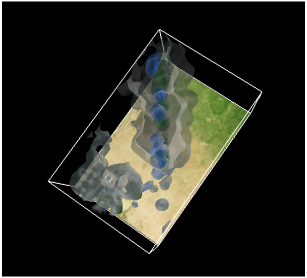
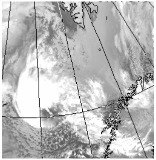
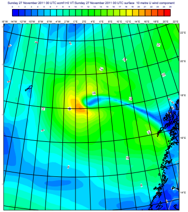
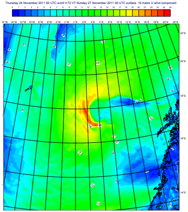
Towards very high resolution global Numerical Weather Prediction

Sylvie Malardel









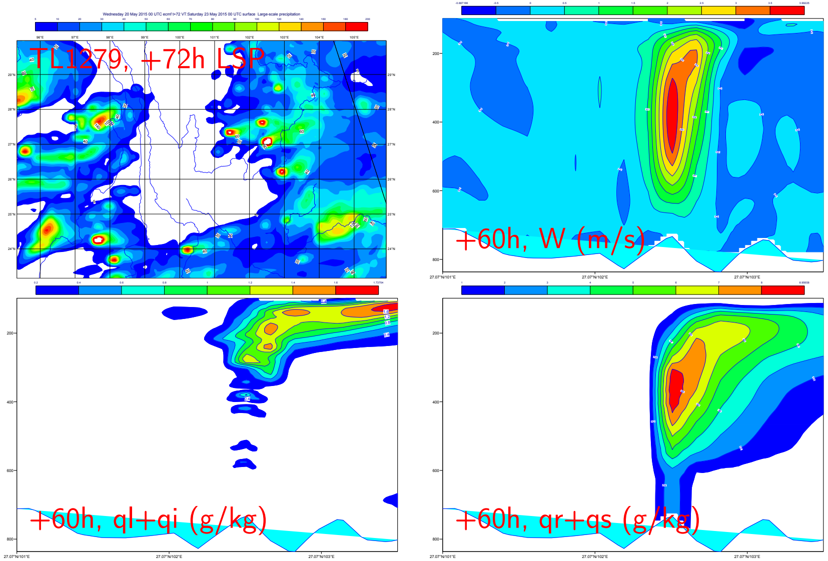
About physics-dynamics interaction...

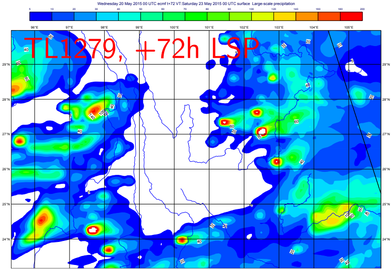
Transition from parametrized to resolved

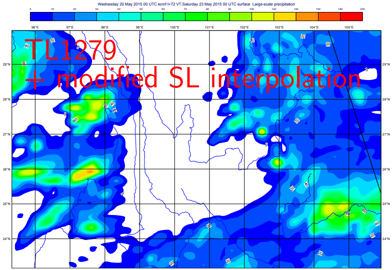
TCo1279 $\Rightarrow \delta x \simeq 9\ km$.
Hydrostatic IFS is able to simulate large vertical velocity.

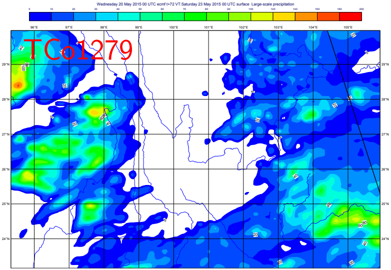
Do we start resolving deep convection at TCo1279 in the IFS?

Actually, we already do sometimes at $\Delta x = 16$ km. But it is by accident!



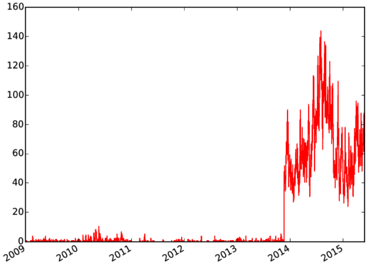

Wednesday 20 May 2015 00 UTC ecmf t+72 VT:Saturday 23 May 2015 00 UTC surface Large-scale precipitation
TL1279, +72h LSP


Wednesday 20 May 2015 00 UTC ecmf t+72 VT:Saturday 23 May 2015 00 UTC surface Large-scale precipitation
TL1279
+ modified SL interpolation


Wednesday 20 May 2015 00 UTC ecmf t+72 VT:Saturday 23 May 2015 00 UTC surface Large-scale precipitation
TCo1279

Climatology of Rainbombs in OPER

- based on the 3-hourly precipitation from OPER
- all ranges until T+144
- total number for each daily, 00 UTC, run
- rainbomb amplitude : xx=50 mm



Large jump on 20th of November 2013 (CY40R1)

$\Longrightarrow$ New convection scheme : Better daily cycle of deep convection $\rightarrow$ Onset of convection is delayed toward evening $\rightarrow$ Leave some potential for the "explicit" convection to start in very special conditions (low-level mainly orographic forcing, moist air) at some individual grid points $\rightarrow$ Grid point cumulonimbus are amplified by a weakness of the SL scheme.

Dynamics versus Physics

Dynamics

- The “resolved” part of the equations
- The “adiabatic” model
- The Meteorology as in “text books”....
- Dynamics = Mathematics and Numerics?

Physics

- The mean subgrid effects
- The diabatism
- The water phase transitions
- one more difficulty : feedback between subgrid vertical motion and water phase change
- Parametrisation = “Fudging” ?

Physics/Dynamics Coupling

Model = Dynamics+Physics

PDC14, PDC16

- Very First Physics/Dynamics Coupling workshop PDC14 in Dec. 2014, Mexico
- PDC16 (Sept) : PNNL, Richland campus, Washington, USA.

IFS primitive equations

$$
\begin{aligned}
\frac{D\vec{v}}{Dt} &= -\frac{1}{\rho}\nabla_h \pi - f\vec{k}\times\vec{v} + \vec{s}_v \\
\frac{DT}{Dt} &= \frac{R}{c_p}\frac{T}{\pi}\frac{D\pi}{Dt} + s_T - L\dot{q} + R \\
\frac{Dq}{Dt} &= s_q + \dot{q} \\
\frac{\partial \pi_s}{\partial t} &= \int_{bot}^{top} D
\end{aligned}
$$

$$
\begin{aligned}
\frac{Dw}{Dt} &<< [-\frac{1}{\rho}\frac{\partial p}{\partial z} - g] \Rightarrow w \text{ diagnostic} \\
p &= \pi \\
&\Rightarrow \text{adjustement to hydrostatic equilibrium} \\
&\text{faster than a time step}
\end{aligned}
$$

Splitting processes

The model is based on a single set of equations without any splitting of the processes.

But, these equations are split into dynamics and parametrisation 1, parametrisation 2, parametrisation 3 etc in order to be solved numerically.

- Recent observation spectra do not really show any clear scale separation (cf Anton's introduction): artificial scale separation between resolved versus parametrised (nightmare in "grey" zones)
- The time split and process split in numerical models are often based more on practical/numerical reasons than theoretical argumentation.

Physics/Dynamics interactions

- the Dynamics "forces" the Physics: for example adiabatic cooling $\Rightarrow$ condensation
- the Physics "forces" the Dynamics: for example latent heat release $\Rightarrow$ divergent circulations/vertical velocity ($\rightarrow$ adiabatic cooling)

Direct tendencies from physics

- diabatic heating (radiation)
- redistributes heat, moisture, momentum (but not mass)
- water phase changes (clouds and precipitation)

Indirect effects

- generate large/mesoscale scale circulations,
- trigger waves (Rossby, Kelvin, gravity)

For example: One time step in the IFS

Grid Point Space

- Compute the adiabatic Source terms (RHS) of the equations (explicitly)
- Compute the evolution due to the resolved motion (advections)
- $\Rightarrow$ an "adiabatic" and explicit guess of the next time step

Compute the evolution due to a series of physical parametrisations from the updated explicit guess (sequential physics)

Spectral Space

- Semi-Implicit Correction (for linearized fast term of the dynamics)
- "Numerical" diffusion

Physics "along" a trajectory

In the IFS, the coupling between the dynamics and the physics and between the parametrisation is mostly sequential.
Some physical tendencies are "averaged" along the trajectory of the semi-Lagrangian scheme.

$$
\begin{aligned}
\psi_A(t^+) \;=\; & \psi_D(t) + (Dyn(\psi_D(t), \psi_A(t)))\,\Delta t \\
& + \left(\frac{1}{2}\left[Phy_{rad,conv,cld^\diamond}(\psi_D(t)) + Phy_{rad,conv,cld}(\psi_A(t^*)) \right] \right) \Delta t \\
& + \left(Phy_{diff,gwd,cld^\diamond}(\psi_A(t^*)) \right) \Delta t + Sl_{cor}(\psi_A(t^*), t^+)
\end{aligned}
$$

where $\psi_A(t^*)$ is the current guess after the previous processes treated in the time step.

($\diamond$) in the cloud scheme, T and q_v tendencies are averaged but q_l, q_i, q_r and q_s are not.

Sequential Coupling

Sequential : order of processes is important

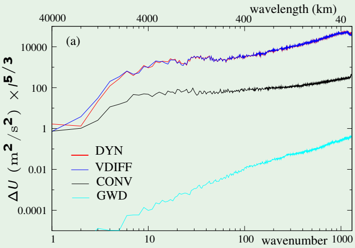
For example, if the radiation "sees" the cloud before rain forms, it "sees" too much cloud (radiation should not be in between the cloud scheme and the microphysics)

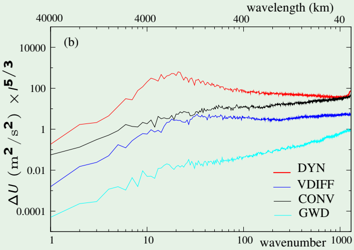
The sequence in the IFS: from Slow to Fast

1. Radiation
2. Gravity Wave Drag (Subgrid Orography)
3. Vertical Diffusion (Boundary Layer)
4. First call of Microphysics and Cloud Scheme
5. Convection (Deep and Shallow)
6. Microphysics and Cloud Scheme

Diagnostic of spectral variance

Physics tendencies: U at 950 hPa and 200 hPa





The Grey zone of convection

As the model resolution increases, the gap between the scales resolved by the model and the scale of convective clouds is vanishing...

- resolution is too low to realistically properly resolve convective updrafts/downdrafts (convection at grid-scale with large numerical errors)
- resolution is too high for the key hypotheses of most deep convection schemes to be valid

Hypotheses to revisit

- Statistical approach
- Equilibrium hypothesis (as the time step becomes small)
- No net mass transport in a grid box: updraft and downdraft cancel in a grid box ($\overline{w} \simeq 0$).

The basic mechanism of explicit moist convection: physics/dynamics coupling

Convective cloud for dummies

[warming - positive buoyancy- ascent - adiabatic cooling] - condensation/ latent heat release - warming - positive buoyancy - ascent - adiabatic cooling - condensation/ latent heat release - warming - positive buoyancy - ascent etc....

Explicit (non-parametrised) convection

- adiabatic cooling in the dynamics "forces" the condensation scheme in the physics
- warming by latent heat release "forces" the vertical motion (diagnostic or prognostic) in the dynamics
- $\rightarrow$ the process of non-parametrised moist convection exists thanks to an interaction between physics and dynamics

Parametrised convection

When the resolution is not fine enough to realistically resolve the convective processes, we have to parametrise the convection processes, i.e. compute the "resolved scales" effect of these processes on the pronostic variables.

Common method

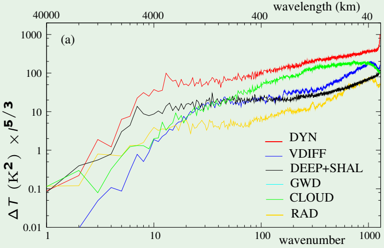
To calculate the collective (statistical) effect of an ensemble of convective clouds (in practice: one generic cloud) in a model column as a function of the model grid-scale prognostic variables.

What for?

- Remove convective instability by subgrid-scale buoyancy driven transport and condensation (and their interaction)
- Produce subgrid-scale precipitation and cloud cover (radiation)
- maintain a realistic climate (for example: correct radiative/convective equilibrium)
- maintain a realistic variability across scales

Diagnostic of spectral variance

Physics tendencies: T at 700 hPa



The Grey zone of convection

Attempts to generalize convection schemes

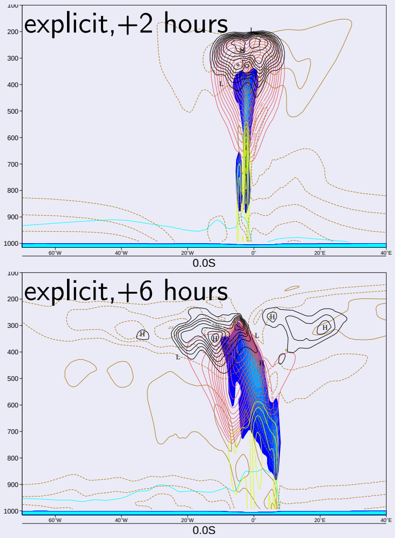
- from the Limited Area Community: L. Gerard (2007)
- Arakawa and Wu (2013), Wu and Arakawa (2014)

Get a better understanding of the problem in the IFS

- academic 3D studies
- test cases at very high resolution

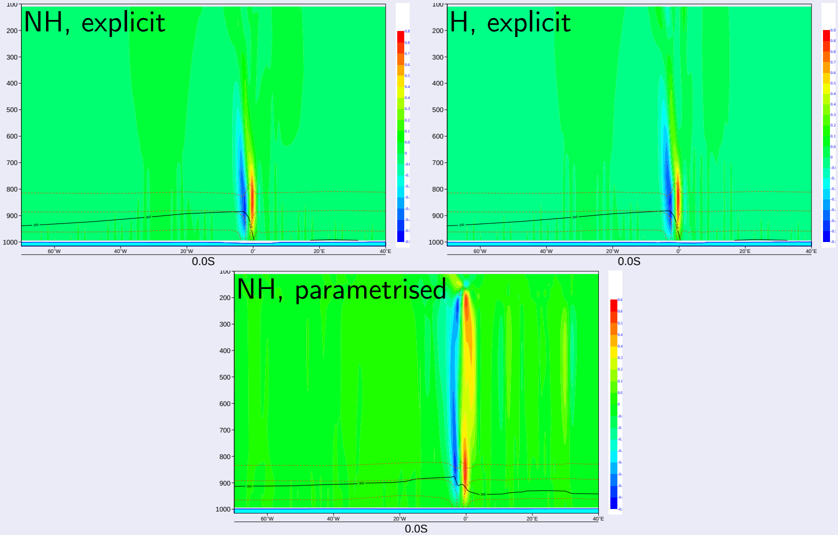
Academic squall line

NH without and with convection scheme at 5km resolution



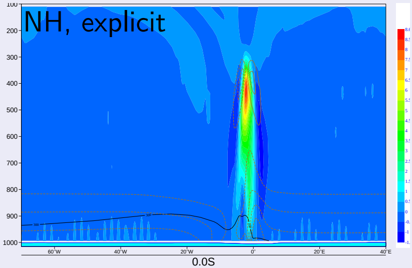
Academic squall line

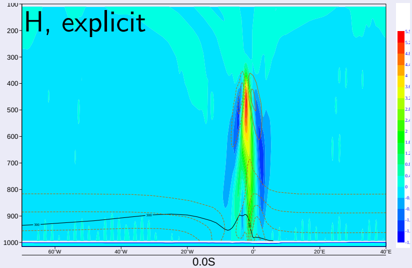
Vertical velocity after 10 min

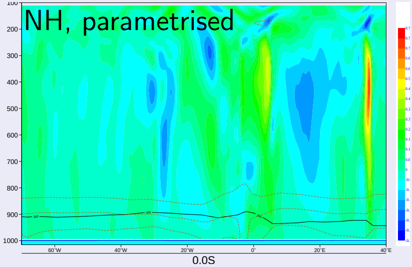


Academic squall line

Vertical velocity after 60 min



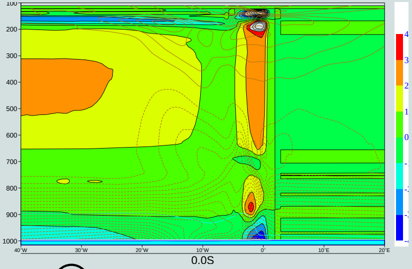




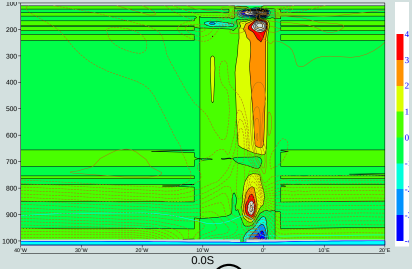
Playing with the convection scheme

- convective tendencies/5 : ☹
- + no convective tendencies at the edge of the cold pool: ☹

Convective tendencies after 30 min



⟹ ☹

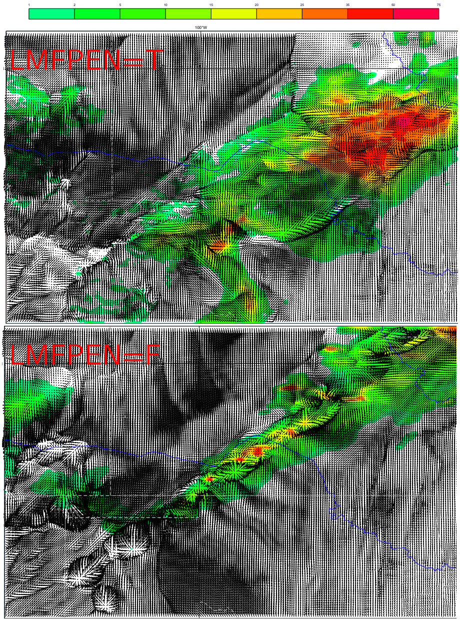


⟹ ☺

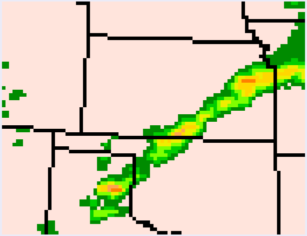
VORTEX2: T3999 simulation from 15/05/2009 12UTC

6h accumulated precipitation and wind

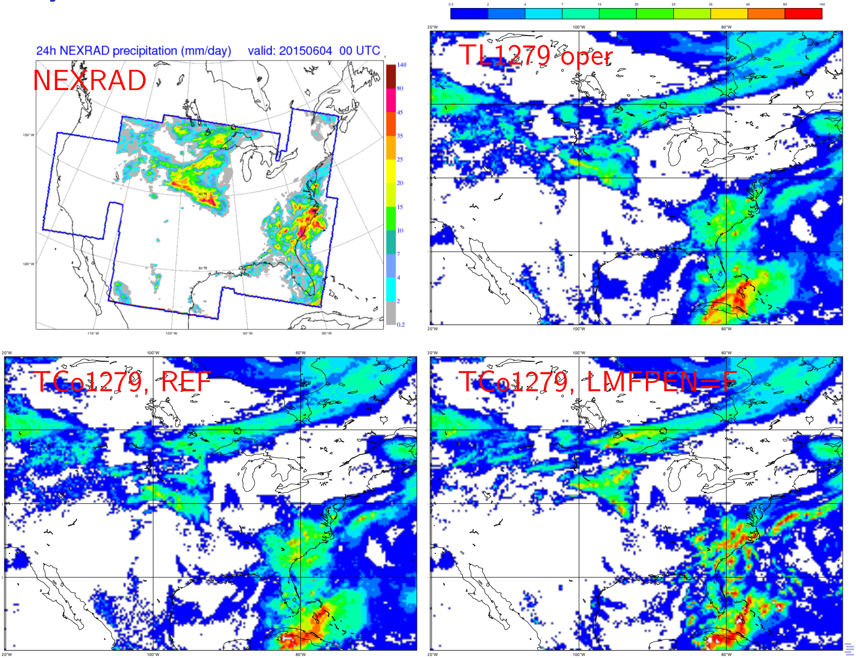
⇒



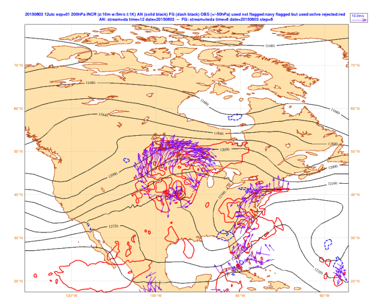
Squall line during VORTEX2 May 2009



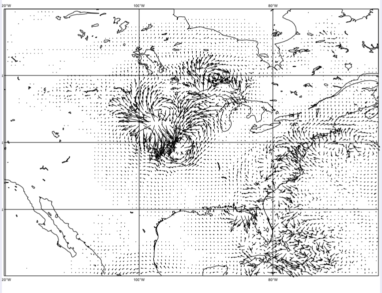
Grey zone of convection: MCs over U.S.



MCs case : 3 June 2015, 00UTC, wind at 200hPa



IFS increment at 3 June 2015, 00UTC +12



200hPa Wind difference between TCo1279 with LMFPEN=F and TCo1279 REF

On going work

- Very high resolution (about 5 km) climate run $\Rightarrow$ PRIMAVERA Project
- Improve the coupling between dynamics and convection parametrisation: compensating subsidence by the dynamics