Coupling the parametrised deep convection (P) with the resolved flow (D) in the IFS via the divergence of mass flux (C)

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Title for PDC16:

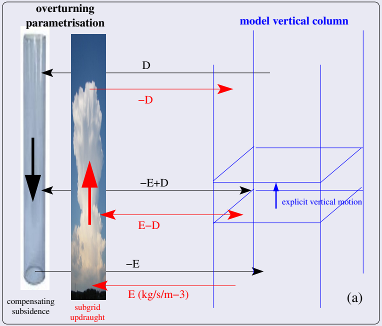
Coupling the physics to the continuity equation in the ECMWF model: Work in progress...

PDC18

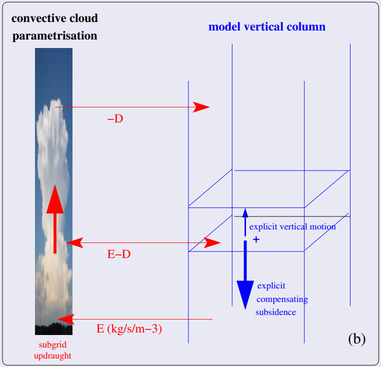
We've made some progress ☺

Objective: to hand over the compensating subsidence associated with subgrid convective updraught to the dynamics (Küll, Gassmann and Bott, 2007)

Traditional formulation



New formulation



Simple formalism for conservation equations

Mass Flux: $M = \rho\sigma_u w_u$

Traditional formulation

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

$$\frac{\partial(\overline{\rho})}{\partial t} = -\vec{\nabla}.(\overline{\rho}\overline{\vec{u}})$$

New formulation

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

$$\frac{\partial\overline{\rho}}{\partial t} = -\vec{\nabla}.(\overline{\rho}\overline{\vec{u}}) - \frac{\partial M}{\partial z}$$

$\sigma_u << 1 \Rightarrow \psi_e = \overline{\psi}$

IFS formalism: Semi-Lagrangian advection in advective form

- Semi-Lagrangian advection, advective form (i.e. subtract continuity eq. from flux form eq. for ψ)
- Hybrid mass based vertical coordinate η
- Hydrostatic pressure $\pi = A_\eta + B_\eta \pi_s$

Traditional formulation

$$\frac{D\overline{\psi}}{Dt} = g\frac{\partial[M(\psi_u - \overline{\psi})]}{\partial\pi} + S_{\mathcal{D}} + S_\varphi$$

New formulation

$$\frac{D\overline{\psi}}{Dt} = g\frac{\partial(M\psi_u)}{\partial\pi} - g\overline{\psi}\frac{\partial M}{\partial\pi} + S_{\mathcal{D}} + S_\varphi$$

with

$$\frac{D\overline{\psi}}{Dt} = \frac{\partial\overline{\psi}}{\partial t} + \overline{\vec{u}_h}\vec{\nabla}_\eta\overline{\psi} + \overline{\dot{\eta}}\frac{\partial\overline{\psi}}{\partial\eta}$$

IFS formalism: mass based vertical coordinate η

3D continuity equation in $\eta - coordinates$

$$\frac{\partial(\frac{\partial\pi}{\partial\eta})}{\partial t} = -\vec{\nabla}_{|\eta}.(\frac{\partial\pi}{\partial\eta}\,\overrightarrow{\vec{u_h}}) - \frac{\partial(\dot{\eta}\frac{\partial\pi}{\partial\eta})}{\partial\eta} + g\frac{\partial M}{\partial\pi}\,\frac{\partial\pi}{\partial\eta}$$

In practice, in IFS:

$$\frac{\partial\pi_s}{\partial t} = -\int_{\eta=0}^{\eta=1}\vec{\nabla}_{|\eta}.(\frac{\partial\pi}{\partial\eta}\,\overrightarrow{\vec{u_h}})d\eta + \underbrace{\int_{\pi=0}^{\pi=\pi_s} g\frac{\partial M}{\partial\pi}\,d\pi}_{=0}$$

$$\omega = \frac{D\pi}{Dt} = -\left[\int_{\eta=0}^{\eta}(\vec{\nabla}_{|\eta}.(\frac{\partial\pi}{\partial\eta}\,\overrightarrow{\vec{u_h}})d\eta\right] + \overrightarrow{\vec{u_h}}.\vec{\nabla}_{|\eta}\pi + \int_{\pi=0}^{\pi} g\frac{\partial M}{\partial\pi}\,d\pi$$

$$\dot{\eta}\frac{\partial\pi}{\partial\eta} = -\frac{\partial\pi}{\partial t} - \left[\int_{\eta=0}^{\eta}\vec{\nabla}_{\eta}.(\frac{\partial\pi}{\partial\eta}\,\overrightarrow{\vec{u_h}})d\eta\right] + \int_{\pi=0}^{\pi} g\frac{\partial M}{\partial\pi}\,d\pi$$

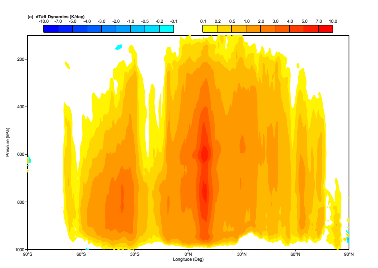
Hydrostatic versus NH-IFS

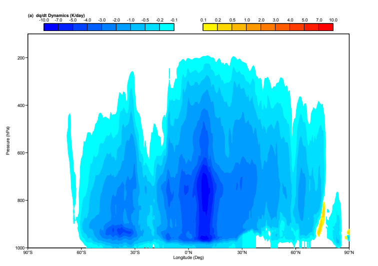
All the testing has been done in the hydrostatic IFS.

But the NH-IFS (ST) is also based on the same hybrid mass based vertical coordinate (hybrid hydrostatic pressure, Laprise, 1992). The mass coupling between with the physics and the dynamics should be the same in the H and NH case.
But, what about the coupling of the extra NH prognostic variables with the convection scheme (as all prognostic variables, they will be advected by the compensating subsidences in the dynamics, but should these variables be advected by the mass flux scheme in the physics then!?)

Basic Validation

Δ Dyn. Tend. (New-Trad)

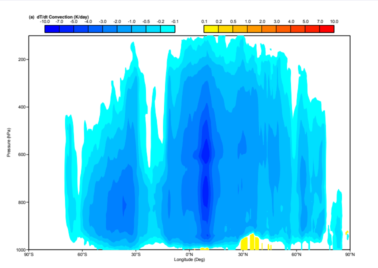


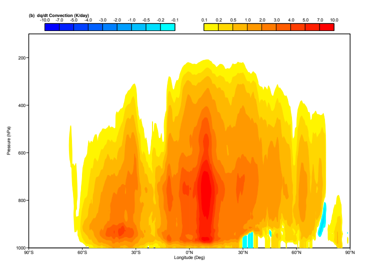


T

q_v

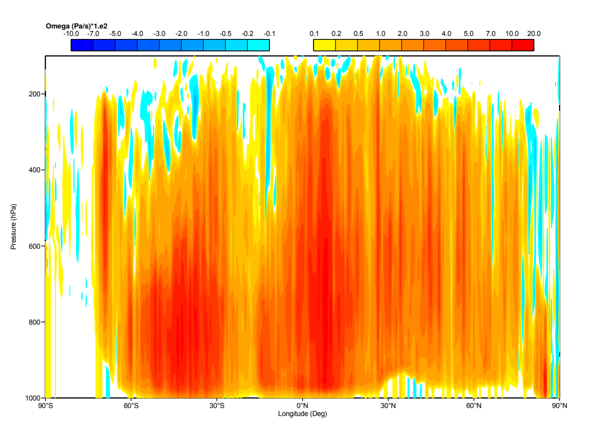
Δ Conv. Tend. (New-Trad)





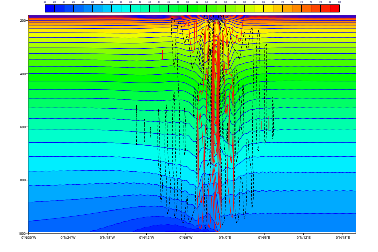
Basic Validation (TCo319, ie $\simeq$ 36 km)

Δ ω (New-Trad)



Academic squall line: θ and w after 1h

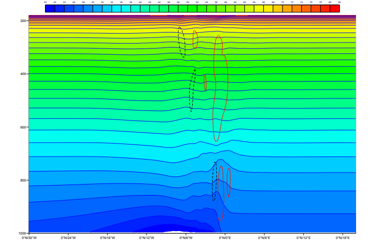
Convection permitting



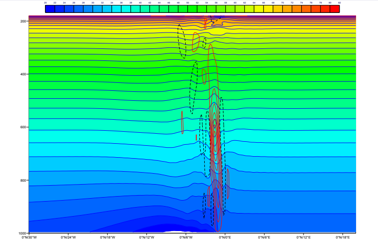
Small Planet ($f = 0$)

Squall Line from Weisman et al, 88
Humidity reduced by 20% outside the cold pool
Resolution about 2.5 km (TCo319, $\gamma = 12$)

Traditional scheme

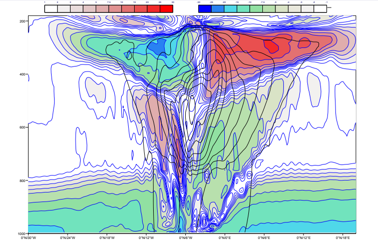


New scheme



Academic squall line: U and hydrometeors after 4 h

Convection permitting

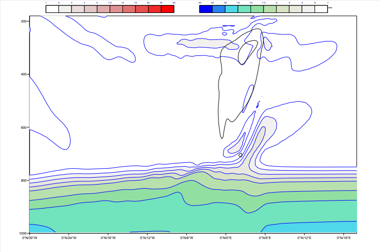


Small Planet

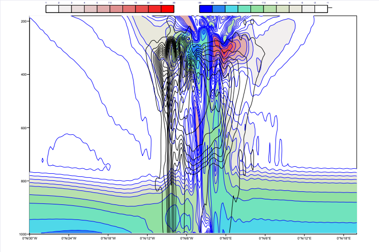
Resolution about 2.5 km

(TCo319, $\gamma = 12$)

Traditional scheme

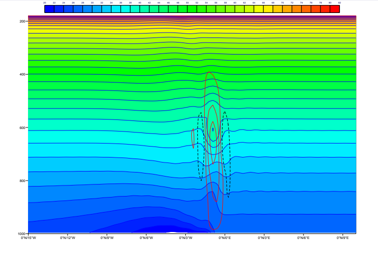


New scheme



Academic squall line: θ and w after 1h

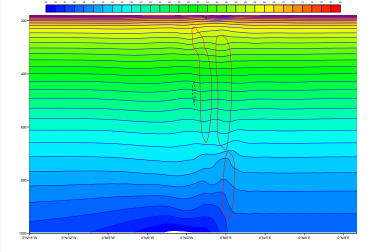
Convection permitting



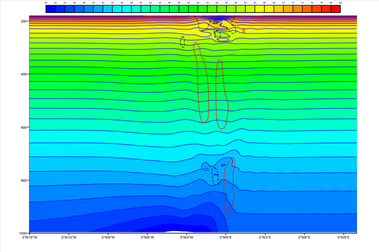
Small Planet

Resolution about 5 km (TCo319, $\gamma = 6$)

Traditional scheme

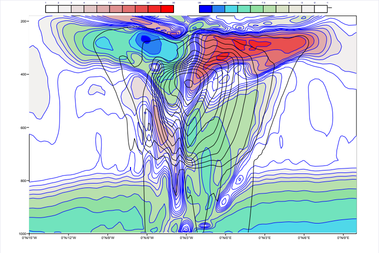


New scheme



Academic squall line: *U* and hydrometeors after 4 h

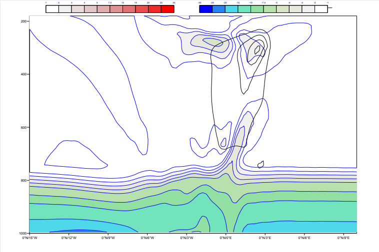
Convection permitting



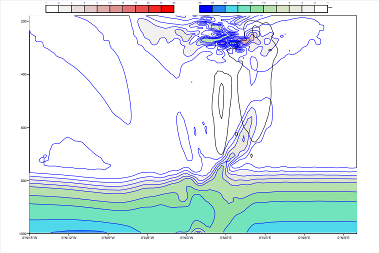
Small Planet

Resolution about 5 km (TCo319, $\gamma = 6$)

Traditional scheme

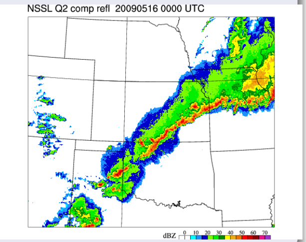


New scheme



Squall line during VORTEX2 (2009/05/16 00UTC)

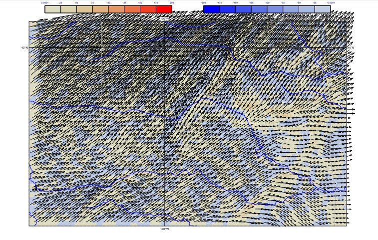
Radar at 00UTC



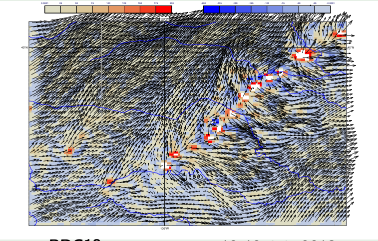
IFS

TCo1999 ($\simeq$ 5 km) +48h FC Wind + Hor.Div. (10^5 s^{-1}) at 250 hPa

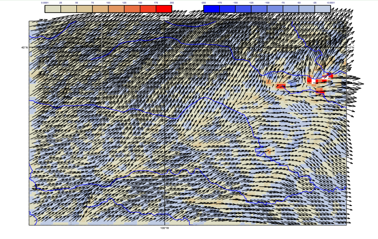
Traditional scheme



Convection permitting

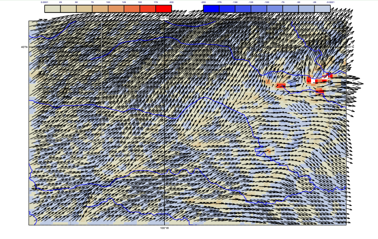


New scheme

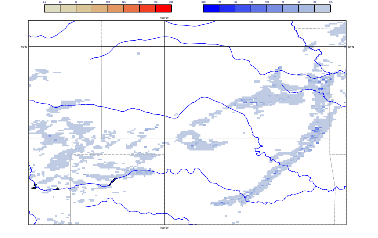


Squall line during VORTEX2 (2009/05/16 00UTC)

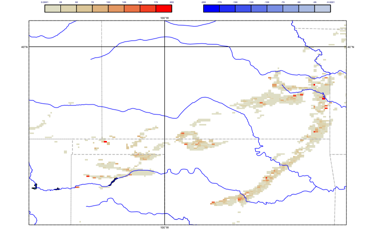
New scheme: Wind+Hor.Div. at 250 hPa



$\frac{1}{\rho}\frac{\partial M}{\partial z}$ $(10^5\ s^{-1})$ near surface

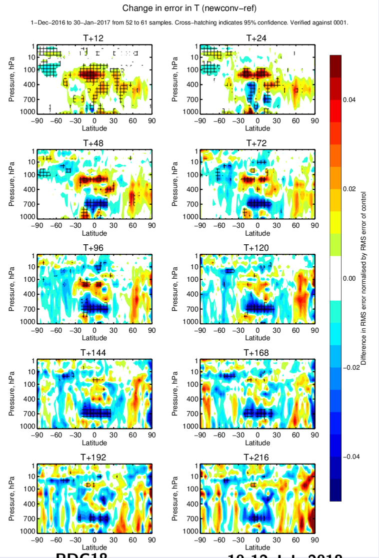


$\frac{1}{\rho}\frac{\partial M}{\partial z}$ $(10^5\ s^{-1})$ at 250 hPa

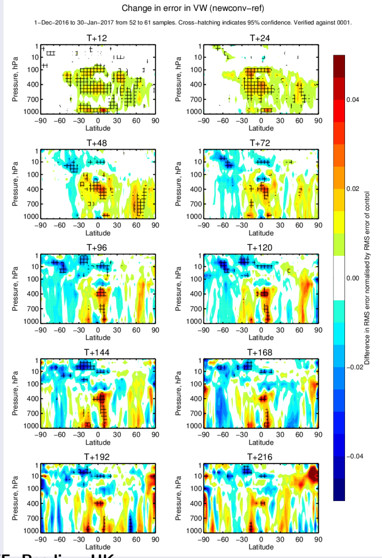


Large scale scores: Dec. 2016-Jan 2017, FC at TCo1279

RMSE - Temperature

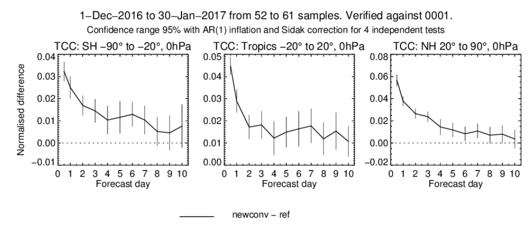


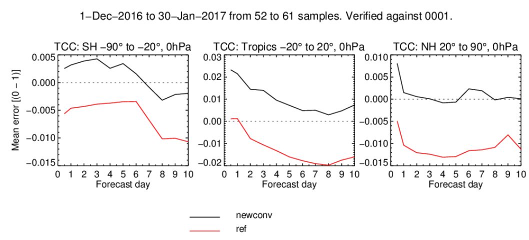
RMSE - Wind



Large scale scores: Dec. 2016-Jan 2017, FC at TCo1279

Total Cloud Cover





Summary

With the new scheme, the parametrisation produces only half of the convective overturning process, the coupling and the consistency with what is done in the dynamics is essential to get the correct convective overturning.

- separate implicit solver, different vertical discretisation, different variables... $\Rightarrow$ conservation degraded by about 0.1%
- all prognostic variables are affected by the compensating subsidence advection in the new scheme. Should all the prognostic variables be affected by the updraft mass flux in the physics (still unclear for rain/snow)?
- large sensitivity to the coupling with the "resolved' cloud scheme
- the new scheme can't be tested with a single column model
- classical diagnostic which may be recomputed offline need an input from physics (for example ω needs $\partial(M)/\partial z$)
- Physics team and Dynamics team need to work together...

Summary

Any future for such a new scheme?

- The current implementation is stable and "converge" towards the fully parametrised solution at low resolution
- At the highest resolutions which are easily accessible to test real cases (TCo1999, ie about 5 km), we could not find any obvious amelioration
- Academic test cases on the small planet indicate some positive effect at higher resolution (2.5km), but then, convection permitting mode is often already used for such resolutions,
- Improving the coupling with the other parametrisations and with the numerics may show more benefits at 5 km resolution.