Some issues about the lateral boundaries

Quo vadis LBC's?

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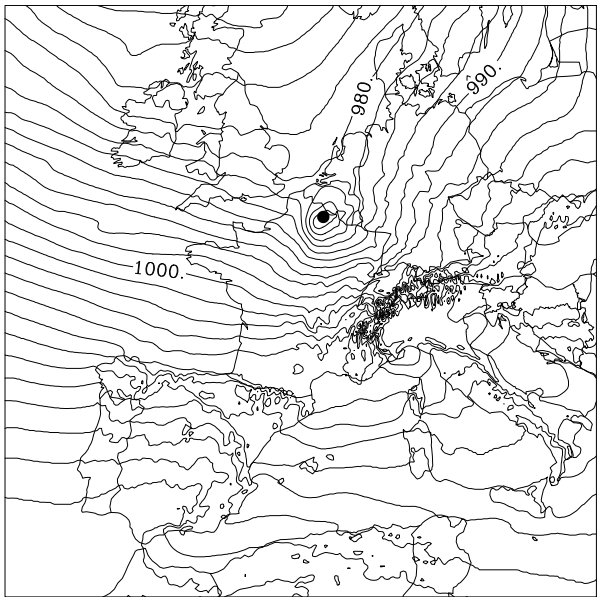
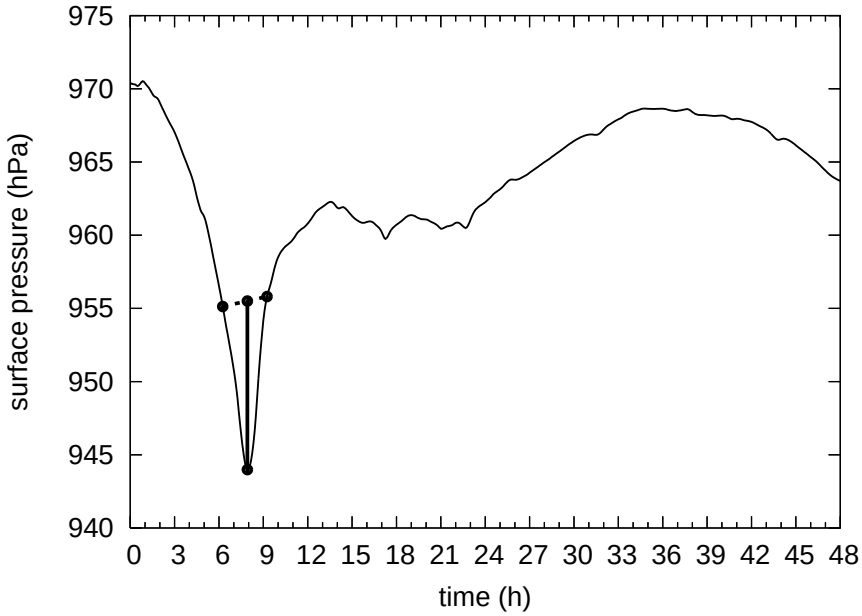
Aims of these 20 min

- To provide a perspective on past research in LBC's
- While doing so, communicate some things I would like you to remember
- Quo vadis LBC's?

The LBC Temporal problem

Warner et al., 1997 describe the *temporal problem*, exemplified n p_s in the ALADIN-Fr Lothar stom run in the indicated point for a field provide with 3-h temporal resolution:

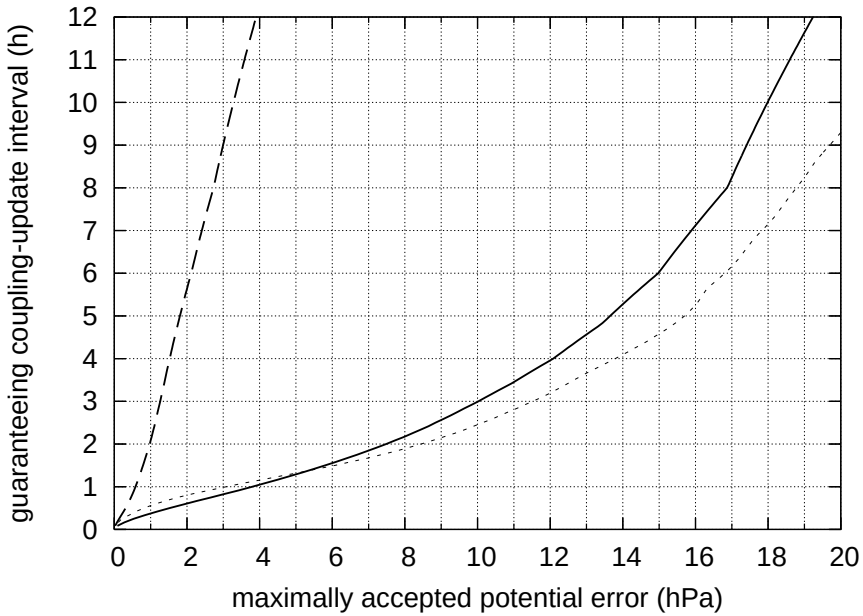




The error between interpolation and real field is 11.5 hPa!!!!

What coupling interval should we use?

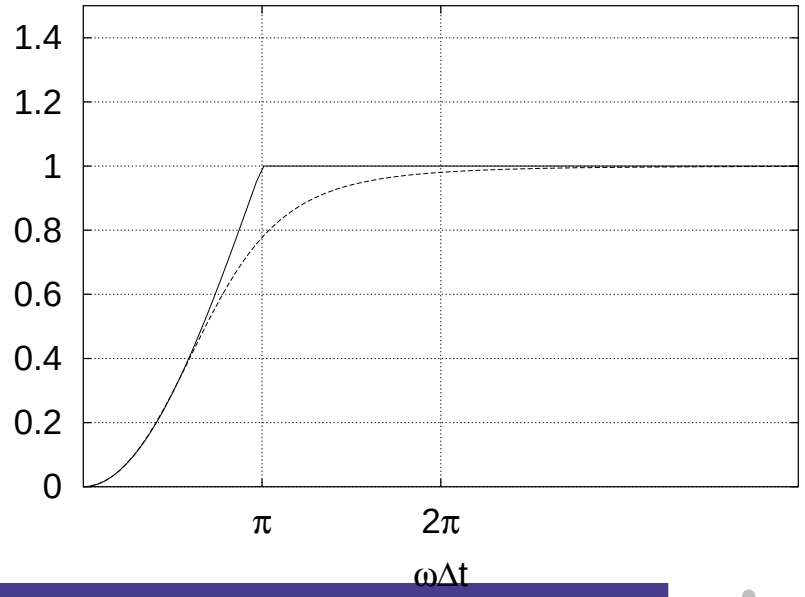
Termonia, Deckmyn, Hamdi, 2009, MWR:



So to have a guarantee that we never make an interpolation error of more than 1 hPa we would need to coupled with about 15-20 min intervals! This is about the time step of ARPEGE. But in normal cases 3h is OK.

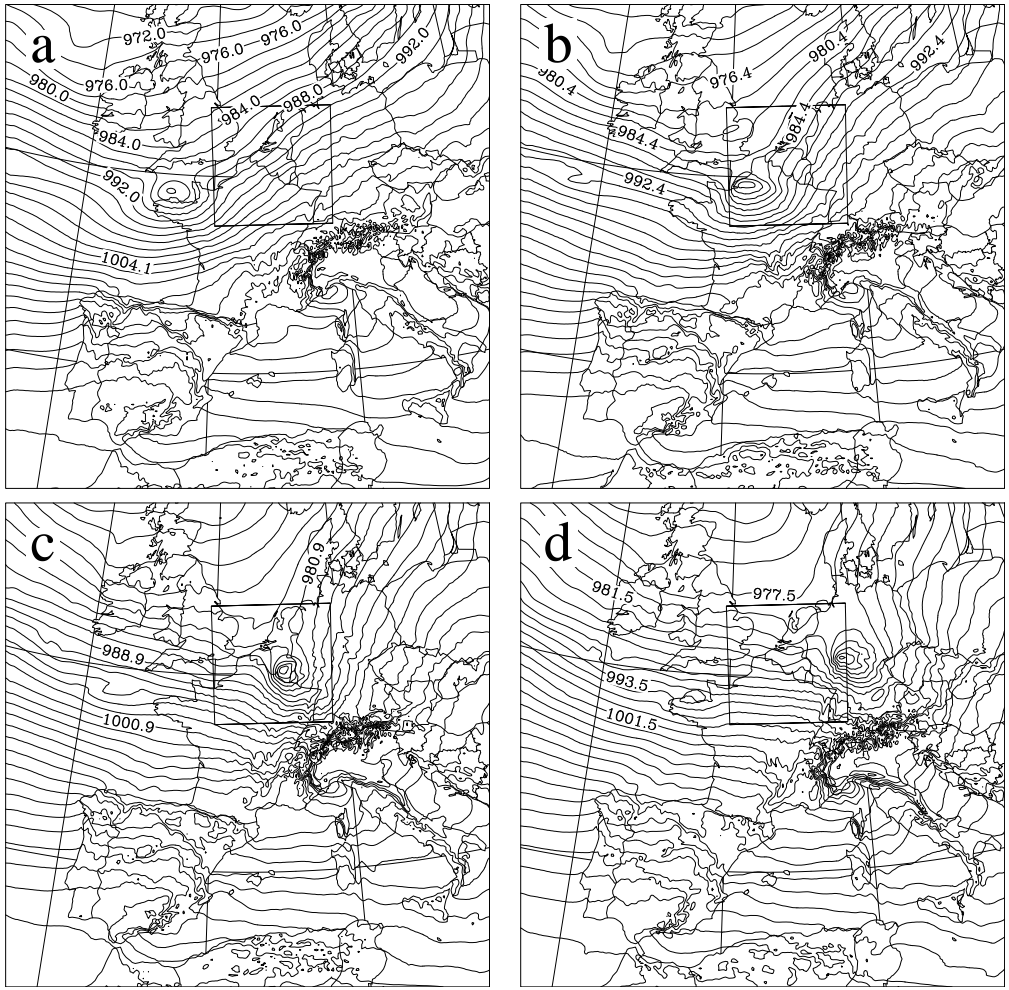
Termonia, 2004, MWR

- This is actually a *sampling* problem, resample a signal with time resolution of Δt with 3h.
- all the modes with frequencies higher than the one corresponding to the LBC Temporal resolution are lost
- BUT we can estimate that in the coupling model by a filter!!! A cheap way to do this is a recursive filter



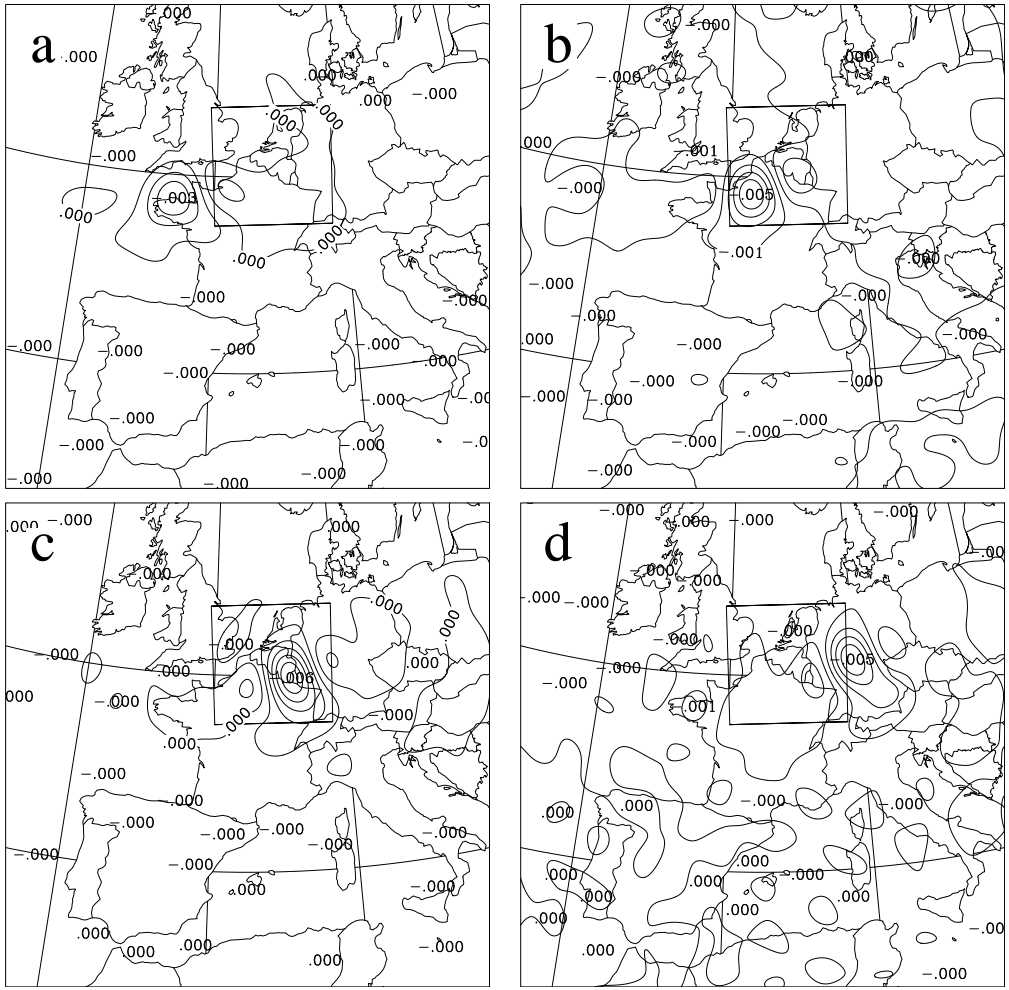
$$y_k = \sum_{m=0}^{N} a_m \, x_{k-m} - \sum_{n=1}^{N} b_n \, y_{k-n} \, ,$$

e.g. ALADIN-France run of Lothar



Think of the rectangle as the coupling domain of a two-nested model. In fact it is the old small ALADIN-Belgium domain.

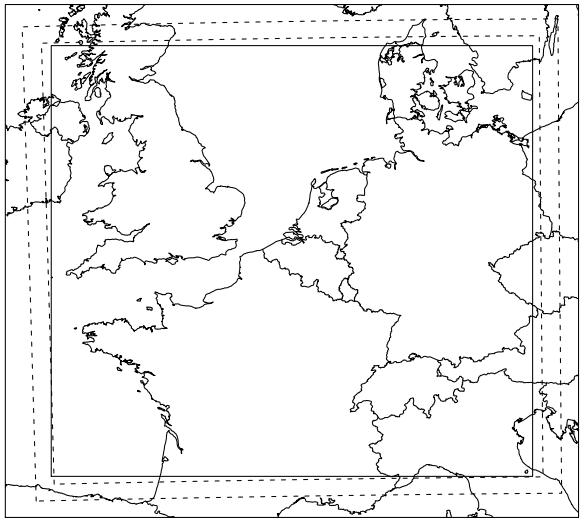
MCUF



The monitoring by the MCUF field is done in ALADIN-France, i.e. the coupling model.

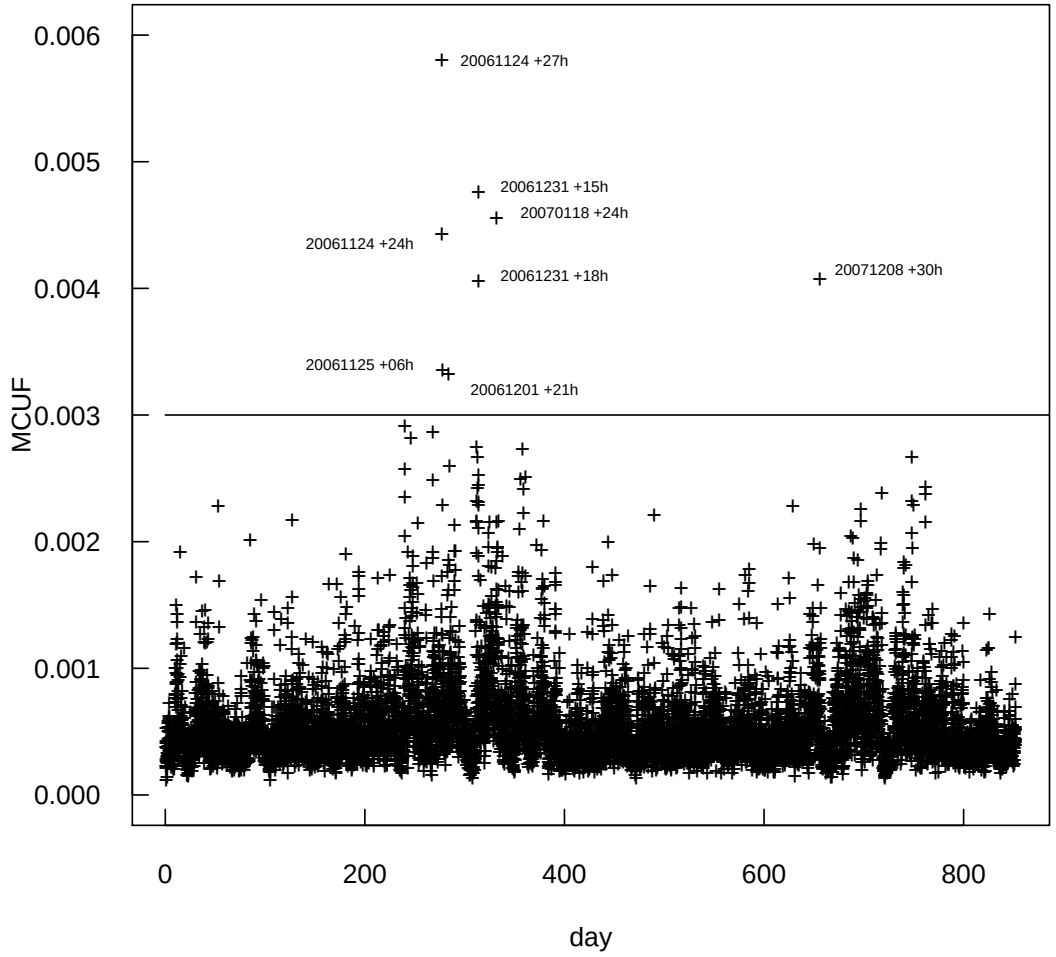
MCUF

This MCUF field is operationally computed in ARPEGE and written to the coupling files of the ALADIN models. We considered it in the frame (solid line) covering the Davies zone (dashed),



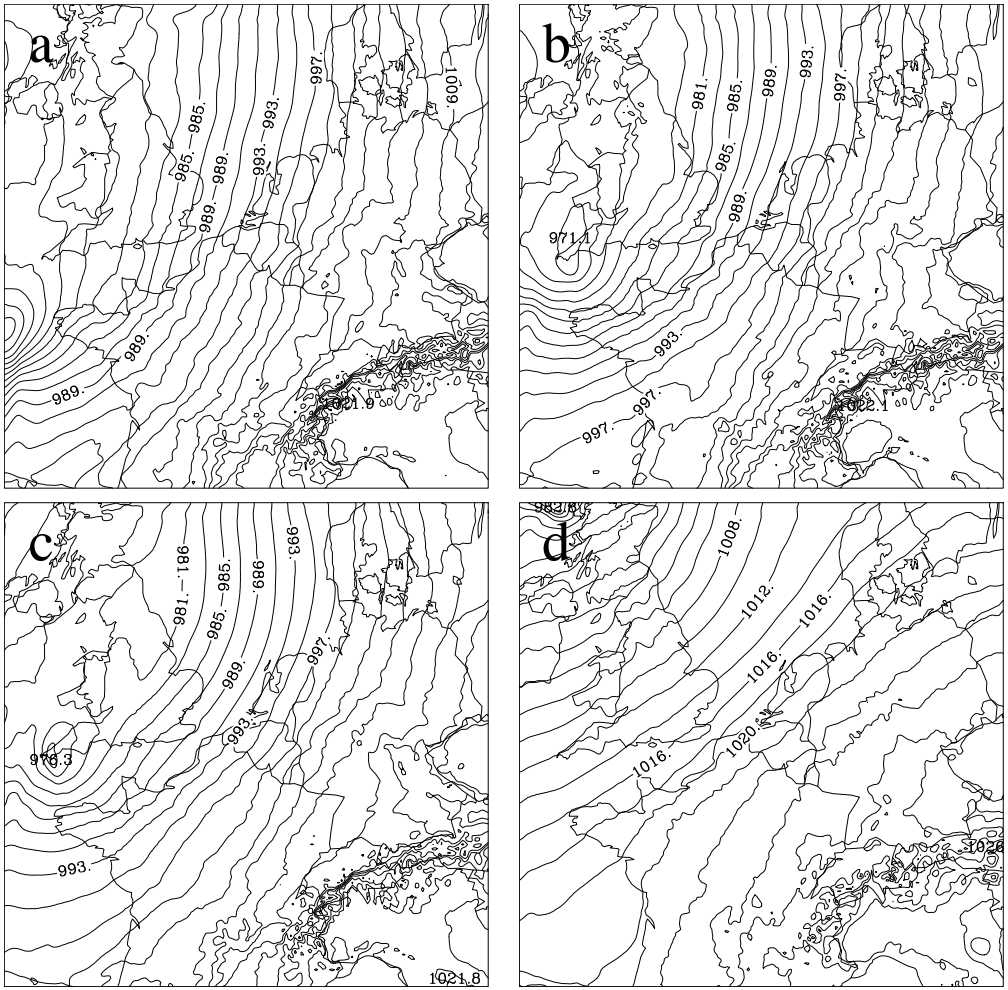
The maximum MCUF in the frame

in the period 21 February 2006 – 30 June 2008

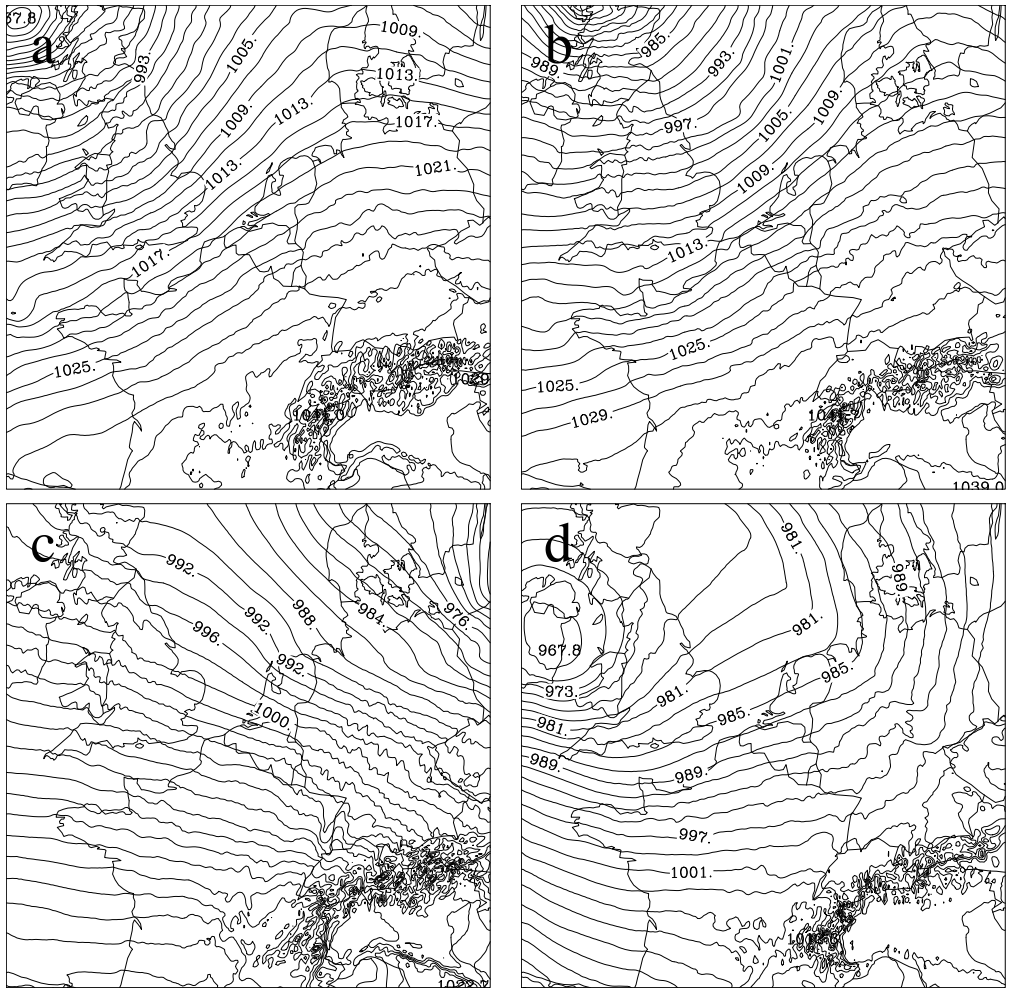


Let us consider a threshold value of 0.003. Then we had 8 alerts.

The cases


a
985.
989.
993.
997.
1009.
989.
1021.9
b
971.1
981.
985.
989.
993.
997.
1022.1
c
976.3
981.
985.
989.
993.
997.
993.
1021.8
d
1008.
1012.
1016.
1016.
1020.
1016.
1026

The cases continued



What to do?

We could now

- couple with roughly 20 min. But this will be pratically be the time step of the global models. So they will be forced to do IO all the time, or
- invent something new:
- we studied boundary-errror restarts (BER). Termonia, Deckmyn, Hamdi (2009)

The maximum MCUF in the frame

date	MCUF time	MCUF value	type	BER time	figure
2006/11/24	+24h	0.0044	*incoming*	+27 h	7a
	+27h	0.0058			7b
2006/11/25	+06h	0.0033	*incoming*	+09 h	7c
2006/12/01	+21h	0.0033	corner (NE)	+24 h	7d
2006/12/31	+15h	0.0047	tangent	+18 h	8a
	+18h	0.0040			8b
2007/01/18	+24h	0.0045	outgoing	+ 30 h	8c
2007/12/08	+30h	0.0041	*incoming*	+ 33 h	8d

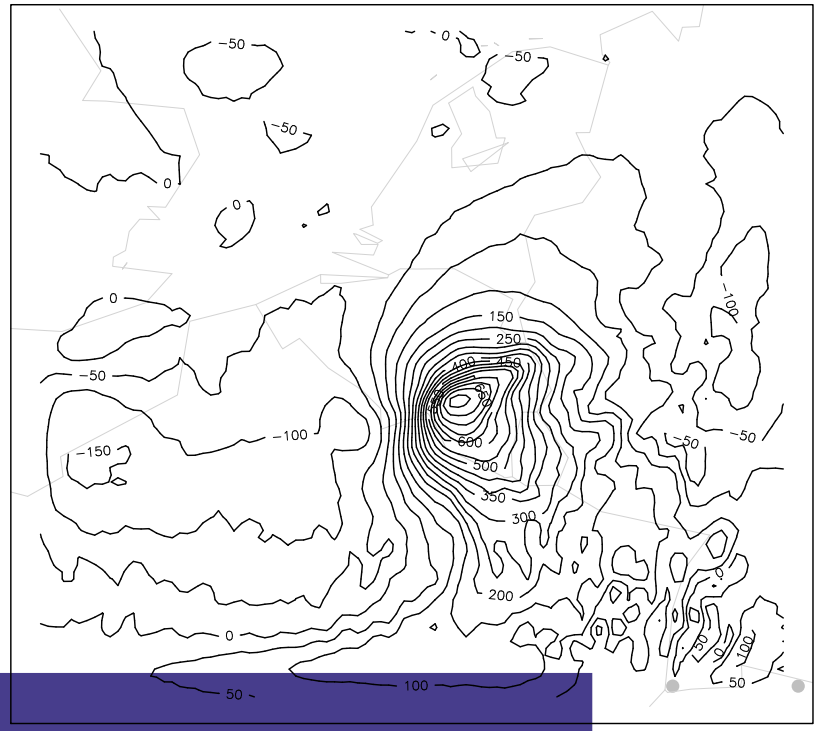
So we only have to do something a few times per year. For the rest it is business as usual: 3h coupling!

Proposal: we carry out a restart 3 hours later than the MCUF alert. *Boundary-Error Restarts* (**BER**).

DFI

However these restarts should be initialized by a DFI!!!

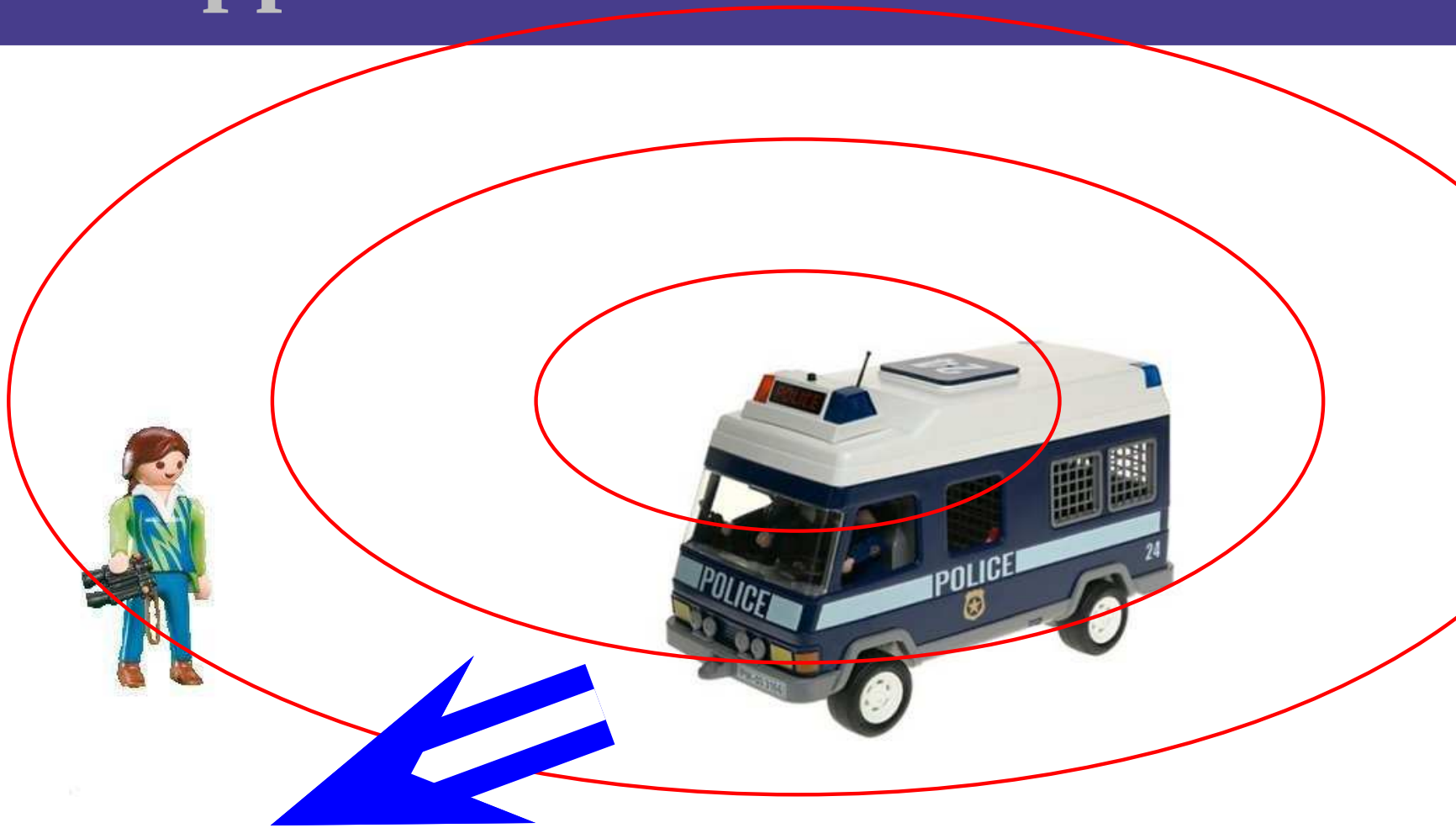
MSLP 26/12/1999 +9h
DFI(3h) − no DFI



max difference of about 8.5 hPa!

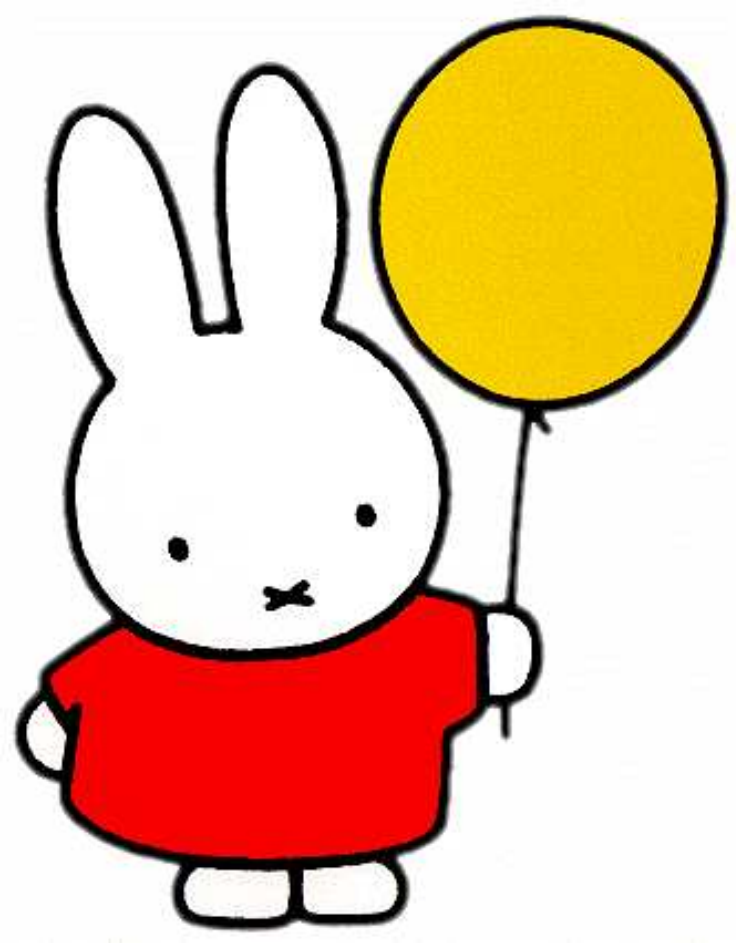
The Doppler effect

The Doppler effect

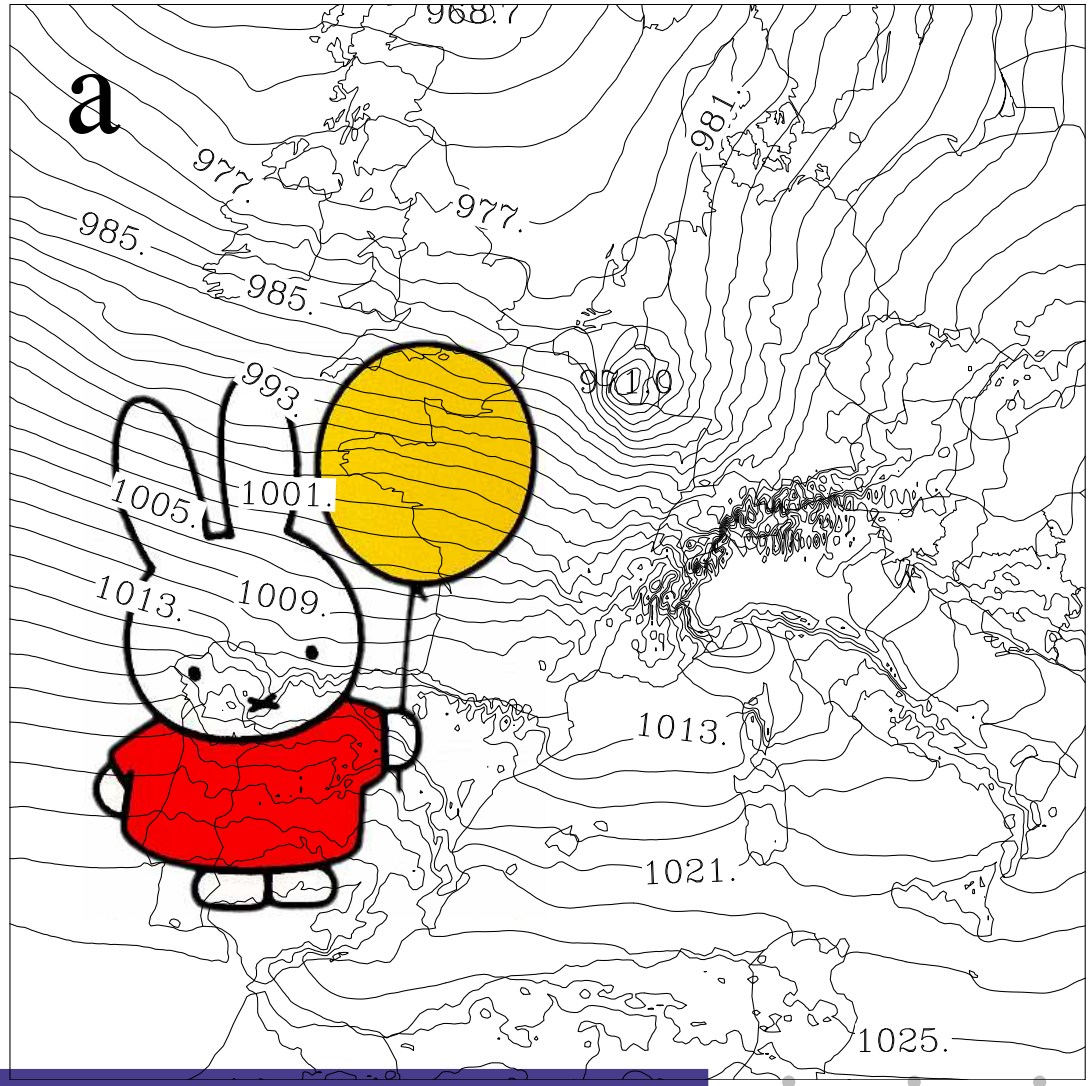


$$\omega = \omega_{siren} + v\,\kappa \qquad with \qquad \kappa = \frac{2\pi}{L}$$

Consider a (Dutch) meteorologist



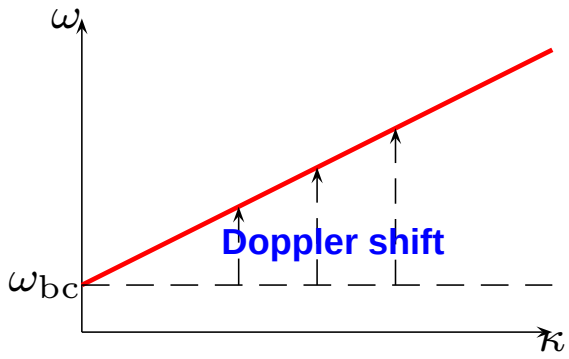
... in a French Storm (Lothar):



For waves superposed on a large-scale flow, we also have a Doppler effect for each mode

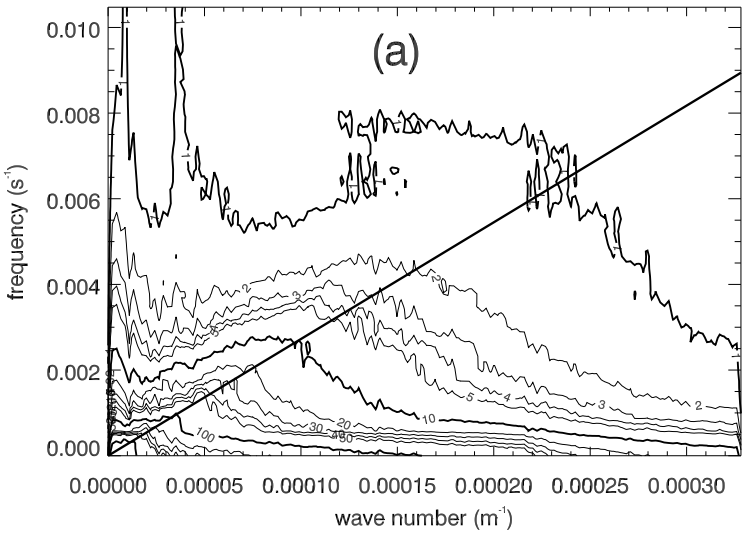
$$\omega = \omega_{\mathrm{bc}} + c\,\kappa$$

with (baroclinic) frequency ω_{bc}, the deeping of the storm is a time evolution that gets shifted.

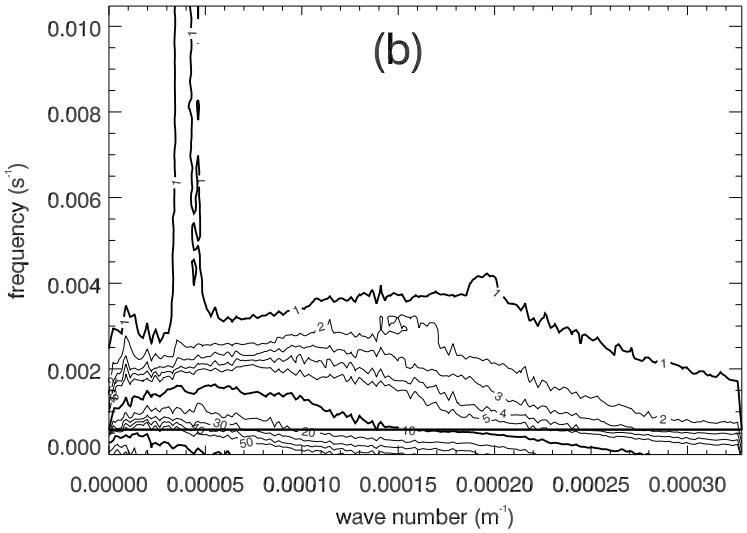


spectrum in time AND space

Termonia, 2008, MWR

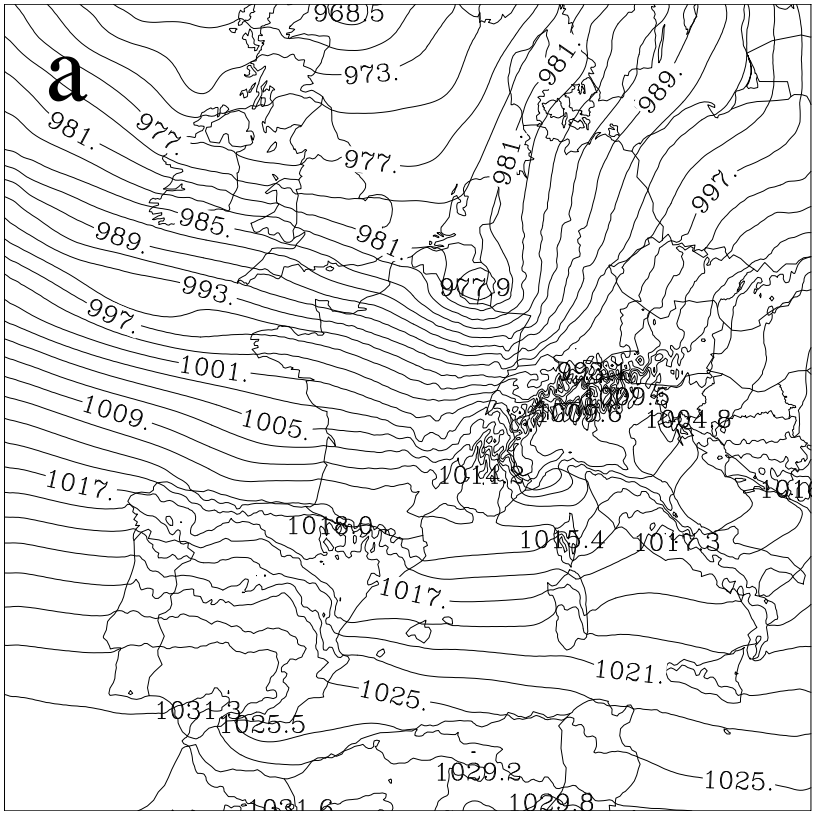


The Lothar storm $\ln p_s$ decomposed between 0600 UTC and 1200 UTC on 28 December 1999. The thick line is the propagation speed of the storm in this time interval: 98 km/h.

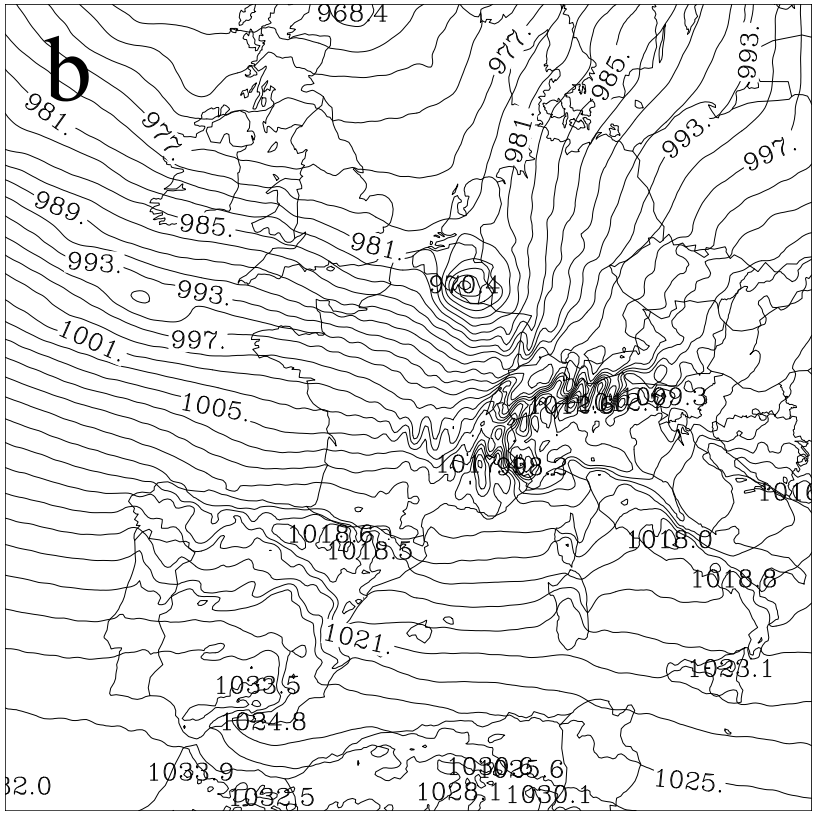


$\ln p_s$ decomposed between 0600 UTC and 1200 UTC of an anticyclonic case on 28 December 1999. The thick horizontal line corresponds to a filter cut-off period of 3 h.

The effect of a DFI

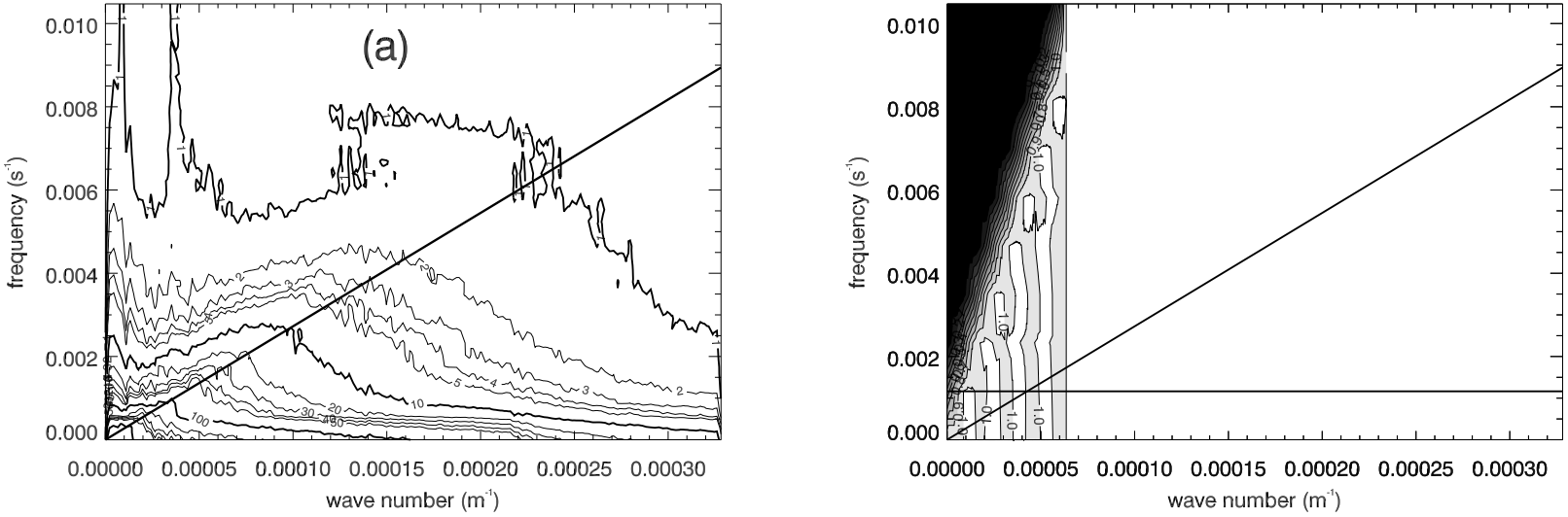


The result of a standard (operationally) used DFI (**977.9 hPa**).



ALADIN forecast after developping for 9 h (**970.4 hPa**).

Scale-selective low-pass windows

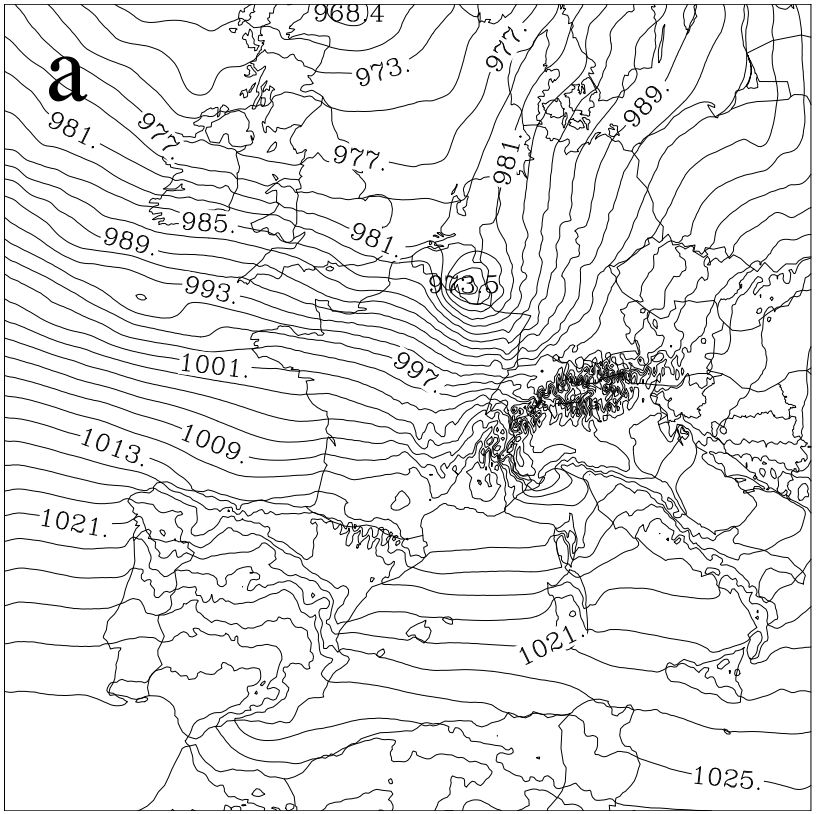


The *scale-selective* cut-off frequency of a low-pass Lancsoz filter:

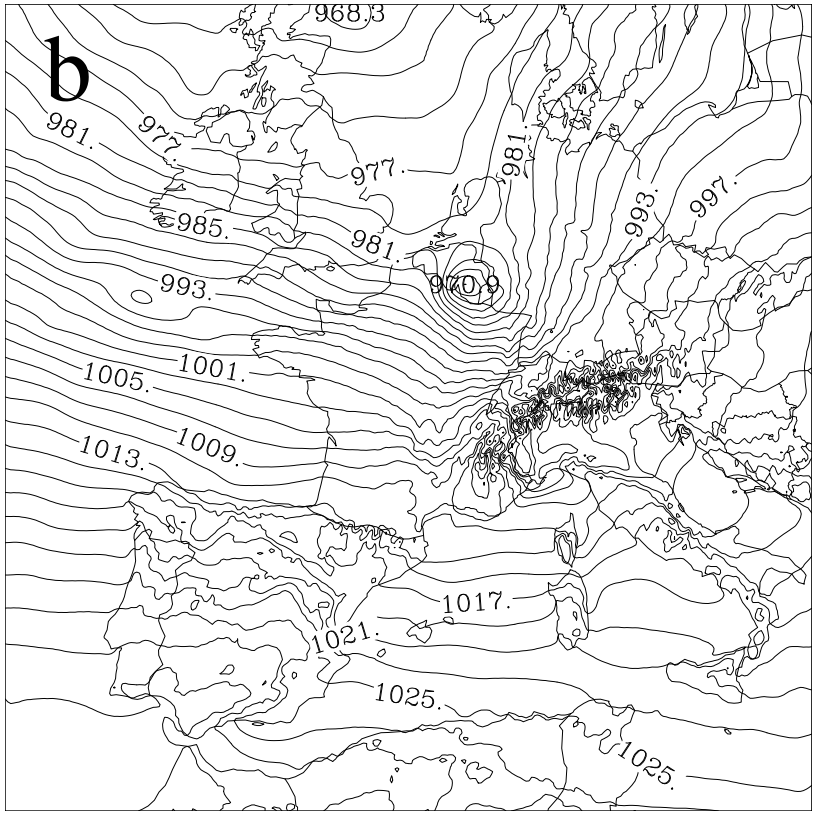
$$\omega_c(\kappa) = \begin{cases} \omega_c^0 + \frac{\kappa}{\kappa_c}\left(\frac{\pi}{\Delta t} - \omega_c^0\right) & \text{if} \quad \kappa \leq \kappa_c \\ \frac{\pi}{\Delta t} & \text{if} \quad \kappa > \kappa_c \end{cases}$$

The cut-ott period is $T_c^0 = 2\pi/\omega_c^0$ while the *slope* of the cut-off frequencies is $c = \pi/(\kappa_c \Delta t)$.

Results:



a run with $T_c^0 = 3h$ (**973.5 hPa**).

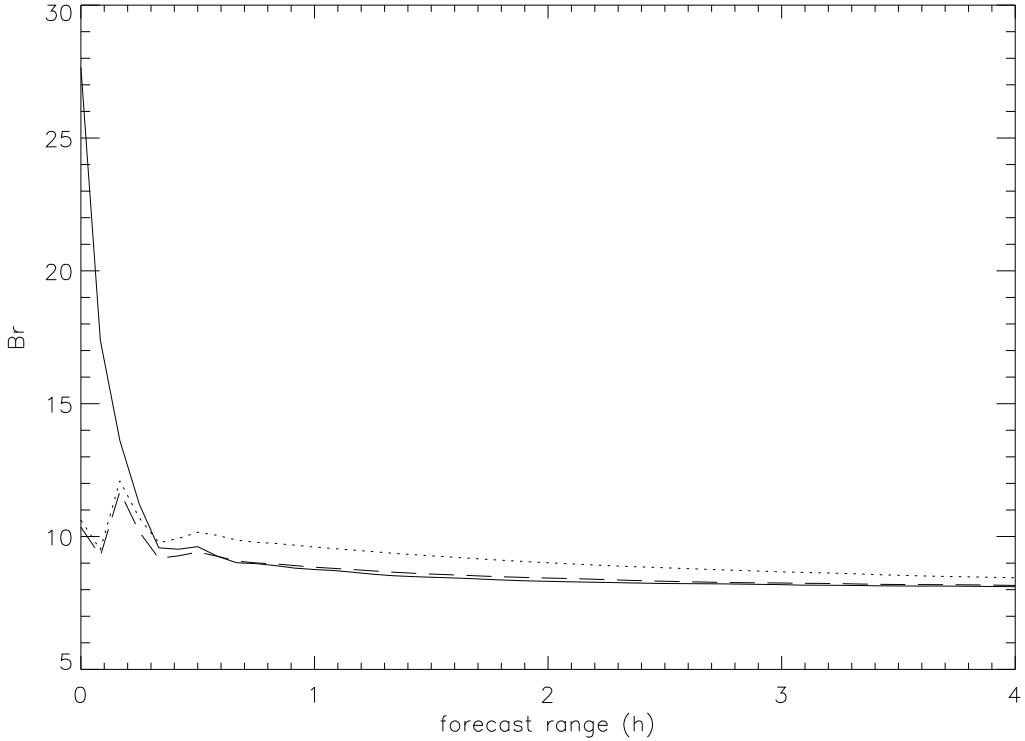


a run with $T_c^0 = 1.5h$ (**970.9 hPa**).

But what about the balance?

Balance

$$Br = 100\,\frac{\sum_{IJ}\left|\sum_{L}\nabla\cdot\Delta p_L\mathbf{V}_{IJL}\right|}{\sum_{IJ}\sum_{L}\left|\nabla\cdot\Delta p_L\mathbf{V}_{IJL}\right|}$$ (Lynch and Huang, MWR, 1992)

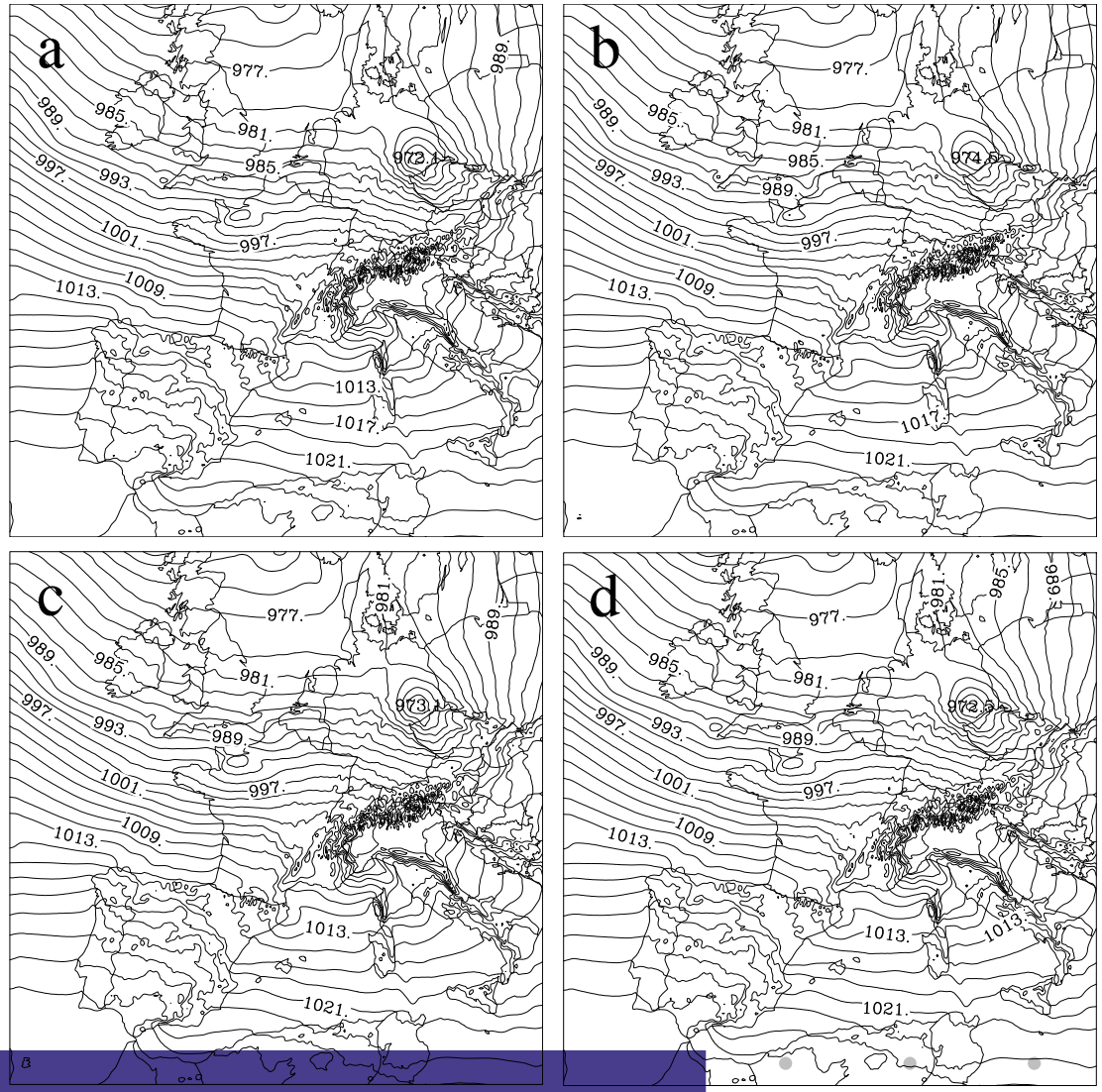


solid: uninitialized
dots: full DFI
dashed: $\mathrm{SSDFI}_{1.5\mathrm{h}}$
There are 2 surprises:

- filtering *less* ($\mathrm{SSDFI}_{1.5\mathrm{h}}$) $\Rightarrow$ *more* balanced!
- but, full DFI is *worse* than uninitialized after *half and hour*!?

DFI actually creates an unbalance in the *slow* part of the part of dynamics! So it needs a longer time to adjust.

After 6 h, i.e. at 1500 UTC 26 Decemb

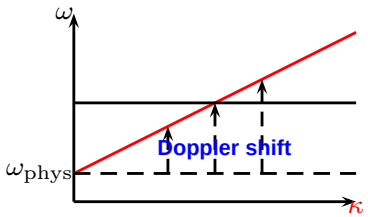


- (a) no initialization (972.4 hPa),
- (b) $\mathrm{DFI}_{3\mathrm{h}}$ (974.5 hPa),
- (c) $\mathrm{SSDFI}_{3\mathrm{h}}$ (973.1 hPa),
- (d) $\mathrm{SSDFI}_{1.5\mathrm{h}}$ (972.5 hPa).

So the improvement carries over later in the forecast.

going to higher resolution

ALADIN$_{10\mathrm{km}} \longrightarrow$ AROME$_{2\mathrm{km}}$: problems smaller with ($5\times$) propagation speeds:



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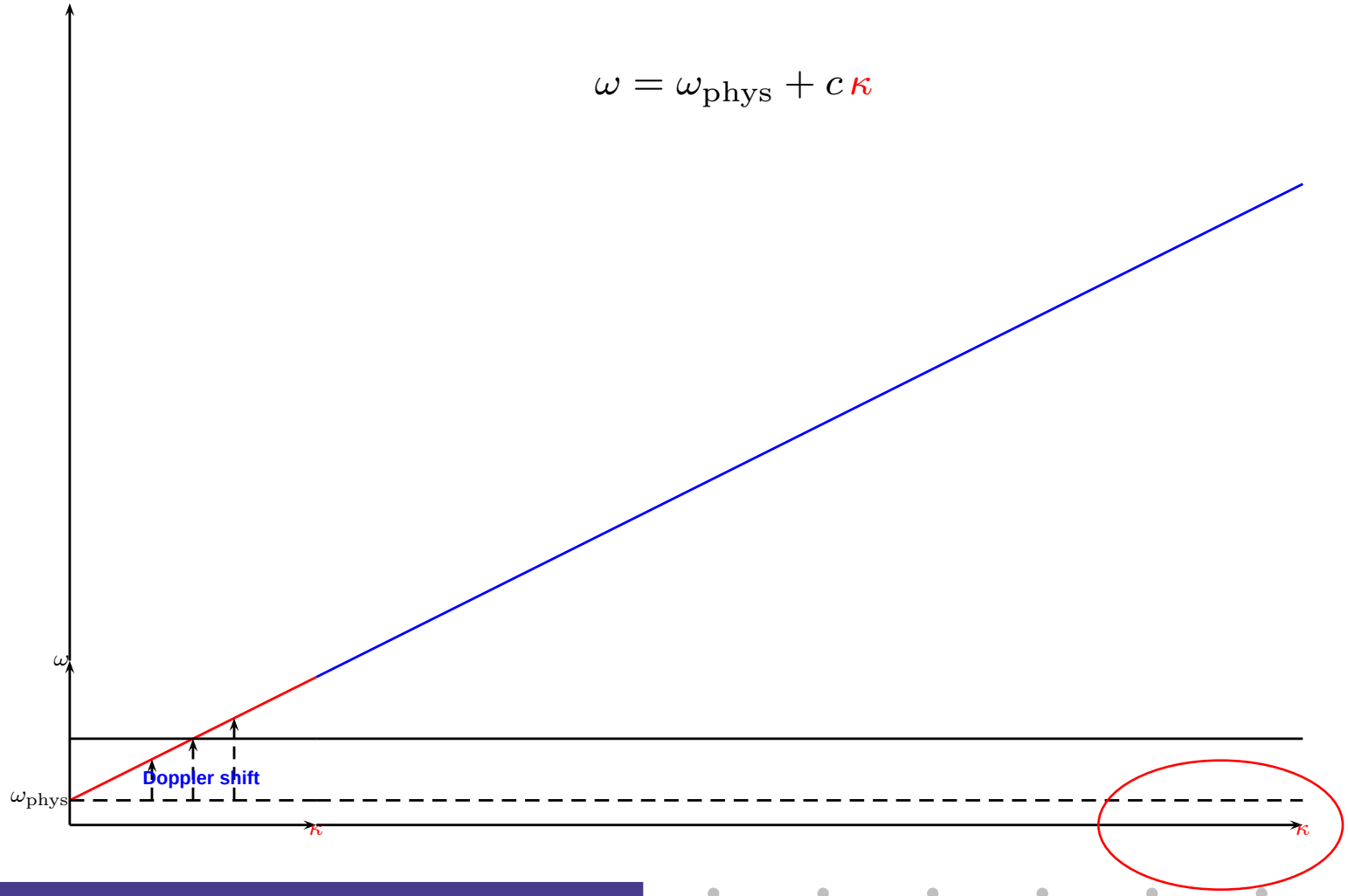

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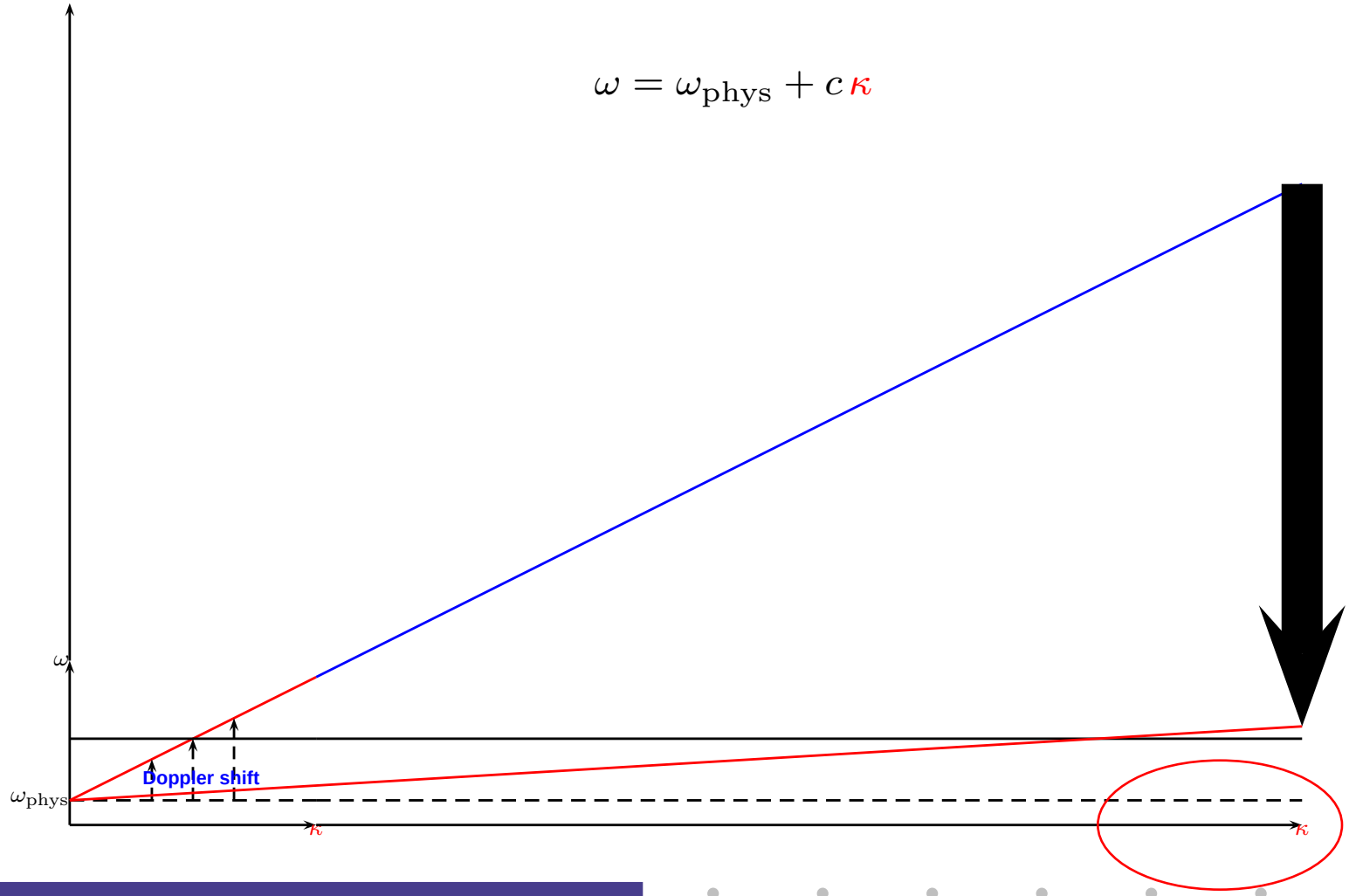
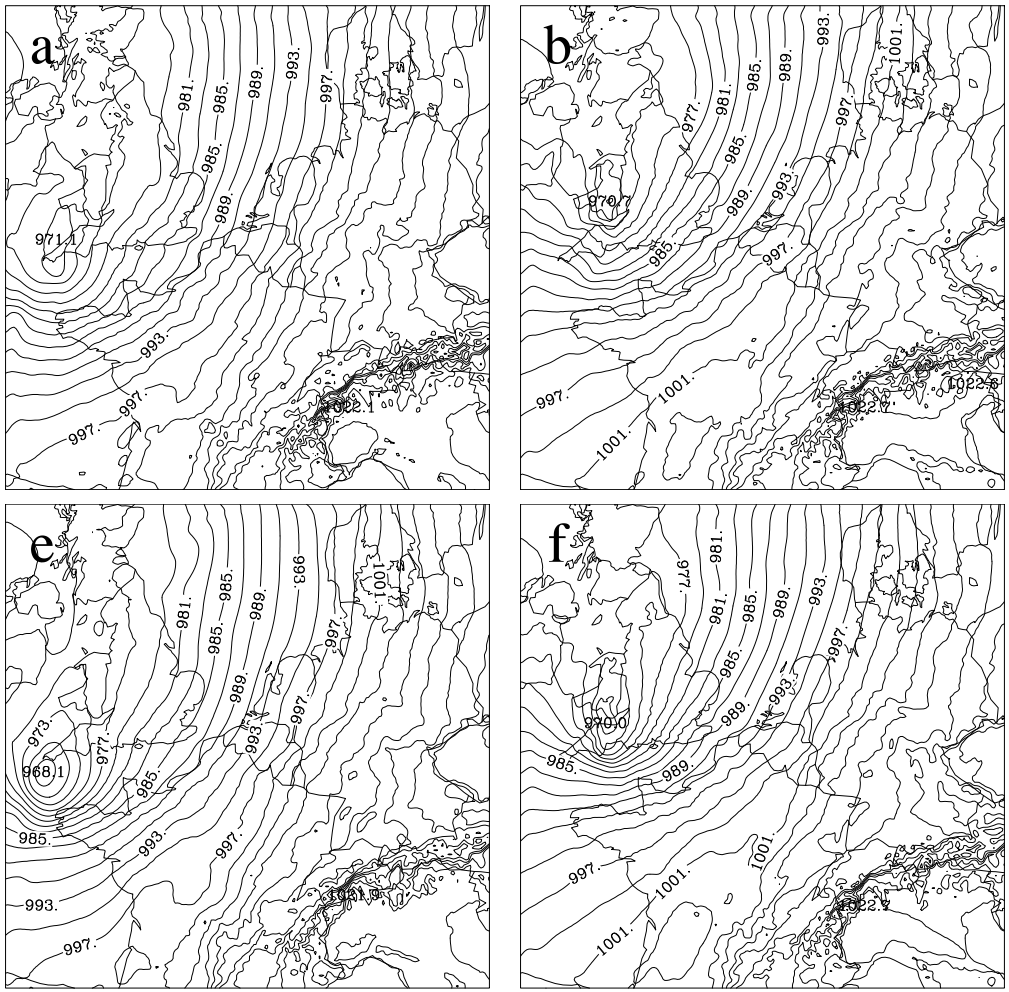


Improvements by a restart with SSDF



- (a) 27-h forecast range (low 971.1 hPa), the
- (b) 30-h forecast range (970.7 hPa) of the 0000-UTC forecast on 24 November 2006;
- (e) BER run performed at 27-h forecast range at 0300 UTC (968.1 hPa) and
- (f) 0600 UTC 25 Novem-ber 2006 (970.0 hPa).

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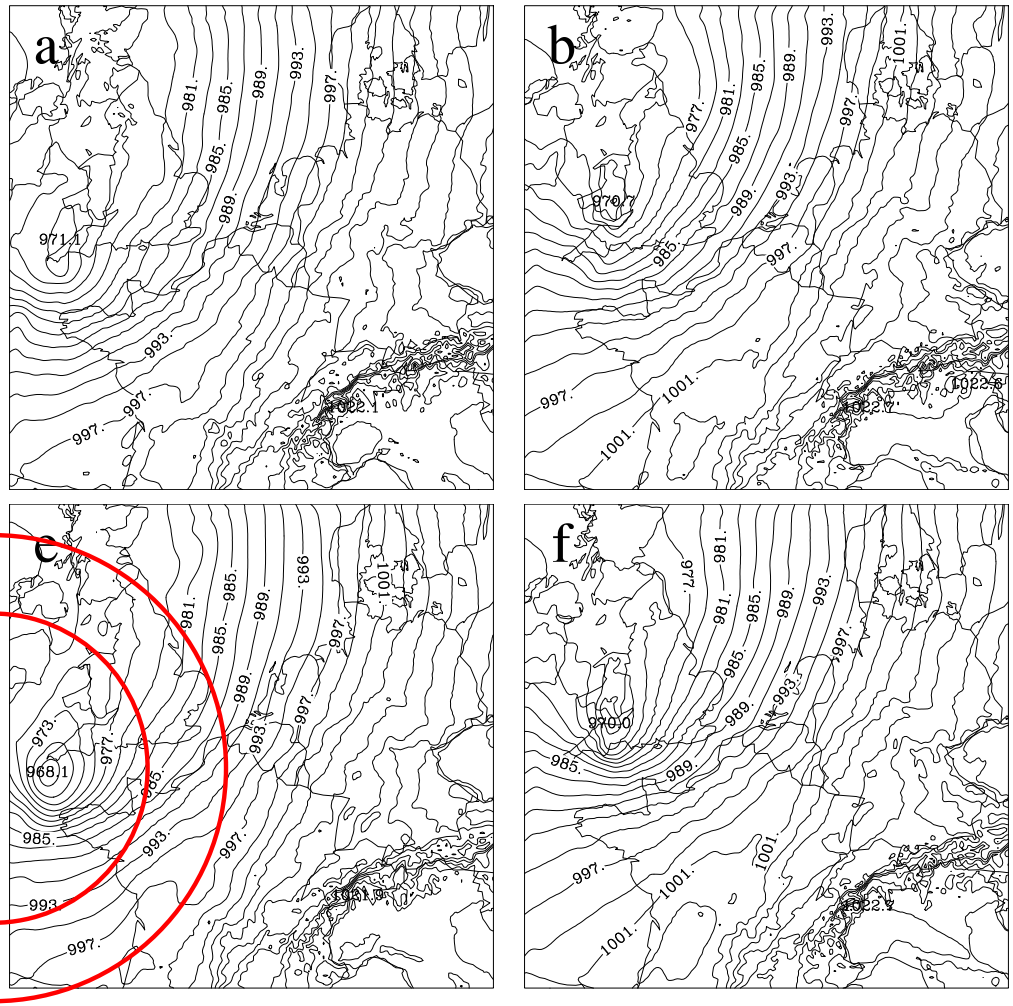

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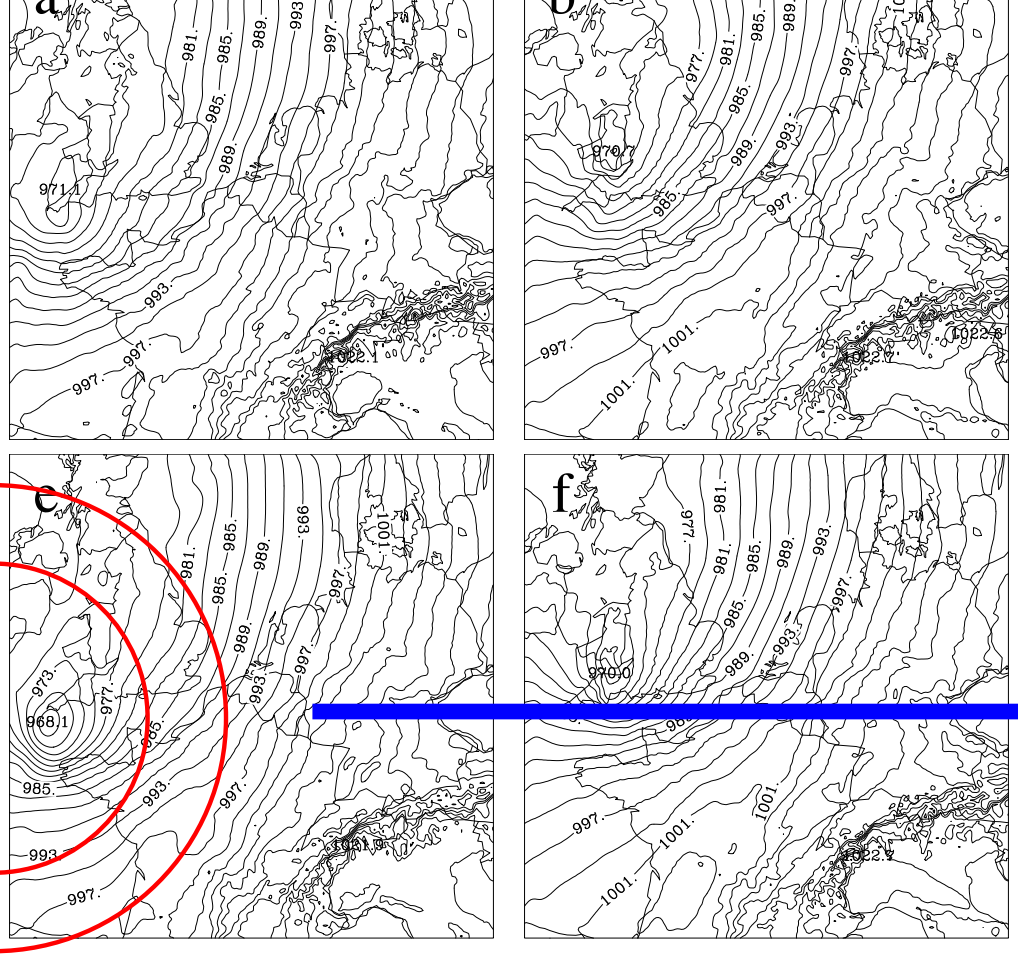

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Transparent LBC's

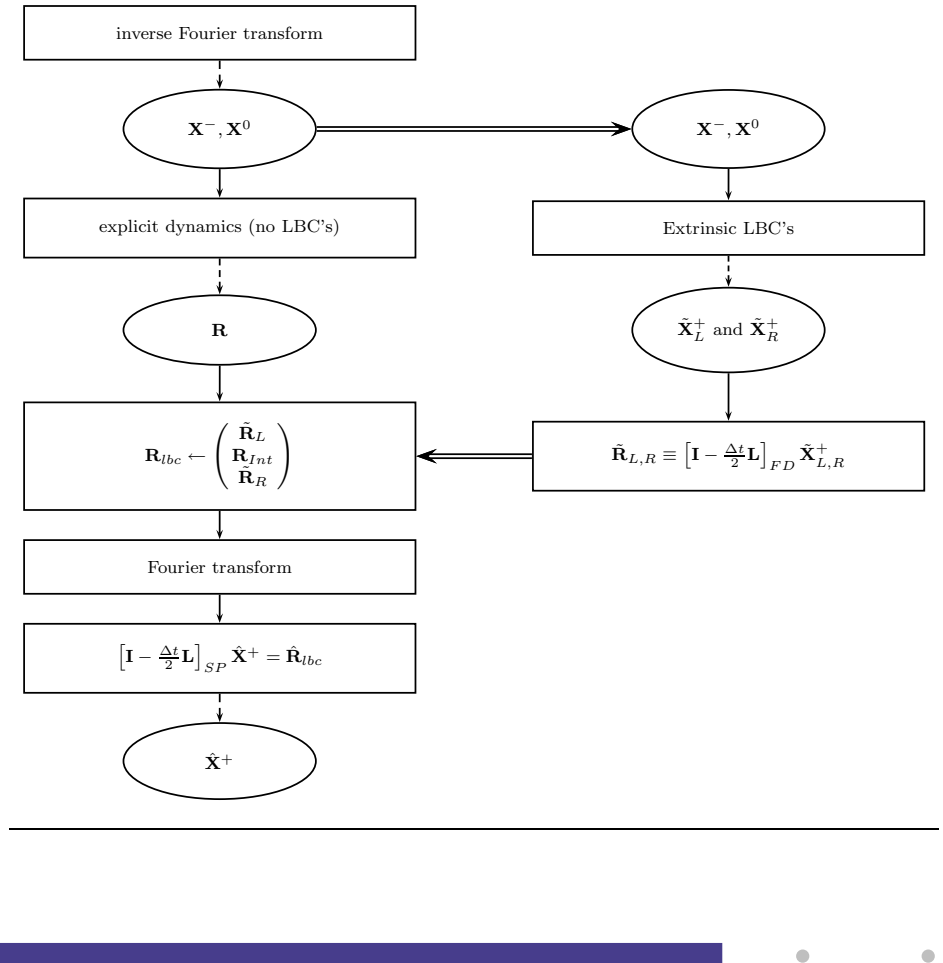
- For this part of the NWP models we cannot make any compromise ragrding the accuracy
- We *have* to correctly distinguish between the incoming and outgoing part of the signal, which is essentially a purely mathematical problem.
- After you know how to do this you can think about efficiency.
- If not, one will always sooner or later need to filter and create some Davies scheme solution.

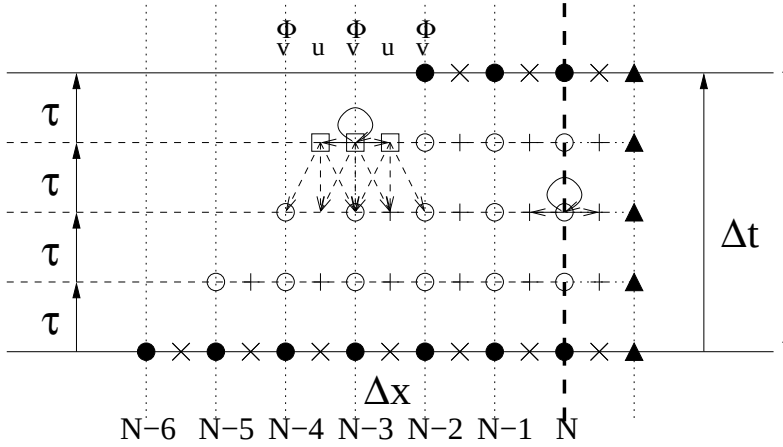
Extrinsics LBC's

In fact the idea here was to start from a numerical system that allows to have the mathematical solution (on paper) as accurate as wanted without bothering about computational efficiency. Afterwards we will look for compromises.
... as opposed to starting from the existing solutions (e.g. iterative procedures) and trying to improve them.

Extrinsics LBC's

Termonia and Voitus, Tellus A, 2008

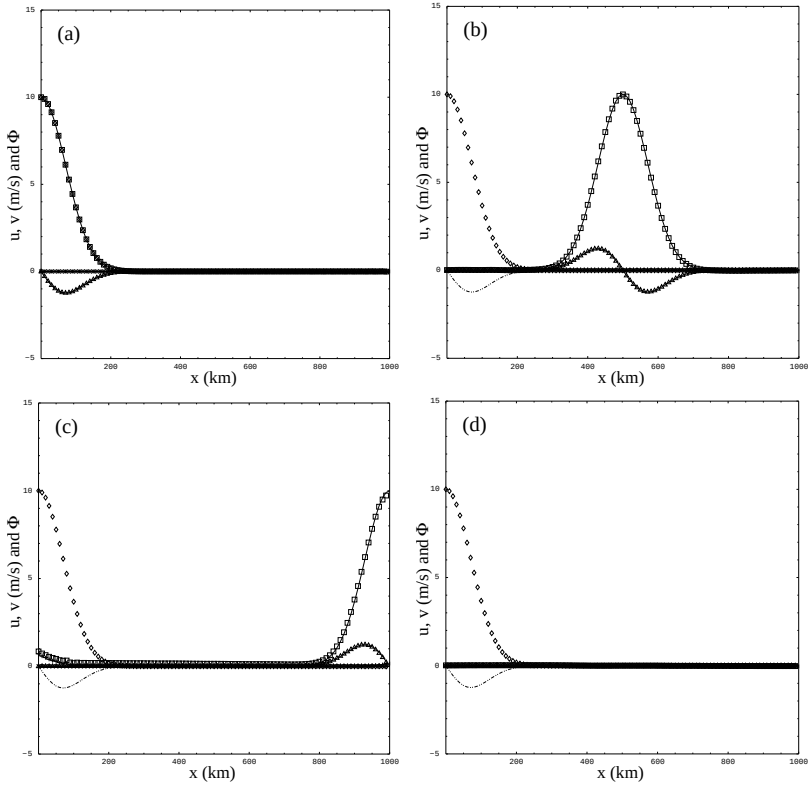




But we have to be careful about

$$\left[\mathbf{I} - \frac{\Delta t}{2}\mathbf{L}\right]^{-1}_{SP} \left[\mathbf{I} - \frac{\Delta t}{2}\mathbf{L}\right]_{FD} = \mathbf{I} + \mathcal{O}[\Delta x^n] \neq \mathbf{I}$$

Extrinsics LBC's



Time evolution of the bell-shaped solution with the SPISL scheme at times (a) $t = 0$, (b) $t = L/(2\bar{u})$, (c) $t = L/\bar{u}$, (d) $t = 3L/(2\bar{u})$, for $\Delta t = 400s$ and $\bar{u} = 12.5m/s$. The conventions are the same as in Fig. **??**.

Change perspective

You shouldn’t dream of having this in an efficient NWP context soon!

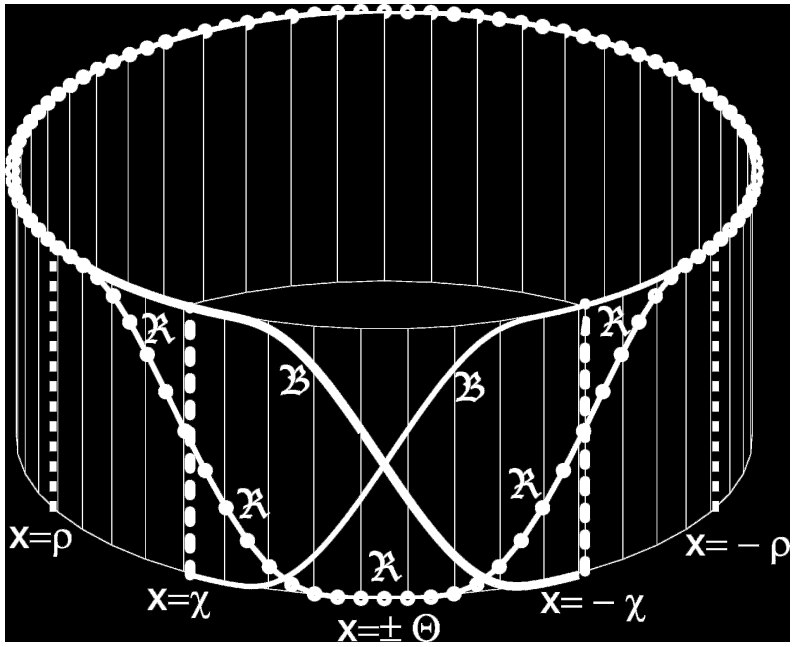
BUT, on the other hand the mathematician may help in finding wath the dicrepancy is between NWP reality and his solution, and perhaps this could be implemented, since it can be externalized.

This could also be used to perturb the boundary fields

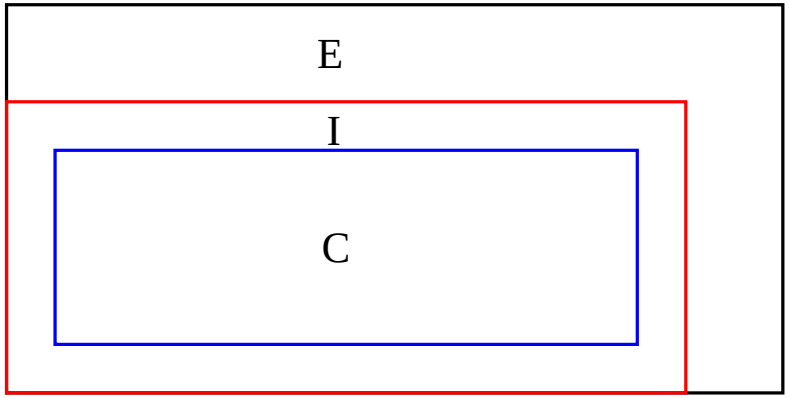
Bottleneck

- Can we have well-posed LBC's for the Euler equations?
- PhD Fabrice Voitus: we have to chose between the gravity waves and the accoustic waves.
- Topic for June 2009

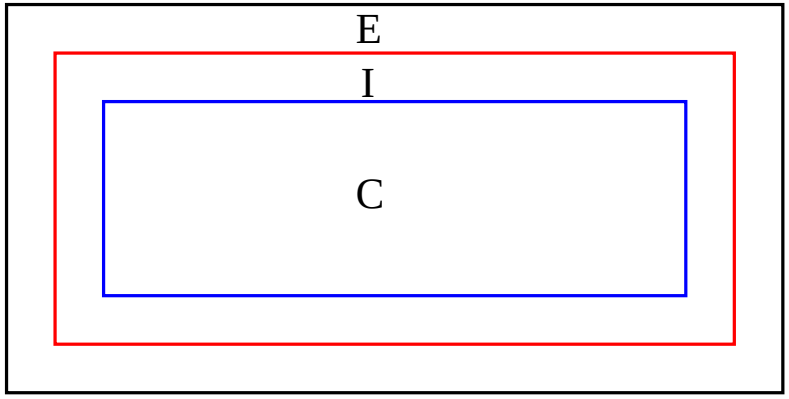
Boyd's Solution



In fact we could use the C,I, and E zone in the code



if we make it symmetric:



Feasibility studied by Benedikt Strajnar.

Quo vadis LBC's

- Experience in both the frequency analysis and trying to find better transparent formulation for the LBC's, suggests that we switch strategy from
  - trying to improved AND efficient LBC's to
  - monitoring the errors and to use them in a probabilistic manner (similar as model error).
- So research on the formulation of the LBC's is certainly justifed but gets an entirely different accent in this context.

To remember

- A Doppler effect may shift the meteorologically relevant features into the frequency domain that are believed to be the one of the gravity waves.
- When we go to higher resolution there will be a time when DFI will start to filter out the features we assimilate at those scales we are interested in.
- MCUF provides a way to estimate the error at the boundaries. This could be used to “perturb” fields near the boundaries in an ensemble kind of way.