

# presentation Ayrton Zadra

### OROGRAPHIC BLOCKING

a new component of the subgrid-scale orographic drag parametrization in the GEM model

by  
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Collaborators  
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### OUTLINE

- what is 'orographic blocking'?
- why include a subgrid blocking in GEM?
- which blocking parametrization is chosen?
- how does the model flow react?
- what is the impact on the forecast?

Note: **500 = Sub-grid scale Orographic**

### MOTIVATION

1- Sensitivity studies by M. Roch, with mountain elevations increased by 20%, suggested that the orographic drag has been underestimated in GEM

### 2- Reports from the ECMWF

- model has a 2-component SOO parametrization: **GWD + blocking**
- large sensitivity w.r.t. to surface drag
- SOO drag in simplified physics, used by 4DVAR, contains the blocking component only

### 3- Article by Scinocca and McFarlane (2000)

- new orographic parametrization, to be employed in the COCMa 3rd generation GCM
- propose a 3-component scheme: **GWD + blocking + low-level (real) wave breaking**

### FAQ:

- Why not simply use an envelope orography?
- Is the blocking scheme a new version of the GEM?
- Doesn't the field  $\omega$  contain an orographic term that generates the blocking already?
- In fact,  $\omega$  has a SOO contribution. But it doesn't seem to generate all the drag needed.

### EXPLAINING THE SCHEME I. The unresolved topography

Example of slope reaching height (m):  $z = 2000$ ,  $h = 500 = 0.25z$  = sub-grid orographic response

### EXPLAINING THE SCHEME II. The gravity-wave drag component

(a) Parametrization used by GEM  
- flow form by McFarlane (97)  
- rotation by McLandress & McFarlane (95) also available

(b) Basic formula:

$$D_{GW} = \frac{1}{2} \frac{\partial \omega}{\partial z} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y}$$

(c)  $D_{GW} = \frac{1}{2} \frac{\partial \omega}{\partial z} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y}$  - if it were blocking layer - otherwise

(d)  $D_{GW} = \frac{1}{2} \frac{\partial \omega}{\partial z} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y}$  - if it were blocking layer - otherwise

(e) General Fourier number:  $F = \frac{U^2 \sigma^2}{g^2 H^2}$  -  $U$  = mean velocity

### III. Studies with 1-D (column model): the overshoot problem

- The column model: 1 dimensional (vertical) model where the wind field is driven by the GWD only

- The GWD is **inconsistent** by nature: the wind speed should always decrease

- Definition of **overshoot**: occurs when the parametrized drag 'over-decelerates' the wind: the wind weakens, goes through zero and the speed-up in the opposite direction sometimes results in an unrealistic (unphysical) situation.

### IV. Minimizing the overshoot problem: (numerical change in the calculation of the GWD for divergence)

Generalized scheme:

$$D_{GW} = \frac{1}{2} \frac{\partial \omega}{\partial z} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} \left( 1 - \frac{1}{2} \frac{\partial \omega}{\partial z} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} \right)$$

Proposed modification:

$$D_{GW} = \frac{1}{2} \frac{\partial \omega}{\partial z} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} \left( 1 - \frac{1}{2} \frac{\partial \omega}{\partial z} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} \right)$$

### Example of impact due to the unaccounted variation in the GWD scheme

model GEM-500  
winter cycle (2003/01/01 to 2004/01/01)  
flow control  
NO orographic drag  
impact: final stable over flow

### EXPLAINING THE SCHEME III. The blocking component

(a) The concept of 'equivalent elliptical mountain'

axis of symmetry:  $\theta = 0$  or  $\theta = \pi$   
direction of slope:  $\theta = \pi/2$  or  $3\pi/2$   
profile equation:  $z = a^2 \frac{y^2}{b^2}$   
Definition of the elliptical mountain:  
-  $z$  length of scale  
-  $a, b$  semi-dimensional parameters

### EXPLAINING THE SCHEME III. The blocking component: (b) combination of the elliptical mountain

### Example: launching height (in $10^{-3}$ m) used by GEM global

### gradient correlation tensor: $\mathcal{G}_{ij} = \langle \frac{\partial \omega}{\partial x_i} \frac{\partial \omega}{\partial x_j} \rangle$

Example: Y7, Y8 & Y9 (in  $10^{-3}$  m) used by GEM global

### Gradient correlation in terms of wavenumbers.

$$\frac{\partial^2 \omega}{\partial x^2} = \left\langle \left( \frac{\partial \omega}{\partial x} \right)^2 \right\rangle - \left\langle \frac{\partial \omega}{\partial x} \right\rangle^2 = \frac{1}{2} \left( \frac{\partial^2 \omega}{\partial x^2} + \frac{\partial^2 \omega}{\partial y^2} \right)$$

$$\frac{\partial^2 \omega}{\partial x \partial y} = \left\langle \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} \right\rangle - \left\langle \frac{\partial \omega}{\partial x} \right\rangle \left\langle \frac{\partial \omega}{\partial y} \right\rangle = \frac{1}{2} \left( \frac{\partial^2 \omega}{\partial x \partial y} + \frac{\partial^2 \omega}{\partial y \partial x} \right)$$

$$\frac{\partial^2 \omega}{\partial y^2} = \left\langle \left( \frac{\partial \omega}{\partial y} \right)^2 \right\rangle - \left\langle \frac{\partial \omega}{\partial y} \right\rangle^2 = \frac{1}{2} \left( \frac{\partial^2 \omega}{\partial x^2} + \frac{\partial^2 \omega}{\partial y^2} \right)$$

### Using Y7, Y8, Y9 to compare other parameters

(a) Mean square gradient in direction  $\theta$ :

$$\left\langle \left( \frac{\partial \omega}{\partial x} \cos \theta + \frac{\partial \omega}{\partial y} \sin \theta \right)^2 \right\rangle = \left\langle \left( \frac{\partial \omega}{\partial x} \right)^2 \cos^2 \theta + \left( \frac{\partial \omega}{\partial y} \right)^2 \sin^2 \theta + 2 \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} \cos \theta \sin \theta \right\rangle$$

(b) Direction of maximum gradient:

$$\frac{\partial^2 \omega}{\partial x^2} \cos \theta - \frac{\partial^2 \omega}{\partial x \partial y} \sin \theta = 0 \Rightarrow \tan 2\theta = \frac{2 \frac{\partial^2 \omega}{\partial x \partial y}}{\frac{\partial^2 \omega}{\partial x^2} - \frac{\partial^2 \omega}{\partial y^2}}$$

### (a) Related terms: $\frac{\partial^2 \omega}{\partial x^2} = \left\langle \left( \frac{\partial \omega}{\partial x} \right)^2 \right\rangle - \left\langle \frac{\partial \omega}{\partial x} \right\rangle^2$

(b) Maximum slope:  $\tan \theta = \left( \frac{\partial \omega / \partial y}{\partial \omega / \partial x} \right) = \frac{1}{2} \frac{\partial^2 \omega}{\partial x \partial y} \frac{2}{\frac{\partial^2 \omega}{\partial x^2} - \frac{\partial^2 \omega}{\partial y^2}}$

(c) Eccentricity:  $e = \frac{\sqrt{\left( \frac{\partial^2 \omega}{\partial x^2} - \frac{\partial^2 \omega}{\partial y^2} \right)^2 + \left( \frac{\partial^2 \omega}{\partial x \partial y} \right)^2}}{\frac{\partial^2 \omega}{\partial x^2} + \frac{\partial^2 \omega}{\partial y^2}}$

### Mountain height

Non-constant:  $H = 2a$

2. Slope zero

3. Major axis

4. Non-constant eccentricity

5. Related coordinates

Non-constant:  $x' = a \cos \theta$ ,  $y' = b \sin \theta$

6. Profile: cross equation:  $z = a^2 \frac{y'^2}{b^2}$

### EXPLAINING THE SCHEME III. The blocking component: (a) blocking force due to elliptical mountain

Based on Lott and Miller (1987):

$$\frac{\partial \omega}{\partial t} = D_{GW} + D_{BL}$$

$$D_{BL} = \left[ -C_1 \frac{\partial \omega}{\partial x} - C_2 \frac{\partial \omega}{\partial y} - C_3 \frac{\partial \omega}{\partial z} - \frac{1}{2} \frac{\partial^2 \omega}{\partial x^2} \right] \frac{z}{H}$$

profile factor related to the mountain geometry

### EXPLAINING THE SCHEME III. The blocking component: (a) blocking height

Non-constant  $H$ :

$$H = \frac{2a}{\sqrt{1 - e^2}}$$

From non-constant wave theory:  $\frac{\partial \omega}{\partial t} = \frac{1}{2} \frac{\partial^2 \omega}{\partial x^2} + \frac{1}{2} \frac{\partial^2 \omega}{\partial y^2}$

Phase change between levels:  $\frac{\partial \omega}{\partial t} = \frac{1}{2} \frac{\partial^2 \omega}{\partial x^2} + \frac{1}{2} \frac{\partial^2 \omega}{\partial y^2}$

### EXPLAINING THE SCHEME III. The blocking component: (a) slope-scale factor

Non-constant  $H$ :

$$F_{BL} = \frac{1}{2a} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y}$$

Non-constant  $H$ :

$$\frac{1}{2a} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} = \frac{1}{2a} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} = \frac{1}{2} \frac{\partial^2 \omega}{\partial x^2} + \frac{1}{2} \frac{\partial^2 \omega}{\partial y^2}$$

$\frac{1}{2a} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} = \frac{1}{2} \frac{\partial^2 \omega}{\partial x^2} + \frac{1}{2} \frac{\partial^2 \omega}{\partial y^2} = 1/2$  wavenumber in the direction of maximum slope

### EXPLAINING THE SCHEME III. The blocking component: (b) directional anisotropy factor

Non-constant  $H$ :

$$F_{BL} = \frac{1}{2a} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} = \frac{1}{2a} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} = \frac{1}{2} \frac{\partial^2 \omega}{\partial x^2} + \frac{1}{2} \frac{\partial^2 \omega}{\partial y^2}$$

modulates slope factor  $F_{BL} = \frac{1}{2a} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y}$

modulates the 'form' of the barrier as seen by particles at different levels.

### EXPLAINING THE SCHEME III. The blocking component: (b) profile factor

Non-constant  $H$ :

$$F_{BL} = \frac{1}{2a} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} = \frac{1}{2a} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} = \frac{1}{2} \frac{\partial^2 \omega}{\partial x^2} + \frac{1}{2} \frac{\partial^2 \omega}{\partial y^2}$$

Profile at  $y = 0$ :  $\frac{\partial \omega}{\partial t} = \frac{1}{2} \frac{\partial^2 \omega}{\partial x^2} + \frac{1}{2} \frac{\partial^2 \omega}{\partial y^2}$

Non-constant  $H$ :

$$\frac{\partial \omega}{\partial t} = \frac{1}{2} \frac{\partial^2 \omega}{\partial x^2} + \frac{1}{2} \frac{\partial^2 \omega}{\partial y^2}$$

### EXPLAINING THE SCHEME III. The blocking component: (b) profile factor

Non-constant  $H$ :

$$F_{BL} = \frac{1}{2a} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} = \frac{1}{2a} \frac{\partial \omega}{\partial x} \frac{\partial \omega}{\partial y} = \frac{1}{2} \frac{\partial^2 \omega}{\partial x^2} + \frac{1}{2} \frac{\partial^2 \omega}{\partial y^2}$$

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Non-constant  $H$ :

$$\frac{\partial \omega}{\partial t} = \frac{1}{2} \frac{\partial^2 \omega}{\partial x^2} + \frac{1}{2} \frac{\partial^2 \omega}{\partial y^2}$$

### IMPACT ON THE FLOW

Tested versions of the blocking:

- Based on the Lott-Miller formulation, with geophysical fields (JH, Y7-B) produced by GEM500
- Based on the Lott-Miller formulation, with 'artificial', isotropic geophysical fields (Y7-B)
- 'Hybrid' version: Lott-Miller force + Scinocca-McFarlane blocking force

### IMPACT ON THE FLOW II. Studies using a 1-D (column) model

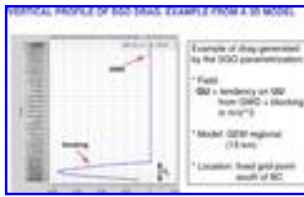
- Column model: fields depend on  $x$  and  $t$

- Input: initial profiles of  $U, V, T, \theta$  and  $P$

- 'Dynamics':  $T, \theta$  and  $P$  constant: wind driven by SOO drag only

$$\frac{\partial U}{\partial t} = -D_{BL} - \frac{\partial \tau}{\partial x} = 0 = \frac{\partial U}{\partial t}$$

- Output: SOO tendencies (GU, GV) after drag wind (SU, VV)



**IMPACT ON THE FLOW**  
 IV. 3-D sensitivity studies with artificial slopes

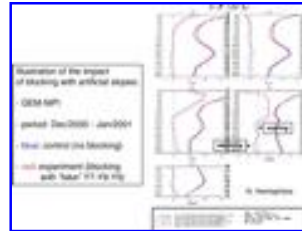
(a) Made before the fields Y7-Y8-Y9 became available

(b) Based on an isotropic 'parametrization' of the slope fields in terms of the launching height (LH):

$$F_{SGO} = \frac{\gamma T}{LH} = \lambda \left( 1 + \frac{LH}{100 \text{ m}} \right)$$

$$\gamma = \gamma_0 + \gamma_1 \frac{LH}{100 \text{ m}}$$

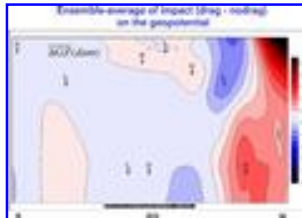
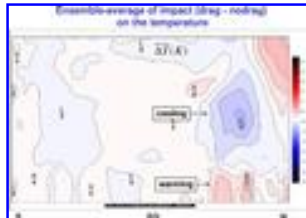
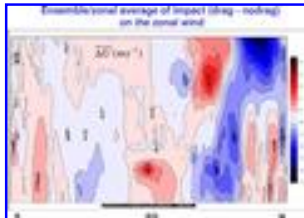
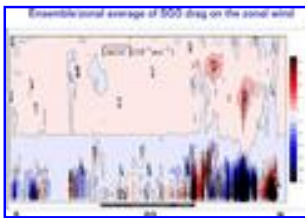
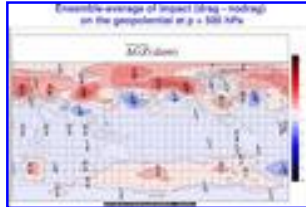
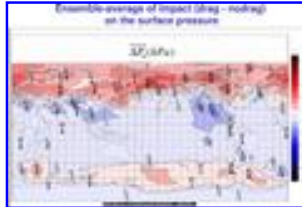
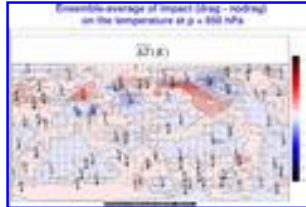
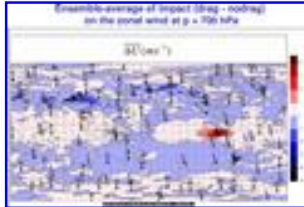
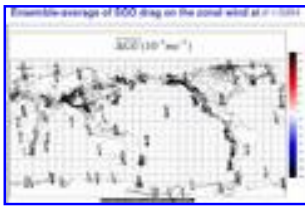
where  $\lambda = 1 \times 10^{-4} \text{ m}^{-1}$  mean characteristic used in the GEM scheme.



**IMPACT ON THE FLOW**  
 IV. 3-D experiments with simplified physics

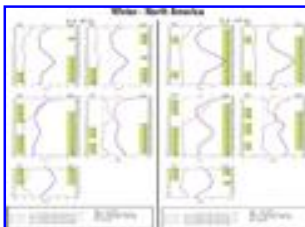
(a) GEM model with dry simplified physics:  
 > simplified vertical diffusion  
 > SGO drag  
 > no moisture  
 > no solar radiation

(b) following figures show various averages of the difference between:  
 > control (GWD, no blocking)  
 > experiment (GWD + blocking)  
 all t = 120h.



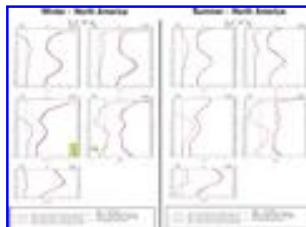
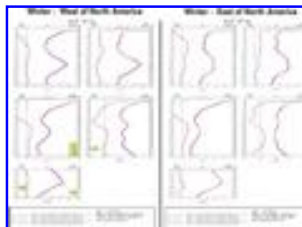
**IMPACT ON THE FORECAST**  
 I. Experiments with GEM-global 400x200

- version 3.4.0.4, T176 analysis with T126 1h
- control in blue
- experiments in red:
  - blocking effect
  - SGO with no overcloud parameter
  - SGO with moisture exchange coefficient modified ( $\beta = 0.05 \rightarrow 1$ )
  - no moisture flux decoupled
- 20 x 10-day forecasts in winter (Feb-Mar 2001)
- 20 x 10-day forecasts in summer (Jun-Jul 2001)



**Experiments with GEM-regional 15 km**

- version 2.3.0 and 3.00
- control in blue
- experiment in red with SGO drag (GWD + blocking) active
- 10 x 48h-forecasts in winter (Jan-Feb 2001)
- 10 x 48h-forecasts in summer (Jul-Aug 2001)



**FAQ:**

Q: At which resolution the SGO parametrization becomes unnecessary?

A: No consensus ... but it might be at quite small scales.

Ex: Young and Pielke (1983):  
 > studied terrain height variance at 3 different areas in the Rockies, near Denver  
 > concluded that 8.3 km is the maximum horizontal grid spacing to neglect subgrid-scale parametrization in these regions

**SUMMARY**

- At the present resolution, it seems that our NWP models still need a SGO drag parametrization
- The parametrization based on the Loft & Miller blocking formula can improve the forecast scores of GEM, especially in the winter

**FUTURE WORK**

- Parametrize and test other SGO effects (topographic IR, lee-wave breaking)
- include new SGO drag in the simplified physics (T176, all-scale sensitivity studies, 47V43)

the end

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**a new component of the**

**subgrid-scale orographic drag parametrization  
in the GEM model**

**by**

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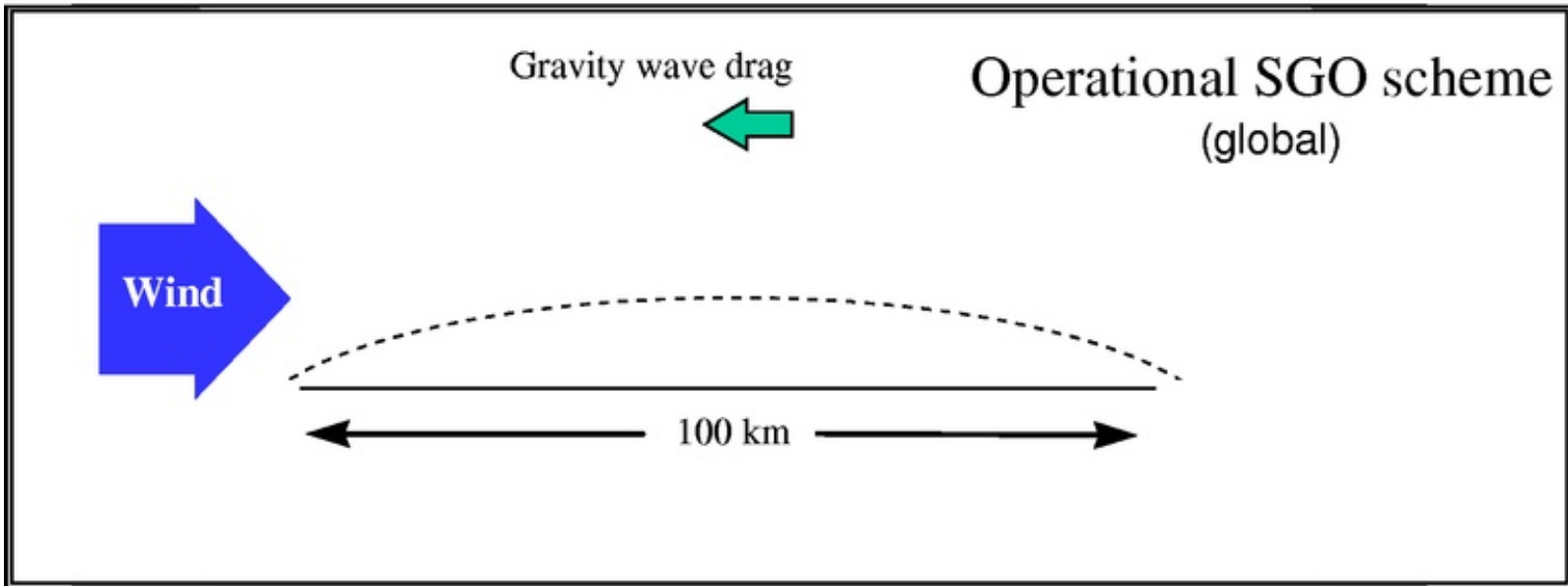
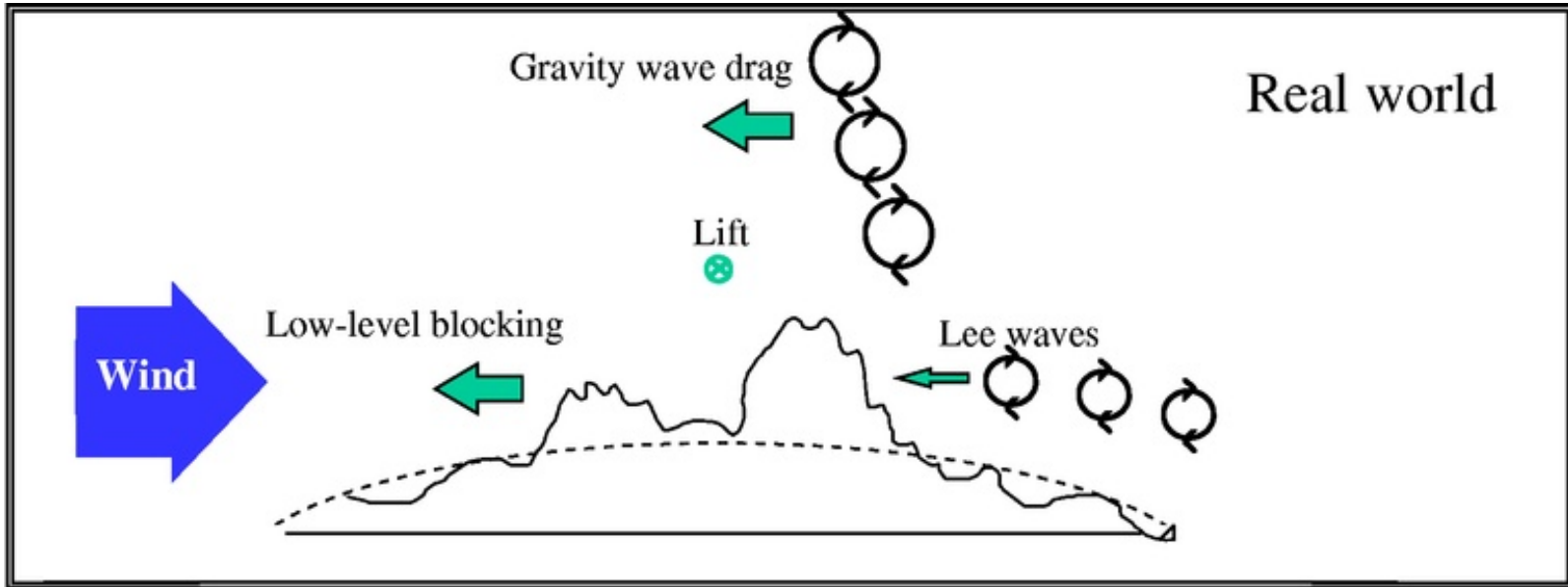
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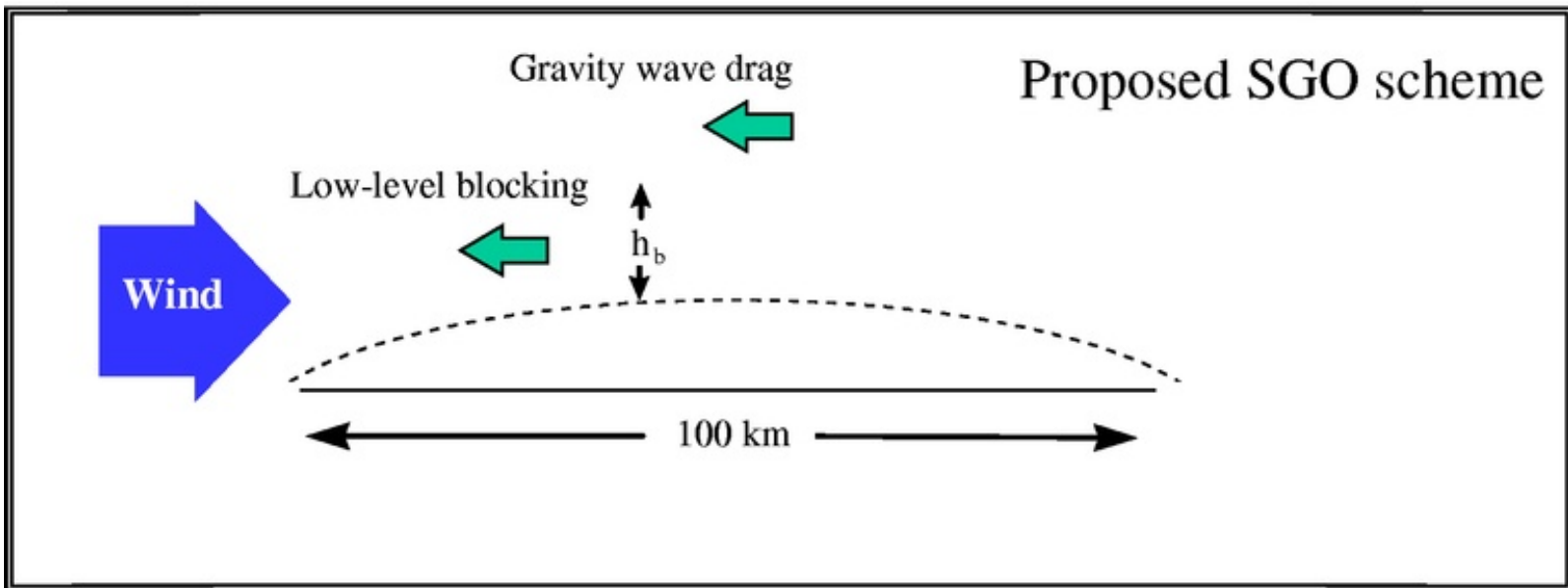
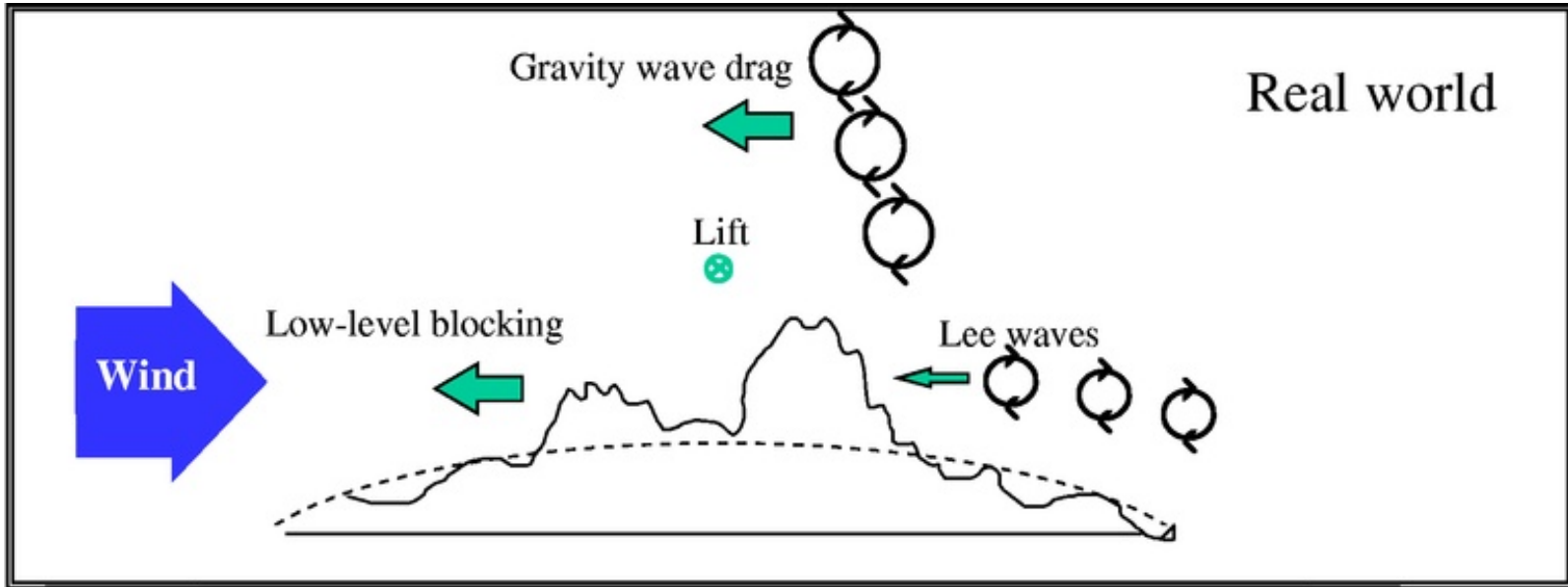
# OUTLINE

- what is “orographic blocking” ?
- why include a subgrid blocking in GEM ?
- which blocking parametrization is chosen ?
- how does the model/flow react ?
- what is the impact on the forecast ?

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Note: **SGO** = **S**ub**G**rid-scale **O**rographic

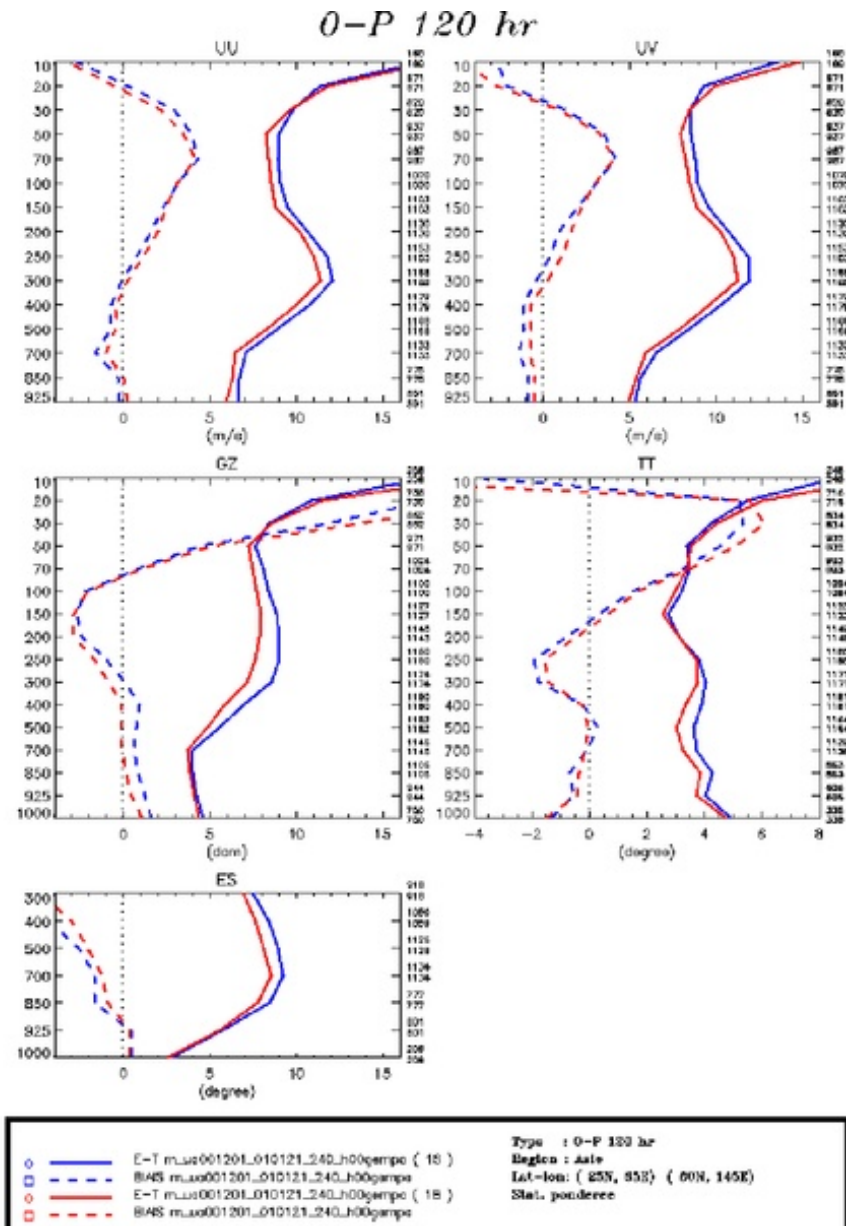




# MOTIVATION

## 1- Sensitivity studies

by M. Roch, with mountain elevations increased by 20%, suggested that the orographic drag has been **underestimated** in GEM



## 2- Reports from the ECMWF

- a) model has a 2-component SGO parametrization:  
GWD + **blocking**
- b) **large sensitivity** w.r.t. to surface drag
- c) SGO drag in simplified physics, used by 4DVAR,  
contains the **blocking component only**

## 3- Article by Scinocca and McFarlane (2000)

- a) new orographic parametrization, to be employed  
in the CCCma 3rd-generation GCM
- b) propose a 3-component scheme:  
GWD + **blocking** + low-level (lee) wave breaking



## FAQ:

**Q:** Why not simply use an envelope orography ?

**A:** 1. Not a good idea for data assimilation, especially when performed on model levels.

2. Too much precipitation on mountains.

**Q:** Is the blocking scheme a new version of the GWD ?

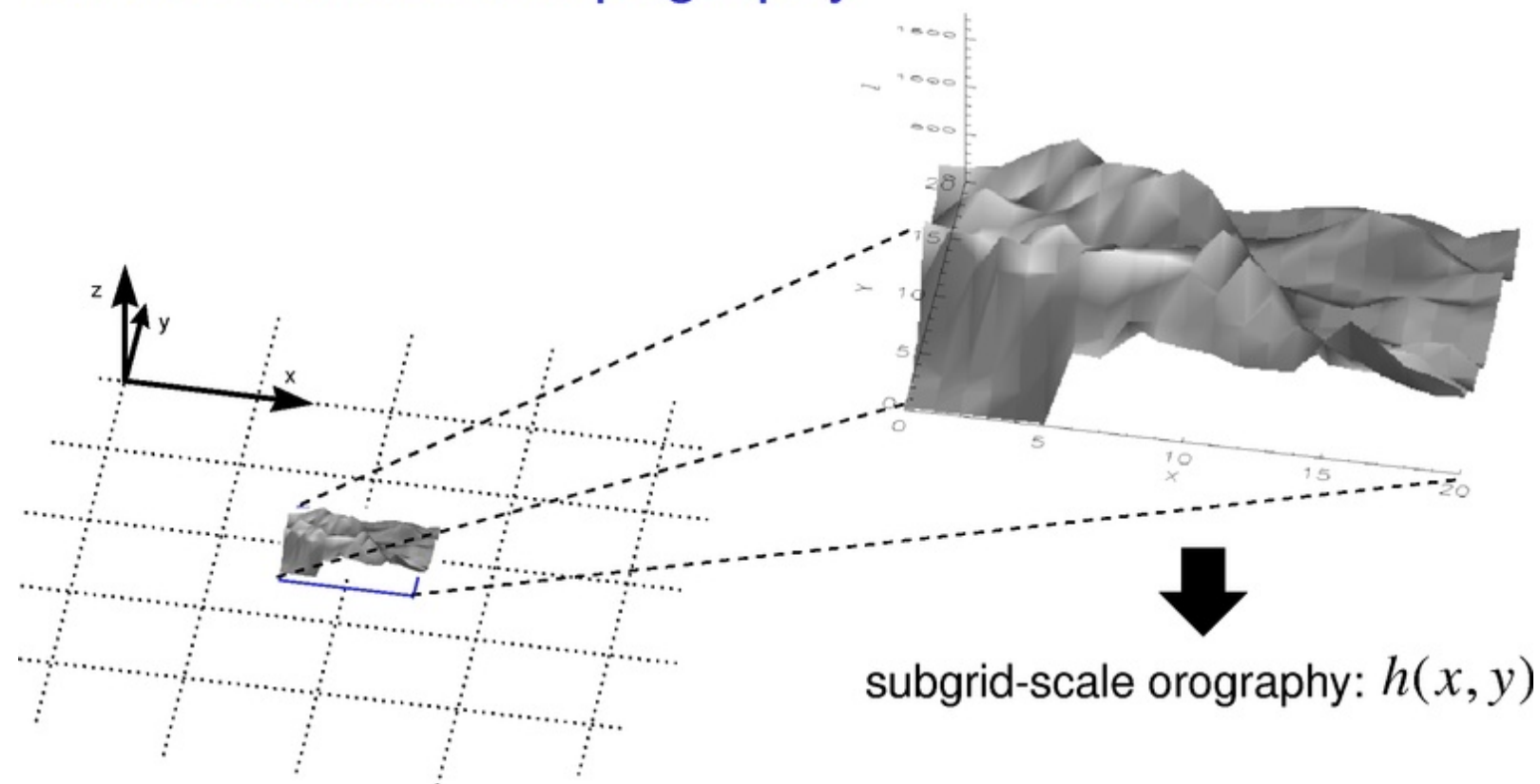
**A:** No! The GWD and the blocking schemes parametrize different phenomena. They complement each other.

**Q:** Doesn't the field  $z_0$  contain an orographic term that generates the blocking already?

**A:** In fact,  $z_0$  has a SGO contribution. But it doesn't seem to generate all the drag needed.

# EXPLAINING THE SCHEME

## I. The unresolved topography



Example of usage: launching height (LH)

$$LH = 2\sigma, \quad \sigma = \langle (h - \langle h \rangle)^2 \rangle^{1/2} = \text{subgrid orography variance}$$

# EXPLAINING THE SCHEME

## II. The gravity-wave drag component

(a) Parametrization used by GEM:

- flux form by McFarlane (87)
- variation by McLandress & McFarlane (95) also available

(b) Basic formula: 
$$\rho \left( \frac{\partial U}{\partial t} \right)_{gwd} = \frac{\partial \tau}{\partial z}$$

$$\text{GW flux} = \tau = \begin{cases} \frac{F_c^2}{2} k \frac{\rho U^3}{N} & , \text{ if in wave - breaking layer} \\ \text{constant} & , \text{ otherwise} \end{cases}$$

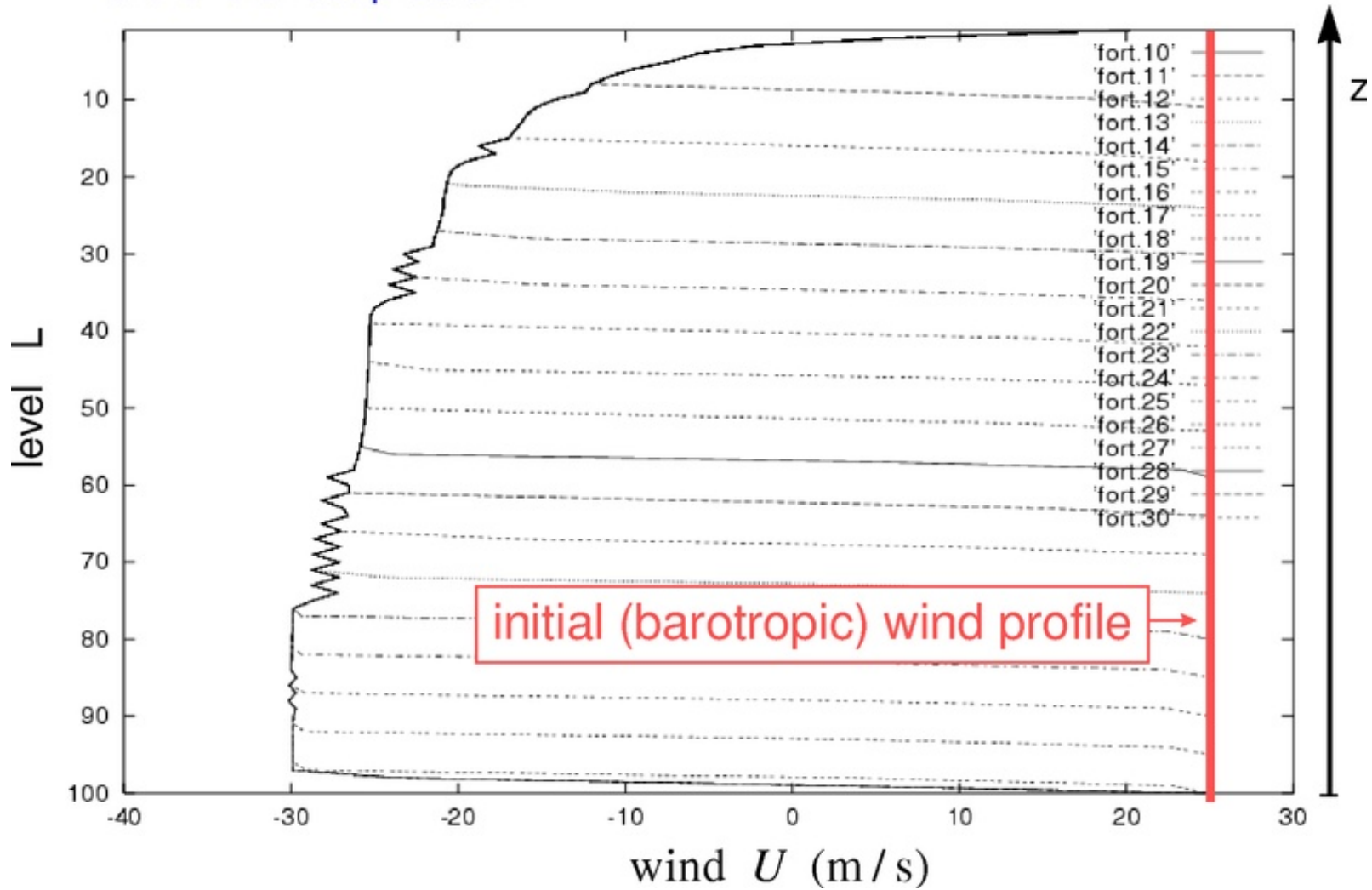
$k$  = mountain wavenumber , wave - breaking if  $F^2 > F_c^2 = 0.5$

(inverse) Froude number =  $F^2 = \frac{N^2 A^2}{U^2}$  ,  $A$  = wave amplitude

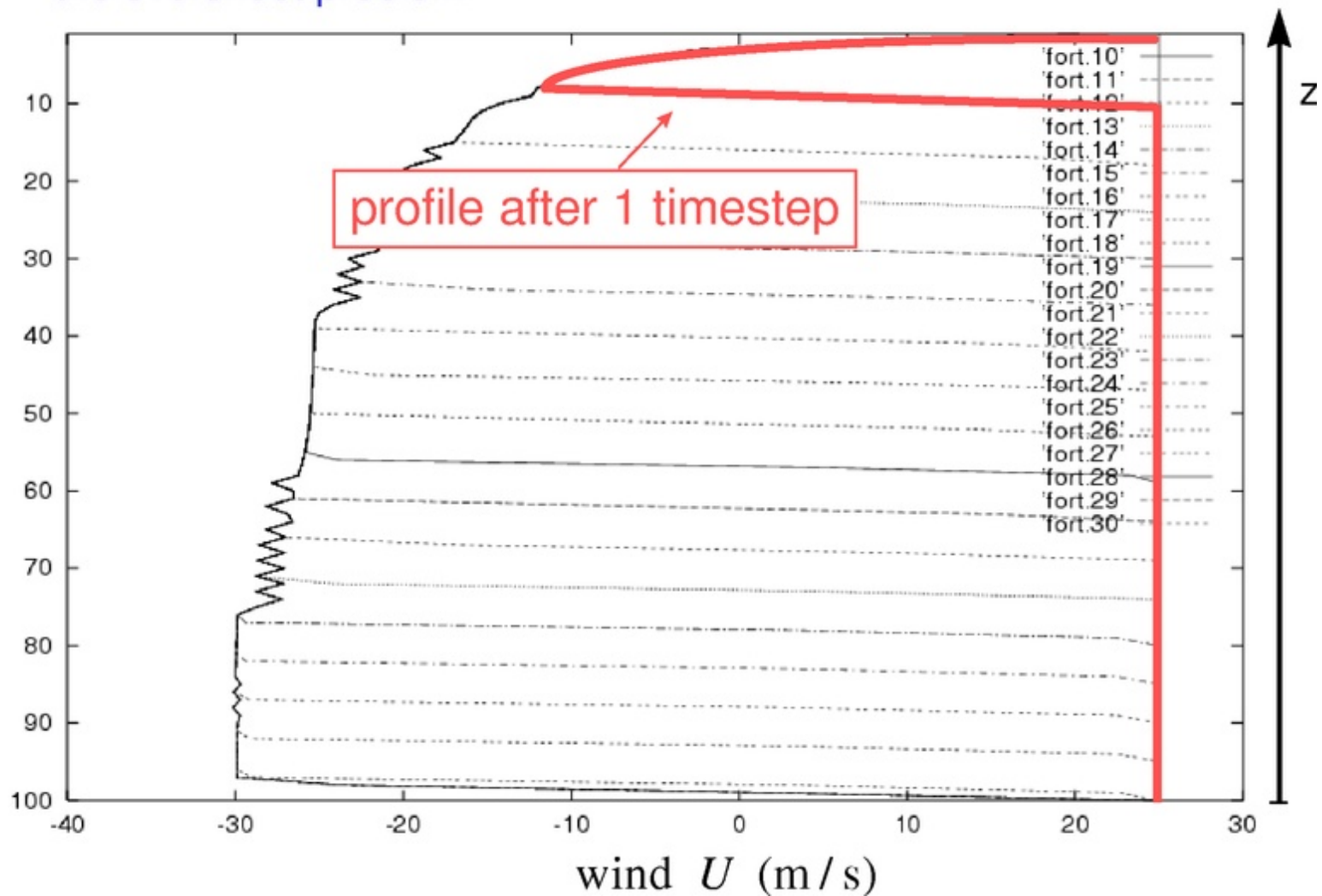
### (c) Studies with 1D (column model): the overshoot problem

- > The column model: 1-dimensional (vertical) model where the wind field is **driven by the GWD only**
- > The GWD is **dissipative** by nature: the wind speed should always decrease
- > Definition of **overshoot**:
  - occurs when the parametrized drag “over-decelerates” the wind
  - the wind weakens, go through zero and the speed up in the opposite direction
  - sometimes visible as an oscillation (numerical instability)

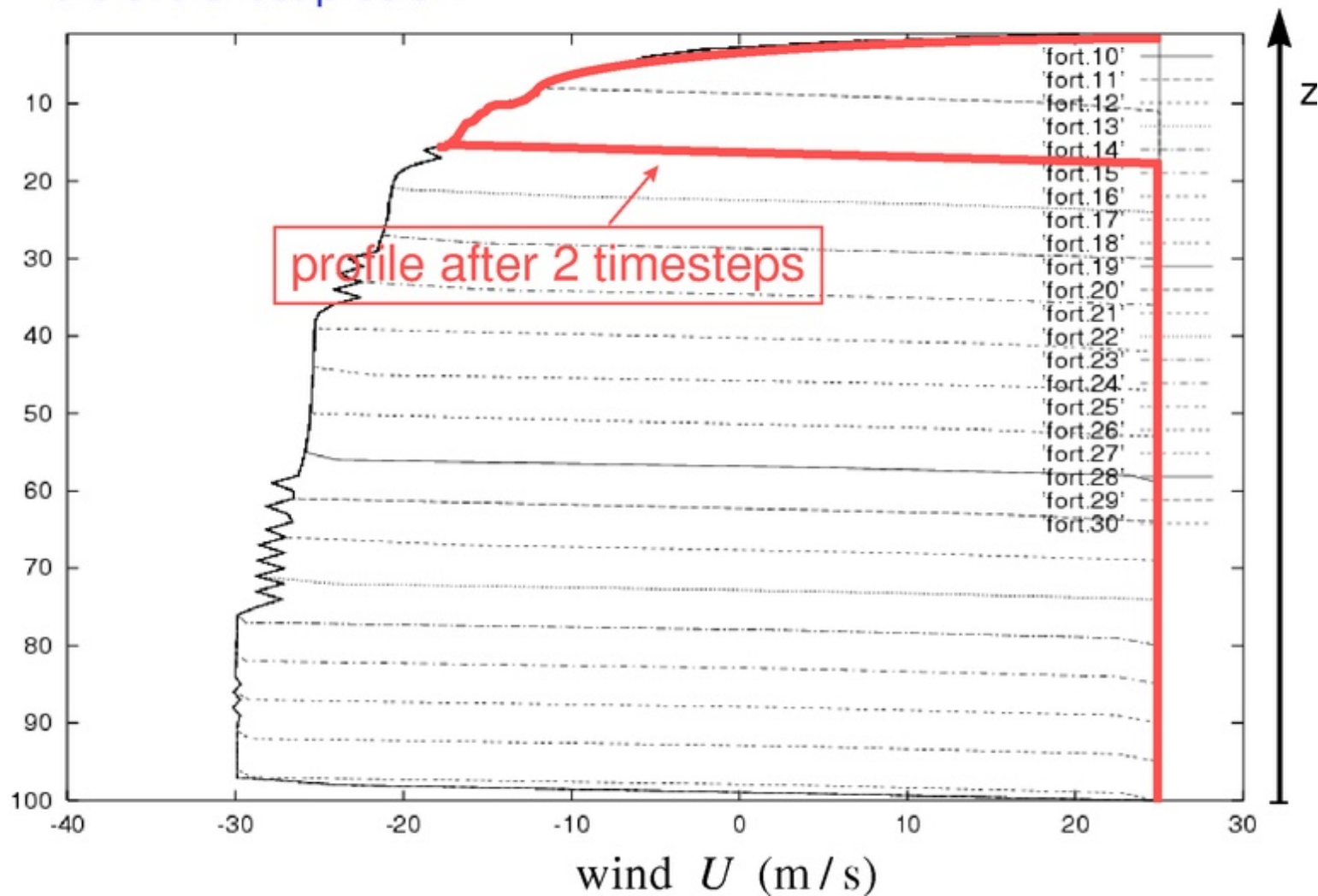
(c) Studies with 1D (column model):  
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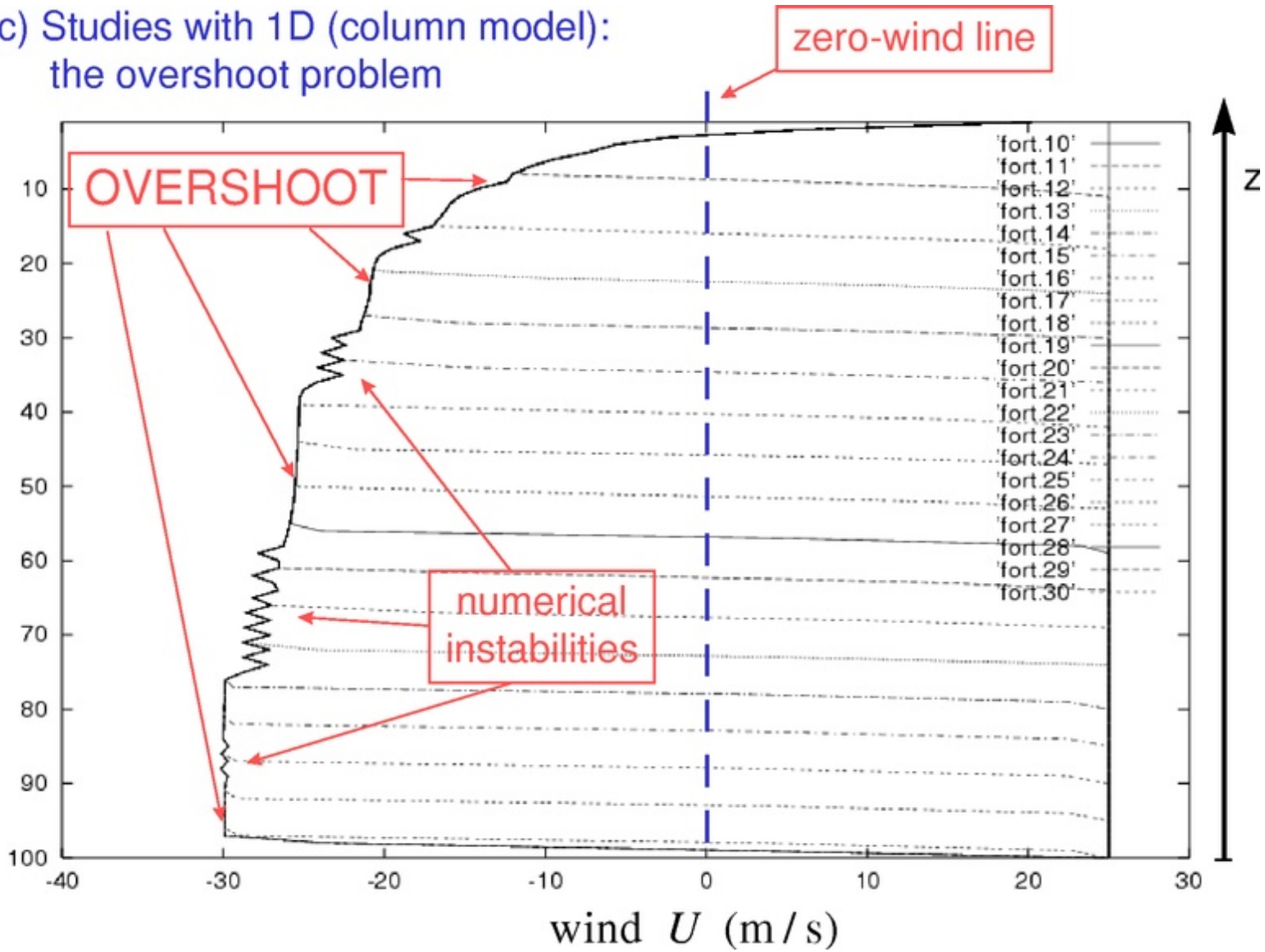
(c) Studies with 1D (column model):  
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the overshoot problem



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the overshoot problem





**(d) Eliminating the overshoot problem:**

[numerical change in the calculation of the GWD flux divergence]

Operational scheme:

$$\frac{\delta U}{\delta t}(l) = - \frac{\tau(l+1) - \tau(l-1) + \eta(l)3\delta t \frac{\tau(l-1)}{U(l-1)} \left( - \frac{\delta U}{\delta t} \right)(l-1)}{2\delta\sigma(l) + \eta(l)3\delta t \frac{\tau(l)}{U(l)}}$$

$$\eta(l) = \begin{cases} 1 & , \text{ if } \tau(l+1) - \tau(l-1) > 0 \\ 0 & , \text{ if } \tau(l+1) - \tau(l-1) \leq 0 \end{cases}$$

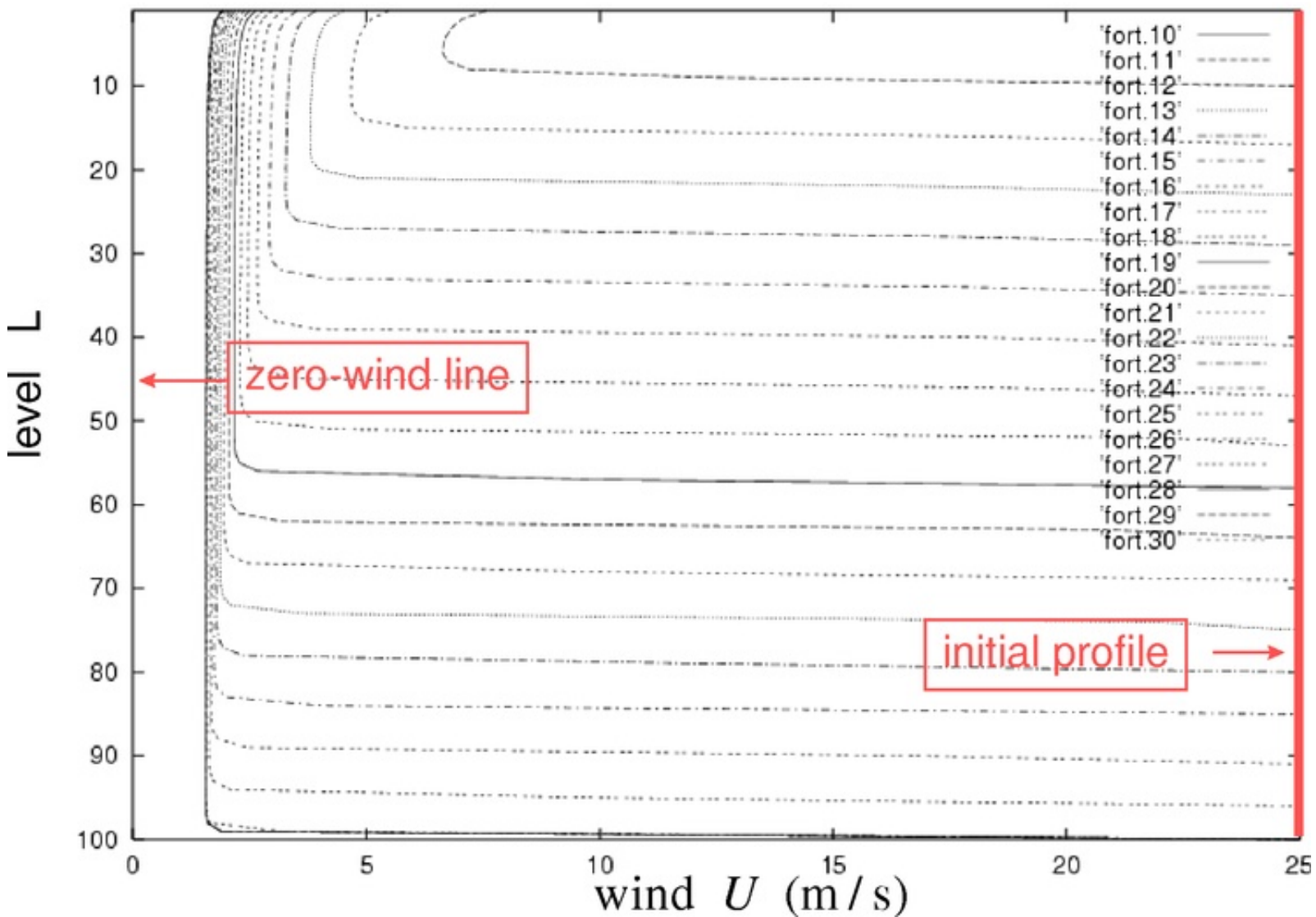
Proposed modification:

$$\frac{\delta U}{\delta t}(l) = - \frac{2\tau(l) - 2\tau(l-1) + \eta(l)3\delta t \frac{\tau(l-1)}{U(l-1)} \left( - \frac{\delta U}{\delta t} \right)(l-1)}{2\delta\sigma(l) + \eta(l)3\delta t \frac{\tau(l)}{U(l)}}$$

$$\eta(l) = \begin{cases} 1 & , \text{ if } \tau(l) - \tau(l-1) > 0 \\ 0 & , \text{ if } \tau(l) - \tau(l-1) \leq 0 \end{cases}$$

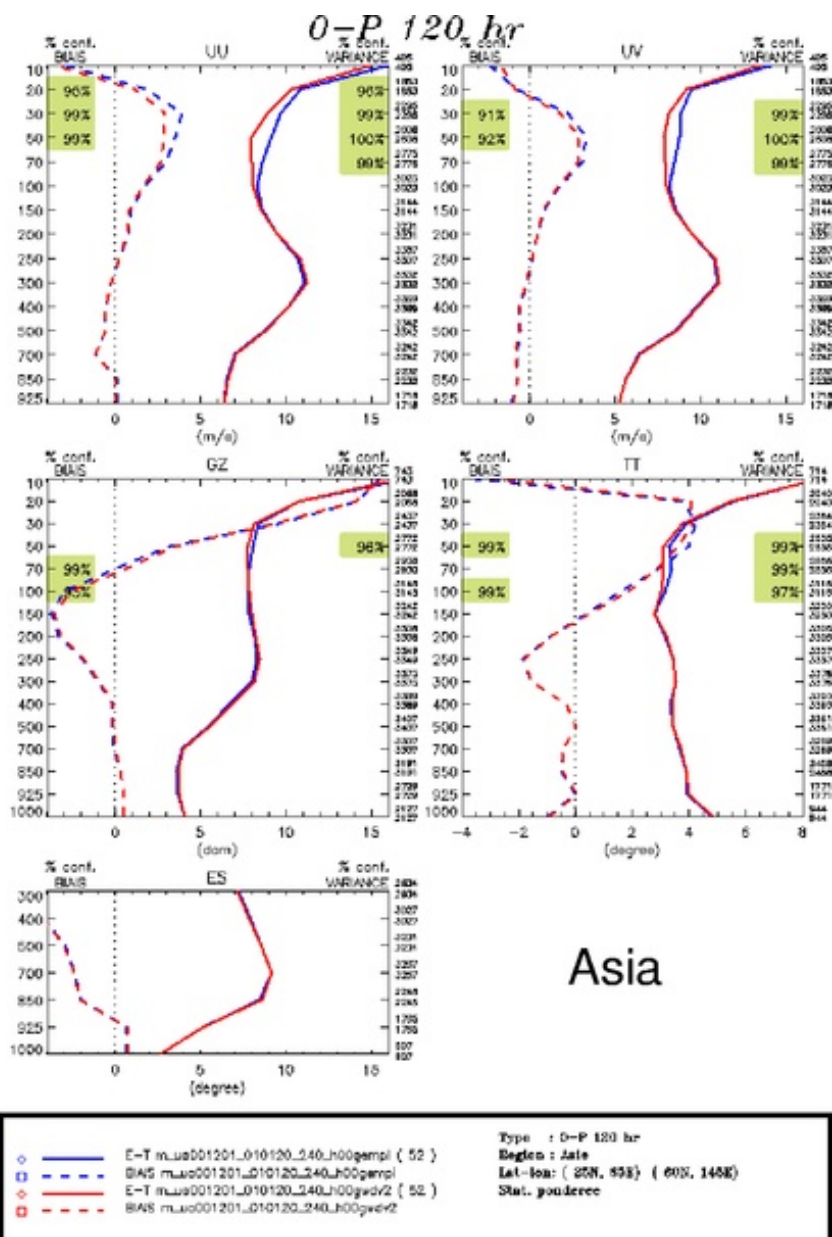
### (d) Eliminating the overshoot problem:

[numerical change in the calculation of the GWD flux divergence]



Example of impact due to no-overshoot correction in the GWD scheme:

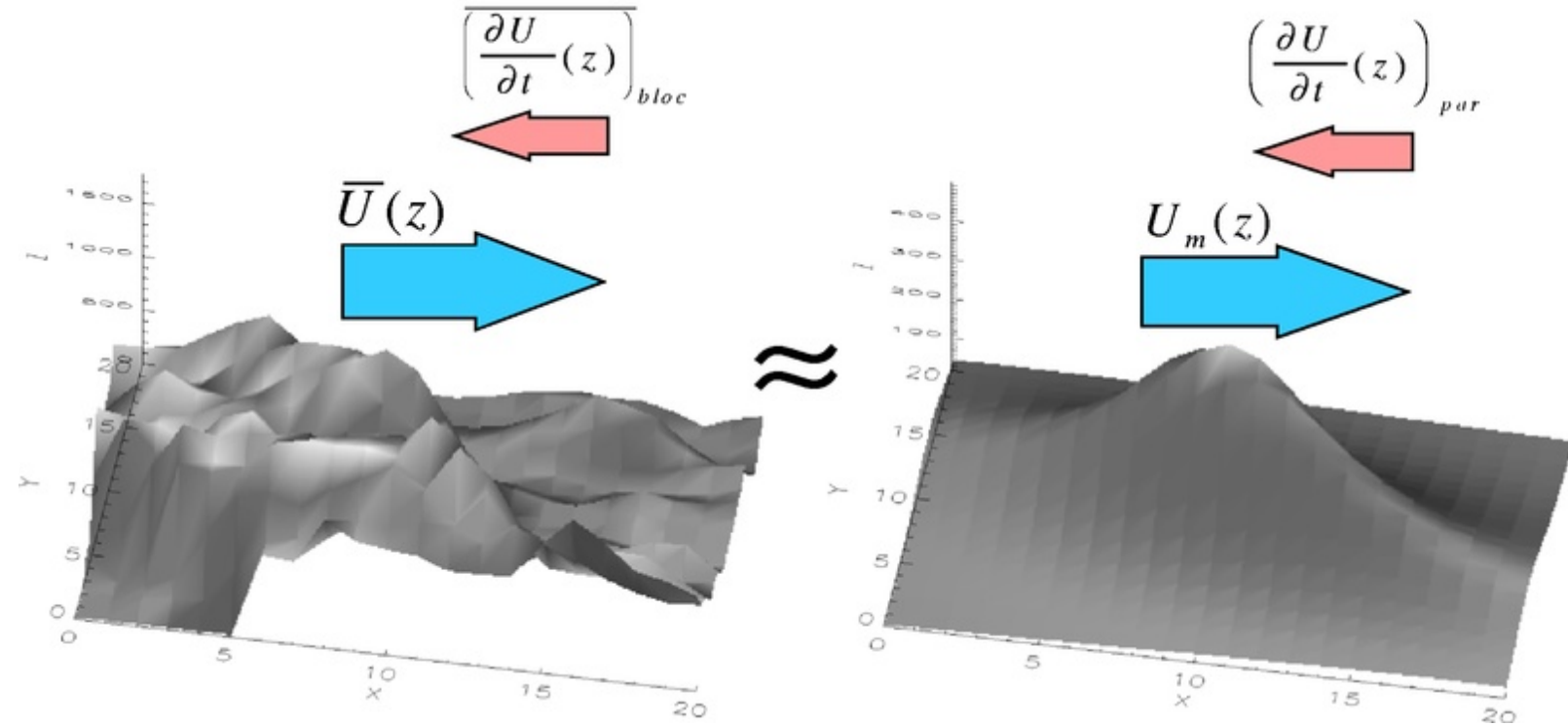
- model GEM-MPI
- winter cycle (2000/Dec/01 to 2001/Jan/20)
- blue: control
- red: no-overshoot experiment
- impact most visible over Asia



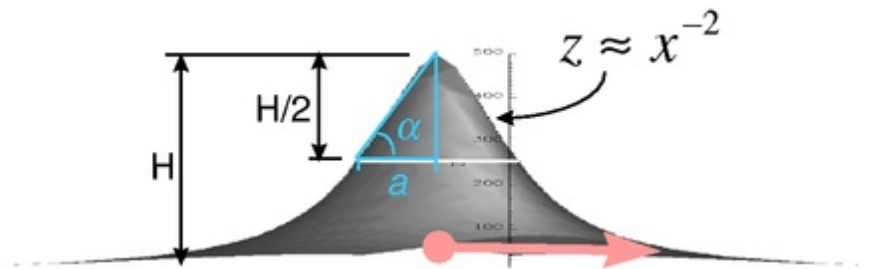
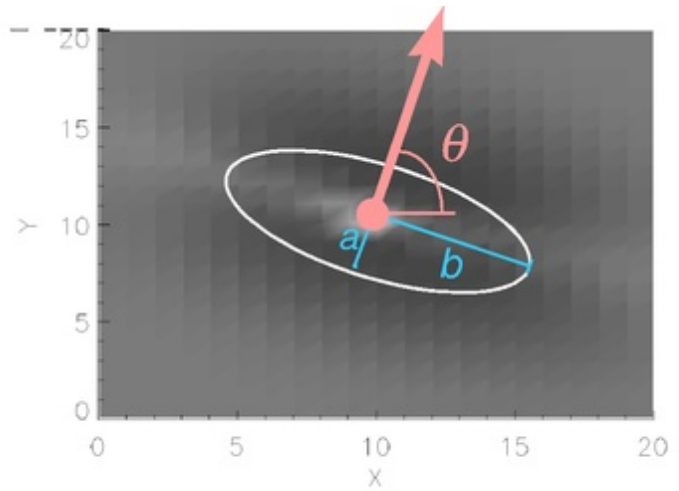
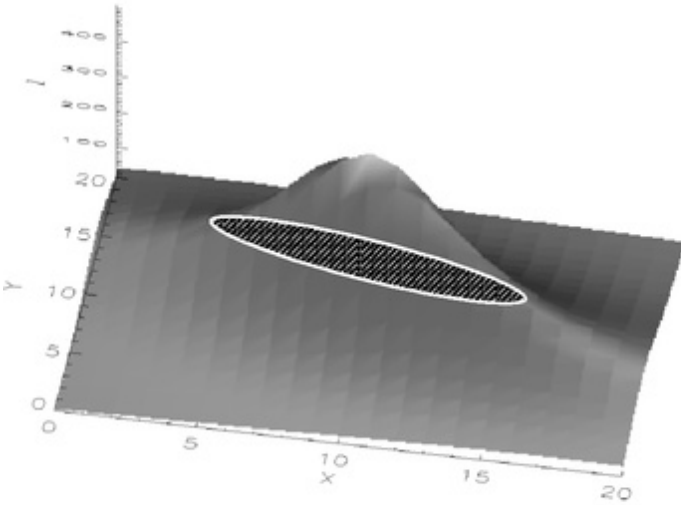
# EXPLAINING THE SCHEME

## III. The blocking component

(a) the concept of “equivalent elliptical mountain”



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scale:  $H$

eccentricity:  $\gamma = a / b$

direction:  $\theta$

slope:  $\tan \alpha = H / 2a$

profile exponent:  $z \approx x^{-2}$

Definition of the elliptical mountain:

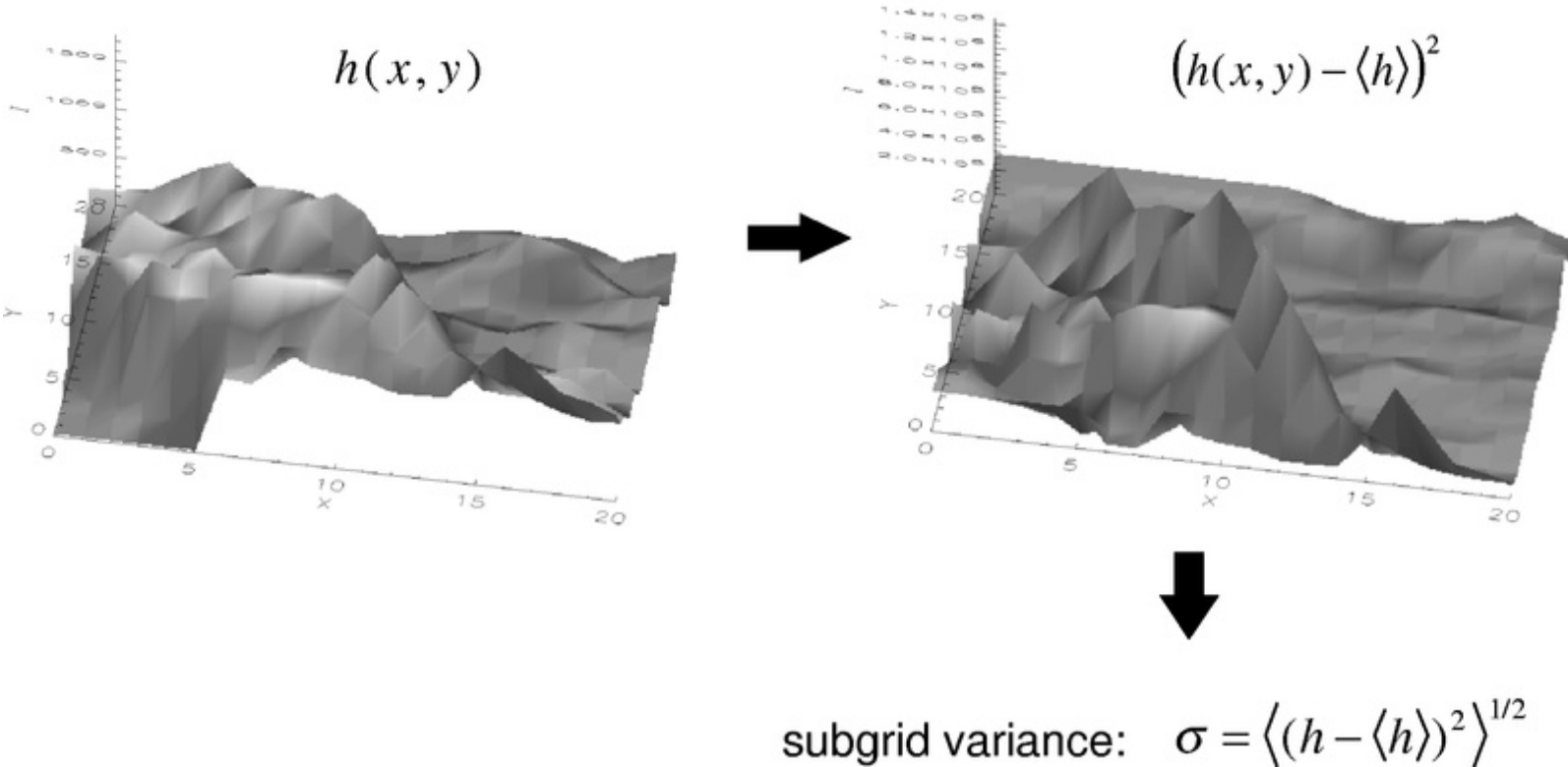
- \* 1 length scale
- \* 4 non-dimensional parameters

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# EXPLAINING THE SCHEME

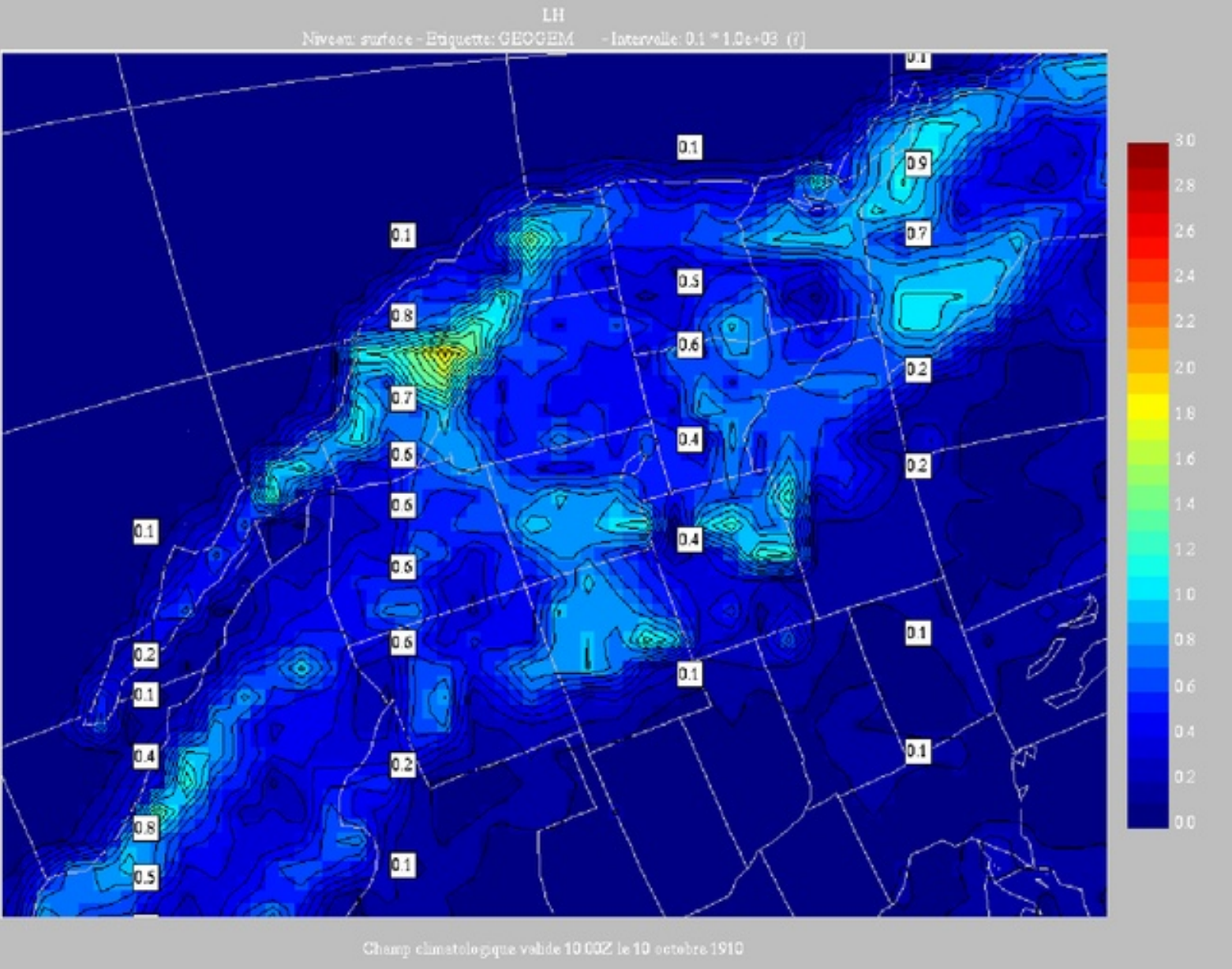
## III. The blocking component:

### (b) construction of the elliptical mountain



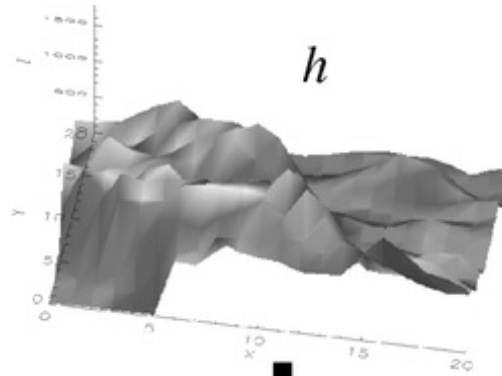
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# Example: launching height (in $10^{**3}$ m) used by GEM-global

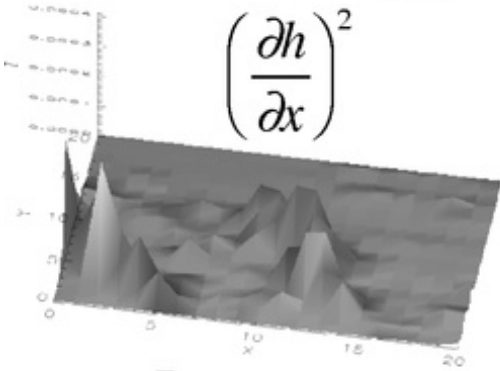


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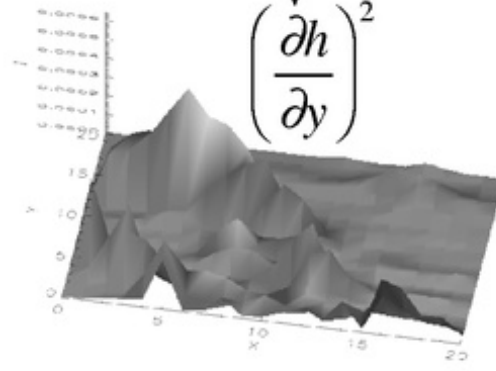


$$\left(\frac{\partial h}{\partial x}\right)^2$$



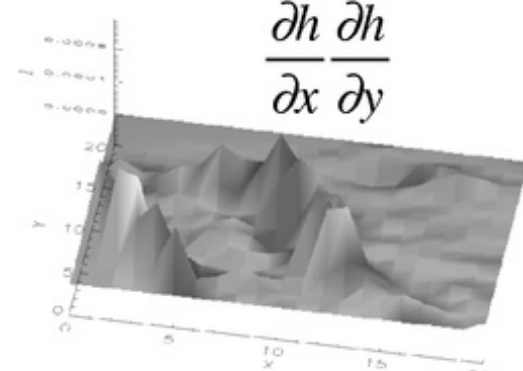
$$Y7 = \left\langle \left(\frac{\partial h}{\partial x}\right)^2 \right\rangle$$

$$\left(\frac{\partial h}{\partial y}\right)^2$$



$$Y8 = \left\langle \left(\frac{\partial h}{\partial y}\right)^2 \right\rangle$$

$$\frac{\partial h}{\partial x} \frac{\partial h}{\partial y}$$



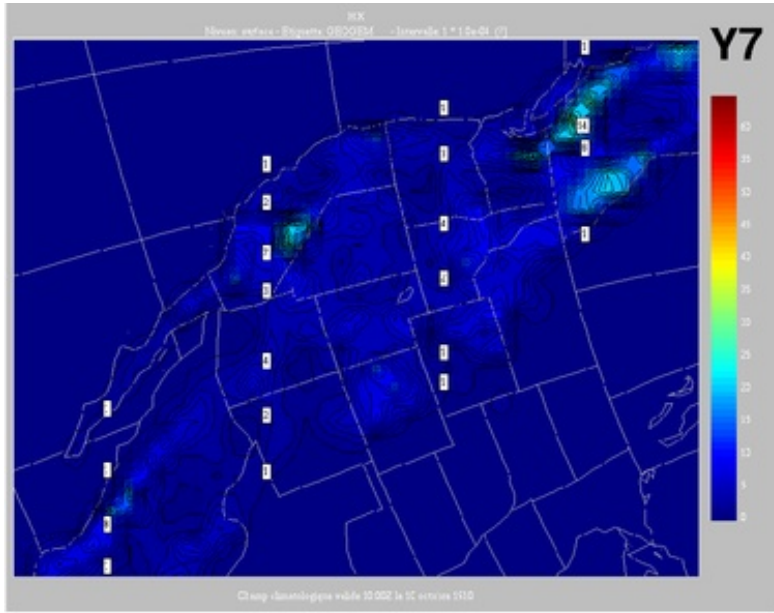
$$Y9 = \left\langle \frac{\partial h}{\partial x} \frac{\partial h}{\partial y} \right\rangle$$

gradient correlation tensor:  $H_{ij} = \begin{pmatrix} Y7 & Y9 \\ Y9 & Y8 \end{pmatrix}$

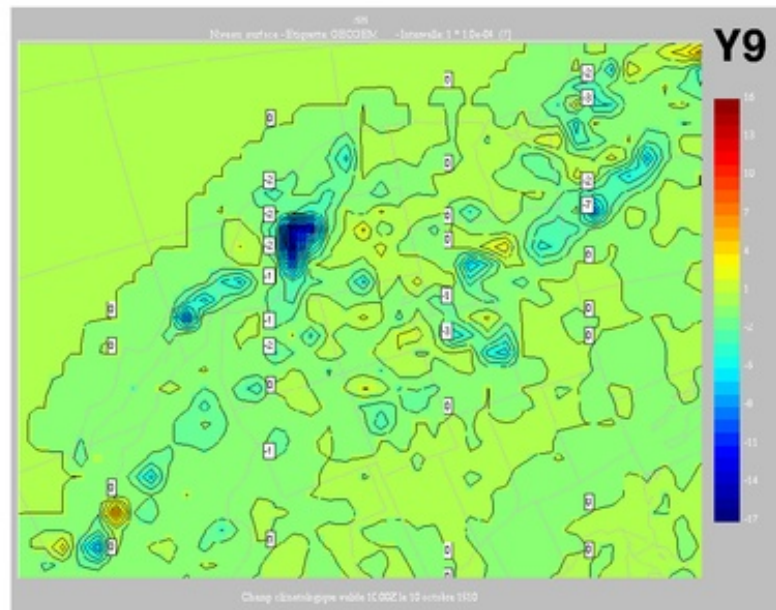
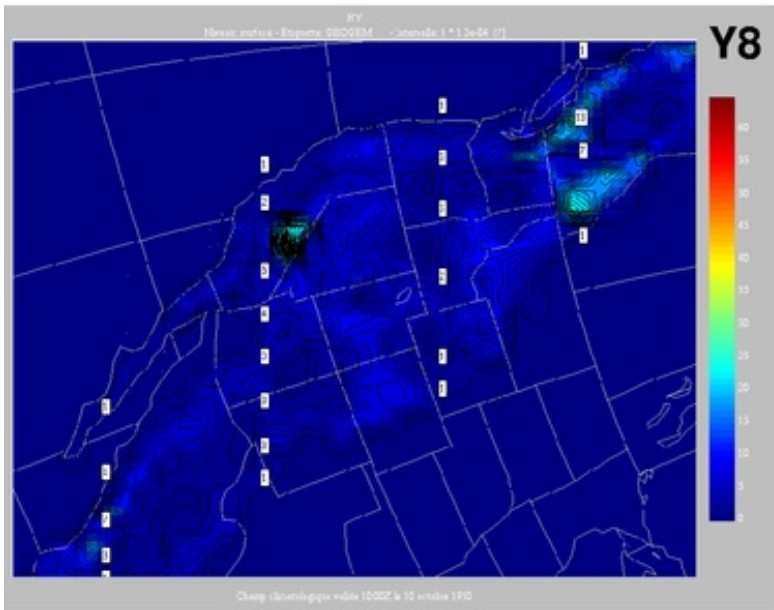
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Example:  
Y7, Y8 & Y9 (in  $10^{**}-4$ )  
used by GEM-global



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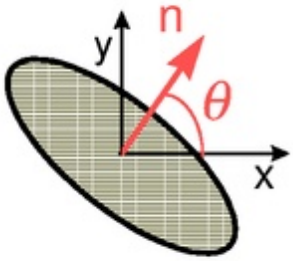
## Gradient correlation in terms of wavenumbers:

$$\frac{Y7}{\sigma^2} = \frac{\left\langle \left( \frac{\partial h}{\partial x} \right)^2 \right\rangle}{\langle h^2 \rangle} \approx - \frac{\left\langle h \frac{\partial^2}{\partial x^2} h \right\rangle}{\langle h^2 \rangle} \approx \overline{k^2}$$

$$\frac{Y8}{\sigma^2} = \frac{\left\langle \left( \frac{\partial h}{\partial y} \right)^2 \right\rangle}{\langle h^2 \rangle} \approx - \frac{\left\langle h \frac{\partial^2}{\partial y^2} h \right\rangle}{\langle h^2 \rangle} \approx \overline{l^2}$$

$$\frac{Y9}{\sigma^2} = \frac{\left\langle \frac{\partial h}{\partial x} \frac{\partial h}{\partial y} \right\rangle}{\langle h^2 \rangle} \approx - \frac{\left\langle h \frac{\partial^2}{\partial x \partial y} h \right\rangle}{\langle h^2 \rangle} \approx \overline{kl}$$

Using Y7-Y8-Y9 to compute other parameters:



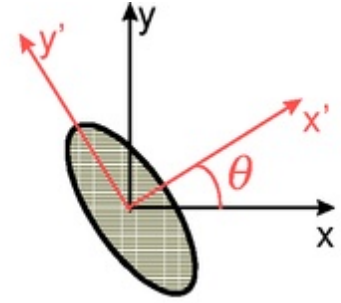
(a) Mean-square gradient at direction  $\theta$  :

$$\begin{aligned} \langle (n \cdot \nabla h)^2 \rangle &= \left\langle \left( \cos \theta \frac{\partial h}{\partial x} + \sin \theta \frac{\partial h}{\partial y} \right)^2 \right\rangle \\ &= [Y7] \cos^2 \theta + [Y8] \sin^2 \theta + [Y9] \sin 2\theta \end{aligned}$$

(b) Direction of maximum gradient:

$$\begin{aligned} \frac{\partial}{\partial \theta} \langle (n \cdot \nabla h)^2 \rangle = 0 &= -[Y7 - Y8] \sin 2\theta + 2[Y9] \cos 2\theta \\ \Rightarrow \theta &= \frac{1}{2} \arctan \left\{ \frac{2[Y9]}{[Y7 - Y8]} \right\} \end{aligned}$$

(c) Rotated frame:  $x' = x \cos \theta + y \sin \theta$   
 $y' = y \cos \theta - x \sin \theta$



$$\begin{aligned} \frac{\partial h}{\partial x'} &= \frac{\partial h}{\partial x} \cos \theta + \frac{\partial h}{\partial y} \sin \theta \\ \frac{\partial h}{\partial y'} &= \frac{\partial h}{\partial y} \cos \theta - \frac{\partial h}{\partial x} \sin \theta \end{aligned} \quad \Rightarrow \quad \begin{aligned} [Y7]' &= [Y7] \cos^2 \theta + [Y8] \sin^2 \theta + [Y9] \sin 2\theta \\ [Y8]' &= [Y8] \cos^2 \theta + [Y7] \sin^2 \theta - [Y9] \sin 2\theta \\ [Y9]' &= [Y9] \cos 2\theta - [Y7 - Y8] \sin 2\theta / 2 = 0 \end{aligned}$$

(d) Maximum slope:  $\tan \alpha = \left\langle \left( \frac{\partial h}{\partial x'} \right)^2 \right\rangle^{1/2} = [Y7]^{1/2}$

(e) Eccentricity:  $\gamma = \frac{\left\langle \left( \frac{\partial h}{\partial y'} \right)^2 \right\rangle^{1/2}}{\left\langle \left( \frac{\partial h}{\partial x'} \right)^2 \right\rangle^{1/2}} = \frac{[Y8]^{1/2}}{[Y7]^{1/2}}$

## 1. Mountain height

from variance:  $H = 2\sigma$

## 2. Minor axis

from slope:  $a = H / 2 \tan \alpha$

## 3. Major axis

from eccentricity:  $b = a / \gamma$

## 4. Rotated coordinates

from direction:  $x' = x \cos \theta + y \sin \theta$

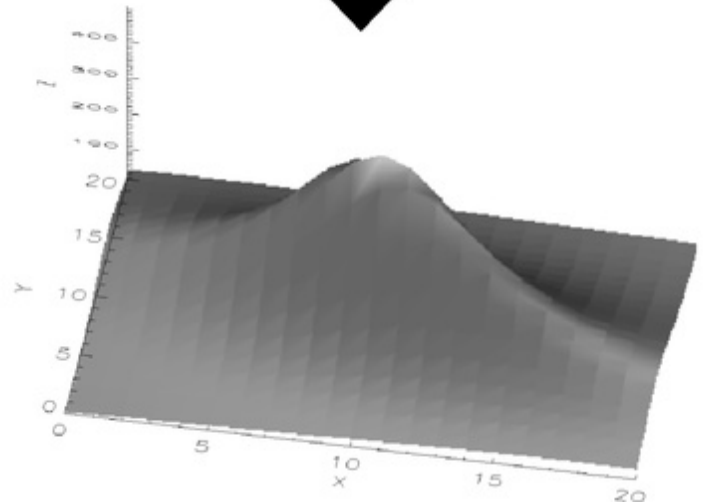
$y' = y \cos \theta - x \sin \theta$

## 5. Profile

choose exponent:  $h \approx x'^{-2}$

## *Elliptical mountain*

$$h_e(x, y) = \frac{H}{(1 + x'^2/a^2 + y'^2/b^2)}$$



# EXPLAINING THE SCHEME

## III. The blocking component:

### (c) blocking force due to elliptical mountain

Based on Lott and Miller (1997):

$$\rho \frac{\partial \vec{U}}{\partial t} = \vec{D}_b$$

$$\vec{D}_b = \begin{cases} 0, & z > h_b \\ - C_d \cdot F_{dir} \cdot F_{slp} \cdot F_{pfl} \cdot \frac{\rho}{2} \vec{U} |\vec{U}|, & z \leq h_b \end{cases}$$



profile factor  
(related to the mountain profile)

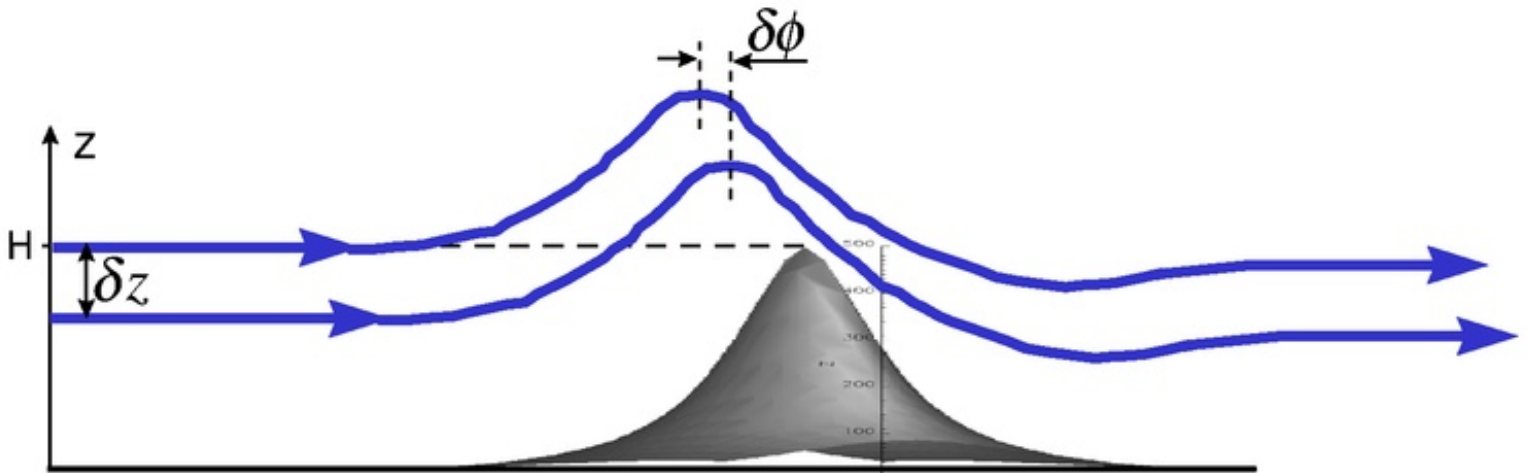
# EXPLAINING THE SCHEME

## III. The blocking component:

(d) blocking height

*flow dependent !!!*

$$h_b = \max\{z\} \quad \text{such that} \quad \int_z^H \frac{N}{U} dz \geq \phi_c, \quad \phi_c = 0.5$$



From mountain/gravity-wave theory

$$\psi \propto \exp i \left( kx + \underbrace{\frac{N}{U} z}_{\phi} \right)$$

Phase change between levels

$$\delta \phi = \frac{N}{U} \delta z \quad \leftarrow \begin{array}{l} \text{inverse} \\ \text{Froude \#} \end{array}$$

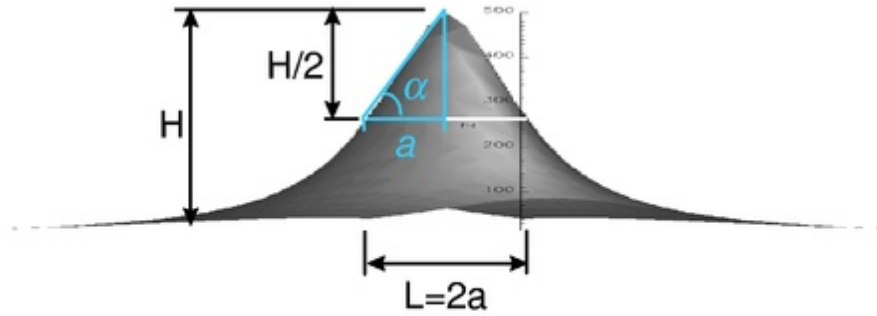
# EXPLAINING THE SCHEME

## III. The blocking component:

### (e) slope/scale factor

$$F_{slp} = \frac{1}{2a}$$

*flow independent !!!*



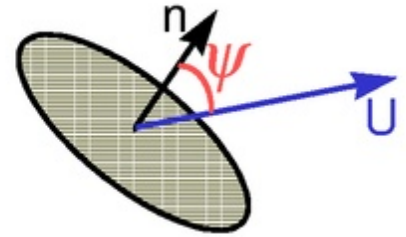
$$\frac{1}{2a} = \frac{\tan \alpha}{H} = \frac{[Y7']^{1/2}}{2\sigma} \approx \frac{\sqrt{k^2}}{2} = \text{1/2-wavenumber in the direction of maximum slope}$$



# EXPLAINING THE SCHEME

## III. The blocking component:

### (f) directional/eccentricity factor



*flow dependent !!!*

$$F_{dir} = \max\left(2 - \frac{1}{r}, 0\right) \cdot (B \cos^2 \psi + C \sin^2 \psi)$$

$$r = \frac{\cos^2 \psi + \gamma \sin^2 \psi}{\gamma \cos^2 \psi + \sin^2 \psi}$$

$$B = 1 - 0.18\gamma - 0.04\gamma^2$$

$$C = 0.48\gamma + 0.3\gamma^2$$

modulates slope factor  $F_{slp} = \frac{1}{2a}$

	$\gamma$	$\psi$	$B, C$	$(B \cos^2 \psi + C \sin^2 \psi)$
	1	?	$B = 0.78 = C$	0.78
	$\ll 1$	$0^\circ$	$B \approx 1, C \approx 0.48\gamma$	$\approx 1.0$
	$\ll 1$	$90^\circ$	$B \approx 1, C \approx 0.48\gamma$	$\approx 0.48 \frac{a}{b}$

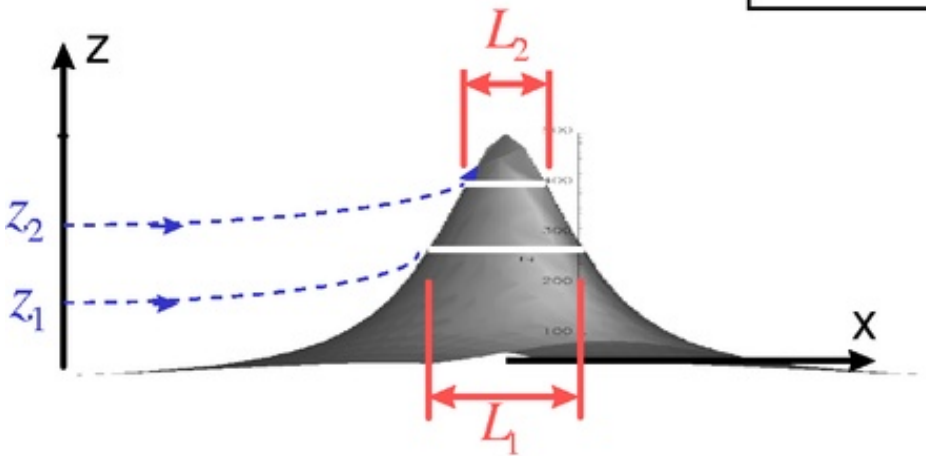
# EXPLAINING THE SCHEME

## III. The blocking component:

*flow dependent !!!*

(g) profile factor

$$F_{pfl} = \left( \frac{h_b - z}{z + \sigma} \right)^{1/2}$$



Modulates the “size” of the barrier as seen by parcels at different levels:

$$\frac{L_2}{L_1} \approx \frac{\left( \frac{h_b - z_2}{z_2 + \sigma} \right)^{1/2}}{\left( \frac{h_b - z_1}{z_1 + \sigma} \right)^{1/2}}$$

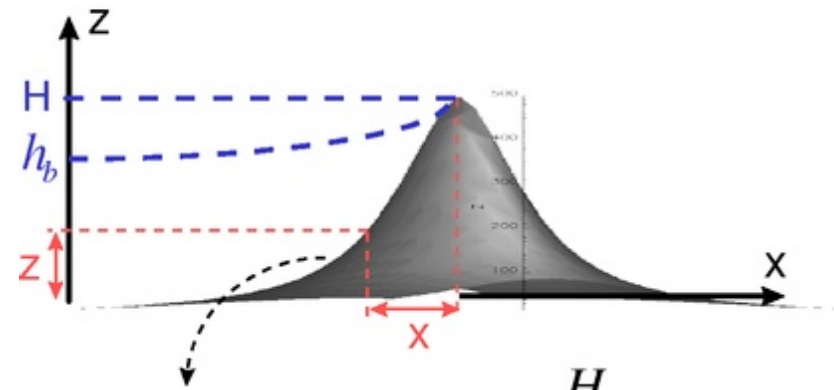
# EXPLAINING THE SCHEME

## III. The blocking component:

(g) profile factor

*flow dependent !!!*

$$F_{pfl} = \left( \frac{h_b - z}{z + \sigma} \right)^{1/2}$$



Profile at  $y=0$ : 
$$z = \frac{H}{1 + x^2 / a^2}$$

Inverse profile: 
$$\frac{x}{a} = \left( \frac{H - z}{z} \right)^{1/2}$$

Assuming model orography is at altitude  $\sigma$  above valley:

$$\frac{x}{a} \approx \left( \frac{h_b - z}{z + \sigma} \right)^{1/2}$$

Isentrope-lifting correction:

$$\frac{x}{a} \approx \left( \frac{h_b - z}{z} \right)^{1/2}$$

# IMPACT ON THE FLOW

## I. Tested versions of the blocking

- (a)** Based on the Lott-Miller formulation,  
with geophysical fields (LH, Y7-9) produced by GENESIS
- (b)** Based on the Lott-Miller formulation,  
with “artificial”, isotropic gradient fields (Y7-9)
- (c)** “Hybrid” version:  
Lott-Miller force + Scinocca-McFarlane blocking height

# IMPACT ON THE FLOW

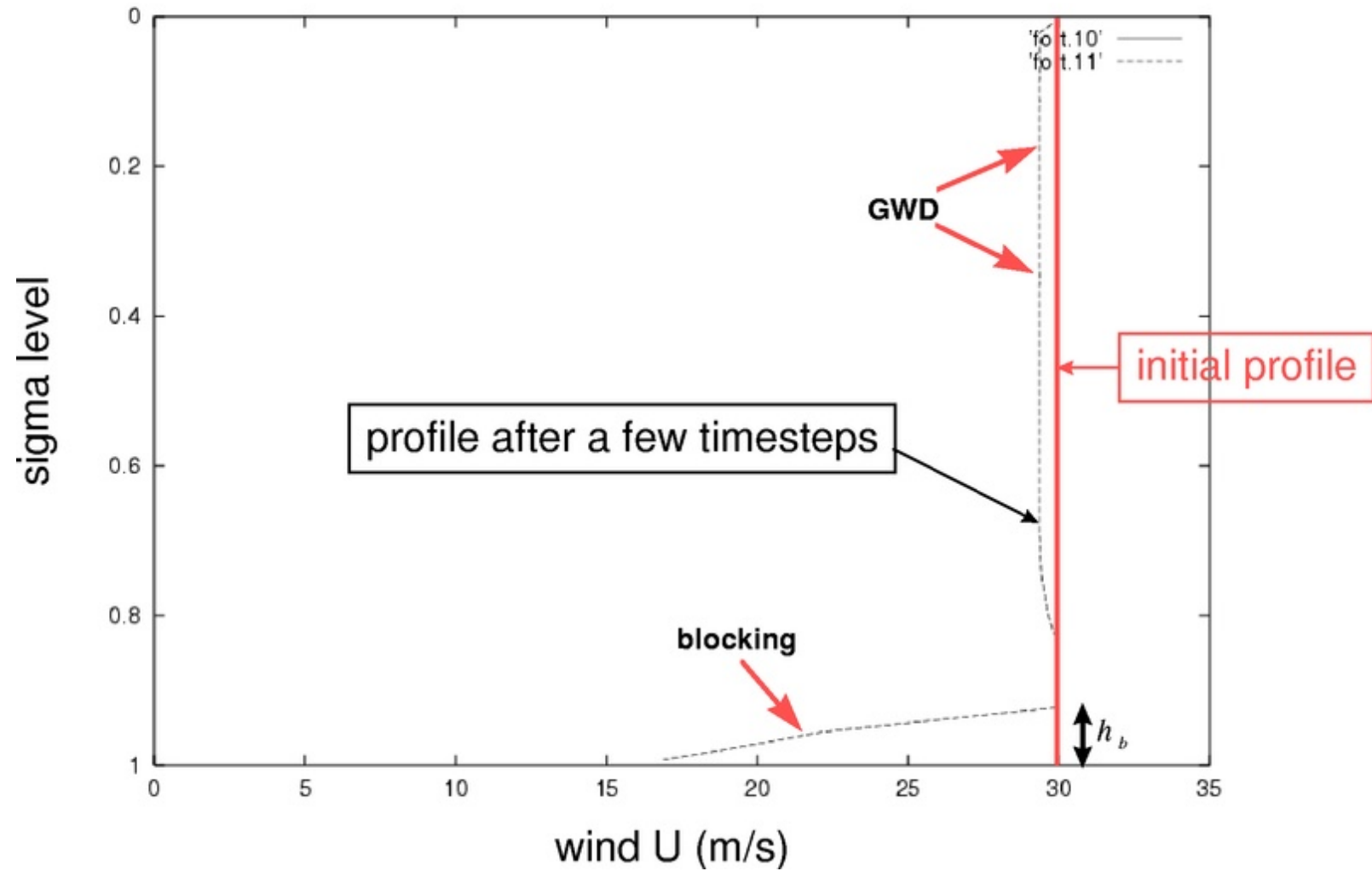
## II. Studies using a 1-D (column) model

- > Column model: fields depend on **z** and **t**
- > Input: initial profiles of **UU**, **VV**, **TT** and **PS**
- > “Dynamics”: **TT** and **PS** constant  
wind driven by SGO drag only

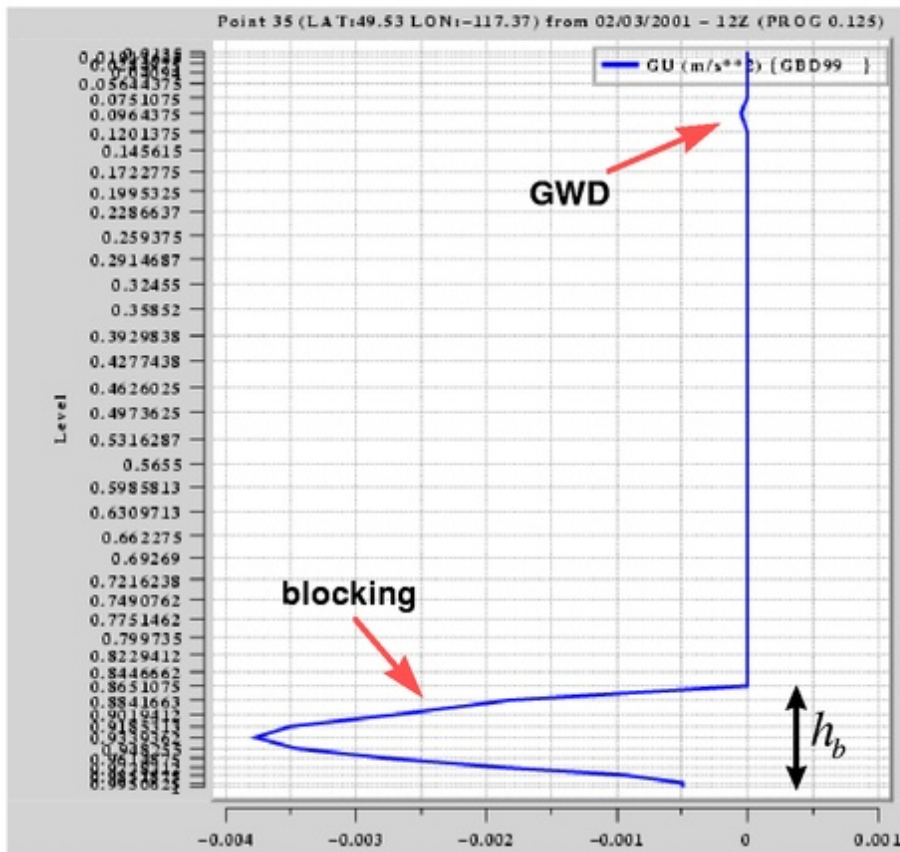
$$\rho \frac{\partial \bar{U}}{\partial t} = \bar{D}_{sgo} \quad , \quad \frac{\partial T}{\partial t} = 0 = \frac{\partial p_s}{\partial t}$$

- > Output: SGO tendencies (**GU**, **GV**)  
after-drag wind (**UU**, **VV**)

## WIND DECELERATION DUE TO SGO DRAG: EXAMPLE FROM A 1D MODEL



## VERTICAL PROFILE OF SGO DRAG: EXAMPLE FROM A 3D MODEL



Example of drag generated by the SGO parametrization:

\* Field:

**GU** = tendency on **UU**  
from GWD + blocking  
in  $\text{m/s}^2$

\* Model: GEM regional  
(15 km)

\* Location: fixed grid-point  
south of BC

# IMPACT ON THE FLOW

## III. 3-D sensitivity studies with artificial slopes

- (a) Made before the fields Y7-Y8-Y9 became available
- (b) Based on an isotropic “parametrization” of the slope fields in terms of the launching height (LH):

$$F_{slp} = \frac{Y7}{LH} = k \times \left( 1 + \frac{LH}{100 \text{ m}} \right) \quad \leftarrow \begin{array}{|l} \text{assuming the slope} \\ \text{varies linearly with LH} \end{array}$$

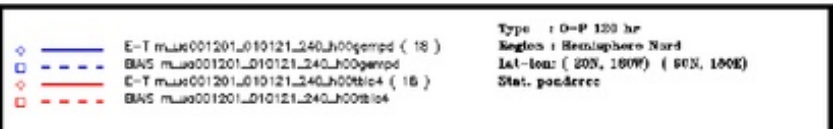
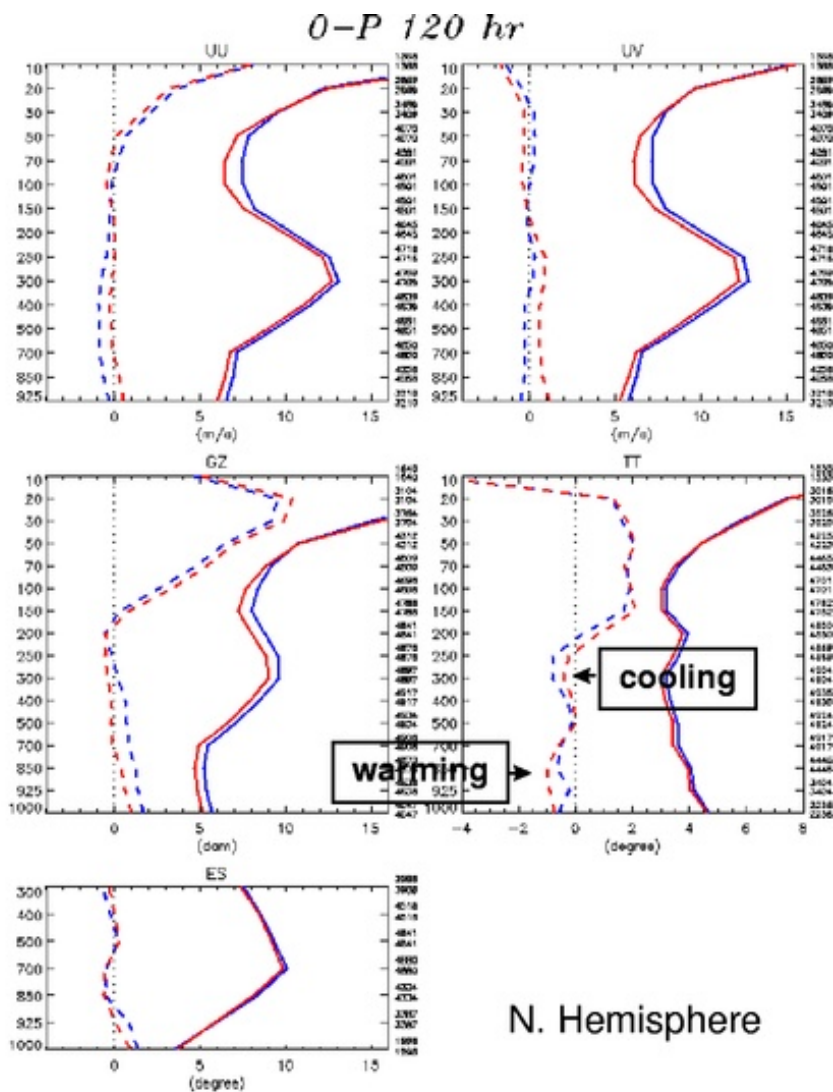
$$Y8 = Y7 \quad , \quad Y9 = 0$$

where  $k \approx 8 \times 10^{-6} \text{ m}^{-1}$  mean wavenumber used in the GWD scheme.



Illustration of the impact of blocking with artificial slopes:

- GEM-MPI
- period: Dec/2000 - Jan/2001
- blue: control (no blocking)
- red: experiment (blocking with "fake" Y7-Y8-Y9)



# IMPACT ON THE FLOW

## IV. 3-D experiments with simplified physics

**(a)** GEM model with dry simplified physics:

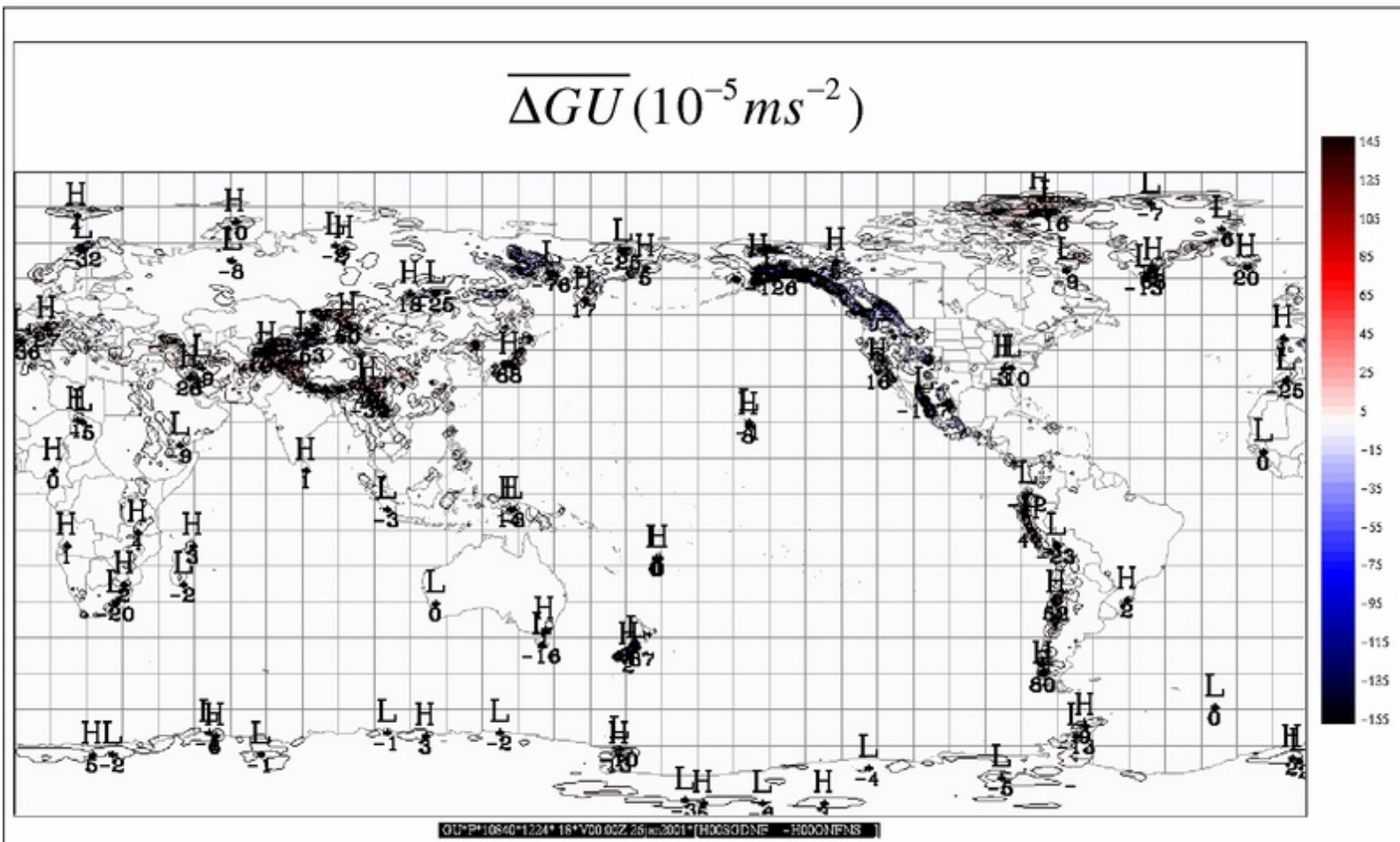
- > simplified vertical diffusion
- > SGO drag
- > no moisture
- > no solar radiation

**(b)** following figures show various averages of the difference between:

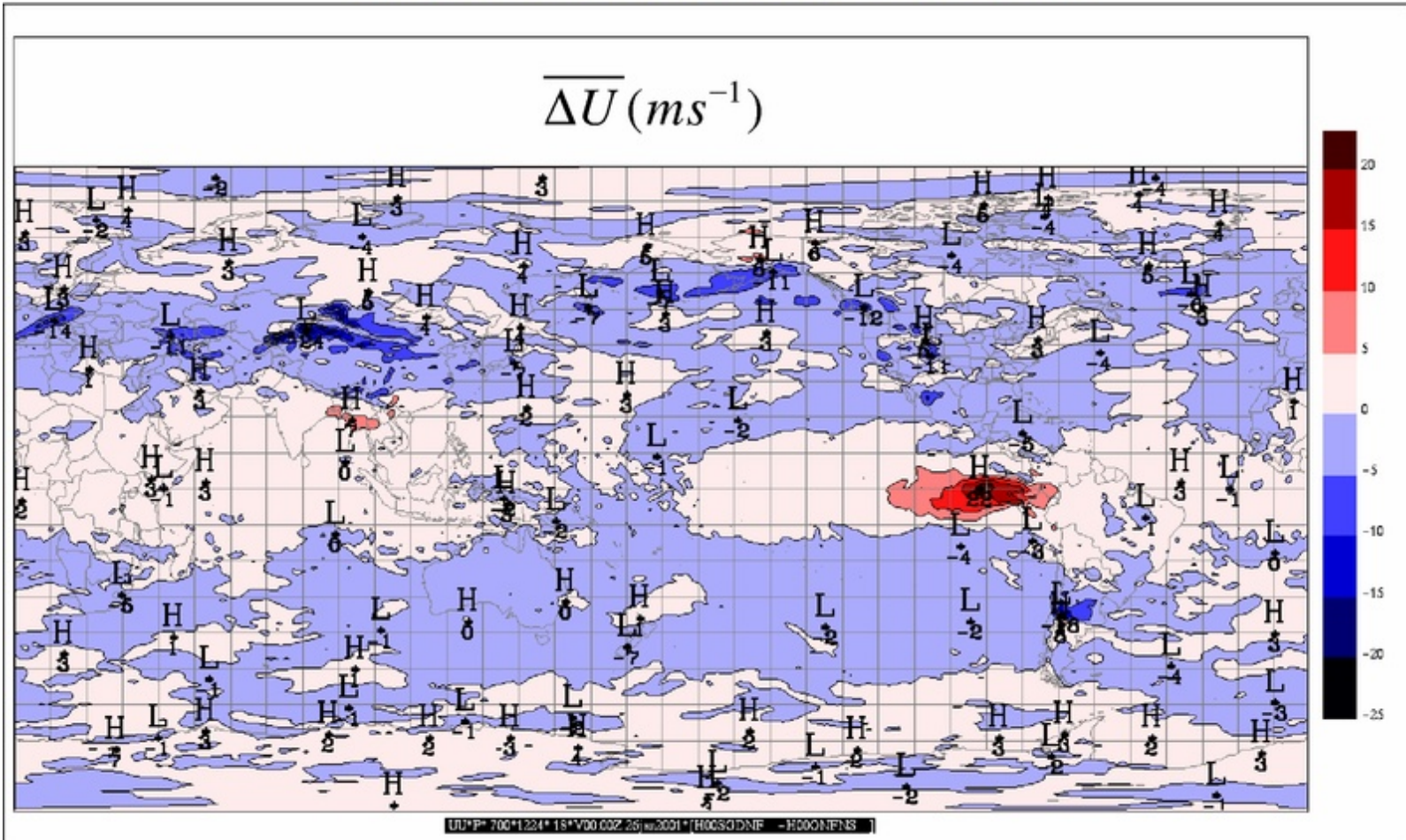
- > control (GWD, no blocking)
- > experiment (GWD + blocking)

at  $t = 120$  h.

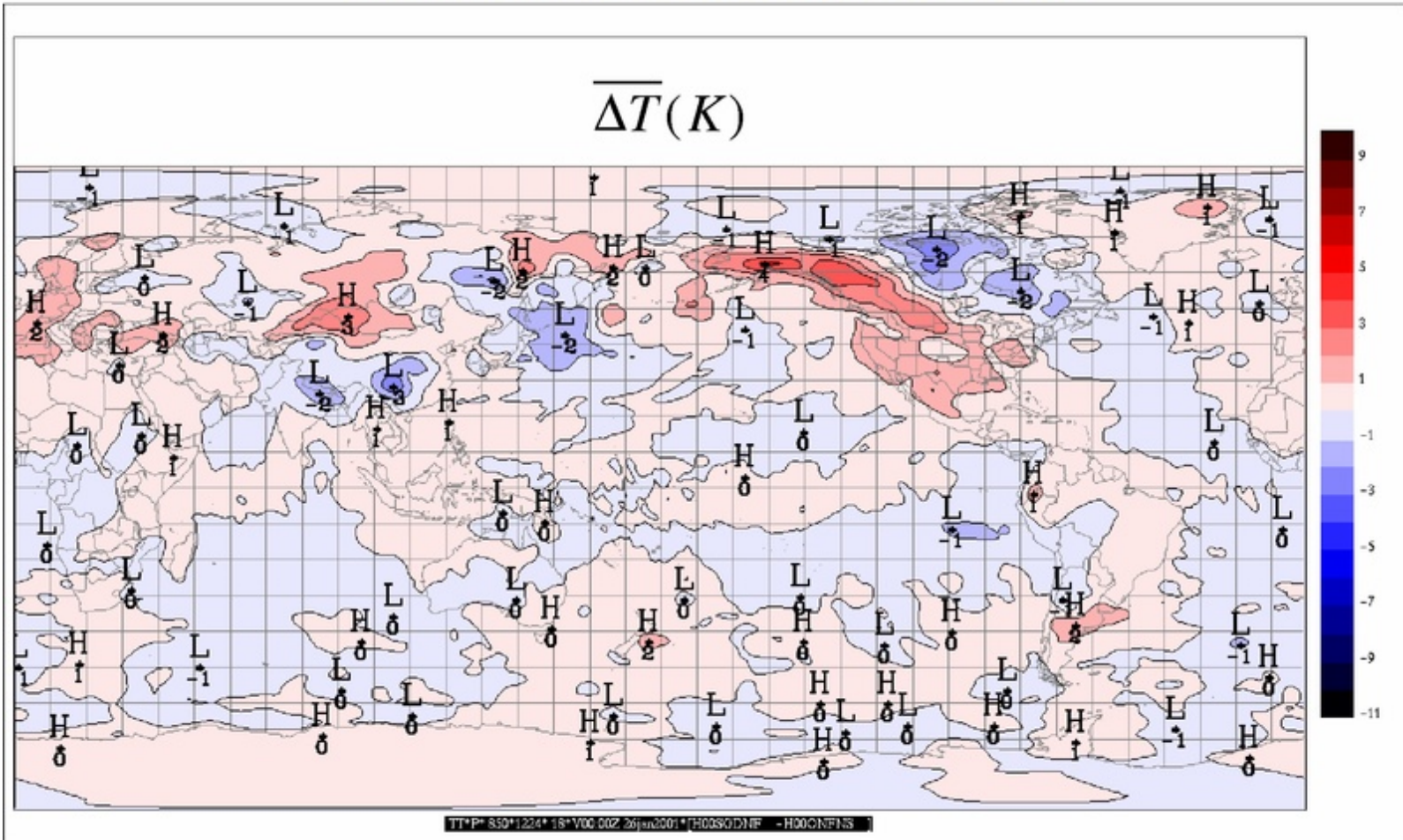
# Ensemble-average of SGO drag on the zonal wind at $\sigma = 0.884$



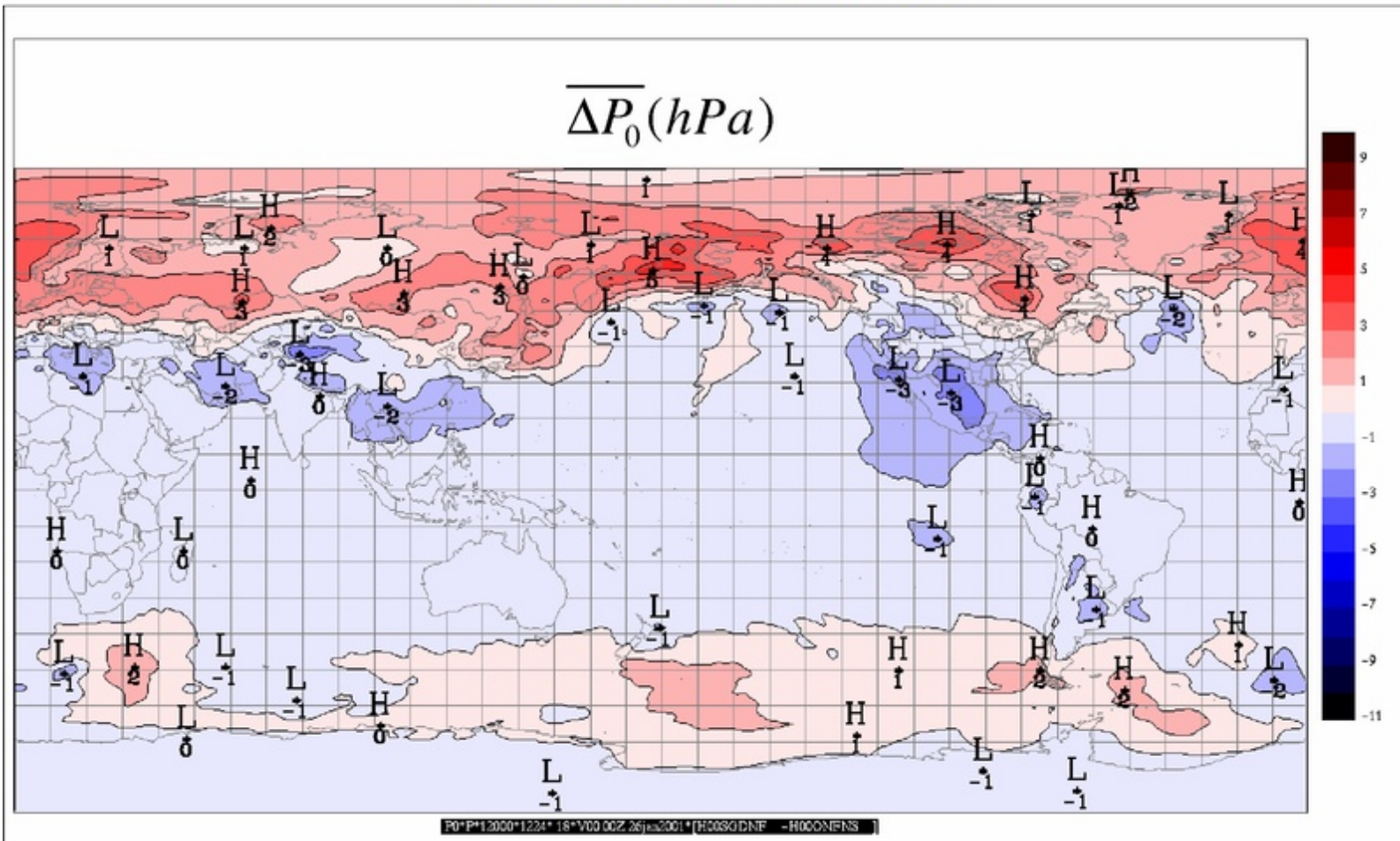
## Ensemble-average of impact (drag - nodrag) on the zonal wind at $p = 700$ hPa



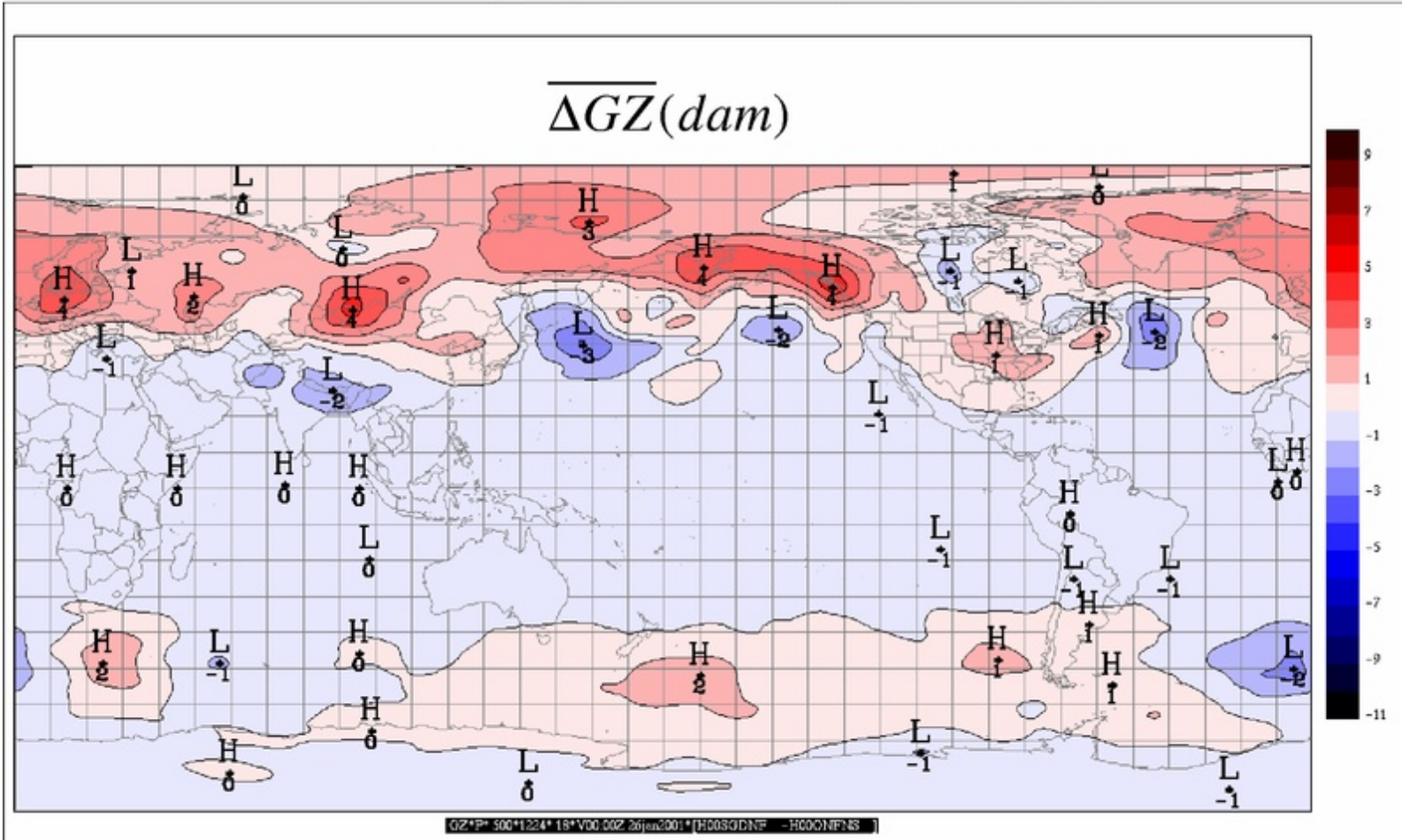
## Ensemble-average of impact (drag - nodrag) on the temperature at $p = 850$ hPa



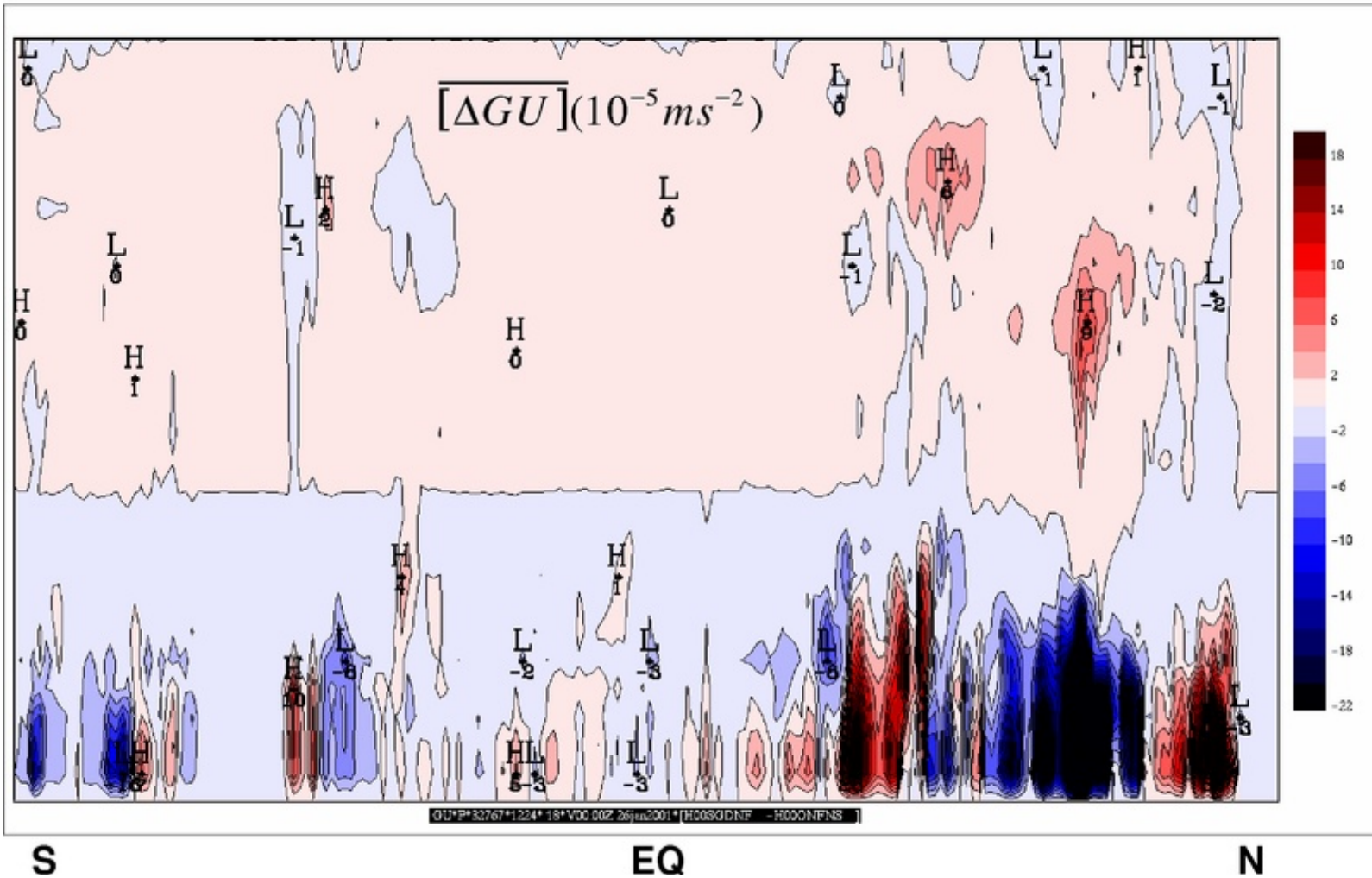
## Ensemble-average of impact (drag - nodrag) on the surface pressure



## Ensemble-average of impact (drag - nodrag) on the geopotential at p = 500 hPa



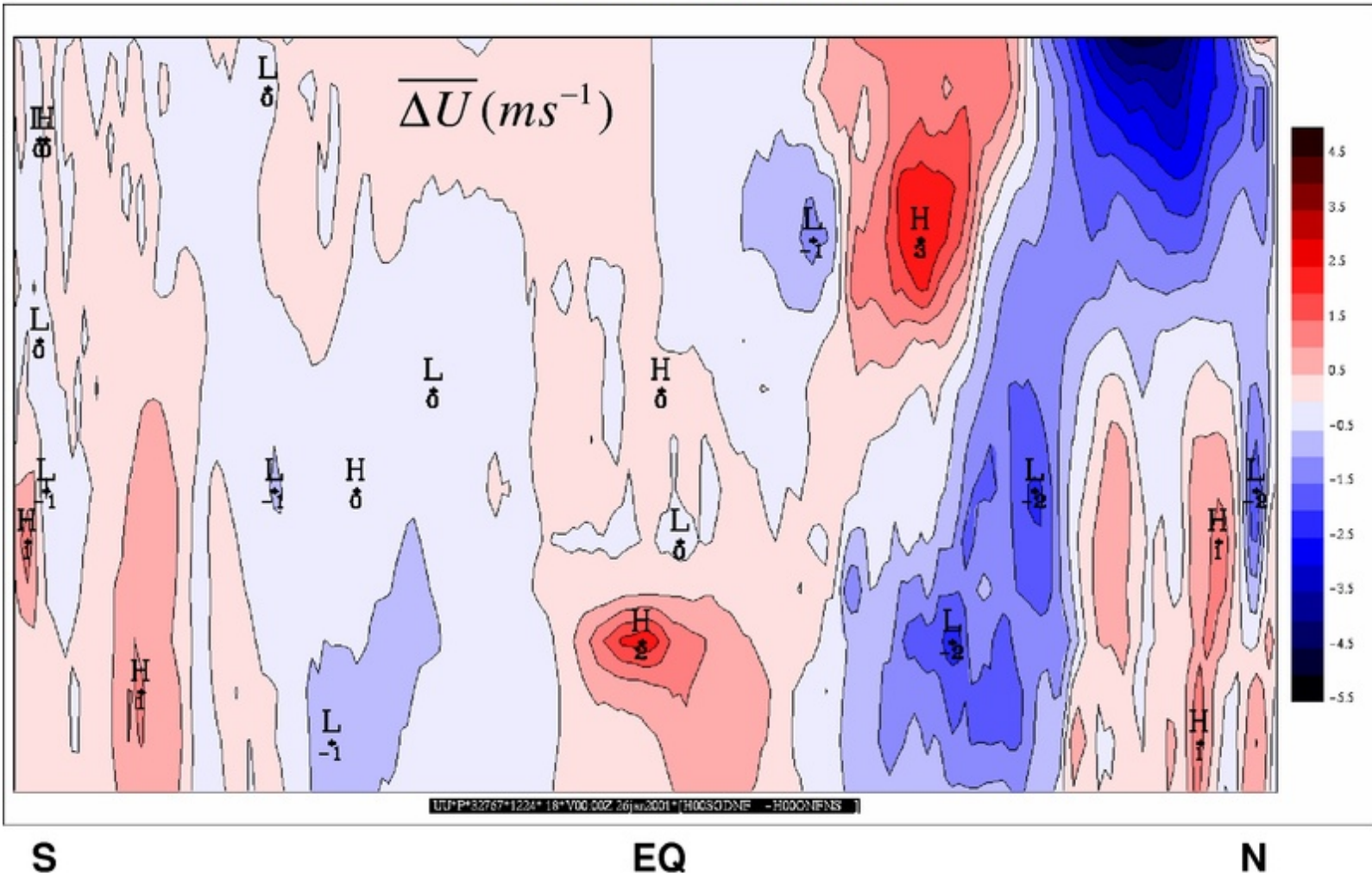
## Ensemble/zonal average of SGO drag on the zonal wind





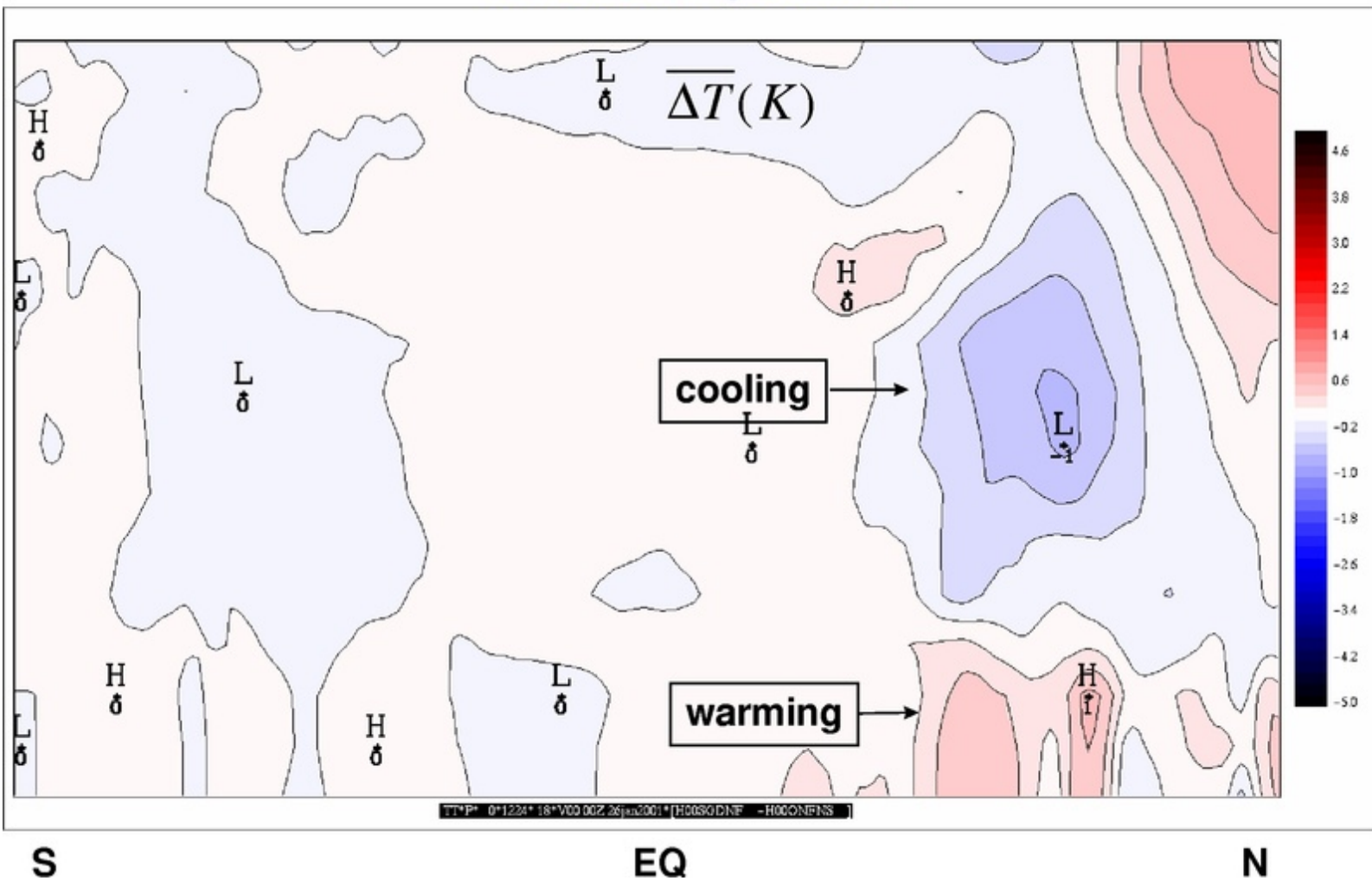
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## Ensemble/zonal average of impact (drag - nodrag) on the zonal wind

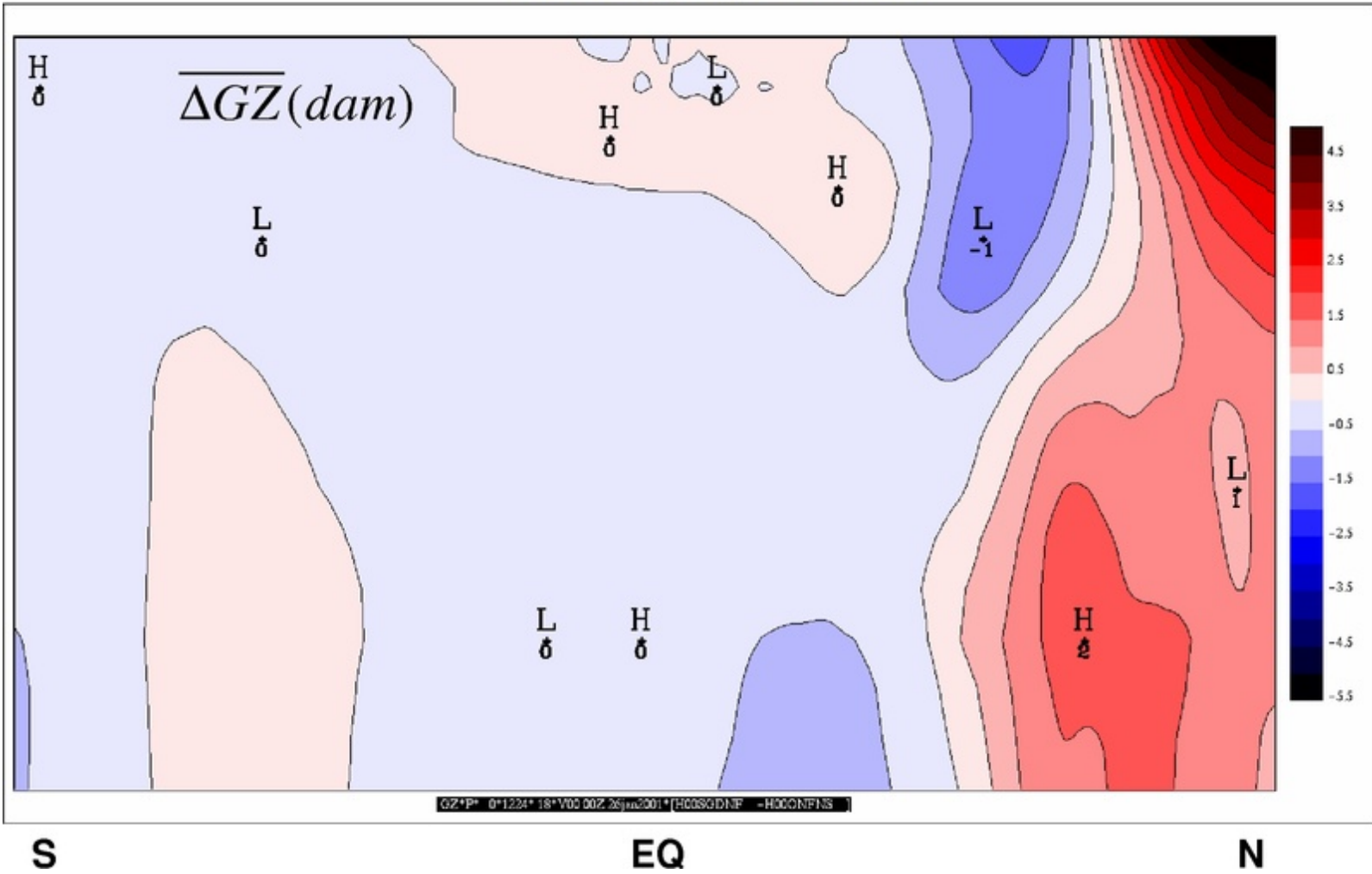
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## Ensemble-average of impact (drag - nodrag) on the temperature

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## Ensemble-average of impact (drag - nodrag) on the geopotential



# IMPACT ON THE FORECAST

## I. Experiments with GEM-global 400X200 \*

> version 3.6.0.4; TT/PS analysis with TOVS 1b+

> control in blue

> experiments in red:

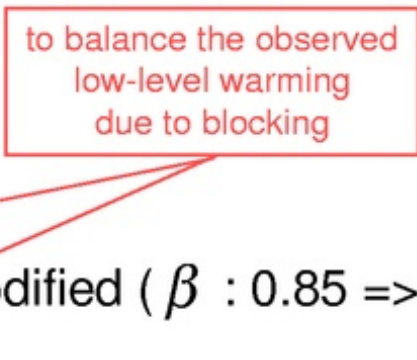
(i) **blocking** added

(ii) GWD with no-overshoot correction

(iii) heat/moisture exchange coefficient modified ( $\beta : 0.85 \Rightarrow 1$ )

(iv) cond/conv filter deactivated

to balance the observed  
low-level warming  
due to blocking



> 29 X 10-day forecasts in winter (Feb-Mar 2001)

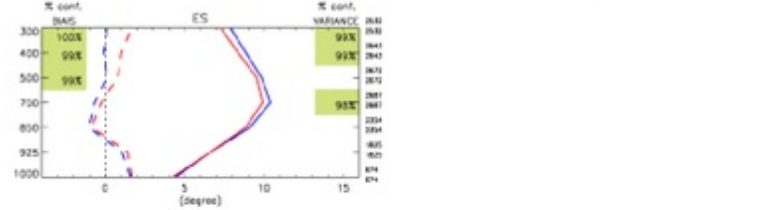
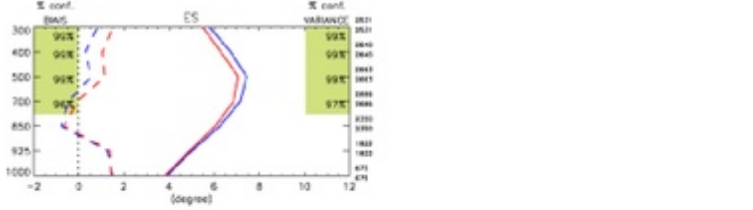
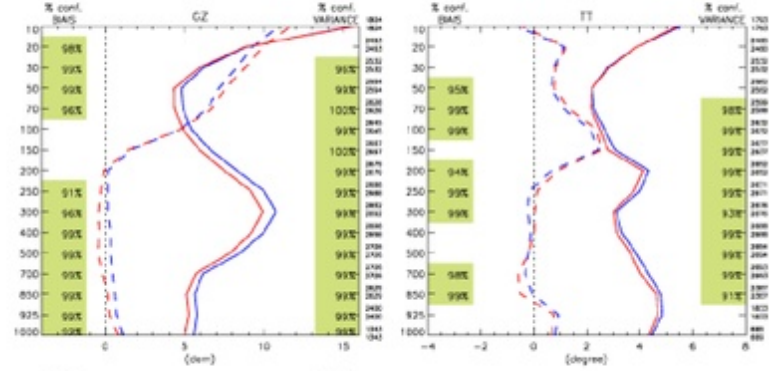
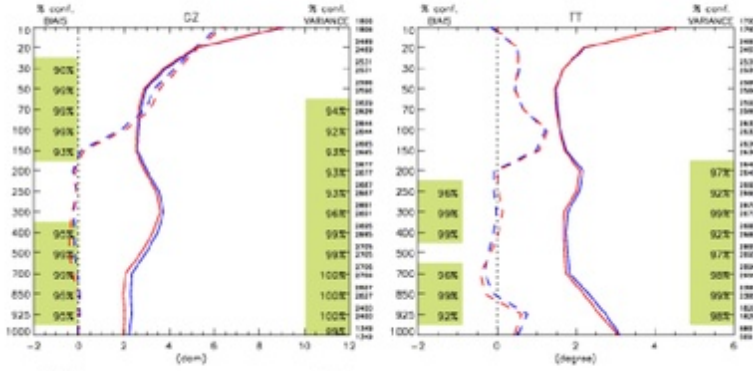
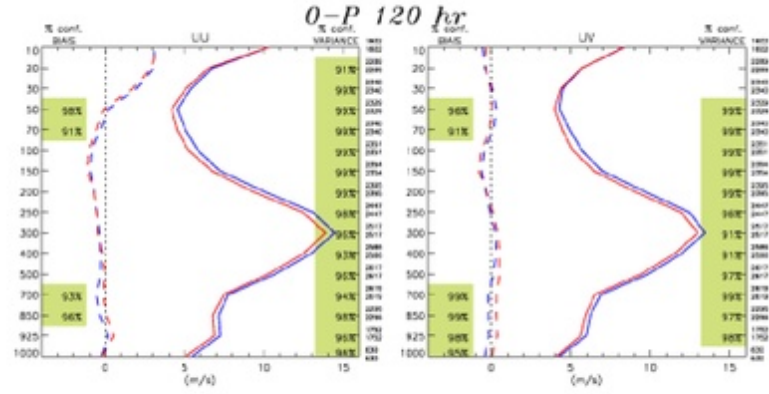
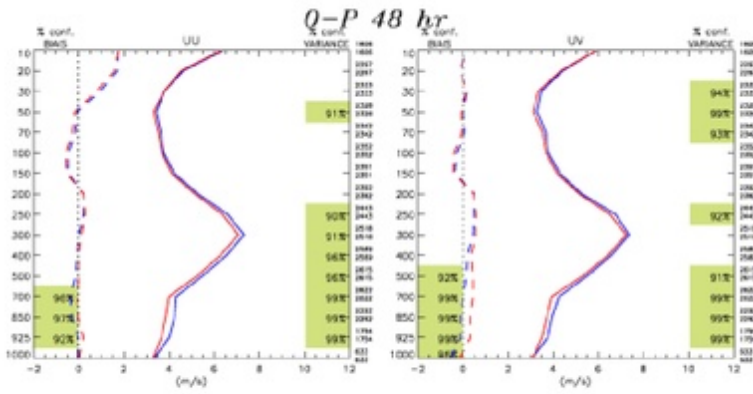
> 32 X 10-day forecasts in summer (Jun-Jul 2001)

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\* Made by M. Roch. Details in:

[http://euclide.cmc.ec.gc.ca/GAG/GLOBAL\\_OPER/VALID\\_BLOCAGE/valid\\_blocage.html](http://euclide.cmc.ec.gc.ca/GAG/GLOBAL_OPER/VALID_BLOCAGE/valid_blocage.html)

# Winter - North America



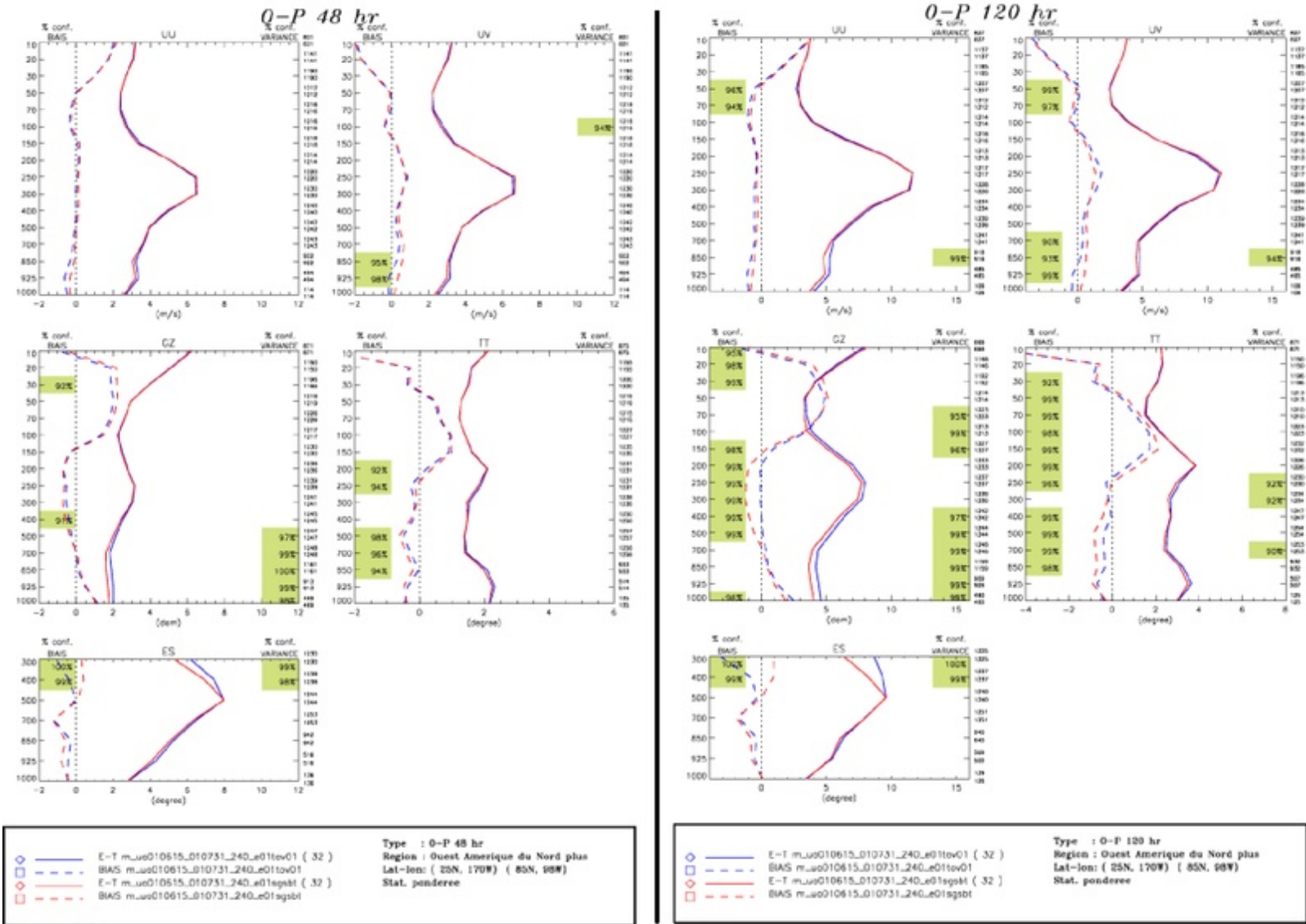
○ E-T m\_u010207\_010321\_240\_h011ov01 ( 29 )  
○ BIAS m\_u010207\_010321\_240\_h011ov01  
○ E-T m\_u010207\_010321\_240\_h011qsb1 ( 29 )  
○ BIAS m\_u010207\_010321\_240\_h011qsb1

Type : Q-P 48 hr  
 Region : Amerique du Nord plus  
 Lat-lon : ( 25N, 170W ) ( 85N, 40W )  
 Stat. ponderee

○ E-T m\_u010207\_010321\_240\_h011ov01 ( 29 )  
○ BIAS m\_u010207\_010321\_240\_h011ov01  
○ E-T m\_u010207\_010321\_240\_h011qsb1 ( 29 )  
○ BIAS m\_u010207\_010321\_240\_h011qsb1

Type : Q-P 120 hr  
 Region : Amerique du Nord plus  
 Lat-lon : ( 25N, 170W ) ( 85N, 40W )  
 Stat. ponderee

# Summer - West of North America



## II. Experiments with GEM-regional 15 km \*

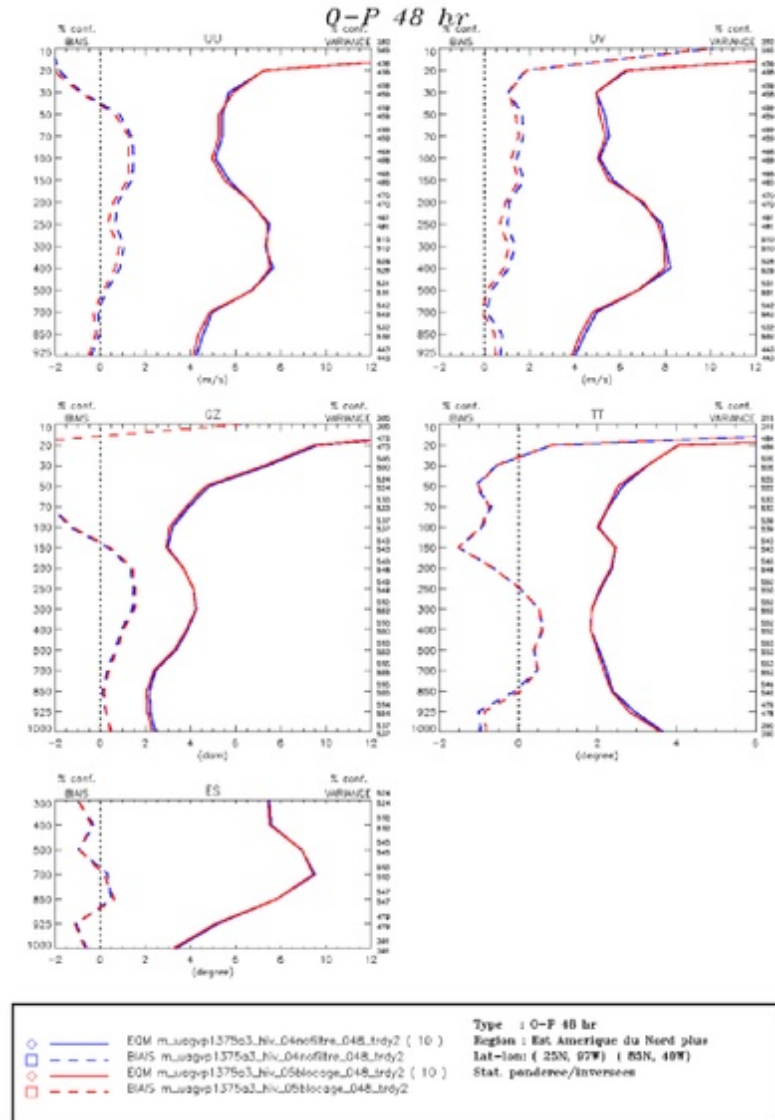
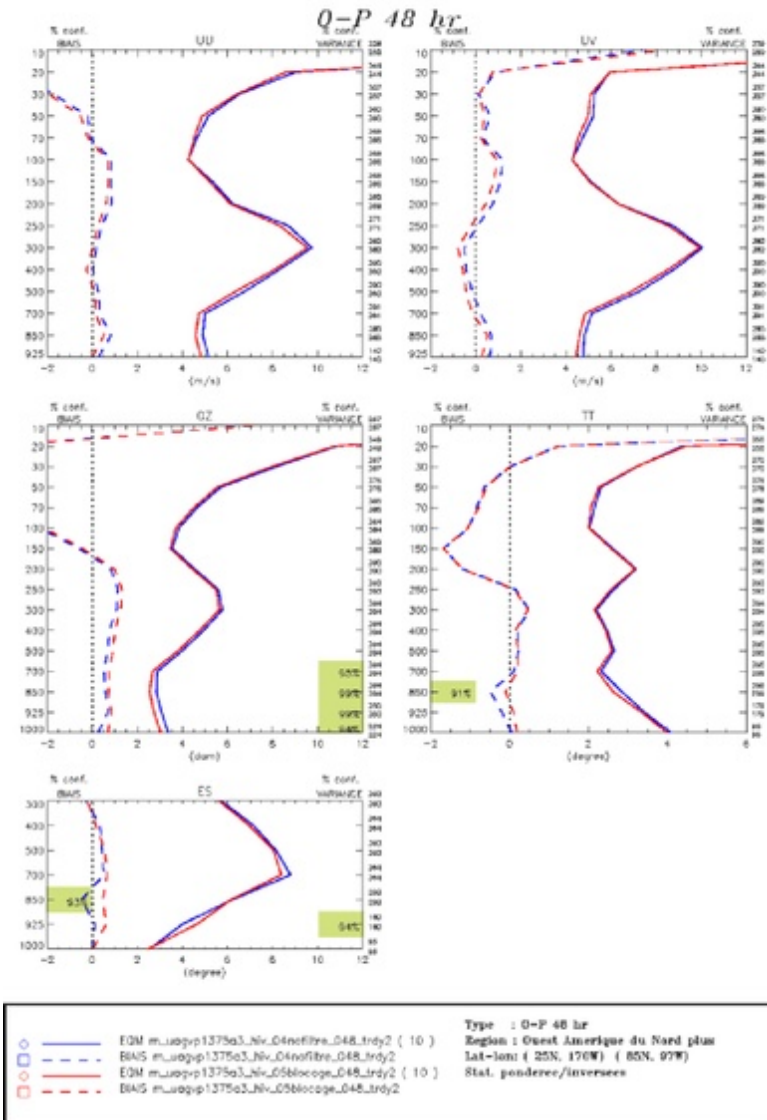
- > version 2.3.0 and 3.69
- > control in **blue**
- > experiment in **red** with SGO drag (GWD + blocking) added
- > 10 X 48h-forecasts in winter (Jan-Feb 2001)
- > 10 X 48h-forecasts in summer (Jul-Aug 2001)

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\* Made by D. Talbot. Details in:  
<http://iweb.cmc.ec.gc.ca/~afsg008/gvp1375a3/>

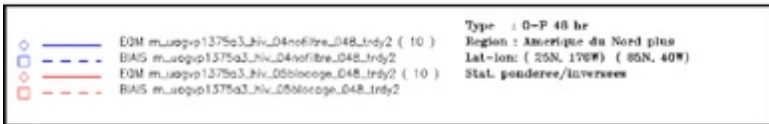
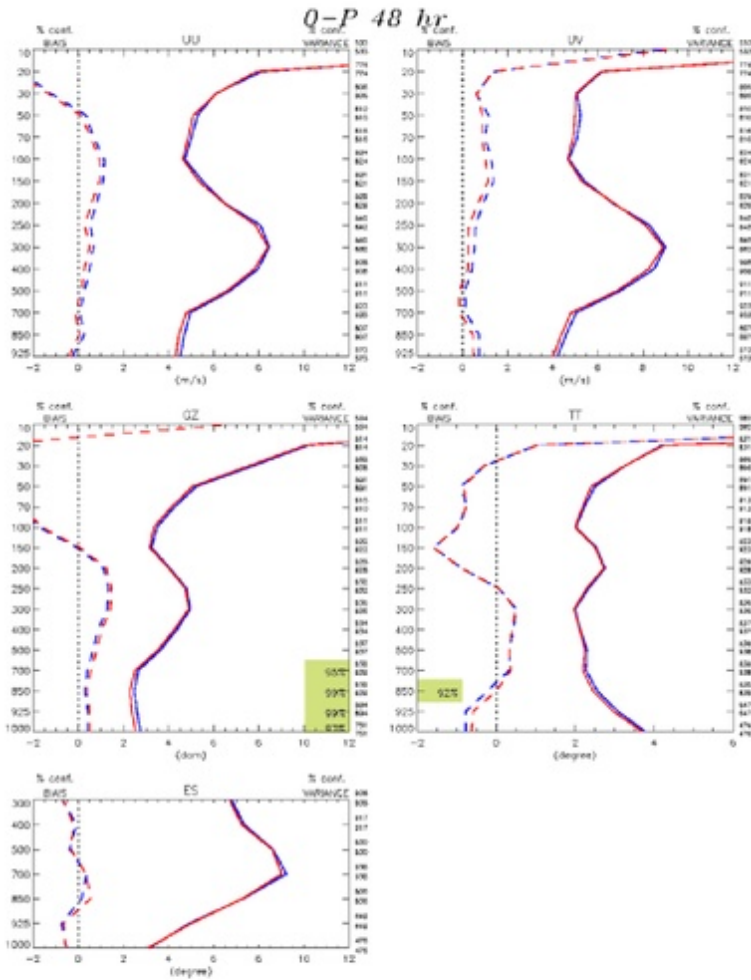
### Winter - West of North America

### Winter - East of North America

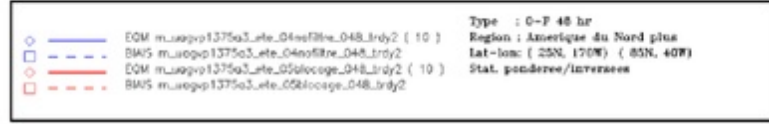
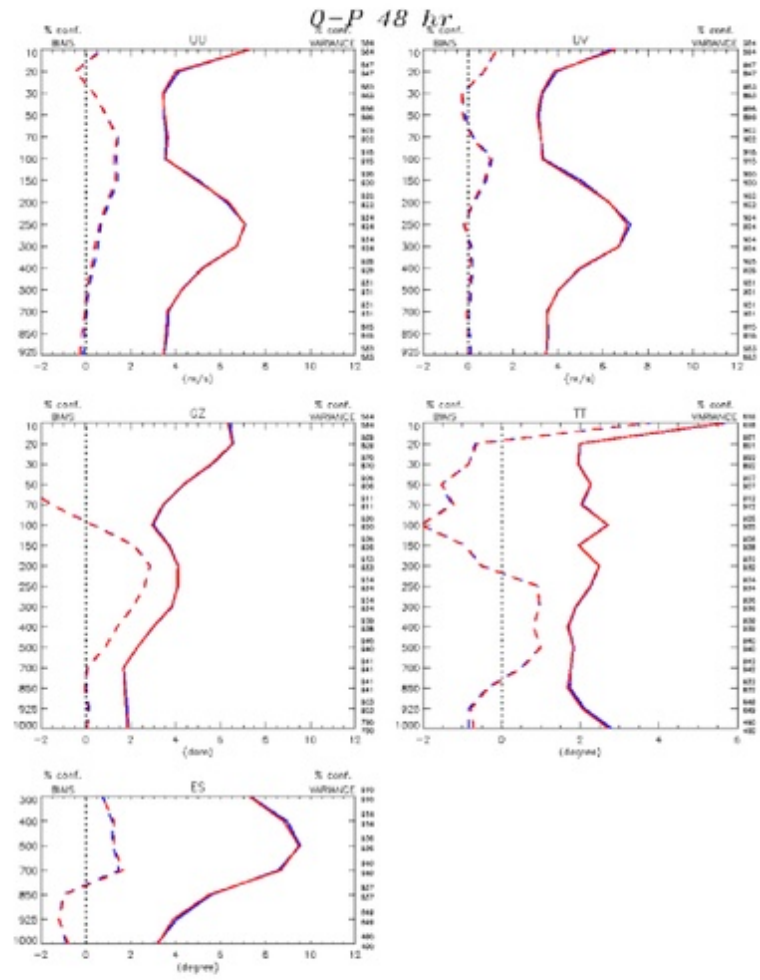




### Winter - North America



### Summer - North America



## FAQ:

**Q:** At which resolution the SGO parametrization becomes unnecessary?

**A:** No consensus ... but it might be at quite small scales.

Ex: Young and Pielke (1983):

- > studied terrain height variance at 3 different areas in the Rockies, near Denver
- > concluded that **0.1 km** is the maximum horizontal grid spacing to neglect subgrid-scale parametrization in those regions

## SUMMARY

- > At the present resolution, it seems that our NWP models still need a SGO drag parametrization
- > The parametrization based on the Lott & Miller blocking formula can improve the forecast scores of GEM, especially in the winter

## FUTURE WORK

- > Parametrize and test other SGO effects (orographic lift, lee-wave breaking)
- > Include new SGO drag in the simplified physics (TLM, adjoint, sensitivity studies, 4DVAR)

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