The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

Spring Colloquium on
'Regional Weather Predictability and Modeling'
April 11 - 22, 2005

1) Workshop on **Design and Use of Regional Weather Prediction Models**, *April 11 - 19*

2) Conference on **Current Efforts Toward Advancing the Skill of Regional Weather Prediction. Challenges and Outlook**, *April 20 - 22*

301/1652-19

"Initialization" unsing an Iterative Matsuno Style Scheme in the Eta Model Adjustment Stage

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"Initialization" Using an Iterative Matsuno Style Scheme in the Eta Model Adjustment Stage

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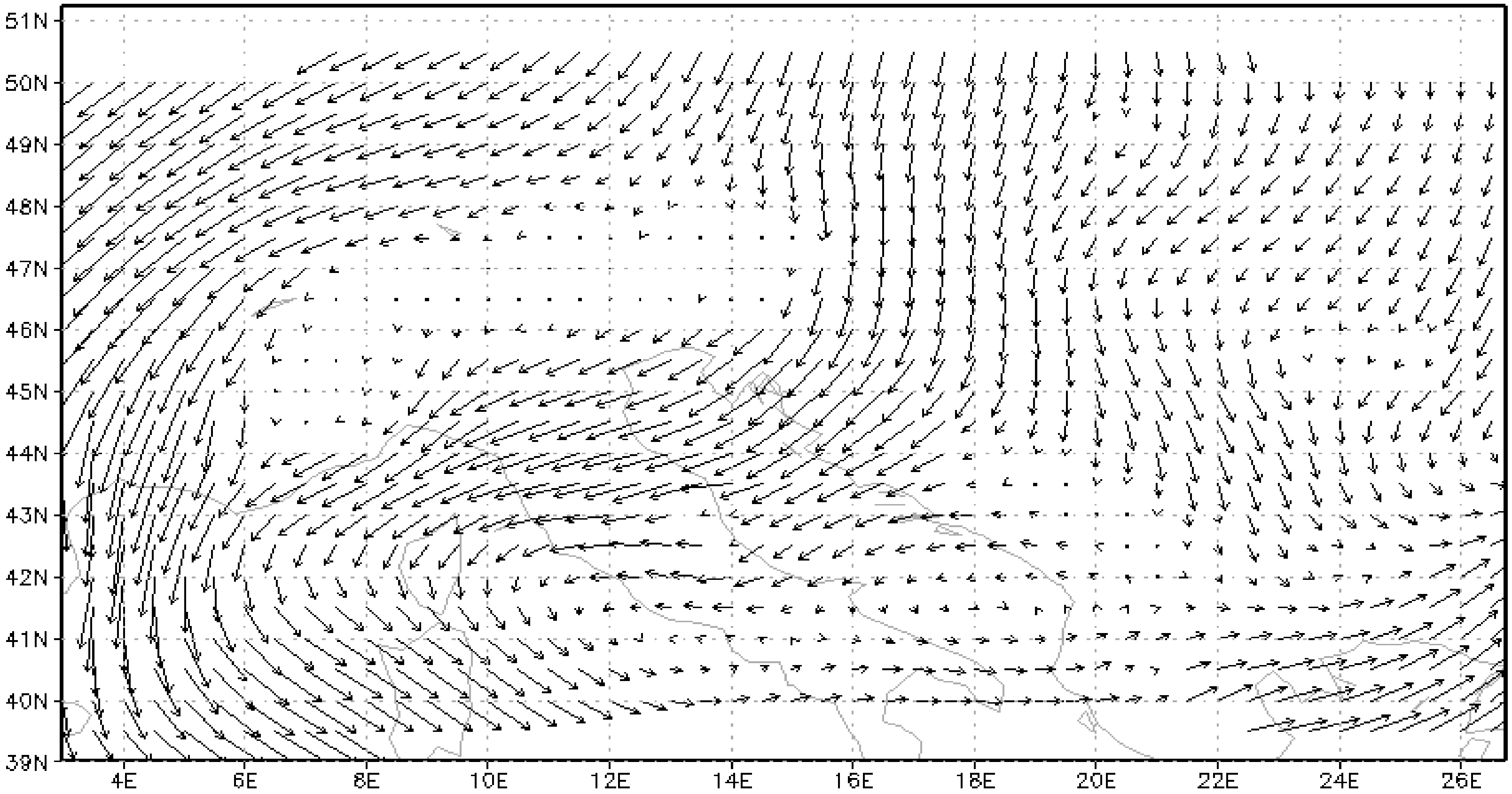
Introduction

- An iterative Matsuno or *a "super-Matsuno" style scheme* is applied as *a filter* in the Eta Model.
- The scheme is applied for the model's *adjustment terms only*.
- During *two hours* (one backward and one forward) "initialization" procedure includes full/diabatic model except convection.
- After this **iterative dynamic diabatic "initialization",** standard model integration is continued, now *very much free of noise*.
- *The super-Matsuno style scheme* is found to *balance* initially unbalanced external and internal modes and to significantly *reduce* the high-frequency.

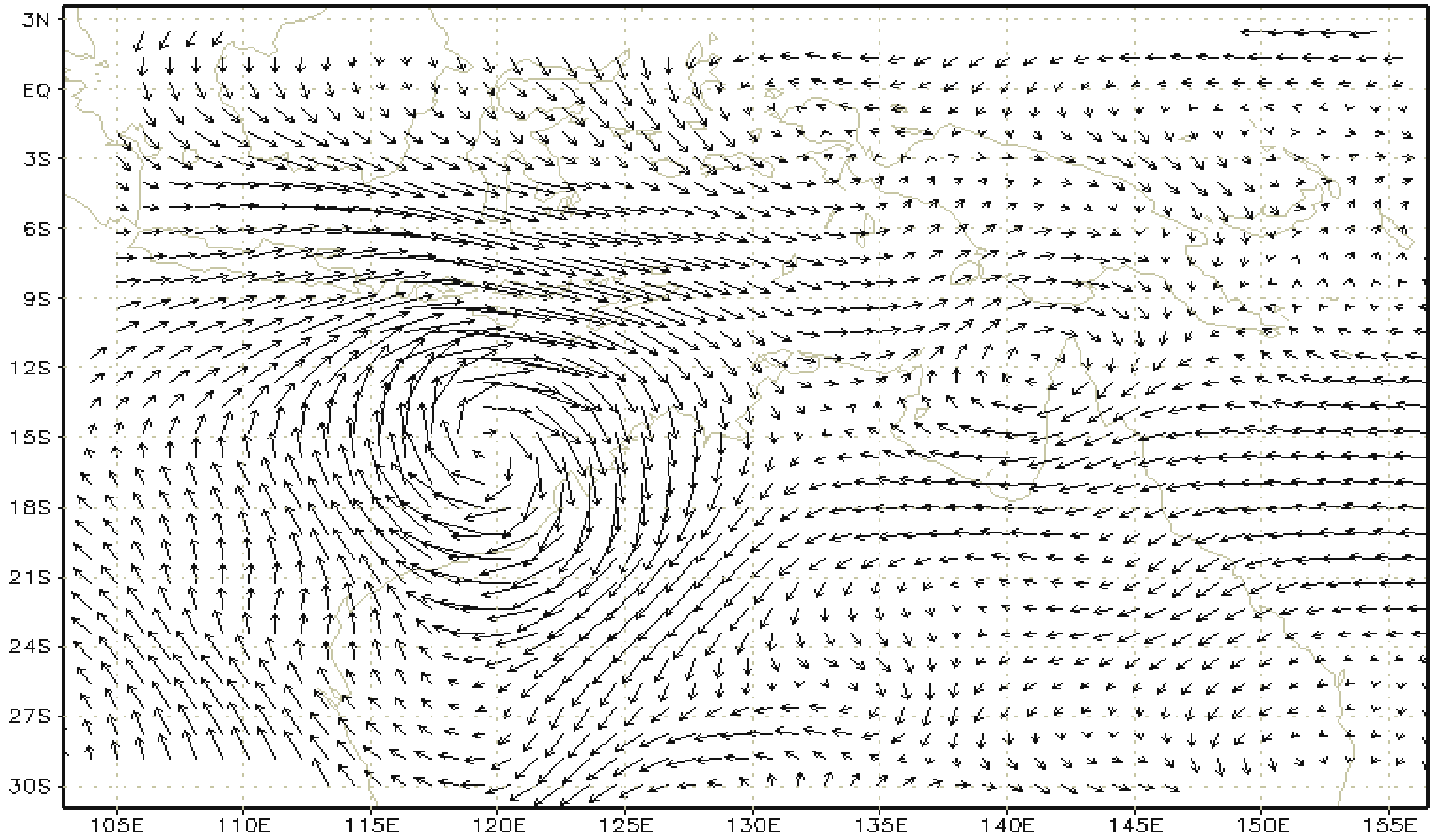
Experiments Set-Up

- *Initial conditions for local bora wind* are of 0000 UTC 01 December 1990.
- Bora is a local, cold, strong, north or north-east low-level wind over the Adriatic coast.



Experiments Set-Up (cont.)

- *Initial conditions for tropical cyclones* are of 0000 UTC 18 January 1987, selected for *the tropical cyclones Connie and Irma* from the AMEX (Australian Monsoon Experiment).



Adjustment Process in the Eta model

- The *forward-backward time integration scheme* for the *adjustment terms*.

$$\frac{\partial u}{\partial t} = -g\frac{\partial h}{\partial x} + fv,$$

$$\frac{\partial v}{\partial t} = -g\frac{\partial h}{\partial y} - fu,$$

$$\frac{\partial h}{\partial t} = -H\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right).$$

- *The mass field* is updated first using *the forward scheme*, and *then* the values of the pressure gradient terms are used to update *the velocity components* using *the backward scheme*.

Adjustment Process in the Eta model (cont.)

- For *the Coriolis terms the trapezoidal implicit scheme* is used, which is always neutral.

$$u^{n+1} = u^n - \Delta t g \delta_x h^{n+1} + \frac{\Delta t}{2} f\left(v^n + v^{n+1}\right)$$

$$v^{n+1} = v^n - \Delta t g \delta_y h^{n+1} - \frac{\Delta t}{2} f\left(u^n + u^{n+1}\right)$$

$$h^{n+1} = h^n - \Delta t H\left(\delta_x u + \delta_y v\right)^n + \left(\Delta t\right)^2 wgH\left(\nabla_\times^2 - \nabla_+^2\right)h^n$$

Super-Matsuno Style Time Differencing Scheme

- *Scheme definition:*

- *The super-Matsuno scheme* (Fox-Rabinovitz, 1996) is a generalization of the Euler backward (Matsuno) scheme, to include *additional corrector iterations*.

- Applying this scheme with the backward scheme for the Coriolis terms:

Super-Matsuno Style Time Differencing Scheme (cont.)

- - *predictor:*

$$u_*^{n+1} = u^n - \Delta t g \delta_x h^n + \Delta t f v_*^{n+1}$$

$$v_*^{n+1} = v^n - \Delta t g \delta_y h^n - \Delta t f u_*^{n+1}$$

$$h_*^{n+1} = h^n - \Delta t H \left(\delta_x u + \delta_y v\right)^n$$

- - *corrector:*

$$u_1^{n+1} = u^n - \Delta t g \delta_x h_*^{n+1} + \Delta t f v_1^{n+1}$$

$$v_1^{n+1} = v^n - \Delta t g \delta_y h_*^{n+1} - \Delta t f u_1^{n+1}$$

$$h_1^{n+1} = h^n - \Delta t H \left(\delta_x u_* + \delta_y v_*\right)^{n+1}$$

Super-Matsuno Style Time Differencing Scheme (cont.)

- along with *iterations of the corrector step*

$$u_2^{n+1} = u^n - \Delta t g \delta_x h_1^{n+1} + \Delta t f v_2^{n+1}$$

$$v_2^{n+1} = v^n - \Delta t g \delta_y h_1^{n+1} - \Delta t f u_2^{n+1}$$

$$h_2^{n+1} = h^n - \Delta t H \left(\delta_x u_1 + \delta_y v_1\right)^{n+1}$$

$$\vdots$$

$$u_k^{n+1} = u^n - \Delta t g \delta_x h_{k-1}^{n+1} + \Delta t f v_k^{n+1}$$

$$v_k^{n+1} = v^n - \Delta t g \delta_y h_{k-1}^{n+1} - \Delta t f u_k^{n+1}$$

$$h_k^{n+1} = h^n - \Delta t H \left(\delta_x u_{k-1} + \delta_y v_{k-1}\right)^{n+1}$$

- where *k* is the *iteration number*.

Super-Matsuno Style Time Differencing Scheme (cont.)

- *Computational diffusion:*
- Let us consider *1D gravity wave system* for the second iteration from the corrector step *simple written*

$$u_2^{\,n+1} = u^n - \Delta t g \delta_x h_1^{\,n+1} = u^n - (\Phi_1)_x^{\,n+1} \Delta t,$$

$$\Phi_2^{\,n+1} = \Phi^n - C^2 (u_1)_x^{\,n+1} \Delta t.$$

- Using the first iteration from the corrector

$$u_2^{\,n+1} = u^n - \Phi_x^{\,n} \Delta t + C^2 u_{xx}^n (\Delta t)^2 - C^2 \Phi_{xxx}^n (\Delta t)^3,$$

$$\Phi_2^{\,n+1} = \Phi^n - C^2 u_x^{\,n} \Delta t + C^2 \Phi_{xx}^n (\Delta t)^2 - \left(C^2\right)^2 u_{xxx}^n (\Delta t)^3.$$

Super-Matsuno Style Time Differencing Scheme (cont.)

- The *first two terms* in rhs represent the *predictor*, or Φ_*^{n+1} and u_*^{n+1}
- The *first three terms* of rhs represent the *first corrector.*
- The *third rhs term* has the form of a *positive second-order computational diffusion*.
- One more iteration:

$$u_3^{n+1} = u^n - \Phi_x^n \Delta t + C^2 u_{xx}^n (\Delta t)^2 - C^2 \Phi_{xxx}^n (\Delta t)^3 + \left(C^2\right)^2 u_{xxxx}^n (\Delta t)^4$$

$$\Phi_3^{n+1} = \Phi^n - C^2 u_x^n \Delta t + C^2 \Phi_{xx}^n (\Delta t)^2 - \left(C^2\right)^2 u_{xxx}^n (\Delta t)^3 + \left(C^2\right)^2 \Phi_{xxxx}^n (\Delta t)^4$$

Super-Matsuno Style Time Differencing Scheme (cont.)

- Using definitions of u_*^{n+1} and Φ_*^{n+1}

$$u_2^{n+1} = u_*^{n+1} + (C\Delta t)^2 \left(u_*^{n+1}\right)_{xx}$$

$$\Phi_2^{n+1} = \Phi_*^{n+1} + (C\Delta t)^2 \left(\Phi_*^{n+1}\right)_{xx}$$

- Expressions for *third iteration*

$$u_3^{n+1} = u_2^{n+1} + (C\Delta t)^4 u_{xxxx}^n$$

$$\Phi_3^{n+1} = \Phi_2^{n+1} + (C\Delta t)^4 \Phi_{xxxx}^n$$

Super-Matsuno Style Time Differencing Scheme (cont.)

- *Final expressions*:

  - *odd iterations*, $k = 2l - 1 \geq 1$:

$$u_k^{n+1} = (C\Delta t)^{k+1} u_{(k+1)x}^{n} + \sum_{l=1}^{(k+1)/2} (C\Delta t)^{2l-2} u_{*}^{n+1}{}_{(2l-2)x},$$

$$\Phi_k^{n+1} = (C\Delta t)^{k+1} \Phi_{(k+1)x}^{n} + \sum_{l=1}^{(k+1)/2} (C\Delta t)^{2l-2} \Phi_{*}^{n+1}{}_{(2l-2)x},$$

  - *even iterations*, $k = 2l \geq 2$:

$$u_k^{n+1} = \sum_{l=1}^{(k+2)/2-1} (C\Delta t)^{2l-2} u_{*}^{n+1}{}_{(2l-2)x},$$

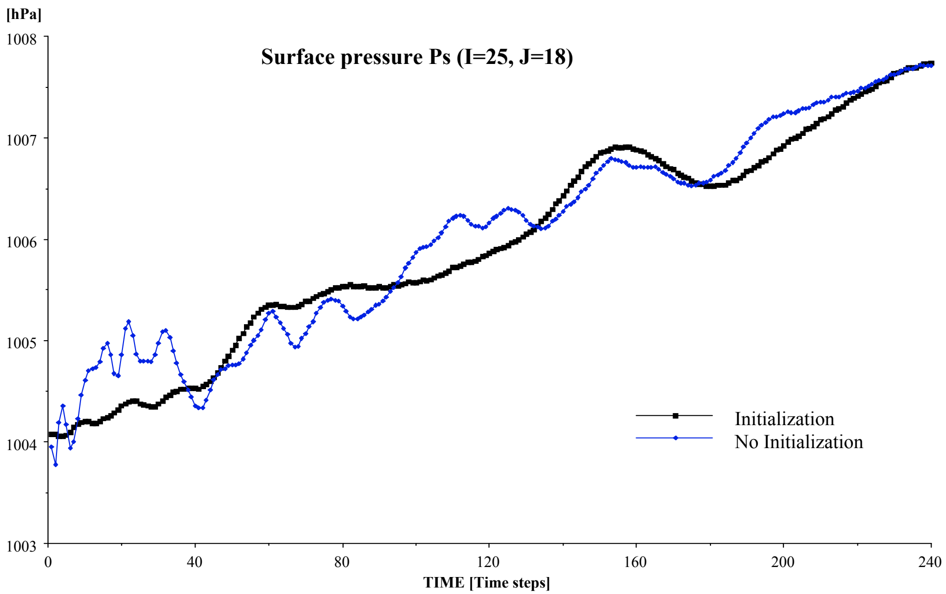
$$\Phi_k^{n+1} = \sum_{l=1}^{(k+2)/2-1} (C\Delta t)^{2l-2} \Phi_{*}^{n+1}{}_{(2l-2)x},$$

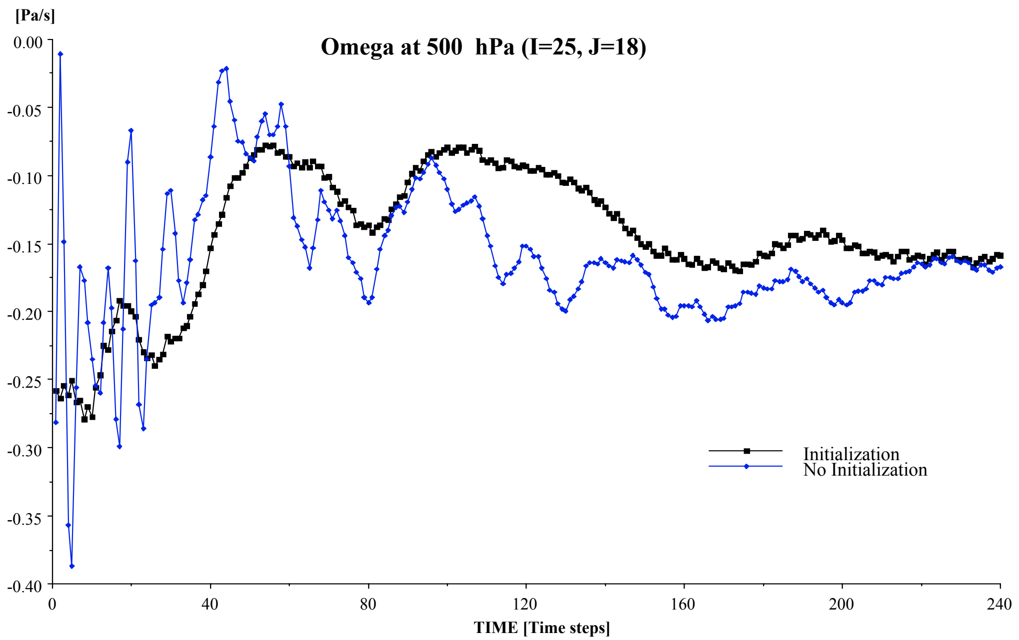
Super-Matsuno Style Time Differencing Scheme (cont.)

- The *super-Matsuno scheme* contain *higher-order diffusion operators*.
- The *Matsuno scheme* (k=1) contain a *second-order* diffusion operators.
- The *super-Matsuno scheme with k=3* contains *a fourth-order* diffusion operators.
- In our experiments we use *k=3.*

Results – Bora Wind

- *The time evolution* for the first 6 h of the forecast of *the surface pressure and 500 hPa vertical velocity* at a model grid point I=25, J=18, *without* ("No initialization") and *with "initialization"*



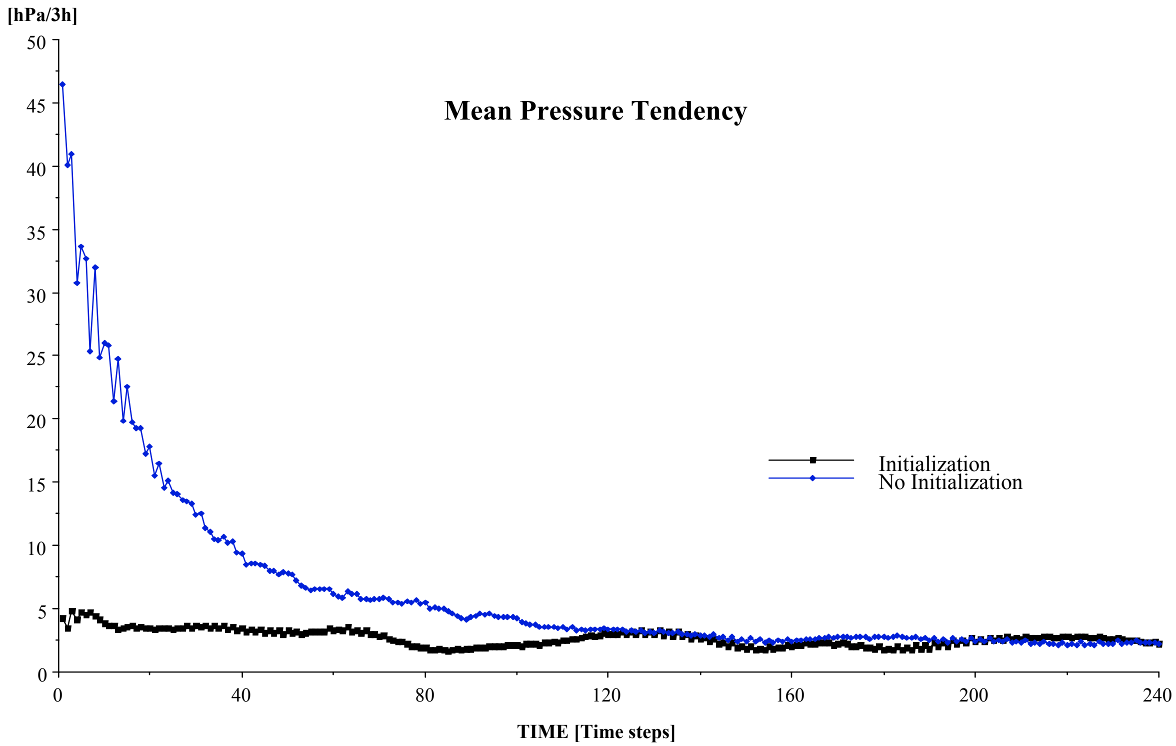


Results – Bora Wind (cont.)

- *The mean absolute surface pressure tendency* (MPT) is chosen to measure *the global noise level*.
- *The MPT* is defined as

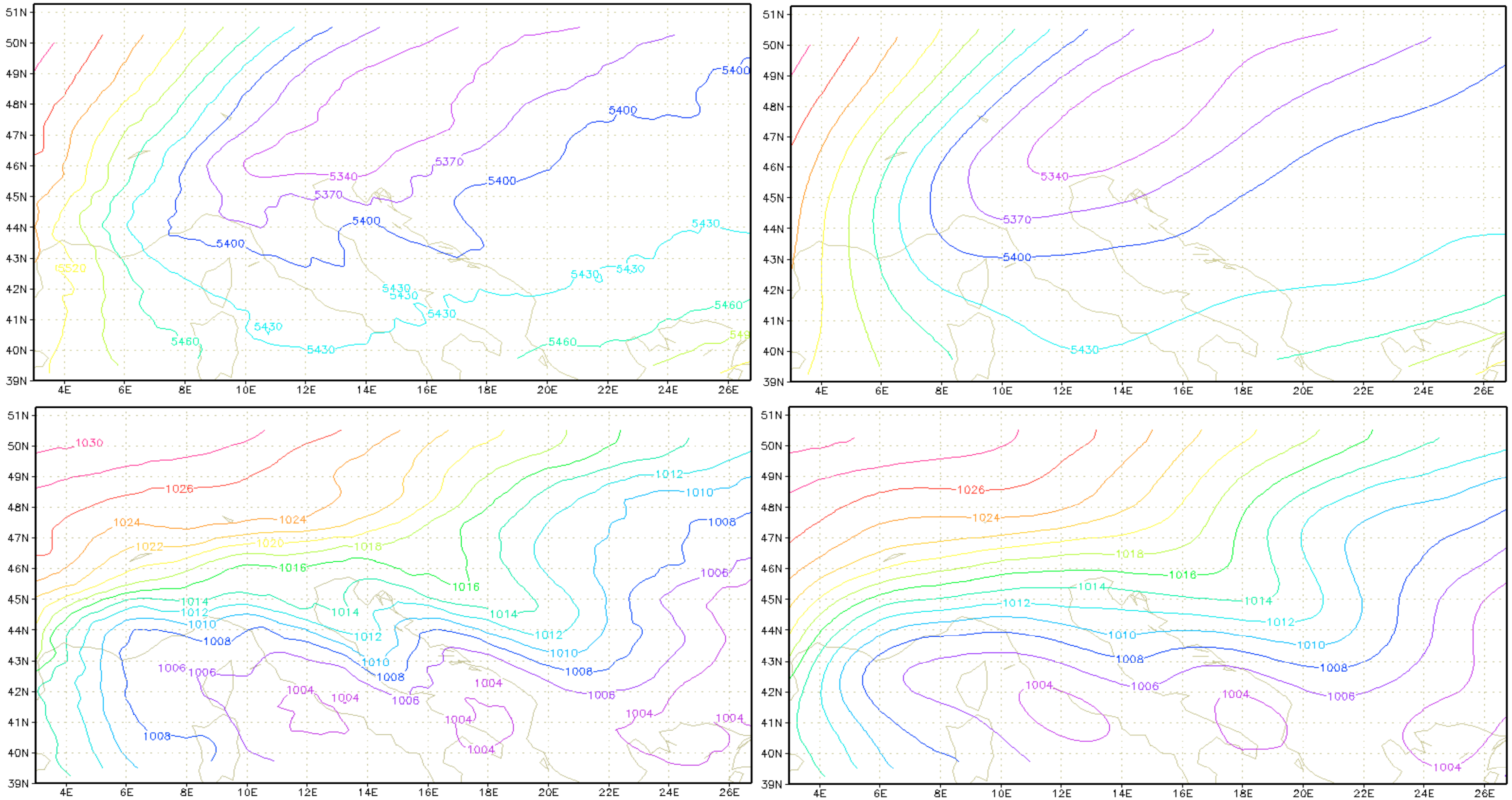
$$MPT = \frac{1}{IMJM} \sum_{K=1}^{IMJM} \left| \frac{\partial p_s}{\partial t} \right|_K$$

Variation of MPT during the first 6h of the forecast



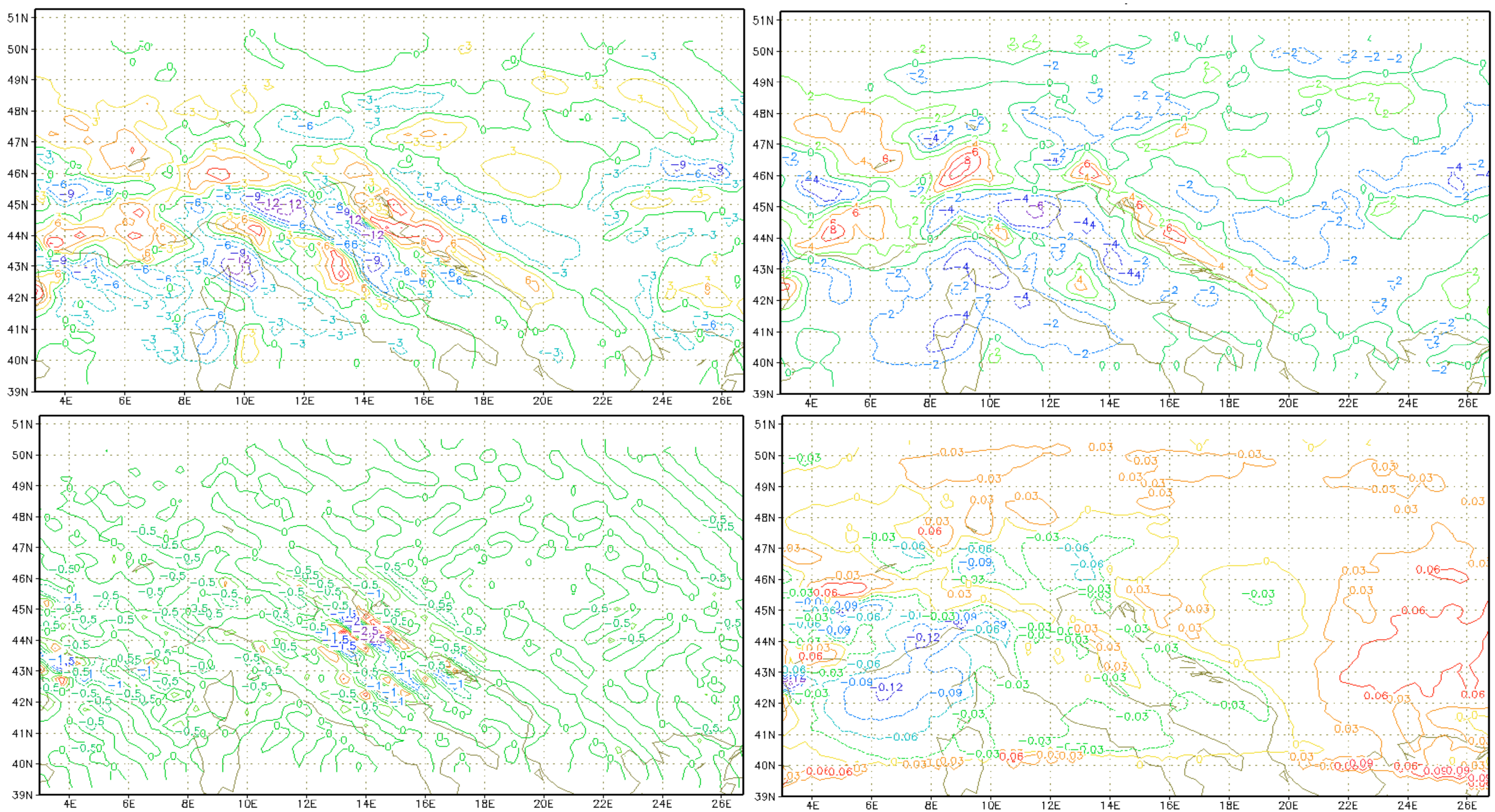
Results – Bora Wind (cont.)

- *Uninitialized and initialized* 500 hPa geopotential height and sea level pressure fields at *the initial time*



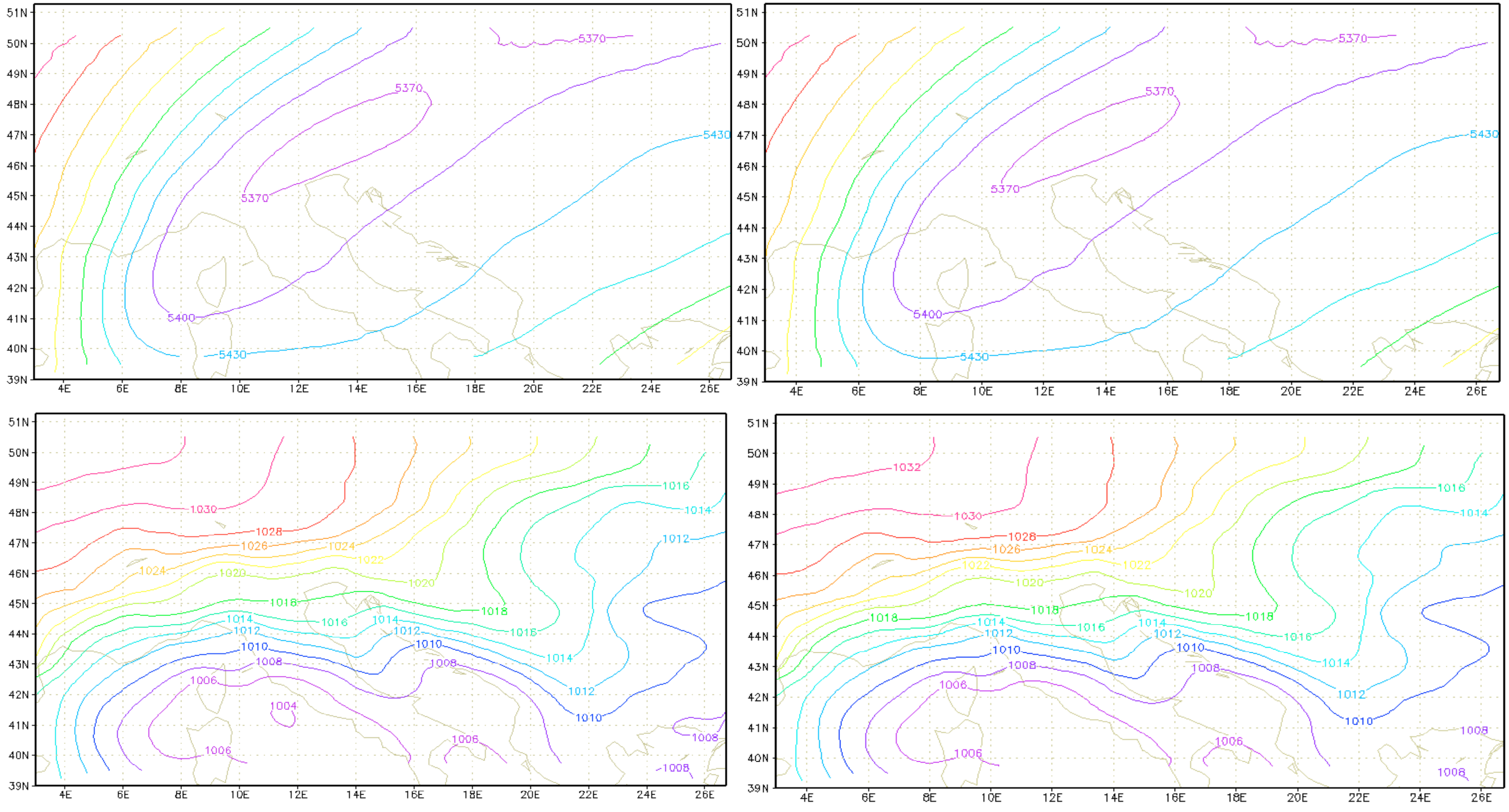
Results – Bora Wind (cont.)

- *Surface pressure tendency* and *the 500 hPa vertical velocity*, with and without initialization, at the *initial time*



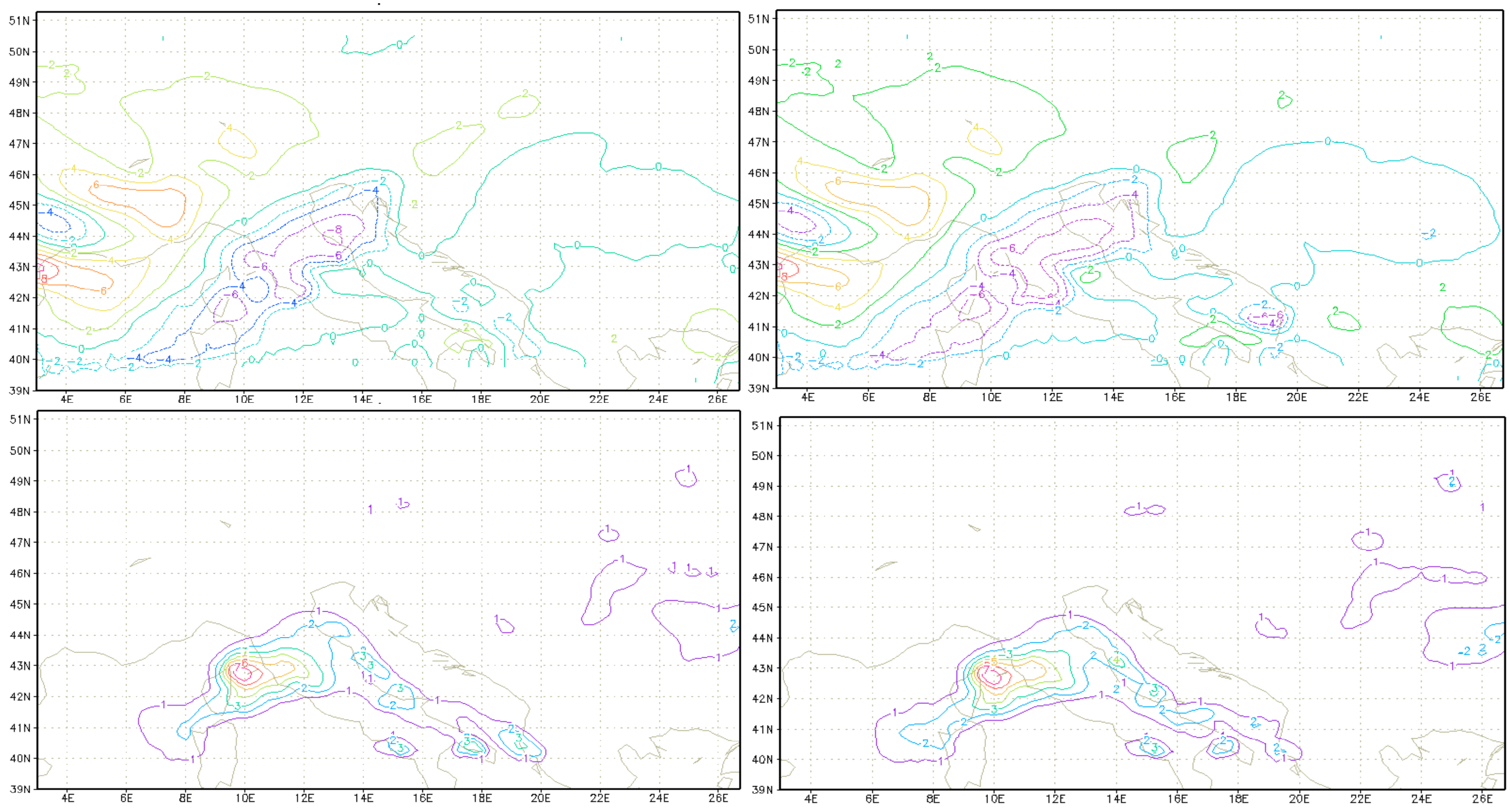
Results – Bora Wind (cont.)

- *The 500 hPa geopotential height* and *the sea level pressure* maps with and without initialization *after 6 h*



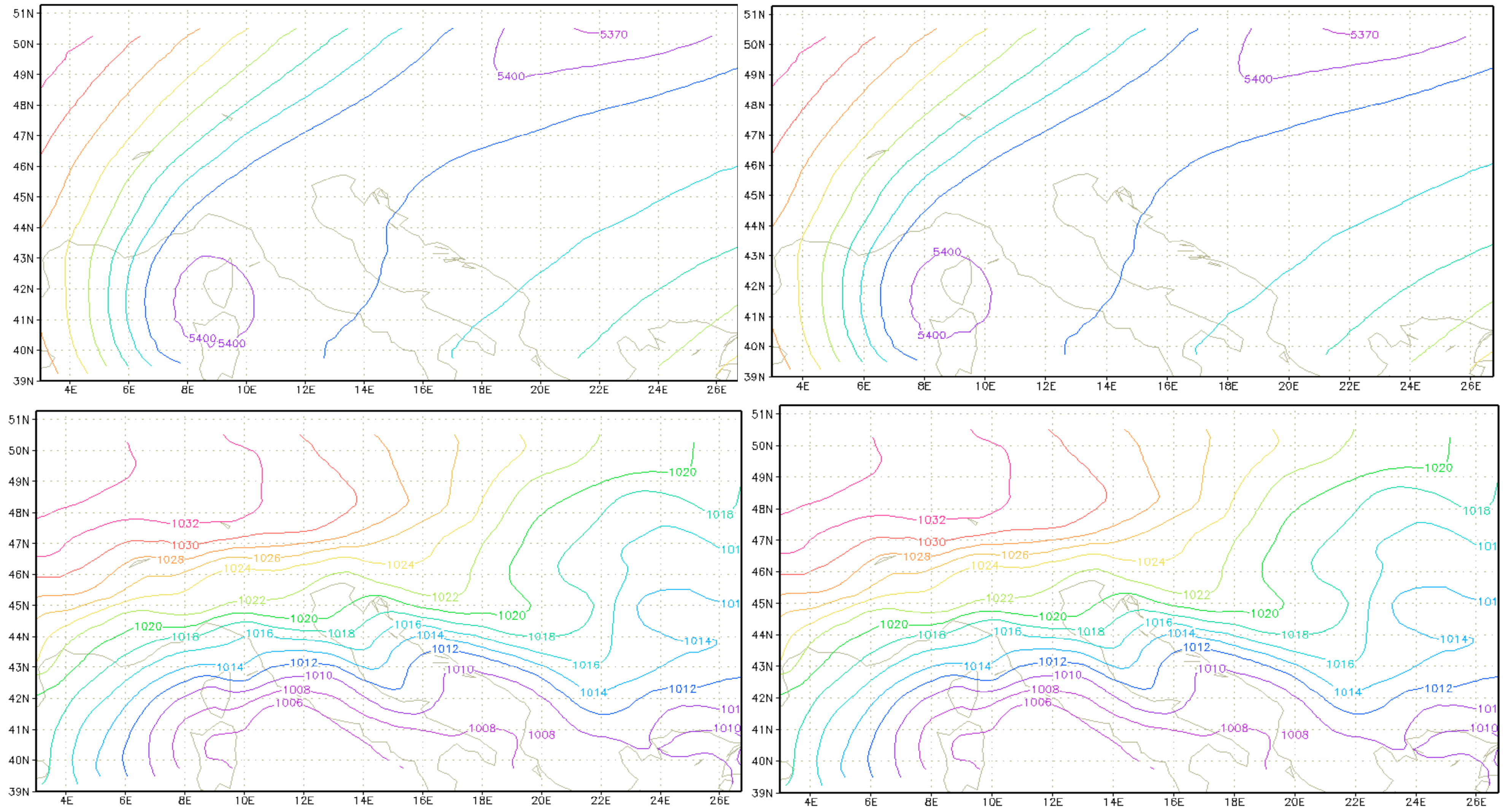
Results – Bora Wind (cont.)

- *The 500 hPa vertical velocity* and *the 12-h accumulated precipitation*, with and without initialization, *after 6 h*



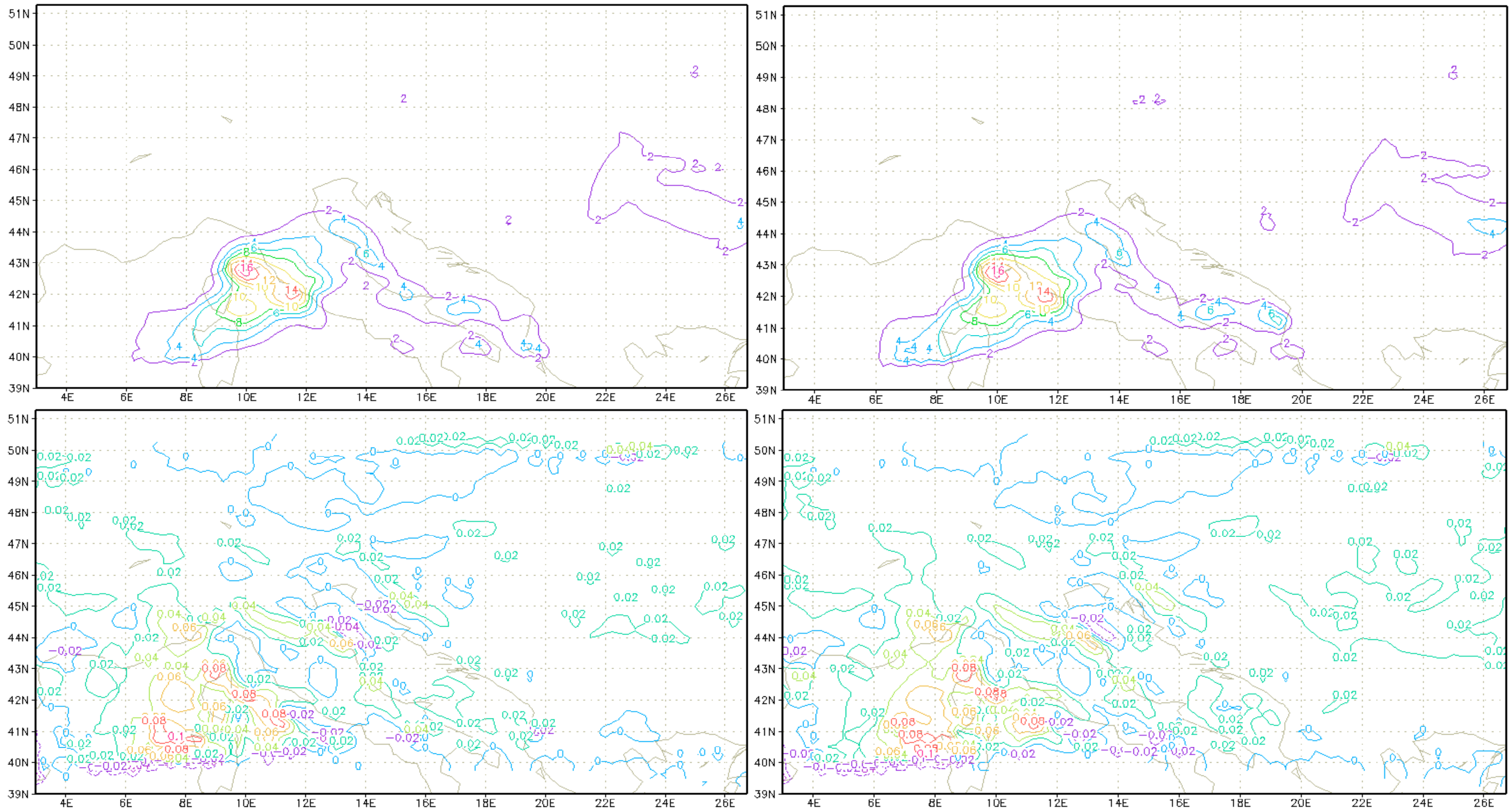
Results – Bora Wind (cont.)

- *The 500 hPa geopotential height* and *the sea level pressure* maps with and without initialization *after 12 h*



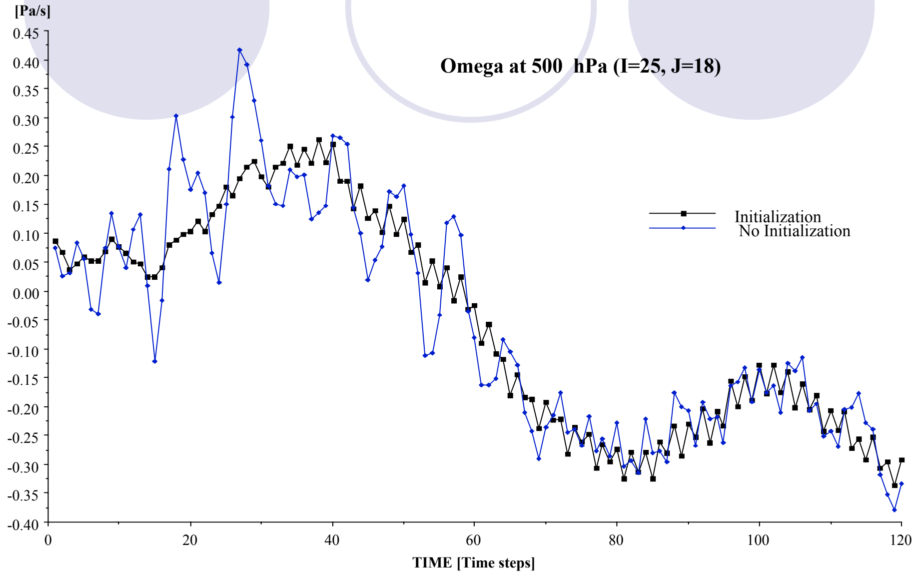
Results – Bora Wind (cont.)

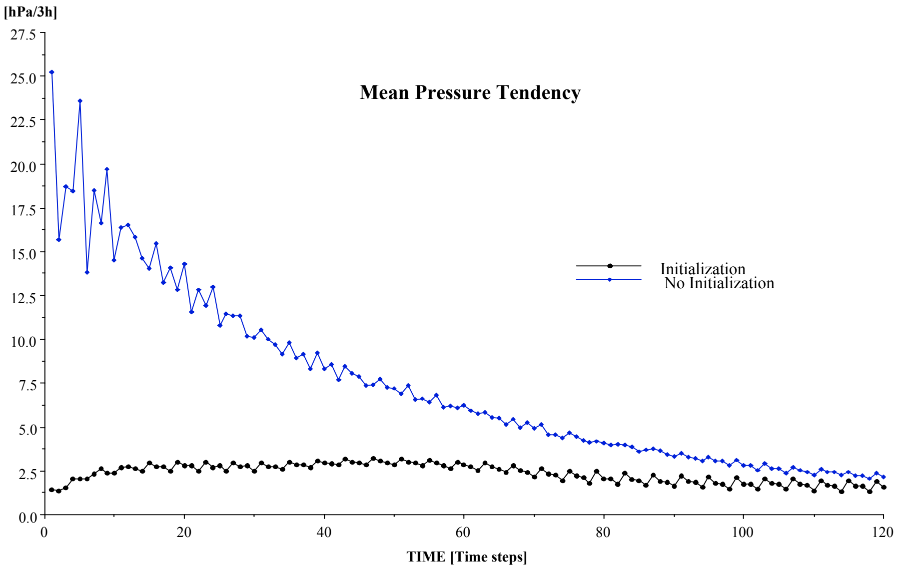
- *Surface pressure tendency* and *the 12-h accumulated precipitation*, with and without initialization, *after 12 h*

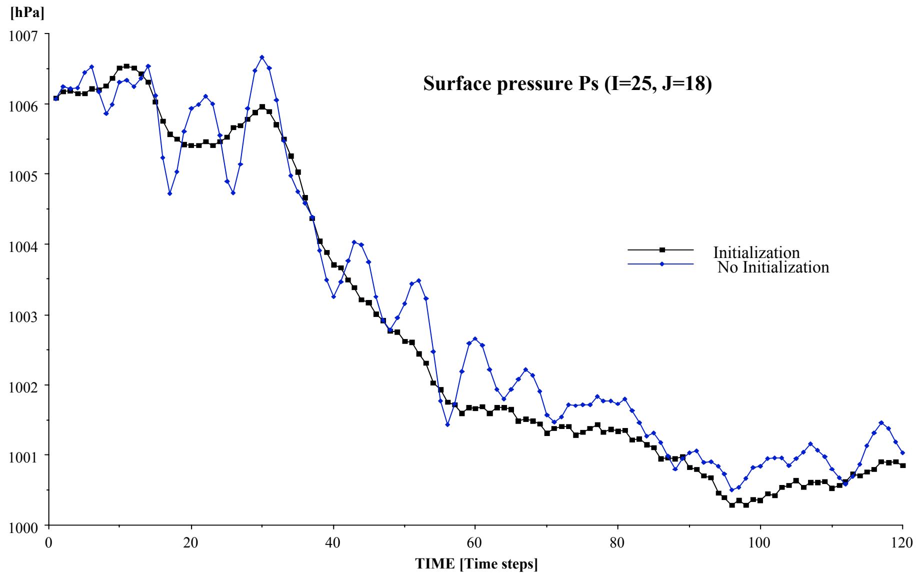


Results – Tropical Cyclone (cont.)

- *The time evolution* for the first 6 h of the forecast of:
- *Mean pressure tendency,*
- *The 500 hPa vertical velocity* and *surface pressure* at a model grid point I=25, J=18, *without* and *with* *"initialization"*

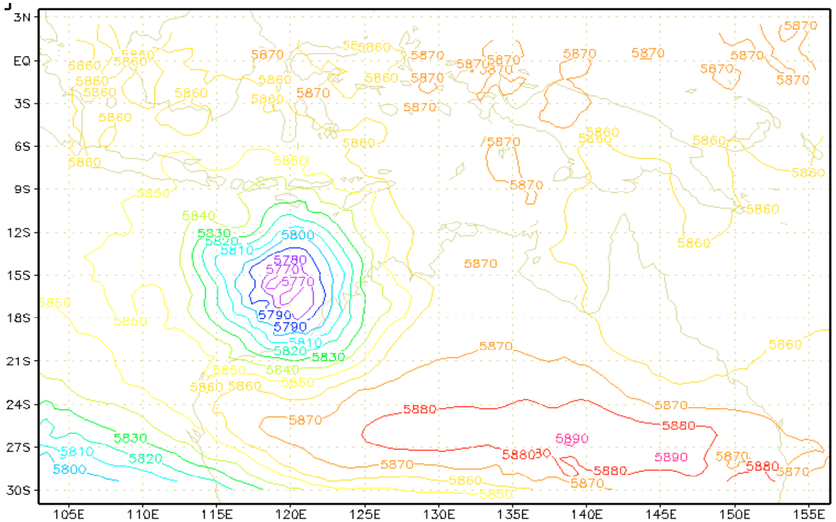


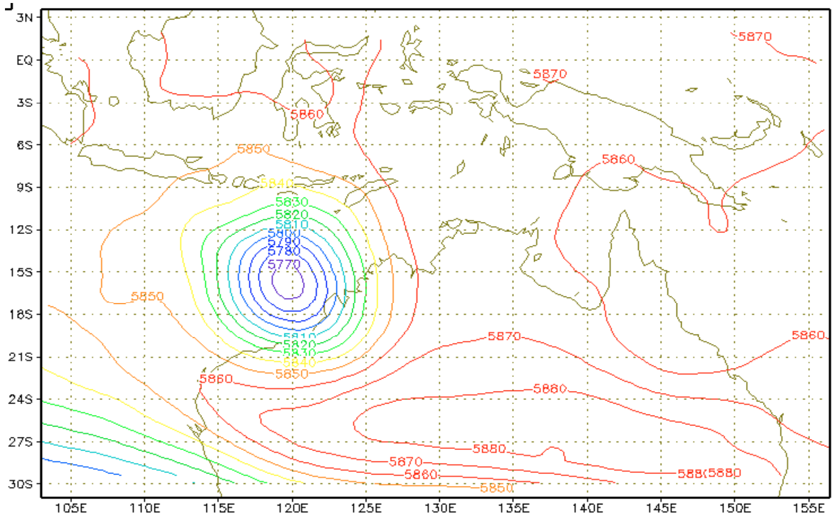


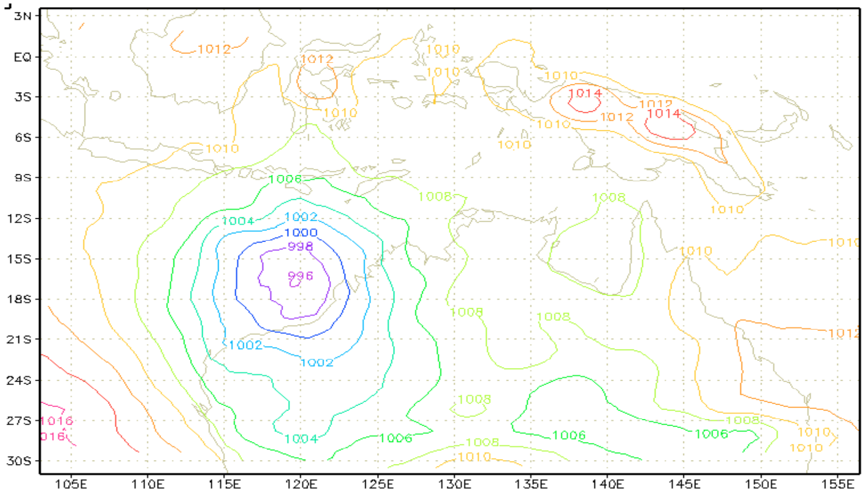


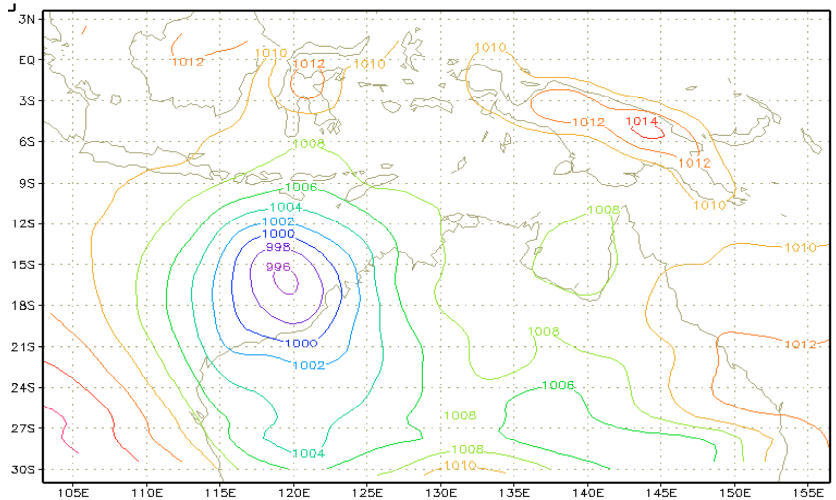
Results – Tropical Cyclone (cont.)

Uninitialized and *initialized* 500 hPa geopotential height and sea level pressure fields at *the initial time*



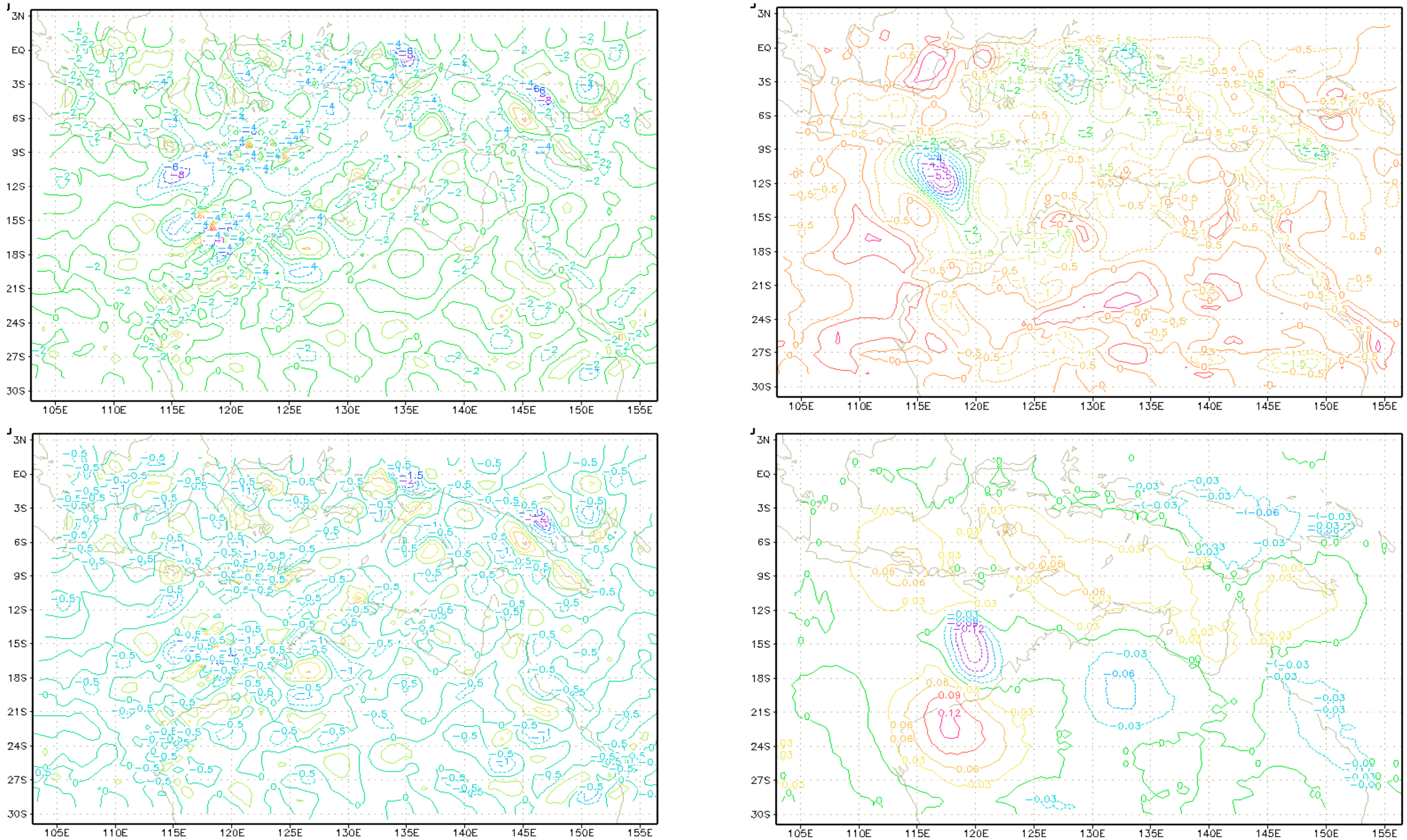






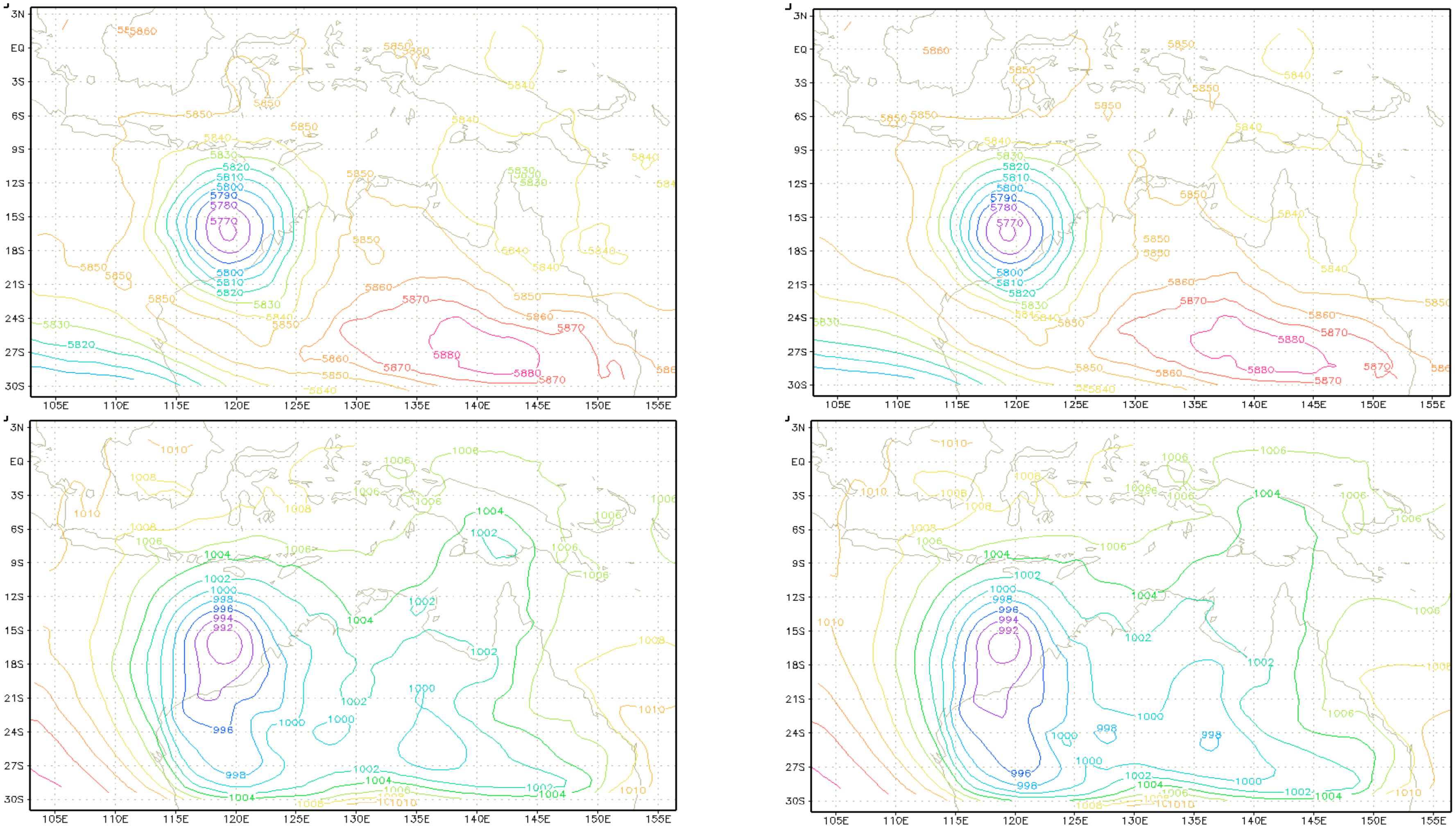
Results – Tropical Cyclone (cont.)

- *Surface pressure tendency* and *the 500 hPa vertical velocity*, with and without initialization, at the *initial time*



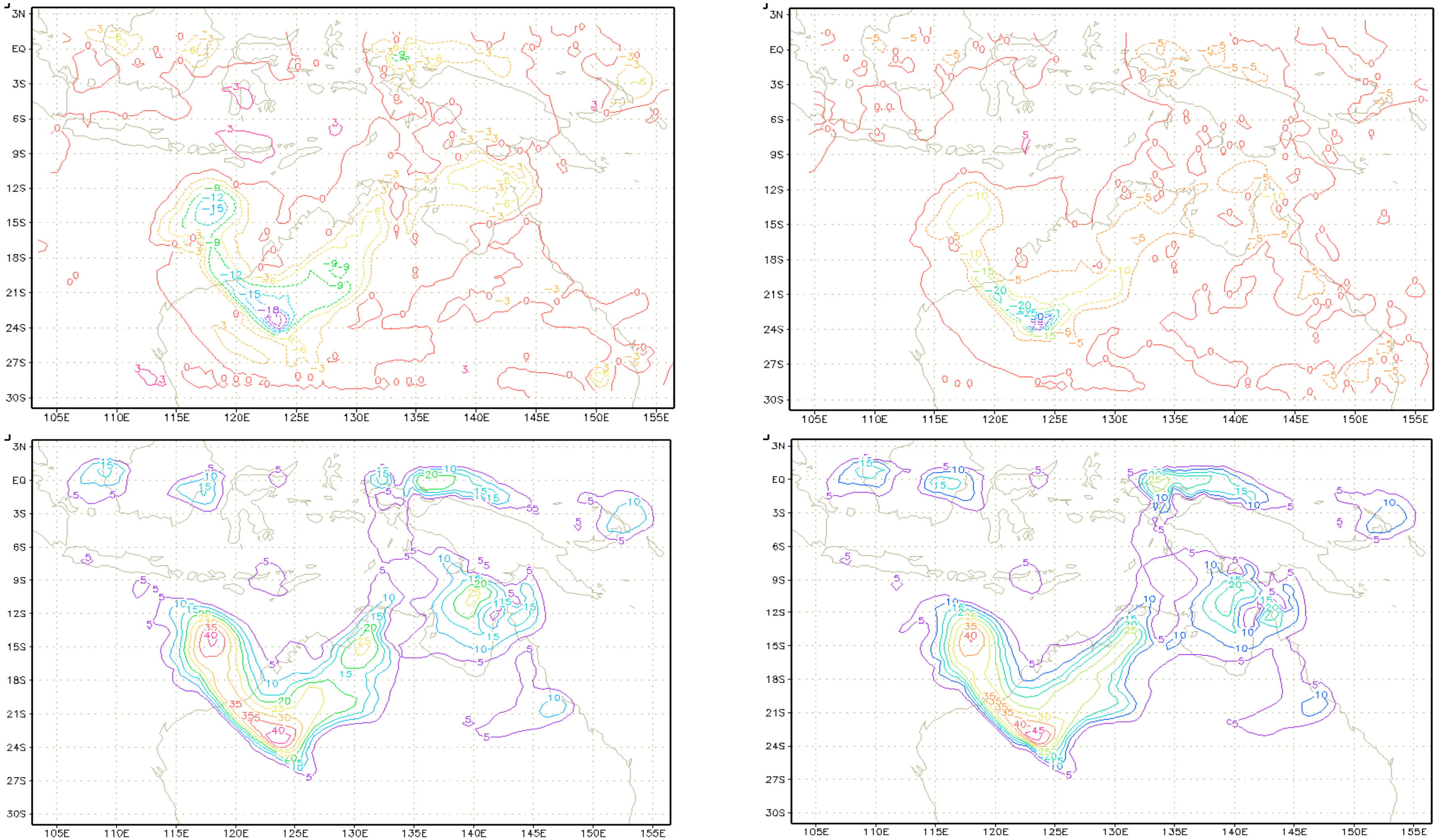
Results – Tropical Cyclone (cont.)

- *The 500 hPa geopotential height* and *the sea level pressure* maps with and without initialization *after 6 h*



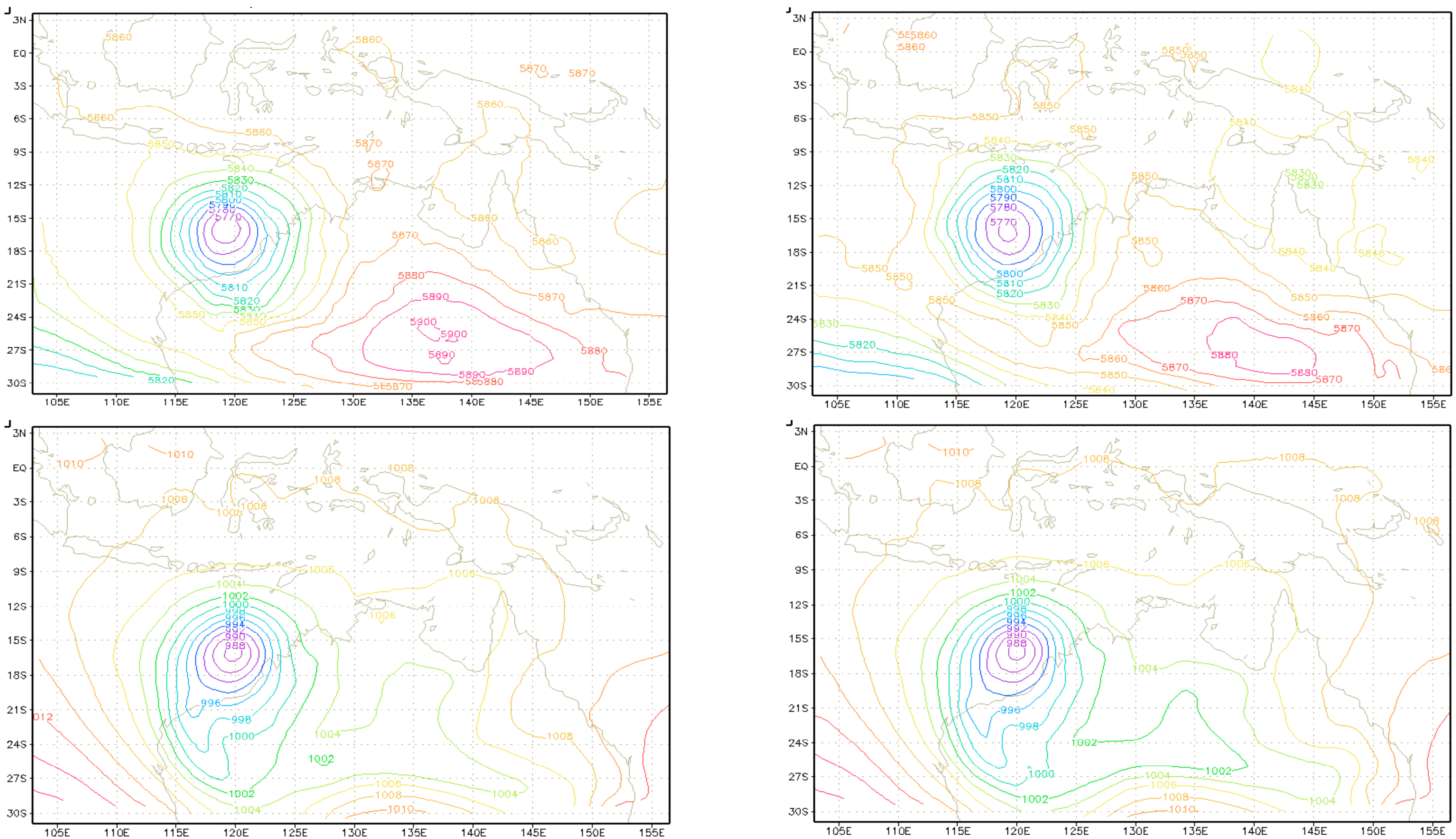
Results – Tropical Cyclone (cont.)

- *The 500 hPa vertical velocity* and *the 6-h accumulated precipitation*, with and without initialization, *after 6 h*



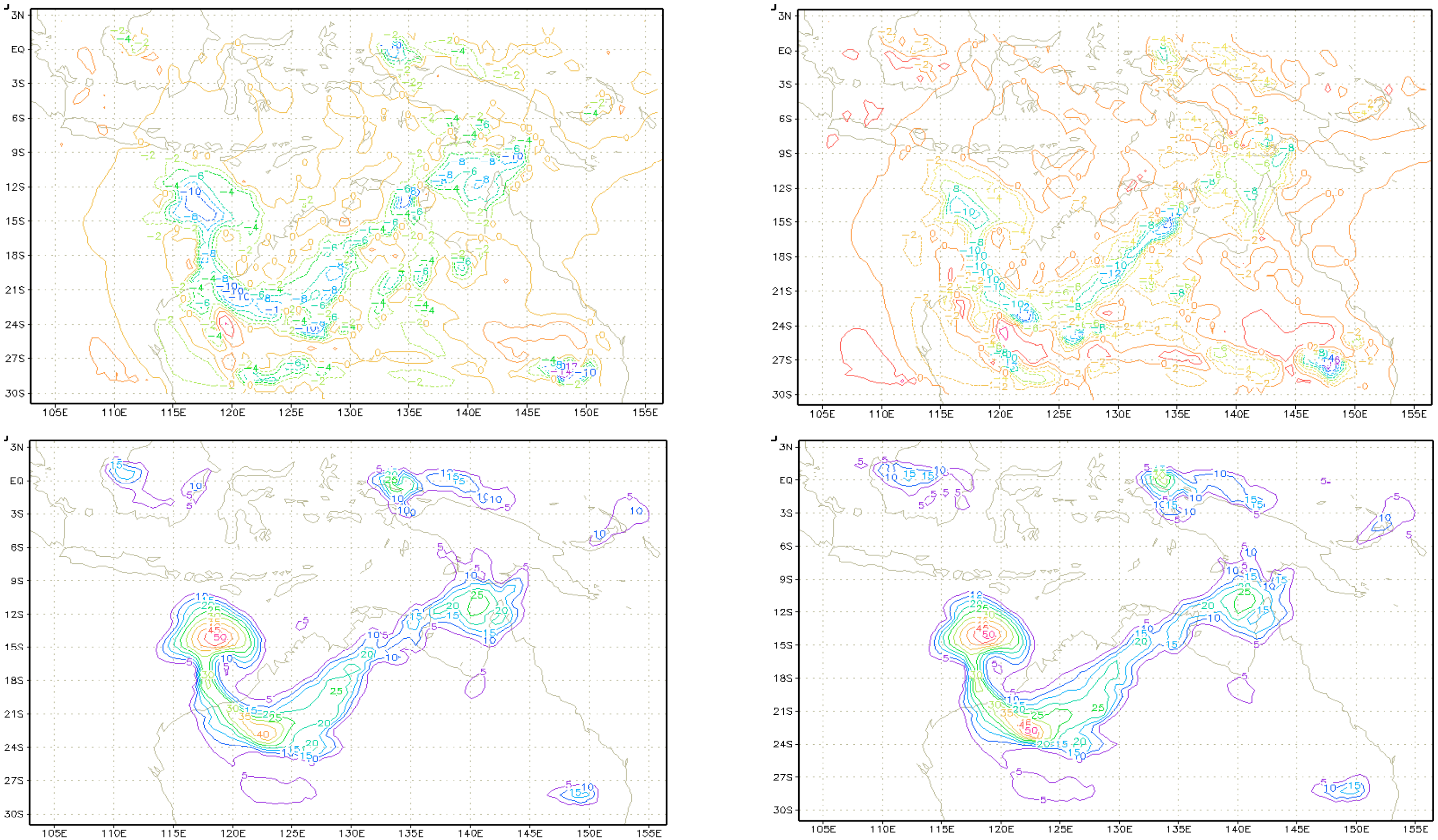
Results – Tropical Cyclone (cont.)

- *The 500 hPa geopotential height* and *the sea level pressure* maps with and without initialization *after 12 h*



Results – Tropical Cyclone (cont.)

- *The 500 hPa vertical velocity* and *the 6-h accumulated precipitation*, with and without initialization, *after 12 h*



Conclusions

- The *super-Matsuno style time differencing scheme* removes the spurious high-frequency oscillations *very efficiently*.
- After initialization fields are *adjusted* and *without noise*. In the control case fields display a high level of noise.
- In the *control case* with a standard forward-backward scheme for the adjustment stage the *noise reduces with time* as well.

Conclusions (cont.)

- The *integration results* with and without initialization after 6 h are *similar*. They are very similar after 12 h and later until the end of the 48-h integration performed.
- It is to be expected that *small differences*, given that they have resulted from the removal of spurious initial noise have *to be beneficial,* especially in the data assimilation.