Progress report:

Global Cloud Resolving Model Development

(Celal Konor and Ross Heikes)

- UZIM (Unified Z-grid Icosahedral Model) development has reached to a *milestone*. We have a global dynamical core (working with a simple 3-D elliptic solver)
- Couple of papers are ready to submit for publication
- Unified equations are written for various vertical coordinates, including the sigma, isentropic and hybrid types

Remaining tasks

- The multigrid based 3-D solver needs to be improved to perform better (with latitudinally varying coefficients)
- Inclusion of physics, and following...

Ideas on Inclusion of Mountains into Atmospheric Dynamical Cores

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Atmospheric Dynamical Cores

- Vorticity-divergence predicting (UZIM)
- Vector-Vorticity predicting (Model II, UVIM)
- All on icosahedral grid
- All based on the unified system

Vector-vorticity dynamical core

- Vector-vorticity prediction allows inclusion of steep mountains
- Elliptic solver is needed to remove a computational mode in the vector-vorticity prediction on an icosahedral or hexagonal grid

Development Directions to Include Mountains

UZIM with sigma
via Vorticity-divergence
1 mile

UZIM with block mountain
via Vorticity-divergence
5 miles

UVIM with block mountain
via Vector-vorticity
5 miles

UZIM: Unified Z-grid Icosahedral Model

UVIM: Unified Vector-vorticity Icosahedral Model

Global vorticity-divergence dynamical core
(with icosahedral horizontal grid)

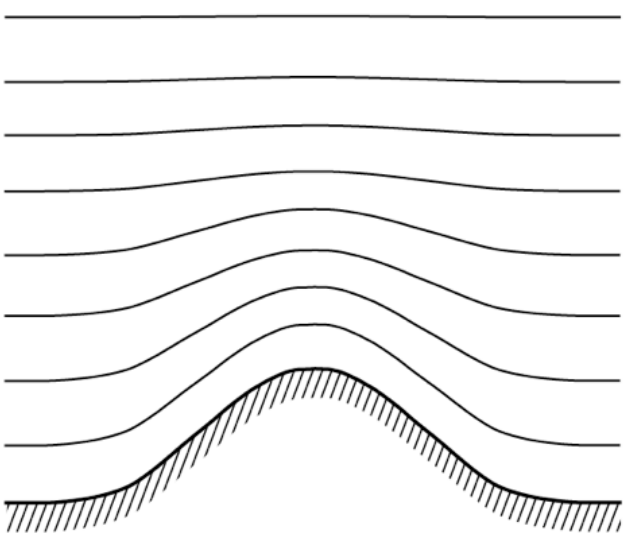
Sigma (or any terrain following) coordinate
for inclusion of mountains

Pros:

- Relatively easy to implement
- Continuous horizontal domain

Cons:

- Pressure gradience force
- Vertical advection



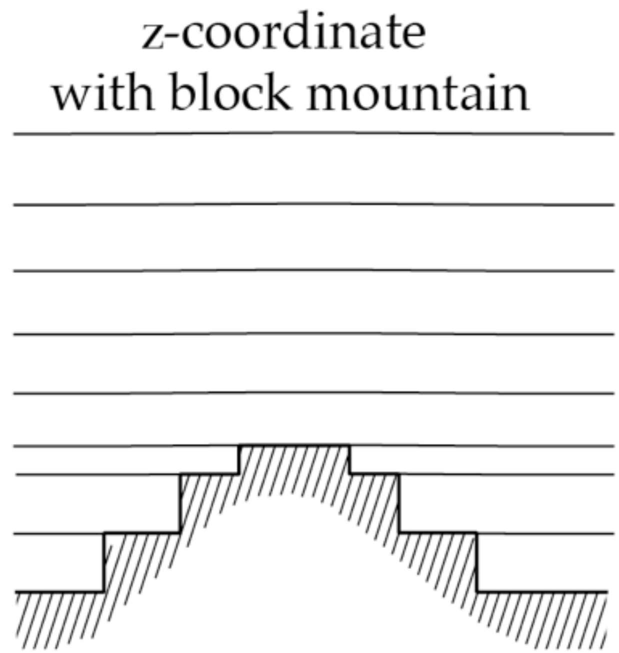
- Equations of the unified system in various vertical coordinates, including sigma, isentropic and hybrid types are derived

Global vorticity-divergence dynamical core
(with icosahedral horizontal grid)

z-coordinate with block mountains

Pros:

- No sigma-like problems



Cons:

- Discontinuous horizontal domain: Island problem
  - Solving elliptic equation
  - Advecting vorticity
- Vertical grid distance defined by mountain blocks

- *Uniqueness of the solution can be guaranteed in a multi-layer model*

Global vector-vorticity dynamical core

(with icosahedral horizontal grid)

z-coordinate with block mountains

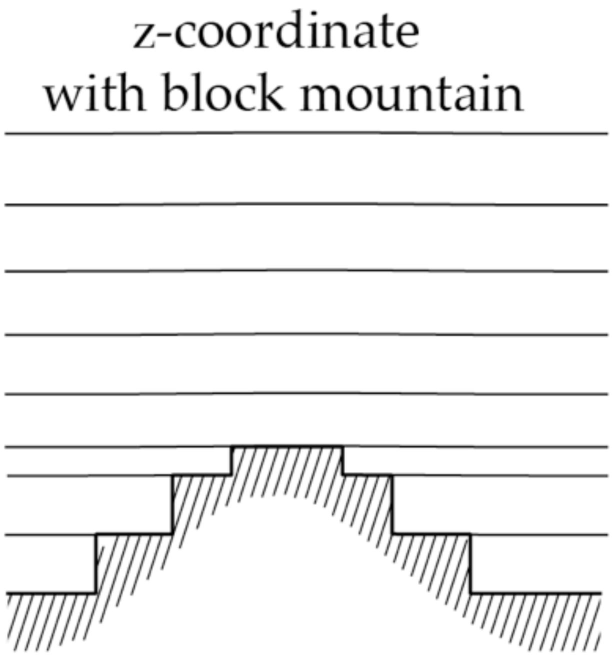
Pros:

- We know it works well on the Cartesian grid in a planar domain

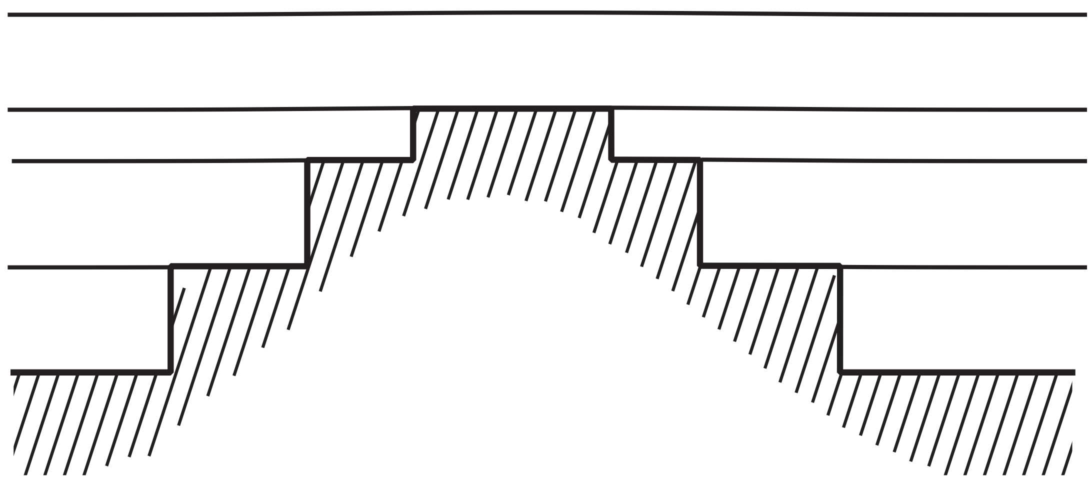
Cons:

- Computational mode removal needs elliptic solver with islands
- No problem with advecting vorticity
- Vertical grid distance defined by mountain blocks

- *No problem with the uniqueness of the solution*



Block mountains form "islands"



- 2D-elliptic solvers on a domain with "islands" requires special techniques. One of these techniques will be discussed here

Obtaining streamfunction from vorticity in a domain with islands

$$\nabla^2 \psi = \zeta$$

Boundary conditions :

$\psi_C = 0$ is prescribed for one of the islands

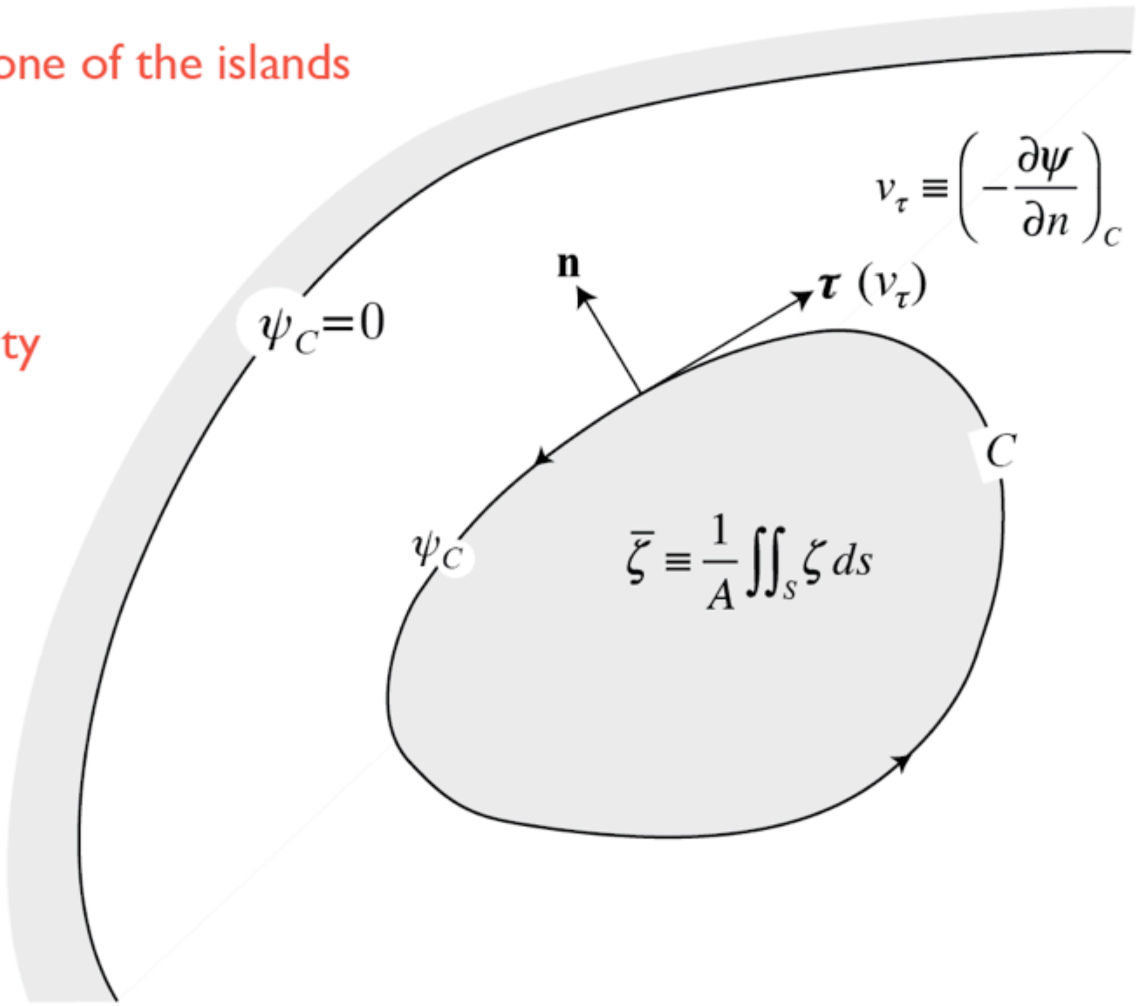
ψ_C : Constant for others

if we know the mean vorticity within the "other" island,

$$\oint_C \left(-\frac{\partial \psi}{\partial n} \right) d\ell = A\bar{\zeta}$$

if we predict the velocity along the boundary,

$$\left(-\frac{\partial \psi}{\partial n} \right)_C = v_\tau$$



Obtaining streamfunction from vorticity in a domain with islands: Solution through successive relaxations in a discrete system

Discrete circulation equation :

$$\oint_C \left(-\frac{\psi_C^{(n+1)} - \psi_-^{(n+1)}}{\delta n} \right) d\ell = -\psi_C^{(n+1)} \oint_C \left(\frac{1}{\delta n} \right) d\ell + \oint_C \left(\frac{\psi_-^{(n+1)}}{\delta n} \right) d\ell = A\overline{\zeta}$$

Value of ψ for next iteration step :

$$\psi_C^{(n+1)} = \frac{1}{L} \oint_C \frac{\psi_+^{(n)} + \psi_-^{(n)}}{2} d\ell$$

$\psi_-^{(n+1)}$ is to be determined

A definition :

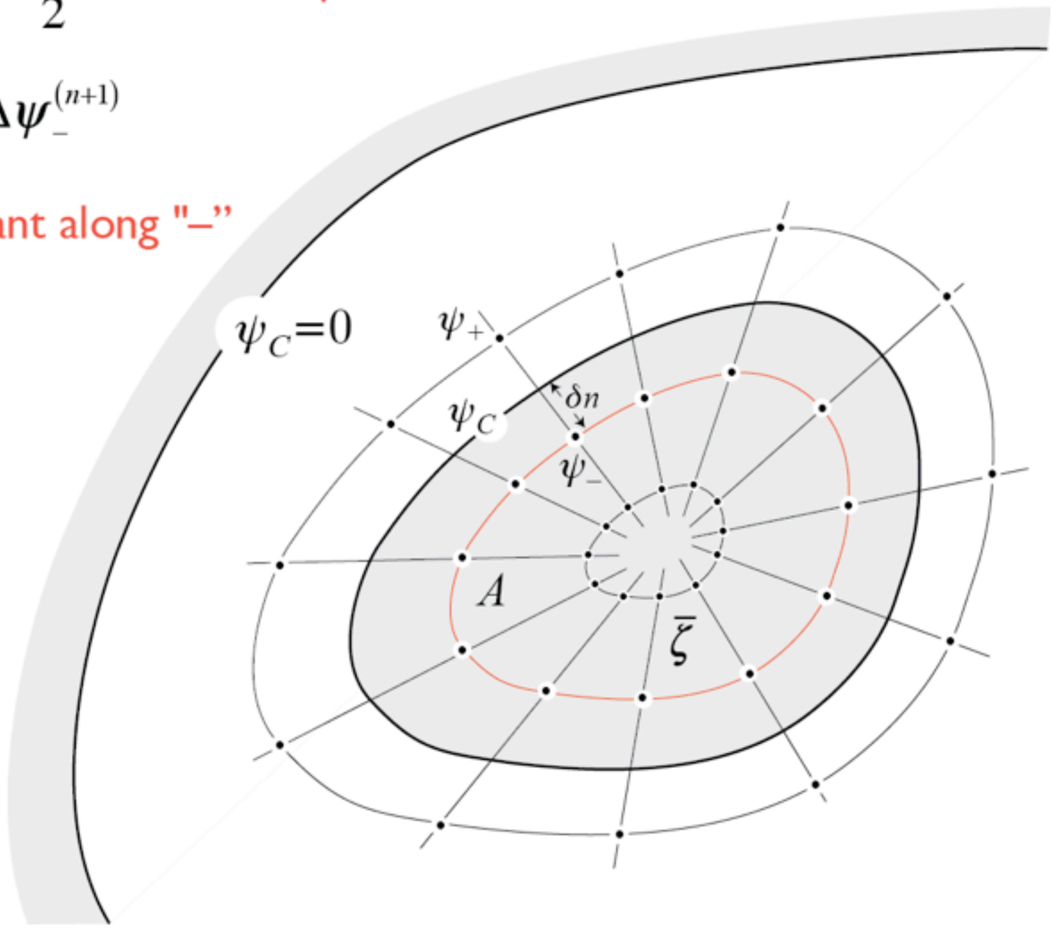
$$\psi_-^{(n+1)} \equiv \psi_-^{(n)} + \Delta\psi_-^{(n+1)}$$

$\Delta\psi_-^{(n+1)}$ is constant along "–"

Equation for $\Delta\psi_-^{(n+1)}$:

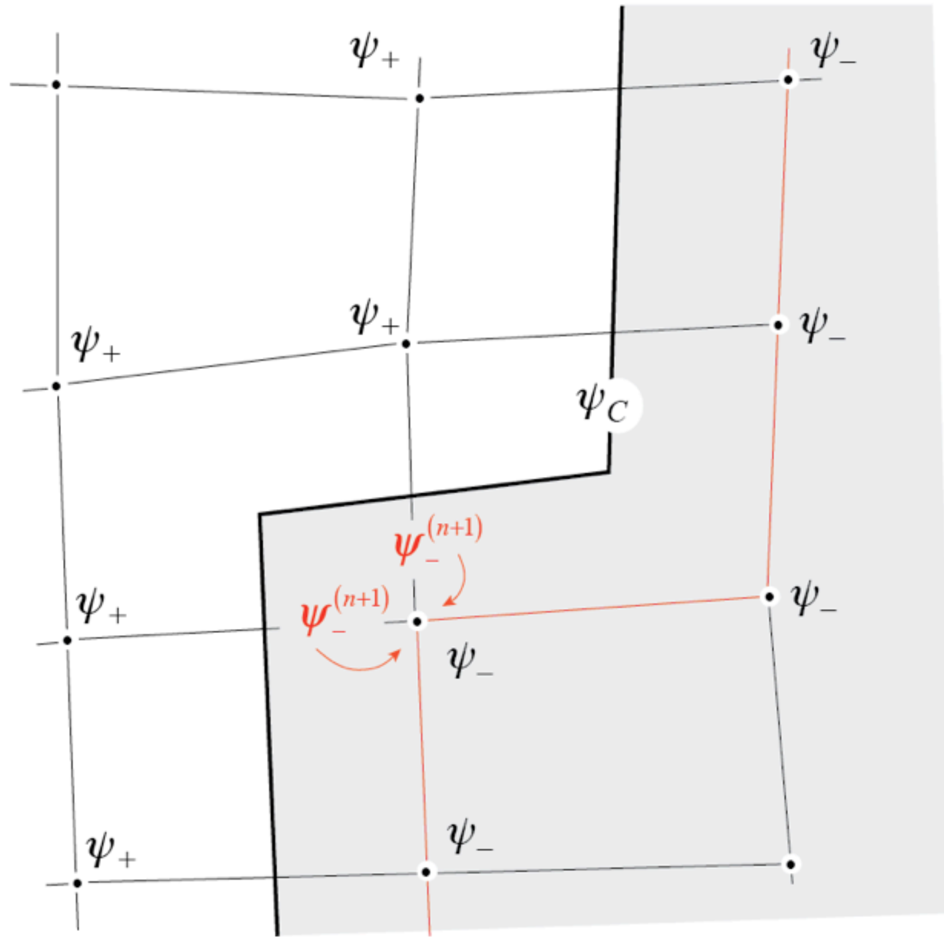
$$\Delta\psi_-^{(n+1)} \oint_C \left(\frac{1}{\delta n} \right) d\ell =$$

$$A\overline{\zeta} + \psi_C^{(n+1)} \oint_C \left(\frac{1}{\delta n} \right) d\ell - \oint_C \left(\frac{\psi_-^{(n)}}{\delta n} \right) d\ell$$



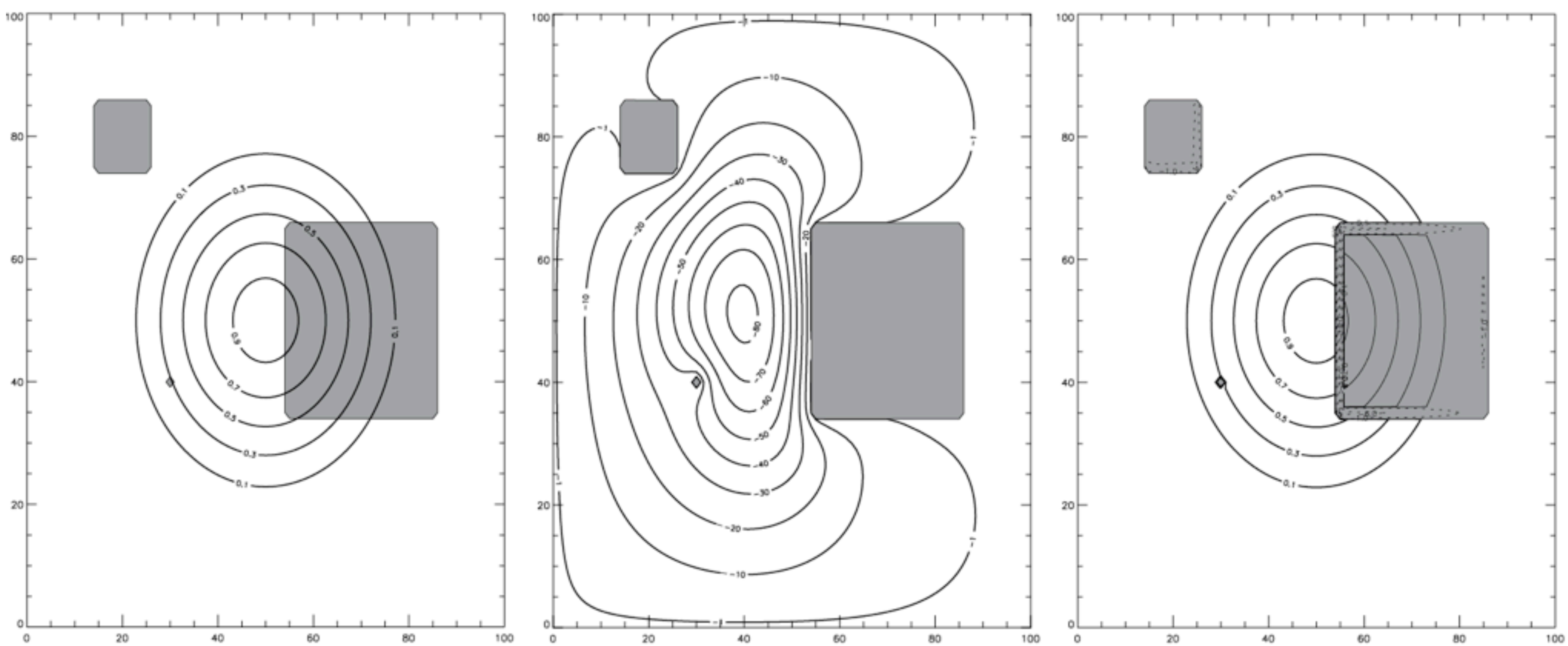
Obtaining streamfunction from vorticity in a domain with islands: Dealing with corners

Average solutions
in case of multiple values



Determination of streamfunction from vorticity in a basin with three islands

Prescribed vorticity | Streamfunction with islands | Vorticity from streamfunction

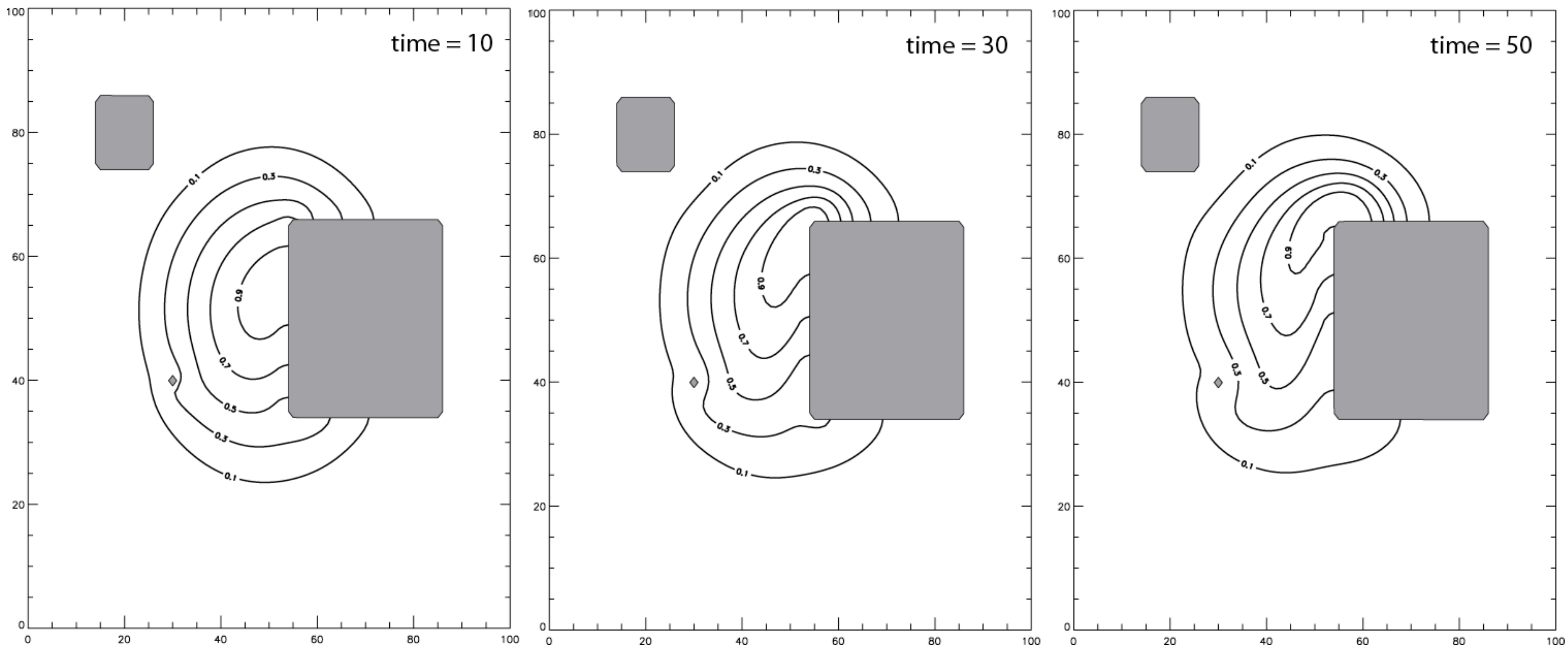


solve_2D_tripple_island.f90

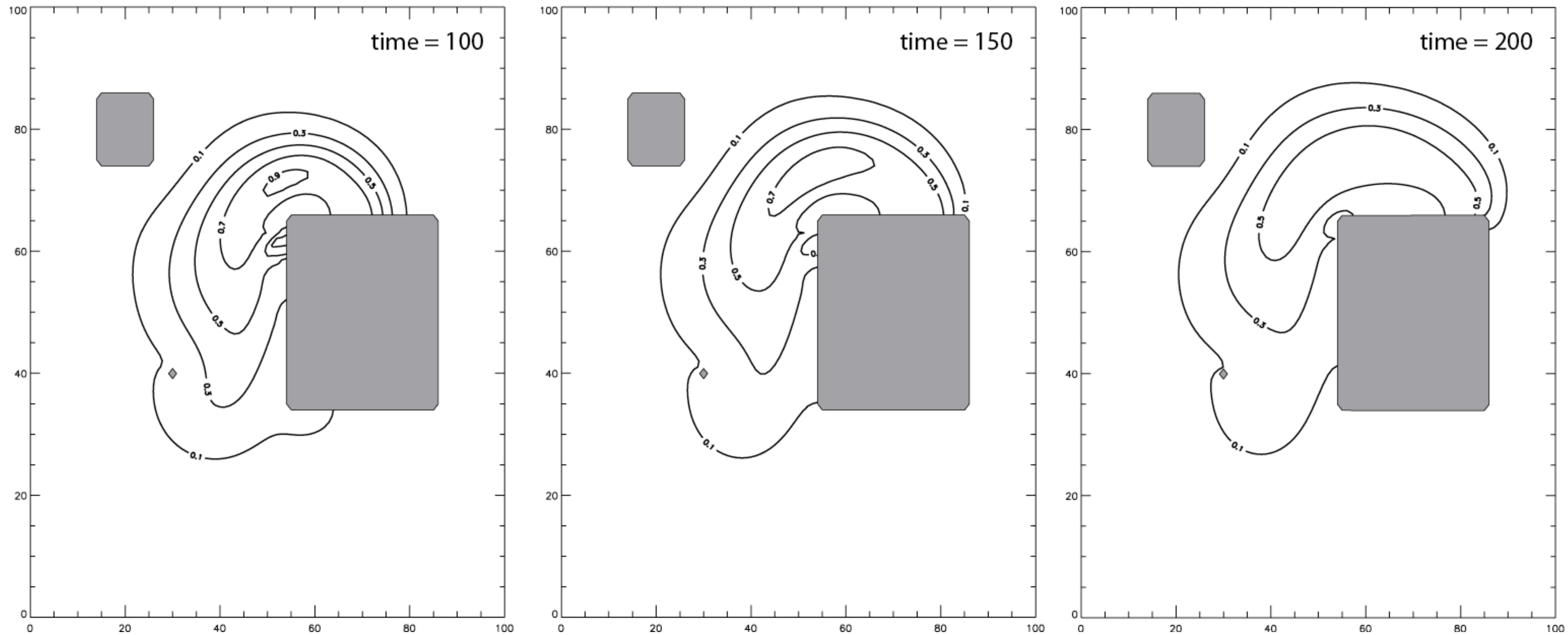
Advection of Vorticity

$$\frac{\partial \zeta}{\partial t} = -\nabla \cdot \left(\zeta \mathbf{v}_{\psi} \right)$$

Advection of vorticity

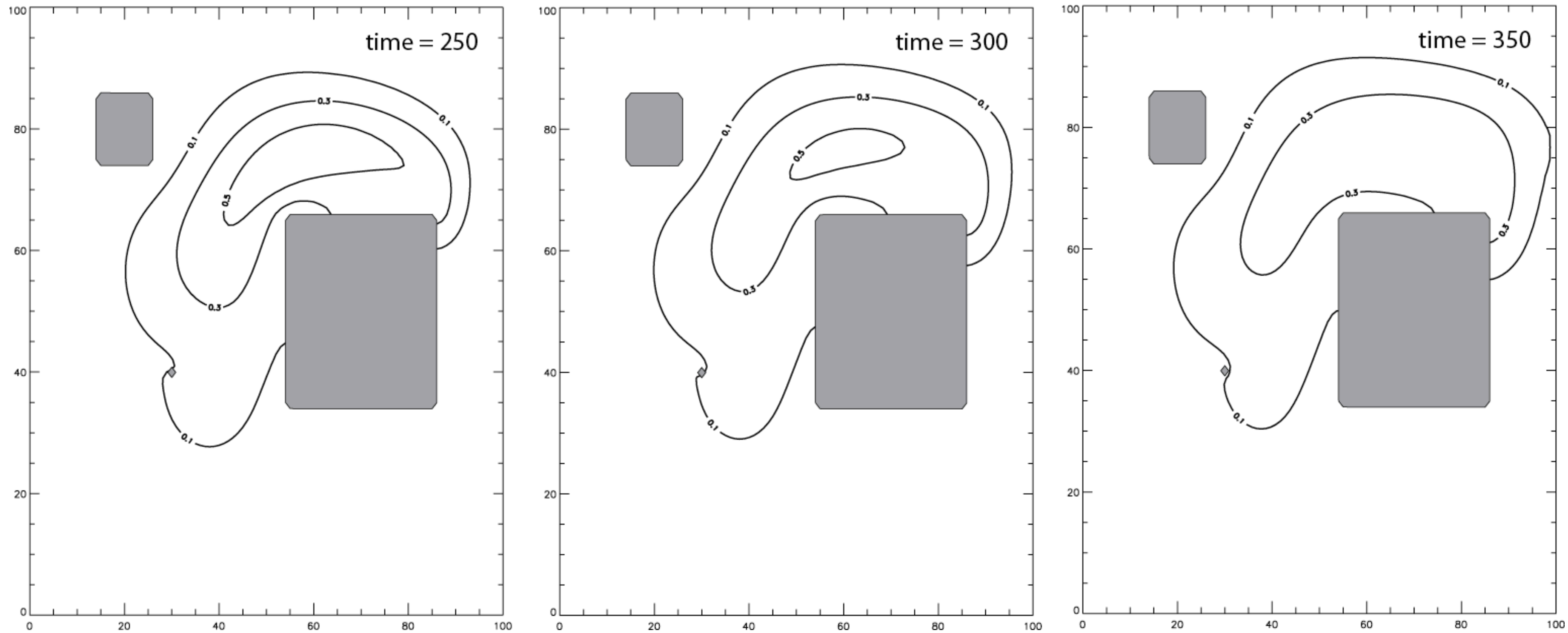


Advection of vorticity



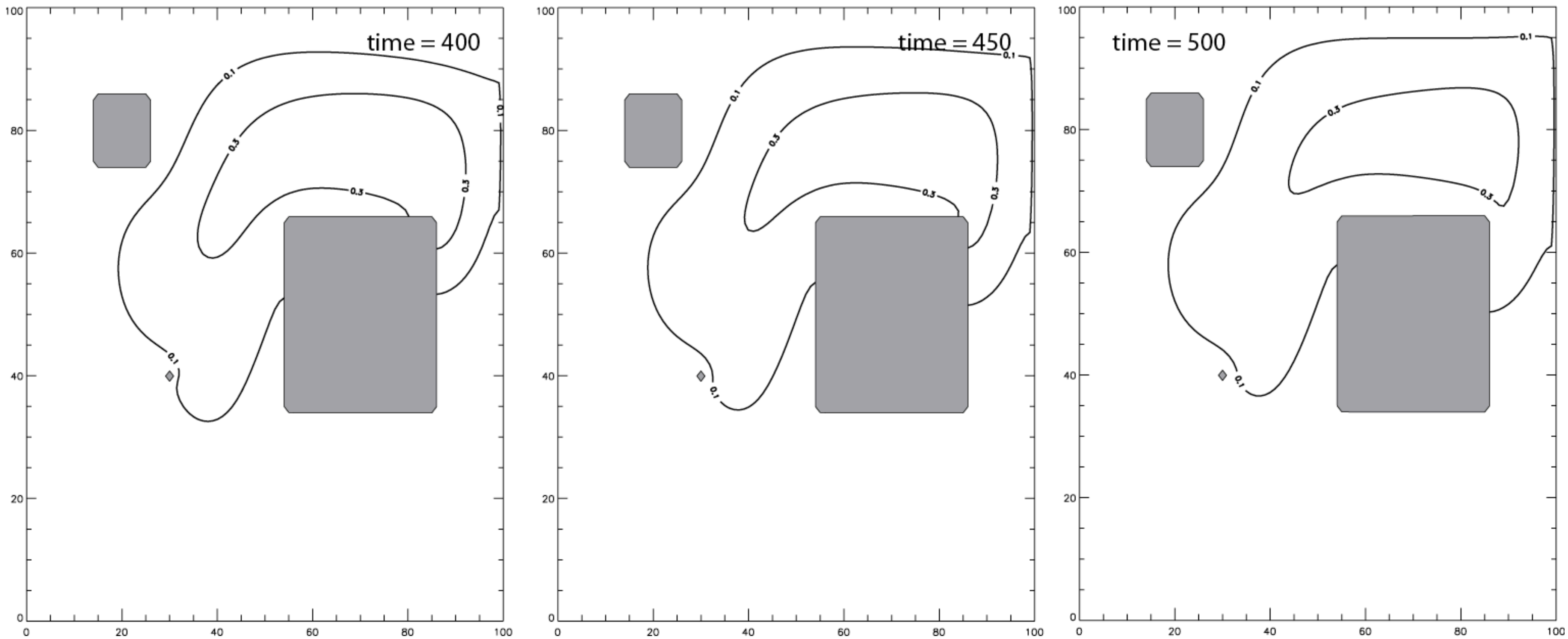
Diffusion is maintaining the stability

Advection of vorticity



Diffusion is eroding the vorticity

Advection of vorticity

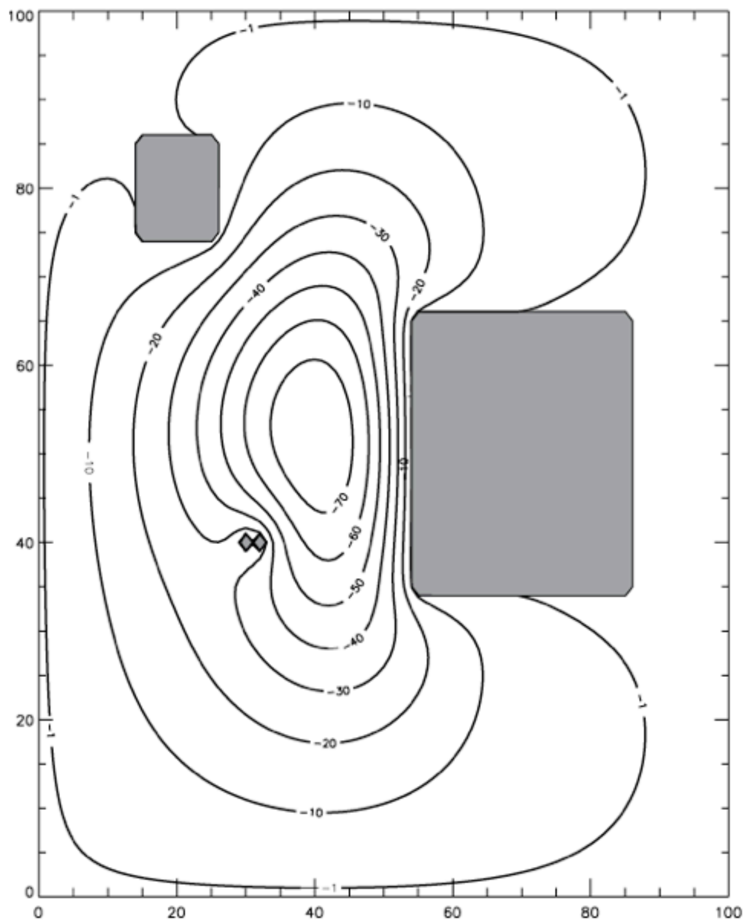


Diffusion is continuing to erode the vorticity

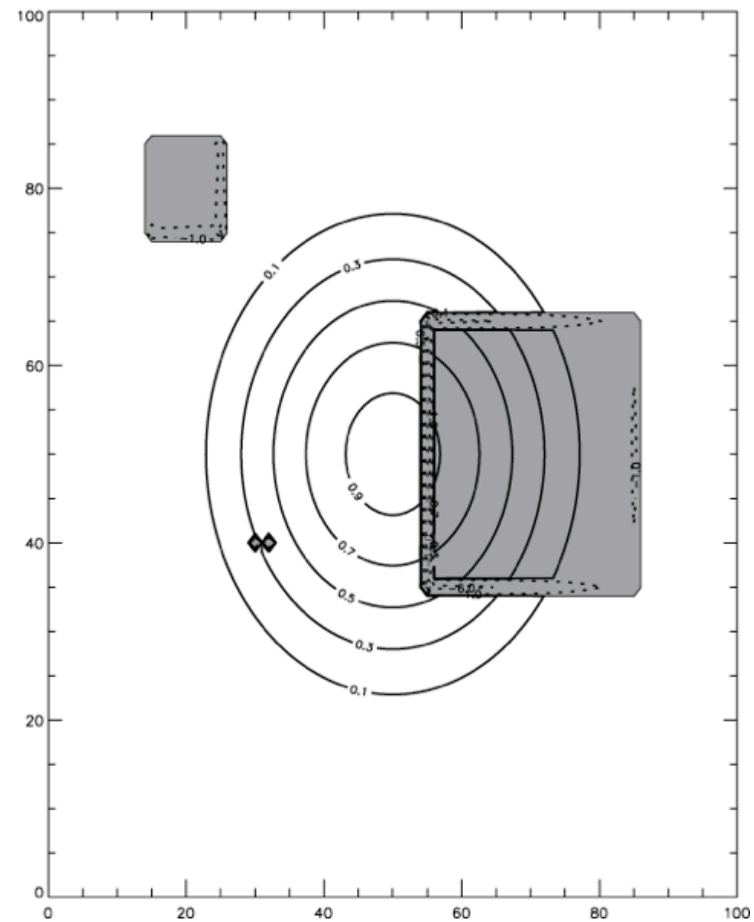
Performance of elliptic solver with more island

Determination of streamfunction from vorticity in a basin with four islands

Streamfunction with islands

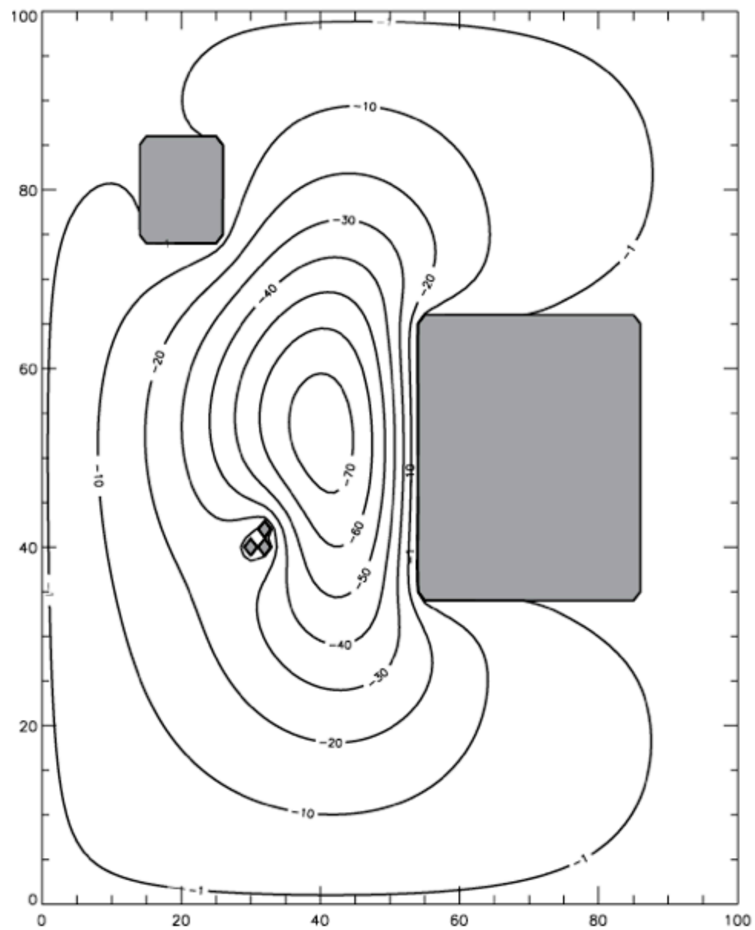


Vorticity from streamfunction

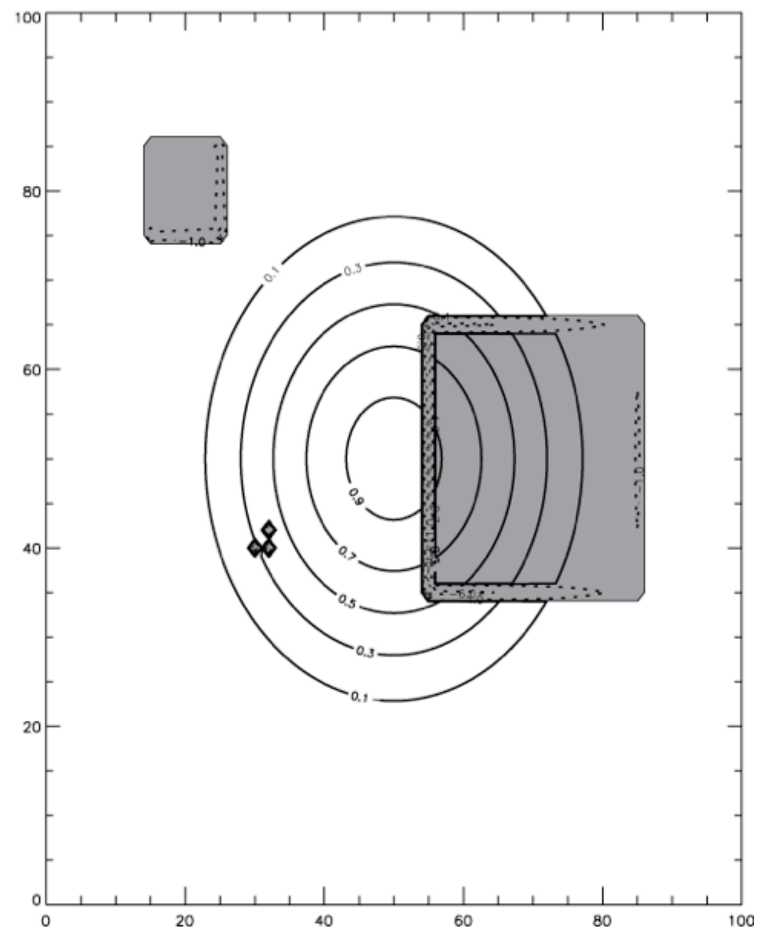


Determination of streamfunction from vorticity in a basin with five islands

Streamfunction with islands

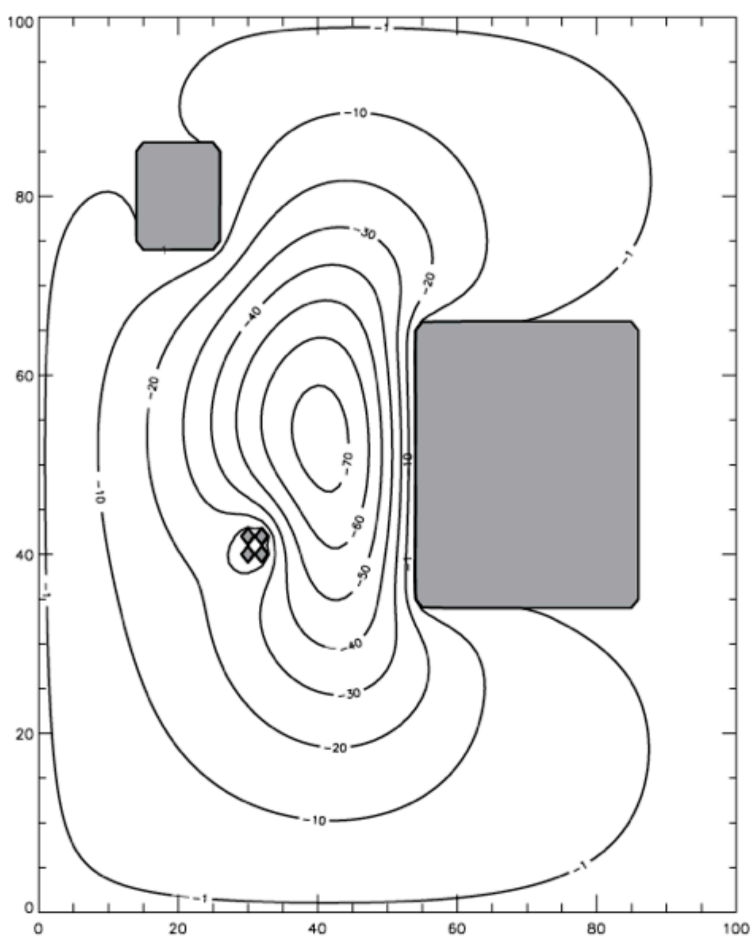


Vorticity from streamfunction

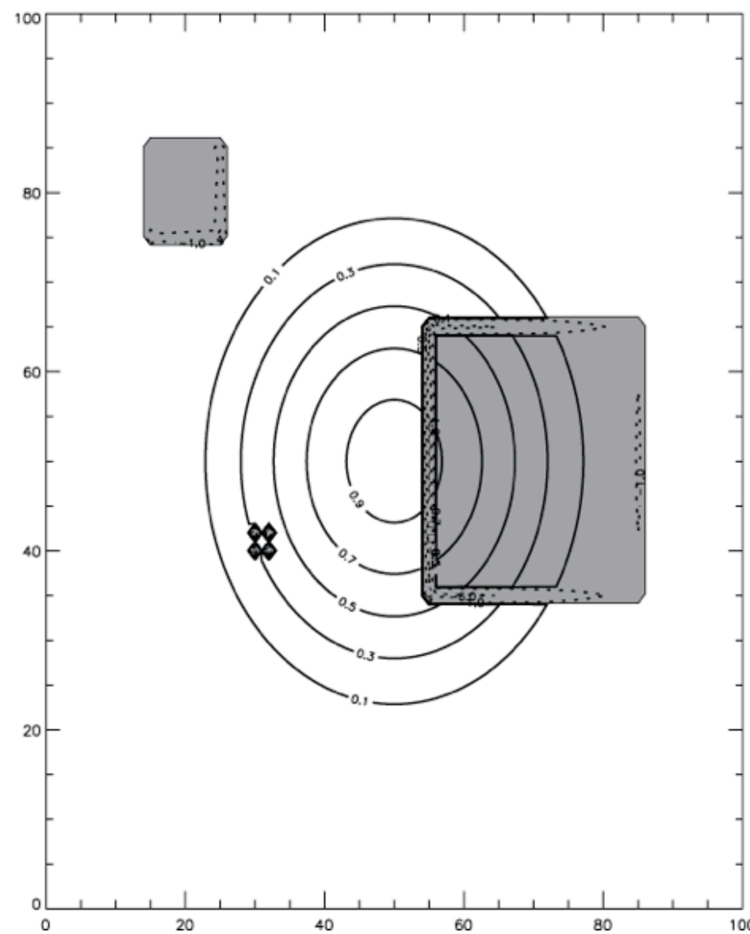


Determination of streamfunction from vorticity in a basin with six islands

Streamfunction with islands

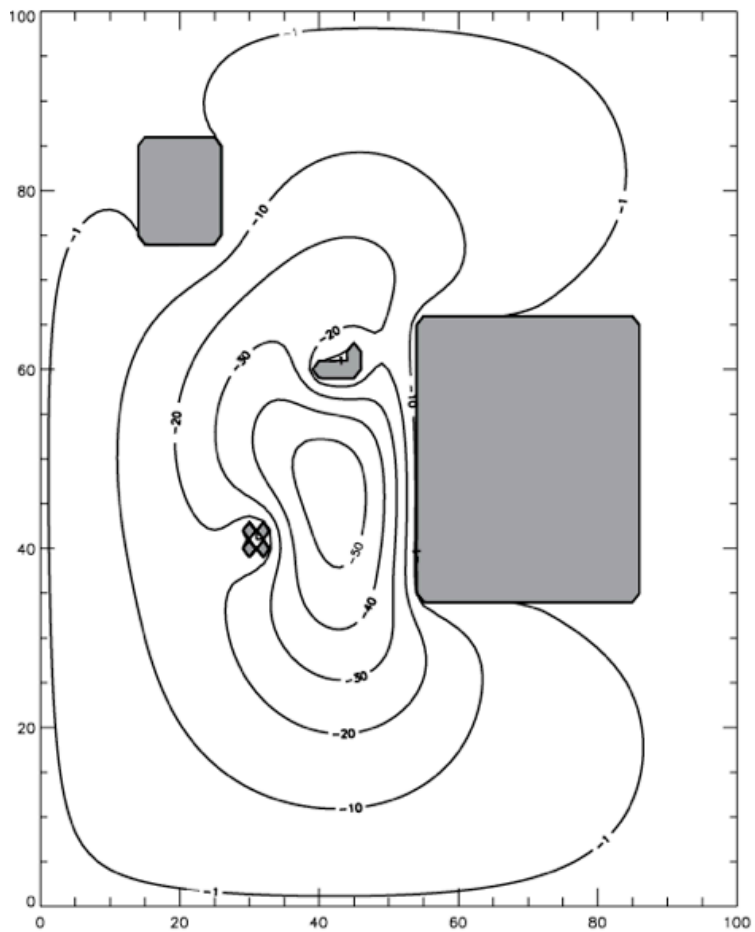


Vorticity from streamfunction

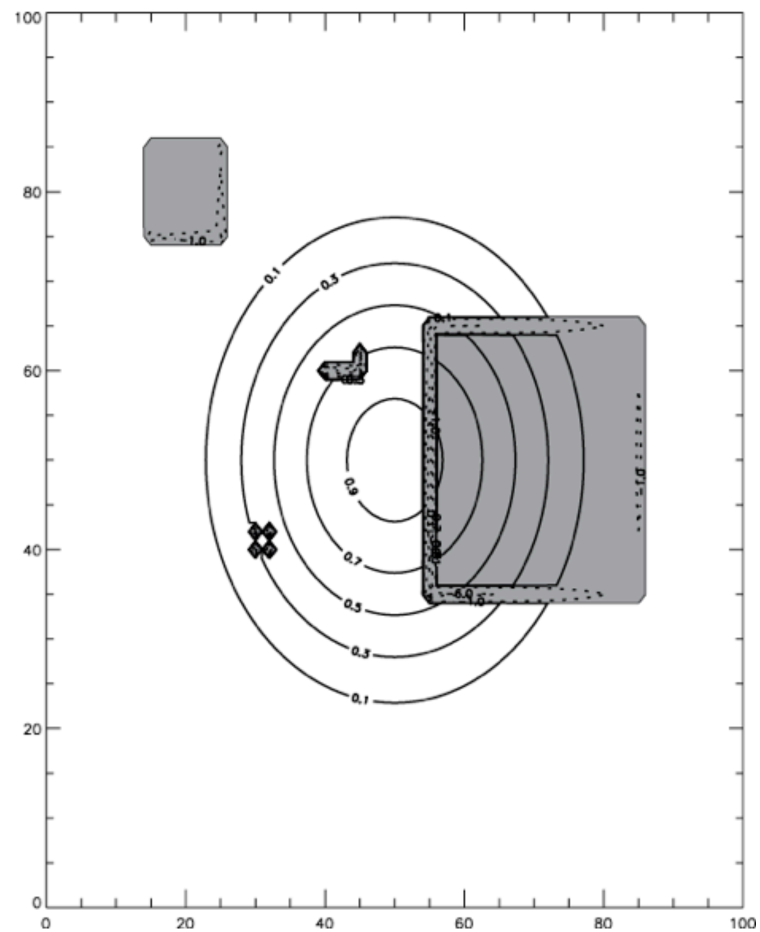


Determination of streamfunction from vorticity in a basin with seven islands

Streamfunction with islands



Vorticity from streamfunction



Concluding remarks

- Three development directions of including mountains in our models are suggested
- Treatment of mountains as islands is discussed (for our models under development)
- A robust elliptic solver applicable to the “island problem” is successfully tested
- The solver can be applied to as many islands as desired including single-point islands
- The solver can be made computationally scaleable by employing an algebraic multigrid method

Concluding remarks (Cont.)

- Advection of vorticity near islands appears problematic
- Islands can be difficult for the vorticity-divergence prediction
- Semi-Lagrangian advection of vorticity may be a remedy
- Inclusion of mountains to the vector-vorticity dynamical core (on the icosahedral grid) can be considered now
- This model may be called UVIM (Unified Vector-Vorticity Icosahedral Model)