Using the Coupled-Ocean-Atmosphere-Waves-SedimentTransport (COAWST) Modeling System to Investigate Storm Dynamics

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University of Florida

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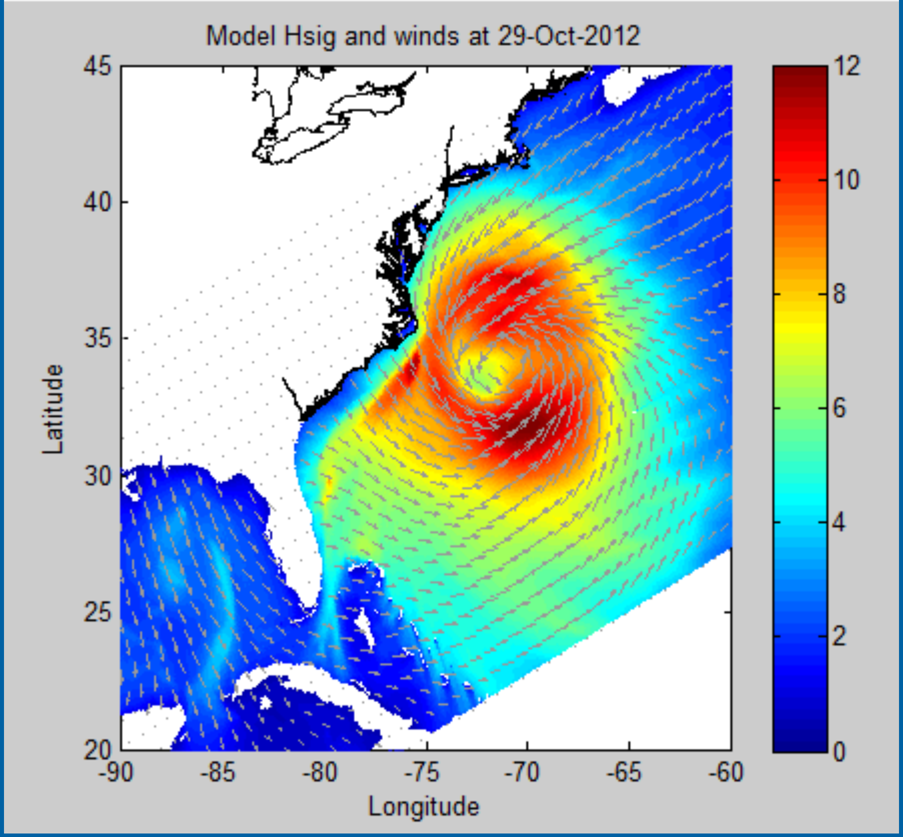
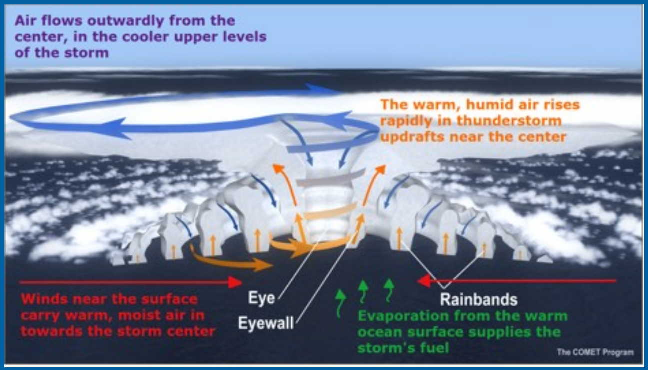


USGS
science for a changing world

U.S. Department of the Interior
U.S. Geological Survey

Coastal processes involve feedbacks between different physical processes.

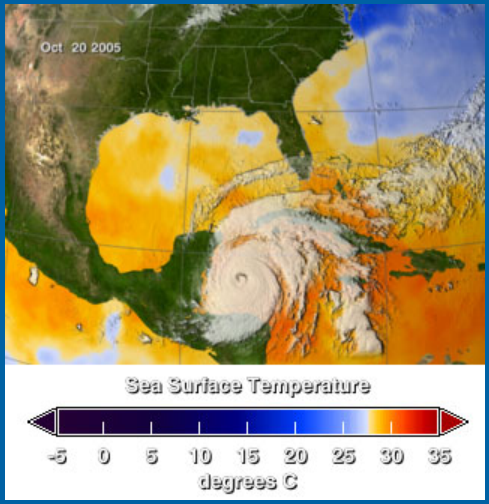
Atmosphere



Usually treated independently but actually occur together

Coastal geomorphology

Ocean

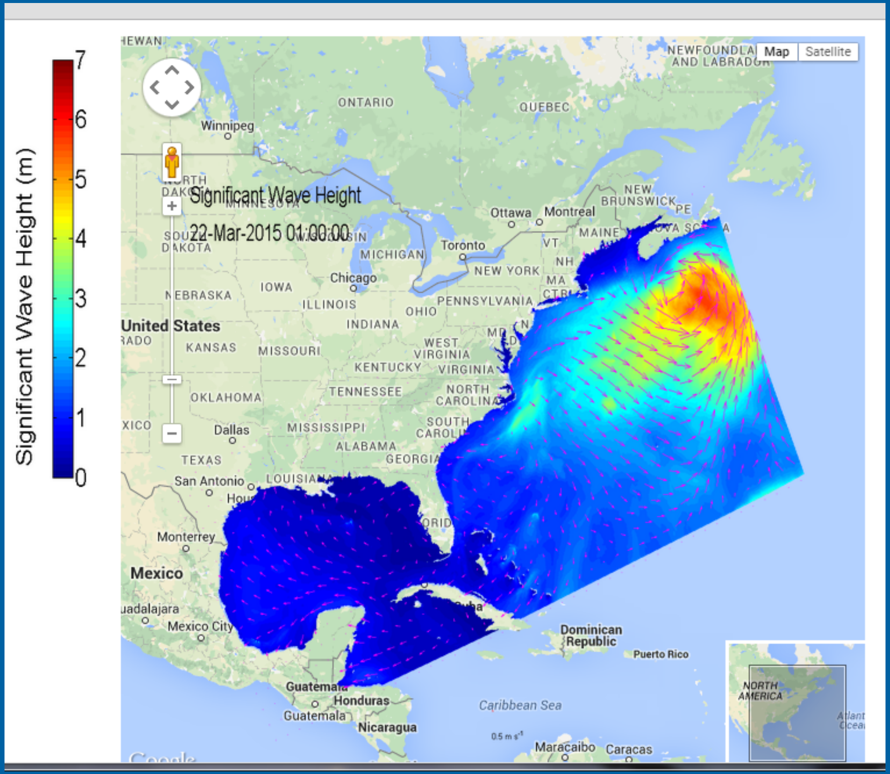


Wave

COAWST Numerical Modeling System

COAWST

Coupled Ocean – Atmosphere – Wave – Sediment Transport
Modeling System to investigate the impacts of storms on coastal environments.



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

ROMS http://www.myroms.org/

WRF http://www.wrf-model.org/

SWAN http://vlm089.citg.tudelft.nl/swan

WWIII http://polar.ncep.noaa.gov/waves/wavewatch/

InWave infragravity wave

CSTMS http://woodshole.er.usgs.gov/

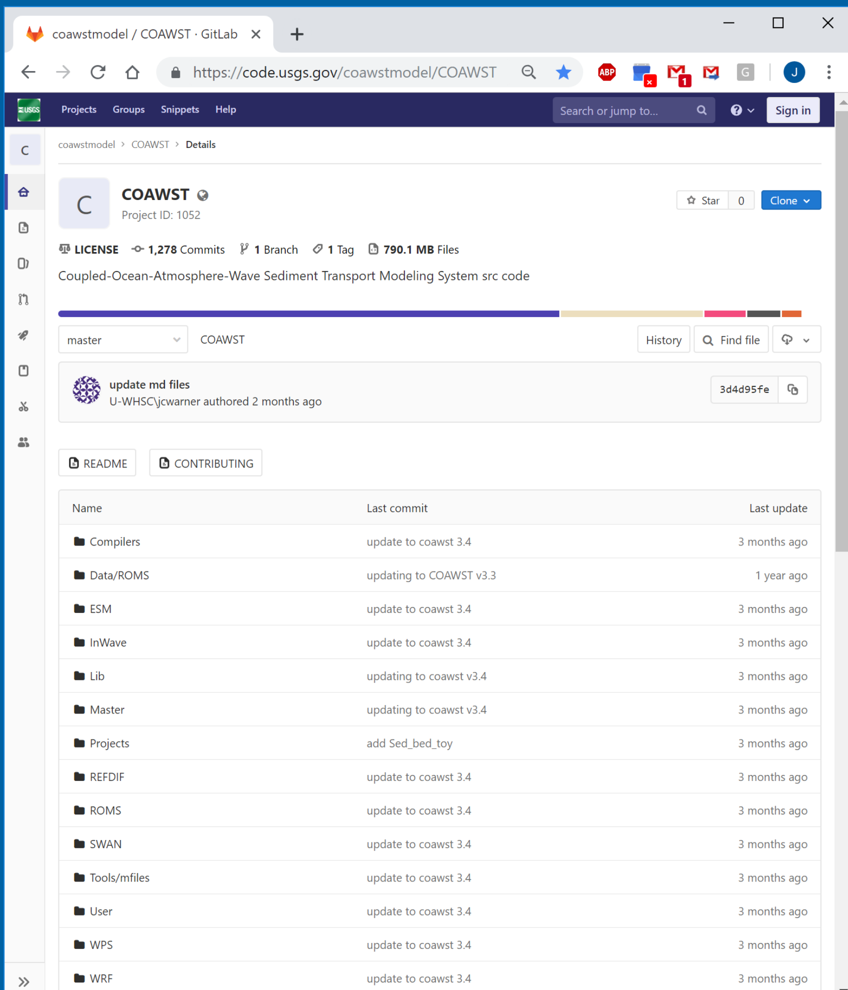
USGS

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

COAWST distribution

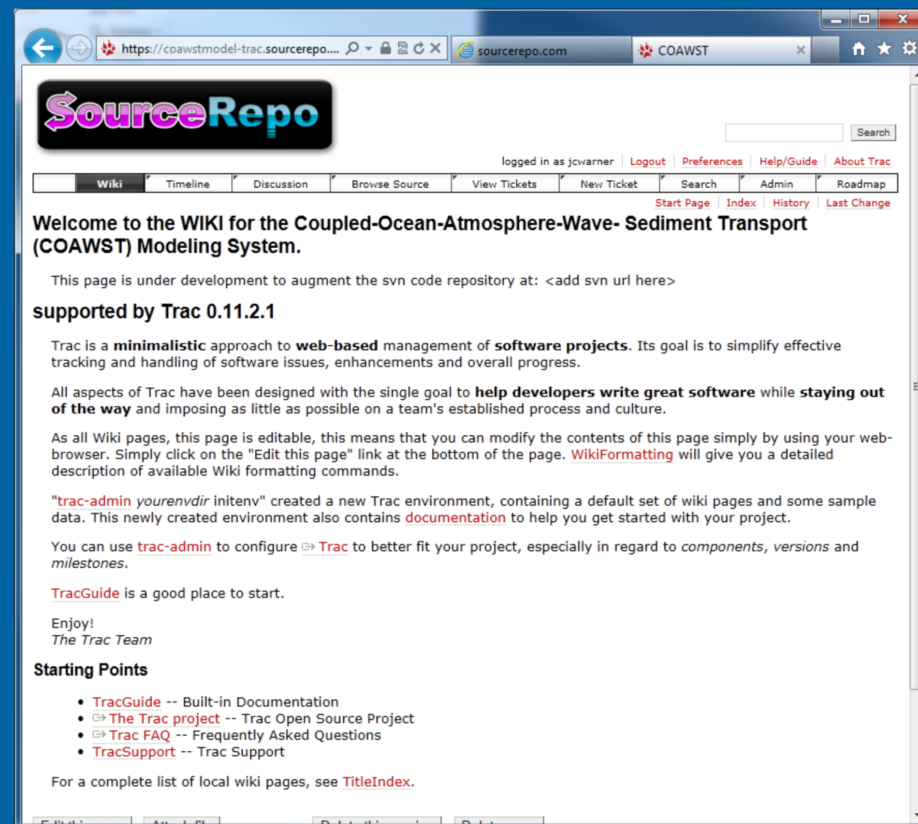
Github

https://code.usgs.gov/coawstmodel/COAWST



svn

https://coawstmodel.sourcerepo.com/coawstmodel/COAWST



User base

* Currently have ~ 800 registered users

* User Manual for model setup, applications, m files, BCs ICs, etc.

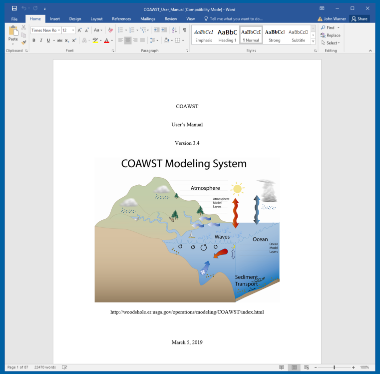
* Several Test Cases – Detailed steps to create coupled applications.

* Forecast systems

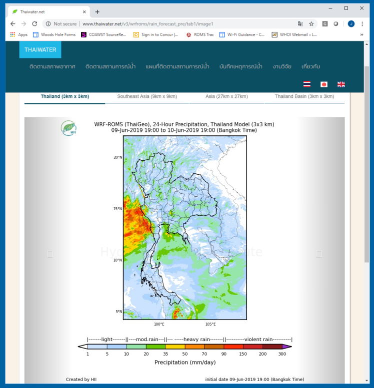
* Trainings (every 2 years)

July 2012 USGS
Aug 2014 WHOI
Aug 2016 WHOI
Feb 2019 NCSU

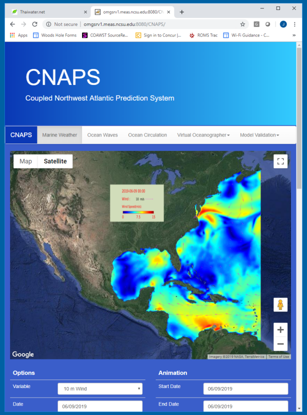
COAWST Modeling System training attendees at Hunt Library, North Carolina State University. February 2019.



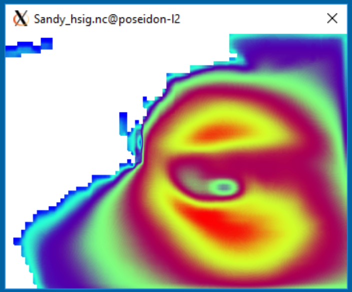
User Manual

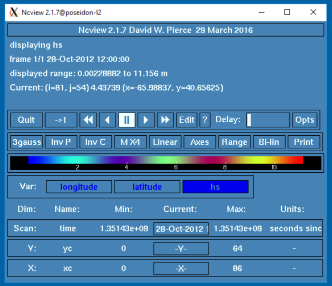


http://www.thaiwater.net/v3/wrfroms/rain_forecast_pre/tab1/image1



http://omgsrv1.meas.ncsu.edu:8080/CNAPS/

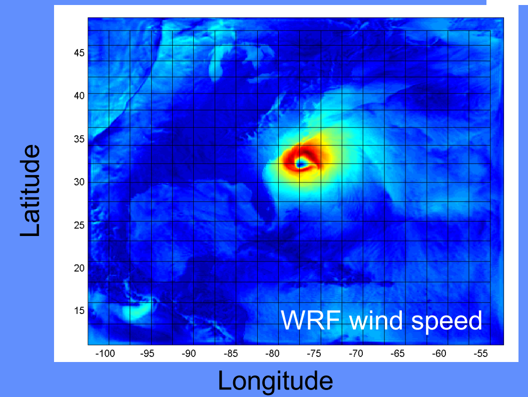




Test Cases

Model setup

ATMOSPHERE



Uwind, Vwind, Patm, RH, Tair, cloud, rain, evap, SWrad, Lwrad, LH, HFX, Ustress, Vstress

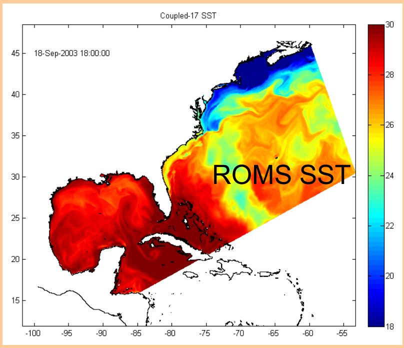
MCT

SST

H_{wave}, L_{pwave}, T_{psurf},

MCT

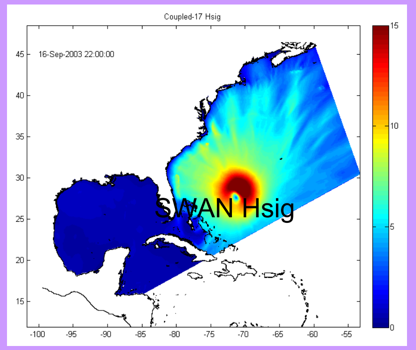
U_{wind}, V_{wind}



H_{wave}, L_{mwave}, L_{pwave}, D_{wave}, T_{psurf}, T_{mbott}, Q_b, $Diss_{bot}$, $Diss_{surf}$, $Diss_{wcap}$, U_{bot}

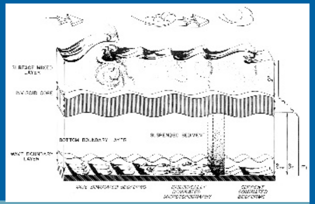
MCT

u_s, v_s, η, bath, Z_0



OCEAN

WAVE



SEDIMENT

CSTMS
Community Sediment Transport Modeling System

USGS

Nesting in all the models

OCN interactions

From the Atmosphere

Use consistent stress roms+wrf
#define
ATM2OCN_FLUXES

or

Use wrf vars in COARE
#define
BULK_FLUXES

τ

Ustress, Vstress, Swrad, Lwrad, LH, HFX

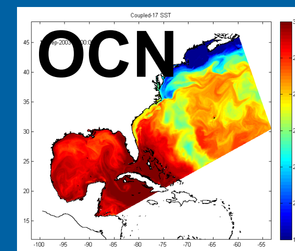
Uwind-ucur, Vwind-vcur, Swrad, Lwrad, RH, Tair, cloud

rain, evap

Patm

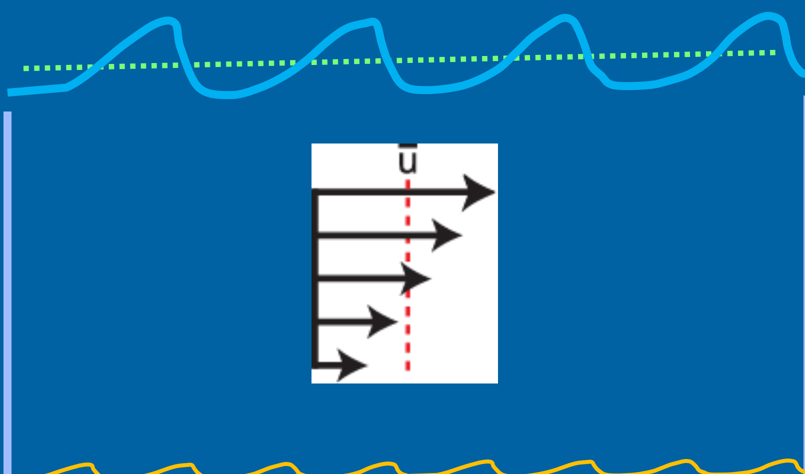
ATM

Uwind, Vwind, Patm, RH, Tair,
cloud, rain, evap, SWrad, Lwrad
LH, HFX, Ustress, Vstress

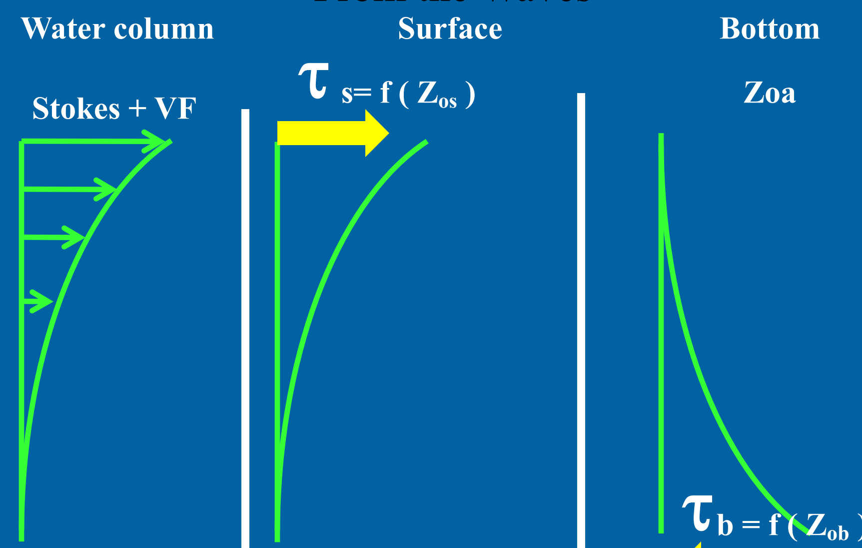


H_{wave}, L_{mwave}, L_{pwave}, D_{wave}, T_{psurf}, T_{mbott}, Q_b, $Diss_{bot}$, $Diss_{surf}$, $Diss_{wcap}$, U_{bot}

WAVE



From the Waves



Water column: H_{wave}, L_{mwave}, D_{wave}, T_{psurf}, Q_b, $Diss_{bot}$, $Diss_{surf}$, $Diss_{wcap}$,

Surface: H_{wave}, L_{pwave}, D_{wave}, T_{psurf},

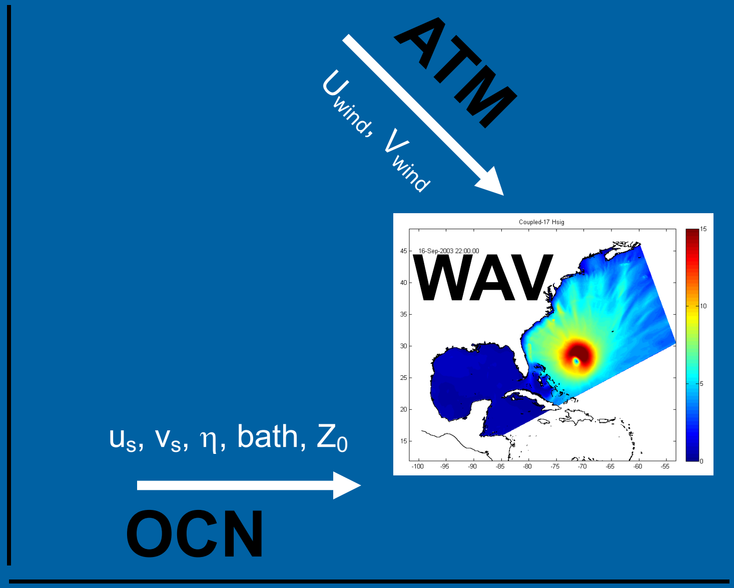
Bottom: H_{wave}, L_{mwave}, D_{wave}, T_{mbott}, U_{bot}

USGS

Integration and Application Network (ian.umces.edu/symbols), University of Maryland Center for Environmental Science.

WAV interactions

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



1) **Generation**

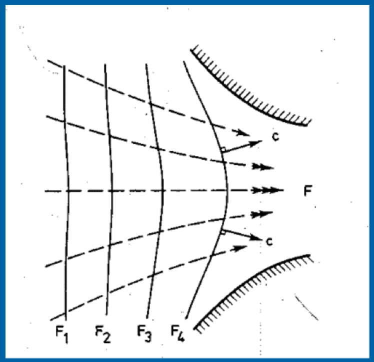
– wind speed is modified by ocean currents:

$S(w) = f(\ U_{wind} - u_s\ ;\ V_{wind} - v_s\ )$

2) **Propagation**

– wave celerity in geographic space is modified by ocean currents

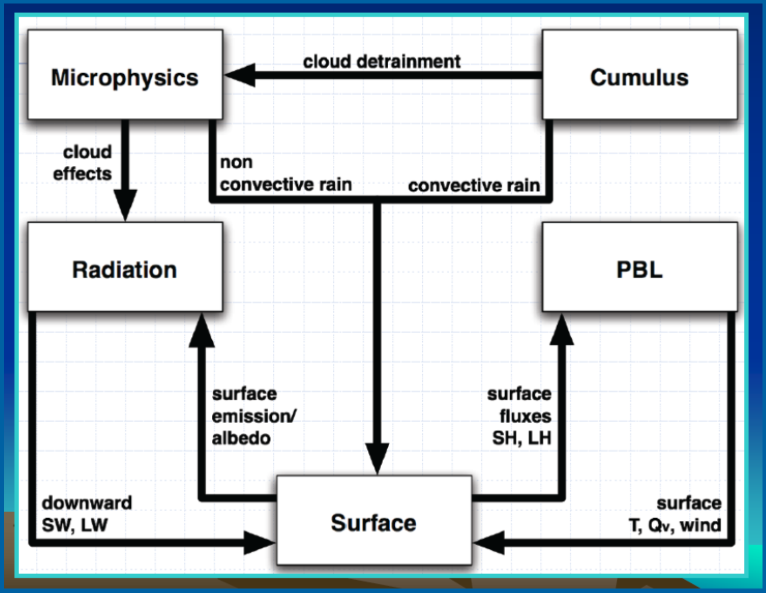
$c_x = c_{gx} + u_s\ ;\ c_y = c_{gy} + v_s$

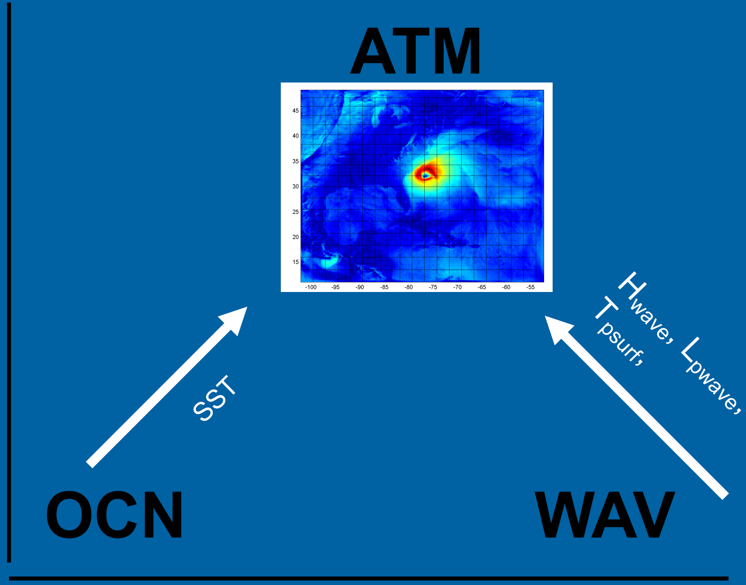


– change of wave direction (refraction) due to η, bathy, and currents:

$$C_{g,\theta}=\frac{\sigma}{\sinh(2kh)}\left(\frac{\partial h}{\partial x}\sin\theta-\frac{\partial h}{\partial y}\cos\theta\right)+\cos\theta\left(\frac{\partial U}{\partial x}\sin\theta-\frac{\partial U}{\partial y}\cos\theta\right)+\sin\theta\left(\frac{\partial V}{\partial x}\sin\theta-\frac{\partial V}{\partial y}\cos\theta\right)$$

ATM interactions





SST **OCN**

Surface fluxes

Momentum $F_m = C_m |\vec{V_{SL}}|^2$,

Heat $F_h = \rho_1 c_p C_{hq} (\theta_{sk} - \theta_1)$,

Moisture $F_q = \rho_1 L C_{hq} M (q_{vsk} - q_{v1})$.

$$|\vec{V_{SL}}|^2 = u^2 + v^2$$

C_m is the exchange coefficient for momentum and is expressed as

$$C_m = \frac{u_*^2}{|\vec{V_{SL}}|^2}.$$

C_{hq} is the exchange coefficient valid for both heat and water vapor as

$$C_{hq} = u_* \kappa \left[\psi_h\left(\frac{z}{L_{MO}}\right) - \psi_h\left(\frac{z_{0T}}{L_{MO}}\right) + \ln\left(\frac{z}{z_{0T}}\right)\right]^{-1},$$

u_* is the friction velocity and is expressed as

$$u_* = \kappa |\vec{V_{SL}}| \left[\psi_m\left(\frac{z}{L_{MO}}\right) - \psi_m\left(\frac{z_{0m}}{L_{MO}}\right) + \ln\left(\frac{z}{z_{0m}}\right)\right]^{-1}$$

$$z_{0m} = f\,(H_{wave}, L_{pwave}, T_{psurf})$$

WAV

OCEAN SURFACE ROUGHNESS CLOSURE MODELS

$H_s =$ significant wave height

$z_0 =$ ocean surface roughness

$u_* =$ wind friction velocity

$C_p =$ peak wave celerity

$L_p =$ peak wave length

$\frac{u_*}{C_p} =$ wave age

CHARNOCK 1955

$$z_{0m} = \frac{0.011(u_*)^2}{g}$$

TAYLOR & YELLAND 2001: TY2001

$$\frac{z_{0m}}{H_s} = 1200\left(H_s/L_p\right)^{4.5}$$

- *Wave steepness based parameterization.*
- *Based on three datasets representing sea-state conditions ranging from strongly forced to shoaling.*

DRENNAN 2003: DGQH

$$\frac{z_{0m}}{H_s} = 3.35\left(u_*/C_p\right)^{3.4}$$

- *Wave age based formula to characterize the ocean roughness.*
- *They combined data from many field experiments representing a variety of condition and grouped the data as a function of the wind friction velocity.*

OOST 2002: OOST

$$\frac{z_{0m}}{L_p} = \frac{25.0}{\pi}\left(u_*/C_p\right)^{4.5}$$

- *Wave age dependent formula but it also considers the effect of the wave steepness.*

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.

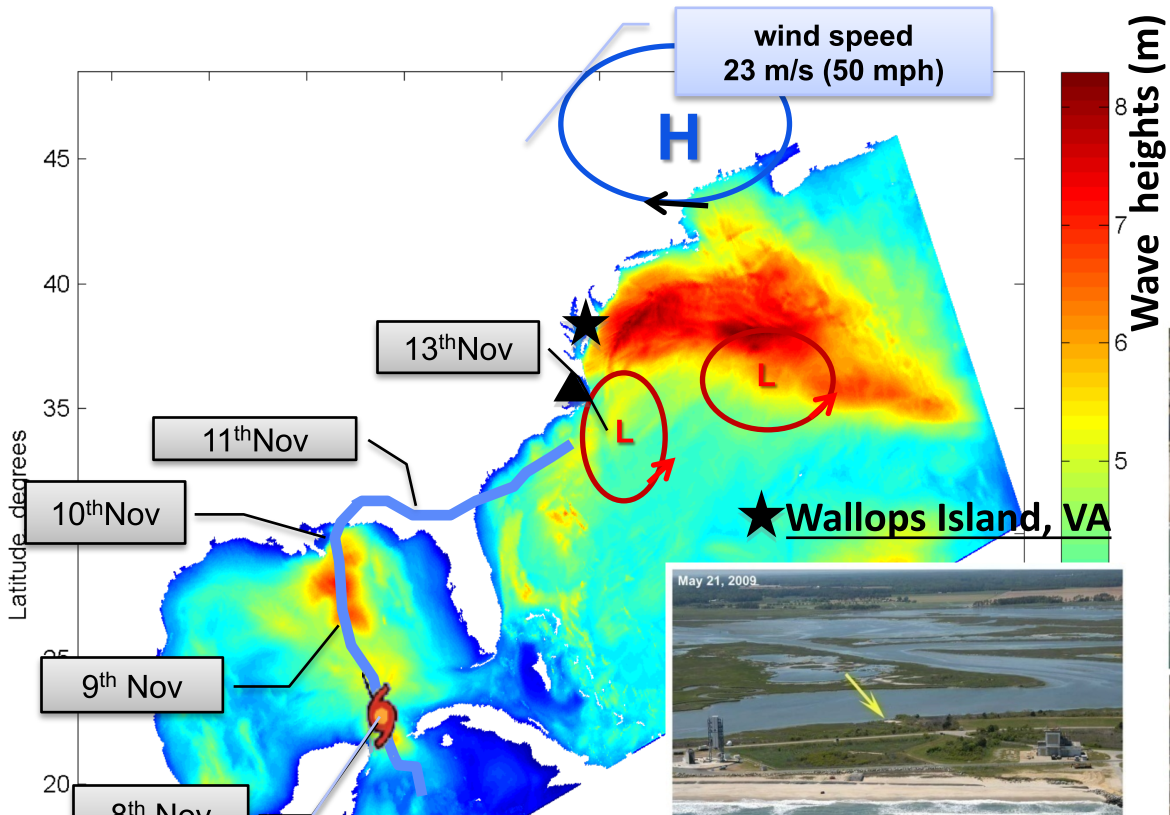
(it also works here)

USGS

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

Example: Nor'Ida Nov 2009

Olabarrieta, M., Warner, J.C., and Armstrong, B. (2012). "Ocean-atmosphere dynamics during Hurricane Ida and Nor'Ida: an atmosphere-ocean-wave coupled modeling system application." Ocean Modelling, 43-44, pp 112-137.

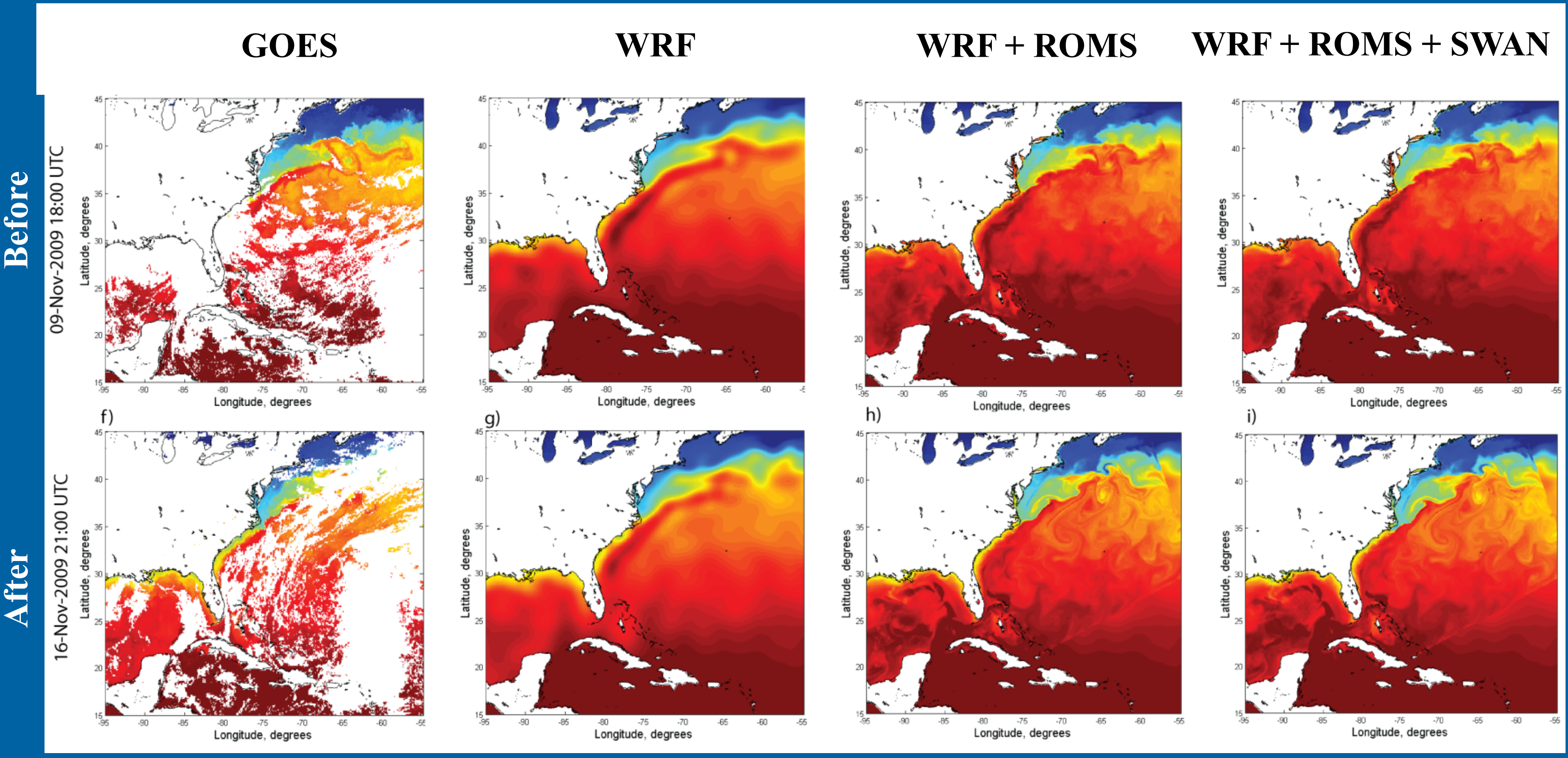


▲Bodie Island, NC

USGS

http://coastal.er.usgs.gov/hurricanes/norida/

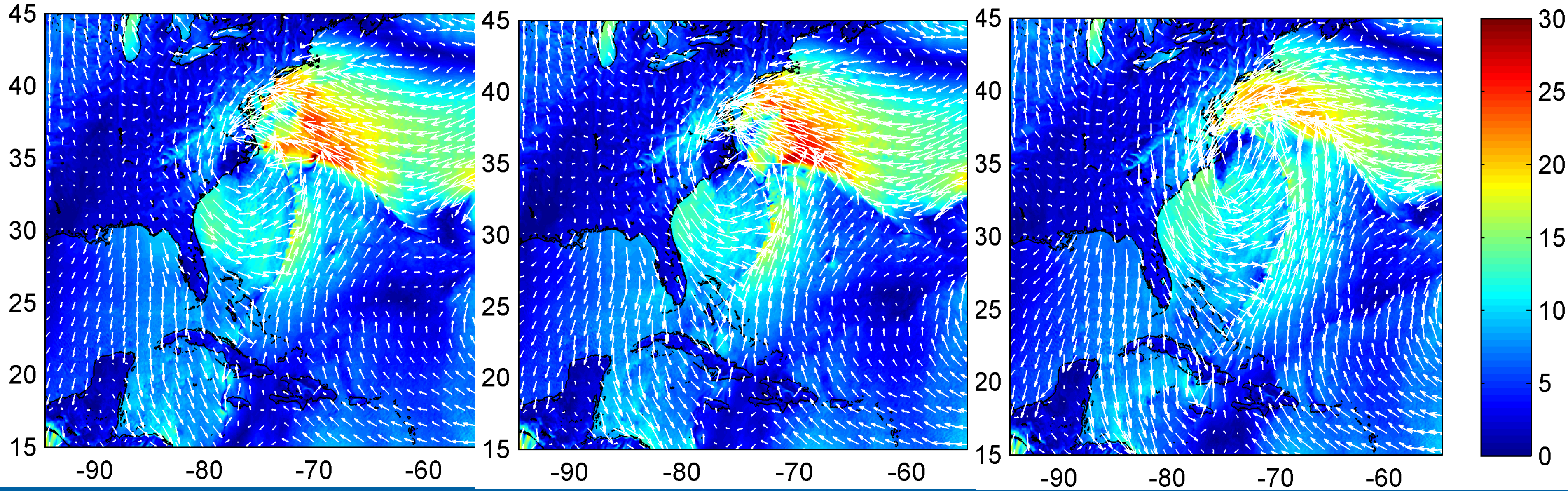
SST



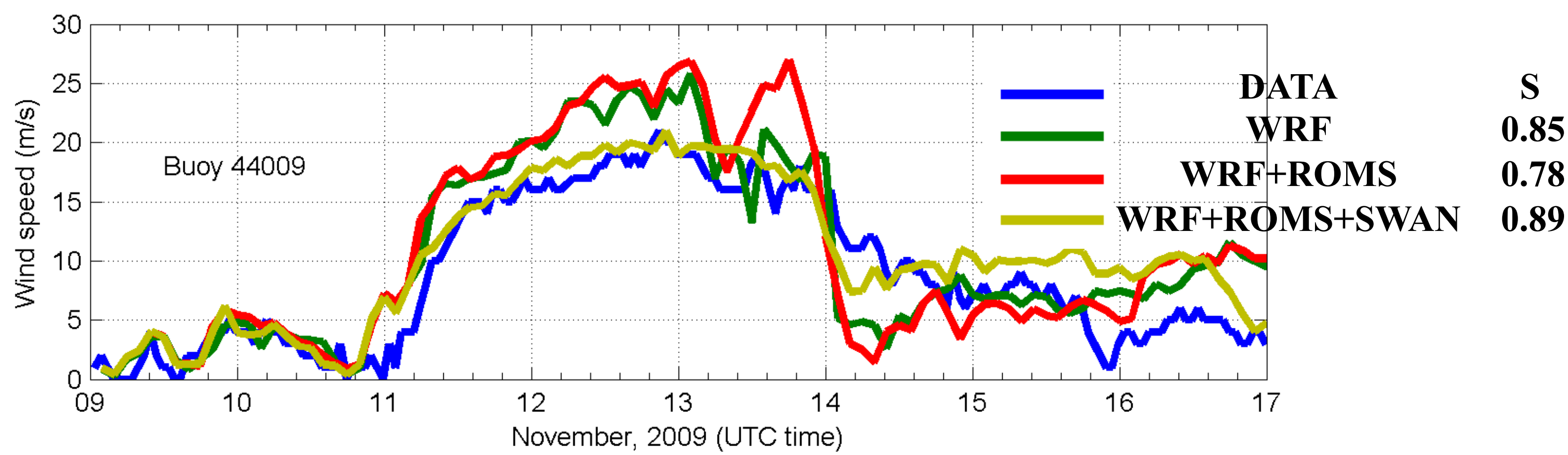
From WRF alone to WRF+ROMS. the SST structure increases.
Adding SWAN does not alter the SST that much.
(This was a rather stationary storm!)

USGS

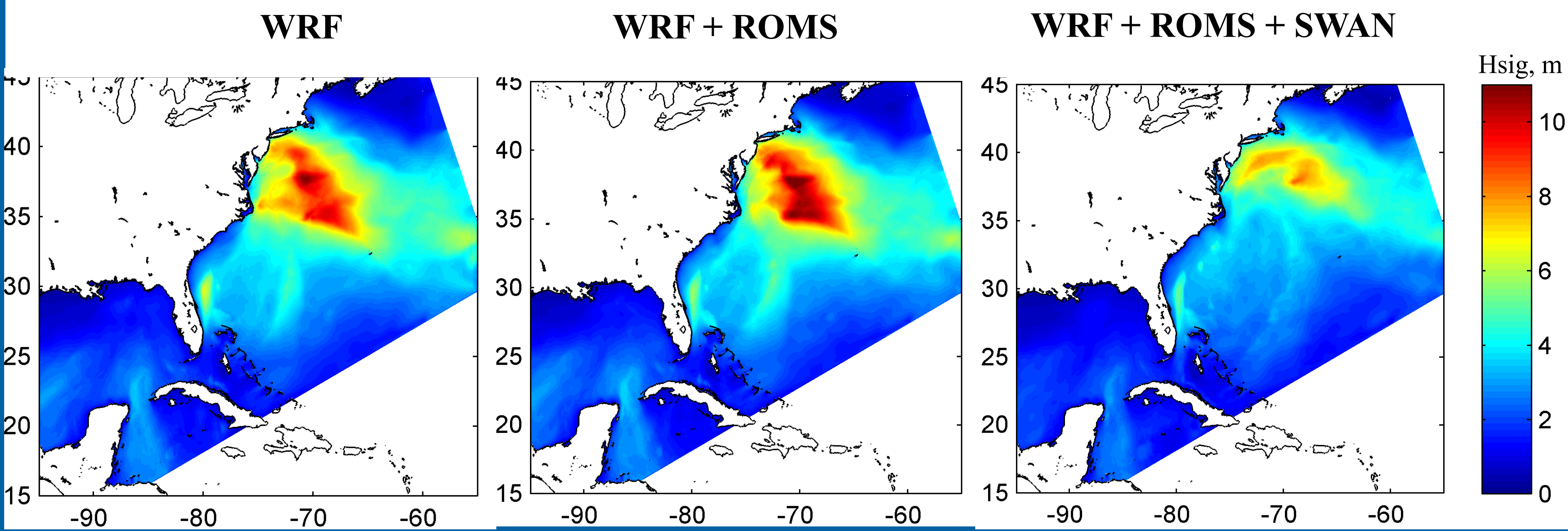
WINDS



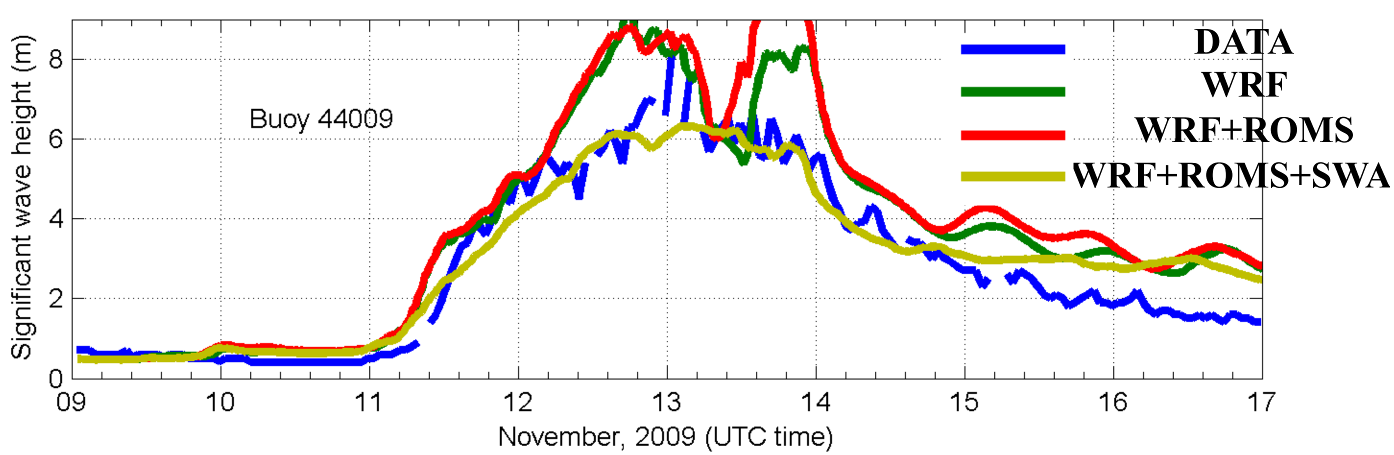
Reduced wind speed with waves coupling.



WAVES

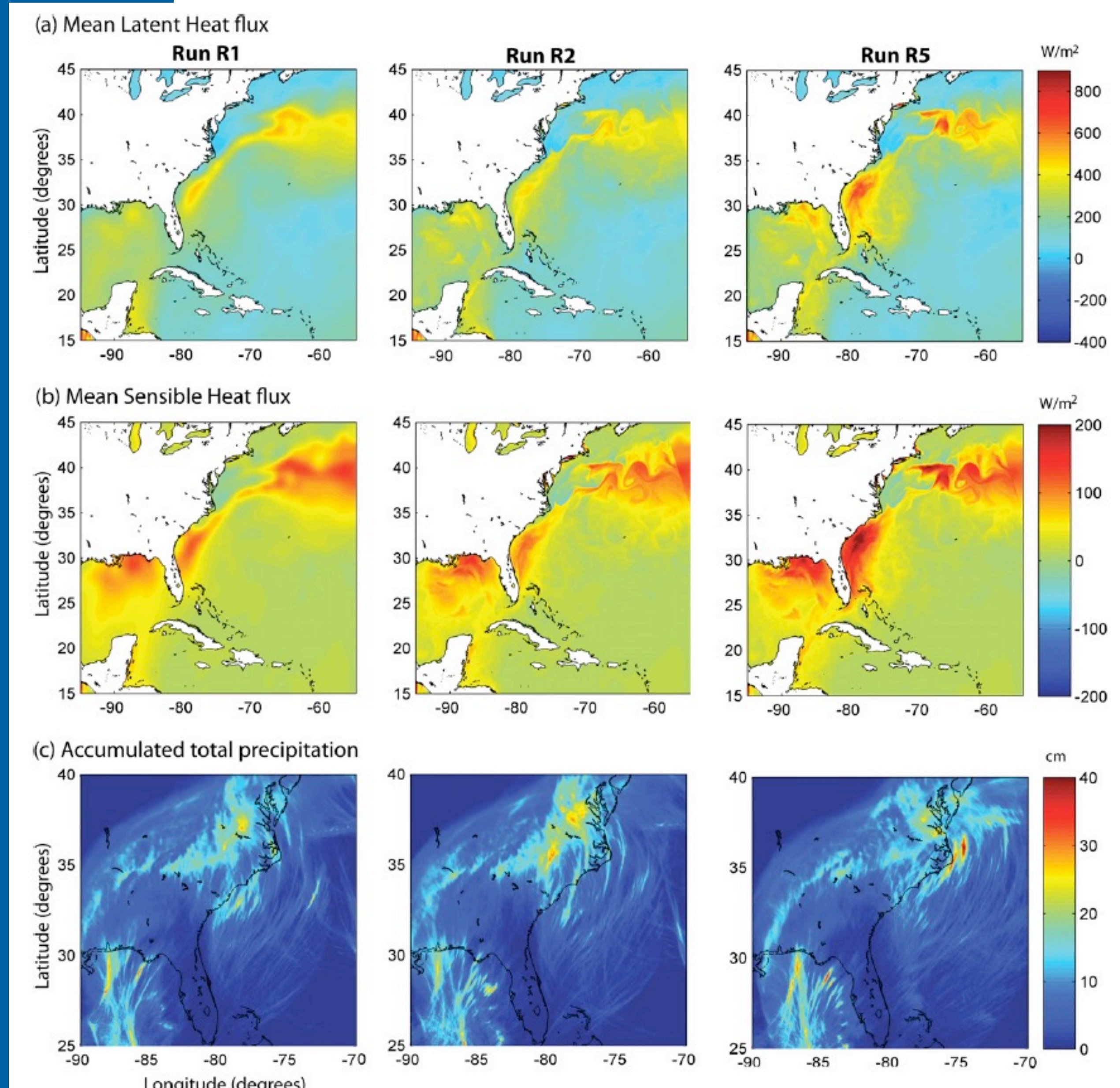


Reduced waves with waves coupling.

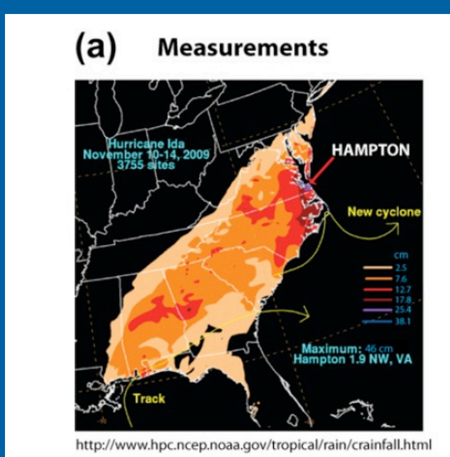


PRECIPITATION

WRF | **WRF + ROMS** | **WRF + ROMS + SWAN**



Waves increased heat fluxes and moisture fluxes to atm, leading to increased max precipitation and location closer to measured area.



Summary

• Developed a Coupled Ocean – Atmosphere - Wave – Sediment Transport Modeling System

• ~ 800 International Users, Trainings, Documentation, Test Cases

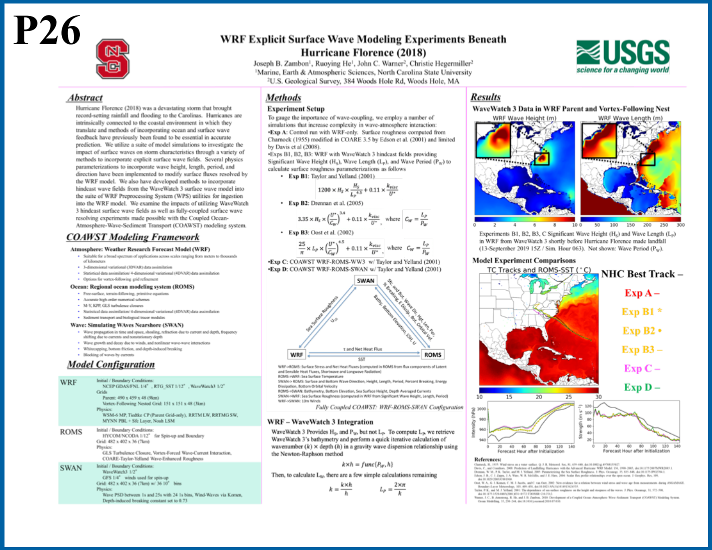
• Sensitivity tests of a strong Nor'Easter identified:
    • Coupling of atm-ocn led to slightly increased storm intensity due to SST updating.
    • Coupling of waves caused increase surface stress that reduced storm strength.
    • Waves also increased moisture flux to atm leading to increased precipitation.

Processes in one model propagate to other models and cause feedbacks !

Have ~ 50 publications listed in User Manual of other applications. If you are interested please let us know!.

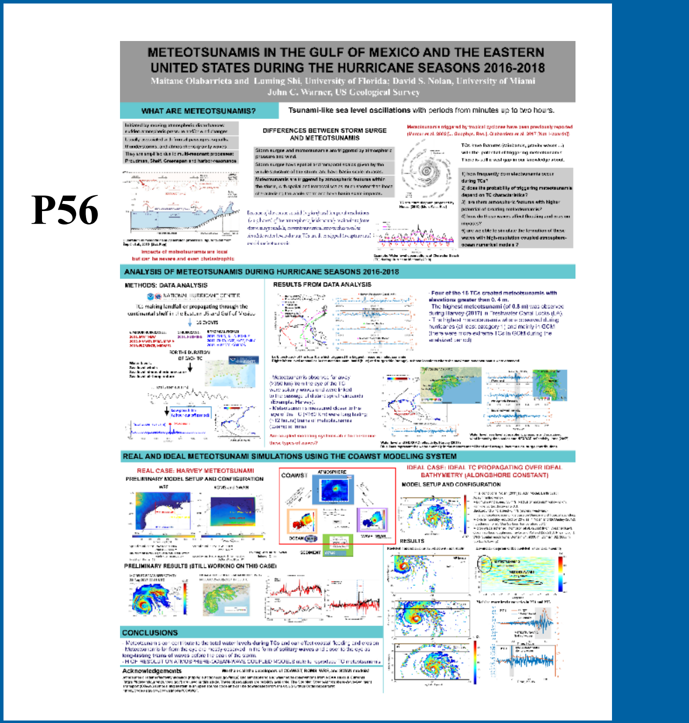
USGS

Posters



WRF explicit surface wave modeling experiments beneath Hurricane Florence (2018).

Zambon, Joe, Ruoying He, *North Carolina State University - Department of Marine, Earth, and Atmospheric Sciences*,
John C. Warner, *United States Geological Survey (USGS),* and
Christie Hegermiller, *Woods Hole Oceanographic Institution*



Meteotsunamis in the Gulf of Mexico and eastern United States during hurricane seasons 2016-2018.

Olabarrieta, Maitane and Luming Shi, *University of Florida*
David S. Nolan, *University of Miami*
John C. Warner, *US Geological Survey*

USGS