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**
- **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 do we need a procedure of initialization for NWP?

- **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 .**

The first NWP made by Richardson

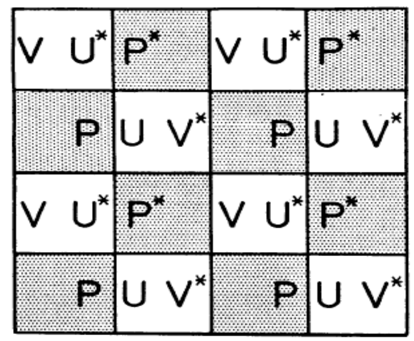
Richardson, 1922

Weather Prediction by Numerical Process

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

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

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



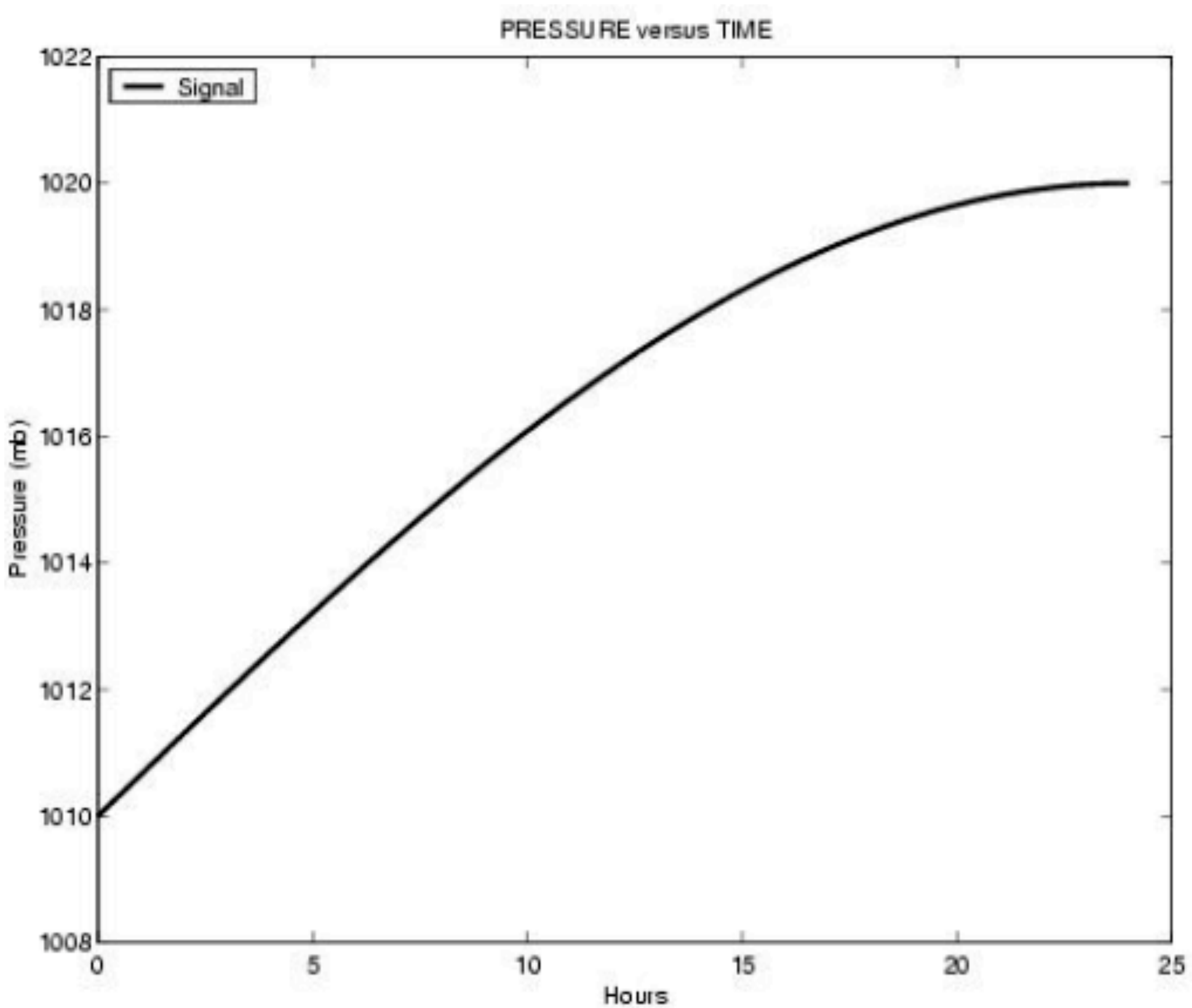
Richardson's failure: a change in surface pressure of 145 hPa in 6 hours!

Richardson's Marvelous Forecast (Lynch 1999)

Six-hour changes in pressure

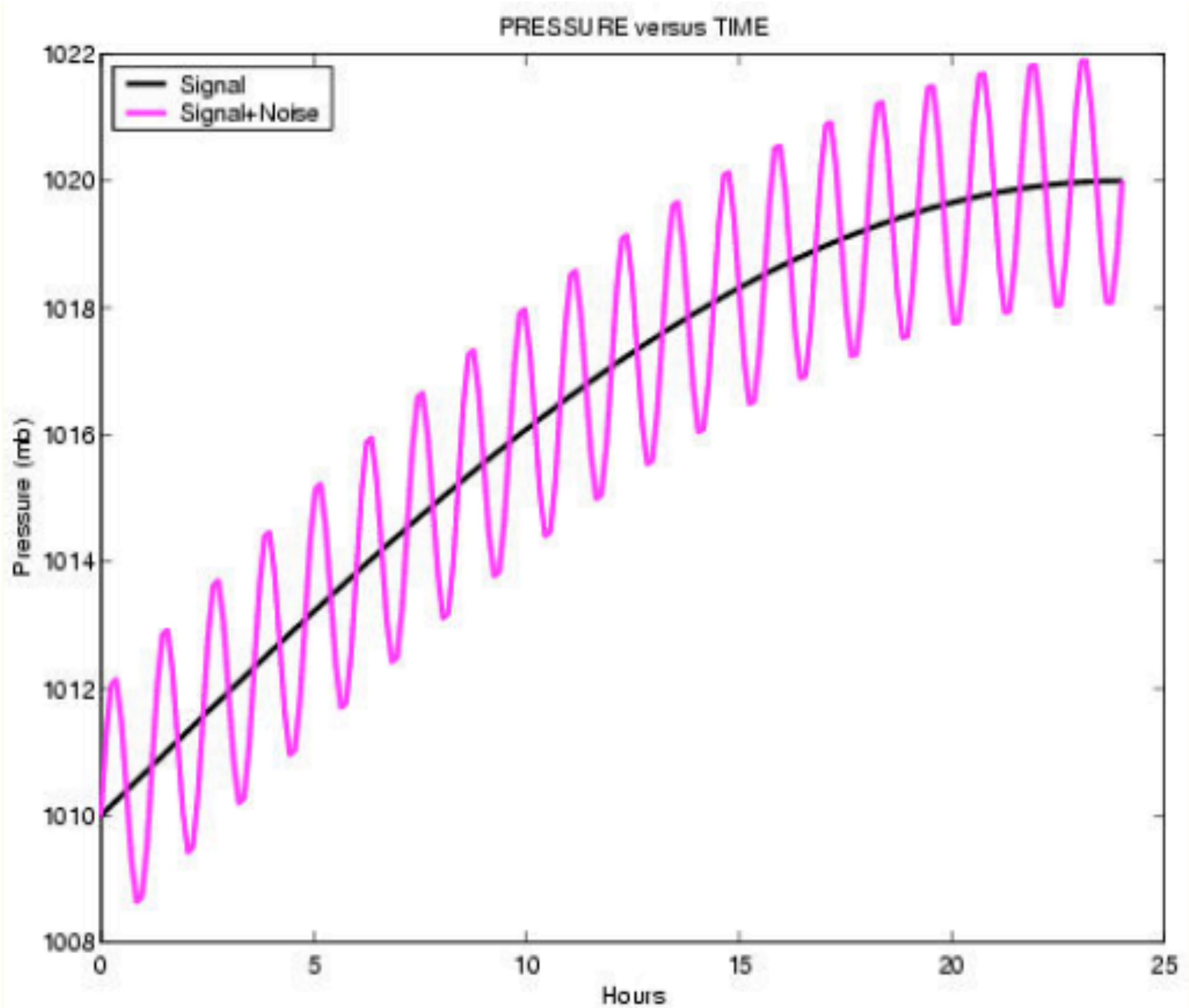
Level	LFR	MOD
1	48.3	48.5
2	77.0	76.7
3	103.2	102.1
4	126.5	124.5
Surface	145.1	

Signal

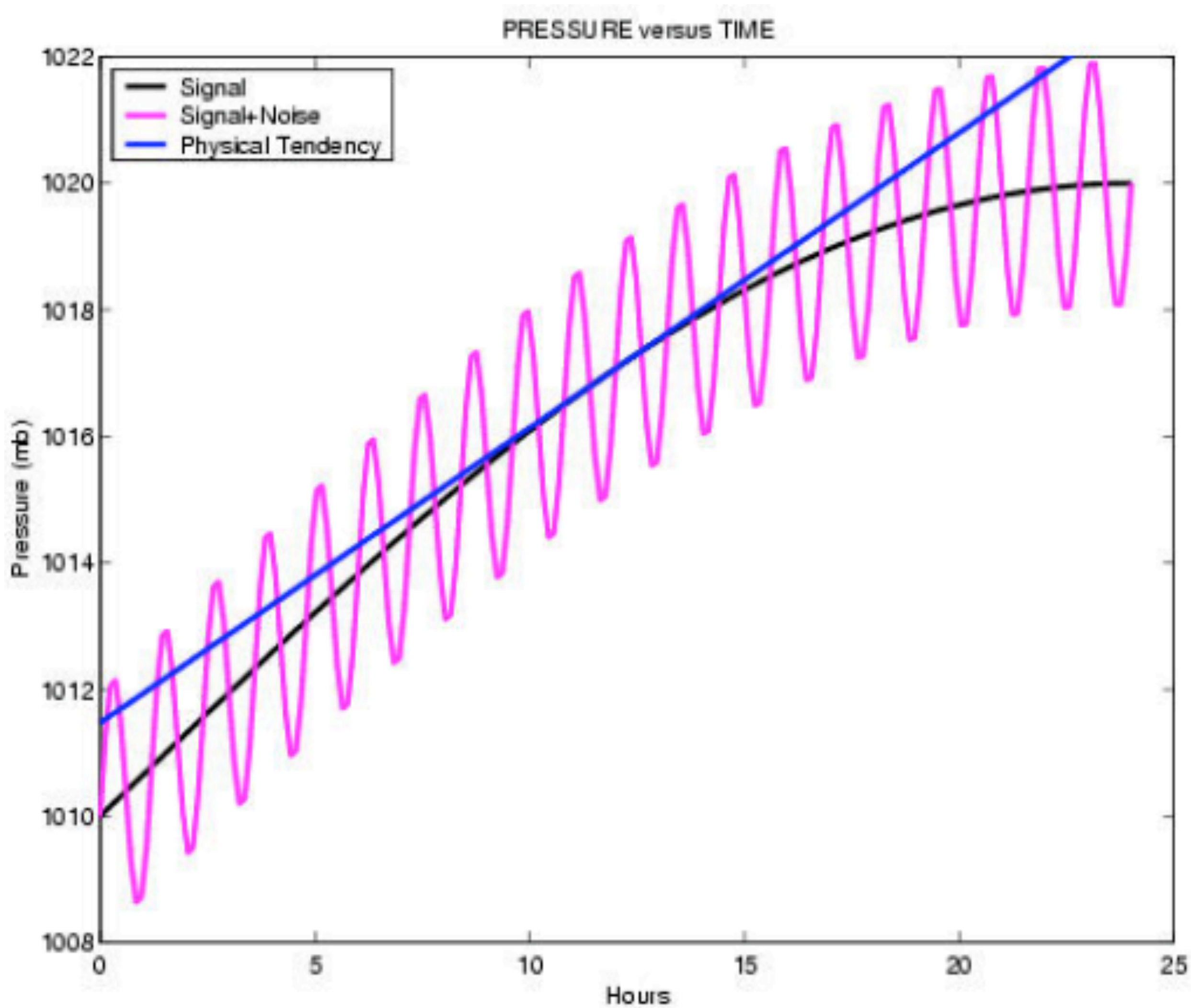


PRESSURE versus TIME
Signal
Pressure (mb)
1022
1020
1018
1016
1014
1012
1010
1008
0
5
10
15
20
25
Hours

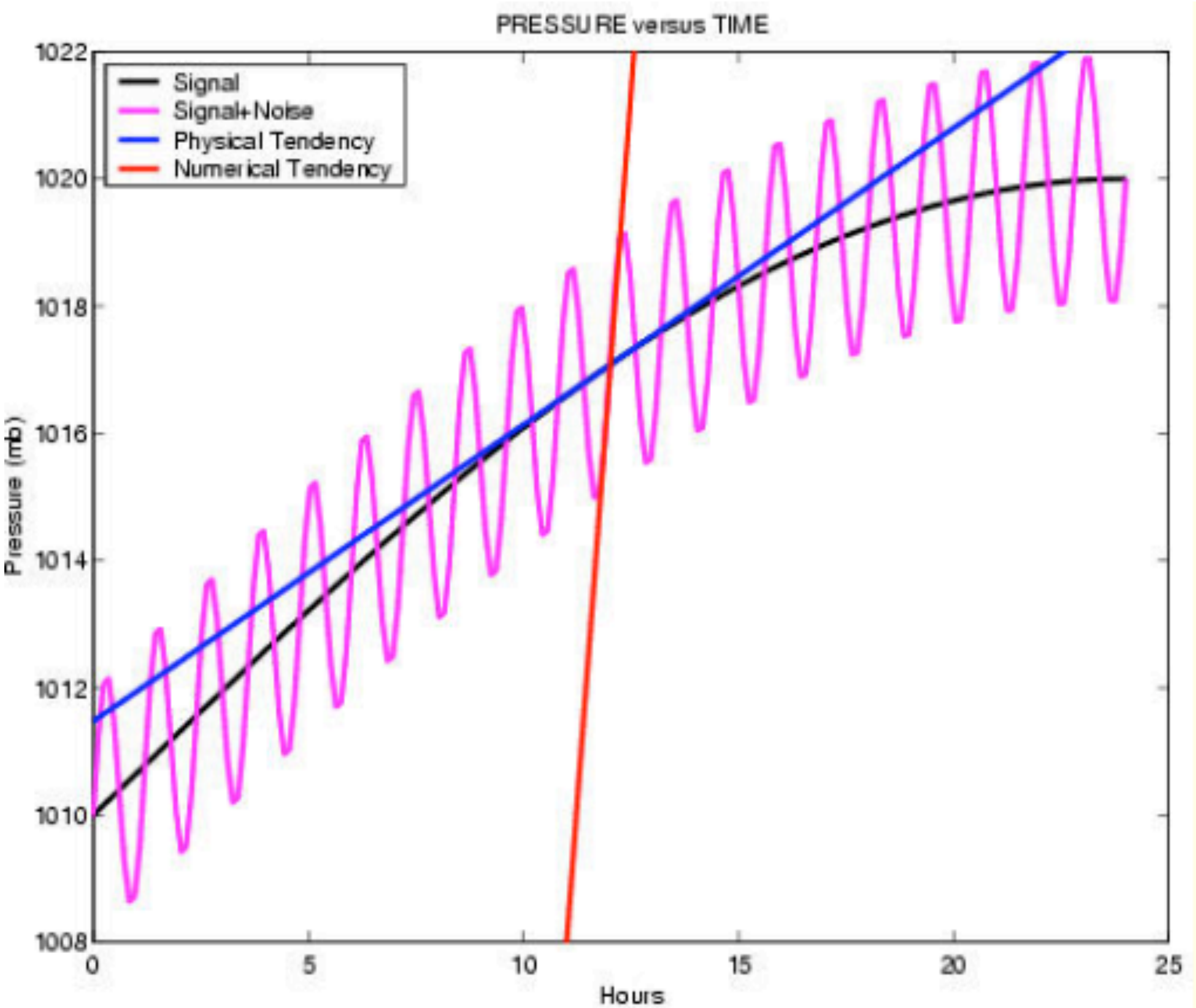
Signal + Noise



Tendency from signal

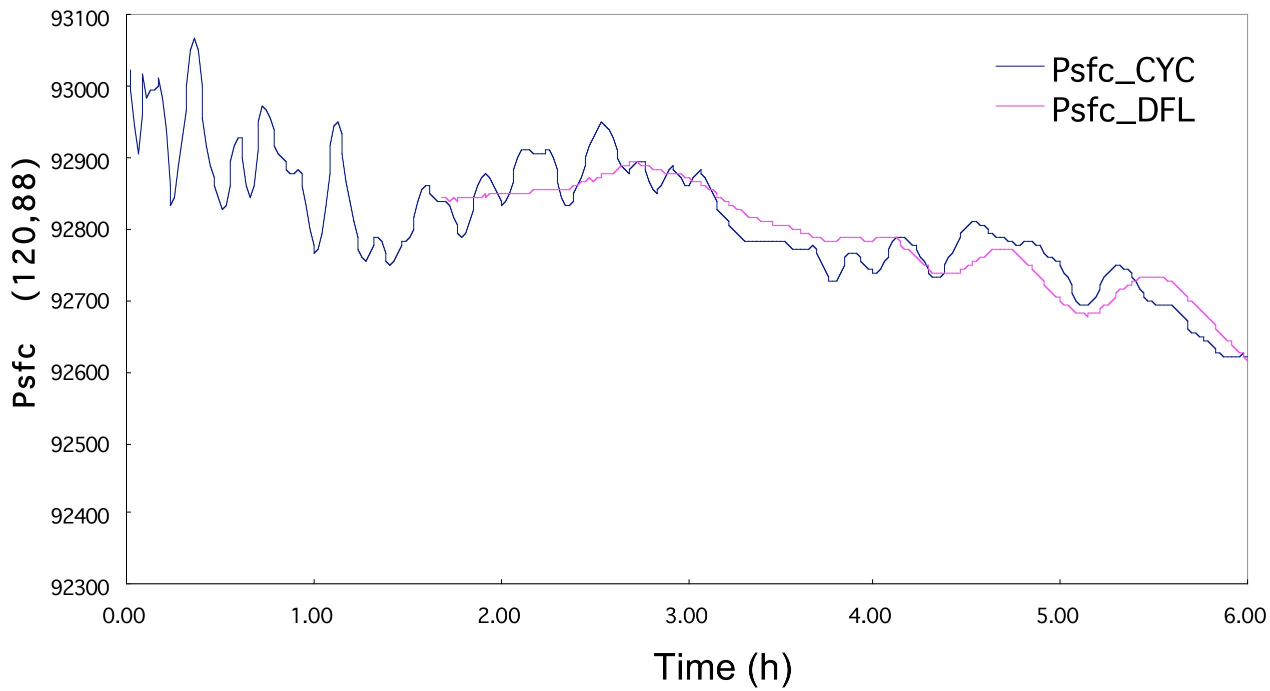


Tendency from noisy signal



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

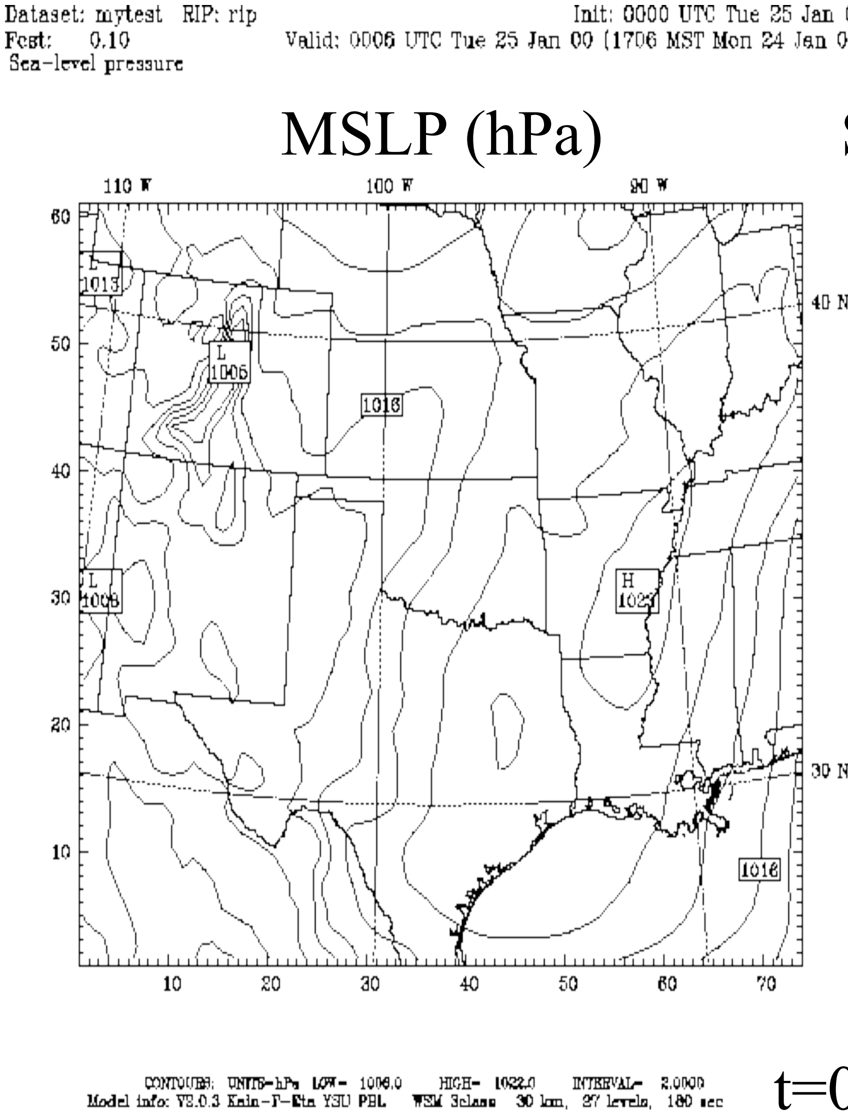
- I have seen this in many models…
- You can (should) try to find such a point in your model!



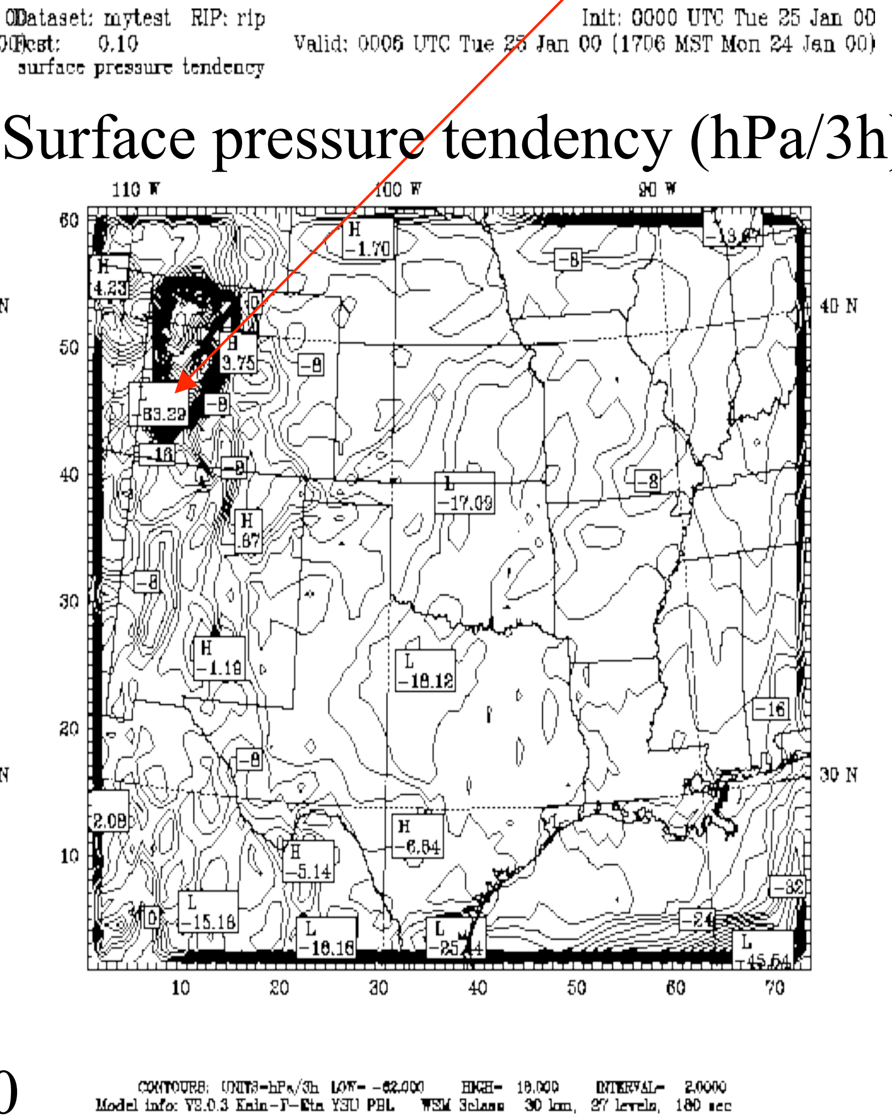
Noise in WRF!

-63.29 (-126.58/6h)

MSLP (hPa)

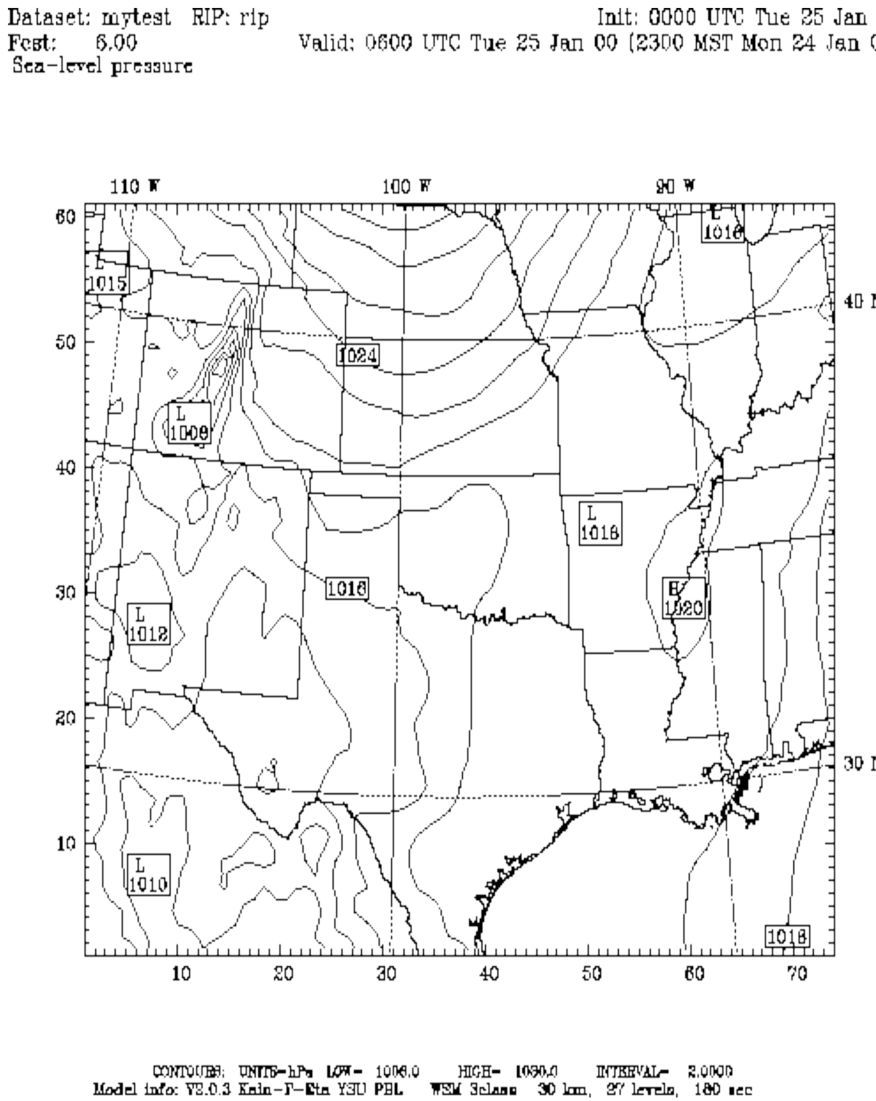


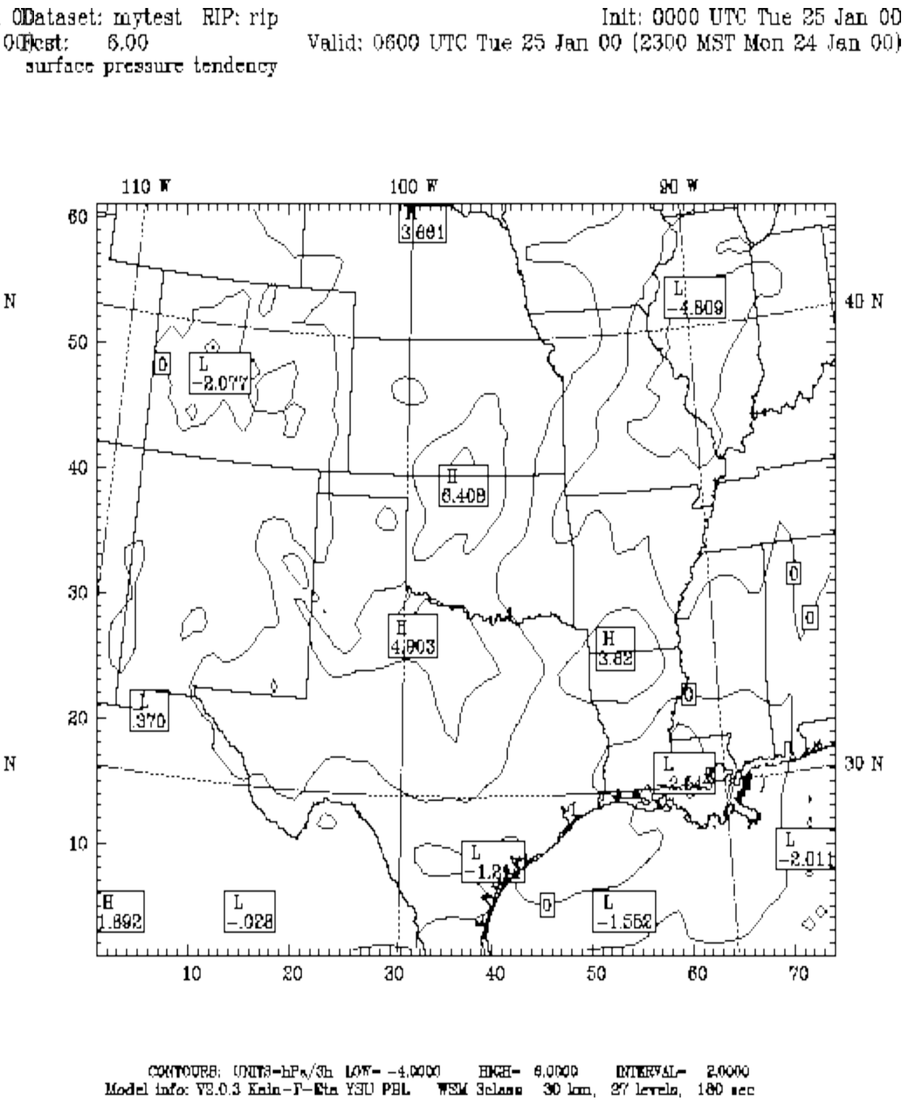
Surface pressure tendency (hPa/3h)

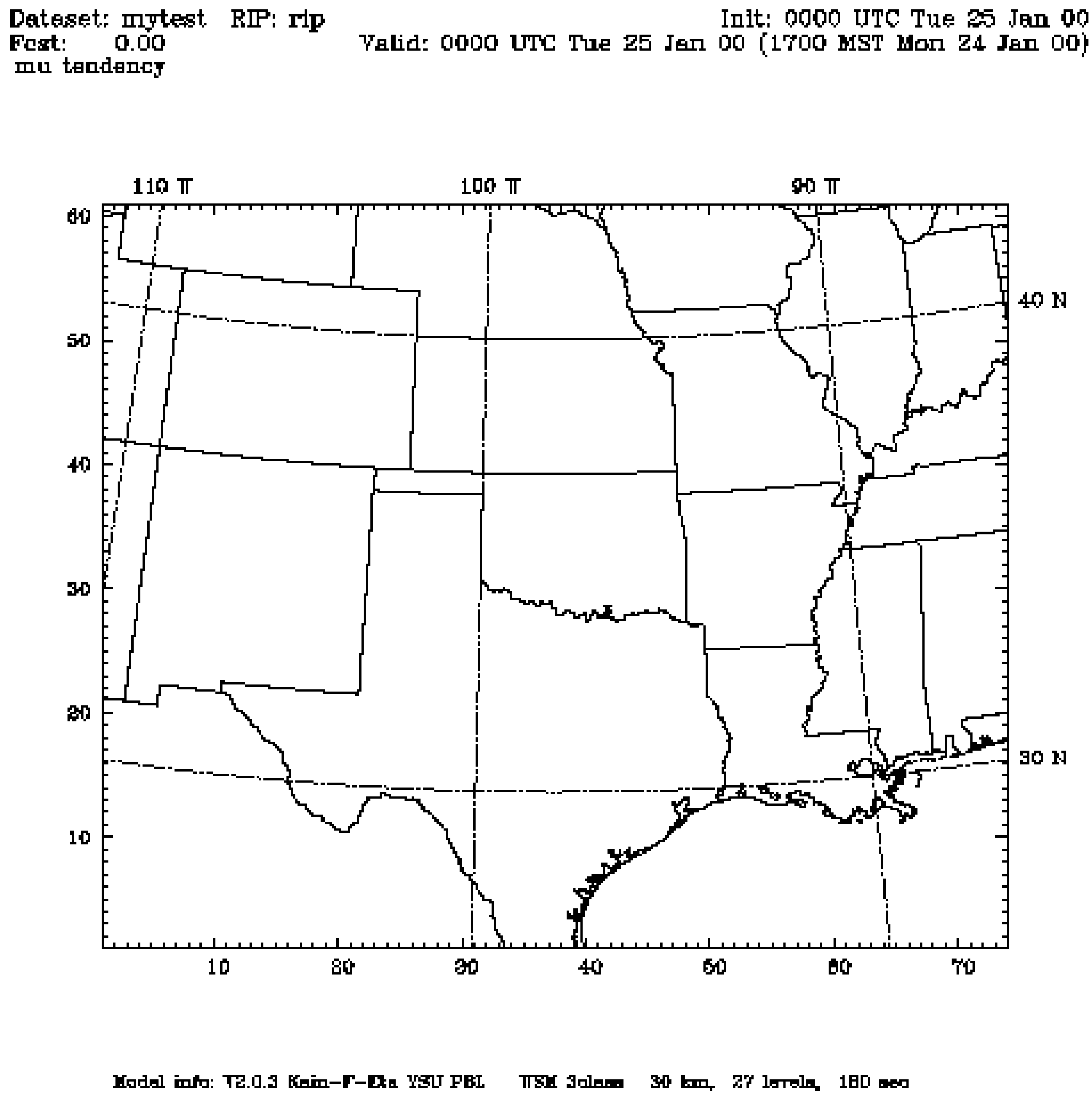


t=0

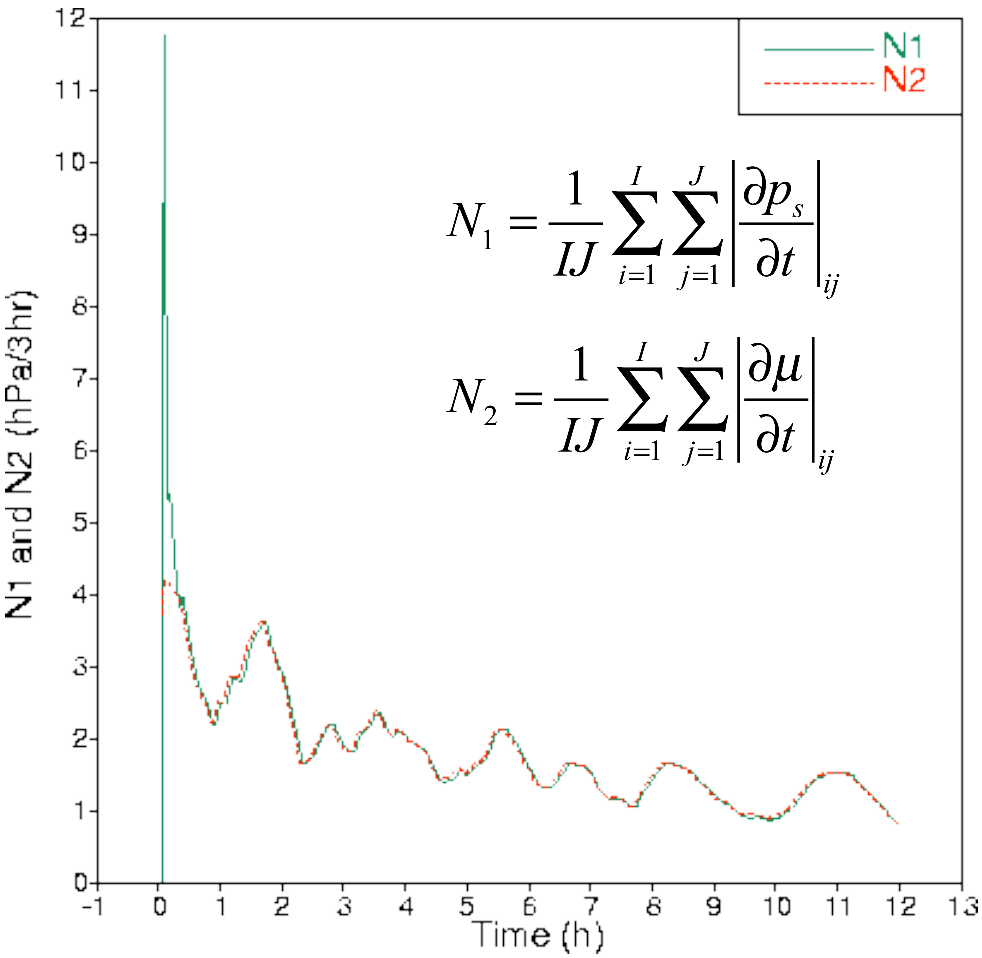
Sea level pressure and surface pressure tendency at +6h






Dataset: mytest RIP: rip
Init: 0000 UTC Tue 25 Jan 00
Fcst: 0.00
Valid: 0000 UTC Tue 25 Jan 00 (1700 MST Mon 24 Jan 00)
mu tendency
110 W
100 W
90 W
40 N
30 N
Model info: V2.0.3 Kain-F-Eta YSU PBL WSM 3class 30 km, 27 levels, 180 sec

Noise level



$$N_1 = \frac{1}{IJ}\sum_{i=1}^{I}\sum_{j=1}^{J}\left|\frac{\partial p_s}{\partial t}\right|_{ij}$$

$$N_2 = \frac{1}{IJ}\sum_{i=1}^{I}\sum_{j=1}^{J}\left|\frac{\partial \mu}{\partial t}\right|_{ij}$$

Grid-points: 74×61×28

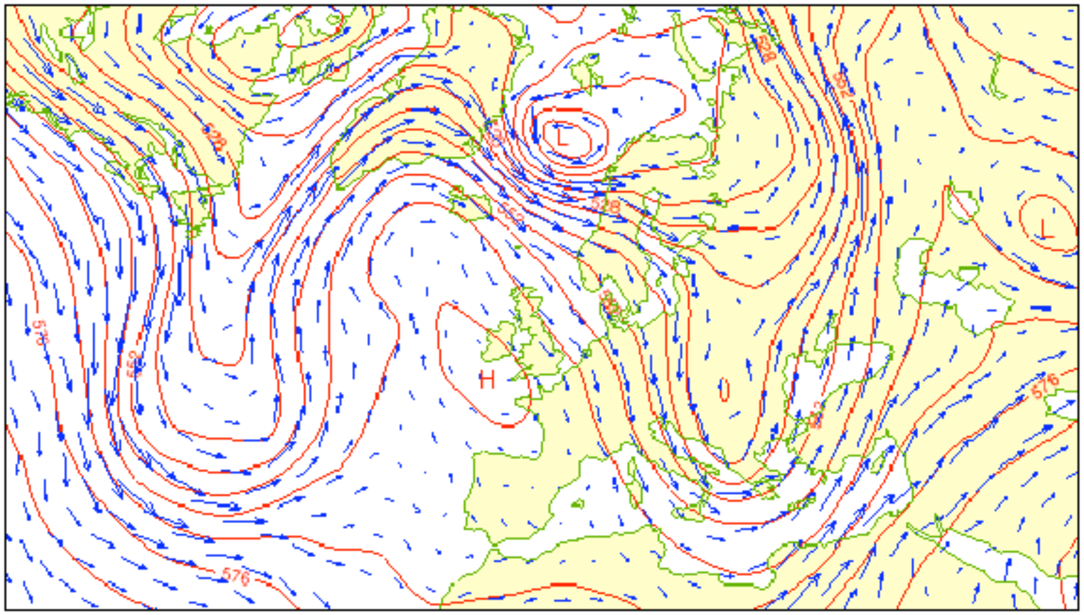
Resolution: 30 km

Time step: 180 s

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

Filtered (Slow) Equations

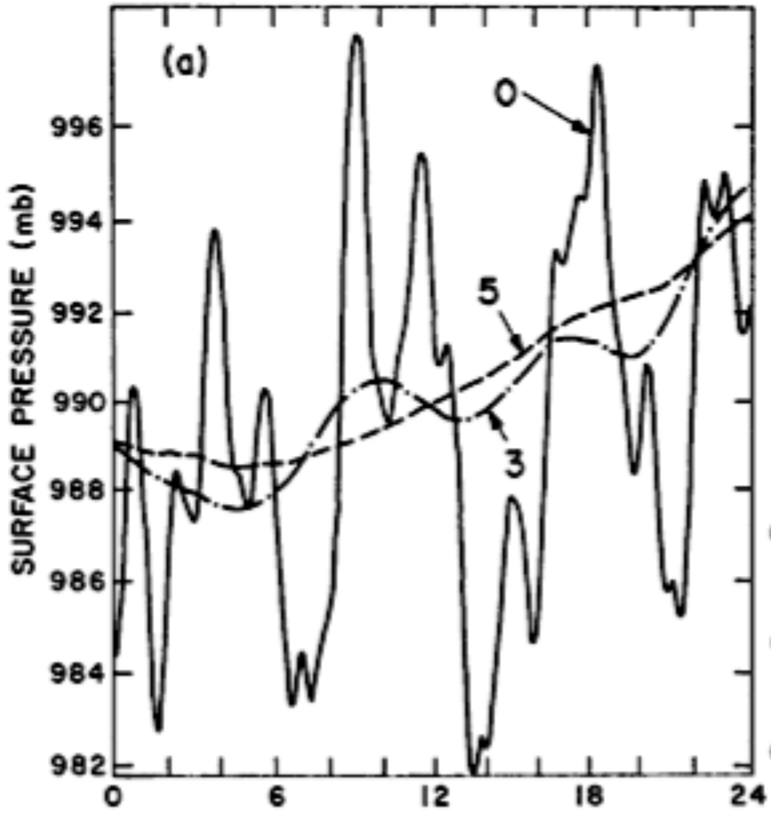
- Barotropic models
- QG model
- … models without gravity



Nonlinear Normal Model Initialization

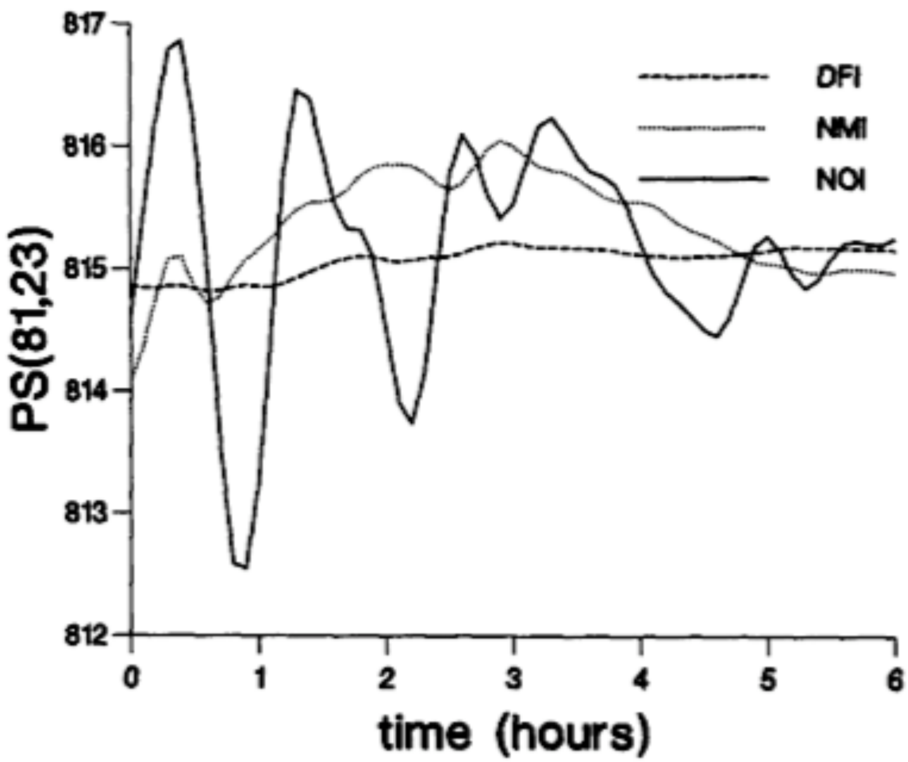
(Machenhauer 1977), Williamson and Temperton (1981)

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

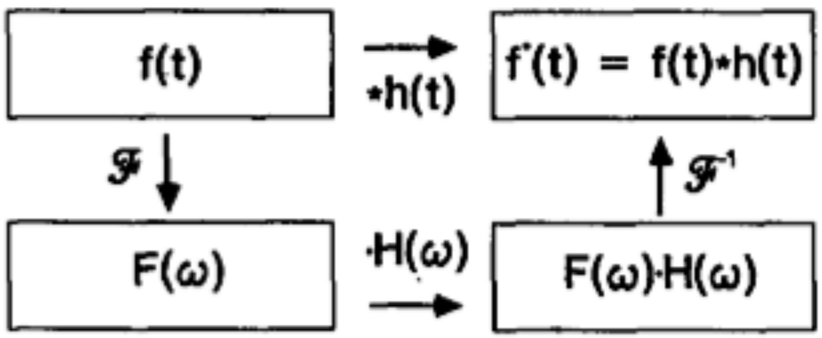


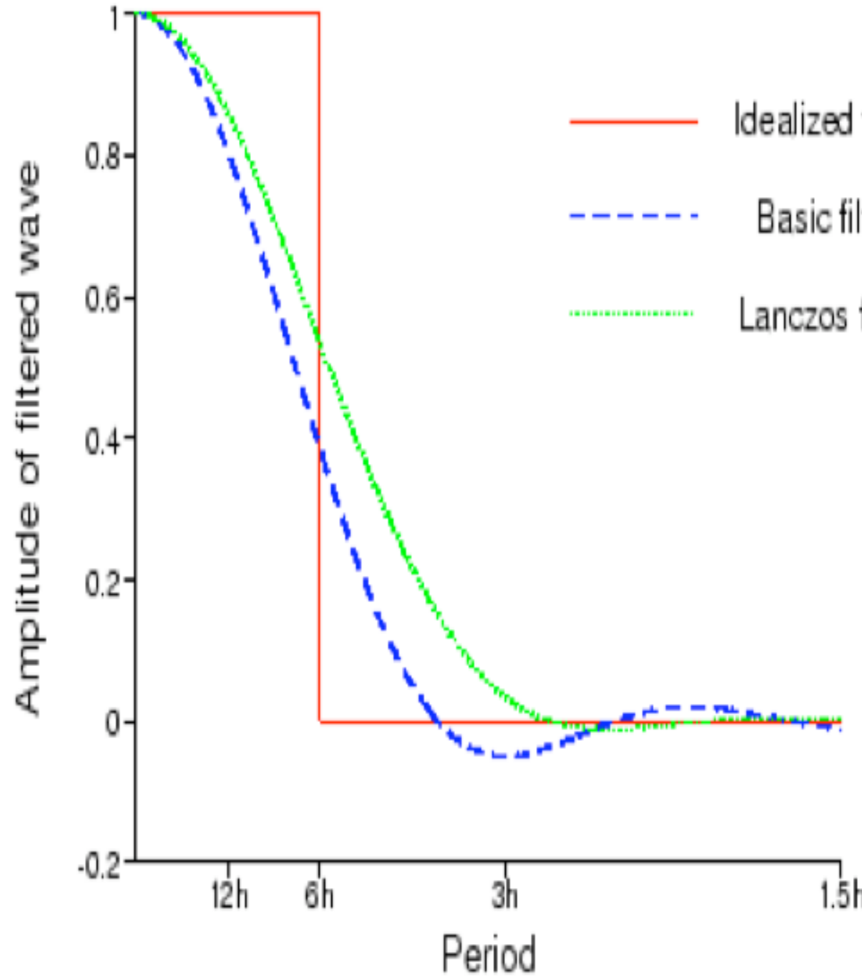
FIG. 1. Schematic representation of the equivalence between convolution and filtering in Fourier space.

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

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

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

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



Filtering…

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

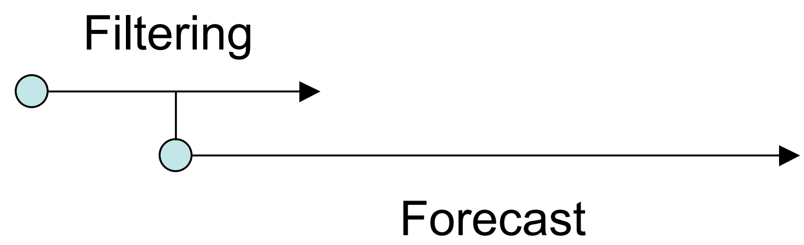
```
xdfi = 0
do n=0,ndfi
     xdfi = xdfi + f(n)*x(n)
enddo
```

WRF-DFI

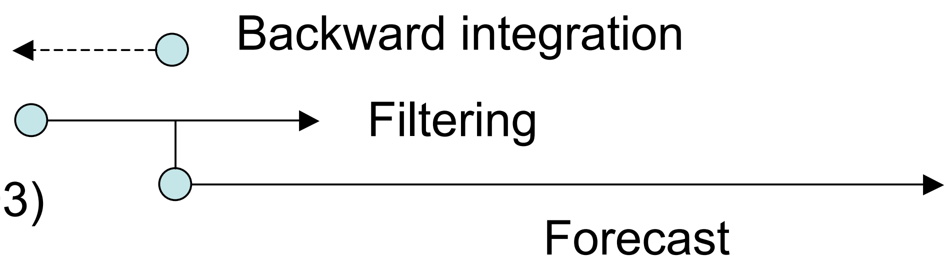
1. Implementation by Huang, Chen, Kim, Wang, Skamarock, Henderson, Duda
2. Smirnova, Peckham of GSD/NOAA
3. Duda (for WRF3.0)

Implemented options of DFI in WRF3.0

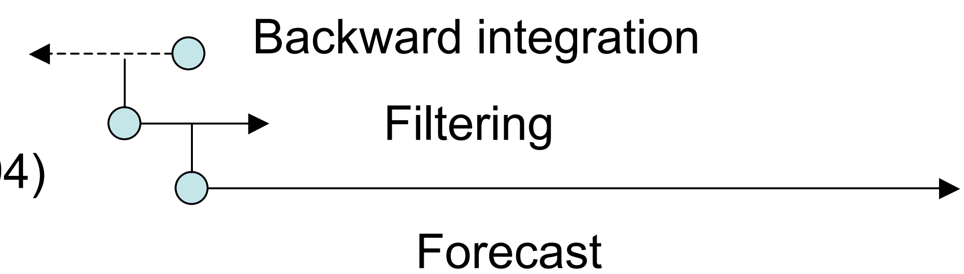
DFL:
(Lynch and Huang, 1994)



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

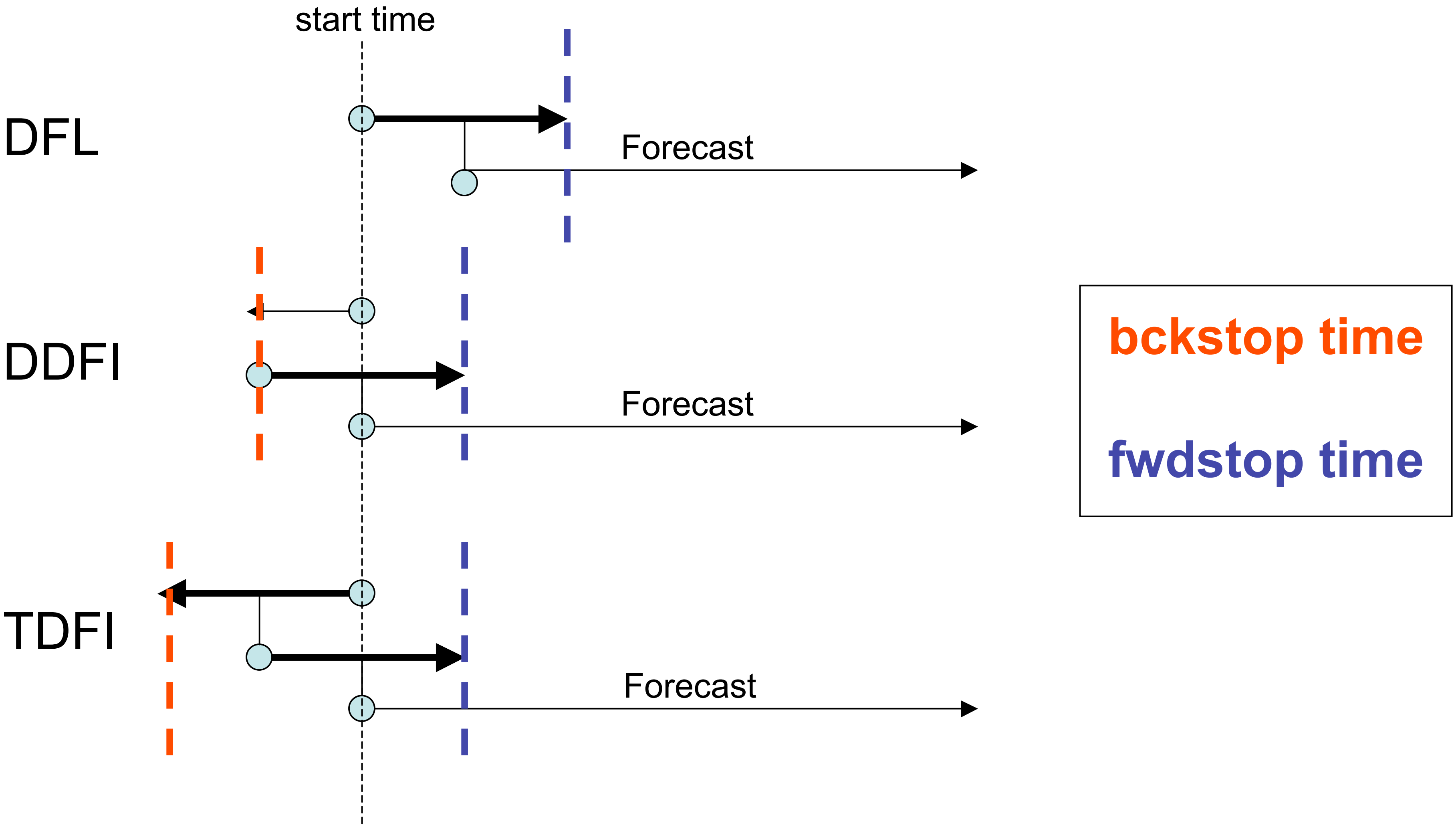
- When a DFI option is set in namelist:
  - Initialization procedure runs
  - Initialized fields are written out with other fields in a WRF input file
    - Useful for re-running a forecast without re-running DFI, or for comparing initialized fields
  - WRF forecast is launched

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



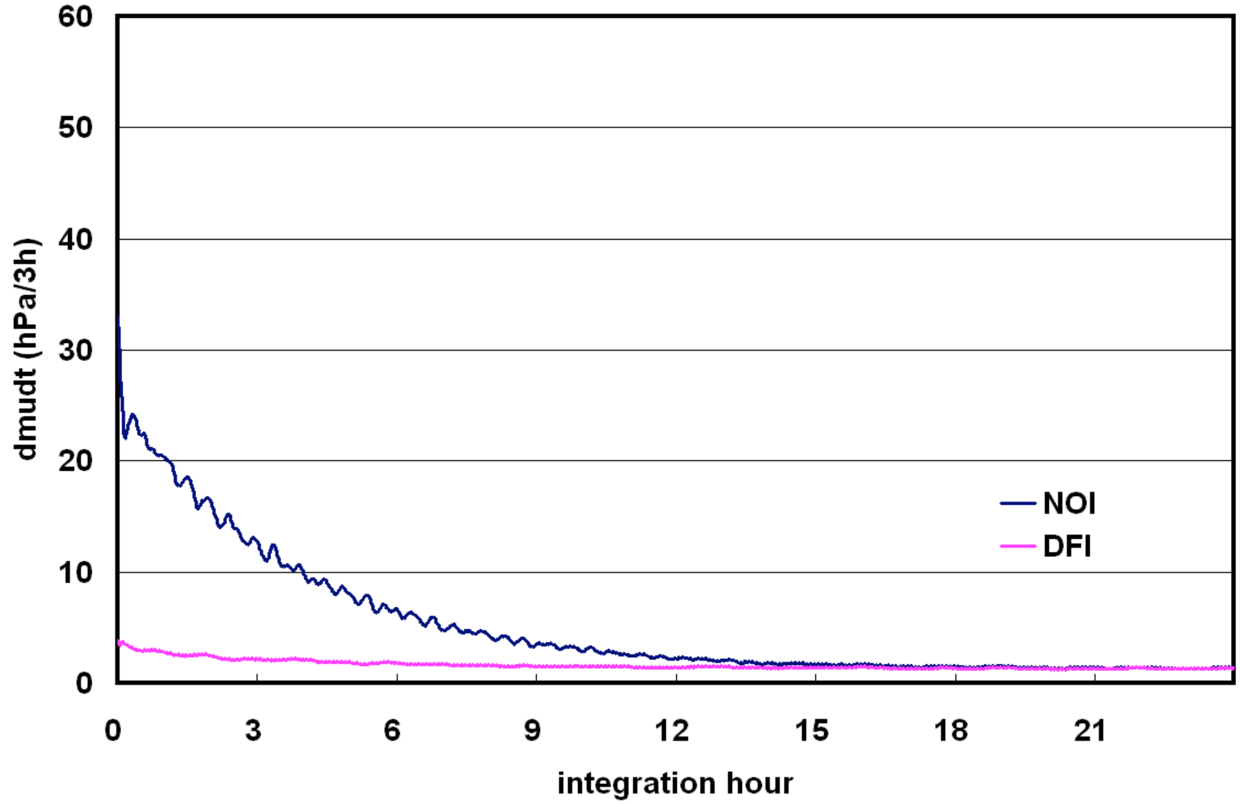
DFI filter options

- 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

12 UTC 25 July - 12 UTC 29 July, 2006.



Impact of DFI: improved verification scores (TEMP)

12 UTC 25 July - 12 UTC 29 July, 2006.

NOI

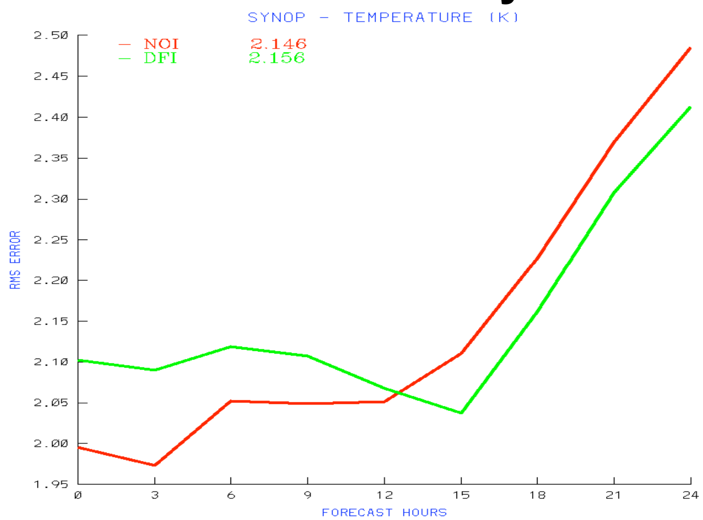
DFI

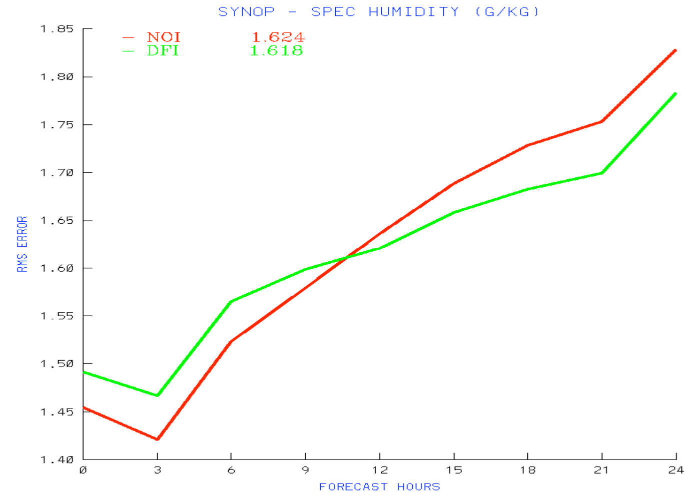
Impact of DFI: improved verification scores (SYNOP)

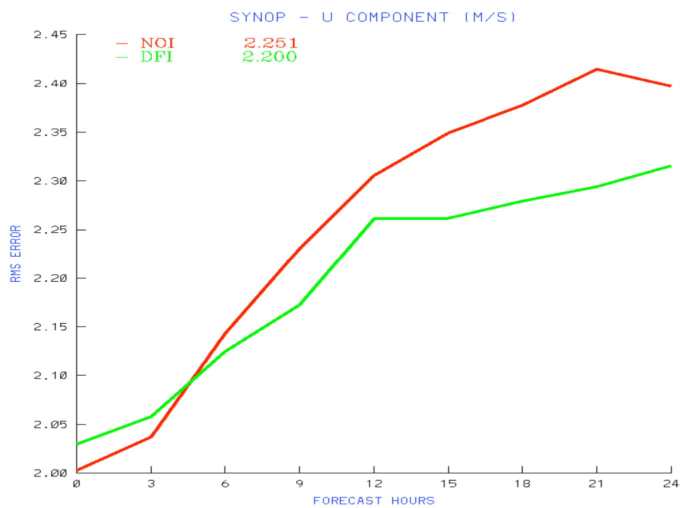
12 UTC 25 July - 12 UTC 29 July, 2006.

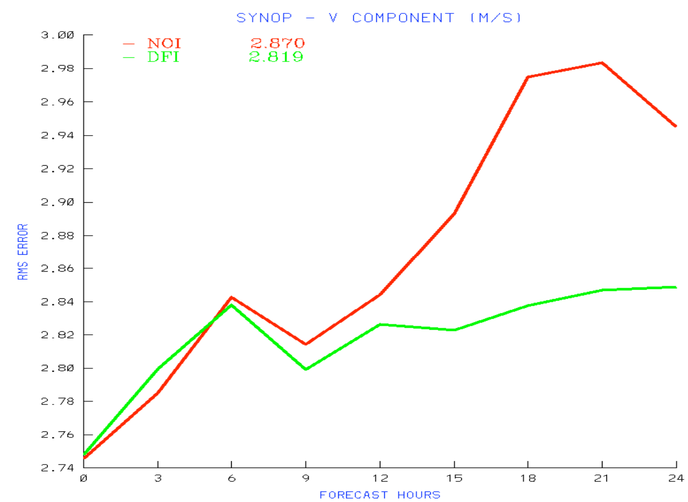
NOI

DFI



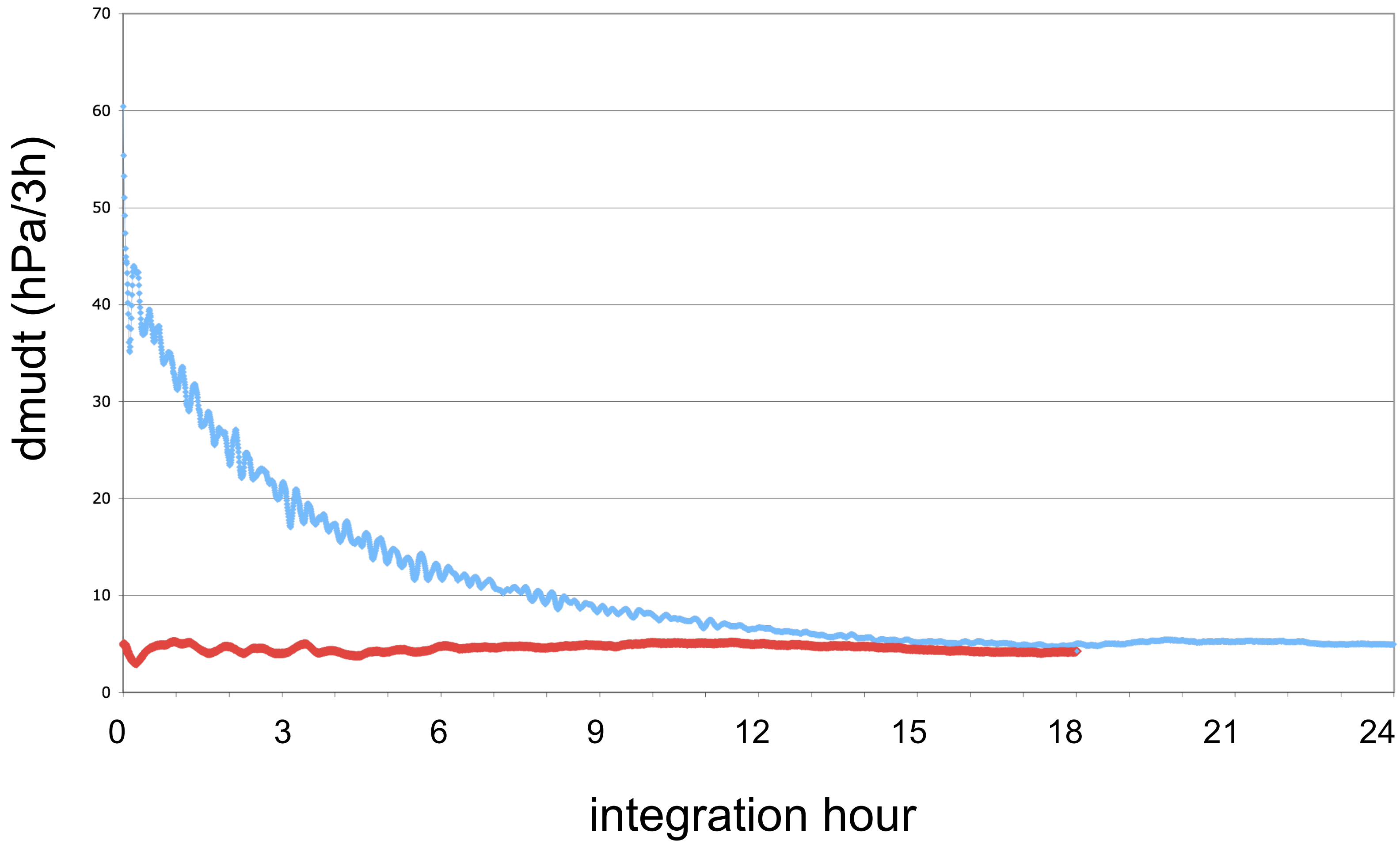






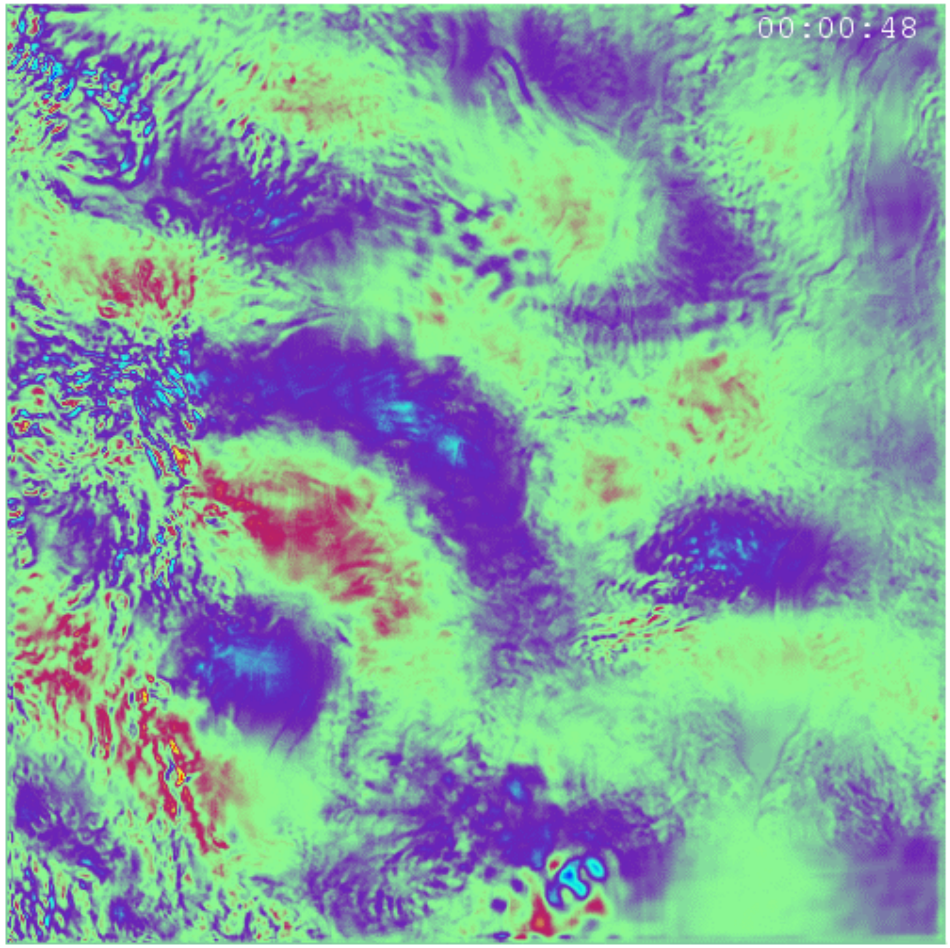
Impact of DFI: noise reduction

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



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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