Improving the mass conservation in the prediction of the ECMWF model

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Spanish Meteorological Agency

Project 4: Formation in technical used in the dynamic of the numerical weather models.

Outline:

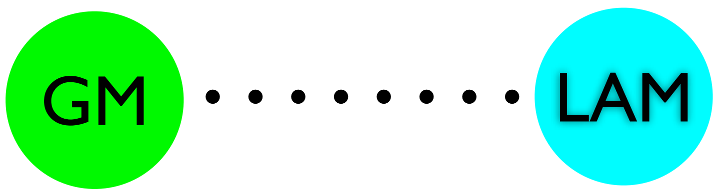
- ***Motivation***
- Previous work.
  - *Grid Points Corrections.*
- Continuity equation in the CY38R2.
- Kinetic Energy Spectrum.
  - *Comparative between CY37R2 and 38R2.*
- Ozone equation.
  - *Quasi-monotone interpolation.*

Motivation

Objective:

- Implementation of new numerical scheme for the semi-Lagrangian advection with the purpose of improving the mass conservation of dry air and the remaining constituents of the atmosphere: ozone, water vapor, NO_x.

- The dynamic kernel of the global model, IFS (ECMWF), and the limited area model, HARMONIE (HIRLAM Consortium), is the same. Thus, initially carried out the modifications in the IFS, where the total mass should be conserved for later transferring the improvements made to HARMONIE LAM.



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Previous work

- Modifications in the semi-Lagrangian trajectory (SLt). (SETTLS algorithm).

$$\mathbf{r}_A^{t+\Delta t} = \mathbf{r}_D^t + \frac{\Delta t}{2}([2\mathbf{v}^t - \mathbf{v}^{t-\Delta t}]_D + \mathbf{v}_A^t)$$

- Modifications in the continuity equation. Semi-Lagrangian semi-implicit scheme (SLSI).

$$Lnp_{sup}^{+} = \sum_{k=1}^{NLEV} \Delta B_j (Lnp_{sup}^{-} + \Delta t\{\frac{\partial Lnp_{sup}}{\partial t} + v_k \nabla (Lnp_{sup})\}^{-}) + \frac{\beta \Delta t}{p_{sup}^{ref}} \Delta_{tt} \{\sum_{j=1}^{NLEV} (\Delta p_j^{ref} D_j)\}$$

- Non-interpolating SL scheme for continuity equation.

(Horizontal $\longrightarrow$ non-interpolating $\longrightarrow$ 2D fields).

(Vertical $\longrightarrow$ lineal interpolation $\longrightarrow$ 3D fields).

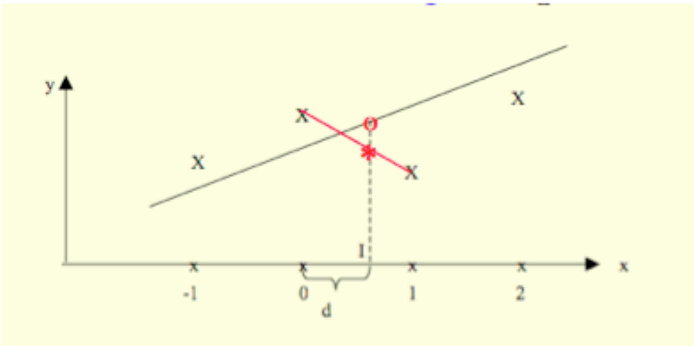
Previous work

$$\mathbf{r}_A^{t+\Delta t} = \mathbf{r}_D^t + \frac{\Delta t}{2}([2\mathbf{v}^t - \mathbf{v}^{t-\Delta t}]_D + \mathbf{v}_A^t)$$

A A

SLt (SETTLS algorithm)

A) Smooth interpolation at Departure and Arrived points of the SL trajectory.



Previous work

Continuity equation (SLSI scheme)

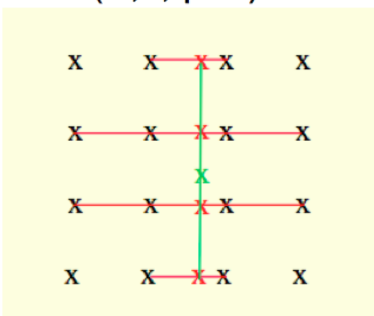
$$Lnp^{+}_{sup} = \sum_{k=1}^{NLEV} \Delta B_j (Lnp^{-}_{sup} + \Delta t\{\frac{\partial Lnp_{sup}}{\partial t} + v_k \nabla (Lnp_{sup})\}^{-}) + \frac{\beta \Delta t}{p^{ref}_{sup}} \Delta_{tt}\{\sum_{j=1}^{NLEV} (\Delta p_j^{ref} D_j)\}$$

B C D

B) Split this term in two (isotherm atmosphere + correction of this).

C) Cubic - linear interpolation at D point of SLt for this term.

(λ,θ,η=91)

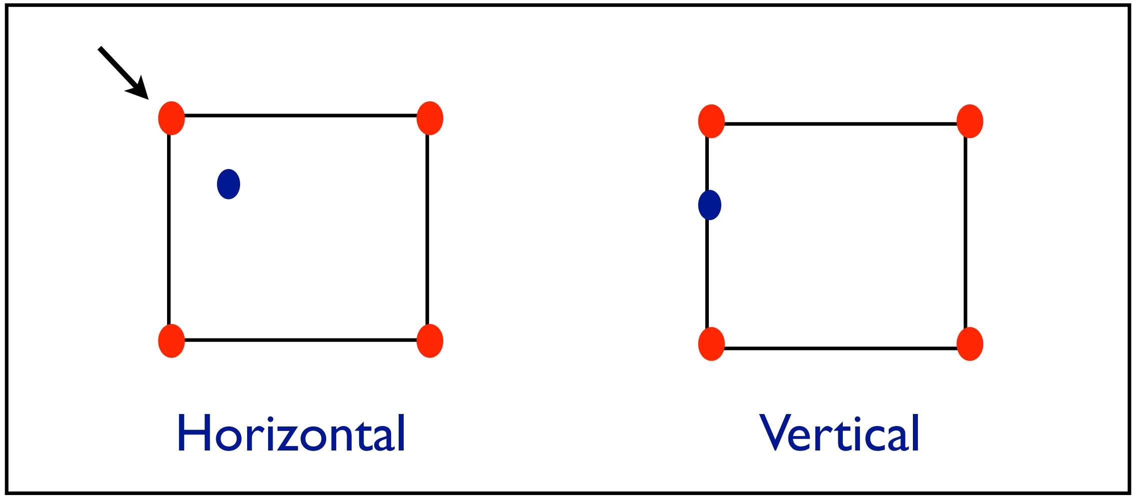


D) Quasi-tri-cubic interpolation

Previous work

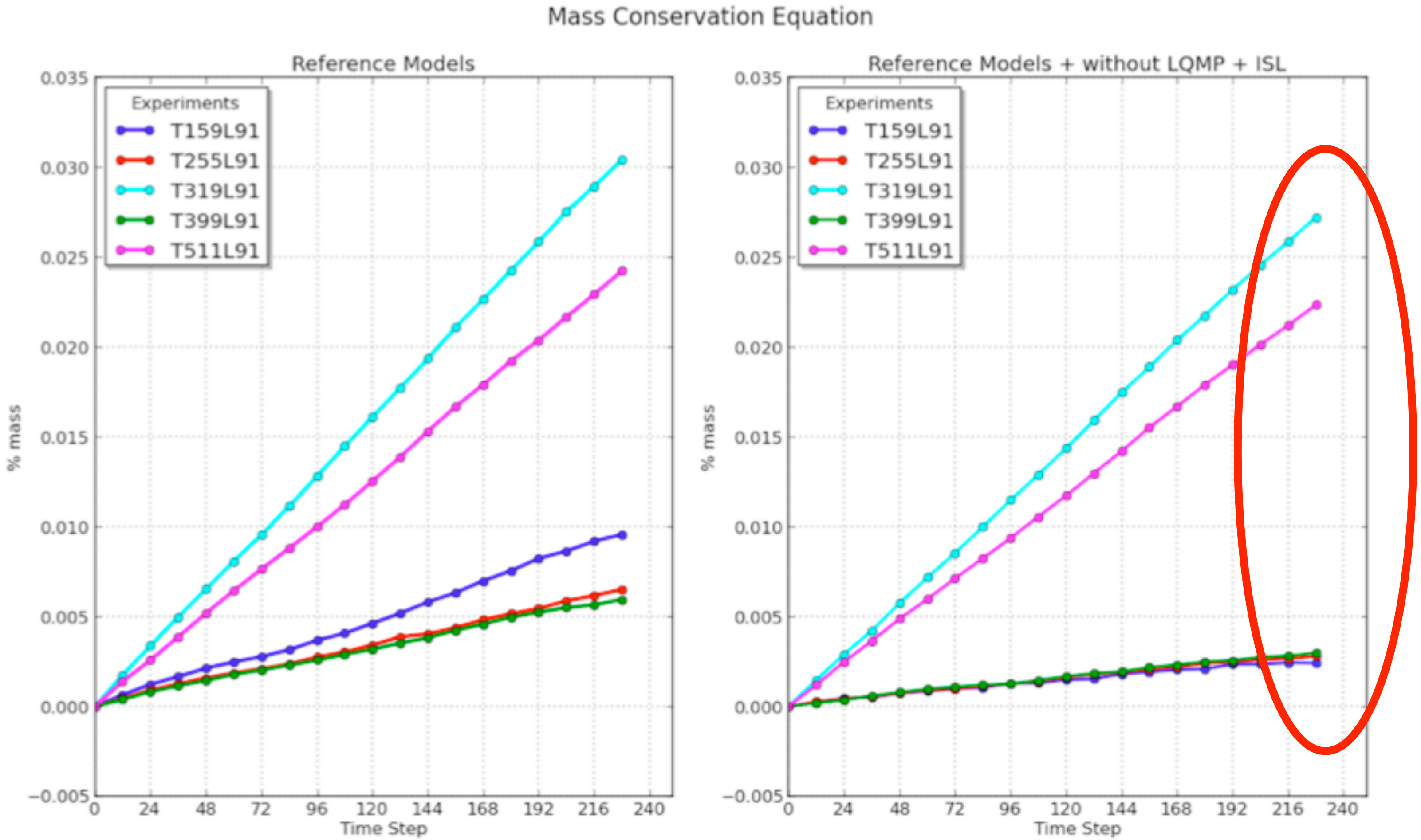
- Non-interpolating SL scheme for continuity equation.
  (Horizontal ⟶ non-interpolating ⟶ 2D fields).
  (Vertical ⟶ lineal interpolation ⟶ 3D fields).

Bad results in the horizontal and vertical.



Previous work

Best improvement: RM without quasi-monotone filter and cubic-lineal interpolation to evaluate the value of the field at the departure point of the SL trajectory.



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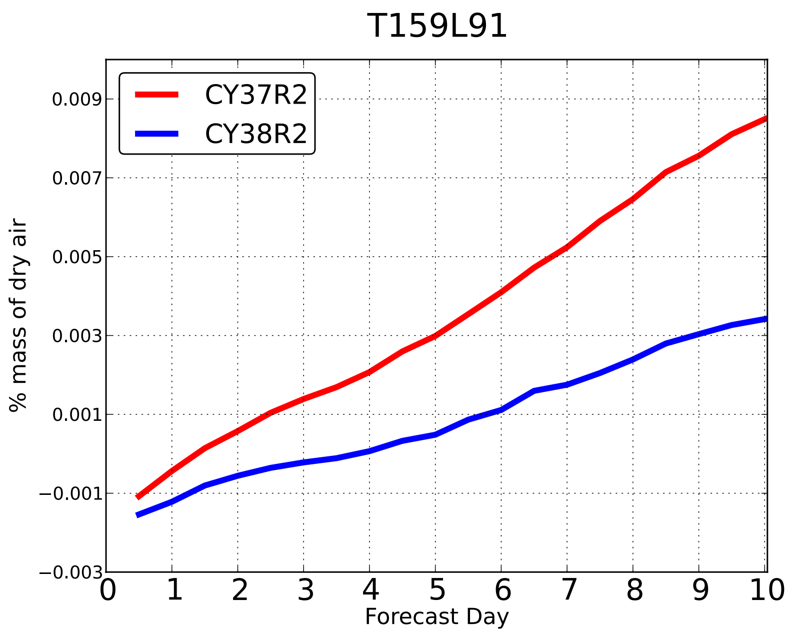
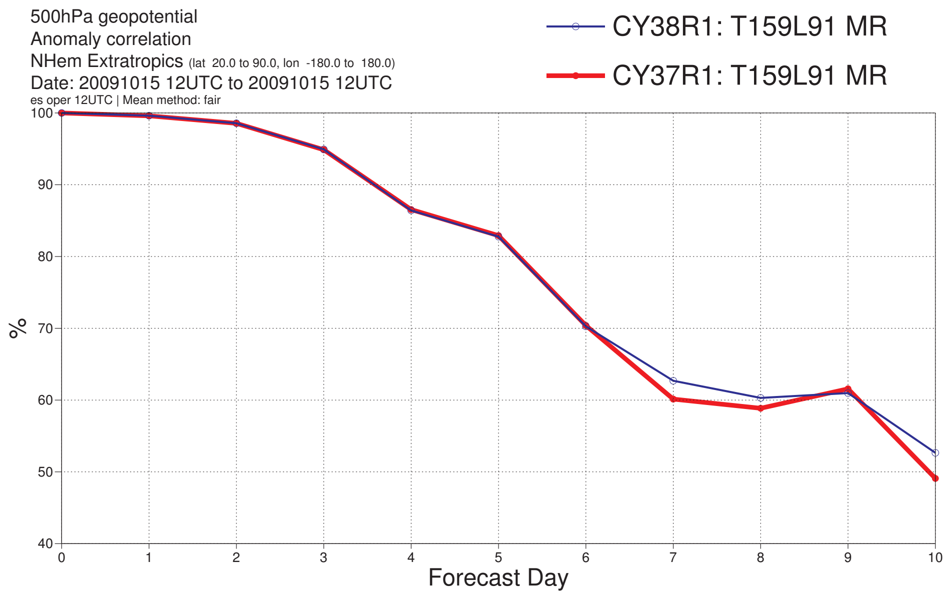
Continuity equation.

T159L91

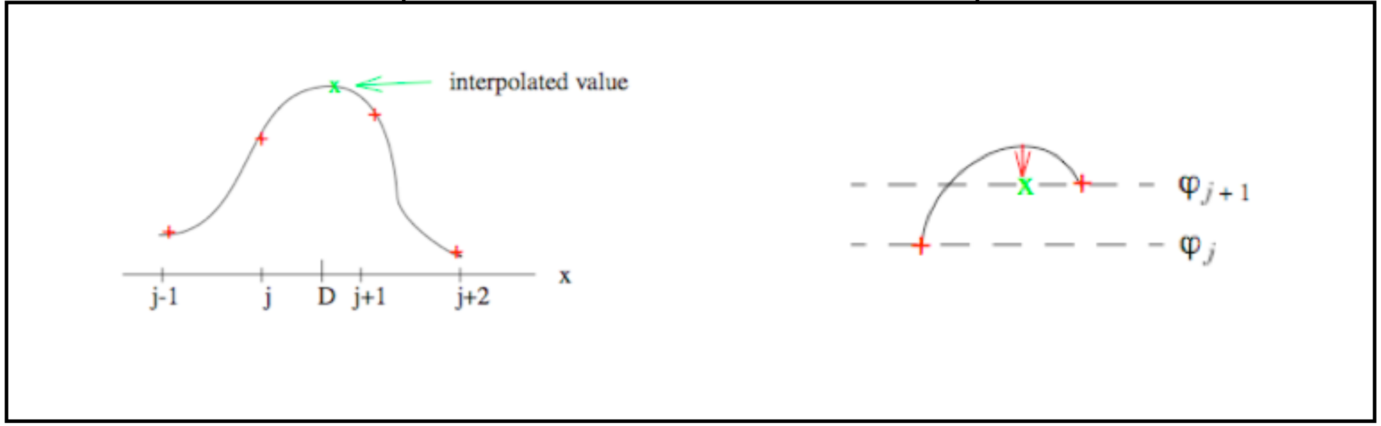
Comparative between CY37R2 and 38R2.
Reference Model (RM).





Continuity equation.

Quasi-monotone filter



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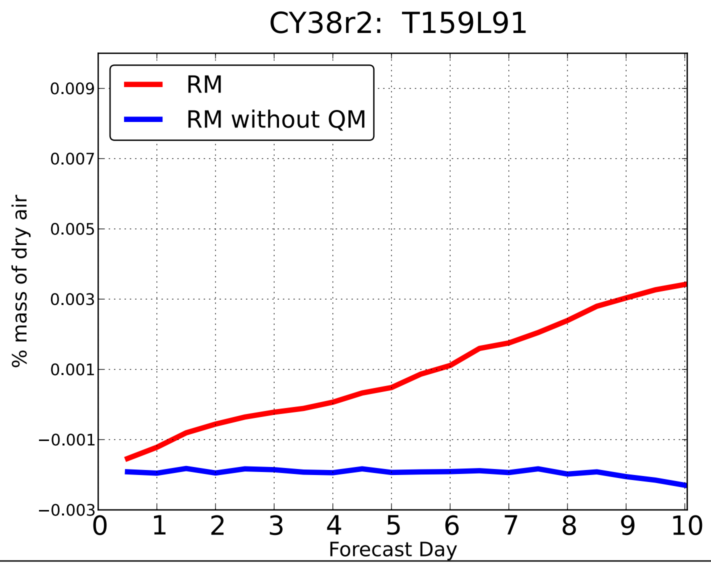

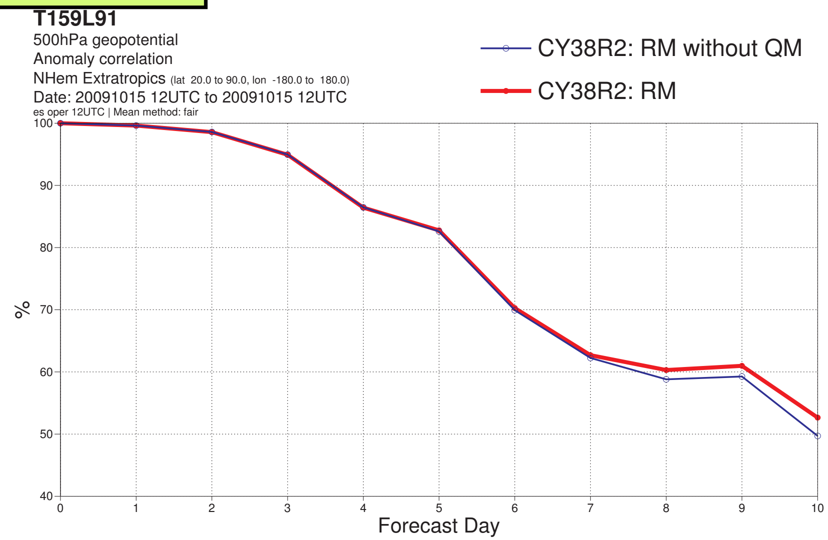

Continuity equation.

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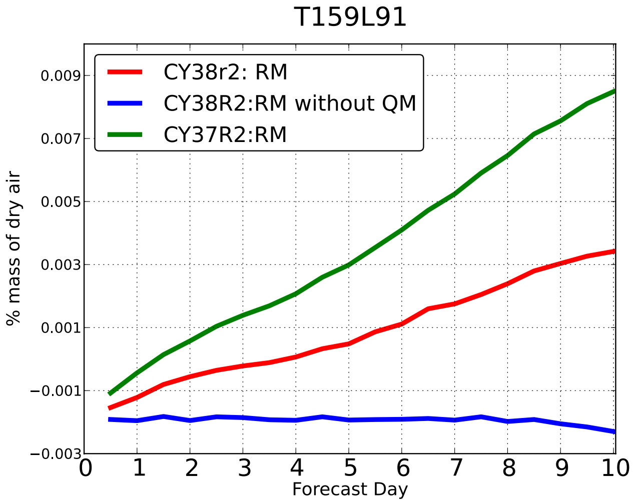

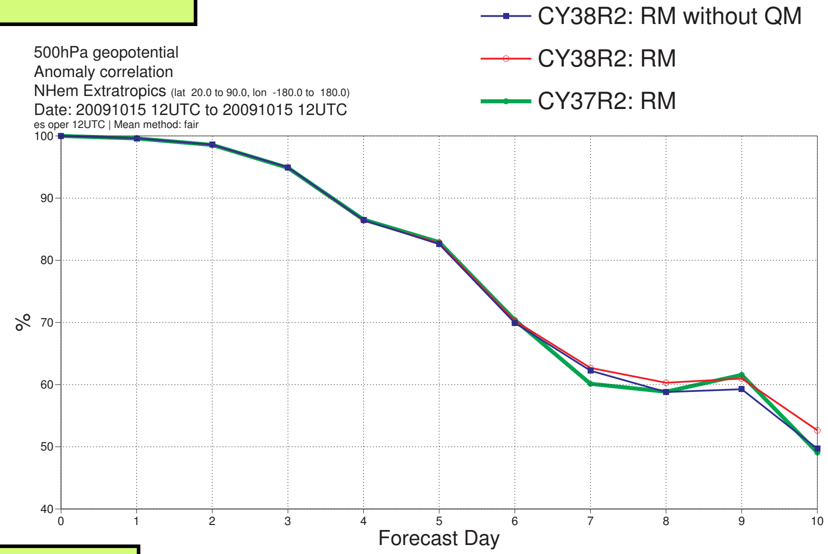

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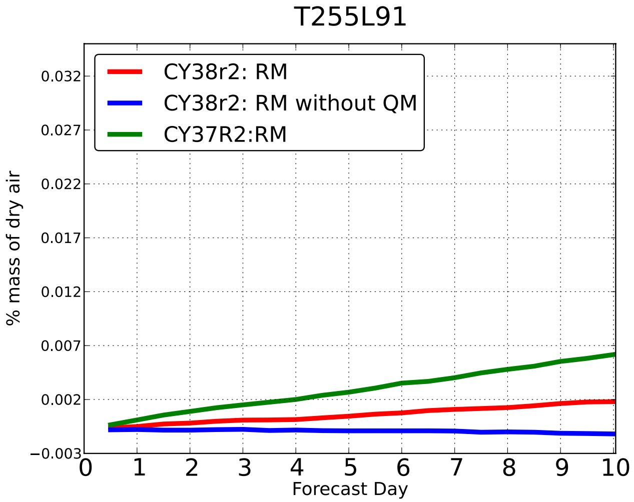

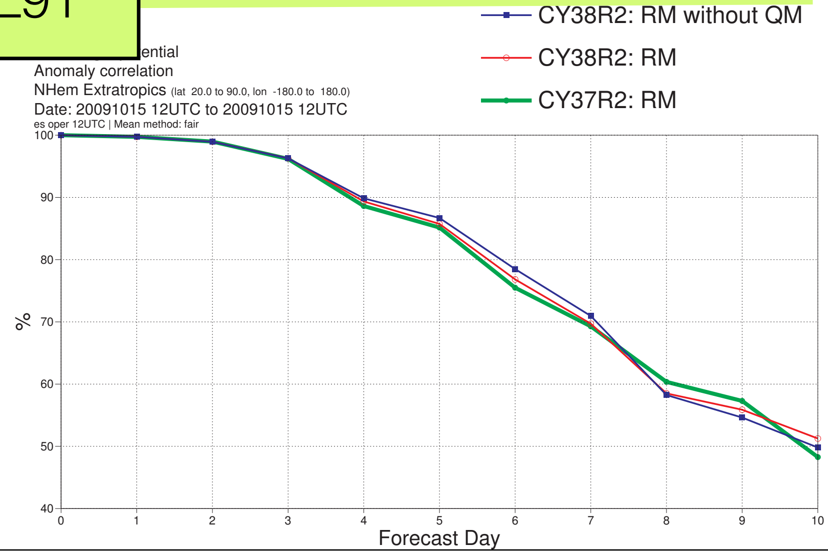

Continuity equation.

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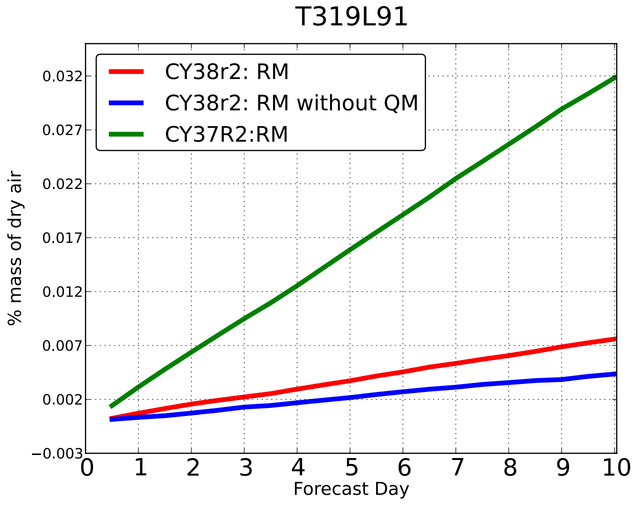

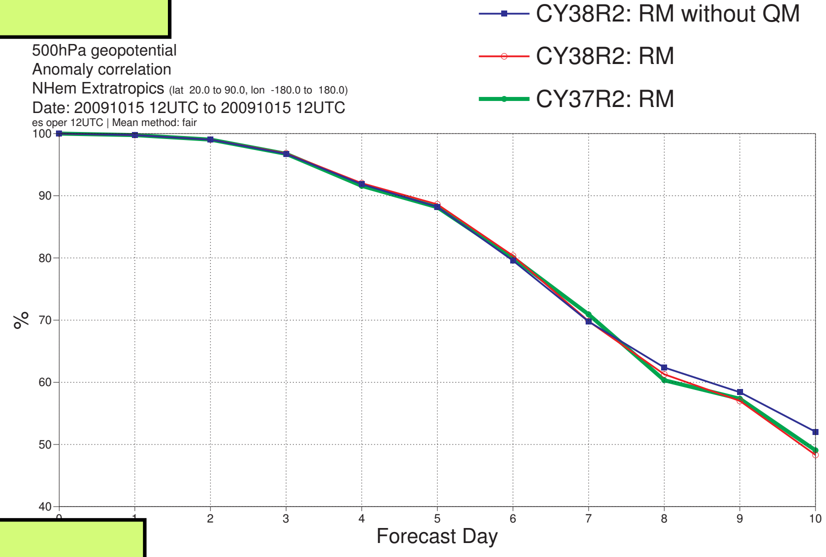

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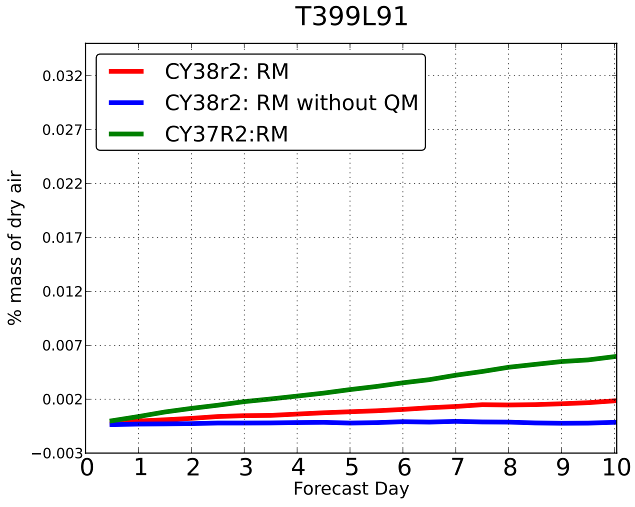
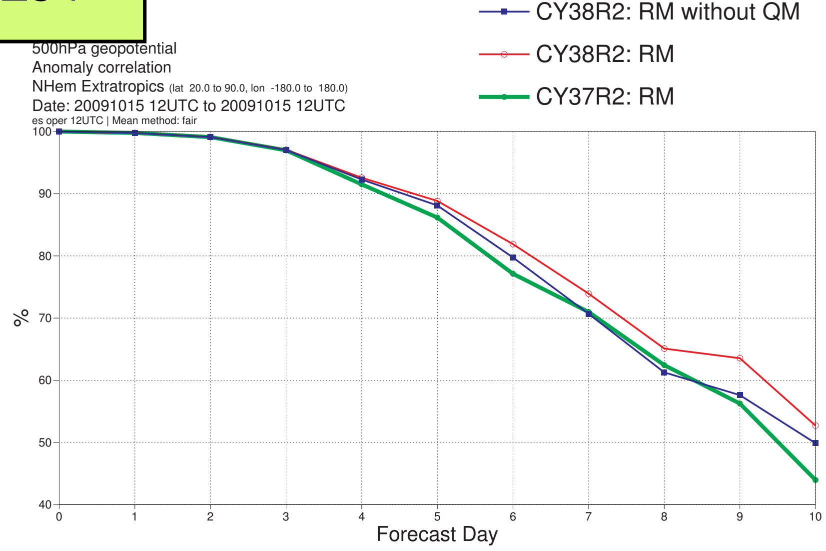
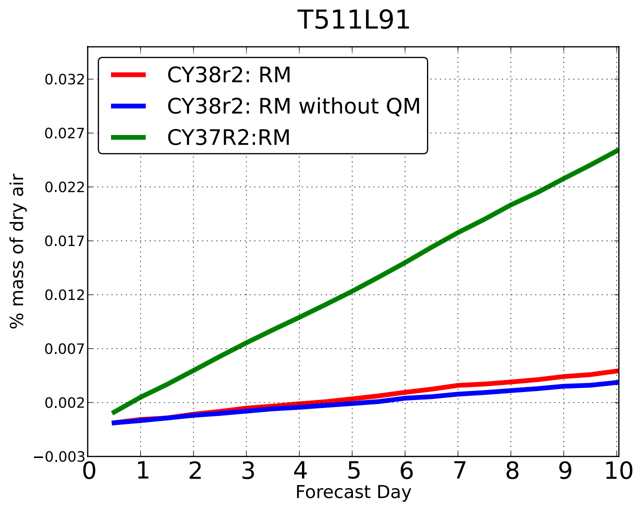
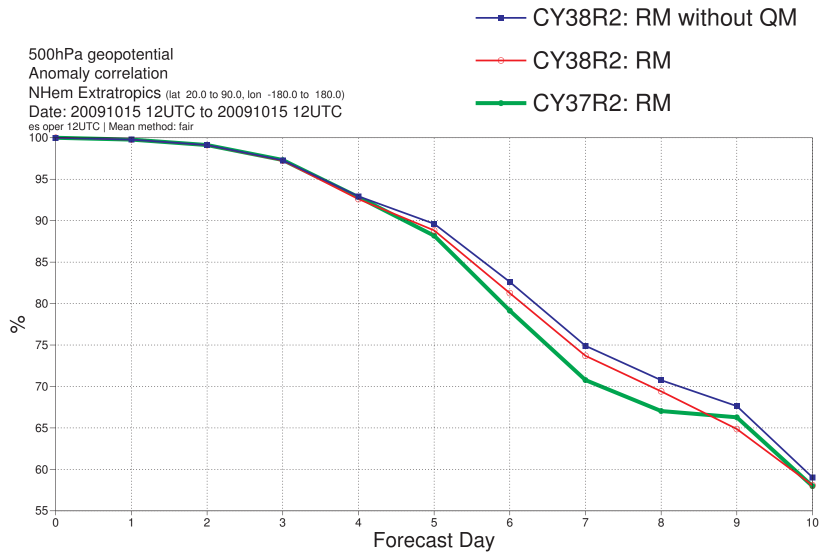




Continuity equation.

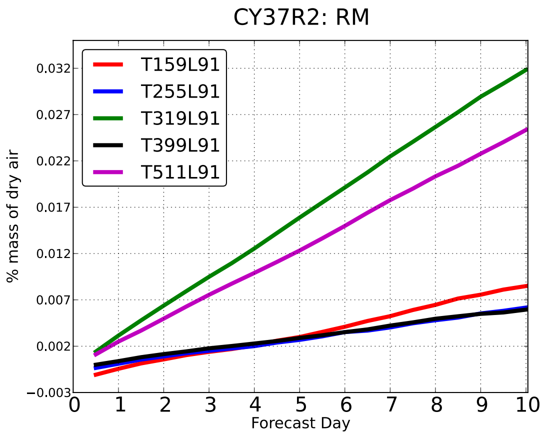
T511L91

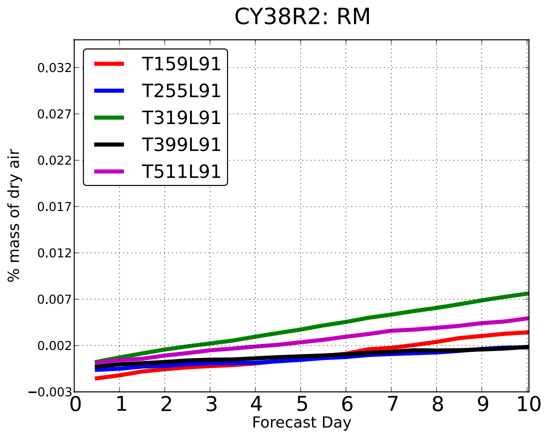


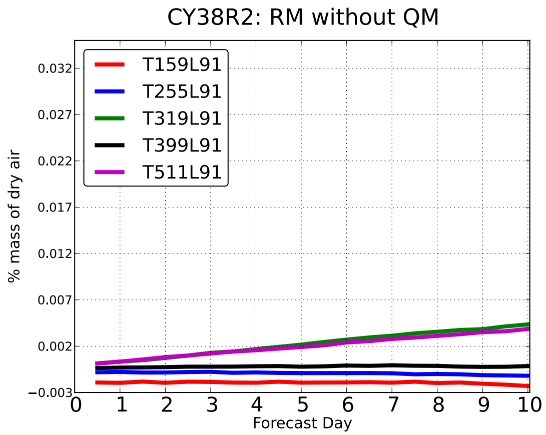


Continuity equation.

Consistency of semi-Lagrangian scheme for the continuity equation:







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- Ozone equation.
  - *Quasi-monotone interpolation.*

Kinetic Energy Spectrum:
Comparative between CY37R2 and 38R2.

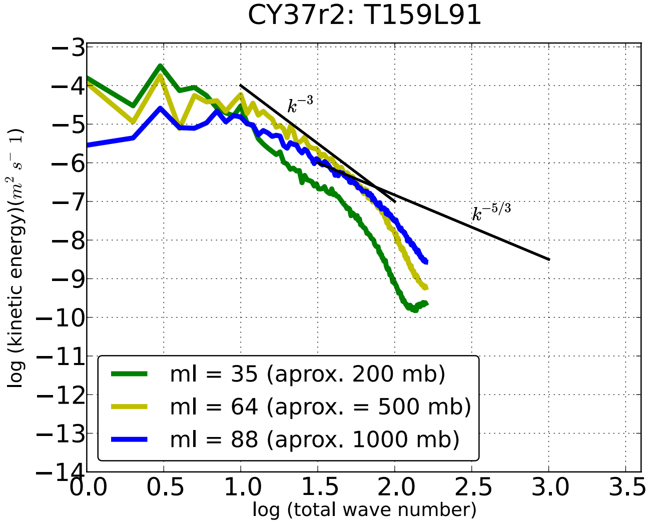
Nils Wedi's modification in CY38L91

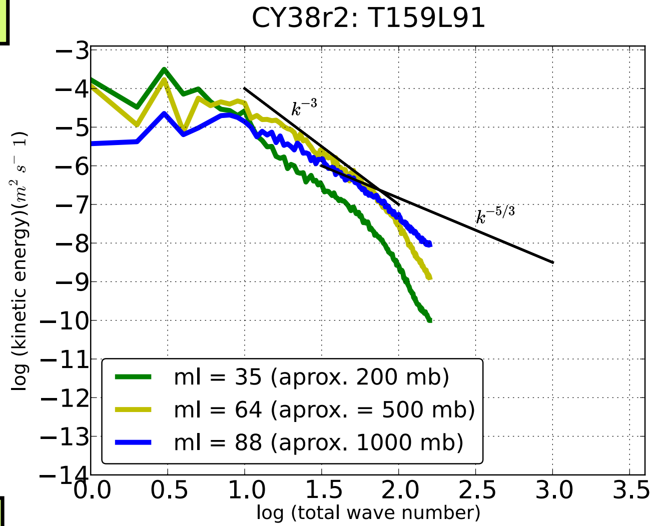
- Reduction of the aliasing in vorticity coming from the pressure gradient terms.

Kinetic Energy Spectrum:

Comparative between CY37R2 and 38R2.

T159L91





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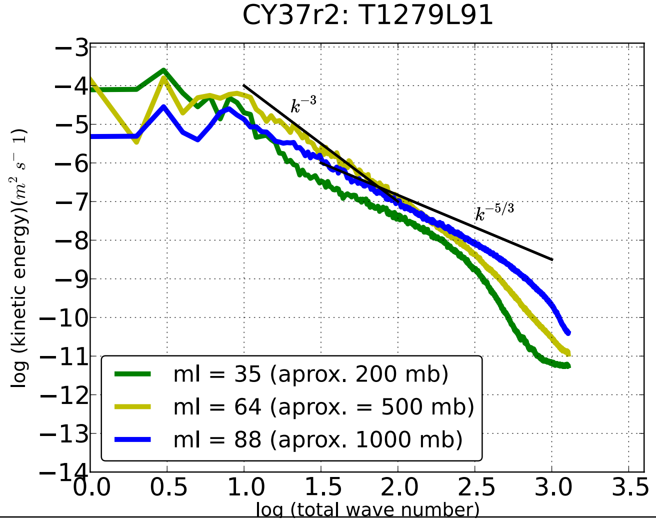
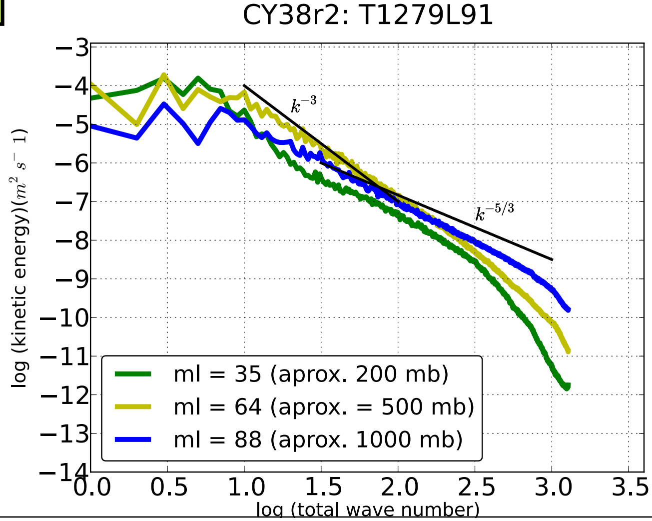


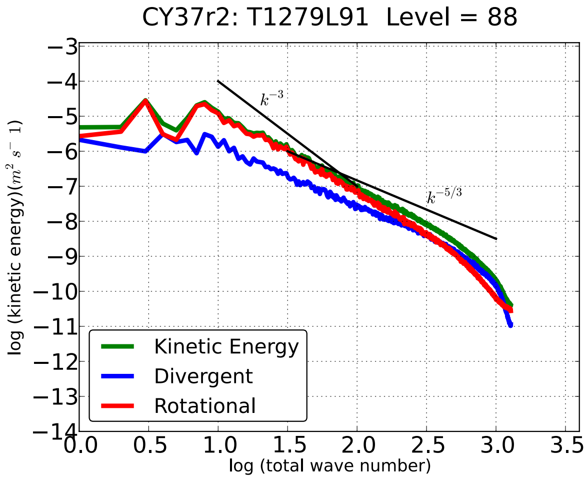


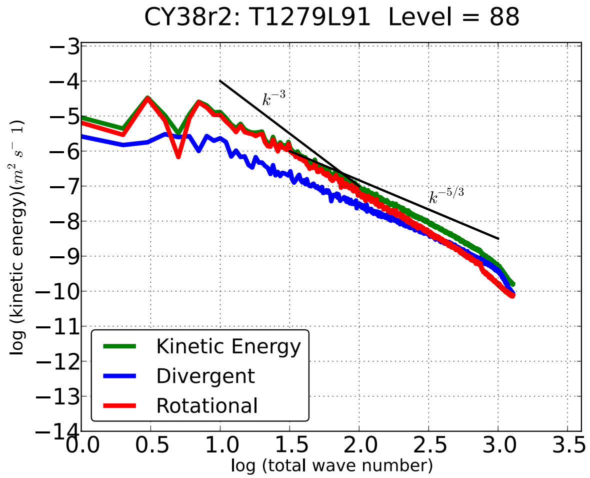
Kinetic Energy Spectrum:

Comparative between CY37R2 and 38R2.

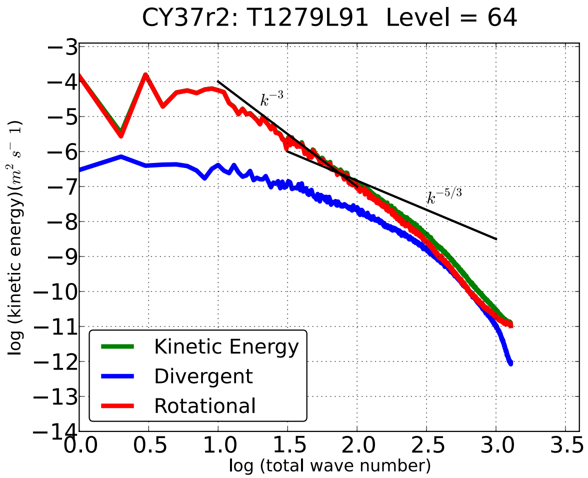
T1279L91

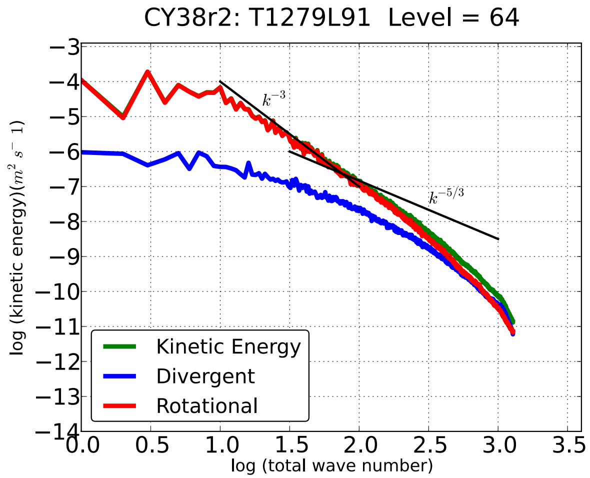
~ 1000 mb





~ 500 mb

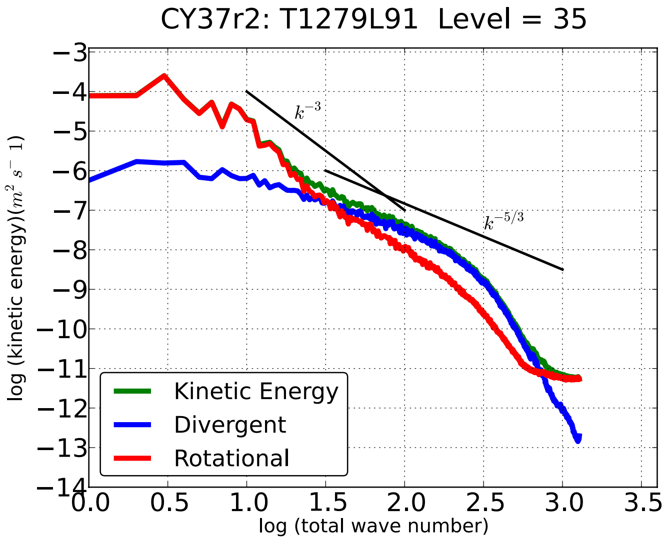




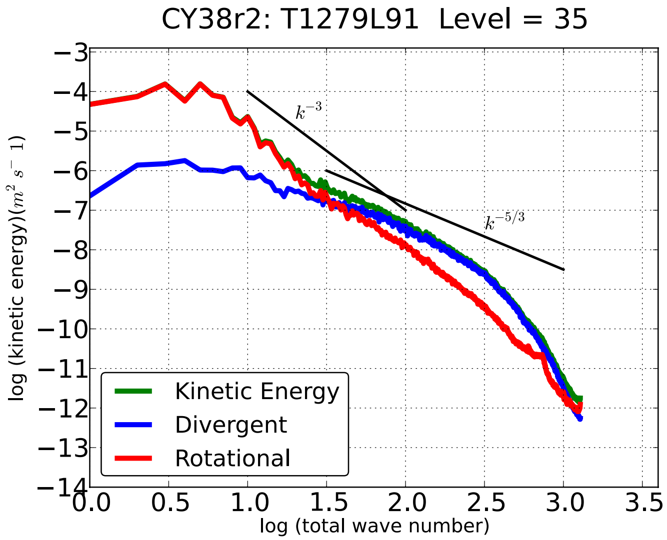
Kinetic Energy Spectrum:

Comparative between CY37R2 and 38R2.

T1279L91



~ 200 mb



CPU time:

The aliasing of gradient term → computation cost of 5% at T1279L91

Kinetic Energy Spectrum:
Comparative between CY37R2 and 38R2.

Nils Wedi's modification in CY38L91

↓

pressure gradient terms $\longrightarrow$ equations (u,v)

↓

$$\mathbf{r}_A^{t+\Delta t} = \mathbf{r}_D^t + \frac{\Delta t}{2}([2\mathbf{v}^t - \mathbf{v}^{t-\Delta t}]_D + \mathbf{v}_A^t)$$

↓

Continuity equation
L and NL terms

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  - ***Quasi-monotone interpolation.***

Ozone equation.

The evolution of the ozone throughout simulation period is the combination of the continuity equation and the evolution of the ozone mixing ratio.

- continuity equation $\longrightarrow$ dry air mass
- ozone mixing ratio evolution $\longrightarrow$ $r_{O_3} = \dfrac{\text{gr} \quad O_3}{\text{Kg Dry Air}}$

$$\frac{DX}{Dt} = \text{sink and source terms} \quad | \quad X \equiv r_{O_3}$$

SL advection scheme
(SETTLS algorithm)

$$X_A^+ = X_D^- + \text{sink and source terms}$$

Ozone equation.

Mass Conservation of ozone $\longrightarrow$ sink and source terms = 0

(Forecast: 10 days)

$$X_A^+ = X_D^-$$

Error: kind of interpolation

$$X_A^+ = \text{value}$$

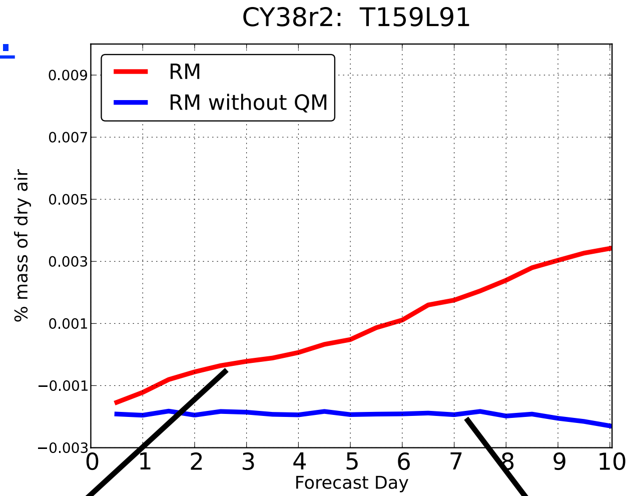
$$\text{gr} \quad O_3 = \text{value} * \text{kg Dry Air}$$

Error: behavior of the continuity equation

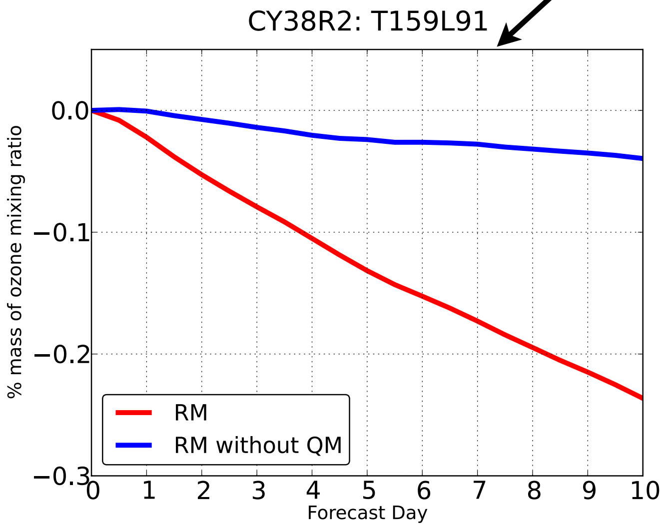
Ozone equation.

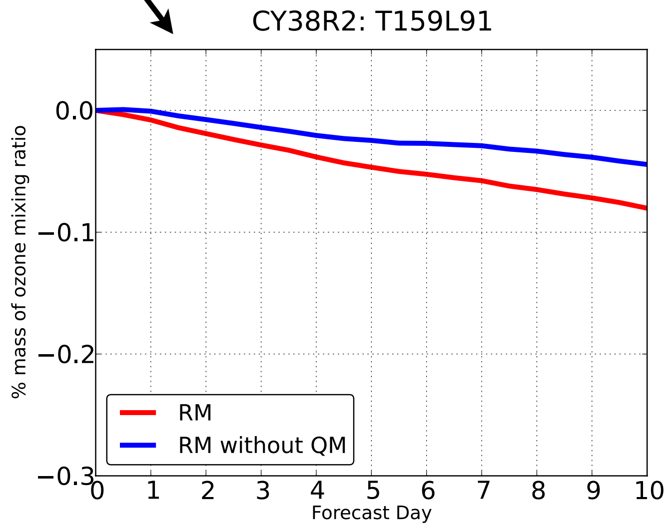
T159L91

Continuity equation.



Ozone equation without sink and source terms.





Conclusions

- It is better to continue using interpolation methods to calculate the value of the field at the departure point of the semi-Lagrangian trajectory.

- Reduction of the aliasing in vorticity coming from the pressure gradient terms improves the mass conservation of dry air in the continuity equation.

- Not to apply the quasi-monotone filter in the continuity equation in the CY38R2 improves more the mass conservation of dry air.