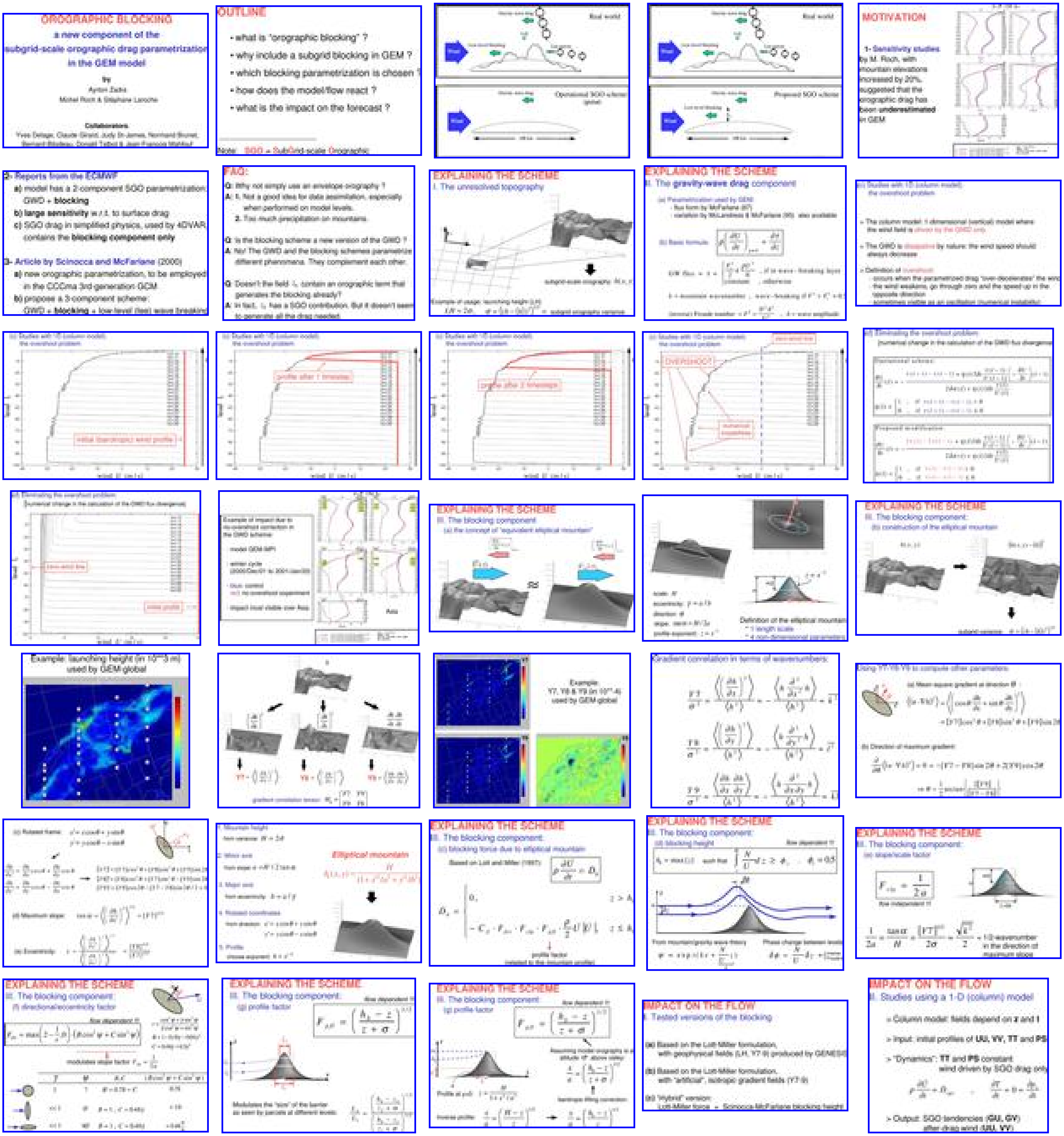
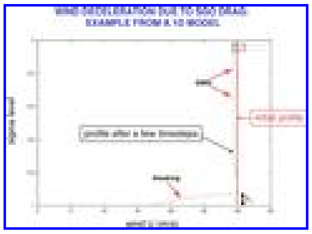
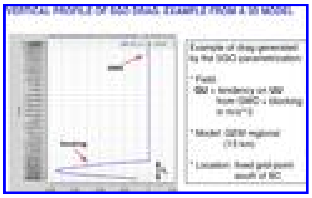
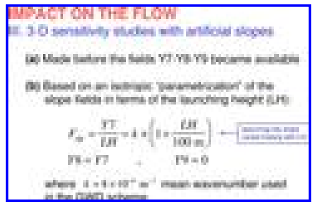
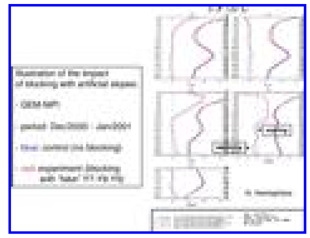
presentation Ayrton Zadra

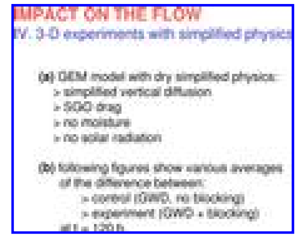


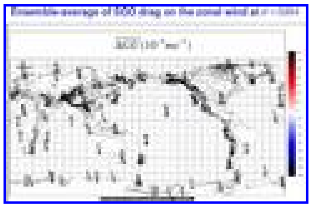

WIND DECELERATION DUE TO SGO DRAG:
EXAMPLE FROM A 1D MODEL
profile after a few timesteps
blocking

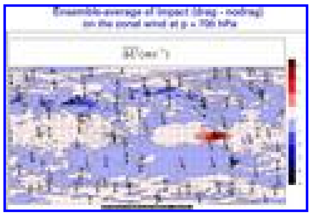

VERTICAL PROFILE OF SGO DRAG: EXAMPLE FROM A 3D MODEL
Example of drag generated by the SGO parametrization

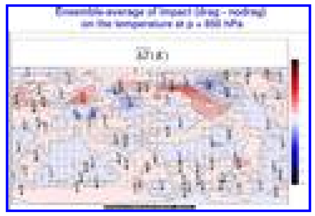

IMPACT ON THE FLOW
III. 3-D sensitivity studies with artificial slopes
(a) Made before the fields Y7-Y8-Y9 became available
(b) Based on an isotropic "parametrization" of the slope fields in terms of the launching height (LH):
Y8 = Y7
Y9 = 0

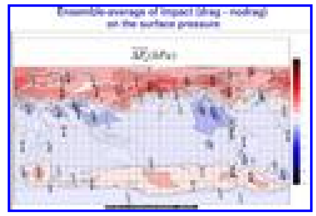

N. Hemisphere

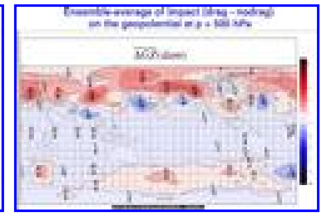

IMPACT ON THE FLOW
IV. 3-D experiments with simplified physics
(a) GEM model with dry simplified physics:
> simplified vertical diffusion
> SGO drag
> no moisture
> no solar radiation
(b) following figures show various averages of the difference between:
> control (GWD, no blocking)
> experiment (GWD + blocking)


Ensemble-average of SGO drag on the zonal wind

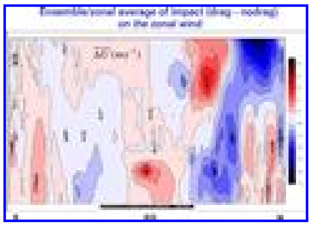

Ensemble-average of impact (drag - nodrag)
on the zonal wind at p = 700 hPa

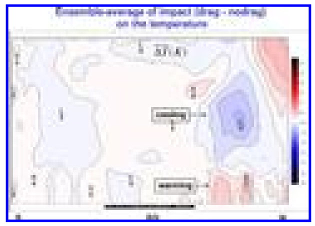

Ensemble-average of impact (drag - nodrag)
on the temperature at p = 850 hPa

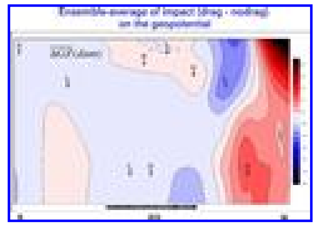

Ensemble-average of impact (drag - nodrag)
on the surface pressure


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

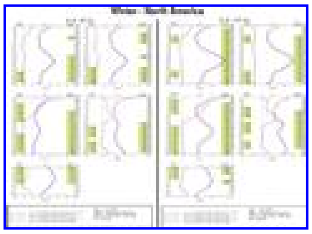

Ensemble/zonal average of SGO drag on the zonal wind

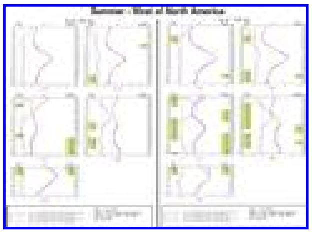

Ensemble/zonal average of impact (drag - nodrag)
on the zonal wind

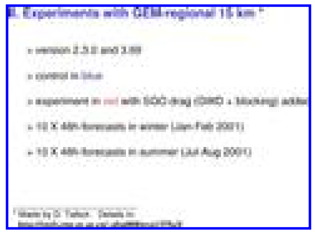

Ensemble-average of impact (drag - nodrag)
on the temperature
cooling
warming

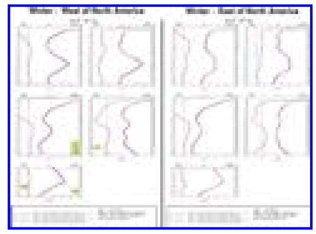

Ensemble-average of impact (drag - nodrag)
on the geopotential


IMPACT ON THE FORECAST
I. Experiments with GEM-global 400X200

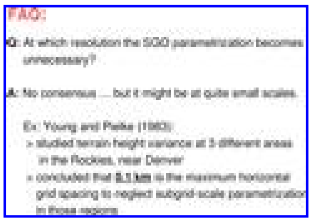

Winter - North America

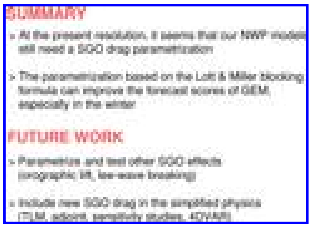

Summer - West of North America


II. Experiments with GEM-regional 15 km


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.


SUMMARY
FUTURE WORK


the end

OROGRAPHIC BLOCKING

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

by

Ayrton Zadra

Michel Roch & Stéphane Laroche

Collaborators:

Yves Delage, Claude Girard, Judy St-James, Normand Brunet, Bernard Bilodeau, Donald Talbot & Jean-François Mahfouf

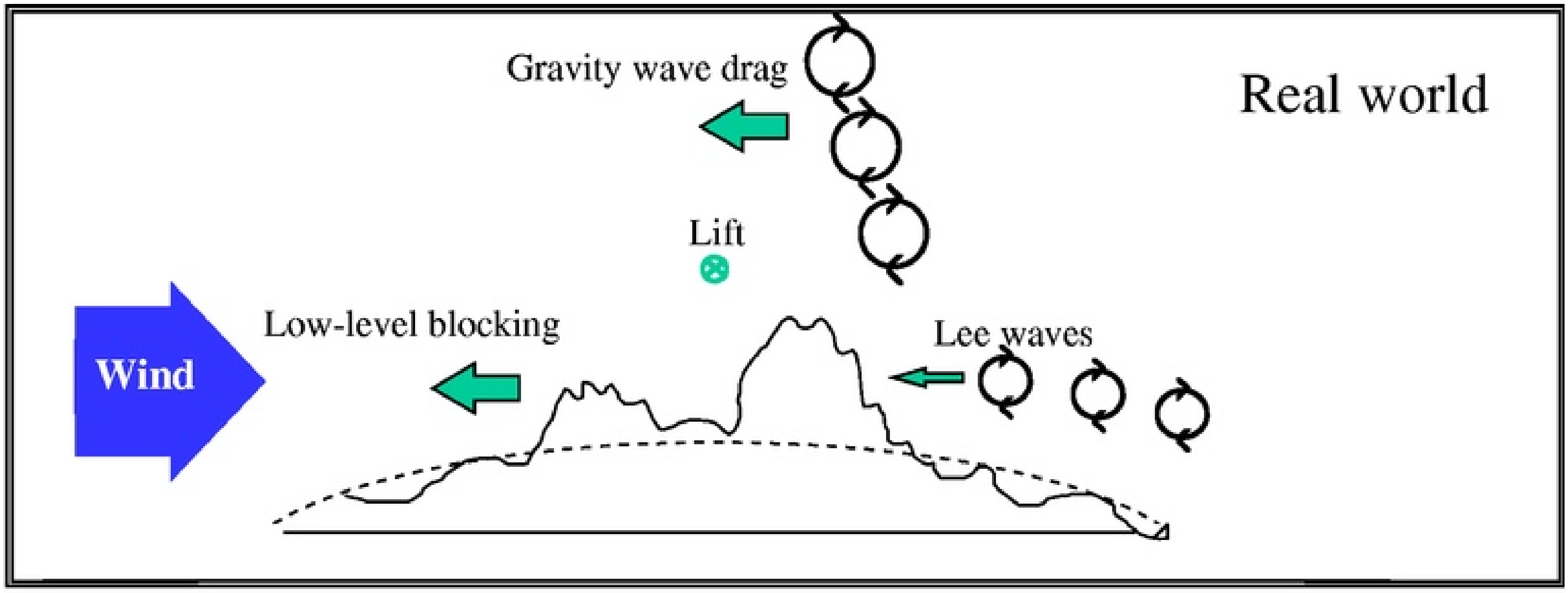
<< Prev | Index | Next >>

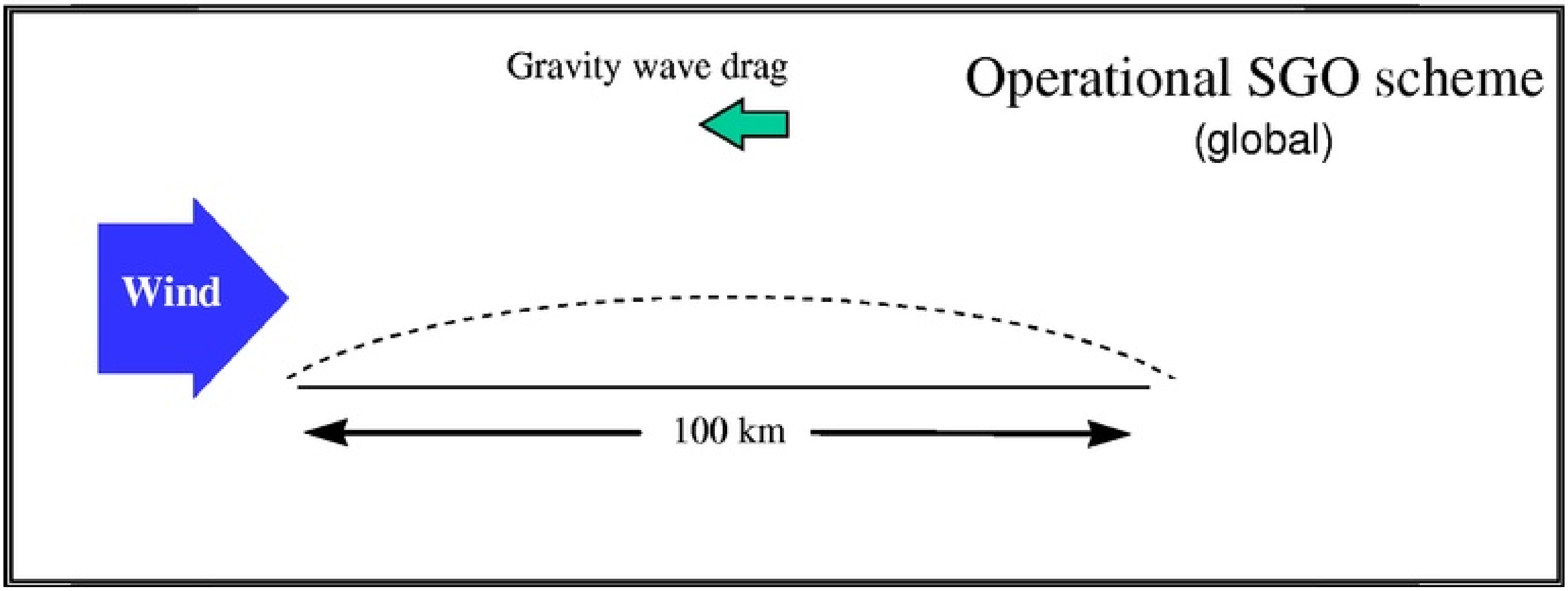
OUTLINE

- 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 ?

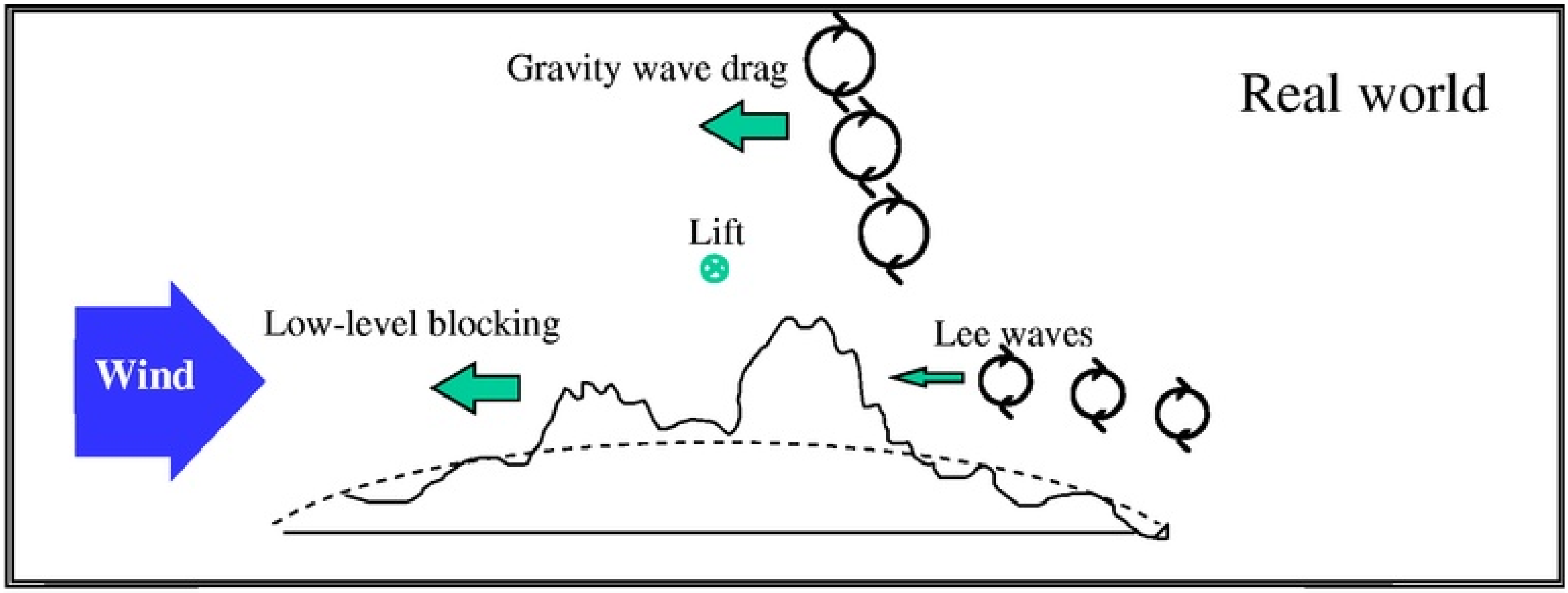
Note: **SGO** = **S**ub**G**rid-scale **O**rographic

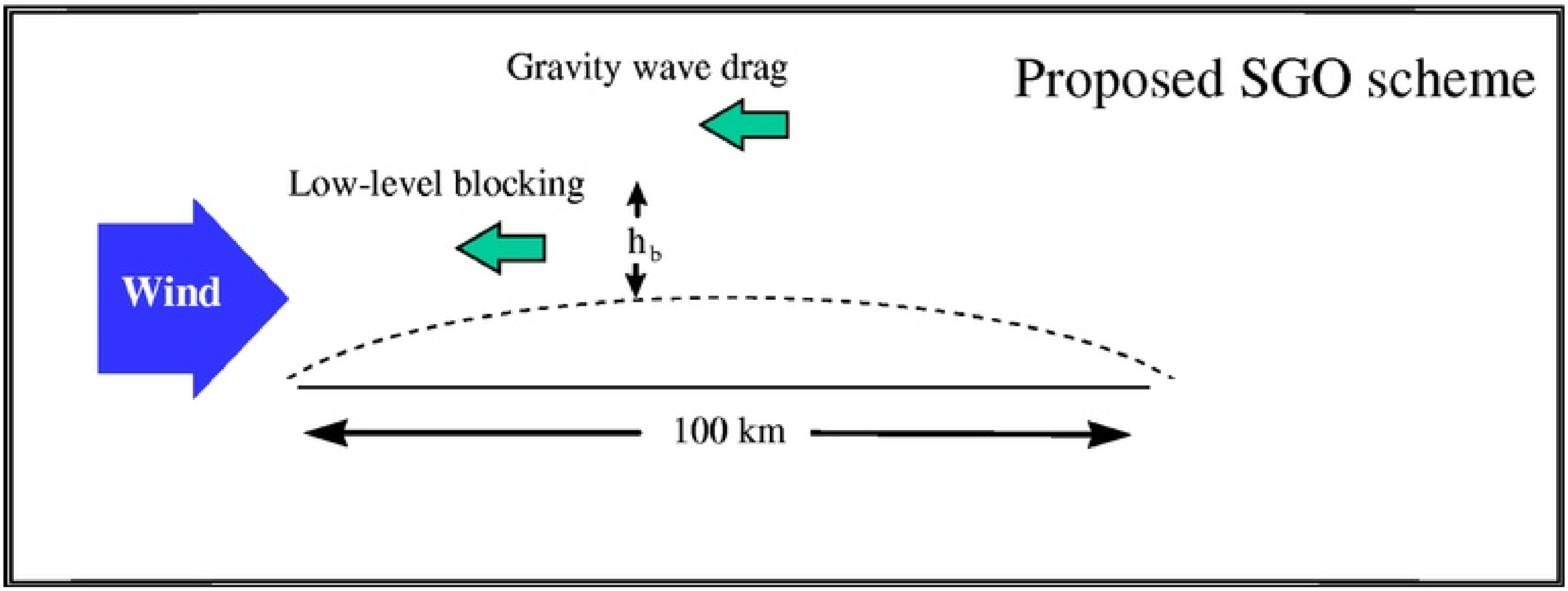
<< Prev | Index | Next >>





<< Prev | Index | Next >>


Gravity wave drag
Real world
Lift
Low-level blocking
Wind
Lee waves

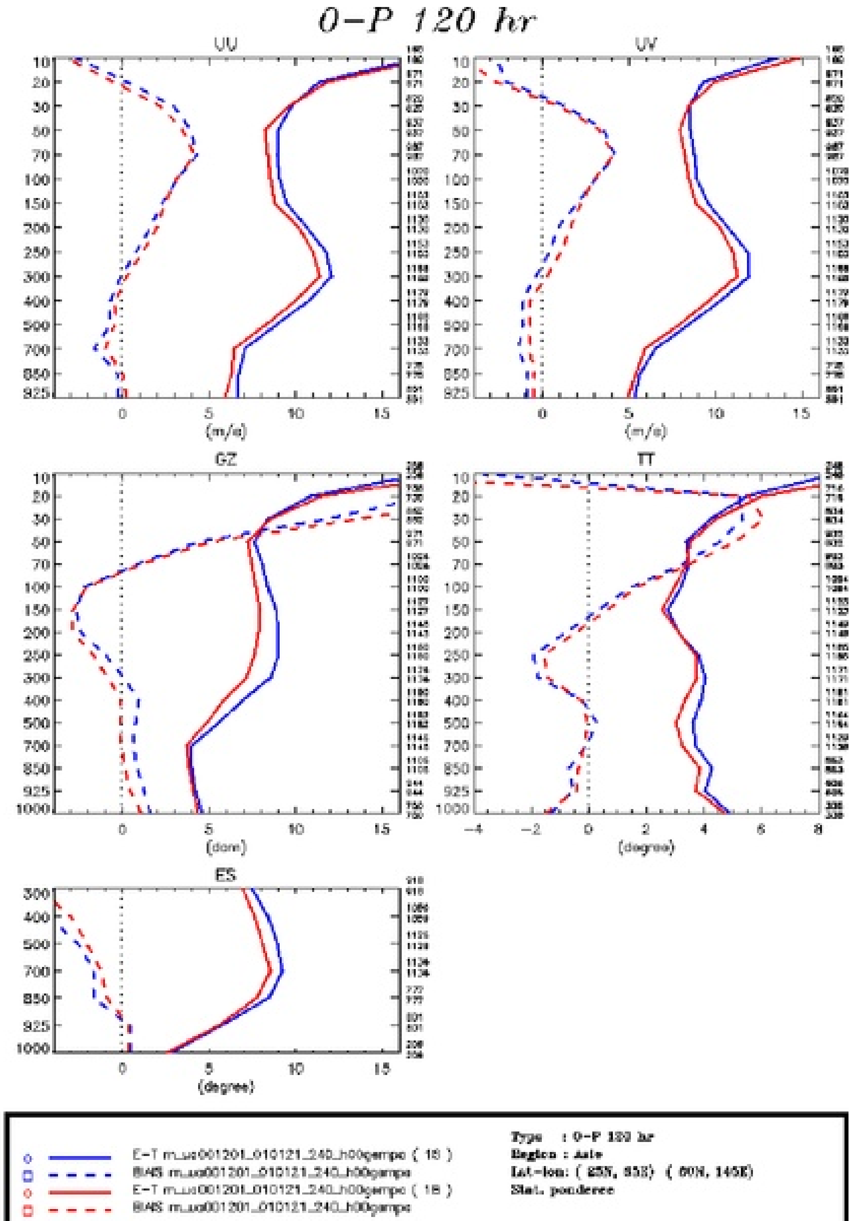

Gravity wave drag
Proposed SGO scheme
Low-level blocking
h b
Wind
100 km

<< Prev | Index | Next >>

MOTIVATION

1- Sensitivity studies

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



<< Prev | Index | Next >>

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.

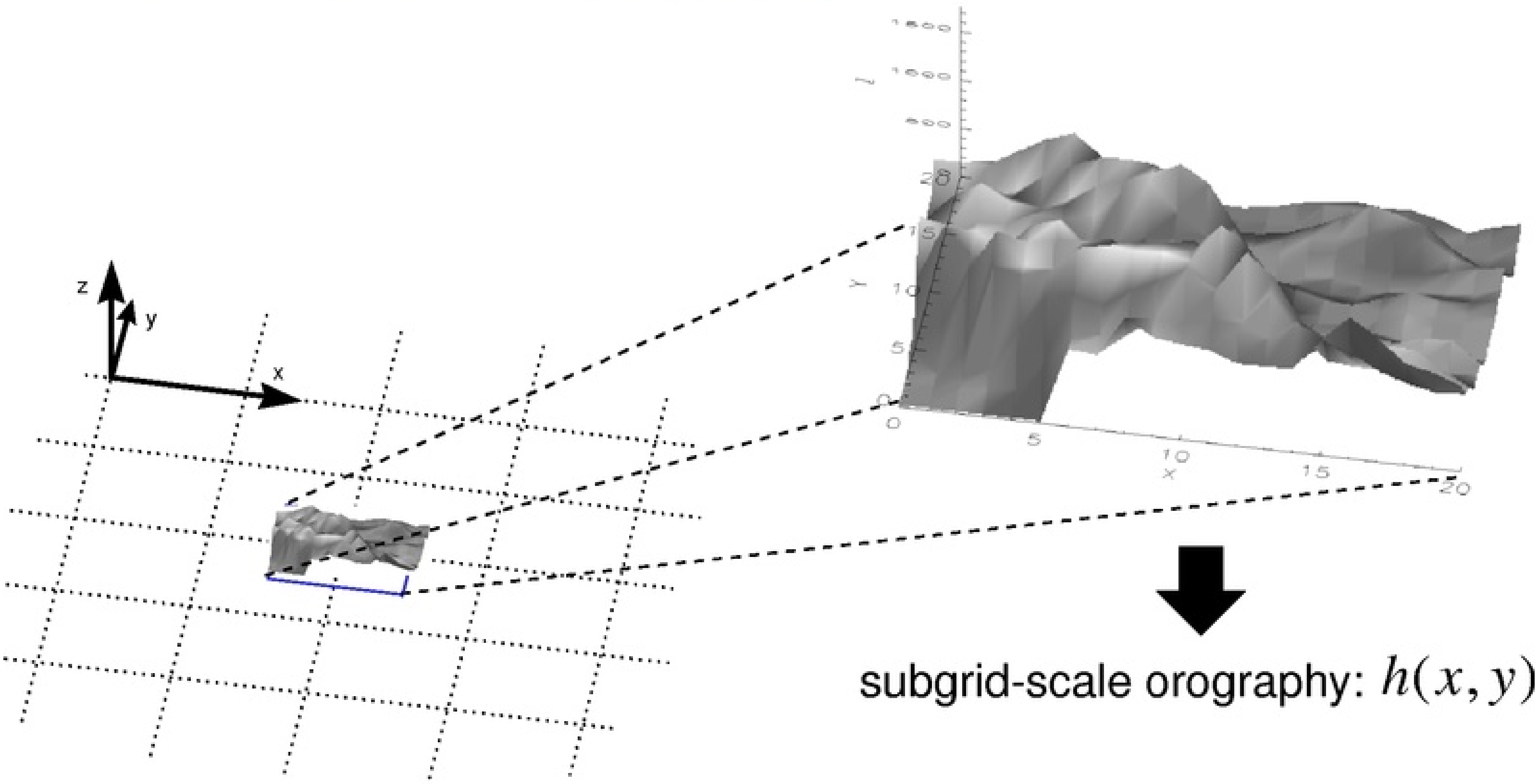
Q: Doesn't the field z_0 contain an orographic term that generates the blocking already?

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

<< Prev | Index | Next >>

EXPLAINING THE SCHEME

I. The unresolved topography



Example of usage: launching height (LH)

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

<< Prev | Index | Next >>

<< Prev | Index | Next >>

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

<< Prev | Index | Next >>

<< Prev | Index | Next >>

(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

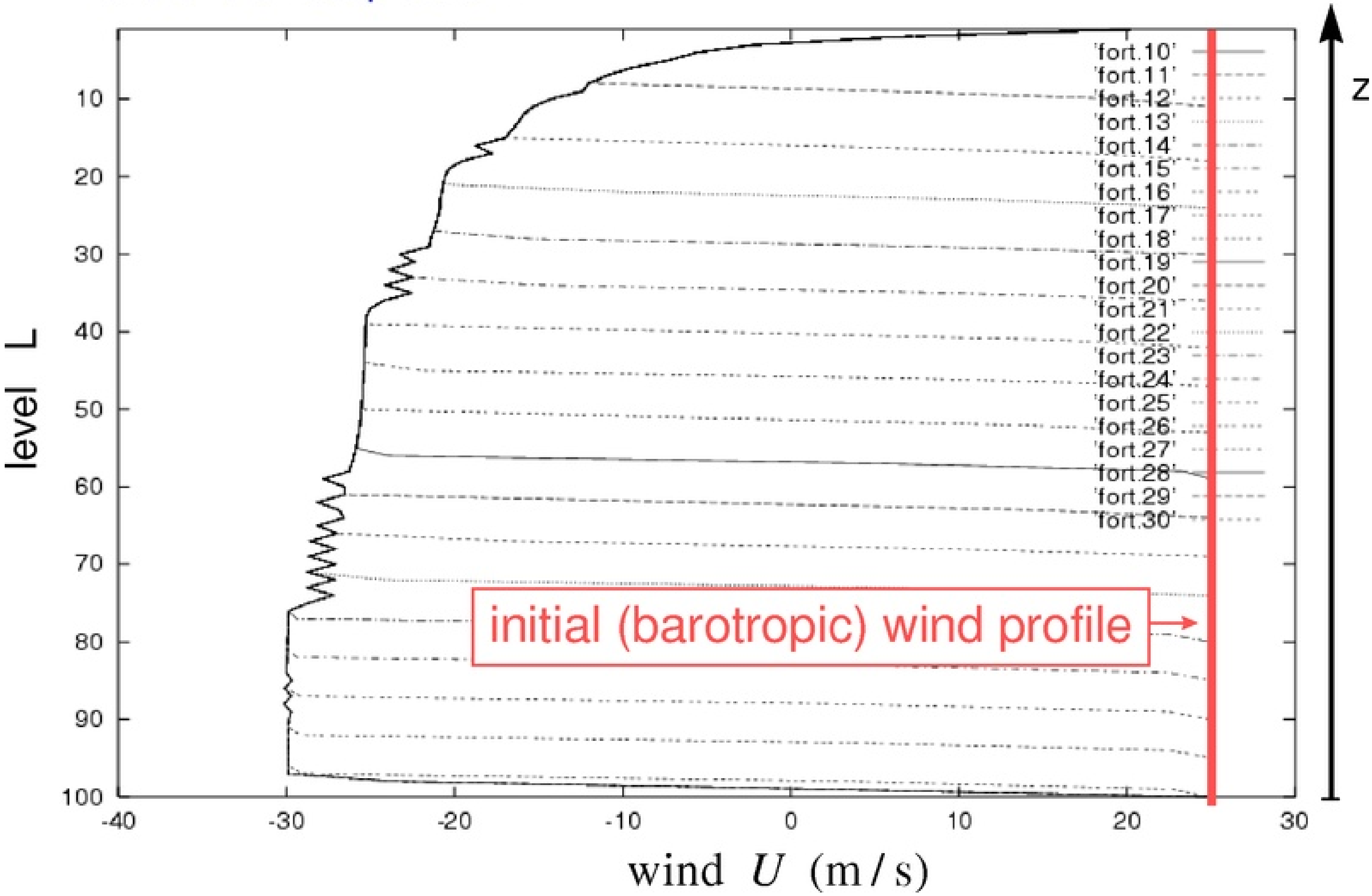
> The GWD is dissipative by nature: the wind speed should always decrease

> 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)

<< Prev | Index | Next >>

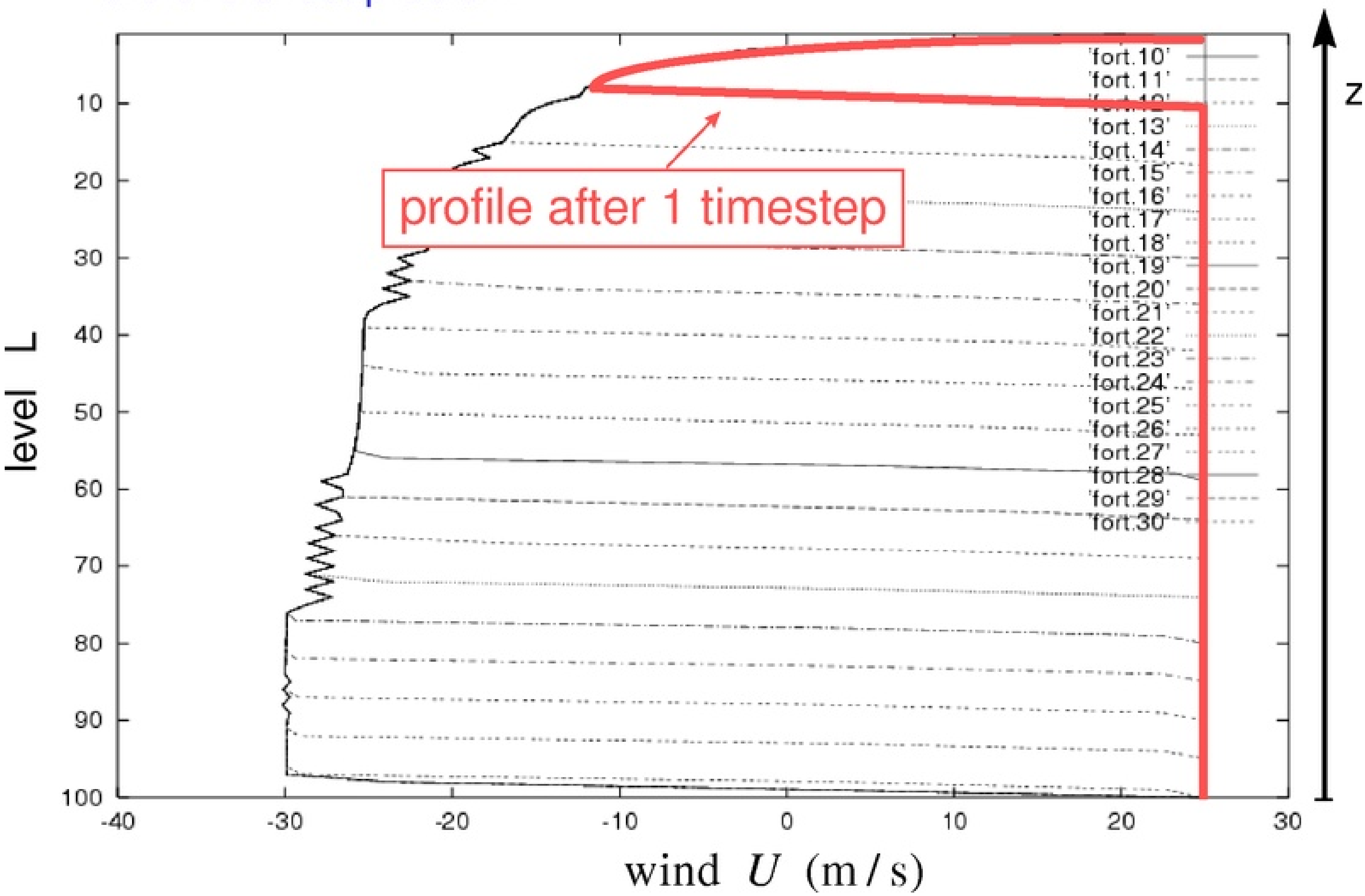
<< Prev | Index | Next >>

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

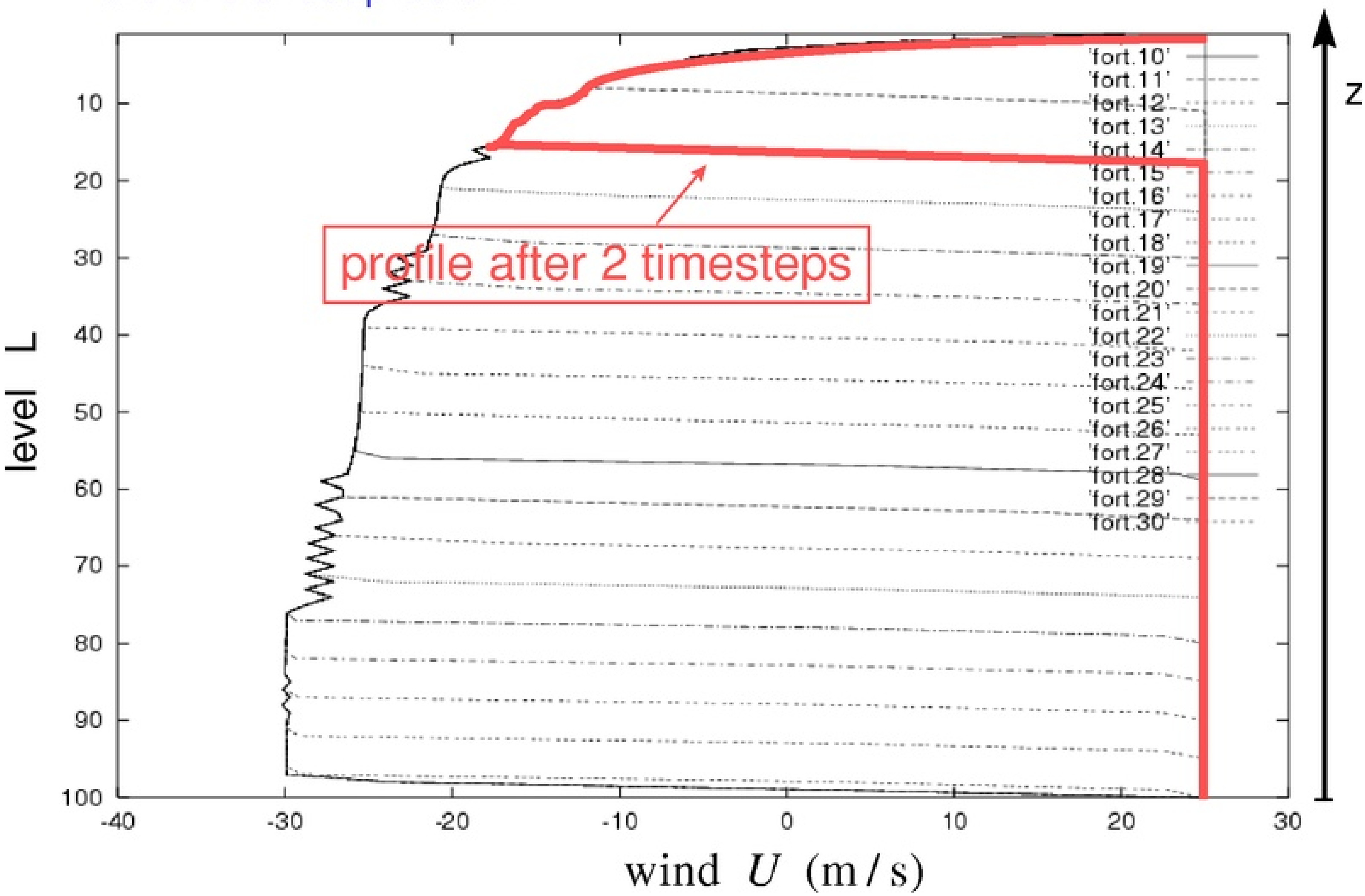


<< Prev | Index | Next >>

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



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



<< Prev | Index | Next >>

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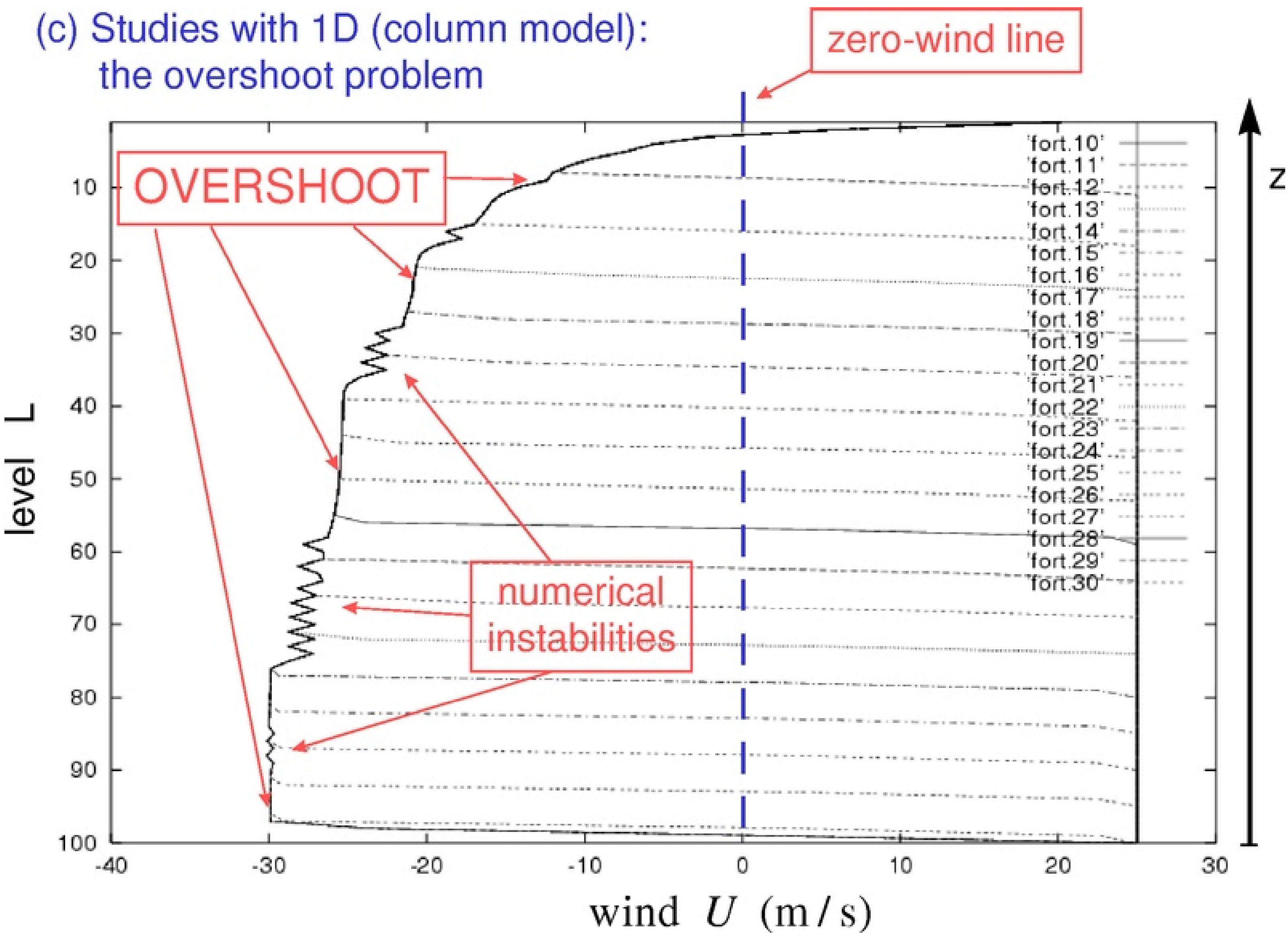


[<< Prev] | [Index] | [Next >>]

(d) Eliminating the overshoot problem:

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

Operational scheme:

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

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

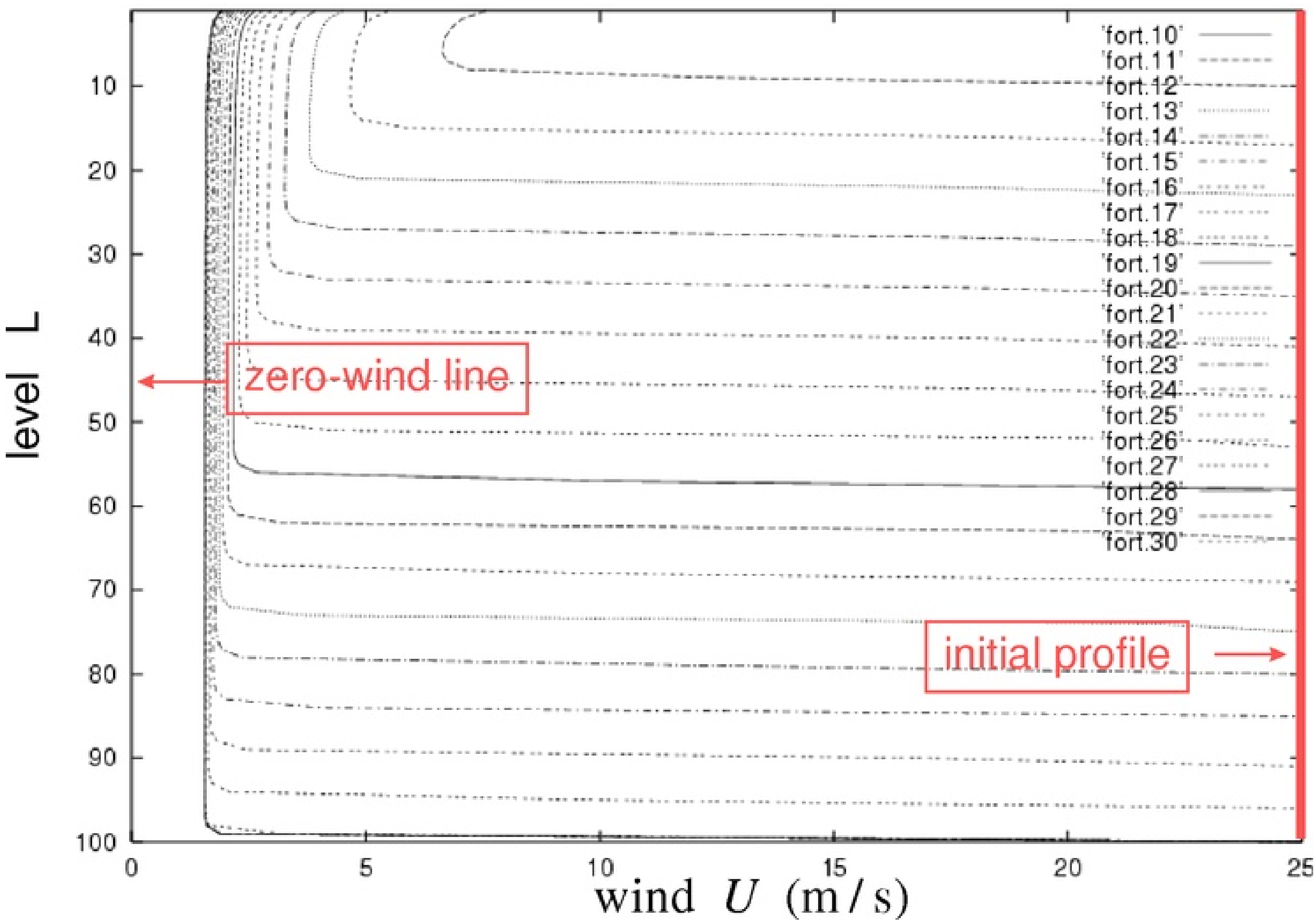
Proposed modification:

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

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

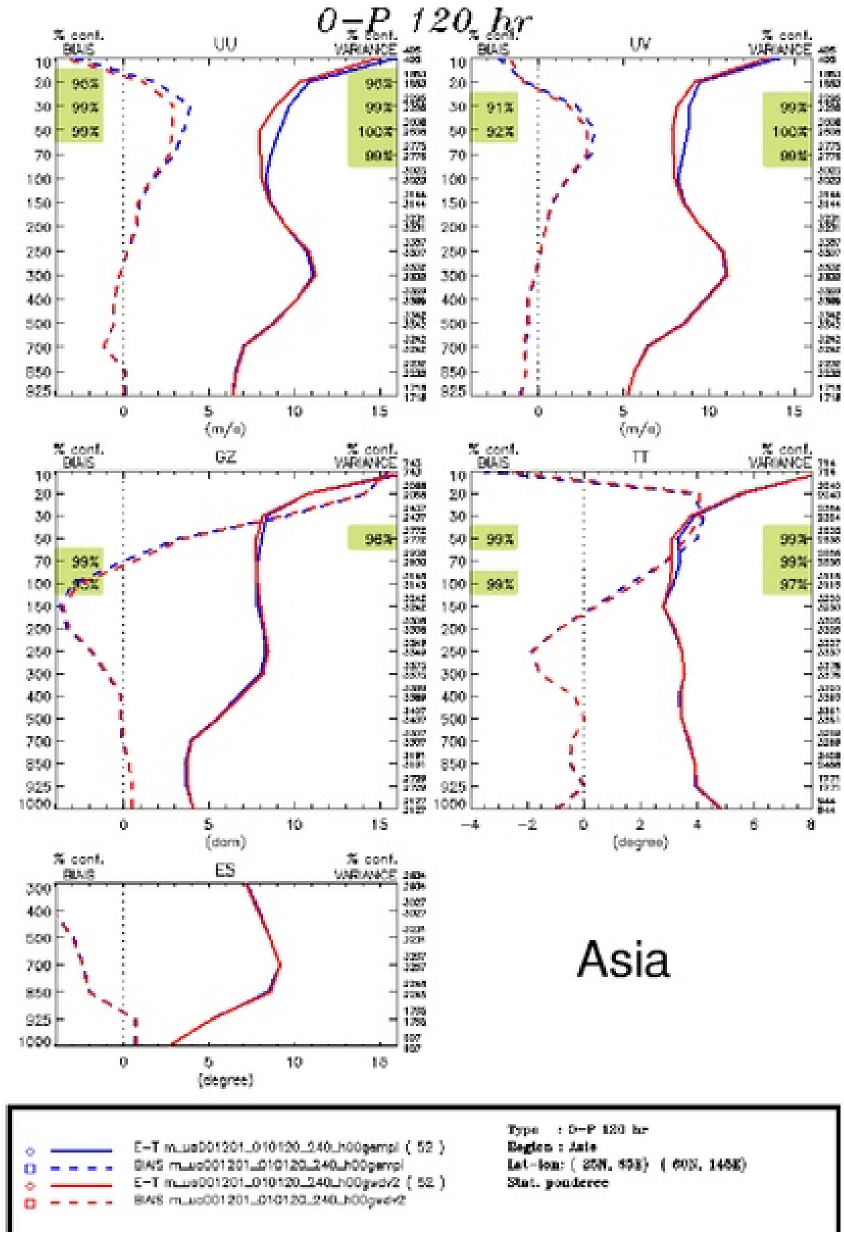
(d) Eliminating the overshoot problem:

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



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

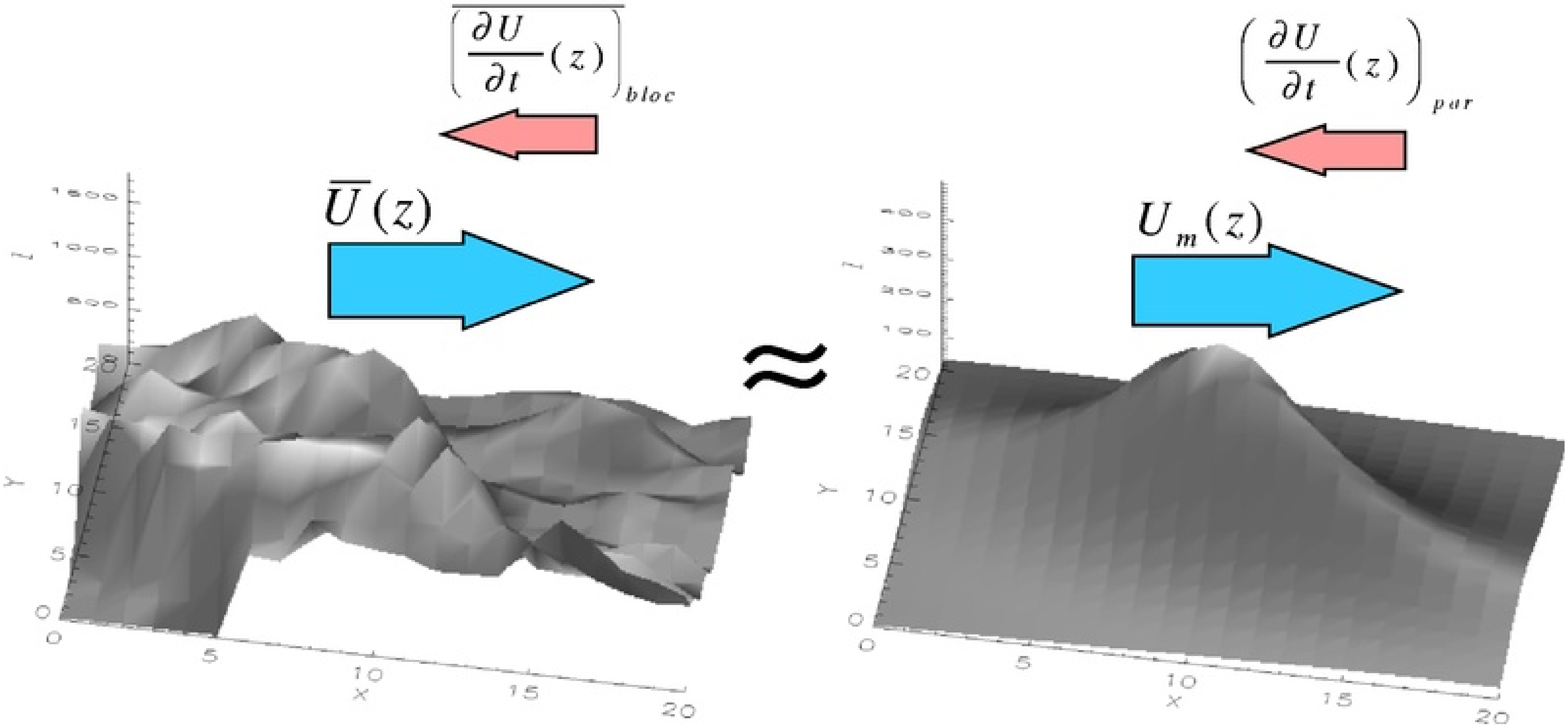
- model GEM-MPI
- winter cycle (2000/Dec/01 to 2001/Jan/20)
- blue: control
  red: no-overshoot experiment
- impact most visible over Asia

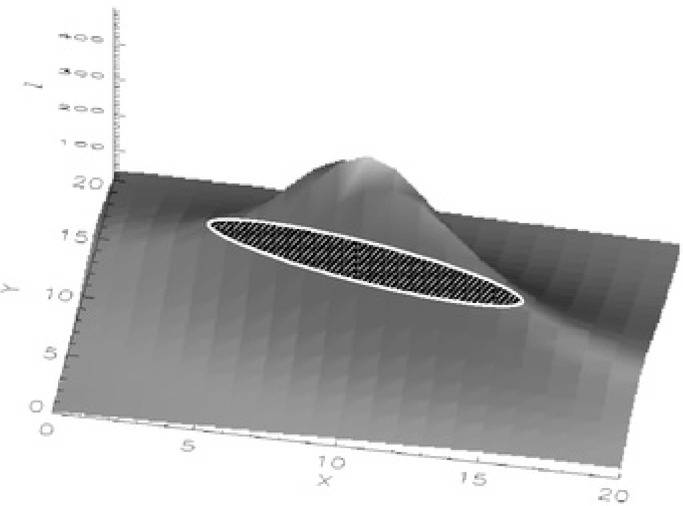


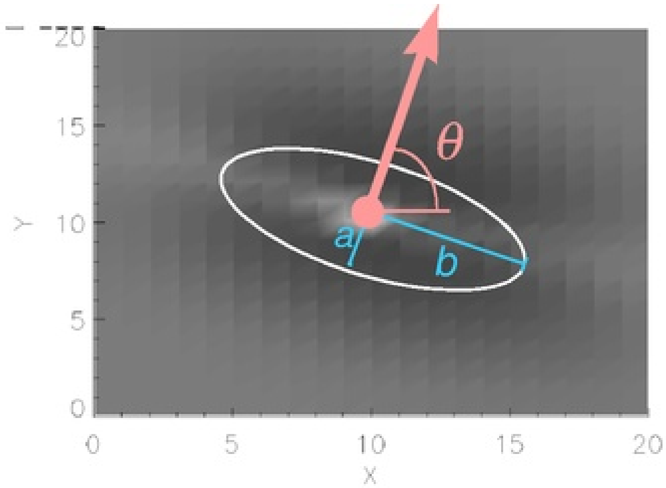
EXPLAINING THE SCHEME

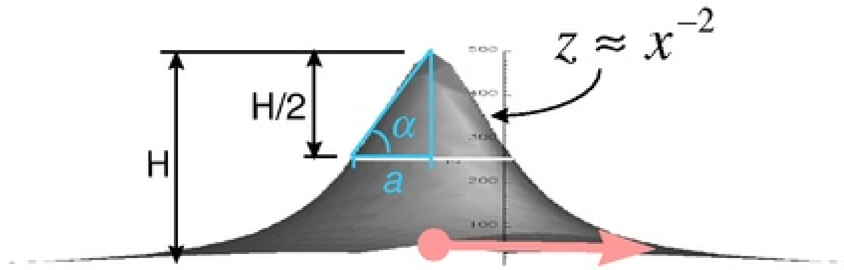
III. The blocking component

(a) the concept of "equivalent elliptical mountain"









scale: H

eccentricity: $\gamma = a / b$

direction: θ

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

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

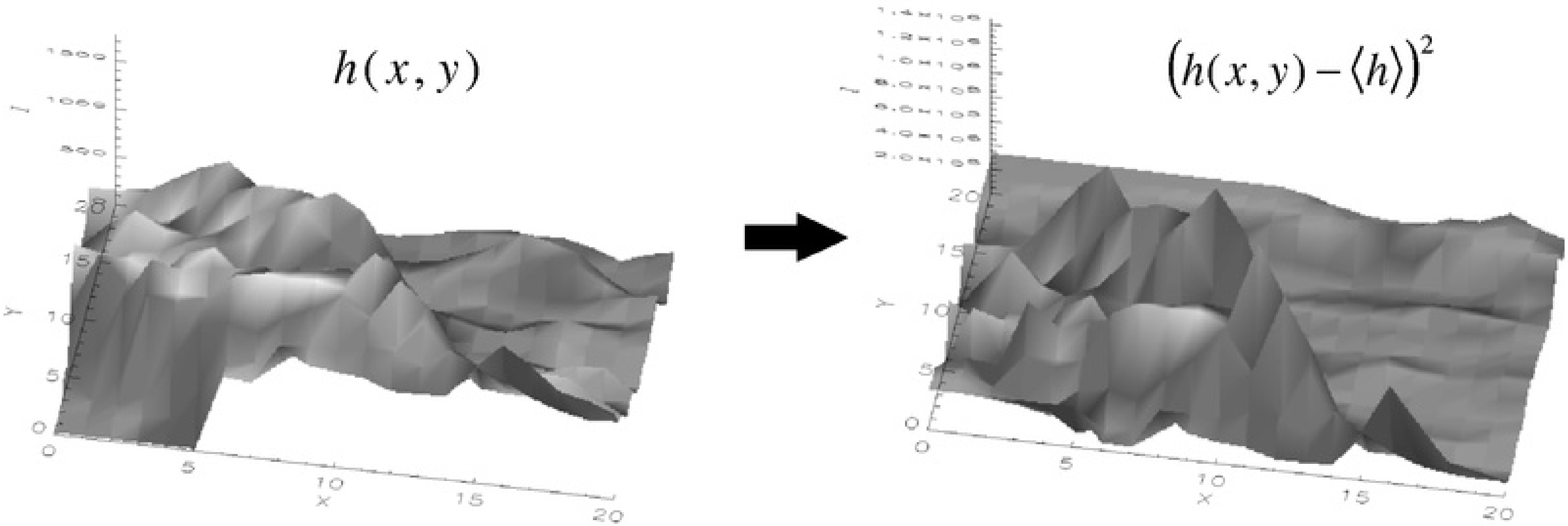
Definition of the elliptical mountain:

* 1 length scale
* 4 non-dimensional parameters

EXPLAINING THE SCHEME

III. The blocking component:

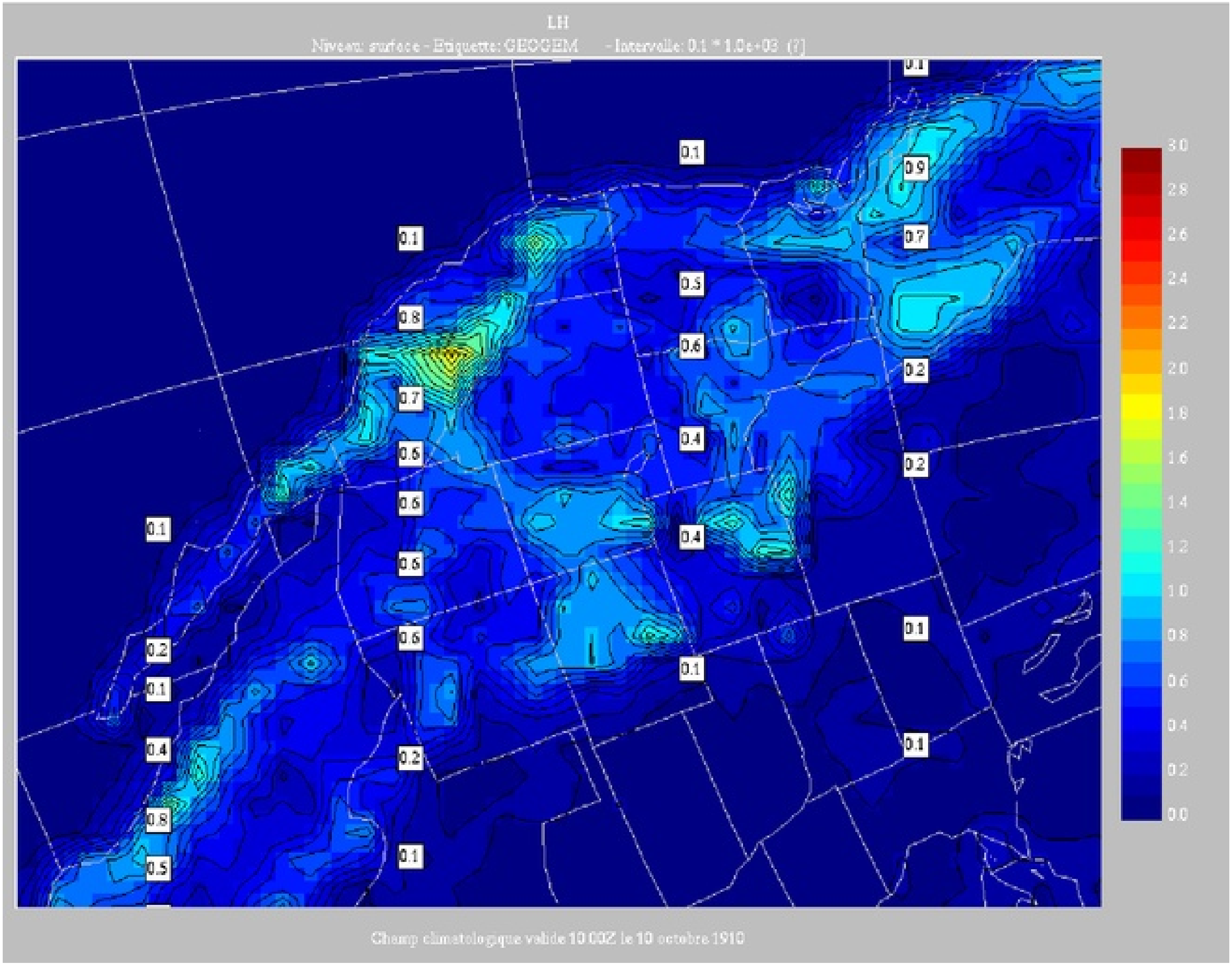
(b) construction of the elliptical mountain



subgrid variance: $\sigma = \left\langle (h-\langle h\rangle)^2 \right\rangle^{1/2}$

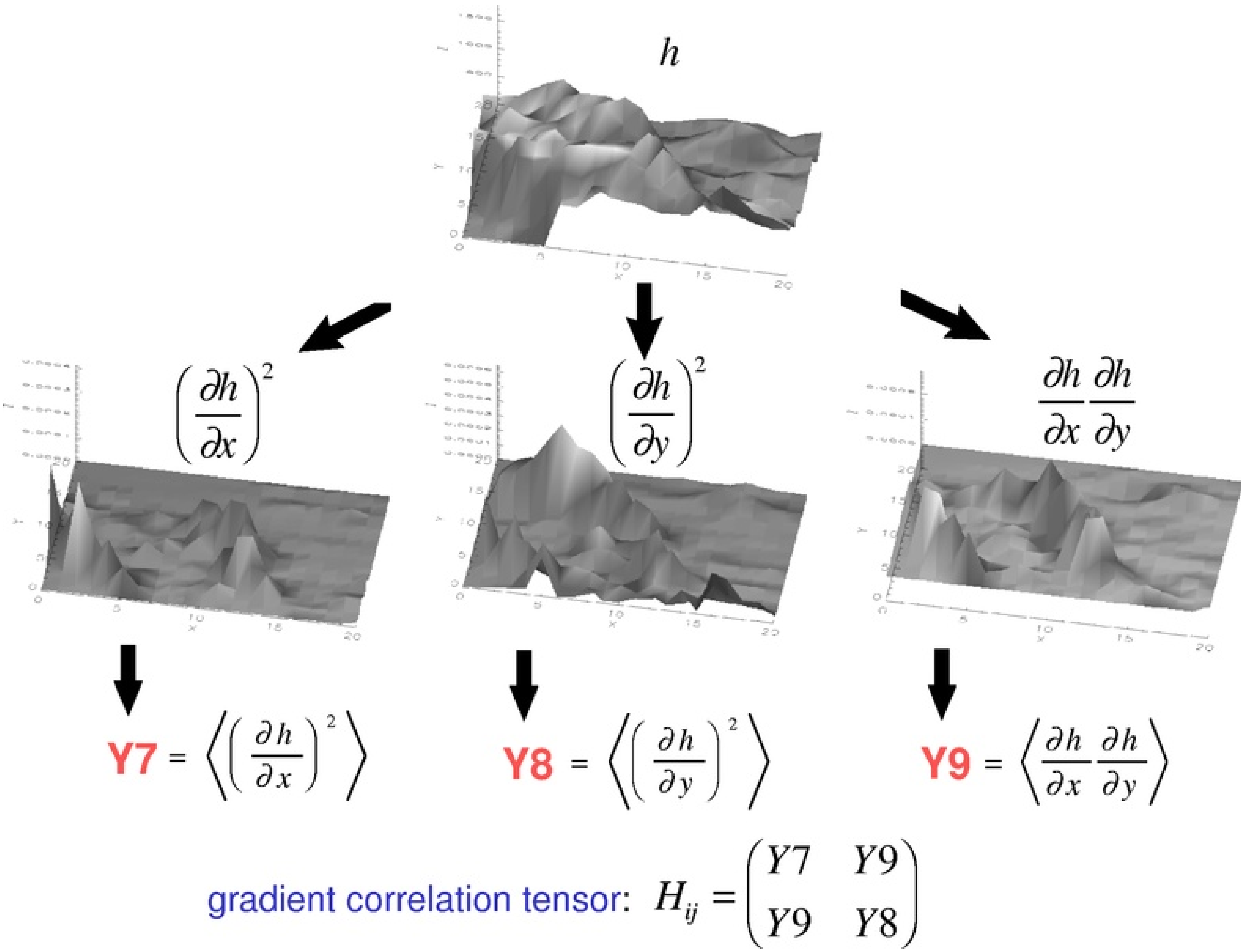
<< Prev | Index | Next >>

Example: launching height (in 10**3 m) used by GEM-global



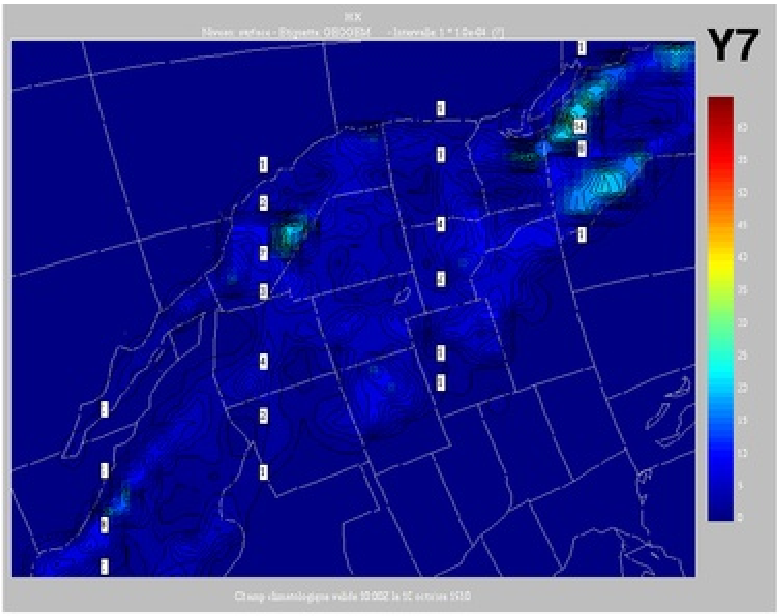
<< Prev | Index | Next >>

<< Prev | Index | Next >>

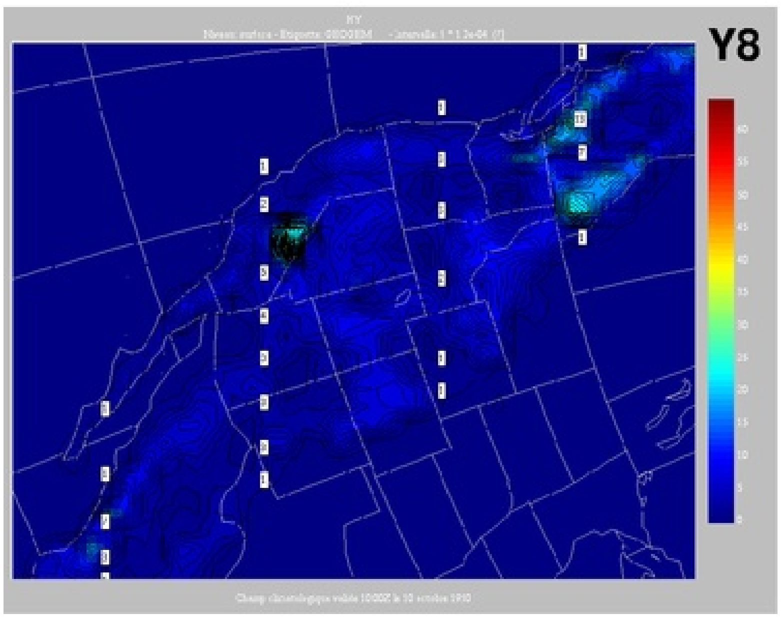


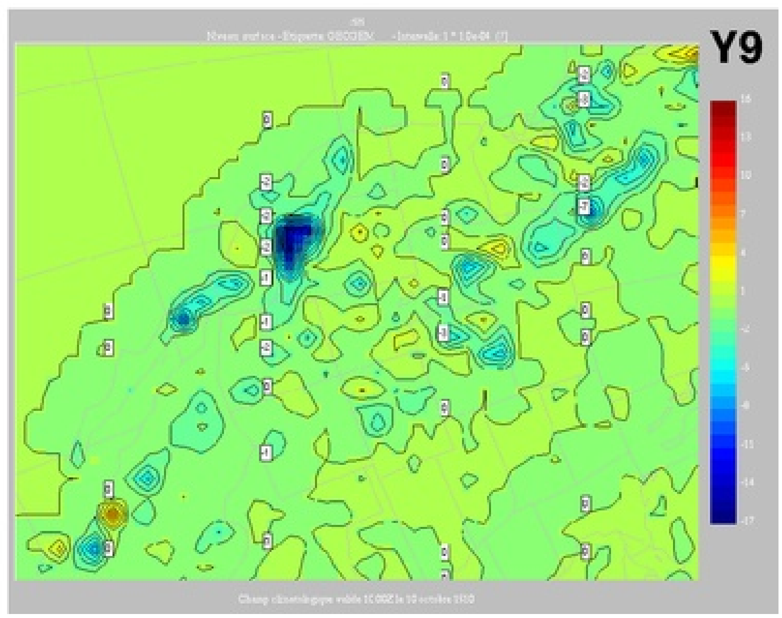
<< Prev | Index | Next >>

<< Prev | Index | Next >>



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





<< Prev | Index | Next >>

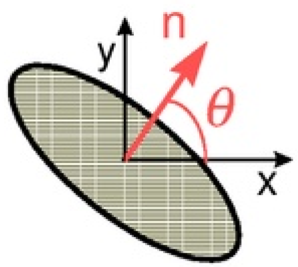
Gradient correlation in terms of wavenumbers:

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

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

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

Using Y7-Y8-Y9 to compute other parameters:



(a) Mean-square gradient at direction θ :

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

$$= [Y7]\cos^2\theta + [Y8]\sin^2\theta + [Y9]\sin 2\theta$$

(b) Direction of maximum gradient:

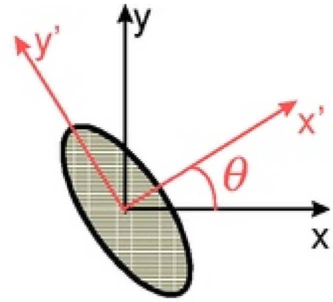
$$\frac{\partial}{\partial \theta}\left\langle (n \cdot \nabla h)^2 \right\rangle = 0 = -[Y7 - Y8]\sin 2\theta + 2[Y9]\cos 2\theta$$

$$\Rightarrow \theta = \frac{1}{2}\arctan\left\{ \frac{2[Y9]}{[Y7 - Y8]} \right\}$$

<< Prev | Index | Next >>

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

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



$$\frac{\partial h}{\partial x'} = \frac{\partial h}{\partial x}\cos\theta + \frac{\partial h}{\partial y}\sin\theta$$

$$\frac{\partial h}{\partial y'} = \frac{\partial h}{\partial y}\cos\theta - \frac{\partial h}{\partial x}\sin\theta$$

$\Longrightarrow$

$$[Y7]' = [Y7]\cos^2\theta + [Y8]\sin^2\theta + [Y9]\sin 2\theta$$

$$[Y8]' = [Y8]\cos^2\theta + [Y7]\sin^2\theta - [Y9]\sin 2\theta$$

$$[Y9]' = [Y9]\cos 2\theta - [Y7 - Y8]\sin 2\theta / 2 = 0$$

(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: $x' = x\cos\theta + y\sin\theta$

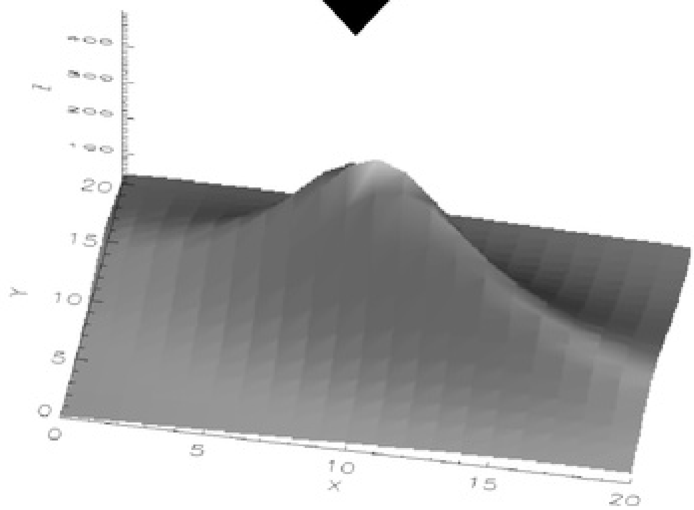
$y' = y\cos\theta - x\sin\theta$

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):

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

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

profile factor
(related to the mountain profile)

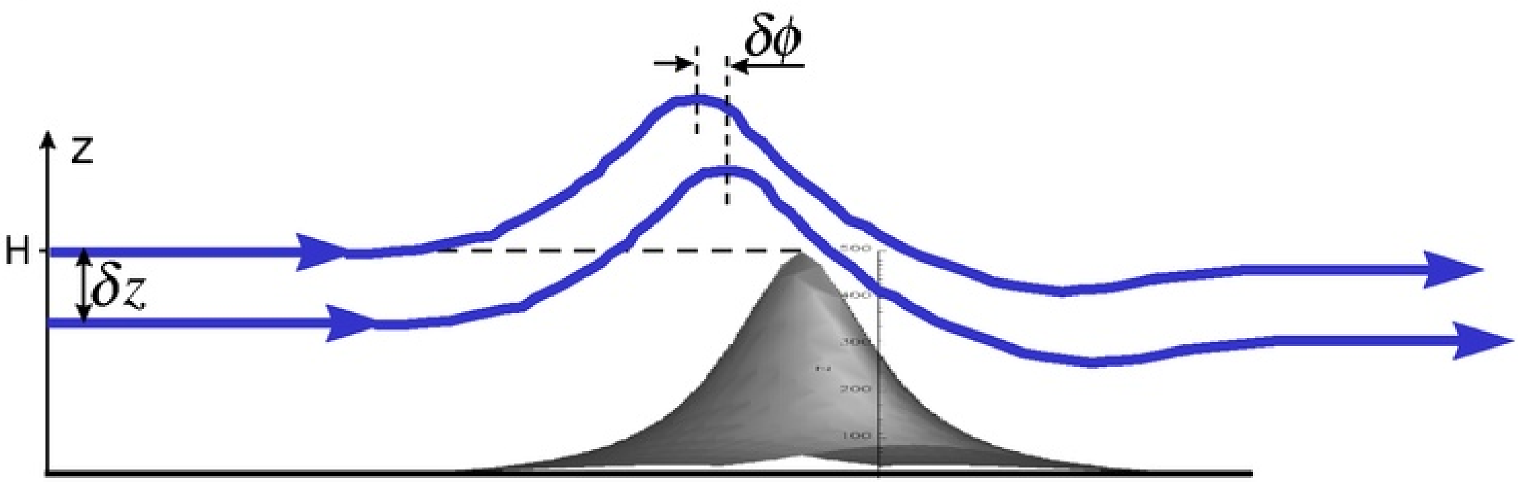
EXPLAINING THE SCHEME

III. The blocking component:

(d) blocking height

flow dependent !!!

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



From mountain/gravity-wave theory

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

Phase change between levels

$$\delta\phi = \frac{N}{U} \delta z$$

← inverse Froude #

<< Prev | Index | Next >>

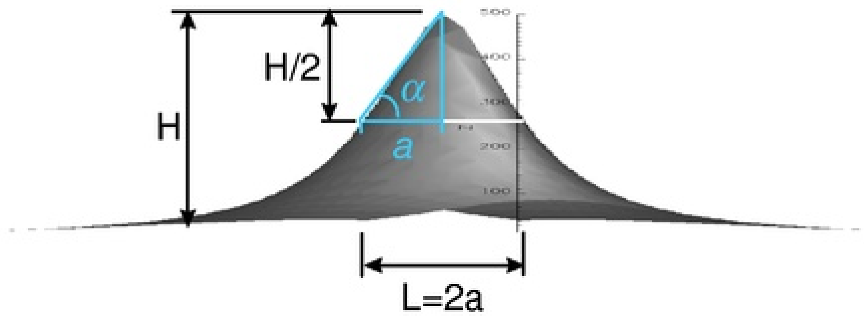
EXPLAINING THE SCHEME

III. The blocking component:

(e) slope/scale factor

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

flow independent !!!



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

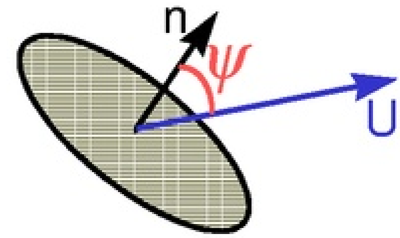
<< Prev | Index | Next >>

<< Prev | Index | Next >>

EXPLAINING THE SCHEME

III. The blocking component:

(f) directional/eccentricity factor



flow dependent !!!

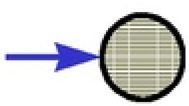
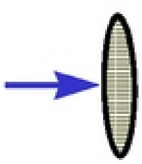
$$F_{dir} = \max\left(2 - \frac{1}{r}, 0\right) \cdot \left(B\cos^2\psi + C\sin^2\psi\right)$$

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

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

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

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

	γ	ψ	B, C	$(B\cos^2\psi + C\sin^2\psi)$
	1	?	$B = 0.78 = C$	0.78
	$<< 1$	0^o	$B \approx 1\ ,\ C \approx 0.48\gamma$	≈ 1.0
	$<< 1$	90^o	$B \approx 1\ ,\ C \approx 0.48\gamma$	$\approx 0.48\dfrac{a}{b}$

<< Prev | Index | Next >>

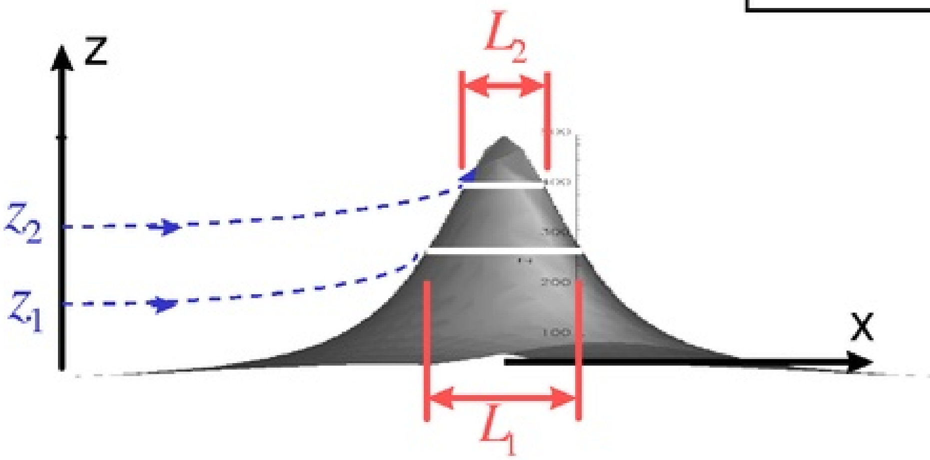
EXPLAINING THE SCHEME

III. The blocking component:

(g) profile factor

flow dependent !!!

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



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

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

<< Prev | Index | Next >>

<< Prev | Index | Next >>

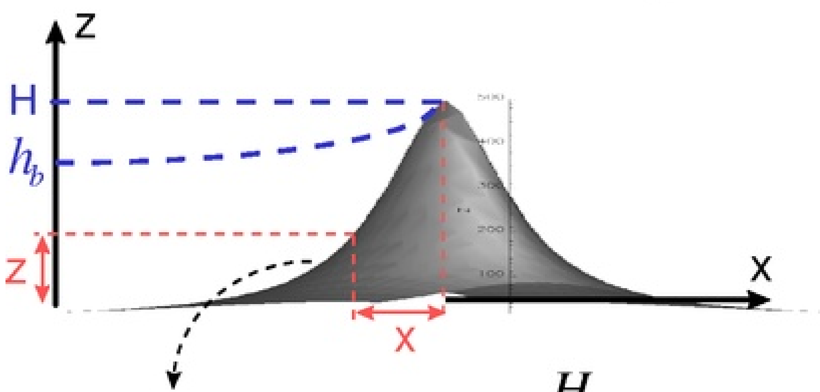
EXPLAINING THE SCHEME

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: $z = \dfrac{H}{1 + x^2 / a^2}$

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

Isentrope-lifting correction:

Assuming model orography is at altitude σ above valley:

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

<< Prev | Index | Next >>

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

<< Prev | Index | Next >>

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

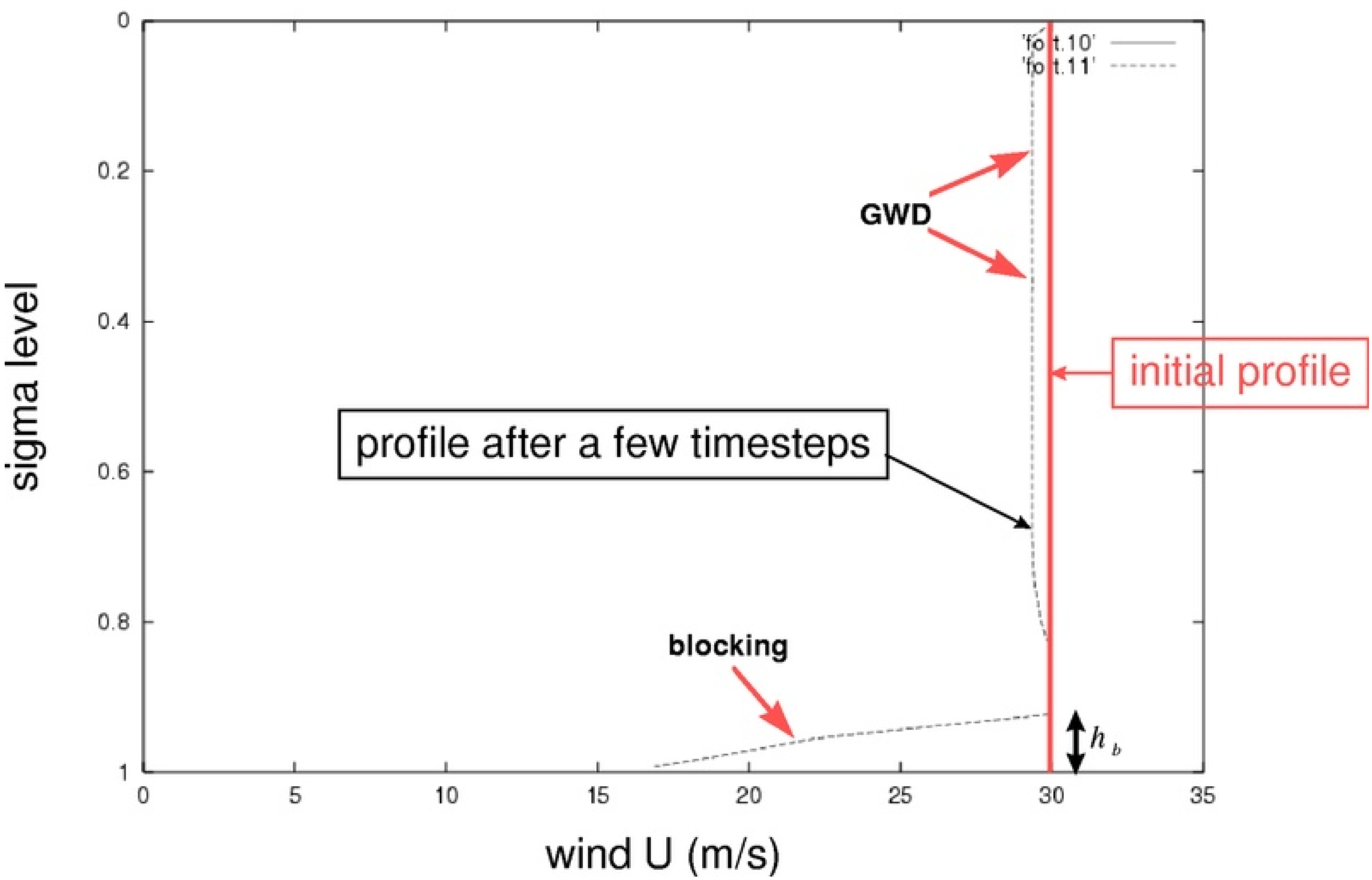
$$\rho \frac{\partial \vec{U}}{\partial t} = \vec{D}_{sgo} \quad , \quad \frac{\partial T}{\partial t} = 0 = \frac{\partial p_s}{\partial t}$$

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

<< Prev | Index | Next >>

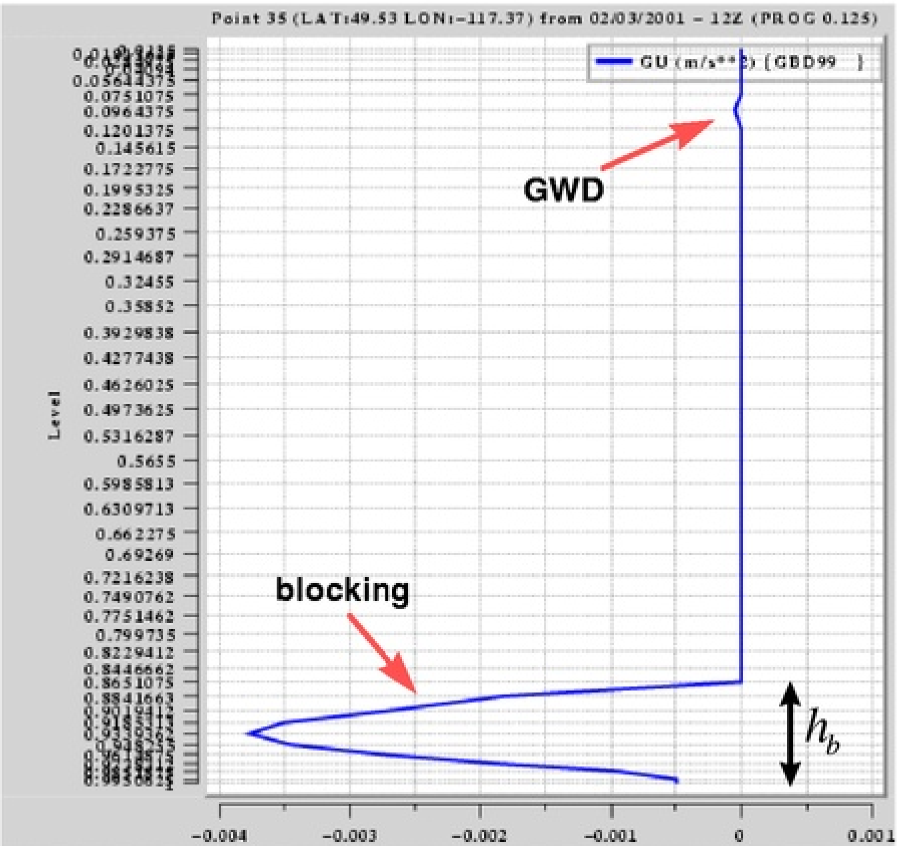
<< Prev | Index | Next >>

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



<< Prev | Index | Next >>

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 m/s**2

* Model: GEM regional (15 km)

* Location: fixed grid-point south of BC

<< Prev | Index | Next >>

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):

$$F_{slp} = \frac{Y7}{LH} = k \times \left(1 + \frac{LH}{100\ \mathrm{m}}\right)$$

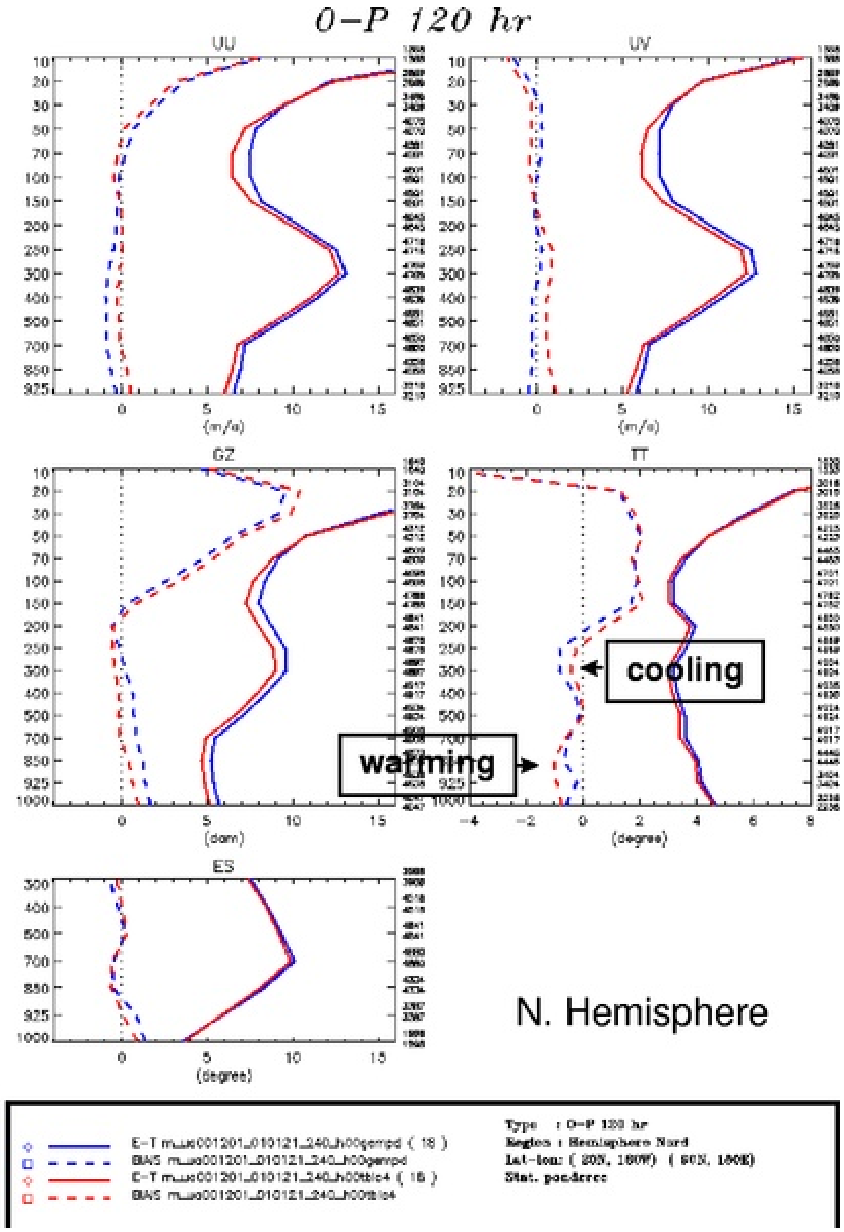
← assuming the slope varies linearly with LH

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

where $k \approx 8 \times 10^{-6}\ \mathrm{m}^{-1}$ 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)



<< Prev | Index | Next >>

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:

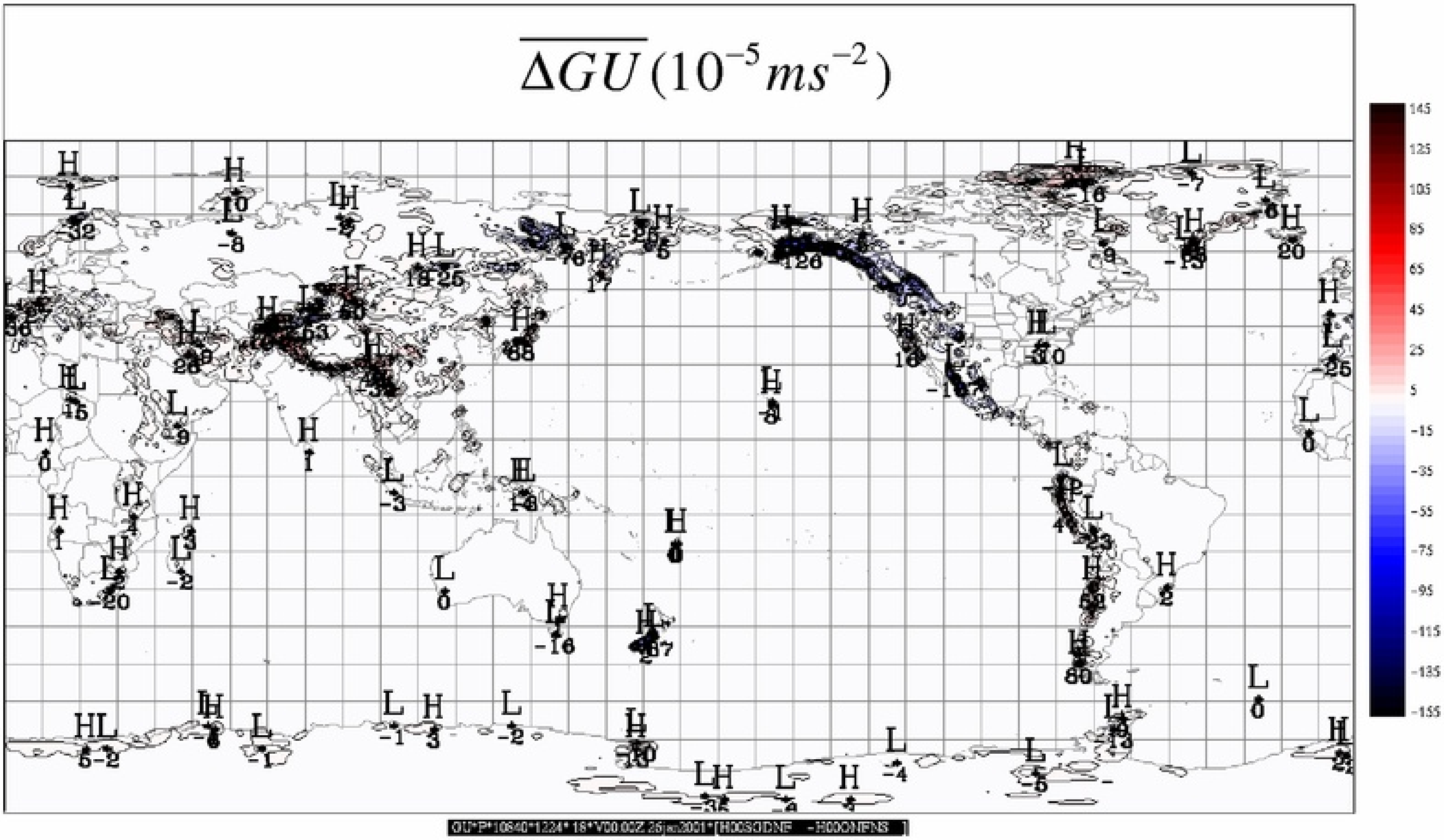
> control (GWD, no blocking)
> experiment (GWD + blocking)

at t = 120 h.

<< Prev | Index | Next >>

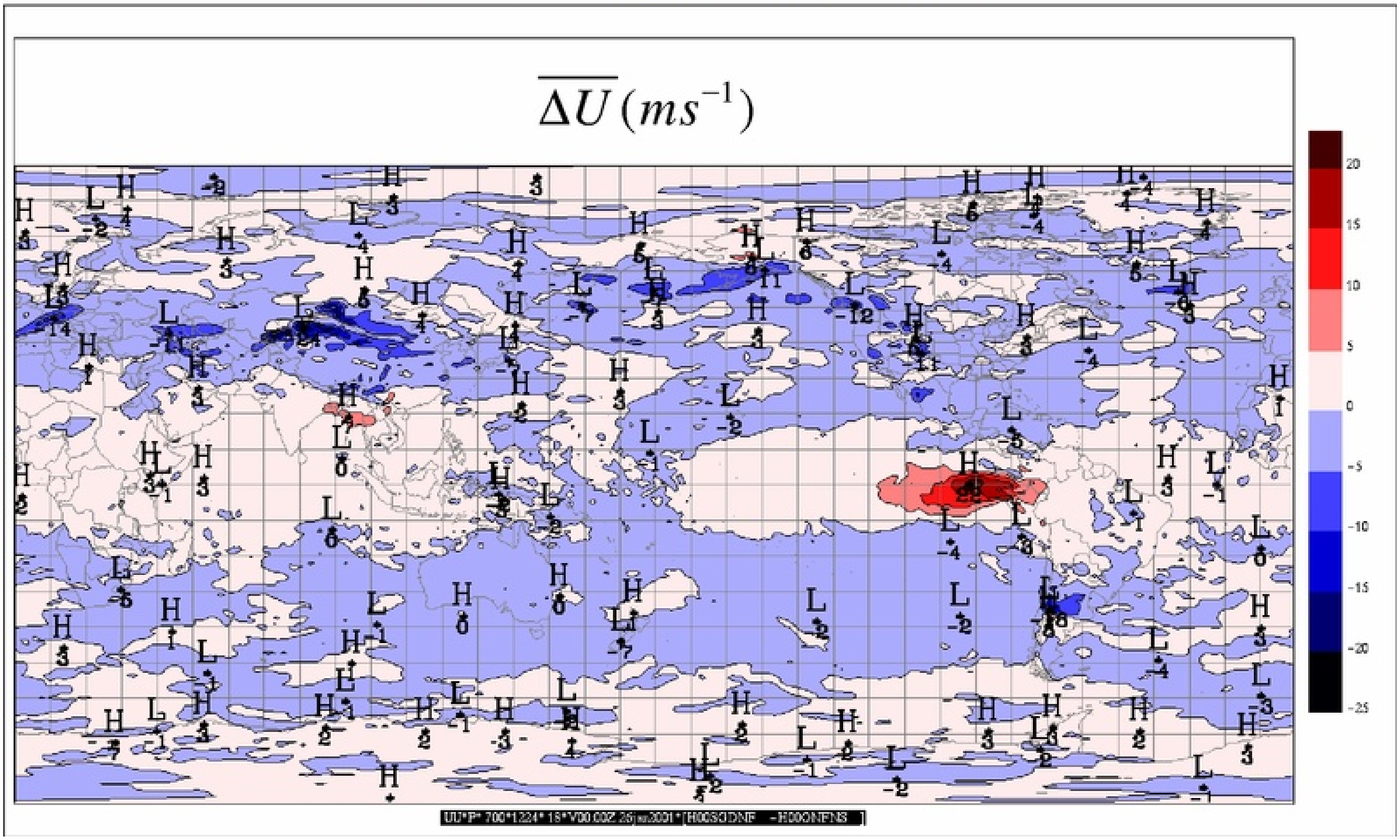
[<< Prev](#) | [Index](#) | [Next >>](#)

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



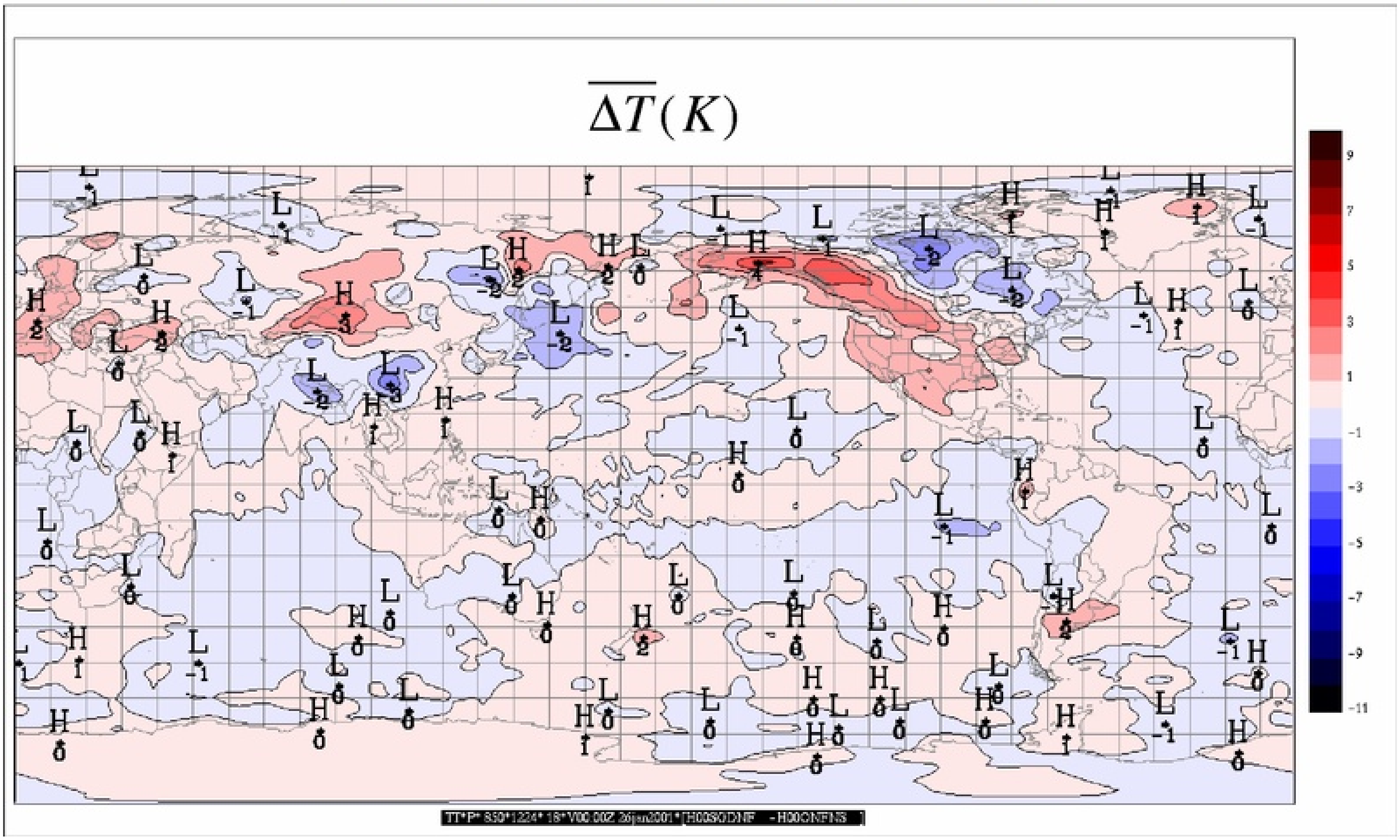
[<< Prev](#) | [Index](#) | [Next >>](#)

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



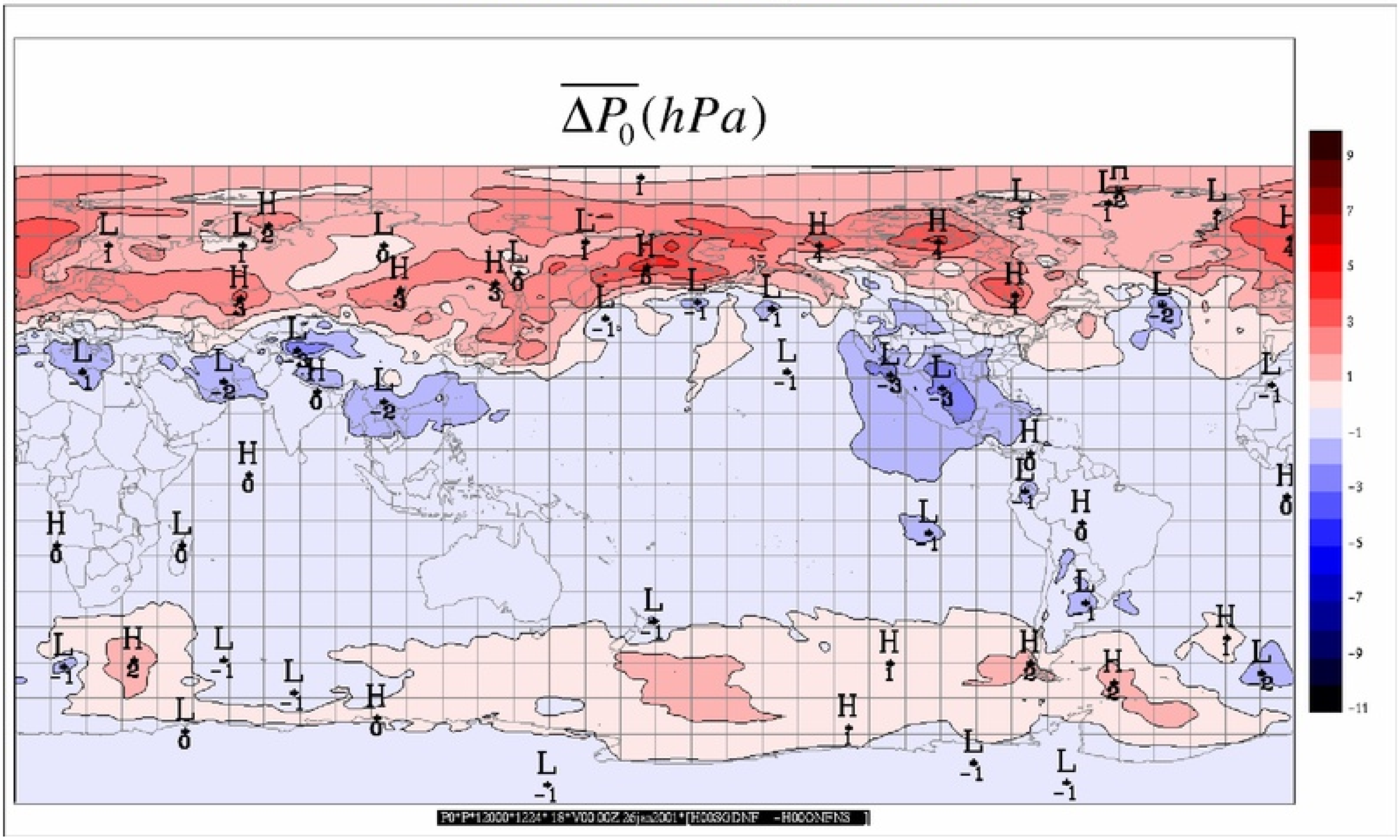
<< Prev | Index | Next >>

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



<< Prev | Index | Next >>

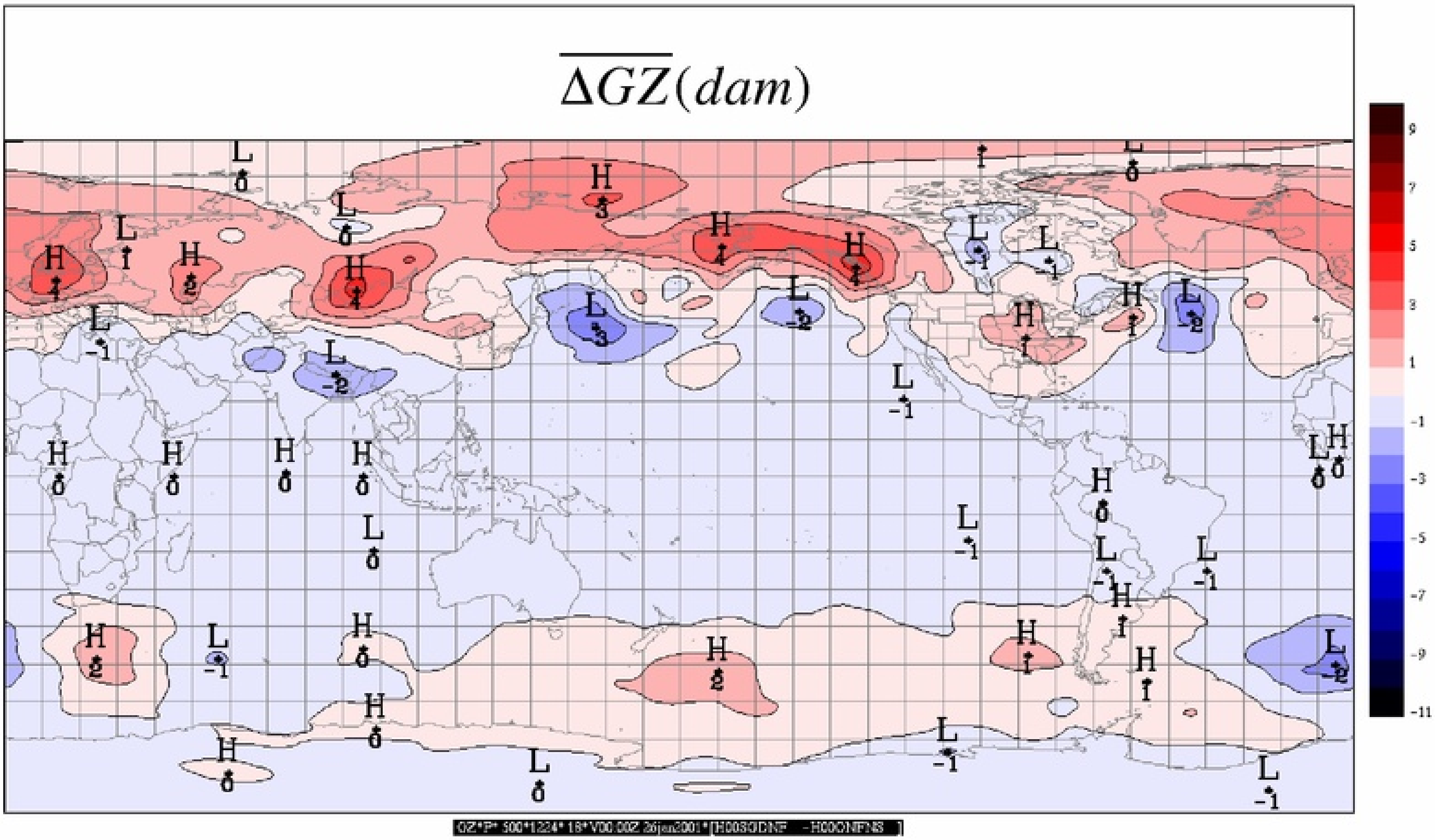
Ensemble-average of impact (drag - nodrag) on the surface pressure



<< Prev | Index | Next >>

<< Prev | Index | Next >>

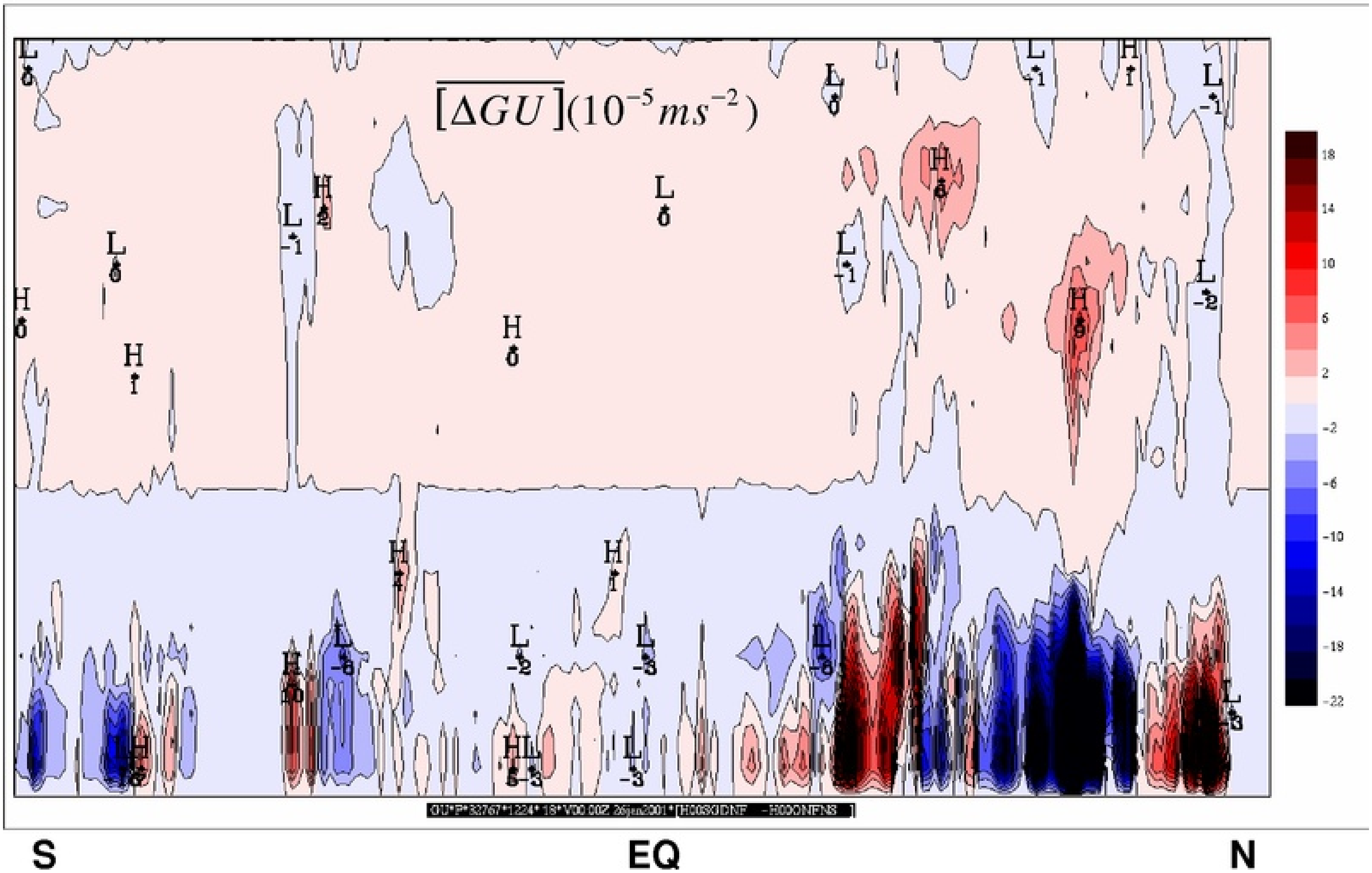
Ensemble-average of impact (drag - nodrag) on the geopotential at p = 500 hPa



<< Prev | Index | Next >>

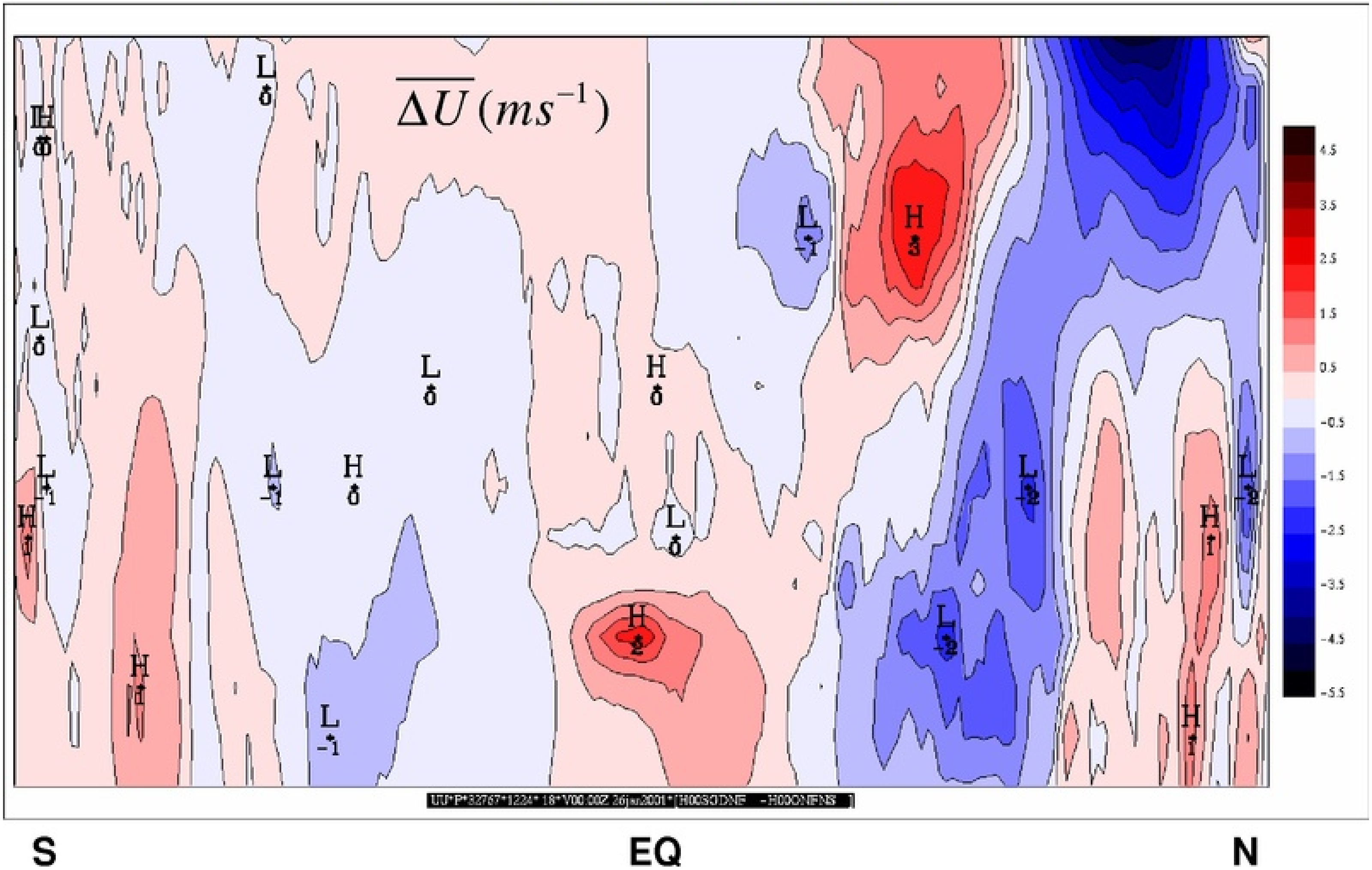
<< Prev | Index | Next >>

Ensemble/zonal average of SGO drag on the zonal wind



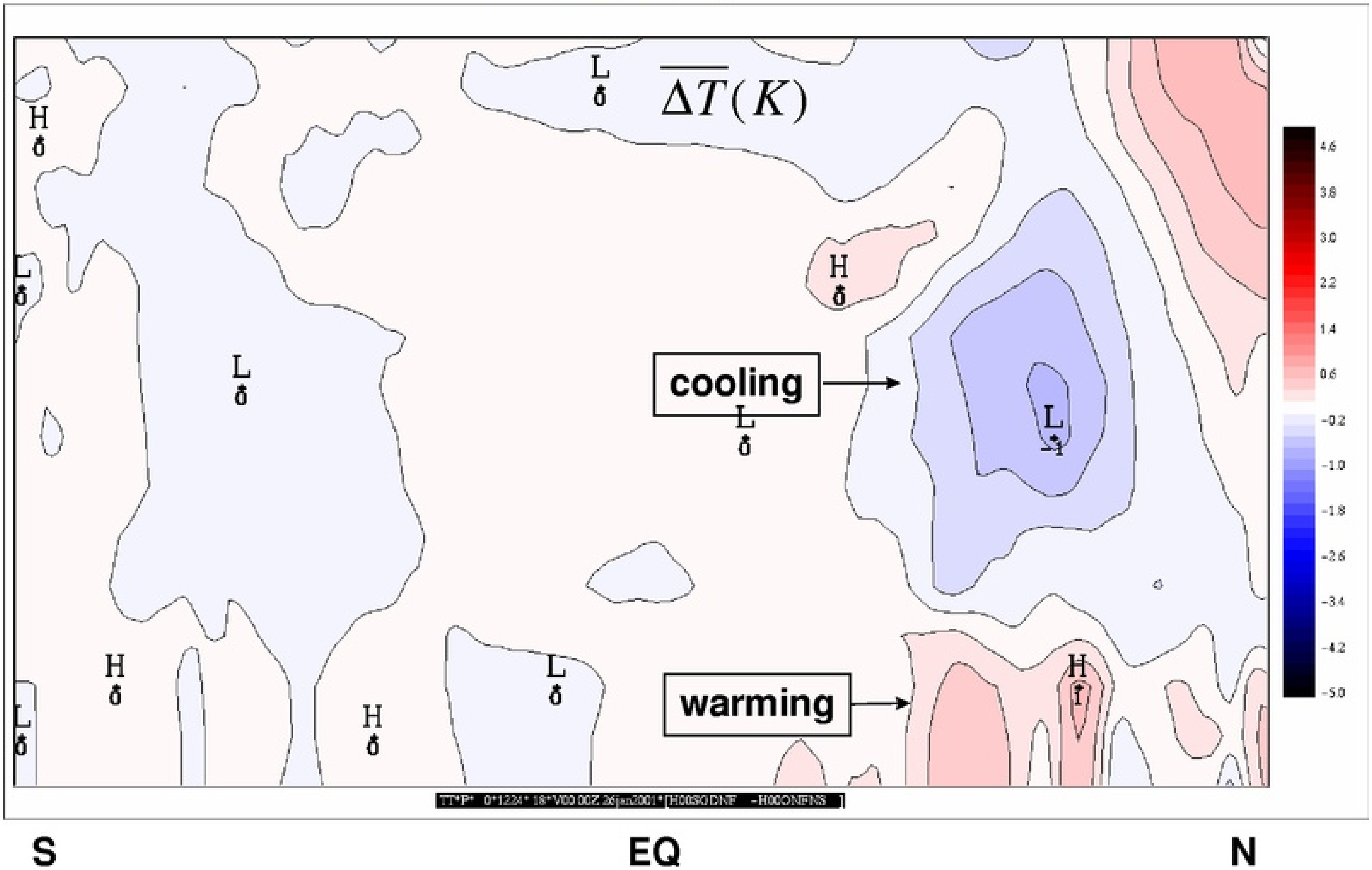
<< Prev | Index | Next >>

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

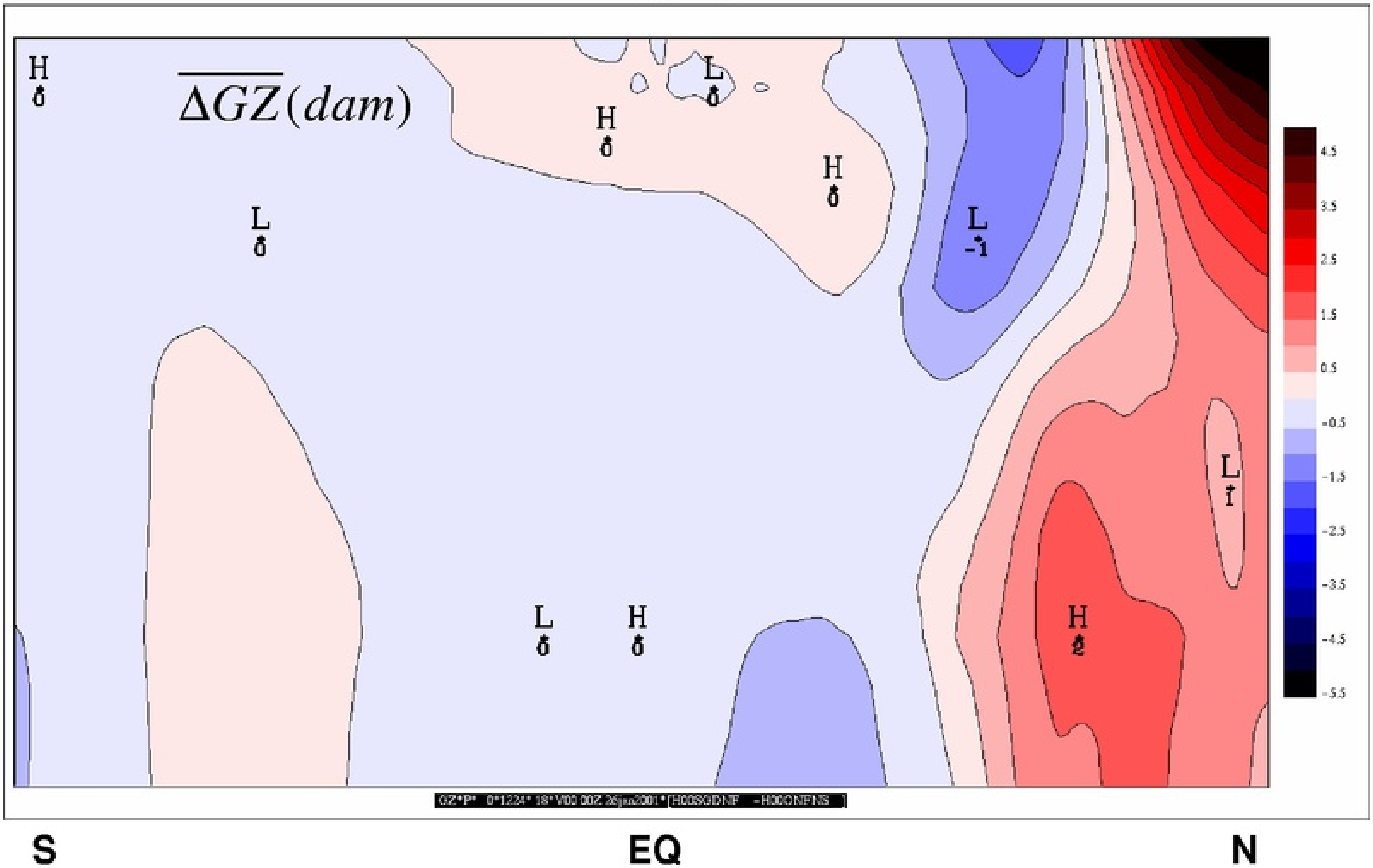


[<< Prev](#) | [Index](#) | [Next >>](#)

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



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



<< Prev | Index | Next >>

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 (β : 0.85 => 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)

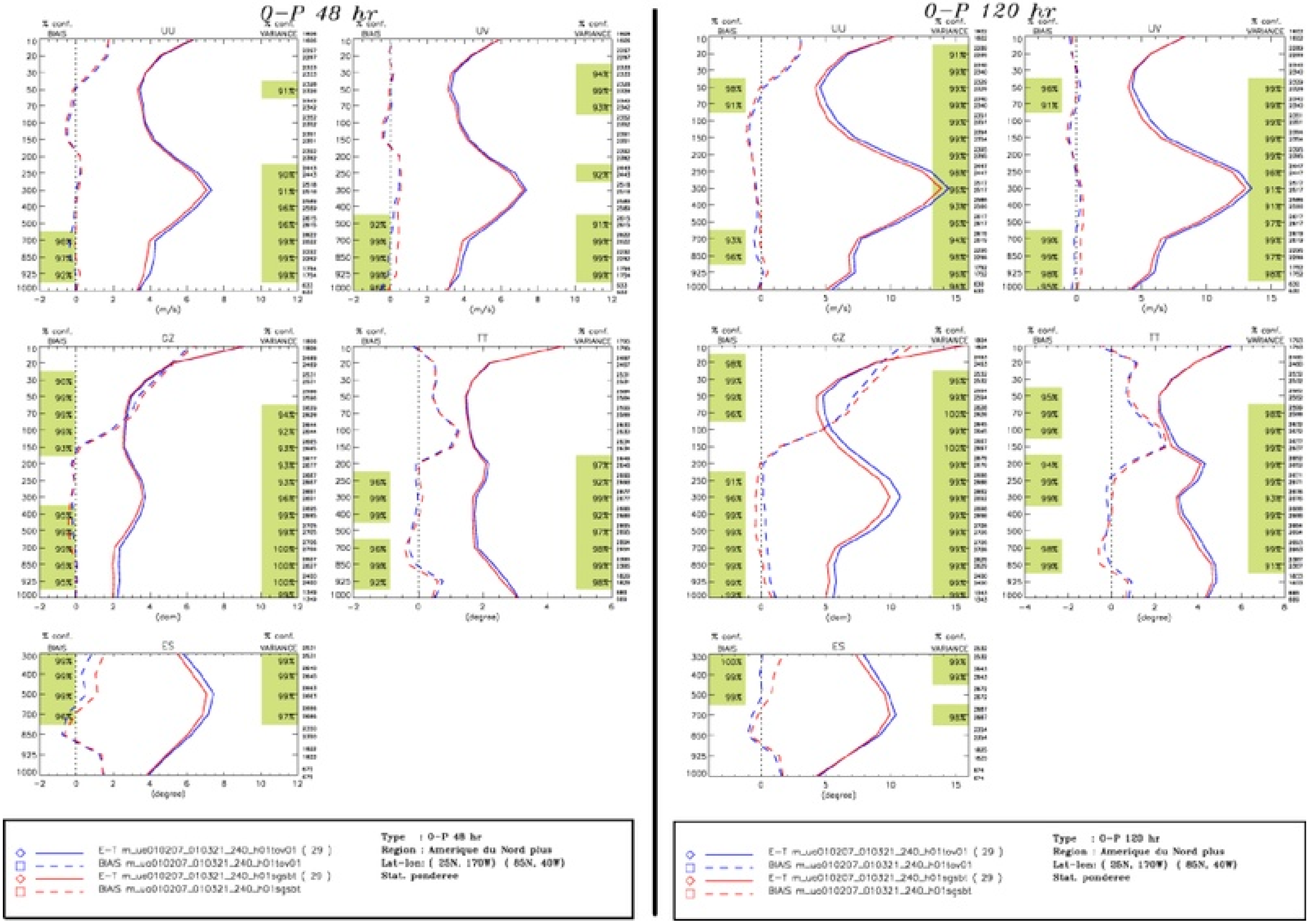
---

* Made by M. Roch. Details in:
http://euclide.cmc.ec.gc.ca/GAG/GLOBAL_OPER/VALID_BLOCAGE/valid_blocage.html

<< Prev | Index | Next >>

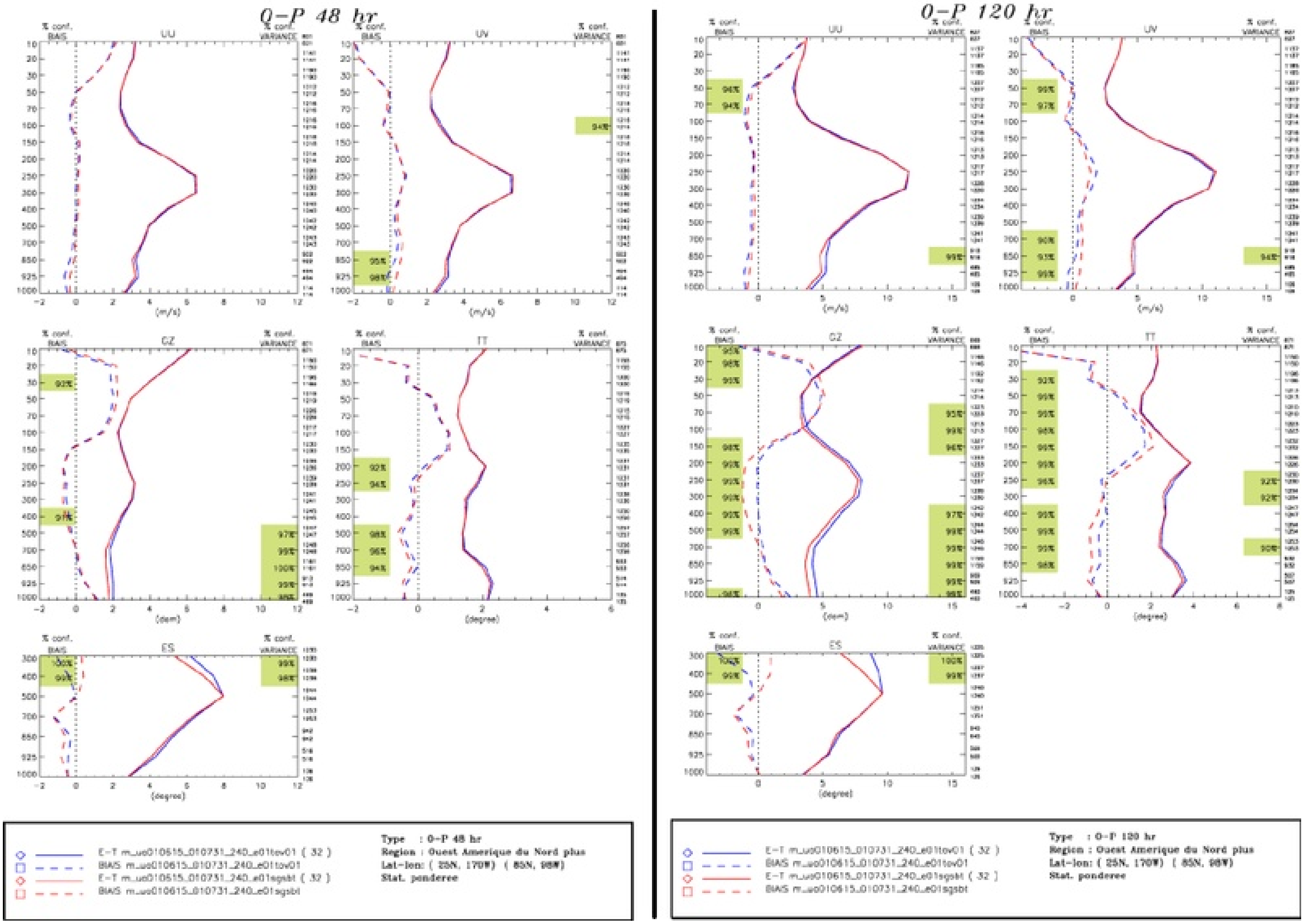
<< Prev | Index | Next >>

Winter - North America



<< Prev | Index | Next >>

Summer - West of North America



II. Experiments with GEM-regional 15 km *

> version 2.3.0 and 3.69

> control in blue

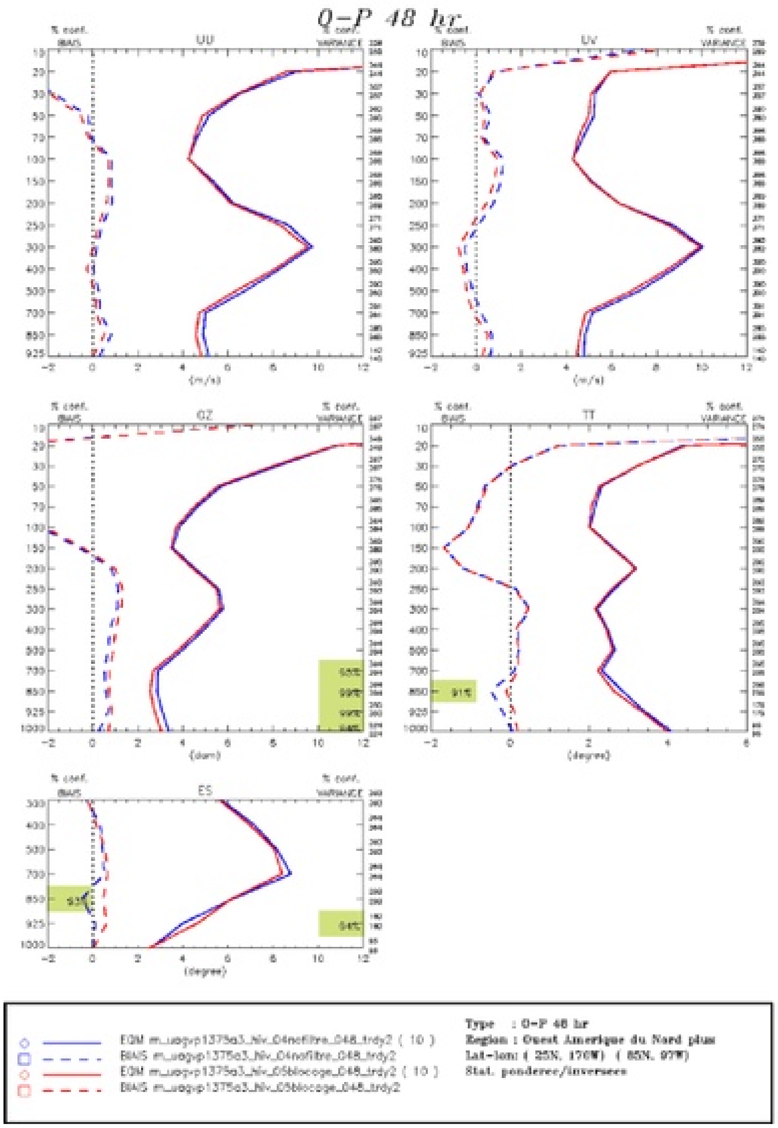
> experiment in red with SGO drag (GWD + blocking) added

> 10 X 48h-forecasts in winter (Jan-Feb 2001)

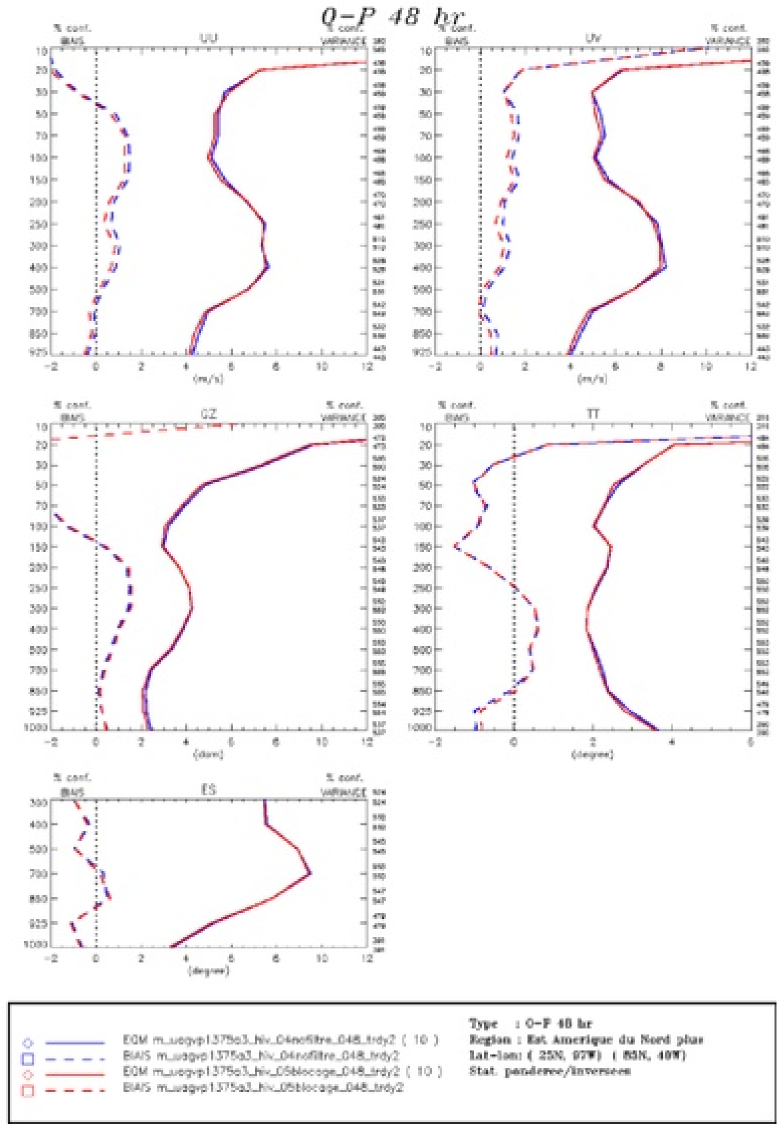
> 10 X 48h-forecasts in summer (Jul-Aug 2001)

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

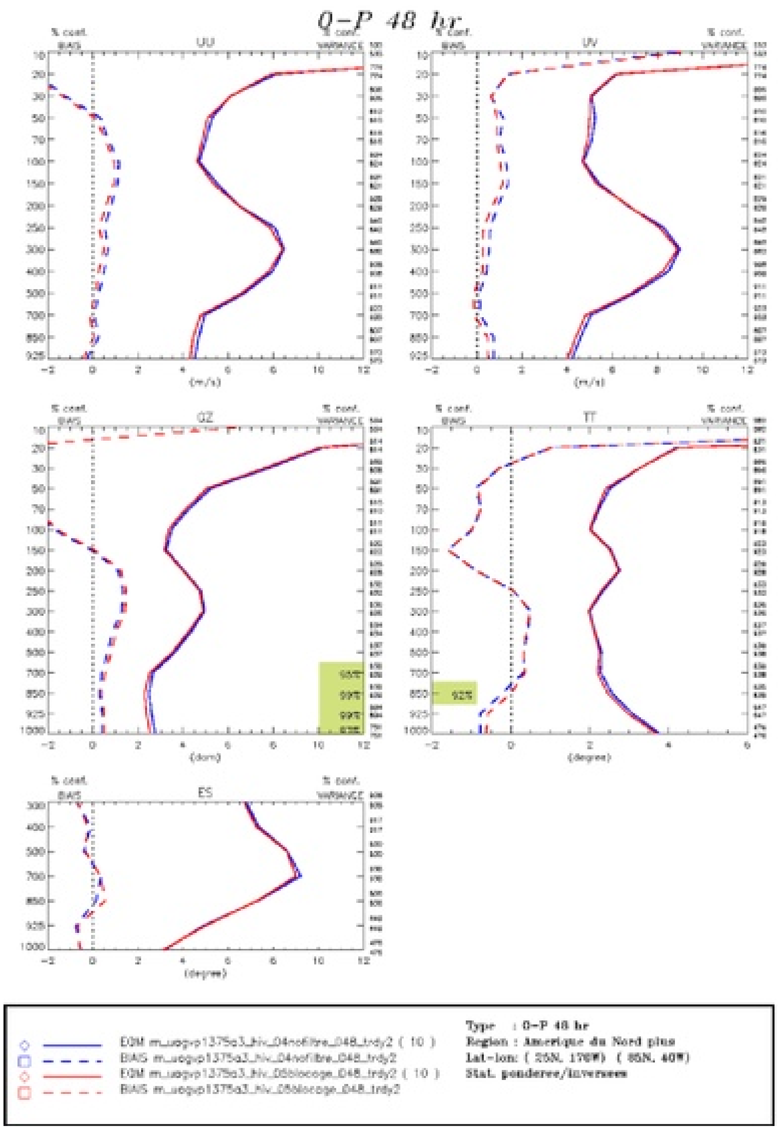
Winter - West of North America



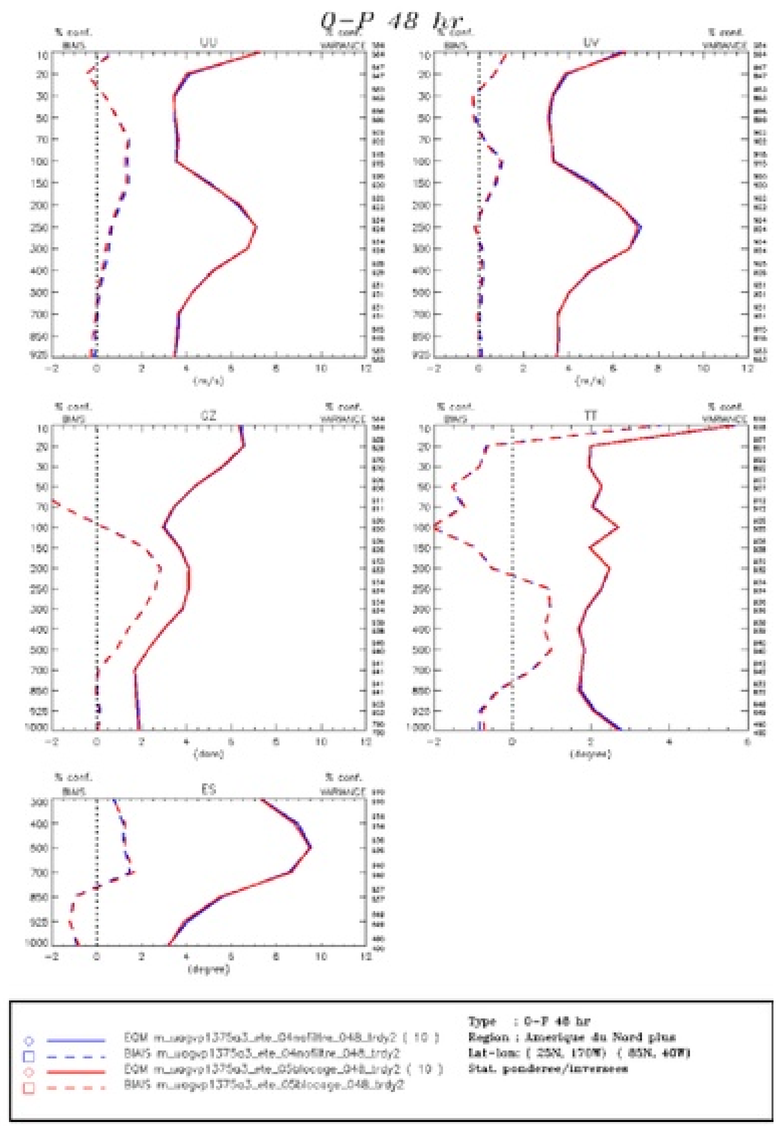
Winter - East of North America



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)

<< Prev | Index | Next >>

<< Prev | Index | Next >>

<< Prev | Index | Next >>