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Modernization of Atmospheric Physics Parameterization in Canadian NWP – Part 2: Changes to the orography, turbulence and surface layer schemes

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RPN-A / ECCC

Part 2 presented by A. Zadra

Seminar – UQaM
22-Jan-2020

Canada

“Clouds & Precipitation Project” Team (alphabetical):

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Main reference:

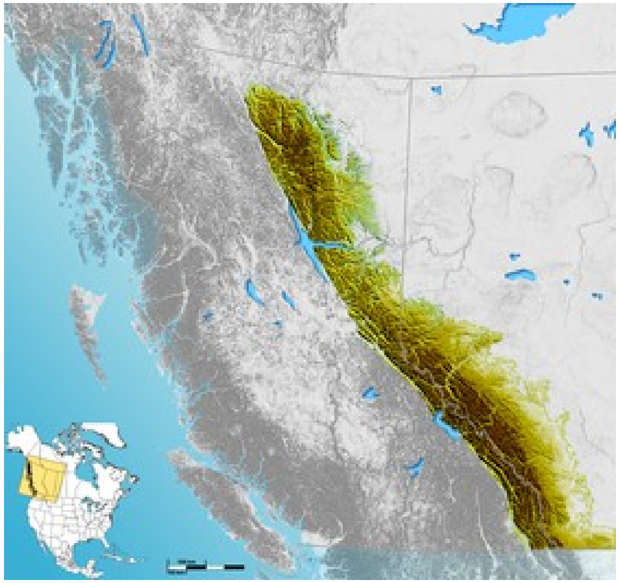
McTaggart-Cowan, R., P. Vaillancourt, A. Zadra, S. Chamberland, M. Charron, S. Corvec, J. Milbrandt, D. Paquin-Ricard, A. Patoine, M. Roch, L. Separovic, J. Yang, 2019:
Modernization of Atmospheric Physics Parameterization in Canadian NWP.
Journal of Advances in Modeling Earth Systems.
https://doi.org/10.1029/2019MS001781

Outline

Here we present & discuss some novelties related to:

- **orography**:
  - *filtering of resolved orography*
  - *blocking and gravity wave drag schemes*
- **turbulence**:
  - *boundary layer scheme*
  - *surface layer calculations*
- **conservation principles**:
  - *conservation of momentum, energy and moisture for physical parametrizations*

Geophysical fields:
novelties for orography



- Acknowledgements:
  - *Ron McTaggart-Cowan, Michel Roch, Claude Girard, Leo Separovic, Paul Vaillancourt, Stéphane Bélair, Stéphane Chamberland, Vivian Lee, Michel Desgagné*
  - *Vanh Souvanlasy, André Plante, Jean-Philippe Gauthier, Alexandre Leroux, Syed Husain*

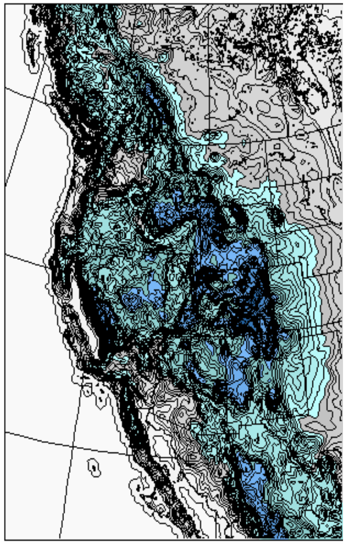
- Full set of geophysical fields now generated by **GenPhysX**

- Here focus on orographic components
  - resolved topography elevation (**ME**): new filter
  - subgrid orography fields for
    - GWD/blocking (**LH, Y7,Y8, Y9**): scale separation
    - turbulence (**Z0, SSS**): scale-separation and bugfix

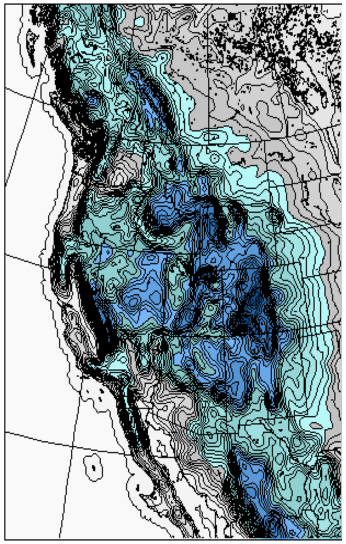
- Ongoing work
  - exploring new databases
  - pre-processing approach for scale-separation
  - participation in international projects (e.g. GASS/WGNE drag project)

Topography: which scales to filter?”

- in early stages of the project, we realized that the topography **filter** previously used was probably “**too aggressive”**, leading to an excessively smoothed topography
- sensitivity tests revealed that removing the filter (or possibly using a sharper filter) could improve the quality of forecasts



non-filtered ME

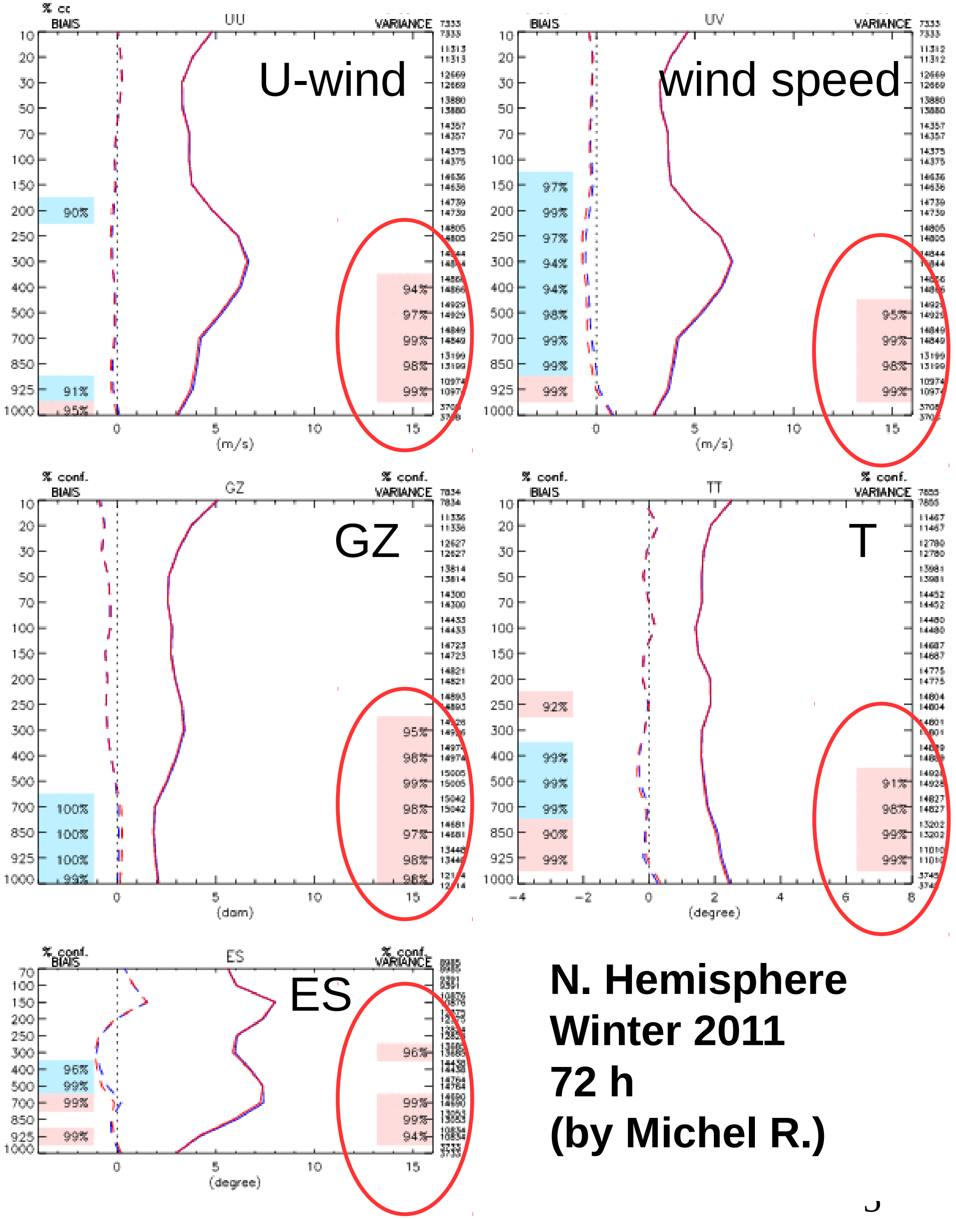


(oper) filtered ME

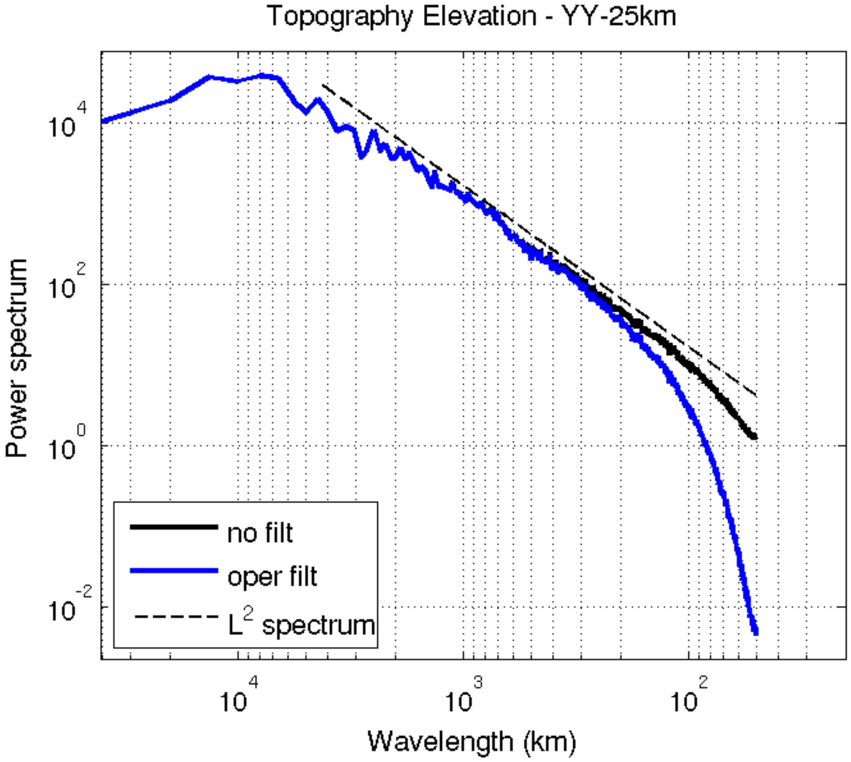
Sensitivity test

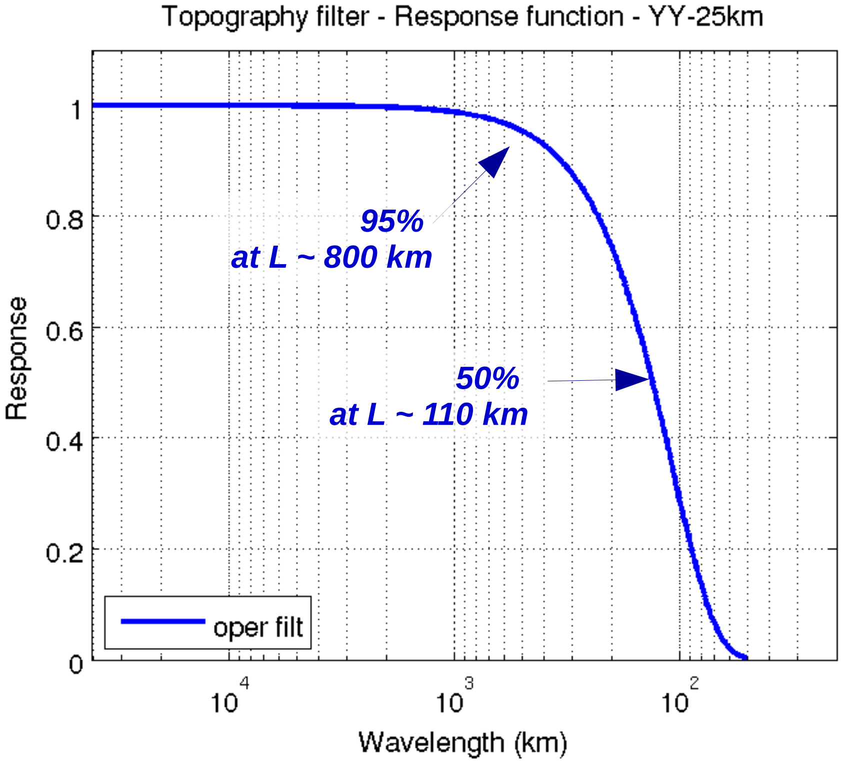
GDPS-25m: (oper) filtered ME

GDPS-25km: non-filtered ME



N. Hemisphere
Winter 2011
72 h
(by Michel R.)

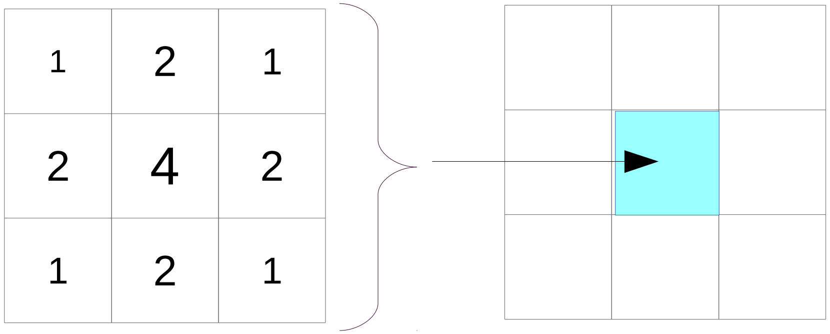




95%
at L ~ 800 km

50%
at L ~ 110 km

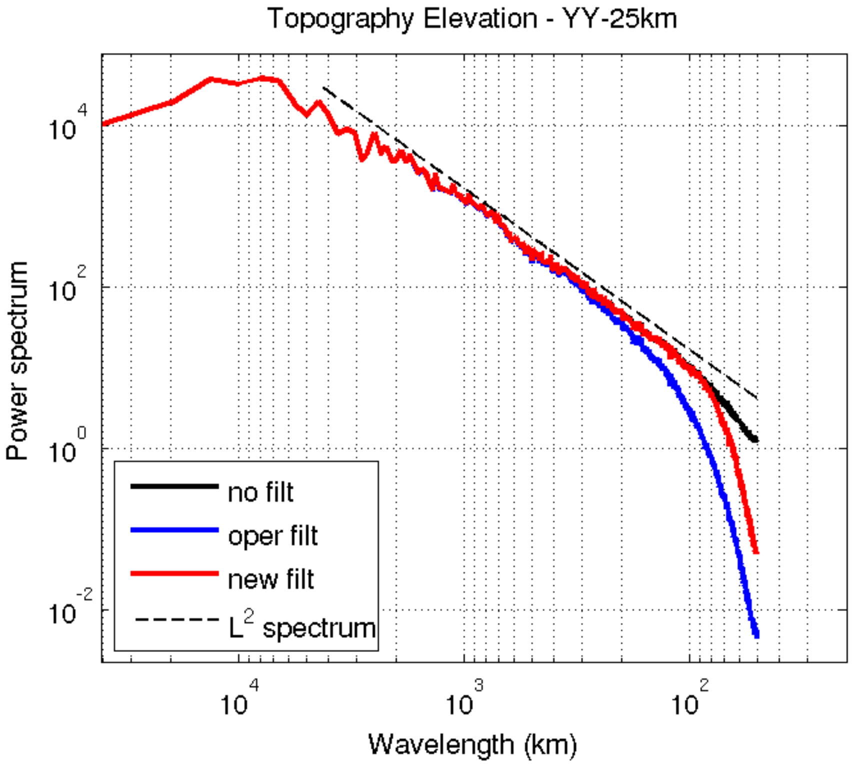
- The “old” filter (sometimes referred to as the “**2-dx filter**”) used a simple 9-point-average of near-neighbor values, with weights indicated in the diagram below:

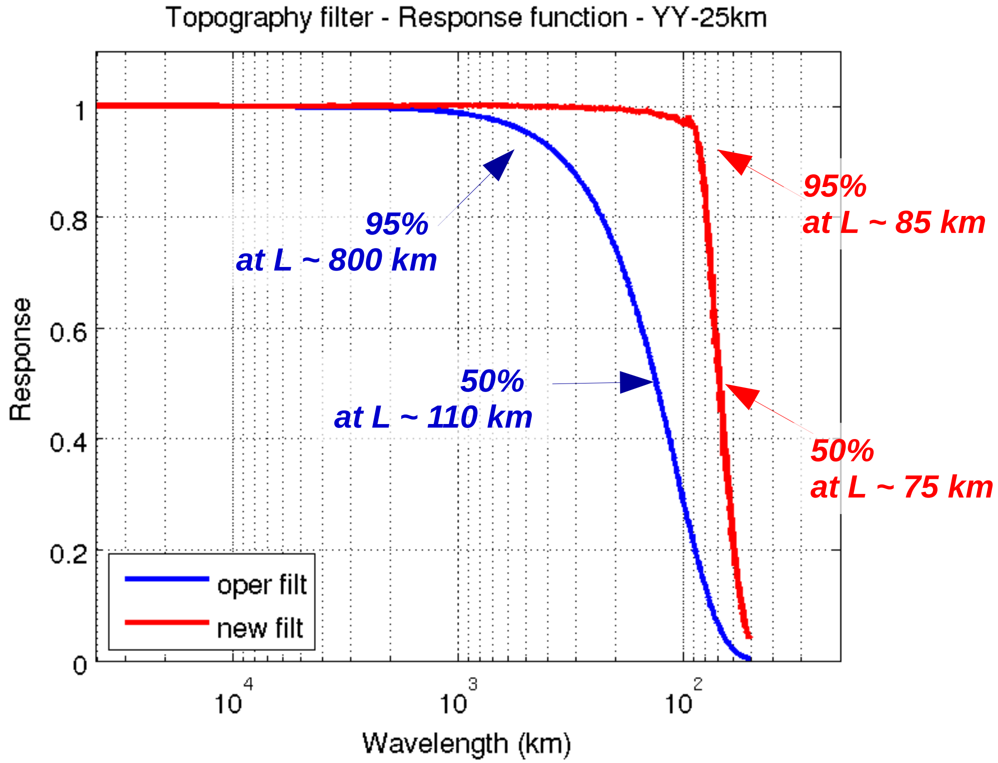


1	2	1
2	4	2
1	2	1

filter
weights

- The primary goal of the filter was to eliminate wavelengths of size 2-dx (where dx is the grid spacing), but the filter weights are such that even wavelengths **up to 30-dx are affected**.
- In the case of the “old” GDPS-25km, this implies a 50% loss in amplitude at ~110 km, and **5% loss at ~800 km**.

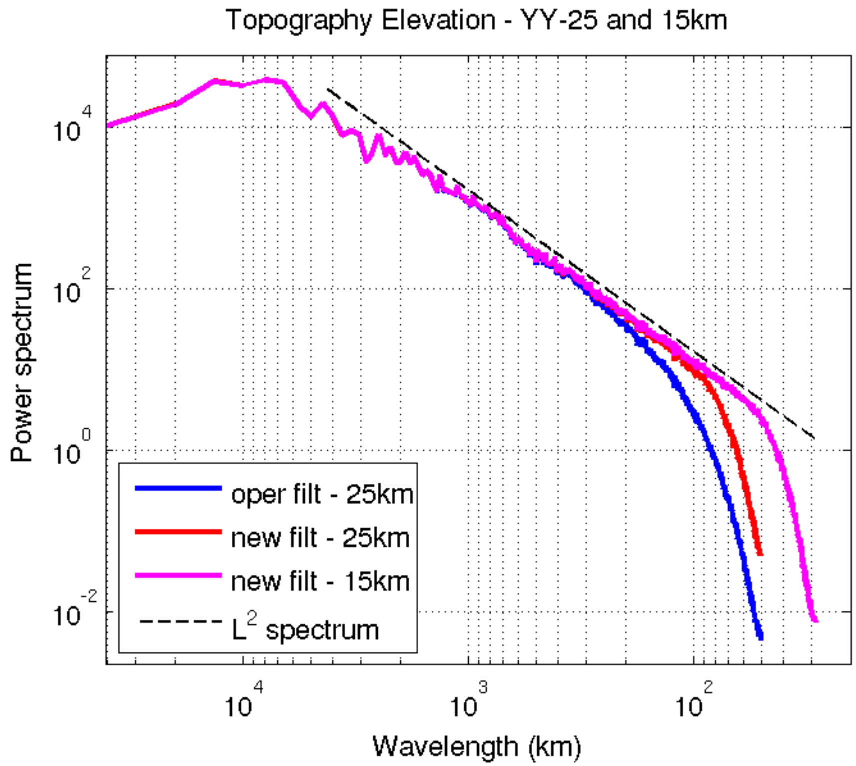




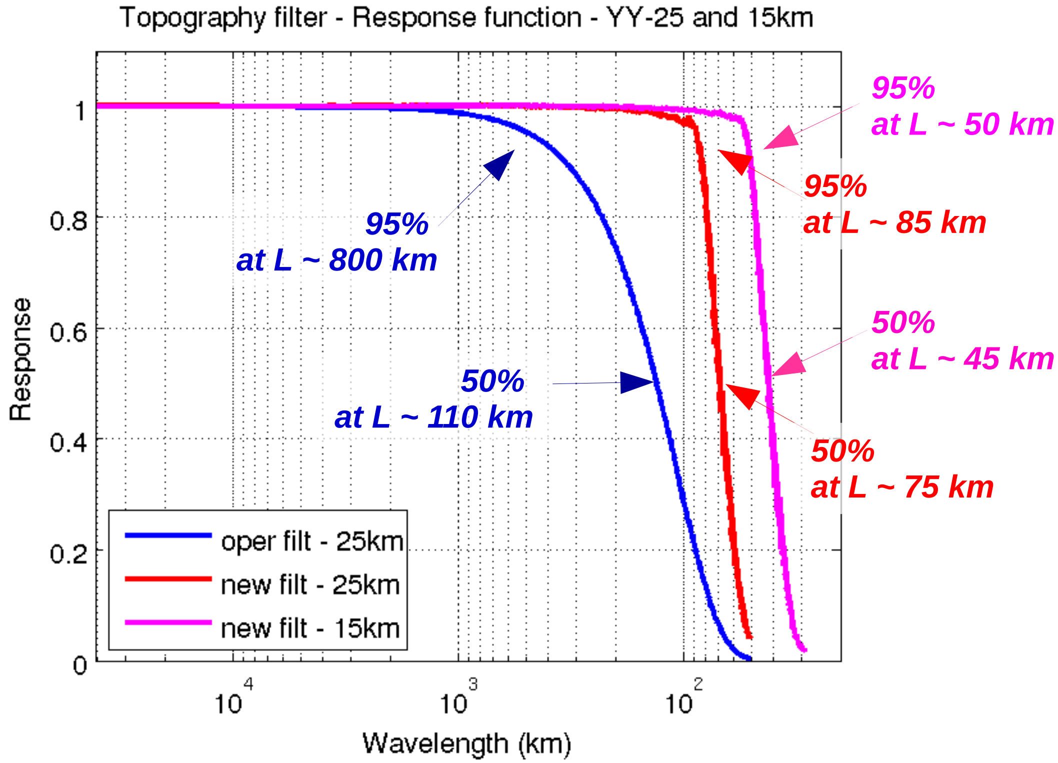
- A **new topography filter** is now available in **GenPhysX**. It is also a N-point-average filter, inspired by the so-called "*topography digital filter*" previously used (in older versions of GEM) for GU grids, to eliminate topography anisotropies near the poles.

- The new filter comes with 2 adjustable parameters that allow the user to control
  (a) its **sharpness** and
  (b) the **wavelength** at which the amplitude should be reduced by **50%**

  - In the example on the left for the GDPS-25km, the new filter gives 50% amplitude at 3x25km = 75km, and reaches **95% at ~85 km** (instead of the 800 km of the operational filter).



Topography Elevation - YY-25 and 15km



Topography filter - Response function - YY-25 and 15km

- The new filter was adopted in the new configurations of the GDPS-15km and RDPS-10km.
- For the GDPS-15km, the new filter gives 50% amplitude at 3x15km = 45km, and reaches **95% at ~50 km**.
- For the RDPS-10km, a slightly different configuration of the new filter (with 50% at 5-dx) was chosen, to improve precipitation forecasts over the Rockies. Based on recent studies by Syed Husain, 5-dx is now the recommended threshold.

- NOTE: In terms of **upper-air scores:** the new filter produces scores similar to those obtained without any filter, but with lower risk of numerical instabilities (there have been a few documented cases of model crash in the early tests with non-filtered topography).

Orography variance and slope covariances

filling spectral gaps and separating scales

An alternative method was introduced in GenPhysX, to compute the orographic geophysical fields required by the GWD and blocking schemes,

- **LH** = launching height = 2 x variance of unresolved orography
- **Y7, Y8, Y9** = covariances of unresolved orography

and by the turbulent orographic form drag (TOFD) scheme,

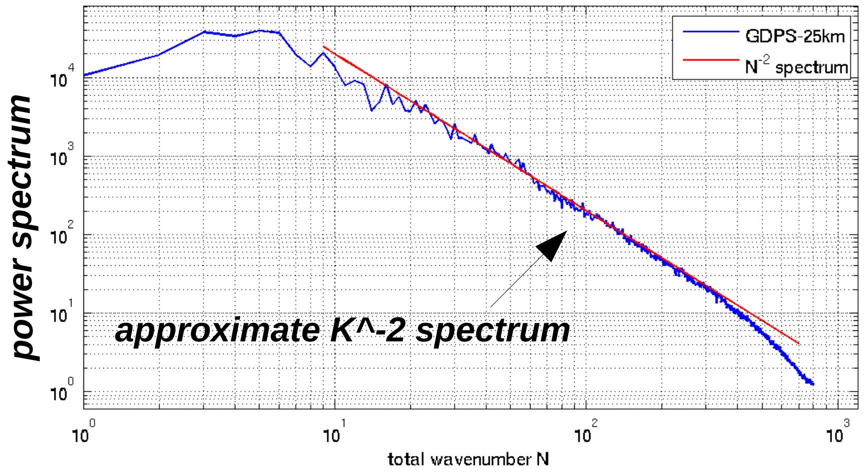
- **SSS** = orographic small-scale sigma (variance from small-scales)

using the available databases, but

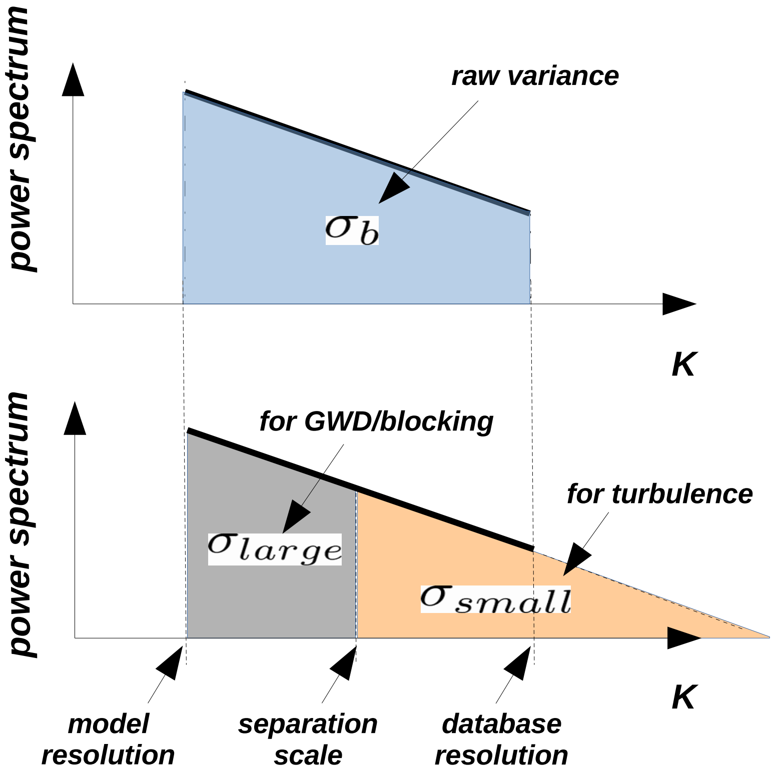
1) filling up the high-wavenumber part of the orography spectrum

2) separating the scales (GWD+blocking *versus* turbulence)

global topography



subgrid orography

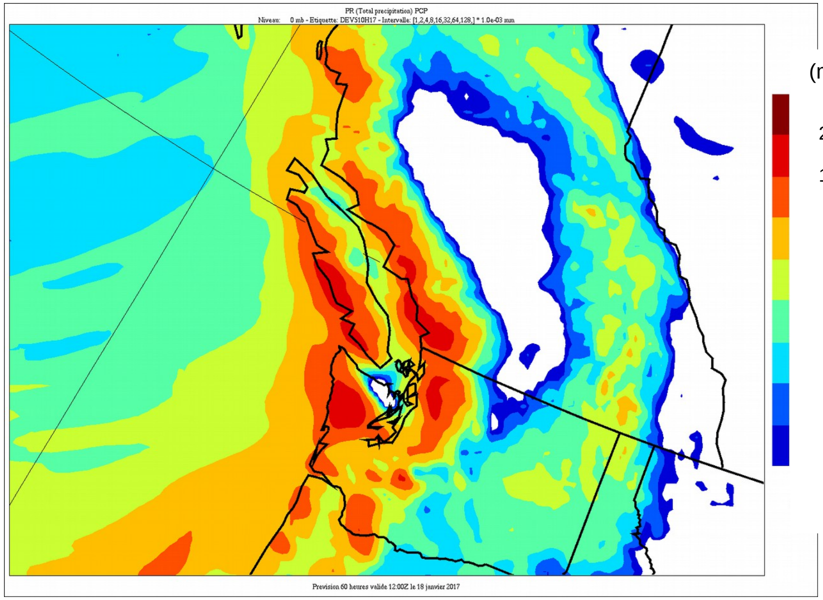


Case study: “Spillover” of precipitation over mountains of the West Coast

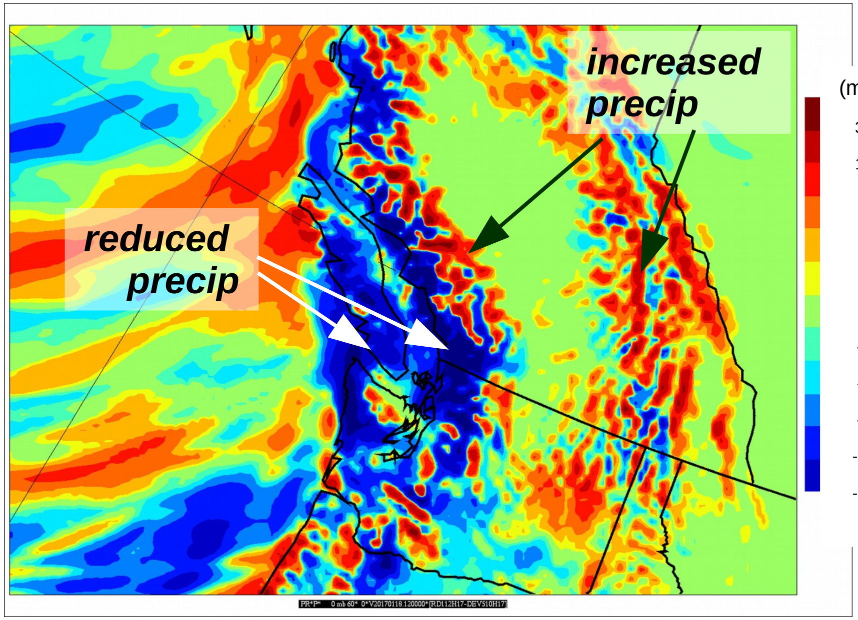
- according to forecasters, the “old” RDPS tended to over-predict precipitation on windward of mountains on the West Coast (under-predict in the lee)
- new model shows improved pattern (more realistic “spillover”) of precipitation
- this improvement is partly due to the new orography fields (LH, Y7-8-9) produced with scale-separation

RDPS-10km forecasts, issued 16 Jan 00Z, PCP 60h-36h (by Leo S.)

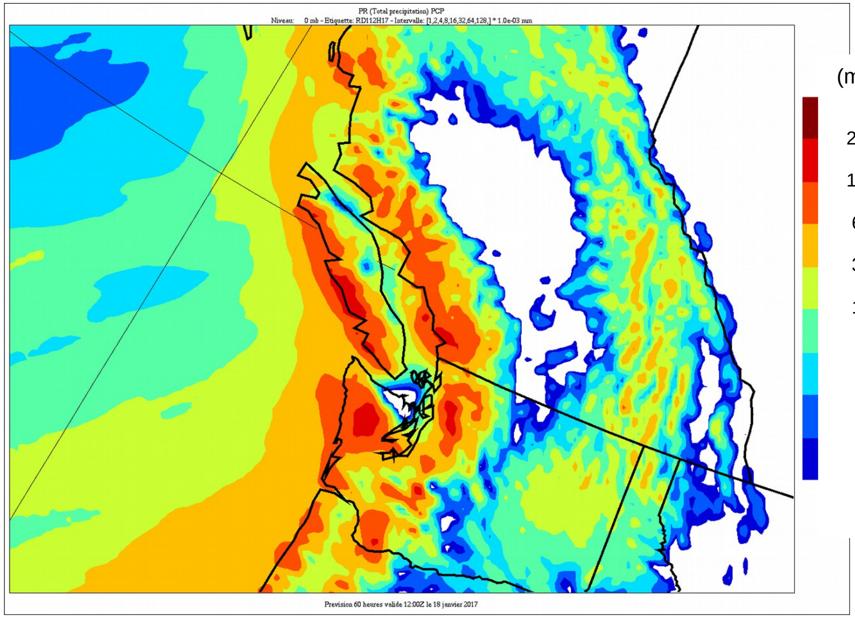
CTL (operational)



EXP - CONTROL



EXP (GEM5)



Corrections to the calculation of the effective roughness length* (Z0) over land

Two errors were found in the “old” calculation of Z0 over land:

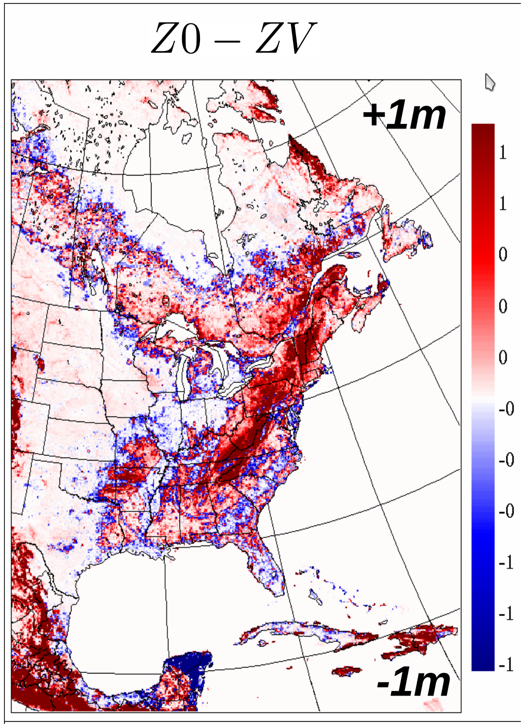
- Z0 was combining the orographic term with the **roughness of the dominant vegetation type** – whereas the latter should be the **aggregated roughness of all vegetation types** (as discussed with Stéphane Belair)
- The **effective roughness length Z0** is supposed to represent the “addition of an orographic effect to the **vegetation roughness length ZV**”, and the resulting value should be larger, that is

$$Z0 \geq ZV$$

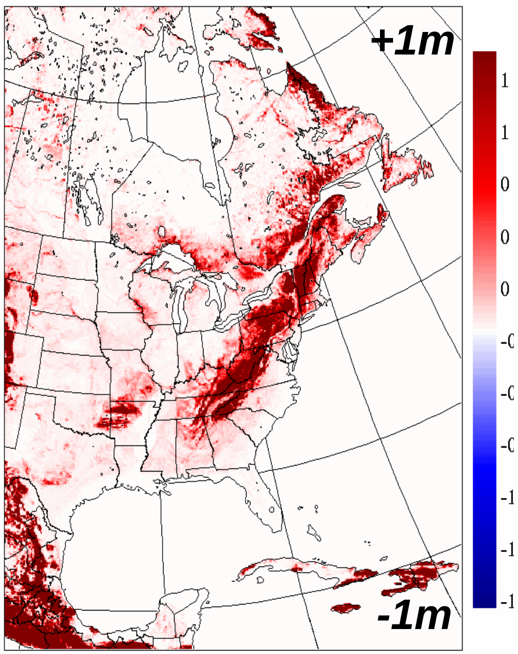
but the “old” formula violated this condition under certain circumstances.

- Two corrections were therefore introduced in GenPhysX.

** Note: Z0 is the roughness length for <u>momentum</u>. Roughness length for scalars (ZT) are computed separately by each surface scheme (e.g. land, glacier, etc)*



Difference between Z0 and ZV: example from the “old” GDPS. Blue indicates problematic zones where the effective (total) roughness is smaller than its vegetation component.



Same, after corrections: now the positive (red) values truly indicate the additional roughness due to orography.

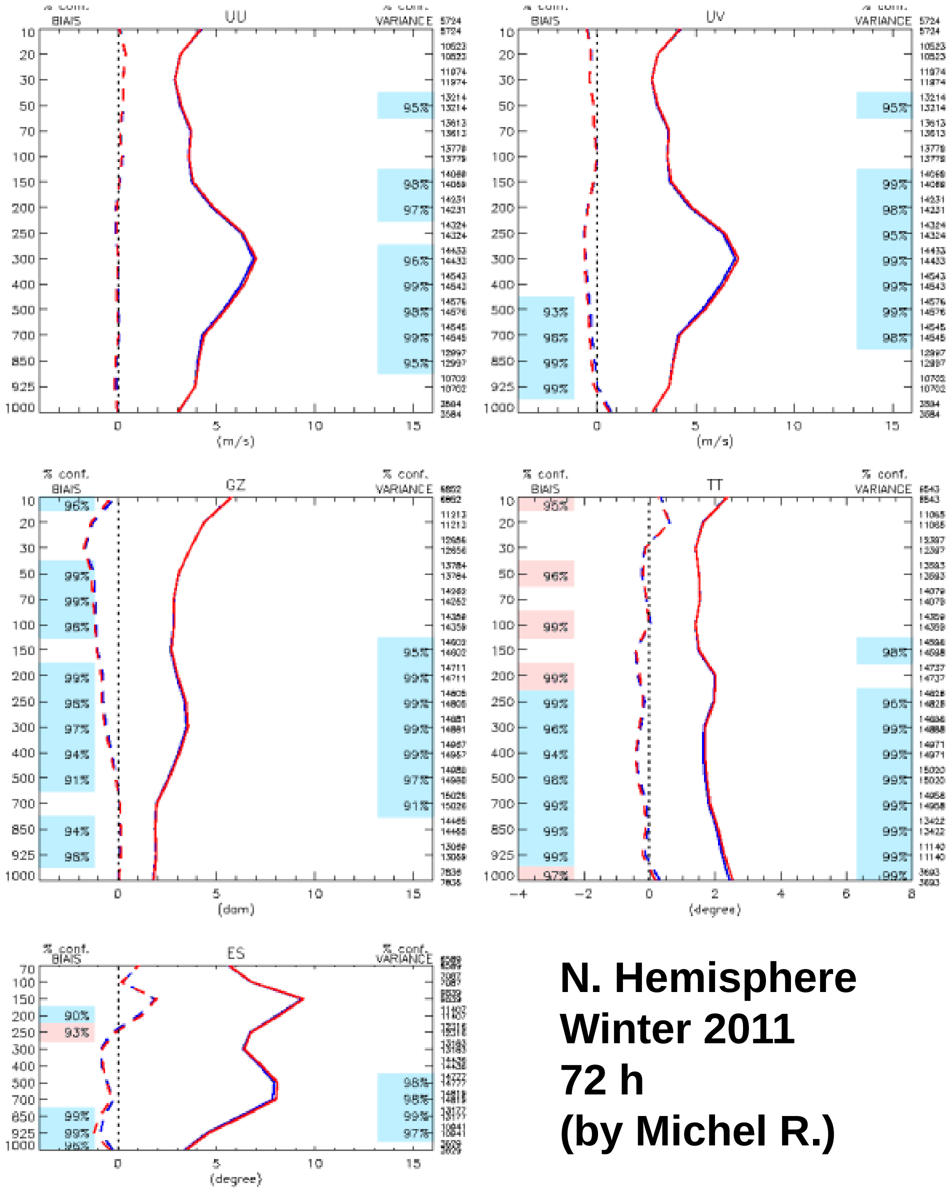
SubGrid-Orography (SGO) scheme: novelties for orographic Gravity Wave Drag (GWD) and blocking

- Acknowledgements:
    - *Michel Roch, Ron McTaggart-Cowan, Stéphane Chamberland, Leo Separovic*
- **GWD scheme**
    - main issue: some noise near model top due to large GWD tendencies
    - solution proposed: horizontally filtered tendencies (not shown here)
- **Orographic blocking scheme**
    - initial motivation: excessive sensitivity to vertical resolution, leading to deterioration of scores (see figure)
    - approach adopted: <u>same formulation</u> (Lott & Miller 97) but with <u>new discretization</u>, combined with some novelties (e.g. new geophysical fields)
- Total **energy conservation** insured with addition of <u>dissipative heating</u> (later on)
- **Ongoing work**
    - GASS/WGNE drag project

The main challenge... results from early tests with GU-25 km, sensitivity to vertical resolution

80 levels (bottom level @ 40m)

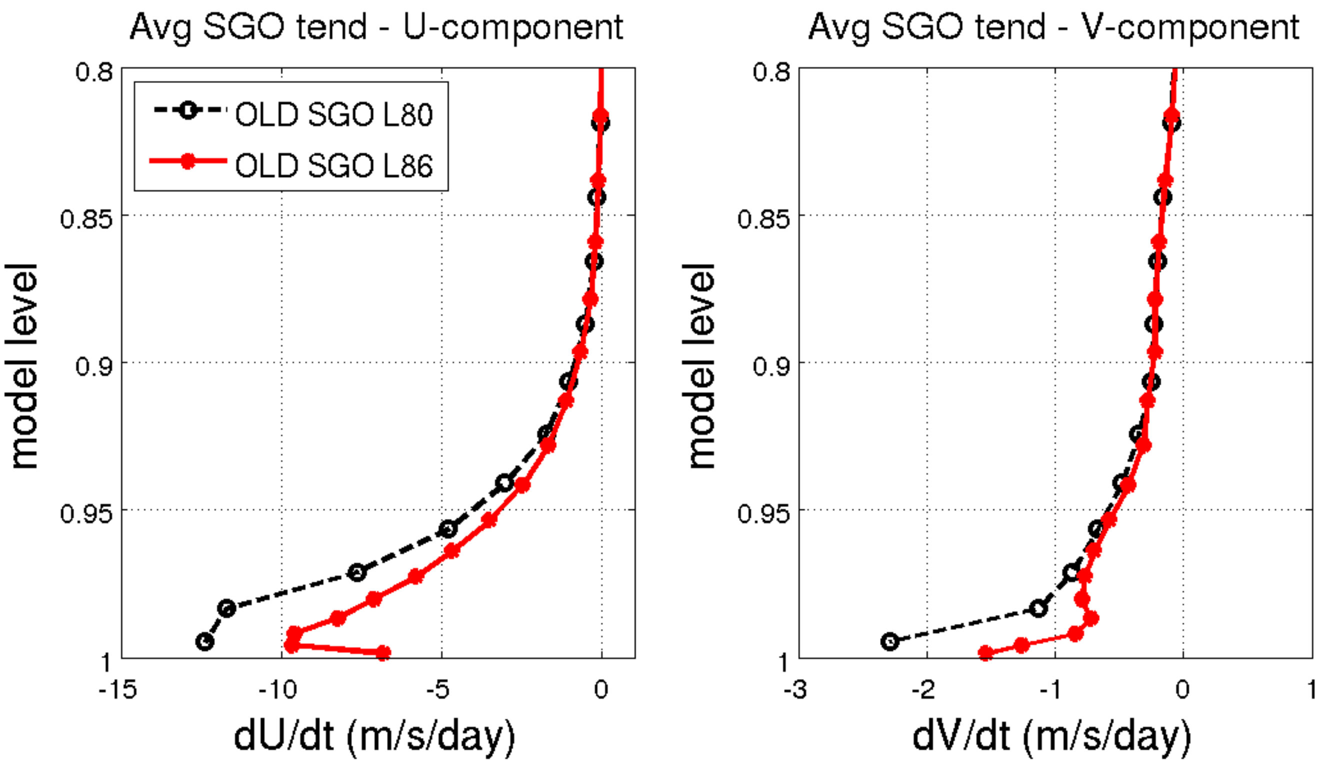
120 levels (bottom level @ 10m)



N. Hemisphere
Winter 2011
72 h
(by Michel R.)

Example of SGO sensitivity to vertical resolution, based on a winter test case:

- *U- and V-components of the operational SGO scheme*
- *averaged in time (24h) & space (South-west of N. America)*
- ***80 levels** (bottom @ 40m) versus **86 levels** (bottom @ 20m)*
- *Higher resolution seemed to generate less blocking...*



Main discretization issues:

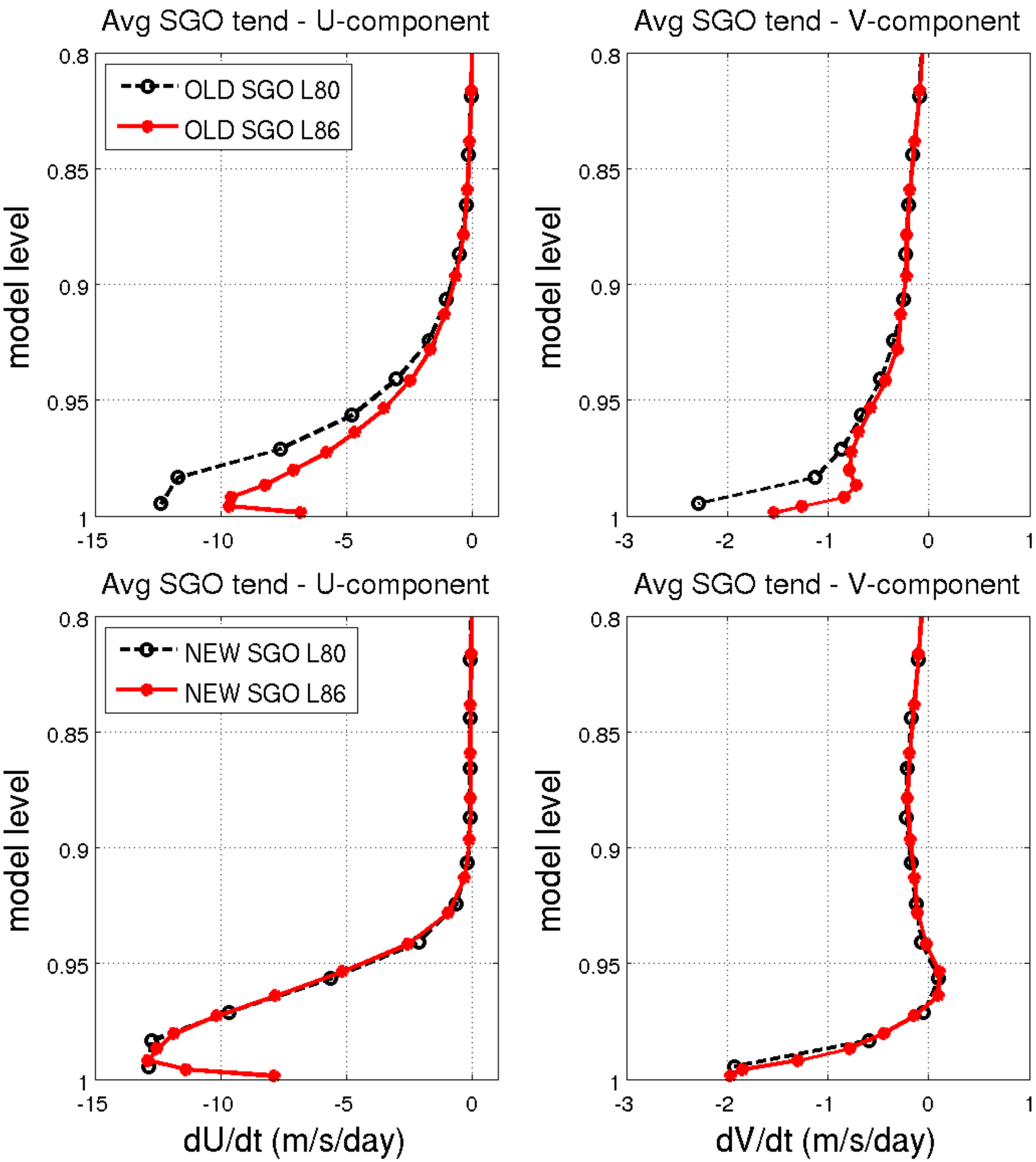
- widespread use of operations of the type "*find the nearest level where...*", instead of "*find the height where...*"
- use of local values instead of background values in some formulas (e.g. some published formulas suggested the use of background/averaged values)
- excessive use of thresholds

Proposed solution/novelties:

- use true values of heights (e.g. height of blocked layer) in the calculation of tendencies, even when they are found between levels
- use the integral module (a higher-order vertical integrator, a novelty of GEM5) to compute averages and integrals
- remove or smooth threshold functions
- reduce the number of tunable parameters

Example of SGO sensitivity to vertical resolution, based on a winter test case:

- *U- and V-components of the operational SGO scheme*
- *averaged in time (24h) & space (South-west of N.America)*
- ***80 levels** (bottom @ 40m) versus **86 levels** (bottom @ 20m)*
- *Higher resolution seemed to generate less blocking...*

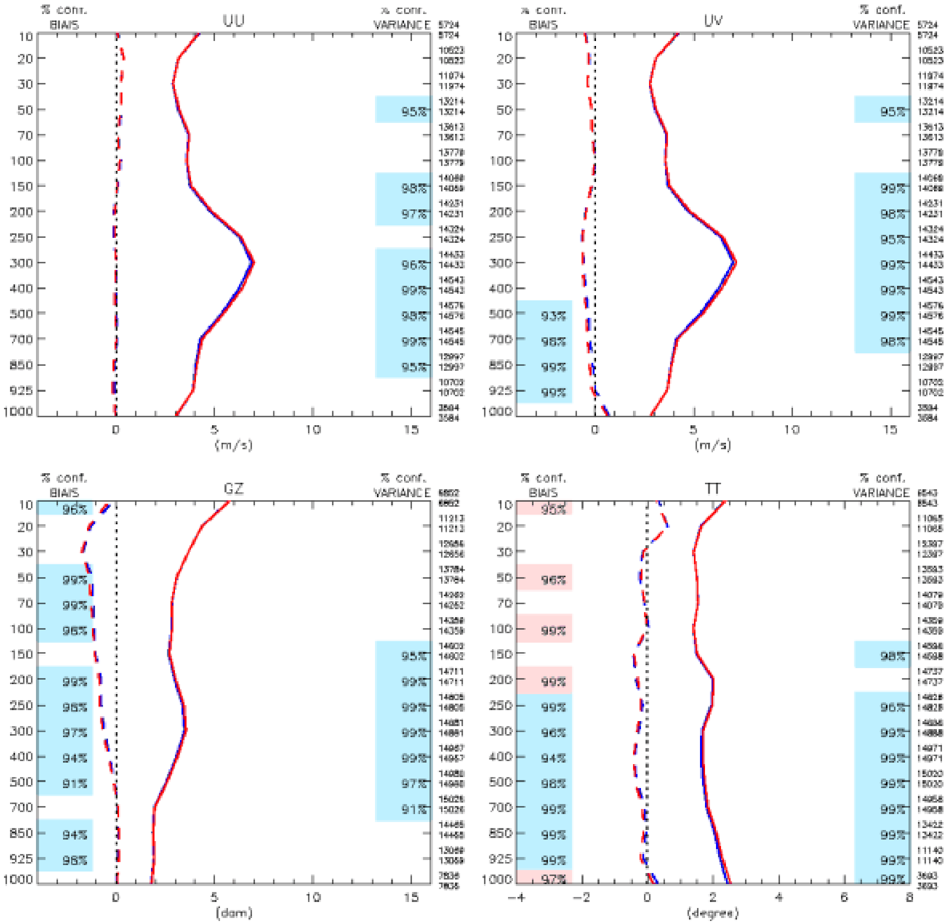


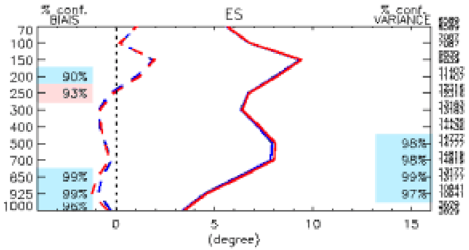
Example of reduced sensitivity to vertical resolution of the **new SGO scheme**, based on the same winter test case as above.

Removing the SGO sensitivity to resolution

Early tests with GU-25 km using "old" SGO scheme :

80 levels (bottom level @ 40m)
120 levels (bottom level @ 10m)

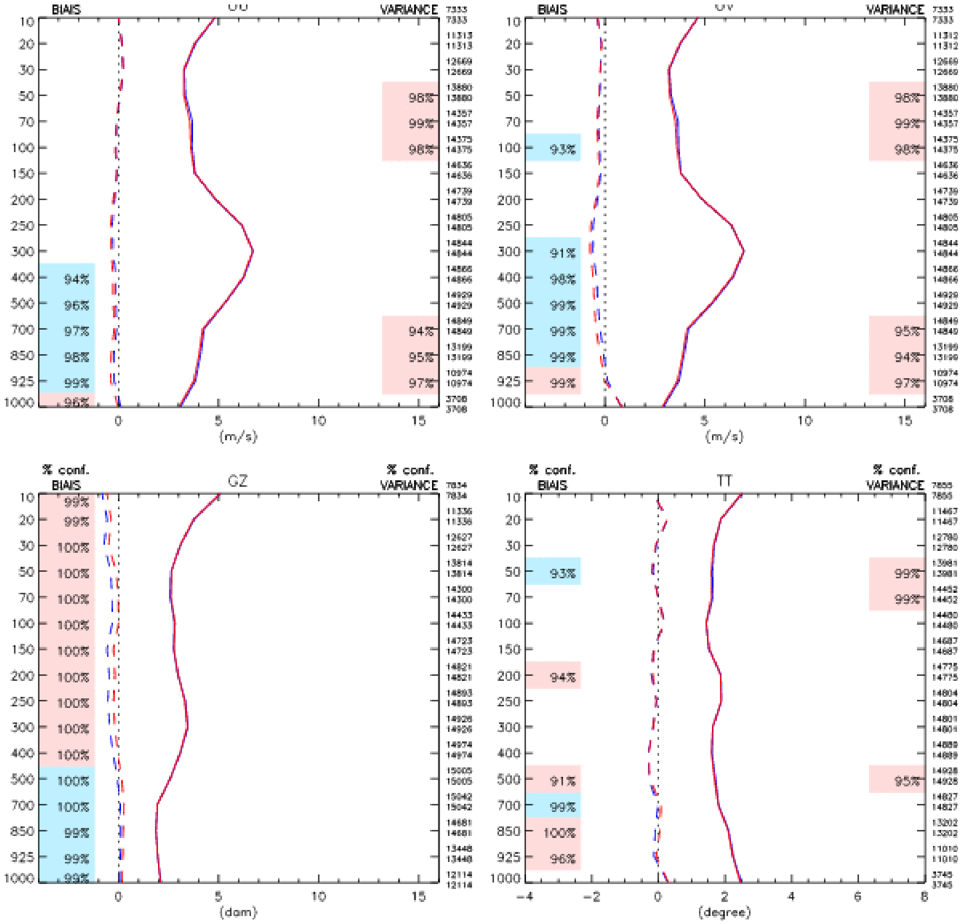


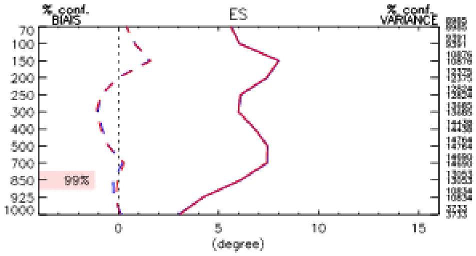


N. Hemisphere
Winter 2011
72 h
(by Michel R.)

Later tests with YY-25 km using new SGO scheme :

80 levels (bottom level @ 40m)
84 levels (bottom level @ 20m)





N. Hemisphere
Winter 2015
72 h
(by Michel R.)

Some recent references:

Elvidge, A.D., I. Sandu, N. Wedi, A. Zadra, S.B. Vosper, F. Bouyssel, M.A. Tolstykh, M. Ujiie, A. Beljaars, A. Van Niekerk, and S. Boussetta, 2019:
Uncertainty in the representation of orography in weather and climate models and implications for parameterized drag.
Journal of Advances in Modeling Earth Systems, 11. https://doi.org/10.1029/2019MS001661.

Sandu, I., A. van Niekerk, T.G. Shepherd, S. Vosper, A. Zadra, J. Bacmeister, A. Beljaars, A. Brown, A. Dornbrack, N. McFarlane, F. Pithan, G. Svensson, 2019:
Impacts of orography on large-scale atmospheric circulation.
Nature Perspectives Journal, Climate and Atmospheric Science, volume 2, Article number: 10 (2019)

Sandu, I., A. Zadra and N. Wedi, 2016:
Orographic drag impacts forecast skill.
ECMWF Newsletter Issue 150, Winter 2017.

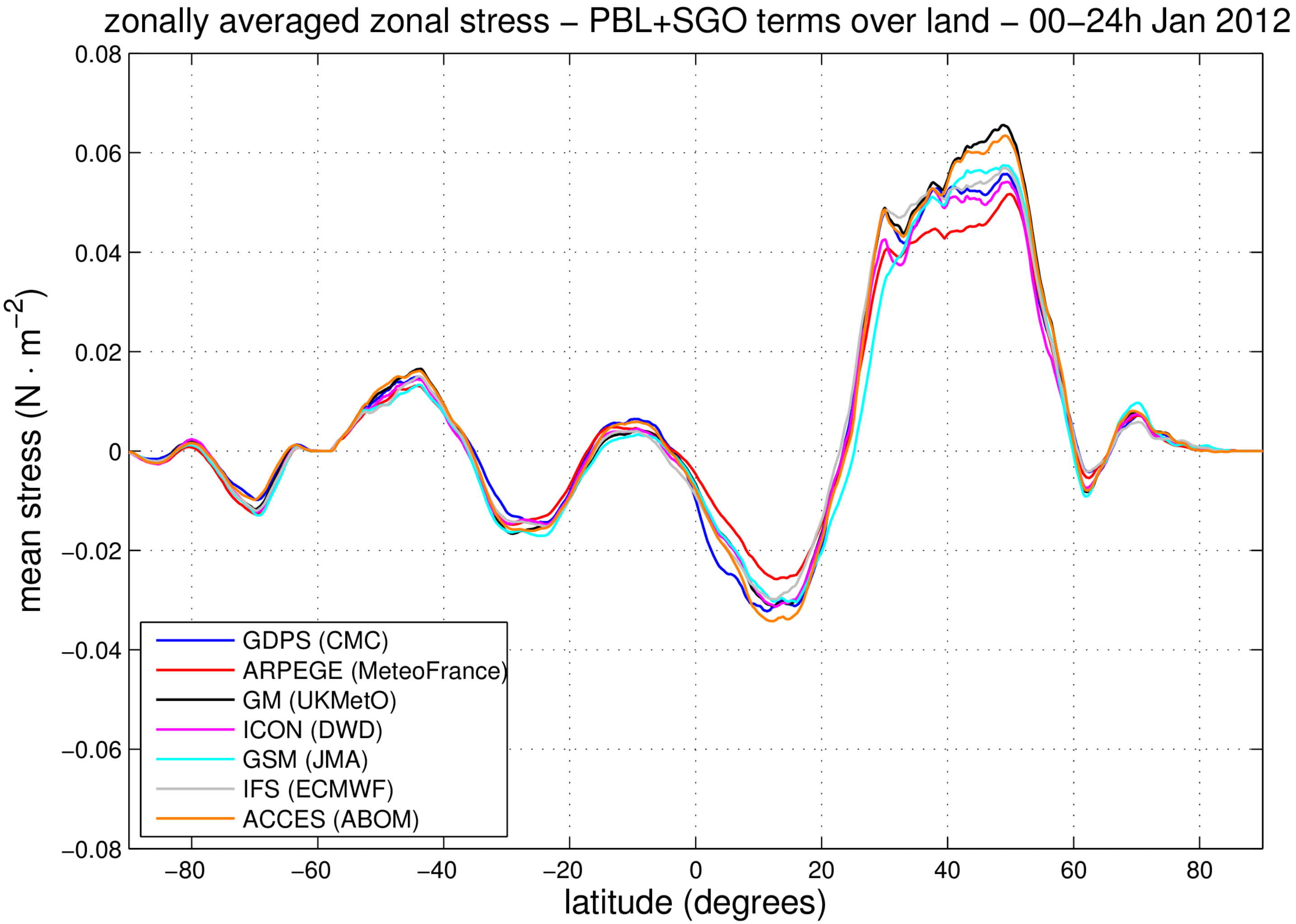
Sandu, I., P. Bechtold, A. Beljaars, A. Bozzo, F. Pithan, T.G. Shepherd and A. Zadra, 2015:
Impacts of parameterized orographic drag on the Northern Hemisphere winter circulation.
Journal of Advances in Modeling Earth Systems, 8, 196-211, doi:10.1002/2015MS000564.

WGNE Drag project:
https://collaboration.cmc.ec.gc.ca/science/rpn/drag_project/

GASS/WGNE COORDE project:
http://www.gewex.org/panels/global-atmospheric-system-studies-panel/gass-projects/

From the WGNE Drag inter-comparison project:

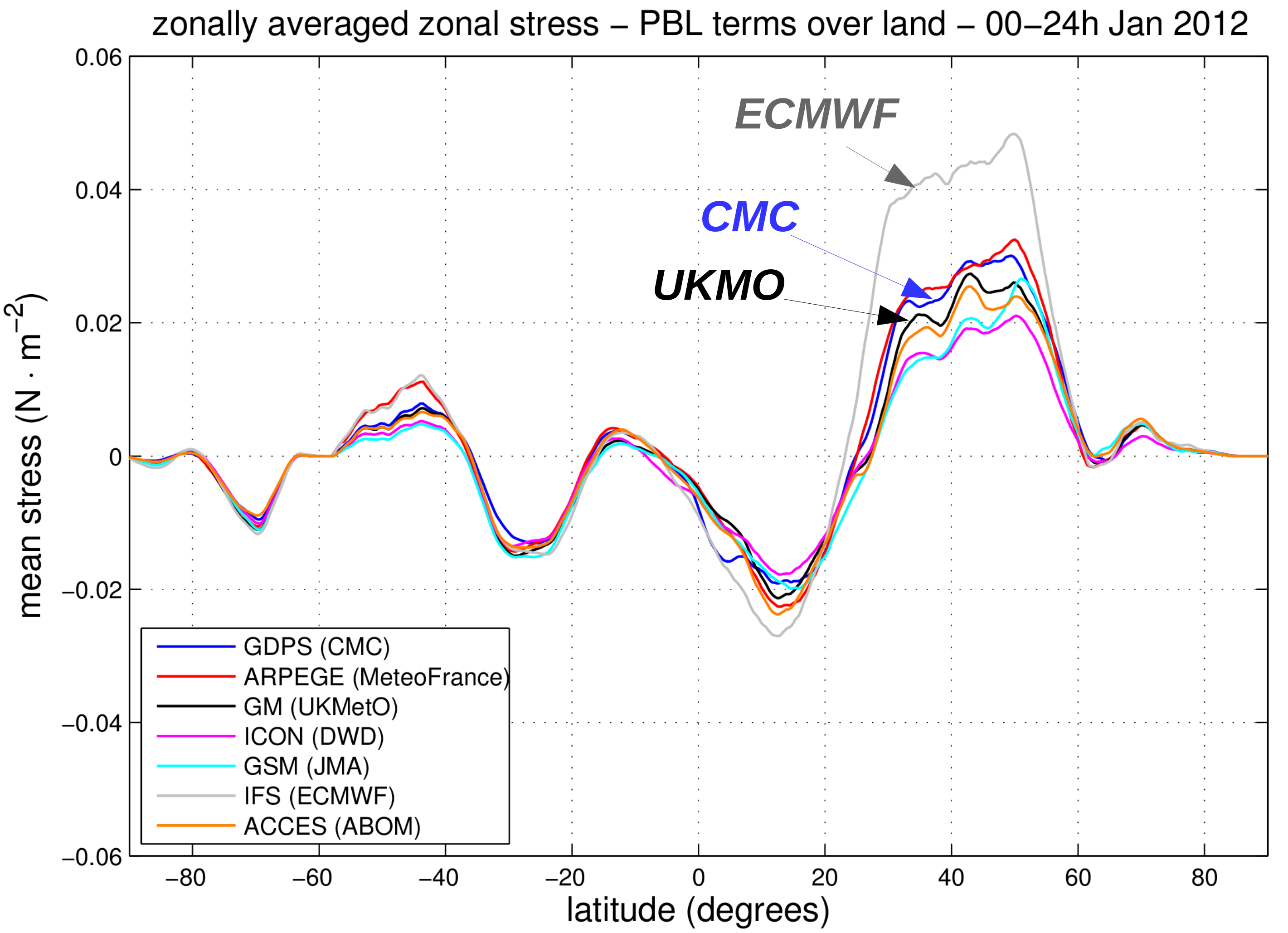
Zonal- & time-average of **parametrized component of zonal stress**



NOTE: ***GDPS (CMC) results shown in slides 17-23 are based on the "old" model configuration – i.e. before the latest (GEM5) version implemented in July 2019.***

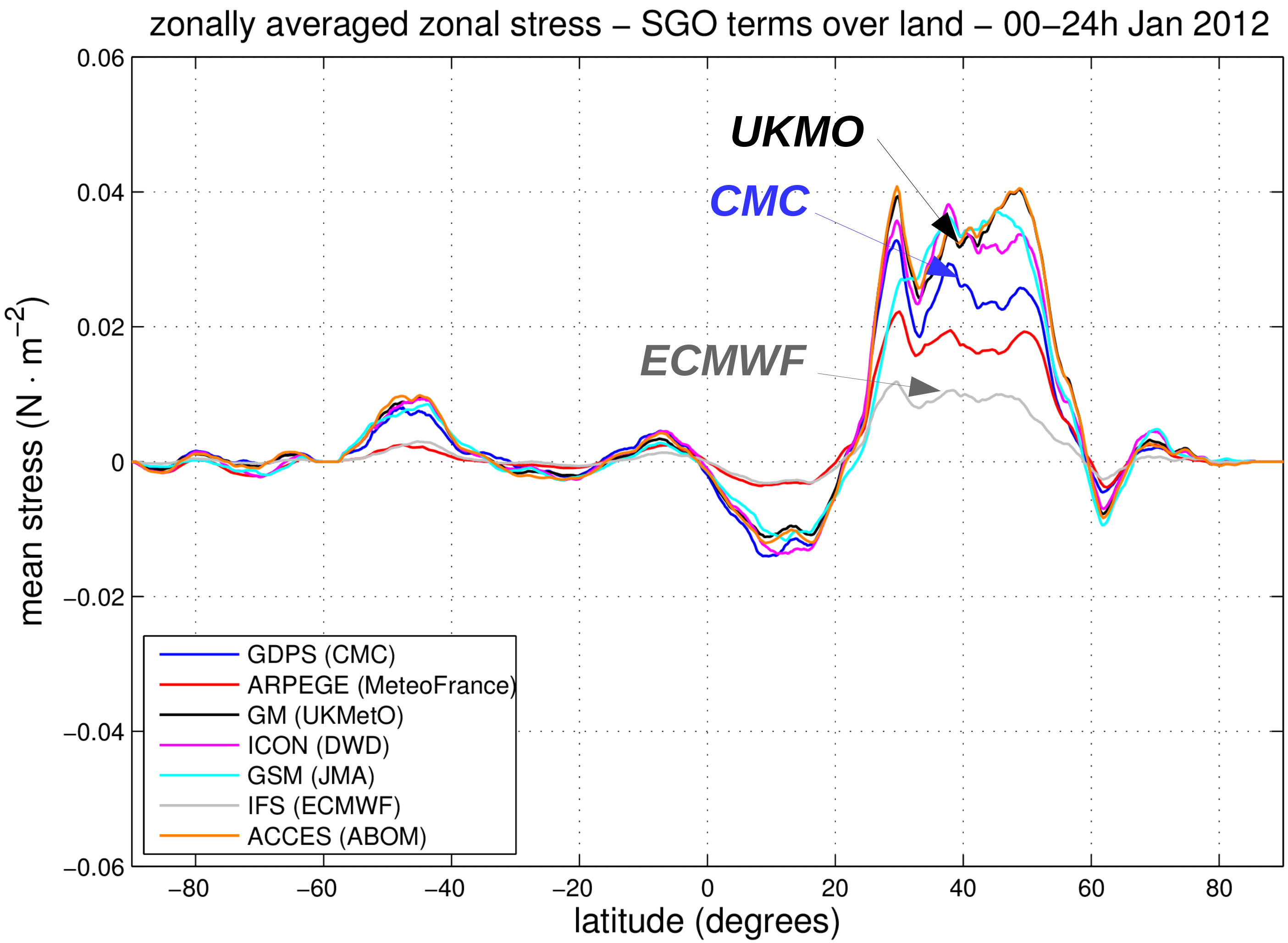
From the WGNE Drag inter-comparison project:

Zonal- & time-average of **zonal stress from PBL scheme**



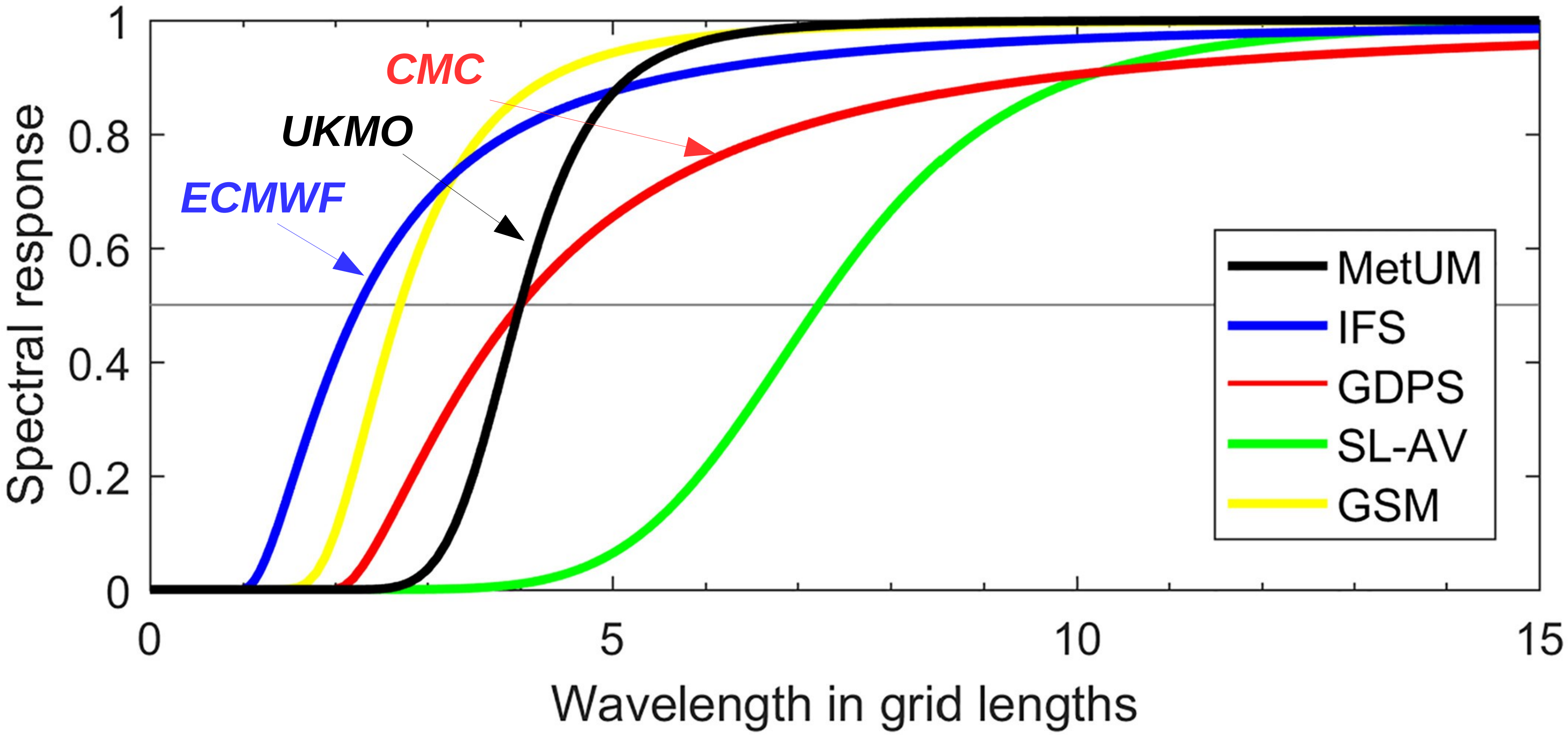
From the WGNE Drag inter-comparison project:

Zonal- & time-average of **zonal stress from SGO scheme**



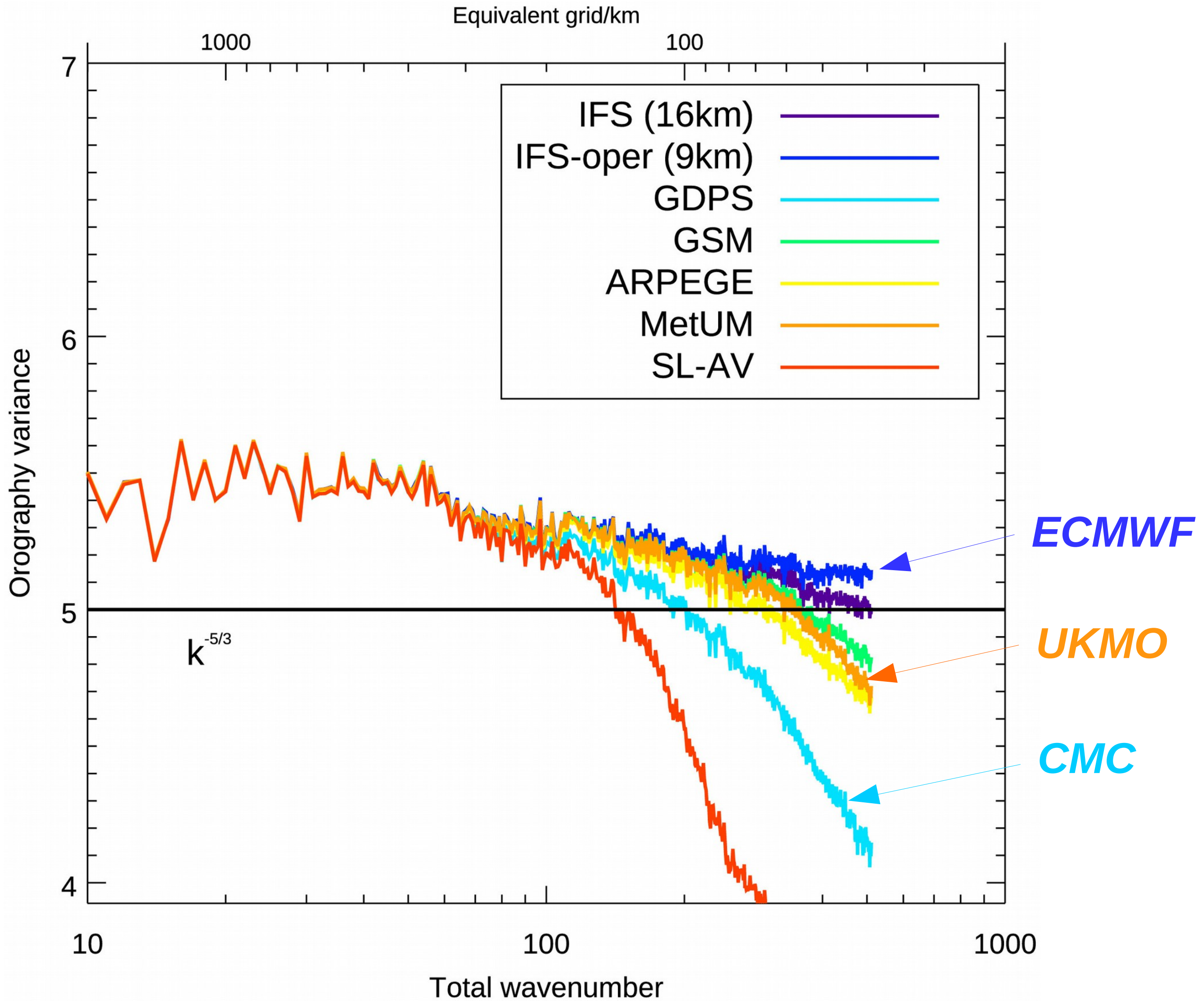
From **Elvidge et al. 2019:**

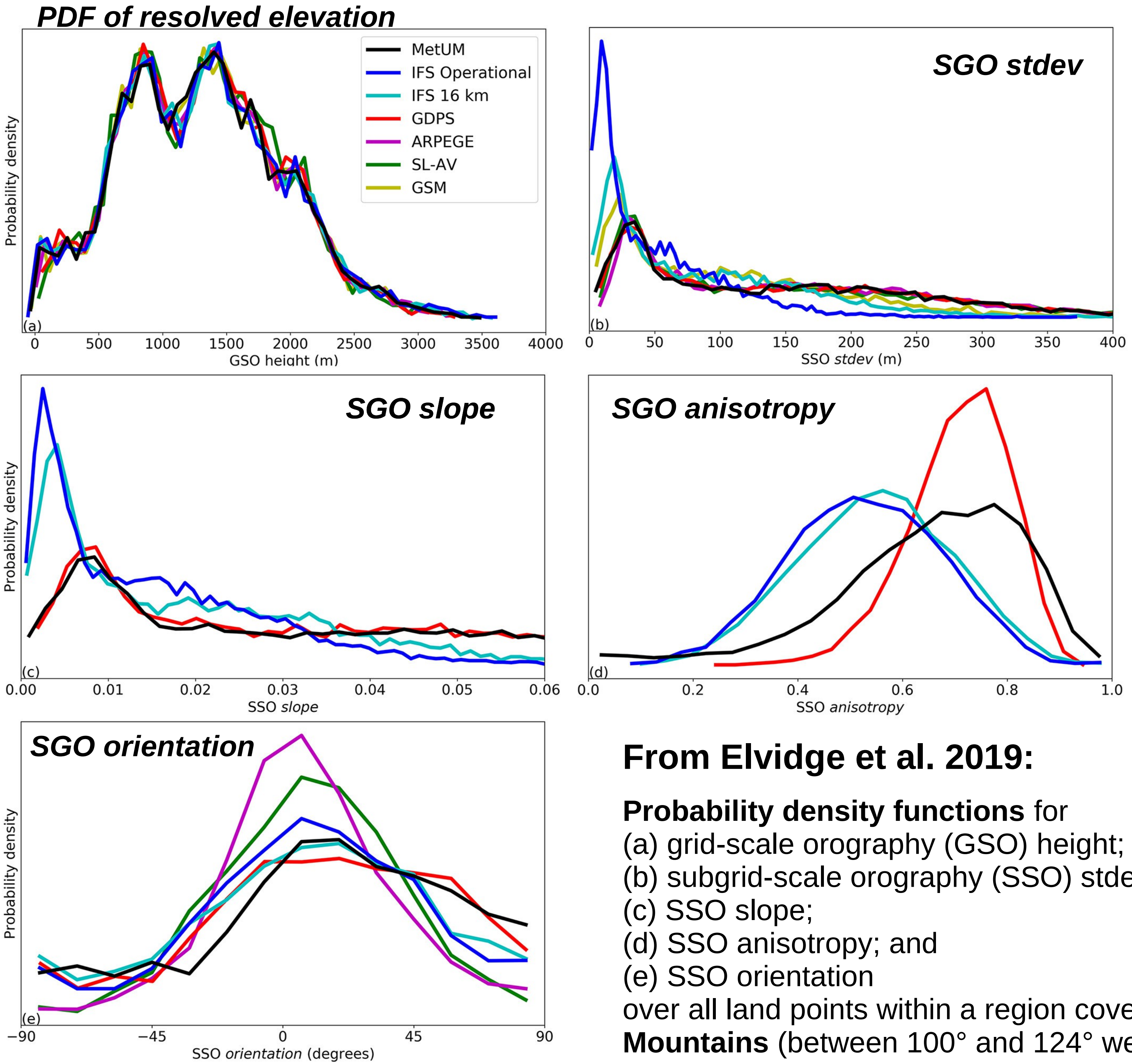
Response functions of the orographic filters applied in the MetUM, IFS, GDPS, SL-AV, and GSM to the pre-filtered source orography prior to the derivation of the subgrid-scale orography. Note the curve for ARPEGE is missing due to the filter it employs not lending itself to illustration in this form.



From **Elvidge et al. 2019:**

Variance of the global grid-scale orography (GSO) as a function of the total wave number, k, for all models. Note that, for clarity, all spectra are multiplied by k^(5/3). The horizontal line identifies k^(-5/3). For this plot the 0.25 × 0.25 degree gridded data have been spectrally truncated to 511 wavelengths (39 km at the equator).





Color code:

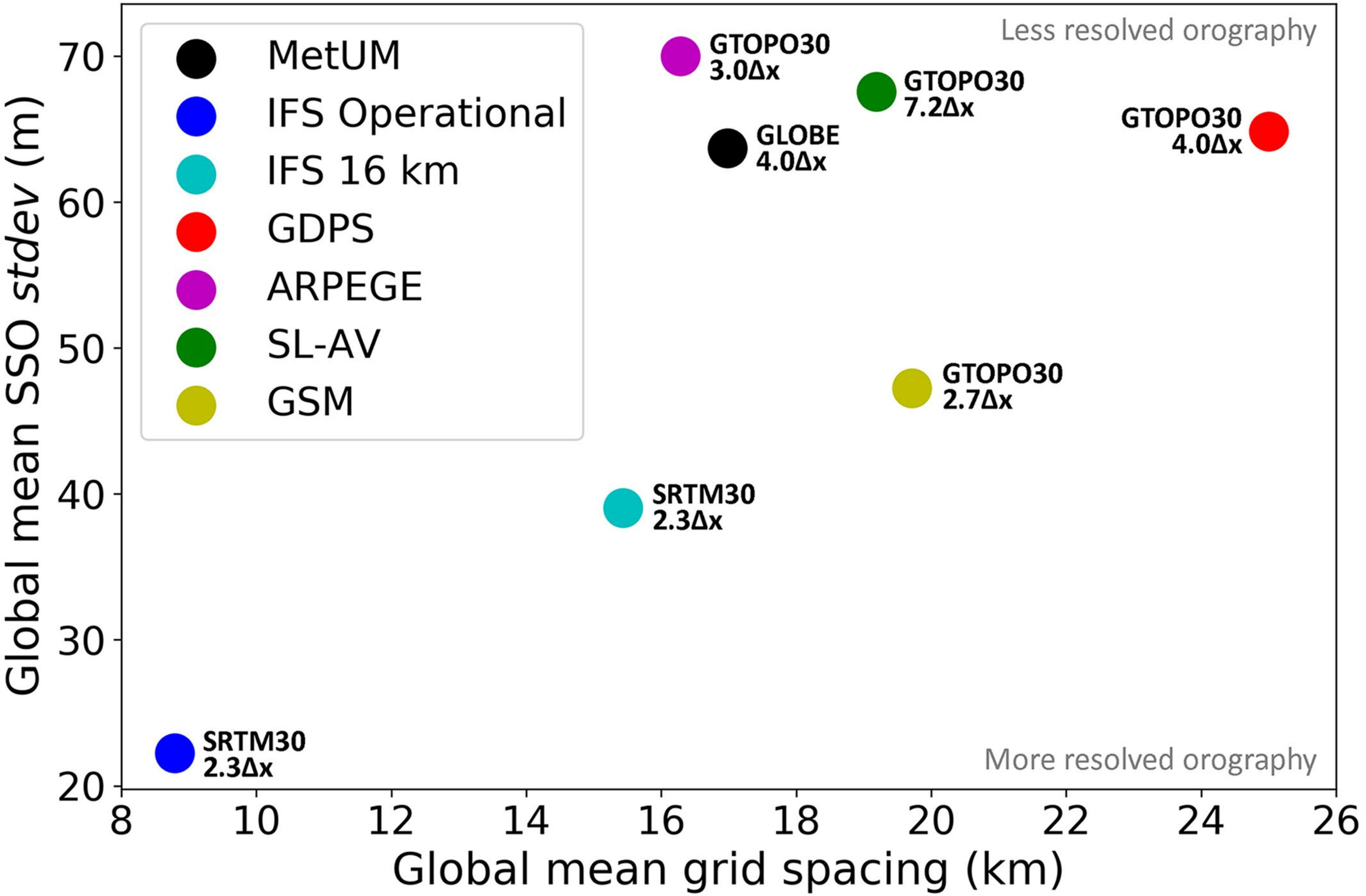
- ***ECMWF***
- ***UKMO***
- ***CMC***

From Elvidge et al. 2019:

Probability density functions for
(a) grid-scale orography (GSO) height;
(b) subgrid-scale orography (SSO) stdev;
(c) SSO slope;
(d) SSO anisotropy; and
(e) SSO orientation
over all land points within a region covering the **Rocky Mountains** (between 100° and 124° west and between 30° and 50° north), for each of the models (for which the respective field is available).

From **Elvidge et al. 2019:**

Global mean subgrid-scale orography (SSO) stdev as a function of global mean **model resolution.** Data points for each model are annotated by the main source orography data sets employed and the filter strengths used to smooth the grid-scale orography before deriving the SSO (where Δx refers to the model grid spacing).



From **Sandu, Zadra and Wedi 2016:**

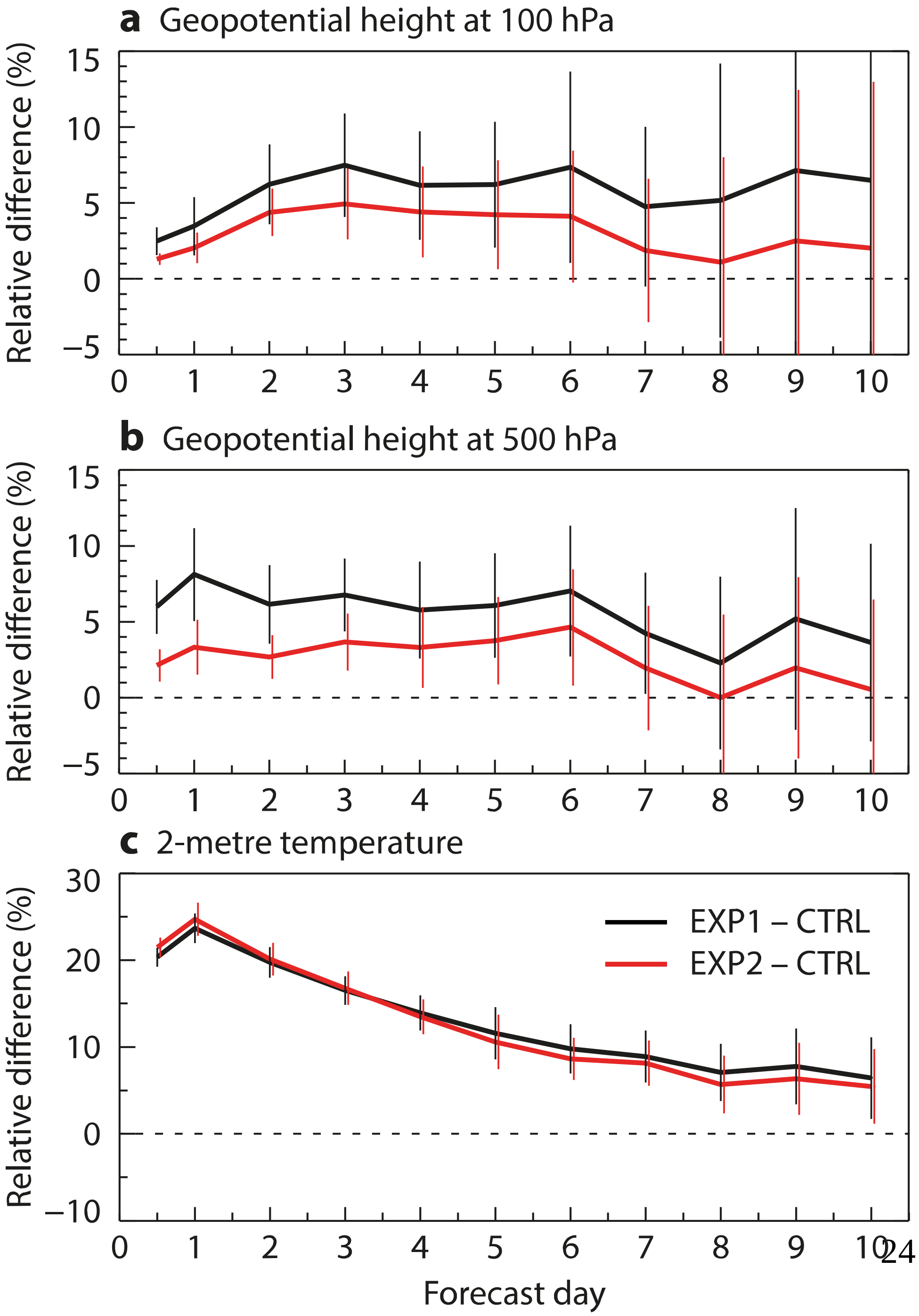
CTRL : IFS configuration at TL799 (~25km at equator)

EXP1 : CTRL + smoothed orography (TL255 or ~80km at equator)

EXP2 : CTRL + smoothed orography + adjusted subgrid-orography

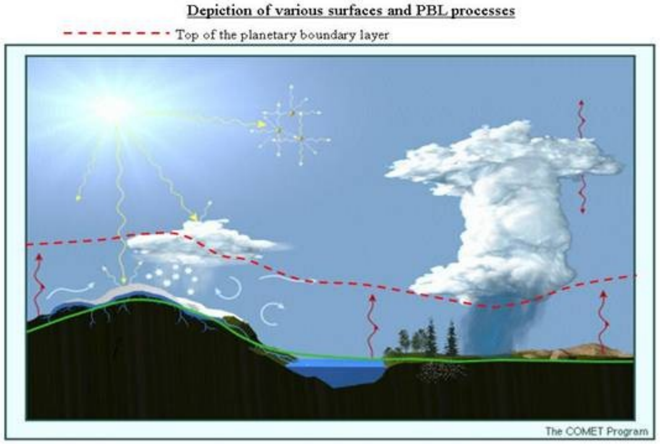
Relative difference in standard deviation (random error) between EXP1 and CTRL and between EXP2 and CTRL for forecasts of
(a) geopotential height at 100 hPa,
(b) geopotential height at 500 hPa, and
(c) 2-metre temperature

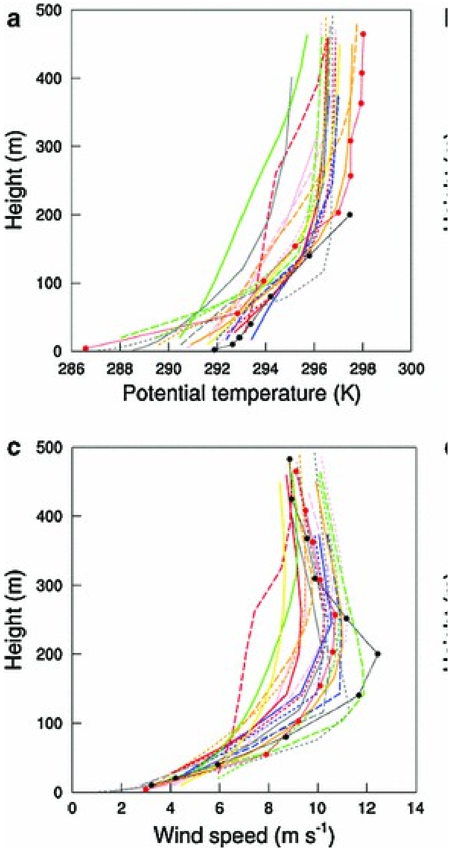
for the northern hemisphere extratropics (20°–90°N) in December 2015. A positive difference indicates a deterioration of the model performance in the experiment with respect to the CTRL. When error bars are entirely above/below the zero line, the performance of the respective experiment is significantly worse/better (95% confidence interval) than the CTRL. For all experiments the standard deviation was computed with respect to the corresponding analysis.



Novelties in the Planetary Boundary Layer (PBL) scheme:

- Acknowledgements:
  - *Ron McTaggart-Cowan, Paul Vaillancourt, Michel Roch, Stéphane Bélair, Stéphane Chamberland, Leo Separovic, Shawn Corvec, Danahé Paquin-Ricard, Alain Patoine*
- Major revision of PBL scheme (an evolved “moistke”)
  - code re-factoring
  - cloud turbulence effects and radiative interactions have been adjusted
  - dissipative heating included
  - energy/water conservation verified
- Mixing and dissipation lengths:
  - a turbulence regime-dependent mixing length is introduced
  - more accurate estimate of integrals (e.g. in the Bougeault-Lacarrere formulation)
  - adjustable relaxation time-scale for mixing length
  - optional upper limit (50m) to dissipation length
- Other novelties:
  - new class of scheme is introduced to represent turbulent orographic form drag (TOFD; Beljaars et al. 2004); an alternative to the orographic roughness approach
  - effects of non-local cloud mixing can be estimated by “moistke”
  - new classes of stability functions available
  - new PBL depth/height calculation implemented





Potential temperature and wind profiles from the “Third GABLS Intercomparison Case for Evaluation Studies of Boundary-Layer Models”. Bosveld and Co-authors, 2014, Boundary-Layer Meteorology, Volume 152, Issue 2, pp 157–187

Turbulent fluxes and PBL tendencies

generic variable that is vertically mixed by turbulence

$$\left(\frac{\partial\psi}{\partial t}\right)_{pbl} = -\frac{1}{\rho}\frac{\partial}{\partial z}\left(\rho\,\overline{w'\psi'}\right)$$

PBL tendency

novelty: optional non-local term

$$\overline{w'\psi'} = -K_\psi\left(\frac{\partial\psi}{\partial z} - \gamma_\psi\right) + N_\psi$$

vertical component of turbulent flux

eddy diffusivity

optional counter-gradient term

Diffusion coefficients:

1. for momentum variables

$$\boxed{K_M = c\,\lambda\sqrt{E}}$$

c = 0.516

λ = mixing length

E = turbulent kinetic energy TKE (prognostic equation)

2. for scalars:

$$\boxed{K_T = \frac{K_m}{Pr}}$$

$Pr = \frac{\phi_T(Ri)}{\phi_M(Ri)}$ ***= Prandtl number***

Ri ***= gradient Richardson number***

ϕ_M, ϕ_T ***= stability functions***

Turbulent fluxes and PBL tendencies

generic variable that is vertically mixed by turbulence

novelty: optional non-local term

$$\left(\frac{\partial\psi}{\partial t}\right)_{pbl} = -\frac{1}{\rho}\frac{\partial}{\partial z}\left(\rho\,\overline{w'\psi'}\right)$$

$$\overline{w'\psi'} = -K_{\psi}\left(\frac{\partial\psi}{\partial z} - \gamma_{\psi}\right) + N_{\psi}$$

PBL tendency

vertical component

ity

optional counter-gradient term

Main novelties:

- new families of stability functions available
- optional dissipative heating available for temperature tendency
- optional non-local term available

Diffusion coeffic

1. for momentum varia

$$\boxed{K_M = c\,\lambda\sqrt{}}$$

equation)

2. for scalars:

$$\boxed{K_T = \frac{K_m}{Pr}}$$

$Pr = \frac{\phi_T(Ri)}{\phi_M(Ri)}$ ***= Prandtl number***

Ri ***= gradient Richardson number***

ϕ_M, ϕ_T ***= stability functions***

Conservative (diffused) variables and PBL cloud scheme

1. **Momentum:** horizontal wind components (*u*,*v*) only

2. **Heat and moisture***

$$\theta_l = \theta - \frac{L}{c_p \Pi} q_c$$ ← *proportional to liquid/ice water static energy* $c_p T - L q_c$

$$q_t = q_v + q_c$$ ← *total water, vapor plus condensate*

Includes 3 cloud paramaters:

qc (PBL cloud condensate)
N (PBL cloud fraction)
FNN (flux enhancement factor)

which are implemented as empirical functions of the *normalized saturation surplus* Q_1

The cloud condensate and the cloud fraction estimates are passed on to and used by the radiate transfer scheme.

qc

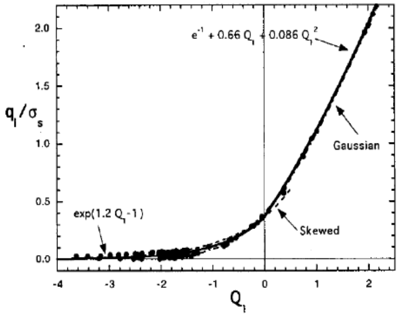


FIG. 4. The normalized cloud water content as a function of Q_1. The full line is Eq. (9b); the dashed–dotted line is the parameterized cloud water content using the Gaussian model; the dashed line is based on the skewed model [Eq. (8b)].

N

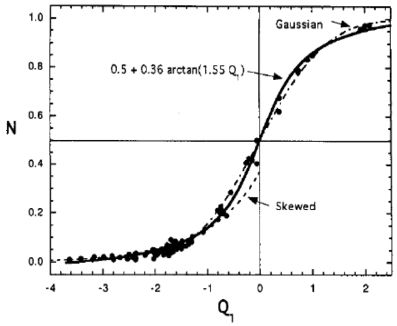


FIG. 3. The partial cloudiness *N* as a function of Q_1. The full line is Eq. (9a); the dashed–dotted line is the parameterized cloud fraction using the Gaussian model; the dashed line is based on the skewed model [Eq. (8a)].

FNN

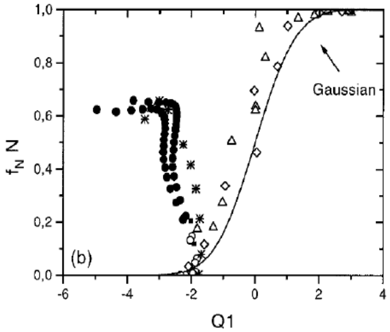


FIG. 4. As in Fig. 3 but for the coefficients f_N (a) and $f_N N$ (b). Additionally, cloud base values for the BOMEX case are denoted by open circles.

(from Cuijpers and Bechtold 1995, and Bechtold and Siebesma 1998)

Conservative (diffused) variables and PBL cloud scheme

1. **Momentum:** horizontal wind components (*u*,*v*) only

2. **Heat and moisture***

$$\theta_l = \theta - \frac{L}{c_p\Pi} q_c$$

proportional to liquid/ice water static energy $c_pT - Lq_c$

$$q_t = q_v +$$

Main novelties:

- vertical extent of PBL <u>cloud properties limited to the PBL depth</u>
- PBL <u>cloud effects</u> assumed to be <u>driven by surface</u>

Includes 3 cloud

qc (PBL cloud c

N (PBL cloud fra

FNN (flux enhan

which are implem
empirical functio
the *normalized saturation
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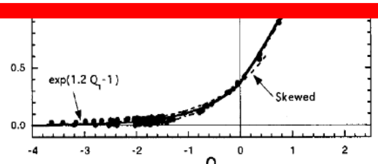
The cloud condensate and the cloud fraction estimates are passed on to and used by the radiate transfer scheme.



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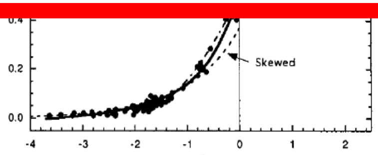


FIG. 3. The partial cloudiness N as a function of Q_1. The full line is Eq. (9a); the dashed–dotted line is the parameterized cloud fraction using the Gaussian model; the dashed line is based on the skewed model [Eq. (8a)].

FNN

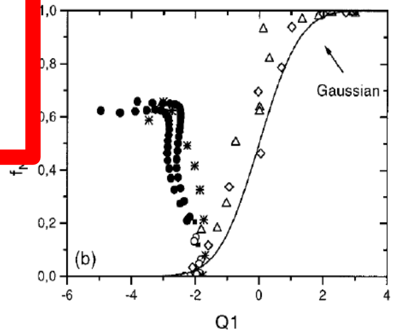


FIG. 4. As in Fig. 3 but for the coefficients f_N (a) and $f_N N$ (b). Additionally, cloud base values for the BOMEX case are denoted by open circles.

(from Cuijpers and Bechtold 1995, and Bechtold and Siebesma 1998)

Mixing and dissipation lengths

Two options were available until recently (and used by different systems):

1. Blackadar's formulation:

- based on *Blackadar JGR 1962*, with asymptotic neutral value of 200m
- $\lambda_{diss} = \lambda_{blac}$

2. Bougeault & Lacarrere's formulation:

- based on *Bougeault and Lacarrere MWR 1989* (use the minimum between up- and down-estimates of mixing length, based on buoyant displacements for a given TKE)
- result is then blended with Blackadar's estimate near the surface and above 450 hPa
- dissipation/mixing length relation depends on flux Richardson number

$$\lambda_{diss} = \lambda_{blend}\left(\frac{1-a_2}{1-2a_2}\right) \quad , \quad a_2 = \min(R_f, 0.4)$$

Mixing and dissipation lengths

Two options were available until recently (and used by different systems):

1. **Blackadar'**
   - based on n
   - $\lambda_{diss} =$
2. **Bougeault**
   - based on ween up- and down-est r a given TKE)
   - result is t above 450 hPa
   - dissipatio r

$$\lambda_{diss} = \lambda_{blend}\left(\frac{1-a_2}{1-2a_2}\right) \quad , \quad a_2 = \min(R_f, 0.4)$$

Main novelties:

- new, regime-dependent option ('**turboujo**') for mixing and dissipation lengths:
  - *if the regime is <u>LAMINAR</u>, then take the <u>Blackadar</u> estimate*
  - *if the regime is <u>TURBULENT</u>, then take the <u>Bougeault-Lacarrere</u> estimate*
- more accurate estimate of integrals in the Bougeault-Lacarrere formulation
- adjustable relaxation time-scale for mixing length
- mixing length estimate based on Lenderink and Holtslag (2004) also available

TKE equation

From Mailhot and Benoit (1982) and Benoit et al. (1989):

$$\boxed{\frac{dE}{dt} = B\,E^{1/2} - C\,E^{3/2} + \frac{\partial}{\partial z}\left(K_M \frac{\partial E}{\partial z}\right)}$$

$$E = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)$$

$$B = c\lambda\left(1 - R_f\right)\left|\frac{\partial \mathbf{V}}{\partial z}\right|^2$$ *(shear production and buoyancy term)*

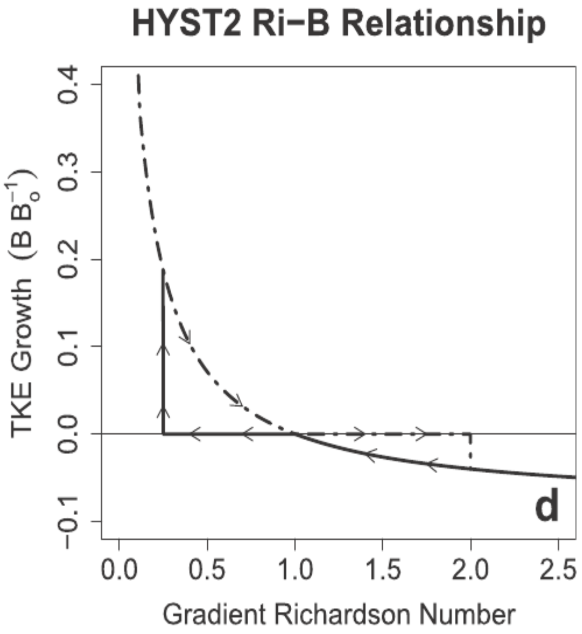
$$C = \frac{0.14}{\lambda_{diss}}$$ *(dissipation term)*

$$R_f = \frac{Ri}{Pr}$$ *(flux Richardson number)*

Note:
- advection of TKE available but currently not used
- optional Richardson number hysteresis available
- TKE equation solved implicitly

$$\frac{E^+ - E^*}{\Delta t} = \frac{\partial}{\partial z}\left(K_M^- \frac{\partial E^+}{\partial z}\right)$$

where E^* is the analytical solution of $\frac{\partial E}{\partial t} = B \cdot E^{1/2} - C \cdot E^{3/2}$



B-Ri relation with hysteresis, from McTaggart-Cowan and Zadra 2014

TKE equation

From Mailhot and Benoit (1982) and Benoit et al. (1989):

$$\boxed{\frac{dE}{dt} = B\,E^{1/2} - C\,E^{3/2} + \frac{\partial}{\partial z}\left(K_M \frac{\partial E}{\partial z}\right)}$$

$$E = \frac{1}{2}\left(\overline{u'^2} + \overline{v'^2} + \overline{w'^2}\right)$$

$$B = c\lambda\,(1 - R_f)\left|\frac{\partial \mathbf{V}}{\partial z}\right|^2$$

(shear production and buoyancy term)

$$C = \frac{0.14}{\lambda_{diss}}$$

$$R_f = \frac{Ri}{Pr}$$

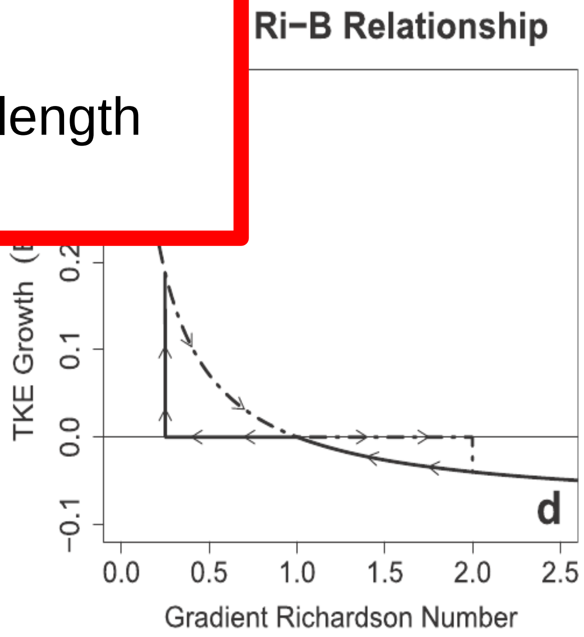
Main novelty:

- optional upper limit (50m) to dissipation length

Note:
- advection of TKE available but currently not used
- optional Richardson number hysteresis available
- TKE equation solved implicitly

$$\frac{E^+ - E^*}{\Delta t} = \frac{\partial}{\partial z}\left(K_M^- \frac{\partial E^+}{\partial z}\right)$$

where *E** is the analytical solution of $\frac{\partial E}{\partial t} = B \cdot E^{1/2} - C \cdot E^{3/2}$



B-Ri relation with hysteresis, from McTaggart-Cowan and Zadra 2014

Impact of the new mixing length formulation

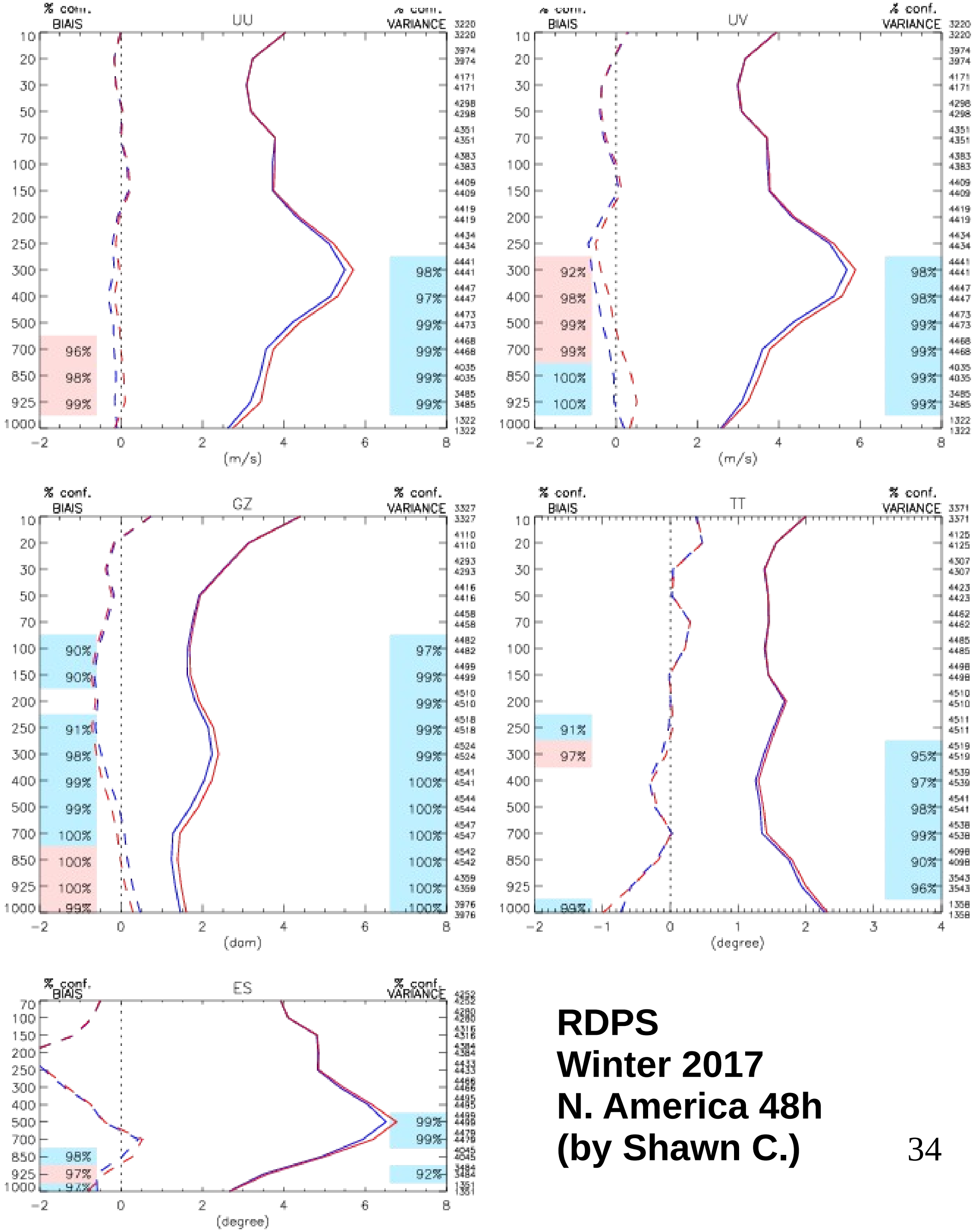
- The new “hybrid”, regime-dependent mixing mixing length **turboujo** was one of the ingredients that finally allowed the “unification” of the physics configurations of the GDPS and RDPS – in average producing equivalent or better results than the individual versions

- The figure on the right compares scores from 2 experiments produced with the RDPS (GEM5), using the operational mixing length (**blackadar**) versus the new formulation (**turboujo**)

- It was also shown that he new mixing length led to significantly improved forecasts (track and intensity) of extra-tropical cyclones and storm track in the RDPS.

RDPS – mixing length sensitivity test

turboujo versus blackadar



RDPS
Winter 2017
N. America 48h
(by Shawn C.)

Dissipative heating in the PBL scheme

- also implemented in the SGO scheme
- same approach is used by the IFS (ECMWF), both for their SGO and PBL schemes
- main impact is <u>warming of boundary layer</u>, mostly in winter
- leads to significant <u>reduction of cold bias at surface and in lower troposphere</u>
- no impact in error standard deviation for most scores

kinetic energy

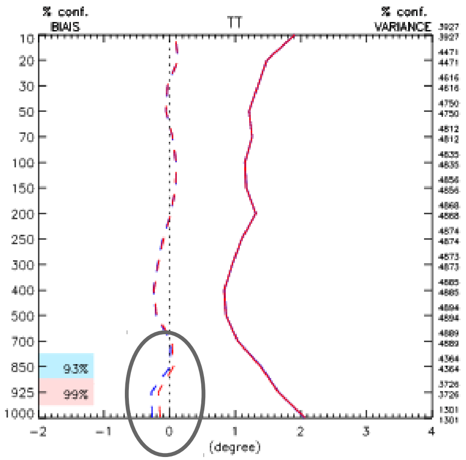
$$K = \frac{1}{2}\left(u^2 + v^2\right)$$

$$\underbrace{\left(\frac{\partial T}{\partial t}\right)^{diss}_{pbl} = -\frac{1}{c_p}\left(\frac{\partial K}{\partial t}\right)_{pbl}}$$

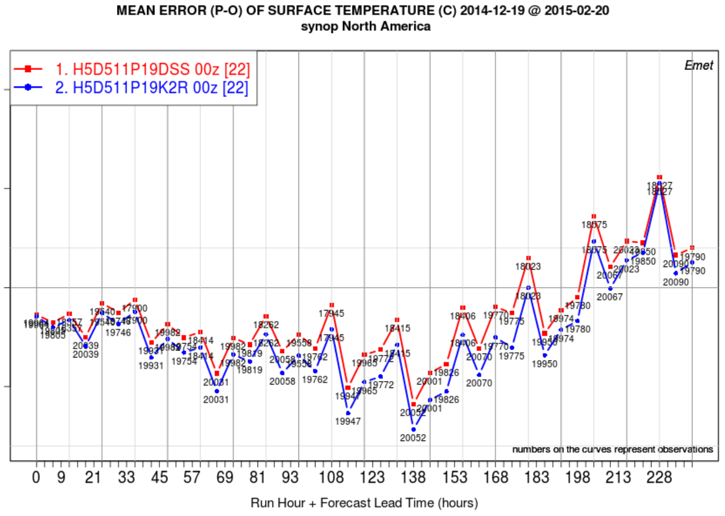
kinetic energy loss due to turbulence is locally converted into heat

Sensitivity tests @ 25km

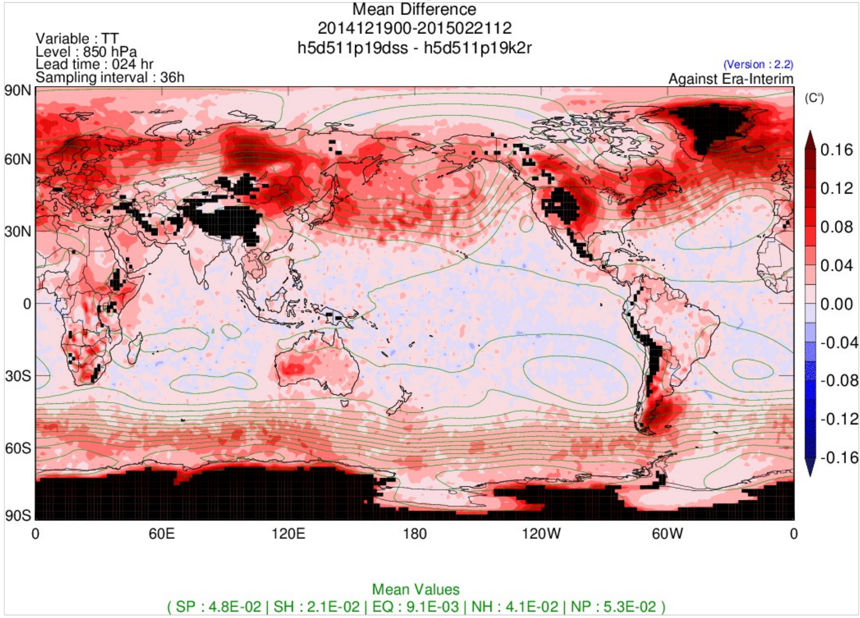
ARCAD, TT 24h
N. America, winter



EMET, T-2m
N. America, winter



VERDICT – TT 850hPa difference winter, 24h

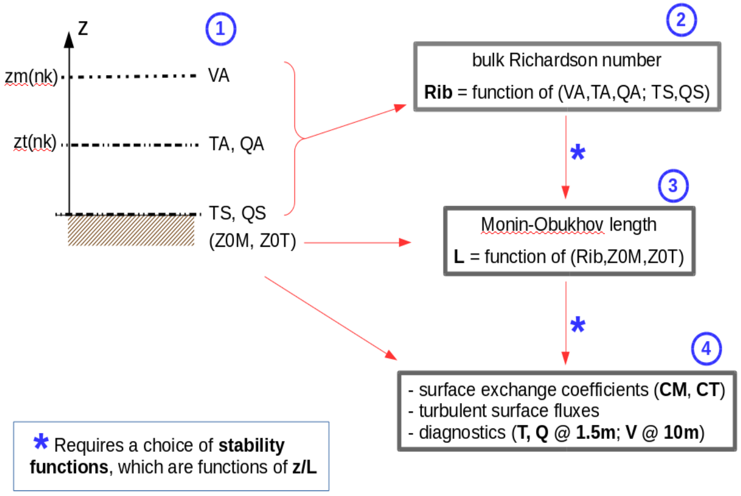


Surface-PBL interactions:

novelties for calculation of turbulent fluxes and diagnostics

- Acknowledgements:
  - *Ron McTaggart-Cowan, Michel Roch, Paul Vaillancourt, Jing Yang, Stéphane Bélair, Stéphane Chamberland, Leo Separovic, Shawn Corvec, Sylvain Heilliette, François Lemay, Thierry Husson, Nicolas Gasset, Maria Abrahamowicz*
- New **surface layer module**
  - gathers together all surface layer calculations (i.e. fluxes, exchange coefficients, screen-level diagnostics)
  - allows surface layer calculations at any point within the physics package and in external utilities
  - used by all surface schemes (e.g. land, water, glacier, sea-ice) and other schemes (e.g. radiation)
  - new classes of stability functions available
  - new diagnostics available (e.g. T2m from land fraction only)
- Over **land**
  - new approach available to reduce decoupling issues, based on Obukhov length
  - new climatology of emissivity available
  - adjustment in ISBA to improve freezing rain forecasts (see Ron's talk)
- Over **water**
  - new options of roughness length for momentum (z0m) and temperature/moisture (z0t) available
  - new diurnal-SST scheme available (see Ron's talk)

Overview of the scheme...



bulk Richardson number
Rib = function of (VA,TA,QA; TS,QS)

Monin-Obukhov length
L = function of (Rib,Z0M,Z0T)

- surface exchange coefficients (**CM**, **CT**)
- turbulent surface fluxes
- diagnostics (**T, Q @ 1.5m**; **V @ 10m**)

* Requires a choice of **stability functions**, which are functions of **z/L**

Here are some of the tested and adopted choices in GEM5 (phase-2) configurations:

sl_lmin_soil = 20.
sl_func_stab = 'beljaars91'
isba_soil_emiss = 'climato'

salty_qsat = .true.
z0mtype = 'beljaars'
z0ttype = 'deacu12'
diusst = 'fairall'

Note: Latitudinal ramp for Z0T not adopted.

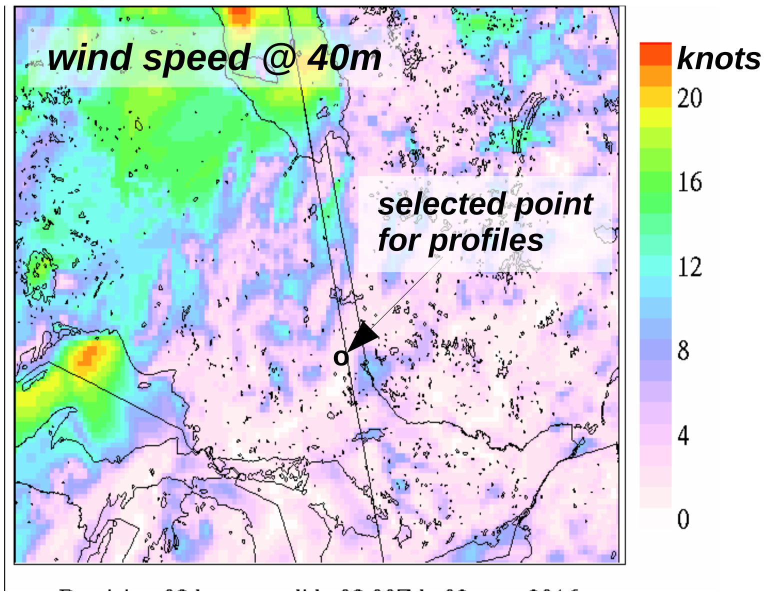
An alternative to the constant minimum wind (*VAmin*) for ISBA / SVS

- The wind speed **VA** at the lowest prognostic level is one of the inputs needed for the calculation of (turbulent) surface fluxes and screen-level diagnostics
- In the old configuration of the operational systems, a constant minimum wind speed **VAmin** = 2.5 m/s was imposed by the land scheme (i.e. ISBA) for those calculations, in an attempt to reduce decoupling in cases of light wind.
- An alternative to this approach is now available, based on values of the Obukhov length (***L***):

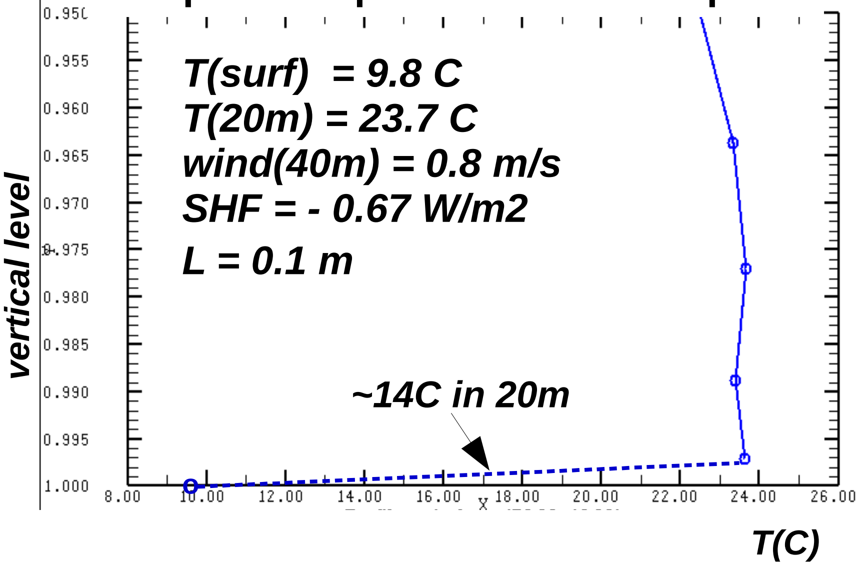
$$L \sim \frac{(\text{momentum flux})^{3/2}}{(\text{bouyancy flux})}$$

- Small values of ***L*** (e.g. less than 20m) usually indicate weak turbulent fluxes, i.e. weak coupling (decoupling) between surface and PBL.

Light wind case study (02-Aug-2016 09Z)



Temperature profile at selected point



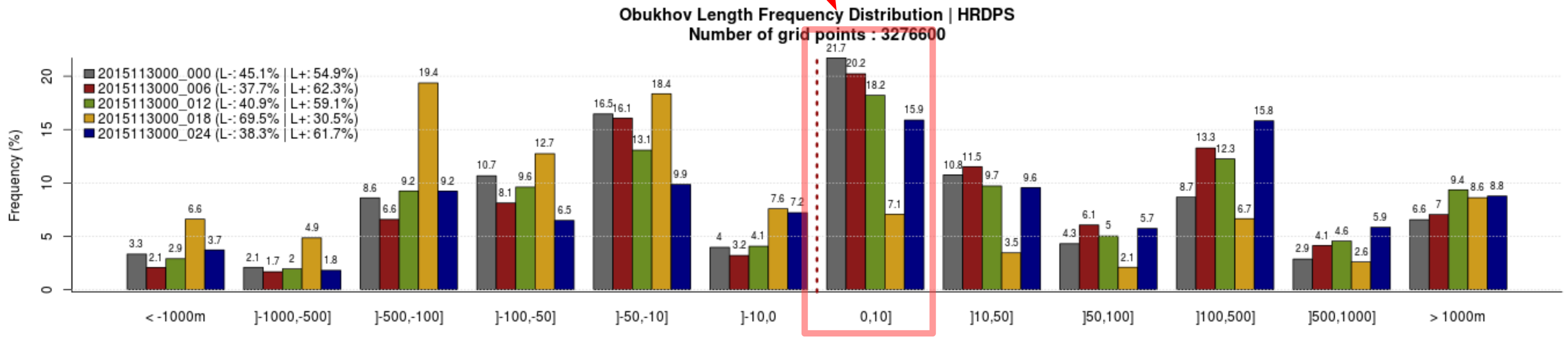
T(surf) = 9.8 C
T(20m) = 23.7 C
wind(40m) = 0.8 m/s
SHF = - 0.67 W/m2
L = 0.1 m

~14C in 20m

- In the new approach, the input value of the wind speed **VA** is adjusted:
  - such that ***L*** is always larger than a chosen minimum value (***Lmin***)
  - only when/where it is necessary to prevent decoupling

From the report « **Importance et détermination d’une plage de validité de la longueur d’Obukhov dans le modèle de dispersion atmosphérique MLCD »** by Philipe Barneoud, SRUE, CMC, 2015.

Recommendation from the report : « *Le seuil minimal* ***Lmin = 20m*** *devrait être appliqué sur la longueur d’Obukhov utilisée par le modèle MLCD (provenant du champ IO ou calculé en post-traitement selon la méthode des flux)* »



“decoupling” symptom
(0 < L < 10m)

Figure*: Frequency distribution of Obukhov length: single winter case of HRDPS; leadtime = 0, 6, 12, 18 and 24h. Note that up to 20% of gridpoints exhibit “decoupling” symptoms.*

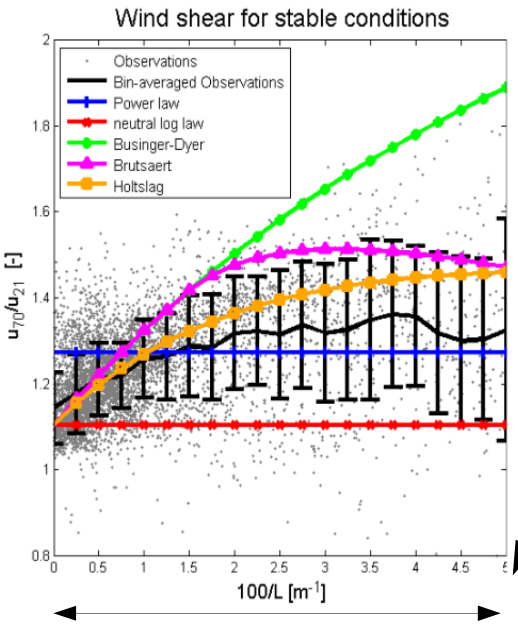
Observations suggest that values of <u>L < 20m</u>

(or equivalently 1/L > 0.05 m^-1)

are <u>rare</u>.

From Holtslag et al. 2014, J. Phys.: Conf. Ser. 555 012052:

Black dots indicate observed values of the (inverse) Obukhov length (100/L, m^-1, on the x-axis) versus a normalized wind shear (y-axis).



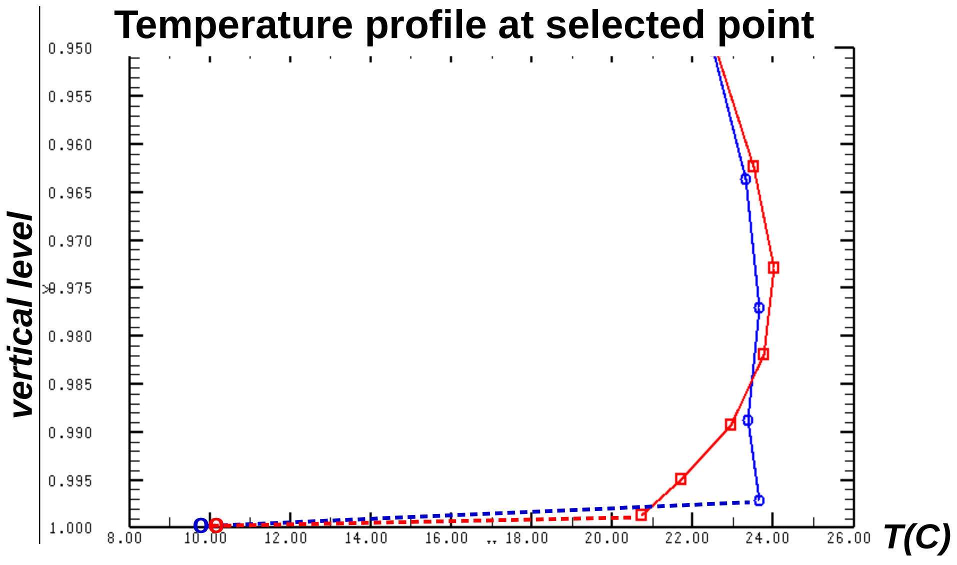
weakly stable

strongly stable

corresponds to L = 20m

Some advantages of the new approach:
- it appears to be more efficient in reducing the problem of “decoupling”
- being based on ***L*** (which is defined at the surface) makes the approach independent of vertical resolution; and it seems to reduce the sensitivity to vertical resolution

Using old approach


Temperature profile at selected point

with 80 levels:

T(surf) = 9.8 C
T(20m) = 23.7 C
➡ *(14 C in 20 m)*
wind(40m) = 0.8 m/s
SHF = - 0.67 W/m2

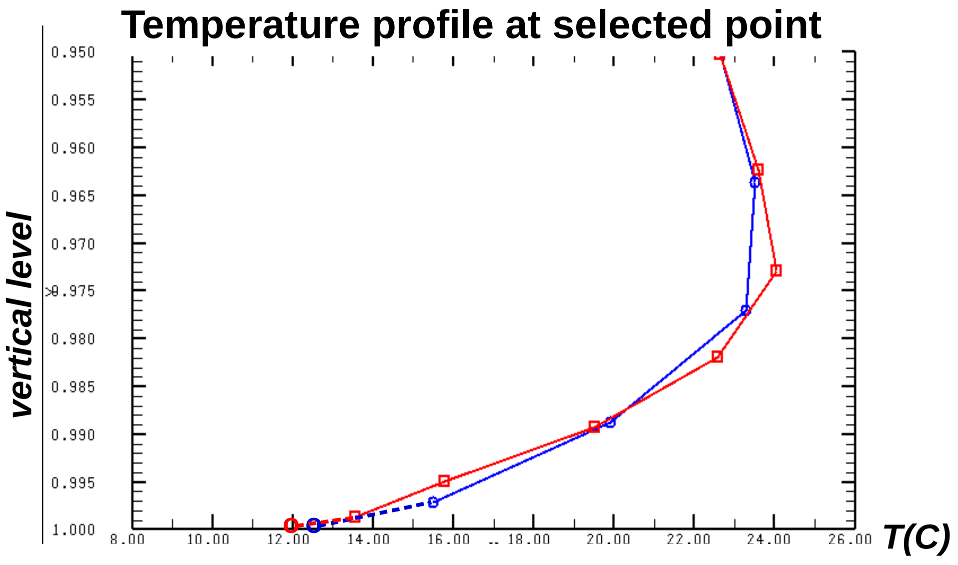
L ~ 0.1 m

with 84 levels:

T(surf) = 10.1 C
T(10m) = 20.7 C
➡ *(10 C in 10 m)*
wind(20m) = 0.7 m/s
SHF = - 0.27 W/m2

L ~ 0.1 m

Using new approach with Lmin = 20m


Temperature profile at selected point

with 80 levels:

T(surf) = 12.5 C
T(20m) = 15.5 C
➡ *(3 C in 20 m)*
wind(40m) = 0.3 m/s
SHF = - 23 W/m2

L ~ 20 m

with 84 levels:

T(surf) = 12 C
T(10m) = 13.5 C
➡ *(1.5 C in 10 m)*
wind(20m) = 0.4 m/s
SHF = - 18 W/m2

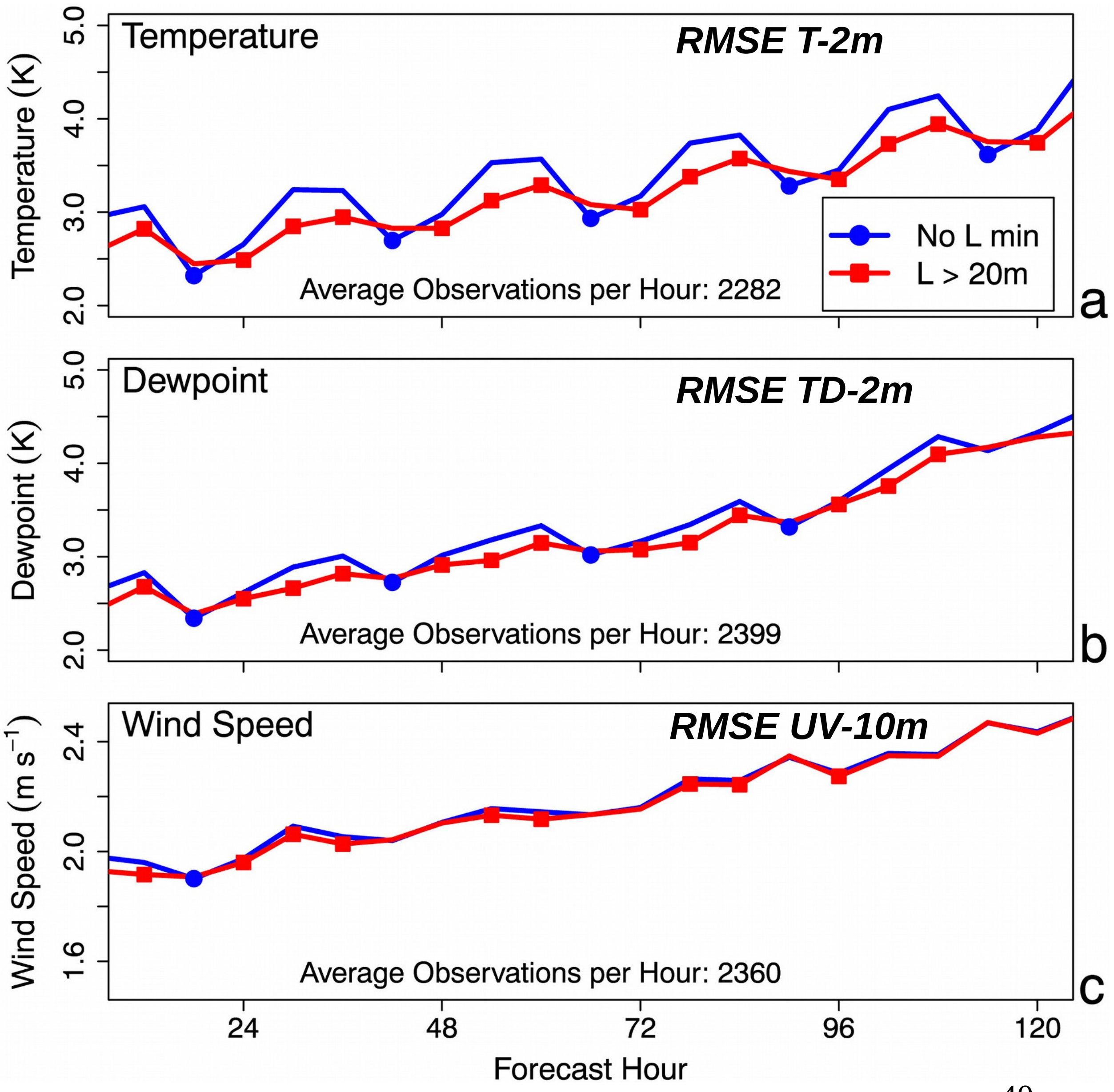
L ~ 20 m

From McTaggart-Cowan et al. 2019:

Root-mean-square errors in a winter forecast sequence against **N.American surface observations** in GDPS integrations initialized at 1200 UTC, for a run without (blue) and with (red) a minimum of 20 m imposed on the Obukhov length (L).

Errors in temperature (a), dew point (b), and wind speed (c) are computed against all available observations whose elevations are within 100 m of the grid cell mean orographic height, with average numbers of observations at each synoptic hour identified in each panel (22 cases total).

Differences that are statistically significant at the 90% level based on a bootstrap test are identified using line markers on the time series corresponding to the improved score.



A correction to the 10m wind diagnostics

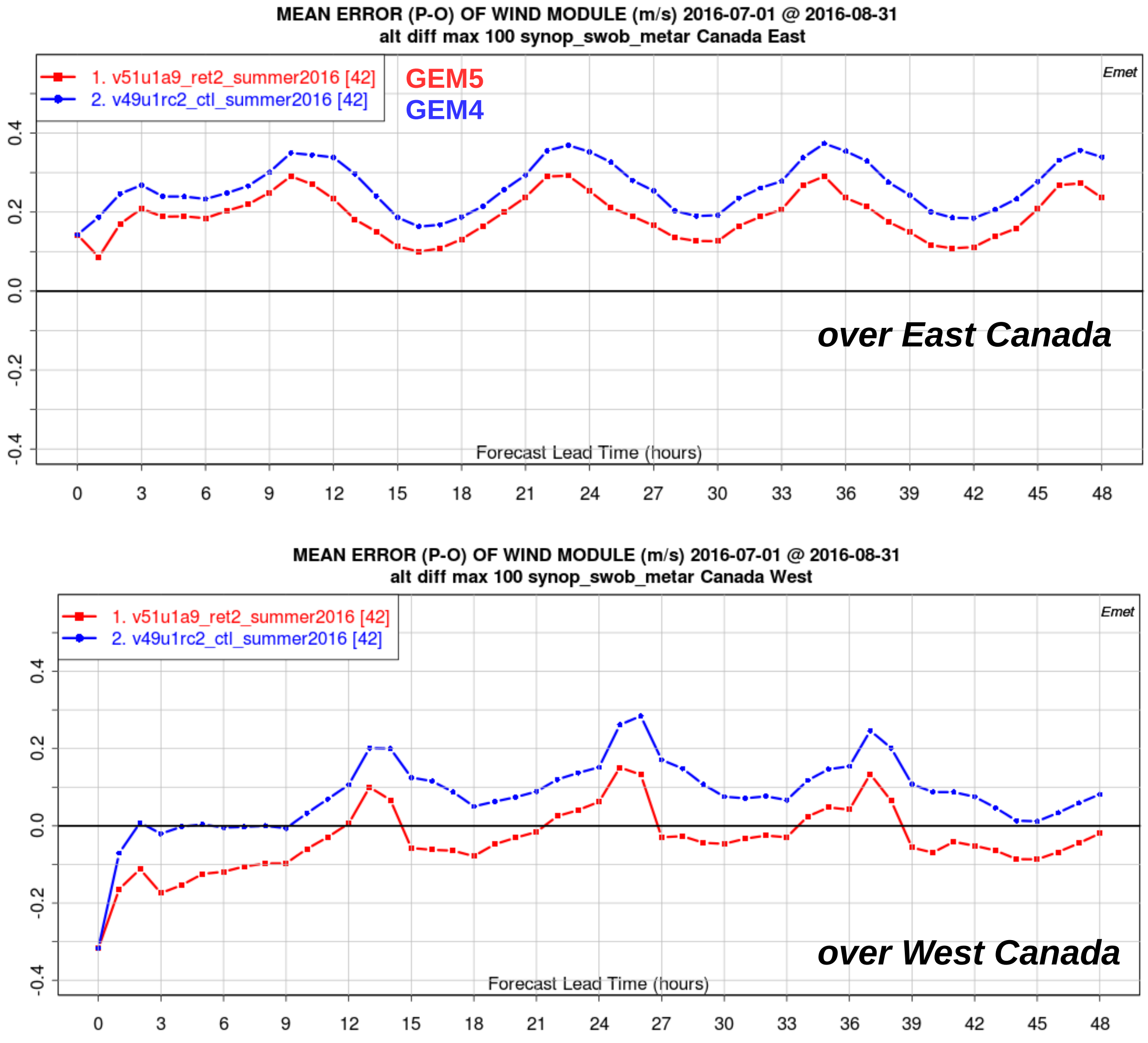
During the development of the *Lmin* approach, a ***bug*** was found in the **diagnostic calculation of 10m-winds.**

The bug is **present in versions GEM4 and older**. It is such that, under light wind conditions, the 10m-wind speed could be larger than the wind speed above (i.e. than the wind speed at the lowest prognostic level). This resulted in a misleading evaluation of near-surface winds in the model. A **bugfix** (independent of *Lmin*) was introduced **in GEM5**.

The figure beside shows results from a sensitivity test – performed without the *Lmin* limiter, but with the “old” minimum wind limiter instead – using the HRDPS configuration:

- ***blue*** *: “bugged” calculation*
- ***red*** *: corrected diagnostics*

Figure: *Sensitivity tests w.r.t. bugfix in the 10m-wind diagnostics, performed with the HRDPS (2.5km resolution): 10m-wind bias against surface observations, summer 2016.*



(Figure provided by Shawn Corvec)

Conservation constraints for parametrizations

(*partly based on Catry et al. 2007, Tellus 59A, 71-79*)

(Horizontal) Momentum

$$\vec{v}_h = (u, v)$$

← *horizontal wind*

$$\vec{\mathcal{P}}_h(x, y) = \int_{surf}^{top} (\vec{v}_h)\ \rho dz$$

← *vertically integrated momentum*

$$\boxed{\left(\frac{d}{dt}\vec{\mathcal{P}}_h\right)_{phy} = \left[\vec{\tau}_{pbl} + \vec{\tau}_{sgo}\right]_{surf}}$$

← *conservation equation*

$\vec{\tau}_{pbl} =$ **momentum flux from PBL scheme**

$\vec{\tau}_{sgo} =$ **momentum flux from SGO* scheme**

* orographic blocking + GWD

Conservation properties for parametrizations

Moisture

$$q_t = \overset{\text{vapor}}{q_v} + (\overset{\text{liquid cond.}}{q_l} + \underset{\text{rain}}{q_r}) + (\overset{\text{ice cond.}}{q_i} + \underset{\text{snow}}{q_s}) =$$ **total water mixing ratio**

$$\mathcal{Q}_t(x,y) = \int_{surf}^{top} (q_t)\ \rho dz$$ ← *vertically integrated water*

$$\boxed{\left(\frac{d}{dt}\mathcal{Q}_t\right)_{phy} = \left[-(P_l + P_i) + J_v\right]_{surf}}$$ ← *conservation equation*

$P_{l|i} =$ **liquid/ice precipitation rates**

$J_v =$ **turbulent flux of vapor**

Conservation properties for parametrizations

Energy

$$E = E_k + E_p$$

$$E_k = \frac{1}{2}(u^2 + v^2) =$$ **kinetic energy**

$$E_p = c_{pm}T - L_l(T)(q_l + q_r) - L_i(T)(q_i + q_s) =$$ **moist static energy**

$$c_{pm}(q_t) = c_{pd} + (c_{pv} - c_{pd})q_t$$ ◄— *specific heat*

$$L_{l|i}(T) = L_{l|i,0} + (c_{pv} - c_{l|i})T$$ ◄— *latent heat*

$$\mathcal{E}_p(x,y) = \int_{surf}^{top} (E_p)\ \rho dz$$

vertically integrated moist static energy

$$\mathcal{E}_k(x,y) = \int_{surf}^{top} (E_k)\ \rho dz$$

vertically integrated kinetic energy

Conservation properties for parametrizations

Energy

$$\begin{aligned} \left(\frac{d}{dt}\mathcal{E}_p\right)_{phy} &= \left[\hat{L}_l(T)\ P_l + \hat{L}_i(T)\ P_i\right]_{surf} \\ &+ \left[J_s + (c_{pv} - c_{pd})T\ J_v\right]_{surf} \\ &+ \left[(J_{rad})_{surf} - (J_{rad})_{top}\right] \\ &+ \mathcal{S}_{dh} \end{aligned}$$

$$\hat{L}_{l|i}(T) = L_{l|i,0} + (c_{pd} - c_{l|i})T$$ ← *(modified) latent heat*

$J_s =$ **turbulent flux of sensible heat**

$J_{rad} =$ **radiative heat flux**

$$\begin{aligned} \mathcal{S}_{dh} &= \int_{surf}^{top} c_{pm}\left[\frac{\partial T}{\partial t}\right]_{dh} \rho\, dz = -\left(\frac{d}{dt}\mathcal{E}_k\right)_{phy} = \text{dissipative heating} \\ &= -\int_{surf}^{top}\left[u\left(\frac{\partial u}{\partial t}\right)_{phy} + v\left(\frac{\partial v}{\partial t}\right)_{phy}\right]\rho\, dz \end{aligned}$$

Conservation properties for parametrizations

- **Some schemes** (e.g. Bechtold scheme for convection) have **built-in** capabilities to impose some of the conservation constraints.
- **New module** available in GEM5 includes:
  - *a **diagnostic tool** to measure the amount by which a scheme violates the conservation constraints*
  - *optional tools to make appropriate **adjustments/corrections** (e.g. to the tendencies, or to the source terms) to **impose conservation***
- Corrections adopted in the latest implementation (as of Jul 2019):
  - *precip correction for moisture conservation in Kain-Fritsch*
  - *tendency correction applied to large-scale condensation*
  - *momentum conservation imposed in all forms of CMT*
  - *dissipative heating activated in PBL and SGO schemes*

Ongoing work

Orography

- *participating in COORDE project*
- *revising topography filter, in collaboration with GEM dynamics group*
- *exploring new (higher resolution) topography databases*
- *revising calculation and partition of subgrid orography fields*
- *testing TOFD scheme, together with improved estimates of vegetation roughness*

PBL scheme

- *exploring new formulations of mixing length*
- *improving representation of cloud effects, including non-local terms (e.g. EDMF approach)*
- *testing turbulent total energy (TTE) approach*
- *revising numerical aspects of PBL scheme (vertical and temporal discretization)*
- *exploring unification with new convective schemes*
- *testing TOFD scheme as an option to orographic roughness*

Surface layer

- *preparing article on Lmin approach for stable regime*
- *exploring new stability functions*
- *investigating alternatives to Lmin approach for stable regime*
- *extending Lmin approach to other surfaces*
- *exploring high-wind modification to Charnock formula for roughness length over water*

Merci de votre attention

Note: Detailed documentation of updated schemes available RPN Physics wiki:
https://wiki.cmc.ec.gc.ca/wiki/Rpnphy