Dynamic Initialization to Improve Tropical Cyclone Intensity and Structure Forecasts

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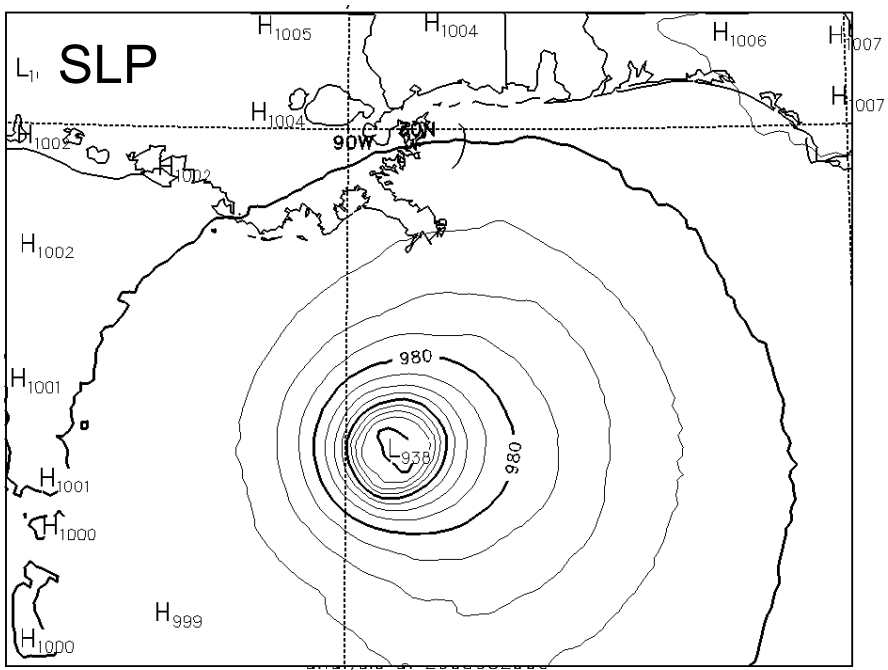
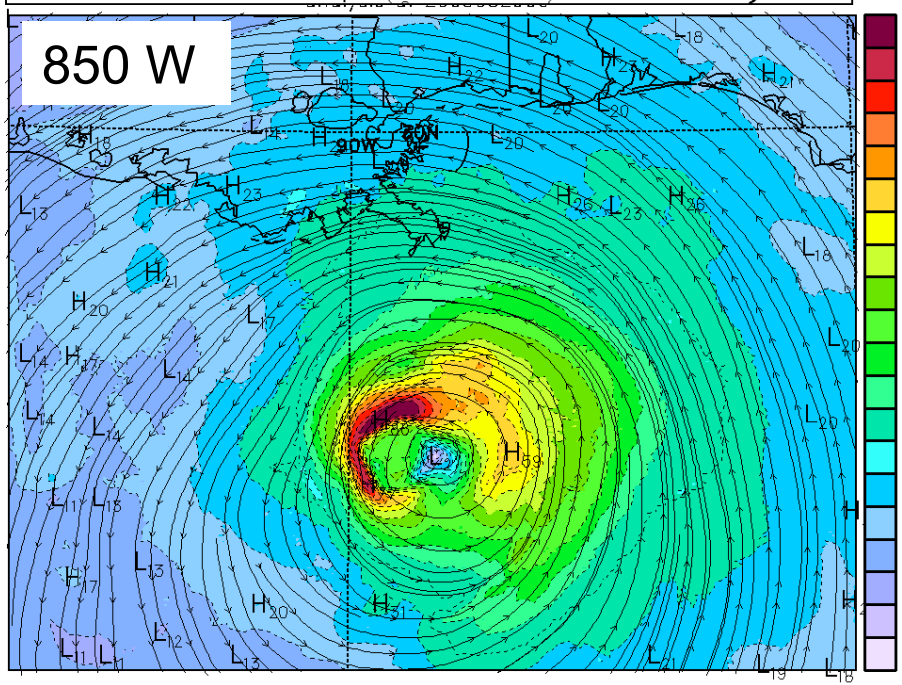
(JHT Project, Progress Report)

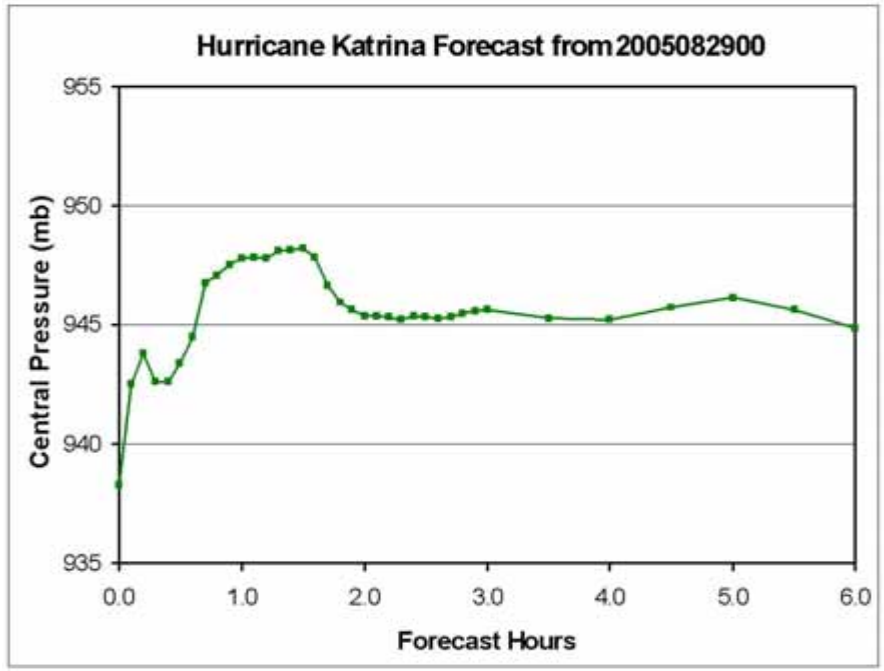
Unbalanced Initial Conditions of a TC Forecast

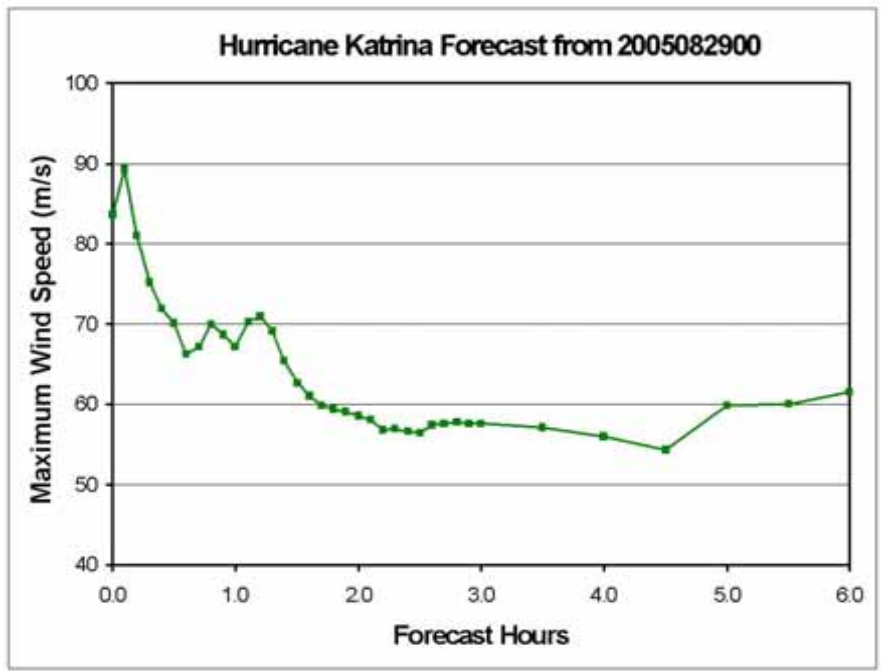
- Improper balance conditions included in analyzing TC circulation
- Diabatic Forcing: an important component in TC circulation balance
  - Forecast model must be involved in getting balanced initial conditions
- Method of getting balanced initial conditions
  - 4D Var, or
  - 3D Var with a proper initialization procedure

Unbalanced Initial Conditions



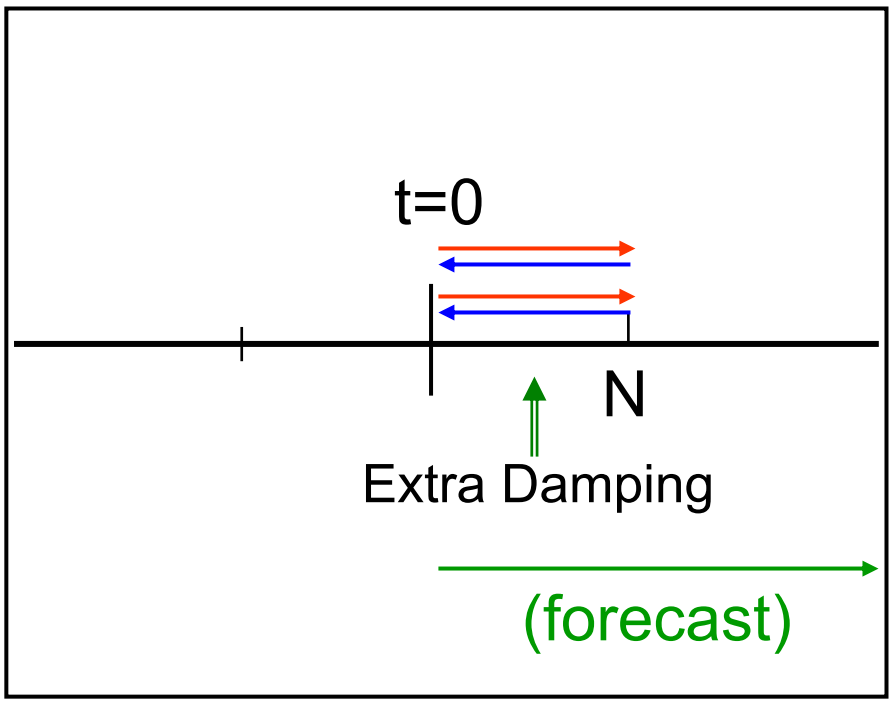


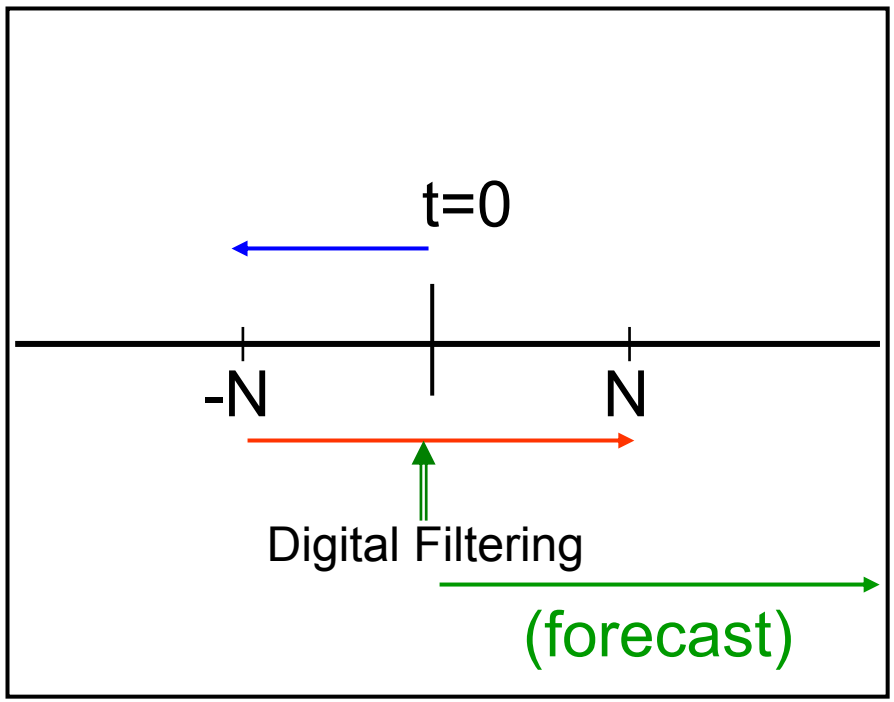




Dynamic Initialization

- Must consider diabatic forcing in TC balance
  - Dynamic initialization
    (assuming unbalanced components are high frequency)
  - Traditional method versus Digital Filter





Digital Filter

- A very selective low pass filter
- Using truncated inverse Fourier transform to remove high frequency components from input signals

In Frequency Domain:

$$F_{out} = F_{in} * H(\omega), \quad H(\omega) = 1, \ |\omega| \le \omega_c$$
$$= 0, \ |\omega| > \omega_c$$

In Physical Time Domain:

$$\tilde{f}_k = \sum_{n=-\infty}^{\infty} (h_n * f_{k-n}), \quad h(t) = \int_{-\infty}^{\infty} H(\omega) * e^{-i\omega t} d\omega$$
$$\approx \sum_{n=-N}^{N} (h_n * f_{k-n}), \quad h_n = \frac{\sin(n\omega_c \Delta t)}{n\pi}$$

Gibbs' Phenomenon

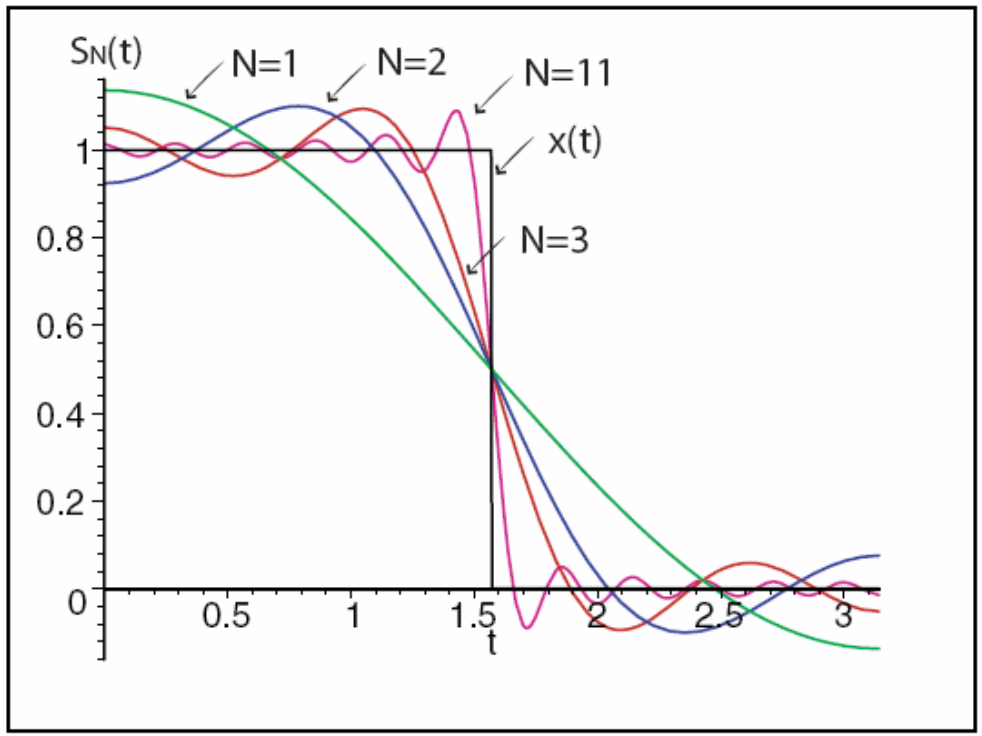
Unfortunately: $H = \sum_{n=-N}^{N} h_n e^{in\omega_c \Delta t}, \; h_n = \int_{-\infty}^{\infty} H e^{-in\mu} d\mu$

converges very slowly !!

For $\omega_c \Delta t = \frac{\pi}{2}$,

$h_n = \frac{2}{\pi} \sin \frac{n\pi}{2}$

H =>



Filter Response Function

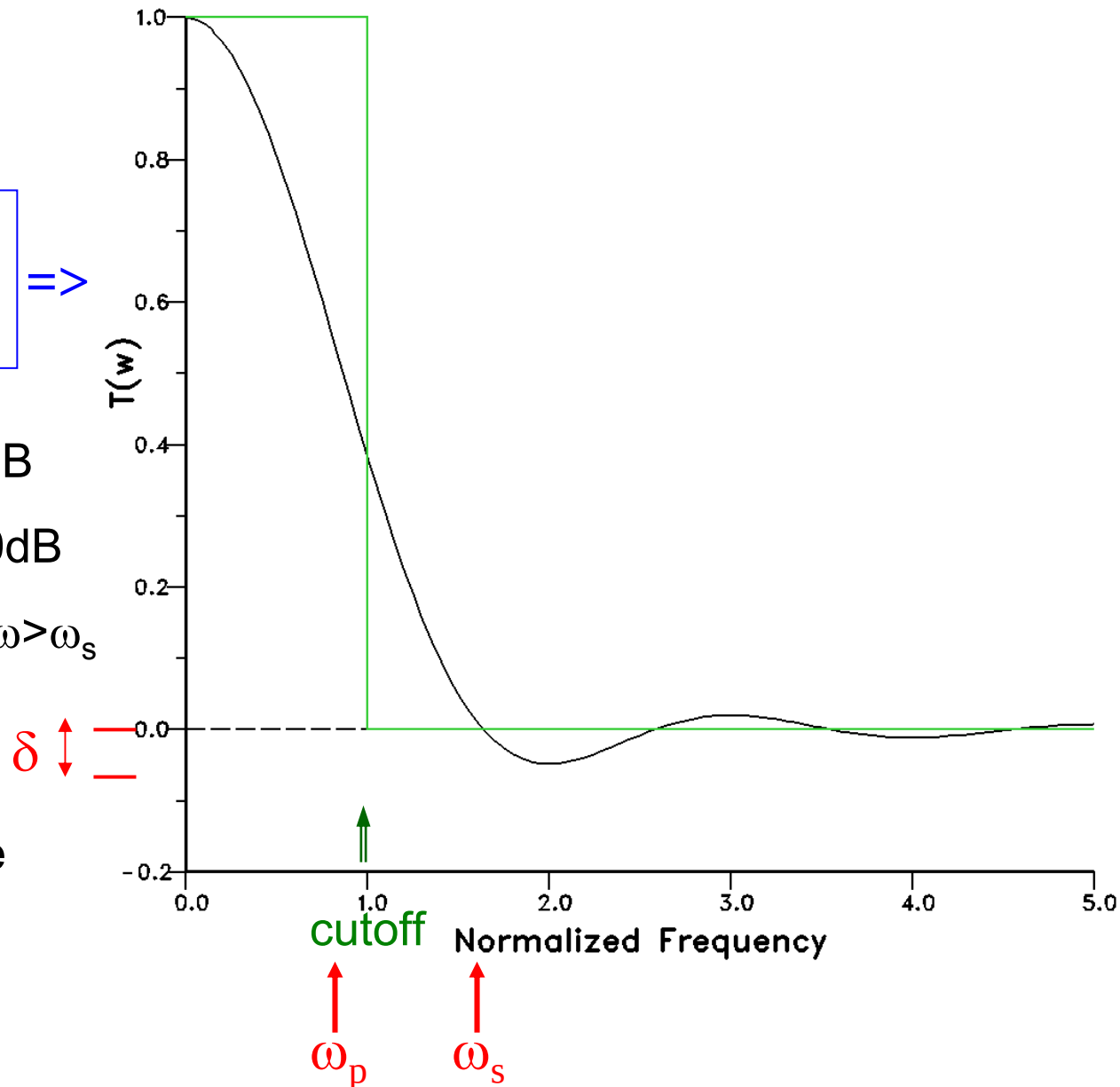
$$T(\omega) = \frac{F_{out}(\omega)}{F_{in}(\omega)}$$

$\omega_c = 2\pi/(6*3600)$ => $\Delta t = 240s$

- Pass band: $\omega < \omega_p$ = -3dB
- Stop band: $\omega > \omega_s$ = -20dB
- Transition band: $\omega_p > \omega > \omega_s$
- Stop band ripple:

  $\alpha_s = -20\log(\delta)$

  δ = largest ripple Size



Window Functions

- Apply a window function to improve convergence:

$$H = \sum_{n=-N}^{N} W_n \frac{\sin(n\omega_c \Delta t)}{n\pi} e^{in\omega_c \Delta t}$$

i.e., $$h_n = W_n \frac{\sin(n\omega_c \Delta t)}{n\pi}$$

- Windows Tested:
  - Lanczos
  - Hamming (Fixed Windows)
  - Riesz
  - Kaiser (Adjustable Windows)
  - Dolph-Chebyshev

Windows Tested

Lanczos: $$w_n = \frac{\sin[\, n\pi /(N+1)]}{n\pi /(N+1)}, \qquad 0 < n < N$$

Hamming: $$w_n = 0.54 + 0.46\cos\left(\frac{2n\pi}{2N+1}\right)$$

Riesz: $$w_n = 1 - \left(\frac{n}{N+1}\right)^2$$

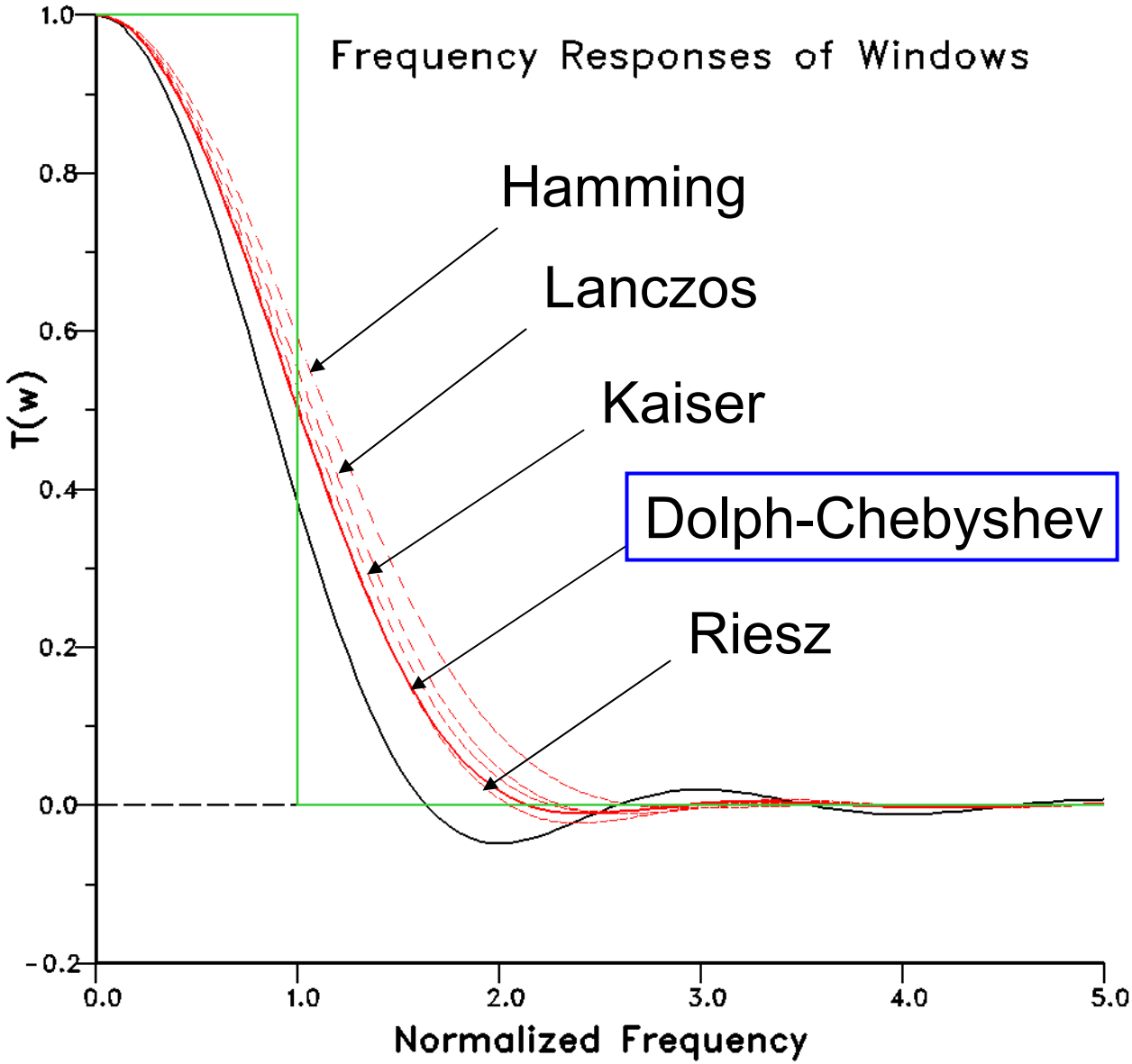
Kaiser: $$w_n = \frac{l_0\{\beta[1-(\frac{n}{N+1})^2]^{1/2}\}}{l_0(\beta)}, \quad l_0(x): \text{ Bessel function}$$

Dolph-Chebyshev: $$w_n = \frac{1}{w_0(2N+1)}\left[1 + 2\gamma\sum_{m=1}^{N} T_{2N}\left(x_0\cos\frac{\theta_m}{2}\right)\cos m\theta_n\right]$$

T_{2N}: Chebyshev polynomial, $x_0 = \cosh(\,{}^{1}\!/_{2N}\cosh^{-1}\gamma)$,

$\theta_m = {}^{2\pi m}\!/_{(2N+1)}$, $\theta_n = {}^{2\pi n}\!/_{(2N+1)}$

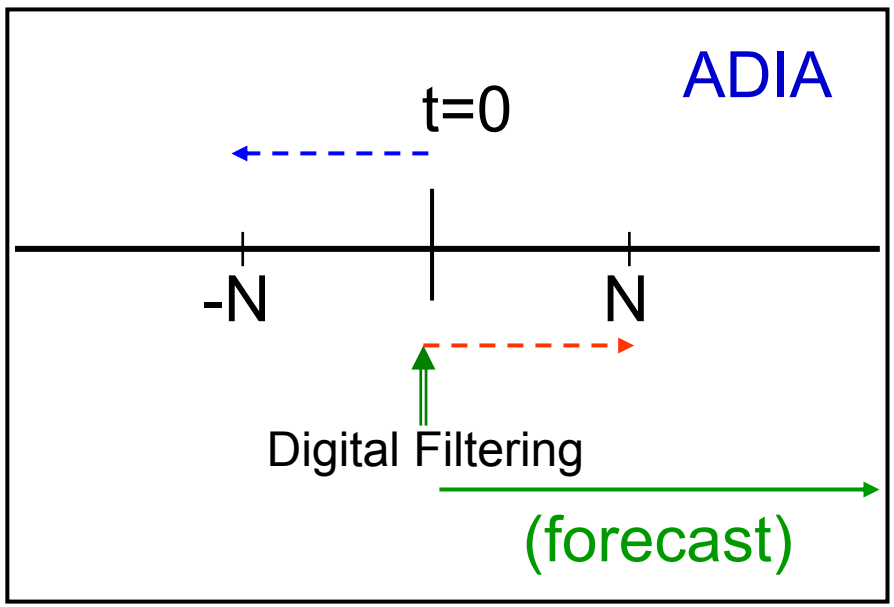
Response Functions with Windows

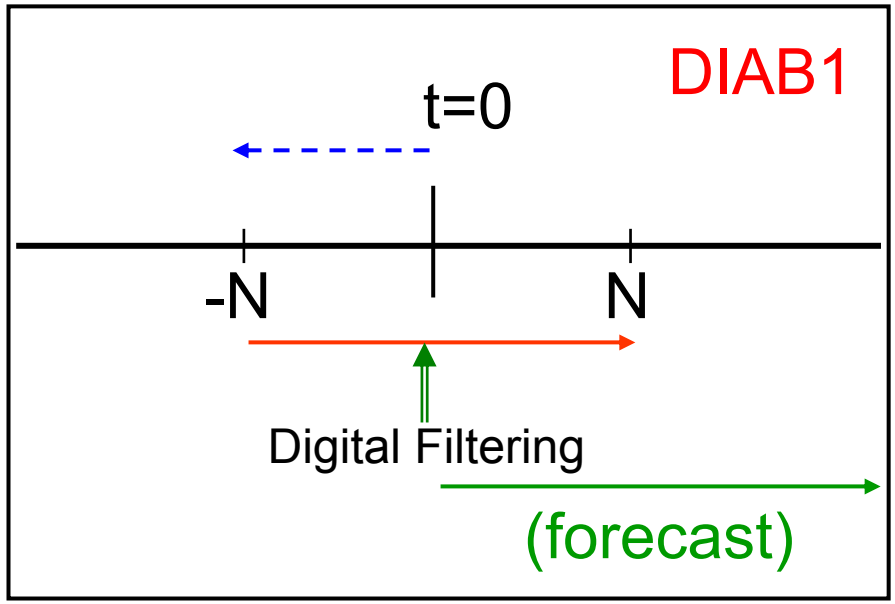


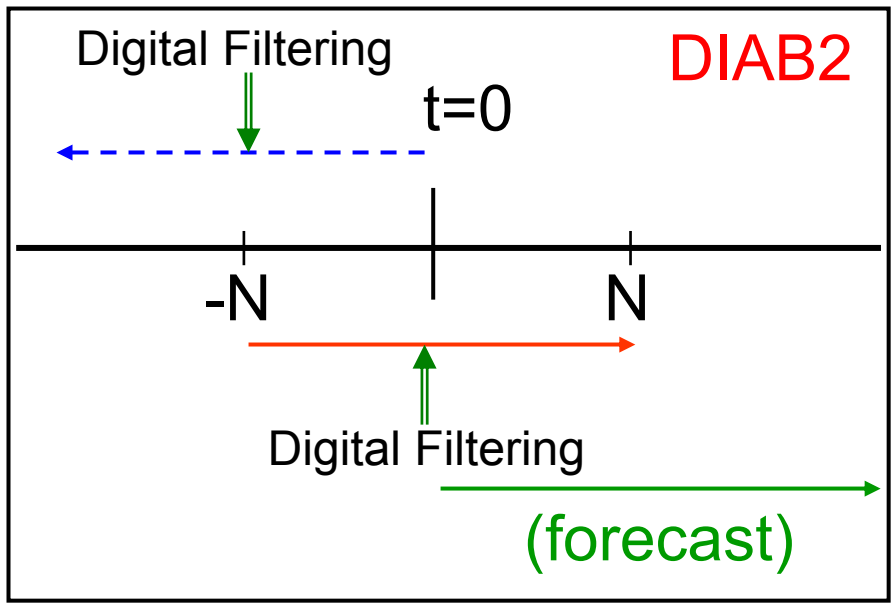
Dynamic Initialization with Digital Filtering

Adiabatic:

Diabatic:







Cost of Digital Filtering Initialization

- Compute filter weights
- Apply filtering
- Perform backward and forward initialization integration

===> 95% cost

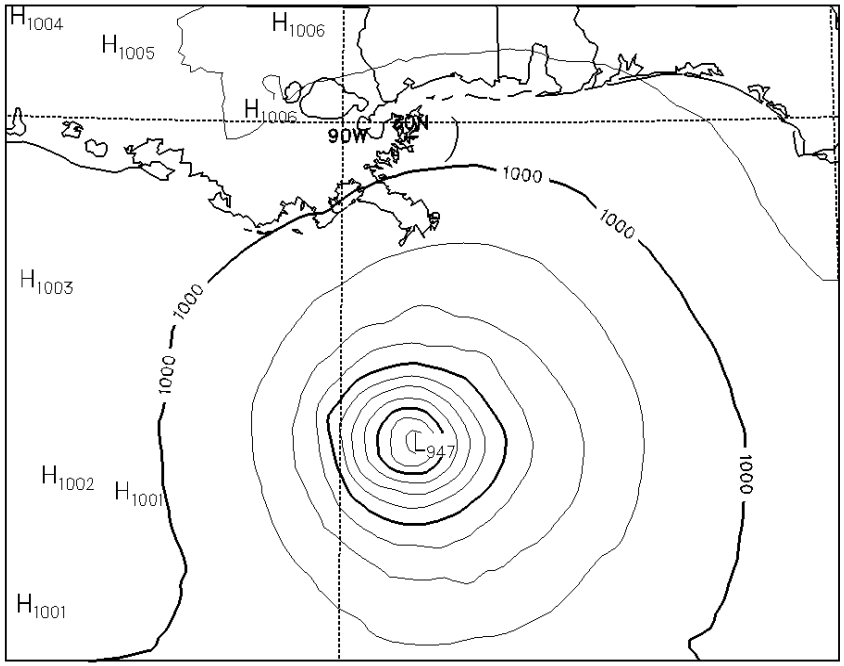
Initialization integration $\propto$ cutoff frequency (period=τ_c):

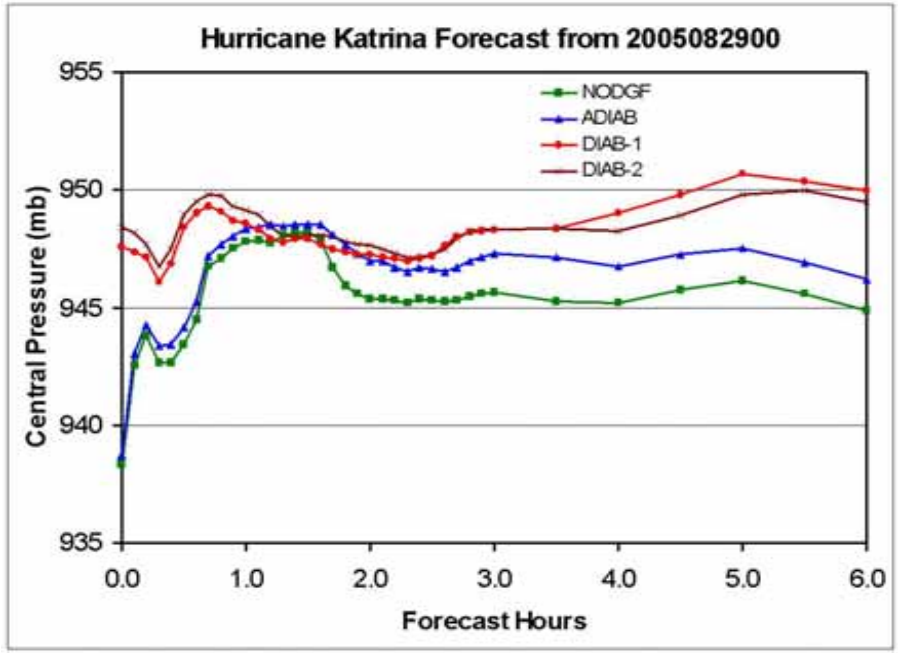
$$N = \frac{\tau_c}{2\Delta t}$$

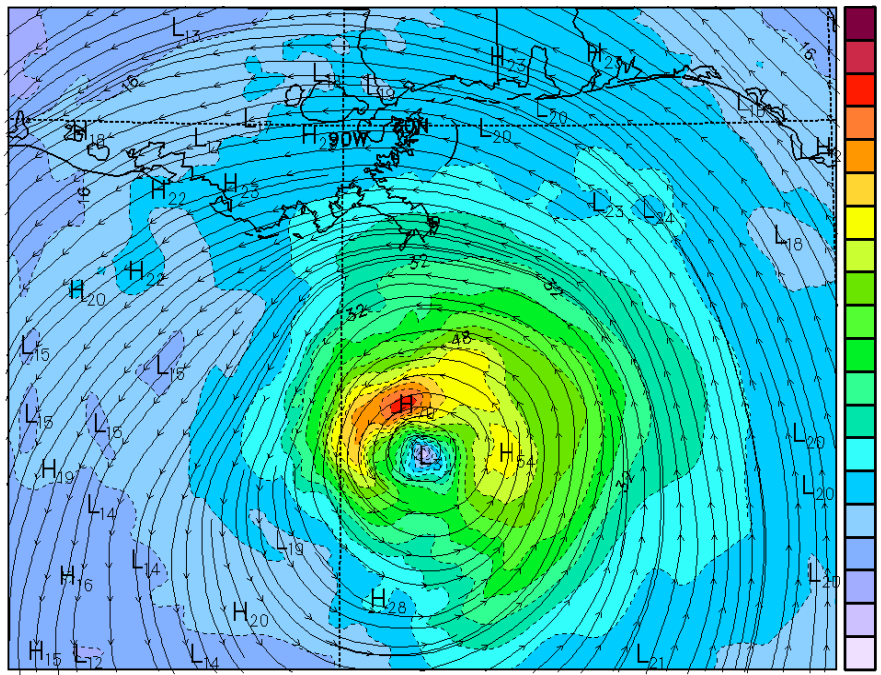
- For tropical cyclone forecast: τ_c = 2 hours

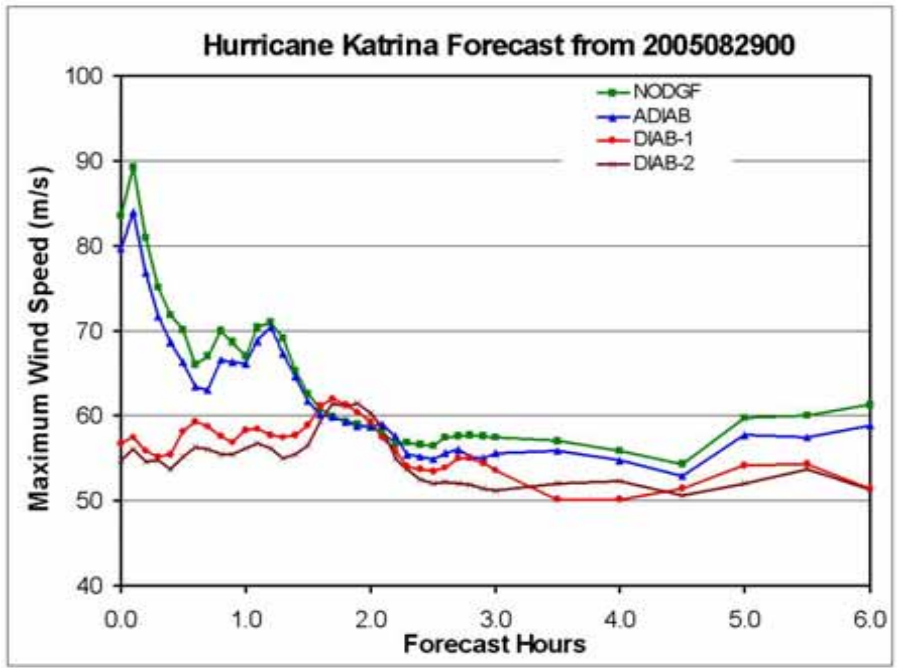
(For NWP forecast with Lanczos window : τ_c= 6 hours)

Initialization with Digital Filtering

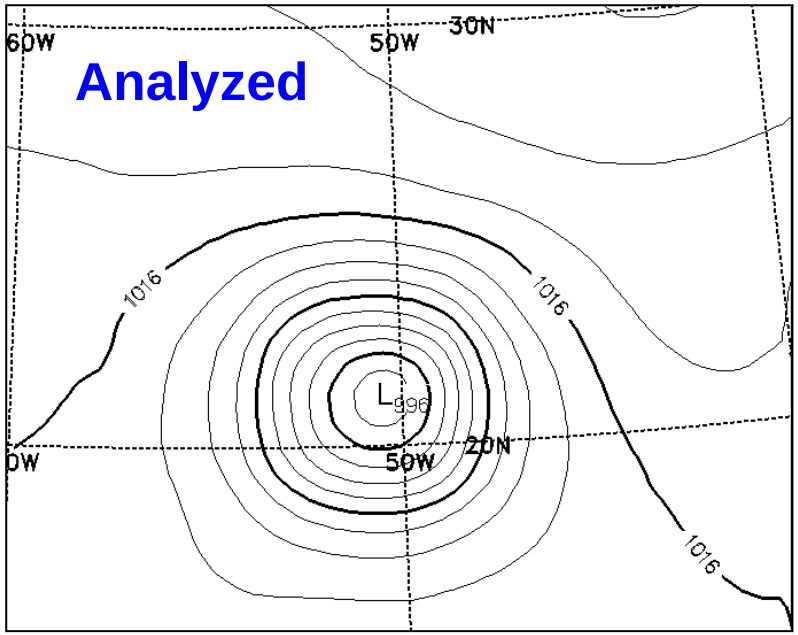


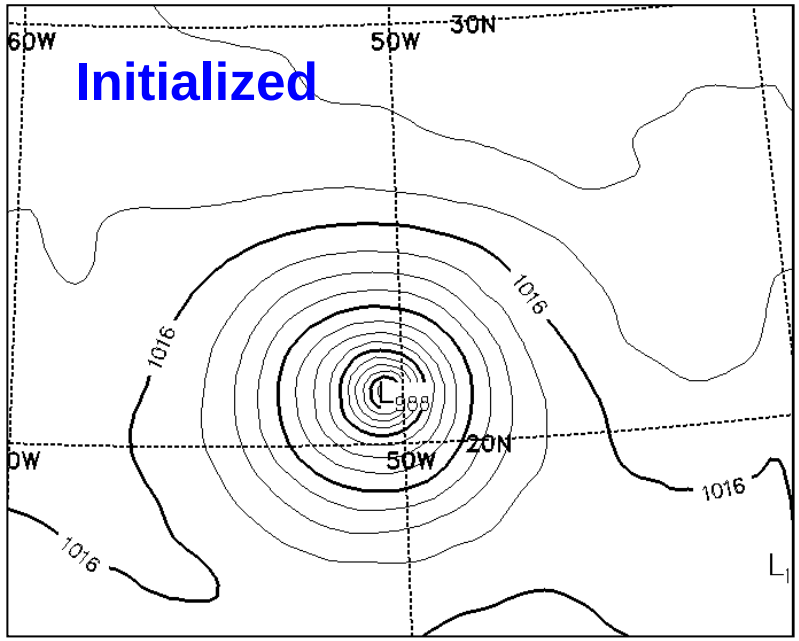


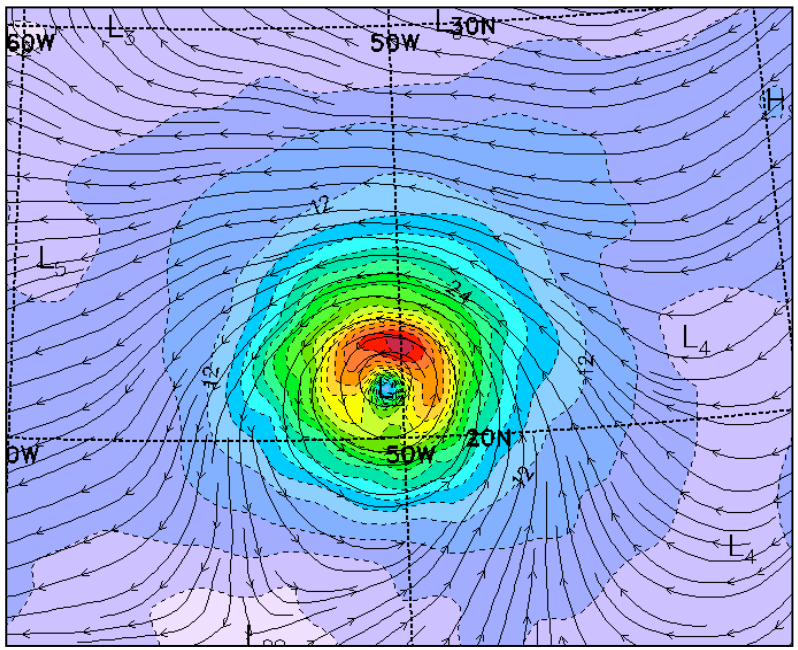


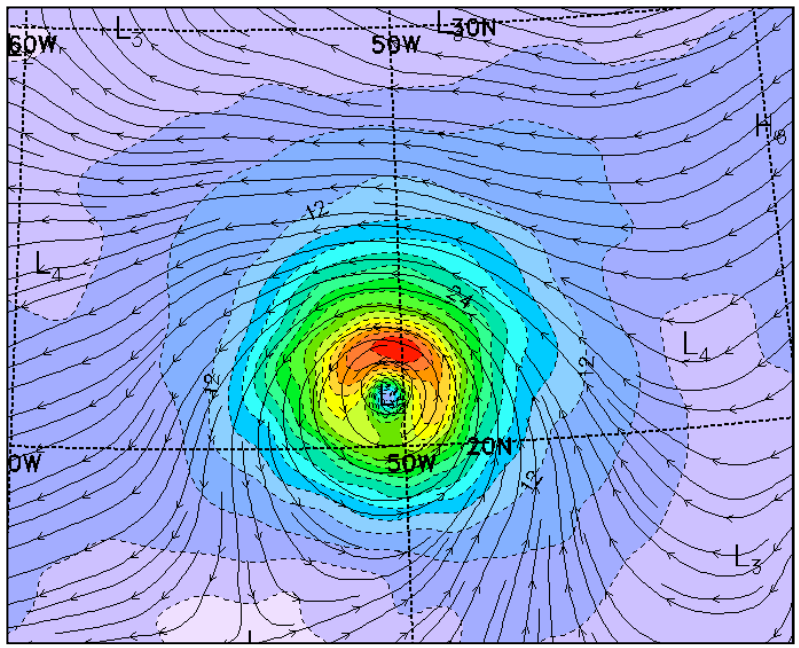


Tropical Cyclone Isabel (2003091012)

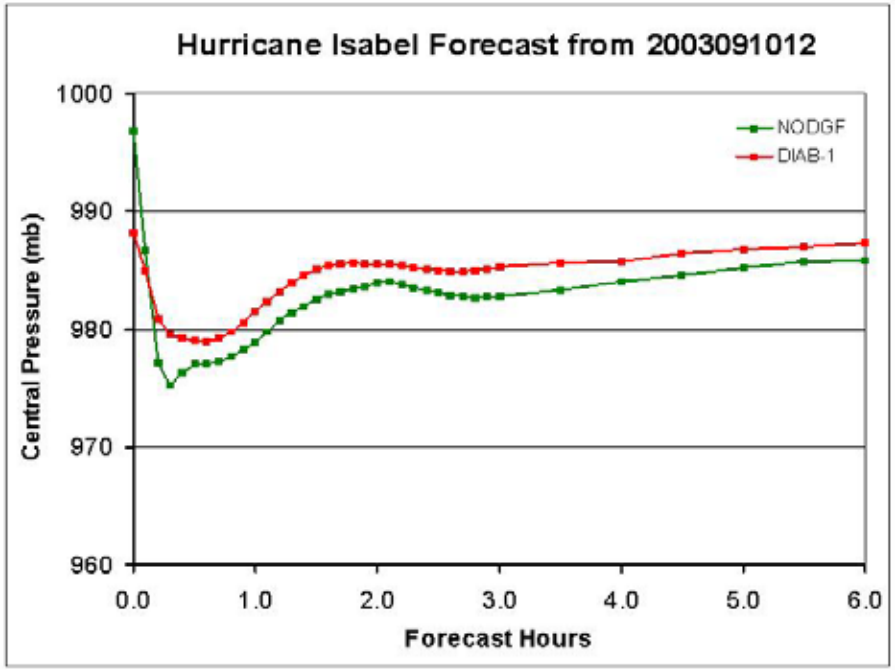


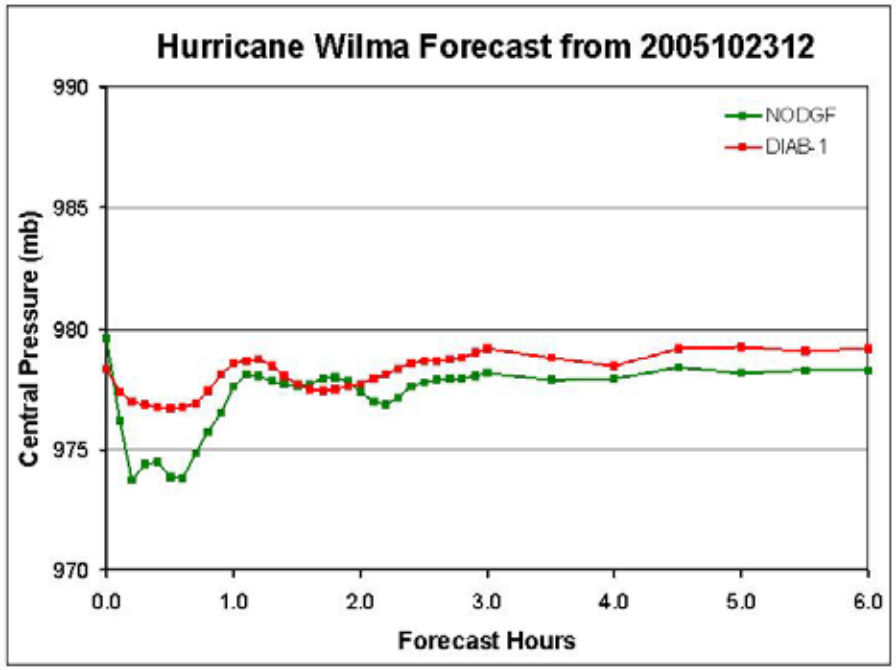


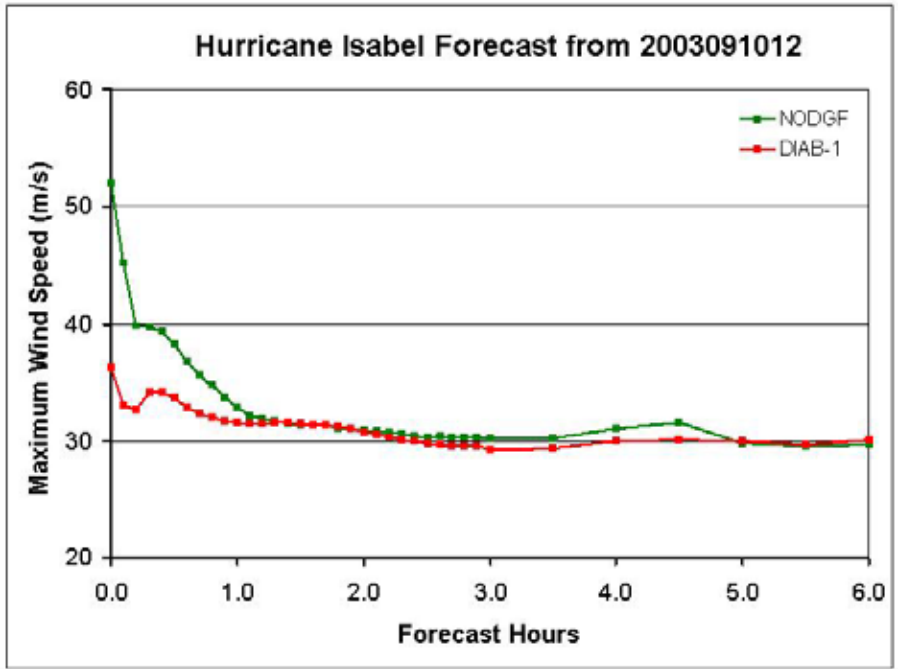


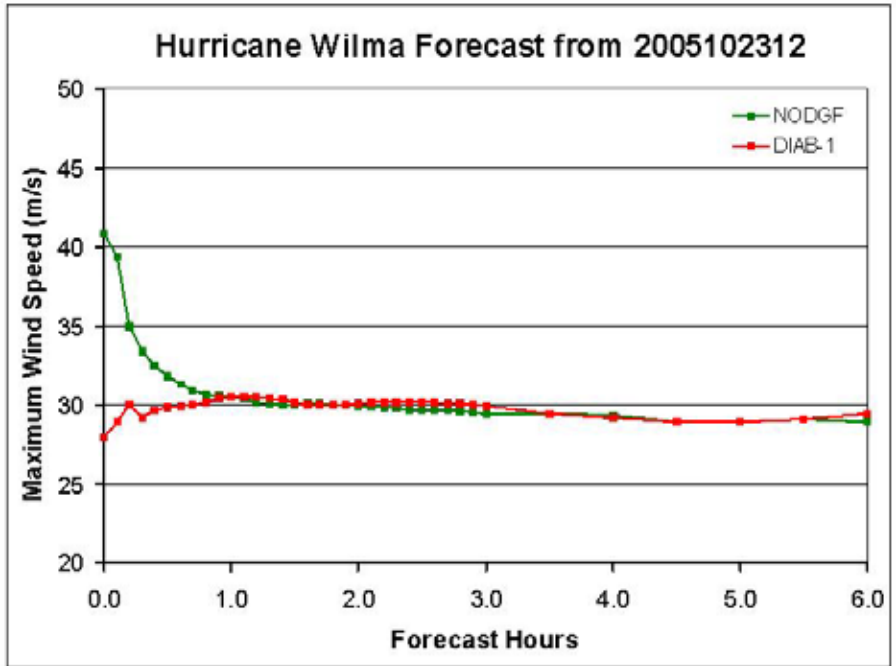


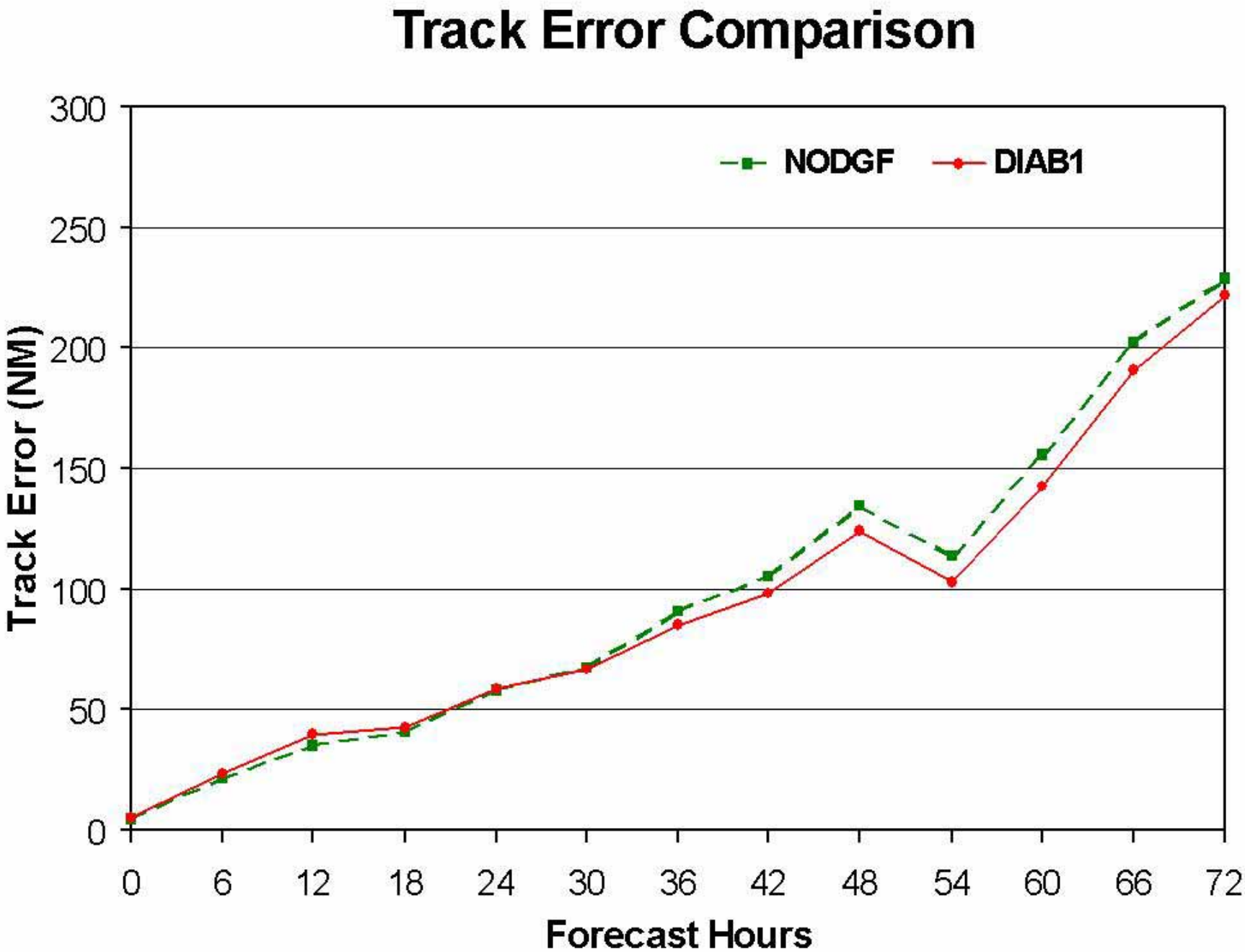
Initialization with Digital Filtering










Track Error Comparison
NODGF
DIAB1
Track Error (NM)
300
250
200
150
100
50
0
0
6
12
18
24
30
36
42
48
54
60
66
72
Forecast Hours

Summary

- With the Dolph-Chebyshev window and 2-h cutoff period, diabatic digital filtering can effectively provide much better balanced initial conditions of a tropical cyclone
- Adiabatic digital filtering only marginally improves initial conditions for tropical cyclone forecast
- The type-2 diabatic digital filtering integration strategy makes very little difference in the results, but cost ¼ more in time integration
- Diabatic digital filtering initialization improves track forecast of COAMPS®