exchanges and non-stationnarities

Méso-NH model IHOP, 12h, 500 m resolution

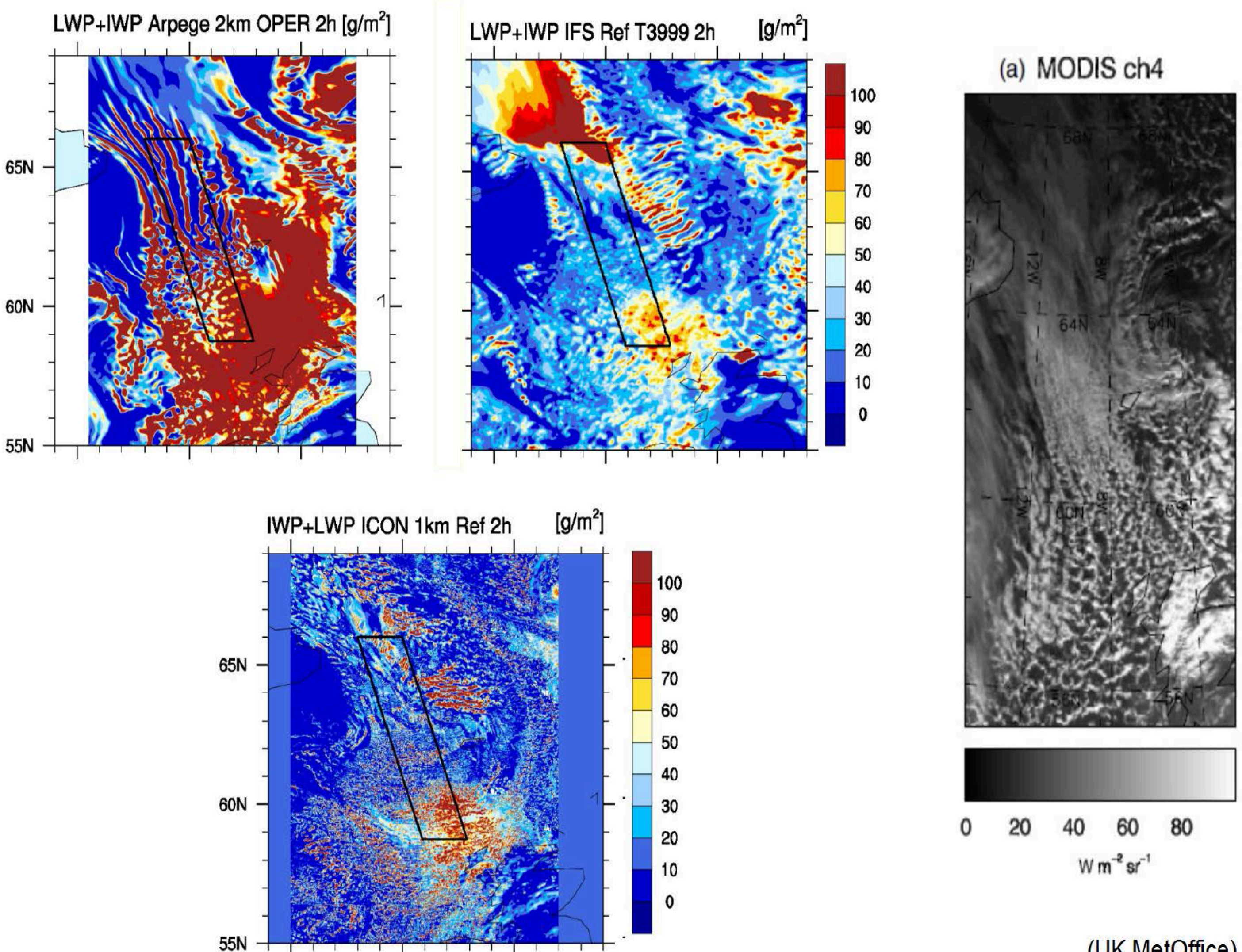


– LES
– with *Pergaud et al. (2009)*
– without *Pergaud et al. (2009)*
– *Honnert et al. (2013)*

At 500 m resolution, the LES produces resolved TKE. The simulation with Pergaud et al. (2009) does not produce resolved TKE. The simulation without Pergaud et al. produces too much resolved TKE. The new scheme produces resolved TKE, less than without Pergaud et al. but still too much.

Grey-Zone Project (WGNE-GASS)

- First workshop in December 2014
- LES, Mesoscale and Global models
- LAM & LES reproduce qualitatively the breaking of the Scu into the Cu very well
- The global models (despite a similar resolution) show a poorer performance
- Switching on/off th convection scheme a O(1km) resolution has different impac depending on model



(UK MetOffice)

Summary

- ✓ Developing seamless atmospheric parameterizations is challenging, in particular for convection.
- ✓ More "grey zone" problems as the integrated forecasts systems will be used at various resolutions
- ✓ Enhancing collaborations between NWP, Climat and process study communities around the development and validation of seamless physical parameterizations is beneficial (more expertise, diagnostics and resources)
- ✓ Multi-scales validation is useful to characterize the growth of model errors in climate models, BUT it remains difficult to make improvements in physical parameterizations reducing model errors in climate models.
- ✓ Research needed on the improvement of physical parameterizations. One way forward: synergy between explicit simulations on larger domain (LES, CSRM) and observations to develop better physically based parameterizations

cnrs dépasser les frontières

METEO FRANCE

Thank you
for your attention