Semi-Lagrangian coupling of physics to dynamics

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All-Staff Meeting/Workshop
Oslo,Norway
23-26 April 2007

Contents

- existing second order accurate solutions for dynamics and physics
- Aladin uses physics from the origin point
- possibilities for coupling of physics to dynamics
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- first results
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Introduction

- semi-lagrangian $\frac{d\psi}{dt} = A + P$
- where *A* is dynamics and *P* physics
- dynamical contribution *A = B + N* is split into a linear term B and a non-linear residual N
- semi-implicit discretization in two-time-levels

$$\psi_F^{t+\Delta t} - \psi_O^t = \frac{\Delta t}{2}(B_F^{t+\Delta t} + B_O^t) + \frac{\Delta t}{2}(N_F^{t+\Delta t} + N_O^t) + \frac{\Delta t}{2}(P_F^{t+\Delta t} + P_O^t)$$

- but in the real world, we use

$$\psi_F^{t+\Delta t} - \psi_O^t = \frac{\Delta t}{2}\beta(B_F^{t+\Delta t} + B_O^t) + \Delta t N_M^{t+\frac{\Delta t}{2}} + \Delta t P_M^{t+\frac{\Delta t}{2}}$$

LSETTLS scheme

- stable extrapolation for a two-time-level scheme (Hortal, 1998)

$$N_M^{t+\frac{\Delta t}{2}} = N_O^t + \frac{1}{2}\left(N_F^t - N_O^{t-\Delta t}\right) = \frac{1}{2}\left(2N_O^t - N_O^{t-\Delta t} + N_F^t\right)$$

  - for the non-linear term

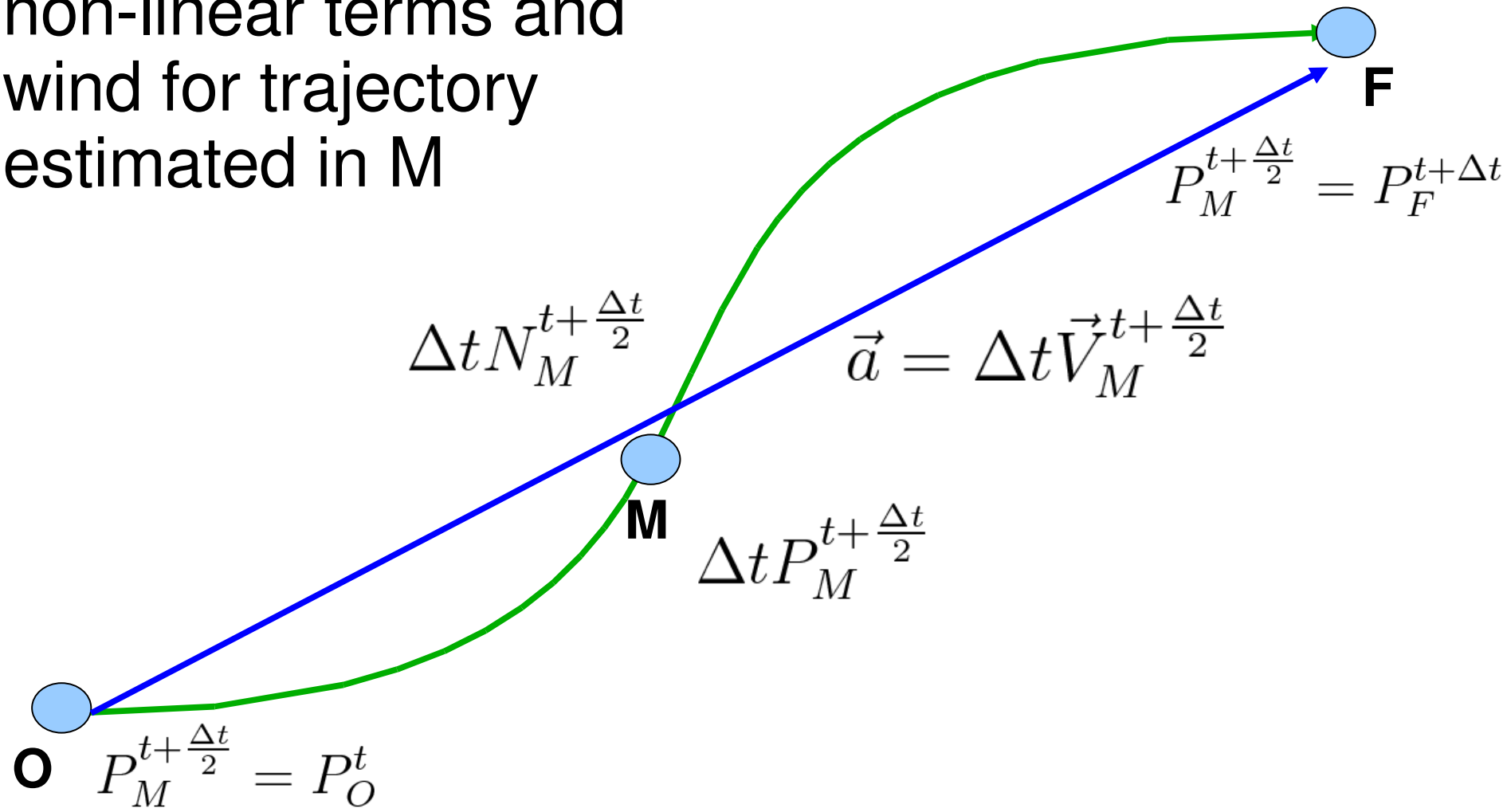
$$\vec{V}_M^{t+\frac{\Delta t}{2}} = \vec{V}_O^t + \frac{1}{2}\left(\vec{V}_F^t - \vec{V}_O^{t-\Delta t}\right) = \frac{1}{2}\left(2\vec{V}_O^t - \vec{V}_O^{t-\Delta t} + \vec{V}_F^t\right)$$

  - to compute the origin point

- second order accuracy accomplished

Dynamics solution

- non-linear terms and wind for trajectory estimated in M



SLAVEPP

- IFS/HIRLAM used

$$P_M^{t+\frac{\Delta t}{2}} = P_F^{t+\Delta t}$$

- semi-lagrangian averaging of physics parameterizations (Wedi, 1999)

$$P_M^{t+\frac{\Delta t}{2}} = \frac{1}{2}P_O^t(rad, cnv, cloud) + \frac{1}{2}P_F^{t+\Delta t}(rad, cnv, cloud) + P_F^{t+\Delta t}(turb, gwd)$$

- call physics after explicit dynamics and interpolate in next time-step

Aladin physics

- computed before the dynamics and interpolated to the origin point

$$P_M^{t+\frac{\Delta t}{2}} = P_O^t$$

  - first order accurate coupling

- how to accomplish second order accuracy in coupling it to the semi-lagrangian dynamics?

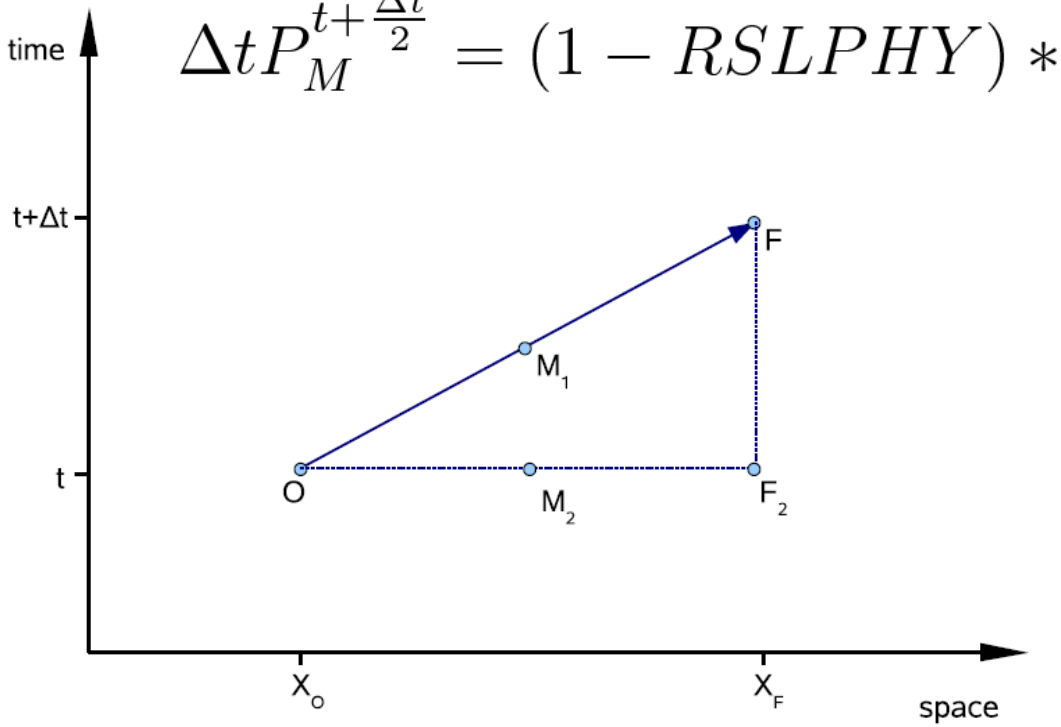
Choices

- Termonia and Hamdi (2007)
  - physics computed before or after dynamics
  - physics and dynamics computed in parallel or sequential manner
  - physics tendency coupled to dynamics in different points on trajectory
- plenty of remaining constraints
  - availability of horizontal derivatives
  - avoid multiple calls to physics

Different points on trajectory

- Coupling of physics to dynamics in different points on trajectory

$$\Delta t P_M^{t+\frac{\Delta t}{2}} = (1 - RSLPHY) * P_O^t + RSLPHY * P_F^t$$



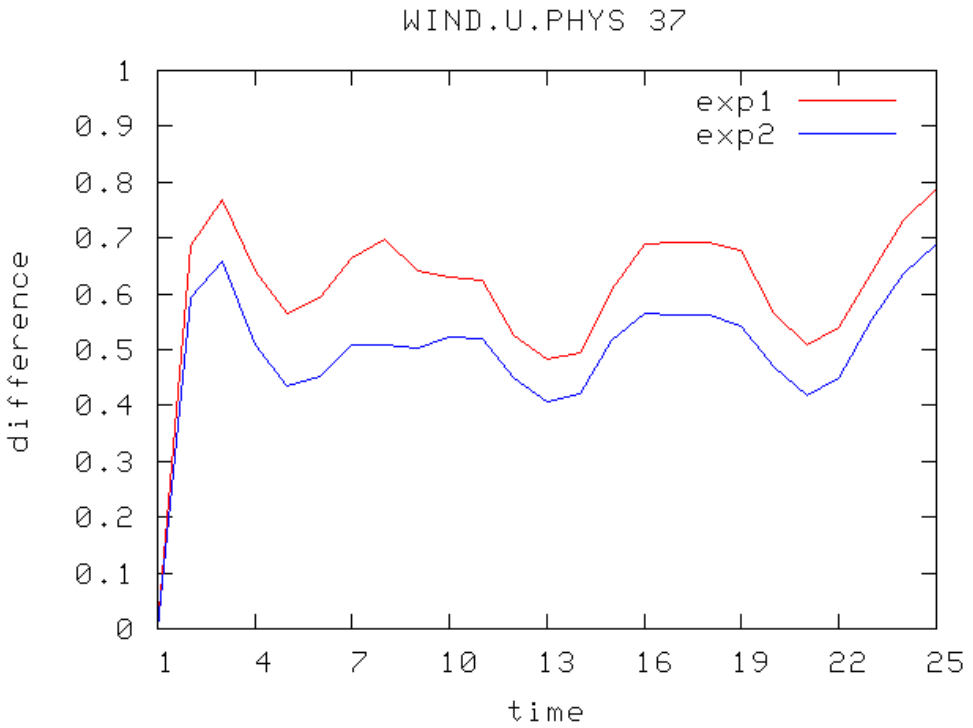
Accuracy criterion

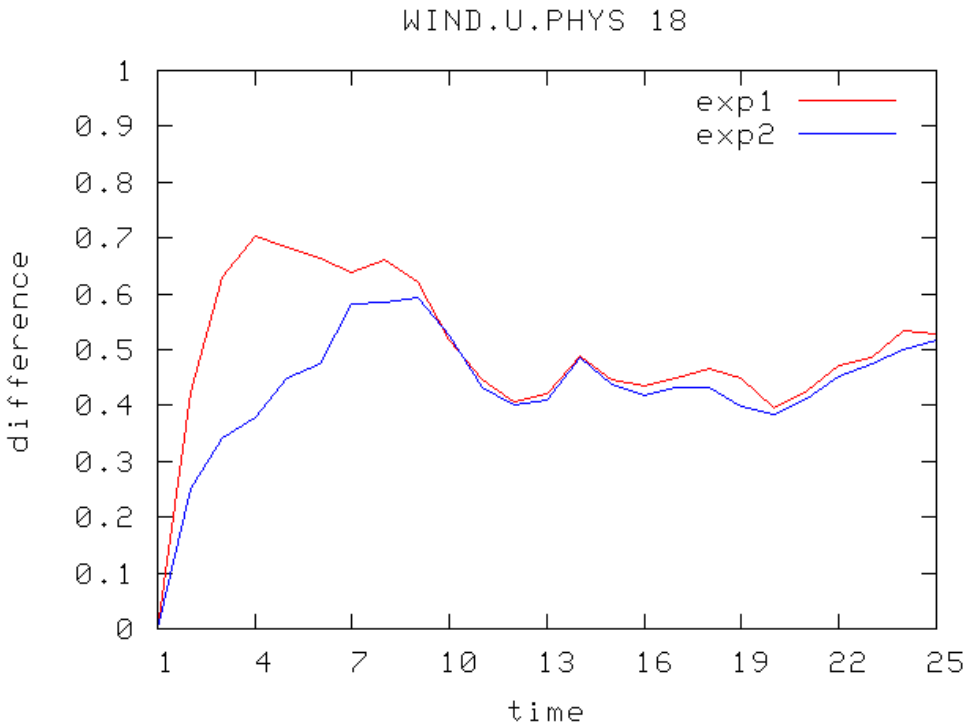
- Integrate the forecast with operational time-step (327.273 sec for Croatian domain, 360 seconds for Czech domain)
- Integrate the forecast with much shorter time-step (30 seconds) and compute the difference

$$dev = \sqrt{\overline{\overline{\left(F_{\Delta t=360} - F_{\Delta t=30}\right)^2}}}$$

- the one with smaller difference is more accurate

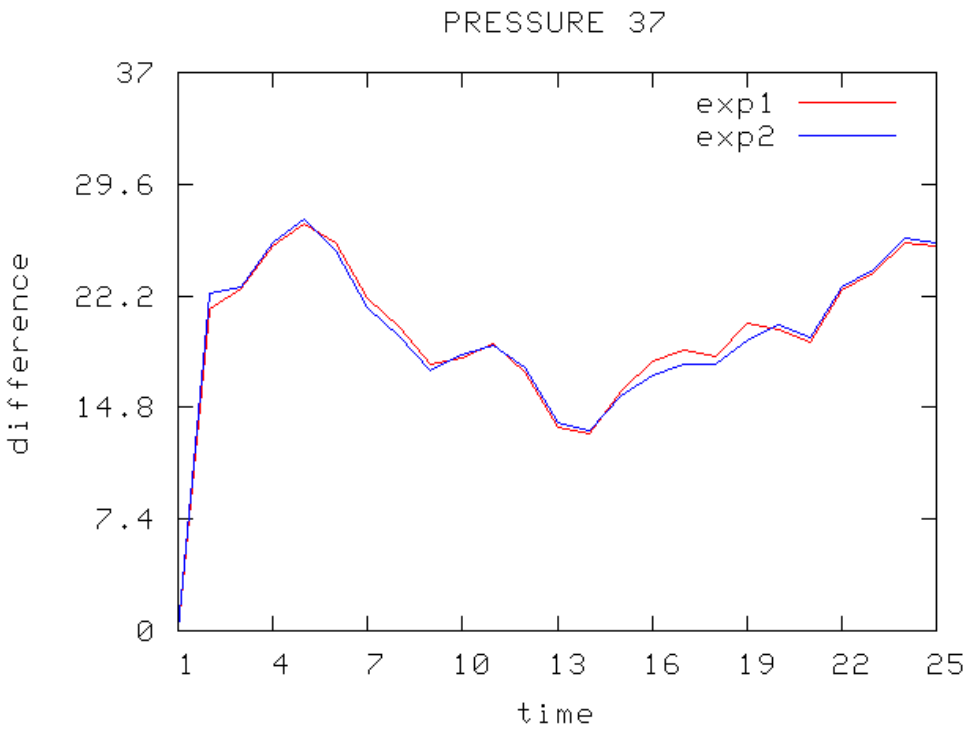
Effect on wind field

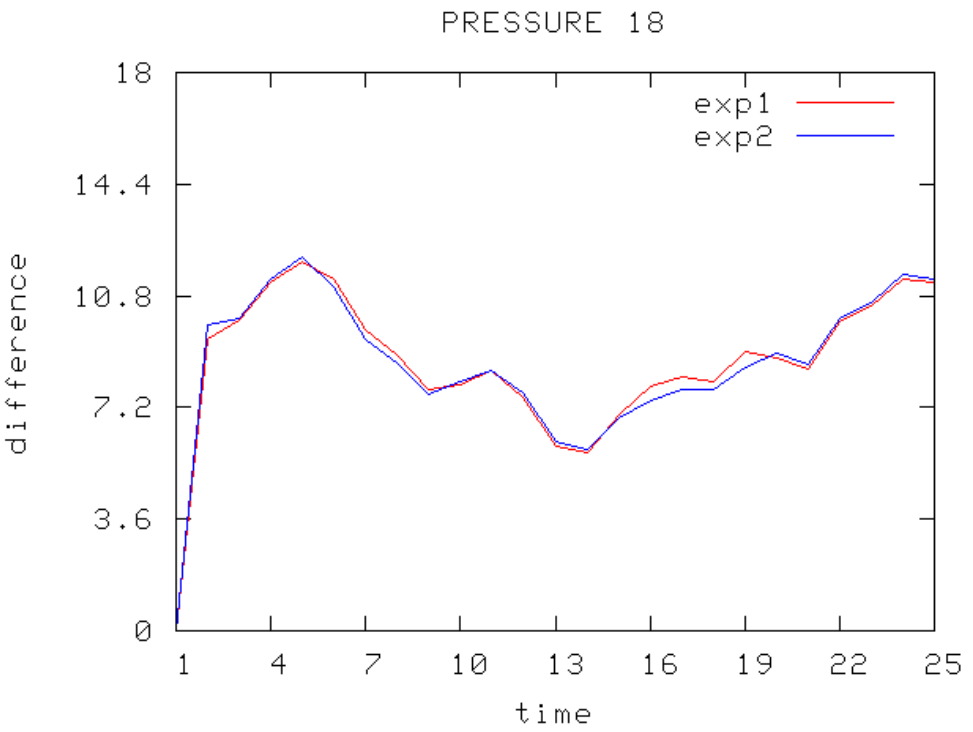




- differences between forecasts computed with operational and very short time-step for operational coupling of physics to dynamics (red) and closer to the middle point (blue) time is 1 for analysis, 4 is 9 hour forecast, 25 is 72 hour forecast.

Effect on pressure field





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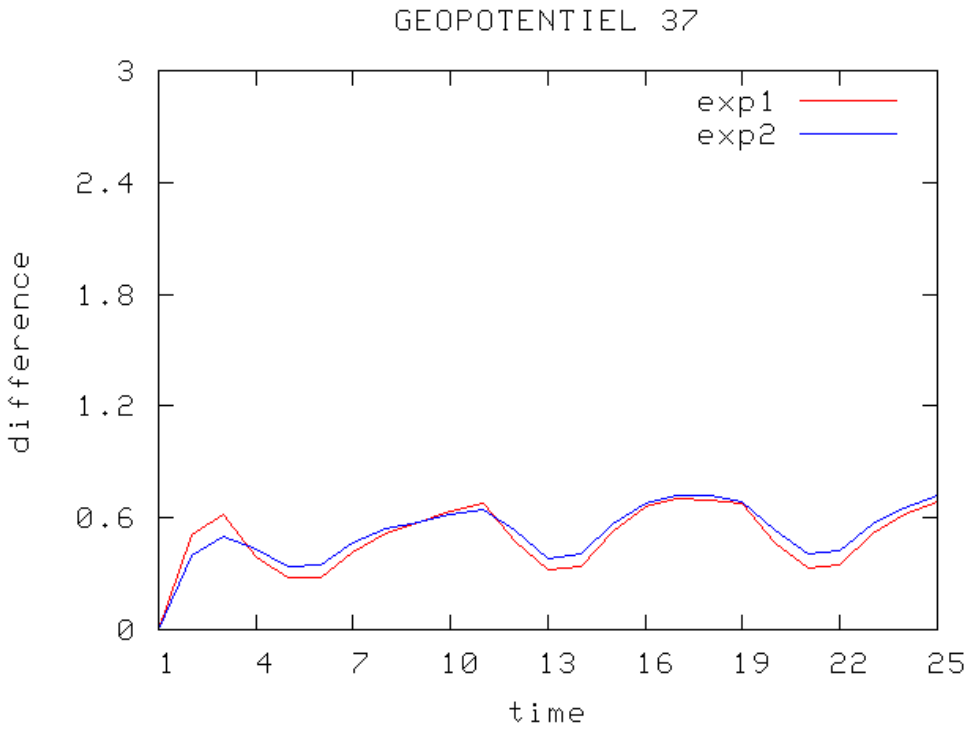
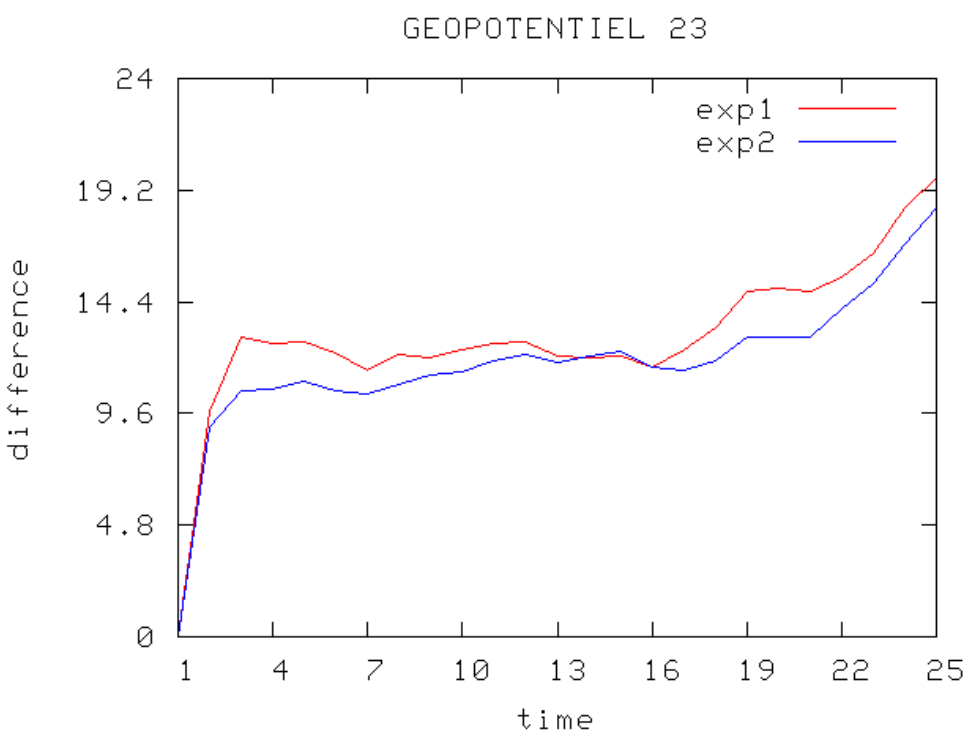
Effect on geopotentiel





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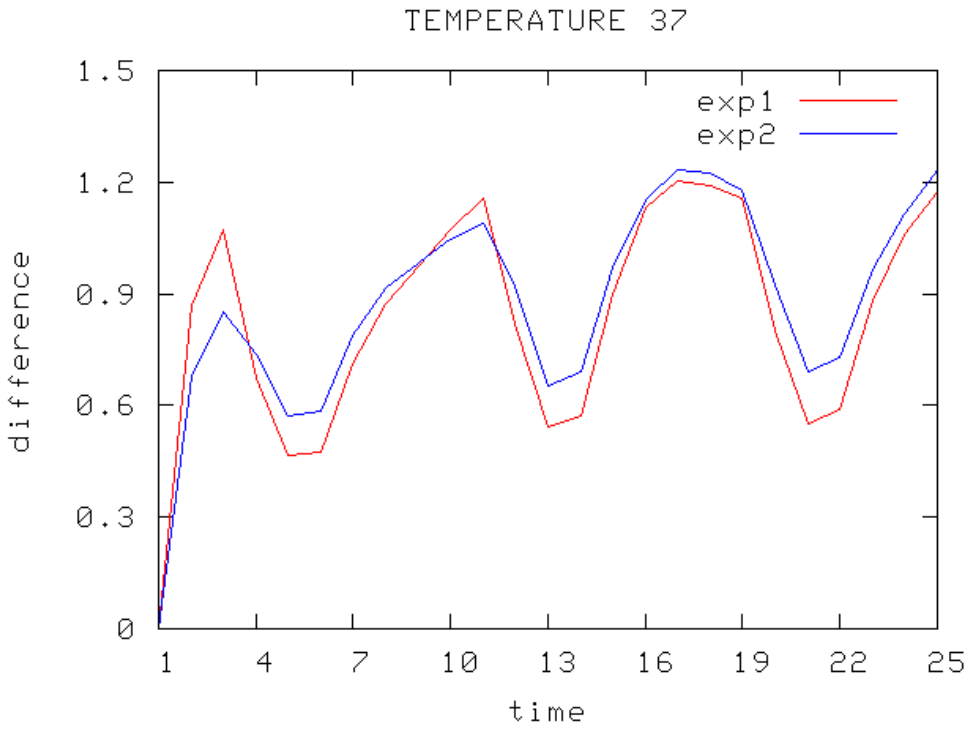
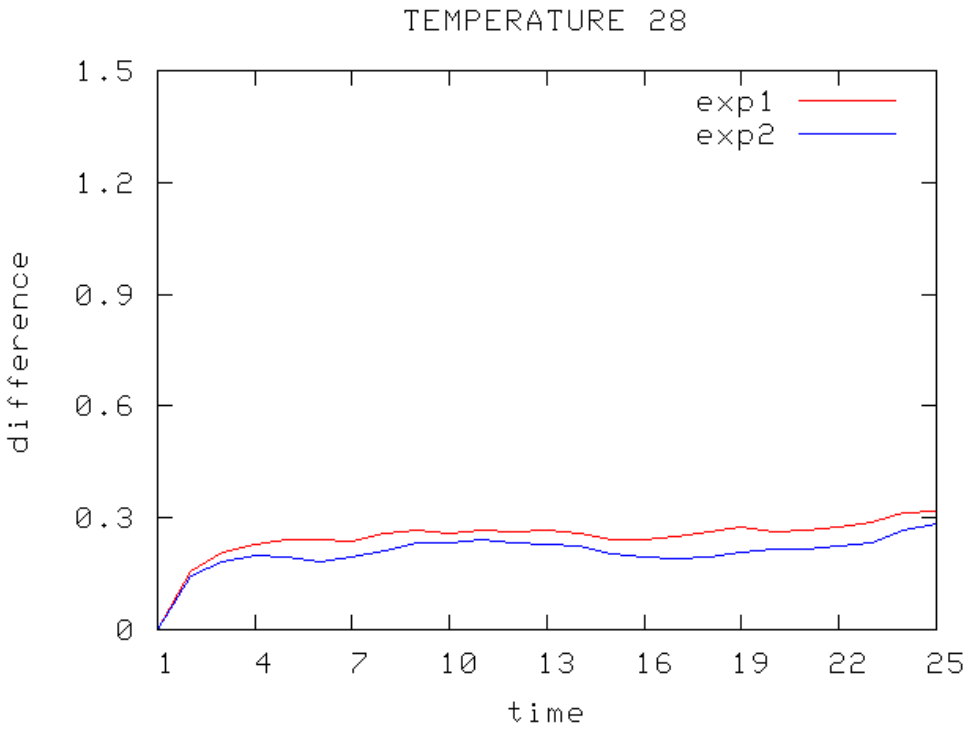
Effect on temperature





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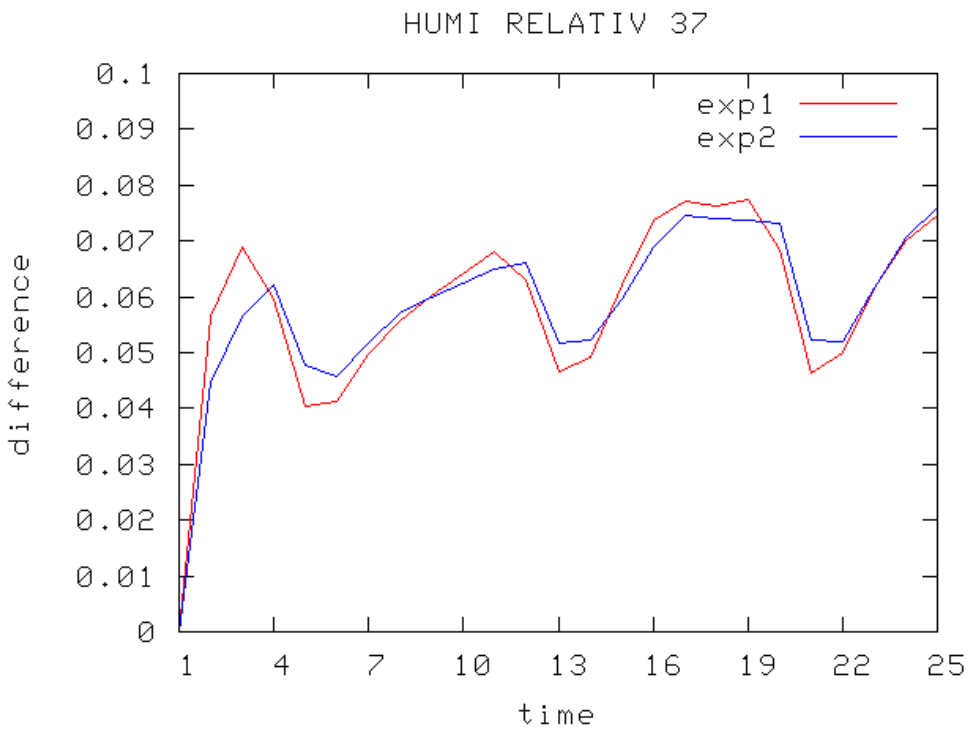
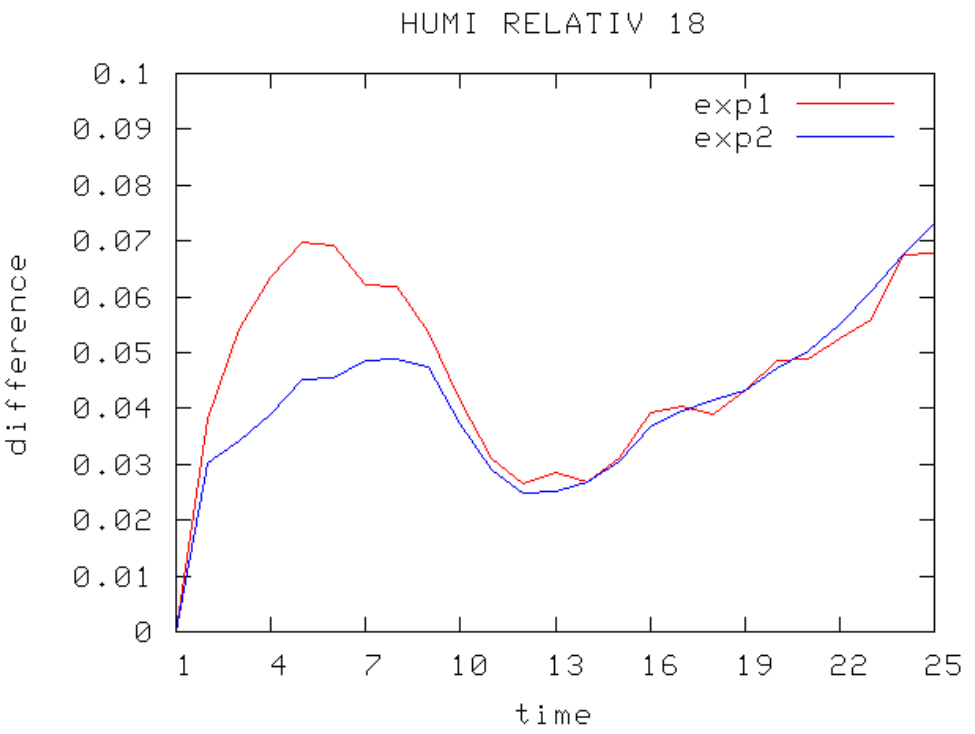
Effect on relative humidity





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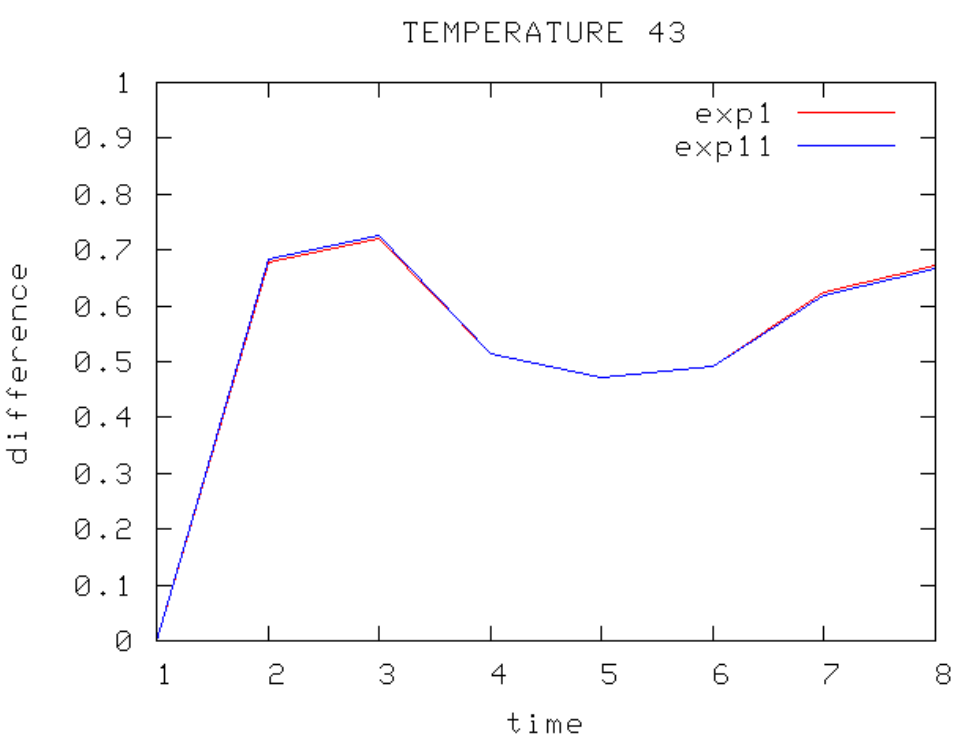
Parallel or sequential

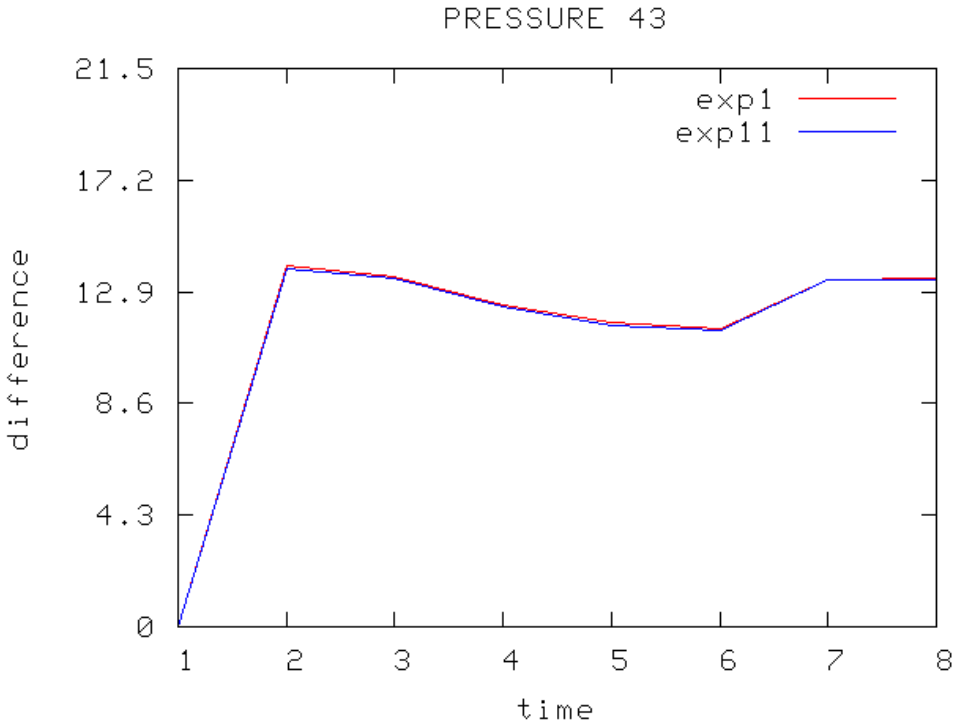
- update the wind field used for trajectory computations with the physics contribution

$$\vec{V}_M^{t+\frac{\Delta t}{2}} = \frac{1}{2}\left[2\left(\vec{V}_O^t + \Delta_{phy}\vec{V}_O^t\right) - \left(\vec{V}_O^{t-\Delta t} + \Delta_{phy}\vec{V}_O^{t-\Delta t}\right) + \left(\vec{V}_F^t + \Delta_{phy}\vec{V}_F^t\right)\right]$$

- coded only for LSETTLS, switch LPIT
  - PXRL0 contains wind used in origin point for trajectory research
  - PXRL contains wind used in final point for trajectory research

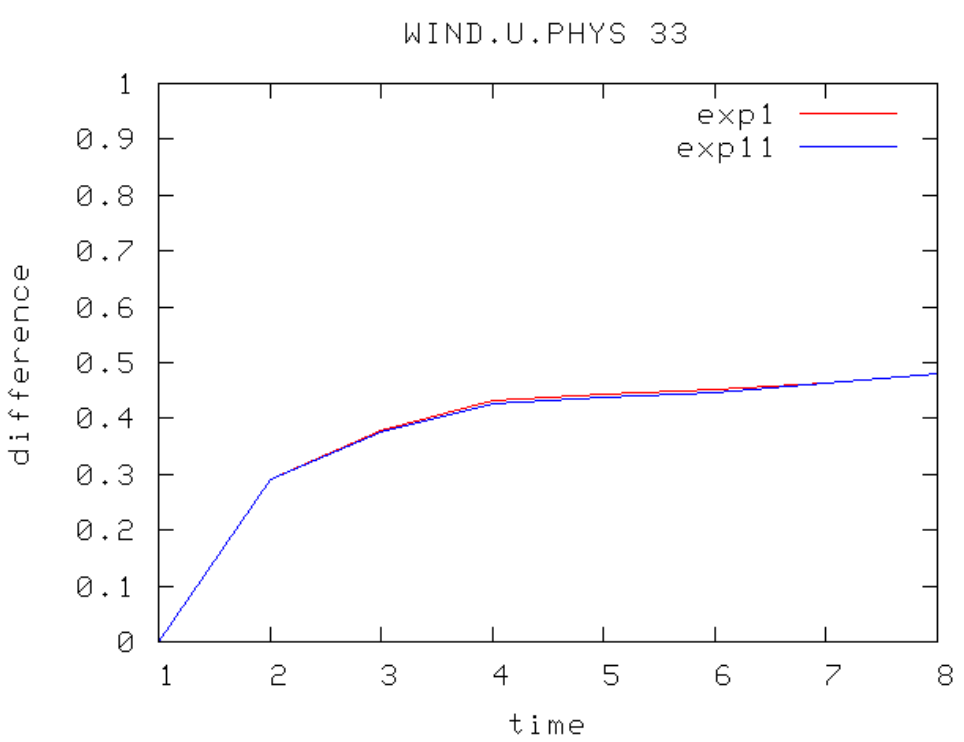
Impact on the forecast

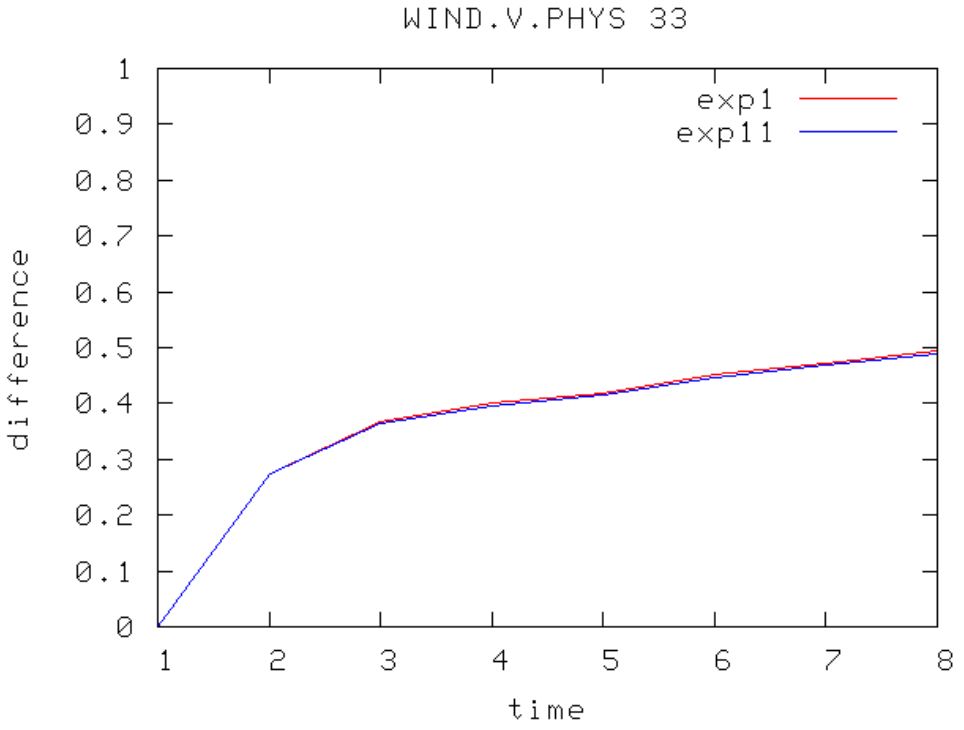




- differences between forecasts computed with operational and very short time-step for operational coupling of physics to dynamics (red) and closer to the middle point (blue), time is 1 for analysis, 4 is 9 hour forecast, 8 is 21 hour forecast.

Impact on the wind field





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Before or after dynamics

- Coupling of physics computed before dynamics in the final point of trajectory is unstable.
- A lagged call to Aladin/Alaro physics package is coded
- it runs but ...
- problems with coupling, DFI, zero accumulated fluxes,
- model blows up for some runs with operational time-step and some other with 30 second time-step.

Conclusions

- Averaging physics tendency between origin and final points has a beneficial impact on accuracy
- Its effects on stability to be studied.
- Problems remaining
  - better consistency in time and space
  - test the lagged option
  - check the surface
- Having sequential instead of parallel computations inside the physics package