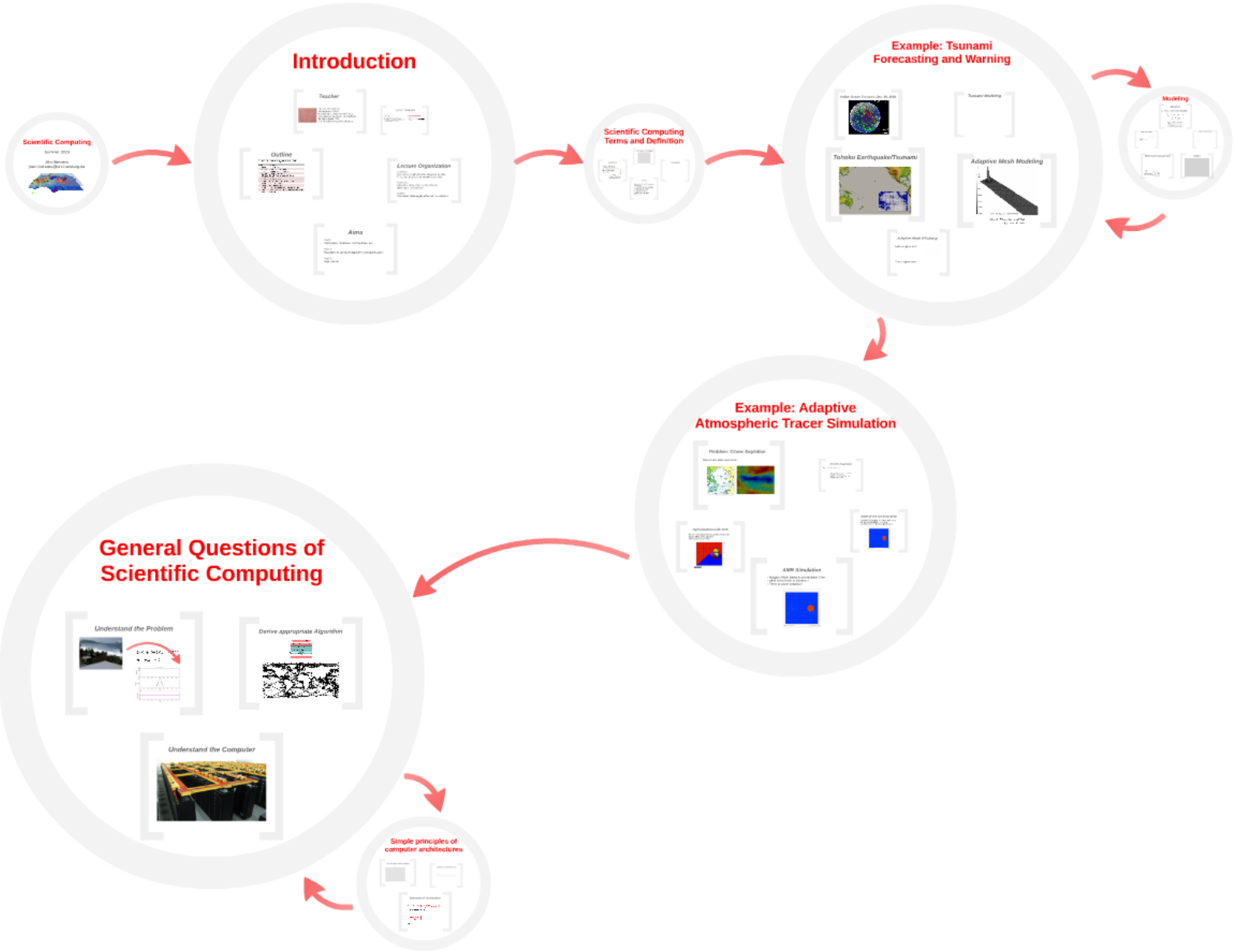
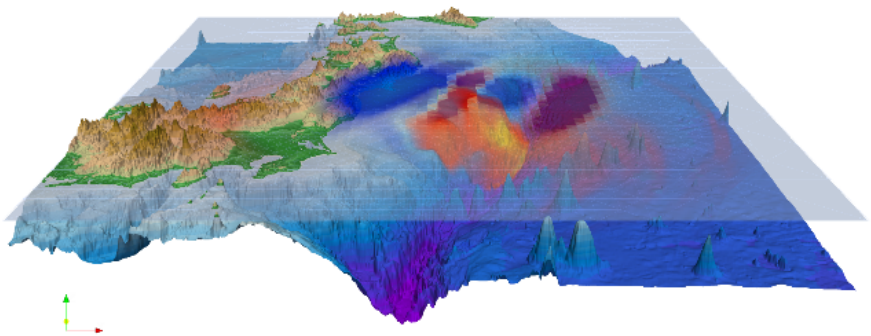

Scientific Computing
Introduction
Teacher
Outline
Lecture Organization
Aims
Scientific Computing Terms and Definition
Example: Tsunami Forecasting and Warning
Tsunami Modeling
Tohoku Earthquake/Tsunami
Adaptive Mesh Modeling
Modeling
Example: Adaptive Atmospheric Tracer Simulation
AMR Simulation
General Questions of Scientific Computing
Understand the Problem
Derive appropriate Algorithm
Understand the Computer
Simple principles of computer architectures

Scientific Computing

Summer 2020

Jörn Behrens
joern.behrens@uni-hamburg.de



Introduction

Teacher

Prof. Dr. Jörn Behrens
Uni Hamburg/ CliSAP
Grindelberg 5, Room 411 (4rd floor)
Bundesstraße 55, Room 120 (1st floor)
Tel. (040) 42838 7734
mail joern.behrens@uni-hamburg.de

Outline

Scientific Computing Summer 2020

Date	Lectures
21.04.20	Introduction
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05.05.20	Performance Assessment
12.05.20	Programming Models
19.05.20	Generic Parallelization Strategies
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50% weight for final mark

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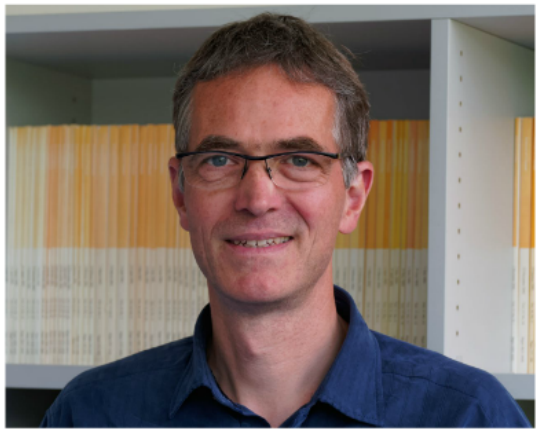
Part1:
Computers, Hardware, Architectures, etc.

Part 2:
Examples of standard algorithms and optimization

Part 3:
Applications

Teacher



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Teacher's Background

Short CV

since 2009 Prof. @ Uni Hamburg, KlimaCampus
2006-2009 Head of Tsunami Group @ AWI, Adjunct Prof. @ Uni Bremen
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1998-2006 Assistant Prof. and Lecturer @ TUM, Scientific Computing
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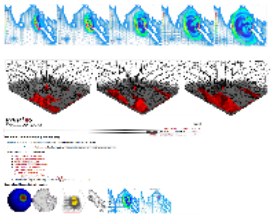
Research Interests

Adaptive Tsunami Modeling

Adaptive Atmospheric Modeling

Grid Generation



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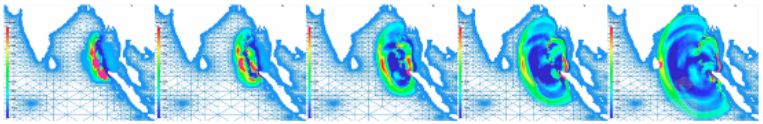

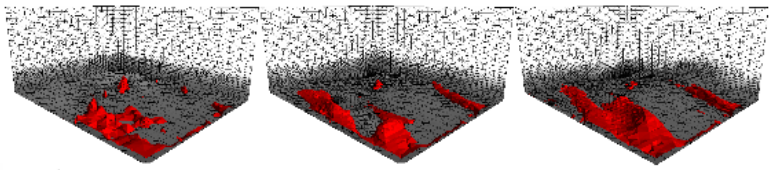

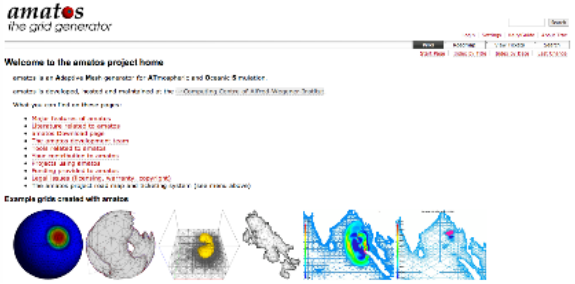

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Scientific Computing Terms and Definition

3 Columns of Knowledge

Definition

Def: Scientific Computing
"The field of study concerned with constructing mathematical models and quantitative analysis techniques and using computers to analyze and solve scientific problems" (University of Cambridge)

"The use of computing to solve scientific and engineering problems, especially by means of simulation, or the construction of mathematical models of physical, chemical or biological processes." (Wiktionary)

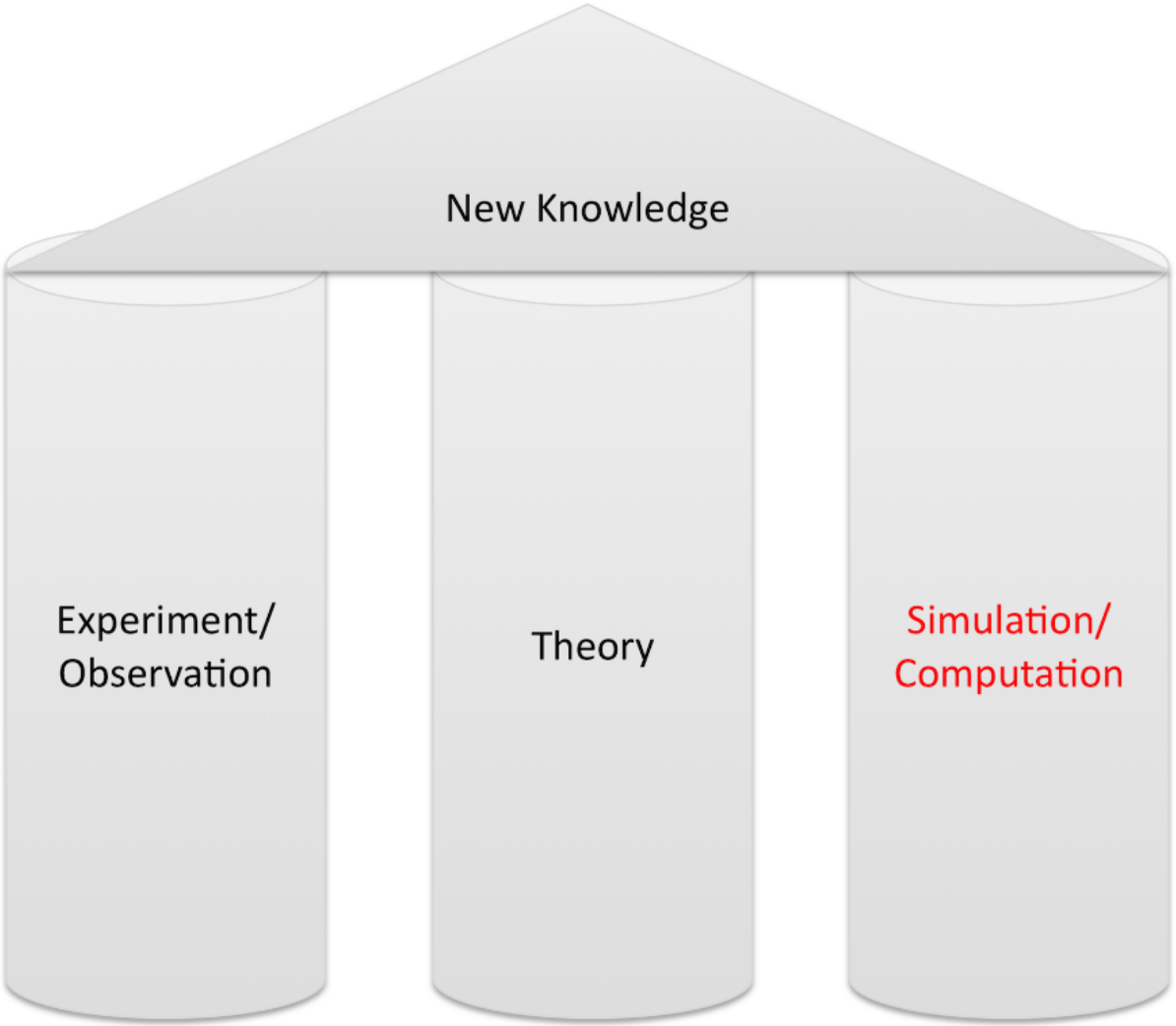
- Computing
- Mathematical Model
- Scientific method

Schematic

Terms

- Mathematical Model Development
- Discretization
- Numerical Solution and Algorithm
- High Performance Computer
- Computing Architecture
- Performance Metrics
- Verification and Validation
- Visualization

3 Columns of Knowledge



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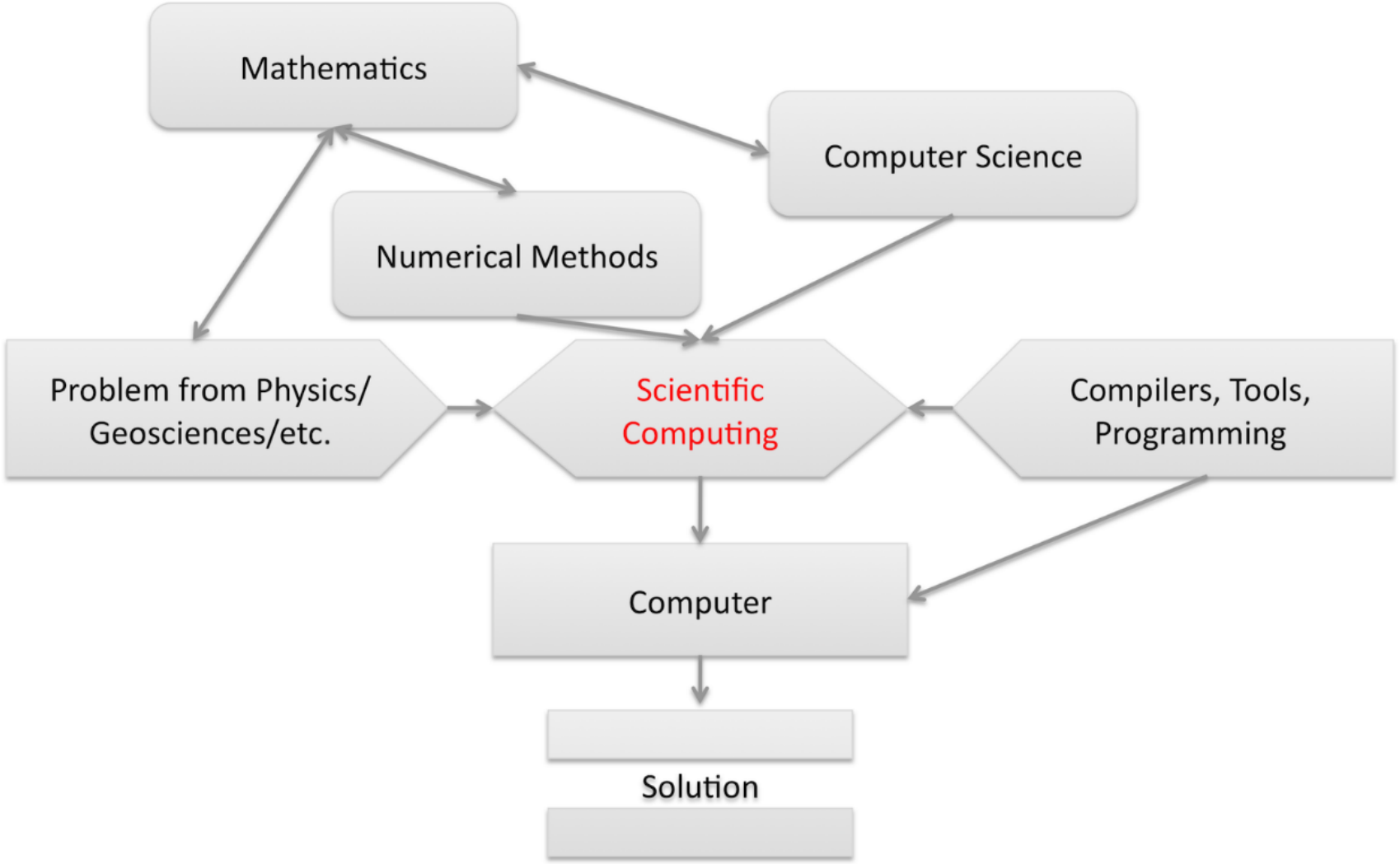
Mathematics
Computer Science
Numerical Methods
Problem from Physics/
Geosciences/etc.
Scientific
Computing
Compilers, Tools,
Programming
Computer
Solution

Terms

- Mathematical Model Development
- Discretization
- Numerical Solution and Algorithm
- High Performance Computer
- Computing Architecture
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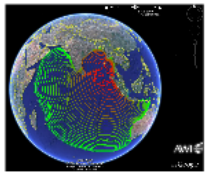
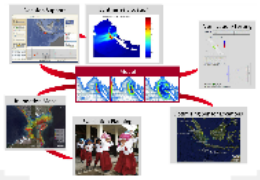
- Visualization

Example: Tsunami Forecasting and Warning

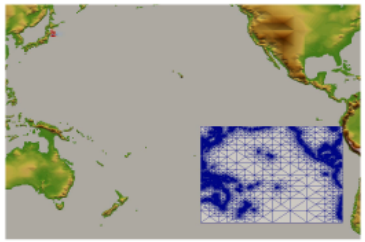
Indian Ocean Tsunami, Dec. 26, 2004



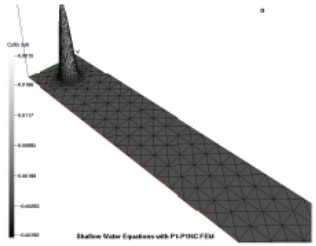
Tsunami Modeling



Tohoku Earthquake/Tsunami



Adaptive Mesh Modeling



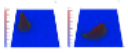
refine if $\nabla h|_\tau > \theta_{\text{ref}} \max(\nabla h|_\tau)$

θ_{ref} threshold value

Adaptive Mesh Efficiency

DOFs for given error:

Time for given error:



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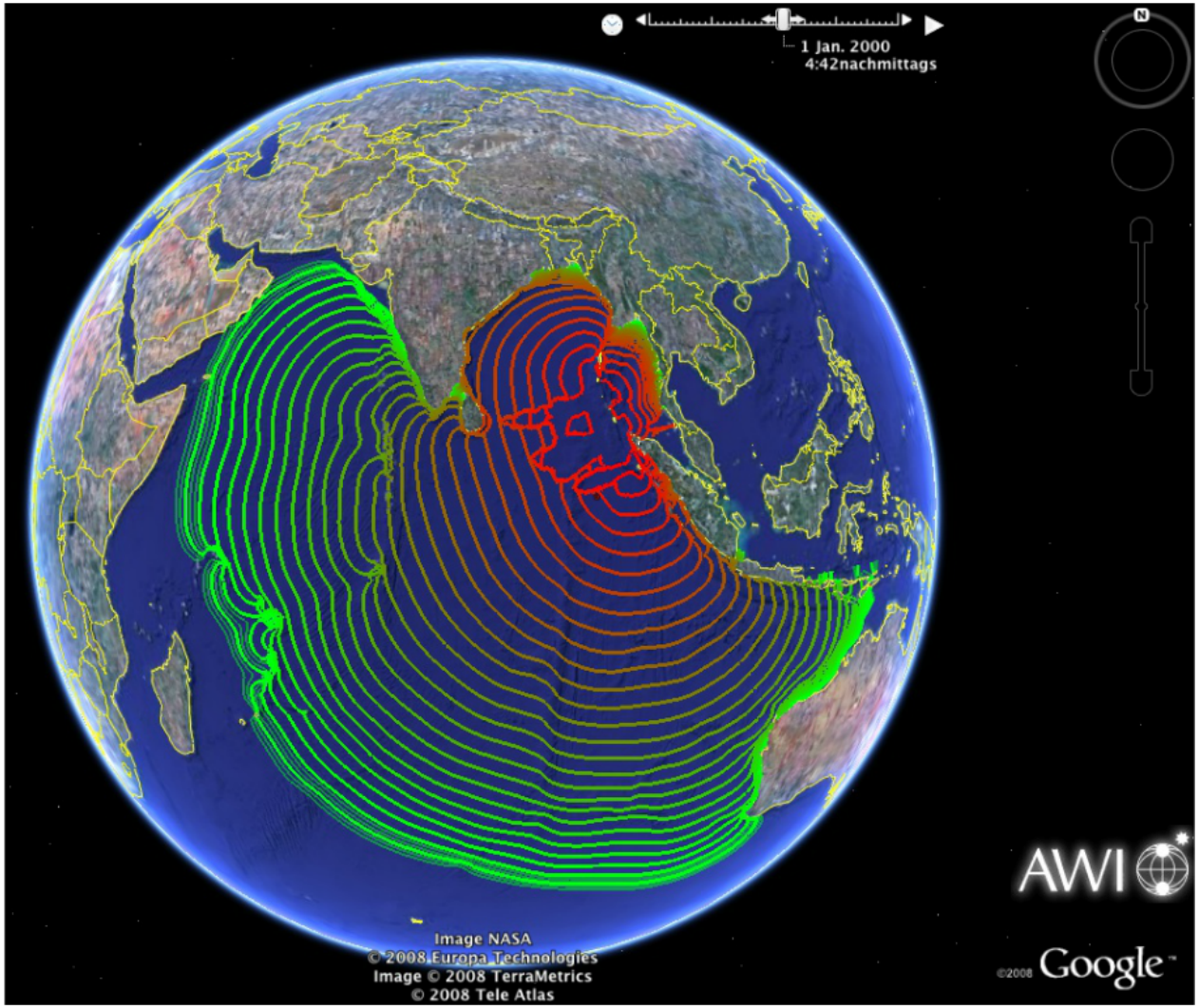
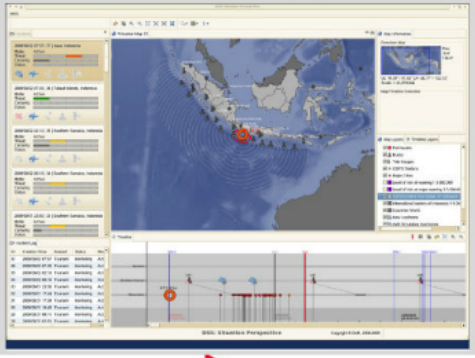


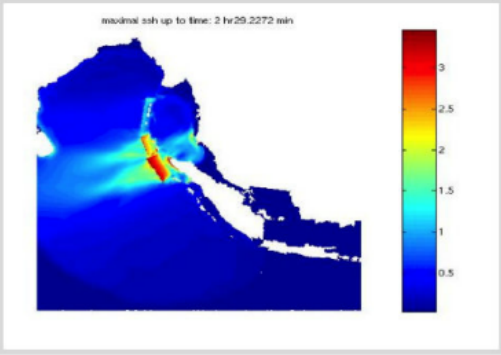
Inundation in Banda Aceh

Tsunami Modeling

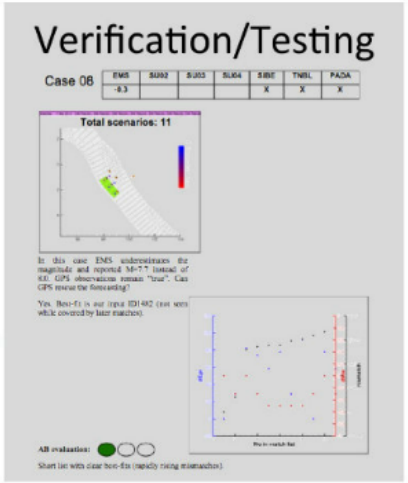
Decision Support



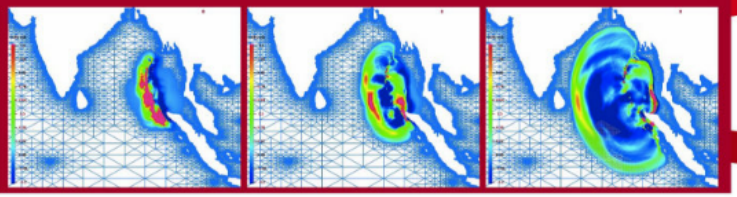
Synthesize Situation



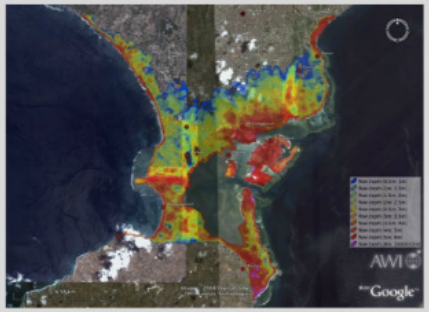
Verification/Testing



Model



Inundation Maps



Evacuation Planning

Optimizing Sensor Locations

Modeling

Equations

Non-linear shallow water equations:

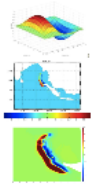
$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \cdot \nabla)\mathbf{v} + g\nabla\eta = R,$$
$$\frac{\partial \eta}{\partial t} + \nabla \cdot (H\mathbf{v}) = 0.$$

$R = -f\mathbf{k} \times \mathbf{v} - rH^{-1}\mathbf{v}|\mathbf{v}| + H^{-1}\nabla(K_h H \nabla \mathbf{v})$

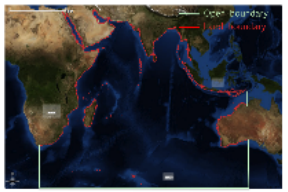
Terms:
- Coriolis
- Bottom friction
- Viscosity (Smagorinsky approach)

Initial Conditions

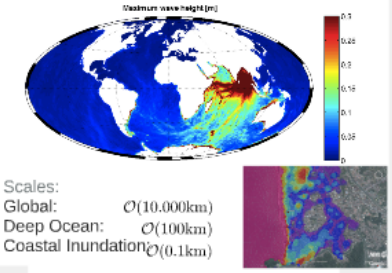
- Simplified
- Okada Plate Model
- Complex



Boundary Conditions



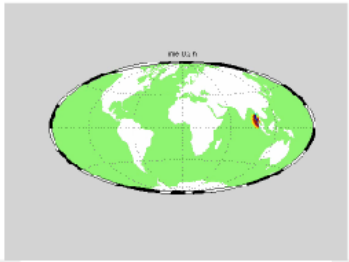
Multi-Scale Characteristic



Scales:

Global:	$\mathcal{O}(10.000\text{km})$
Deep Ocean:	$\mathcal{O}(100\text{km})$
Coastal Inundation:	$\mathcal{O}(0.1\text{km})$

Extent



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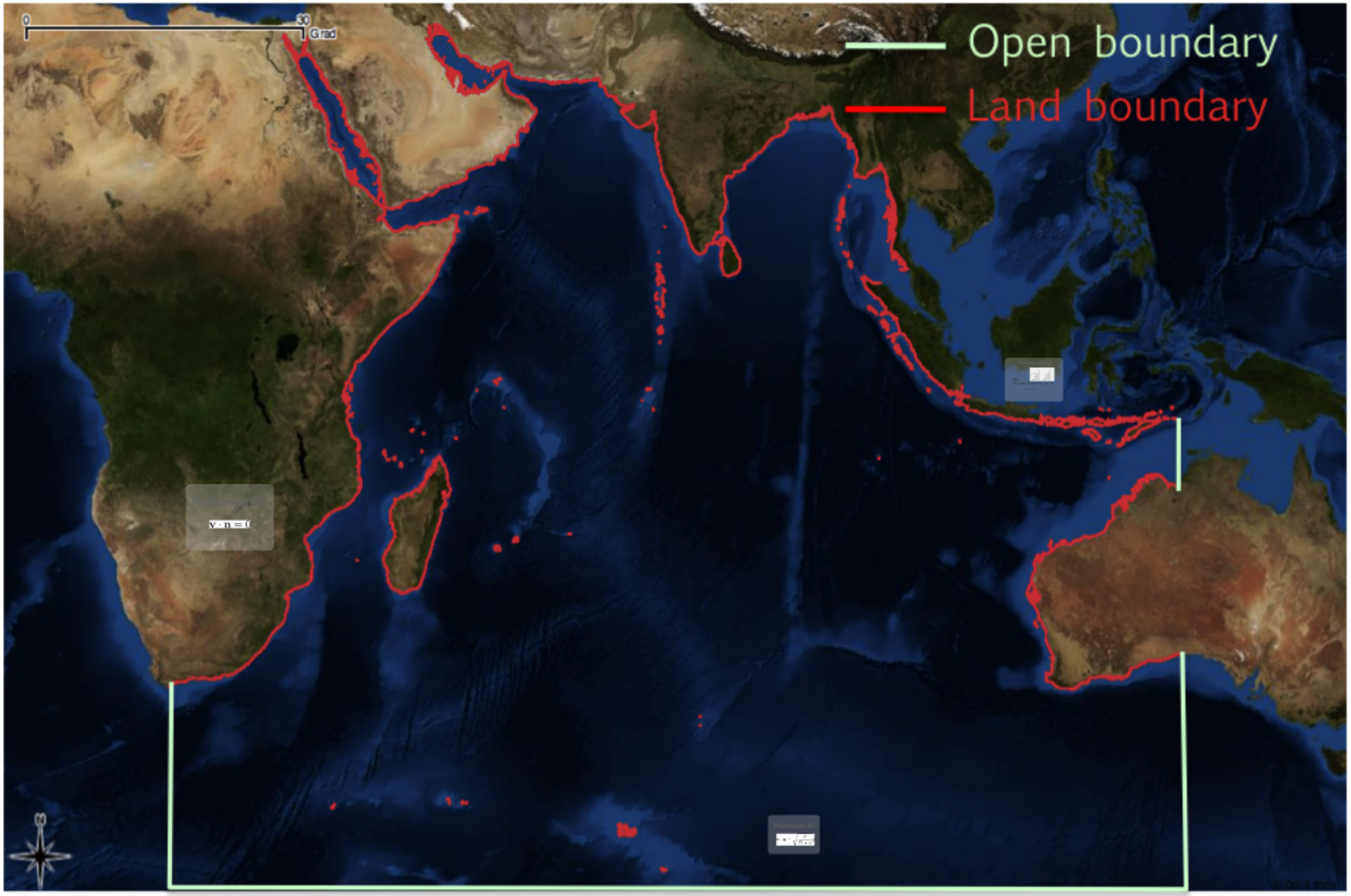
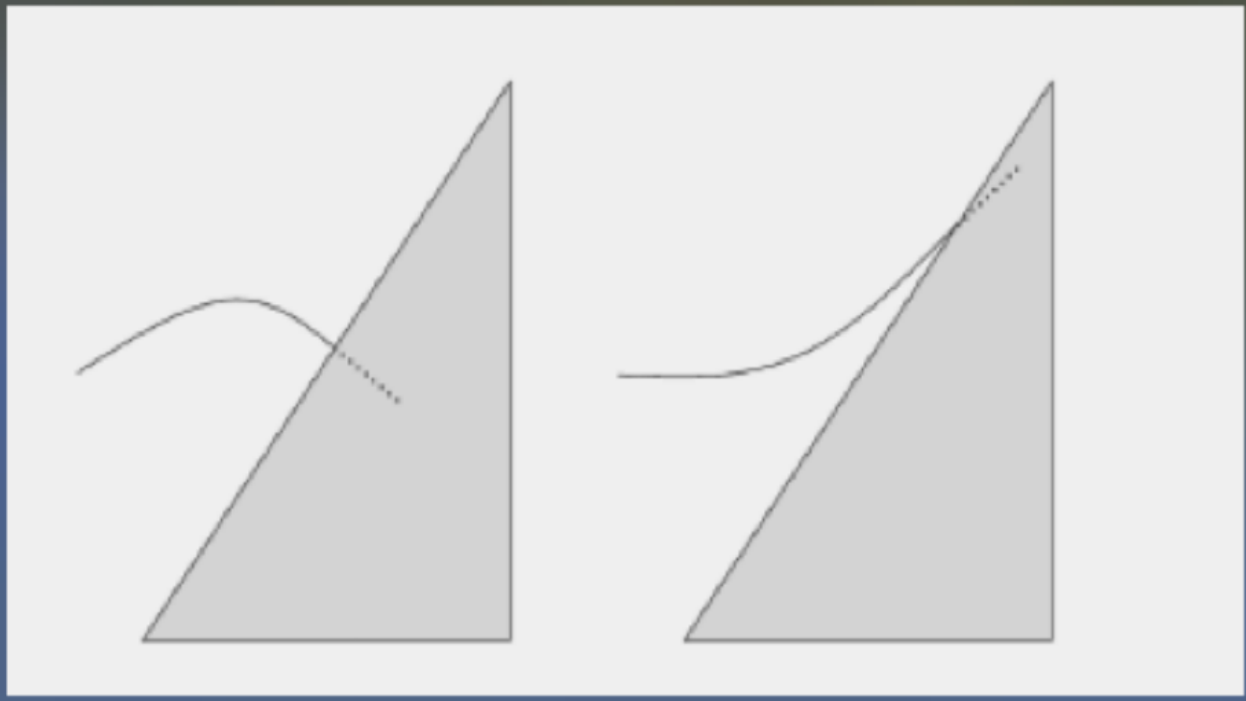


Reflecting BC

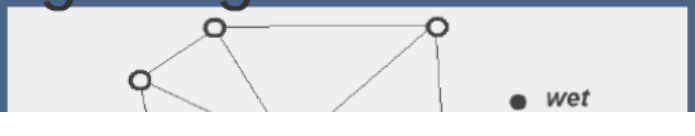
$$\mathbf{v} \cdot \mathbf{n} = 0$$

Inundation BC



Idea:
Extrapolate from dry to wet

On triangular grids:



Radiation BC

$$\mathbf{v} \cdot \mathbf{n} = \sqrt{\frac{g}{H+\eta}}\eta$$

Initial Conditions

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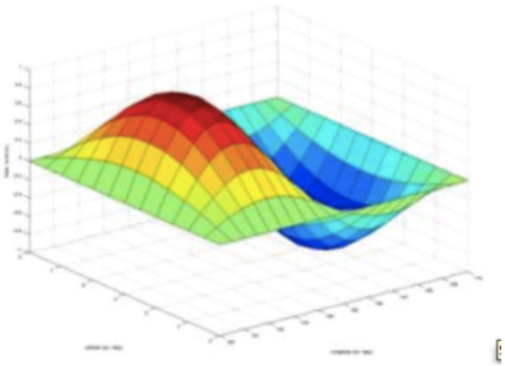

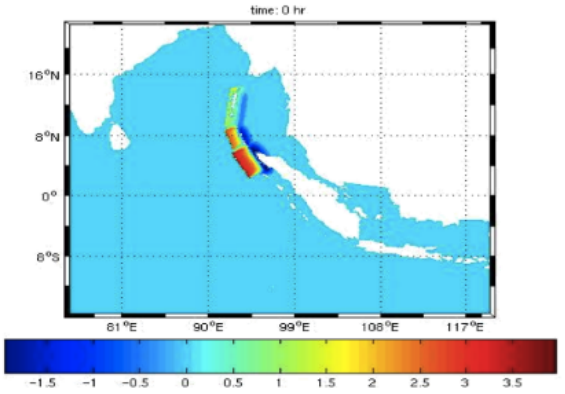

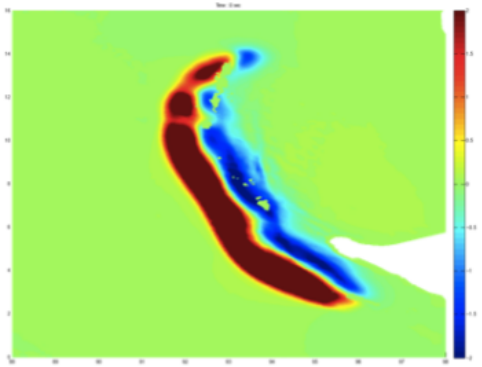

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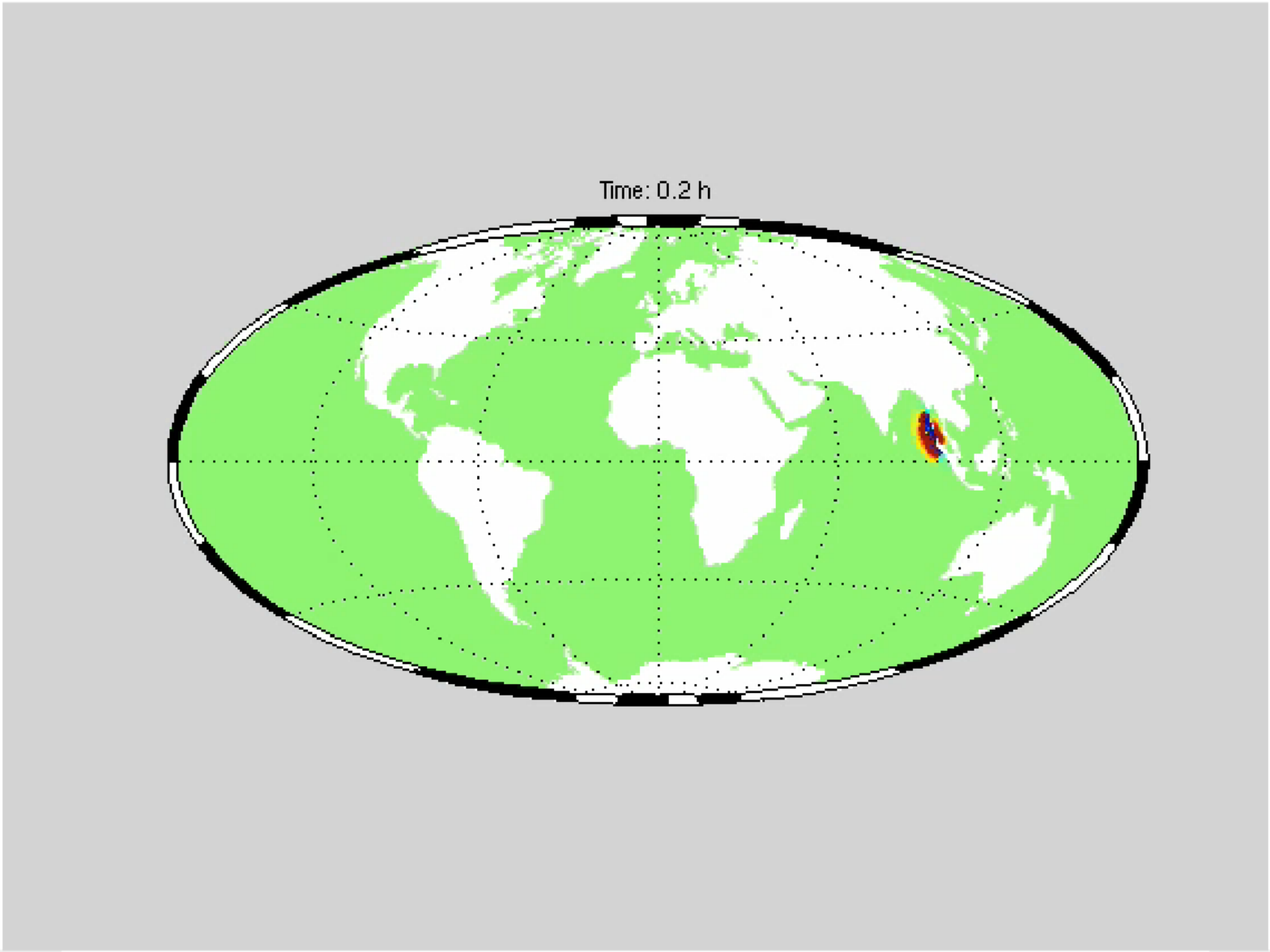

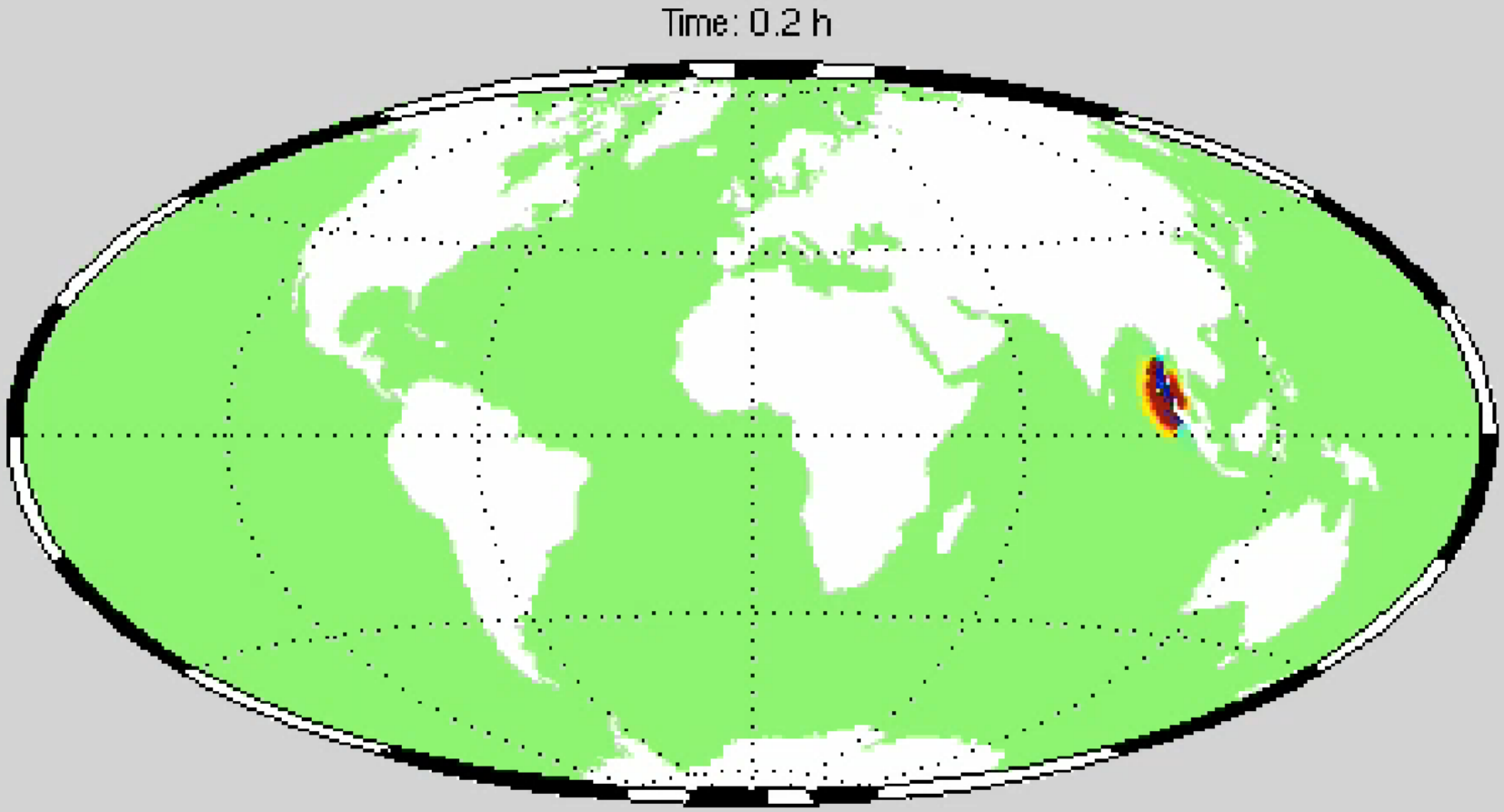
Time: 0.2 h

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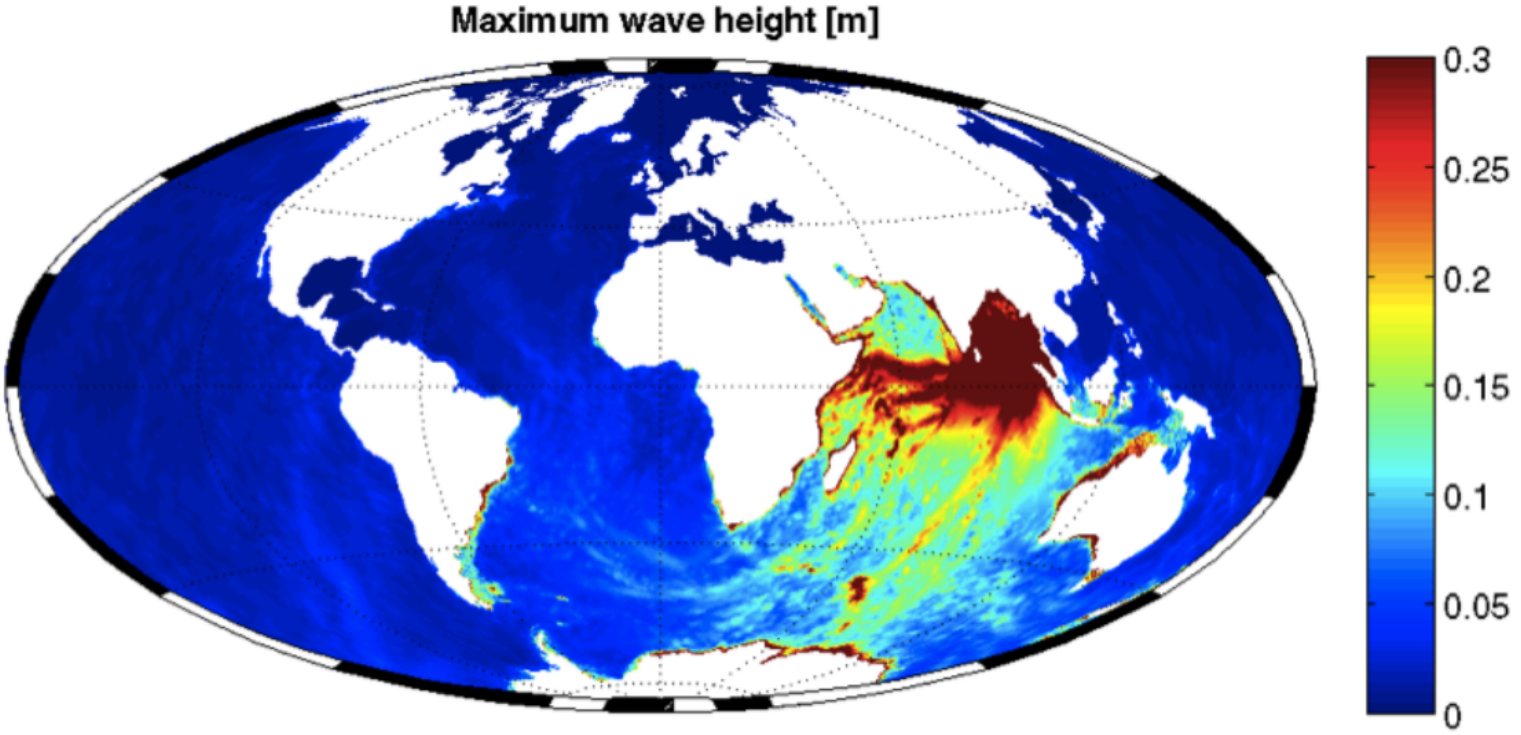

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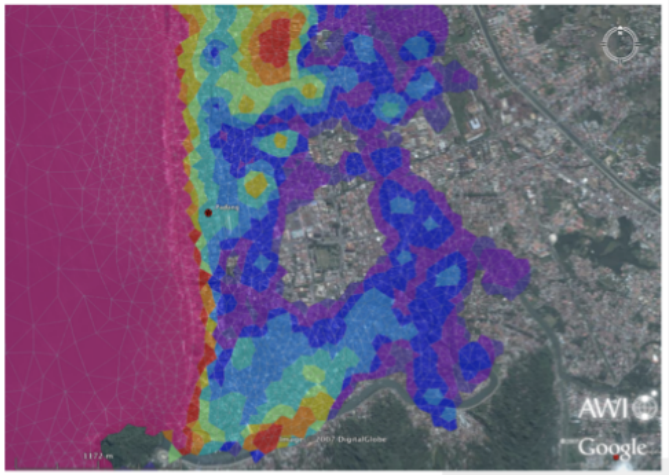
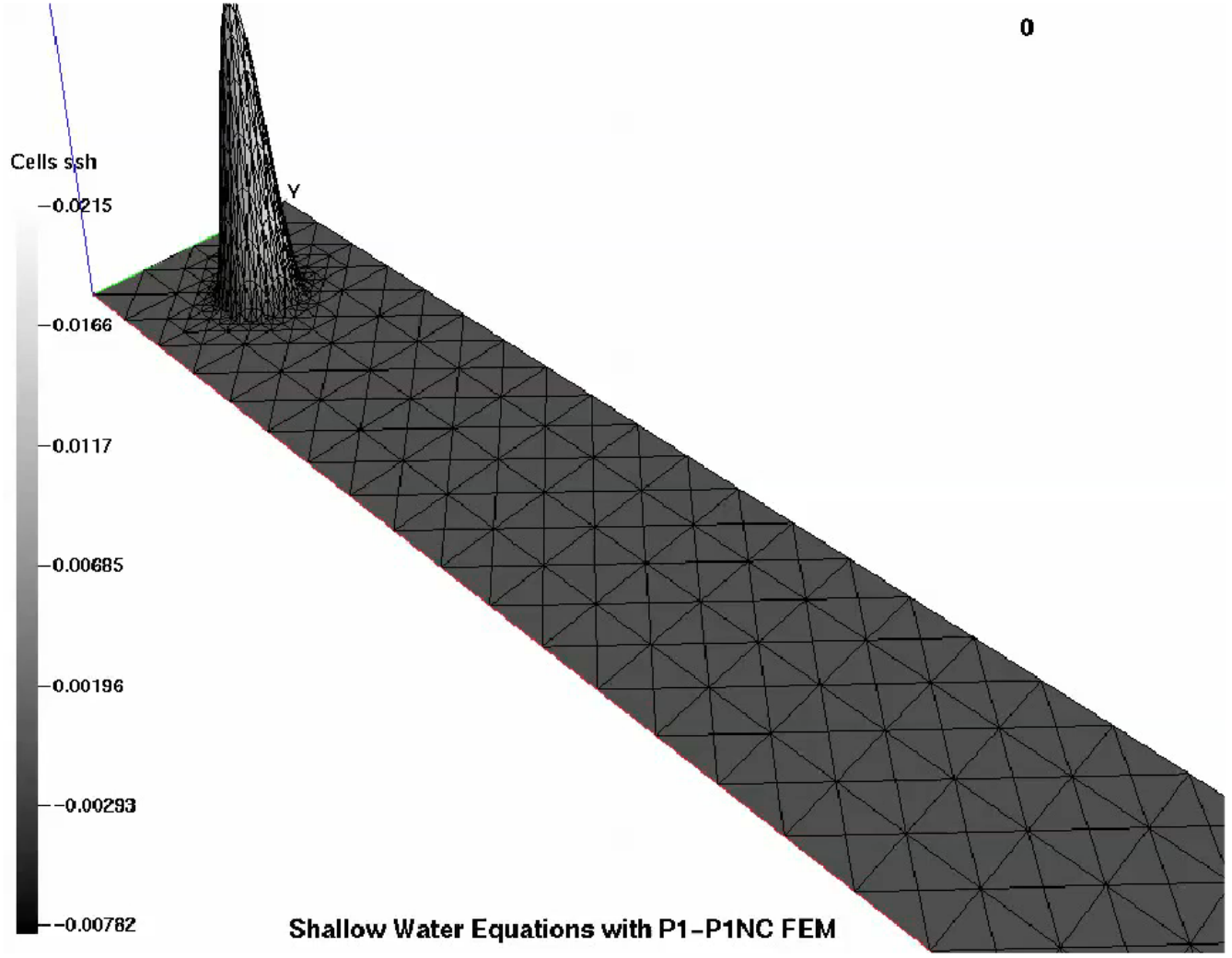


Adaptive Mesh Modeling



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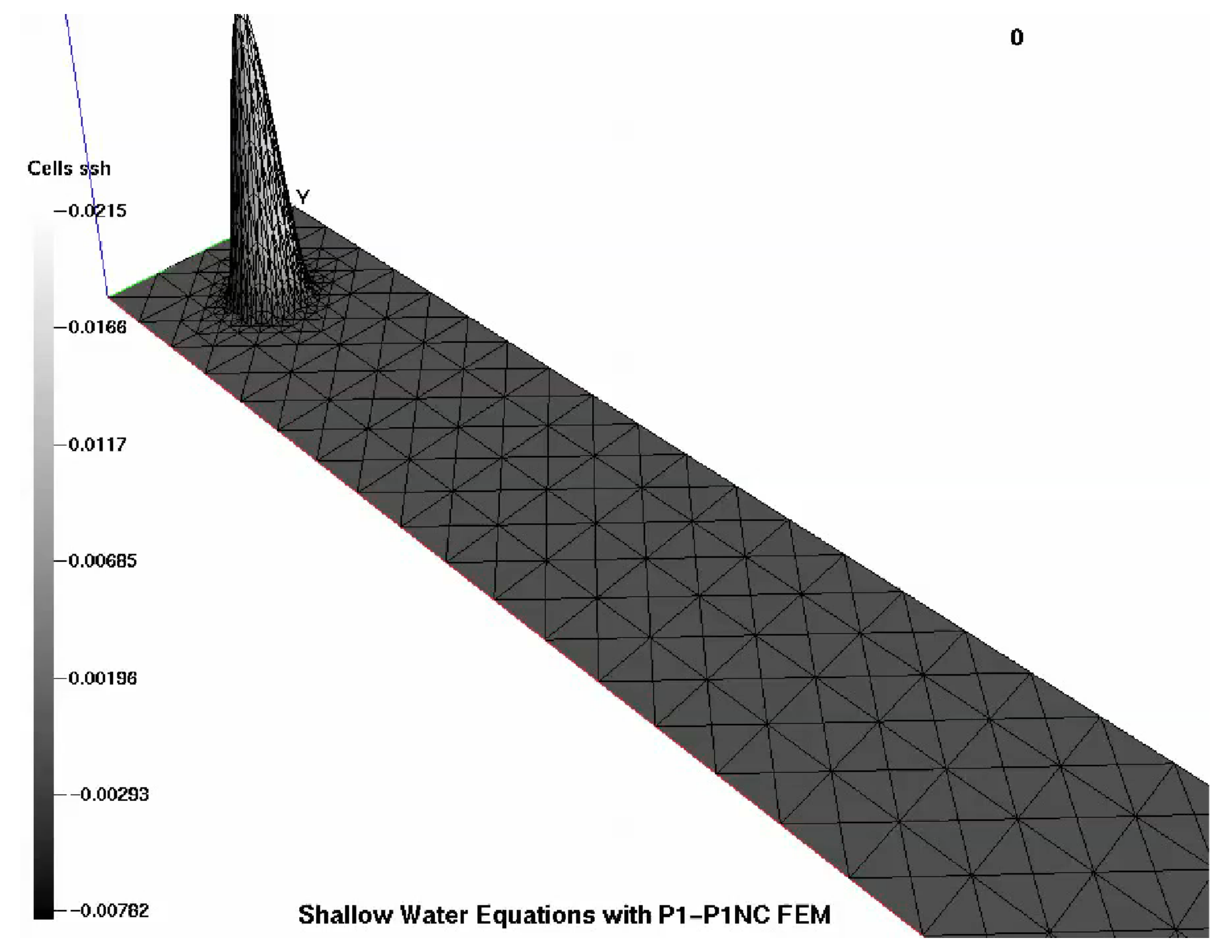
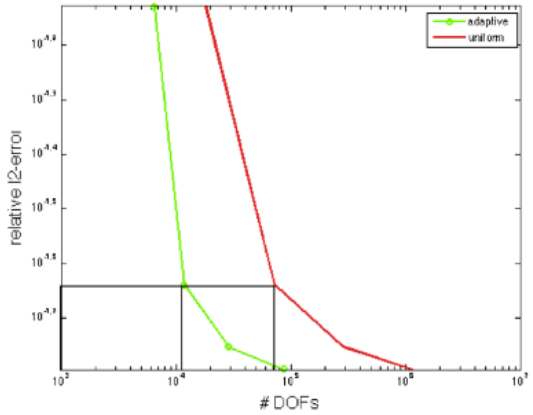

0
Cells ssh
Y
−0.0215
−0.0166
−0.0117
−0.00685
−0.00196
−0.00293
−0.00762
Shallow Water Equations with P1−P1NC FEM

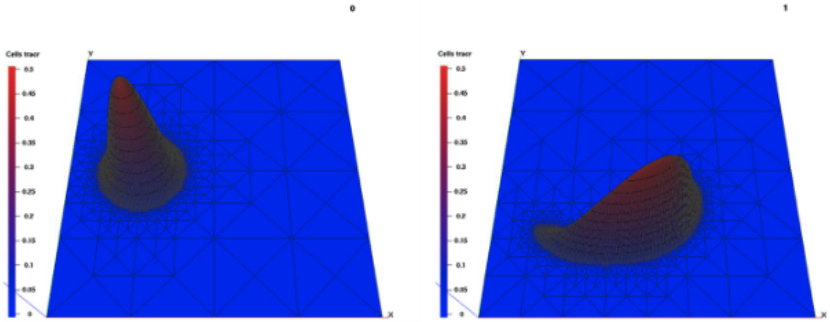
Adaptive Mesh Efficiency

DOFs for given error:

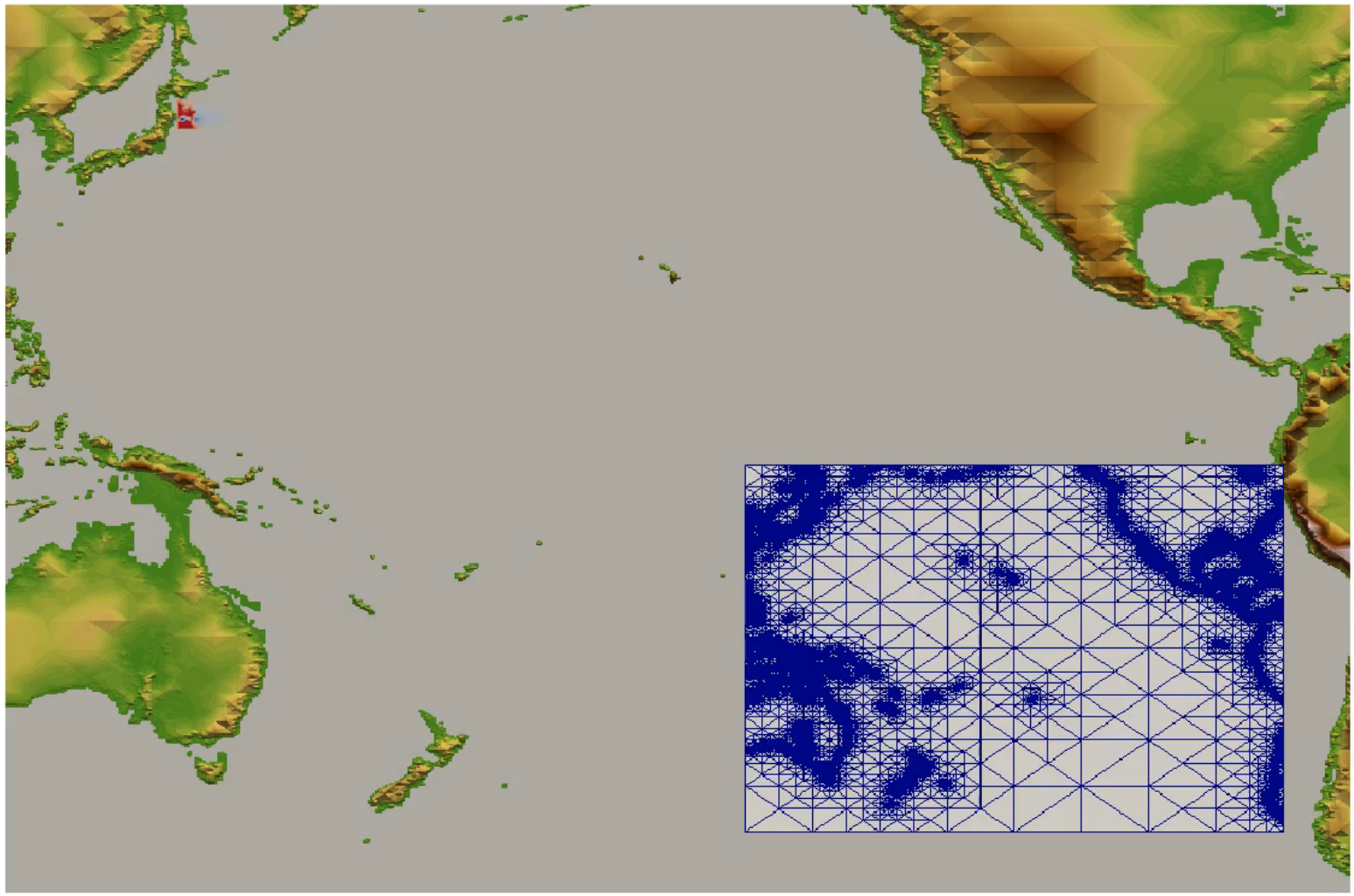


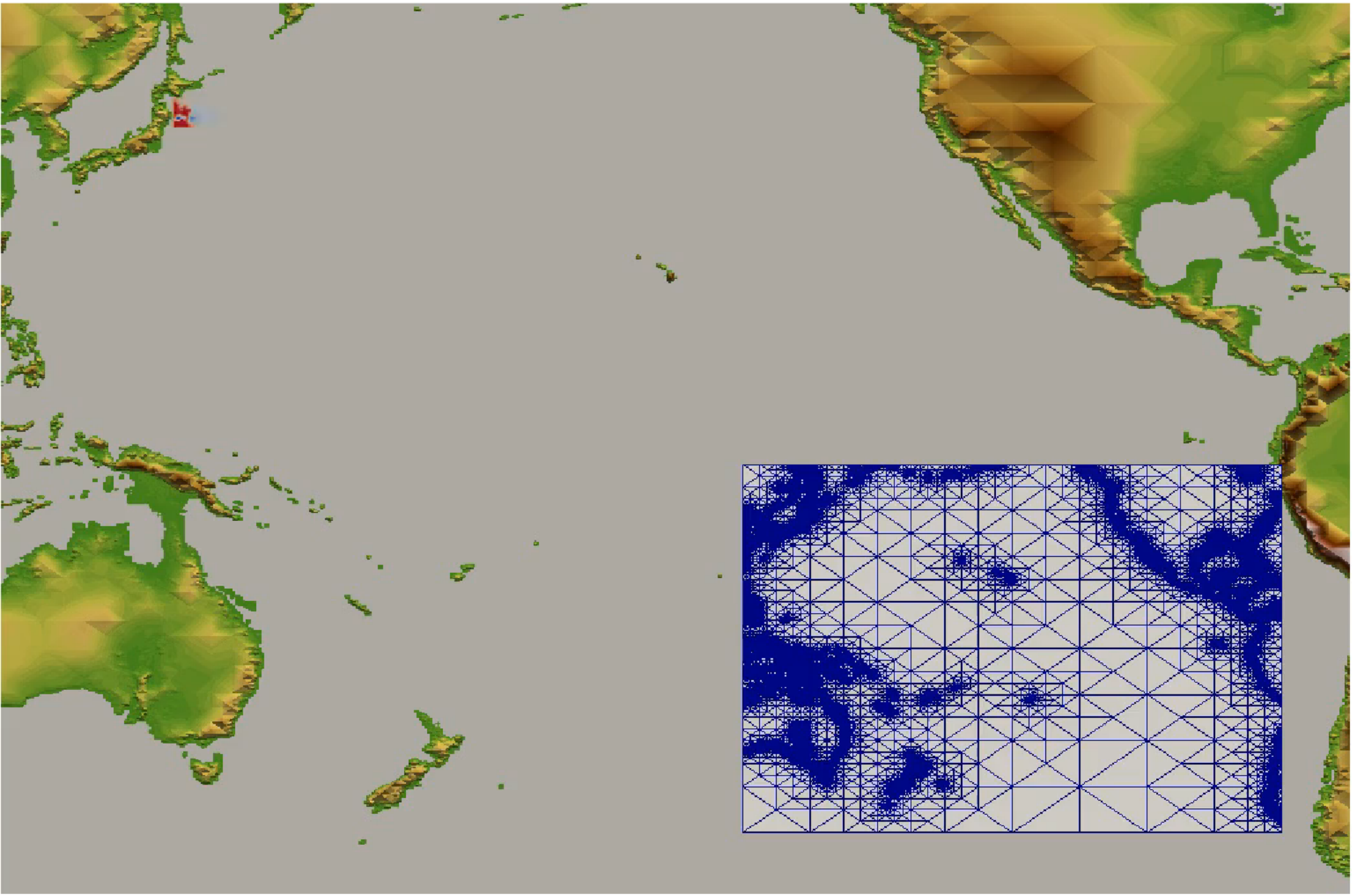
Time for given error:

Error:	10^{-7}	
Adaptive:	6.1 s	(5k nodes)
Uniform:	230.5 s	(66k nodes)



Tohoku Earthquake/Tsunami

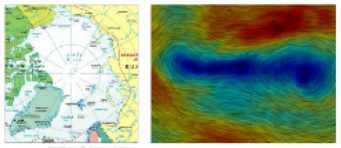




Example: Adaptive Atmospheric Tracer Simulation

Problem: Ozone Depletion

Does it take place over Arctic?



Situation Description

Does it take place over Arctic?

- Physics works the same as Antarctic
- No ozone hole observed
- But small areas of ozone depletion
- Dynamics quite different

State-of-the-Art Simulation

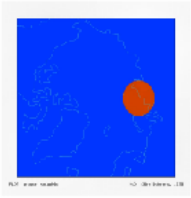
- Resolution: 50 km (High for climate applications)
- Wind also given with 50 km resolution
- Simplification: 2D (only stratospheric layer)

Optimization with SFC

- Domain decomposition for parallel computation
- Space-filling curve approach
- Dynamic load balancing

AMR Simulation

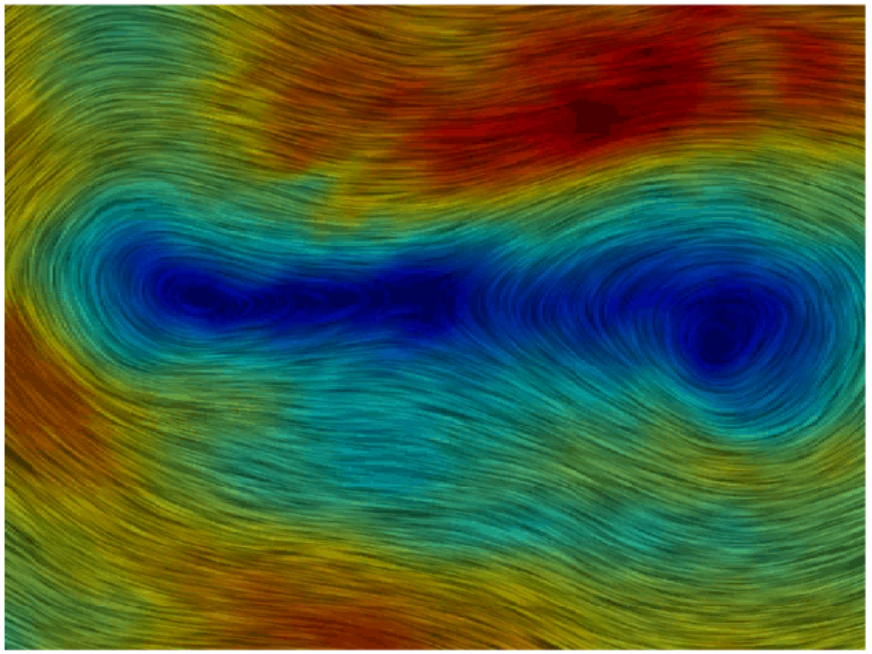
- Adaptive Mesh allows local resolution 5 km
- Wind shear leads to filaments!
- There is ozone depletion!

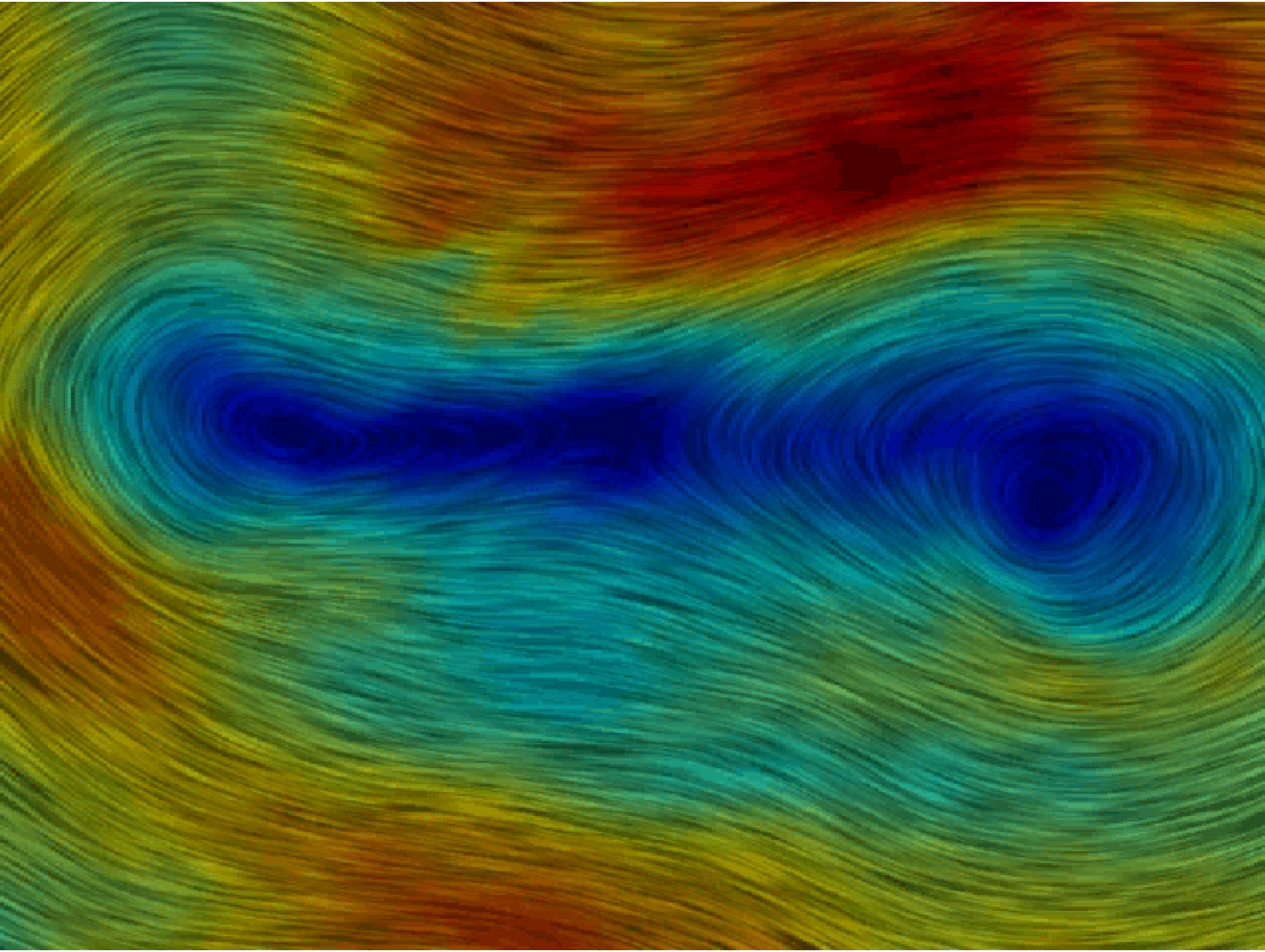


Problem: Ozone Depletion

Does it take place over Arctic?

http://www.lib.utexas.edu/maps





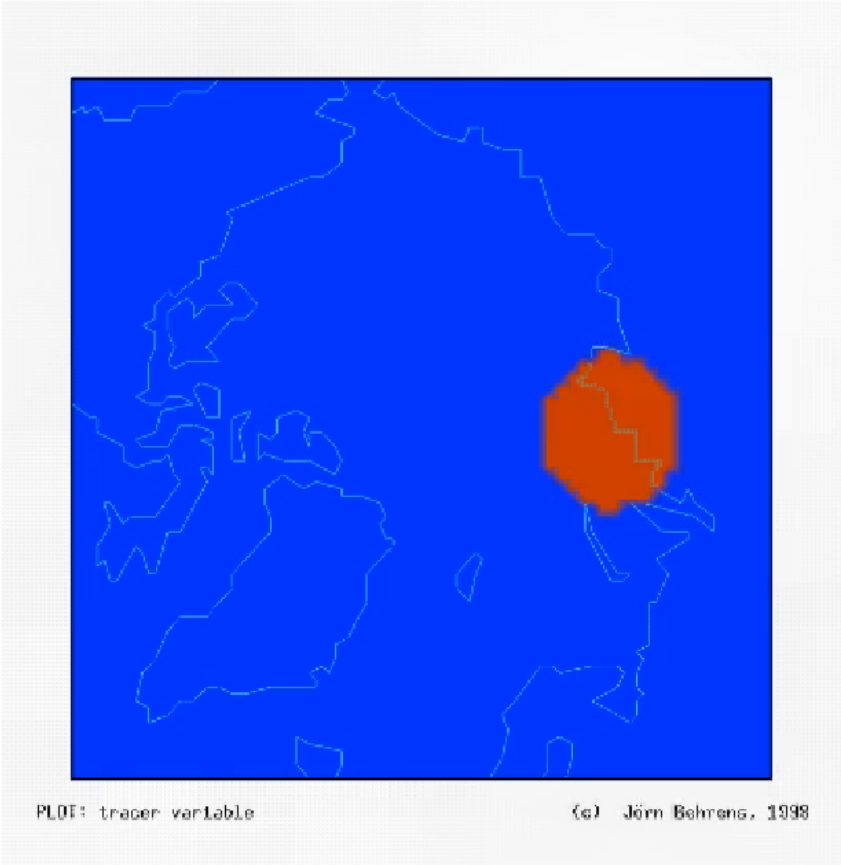
Situation Description

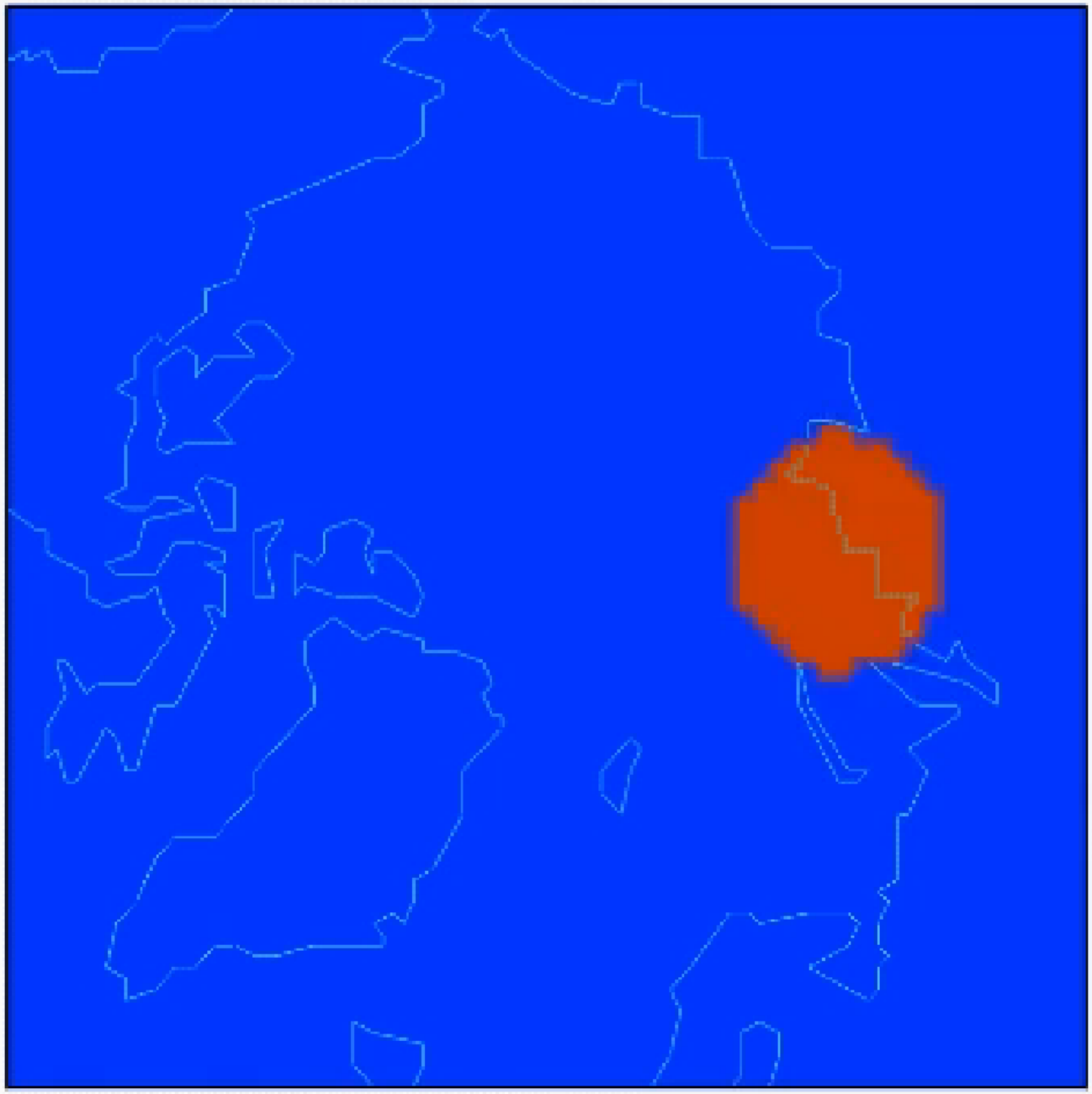
Does it take place over Arctic?

- Physics works the same as Antarctic
- No ozone hole observed
- But small areas of ozone depletion
- Dynamics quite different

State-of-the-Art Simulation

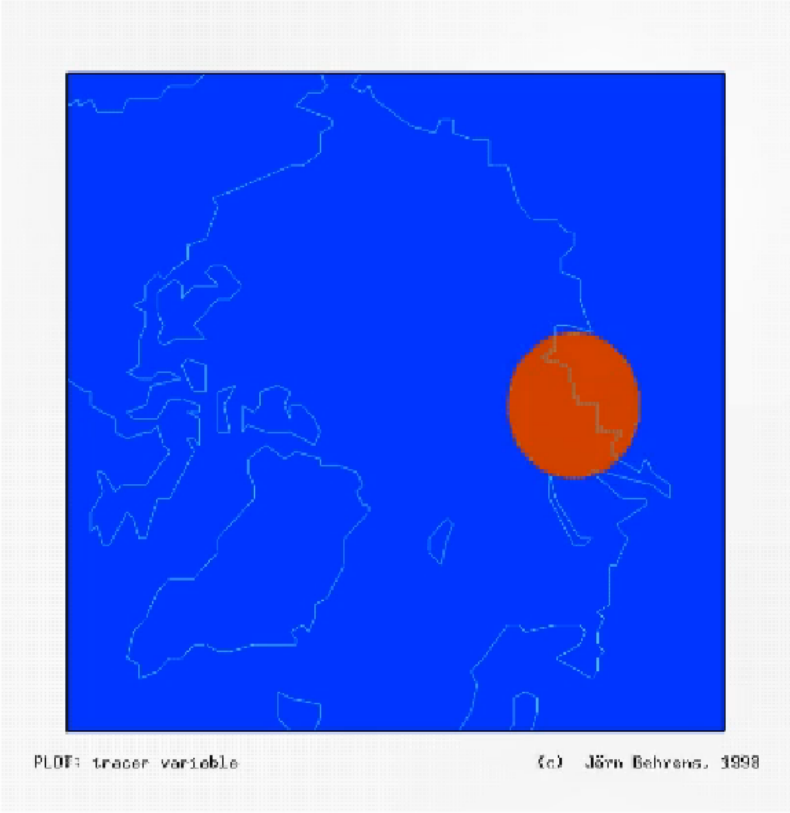
- Resolution: 50 km (high for climate applications)
- Wind also given with 50 km resolution
- Simplification: 2D (only stratospheric layer)

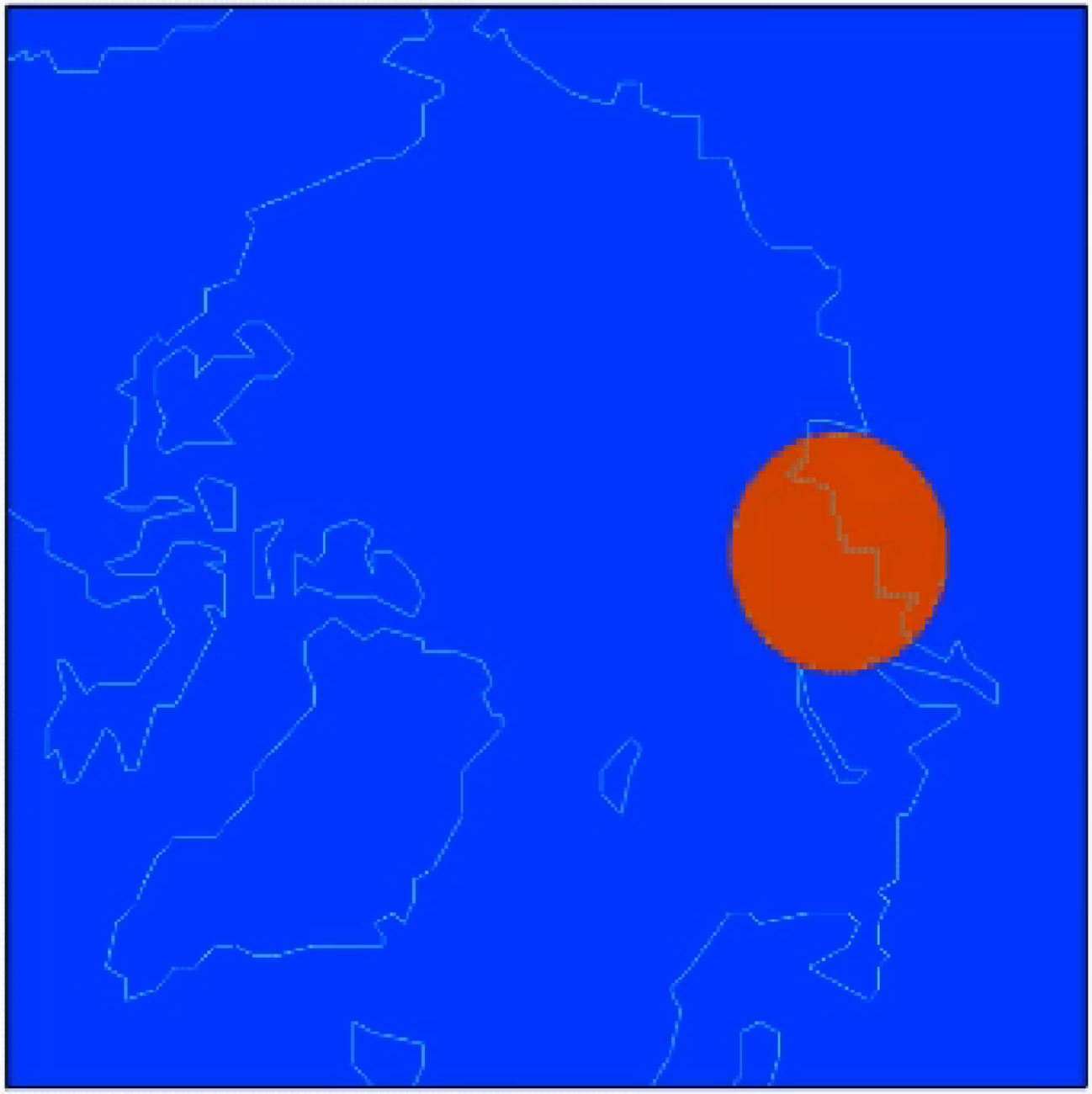



PLOT: tracer variable
(c) Jörn Behrens, 1998

AMR Simulation

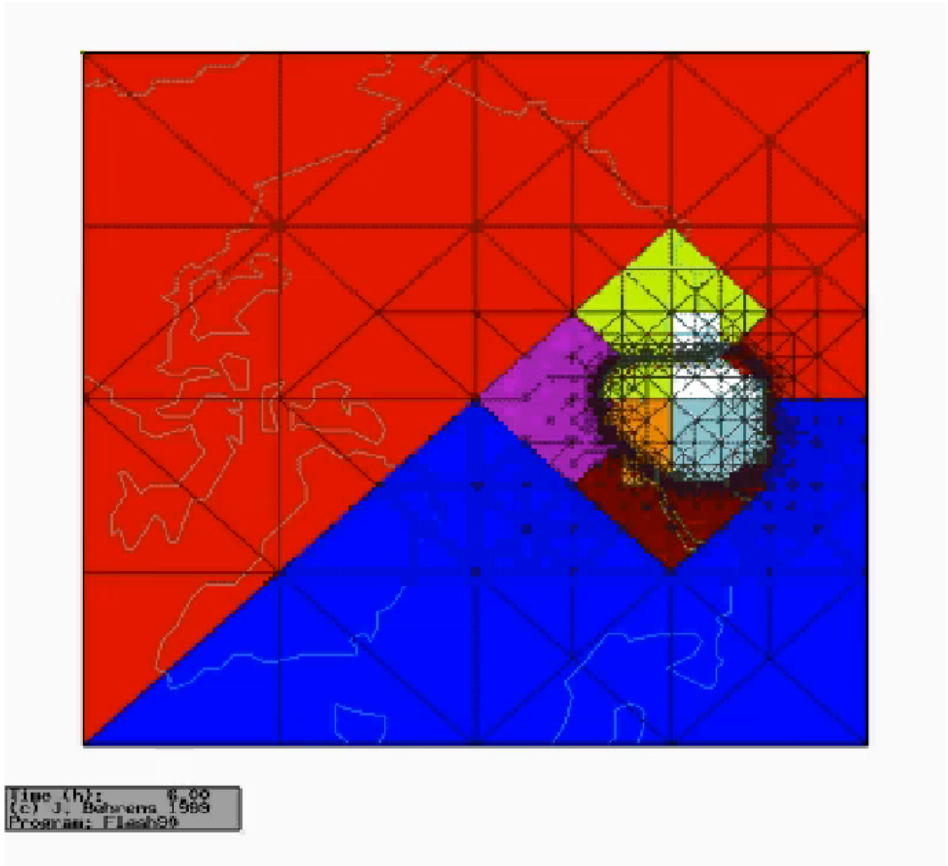
- Adaptive Mesh allows local resolution 5 km
- Wind shear leads to filaments!
- There is ozone depletion!

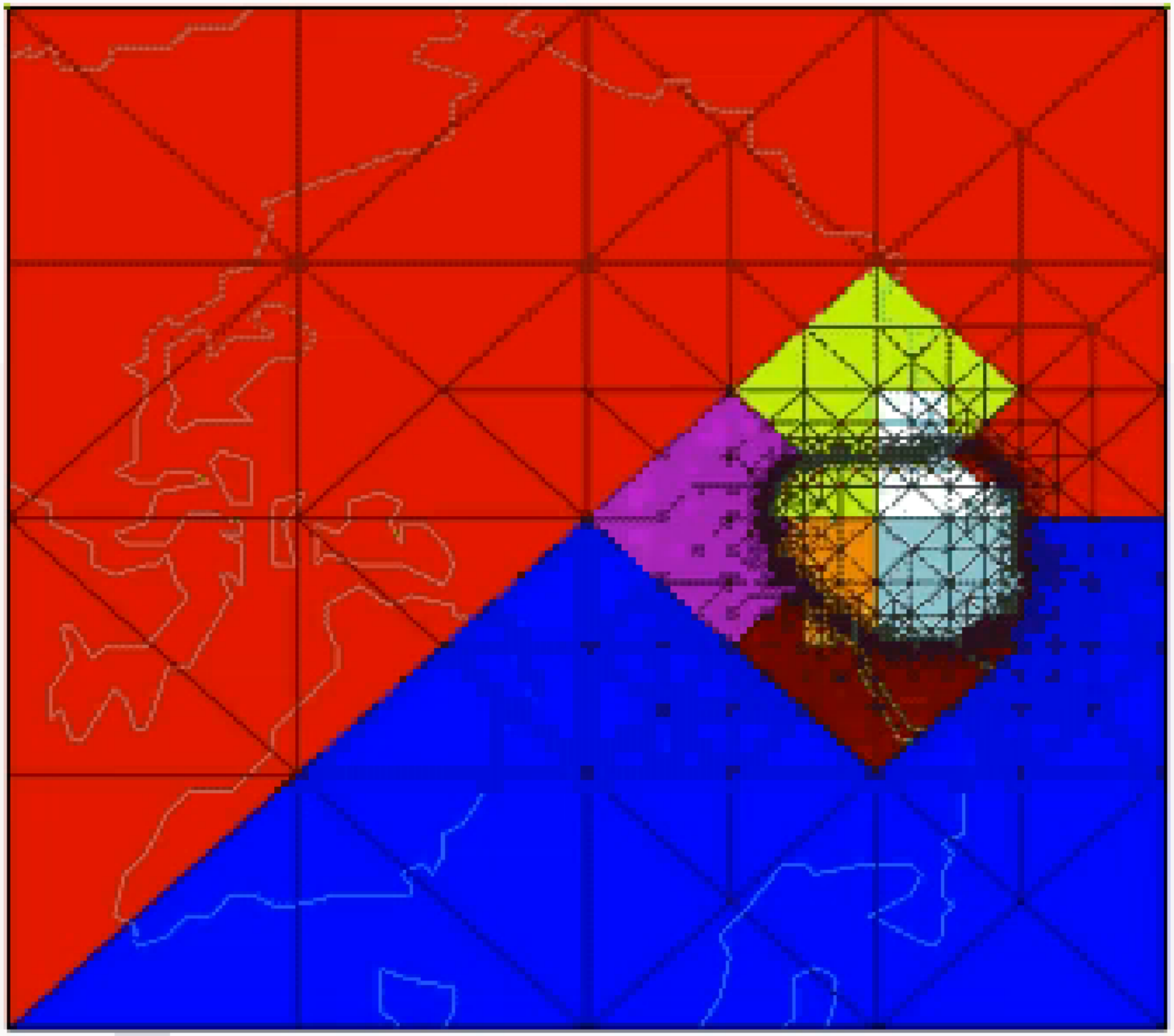



PLOT: tracer variable
(c) Jörn Behrens, 1998

Optimization with SFC

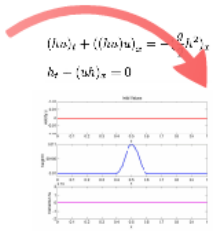
- Domain decomposition for parallel computation
- Space-filling curve approach
- Dynamic load balancing



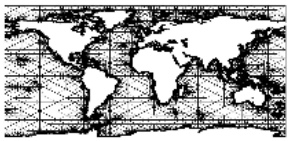

Time (h): 6.00
(c) J. Bahrenberg 1999
Program: Flash30

General Questions of Scientific Computing

Understand the Problem



Derive appropriate Algorithm



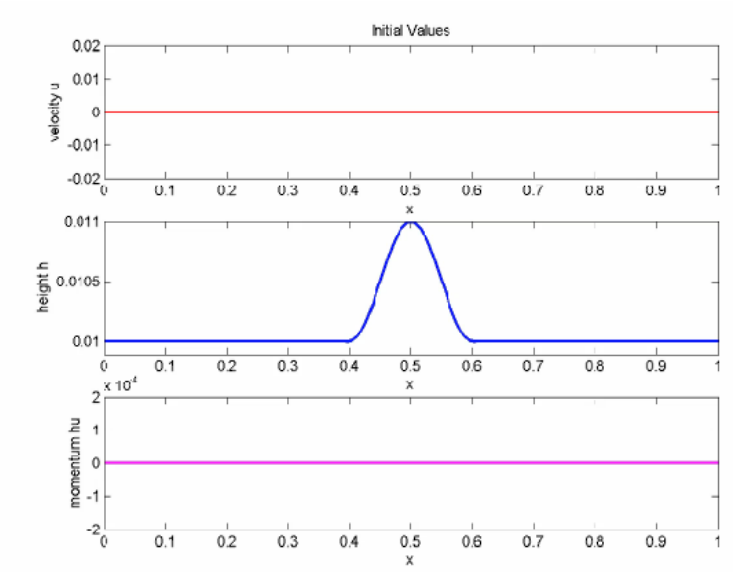
Understand the Computer

Simple principles of computer architectures

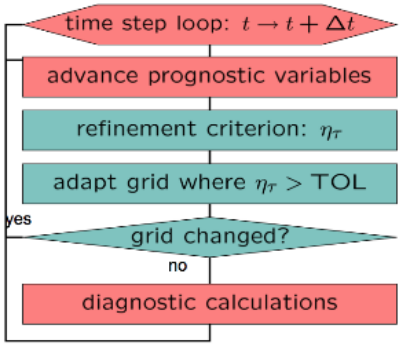
Understand the Problem

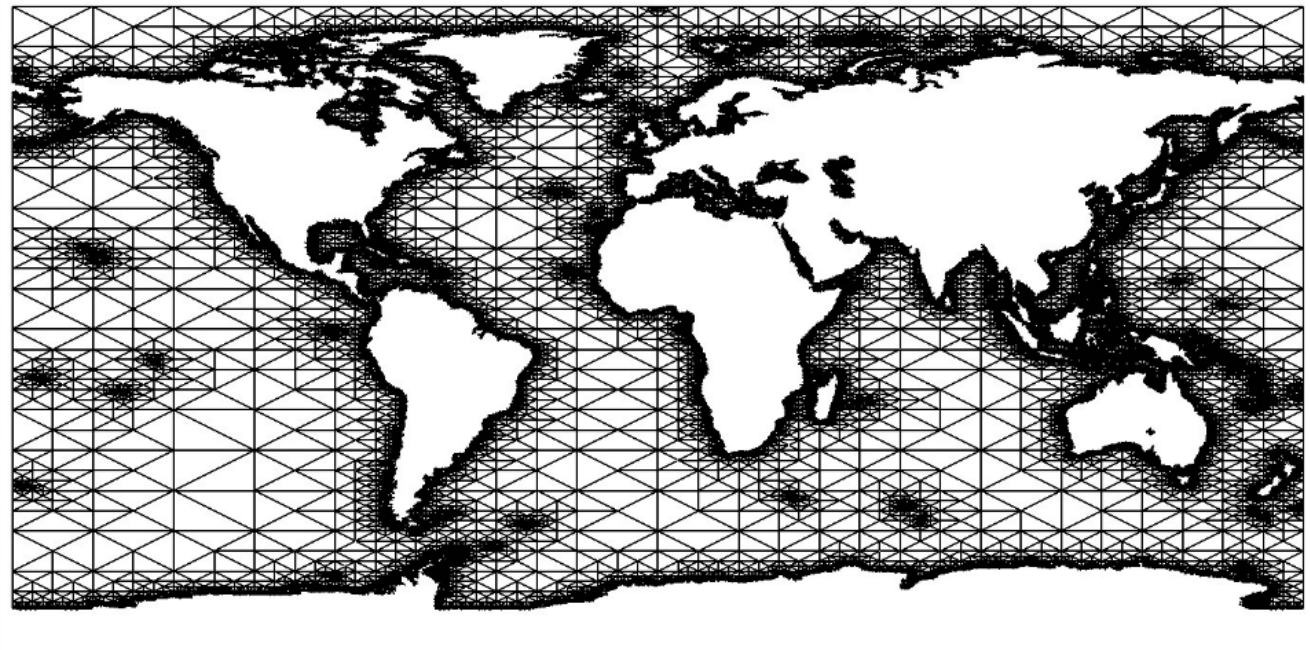
$$(hu)_t + ((hu)u)_x = -\left(\frac{g}{2}h^2\right)_x$$

$$h_t + (uh)_x = 0$$



Derive appropriate Algorithm

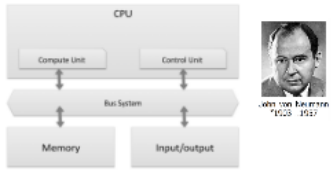




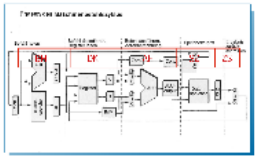
Understand the Computer

Simple principles of computer architectures

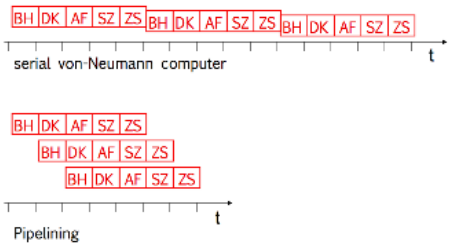
Von Neumann Architecture



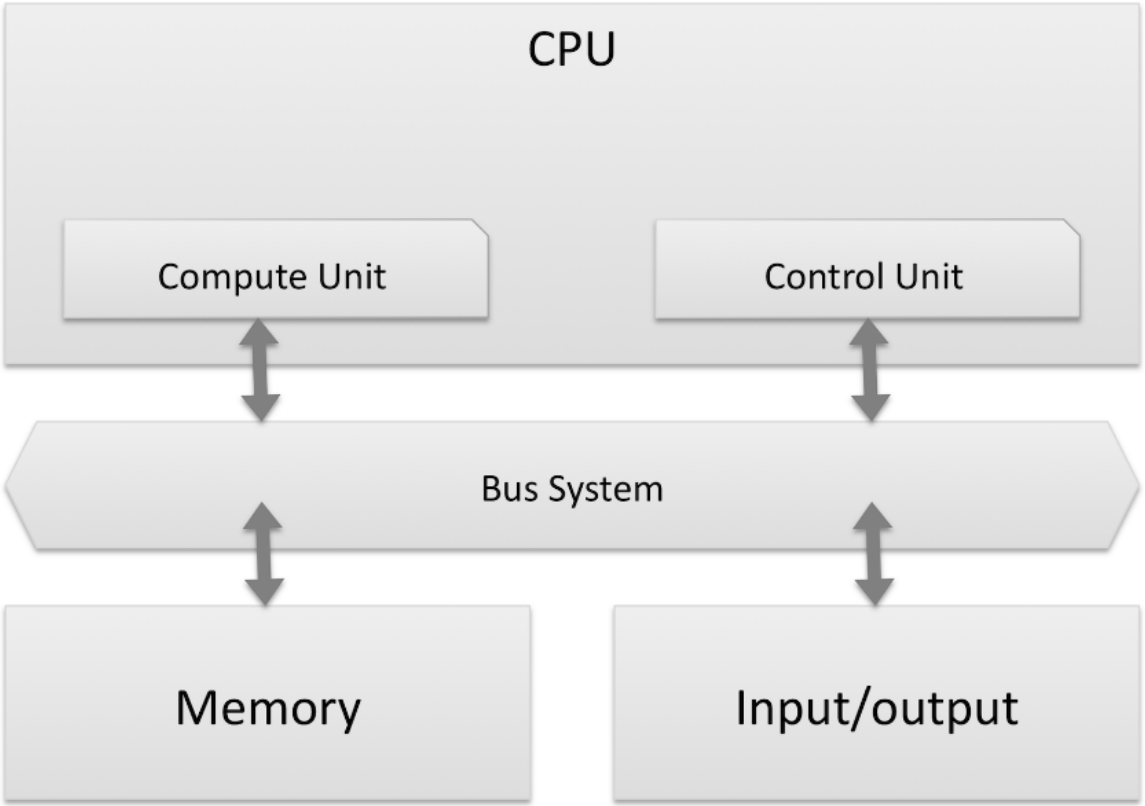
Operation via Instructions



Elements of Acceleration

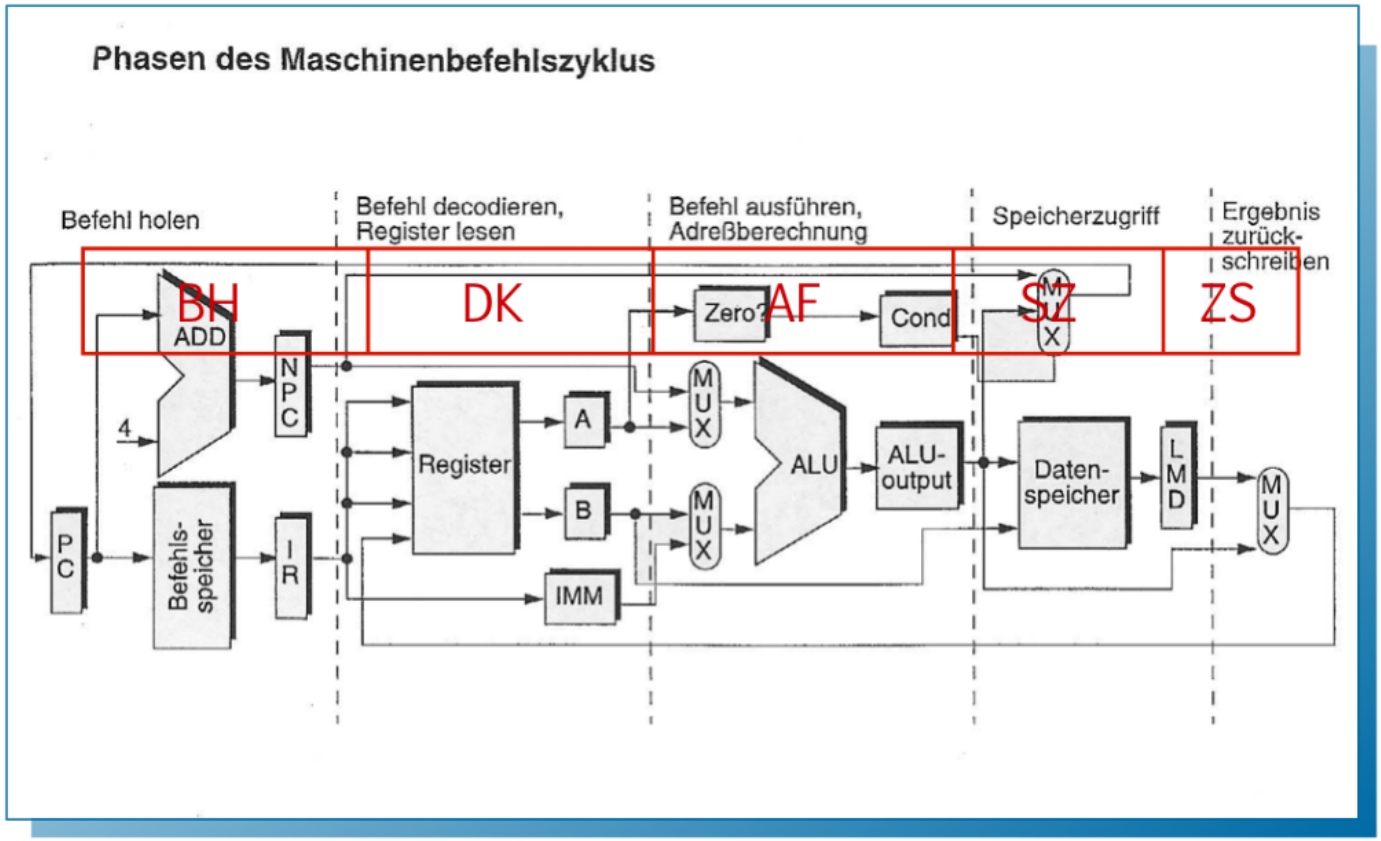


Von Neumann Architecture

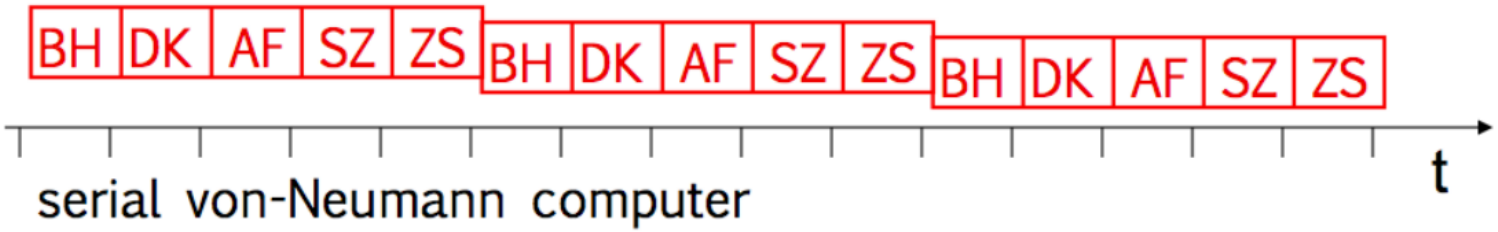


John von Neumann
*1903 ..1957

Operation via Instructions

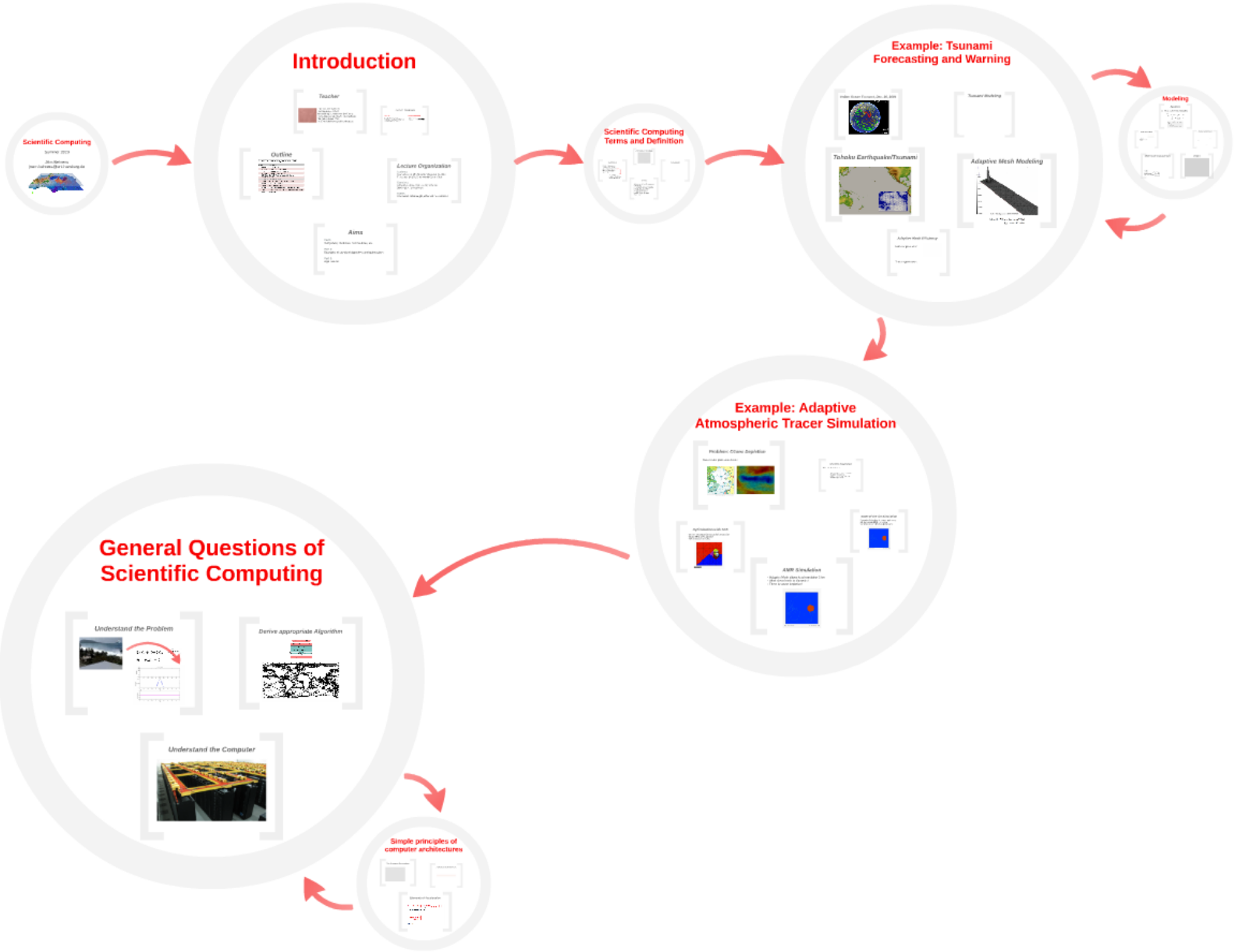


Elements of Acceleration



serial von-Neumann computer

Pipelining


Scientific Computing
Introduction
Teacher
Outline
Lecture Organization
Aims
Scientific Computing Terms and Definition
Example: Tsunami Forecasting and Warning
Tsunami Modeling
Tohoku Earthquake/Tsunami
Adaptive Mesh Modeling
Modeling
Example: Adaptive Atmospheric Tracer Simulation
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