# Simulations of geophysical fluids and planetary atmospheres

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# General introduction

- In our group, members are working on simulations on phenomena in an idealized atmosphere and its simplified form, a shallow water system.
- Atmosphere and shallow water system show many kinds of phenomena. In our project, we are focusing on following two topics:
  - advection of materials,
    - Shu and Zheng
  - atmospheric waves.
    - Hirokazu and Will

# Advection

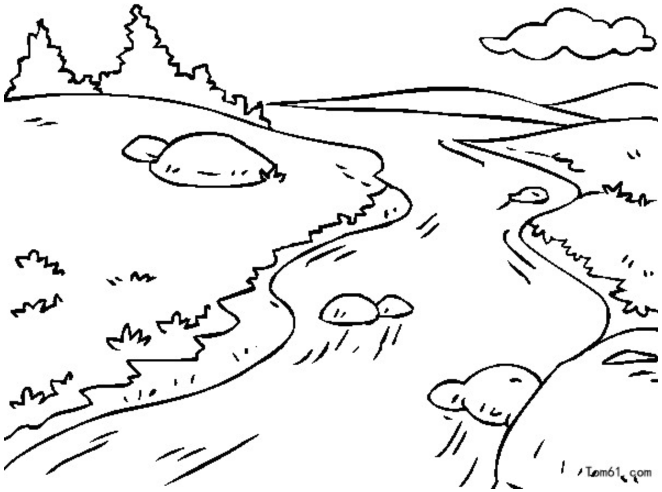
- **Definition**

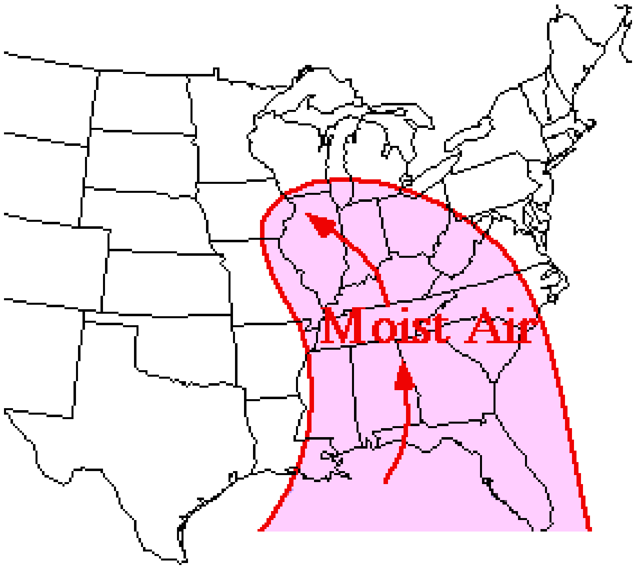
  Advection is a transport mechanism caused by fluid’s bulk motion.

- **Examples**
  - Movement of silt in a river by bulk water flow downstream.
  - Transportation of moist air mass by the winds.

- **Remarks**

  Not only materials, but also energy and enthalpy are transported via advection.





# Advection of Clouds

- We focus on simulating cloud movement under advection.
- Shu works on tracking a single small batch of clouds in Lagrangian coordinates.
- Zheng simulates the transport and shape changes for a huge group of clouds in Euler coordinates.

# Simulation of a Single Cloud

- I simulated how a single cloud moves in winds.
  - A single cloud … its mass and size can be ignored.
  - Using "Lagrangian coordinates".

- The velocity vector of such a cloud COINSIDES with that of winds

$$(\dot{x}, \dot{y}, \dot{z}) = (u, v, w)$$

- I use Forward Difference Method for digitizing

$$\frac{x^{n+1} - x^n}{\Delta t} = u, \quad \frac{y^{n+1} - y^n}{\Delta t} = v, \quad \frac{z^{n+1} - z^n}{\Delta t} = w$$

# DCPAM (Dennou-Club Planetary Atmospheric Model)

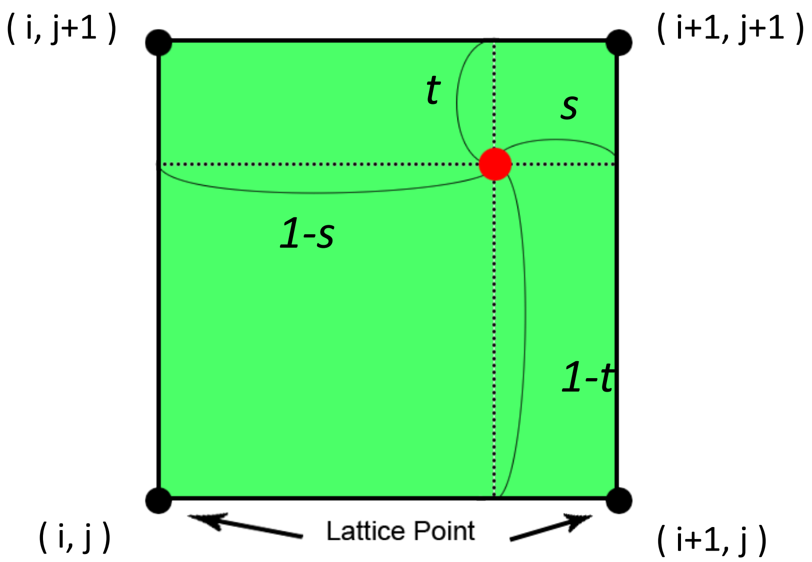
- The numerical model for computing an atmospheric circulation on a sphere

- Fortran codes to solve primitive equations are provided by using this model
  - Primitive equations are used widely for weather forecast
  - By using codes, we can simulate a circulation easily
  - The visualization of results can also be obtained easily

- Dennou is a Japanese literary word, which stands for a computer
  - Dennou-club is a group of Japanese scientists interested in planetary hydrodynamics

# Computing the wind-velocity correctly

- In DCPAM, the wind velocity is computed only on specific lattice points
- To compute the wind velocity more accurately, I used weighting coefficients as below:




The wind velocity on the red point:

$$
\begin{aligned}
&v(i, j) * s\,t \; + \\
&v(i+1, j) * (1-s)\,t \; + \\
&v(i, j+1) * s\,(1-t) \; + \\
&v(i+1, j+1) * (1-s)(1-t)
\end{aligned}
$$

# Simulations

- Let’s Watch a 3D Video !

# Model for a Group of Clouds

- **Difficulty**

  Tracking each small cloud calls for huge amount of works.

- **Model**

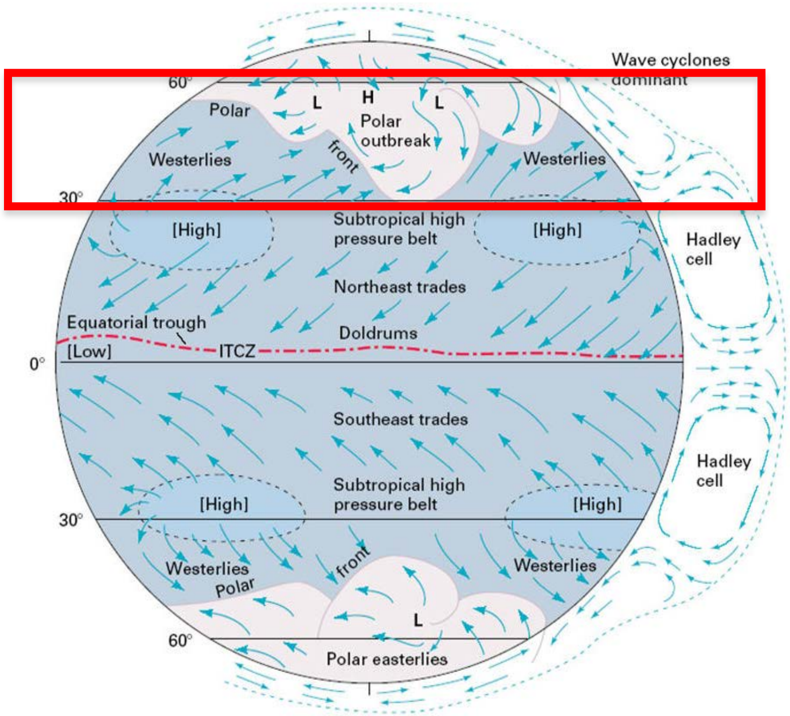
  We treat the cloud as a mixture of tiny water drops and the air. We could determine the shape and the thickness of the clouds if we know the mass ratio of the water drops.

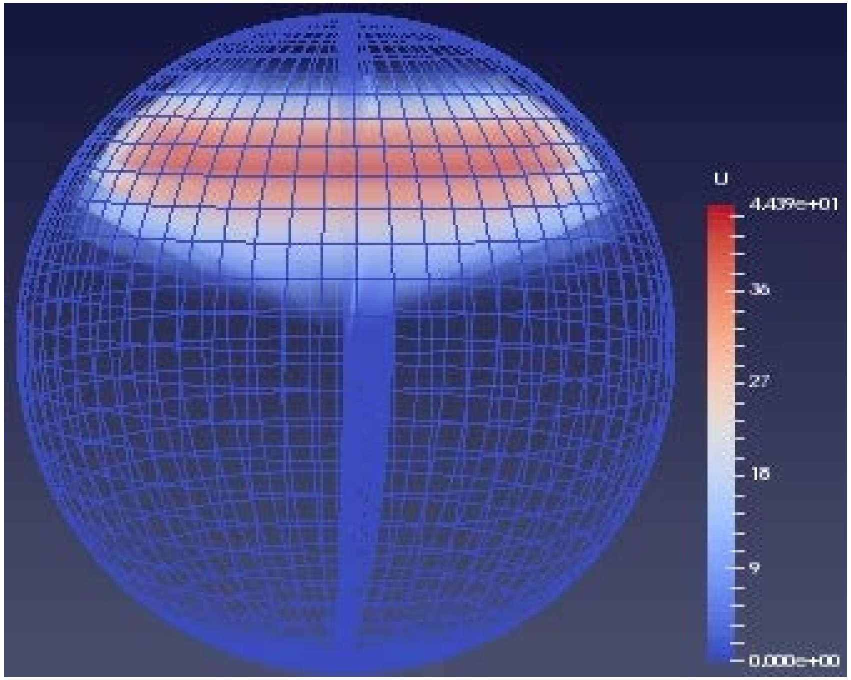
- **Equation**

$$\frac{\partial r}{\partial t} + (\vec{u}.\nabla)r = 0 \qquad r = r(t,x,y,z) = \frac{\rho_{water}}{\rho_{total}}$$

# Winds and Areas of Interest

- **Area:** We focus on the winds in the middle latitudes.
- **Winds:** We use the DCPAM to calculate the wind velocity in this area. There is only east wind at the very beginning.



# Numerical Methods

- **Scheme**

- Freeze wind velocity in each step.
- Use leap-frog method to solve the equation.

$$\frac{r_{i,j,k}^{n+1} - r_{i,j,k}^{n-1}}{2\Delta t} + u_{i,j,k}^{n} \cdot \frac{r_{i+1,j,k}^{n} - r_{i-1,j,k}^{n}}{2\Delta x} + v_{i,j,k}^{n} \cdot \frac{r_{i,j+1,k}^{n} - r_{i,j-1,k}^{n}}{2\Delta y} + w_{i,j,k}^{n} \cdot \frac{r_{i,j,k+1}^{n} - r_{i,j,k-1}^{n}}{2\Delta z} = 0$$

- **Boundary Conditions**

- Periodic b.c. for longitude: $r(t,0,y,z) = r(t,x_0,y,z)$
- Zero Neumann b.c. for other directions: $\frac{\partial r}{\partial \vec{n}} = 0, z = 0, z_0 \parallel y = 0, y_0$

# Simulations

- Let’s Watch a 3D Video !

# Summary of Our Part

- We are simulating the same object with different scales and different view points.

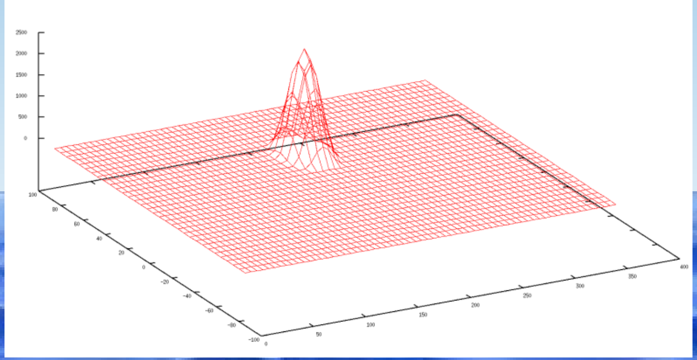
- Lagrangian coordinates can be used to track the movement of a single object, while Euler coordinates are suitable for describing the material distribution.

# Atmospheric Waves Simulation

**The aim**

To see how do atmosphere waves going on after they hit a mountain or the real geography

- Solve the fluid dynamic with "DCPAM" or "Shallow Water Model"
- Compare and Consider in 2D or 3D



# Shallow Water Equations

$$\frac{\partial u}{\partial t} + \frac{u}{a\cos\phi}\frac{\partial u}{\partial \lambda} + \frac{v}{a}\frac{\partial u}{\partial \phi} - uv\frac{\tan\phi}{a} - 2\Omega v\sin\phi = -\frac{g}{a\cos\phi}\frac{\partial h}{d\lambda} - \frac{u - u_o bs}{\tau} - \nu\nabla^4 u$$

$$\frac{\partial v}{\partial t} + \frac{u}{a\cos\phi}\frac{\partial v}{\partial \lambda} + \frac{v}{a}\frac{\partial v}{\partial \phi} + 2u^2\tan\phi + +2\Omega u\sin\phi = -\frac{g}{a}\frac{\partial h}{\partial \phi} - \nu\nabla^4 v$$

$$\frac{\partial h}{\partial t} + \nabla\cdot\begin{bmatrix} u(h - h_{\text{topo}}) \\ v(h - h_{\text{topo}}) \end{bmatrix} = -\nu\nabla^4 h$$

$u$ = zonal velocity ($x$-axis direction)

$v$ = meridional velocity

$\lambda$ = spherical longitude variable

$\phi$ = spherical latitude variable

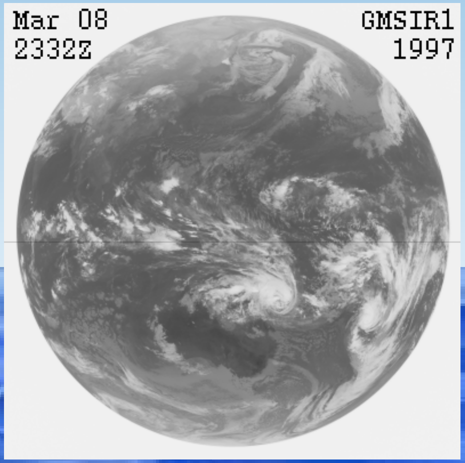
$h$ = height deviation of horizontal pressure from mean H

$g$ = acceleration due to gravity

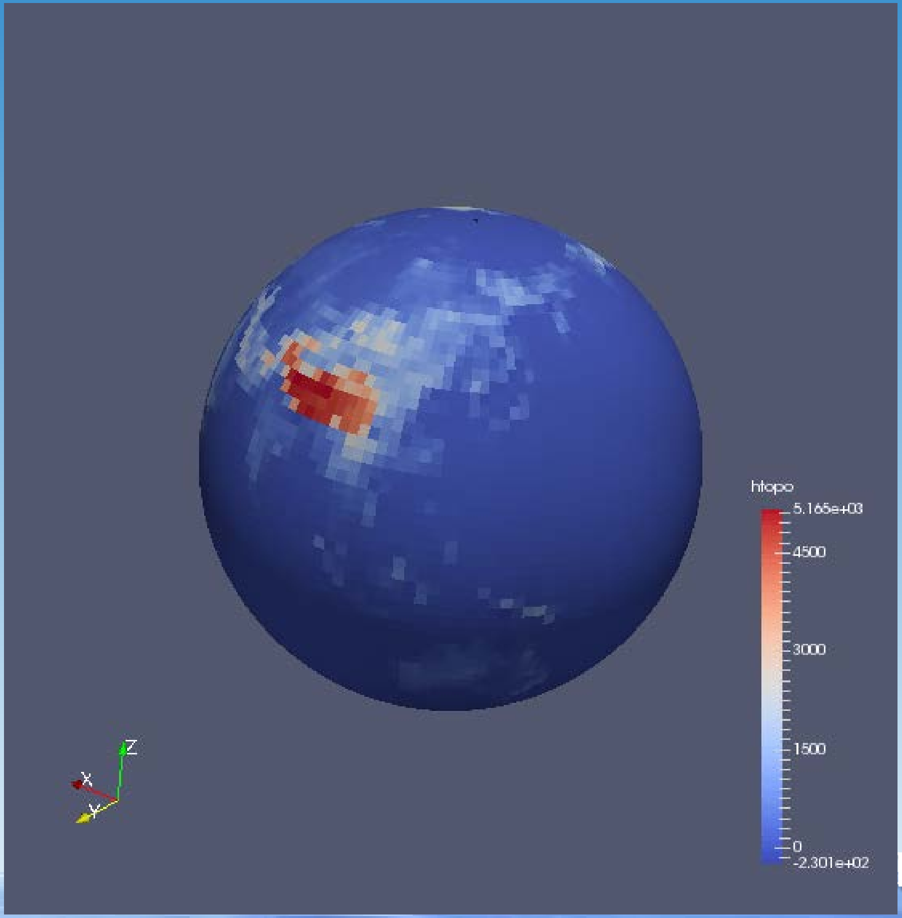
$a$ = radius of Earth

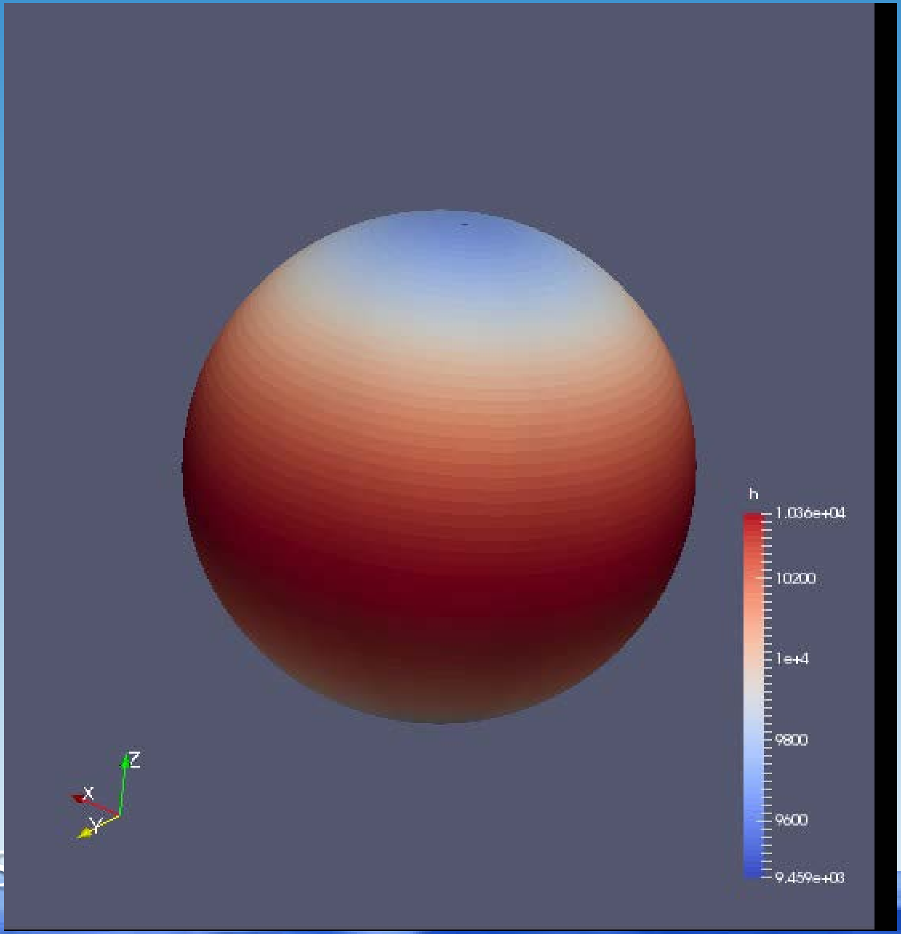
# Setup and Initial Conditions

- Shallow water topography
  - Mesh of Earth terrain
  - Flat mesh with single mountain
- Both begin with higher pressure at the equator and lower pressure at poles
- Zonal velocity equation has wind forcing term to model northern hemisphere flow

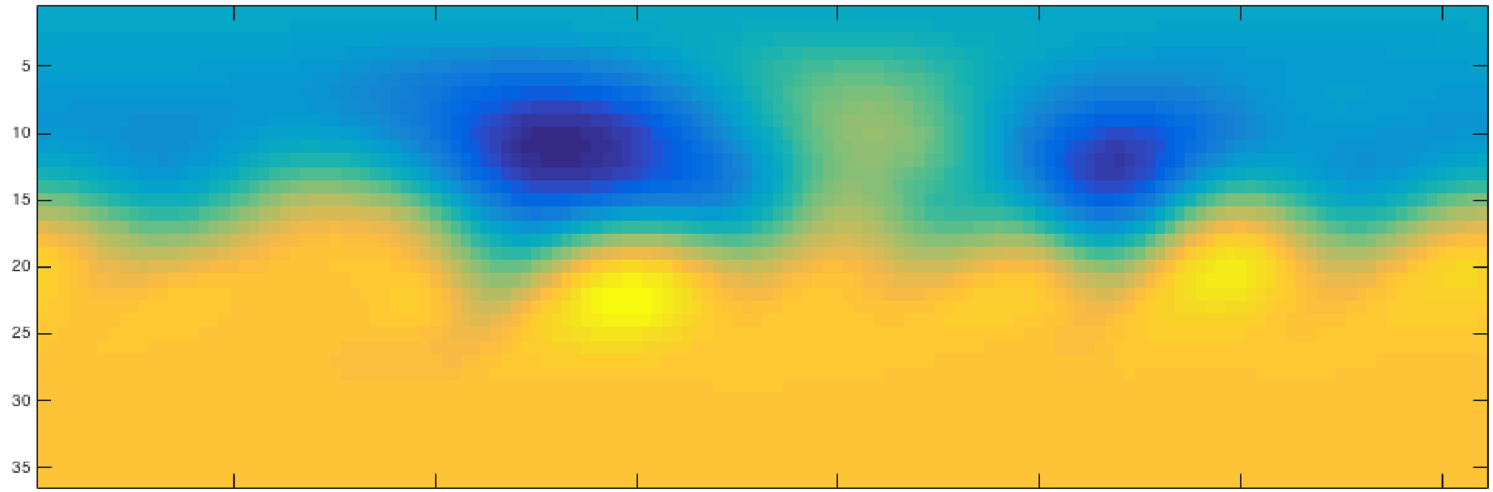


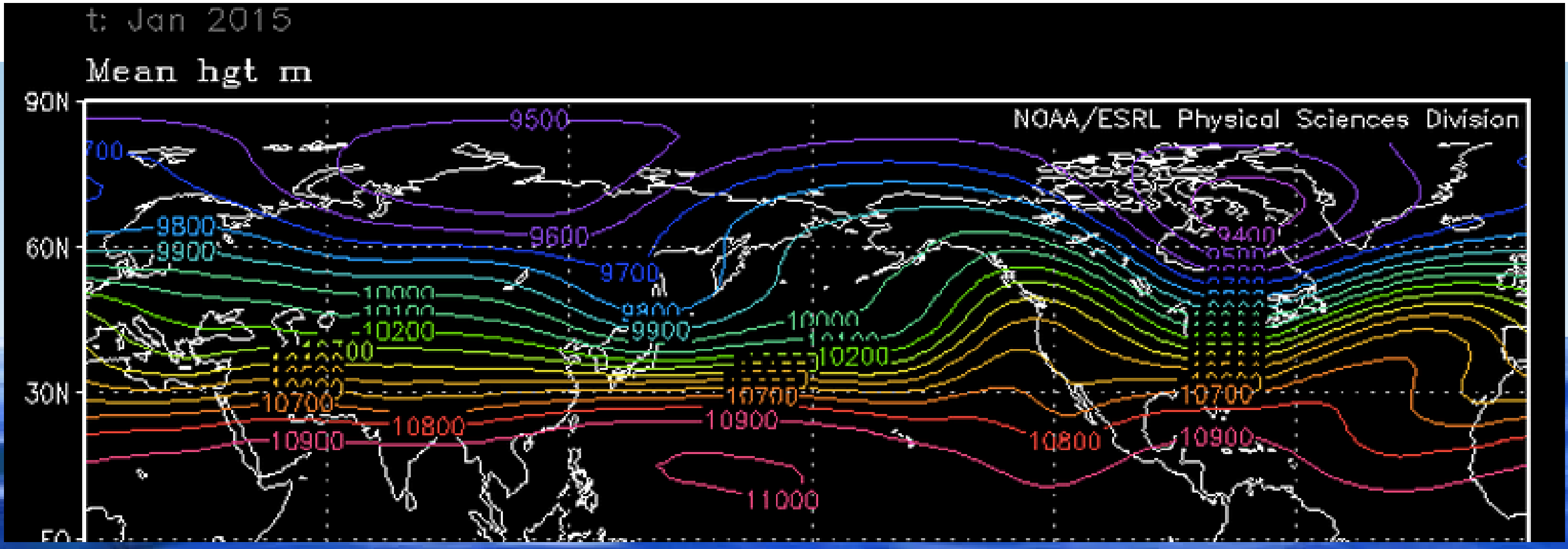
# Pressure Level in Shallow Water Simulation Northern Hemisphere over Two Months



# Time Averaged Simulation
# vs
# Actual Results over January 2015

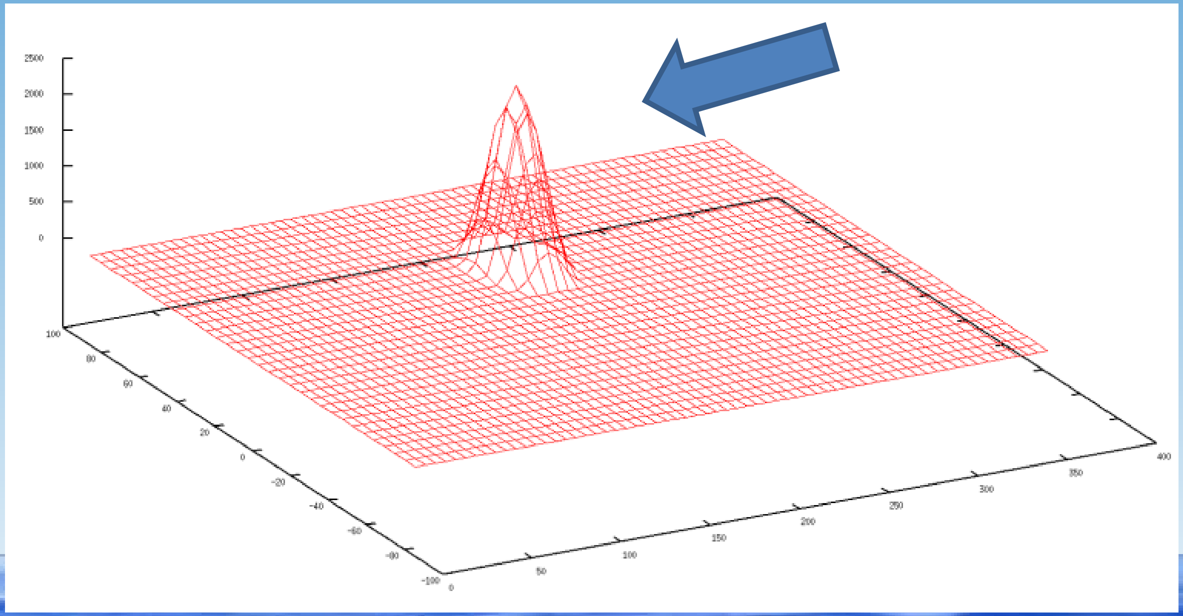


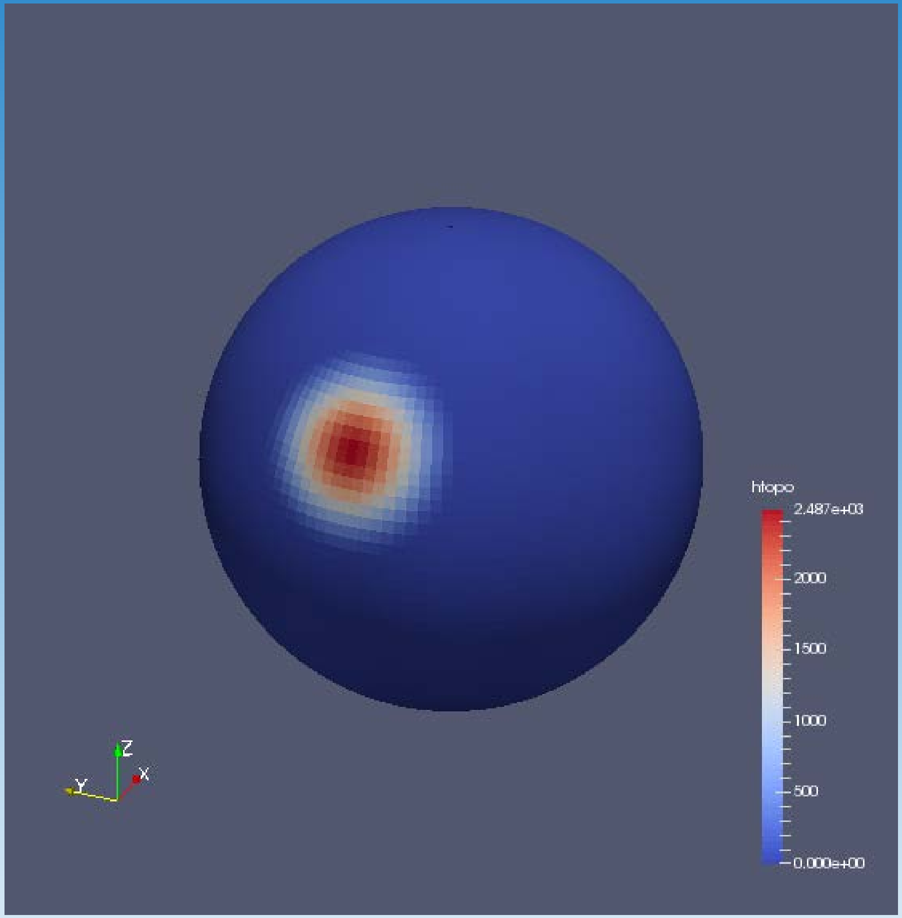
# Shape of Mountain

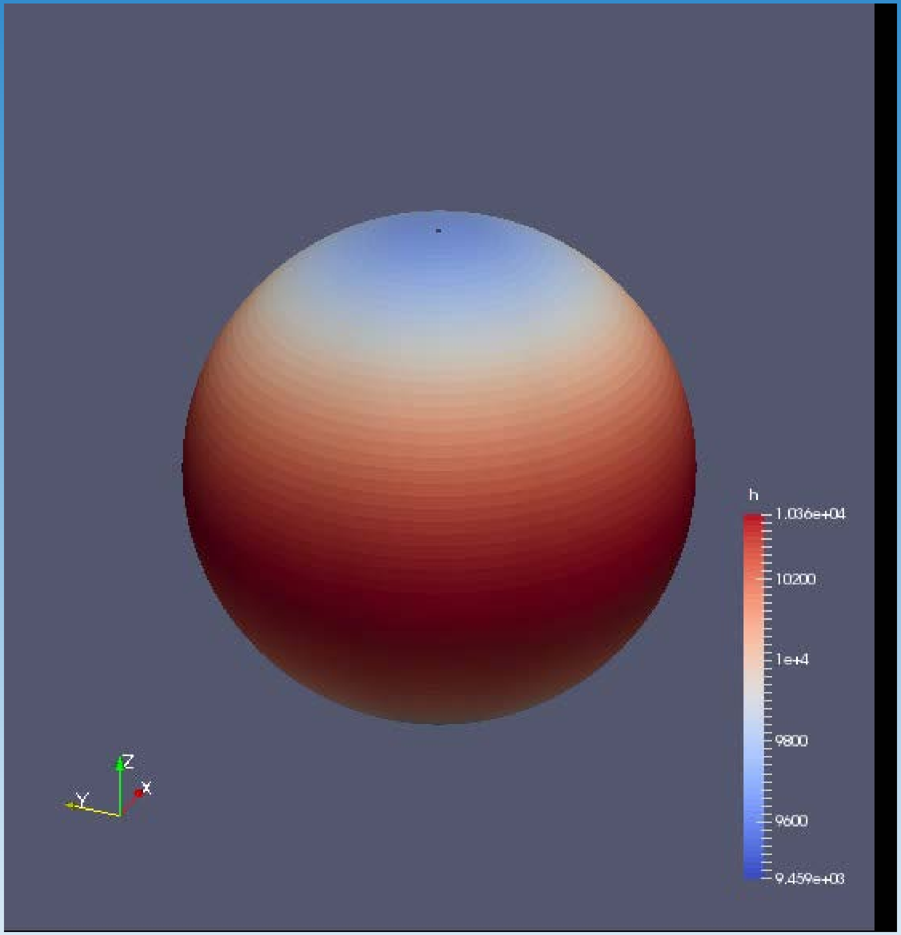
**How to make**

- To use “Gnuplot”, we drew a mountain which has 2500m height.



# 2D Simulation

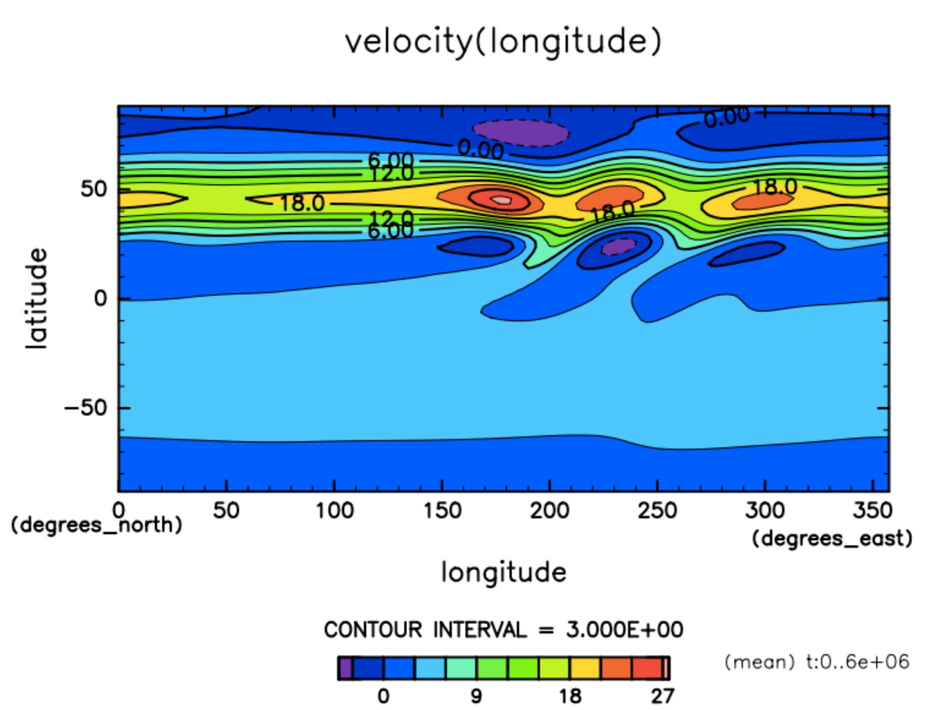


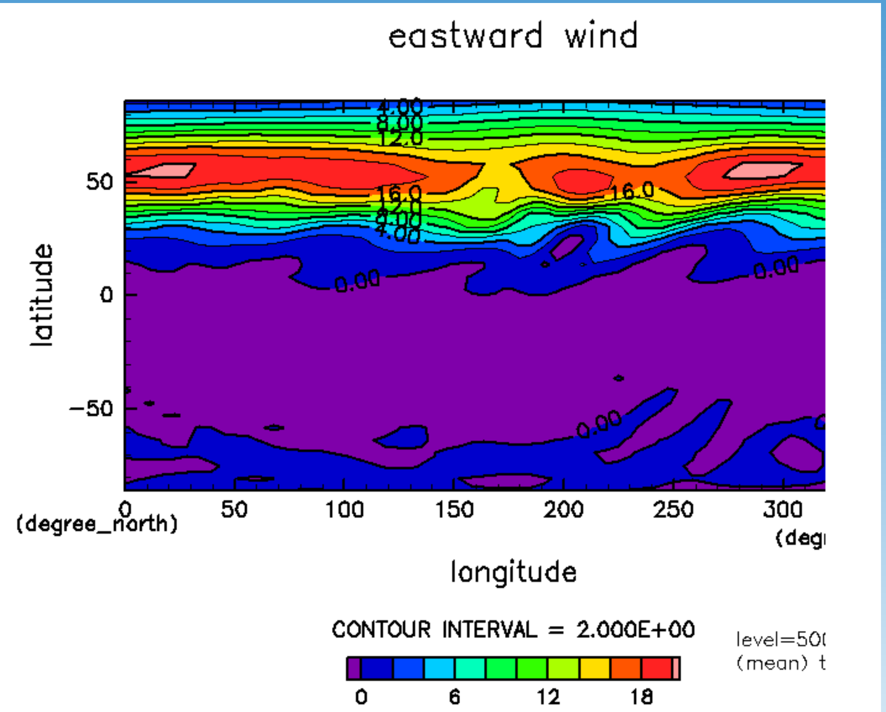



# Comparing 2D to 3D Results

**Shallow Water Model**

**DCPAM**

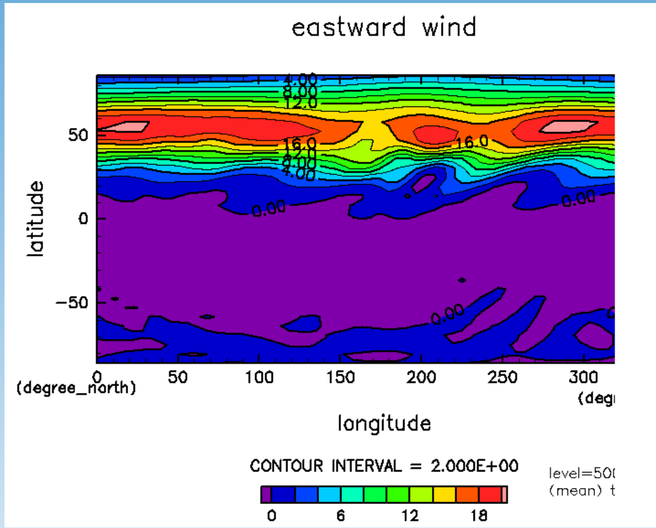


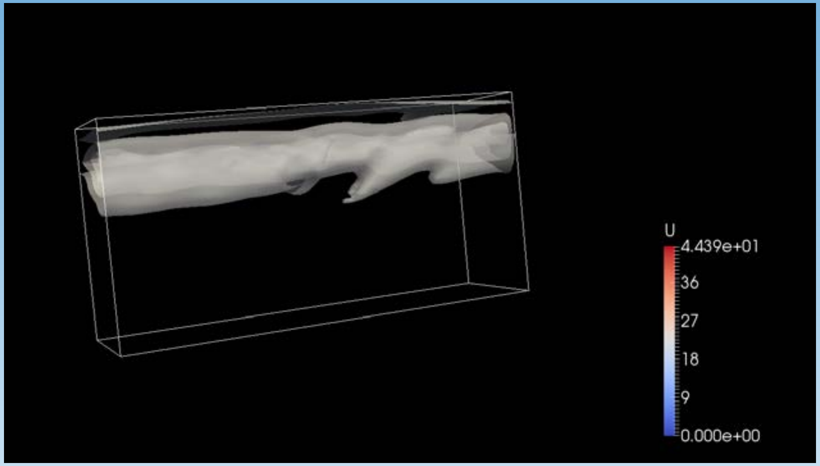



# 3D Visualizing

**How to make**

To use “paraview” which is software of visualize




- We tried to visualize “wind velocity”

# 3D Visualizing

- Let’s Watch 3D Videos !

# Summary of our part

- The shallow water simulation is a decent model for large pressure trends over longer intervals
- The Shallow Water Model results closely resemble those of the DCPAM
- We could see the atmosphere flows more clearly in 3D simulation

# Summary of our project

- We worked on simulations of advection of a material and atmospheric waves. All members made codes from scratch or modify pre-existing codes, and perform simulations.
- Simulations of advection show fluctuations caused by atmospheric mean flow and waves. And, simulations with Eulerian and Lagrangian frameworks can give some insights into material movement in different points of view.
- Simulations of waves in 2D and 3D systems show atmospheric response by geography (idealized and realistic). And, a result of 3D system can be interpreted by that of 2D system in some senses.

# Thank you.