

Change record

Version	Date	Author	Remarks
1.0	24-Nov-2008	A. Zadra	First draft
2.0	25-Nov-2008	J.-P. Gauthier	Added running options, averaging method and some corrections
3.0	25-Nov-2008	A. Leroux	Various suggestions & corrections
4.0	30-Nov-2008	A. Zadra, J.-P. Gauthier	Various corrections, added output list
5.0	01-Dec-2008	A. Zadra, J.-P. Gauthier	A few corrections
6.0	02-Dec-2008	A. Leroux	Some corrections, added slide about databases
7.0	07-Dec-2008	A. Zadra	Modification of roughness length method, plus a few corrections
8.0	08-Dec-2008	J.-P. Gauthier	Change to the parameters related to the new -target
9.0	30-Jan-2009	A. Zadra, J.-P. Gauthier	Changes related to batch-mode calculation; correction in table of vegetation classes
10.0	05-Feb-2009	A. Zadra, J.-P. Gauthier, A. Leroux	Updates related to new land/water data (GlobCover)





Environment
Canada

Environnement
Canada

Canada

GenPhysX

a user's guide to input/output and methods

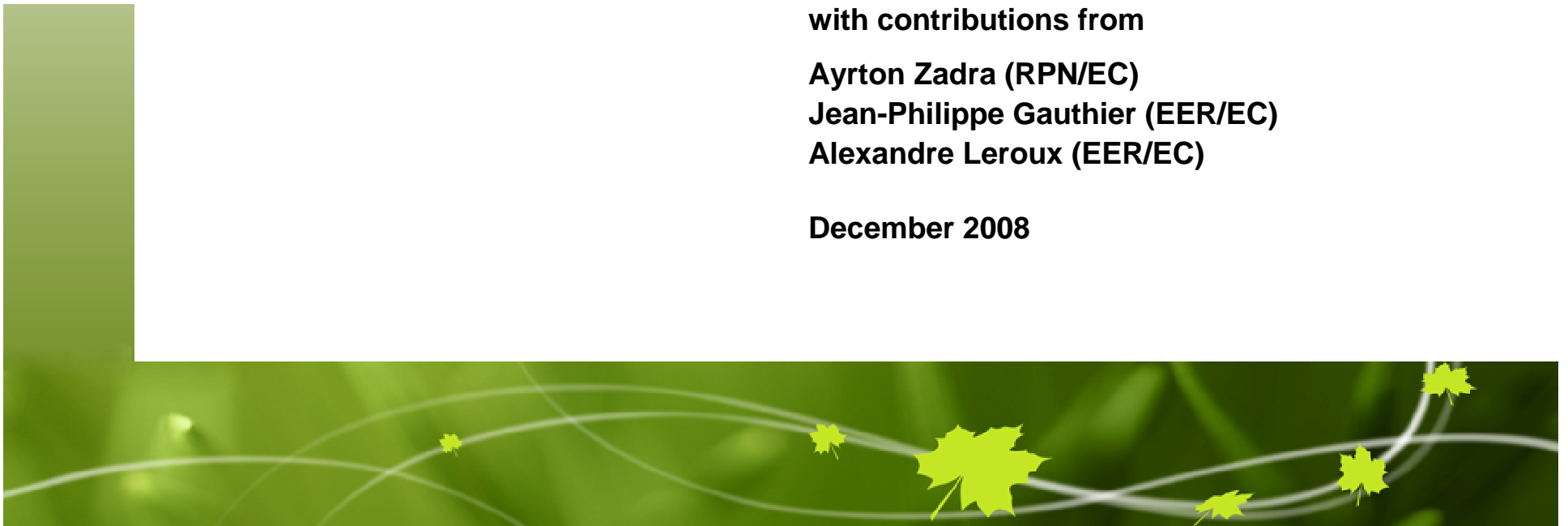
with contributions from

Ayrton Zadra (RPN/EC)

Jean-Philippe Gauthier (EER/EC)

Alexandre Leroux (EER/EC)

December 2008



Contents (1)

GENERAL INFORMATION

- What is GenPhysX?
- GenPhysX flowchart
- GenPhysX standard output
- GenPhysX auxiliary output
- GenPhysX running options
- Geospatial databases highlights

SIMPLE AVERAGING / COUNTING

- ME: topography (mean elevation)
- MG: land fraction (land-water “mask”)
- VF(n): vegetation fractions
- VF Table: 26 surface classes and associated roughness length values
- J1(n) and J2(n): multi-layer sand and clay percentages
- Topography Slope (SLA) and Aspect (FSA)

CONSISTENCY CHECKS AND DERIVED FIELDS

- Consistency among simple averaging/counting fields
- Derived fields



Contents (2)

SUBGRID CALCULATIONS

Separation of topographic scales for subgrid fields

Resolution dependent correction factors

Launching height (LH)

Topography gradient correlations (Y7, Y8, Y9)

Roughness length: local or vegetative component (ZVG1 & ZVG2)

Roughness length: topographic component (ZTOP)

Roughness length: ice-free soil component (Z0S; ZPS)

Roughness length: ice/glacier component (Z0G; ZPG)

Roughness length (Z0; ZP): combining all components

Roughness length: optional filter



What is GenPhysX?

Running NWP models, such as GEM, requires a set of **geophysical fields** (e.g. topography elevation, land-water fraction, land cover, soil type, roughness, etc.). These fields are meant to represent characteristic surface values (averages, percentages, dominant type, etc.) at each grid cell of model.

GenPhysX is a program designed to generate the geophysical fields required by the GEM model. Like its predecessors (Genesis, Gengeo), **GenPhysX** reads and processes data from a set of databases, and produces an output file in a format appropriate for GEM. One of the assets of **GenPhysX** is its capacity to read databases in their original formats.

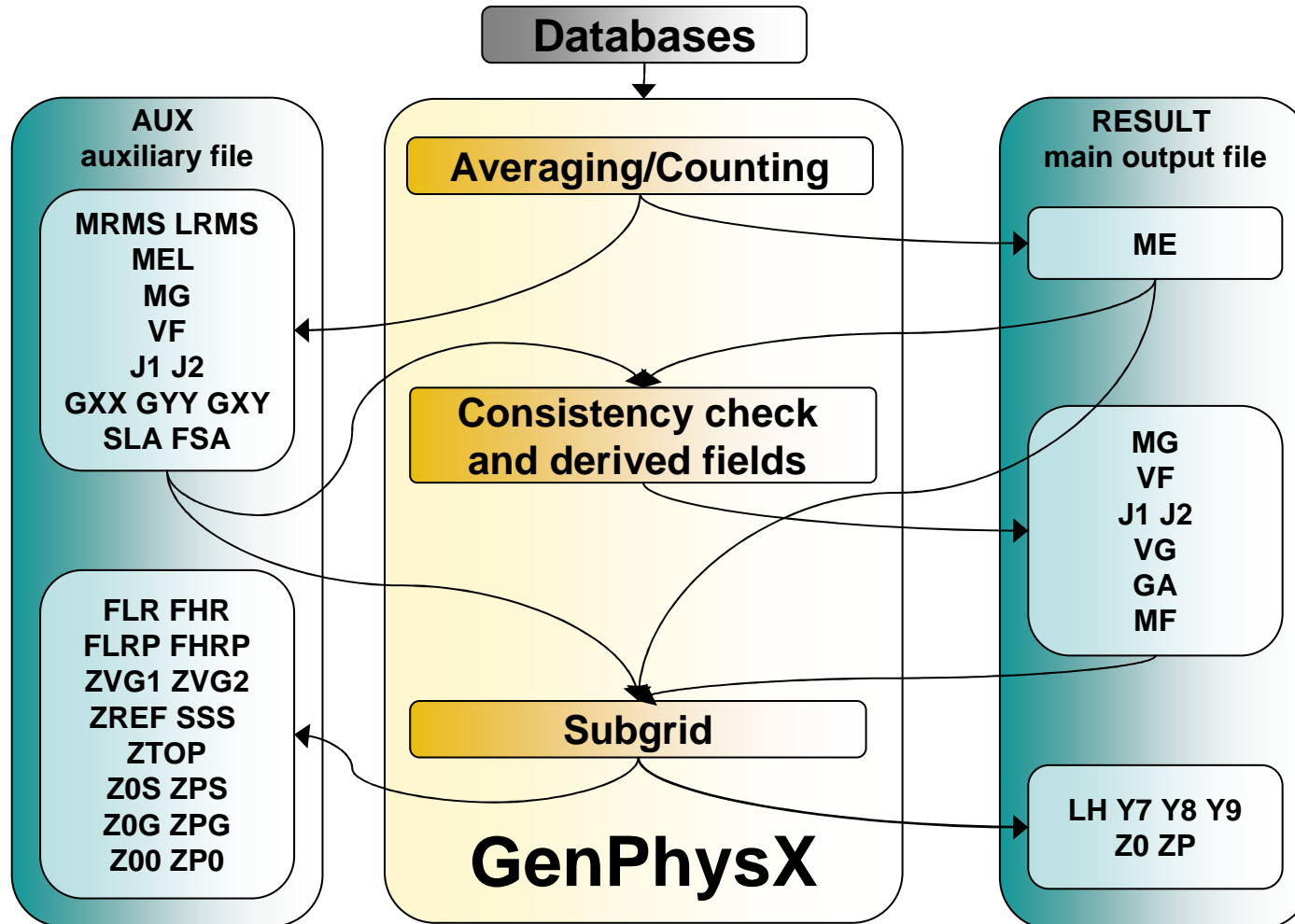
This document summarizes some of the features of **GenPhysX** and the methods used to compute the set of geophysical fields.

Users should join the **GenPhysX** mailing list:

<http://internallists.cmc.ec.gc.ca/cgi-bin/mailman/listinfo/genphysx>



GenPhysX flowchart



GenPhysX standard output

- ME topography elevation (on 3 grids if using gem_settings)
- MG land fraction (“land-sea mask”)
- VF vegetation type fraction (26 classes)
- J1 sand percentage (5 layers)
- J2 clay percentage (5 layers)
- VG dominant vegetation type
- GA glacier fraction
- MF filtered ME (using GEM topo filter)
- LH launching height
- Y7,Y8,Y9 subgrid topography gradient correlations
- Z0,ZP roughness length and its logarithm
- META metadata (use SPI to read the metadata)



GenPhysX auxiliary output

- MRMS,LRMS high- and low-resolution rms of topography
- MEL low-resolution average of topography
- FLR,FHR low- and high-resolution correction factor
- FLRP,FHRP low- and high-resolution correction factor (land only)
- GXX,GYY,GXY topography gradient correlations (non-rotated)
- SSS small-scale standard deviation of topography
- HCOF height coefficient
- ZREF reference height (for roughness length)
- ZTOP topography roughness length
- ZVG1,ZVG2 overall and local vegetation roughness length
- Z0S,ZPS roughness length over soil and its logarithm
- Z0G,ZPG roughness length over glacier and its logarithm
- FSA0 average aspect
- FSA average aspect per quadrant
- SLA0 average slope
- SLA average slope per quadrant



GenPhysX running options (1)

Information parameters:

[-help] : This information
[-version] : GenPhysX version
[-verbose] (2) : Trace level (0 none, 1 some, 2 more, 3 Debug)

Input parameters:

[-nml] () : GEM namelist definition file
[-gridfile] () : FSTD file to get the grid from if no GEM namelist
[-result] (genphysx) : Result filename
[-target] () : Set necessary tags for model target { GEMMESO }
[-script] () : User definition script to include

Processing parameters:

Specify databases in order of processing joined by + ex: STRM+USGS

[-topo] () : Topography method(s) among { USGS SRTM CDED250 CDED50 }
[-mask] () : Mask method, one of { USGS GLOBCOVER CANVEC }
[-vege] () : Vegetation method(s) among { USGS GLOBCOVER CCRS EOSD CORINE }
[-soil] () : Soil method among { USDA AGRC FAO }
[-aspect] () : Slope and aspect method(s) among { SRTM CDED250 CDED50 }
[-biogenic] () : Biogenic method(s) among { BELD VF }
[-check] () : Do consistency checks { STD }
[-subgrid] () : Calculates sub grid fields { STD }
[-diag] : Do diagnostics (Not implemented yet)



GenPhysX running options (2)

Specific processing parameters:

`[-z0filter]` : Apply GEM filter to roughness length
`[-celldim] (1)` : Grid cell dimension (1=point, 2 =area)

Batch mode parameters:

`[-batch]` : Launch in batch mode
`[-mail] ()` : EMail address to send completion mail
`[-mach] (hawa)` : Machine to run on in batch mode
`[-t] (7200)` : Reserved CPU time (s)
`[-cm] (400000)` : Reserved RAM (MB)



GenPhysX running options (3)

- To get a help list:

```
GenPhysX.tcl -help
```

- IMPORTANT: On top of all the options shown below, you're supposed to launch the calculation in **batch-mode on the machine hawa** i.e. your options should always include `-batch` and `-result`

```
GenPhysX.tcl -batch -result [working directory]/[output name]
```

In the following examples shown, these 2 options are not explicitly written, but are understood.

- To generate geophysical fields (using default databases of GEM meso-global model) for a GEM grid defined in you namelist file `gem_settings.nml`:

```
GenPhysX.tcl -target GEMMESO -nml gem_settings.nml
```

- To generate geophysical fields (using default databases of GEM meso-global model) for a GEM grid defined by grid descriptors (fields “`^^`” and “`>>`”) found in an RPN file (`mygrid.fst`):

```
GenPhysX.tcl -target GEMMESO -gridfile mygrid.fst
```

- To choose the name (e.g. `toto`) of the output files (`toto.fst` and `toto_aux.fst`):

```
GenPhysX.tcl -target GEMMESO -result [working directory]/toto
```



GenPhysX running options (4)

- To choose specific topography database(s):
 - if you want to use the SRTM database only

```
GenPhysX.tcl -topo STRM
```

- if you want the database SRTM first (and so fill the domain of your grid covered by SRTM data), then the database USGS GTOPO30 (for a sub-domain not covered by SRTM):

```
GenPhysX.tcl -topo STRM+USGS
```

- if you want CDED250 first, then SRTM, then USGS GTOPO30

```
GenPhysX.tcl -topo CDED250+STRM+USGS
```

- Similarly, here is an example of database choice for other fields (except for the land/water mask, which can only take one option at the moment):

```
GenPhysX.tcl -vege E0SD+USGS -mask USGS -soil AGRC+FAO -aspect CDED50+SRTM
```



GenPhysX running options (5)

- To request the standard consistency check among averaged fields:
`GenPhysX.tcl -check STD`
- To request the calculation of subgrid fields:
`GenPhysX.tcl -subgrid STD`
- To request that the roughness length field be filtered:
`GenPhysX.tcl -z0filter`



GenPhysX running options (6)

Frequently asked questions:

- *Is GenPhysX capable of generating exactly the same (bit-by-bit) fields obtained with Genesis or Gengeo?*

No. If you use the same databases, then the simple-average fields (e.g. ME, VG, etc.) may be quite similar. But the subgrid fields (e.g. LH, Z0) are likely to be quite different, because GenPhysX uses a scale separation for topographic scales, and new formulas to compute subgrid fields.

- *If I choose only one topography database (e.g. SRTM) that covers only part of my model domain, will GenPhysX find a complementary database and fill in the holes by itself?*

No. If you choose a non-default combination of topography databases, GenPhysX will follow your choice. If you say SRTM only, then GenPhysX will use SRTM only; if SRTM has no data for some of your gridboxes, then your field ME will be zero at those points. Same for vegetation or soil fields. You have to specify by yourself the complementary database e.g. SRTM+USGS.



GenPhysX running options (7)

Frequently asked questions:

- *How come there's no field AL (albedo) in the output?*

The albedo is not a field generated by GenPhysX (or Genesis, for that matter). This field comes from the analysis and/or the climatology files. Some users seem to like to “include” a copy of AL in the geophys file -- that's their choice.

- *What's in the META field?*

A while ago, it became possible to save text (ASCII) in rpn standard files. META contains metadata about your geophysical fields, such as:

- date, machine and user
- call parameters, code version
- copy of your gem_settings.nml

You may open/view the contents of META using various applications (e.g. SPI).



GenPhysX running options (8)

Frequently asked questions:

- *I only need the land-sea mask field MG for my project. Can I generate it alone?*

Yes, you can do that. Try something like:

```
GenPhysX.tcl -nm1 [your gem_settings] -mask [choose you database]
```

- *What is the auxiliary output file for?*

The main output file contains the standard set of geophysical fields used by GEM. The auxiliary file is available for verification/debugging and for special applications. For example it contains raw fields (e.g. VF and J1/J2 before consistency check), some fields needed by special projects (e.g. FSA, SLA), fields that may become operational in future versions of GEM (e.g. Z0S, Z0G), and some fields used in intermediate subgrid calculations (e.g. FLR,ZTOP,ZREF).



GenPhysX running options (9)

Frequently asked questions:

- *I already have a complete set of geophysical fields. But I just discovered I made a mistake in the calculation of VG, so I need to re-generate it (as well as the subgrid fields that depend on it). Do I have to start from scratch?!*

No. As long as you use the same name for your output files (defined by the option `-result`), you may re-start the calculation in the middle, for example:

```
GenPhysX.tcl -nml [your gem_settings] -vege [your databases] -check STD  
              -result [working directory]/[your output name]
```

The other fields (e.g. ME) will remain safe and unchanged.

- *What about that strange little file *_gfilemap.txt ?*

This text file (one line only) is automatically generated by the command `gemgrid` from `armnlib`, called by `GenPhysX` to build the tictacs for the 3 (staggered) GEM grids. The contents of `gfilemap` will be important for future versions of GEM. For now, you don't need it and shouldn't worry about it.



Geospatial databases highlights

Metadata highlights for the -topo, -mask, -vege and -aspect flags

- USGS: GTOPO30 worldwide topography at ~900m
- SRTM: quasi-worldwide (up to 60 deg north/south) topography at 90m spatial resolution. Using SRTM-DEM CSI-CGIAR v4.
- CDED50 and CDED250: Canada-wide topography at scale 1:50,000 (spatial resolution of about 20m) and 1:250:000
- CanVec: Canadian 1:50,000 vector database. About 100 thematic layers with 1000+ attributes.
- EOSD: Canadian forest inventory circa year 2000 at 25m
- CORINE: European land cover for year 2000 at 250m
- For land cover / vegetation: GlobCover LC v2.1 (worldwide at 250m) and CCRS-LC2005 (Canada at 250m) to be added to GenPhysX
- For additional information, see [this presentation](#) or ask the [GenPhysX mailing list](#)



ME: topography (mean elevation)

The field **ME** is simply the mean elevation (w.r.t. sea level) of a gridbox, in meters. It is calculated as a simple average, using values given by a chosen high-resolution database.

Note: Since the GEM model currently uses **3 horizontal grids** (one for scalar fields, one for the zonal wind component UU, and one for the meridional wind VV), the field **ME** is actually calculated 3 times, one for each grid:

NOMVAR	IP1	meaning
ME	1200	topography elevation, scalar grid
ME	1199	topography elevation, UU grid
ME	1198	topography elevation, VV grid

All the other geophysical fields are generated on the scalar grid only!



MG: land fraction (land-water “mask”)

The field **MG** varies from 0.0 to 1.0 represents the fraction of the gridbox occupied by land (1.0 means 100% land). It is often called “land-sea mask” or “land-water mask” but it is not a simple binary (0 or 1) field, and it actually includes lakes and rivers.

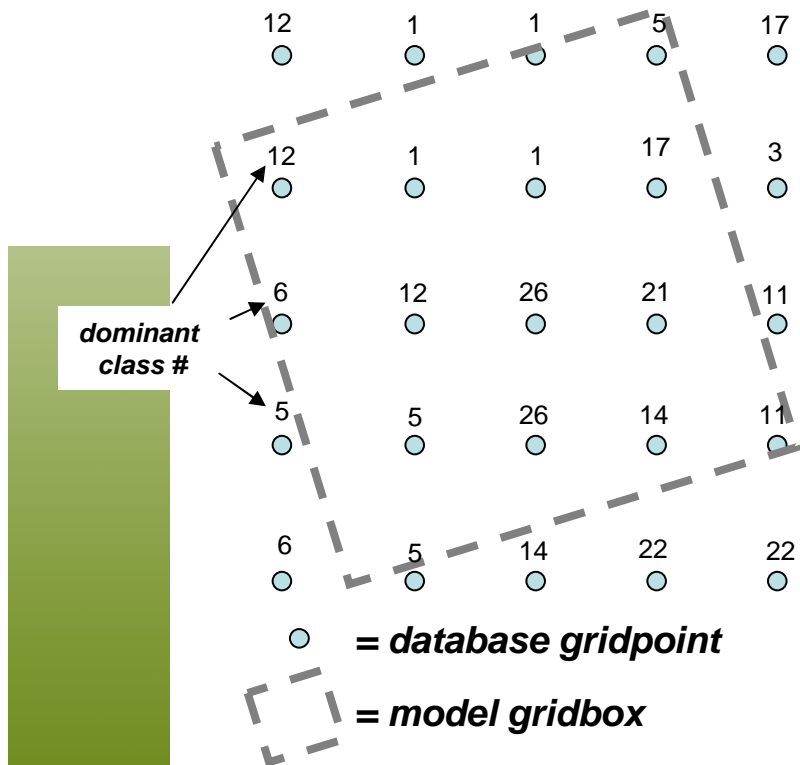
As the topography **ME**, it is calculated as a simple average, using values given by a chosen high-resolution database -- a database exclusive for **MG**, distinct and separate from the topography and vegetation databases.

This separation of databases (which may be chosen and combined by the user) may cause inconsistencies among the various geophysical fields. Therefore an optional sequence of consistency checks and corrections is available in GenPhysX (description later on). Some consistency checks are also applied in the code of the GEM model itself.



VF(n): vegetation fractions

Usually, the land-cover/land-use database provides the dominant class (e.g. deciduous shrubs) for a given pixel/gridpoint. For simplicity, we often refer to these classes as “vegetation classes or types”.



In GenPhysX, the database classes are first “translated” into the 26 classes used by the GEM model (see Table 1, next slide). Then for each model gridbox, the number of points dominated by **class n** are counted, and finally the field **VF(n)** is computed as the fraction of the gridbox dominated by “vegetation” class n. The resulting 26 fields are saved in the auxiliary output file.

Note: A consistency check is applied among the fields **VF** and **MG**, before the final values of **VF(n)** are saved in the main output file.

VF Table: 26 surface classes and associated roughness length values

Table 1

n	class	roughness length (m)	n	class	roughness length (m)
1	(sea) water	0.001	14	long grass	0.08
2	glacier	0.0003	15	crops	0.08
3	inland lake	0.001	16	rice	0.08
4	evergreen needle-leaf trees	1.5	19	sugar	0.35
5	evergreen broadleaf trees	3.5	18	maize	0.25
6	deciduous needle-leaf trees	1.0	19	cotton	0.1
7	deciduous broadleaf trees	2.0	20	irrigated crops	0.08
8	tropical broadleaf trees	3.0	21	urban	1.35
9	drought deciduous trees	0.8	22	tundra	0.01
10	evergreen broadleaf shrubs	0.05	23	swamp	0.05
11	deciduous shrubs	0.15	24	desert	0.05
12	thorn shrubs	0.15	25	mixed wood forests	1.5
13	short grass and forbs	0.02	26	mixed shrubs	0.05



J1(n) and J2(n): multi-layer sand and clay percentages

These are fields representing percentages of soil types at 5 different layers of the earth's crust (each layer labeled by a value of IP1). Soil types are classified according to 3 complementary categories: **sand**, **clay** and **silt**.

The field **J1** gives the percentage of **sand**. As the field **MG**, it represents a fraction, but it varies between in 0.0 to 100.0 (i.e. it is in units of %). It is calculated for each gridbox as a simple average, using values from chosen high-resolution databases.

Similarly, **J2** gives the fraction of **clay** and also varies between in 0.0 to 100.0.

Notice that the percentage of **silt** is not calculated – after all, it is simply defined as $100\% - \mathbf{J1} - \mathbf{J2}$ over land.

Note: Over water, we arbitrarily set $\mathbf{J1} = 0.0 = \mathbf{J2}$ (GEM doesn't ask for any soil percentages over water, so any value would do). Over other surfaces, and if data is missing, default values ($\mathbf{J1} = 43.0\%$ and $\mathbf{J2} = 19.0\%$) are set.

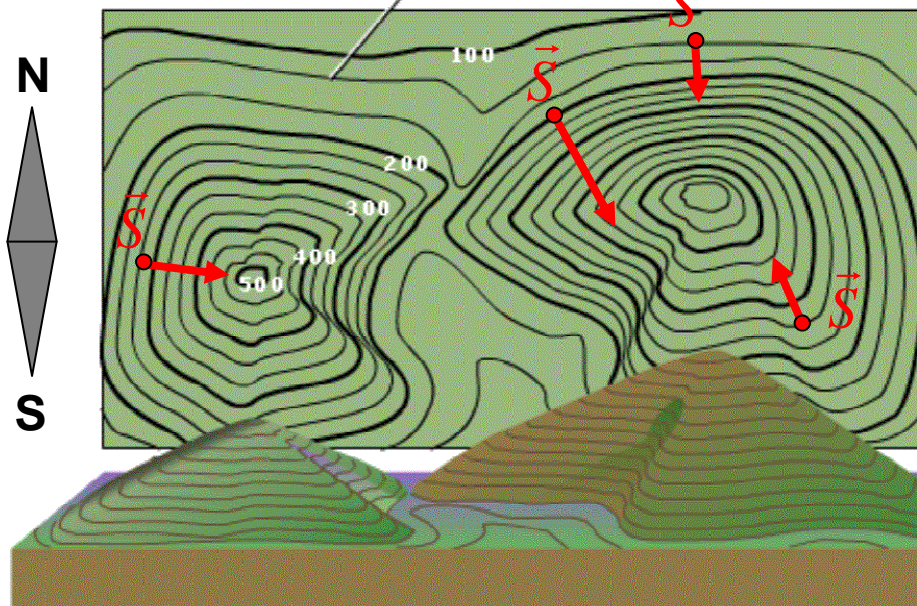


Topography Slope (SLA) & Aspect (FSA)

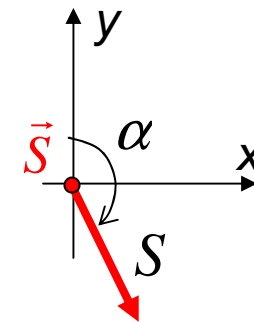
The topography gradient \vec{S} is a 2-d vector field, calculated from the elevation field $h(x,y)$. It is perpendicular to the topography contour lines and points upslope.

$$\vec{S} = \vec{\nabla}h = \left(\frac{\partial h}{\partial x}, \frac{\partial h}{\partial y} \right)$$

Contour Map

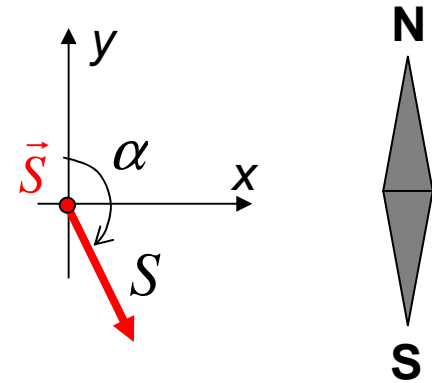


It may be represented by its pair of cartesian components (see above) or by its magnitude ($S = \text{slope}$) and azimuthal angle ($\alpha = \text{aspect}$):



Topography Slope (SLA) & Aspect (FSA)

The azimuthal angle (here called *aspect*) indicates the direction of the upslope gradient w.r.t north-south. In GenPhysX, this angle is measured *in degrees*. For instance, in the figure beside, $\alpha \sim 150^\circ$.



The *slope* is a non-dimensional quantity, often measured as a percentage. However, in GenPhysX, the slope is measured *in degrees*. For instance:

$$S = 7\% \sim 4^\circ$$

i.e. $4^\circ \sim \text{atan}(0.07)$.

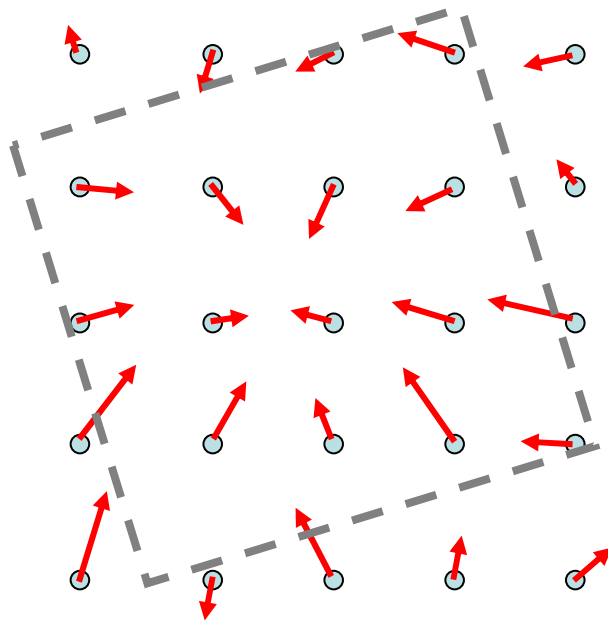


Topography Slope (SLA) & Aspect (FSA)

GenPhysX computes the topography gradient parameters (slope & aspect) at each point of the database, and then averages the results inside each of the model gridboxes.

$$SLA0 = \langle S_i \rangle = \text{gridbox average of slopes}$$

$$FSA0 = \langle \alpha_i \rangle = \text{gridbox average of aspects}$$



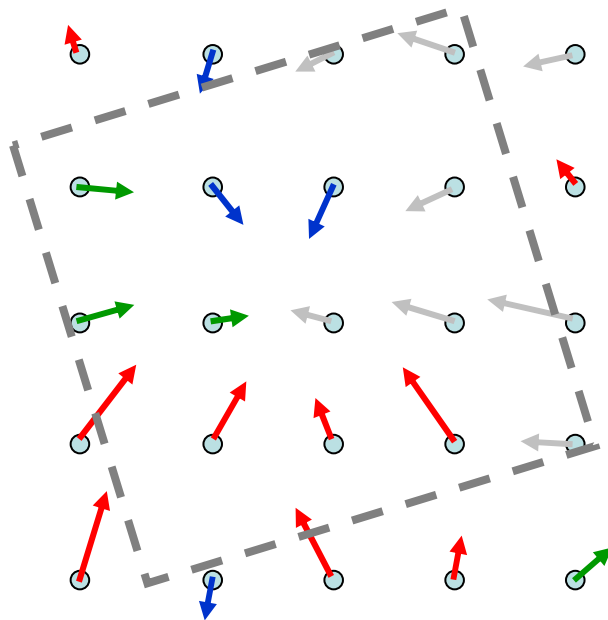
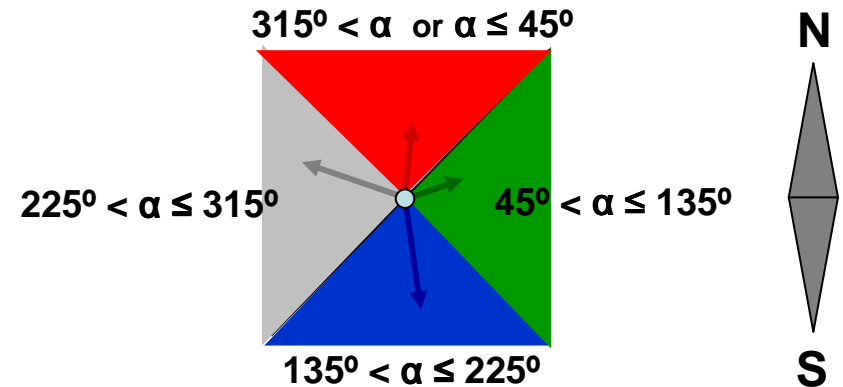
○ = *database gridpoint*

→ = *topo gradient at database gridpoint*

□ = *model gridbox*

Topography Slope (SLA) & Aspect (FSA)

GenPhysX also computes separate averages for each of the **4 quadrants** (see figure beside). The idea is to compute each average considering only the pixels whose gradient points to a given quadrant (see color representation below).



- SLA(0) = average slope for points with $315^\circ < \alpha_i \leq 45^\circ$
- SLA(90) = average slope for points with $45^\circ < \alpha_i \leq 135^\circ$
- SLA(180) = average slope for points with $135^\circ < \alpha_i \leq 225^\circ$
- SLA(270) = average slope for points with $225^\circ < \alpha_i \leq 315^\circ$
- FSA(0) = fraction of points with $315^\circ < \alpha_i \leq 45^\circ$
- FSA(90) = fraction of points with $45^\circ < \alpha_i \leq 135^\circ$
- FSA(180) = fraction of points with $135^\circ < \alpha_i \leq 225^\circ$
- FSA(270) = fraction of points with $225^\circ < \alpha_i \leq 315^\circ$

NOTE: *SLA = Slope Angles*
FSA = Fraction of Slope Aspect
 Indices 0, 90 180 ad 270 are given by IP3

Topography Slope (SLA) & Aspect (FSA)

Note: For **flat terrains** (e.g. sea, sea-ice, lakes) the azimuthal angle is not defined, so the following **special convention** has been adopted:

$$SLA_0 = 0$$

$$FSA_0 = -1$$

$$SLA(0) = 0$$

$$SLA(90) = 0$$

$$SLA(180) = 0$$

$$SLA(270) = 0$$

$$FSA(0) = 0$$

$$FSA(90) = 0$$

$$FSA(180) = 0$$

$$FSA(270) = 0$$

Otherwise, in **non-flat terrains** the sum of the 4 aspect fractions should add up to 100%. If not, the missing part is the percentage of flat terrain in the grid cell:

$$\sum_i FSA(i) = 1$$



Topography Slope (SLA) & Aspect (FSA)

In sum, the slope/aspect calculation reads the topography database (input) and produces 10 geophysical fields (output, on the model grid):

average values { $SLA0 = \langle S_i \rangle =$ gridbox average of slopes
 $FSA0 = \langle \alpha_i \rangle =$ gridbox average of aspects

average values { $SLA(0) =$ average slope for points with $315^\circ < \alpha_i \leq 45^\circ$
 $SLA(90) =$ average slope for points with $45^\circ < \alpha_i \leq 135^\circ$
 $SLA(180) =$ average slope for points with $135^\circ < \alpha_i \leq 225^\circ$
 $SLA(270) =$ average slope for points with $225^\circ < \alpha_i \leq 315^\circ$

fractions { $FSA(0) =$ fraction of points with $315^\circ < \alpha_i \leq 45^\circ$
 $FSA(90) =$ fraction of points with $45^\circ < \alpha_i \leq 135^\circ$
 $FSA(180) =$ fraction of points with $135^\circ < \alpha_i \leq 225^\circ$
 $FSA(270) =$ fraction of points with $225^\circ < \alpha_i \leq 315^\circ$

IMPORTANT: Note that FSA0 and FSA(n) have different meaning & units !



Consistency among simple average/counting fields

A “standard consistency check” is available in GenPhysX. It involves the fields MG, VF, J1 and J2, and is based on the following rules:

if	MG = 0.0 (land fraction says “no land”) and VF(3) = 0.0 (vegetation says “no lake/river”)	then	VF(1) = 1.0 and VF(n≠1)=0.0 (impose “100% sea water”)
if	MG < 0.001 (practically “no land”)	then	J1(n) = 0.0 and J2(n)=0.0 (no need for sand/clay)
if	VF(2) = 1.0 (“100% glacier”)	then	J1(n) = 43.0 and J2(n)=19.0 (impose default values for sand/clay)
if	MG > 0.001 (mask says “some land”) but J1(n)=0.0 and J2(n)=0.0 (missing data for sand/clay)	then	J1(n) = 43.0 and J2(n)=19.0 (impose default values for sand/clay)



Derived fields

Once the consistency between fields is completed, the following derived fields are generated:

GA = VF(2) = fraction of gridbox covered by ice/glaciers

VG = class number (integer n, from 1 to 26) of the dominant vegetation class
[n from maximum VF(n)]

MF = filtered topography; results from the application of a filtering/smoothing operator onto the field ME (scalar grid only), based on the topo-filter operator used by the GEM model, and according to values given to the 4 logical parameters

Topo_init_L, Topo_filmx_L

Topo_dgfmx_L, Topo_dgfms_L

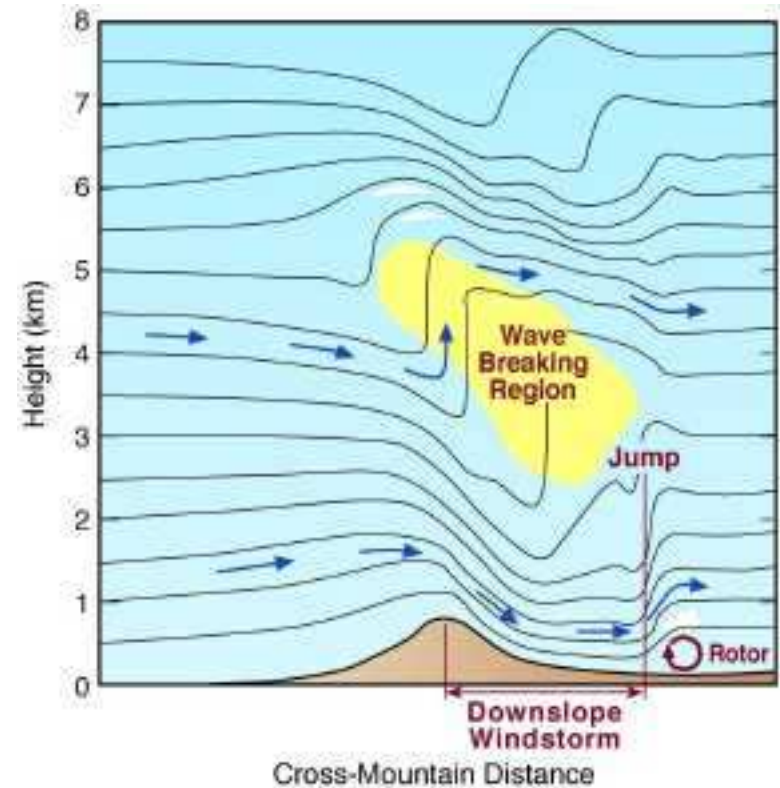
defined in the namelist (gem_settings.nml) provided by the user.



Separation of topographic scales for subgrid fields

Stationary gravity waves may be excited by mountains. These may propagate, grow in amplitude and break at upper levels, causing a deceleration of the background flow (gravity wave drag).

However, not all these waves propagate upwards. According to linear theory, some of them remain trapped near the surface. The condition for trapping depends on the atmospheric conditions (incident wind, temperature profile, etc.) and on the horizontal scales of the mountains.



Separation of topographic scales for subgrid fields

In “typical” atmospheric conditions, waves generated by “small-scale” mountains – i.e. **mountains with horizontal scales less than ~5km** – are expected to remain trapped.

Therefore the interest in a “decomposition” or “separation” of horizontal scales of topography for physical parametrizations of different subgrid processes:

- only the “large horizontal scales” ($> 5\text{km}$) of the topography field should be considered in the parametrization of physical processes such as gravity wave drag, blocking, etc.
- on the other hand, the “small horizontal scales” ($< 5\text{km}$) should be used in the parametrization of near-surface physical processes such as surface drag – e.g. in the estimate of surface roughness lengths.

Based on these hypotheses, the value of 5km was chosen as the threshold between “large” and “small” horizontal scales of topography.



Resolution-dependent correction factors

Some of the subgrid fields related to topography (**LH,Y7,Y8,Y9,ZTOP**) involve gridbox estimates of variances and other calculations, which can only be trusted if the database resolution is high enough, compared to the model resolution.

The resolution of a topography database (r_{db}) is either:

- defined by construction (e.g. the smoothed 'large-scale' topography which, by construction, contains scales larger than 5km only; in this case, $r_{db} = 5,000$)
- or defined by the source data (e.g. USGS GTOPO30 has a resolution of 900m, in which case $r_{db}=900$)

The resolution of a gridbox (r_{gb}) is estimated by GenPhysX:

- first, the gridbox sizes (dx and dy , in meters) are calculated;
- the gridbox resolution is then estimated as $r_{gb} = \sqrt{dx*dy}$



Resolution-dependent correction factors

Once the resolutions r_{db} and r_{gb} are known, a correction factor (a filter based on hyperbolic functions) is calculated as follows

$$F(x) = \frac{1}{2} \left[1 + \frac{1 - E(x)}{1 + E(x)} \right]$$

$$E(x) = \exp[-(c_1 x - c_2)]$$

$x = r_{gb} / r_{db}$ = ratio between gridbox and database resolutions

c_1, c_2 constants

Notice that it only depends on the ratio between resolutions, $x = r_{gb}/r_{db}$.

The function **F(x)** is called a correction factor because it is used in GenPhysX, at each gridbox, as a multiplicative factor in the calculation of the averages and standard deviations for some subgrid fields.



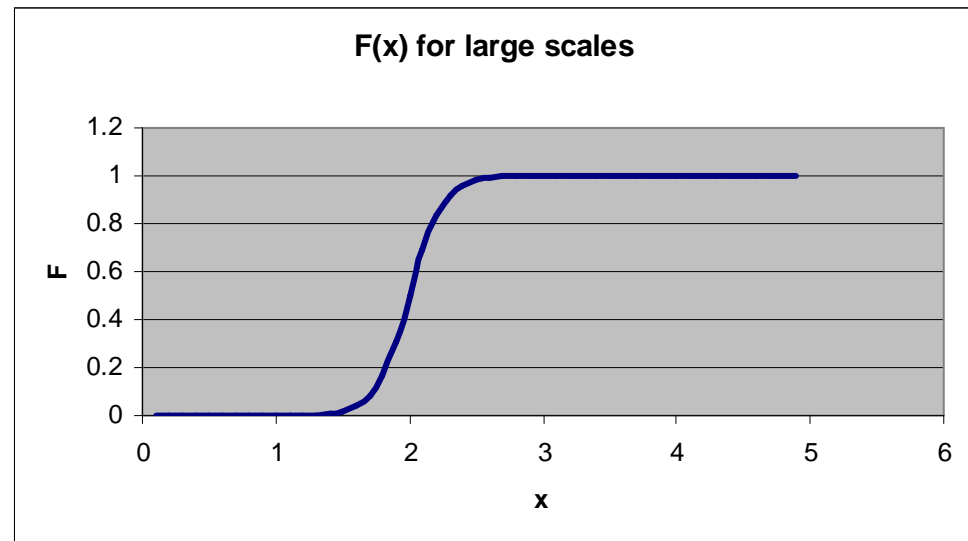
Resolution-dependent correction factors

For the “large-scale” subgrid fields (**LH,Y7,Y8,Y9**), we have chosen the values

$$c1 = 8 \text{ and } c2 = 16$$

which give the correction function shown in the plot beside.

This choice implies that we require a resolution ratio to be roughly 2 or higher (i.e. gridboxes of 10km size or larger) in order to trust and consider the fields **LH,Y7-9**.



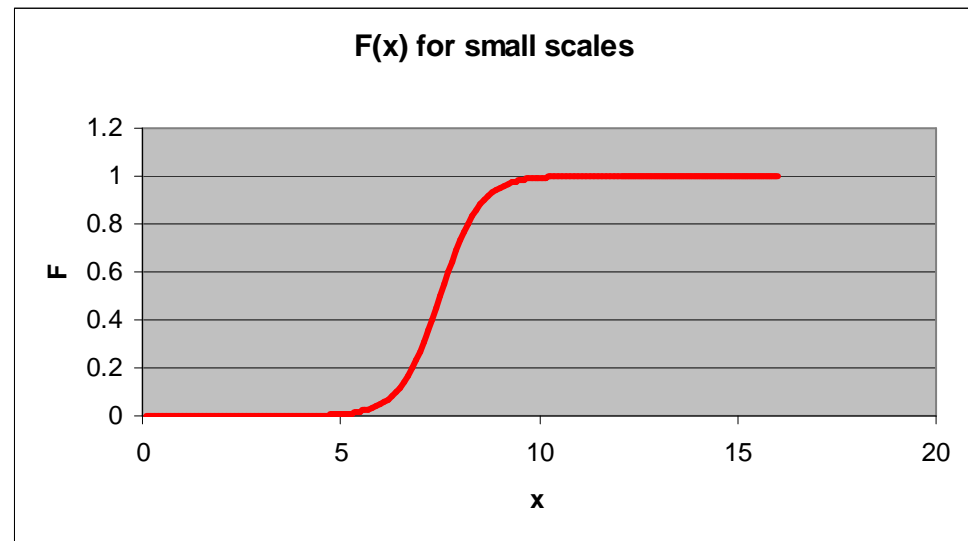
Resolution-dependent correction factors

For the “small-scale” subgrid fields (**ZTOP**), we have chosen more restrictive values

$$c1 = 2 \text{ and } c2 = 15$$

which give the correction function shown in the plot beside.

This is a more “severe” choice: we require the resolution ratio to be roughly 7 or higher (i.e. ~50 data values per gridbox) in order to trust the estimates of the averages/rms used to compute the roughness length.



Resolution-dependent correction factors

For verification, the values of the correction factors at each gridbox are saved in the auxiliary output file:

FLR: correction factor for large scales
FHR: correction factor for small scales

Two additional fields are also computed, in an attempt to include only the land fraction of each gridbox:

FLRP: correction factor for large scales, using MG
FHRP: correction factor for small scales, using MG

but these fields remain to be evaluated and are not yet used.

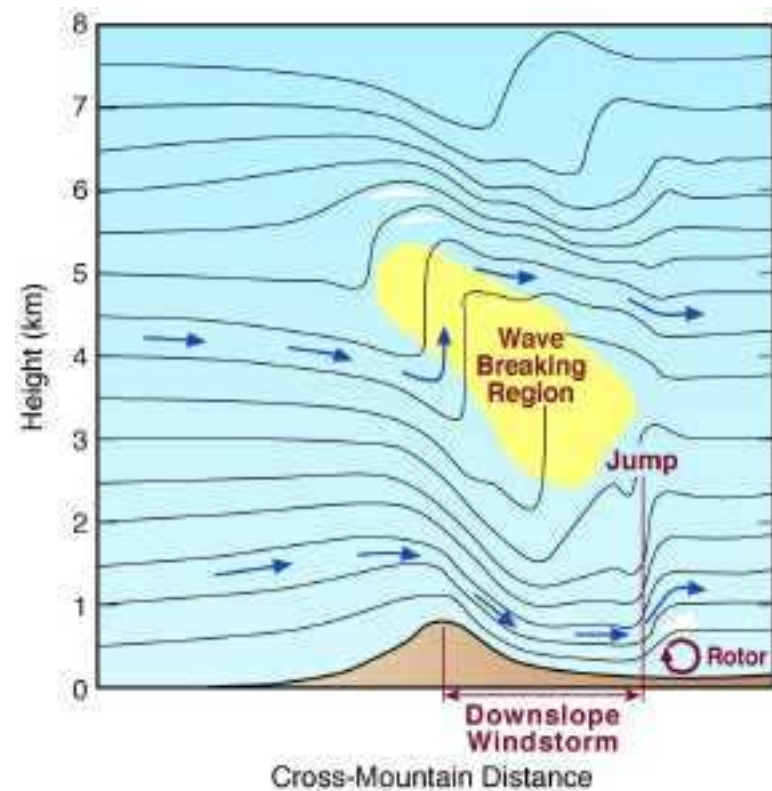


Launching height (LH)

Consider propagating gravity waves excited or “launched” by mountains.

Near the surface, the **amplitude** of these waves is related to the characteristic height scale of the mountains.

Here, the term **launching height** refers to this characteristic height scale of the unresolved (subgrid) topography.



Launching height (LH)

A “coarse” or “low resolution” topography database ($h_{large-scales}$) has been prepared, from high resolution data whose scales smaller than 5km were removed/filtered out.

In GenPhysX, the average (**MEL**) and rms (**LRMS**) of this “coarse” topography are calculated for each model gridbox, and saved in the auxiliary output file. The launching height **LH** field (in meters) is then defined as two times the standard deviation of this “coarse” topography. It is saved in the main output file.

Notice that **LH** still is a subgrid quantity. For high resolution models (with grid spacing < 5km), the “large scale” topography is supposed to be resolved, and so **LH** should vanish.

$$LH = 2\sigma_{LS}$$

where

$$\sigma_{LS} = \sqrt{LRMS^2 - MEL^2}$$

$$MEL = \langle h_{large\ scales} \rangle$$

$$LRMS = \langle (h_{large\ scales})^2 \rangle^{1/2}$$



Topography gradient correlations (Y7, Y8, Y9)

A pre-processed database of horizontal gradients of the coarse topography (the same $h_{large-scales}$, with scales > 5km, used to compute the launching height field **LH**) has been generated,

$$GX = \frac{\partial h_{large\ scales}}{\partial x} = \text{east - west topography gradient (large - scales only)}$$

$$GY = \frac{\partial h_{large\ scales}}{\partial y} = \text{north - south topography gradient (large - scales only)}$$

from which 3 gridbox averages (correlations) are computed:

$$GXX = \langle GX * GX \rangle$$

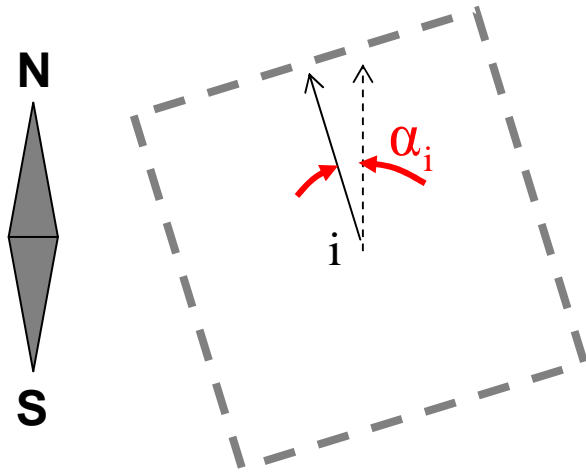
$$GYY = \langle GY * GY \rangle$$

$$GXY = \langle GX * GY \rangle$$

and saved in the auxiliary output file.



Topography gradient correlations (Y7, Y8, Y9)



Since the model grid may be rotated, so the local x-y directions of a gridbox generally form an angle α with respect to the true (geographic) north-south orientation. The physical parametrization called “low-level blocking” requires the gradient correlations with respect to the local (rotated) directions. Therefore GenPhysX computes the angle α for each gridbox, and the **local (rotated) correlations**:

$$Y7 = GXX * \cos^2 \alpha + GYY * \sin^2 \alpha - 2 * GXY * \sin \alpha * \cos \alpha$$

$$Y8 = GYY * \cos^2 \alpha + GXX * \sin^2 \alpha + 2 * GXY * \sin \alpha * \cos \alpha$$

$$Y9 = GXY * (\cos^2 \alpha - \sin^2 \alpha) + (GXX - GYY) * \sin \alpha * \cos \alpha$$

which are saved in the main output file.

Topography gradient correlations (Y7, Y8, Y9)

Finally, a few adjustments and consistency checks are applied to the fields **LH, Y7, Y8 and Y9**:

- consistency with land-water fraction: the four fields are multiplied by **MG**;
- minimum launching height (*lhmin*): if **LH** < 3m, the four fields are set to zero. This is ok because the associated physics parametrizations (gravity wave drag and blocking) are not applied when **LH** < 3m.



Roughness length: local or vegetative component (ZVG1 & ZVG2)

Two gridbox averages of the local (vegetative) roughness length are computed by GenPhysX:

- including all classes \longleftrightarrow
$$ZVG1 = \frac{\sum_{n=1}^{26} VF(n) * ZV(n)}{\sum_{n=1}^{26} VF(n)}$$

- excluding water and ice cover (i.e. including classes 4-26 only) \longleftrightarrow
$$ZVG2 = \frac{\sum_{n=4}^{26} VF(n) * ZV(n)}{\sum_{n=4}^{26} VF(n)}$$

In the formulas above, **VF(n)** is the vegetation fraction previously calculated, and **ZV(n)** is the corresponding roughness length for class **n**, listed in Table 1.

The fields **ZVG1** and **ZVG2** are [saved on the auxiliary output file *_aux.fst](#).



Roughness length: topographic component (ZTOP)

In GenPhysX, the topographic roughness length (**ZTOP**) is a smooth monotonic function (see plot beside) of the subgrid **small-scale standard deviation (SSS)** of the elevation / topography field, defined as follows:

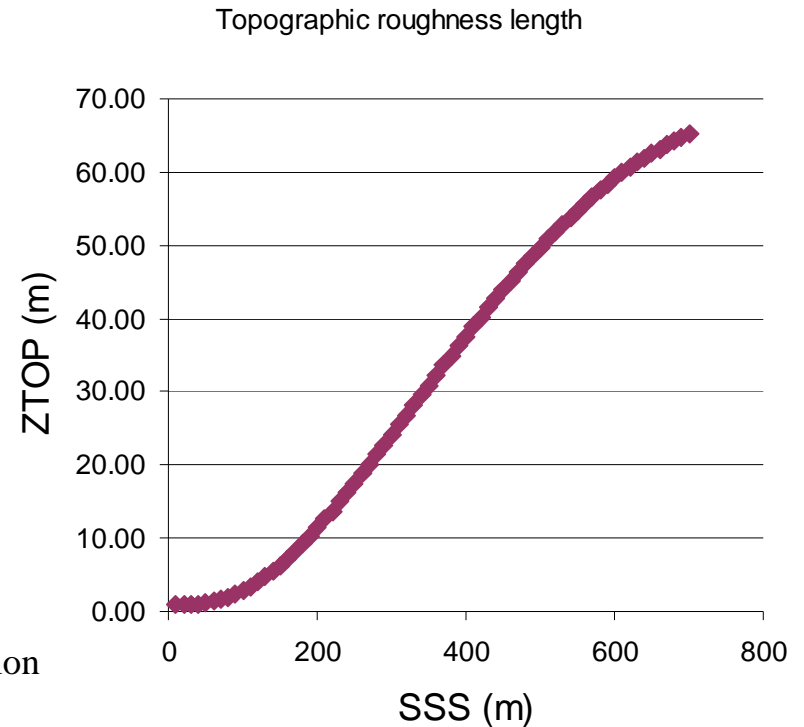
$$SSS = \sqrt{\sigma^2 - \sigma_{LS}^2}$$

where

σ = standard deviation of subgrid elevation
(all subgrid horizontal scales)

σ_{LS} = standard deviation of 'large - scale' subgrid elevation
(only subgrid horizontal scales larger than 5 km)

Recall that a threshold of 5km was chosen to define the separation between “small” and “large” horizontal topographic scales (defined by the constant **lres** in GenPhysX).



Roughness length: topographic component (ZTOP)

The standard deviation of the subgrid elevation is derived from the average elevation (**ME**, saved in the main output file) and the rms elevation (**MRMS**, saved in the auxiliary output file) calculated from a high-resolution topography database.

$$\sigma = \sqrt{\text{MRMS}^2 - \text{ME}^2}$$

where

$$\text{ME} = \langle h_{\text{high res}} \rangle$$
$$\text{MRMS} = \langle (h_{\text{high res}})^2 \rangle^{1/2}$$

Similarly, the standard deviation of the “large-scale” (larger than 5km) elevation field is computed, using the pre-processed low-resolution database (average and rms are named **MEL** and **LRMS**, saved in auxiliary output file). Note: this contribution is non-zero only when the model grid spacing > 5km.

$$\sigma_{\text{LS}} = \sqrt{\text{LRMS}^2 - \text{MEL}^2}$$

where

$$\text{MEL} = \langle h_{\text{large scales}} \rangle$$
$$\text{LRMS} = \langle (h_{\text{large scales}})^2 \rangle^{1/2}$$



Roughness length: topographic component (ZTOP)

The concept of topographic roughness length is based on the formula:

$$C_d^{\text{topo}} = \frac{\kappa^2}{\left(\ln \frac{\text{ZREF}}{\text{ZTOP}}\right)^2} \quad \text{where}$$

C_d^{topo} = topographic drag coefficient
 ZREF = reference height
 $\kappa = 0.4$ = von Karman constant

In GenPhysX, the topographic drag coefficient and the reference height are estimated from the small-scale standard deviation **SSS**, and the formula above is then used to determine the roughness length **ZTOP**:

$$C_d^{\text{topo}} = C_d^{\text{topo}}(\text{SSS}) \quad \Rightarrow \quad \text{ZTOP}(\text{SSS}) = \text{ZREF}(\text{SSS}) * \exp\left(-\frac{\kappa}{\sqrt{C_d^{\text{topo}}(\text{SSS})}}\right)$$
$$\text{ZREF} = \text{ZREF}(\text{SSS})$$



Roughness length: topographic component (ZTOP)

The reference height and the topographic drag coefficient are computed from **SSS** according to the formulas* below:

$$ZREF = H_{coef} * SSS$$

$$C_d^{topo} = \frac{1}{2} C_d^{bulk} * SLP$$

where

$$H_{coef}(SSS) = \left\{ \begin{array}{ll} 1.5 - 0.5 \frac{(SSS - 20)}{680} & , \text{ if } SSS \leq 700\text{m} \\ 1.0 & , \text{ if } SSS > 700\text{m} \end{array} \right\} = \text{height coefficient}^{**}$$

$$SLP(SSS) = H_{coef}^2 \frac{SSS}{c_{ires}} = \text{slope parameter}$$

$$c_{ires} = 5000\text{m} = \text{separation scale (5km)}$$

$$C_d^{bulk} = 0.40 = \text{bulk drag coefficient}$$

* *Formulation developed and proposed by Daniel Deacu (RPN, U. Manitoba).*

** *Notice that $1.0 < H_{coef} < 1.5$*



Roughness length: topographic component (ZTOP)

In the code, some extreme cases receive special treatment:

- consistency with land-water mask (**MG**): minimum land fraction required
if **MG** ≤ **mgmin**, then **SSS** = 0.0 ; **mgmin** = 0.001
- minimum & maximum values for **ZREF** are imposed:
ZREF_min = 10m , **ZREF_max** = 1500m
- **ZTOP** considered only when the slope parameter is large enough:
if **SLP** ≤ **slpmin**, then **ZTOP** = 0.0 ; **slpmin** = 0.001
- simplified **ZTOP** formula for low values of **SSS**:

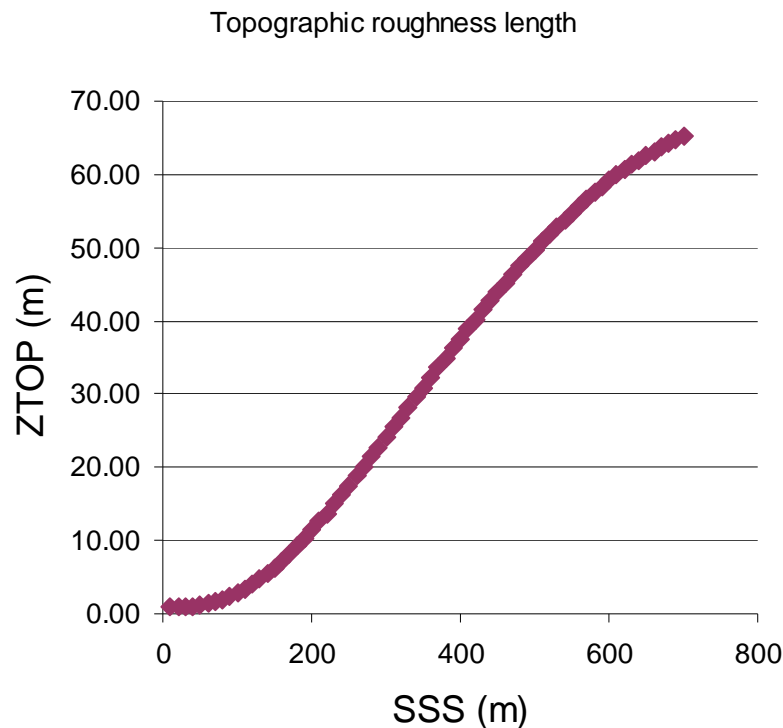
$$ZTOP(SSS) = \begin{cases} 1.0 + ZREF(SSS) * \exp\left(-\frac{\kappa}{\sqrt{C_d^{topo}(SSS)}}\right) & , \text{ if } SSS > sssmin \\ 0.1 * SSS & , \text{ if } SSS \leq sssmin \end{cases}$$

where **ssmin** = 20m



Roughness length: topographic component (ZTOP)

The procedure and formulas may seem complicated, but the result is a smooth monotonic relation between the standard deviation of subgrid topography (**SSS**) and the roughness length (**ZTOP**) – see plot below.



As model resolution increases, the standard deviation of unresolved topography (**SSS**) will decrease* in average. From the figure, one can see that **ZTOP** decreases when **SSS** decreases. Therefore, in average the values of the (topographic) roughness length should go down as the resolution of our models go up.

* *As long as the information in the database remains fixed.*

Roughness length: ice-free soil component (**Z0S**; **ZPS**)

The local (vegetative) roughness length **ZVG2** and the topographic roughness length **ZTOP** are then combined, according to the formula

$$\frac{1}{\left(\ln \frac{\text{ZREF}}{\text{Z0S}}\right)^2} = \frac{1}{\left(\ln \frac{\text{ZREF}}{\text{ZTOP}}\right)^2} + \frac{1}{\left(\ln \frac{\text{ZREF}}{\text{ZVG2}}\right)^2}$$

to produce the **effective roughness over soil Z0S**.

Note: This formula seems complicated, but it basically says how the vegetation roughness is “added” or superimposed to the topographic roughness (i.e. **Z0S** ~ **ZTOP** + **ZVG2**, approximately). It is not an average between **ZTOP** and **ZVG2** ! Over ice-free gridboxes, **Z0S** should be larger than the two components, **ZTOP** and **ZVG2**.

The field **Z0S** and its logarithm **ZPS** are saved in the auxiliary output file. The reference height field **ZREF** is also saved there.

*Notes: If $VF(2) > 99.9\%$, then the gridbox is considered ice-covered and **Z0S** is virtually zero. In this case, to avoid $\log(0.0)$, a minimum value ($z0min = 10e-5$ m) is imposed.*

Page 51 – February 5, 2009



Roughness length: ice/glacier component (**Z0G**; **ZPG**)

The roughness length over ice/glaciers also includes a topographic component, and is calculated according to the formula

$$\frac{1}{\left(\ln \frac{ZREF}{Z0G}\right)^2} = \frac{1}{\left(\ln \frac{ZREF}{ZTOP}\right)^2} + \frac{1}{\left(\ln \frac{ZREF}{z0_{ice}}\right)^2}$$

where **z0_ice** = 3e-4 m is a constant (roughness length for ice).

Note: As in the previous slide, this formula shows how the ice roughness is “added” to the topographic roughness (i.e. **Z0G** ~ **ZTOP** + **ZVG2**, approximately). It is not an average between **ZTOP** and **z0_ice** ! Over glaciers, **Z0G** should be larger than **ZTOP** and **z0_ice**.

The field **Z0G** and its logarithm **ZPG** are saved in the auxiliary output file.

Note: The field Z0G is computed only if VF(2)>0.1%. Again, to avoid log(0.0), a minimum value (z0min = 10e-5 m) is imposed.



Roughness length (Z0; ZP): combining all components

To combine all components (soil, glaciers and water) and produce the effective roughness length **Z0** for a gridbox, we use a simple “average of logarithms” -- inspired by the aggregation method used in the GEM physics:

$$\ln(Z0) = \underbrace{MG * [\overbrace{VF(2) * \ln(Z0G)}^{\text{ice/glacier}} + \overbrace{(1 - VF(2)) * \ln(Z0S)}^{\text{soil (ice-free)}}]}_{\text{land component}} + \underbrace{(1 - MG) * \ln(z0_{\text{water}})}_{\text{water component}}$$

where **MG** is the land/soil fraction, **VF(2)** is the ice/glacier fraction and **z0_water** = 0.001 m = roughness length for water.

Note: The formula above is not a sum, but a weighted average of the roughness from 3 types of surface (glacier, ice-free soil, water).

The field **Z0** and its logarithm **ZP** are saved in the main output file.

Roughness length: optional filter

It was noticed that the roughness length field **Z0** produced by GenPhysX is sometimes rather “noisy”, specially for high-resolution model grids. Therefore, an optional filter/smoothing operator for the field **Z0** is available, and may be activated in GenPhysX through the option

-z0filter

This is actually the same filter/smoothing operator currently used by GEM to filter the field **ME** and thus generate the filtered topography **MF**. (In GEM, this filter is applied to **ME** only, according to user-defined parameters in the `gem_settings.nml` namelist).

At this point, the application of this filter to **Z0** is **optional but recommended**.

Notice that, even when the filter is applied, a copy of the original (non-filtered) field and its logarithm are saved in the auxiliary output file, under the names **Z00** and **ZP0**.

