If You Build It, Will They Come? Evolution Towards the Application of Multi-Dimensional GIS to Fisheries-Oceanography

Tiffany C. Vance

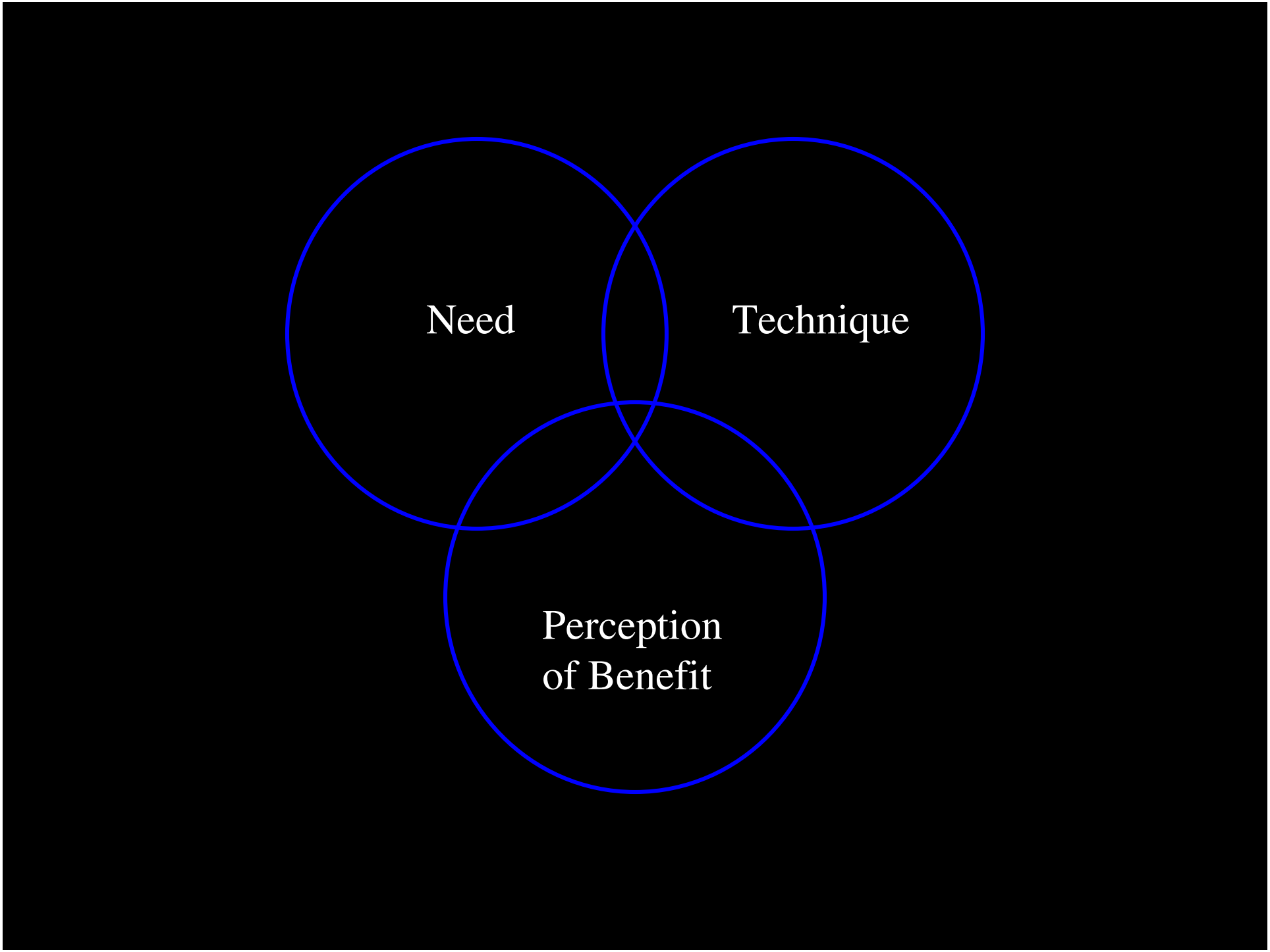
30 November 2007

Outline

- Factors driving the development of new techniques
- Henry Stommel and the Stommel diagram
- The history of GIS and multidimensional GIS
- GeoModeler: a prototype multi-dimensional GIS
- Analysis and and volumetric visualization of environmental factors affecting otolith daily increments in *Theragra chalcogramma*
- Conclusions

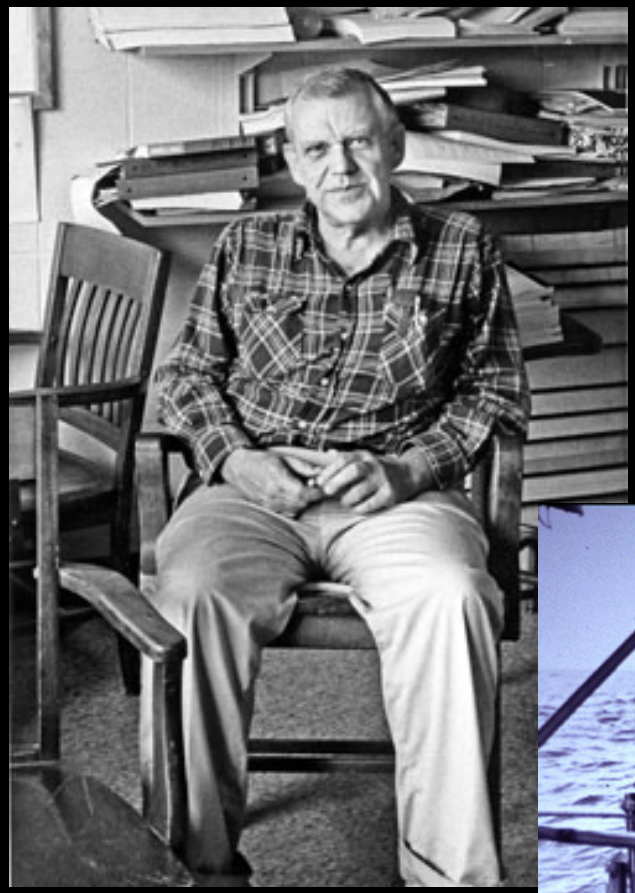
"If you build it, he will come."

Field of Dreams, W. P. Kinsella, 1989


Need
Technique
Perception
of Benefit

Oceanographic data collection after WWII

- Surplus ships
- Trained personnel
- Acoustic methods
- Moorings
- Current meters
- Electronic recording of data
- International research campaigns



WHOI official photo

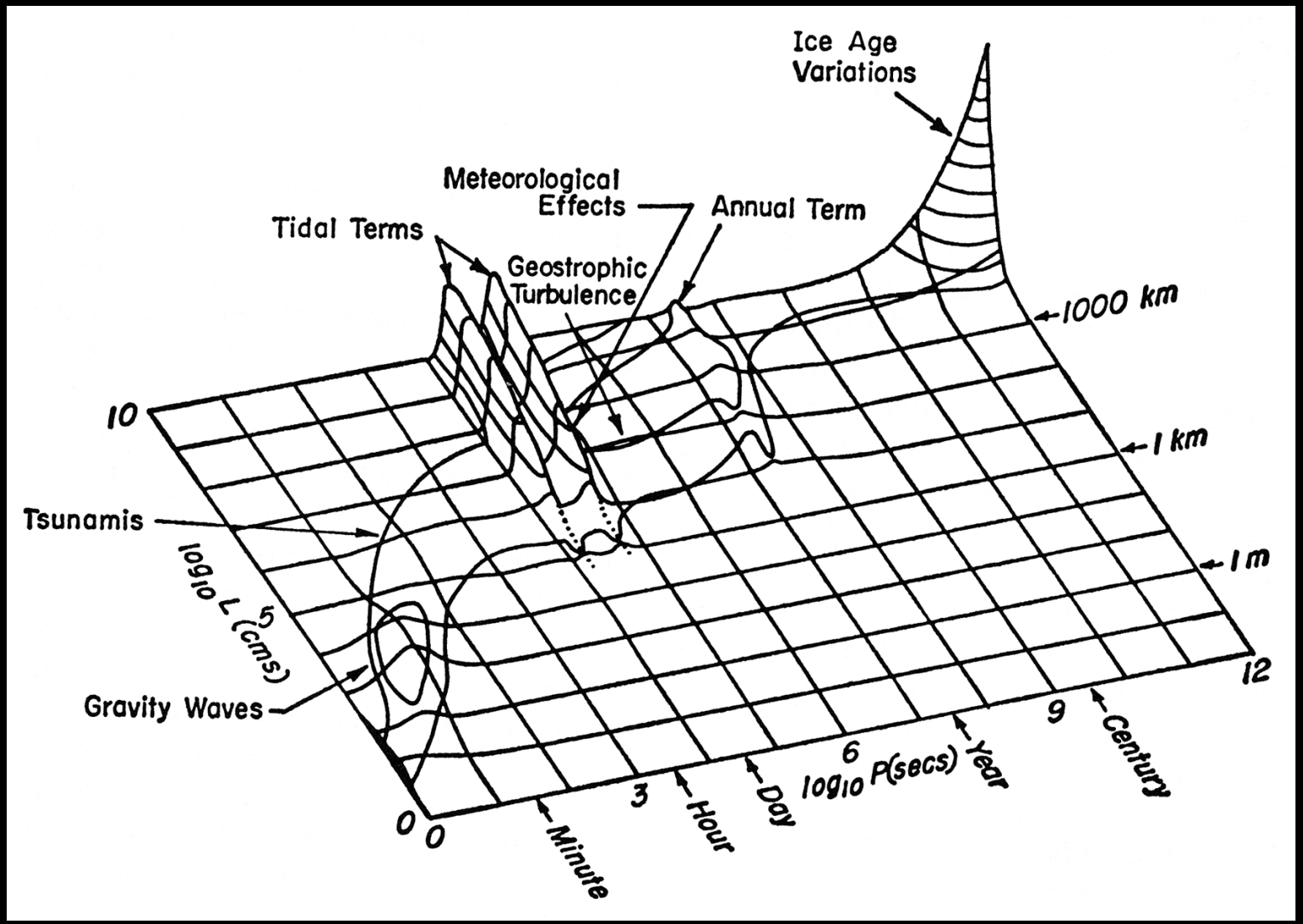
WHOI -
http://www.marine.whoi.edu/arcfotos.nsf?OpenDatabase

UCSD -
http://www.igpp.ucsd.edu/about igpp/doors.cfm

"Luyten lists three essential Stommel qualities: insatiable curiosity, extraordinary intuition, and the ability to visualize physical processes fully in three dimensions.

Hank was also well known for his generosity with ideas—he sparked many individuals' research directions and initiated a number of collaborative oceanographic programs, both large and small."

WHOI staff listing for Stommel,
http://www.whoi.edu/75th/gallery/week25.html

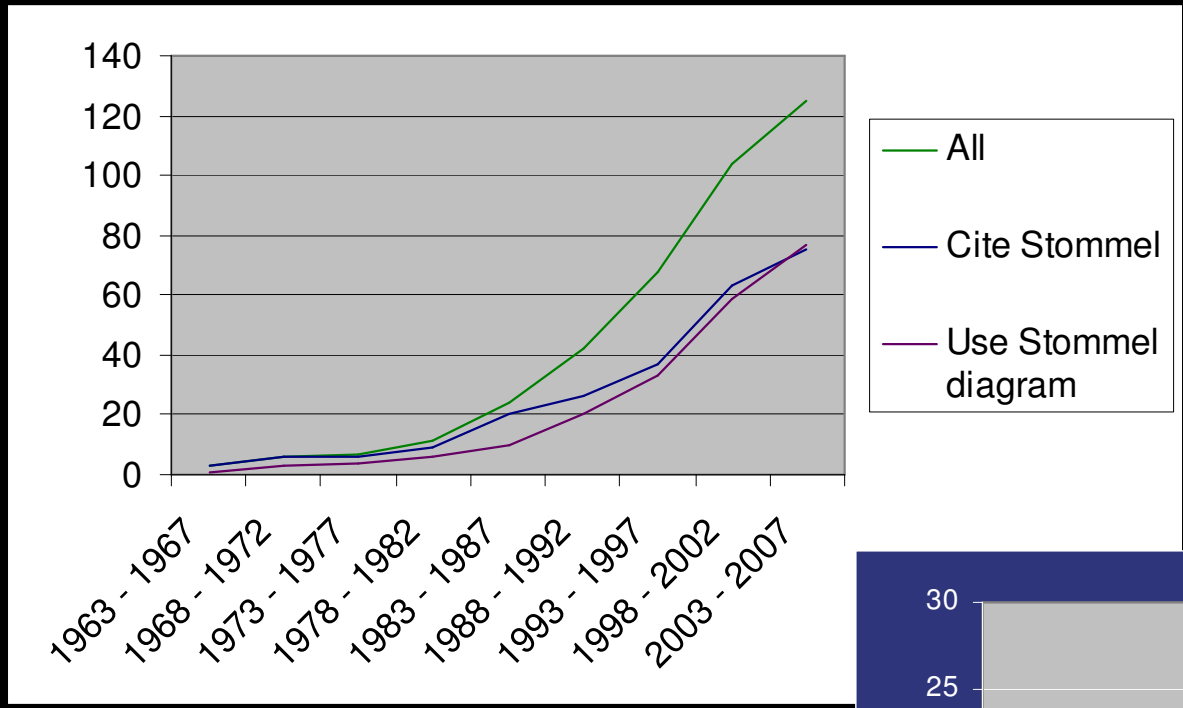

Ice Age
Variations
Meteorological
Effects
Annual Term
Tidal Terms
Geostrophic
Turbulence
1000 km
1 km
1 m
10
Tsunamis
log10 L (cms)
5
Gravity Waves
12
9
Century
6
log10 P(secs)
Year
3
Hour
Day
0
0
Minute

Diffusion of the Stommel diagram

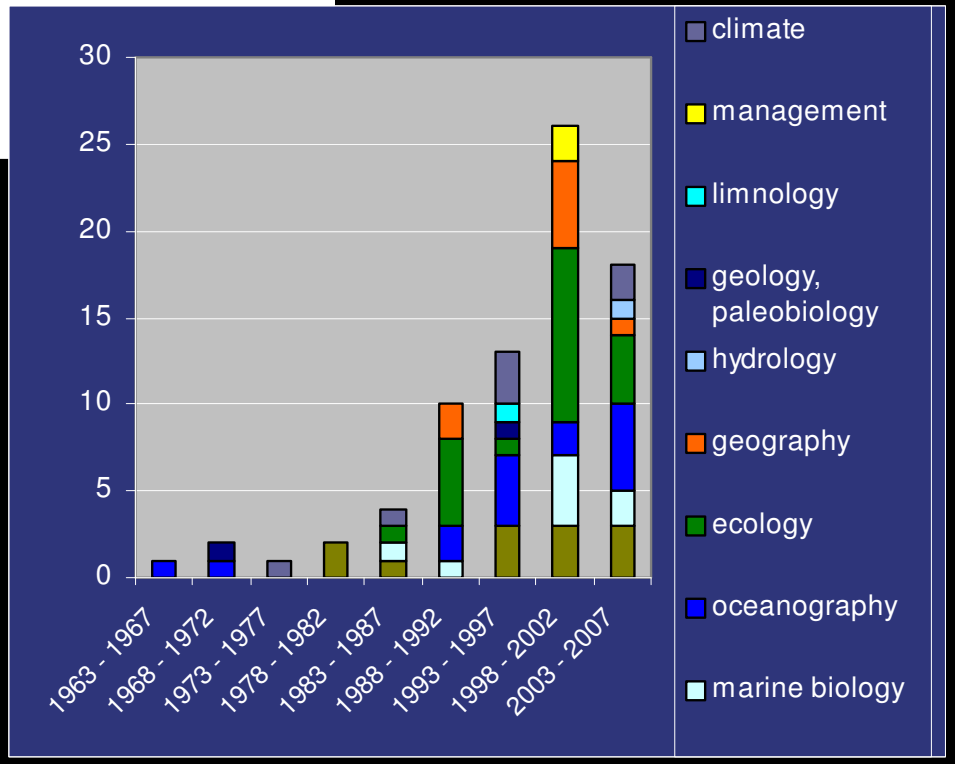
- Spread within physical oceanography
- Spread to other disciplines
- Modifications
- Became outdated?
- What can the diffusion tell us about the adoption of other new graphical techniques?

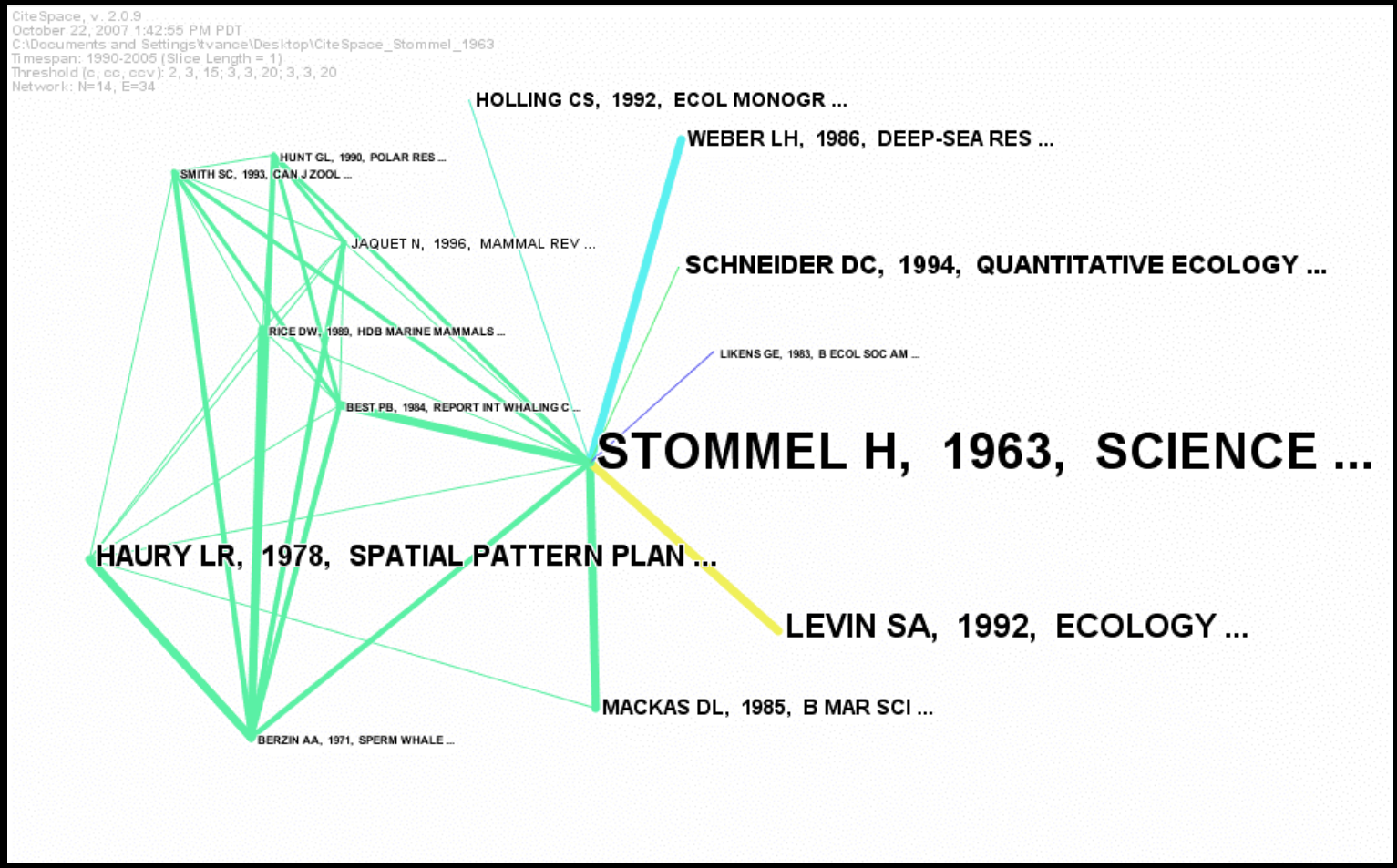
Tracing the diffusion of the diagram

- Techniques
  - Innovation diffusion
  - Epidemic models
  - Scientific and research schools
  - Information technology
- Data sources
  - Archival materials - WHOI, Scripps, AIP, Library of Congress
  - Electronic and hardcopy citations - “Stommel web”
  - Interviews - contacting Stommel students and colleagues
  - Other studies of use of “scale” - ecologists

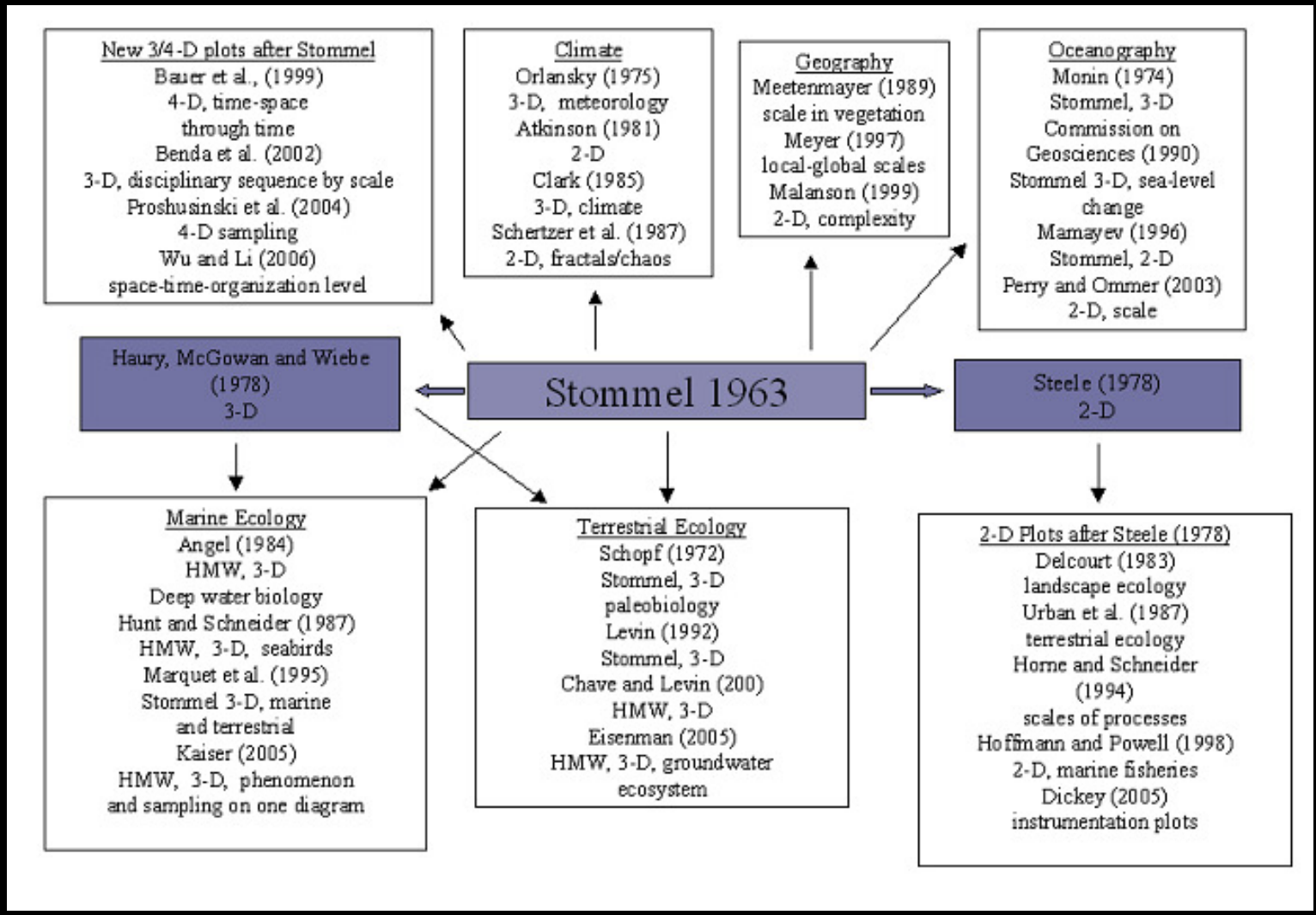


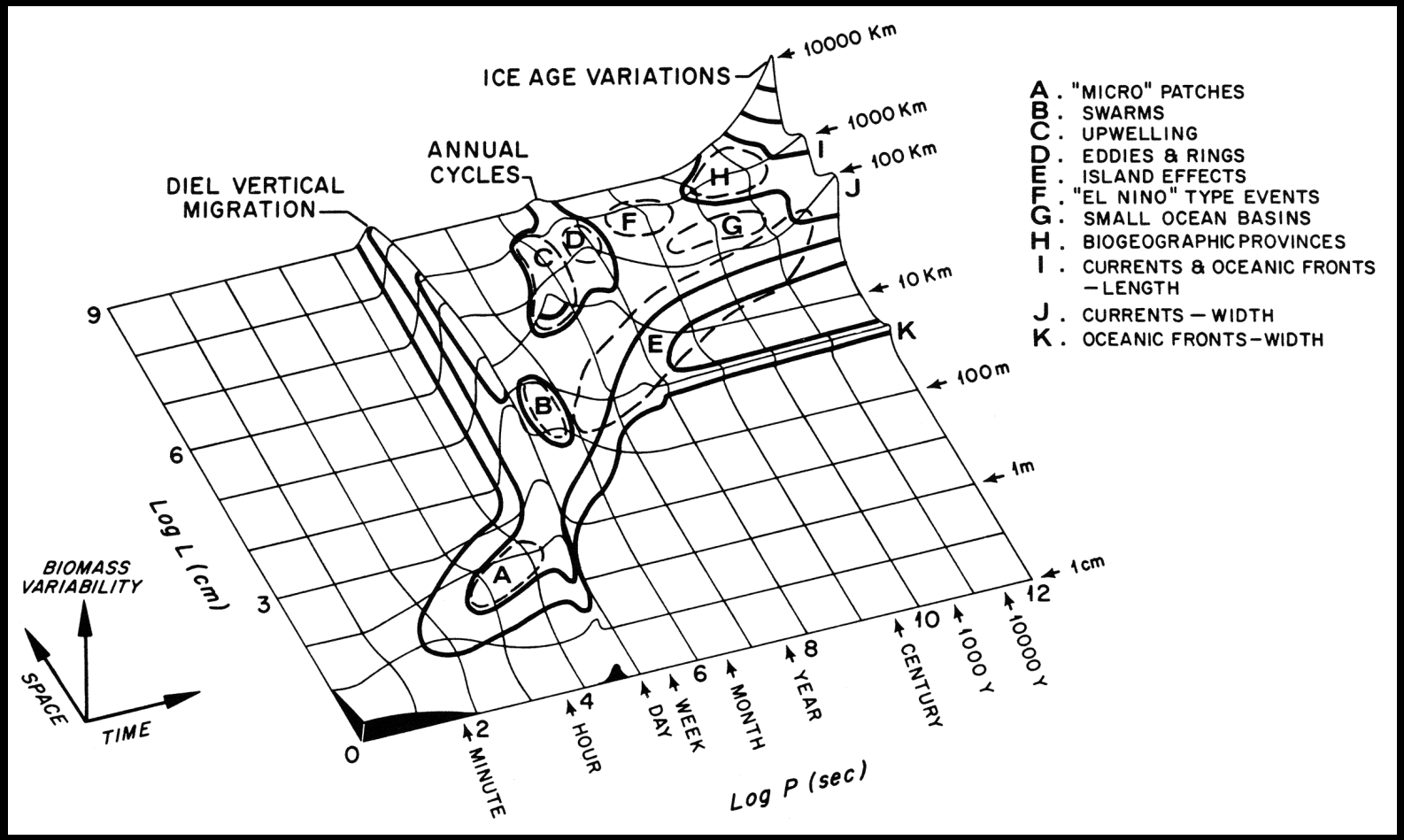
Hard copy citations



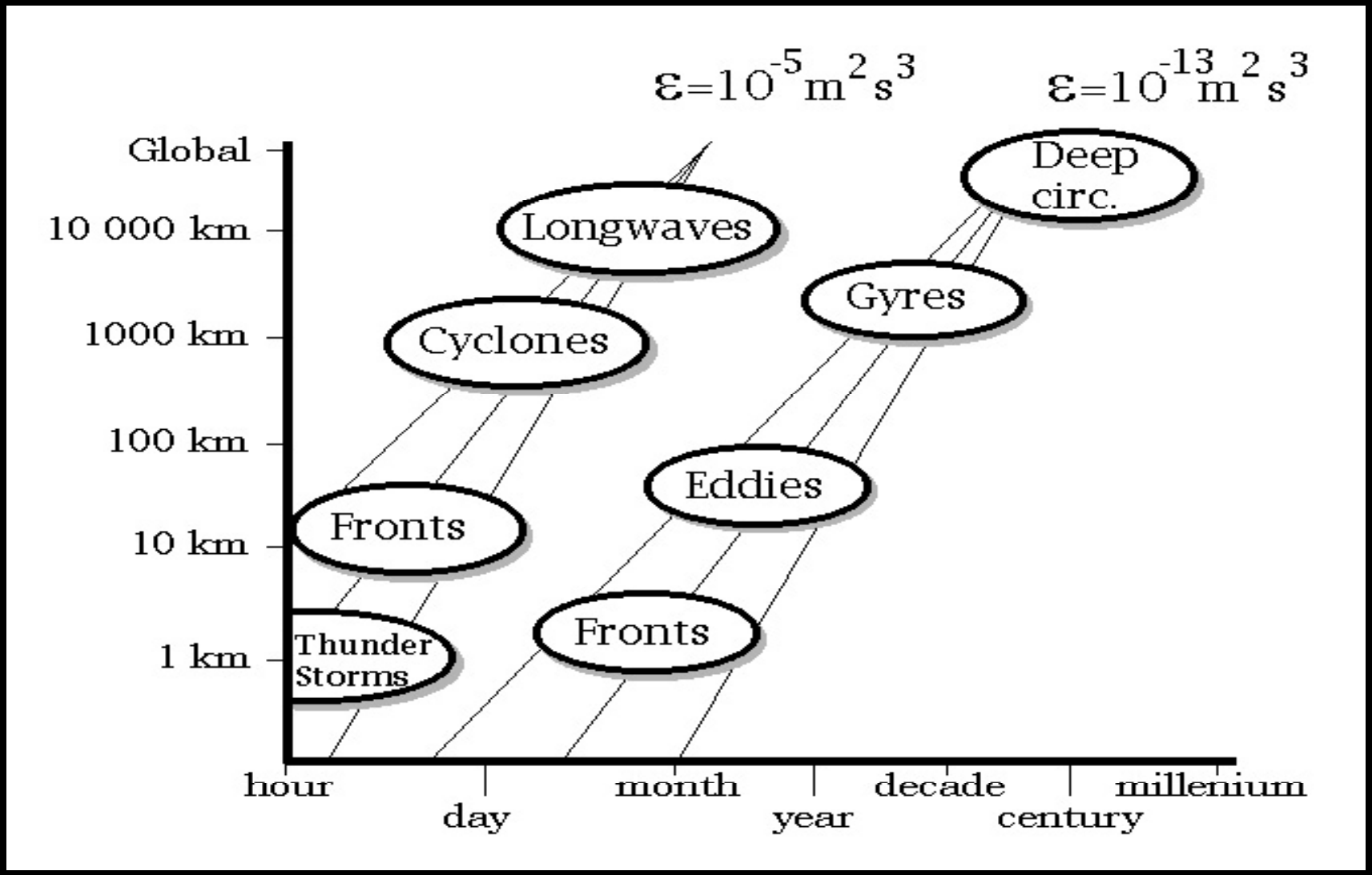


CiteSpace representation of ISI/Web of Science citations

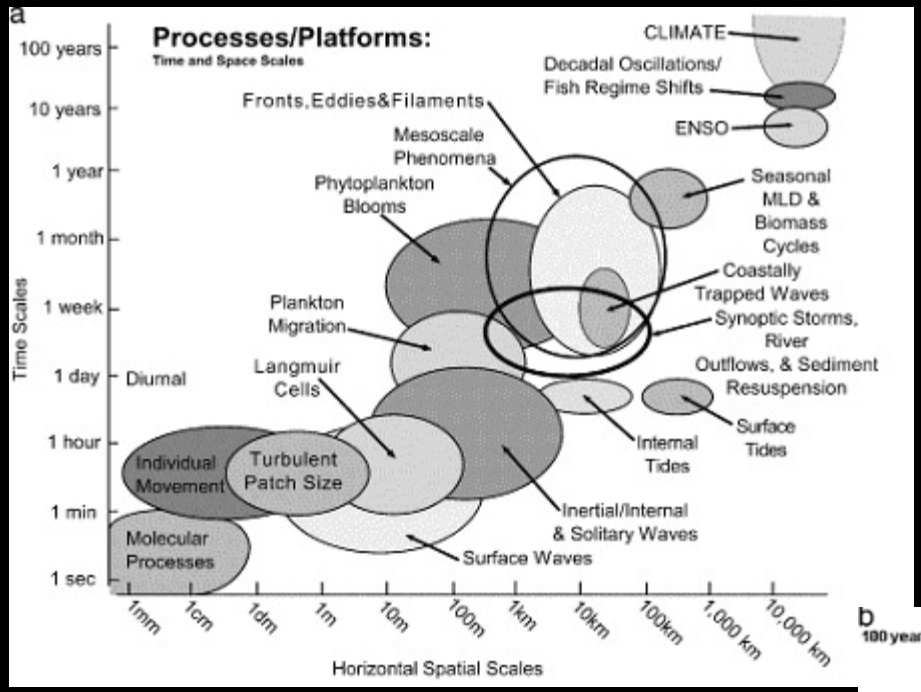

New 3/4-D plots after Stommel
Bauer et al., (1999)
4-D, time-space
through time
Benda et al. (2002)
3-D, disciplinary sequence by scale
Proshusinski et al. (2004)
4-D sampling
Wu and Li (2006)
space-time-organization level
Climate
Orlansky (1975)
3-D, meteorology
Atkinson (1981)
2-D
Clark (1985)
3-D, climate
Schertzer et al. (1987)
2-D, fractals/chaos
Geography
Meetenmayer (1989)
scale in vegetation
Meyer (1997)
local-global scales
Malanson (1999)
2-D, complexity
Oceanography
Monin (1974)
Stommel, 3-D
Commission on
Geosciences (1990)
Stommel 3-D, sea-level
change
Mamayev (1996)
Stommel, 2-D
Perry and Ommer (2003)
2-D, scale
Haury, McGowan and Wiebe
(1978)
3-D
Stommel 1963
Steele (1978)
2-D
Marine Ecology
Angel (1984)
HMW, 3-D
Deep water biology
Hunt and Schneider (1987)
HMW, 3-D, seabirds
Marquet et al. (1995)
Stommel 3-D, marine
and terrestrial
Kaiser (2005)
HMW, 3-D, phenomenon
and sampling on one diagram
Terrestrial Ecology
Schopf (1972)
Stommel, 3-D
paleobiology
Levin (1992)
Stommel, 3-D
Chave and Levin (200)
HMW, 3-D
Eisenman (2005)
HMW, 3-D, groundwater
ecosystem
2-D Plots after Steele (1978)
Delcourt (1983)
landscape ecology
Urban et al. (1987)
terrestrial ecology
Horne and Schneider
(1994)
scales of processes
Hoffmann and Powell (1998)
2-D, marine fisheries
Dickey (2005)
instrumentation plots

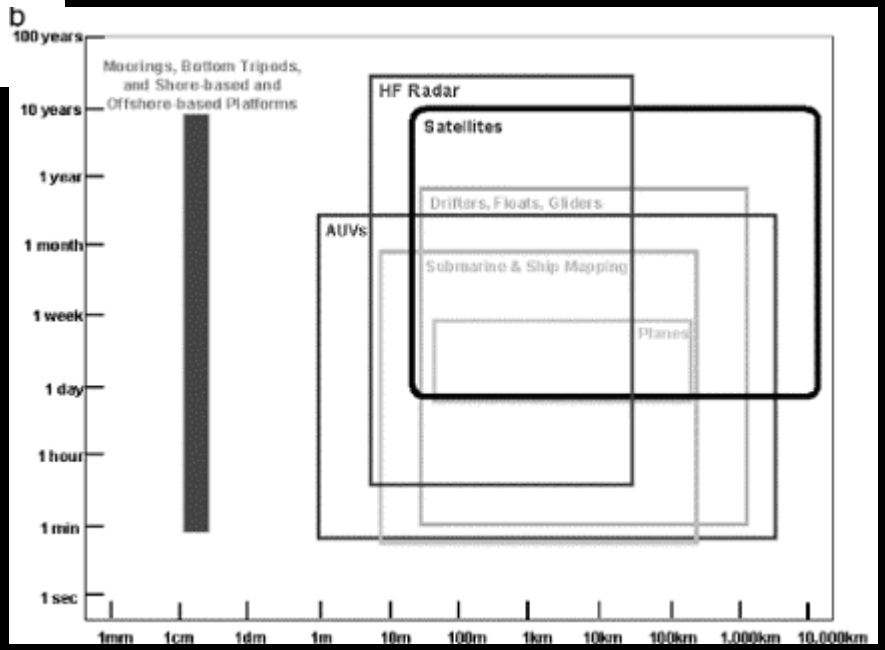


Haury et al., 1978


ε=10^-5 m^2 s^3
ε=10^-13 m^2 s^3
Global
10 000 km
1000 km
100 km
10 km
1 km
Longwaves
Cyclones
Fronts
Thunder Storms
Deep circ.
Gyres
Eddies
Fronts
hour
day
month
year
decade
century
millenium

Steele, 1994


a
Processes/Platforms:
Time and Space Scales
CLIMATE
Decadal Oscillations/
Fish Regime Shifts
ENSO
Fronts, Eddies&Filaments
Mesoscale
Phenomena
Phytoplankton
Blooms
Seasonal
MLD &
Biomass
Cycles
Coastally
Trapped Waves
Synoptic Storms,
River
Outflows, & Sediment
Resuspension
Plankton
Migration
Langmuir
Cells
Diurnal
Surface
Tides
Internal
Tides
Individual
Movement
Turbulent
Patch Size
Inertial/Internal
& Solitary Waves
Molecular
Processes
Surface Waves
Time Scales
100 years
10 years
1 year
1 month
1 week
1 day
1 hour
1 min
1 sec
1mm
1cm
1dm
1m
10m
100m
1km
10km
100km
1,000 km
10,000 km
Horizontal Spatial Scales


b
100 years
10 years
1 year
1 month
1 week
1 day
1 hour
1 min
1 sec
Moorings, Bottom Tripods,
and Shore-based and
Offshore-based Platforms
HF Radar
Satellites
Drifters, Floats, Gliders
AUVs
Submarine & Ship Mapping
Planes
1mm
1cm
1dm
1m
10m
100m
1km
10km
100km
1,000km
10,000km

Dickey, 2003

Technological transition in oceanographic data display

Stommel diagram

- Need
  - pedagogical tool, reflected concerns about use of new tools for data collection
  - simplified rendition of space-time properties of new, large datasets
- Technology
  - current meters, buoys, drifters and acoustic methods
  - ever increasing computer processing power but limited graphics
- Perception of benefit
  - biological/ecological vs. physical scientists

Analysis/representation of multi-dimensional data

- Need
  - analysis of new multidimensional datasets
  - expansion of disciplines such as ecology
- Technology
  - rise of computer cartography, databases, GIS, and visualization
- Perception of benefit
  - uncertainty about advantages, human processing overhead

Outline

- Background: technologies for gathering oceanographic data
- Henry Stommel and the Stommel diagram
- The history of GIS and multidimensional GIS
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Technological developments after 1960

- Continuing improvements to oceanographic sensors and sanplers
- Biological samplers such as multiple nets and continuous plankton recorders
- Mini, personal and super computers
- Graphics input and output devices
- Graphics cards
- Software and programming languages

Origins of GIS

- Mid 1960's - Harvard Labs, 2-D and 3-D mapping
- Mid-1960's - Canadian Geographic Information System (CGIS)
- 1971 - Military Geographic Information Systems (MGIS)
- 1982 - ESRI ArcInfo
- None explicitly 3-D

Multidimensional GIS

- Database development
  - storage structures
  - queries
- Analysis
  - Voxel Analyst
  - System 9
- Display
  - VRML
  - Interactive Volume Model (IVM)

Current “state of the art”

- Display versus analysis
- 2.5-D versus 3-D

- ArcGIS 3D Analyst
- GRASS
- Fledermaus, IVS and EVS
- Vis5D

GeoModeler: a prototype multi-dimensional GIS

Pragmatic question - potential users/uses of GeoModeler

- Integrating models with GIS
- Fisheries biologists who are familiar with GIS – especially ESRI products
- Oceanographers who are familiar with scientific analytical tools – MATLAB etc.
- Emergency managers who use GIS, but need to do scenario testing
- Testing true 3-D visualization in GIS

Analytical needs

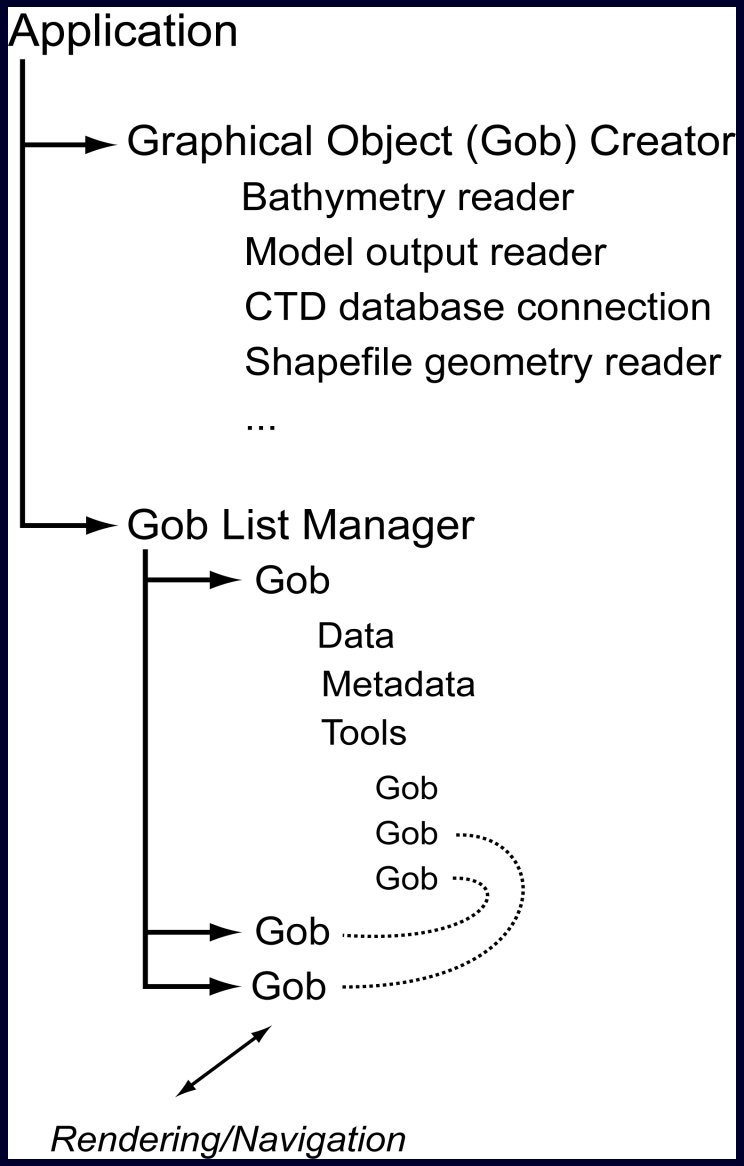
- A graphical front end would
  - make setting parameters easier
  - allow non-modelers to test scenarios
- Volumetric visualization would allow the user to see
  - intricate details inside a volume
  - spatial trajectories of individual cohorts
  - cohort attributes and conditions of the physical environment in time and space.

Software components

- GeoTools - Java based tools to read in shapefiles
- Visualization ToolKit (VTK) - to render and visualize data
- Java3D - for 3-D rendering
- ArcGIS - for GIS-based analysis
- ArcEngine - Java applications programming interface (API) to ArcGIS analysis code

Application diagram

- Graphical objects (Gob) are created for various functions
- The Gob List Manager keeps track of objects
- Each Gob has specific functionality and tools

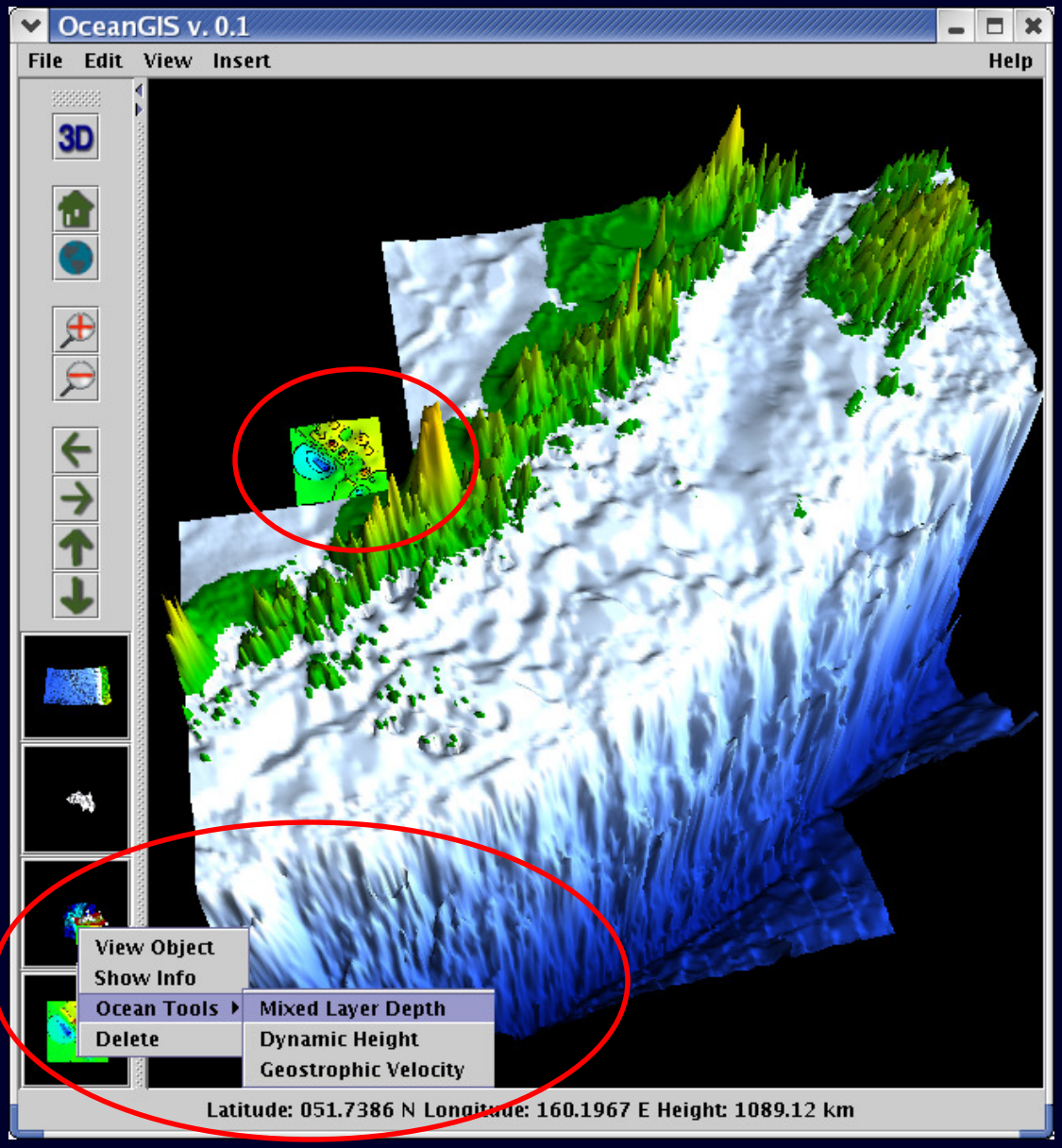


GeoModeler prototype

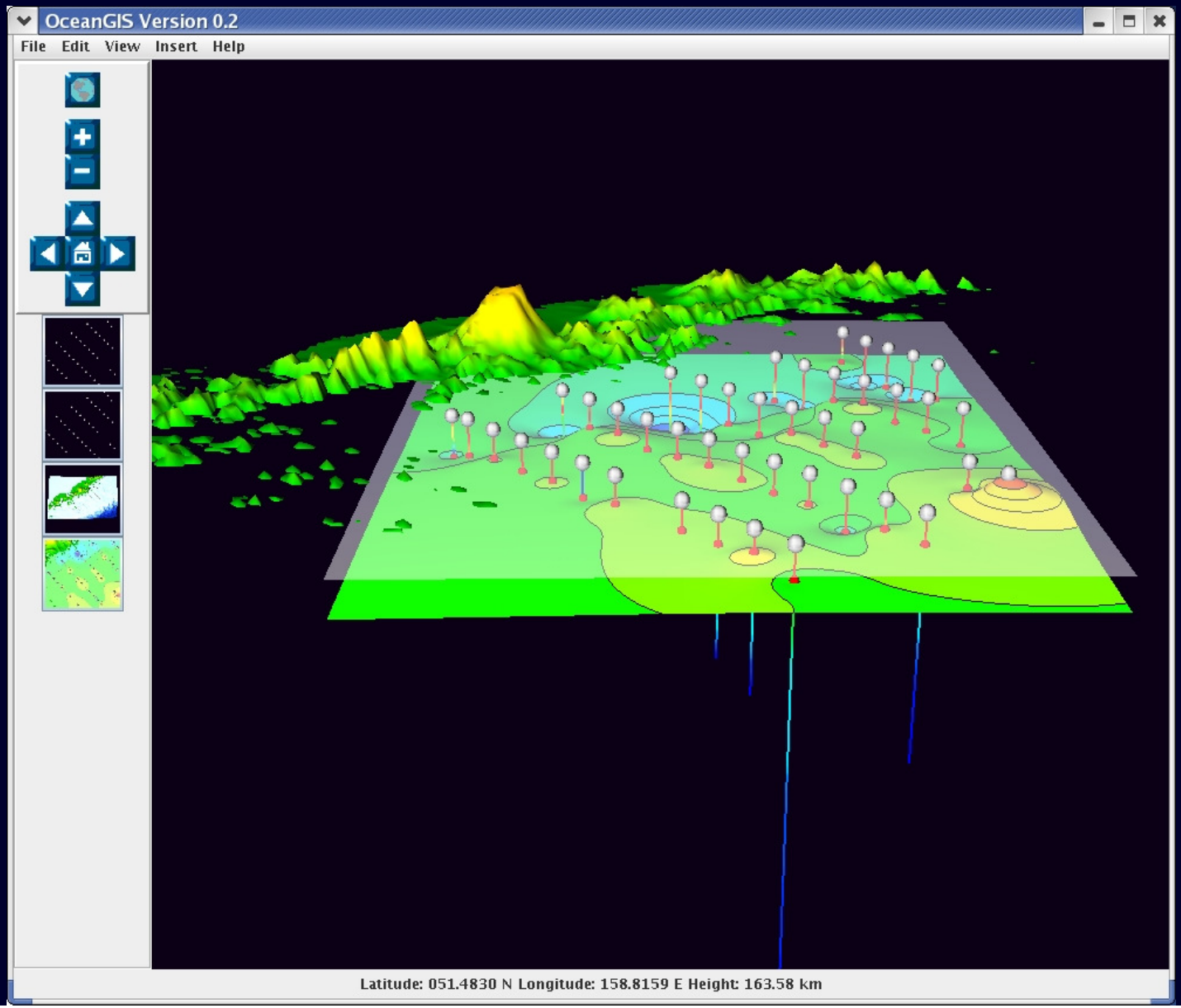
- Analysis of oceanographic data and direct integration of GIS with modeling tools
- GIS as the front-end to set up model parameters
- Hand parameters to the model
- Model runs
- Results handed back to the front-end for display and analysis

1. Oceanographic analyses

- The Java API allows re-use of code.
- Our oceanographic tools are embedded in a graphical object data model.
- ArcGIS Engine will allow us to embed ESRI statistical analysis tools (or any ArcObject tool)

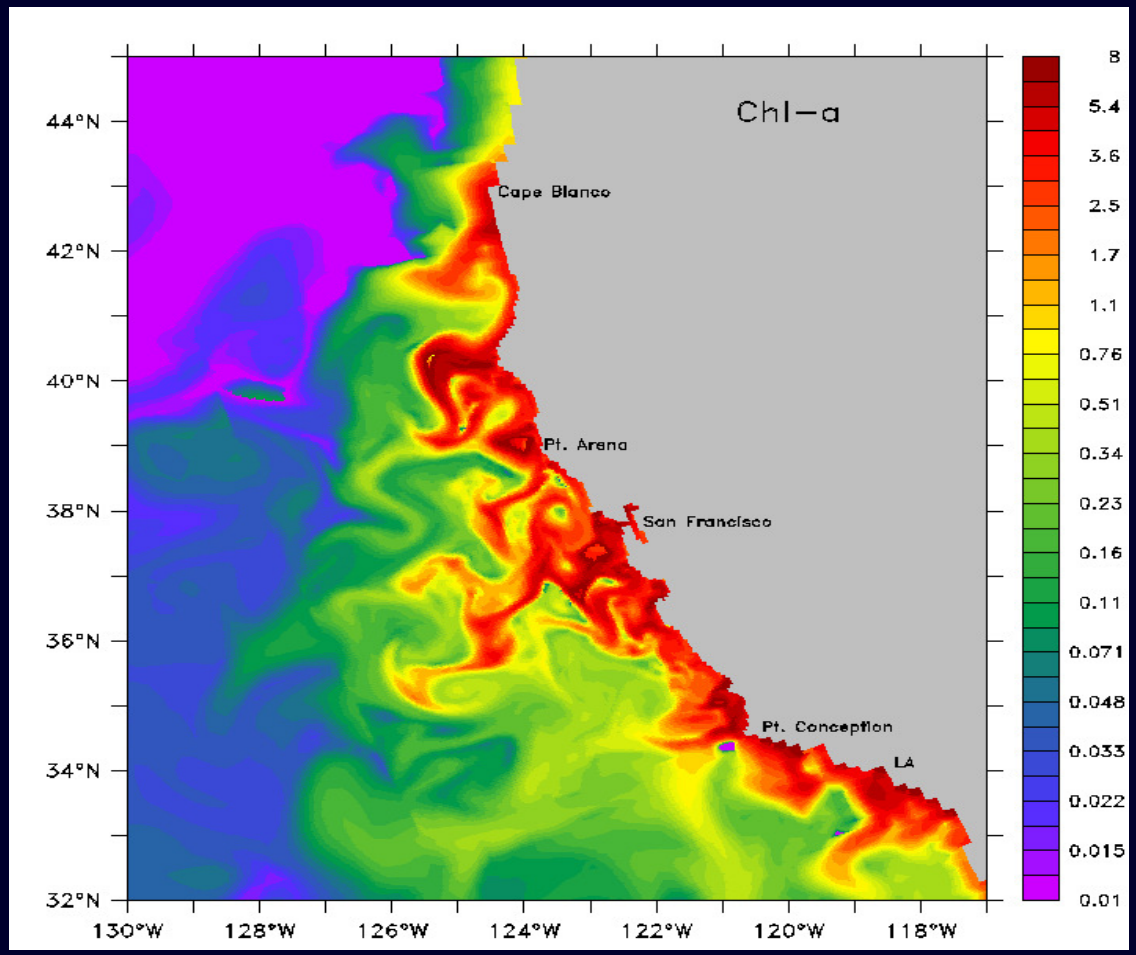


Analysis - surface interpolation



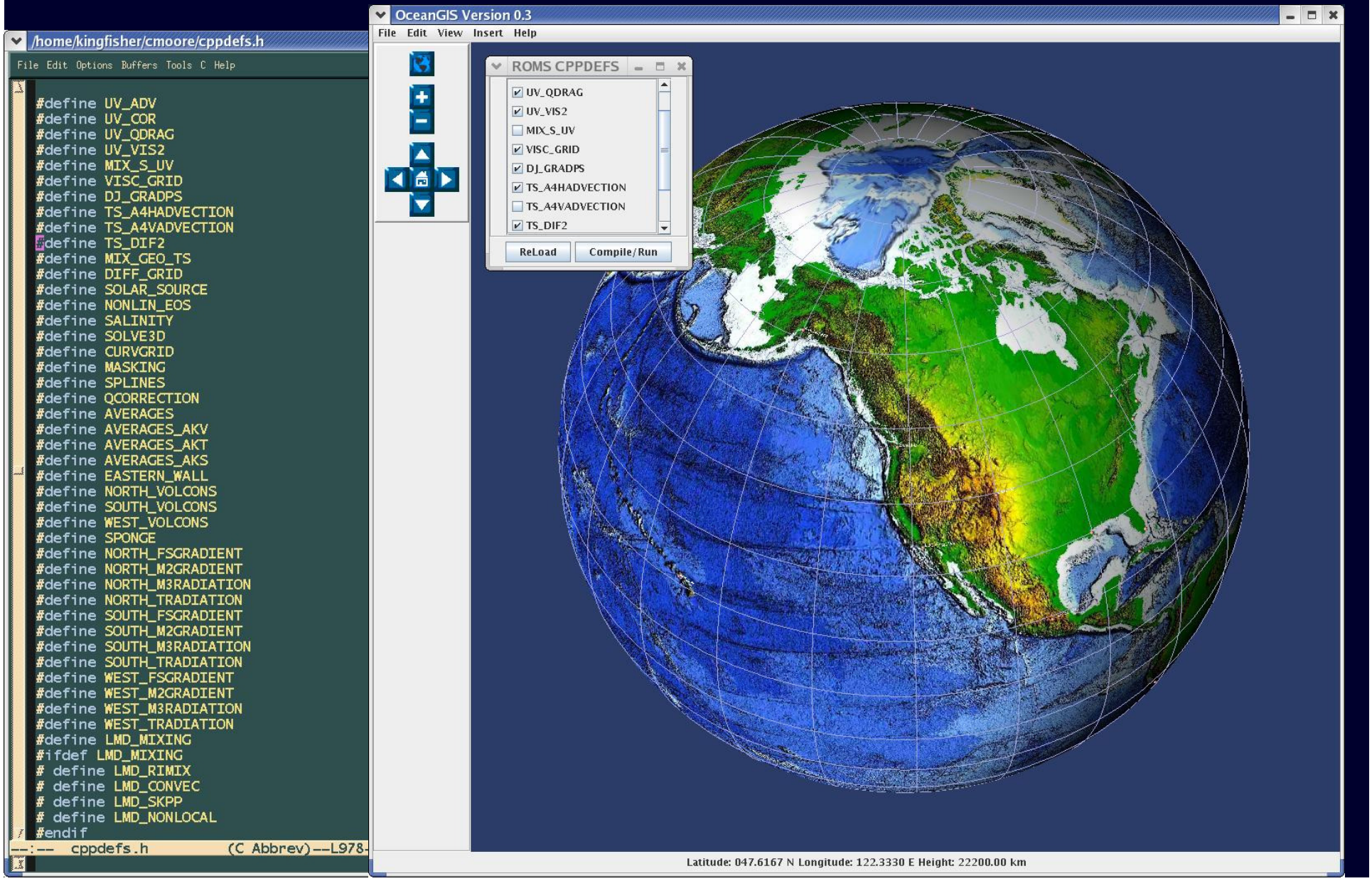
2. Oceanographic model integration - Regional Ocean Modeling System (ROMS)

Three-dimensional numerical oceanic model intended for simulating currents, ecosystems, biogeochemical cycles, and sediment movement in various coastal regions

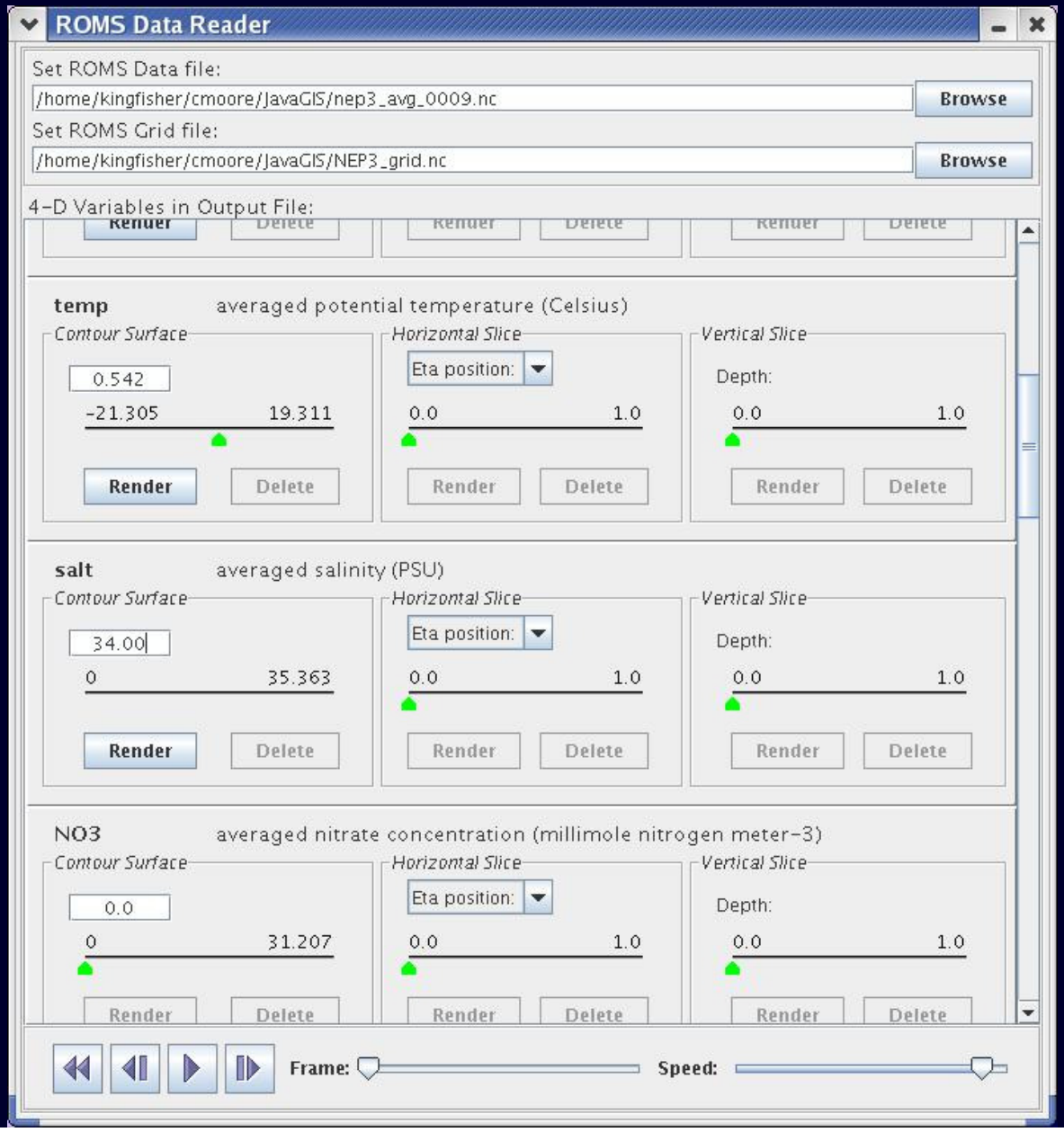


http://www.atmos.ucla.edu/cesr/ROMS_page.html

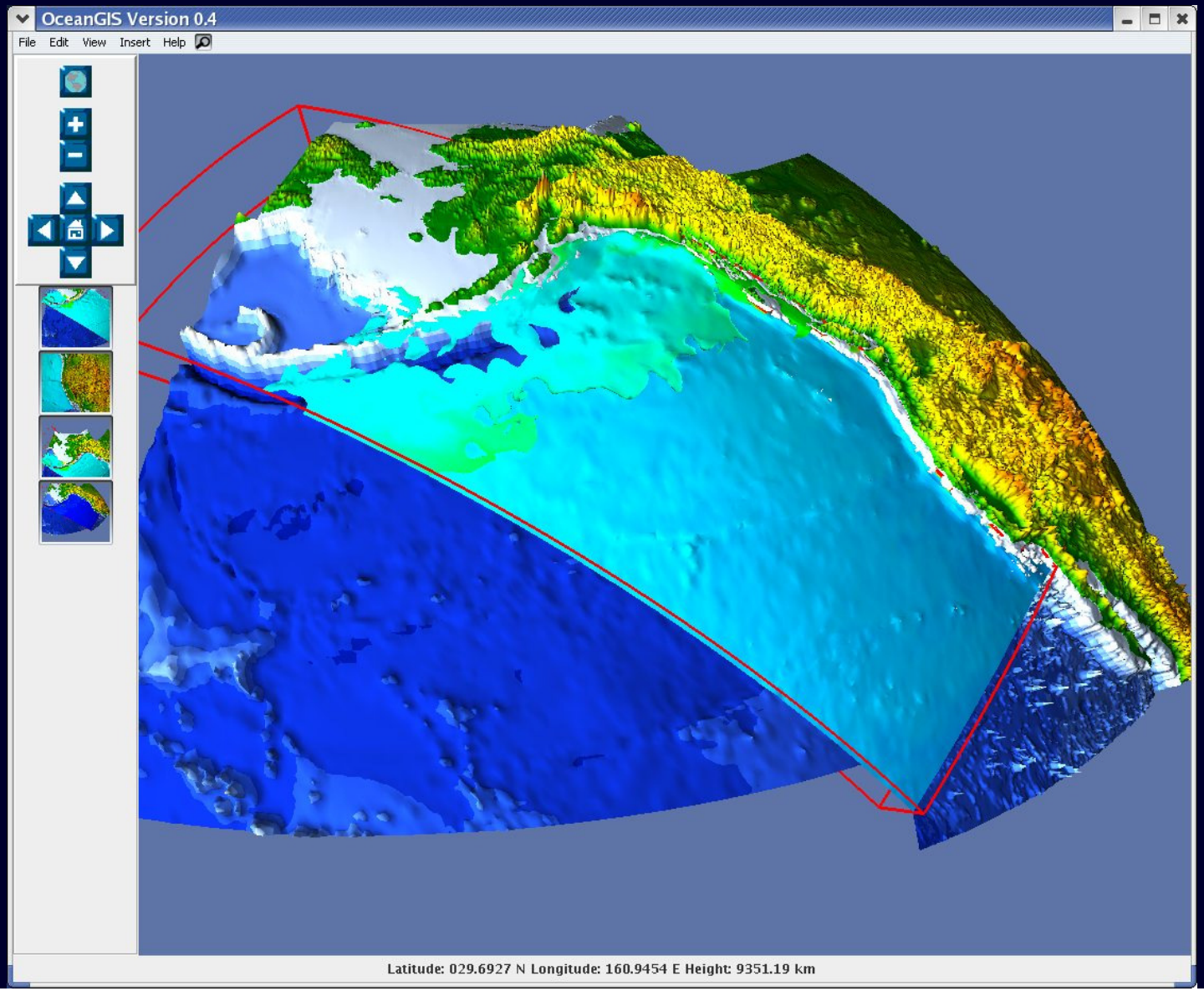
Setting model parameters



Setting output display parameters



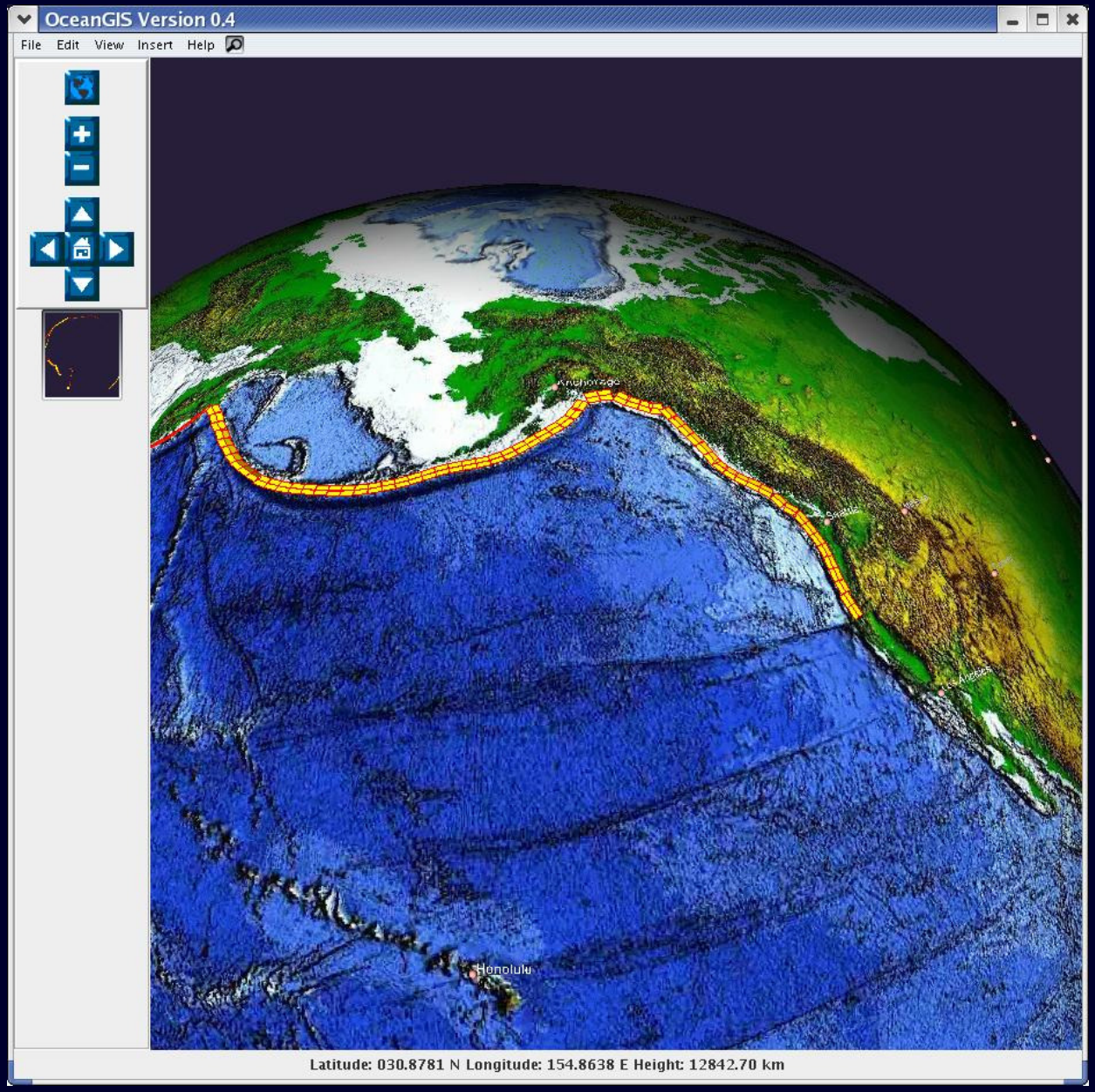
ROMS output draped on a globe



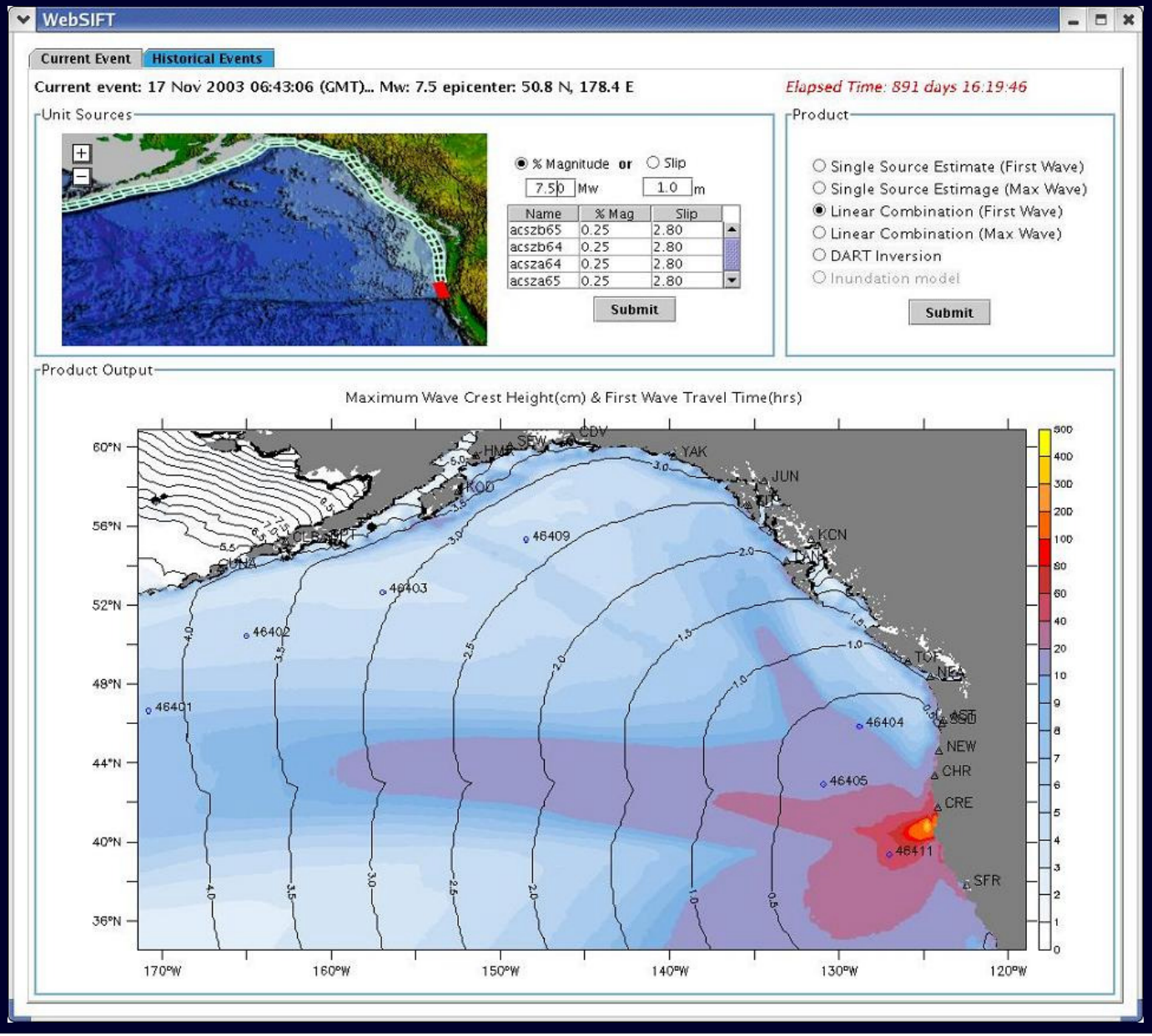
3. Scenario testing for emergency managers

- Models
  - Tsunami inundation models
- Inputs
  - Earthquake intensity, location
  - Time of day
- Outputs
  - Tsunami arrival and heights
  - Eventually linking with runup models to predict inundation
- Rerun with different inputs

Setting source regions for tsunami



Output tsunami



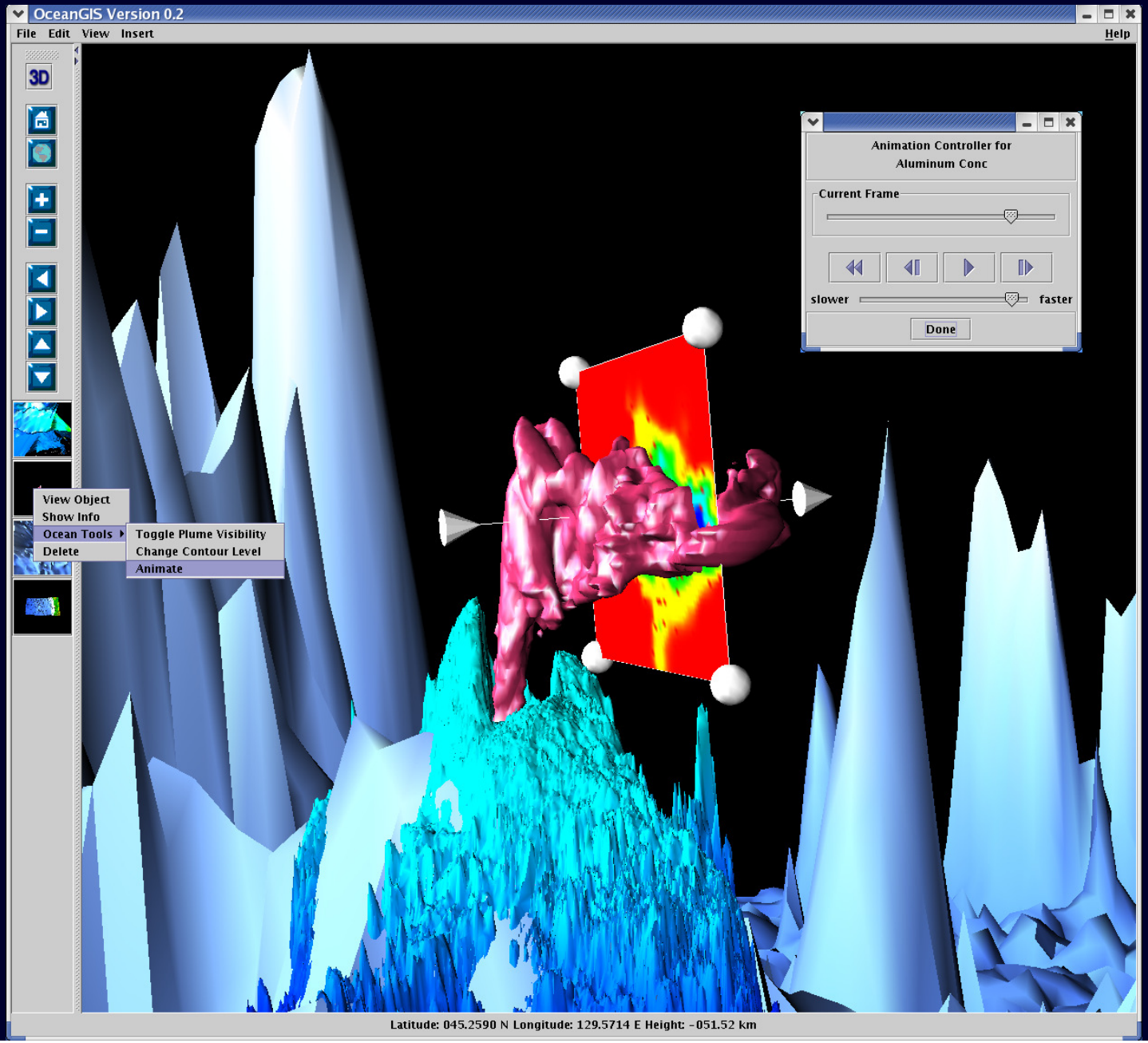
Other applications

- Animations
- Slicing volumes
- Volume on volume intersections
- Path through a volume

4. Slicing and animating 3-D data

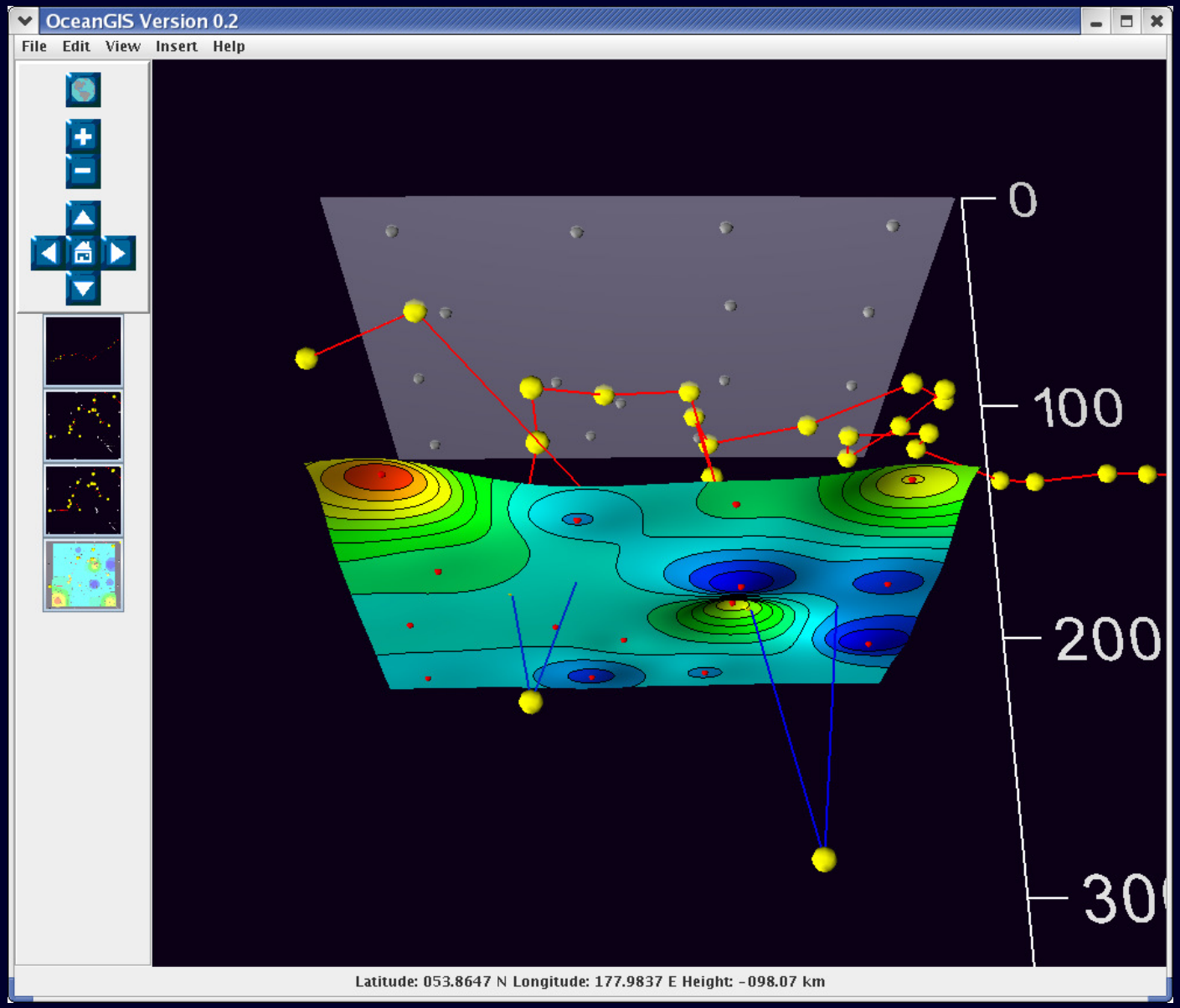
VTK/Java3D allows volume calculations, rendering, and analysis.

- 3D probe
- animation
- bathymetry
- multibeam



5. Intersection of a path with a surface/volume

- Path of a sealion diving and time spent below the mixed layer
- vtkLocator class to test for inside or outside



GeoModeler accomplishments/*plans*

- Integration of GIS data with visualizations
- Integration of models with GIS
- Visualization of data in 3-D
- Exploration of GIS analyses in 3-D
- *Volume on volume intersections*
- *Better interpolation*
- *GIS functions such as buffering*

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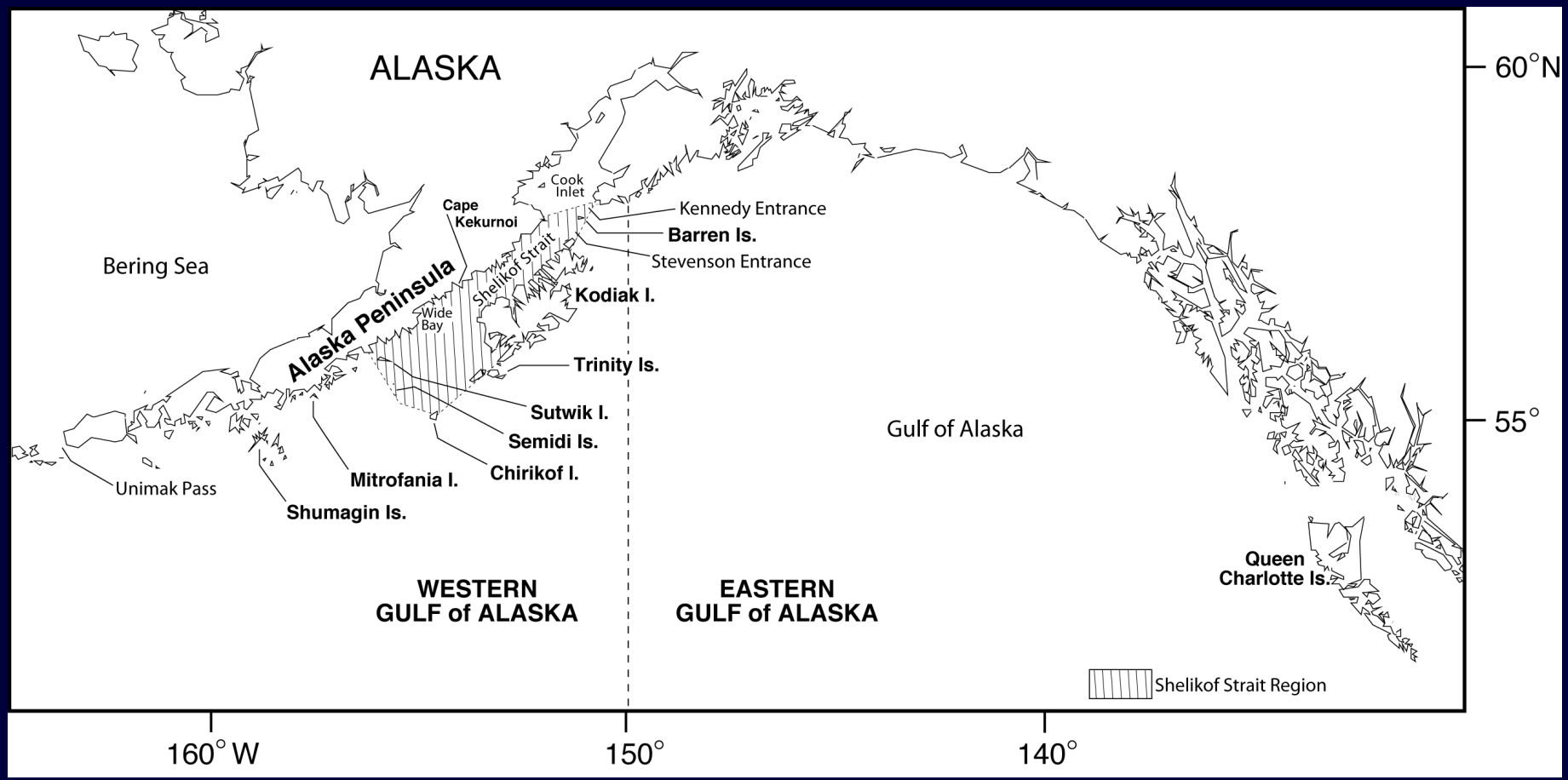
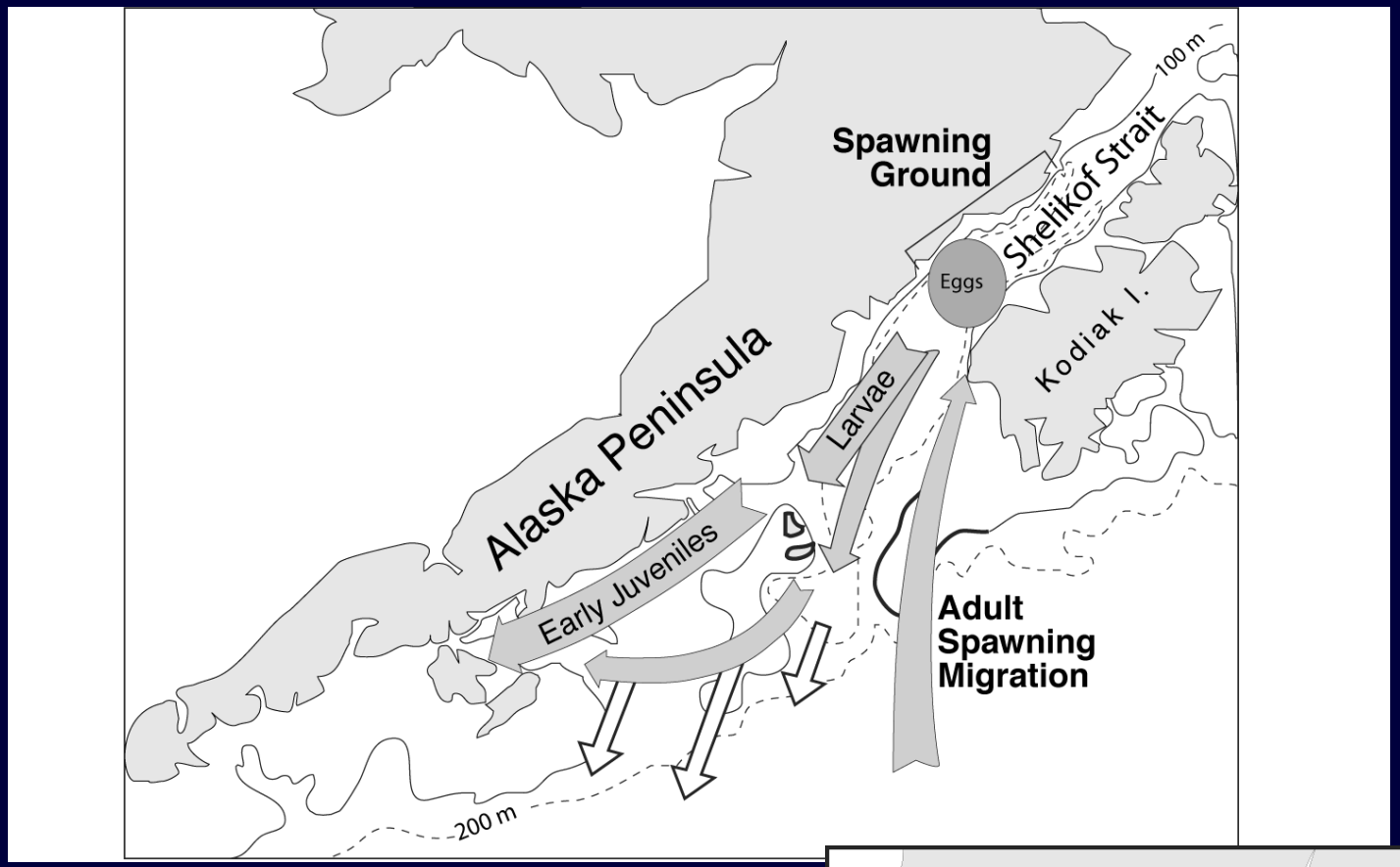
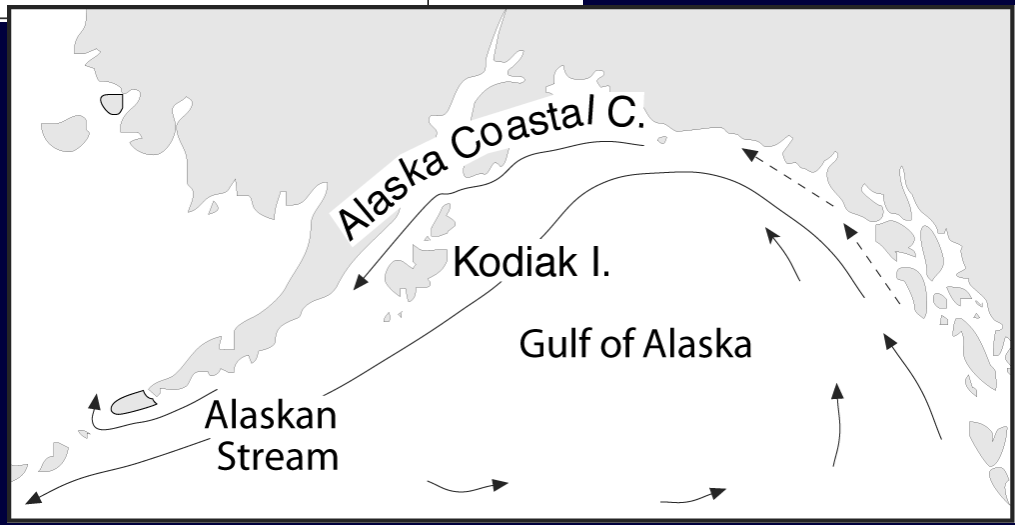
Walleye Pollock larvae in Shelikof Strait

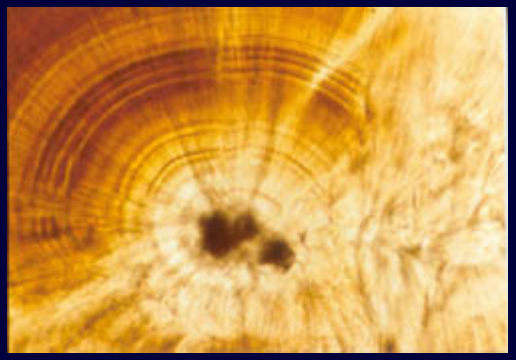

ALASKA
Bering Sea
Cook Inlet
Cape Kekurnoi
Kennedy Entrance
Barren Is.
Stevenson Entrance
Shelikof Strait
Kodiak I.
Wide Bay
Alaska Peninsula
Trinity Is.
Sutwik I.
Semidi Is.
Chirikof I.
Mitrofania I.
Unimak Pass
Shumagin Is.
Gulf of Alaska
Queen Charlotte Is.
WESTERN GULF of ALASKA
EASTERN GULF of ALASKA
Shelikof Strait Region
60°N
55°
160° W
150°
140°


Spawning Ground
Shelikof Strait
100 m
Eggs
Kodiak I.
Alaska Peninsula
Larvae
Early Juveniles
Adult Spawning Migration
200 m


Alaska Coastal C.
Kodiak I.
Gulf of Alaska
Alaskan Stream

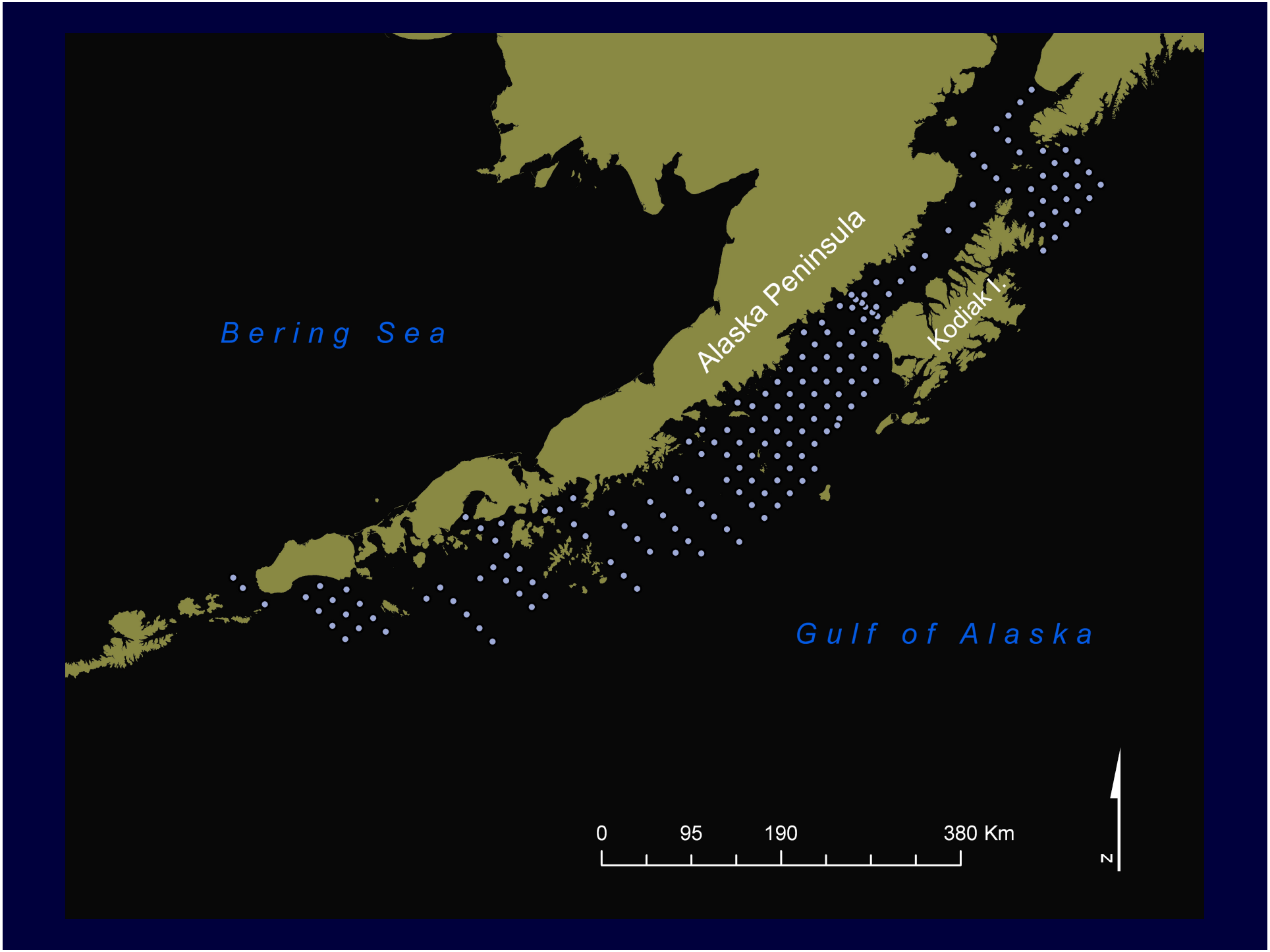
Pollock otoliths

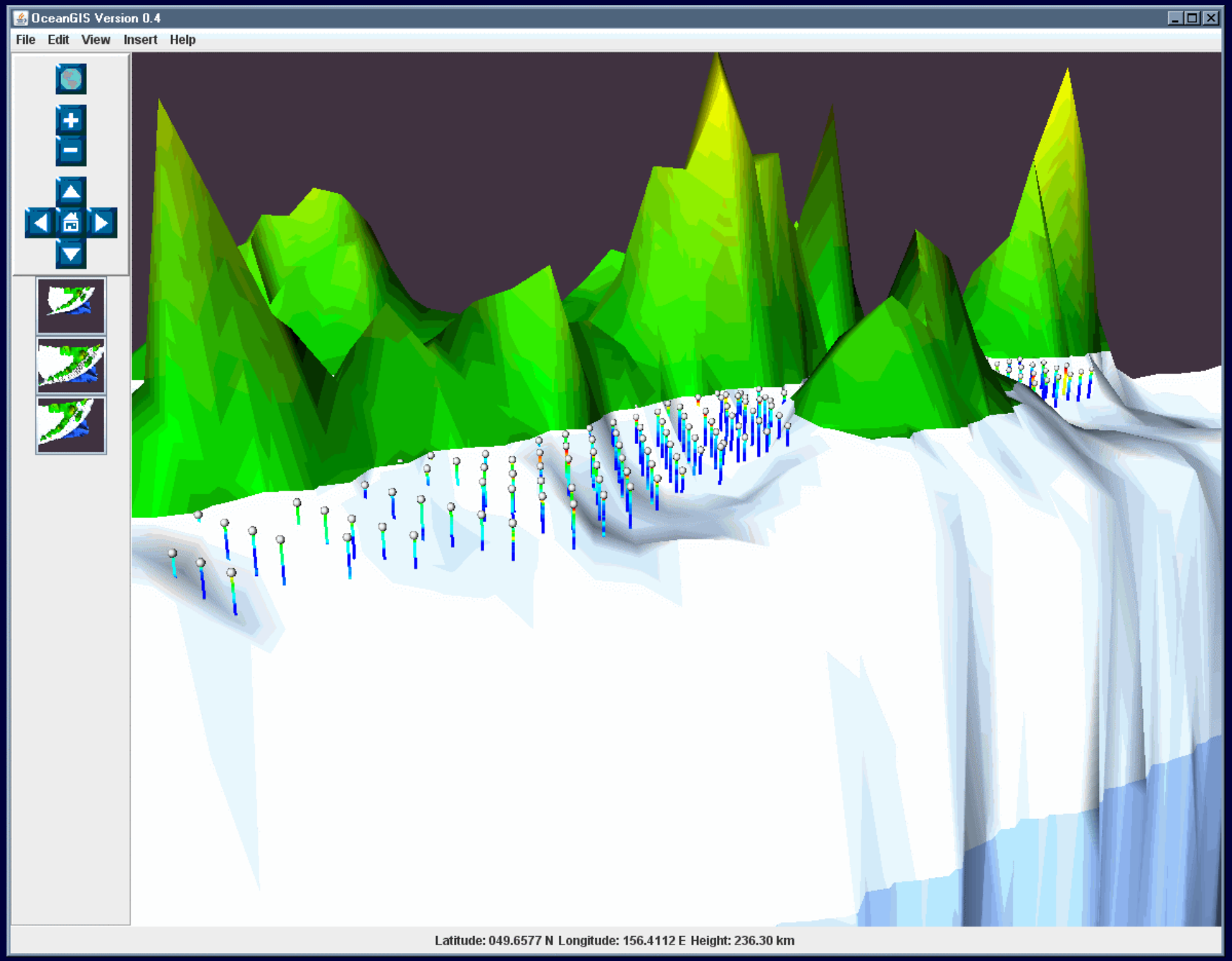
- Daily increment
- Equivalent of tree rings
- Temeperature
- Decreased intensity of rings



Questions for GIS-based analysis

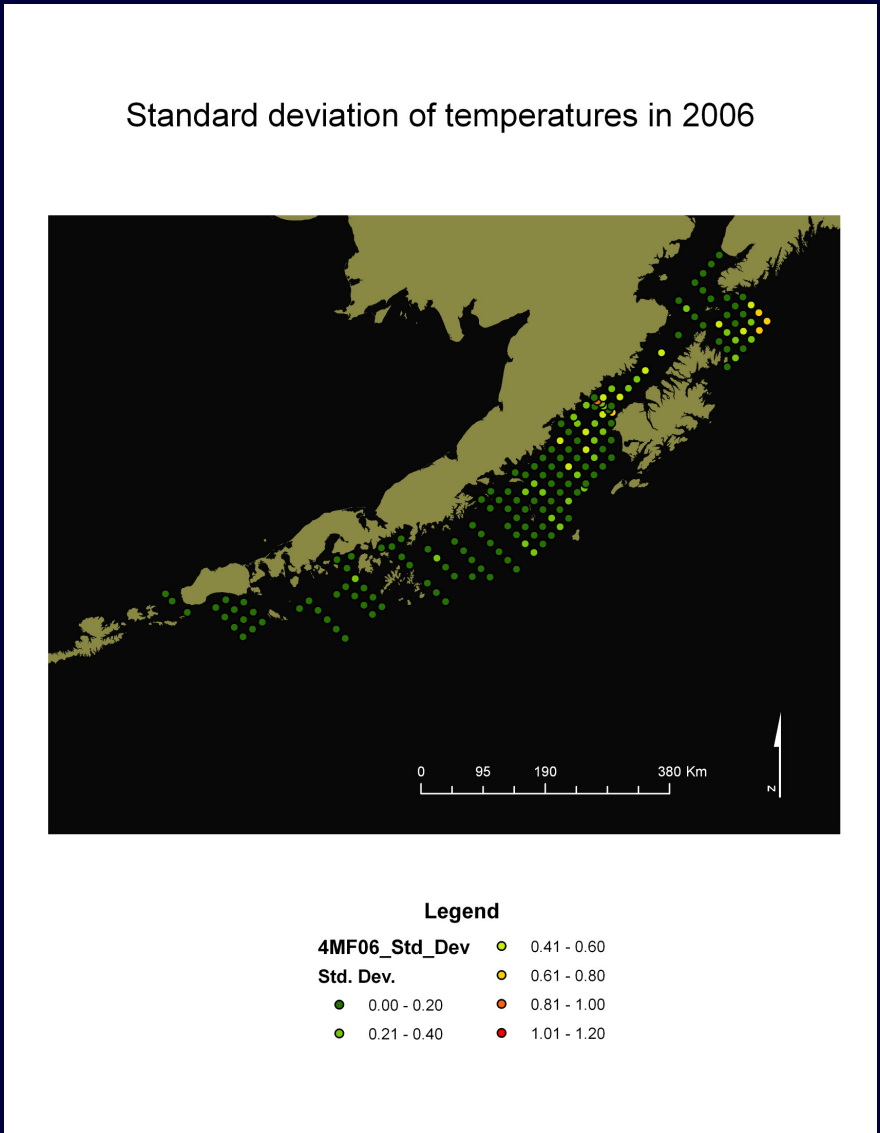
- QC/QA of raw data
- Temperature patterns over the sampling grid volume – temperature affects growth of fish and intensity of the individual otolith increments
- Mixed layer depth and other oceanographic measures
- Granularity and connectedness of patches
- Mean and variance of temperatures
- Location of currents and eddies
- Inter-annual variations


Bering Sea
Alaska Peninsula
Kodiak I.
Gulf of Alaska
0
95
190
380 Km
N

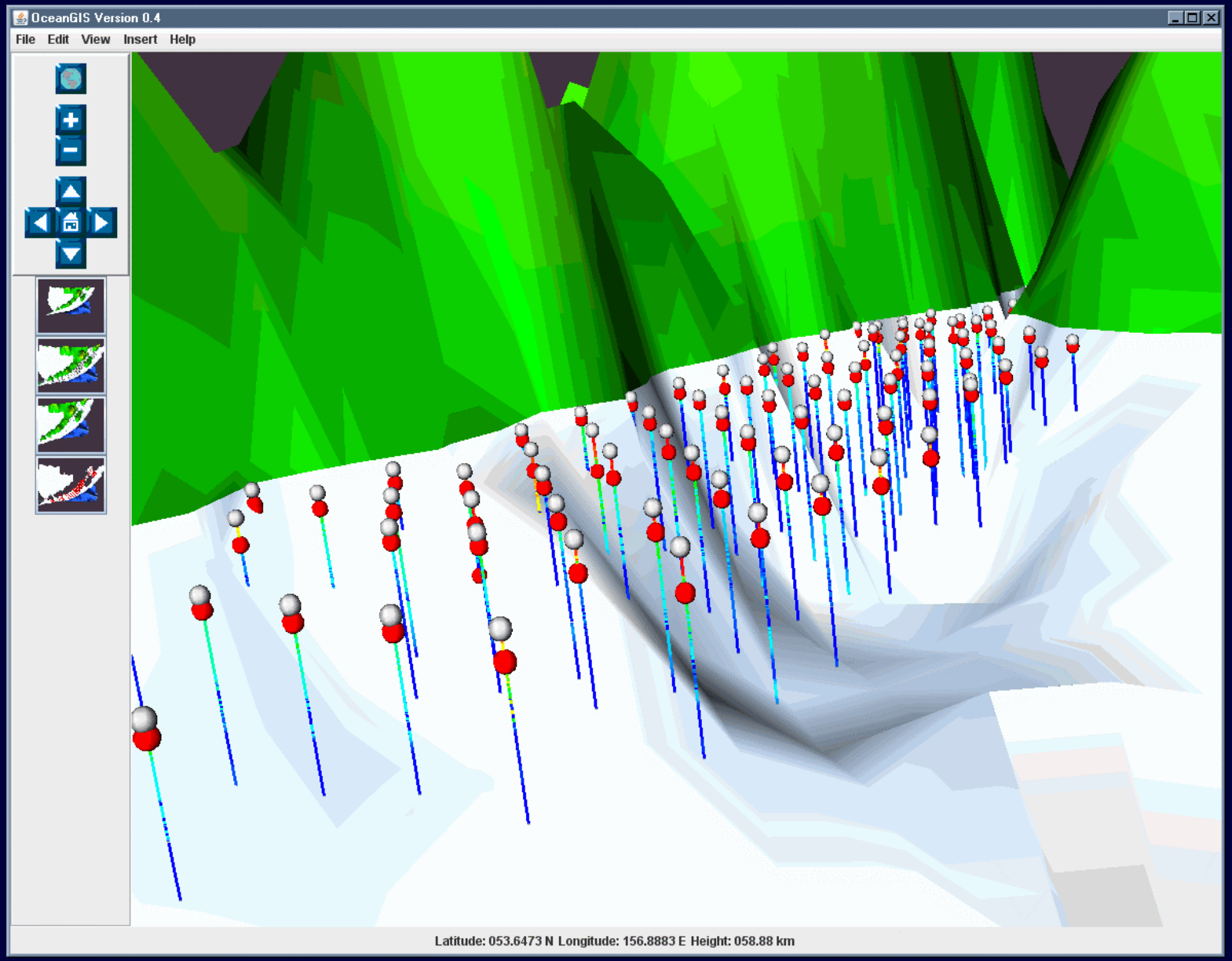

OceanGIS Version 0.4
File Edit View Insert Help
Latitude: 049.6577 N Longitude: 156.4112 E Height: 236.30 km

Analyses in GeoModeler and ArcGIS

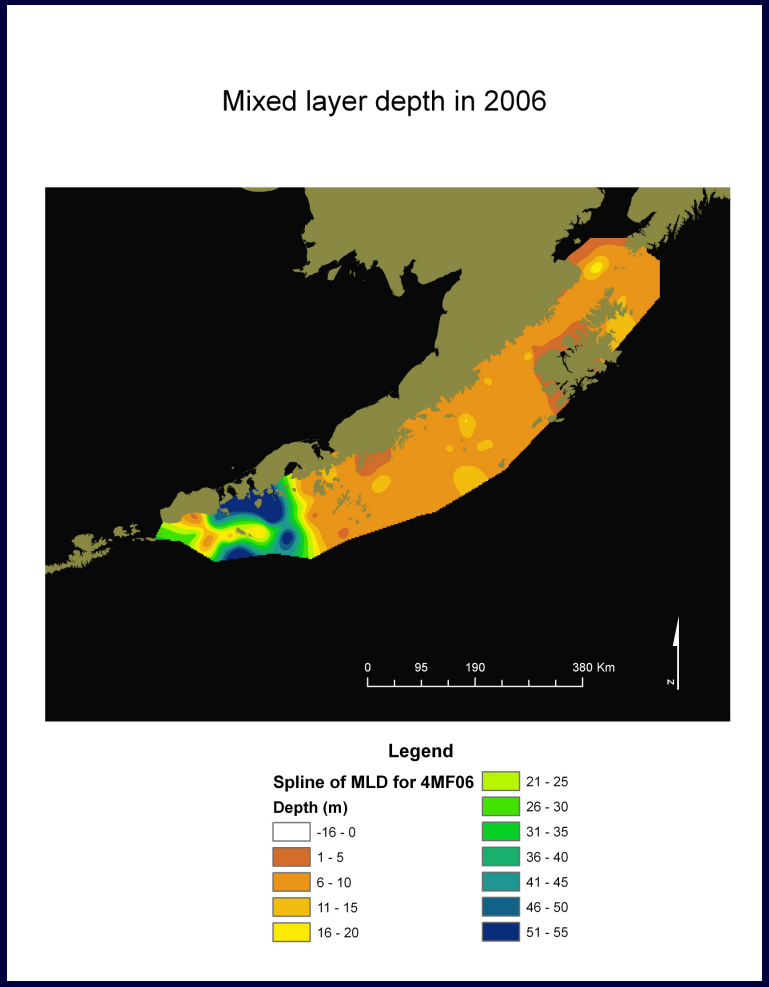
- Patterns of variability within a year
- Standard deviation calculated for each vertical profile
- Values plotted on same scale for all years
- 2006 shows above average variability



Mixed layer depth

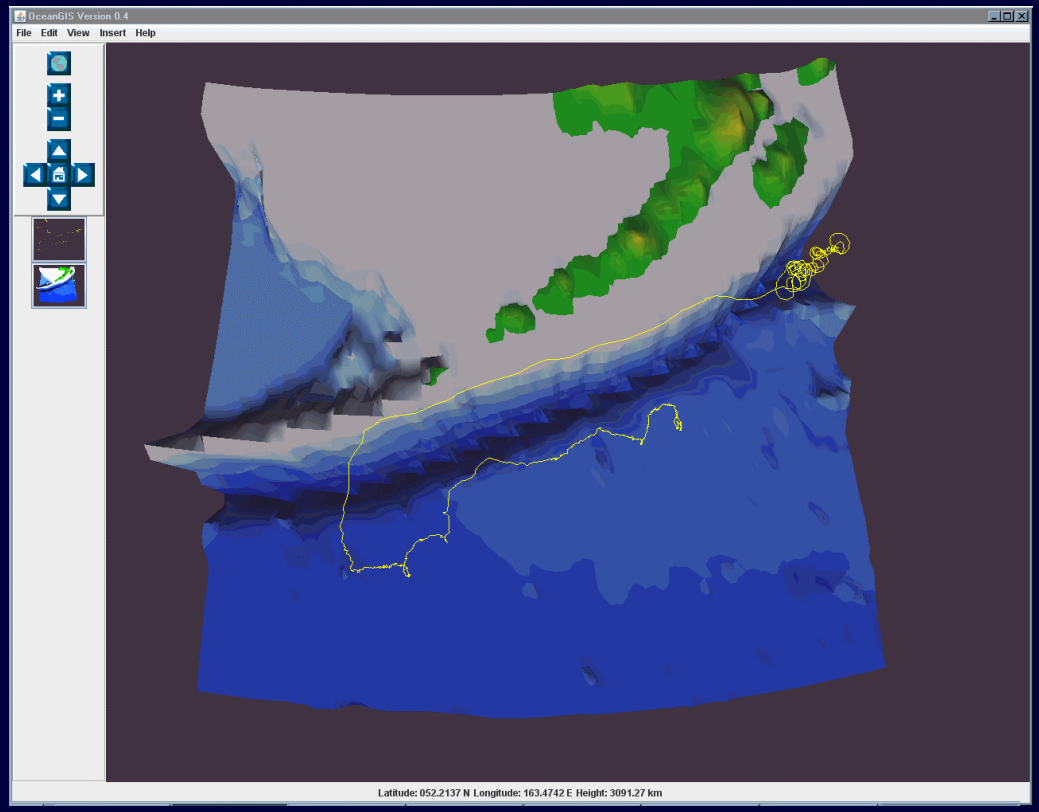


- Physical factors that affect where larvae reside and the conditions they experience
- Larvae do not use the whole water column
- What depths they use may vary from year to year



Displaying drifter tracks

- Larvae are not free-swimming
- Currents determine where they end up
- Location affects survival and growth



Results

- GeoModeler tools and analyses are useful for some users. But, technology is not enough.
- Interaction with the 3-D displays is crucial.
- Need better 3-D statistics and landscape metrics.
- Still don't fully understand the environment, and may well not have enough data to do this.
- Need to quantify otolith increment intensity.
- Need to integrate trajectories based upon circulation models to create temperature histories for larvae.
- Role of GoogleEarth and other new technologies?

Conclusions from this "long strange journey"

- History as a guide for current development efforts
  - Context and motivation – technological, scientific, and human
  - Diffusion of techniques and ideas
  - Provides examples and lessons
- Creating a "new Stommel diagram" versus learning from the history of the original?
  - Stommel as a unique thinker at a key time
  - Rise of "big oceanography"
  - Qualitative versus quantitative
  - Need to simplify versus ability to display a virtual reality
  - Role of derivative diagrams

Oceanographic data display in 1963

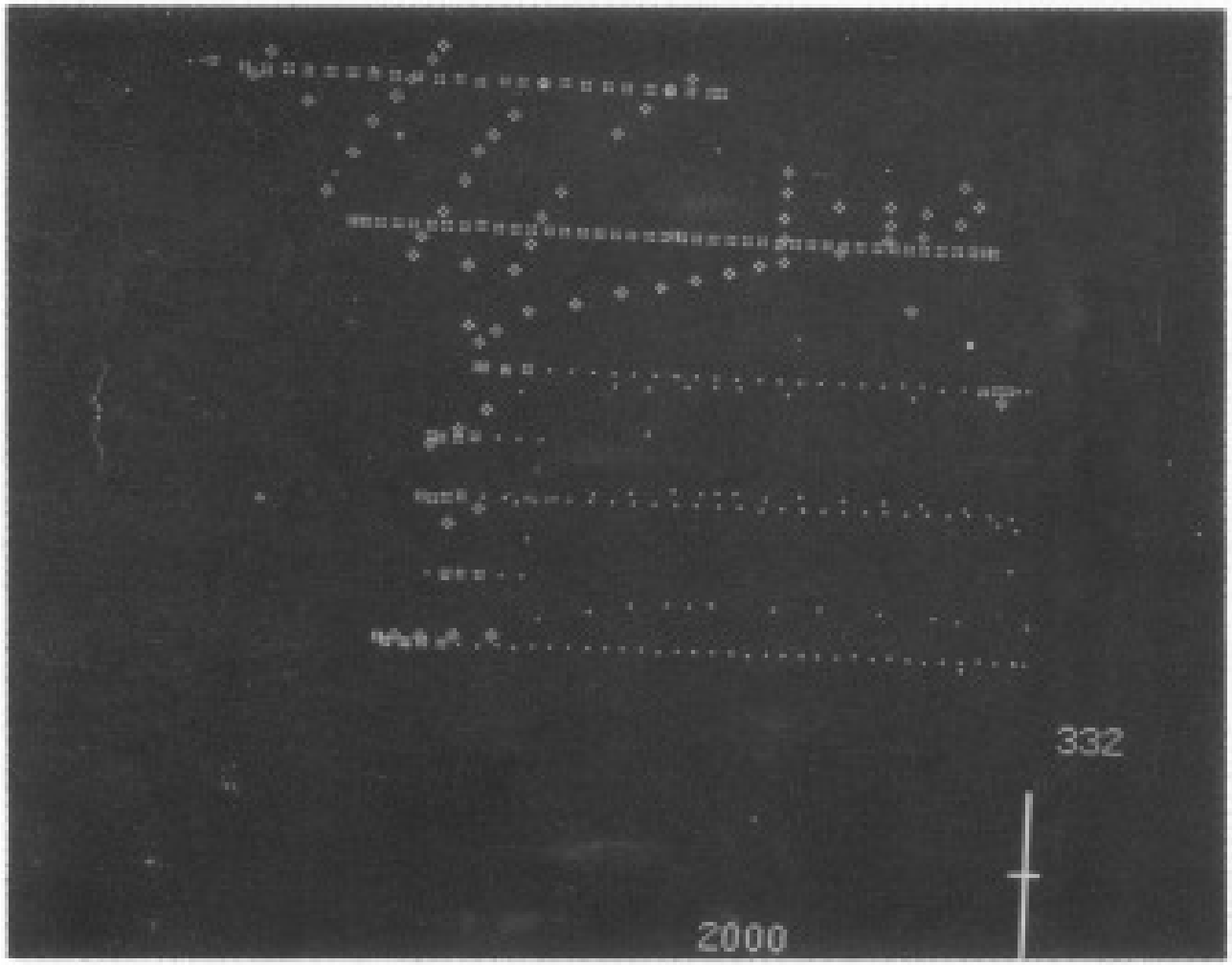
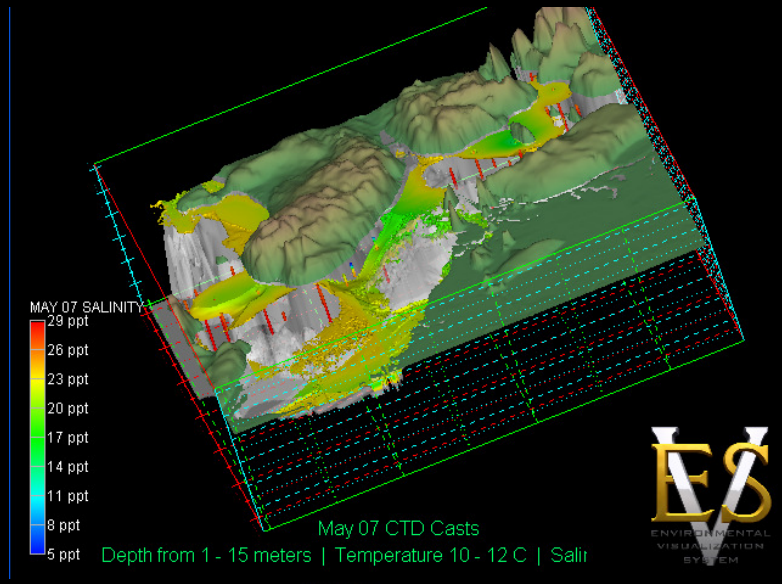
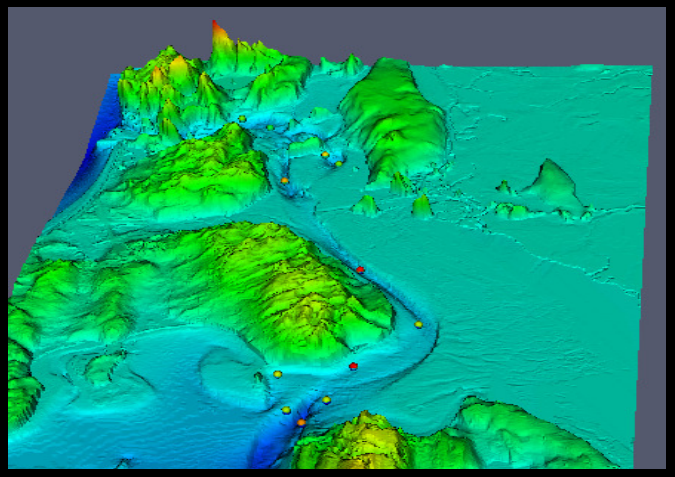


FIG. 2.—IGY data superposed upon *Meteor* data in smaller area. Temperature is set at 3.32°C; depth at 2,000 meters. See text for explanation.

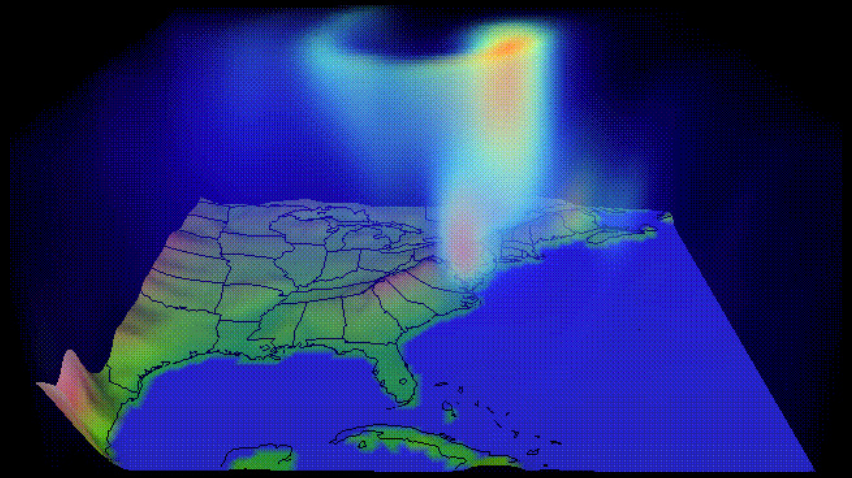
Pivar et al., *PNAS*, 1963

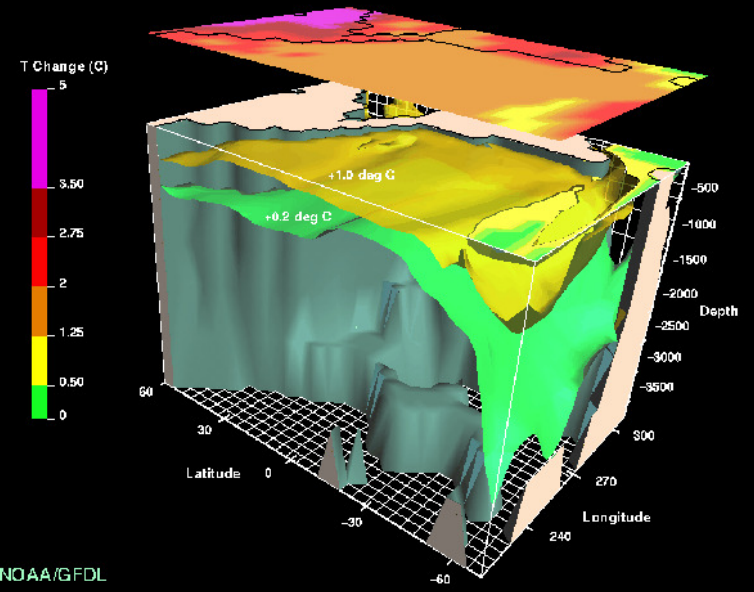
Oceanographic data display in 2007





ATMOSPHERIC AND OCEANIC TEMPERATURE CHANGE





http://www.ssec.wisc.edu/~billh/vis.html

http://www.nitrd.gov/pubs/bluebooks/1996/section.2.6.2.html

Conclusions II

- Balance of need, technology and perception of benefit
- A great idea may not be used if it doesn't fit a need.
- Adopters might not be that you expect – pedagogy leads to new analysis tool
- Understand your audience and how they use visual tools, e.g. dynamic versus static displays
- Original intent of the Stommel diagram still important – make sure the data you are collecting are the right data for the questions you are asking. Not as simple as it sounds.

Credits: the SMSA

- My committee and the Geosciences office staff
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- Lynn and Ed Long
- Colleagues in Geography department and History of Science program
- *Amtrak Cascades* and the Horizon Airlines *Portland Shuttle*
- All who believed it could happen, and helped make it happen


The End