Development and application of a Coupled-Ocean-Atmosphere-Waves-Sediment Transport (COAWST) Modeling System

John Warner, Brandy Armstrong, Maitane Olabarrieta

US Geological Survey, Woods Hole, MA

Ruoying He, Joseph Zambon

Marine, Earth & Atmospheric Sciences, North Carolina State University

George Voulgaris, Nirnimesh Kumar

Department of Earth & Ocean Sciences, University of South Carolina

Kevin Haas

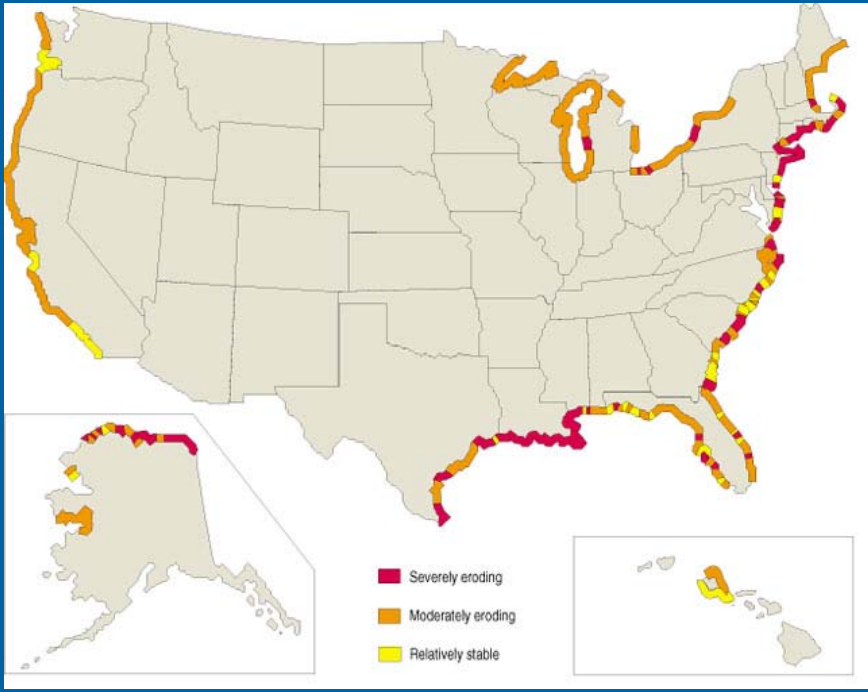
Dept. of Civil and Environmental Engineering, Georgia Institute of Technology

Outline

- Research Direction
- Model development
  - ROMS
  - Sediment
  - Wave
  - Atmosphere
  - Coupled system
- Application
  - Hurricane Isabel
  - Forecasting system

USGS

Develop capabilities to predict coastal erosion



Williams and Johnston, 1995

Rates of Coastal Erosion

Myrtle Beach, SC

Kitty Hawk, NC

USGS

Want to use numerical models to investigate coastal processes

Atm-ocn interactions

Wave-driven flows

Morphological Change

USGS

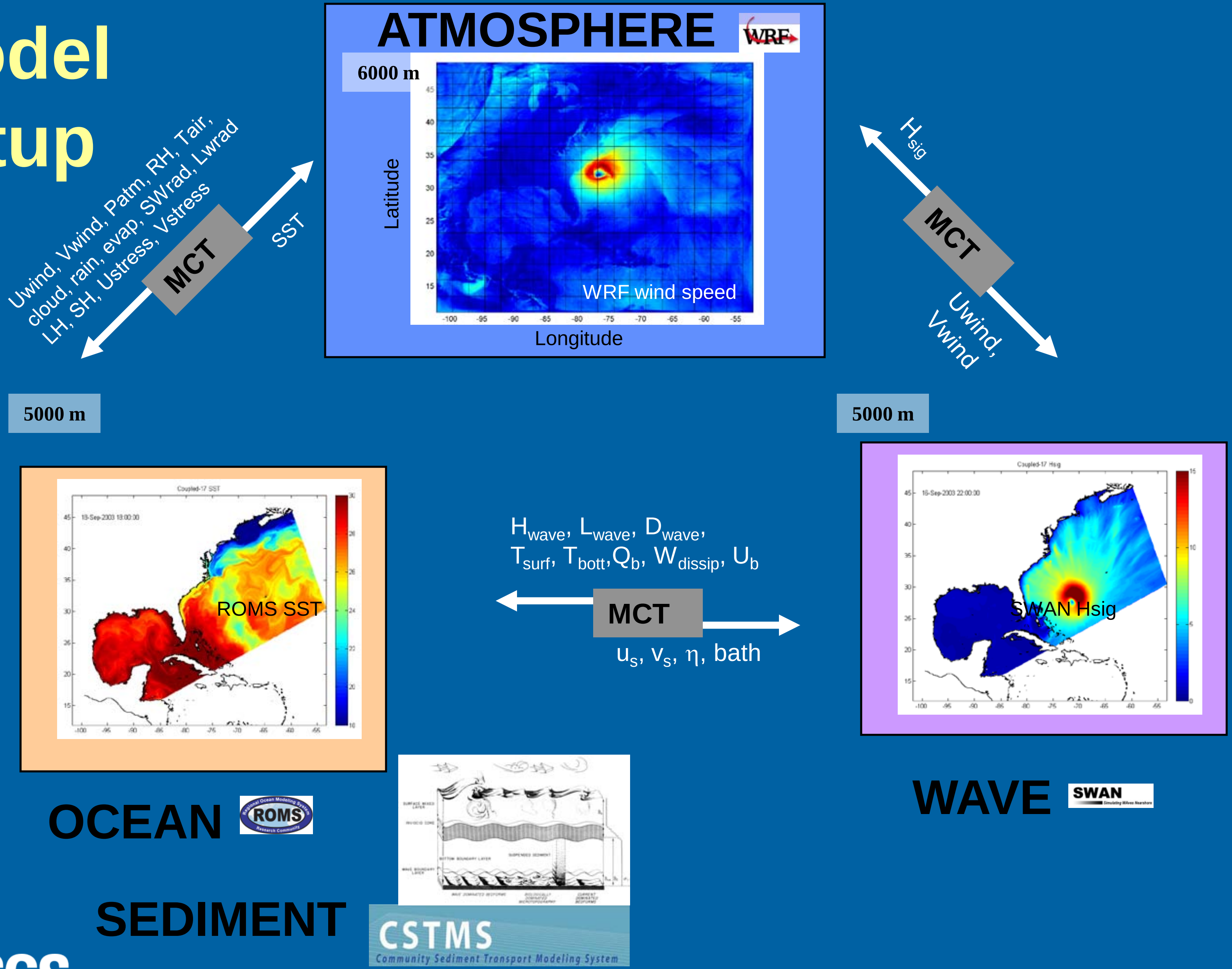
COAWST Modeling System

We are developing a Coupled Ocean – Atmosphere – Wave – Sediment Transport (**COAWST**) Modeling System to investigate the impacts of storms on coastal environments.

C = Coupled	MCT v 2.6.0	http://www-unix.mcs.anl.gov/mct/
O = Ocean	ROMS svn 455	http://www.myroms.org/
A = Atmosphere	WRF v 3.1.1	http://www.wrf-model.org/
W = Wave	SWAN v 40.72ABCDE	http://vlm089.citg.tudelft.nl/swan
ST = Sediment Transport	CSTMS	http://woodshole.er.usgs.gov/project-pages/sediment-transport/

Modeling System

Model setup



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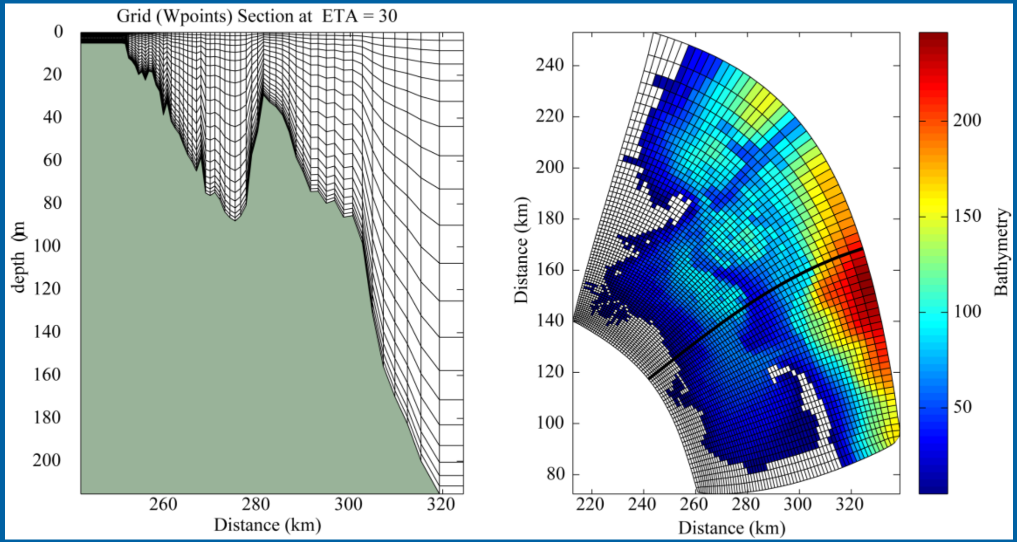
Regional Ocean Modeling System

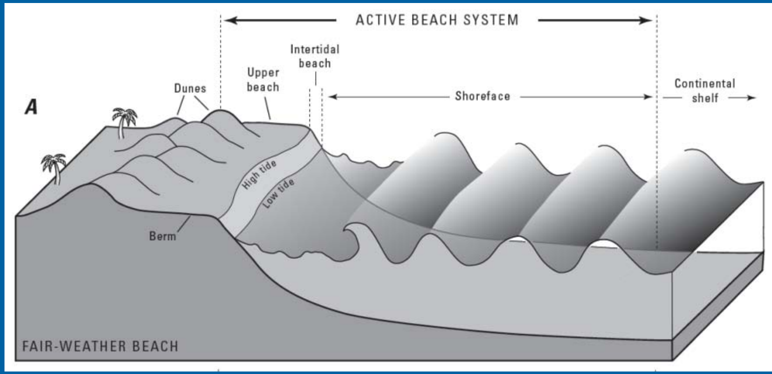
- Free surface, hydrostatic ocean model
- Finite-difference 3D Reynolds-averaged Navier-Stokes equations
- Horizontal orthogonal curvilinear Arakawa C grid
- Vertical stretched terrain-following Sigma coordinates
- Wide range of advection schemes: (e.g. 3rd-order upstream-biased, 4th-order)
- Wide range of open boundary conditions: (e.g. Radiation, clamped, nudged)
- CF-compliant NetCDF I/O
- Wide range of vertical mixing schemes (k-epsilon, k-omega, MY2.5, KPP, GLS)



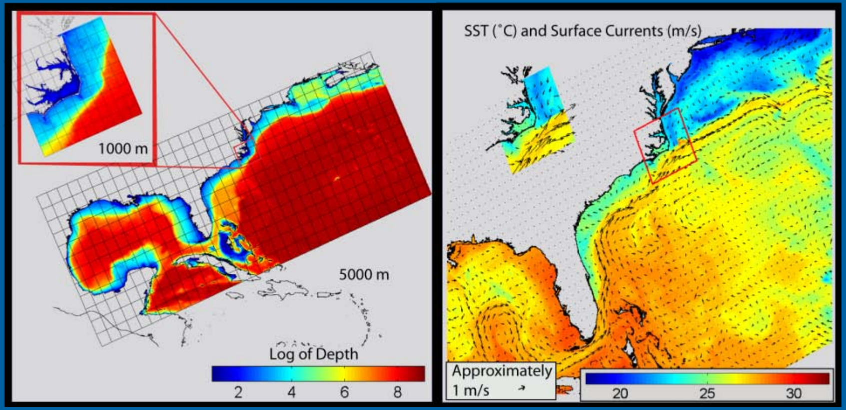
- Ice models
- Biological modules
- Model adjoint for data assimilation
- Fortran 90; Runs on any Unix, Mac, and Windows
- Parallel code in MPI and OpenMP

Some recent advancements in ROMS

- **Nearshore processes**
  - **Wave-current interactions**
    WEC (Uchiyama, et al 2010)
    Mellor 03, 05, 08, 10, ….
  - **Reniers roller model**



- **Grid manipulations**
  - **Composed grids**
  - **Refined grids**



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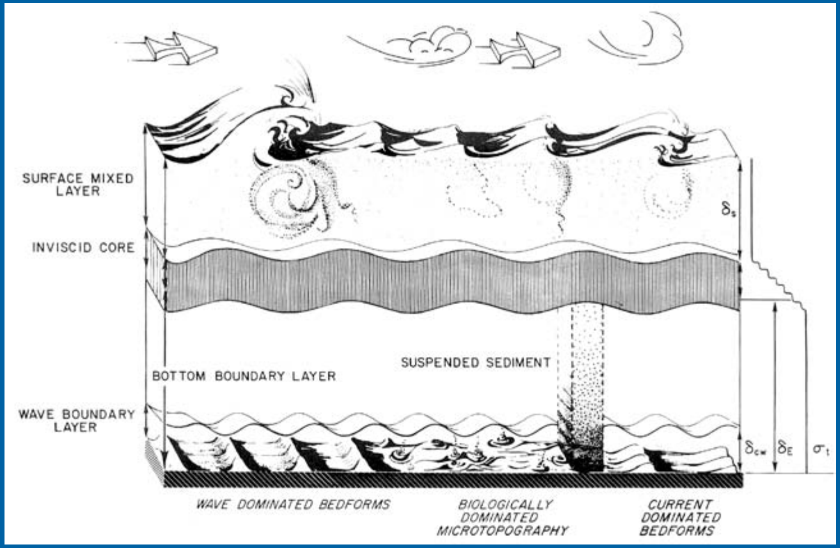
Sediment Model

CSTMS
Community Sediment Transport Modeling System



<u>Sediment Model Components</u>

- BBL
- Bedload Transport
- Suspended Sediment
- Bed Model
- Multiple Sediment Classes
- Morphology

Warner, J.C., Sherwood, C.R., Signell, R.P., Harris, C.K., and Arango, H.G. (2008). Development of a three-dimensional, regional, coupled wave, current, and sediment-transport model, Computers & Geosciences 34, 1284–1306.

USGS

SWAN

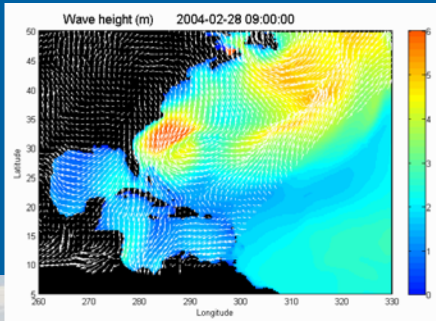
$$\frac{\partial N}{\partial t}+\frac{\partial c_x N}{\partial x}+\frac{\partial c_y N}{\partial y}+\frac{\partial c_\sigma N}{\partial \sigma}+\frac{\partial c_\theta N}{\partial \theta}=\frac{S_w}{\sigma}$$

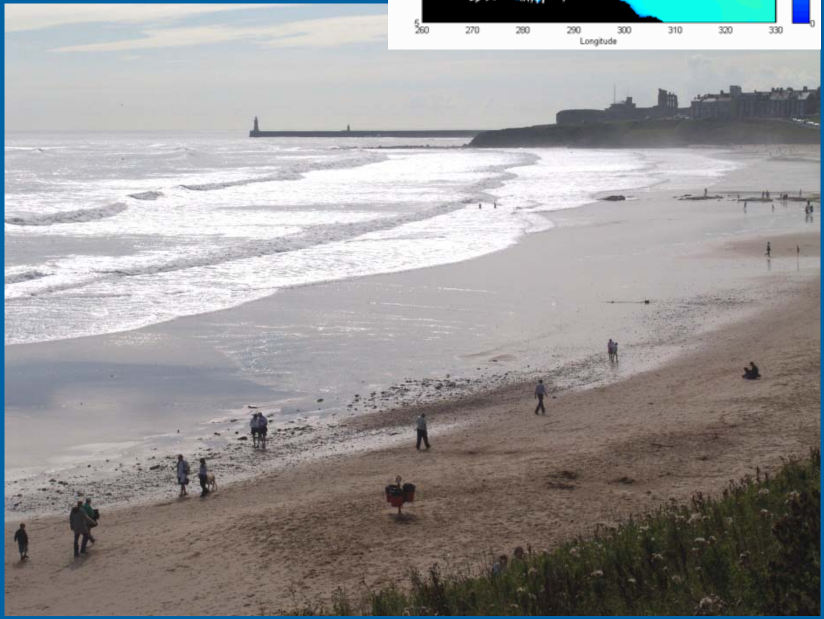
N = wave action density
(energy density / relative frequency)

cx, *cy* = propagation velocities (*x*- and *y*- directions)
σ = relative frequency
θ = wave direction

S = source/sink term for:
- wind-wave generation
- wave breaking
- bottom dissipation
- nonlinear wave-wave interactions

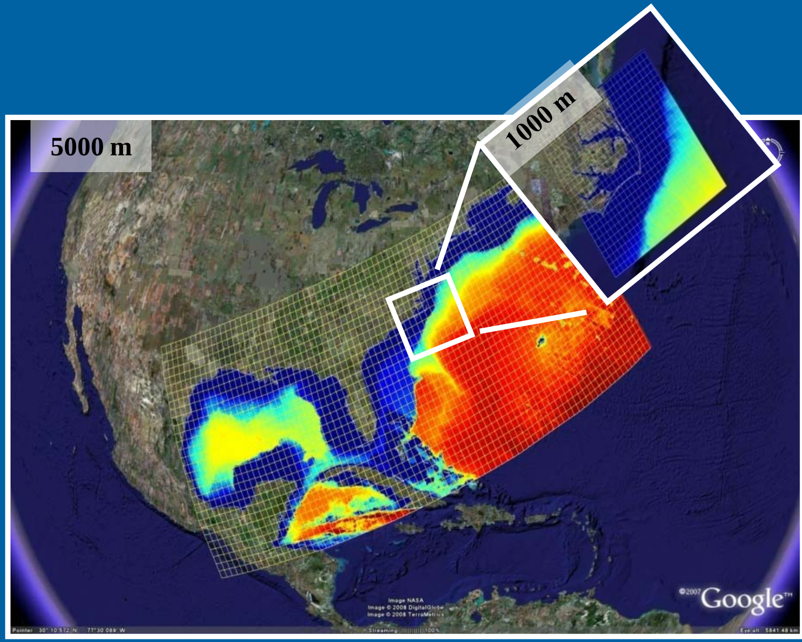
SWAN accounts for shoaling, diffraction, partial transmission, and reflection.

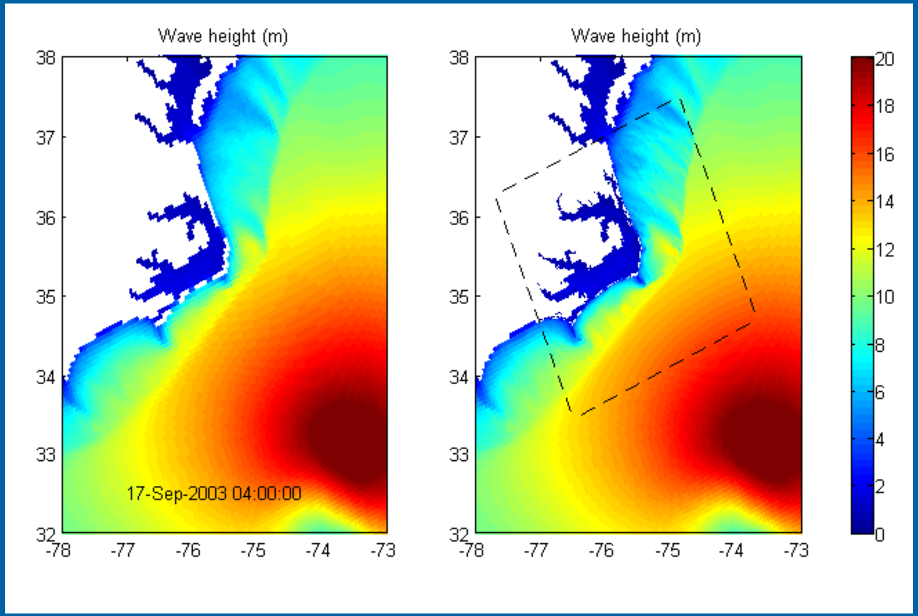




Booij, N., R.C. Ris and L.H. Holthuijsen, 1999, A third-generation wave model for coastal regions, Part I, Model description and validation, J.Geoph.Research, 104, C4, 7649-7666.
Booij, N., R.C. Ris and L.H. Holthuijsen, 1999, A third-generation wave model for coastal regions, Part II, Model description and validation, J.Geoph.Research, 104, C4, 7649-7666.
Booij, N., Haagsma, IJ.G., Holthuijsen, L.H., Kieftenburg, A.T.M.M., Ris, R.C., van der Westhuysen, A.J., and Zijlema, M. (2004). SWAN Cycle III version 40.41 User Manual, Delft University of Technology.

Implement concurrent grid refinement in SWAN





Coarse grid ~ 5 km

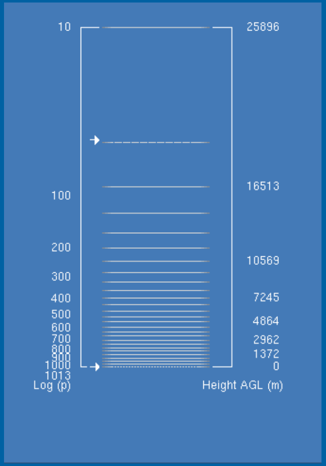
Coarse grid ~ 5 km
Refined grid ~ 1 km

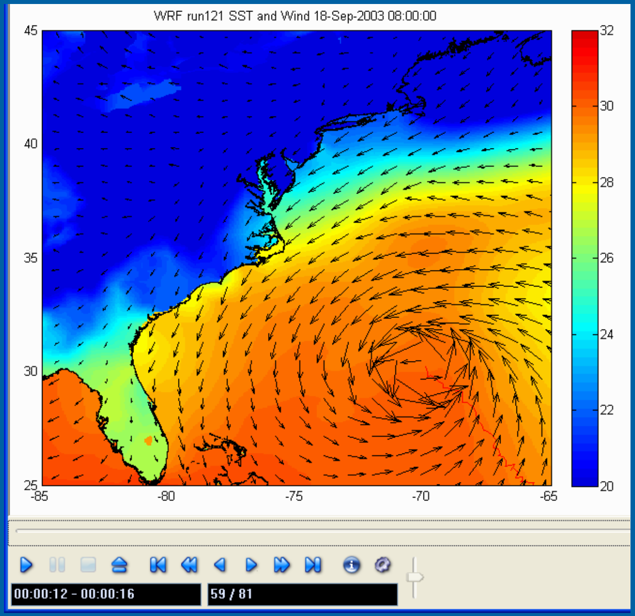
One-way refinement

- Parent grid steps 1 dt
- provides wave energy density to child grid perimeter
- Child grid steps nrefined times

WRF

The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system designed to serve both operational forecasting and atmospheric research needs. It features multiple dynamical cores, a 3-dimensional variational (3DVAR) data assimilation system, and a software architecture allowing for computational parallelism and system extensibility. WRF is suitable for a broad spectrum of applications across scales ranging from meters to thousands of kilometers.





WRF modification:

Mellor-Yamada-Janjic surface layer scheme.

- Original

z_0 = czo u* u*/g+ n/u*

-Modified to include wave effects based on Taylor and Yelland (2000)

$z_0 = 1200.0\ H_{wave}\ (H_{wave}/L_{wave})^{4.5} + 0.11\ n/u^*$

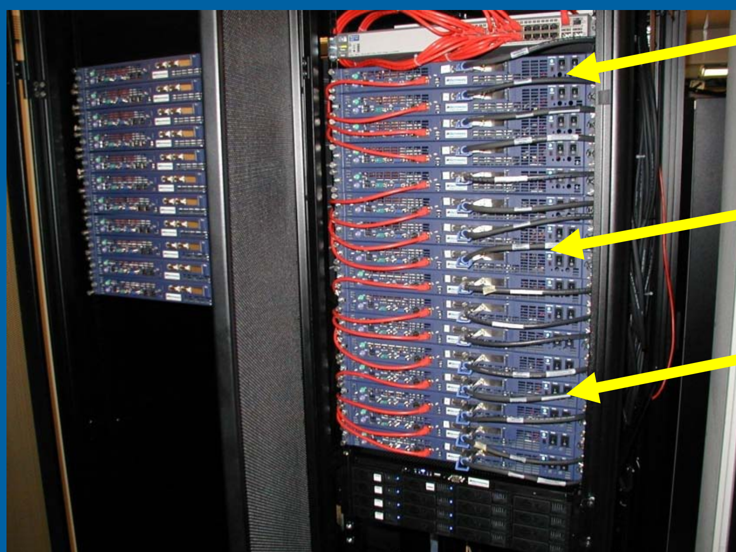
MCT

Model Coupling Toolkit

Mathematics and Computer Science Division Argonne National Laboratory

http://www-unix.mcs.anl.gov/mct/

MCT is an open-source package that provides MPI based communications between all nodes of a distributed memory modeling component system. Download and compile as libraries that are linked to.



Model A running on M nodes.

Model B running on N nodes.

Model C ………

………

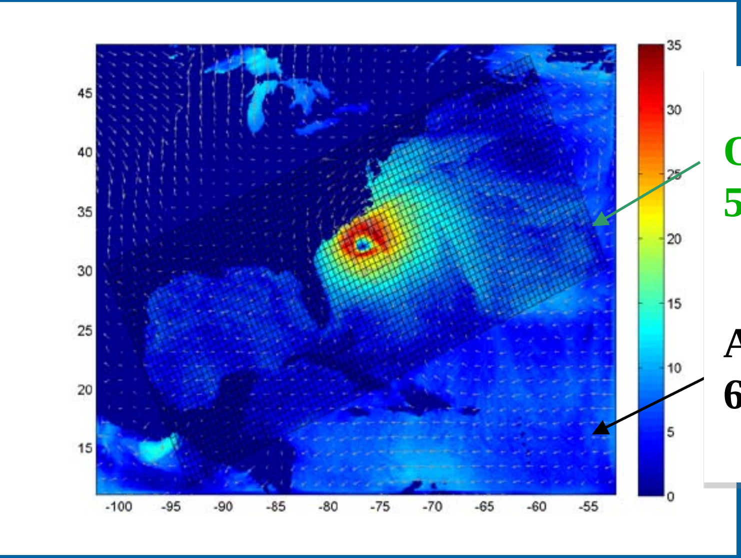
MCT provides communications between all models.

(it also works here)

Warner, J.C., Perlin, N., and Skyllingstad, E. (2008). Using the Model Coupling Toolkit to couple earth system models. Environmental Modeling and Software

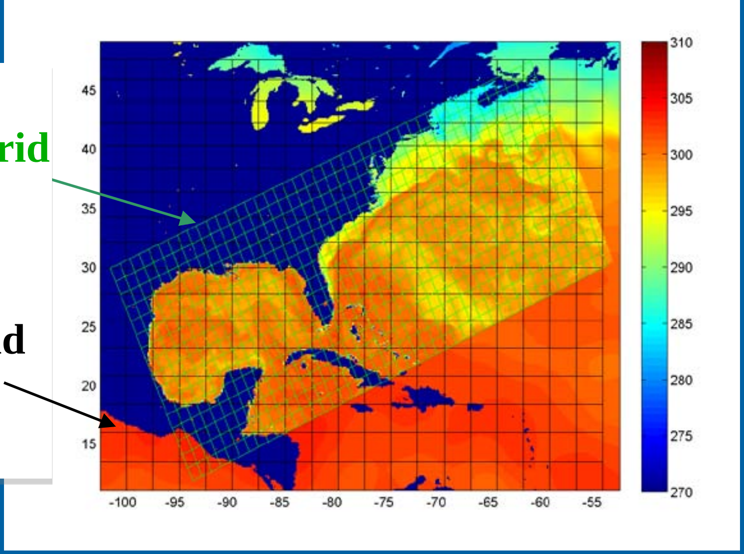
SCRIP - grid interpolation

http://climate.lanl.gov/Software/SCRIP/



Ocean grid 5 km

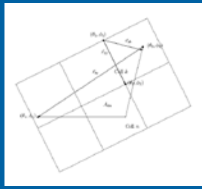
Atm Grid 6 km



WRF → winds → ROMS, SWAN, SCRIP

1° GFS data, ROMS → SST → WRF

Atmosphere model provides wind stress to cover entire ocean grid. SCRIP interpolations weights needed to remap data fields.



Remapping Schemes:
-flux conservative
- nearest neighbor

Ocean model provides higher resolution and coupled response of SST to atmosphere. But the ocean grid is limited in spatial coverage so atmosphere model must combine data from different sources, which can create a discontinuity in the forcing.

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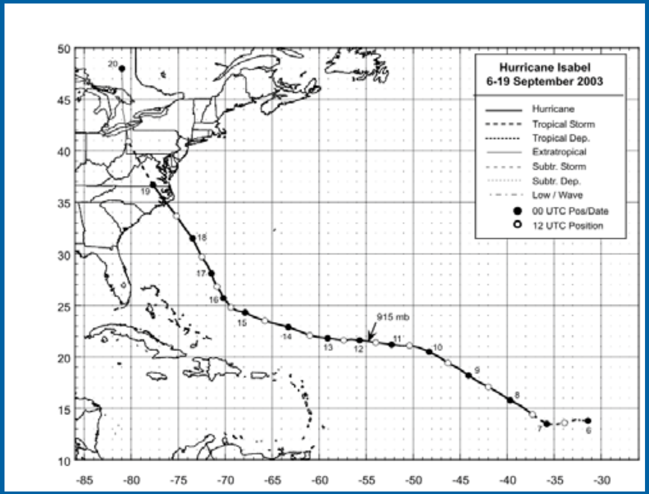
Application: Hurricane Isabel

http://visibleearth.nasa.gov/

http://coastal.er.usgs.gov/hurricanes/isabel/site-index.php?storm_id=4&site_id=11

USGS Oblique aerial photography of the breach caused by Hurricane Isabel.



Use the COAWST modeling system to hindcast Hurricane Isabel.

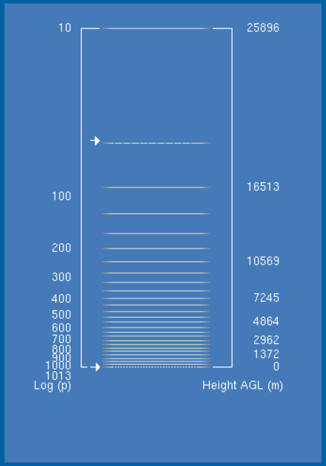
USGS

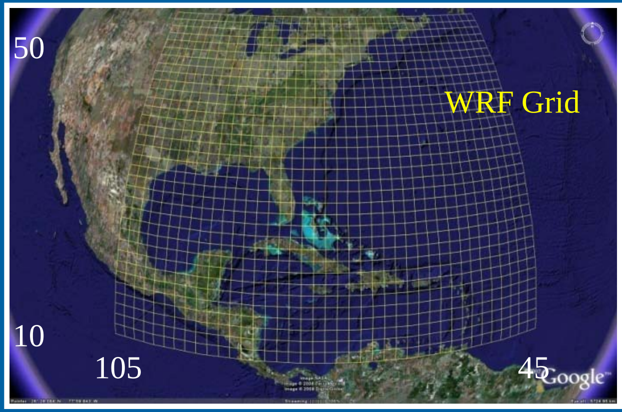
Track of Hurricane Isabel making landfall on the Outer Banks on 18 Sept 2003.

Model setup

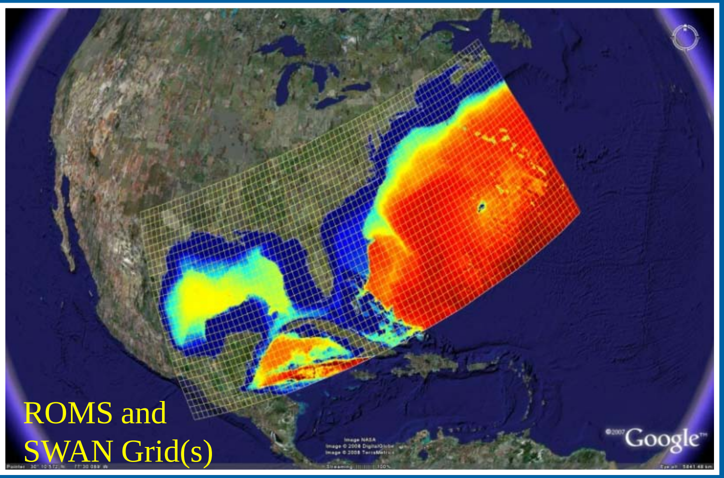
- WRF (Atmosphere)
  - 27 vertical levels
  - dt 36 s
  - Physics
    - Lin microphysics
    - RRTM longwave, Dudhia shortwave
    - Mellor-Yamada-Janjic (MYJ) PBL
    - Kain-Fritsch (KF) cumulus scheme

- ROMS (Ocean)
  - 16 vertical levels
  - dt 240, 48, 9.6
  - Physics
    - GLS turbulence closure
    - COARE bulk fluxes
    - BC's from HYCOM
    - Timestep = 240s
- SWAN (Wave)
  - BC’s from WW3
  - dt 600 s
  - Physics
    - Komen wave growth





6 km and 3 km grid spacing



5km and 1km grid spacings

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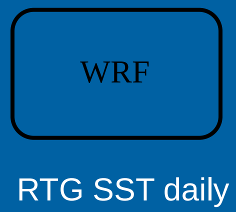
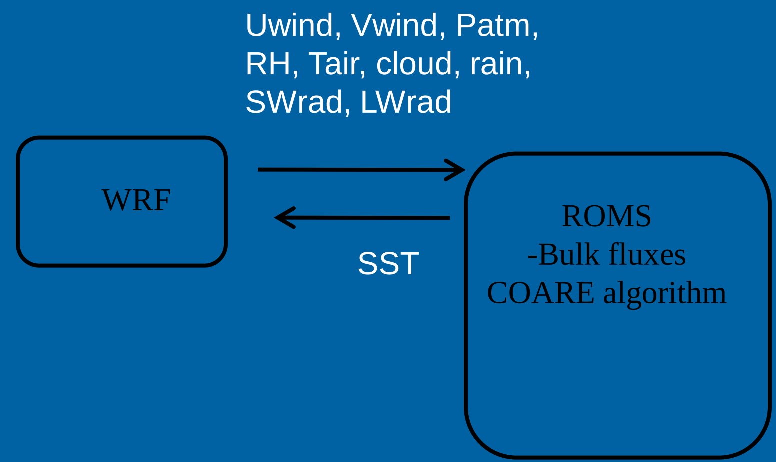
Simulation 12 Sept to 21 Sept, 2003.

Interaction tests

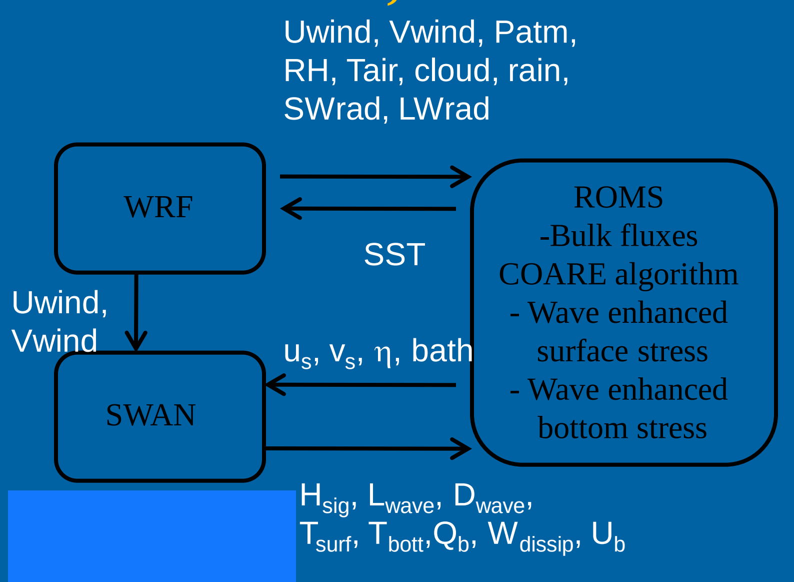
WRF



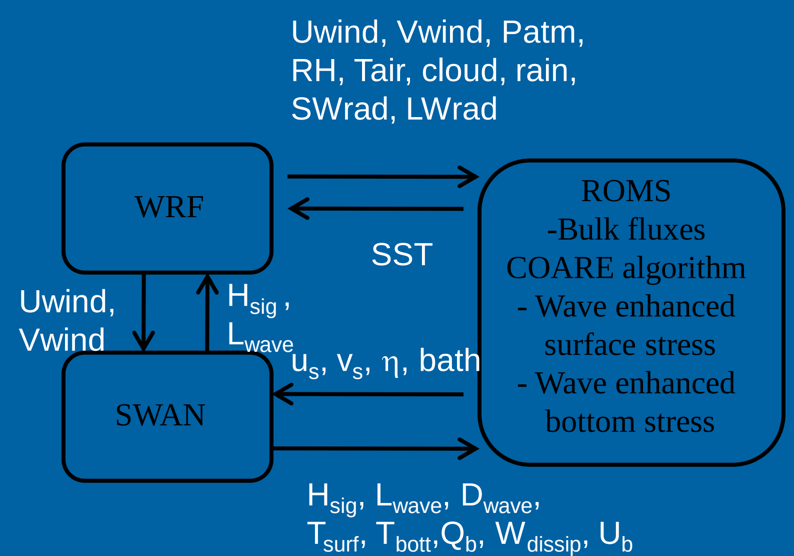
WRF + ROMS



WRF + ROMS, ROMS + SWAN



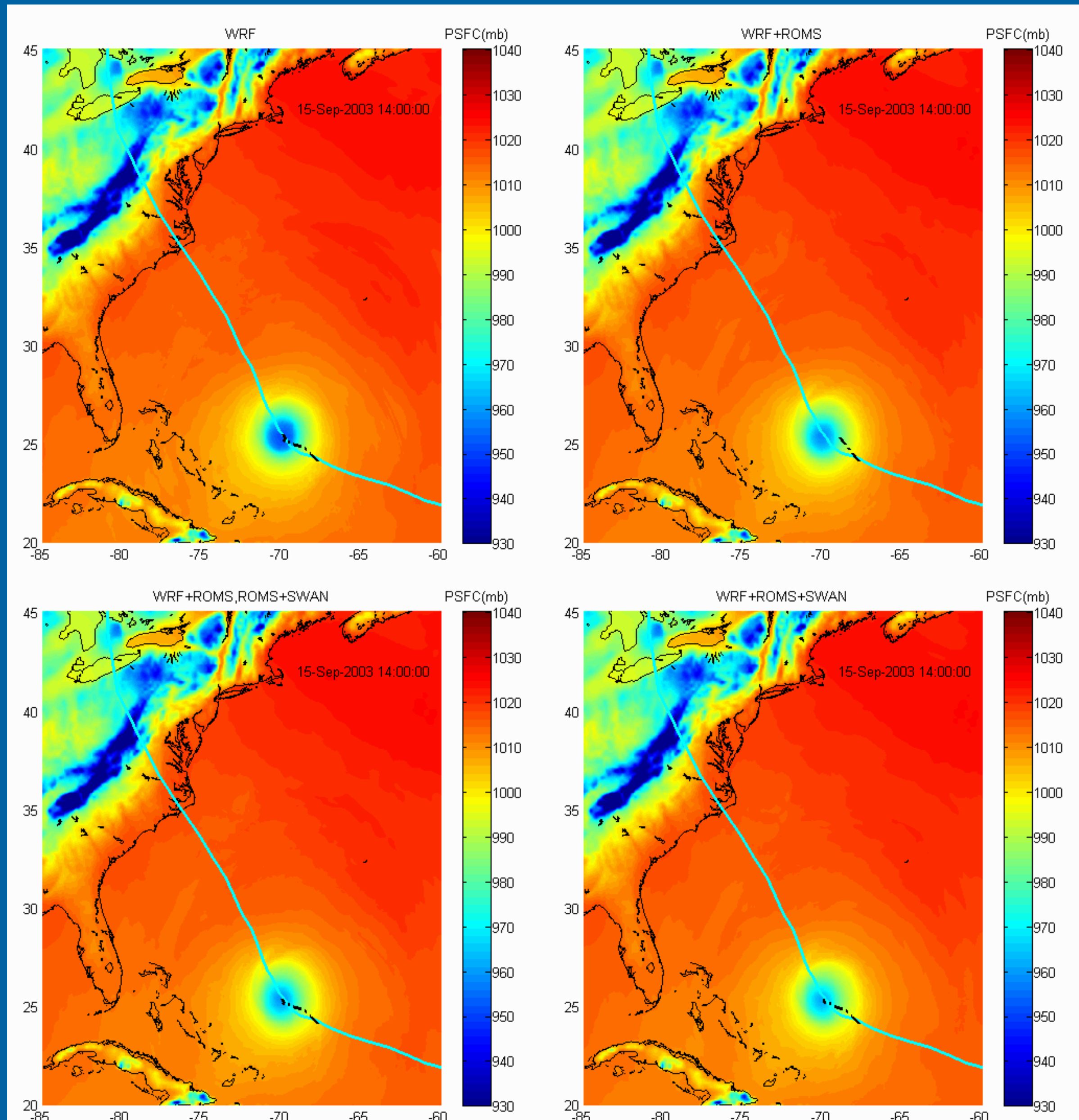
WRF + ROMS + SWAN



Hurricane Track and Intensity

WRF only,
dynamic SST
(updated daily)

WRF + ROMS

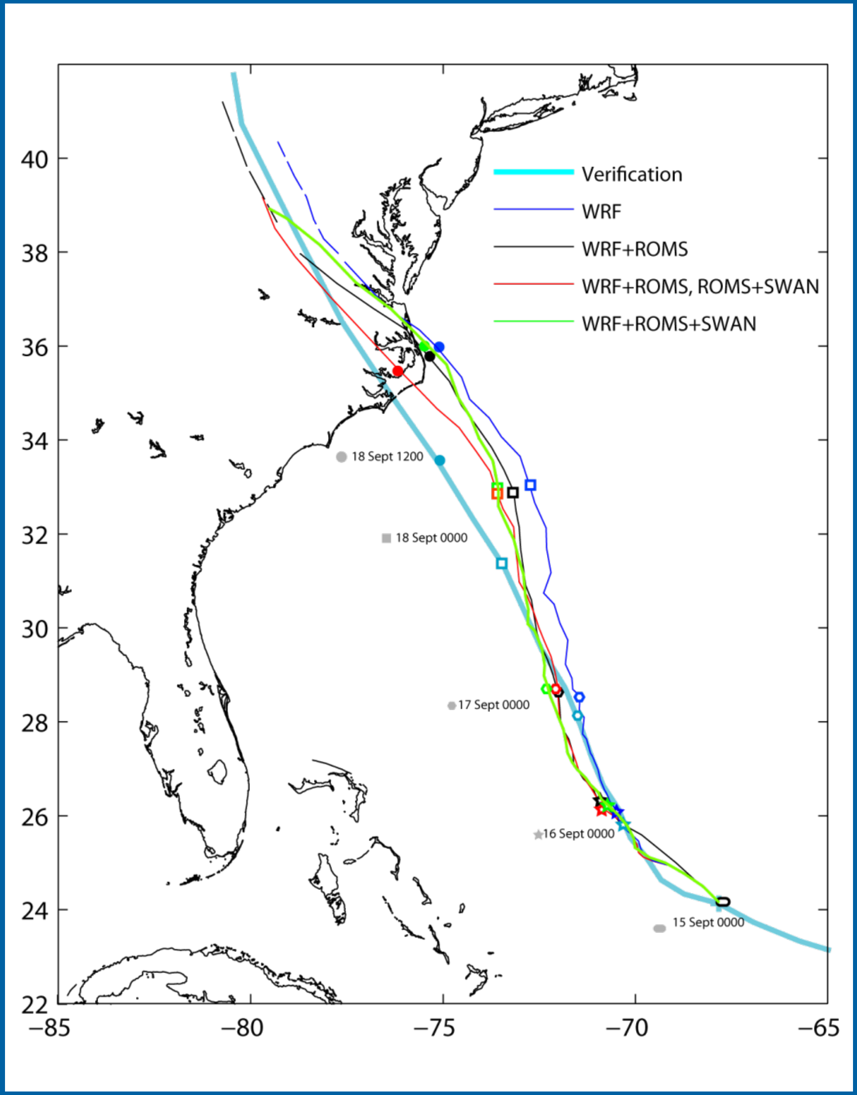


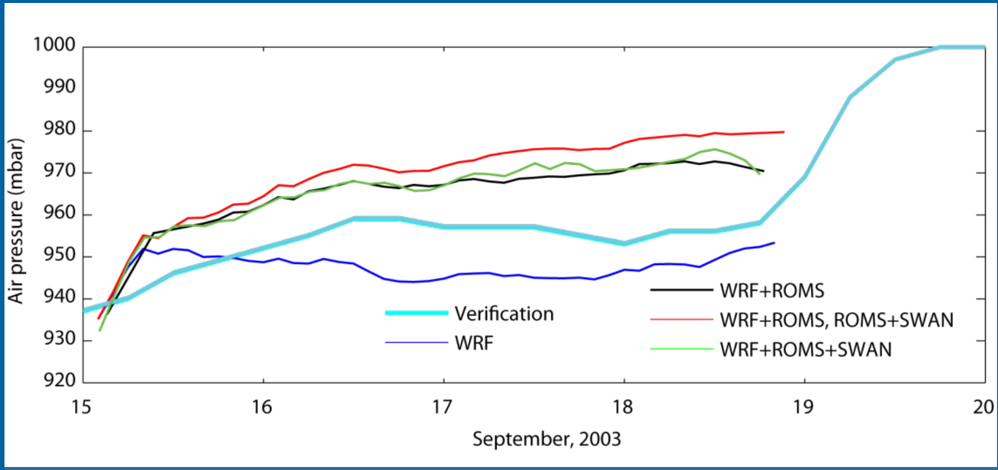
WRF + ROMS,
ROMS + SWAN

WRF + ROMS +
SWAN

USGS

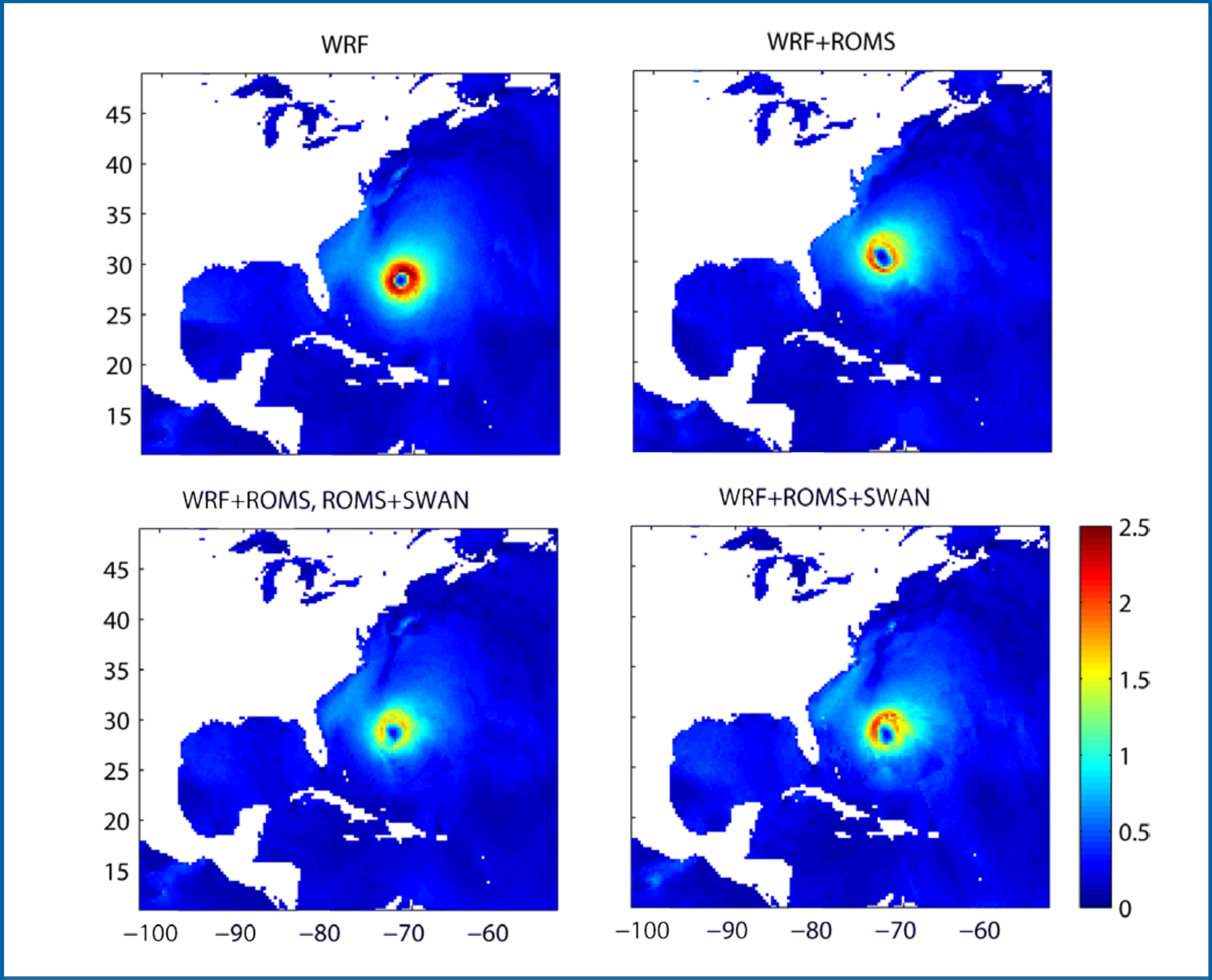
Hurricane track and Intensity





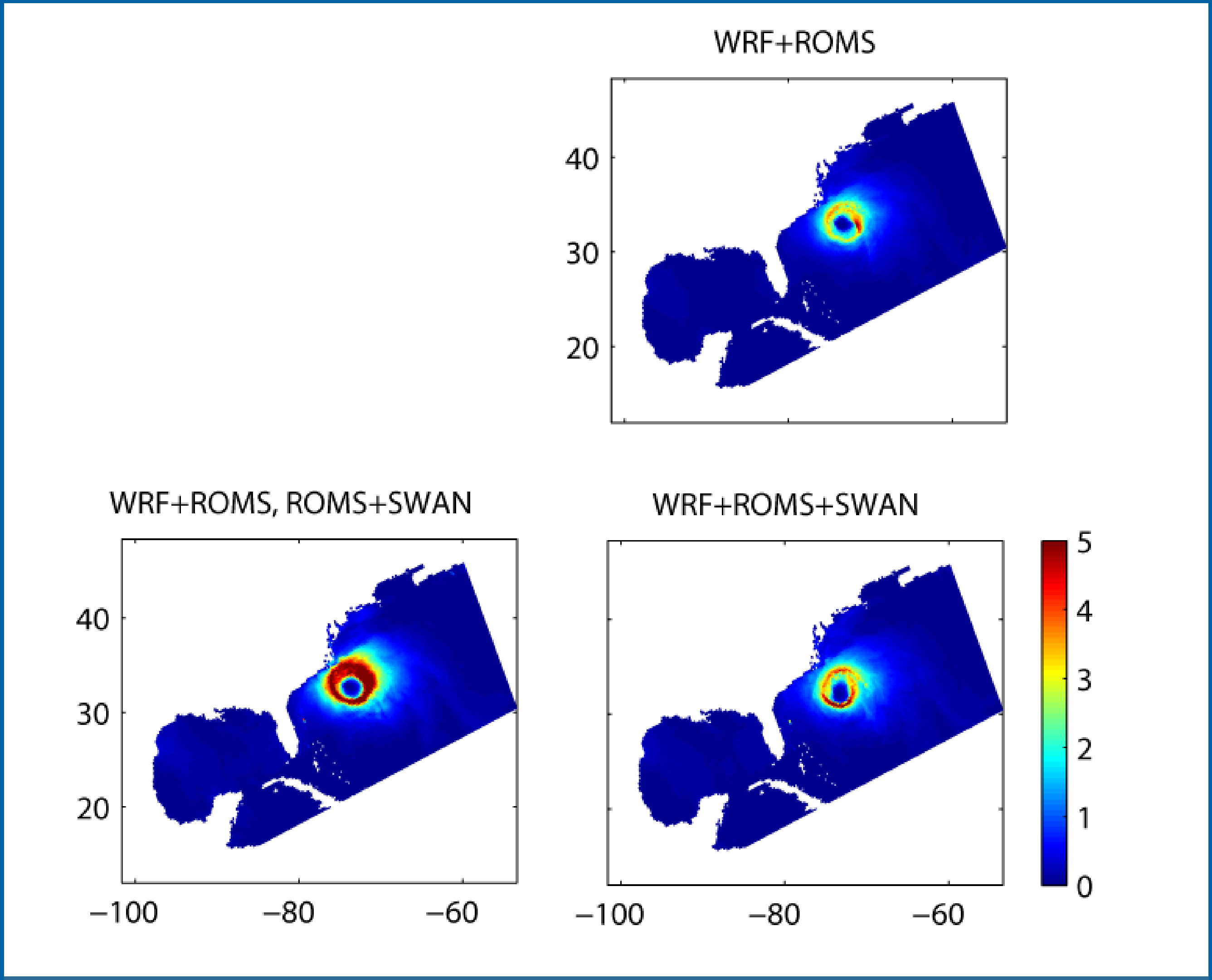
USGS

Atmosphere bottom stress (UST)



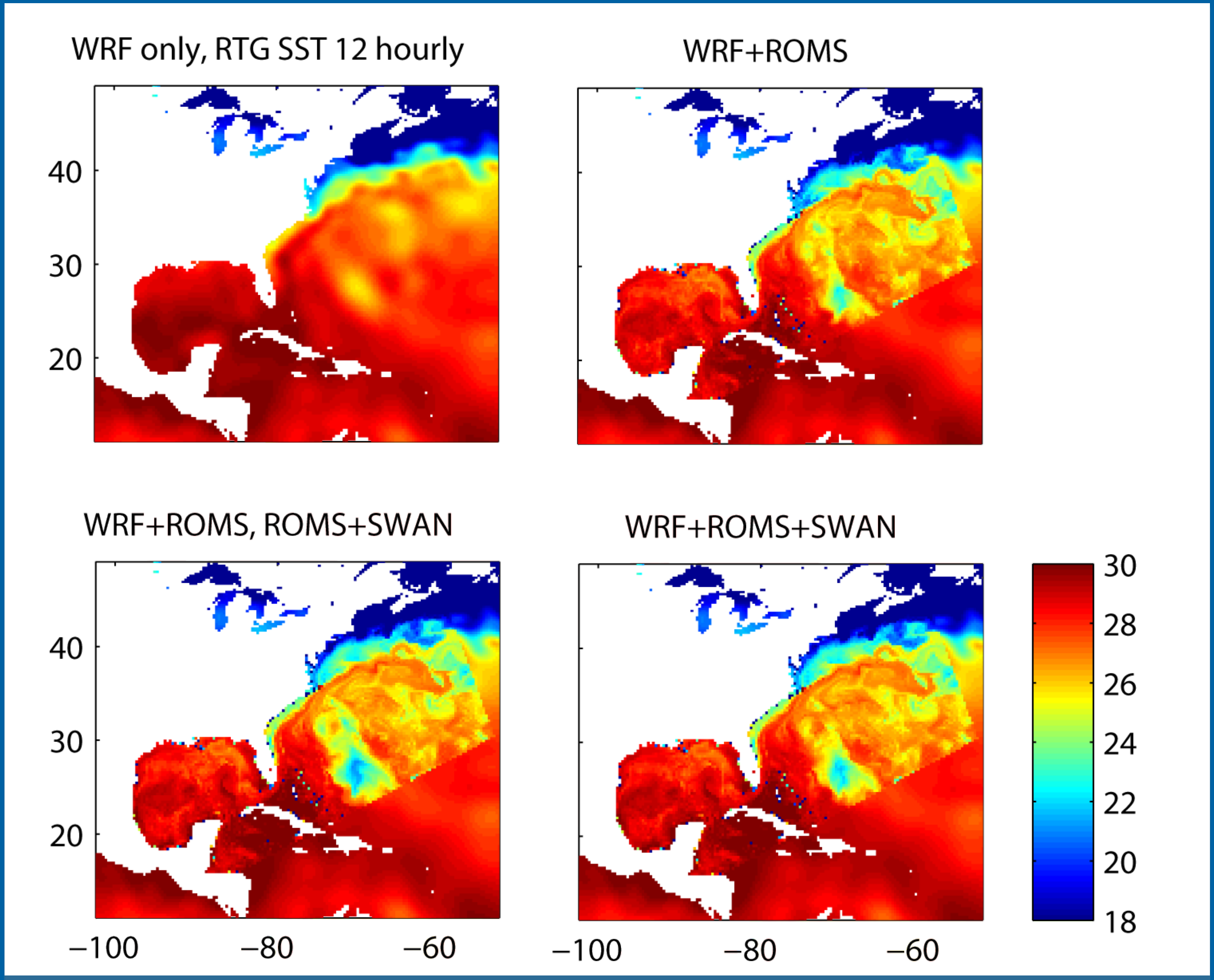
USGS

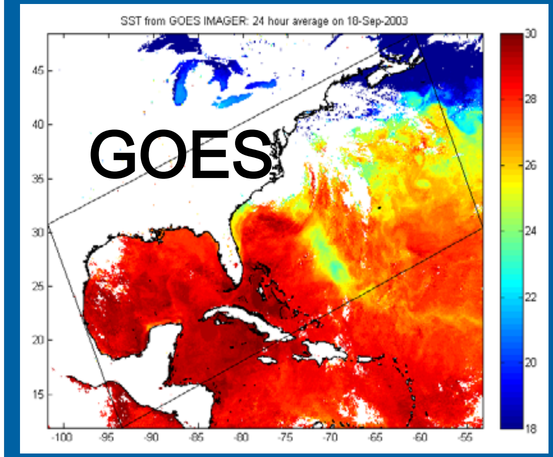
Ocean surface stress (su/vstr)



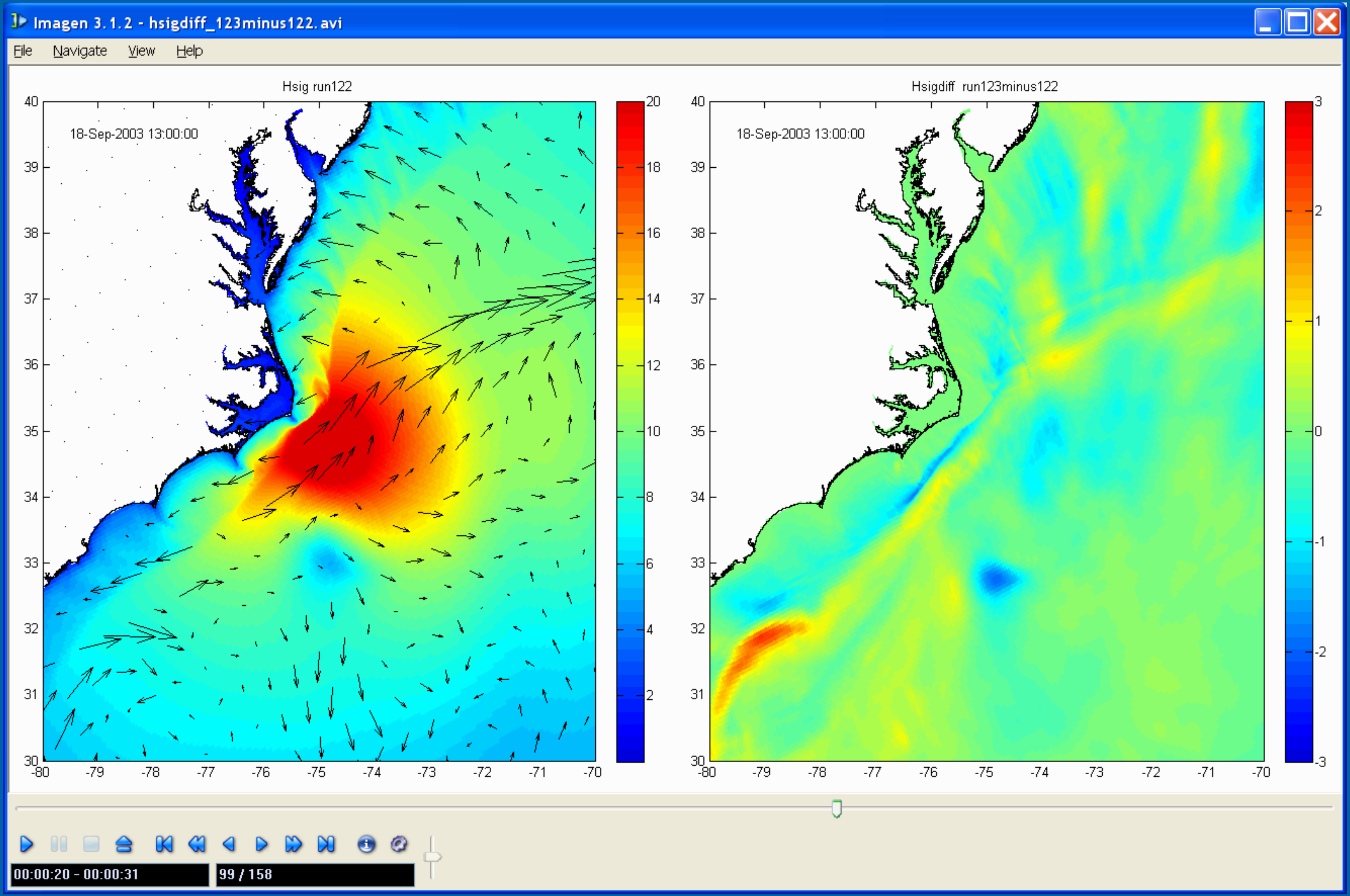
USGS

Sea surface temperature (SST)





Gulf Stream effects on waves

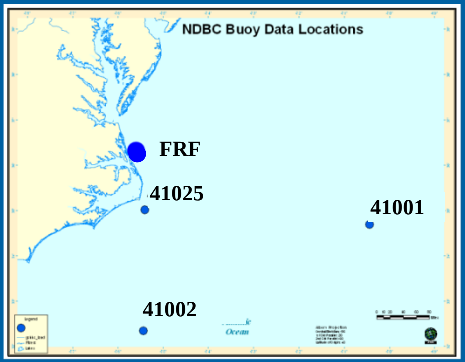


Same Winds

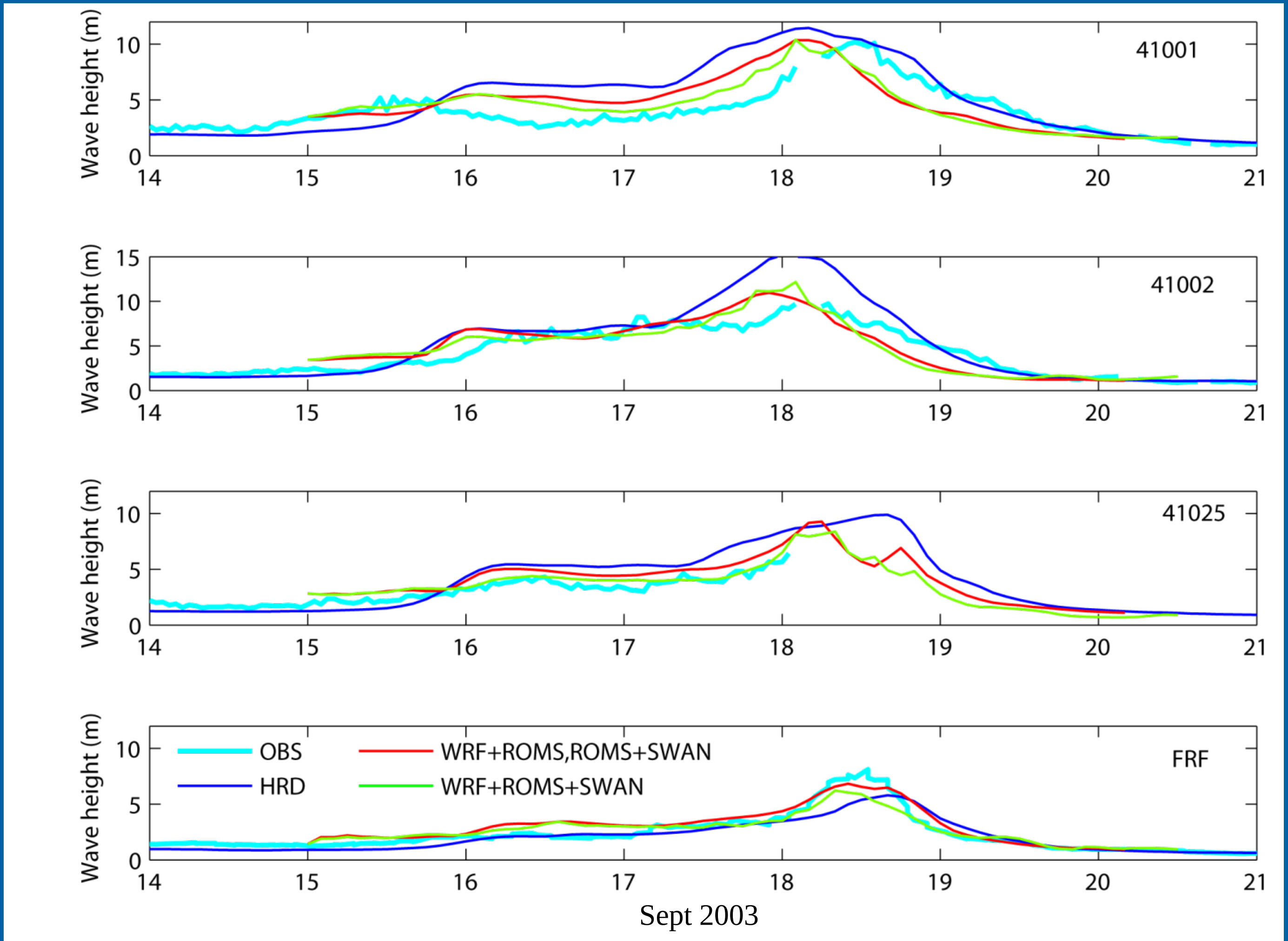
No currents to SWAN

Difference in wave heights:
Yes – No currents to SWAN

Wave heights



Predicted and observed wave heights.



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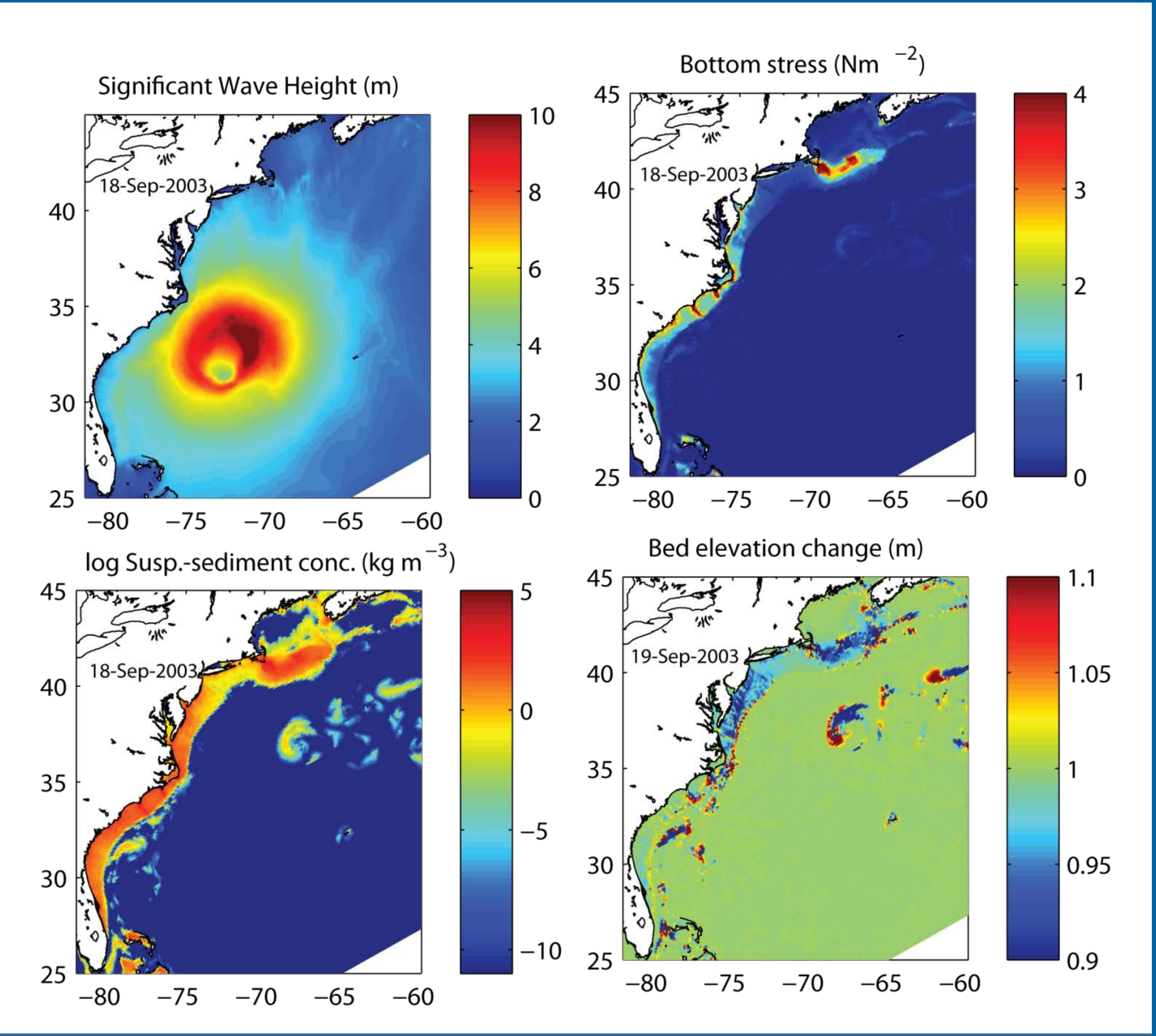
Sediment transport



<u>Sediment Class</u>

0.17 mm dia

2650 kg/m3

ws = 20 mm/s

E = 1d-4 kg/m2/s

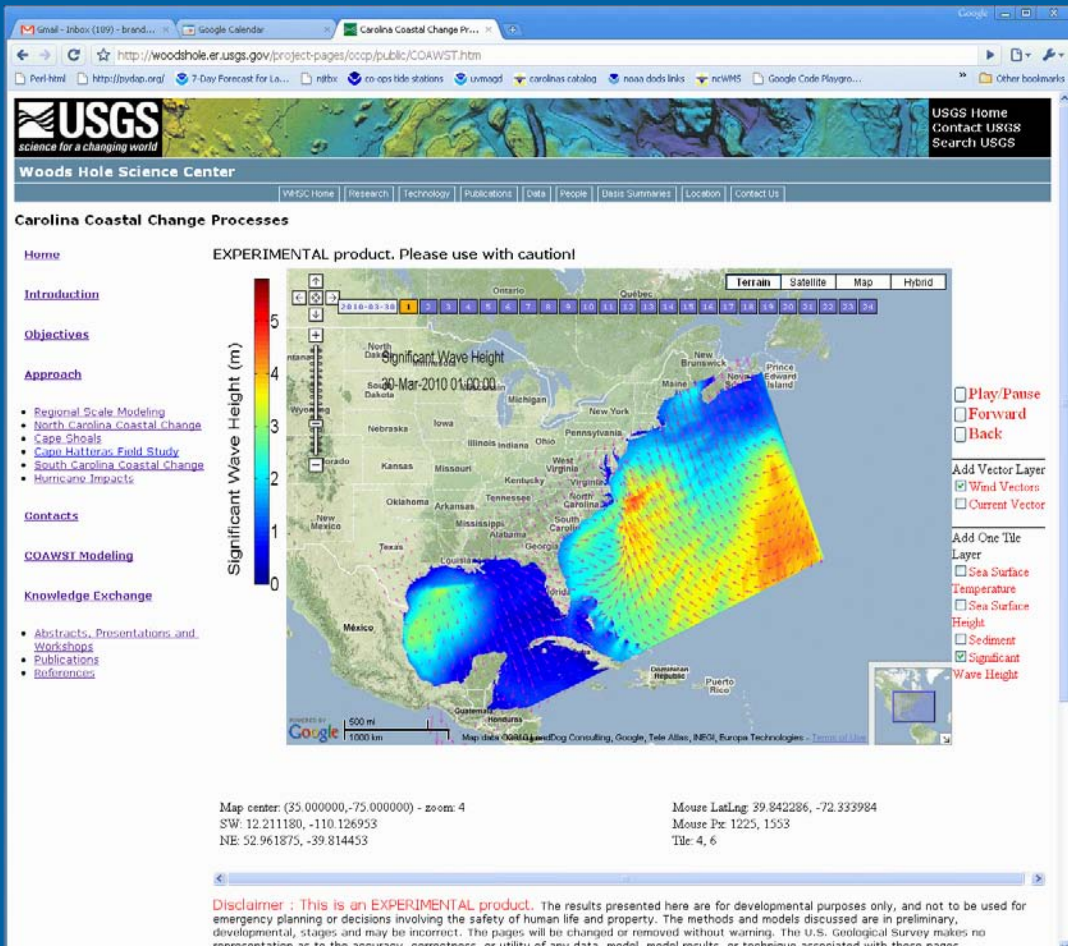
poro = 0.5

tce = 0.15 N/m2

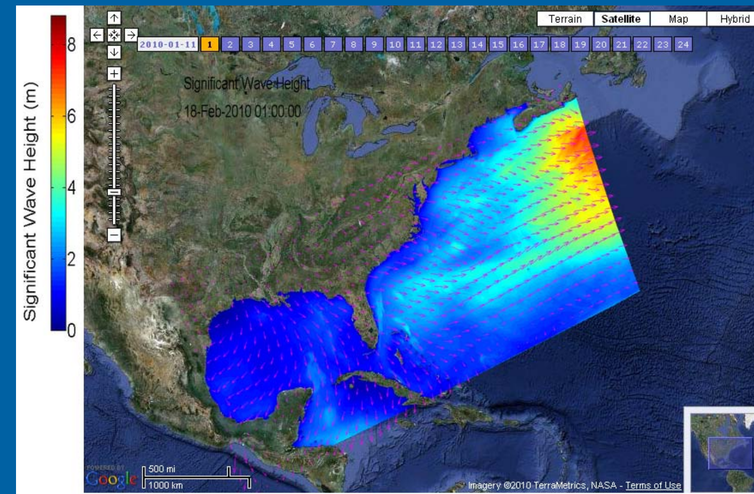
USGS

Coastal Forecasting System

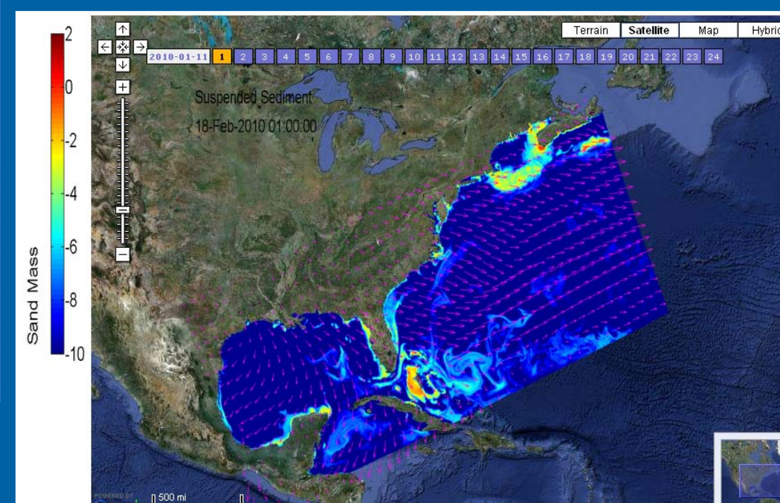
Daily Forecast



http://woodshole.er.usgs.gov/project-pages/cccp/public/COAWST.htm



Wave Height



Sediment Concentration

Summary

- Developed a coupled Ocean – Atmosphere - Wave – Sediment Transport Modeling System
- Operates on multiple processor clusters
- Grid remapping and conservative flux interpolation
- Hurricane application demonstrated:
    - WRF alone was too strong
    - Coupling of waves to ocn increased ocn surf mixing and decreased atm intensity
    - Coupling of waves to both ocn and atm increased mixing in the atm and slightly increased intensity.
    - Waves best simulated with coupled model but the atm intensity is slightly low.
    - Sediment mobilization requires accurate wave modeling and extended along entire US Coast.

Some issues:

- Time stepping of the different models
    - different physics for each model
    - synchronization interval
- Grid spacing of different models
    - Overlap / extrapolate between models (ie atm grid covers ocn+land)
    - Wave also has freq and direction spacings !
- Wet dry limitations for wav + ocn models
- Model physics : wave growth formulations, atm PBL, surface layer physics, ….
- Process in one model will propagate to other models and cause feedback
  (need to understand dynamics of the other models!)

USGS