Strong coupling between physics and dynamics

The end of the 1D model?

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Model = Physics + Dynamics + Coupling

This seminar is mostly about **Physics** (parametrisations)

$\Downarrow$

But the Physics has got a ”better half”: **the Dynamics**.

$\Downarrow$

Physics and Dynamics complement each other and the full model is the result of the **coupling** of both halves.

So what is the difference between Physics and Dynamics?

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Physics versus Dynamics

Dynamics	Physics
Terms of the equations expressed only with fields at ”resolved” scales	The rest !
adiabatic (but not dry)	diabatic (interactions with space and Earth), water phase change and water micro-physics, effet of subgrid non-linear processes on the resolved scales.
3D global solver (i.e. solving for all the processes and the whole domain together)	collection of simplified, usually 0D or 1D, mini solvers, each one specialised in the treatment of a particular process.

Physics-Dynamics Coupling

$\Rightarrow$ P+D = nothing missing and no double counting

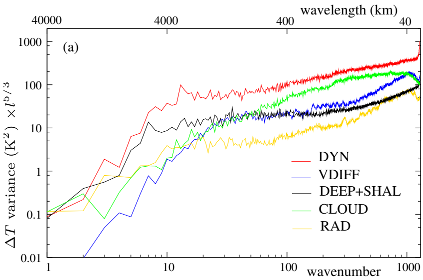
$\Rightarrow$ Be careful that the dynamics is not taking over processes which are not yet well resolved as large errors at the truncation scale may propagate upscale.

$\Rightarrow$ Holy grail: seamless transition from physics (parametrised) to dynamics (resolved) when the resolution changes

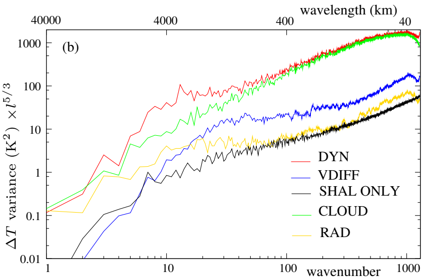
$\Rightarrow$ Consistency between hypotheses made in the Physics and in the Dynamics (and the devil is in the details)...

Physics directly modifies all resolved scales

Physics tendency spectra at 700 hPa (TC1279)



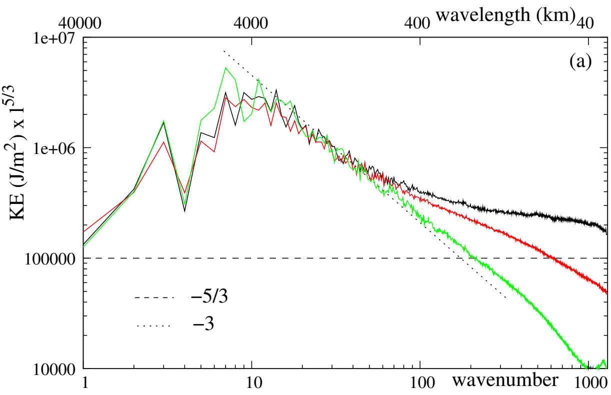
With deep convection scheme on



With deep convection scheme off

(Malardel&Wedi, 2016)

Physics annihilates the natural energy cascades



adiabatic with orography

full model

adiabatic, no orography

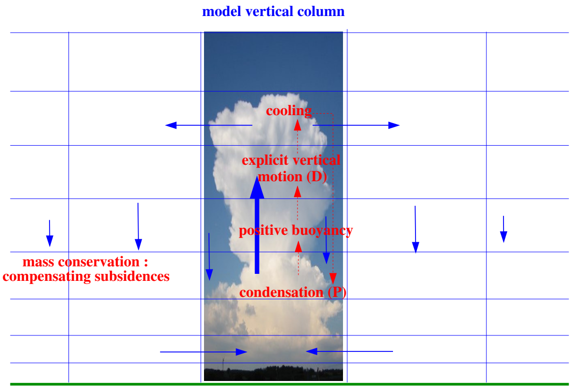
(Malardel&Wedi, 2016)

Strong coupling : Definition

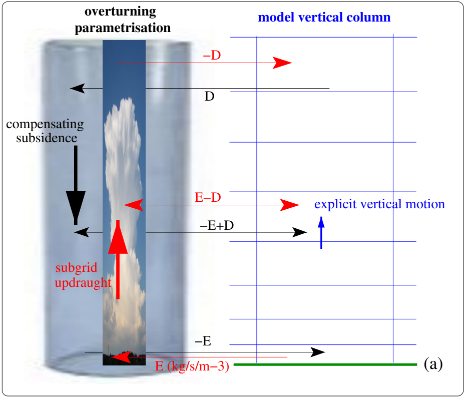
1. Only one part of a process is parametrised, the complementary part is resolved by the dynamical core (and vice versa).

2. The parametrised part can't be tested with a 1D (column) model because the dynamics can't be considered as a "pre-computed forcing" of the parametrisation any more. In this case, the modeling of the full process is done at each time step together by both halves.

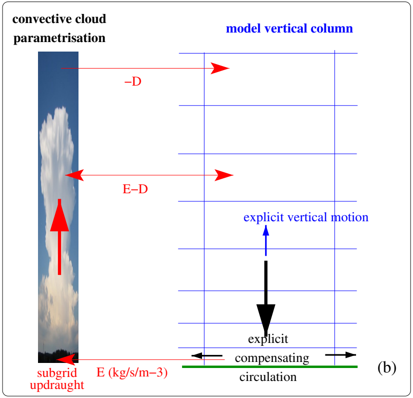
Explicit convection = strong coupling between vertical advection (D) and condensation (P)



Compensating subsidence (P or D) and convective updraft (P) - Malardel&Bechtold, 2019



Current convection scheme



Updraft parametrisation

Compensating subsidence (D) and convective updraft (P) - Malardel&Bechtold, 2019

Equation for a conservative variable ψ

$$\frac{\partial(\overline{\rho}\,\overline{\psi})}{\partial t} = -\vec{\nabla}_h.(\overline{\rho}\,\overline{\psi}\,\vec{\overline{u}}_h) - \frac{\partial(\overline{\rho}\,\overline{\psi}\,\overline{w})}{\partial z} - \frac{\partial[M(\psi_u - \overline{\psi})]}{\partial z}\,.$$

$$\Longrightarrow \quad \frac{\partial(\overline{\rho}\,\overline{\psi})}{\partial t} = -\vec{\nabla}_h.(\overline{\rho}\,\overline{\psi}\,\vec{\overline{u}}_h) - \frac{\partial(\overline{\rho}\,\overline{\psi}\,\overline{w})}{\partial z} - \frac{\partial(M\psi^u)}{\partial z}$$

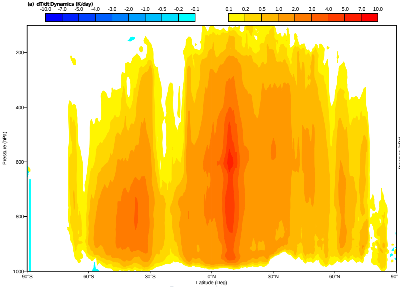
Continuity equation ($\psi = 1$)

$$\frac{\partial(\overline{\rho})}{\partial t} = -\vec{\nabla}_h.(\overline{\rho}\,\overline{\vec{u_h}}) - \frac{\partial(\overline{\rho}\,\overline{w})}{\partial z}$$

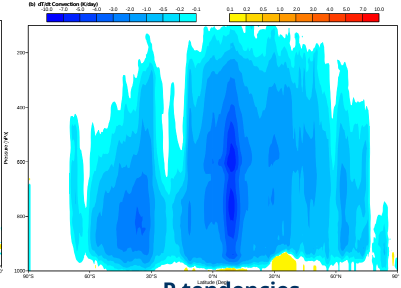
$$\Longrightarrow \quad \frac{\partial\overline{\rho}}{\partial t} = -\vec{\nabla}_h.(\overline{\rho}\,\overline{\vec{u_h}}) - \frac{\partial(\overline{\rho}\,\overline{w})}{\partial z} - \frac{\partial M}{\partial z}$$

Compensating subsidence (D) and convective updraft (P) - Malardel&Bechtold, 2019

Temperature tendency difference between the new and the current scheme



D tendencies



P tendencies

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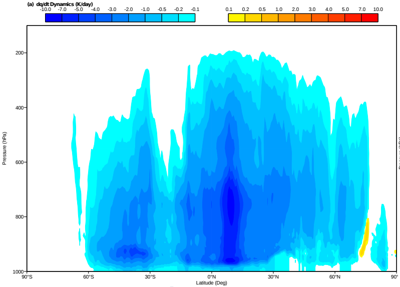
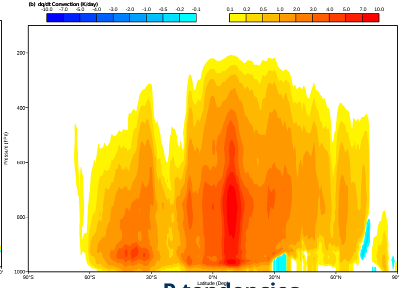
Compensating subsidence (D) and convective updraft (P) - Malardel&Bechtold, 2019

Humidity tendency difference between the new and the current scheme



D tendencies



P tendencies

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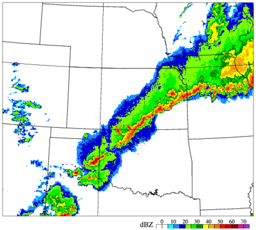
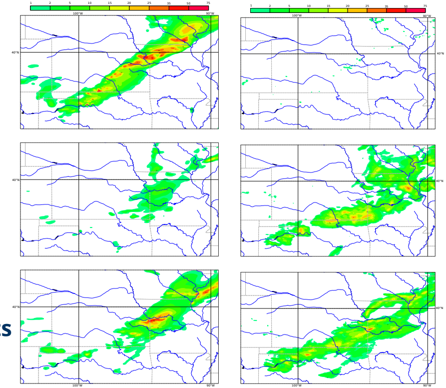
Compensating subsidence (D) and convective updraft (P) - Malardel&Bechtold, 2019

"VORTEX2" squall line, 16 May 2009



RADAR

IFS +48h forecasts TCo1999 (5km)



NO scheme

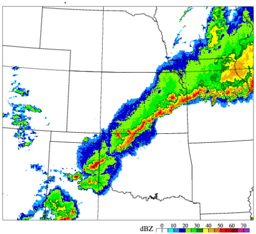
CURRENT scheme

NEW scheme

"resolved" precipitation **"convective" precipitation**

Compensating subsidence (D) and convective updraft (P) - Malardel&Bechtold, 2019

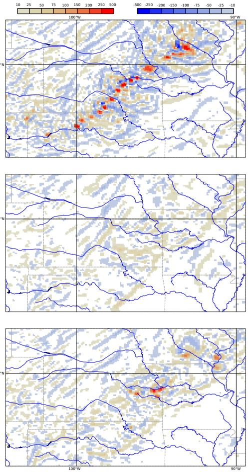
”VORTEX2” squall line, 16 May 2009



RADAR

IFS +48h forecasts

divergence at 250 hPa



NO scheme

CURRENT scheme

NEW scheme

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Compensating subsidence (D) and convective updraft (P) - Malardel&Bechtold, 2019

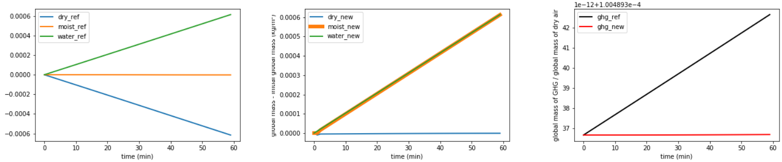
- At low resolutions, the new ”strongly coupled” deep convection parametrisation gives very similar results compared to the current one: the dynamics is properly taking over the compensating subsidence.
- It is numerically stable. The conservation laws are only marginally worse than with the current scheme.
- In the grey zone of deep convection, the new scheme leaves a bit more room to the dynamics.
- but other hypotheses in the design of the mass flux equation may have to be further revisited to really allow a shared work between physics and dynamics in the grey zone.

PDC and subgrid change of water mass

Continuity equation

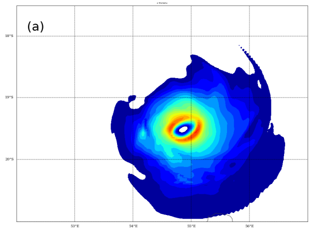
$$
\begin{aligned}
\frac{\partial(\overline{\rho})}{\partial t} &= -\vec{\nabla}_h.(\overline{\rho}\,\overline{\vec{u_h}}) - \frac{\partial(\overline{\rho}\,\overline{w})}{\partial z} \\
\Longrightarrow \quad \frac{\partial \overline{\rho}}{\partial t} &= -\vec{\nabla}_h.(\overline{\rho}\,\overline{\vec{u_h}}) - \frac{\partial(\overline{\rho}\,\overline{w})}{\partial z} + S_w
\end{aligned}
$$

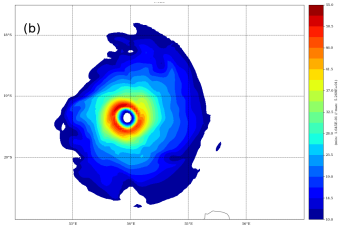
where S_w is the subgrid source/sink of water mass in a grid box (turbulent subgrid flux of water species, precipitation).

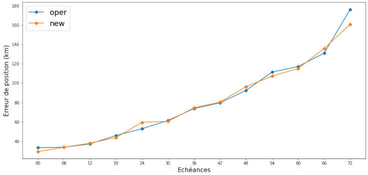


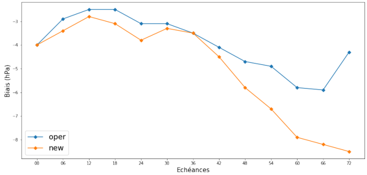
PDC and subgrid change of water mass

Impact on TC forecast in AROME ($\Delta x = 2.5$ km)









Conclusion

- As the resolution increases, the hypotheses and the concept behind the design of parametrisations may have to be revisited.
- Strong mass coupling between the spectral SISL dynamics of IFS and AROME and the physics is stable and the dynamics is able to close the continuity equation (hydrostatic pressure) if fed with mass tendencies from the physics.
- In case of such a strong coupling,
  - The parametrisation can't work "on its own": the parametrisation can not be tested with a 1D model.
  - The advection is directly coupled to the physics. For example: offline diagnostics of ω, $\dot{\eta}$ or of advection tendencies need the mass tendencies computed in the physics .
  - All advected variable (D) must also be transported by the convective mass flux (P) and vice versa.
  - **Need of a strong coupling between the development teams in order to ensure the consistency of the code developments in the P and in the D parts of the same process..**

Messages to think about

- Design new full models ”from scratch” rather than design new dynamical cores on one side and physics on the other side?
- Keep physics as a full package or use each parametrisation where it is the most relevant along a time step?
- Think how we could include part of the current physics in the dynamical 3D solver (for example condensation)?