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

John Warner
US Geological Survey, Woods Hole, MA

Joe Zambon, Ruoying He
North Carolina State Univ

Maitane Olabarrieta
University of Florida

Christie Hegermiller
Woods Hole Oceanographic Institution
Coastal processes involve feedbacks between different physical processes. Usually treated independently but actually occur together.
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/

COAWST distribution

**Github**

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

**SVN**

https://coawstmodel.sourcerpo.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


http://www.thaiwater.net/v3/wrf/oms/rain_forecast_pre/tab1/image1

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

Test Cases
Model setup

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

ATMOSPHERE

- Hwave, Lmwave, Lpwave, Dwave, Tpsurf, Tmbott, Qb
- Dissbot, Dissurf, Disswcap, Ubot
- w, vs, \eta, bath, Z0

OCEAN

- ROMS SST

WAVE

- SWAN Hsig

SEDIMENT

- USGS

Nesting in all the models
OCN interactions

Use consistent stress
roms+wrf
#define
ATM2OCN_FLUXES

or

Use wrf vars in
COARE
#define
BULK_FLUXES

From the Atmosphere

Ustress, Vstress, Swrad, Lwrad, LH, HFX

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

Patm

From the Waves

Stokes + VF

$\tau_s = f \left( Z_{os} \right)$

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

From the Water column

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

Water column

Surface

Bottom

Zoa

$\tau_b = f \left( Z_{ob} \right)$

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

USGS

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

1) Generation
- wind speed is modified by ocean currents:

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

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 \( \eta \), bathy, and currents:

\[ C_{g,\theta} = \frac{\sigma}{\sinh(2kh)} \left( \frac{\partial h}{\partial x} \sin \theta - \frac{\partial h}{\partial y} \cos \theta \right) + \cos \theta \left( \frac{\partial U}{\partial x} \sin \theta - \frac{\partial U}{\partial y} \cos \theta \right) + \sin \theta \left( \frac{\partial V}{\partial x} \sin \theta - \frac{\partial V}{\partial y} \cos \theta \right) \]
Surface fluxes
- Momentum
- Heat
- Moisture

### ATM Interactions

**Microphysics**
- Cloud detrainment
  - Non convective rain
  - Convective rain

**Radiation**
- Surface emission/albedo
  - Downward SW, LW
- Surface fluxes SH, LH

**PBL**
- Surface fluxes

**Surface**

\[
F_m = C_m |V_{SL}|^2
\]

\[
F_h = \rho_1 c_p C_{hq} (\theta_{sk} - \theta_1)
\]

\[
F_q = \rho_1 R C_{hq} M (q_{sk} - q_{v1})
\]

\( |V_{SL}|^2 = u^2 + v^2 \)

\( C_m \) is the exchange coefficient for momentum and is expressed as

\[
C_m = \frac{u^2}{|V_{SL}|^2}
\]

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

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

\( u_* \) is the friction velocity and is expressed as

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

\( z_{0m} = f \left( H_{wave}, L_{pwave}, T_{psurf} \right) \)
CHARNOCK 1955

\[
\frac{z_{0m}}{g} = 0.011 (u^*)^2
\]

TAYLOR & YELLAND 2001: TY2001

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

DRENNAN 2003: DGQH

\[
\frac{z_{0m}}{H_s} = 3.35 \left( \frac{u^*}{C_p} \right)^{3.4}
\]

OOST 2002: OOST

\[
\frac{z_{0m}}{L_p} = \frac{25.0}{\pi} \left( \frac{u^*}{C_p} \right)^{4.5}
\]

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

- 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.

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

\[H_s = \text{significant wave height}\]
\[z_0 = \text{ocean surface roughness}\]
\[u^* = \text{wind friction velocity}\]
\[C_p = \text{peak wave celerity}\]
\[L_p = \text{peak wave length}\]
\[\frac{u^*}{C_p} = \text{wave age}\]
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)

Example: Nor’Ida Nov 2009

- Wind speed 23 m/s (50 mph)
- Wave heights (m)
- "Ocean-atmosphere dynamics during Hurricane Ida and Nor’Ida: an atmosphere-ocean-wave coupled modeling system application." Ocean Modelling, 43-44, pp 112-137.

L: bodie island, NC

http://coastal.er.usgs.gov/hurricanes/norida/
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!)
Reduced wind speed with waves coupling.
Reduced waves with waves coupling.
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!
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