Ocean-Land-Atmosphere Model (OLAM)

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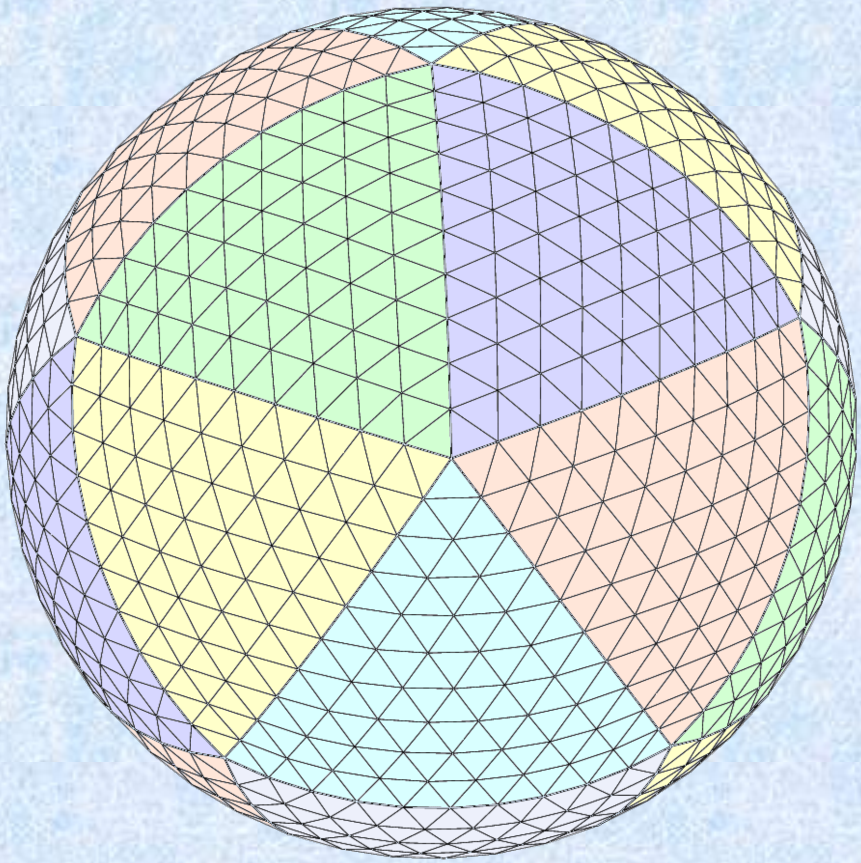
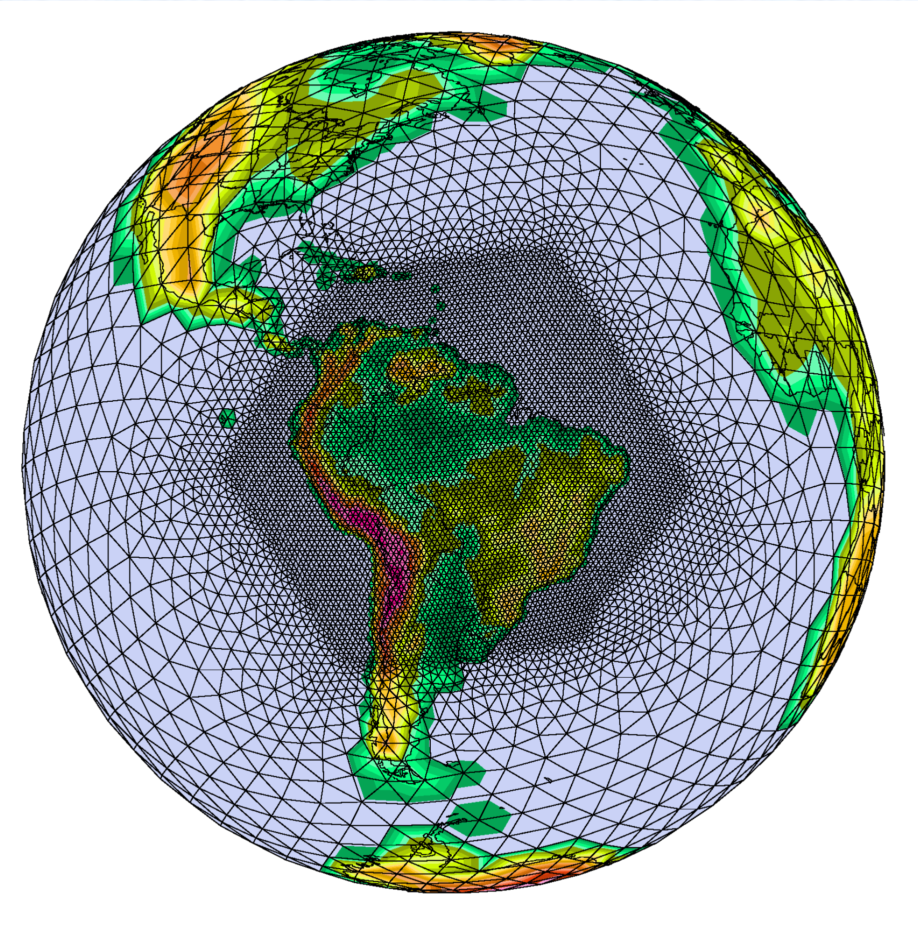
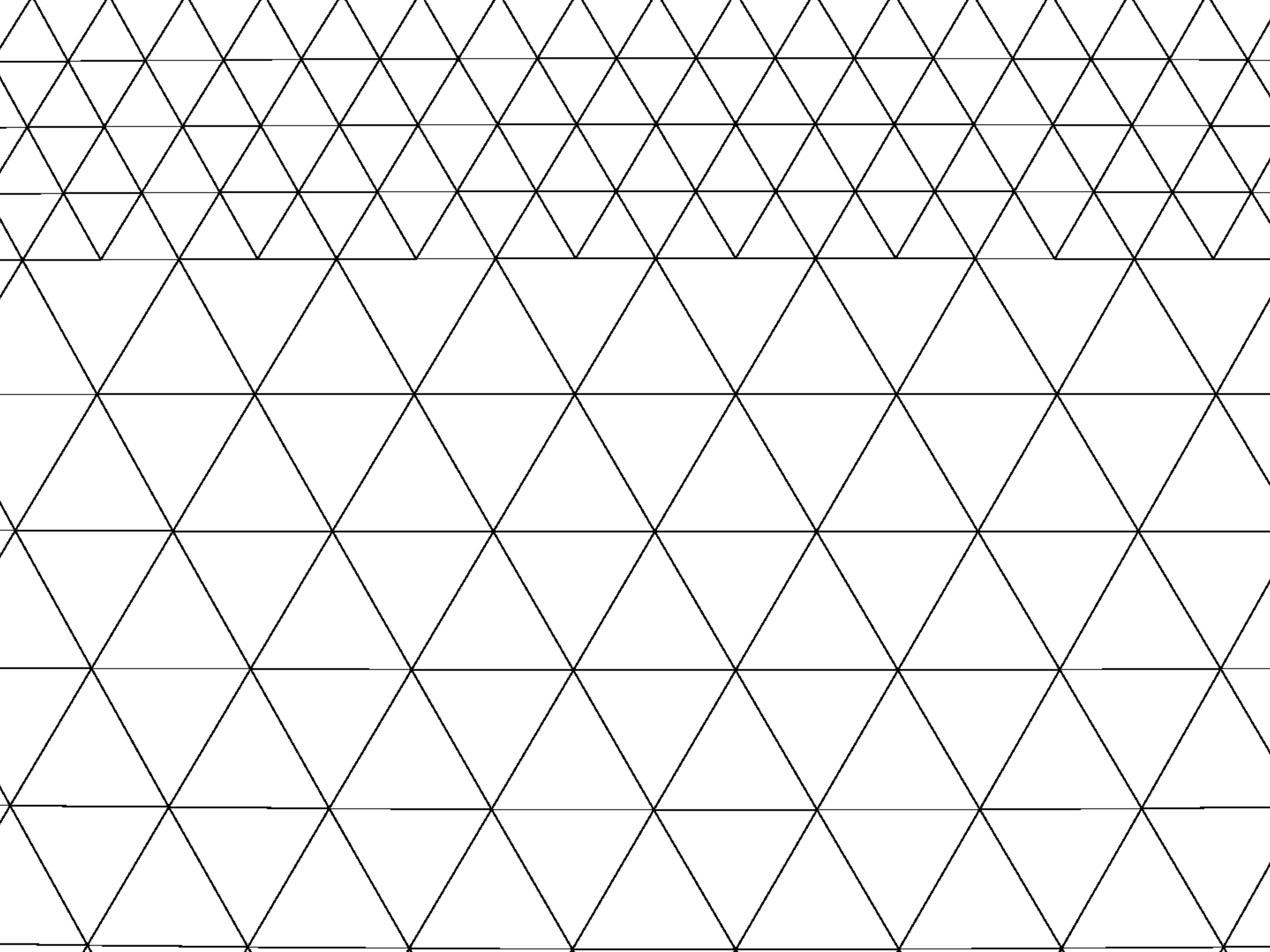
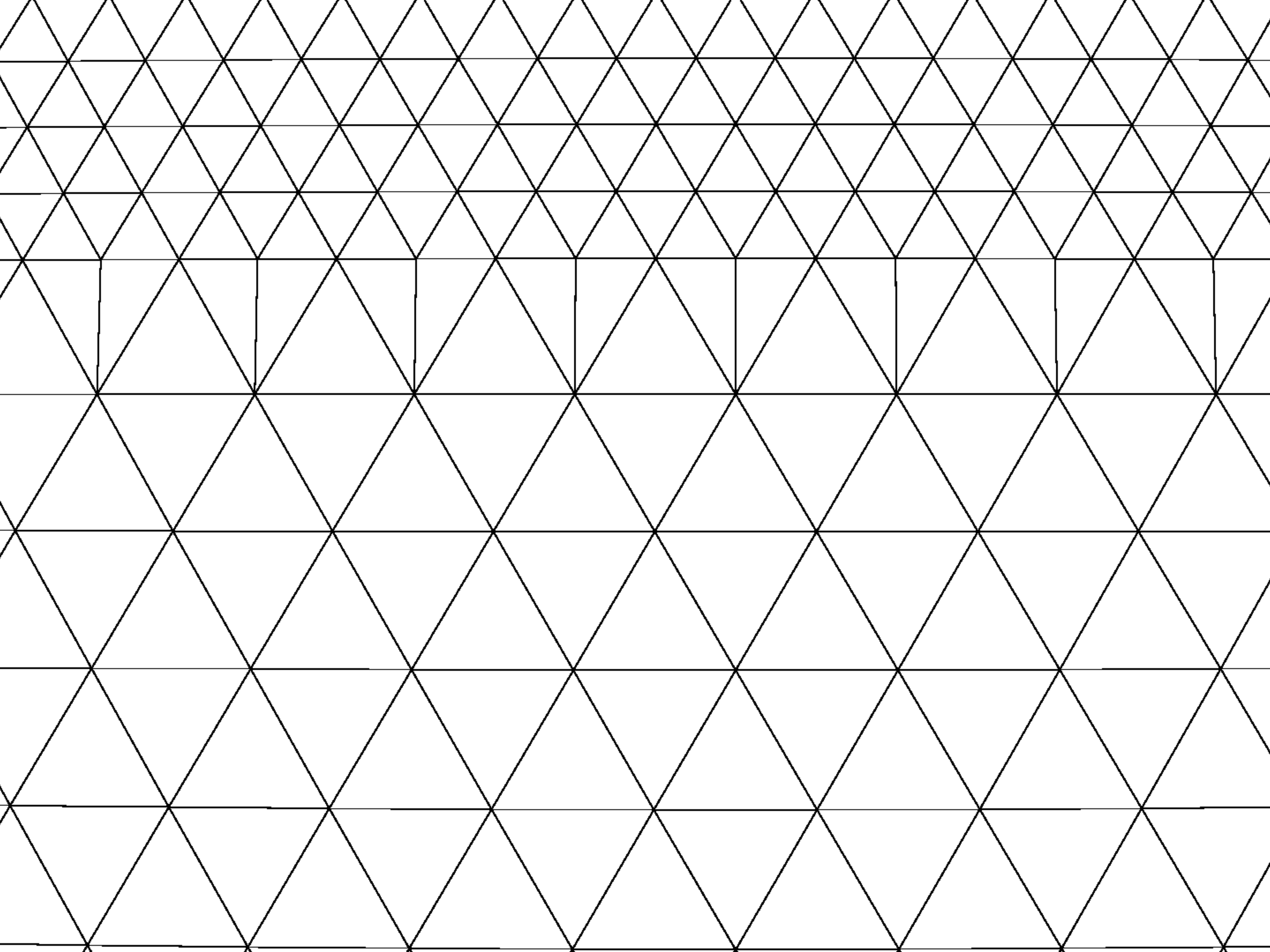
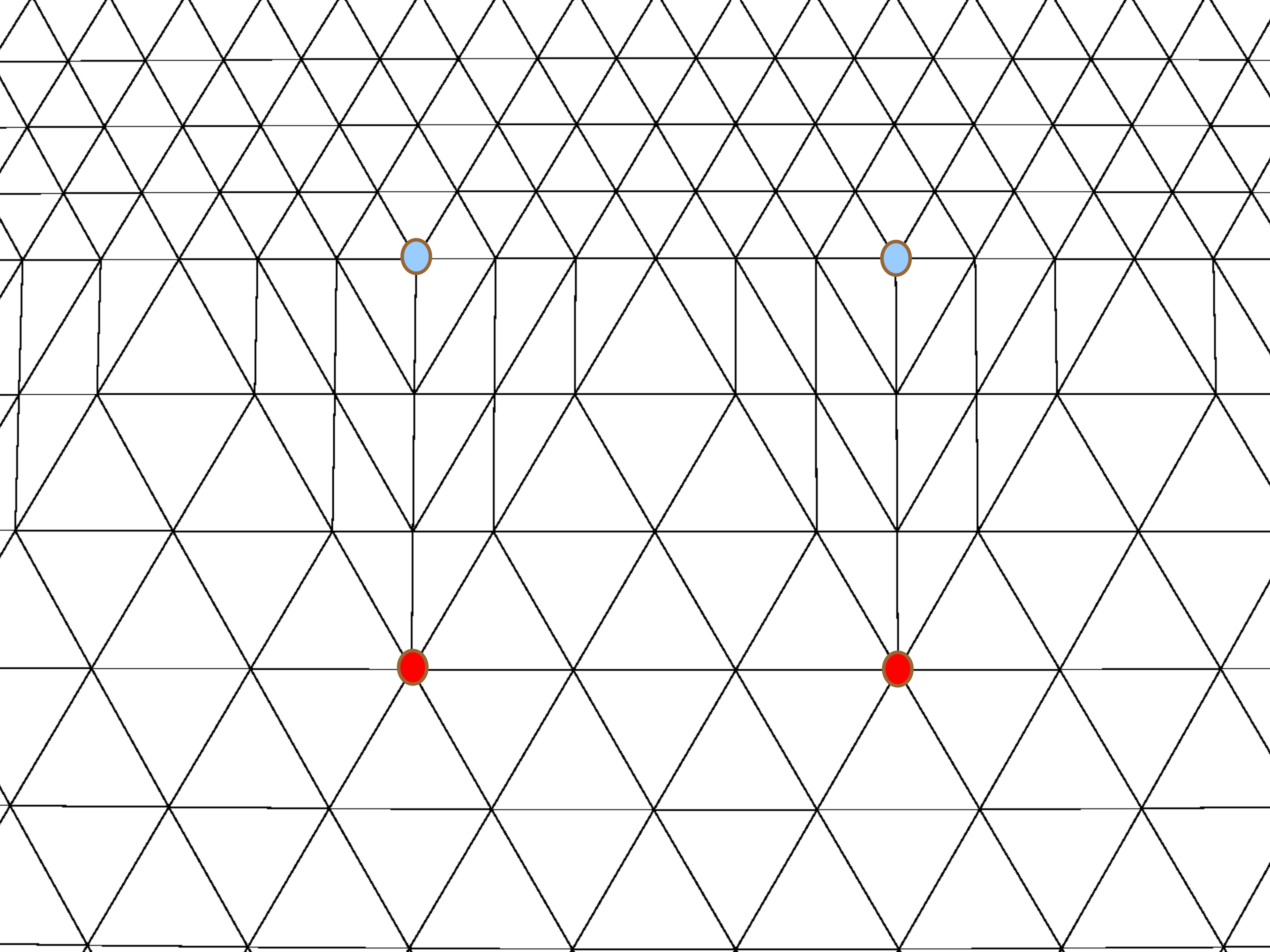
Dynamic Core Model Intercomparison Project (DCMIP 2016)
NCAR – Boulder, CO, 14 June 2016

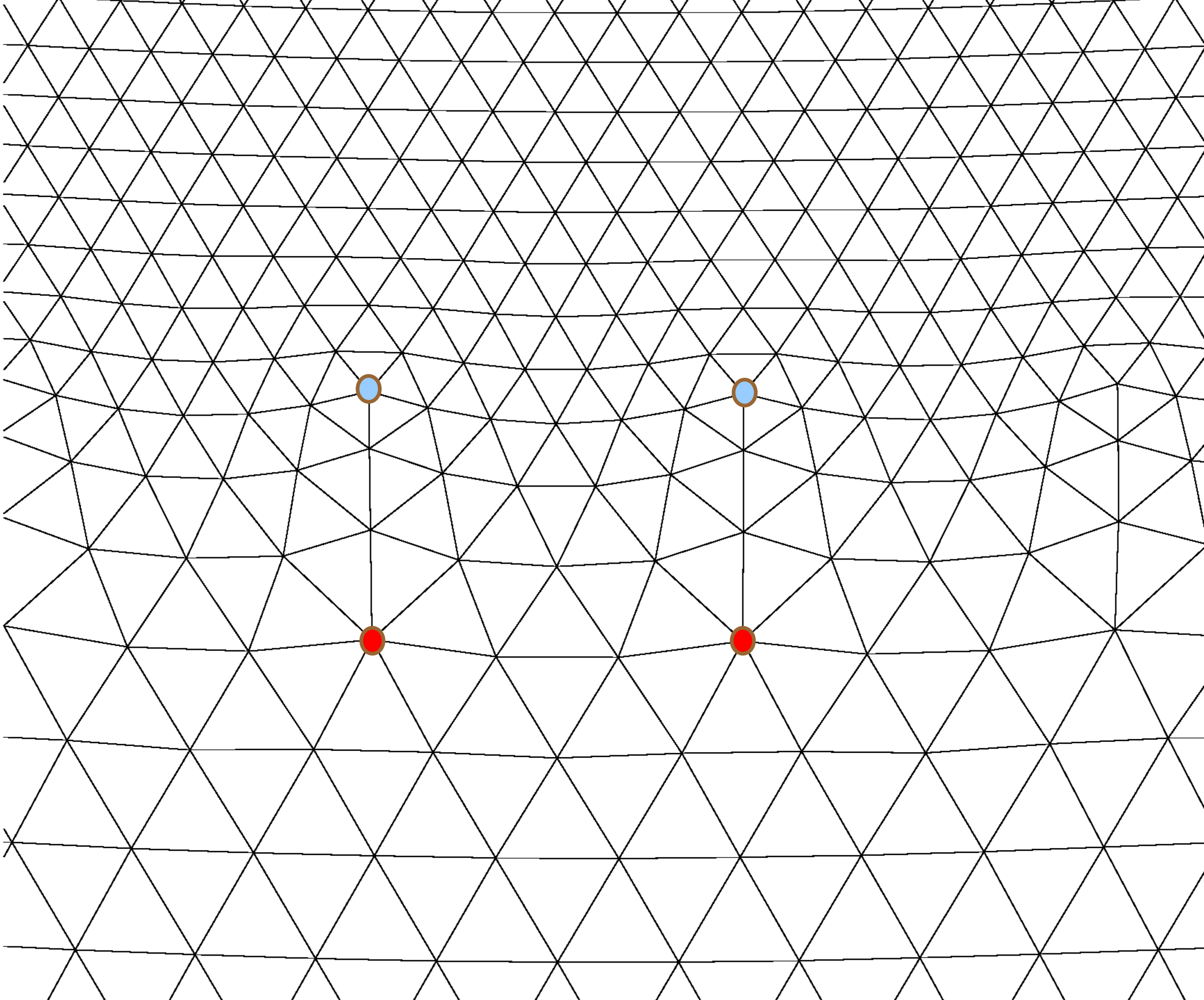




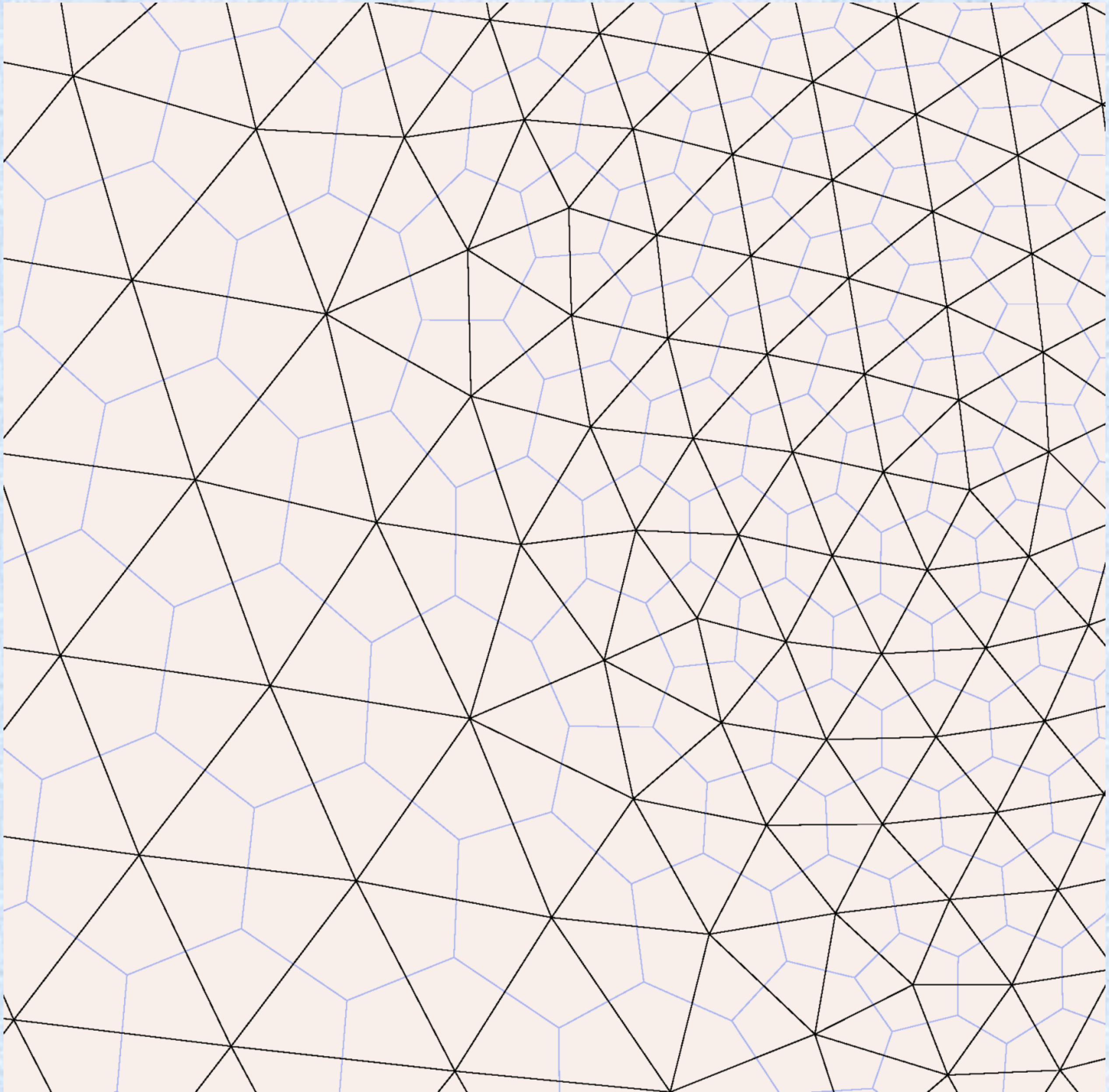


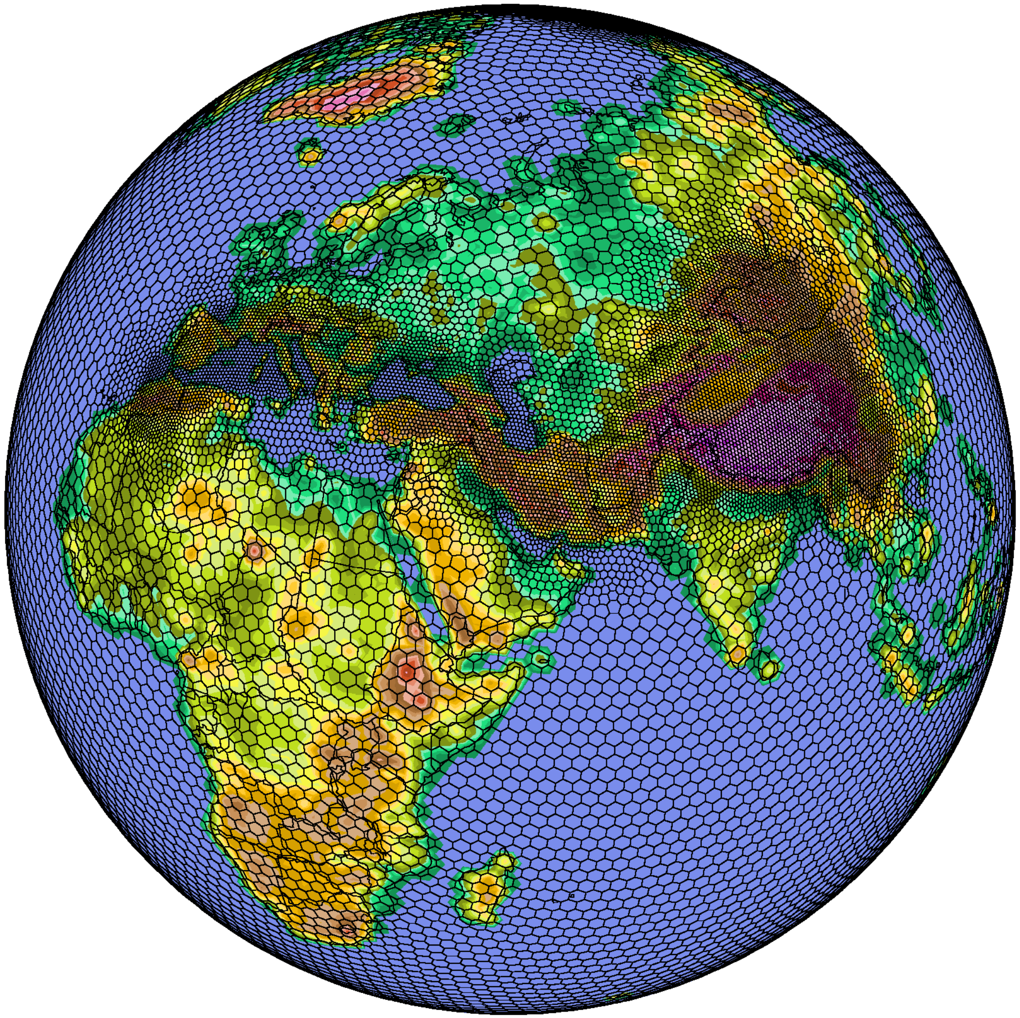


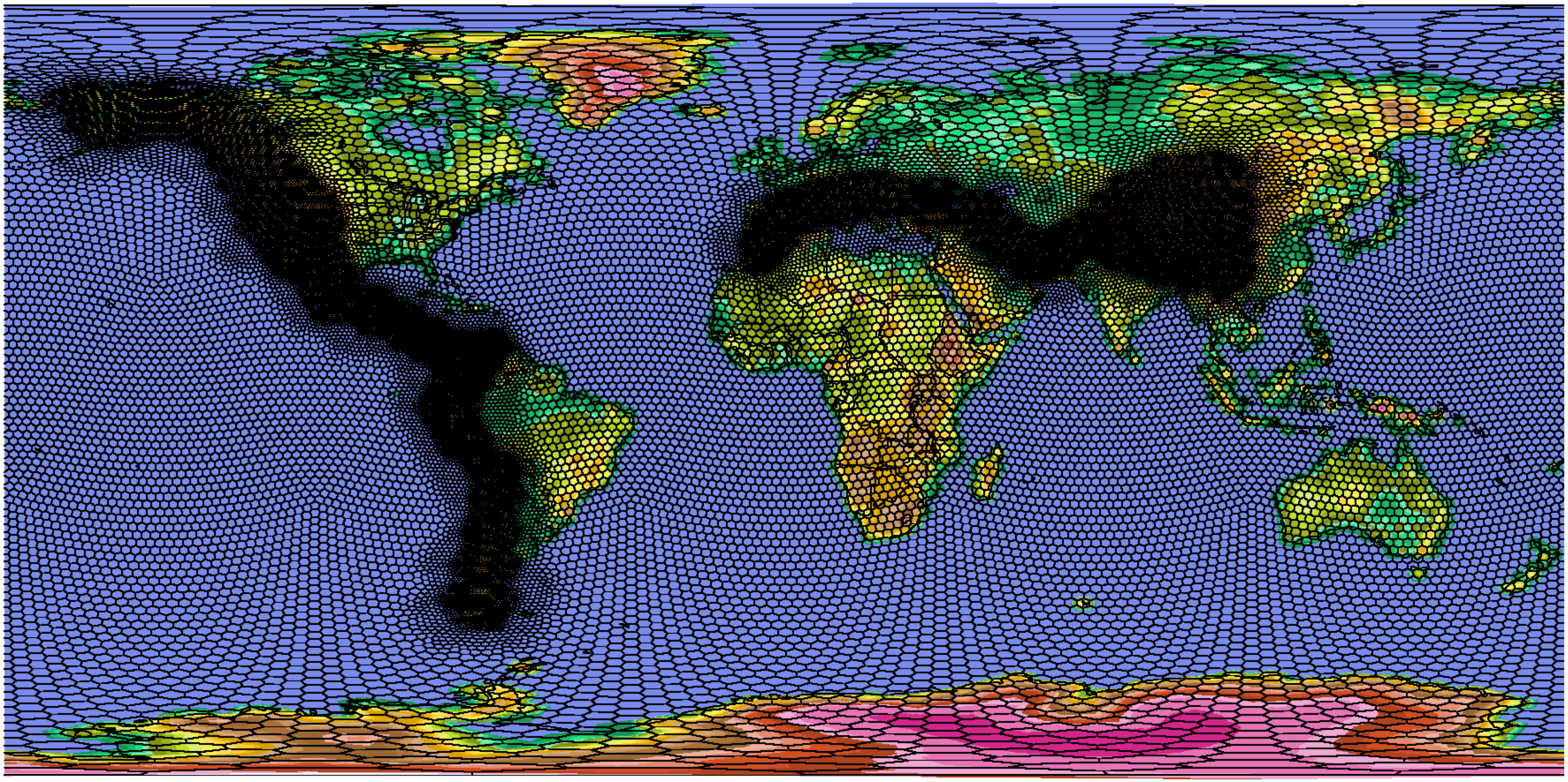


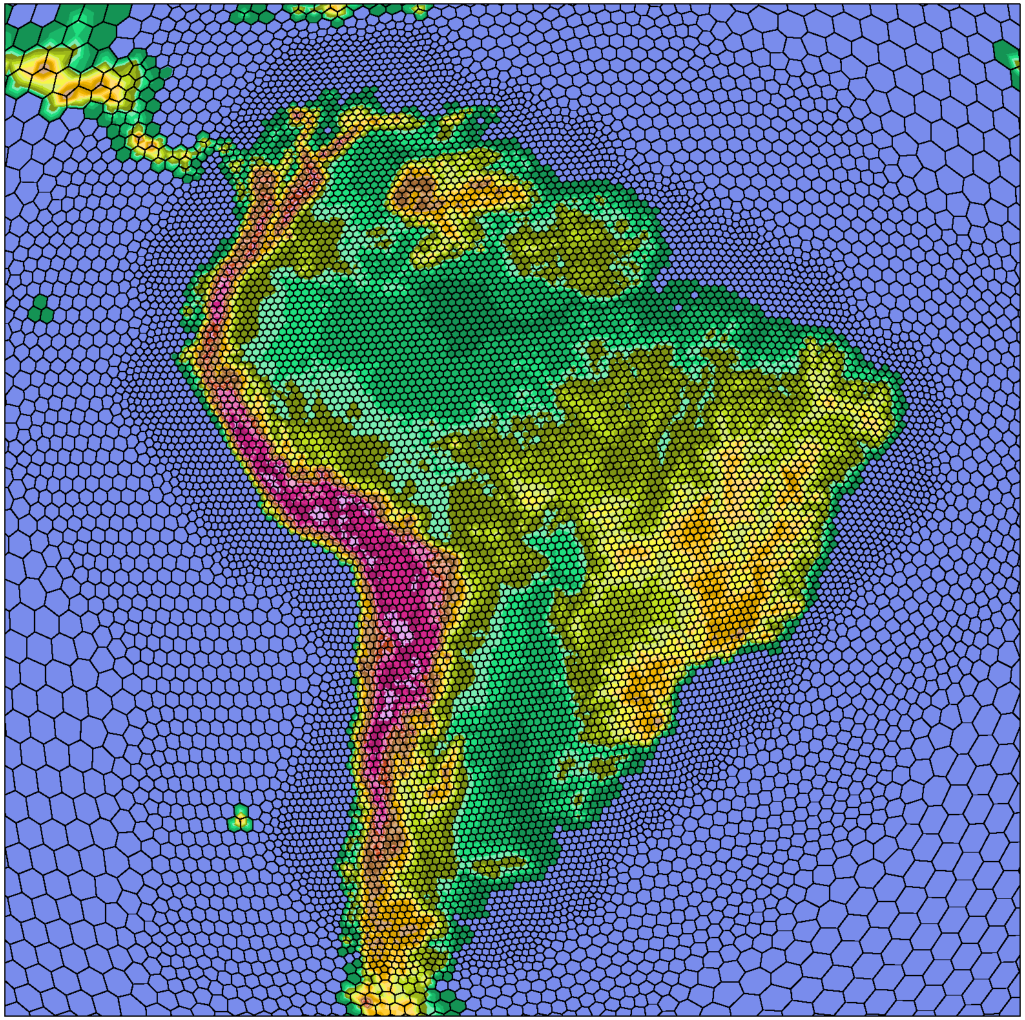


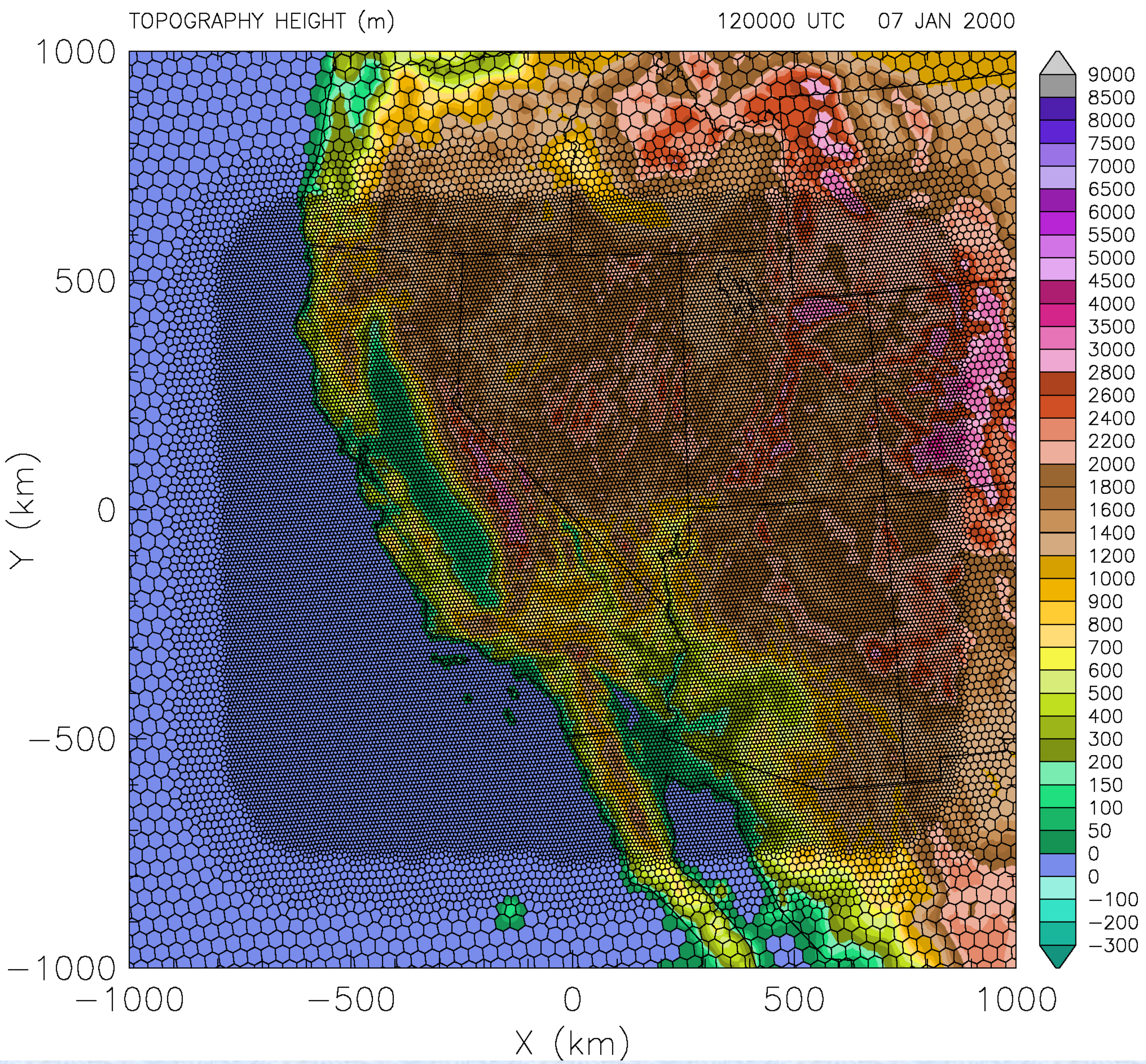
Spring dynamics iteration with spatially variable equilibrium spring length plus angle forcing term





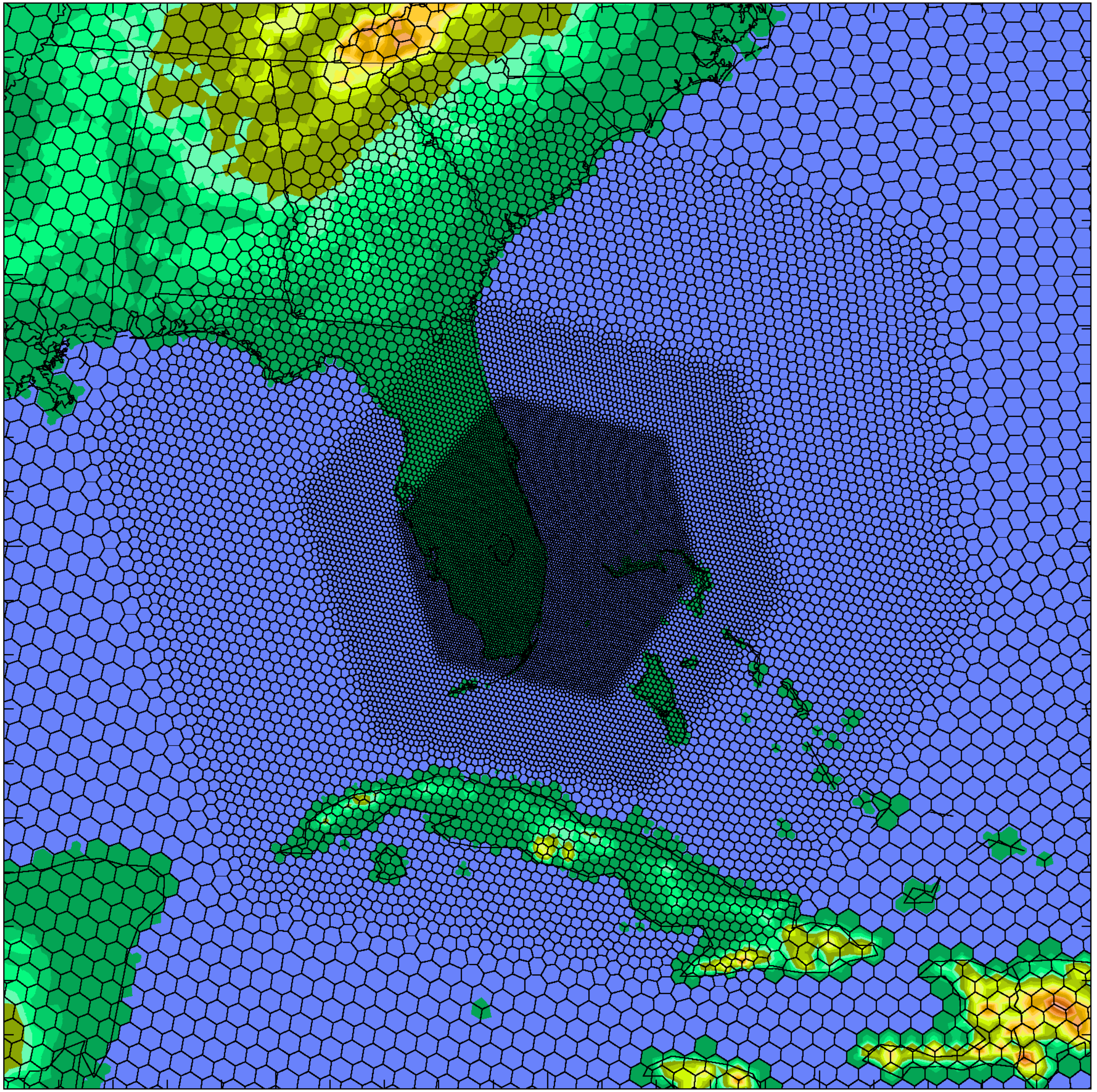


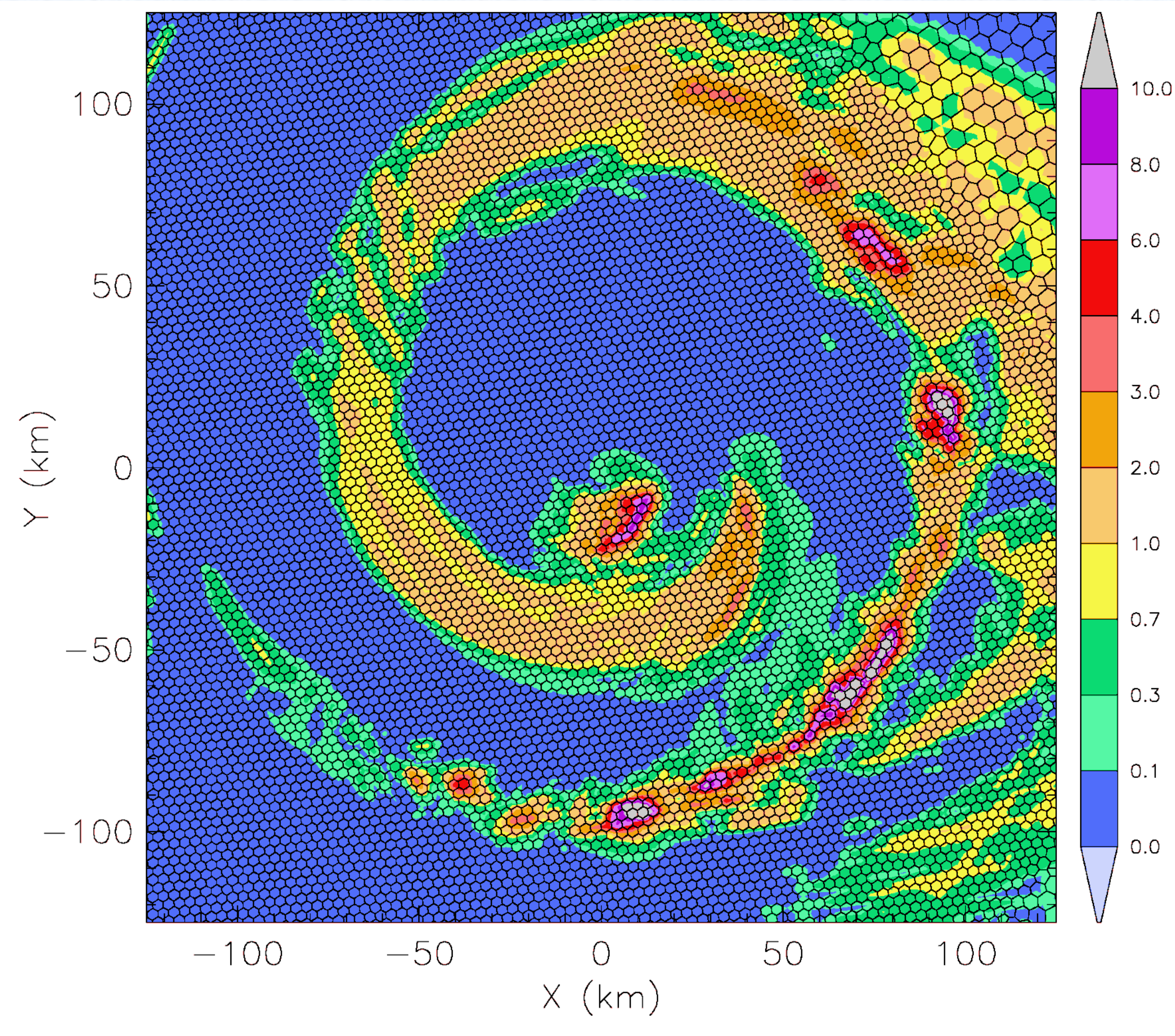




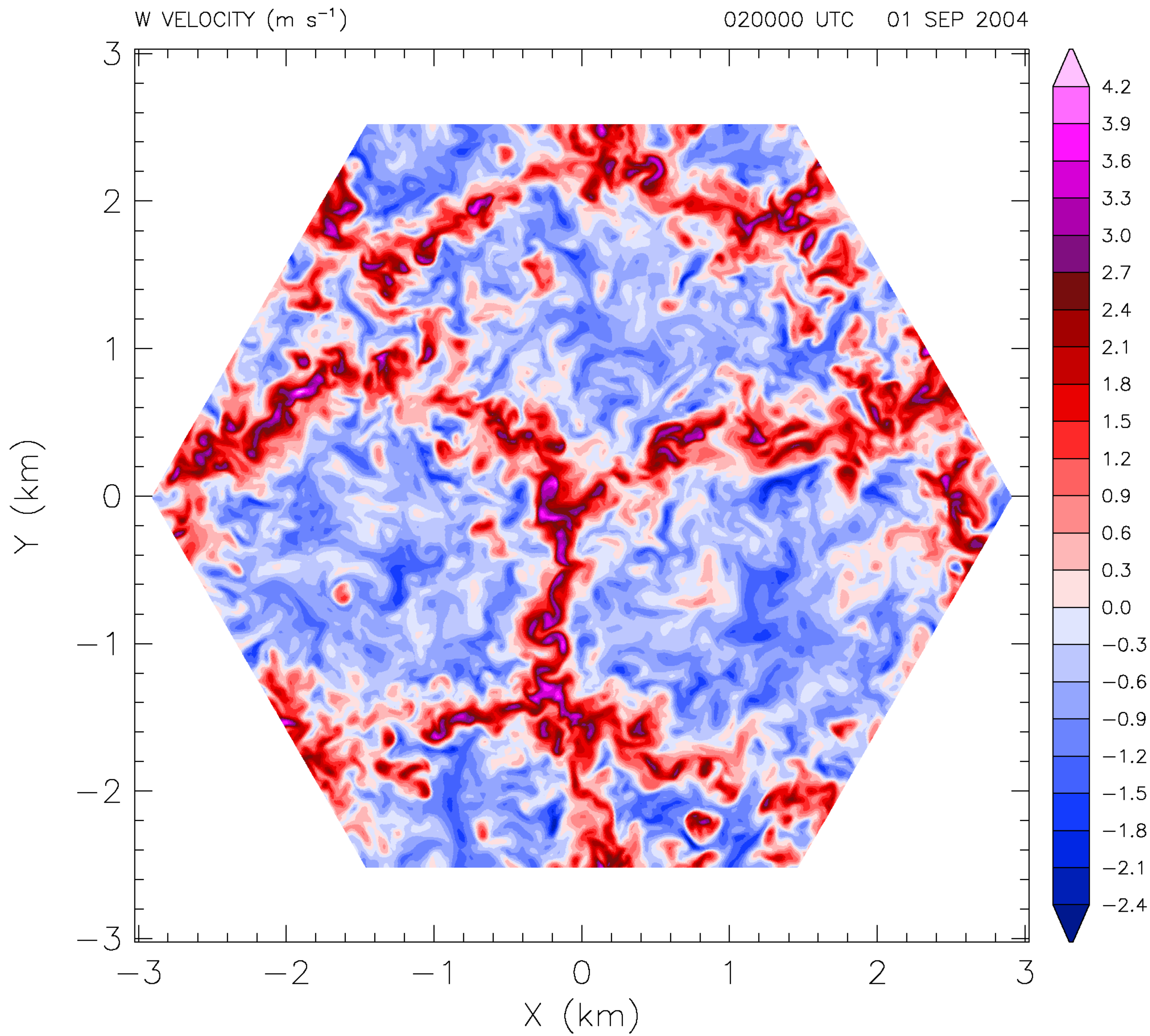
TOPOGRAPHY HEIGHT (m)
120000 UTC 07 JAN 2000
1000
500
0
−500
−1000
Y (km)
−1000
−500
0
500
1000
X (km)
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
900
800
700
600
500
400
300
200
150
100
50
0
0
−100
−200
−300

<u>OLAM:</u>
Hexagonal grid cells





Y (km)
100
50
0
−50
−100
X (km)
−100
−50
0
50
100
10.0
8.0
6.0
4.0
3.0
2.0
1.0
0.7
0.3
0.1
0.0


W VELOCITY (m s^{-1})
020000 UTC 01 SEP 2004
Y (km)
X (km)
3
2
1
0
−1
−2
−3
4.2
3.9
3.6
3.3
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0
−0.3
−0.6
−0.9
−1.2
−1.5
−1.8
−2.1
−2.4

Continuous equations in conservation form

$$\frac{\partial V_i}{\partial t} = -\nabla \bullet \left(v_i \vec{V}\right) - (\nabla p)_i - \left(2\rho\,\vec{\Omega} \times \vec{v}\right)_i + \rho\, g_i + F_i$$

Momentum conservation (component i)

$$\frac{\partial \rho}{\partial t} = -\nabla \bullet \vec{V} + M$$

Total mass conservation

$$\frac{\partial (\rho\,\Theta)}{\partial t} = -\nabla \bullet \left(\Theta \vec{V}\right) + H$$

Θ conservation

$$p = \left[\left(\rho_d R_d + \rho_v R_v\right)\theta\right]^{\frac{C_P}{C_V}} \left(\frac{1}{p_0}\right)^{\frac{R_d}{C_V}}$$

Equation of State

$$\frac{\partial (\rho\, s)}{\partial t} = -\nabla \bullet \left(s \vec{V}\right) + Q$$

Scalar conservation
(e.g. $s_v = \rho_v / \rho$)

$$\rho = \rho_d + \rho_v + \rho_c$$

Total density

$$\vec{V} \equiv \rho\, \vec{v}$$

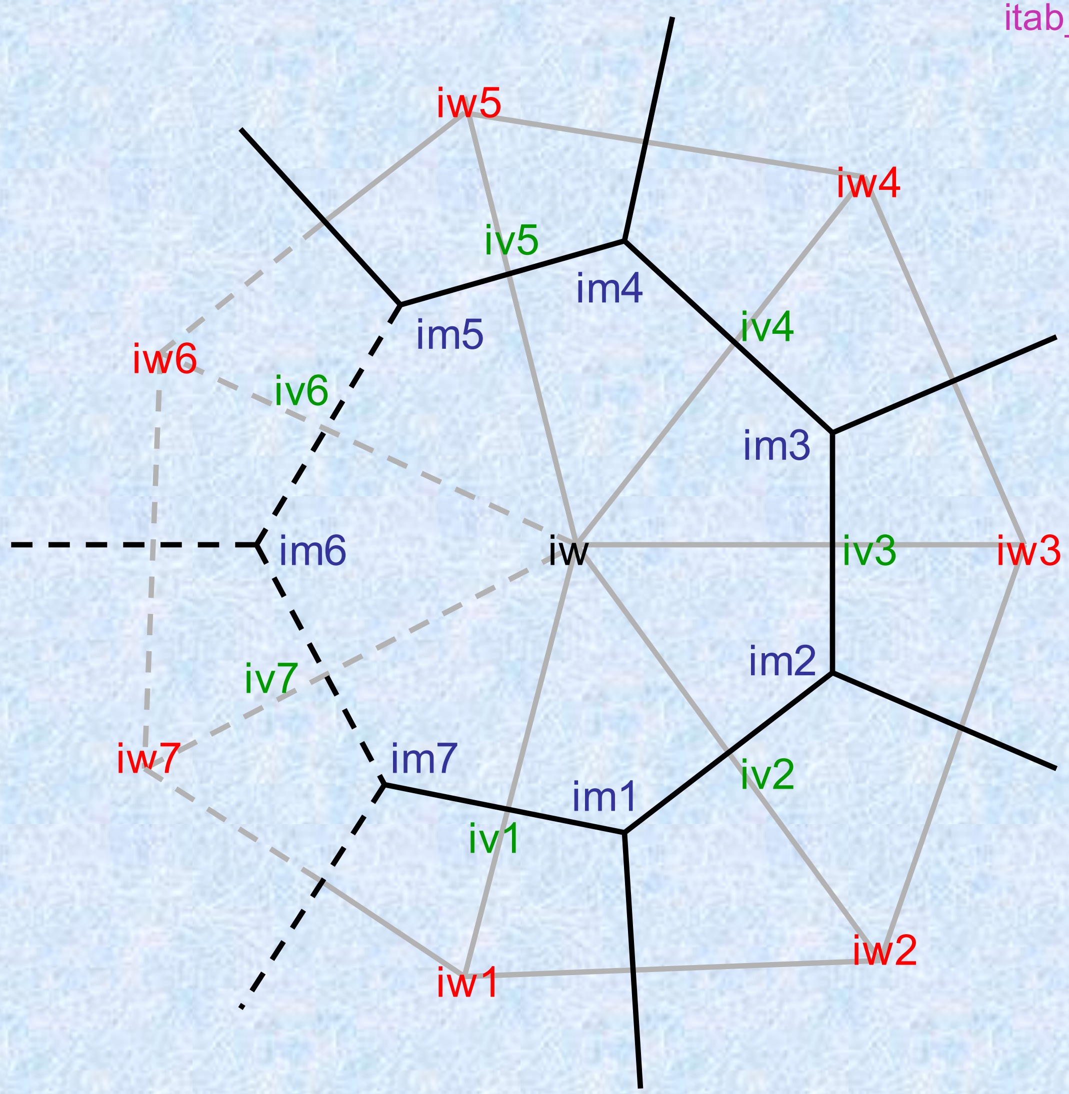
Momentum density

$$\theta = \Theta \left[1 + \frac{q_{lat}}{C_p \max(T, 253)}\right]$$

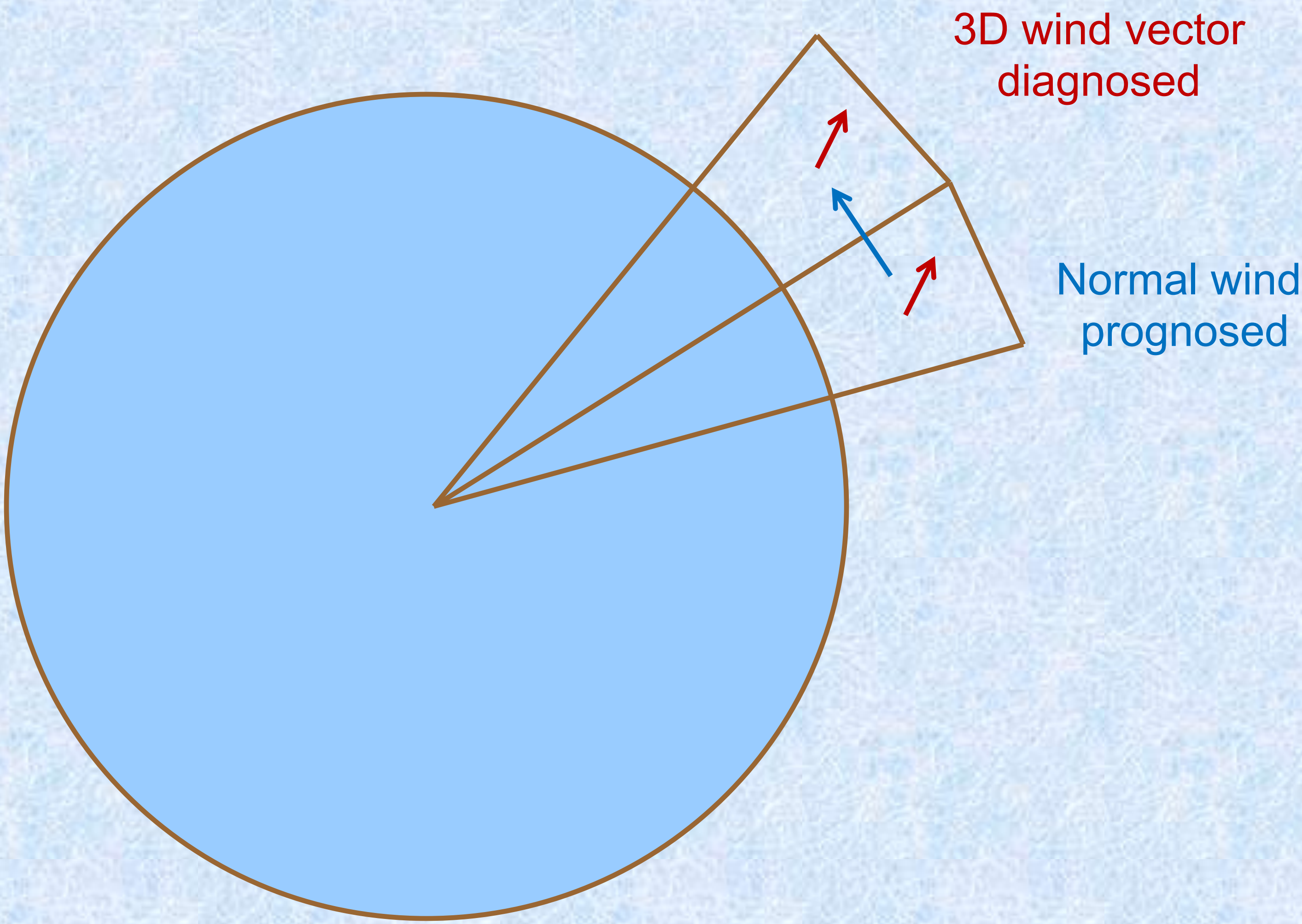
θ = potential temperature
Θ = ice-liquid potential temperature

Neighbors of W point on hexagonal mesh

itab_w(iw)%im(1:7)
itab_w(iw)%iv(1:7)
itab_w(iw)%iw(1:7)

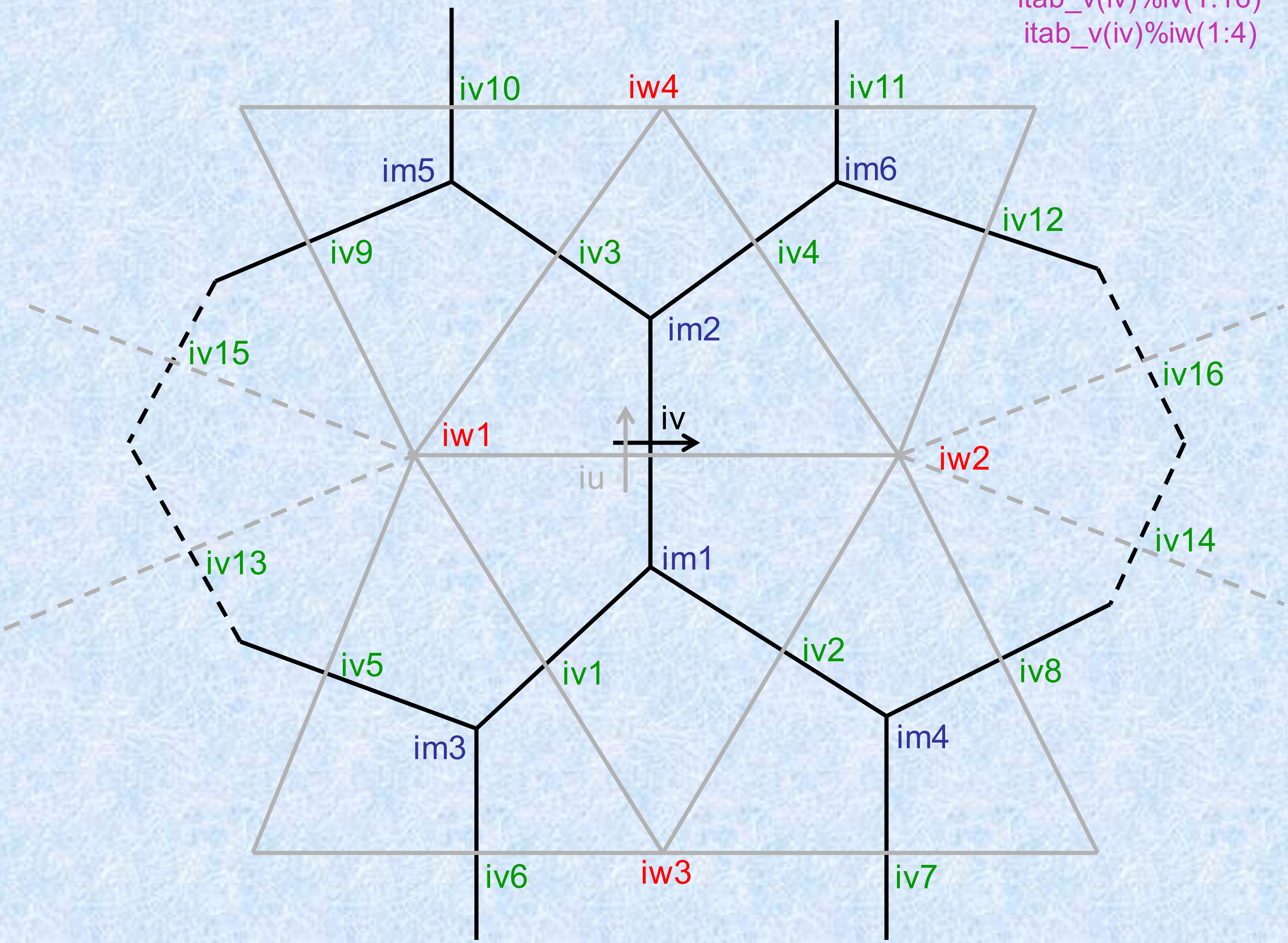


OLAM uses a hybrid A-C grid stagger method following Perot (JCP 2002)



Neighbors of V point on hexagonal mesh

itab_v(iv)%im(1:6)
itab_v(iv)%iv(1:16)
itab_v(iv)%iw(1:4)



Time discretization

$$\frac{\partial V_i}{\partial t} = -\nabla \bullet \left(v_i \vec{V}\right) - \left(\nabla p\right)_i - \left(2\rho\,\vec{\Omega} \times \vec{v}\right)_i + \rho\, g_i + F_i$$

Fully explicit horizontally, including sound waves. Implicit vertical solver to control vertical propagation of acoustic modes.

Durran showed that AB2 can be more accurate than RK for equivalent computational cost because more efficient AB2 permits smaller timesteps. However, AB2 is unstable with implicit vertical solver.

However, can use AB2-like method to extrapolate horizontal mass flux forward to half-forward time level. Then, evaluate vertical momentum equation implicitly, which recovers half-forward vertical mass flux as well. Velocity v_i advected using Lax-Wendroff method.

Next, evaluate remaining terms in horizontal momentum equation.

Advect scalars with time-averaged mass fluxes.

$$\frac{\partial(\rho\, s)}{\partial t} = -\nabla \bullet \left(s\,\vec{V}\right) + Q$$

Conservation equations in discretized finite-volume form

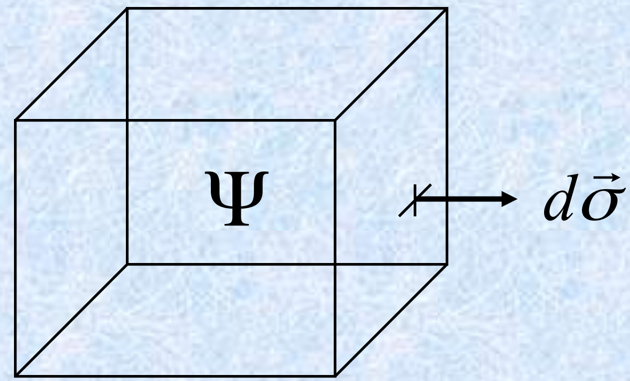
(SGS = "subgrid-scale eddy correlation")

$$\frac{\partial \overline{V}_i}{\partial t} = -\Psi^{-1} \sum_j \left[\left(\overline{v}_{ij} \underline{\overline{V}_j} + SGS\{v_{ij}, V_j\} \right) \sigma_j \right] - \frac{\Delta \overline{p}}{\Delta x_i} - \left(2 \overline{\rho}\, \vec{\Omega} \times \overline{\vec{v}} \right)_i + \overline{\rho}\, g_i + \overline{F}_i$$

cell volume

cell face area

$$\frac{\partial \overline{\rho}}{\partial t} = -\Psi^{-1} \sum_j \left[\underline{\overline{V}_j} \sigma_j \right]$$



$$\frac{\partial \left(\overline{\rho \Theta} \right)}{\partial t} = -\Psi^{-1} \sum_j \left[\left(\overline{\Theta}_j \underline{\overline{V}_j} + SGS\{\Theta_j, V_j\} \right) \sigma_j \right] + \overline{H}$$

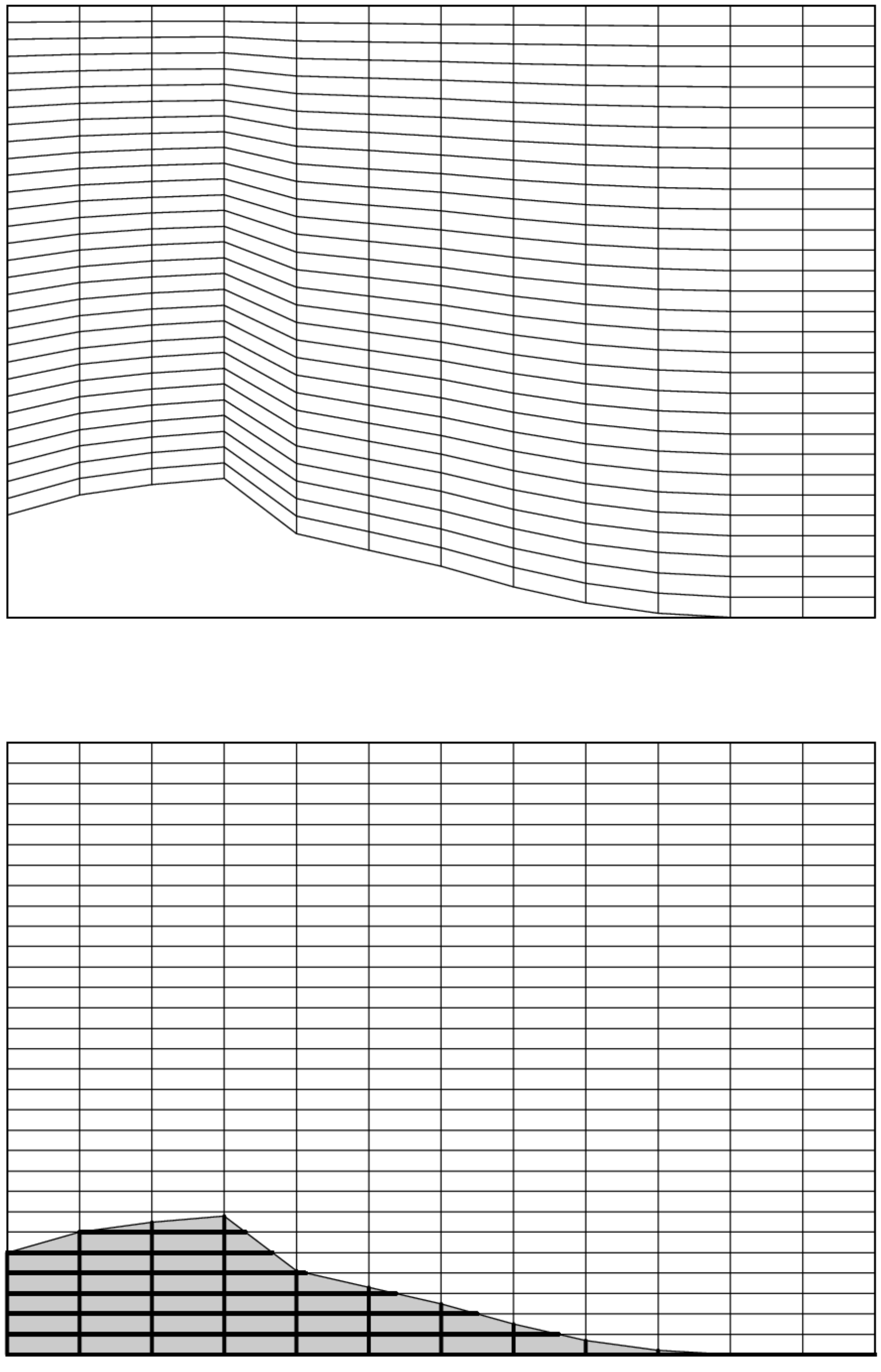
$$\frac{\partial \left(\overline{\rho s} \right)}{\partial t} = -\Psi^{-1} \sum_j \left[\left(\overline{s}_j \underline{\overline{V}_j} + SGS\{s_j, V_j\} \right) \sigma_j \right] + \overline{Q}$$

$$\overline{p} = \left[\left(\overline{s}_d R_d + \overline{s}_v R_v \right) \overline{\rho \theta} \right]^{\frac{C_P}{C_V}} \left(\frac{1}{p_0} \right)^{\frac{R_d}{C_V}}$$

Discretized momentum density is consistent between all conservation equations

Terrain-following coordinates used in most models

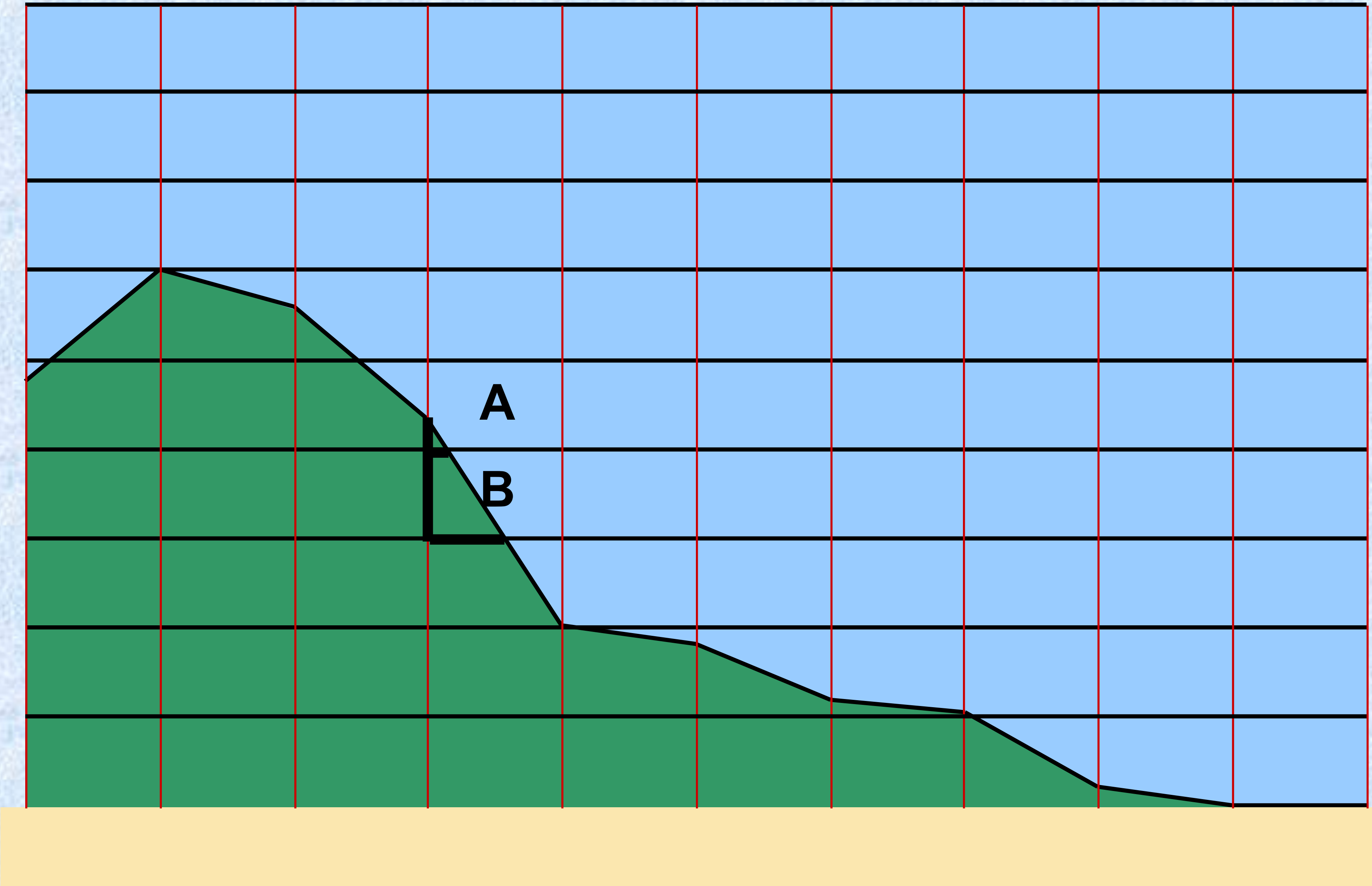
OLAM uses cut cell method



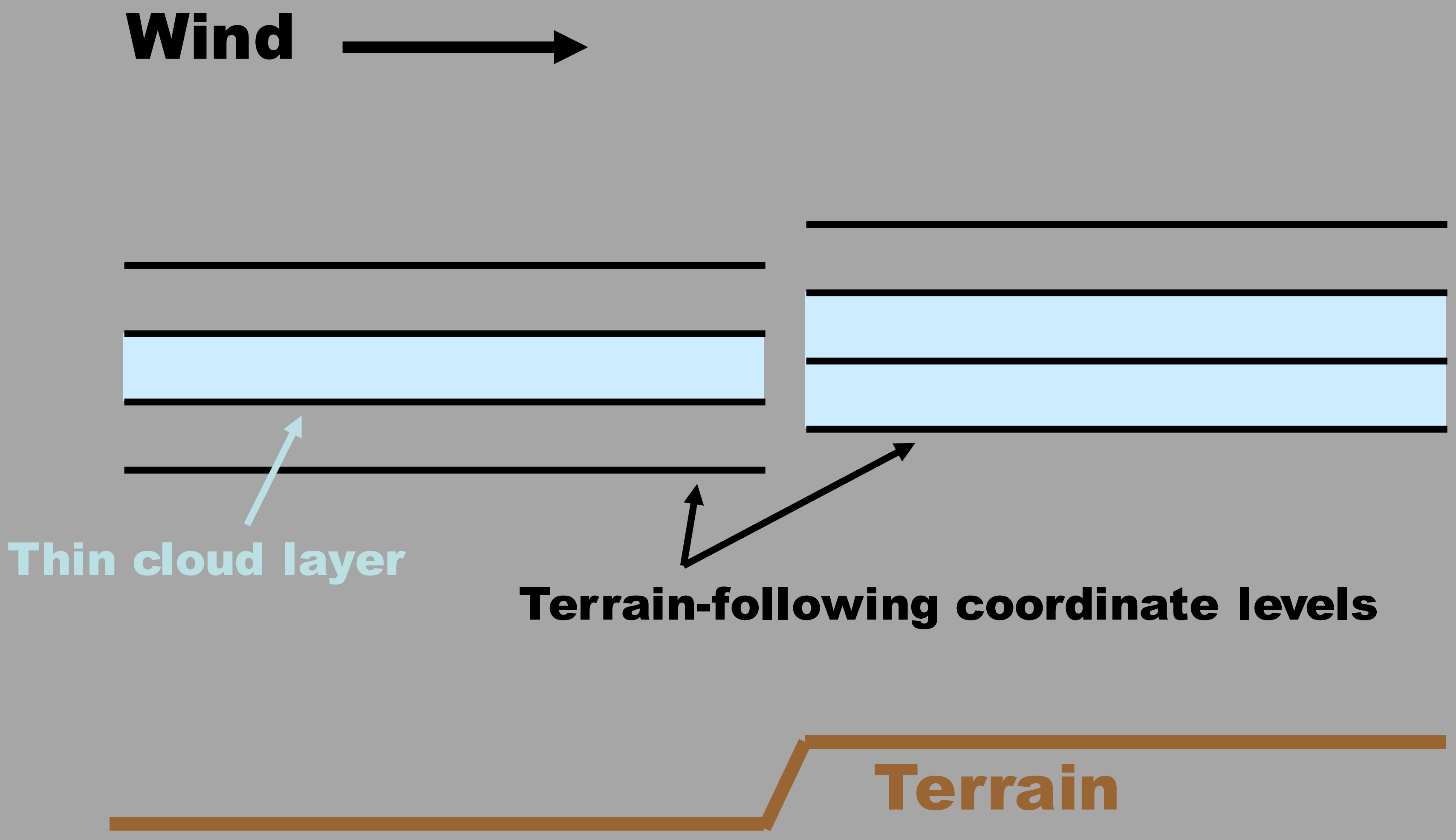
Grid cells A and B have reduced volume and surface area

Fully-underground cells have zero surface area

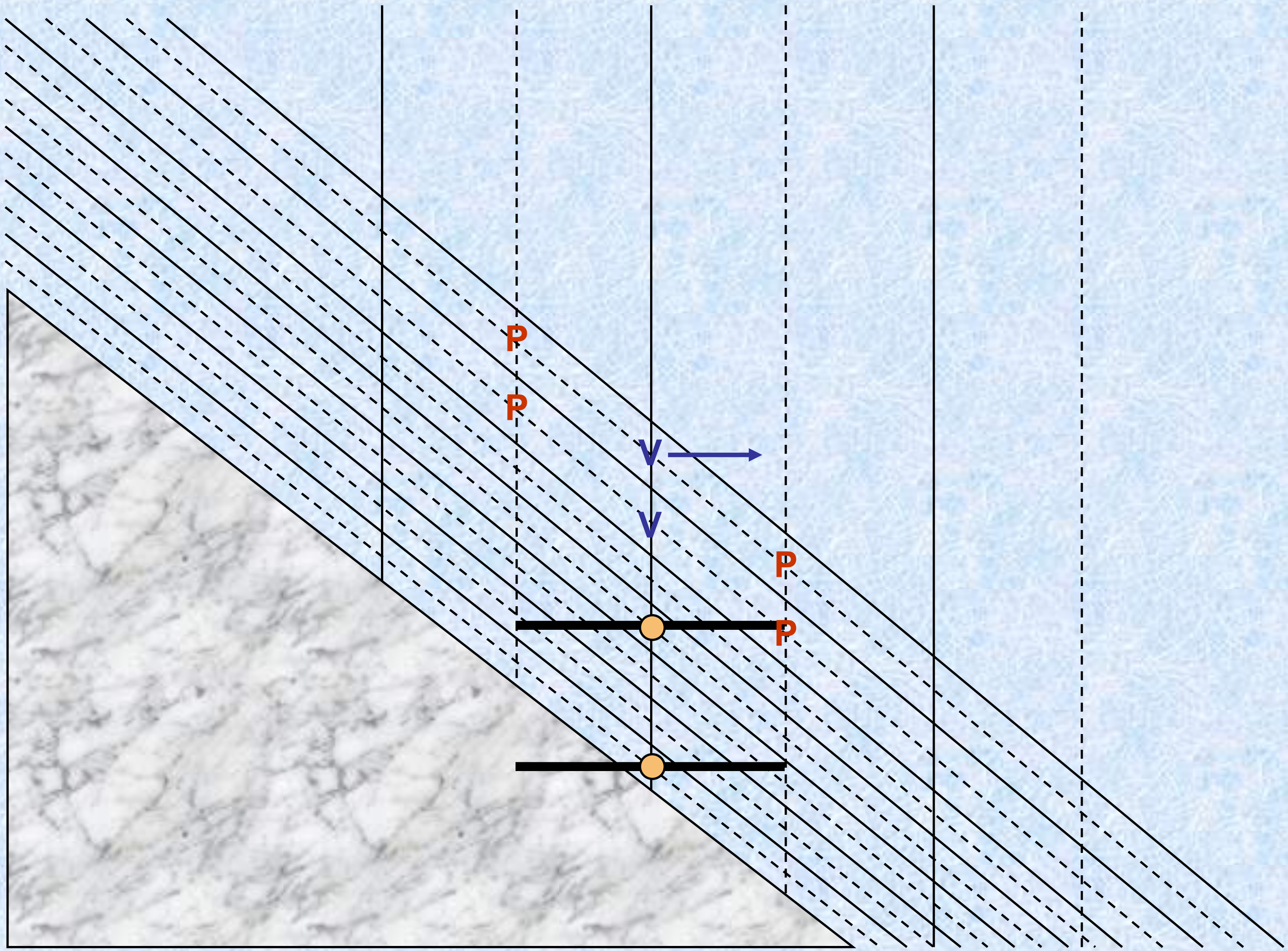
A and B centers of mass remain at original height



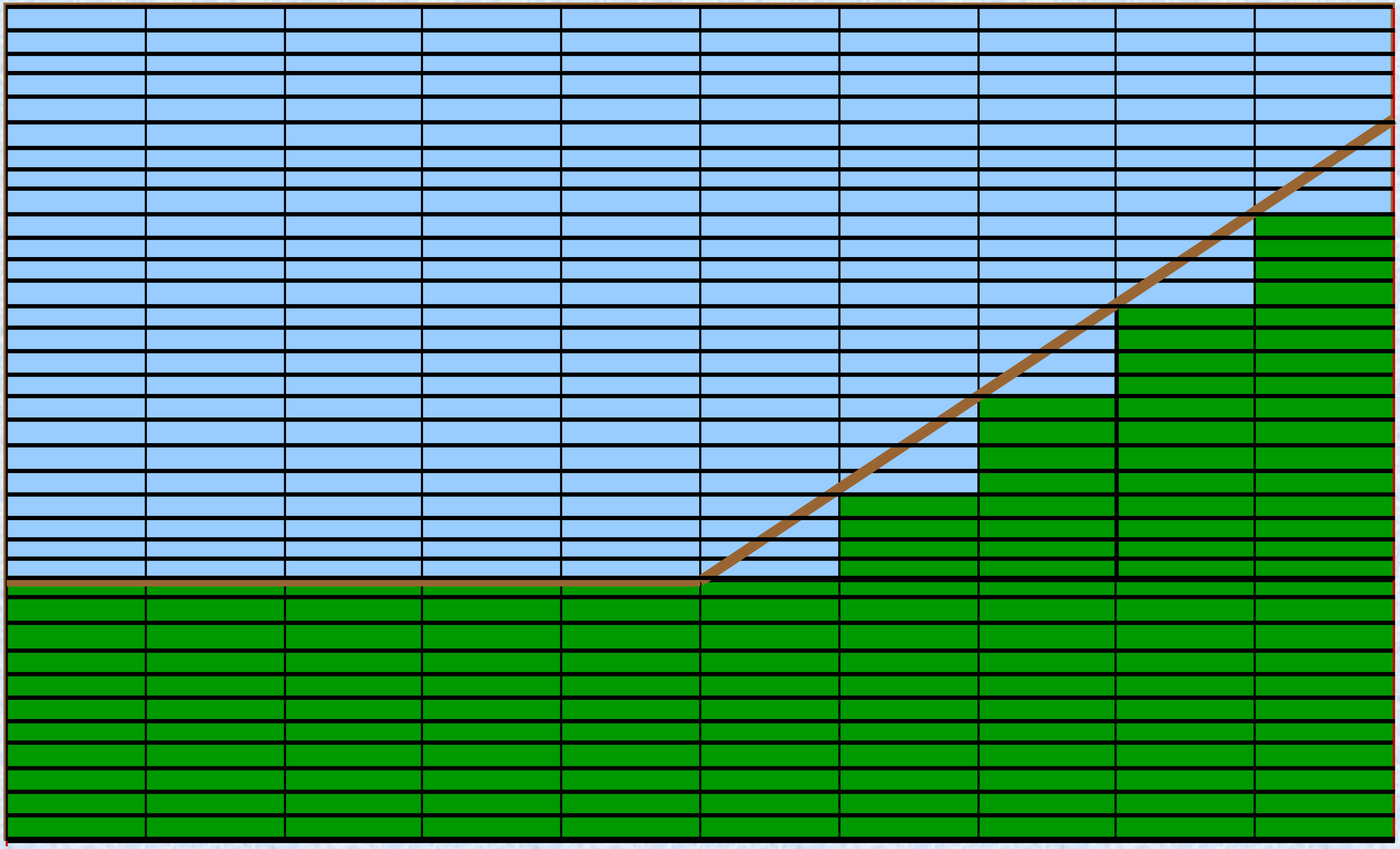
One reason to avoid terrain-following grids:
Anomalous vertical dispersion



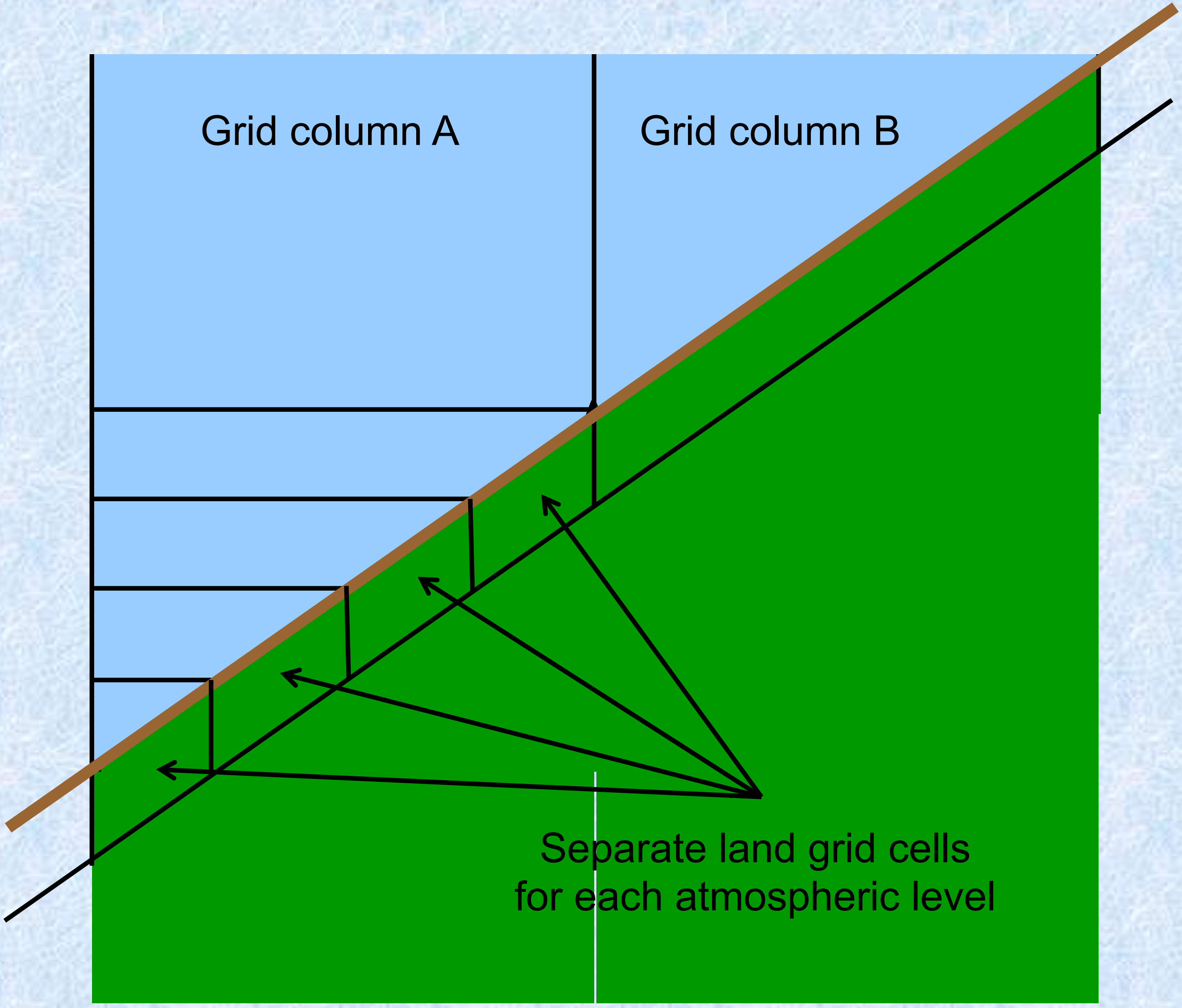
Another reason:
Error in horizontal gradient computation (especially for pressure)



Other considerations: Steep topography and/or high vertical resolution

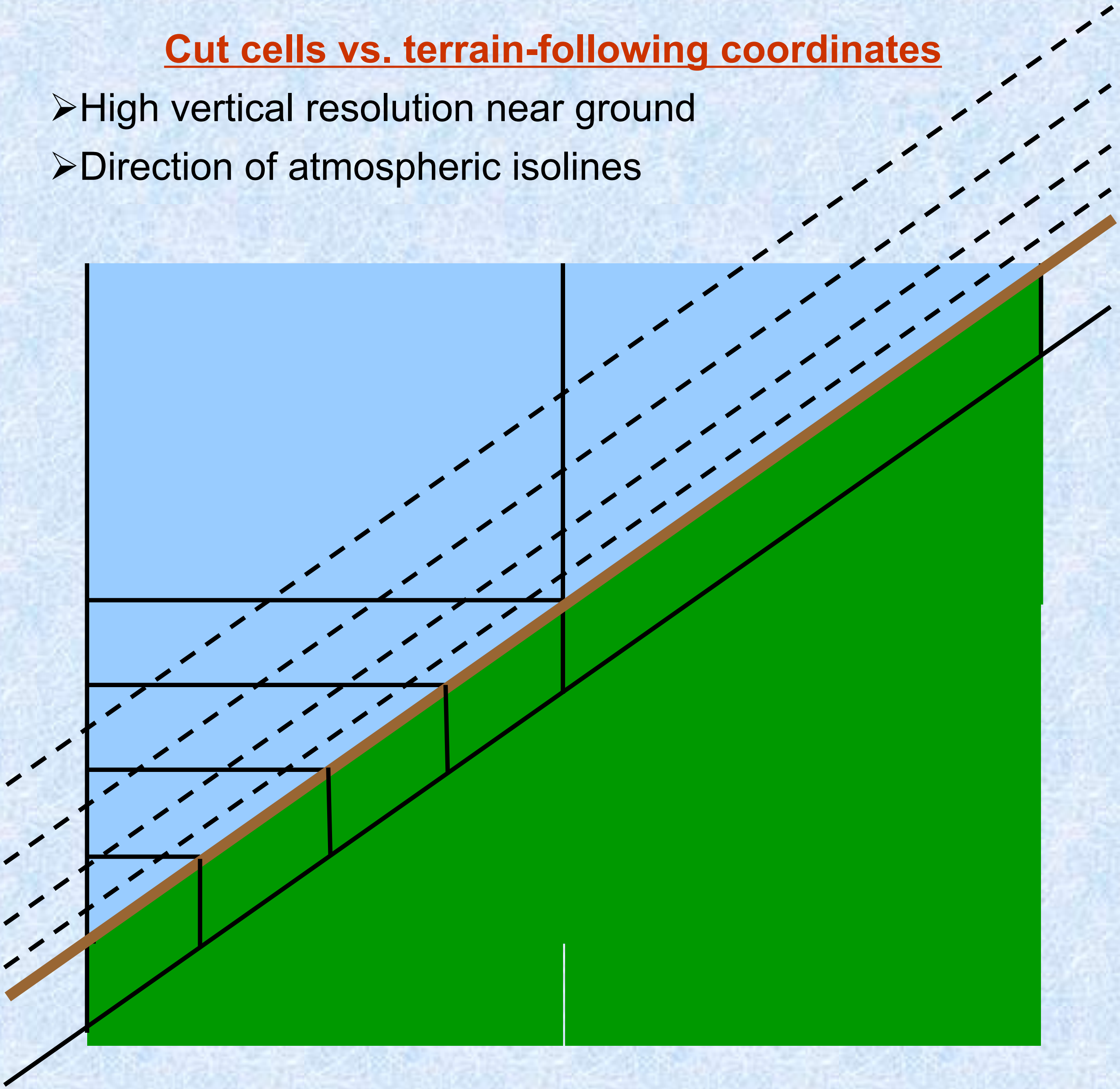


Land cells are defined such that each one interacts with only a single atmospheric level

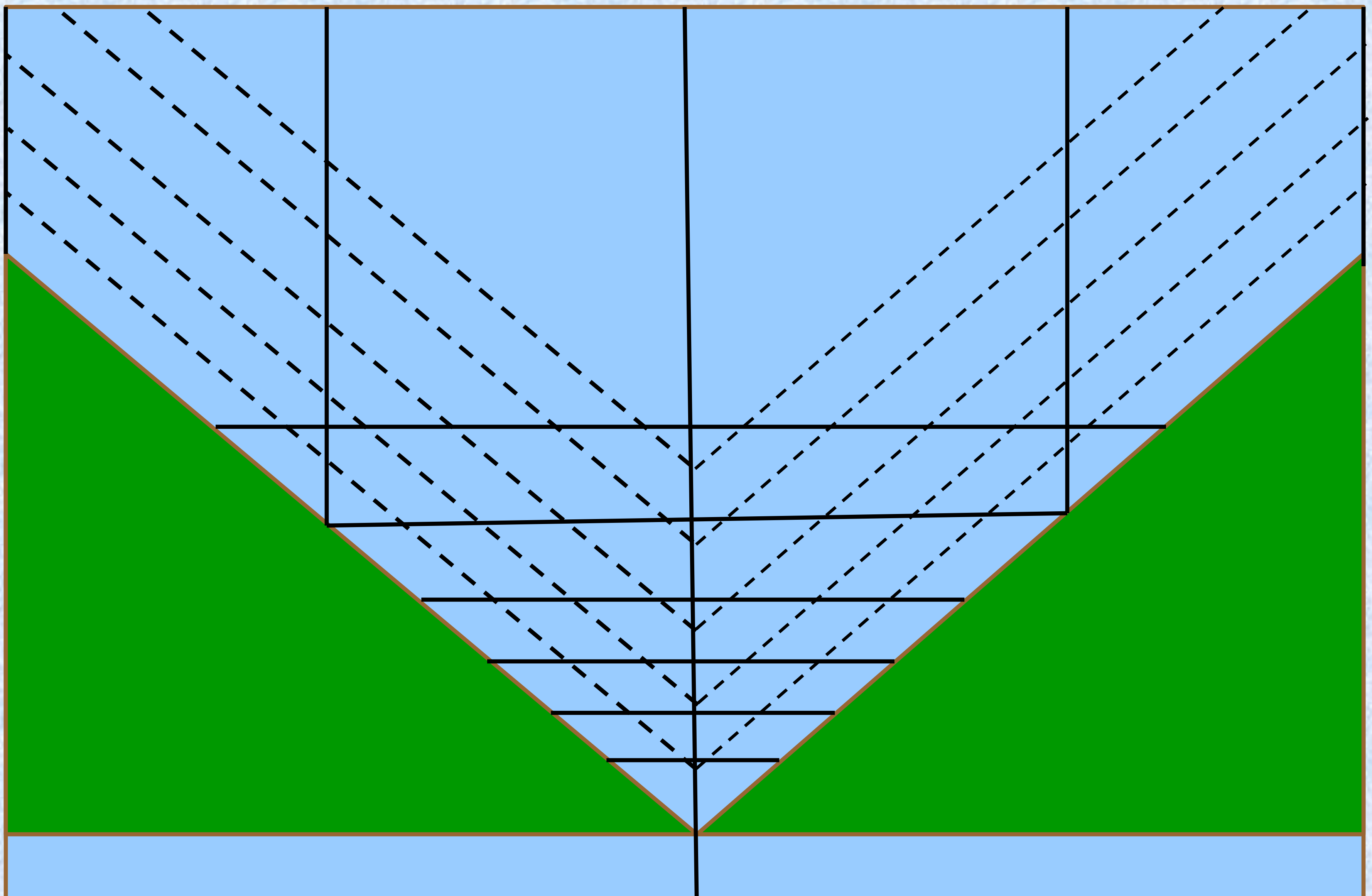


Cut cells vs. terrain-following coordinates

- High vertical resolution near ground
- Direction of atmospheric isolines



Nocturnal stratification in narrow valleys is often better represented with horizontal model levels



OLAM Summary:

Global variable-resolution seamless hexagonal mesh

FV conservation of mass, momentum, and ice-liquid potential temperature on a C-staggered grid

Horizontal grid levels with cut-cell representation of topography

Cut cells have advantages and disadvantages relative to terrain-following coordinates.

At very high resolution where steep orographic slopes are represented, the advantage of cut cells increases