

Digital Filter Initialization and Numerical Weather Prediction

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DFI & NWP

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Outline

1. Initialization - what we are talking about
2. Noise - what we normally (not) look for
3. DFI
 - The idea of filtering
 - Implemented options in WRF
 - Some results
4. Summary

Initialization

- Not SI or WPS
- Not Bogusing
- Not analysis (Nudging, OI, 3/4D-Var, EnKF, etc)
- ...

- Roger Daley (Atmospheric Data Analysis, 1991):
“Integration of the primitive equations requires the modification of the initial state to prevent the excitation of inertia-gravity modes. This process is called *initialization*.”

- Examples of initialization schemes:
 - NNMI (Machenhauer, 1977)
 - **DFI** (Lynch and Huang, 1992)

Why?

- **To remove noise due to the imbalances between the wind and mass in the initial fields.**
 - **The imbalance can be introduced, e.g., by objective analyses or by simple interpolations.**
 - **The noise could cause spurious precipitation, lead to numerical instabilities, degrade the forecast, and *damage the subsequent data assimilation* through noisy first-guesses.**
- **To construct consistent fields which are not analyzed or do not exist initially, e.g., cloud water content, vertical velocity.**
- **To reduce the spin-up problem in the early stage .**

Where?



The first NWP made by Richardson



Richardson, 1922

Weather Prediction by Numerical Process

$$\frac{\partial u}{\partial t} - fv + \frac{\partial}{\partial x} \left(\frac{p'}{\rho_0} \right) = 0$$

$$\frac{\partial v}{\partial t} + fu + \frac{\partial}{\partial y} \left(\frac{p'}{\rho_0} \right) = 0$$

$$\frac{\partial}{\partial t} \left(\frac{p'}{\rho_0} \right) + gH \nabla \cdot \mathbf{V} = 0$$

V	U*	P*	V	U*	P*	
	P	U	V*	P	U	V*
V	U*	P*	V	U*	P*	
	P	U	V*	P	U	V*

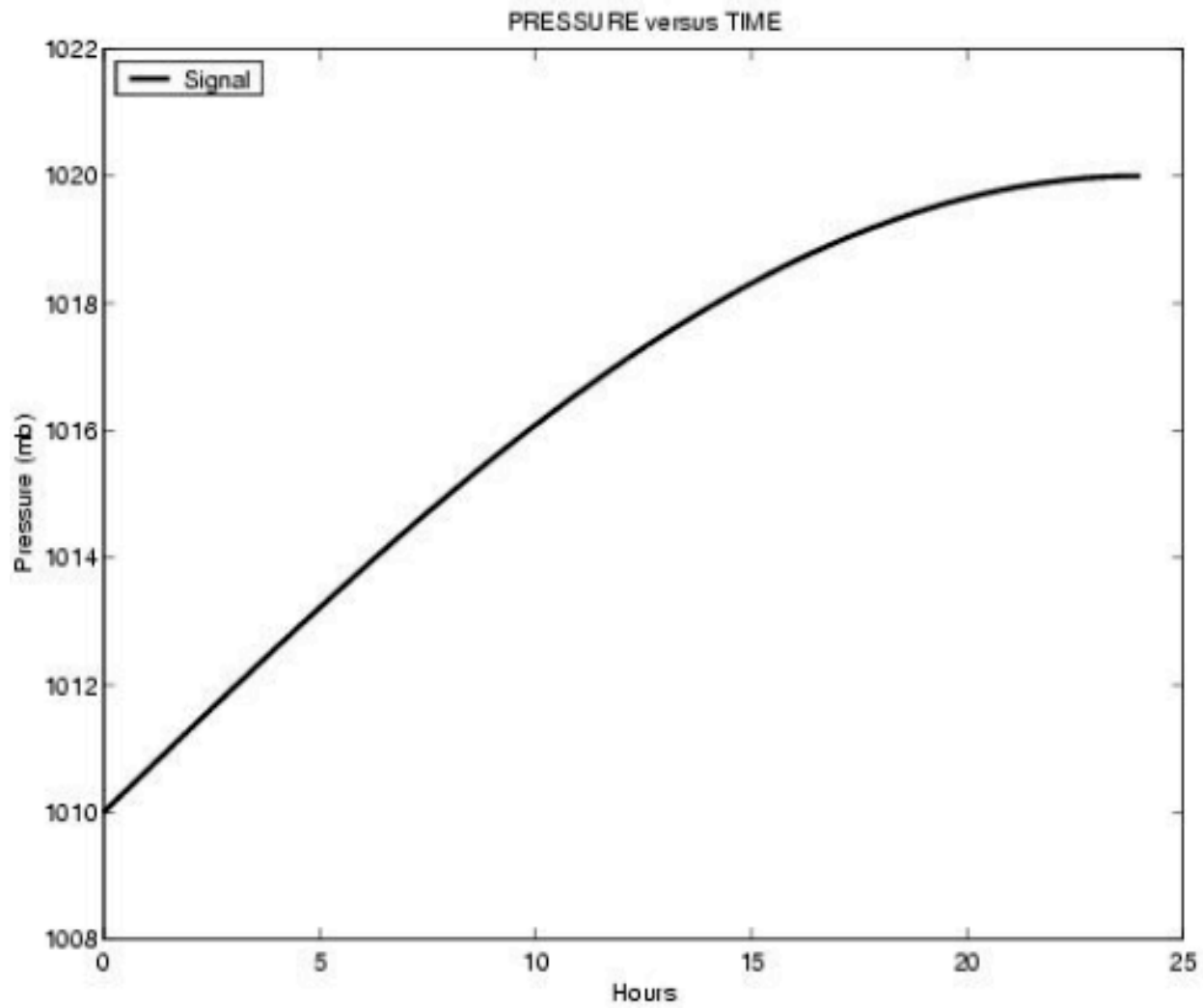
Richardson's failure: a change in surface pressure of 145 hPa in 6 hours!

Richardson's Marvelous Forecast (Lynch 1999)

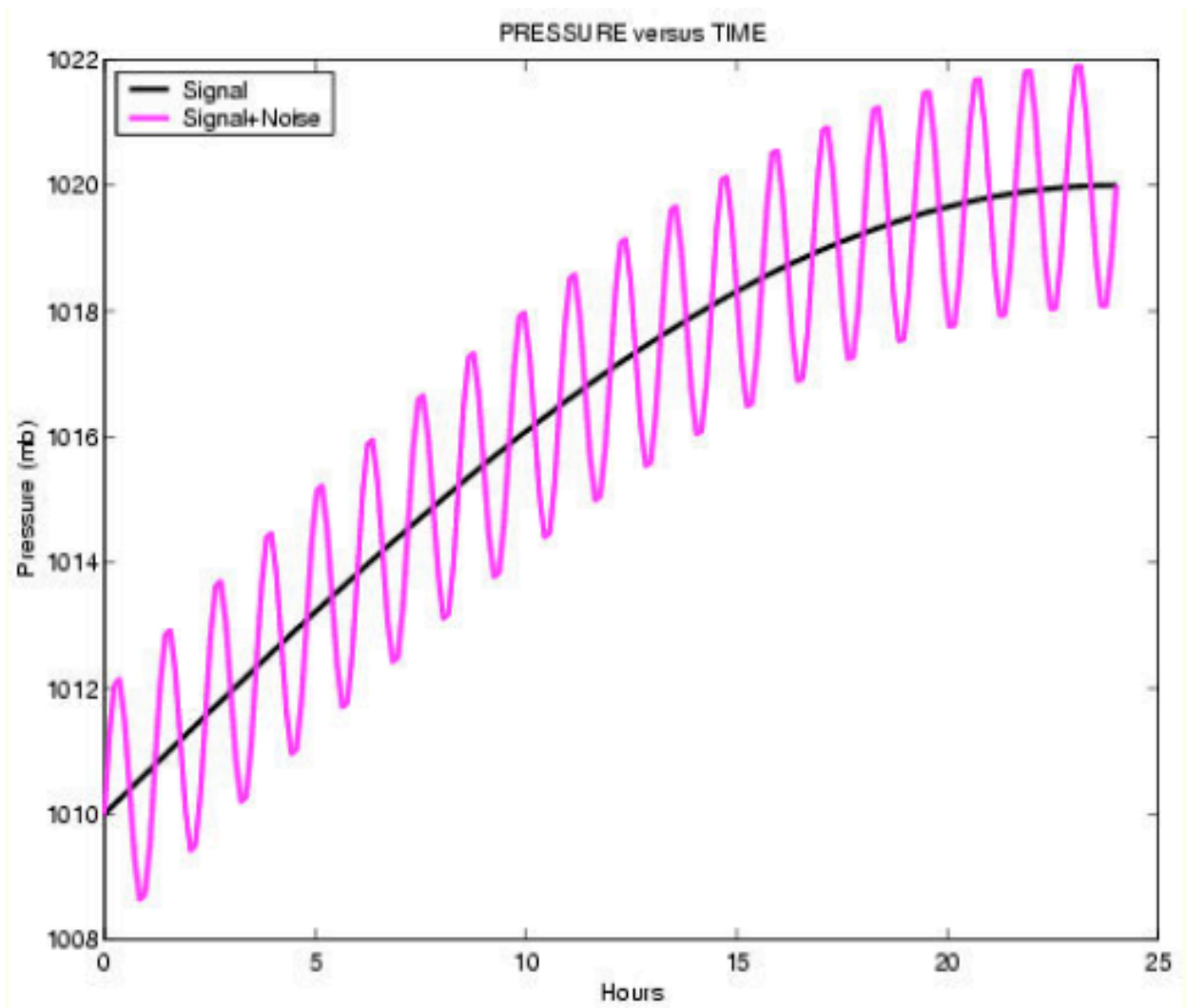
Six-hour changes in pressure

Level	LFR	MOD
1	48.3	48.5
2	77.0	76.7
3	103.2	102.1
4	126.5	124.5
Surface	145.1	

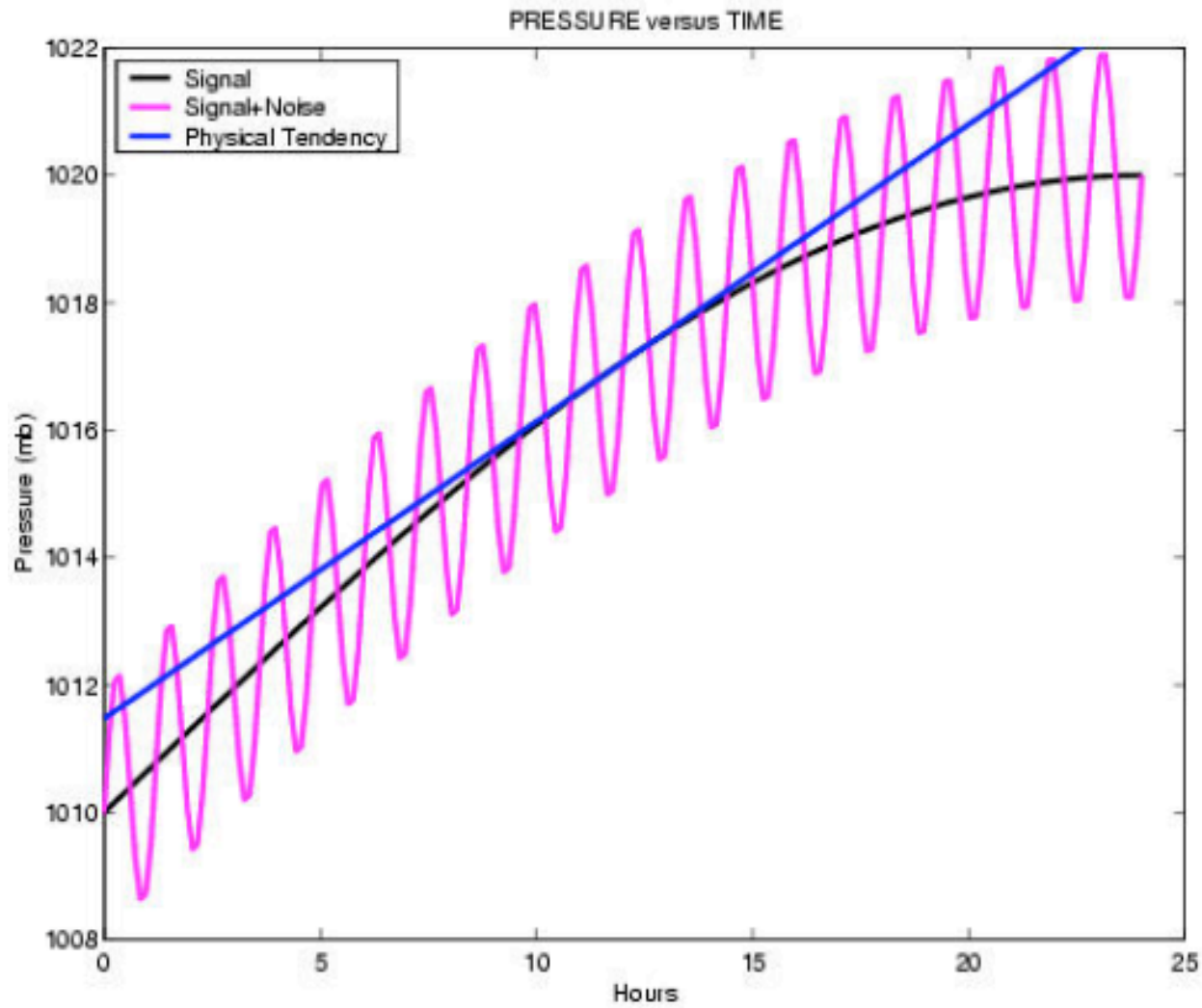
Signal



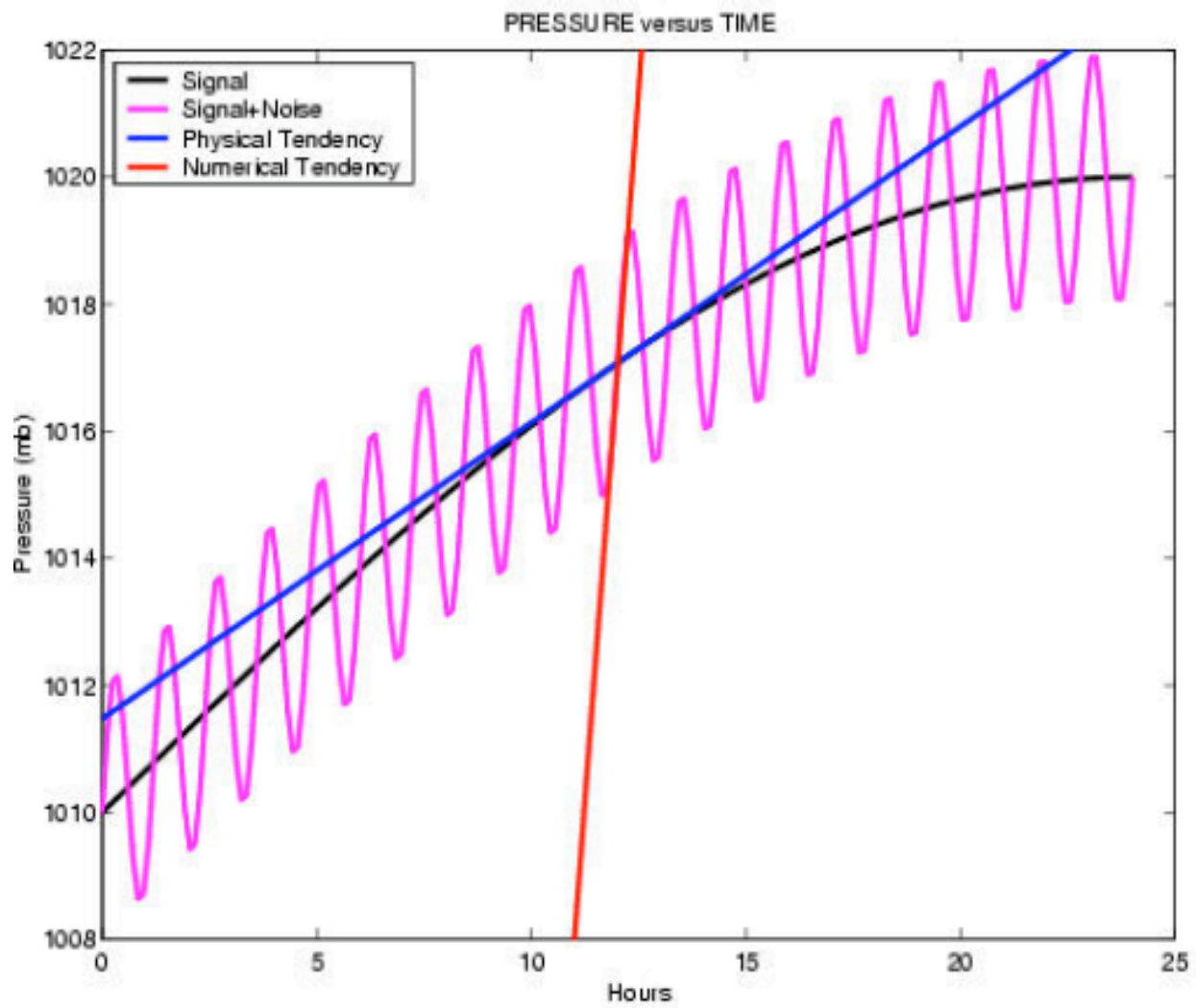
Signal + Noise



Tendency from signal

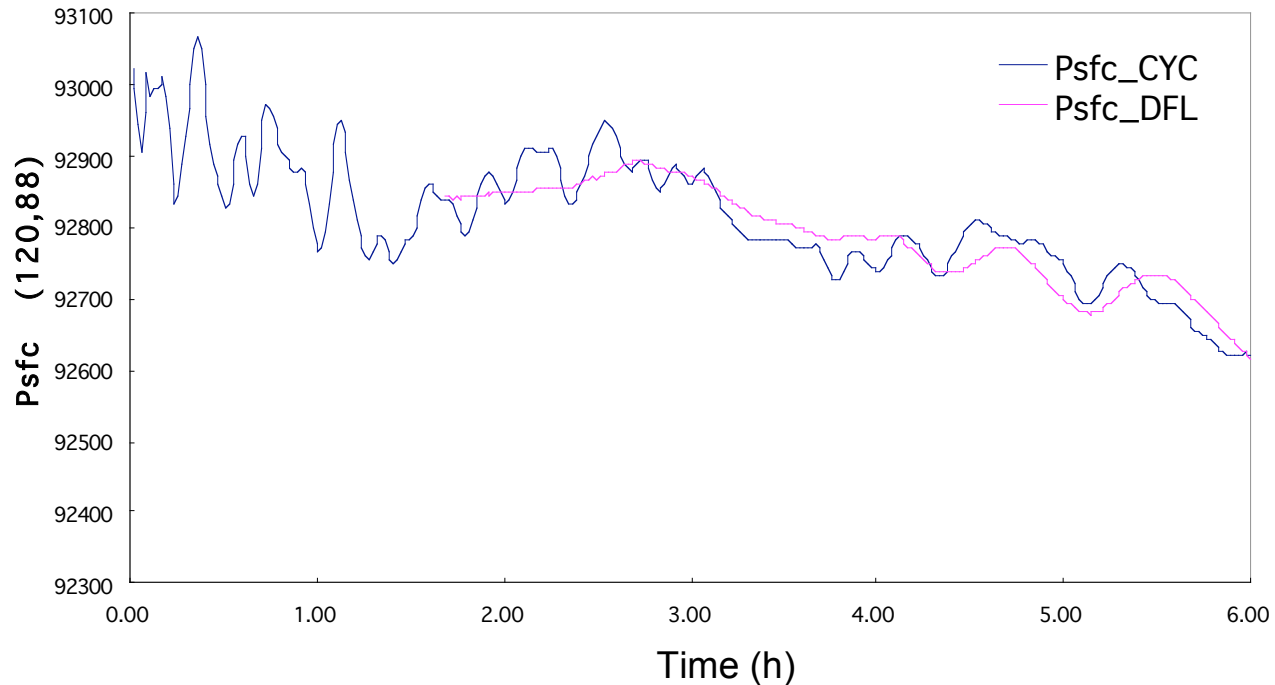


Tendency from noisy signal



Example. Surface pressure at one model grid point in a WRF model integration.

- I have seen this in many models...
- You can (should) try to find such a point in your model!



Noise in WRF!

-63.29 (-126.58/6h)

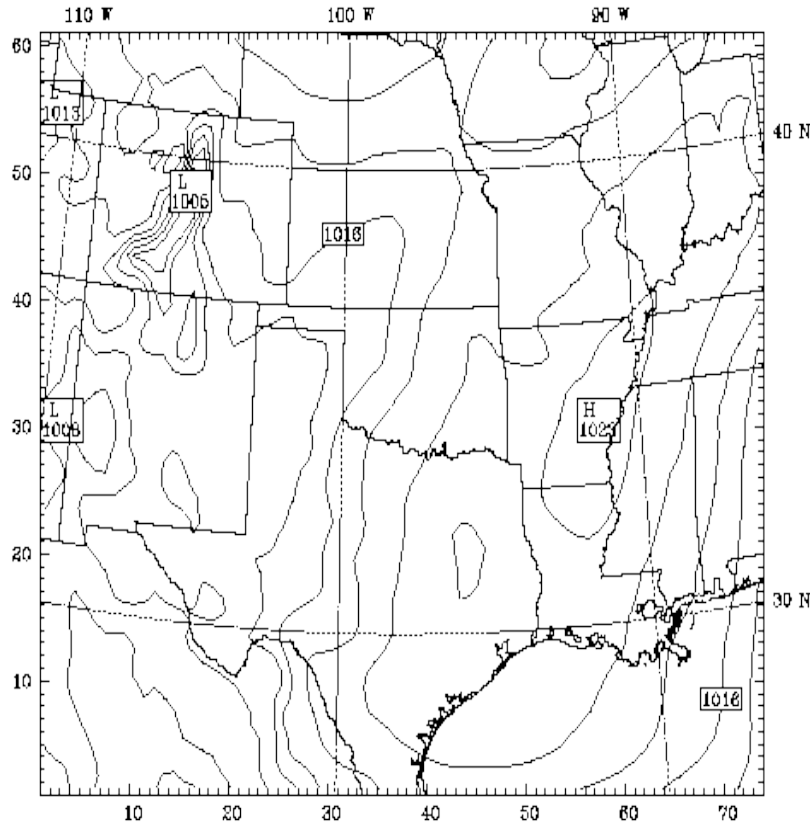
Dataset: mytest RIP: rip
 Test: 0.10
 Sea-level pressure

Init: 0000 UTC Tue 25 Jan 00
 Valid: 0006 UTC Tue 25 Jan 00 (1706 MST Mon 24 Jan 00)

Dataset: mytest RIP: rip
 Test: 0.10
 surface pressure tendency

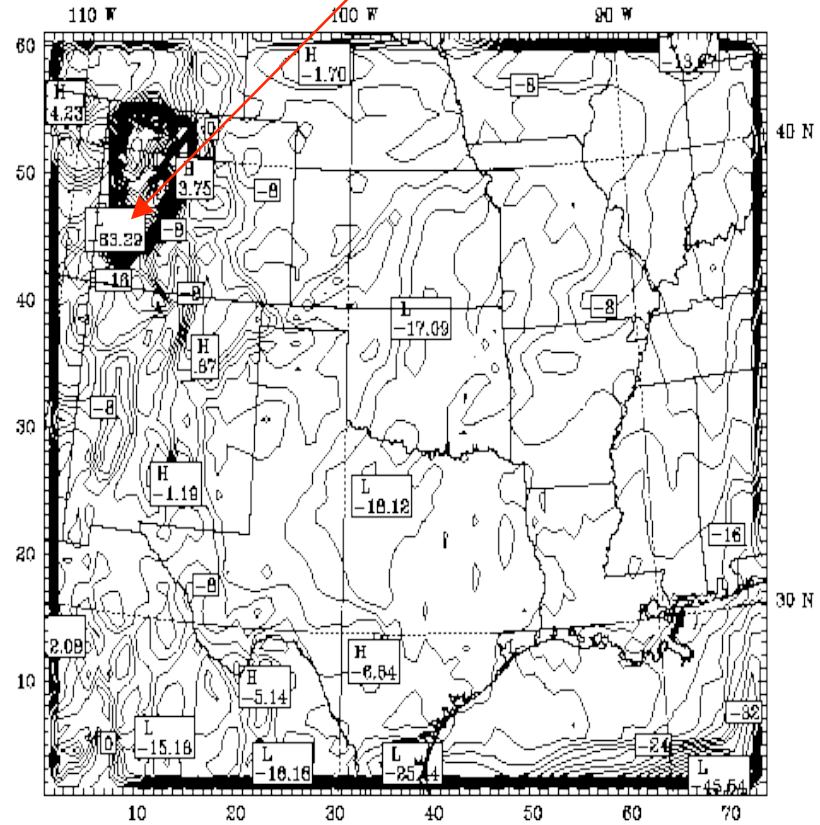
Init: 0000 UTC Tue 25 Jan 00
 Valid: 0006 UTC Tue 25 Jan 00 (1706 MST Mon 24 Jan 00)

MSLP (hPa)



CONTOUR: UNITS=hPa LOW= 1006.0 HIGH= 1032.0 INTERVAL= 2.0000
 Model info: V8.0.3 Enln-F-Eta YSU PBL WSM Scheme 30 km, 27 levels, 180 sec

Surface pressure tendency (hPa/3h)



CONTOUR: UNITS=hPa/3h LOW= -22.000 HIGH= 19.000 INTERVAL= 2.0000
 Model info: V8.0.3 Enln-F-Eta YSU PBL WSM Scheme 30 km, 27 levels, 180 sec

t=0

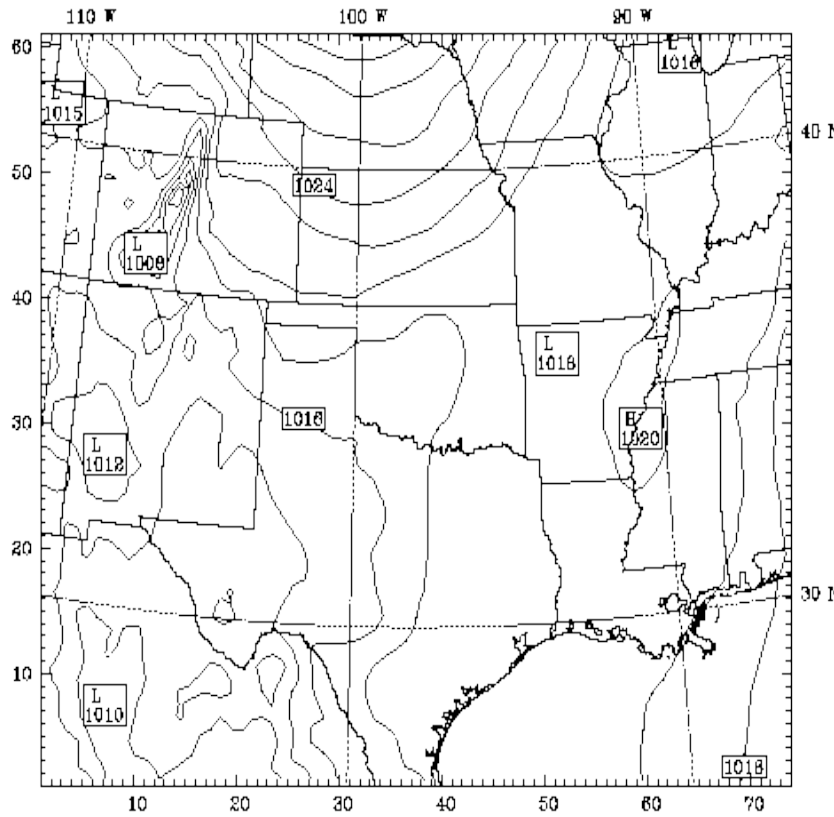
Sea level pressure and surface pressure tendency at +6h

Dataset: mytest RIP: rip
 Test: 6.00
 Sea-level pressure

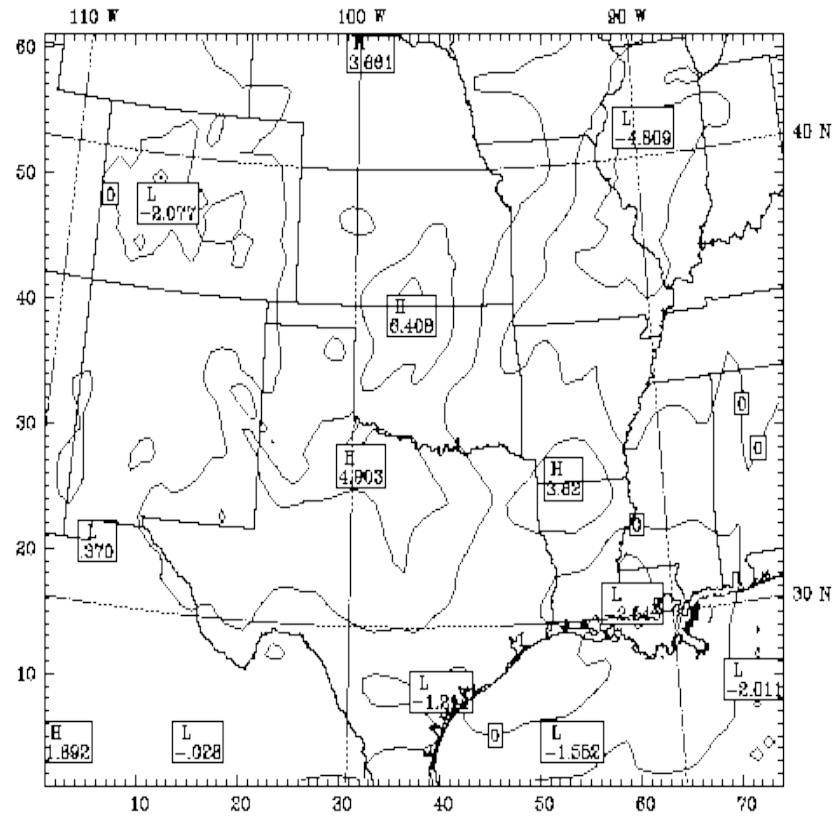
Init: 0000 UTC Tue 25 Jan 00
 Valid: 0600 UTC Tue 25 Jan 00 (2300 MST Mon 24 Jan 00)

Dataset: mytest RIP: rip
 Test: 6.00
 surface pressure tendency

Init: 0000 UTC Tue 25 Jan 00
 Valid: 0600 UTC Tue 25 Jan 00 (2300 MST Mon 24 Jan 00)



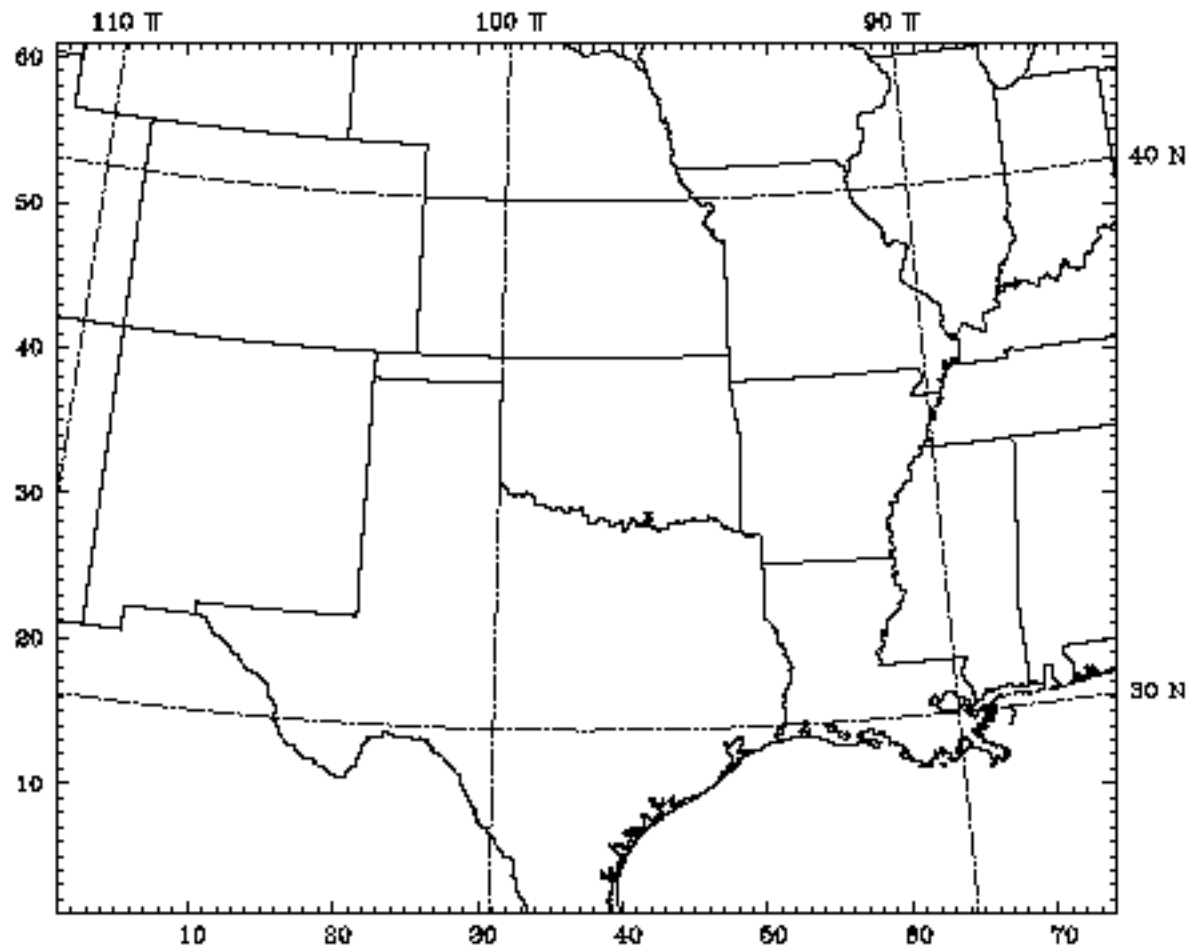
CONTOURS: UNITS=hPa LOW= 1006.0 HIGH= 1030.0 INTERVAL= 2.0000
 Model info: V3.0.3 Kain-F-Rta YSU PBL WSM Sclass 30 km, 27 levels, 180 sec



CONTOURS: UNITS=hPa/h LOW= -4.0000 HIGH= 6.0000 INTERVAL= 2.0000
 Model info: V3.0.3 Kain-F-Rta YSU PBL WSM Sclass 30 km, 27 levels, 180 sec

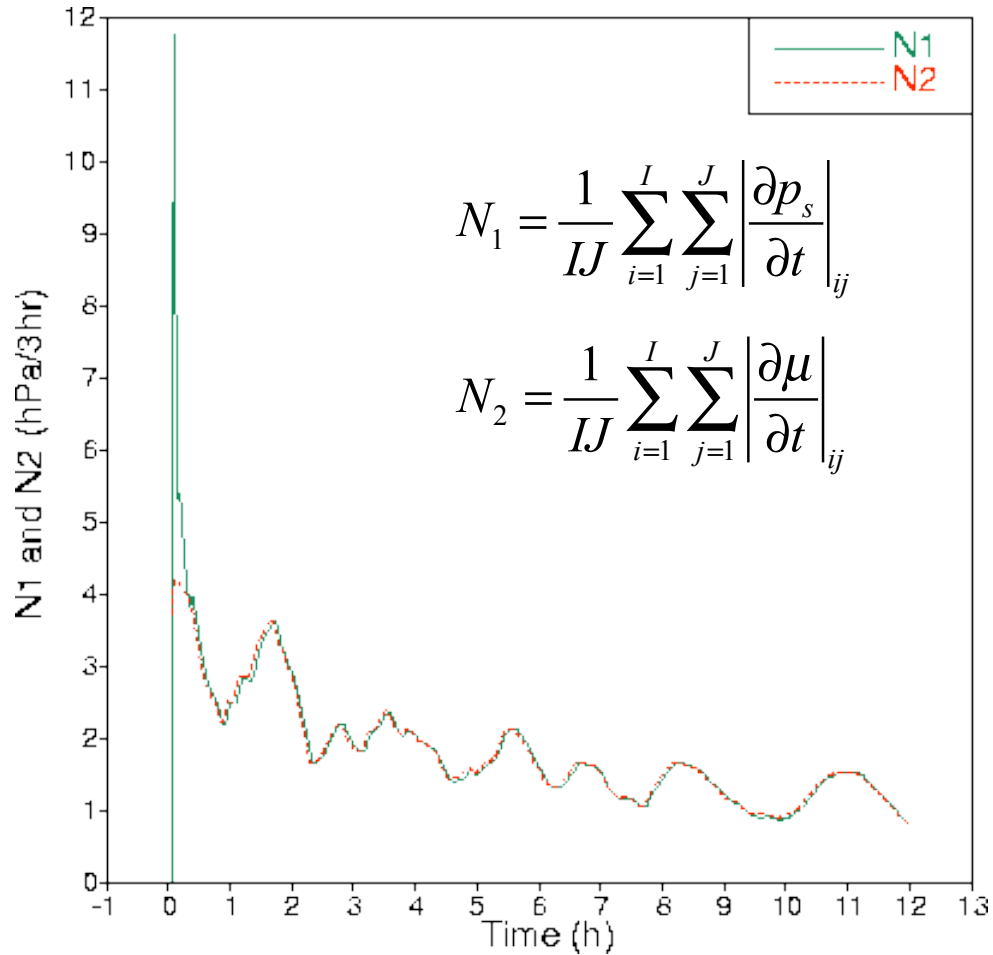
Dataset: mytest RIP: rip
Fast: 0.00
mu tendency

Init: 0000 UTC Tue 25 Jan 00
Valid: 0000 UTC Tue 25 Jan 00 (1700 MST Mon 24 Jan 00)



Model info: V2.0.3 Kain-F-Eta YSU PBL TSM Solas 30 km, 27 levels, 180 sec

Noise level



Grid-points: 74×61×28

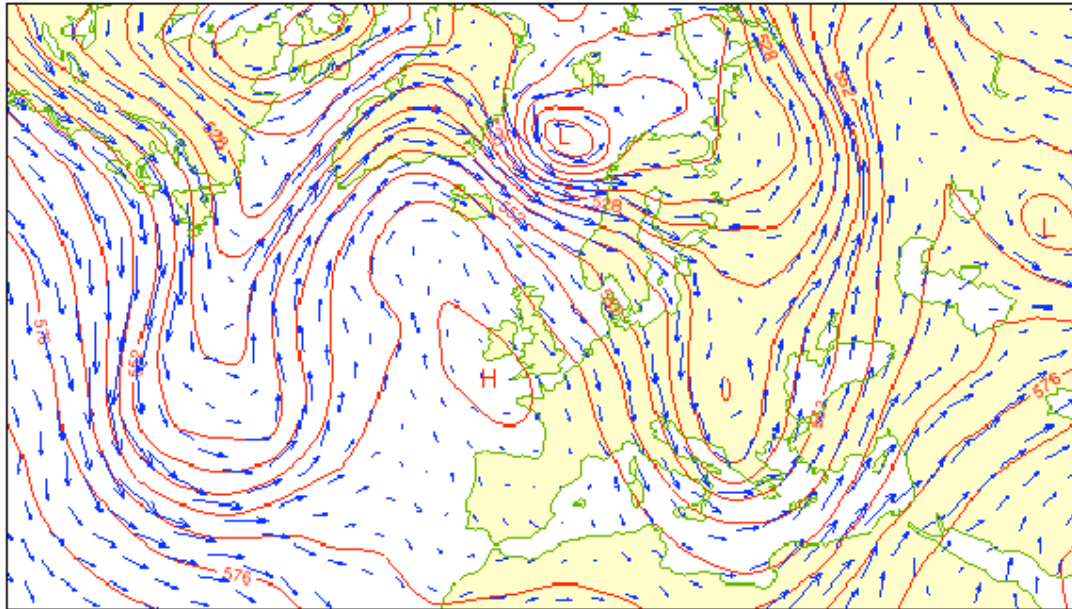
Resolution: 30 km

Time step: 180 s

**Initial state: 3DVAR
analysis at 2000.01.25.00
(the second cycle)**

Filtered (Slow) Equations

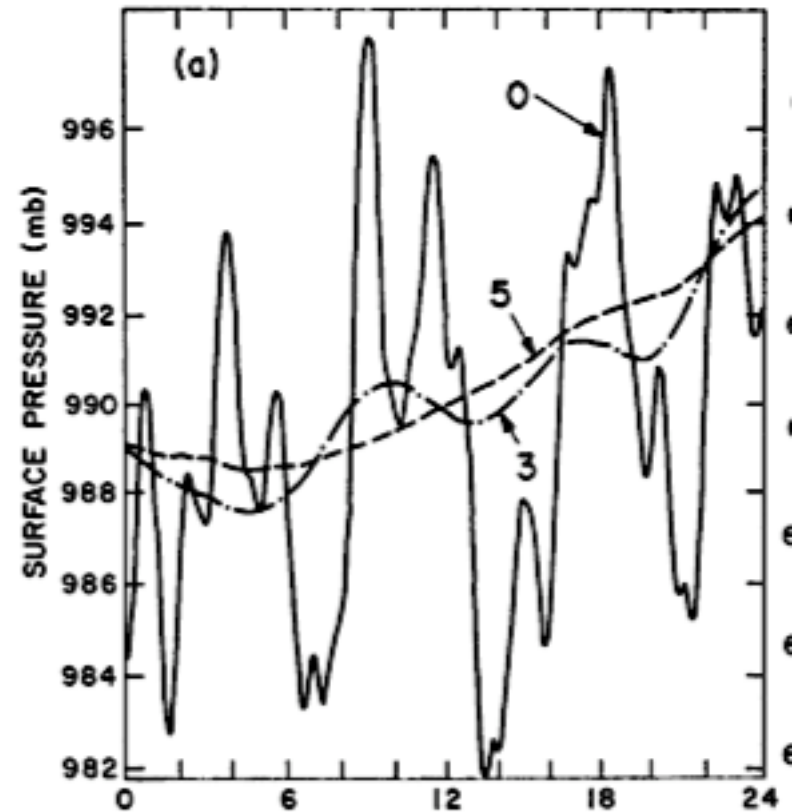
- Barotropic models
- QG model
- ... models without gravity



Nonlinear Normal Model Initialization

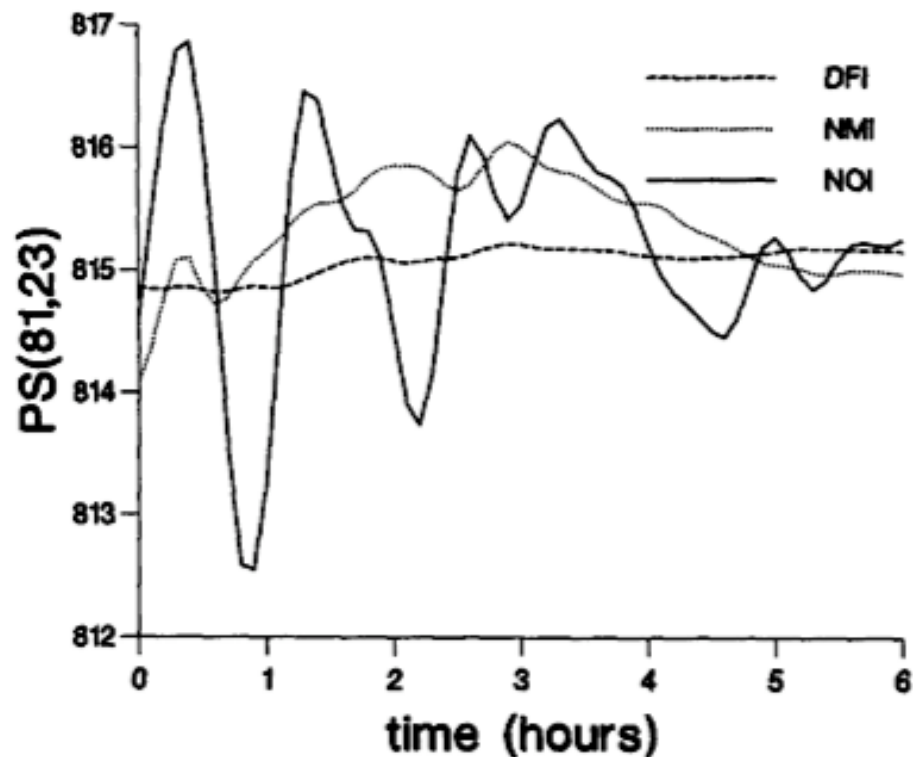
(Machenhauer 1977), Williamson and Temperton (1981)

1. Compute the normal modes
 - Rossby wave mode
 - Gravity wave mode
2. Project model initial state to the normal mode space.
3. Set the gravity wave tendency to 0
4. Go back to the model space.



Digital Filter Initialization

- ADFI (Lynch and Huang, 1992)
- DDFI (Huang and Lynch, 1993)
- ... Schemes based on DFI



DFI: Digital Filter Initialization

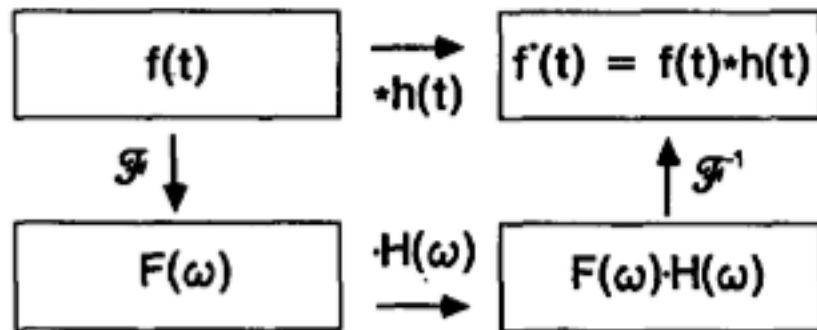


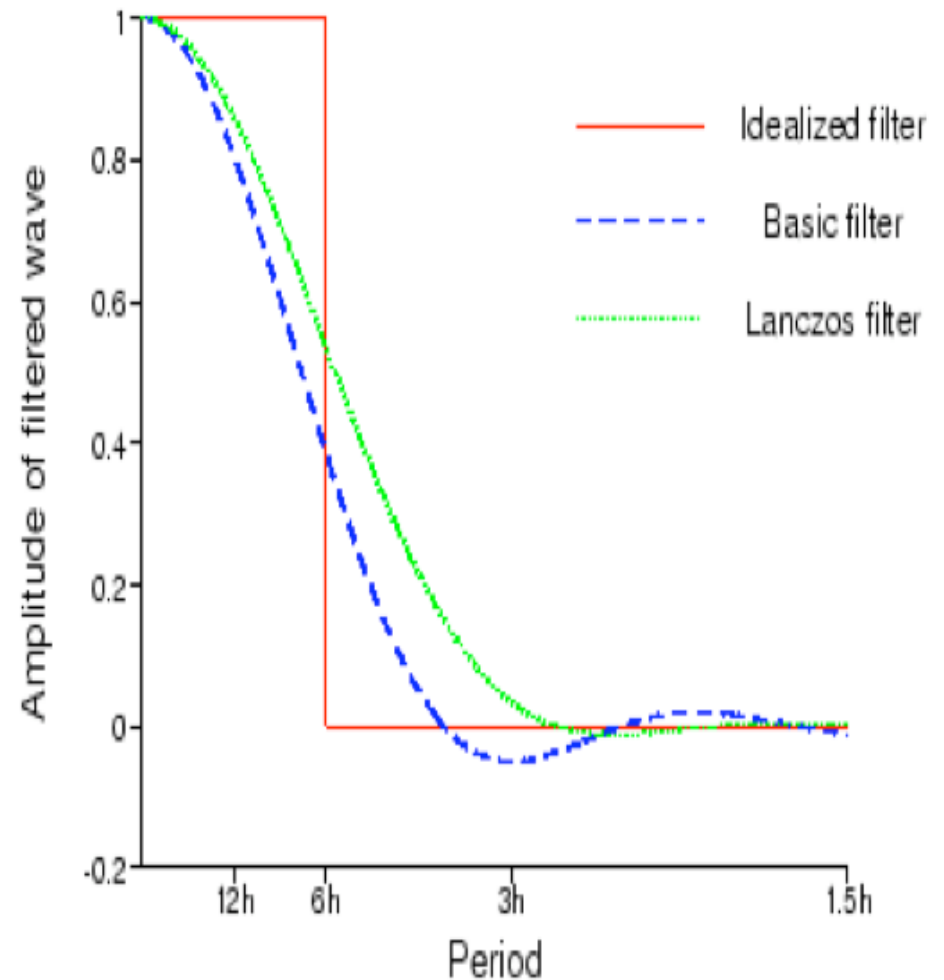
FIG. 1. Schematic representation of the equivalence between convolution and filtering in Fourier space.

$$H(\theta) = \begin{cases} 1, & |\theta| \leq |\theta_c|; \\ 0, & |\theta| > |\theta_c|, \end{cases}$$

$$H(\theta) = \sum_{n=-\infty}^{\infty} h_n e^{-in\theta},$$

$$h_n = \frac{1}{2\pi} \int_{-\pi}^{\pi} H(\theta) e^{in\theta} d\theta.$$

$$h_n = \frac{\sin n\theta_c}{n\pi}.$$



Filtering...

$$\overline{x_{N/2}} = \sum_{n=0}^N f_n x_n$$

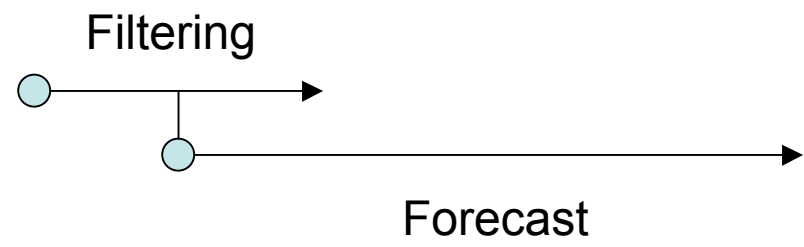
```
xdfi = 0
do n=0,ndfi
    xdfi = xdfi + f(n)*x(n)
enddo
```

WRF-DFI

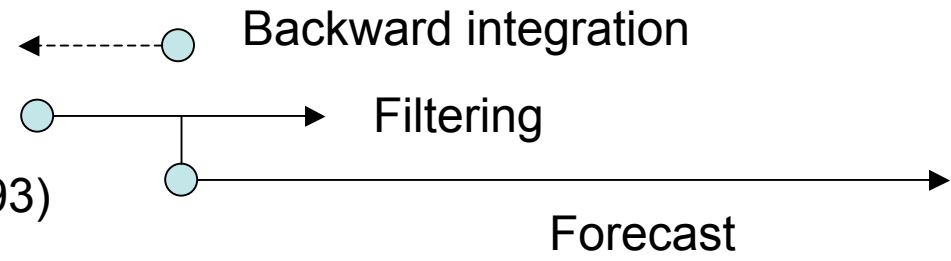
1. Implementation by Huang, Chen, Kim, Wang, Skamarock, Henderson, Duda
2. Smirnova, Peckham of GSD/NOAA
3. Duda (for WRF3.0)

Implemented options of DFI in WRF3.0

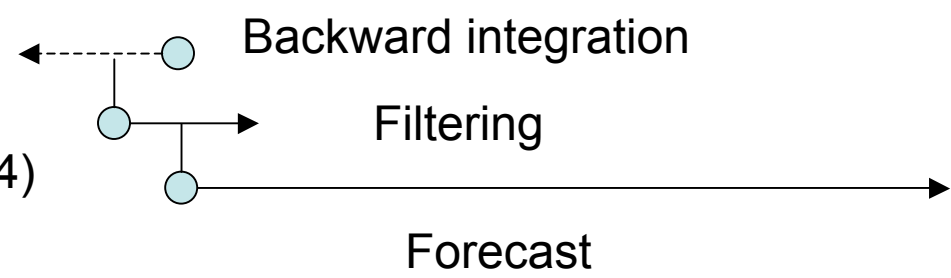
DFL:
(Lynch and Huang, 1994)



DDFI:
(Huang and Lynch, 1993)



TDFI:
(Lynch and Huang, 1994)



Running DFI in WRF 3.0

- Digital filter initialization can be selected at runtime through the `namelist.input` file
 - In `&dfi_control` namelist, select a DFI option with `dfi_opt`

0 = no DFI (default)

1 = DFL

2 = DDFI

3 = TDFI

Running DFI in WRF 3.0

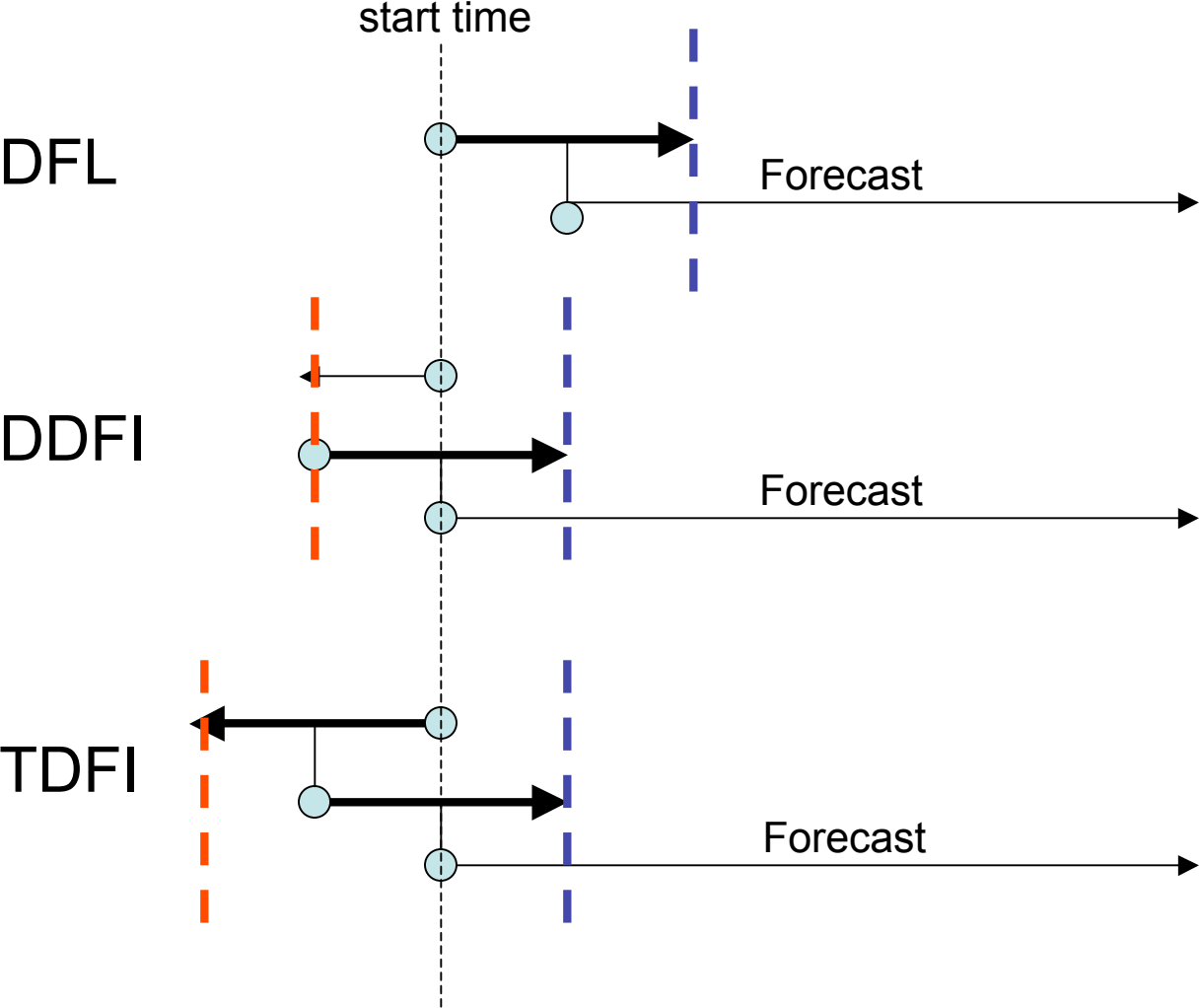
- When a DFI option is set in namelist:
 - Initialization procedure runs
 - Initialized fields are written out with other fields in a WRF input file
 - Useful for re-running a forecast without re-running DFI, or for comparing initialized fields
 - WRF forecast is launched

The DFI namelist – time control

dfi_bckstop_year = 2007,
dfi_bckstop_month = 12,
dfi_bckstop_day = 10,
dfi_bckstop_hour = 10,
dfi_bckstop_minute = 00,
dfi_bckstop_second = 00,

dfi_fwdstop_year = 2007,
dfi_fwdstop_month = 12,
dfi_fwdstop_day = 10,
dfi_fwdstop_hour = 14,
dfi_fwdstop_minute = 00,
dfi_fwdstop_second = 00,

The DFI namelist – time control



bckstop time
fwdstop time

DFI filter options

- Besides the DFI option, user can select window function in namelist with `dfi_nfilter`

0 = Uniform

5 = Potter

1 = Lanczos

6 = Dolph

2 = Hamming

7 = Dolph2

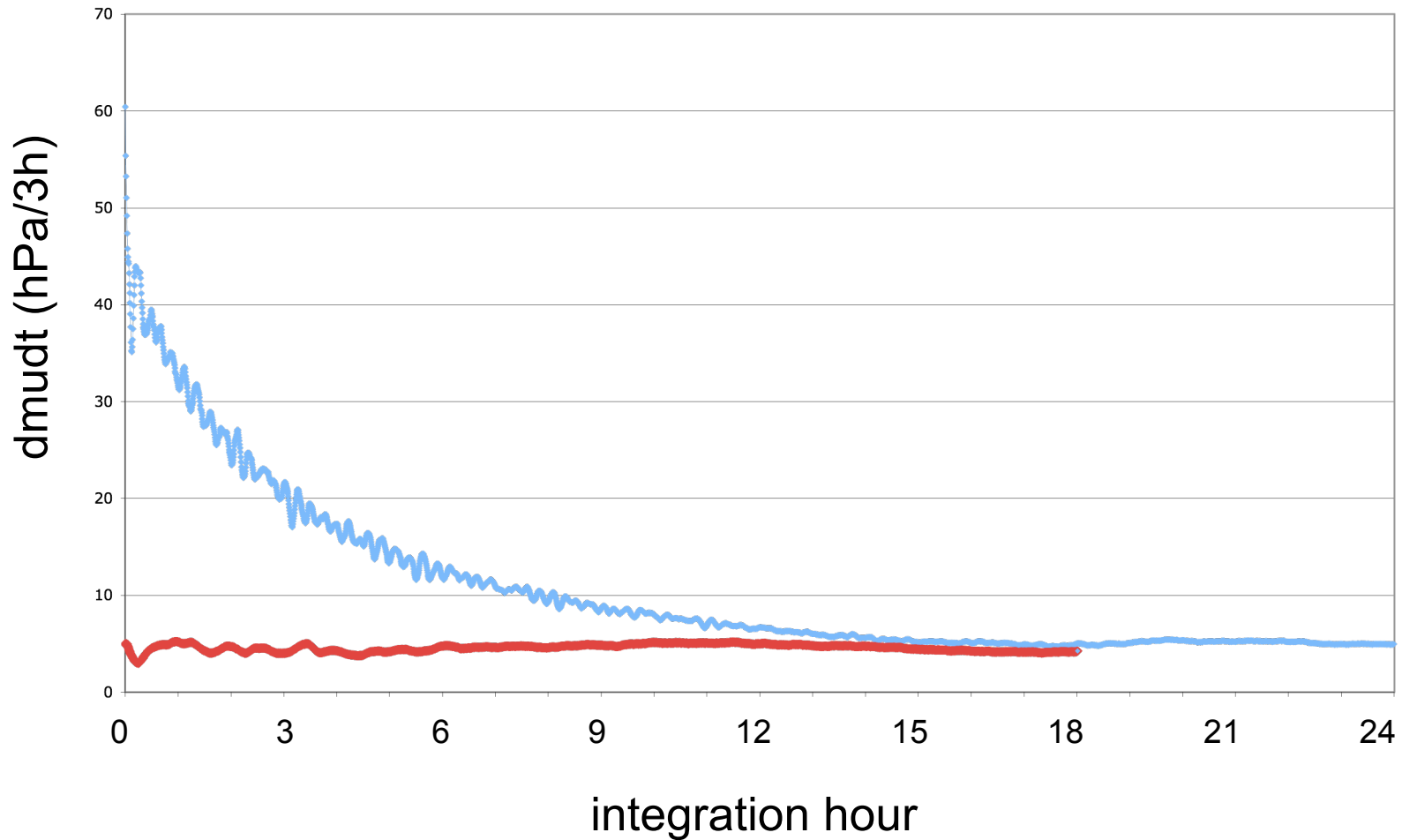
3 = Blackman

8 = Recursive High-Order

4 = Kaiser

Impact of DFI: noise reduction

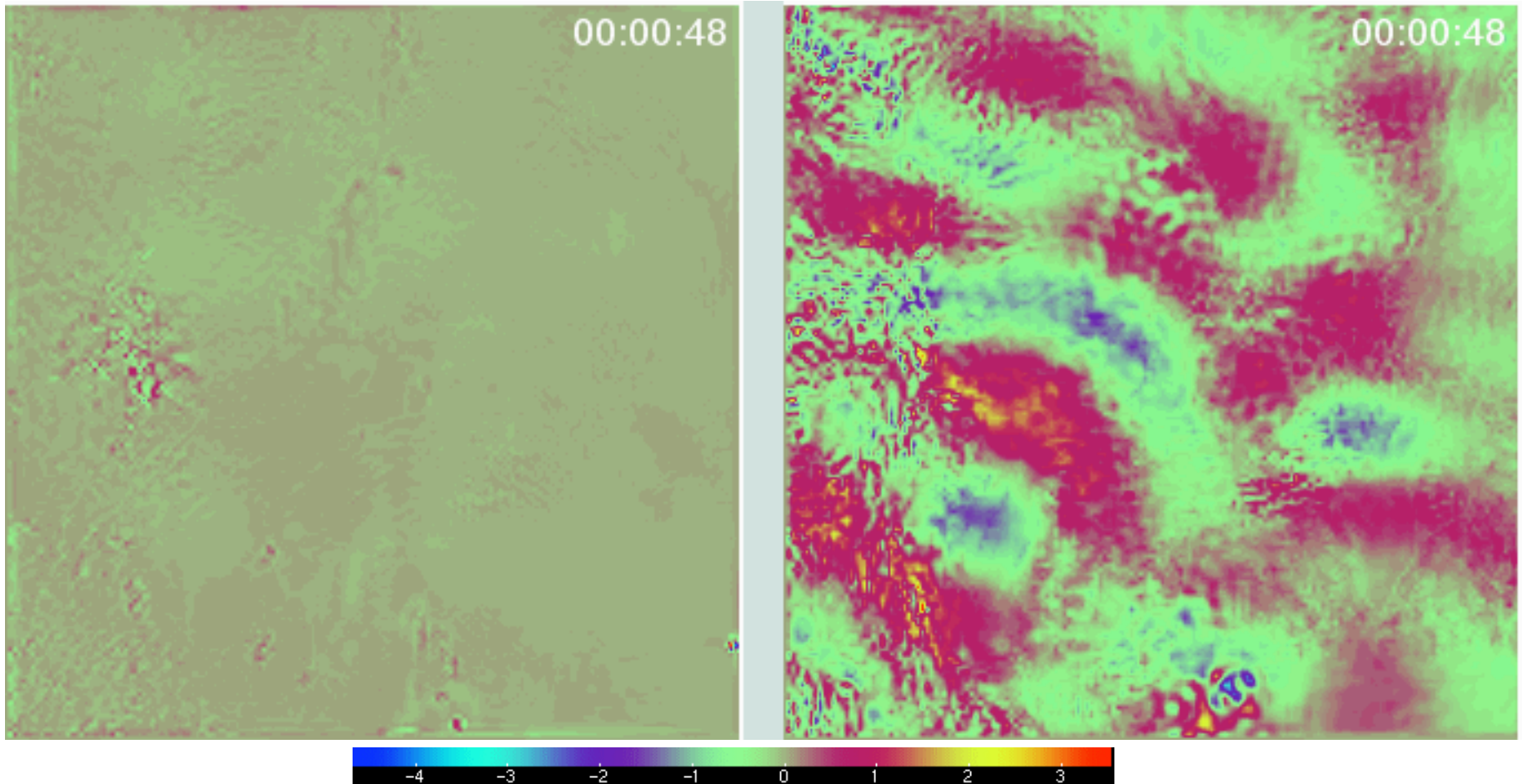
0000 UTC May 7 - 8, 2008, center US, 4km grid



(Dry) Surface Pressure Tendency (hPa/3h)

DFI

No DFI



Summary

1. Initialization - what we are talking about
2. Noise - what we normally (not) look for
3. DFI
 - The idea of filtering: slow equations, NNMI, DFI
 - Simple!?
 - Implemented options in WRF: DFL, DDFI and TDFI
 - Some results: WRF-DFI works well (so far)
4. Problems and challenges
 - Cost too much
 - Backward integration
 - Filter too much
5. DFI in 4D-Var - an ideal application of DFI