

Summary of Dynamical Framework Presentations

UNIFIED PARAMETERIZATION – AN UPDATE

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- Better justification
- More complete description
- Inclusion of uncertainty
- Vertical structure
- Physical sources and sinks

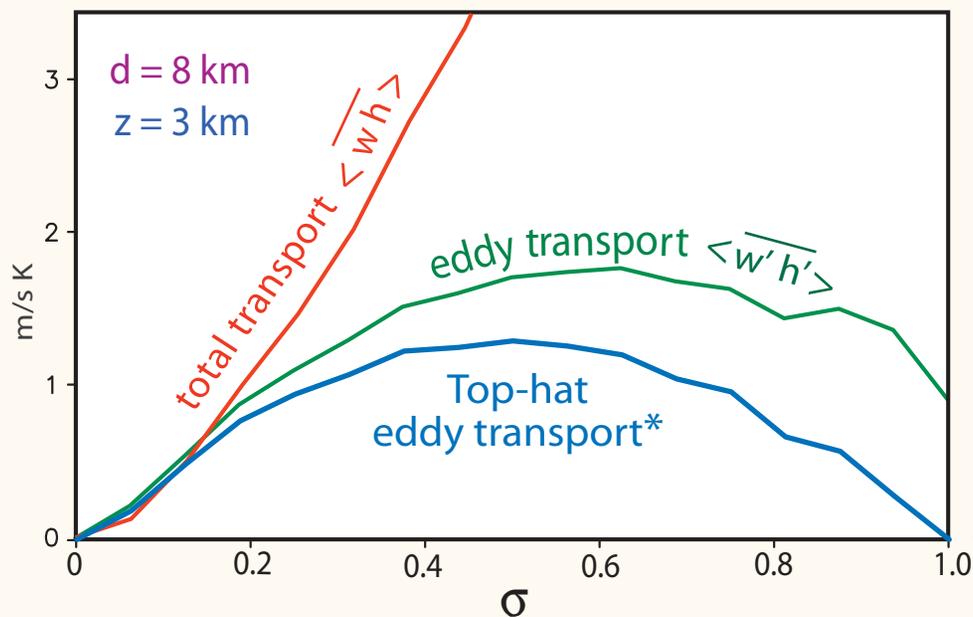
CMMAP Team Meeting
August 7-9, 2012

FIRST STEP TOWARD UNIFIED PARAMETERIZATION

Most conventional parameterizations assume that clouds and the environment are horizontally homogeneous.

— “top-hat profile” — 

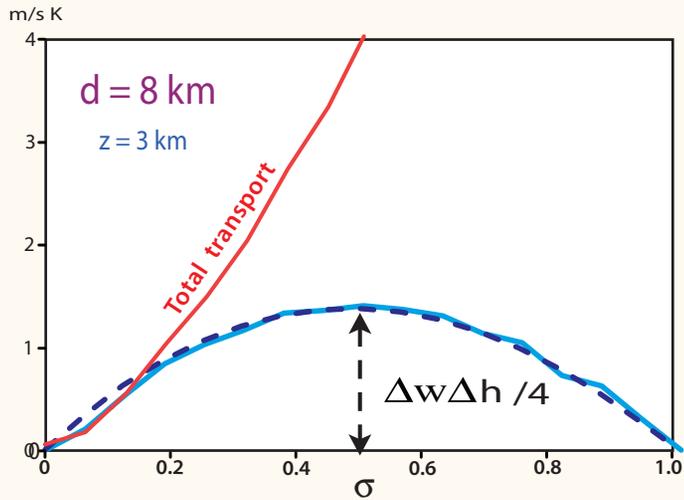
Continue to use this assumption to start.



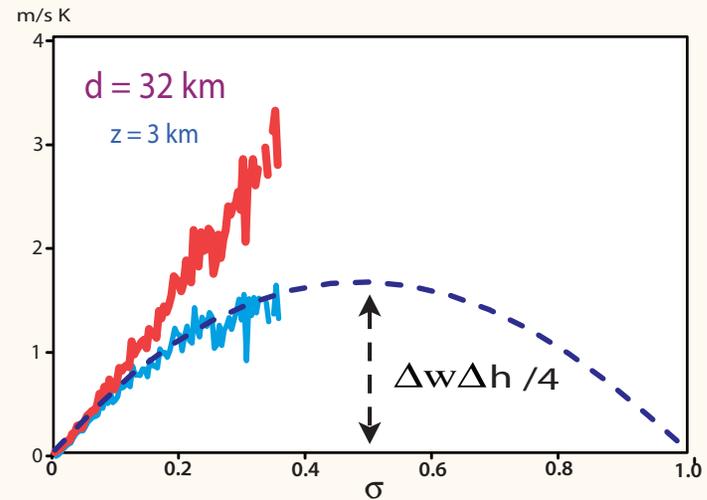
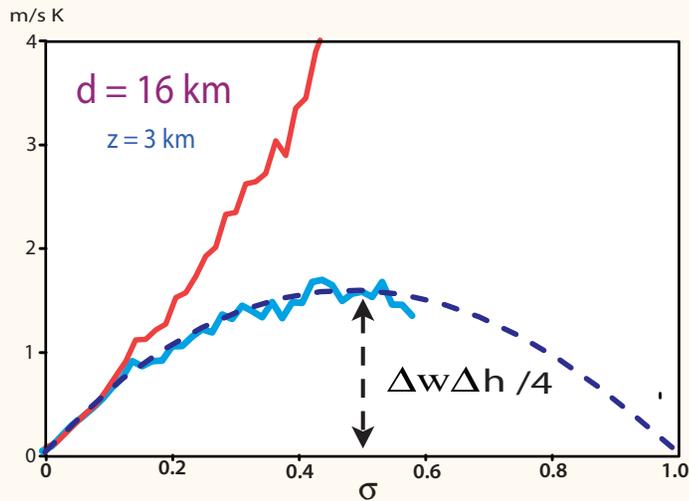
* Diagnosed from the dataset modified to fit a top-hat profile

Transport due to the internal structure of clouds

SIMILARITY BETWEEN DIFFERENT RESOLUTIONS



- The σ -dependence of the eddy transport is similar between different resolutions.
- The value of $\Delta w \Delta \psi$ is also similar.



DETERMINATION OF σ IN PRACTICAL APPLICATIONS, I

$$\Delta\psi \equiv \psi_c - \tilde{\psi}$$

environment value
not given

$$\delta\psi \equiv \psi_c - \bar{\psi}$$

grid-point value
given

We have chosen

$$\sigma = (\overline{w'h'})_E / [\Delta w \Delta h + (\overline{w'h'})_E]$$

A plume model applied to grid-point values gives $\delta w \delta\psi$, not $\Delta w \Delta\psi$.

We can derive

$$\Delta w \Delta h = \delta w \delta h / (1 - \sigma)^2$$

Define

$$\lambda \equiv (\overline{w'h'})_E / \delta w \delta h$$

A measure of grid-scale destabilization
normalized by eddy transport efficiency

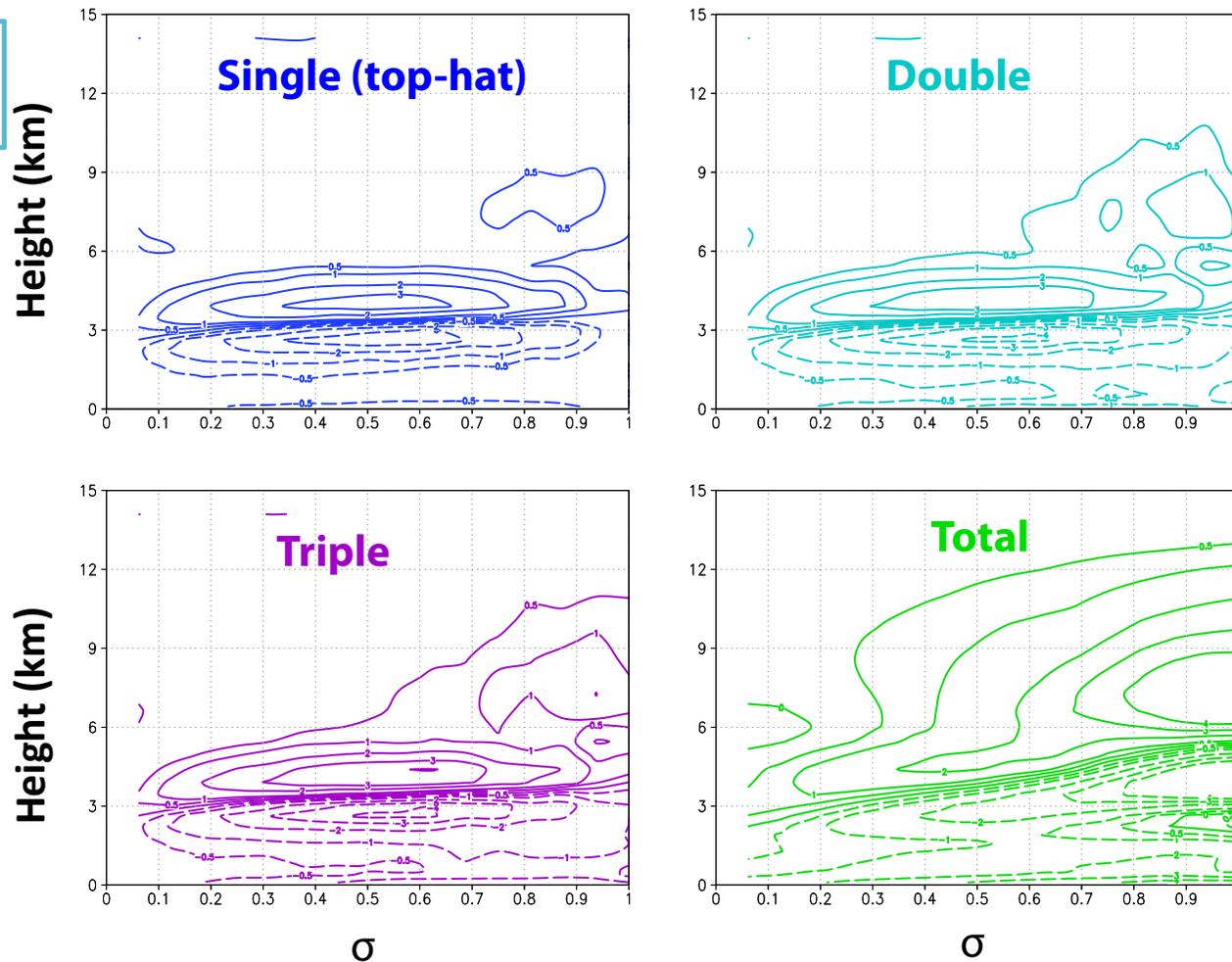
$$\sigma = (\lambda - \lambda\sigma)(1 - \sigma)^2$$

THE EFFECT OF MULTIPLE CLOUD STRUCTURE/CLOUD TYPE

SOURCES OF MOIST STATIC ENERGY DUE TO EDDY TRANSPORT

Multiple cloud structure/type better capture the complicated vertical structure when σ is large.

SHEAR CASE
 $d=8\text{km}$
(K/hr)



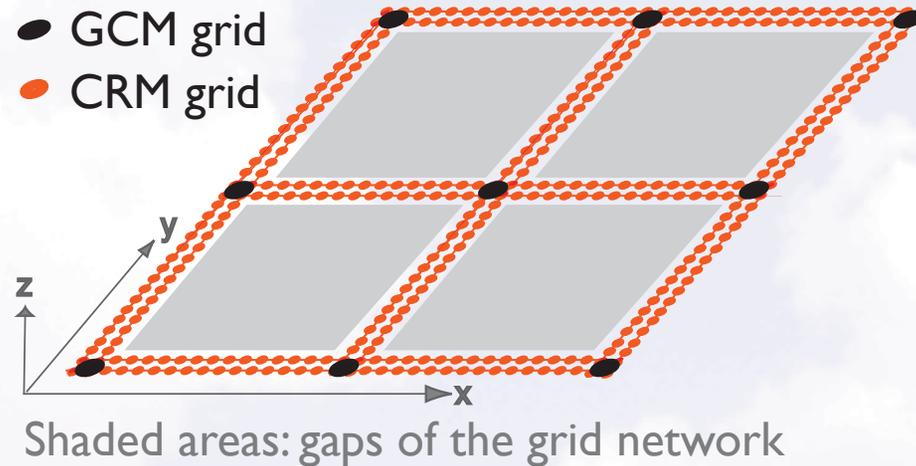
Progress Report

Research Objective 2:
Development of a Q3-D MMF

Joon-Hee Jung and Akio Arakawa

August 2012 CMMAP Team Meeting

Grid System of Q3-D MMF

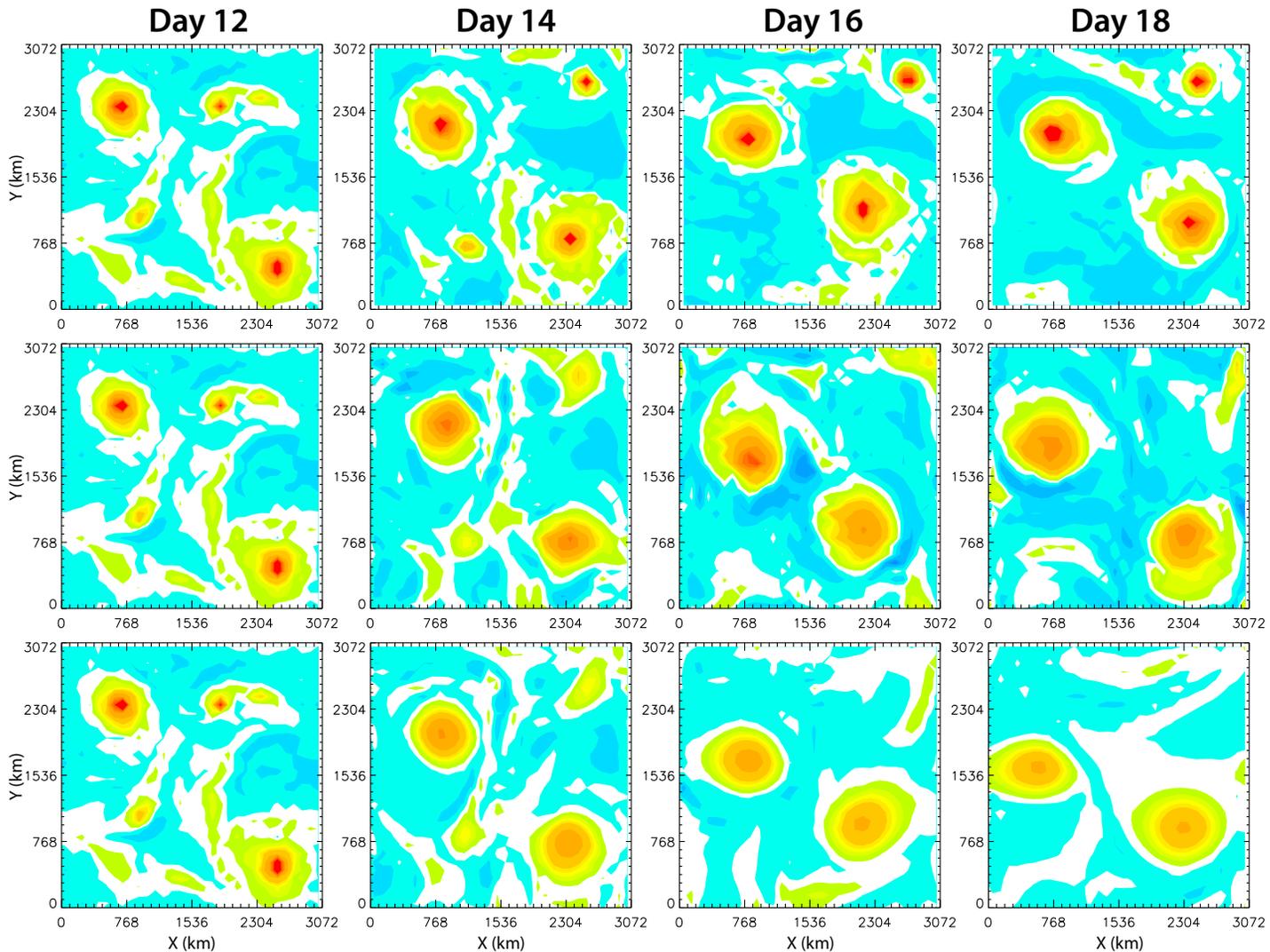


- A combination of a GCM grid and two perpendicular sets of cloud-resolving grid channels.
- Perpendicular channels are coupled only through the GCM to avoid singularity.
- The channel width is chosen to be a typical cloud size.

Vertical component of vorticity

start from day 12 $z \sim 2.8$ km

**BM
(3-D)**



**Q3-D
MMF**

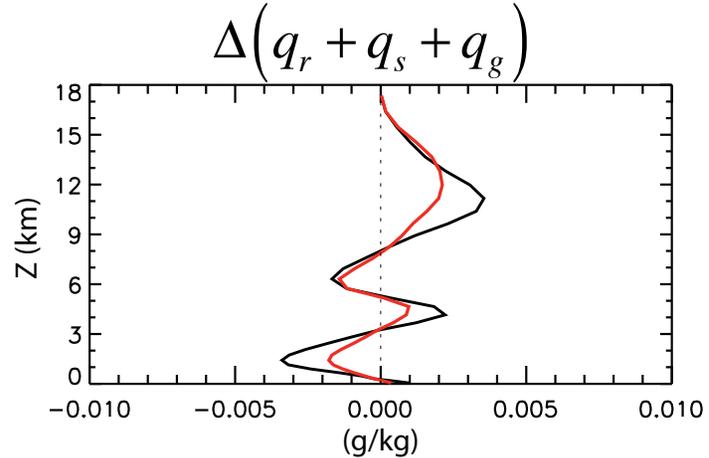
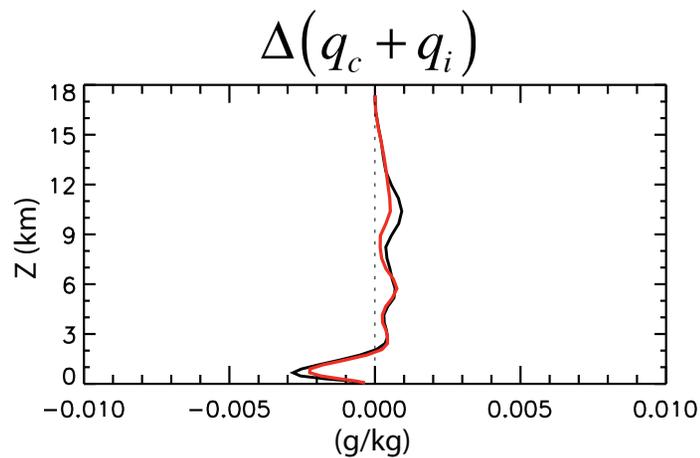
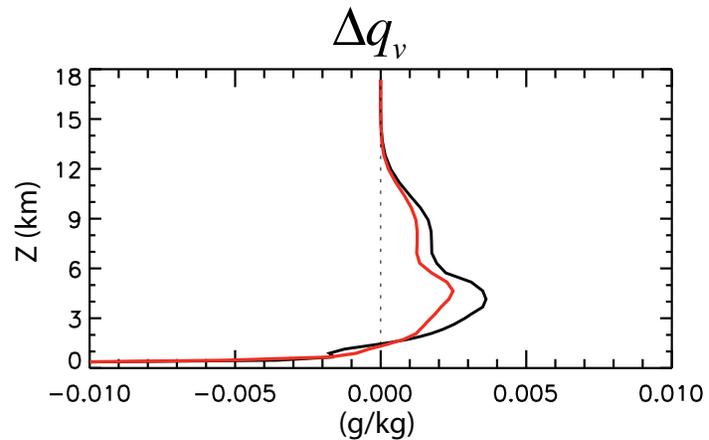
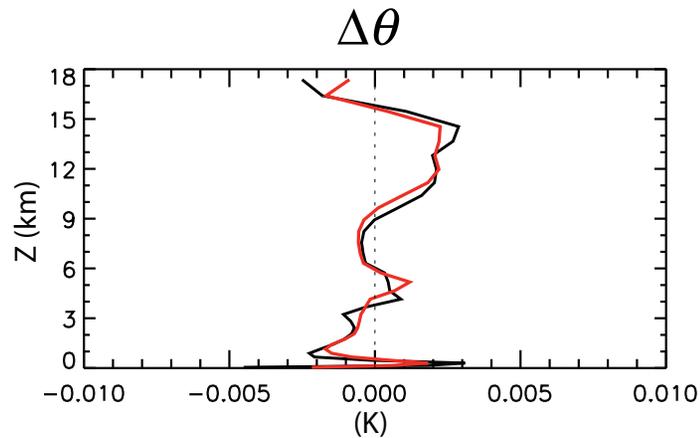
**GCM
only**

-55 -45 -35 -25 -15 -9 -7 -5 -3 -1 1 3 5 7 9 15 25 35 45 55
(10^{-5} s^{-1})

“Maintenance of the well-defined vortex pattern”

Time- and Domain-Averaged Eddy Transport Effect

— BM — Q3-D (day 12 - day 19)



$$\Delta q \equiv \left(\frac{\partial q}{\partial t} \right)_{eddy} \cdot dt_{GCM}$$

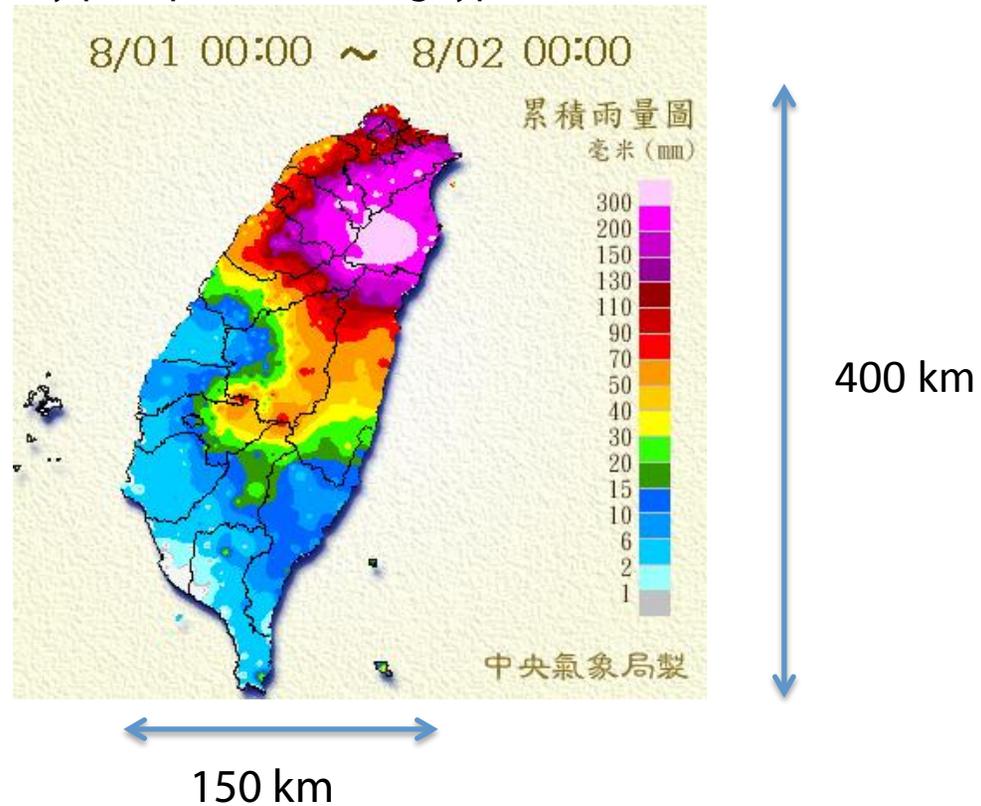
Current work on topography in parallel VVM

Chien-Ming Wu
National Taiwan University

CURRENT WORK ON TOPOGRAPHY IN PARALLEL VVM

High-resolution simulation of flow over complex topography is necessary in understanding atmospheric processes in Taiwan.

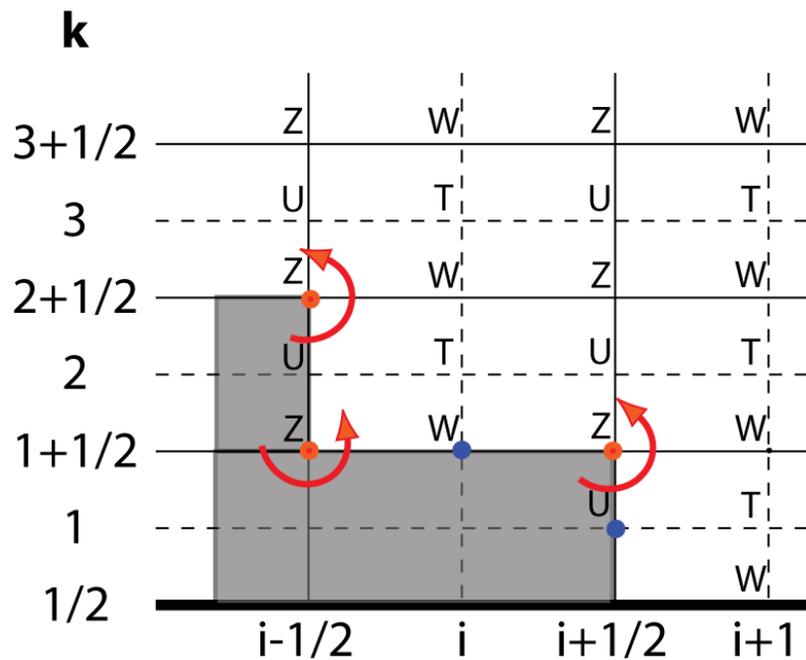
Daily precipitation during typhoon SAOLA



Determining the vorticity at the corners of the topography

- The strength of the vorticity at the corners is determined through vorticity definition.

$$\eta_b = \frac{\partial u}{\partial z} - \frac{\partial w}{\partial x} \quad u_b = w_b = 0$$



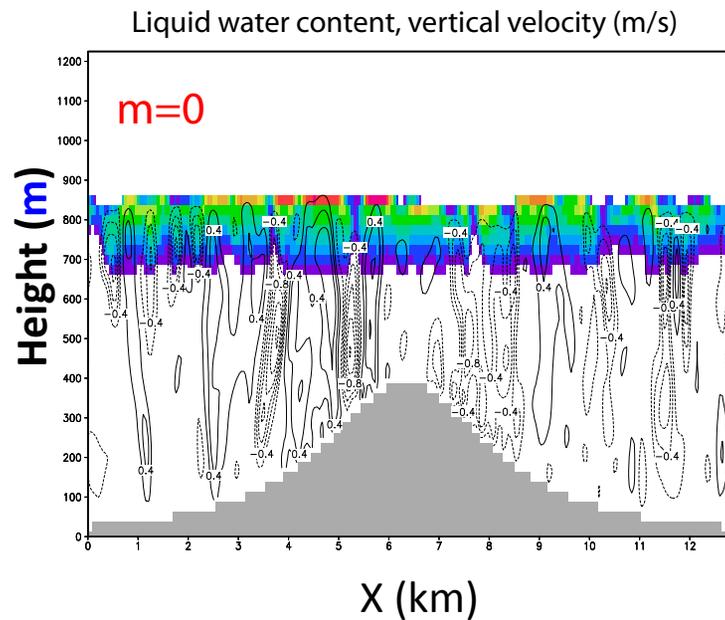
$$(\eta_b)_{i,1+1/2} = \frac{u_{i,2} - (u_b)_{i,1}}{\Delta z} - \frac{w_{i+1/2,1+1/2} - (w_b)_{i-1/2,1+1/2}}{\Delta x}$$

$$(u_b)_{i,1} = (w_b)_{i-1/2,1+1/2} = 0$$

STRATOCUMULUS OVER SMOOTH TOPOGRAPHY IN PARALLEL VVM

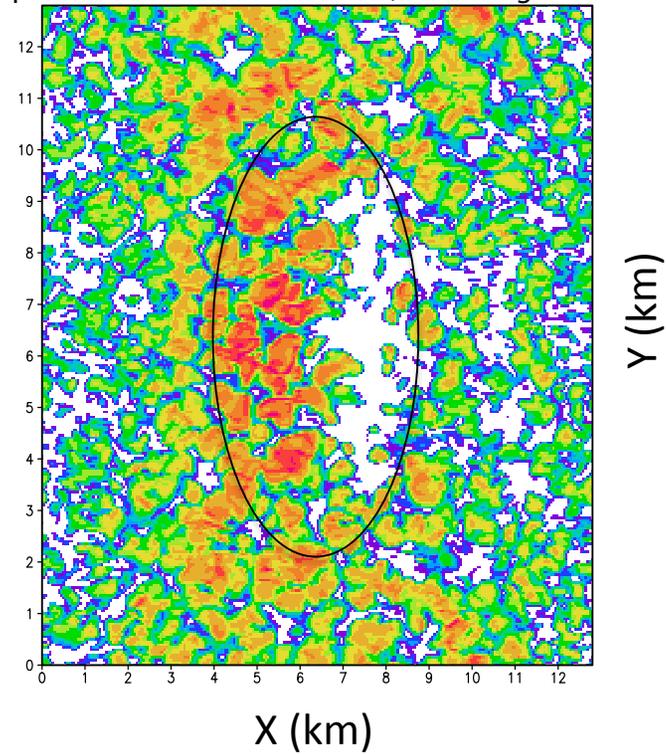
Stratocumulus with elliptic shaped mountain, no surface fluxes

$\Delta x = \Delta y = 2\Delta z = 50\text{m}$, 6 hr simulation



m : an index for the roughness of the topography

Liquid water content at $z=850\text{m}, 200\text{m}$ height contour



FUTURE WORK

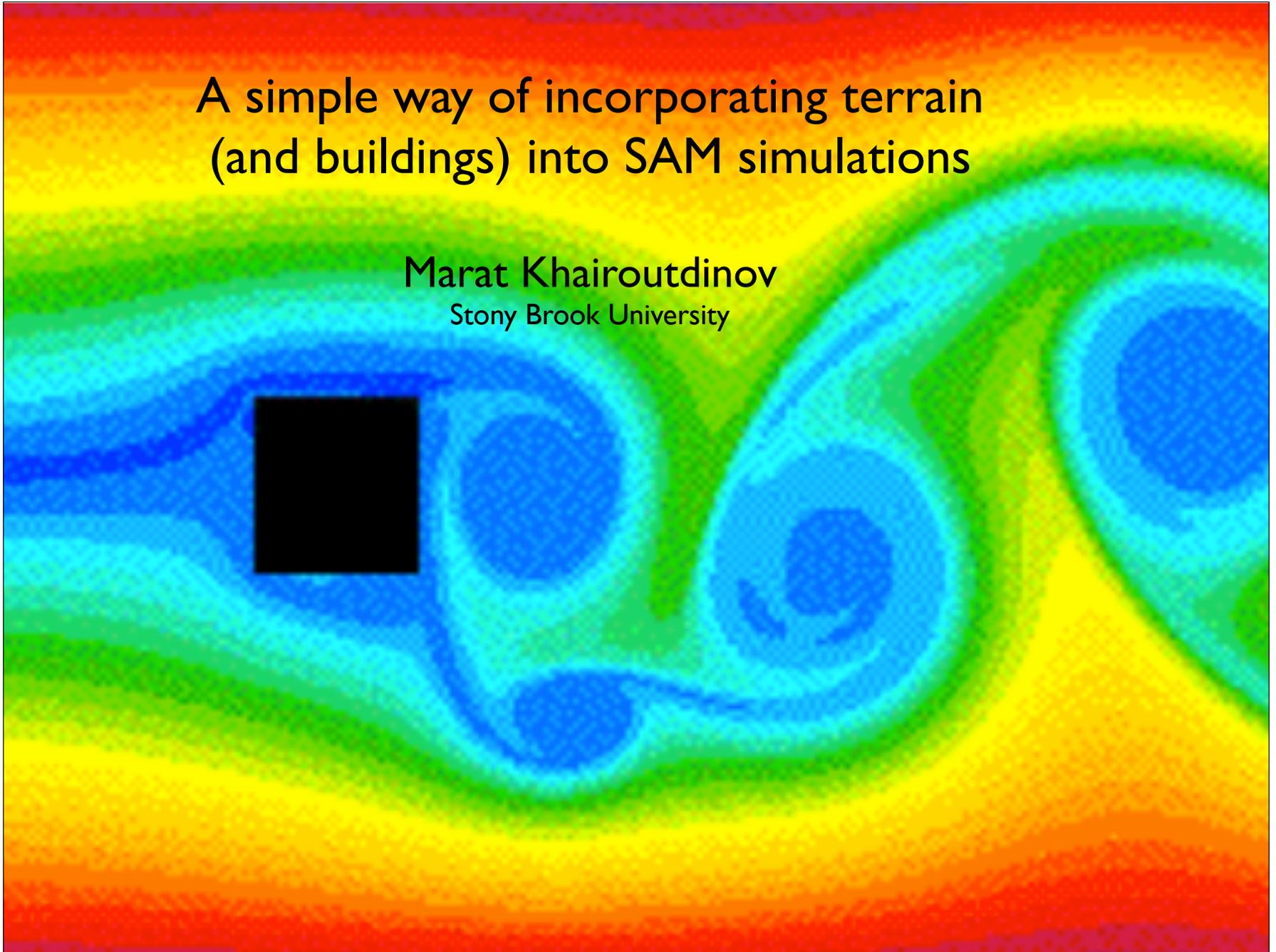
The topography is implemented in pVVM with only barrier effects. Future work will focus on implementation of turbulence, radiation, and land-surface processes near the bottom topography.

Cloud Forest



A simple way of incorporating terrain (and buildings) into SAM simulations

Marat Khairoutdinov
Stony Brook University

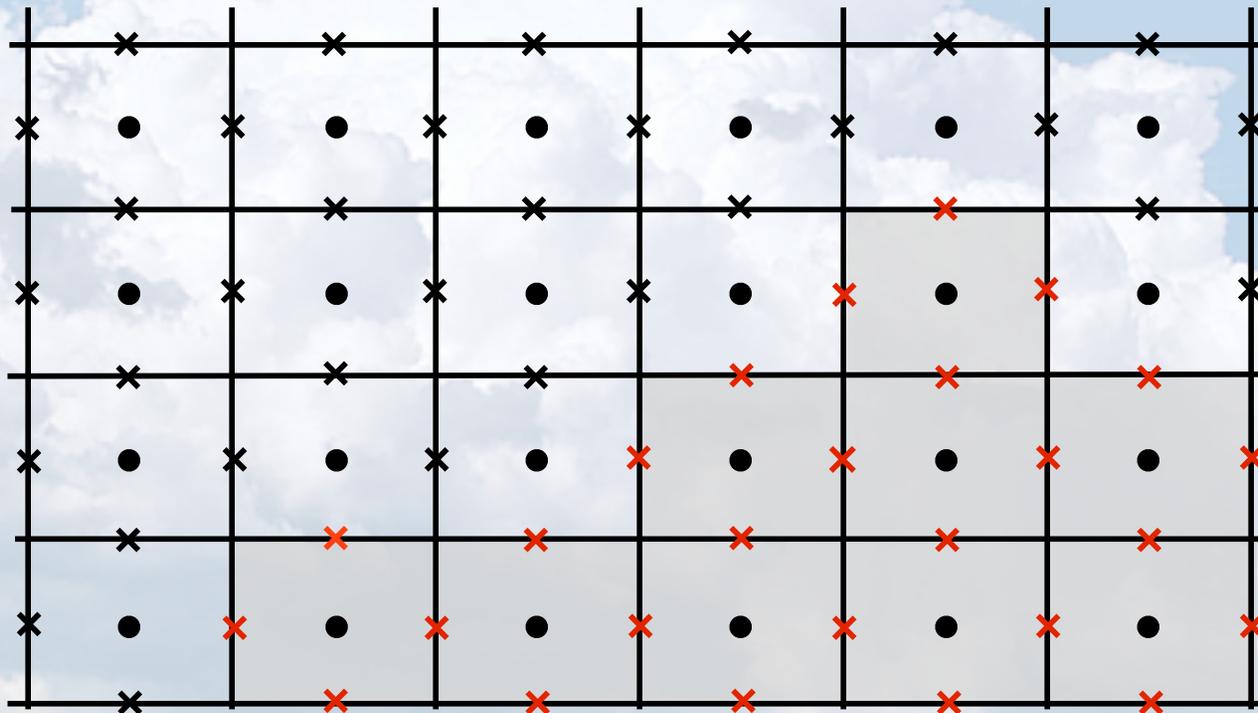


A variant of Immersed-Boundary Method (IBM)

$$u^{n+1} = \sigma_u u^n + \alpha \Delta t [-\nabla_x p^n + \sigma_u \tilde{F}_u^n + \sigma_u \beta F_u^{n-1} + \sigma_u \gamma F_u^{n-2}]$$
$$\text{div}(\rho u^{n+1}) = 0 \quad \text{everywhere in the domain}$$

Reference profiles for buoyancy calculation are calculated averaging over the grid points that are not inside the terrain.

- ✕ wind $\sigma=1$ ✕ zero-wind enforced $\sigma=0$
- pressure, scalars



2-D flow around a building 50 m wide and 50 m tall

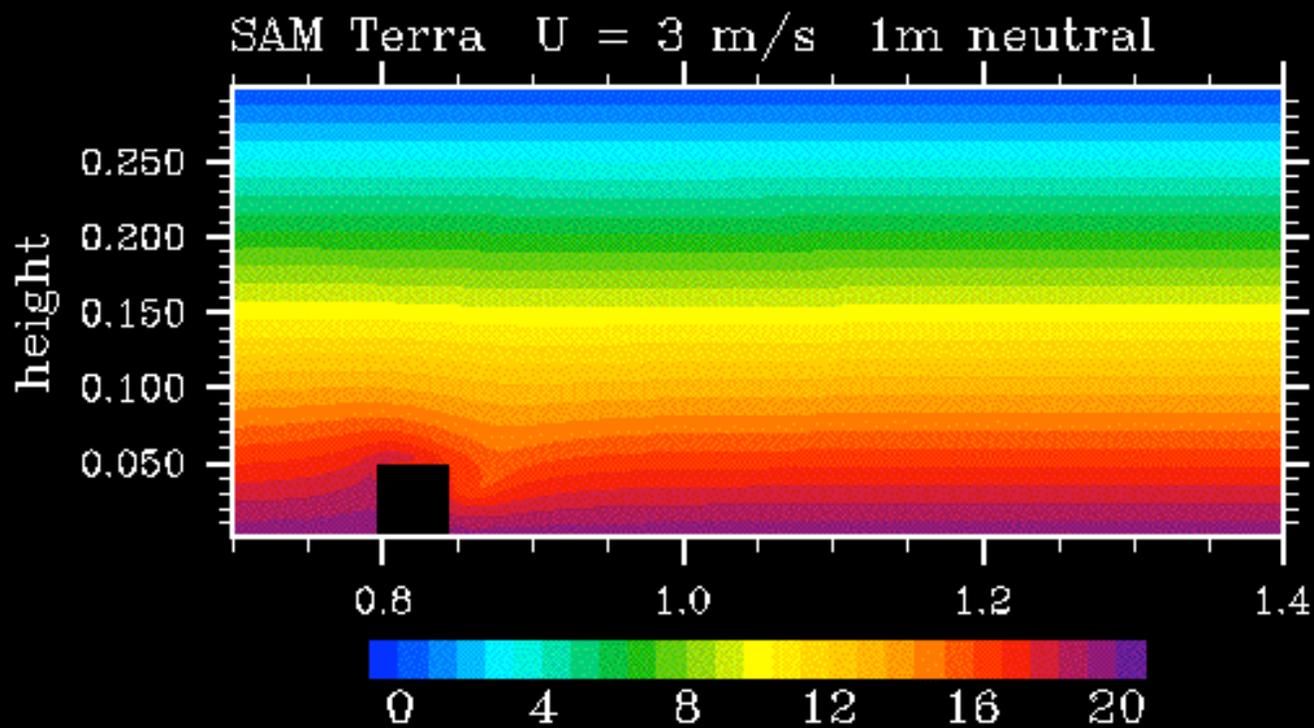
$\Delta x = \Delta z = 1$ m

Stratification: Neutral

Wind: 3 m/s

0

Field: Passive Scalar

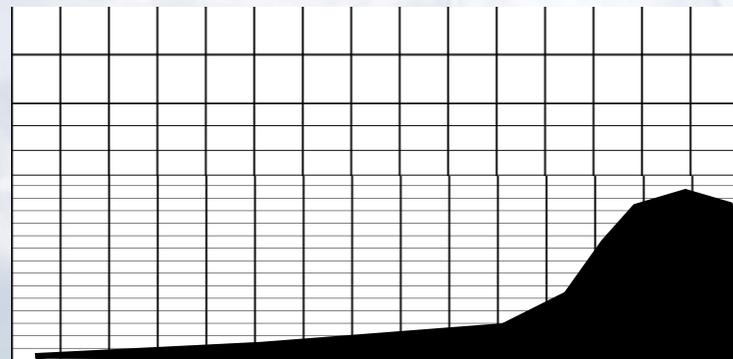
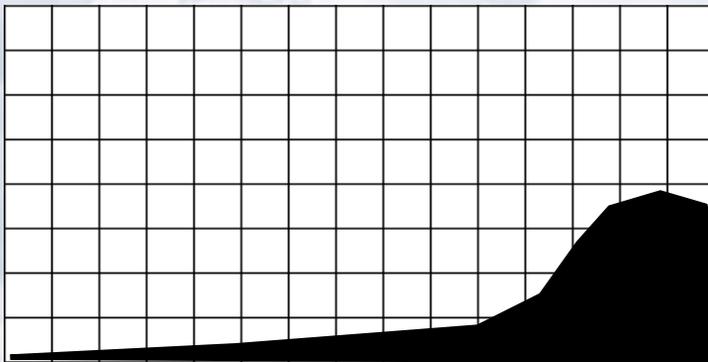


Advantages

- Simplicity
- So many new problems to simulate!
- Cartesian grid
- FFT in horizontal in pressure solver (no multi-grid iterators)
- Steep terrain and buildings easily simulated.

Challenges

- Gently sloping terrains would require high vertical resolution to resolve the slopes).
- Intermediately steep terrains would dictate horizontal resolution everywhere in the domain (because of horizontal FFT in pressure solver the horizontal grid spacing is constant).
- Cells that are inside the terrain/buildings are wasted.



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...

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

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

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

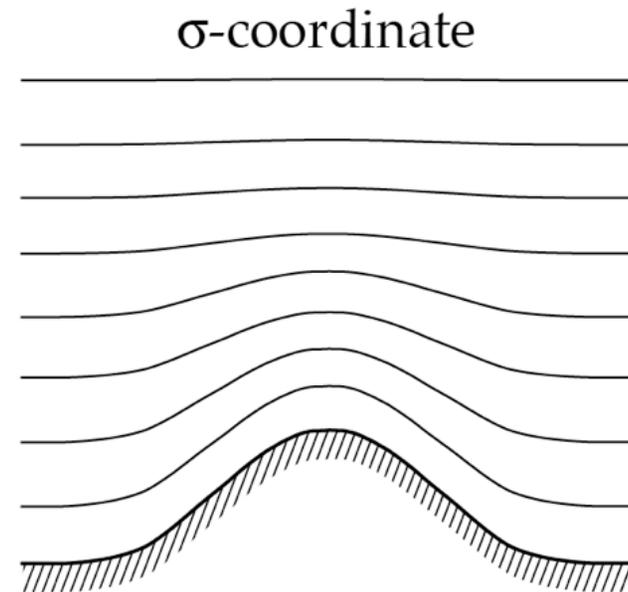
Sigma (or any terrain following) coordinate
for inclusion of mountains

Pros:

- Relatively easy to implement
- Continuous horizontal domain

Cons:

- Pressure gradient 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)

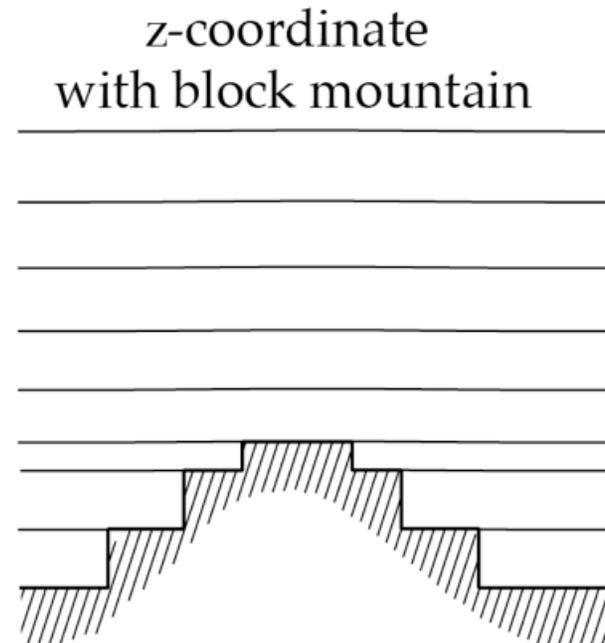
z-coordinate with block mountains

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)

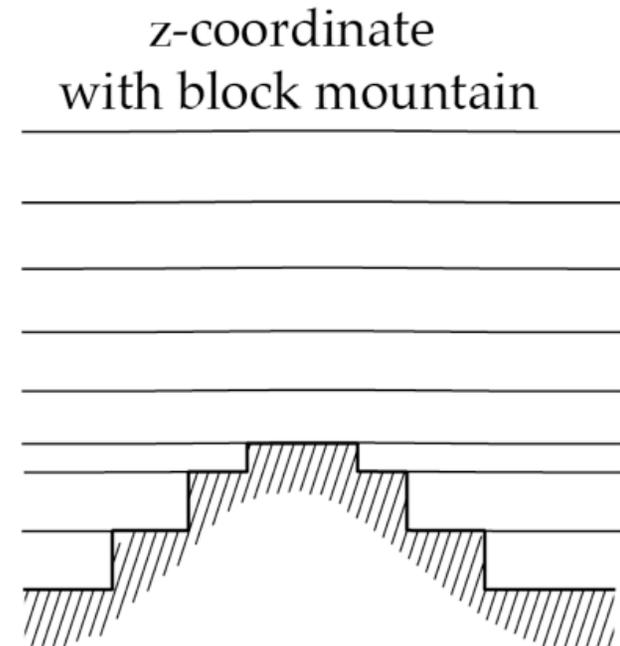
z-coordinate with block mountains

Pros:

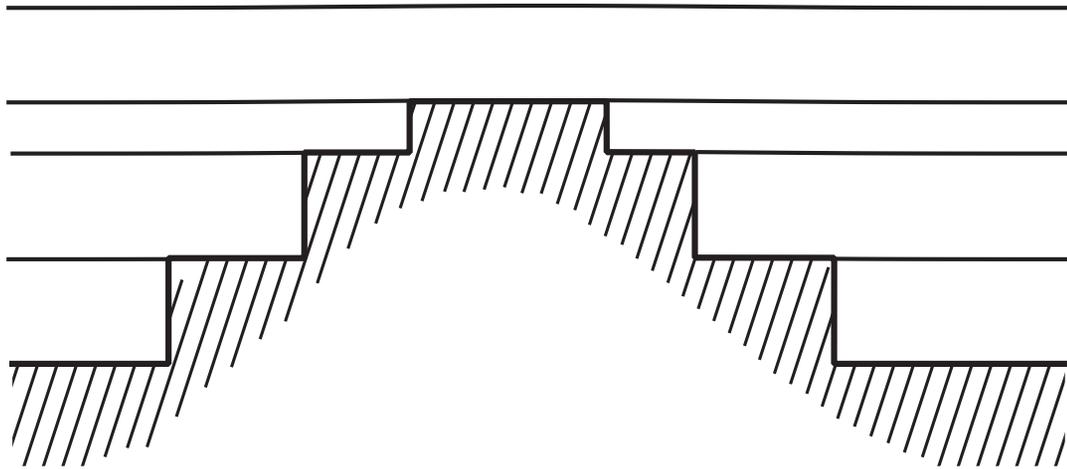
- We know it works well on the Cartesian grid in a planar domain

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: Solution through successive relaxations in a discrete system

Discrete circulation equation :

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

Value of ψ
for next iteration step :

$$\psi_C^{(n+1)} = \frac{1}{L} \oint_C \frac{\psi_+^{(n)} + \psi_-^{(n)}}{2} d\ell \quad \psi_-^{(n+1)} \text{ is to be determined}$$

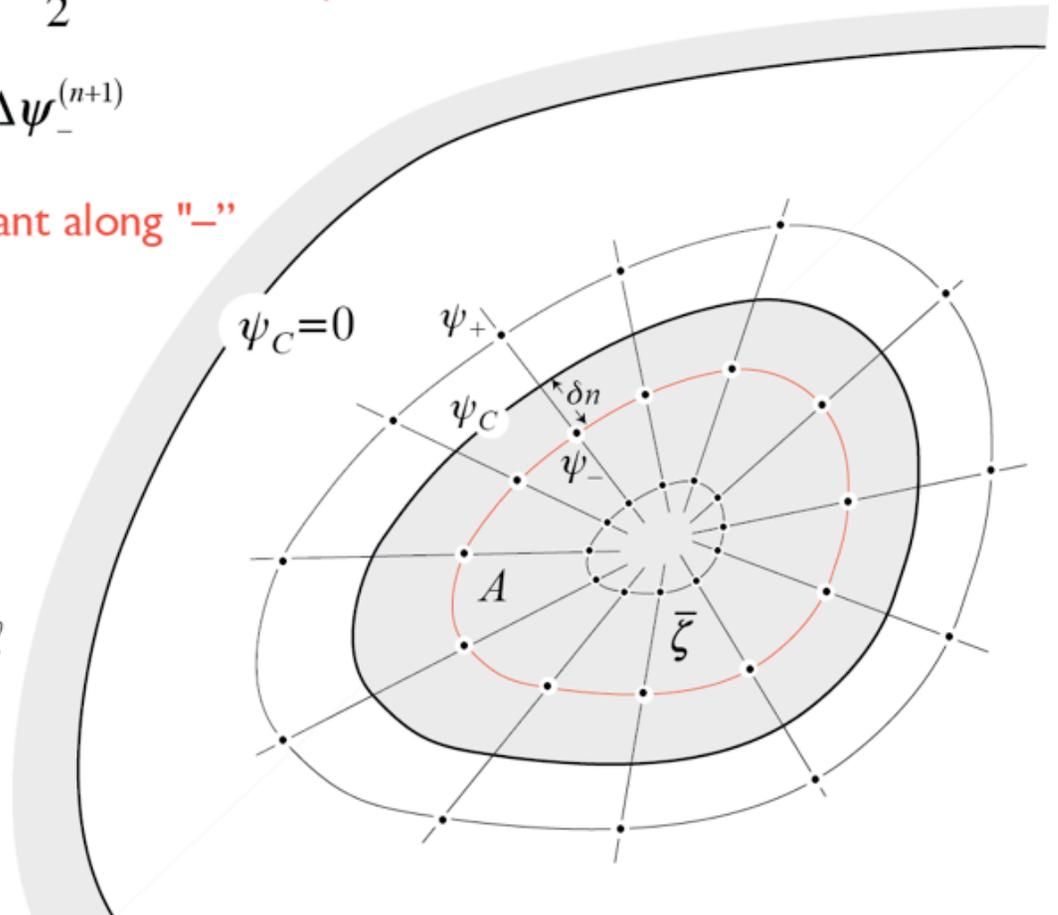
A definition :

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

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

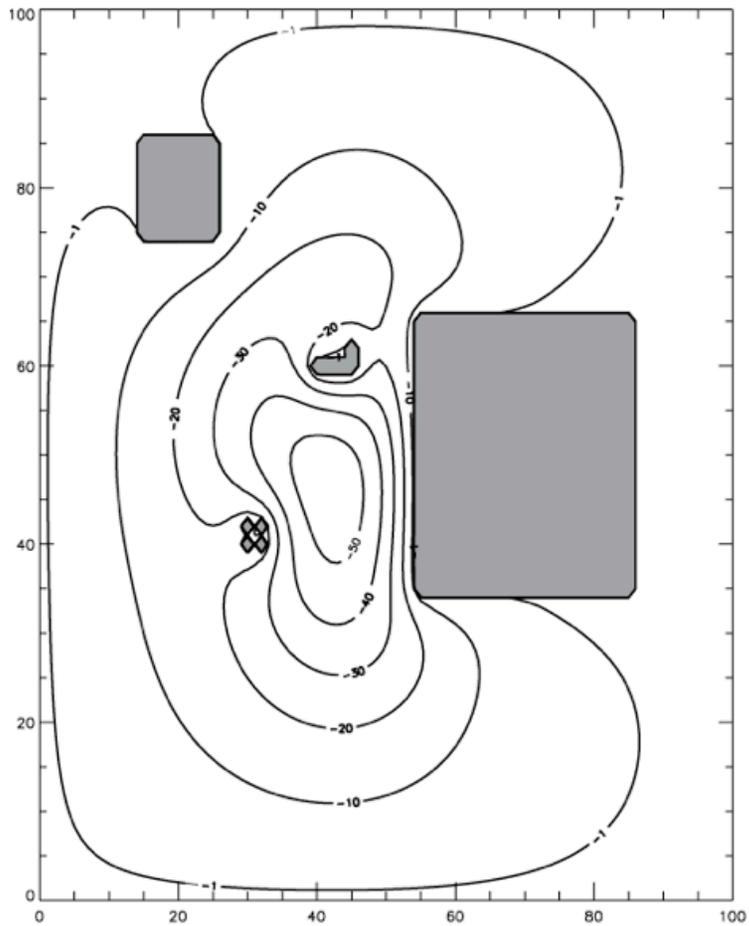
Equation for $\Delta\psi_-^{(n+1)}$:

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

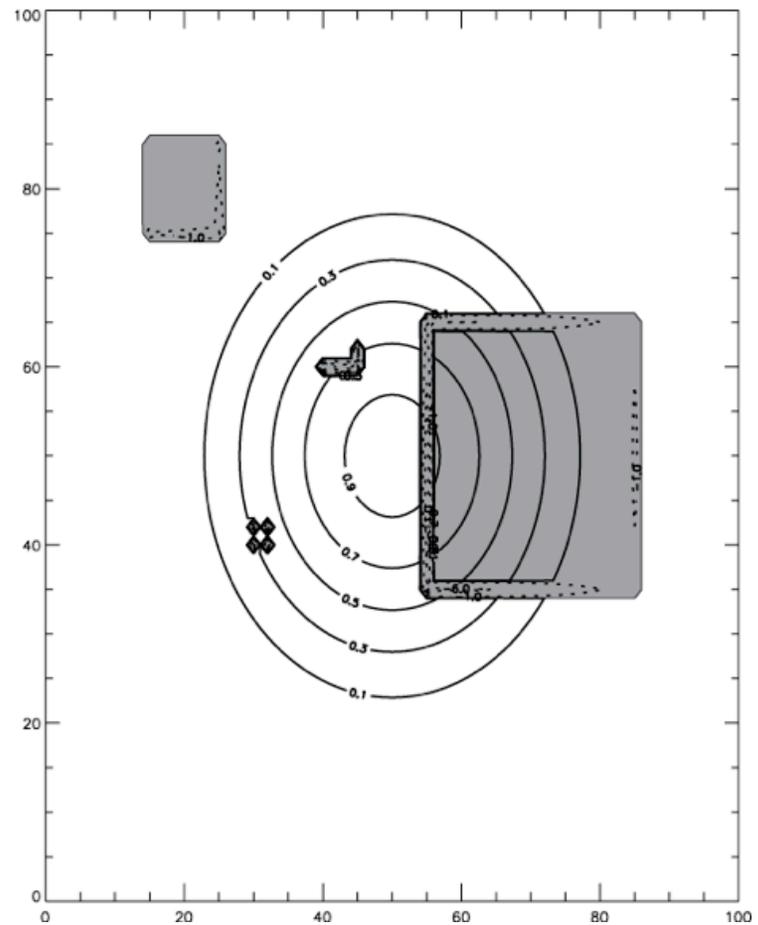


Determination of streamfunction from vorticity in a basin with seven islands

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

A Vorticity-Divergence Dynamical Core based on the Nonhydrostatic Unified System of Equations on the Icosahedral Geodesic Grid

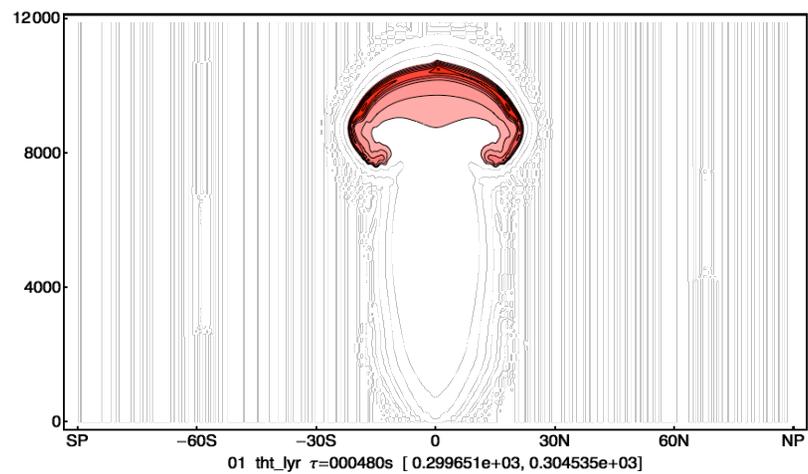
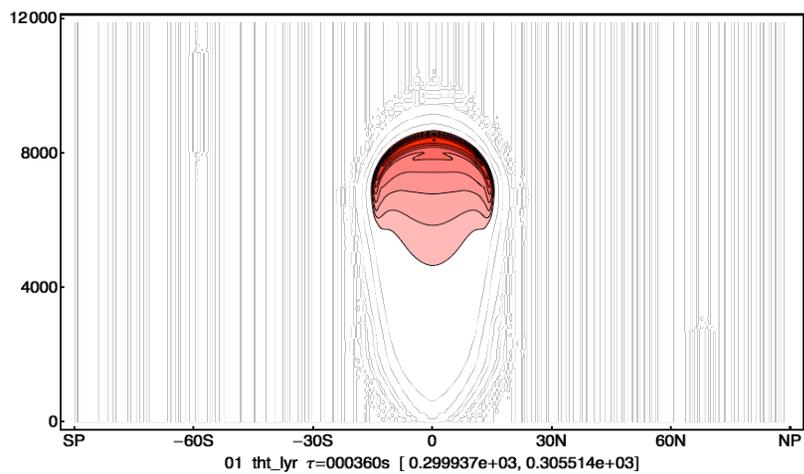
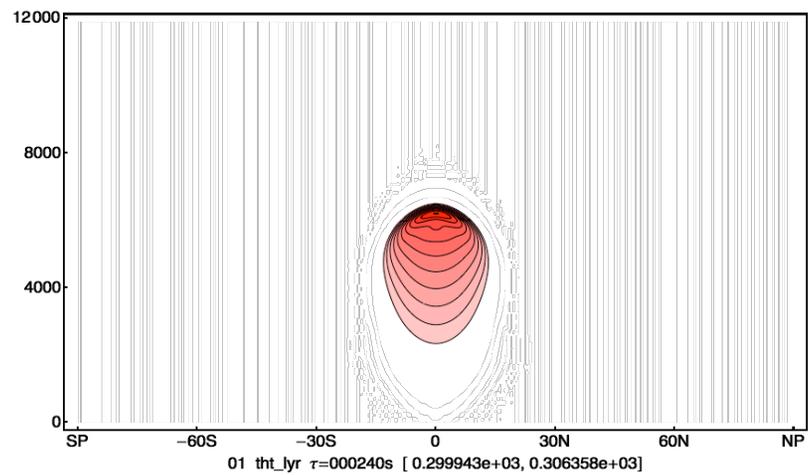
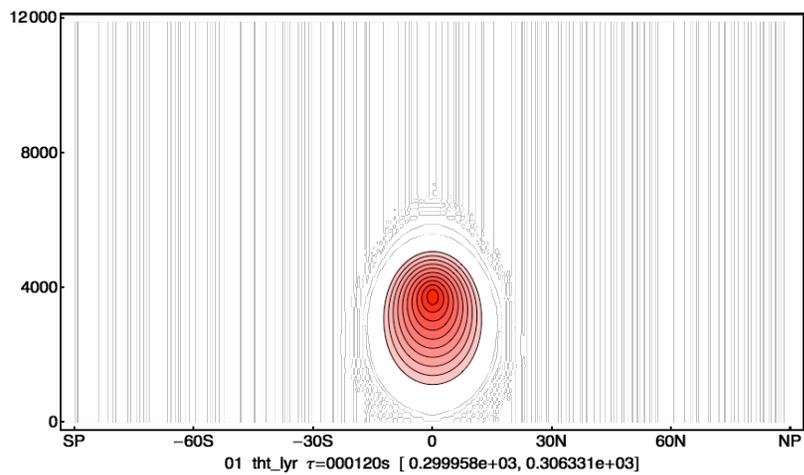
Ross Heikes, C.S. Konor and D. Randall

Dept. of Atmospheric Science
Colorado State University



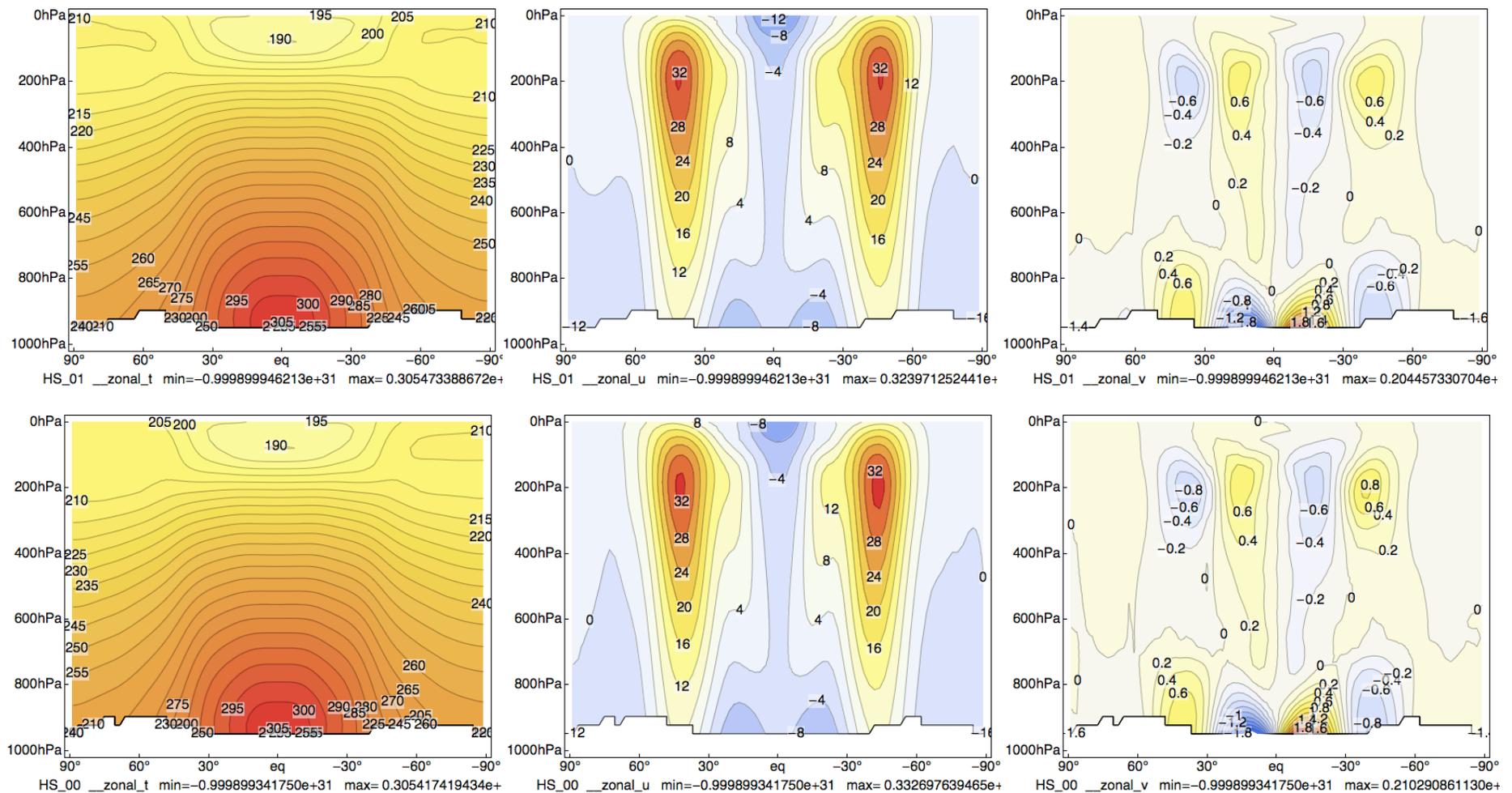
Warm Bubble Test

- Times are 120, 240, 360 and 480 seconds.



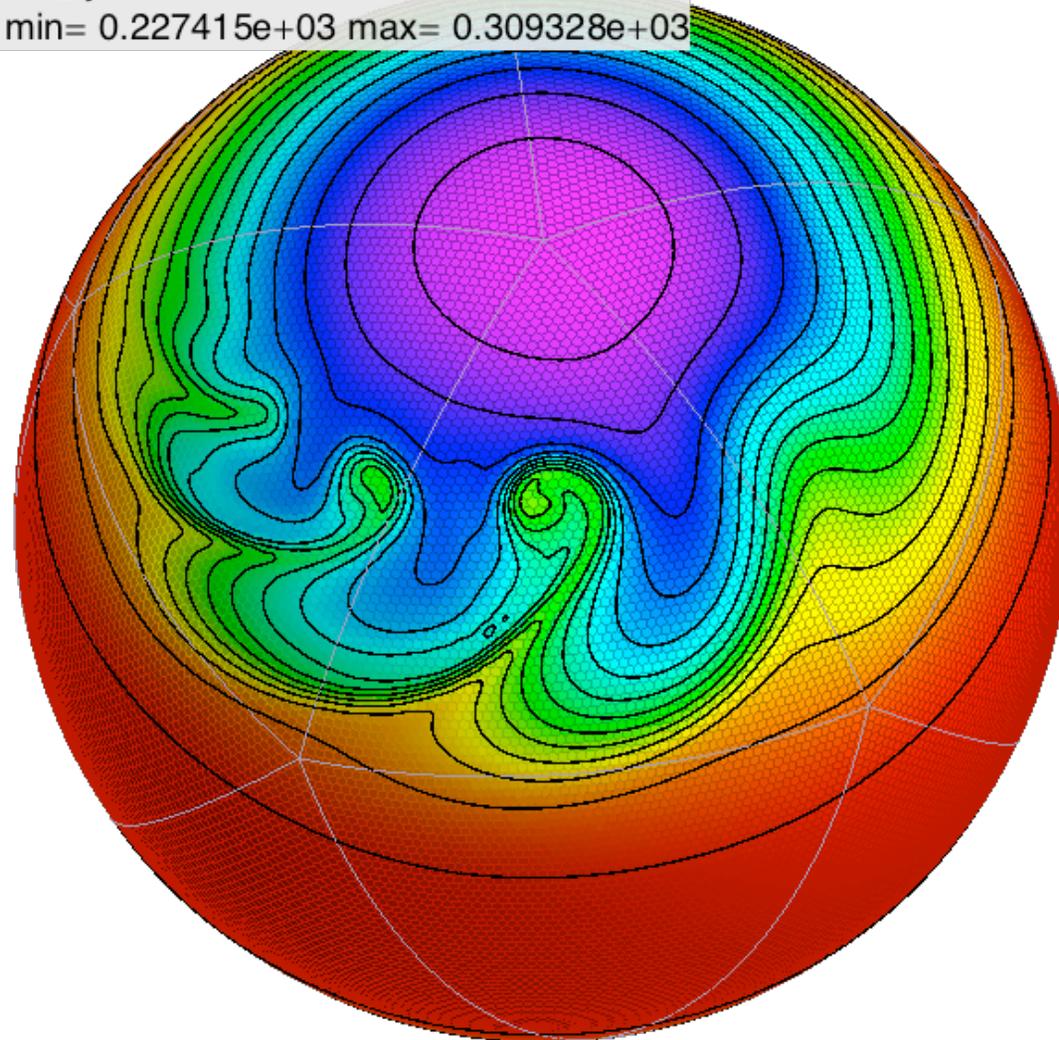
Held Suarez test case with grid 5 (250 km). 200 Days. 50 Samples

- Held-Suarez 1994. Newtonian relaxation toward prescribed temperature.
- Top row is non-hydrostatic. Bottom row is hydrostatic.
- Columns show temperature, zonal and meridional winds



Extratropical cyclone

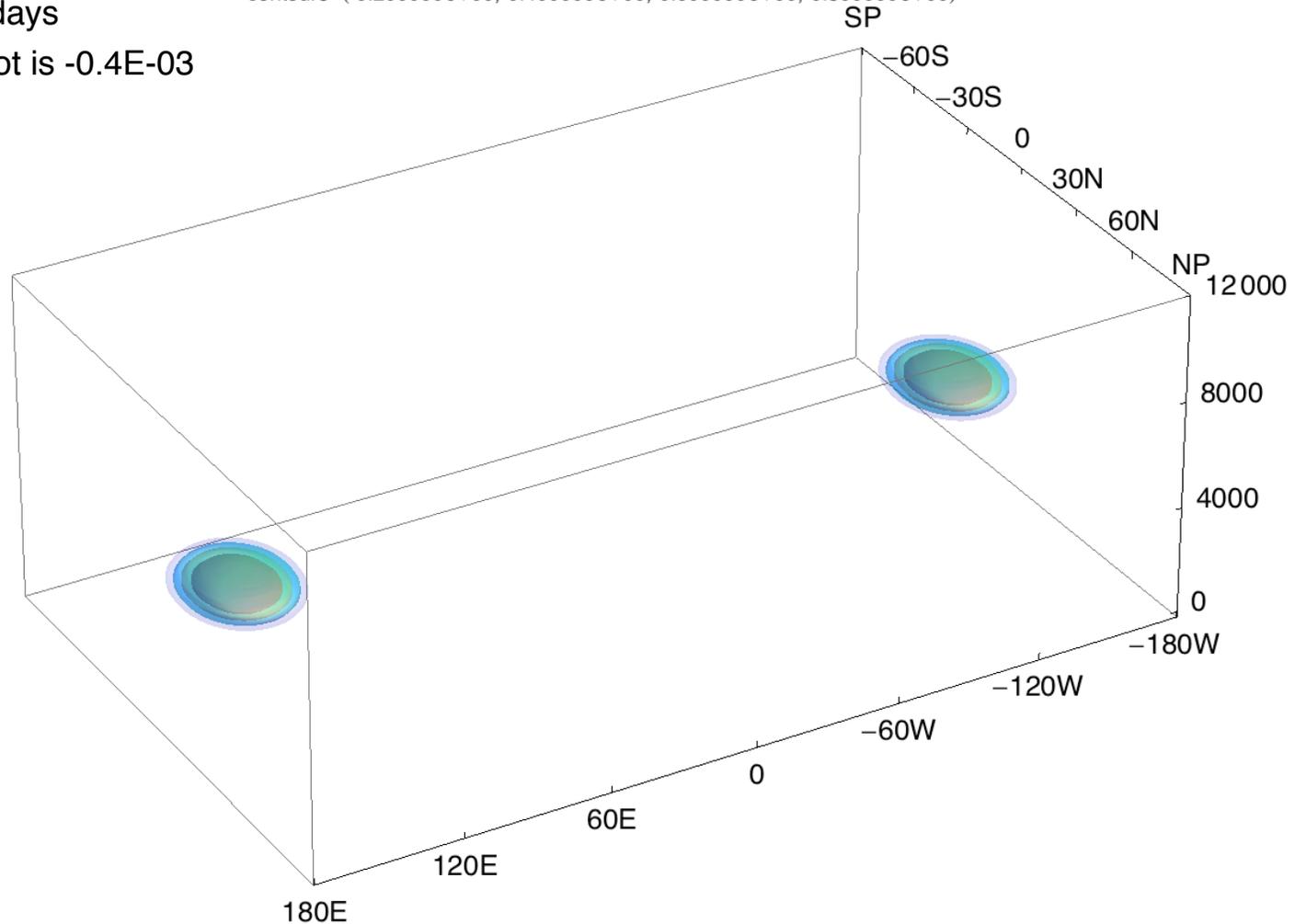
tht_lyr 000216h k= 1
min= 0.227415e+03 max= 0.309328e+03



Improvements to tracer transport

- The 3D deformational flow test is based on the 2D approach by Nair and Lauritzen JCP (2010)
- Time reversal ensures that the original profile is returned to its original position, so an analytic solution is known.
- Two cosine bells.
- Grid 7. 60 level. 12 days
- Minimum under-shoot is $-0.4E-03$

```
01 trc1  $\tau=000000h$   
(min,max)=( 0.000000e+00(0, 90, 1), 0.999750e+00(150, 0, 25))  
contours=( 0.200000e+00, 0.400000e+00, 0.600000e+00, 0.800000e+00)
```



Inclusion of simple moist physics

wnd 000004h k= 9
vecmag= 0.1809e+02

- Grid 6. 125 km resolution.
- This animation shows the winds at 2500 m
- Each frame is 4 hours
- 11 days
- Maximum wind 41 m/s

