Coupled COAMPS-LIS-WRF-HYDRO Coastal Flood Applications – Preliminary Results

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Objectives

To provide a new baseline capability for Naval LIS-hydrological modeling by:
• quantifying the impact of the water cycle budget on LND dynamics, via
  the interactive feedback of LIS and WRF-Hydro within the COAMPS ESMF coupling framework
• quantifying the impact of enhanced cloud-microphysical to severe flood
  processes via linkage with COAMPS moist physics parameterizations
• quantifying the feasibility of a “generalized” LND and hydrological
  components within COAMPS

Outlines

• Introduction of NRL Coupled Ocean/Atmosphere Mesoscale Prediction System
• Approach to couple LIS and WRF Hydro with COAMPS
• Preliminary results
  • Atmosphere precipitation and surface parameters
  • LIS soil temperature, soil moisture fraction
  • WRF-HYDRO surface and subsurface runoffs
• Summary
• Future plans
Air-Ocean-Wave-ICE-LSM-Hydro Coupled COAMPS Forecast and Data Assimilation System

User configurable 6 or 12 hr atmosphere update cycle

Atmos OBS

Navgem

Atmosphere BC (Analysis)

GALWEN-LIS

Atmosphere Setup

NCODAQC

SST, SSH ICE, PROF SHIP, GLDR

Ocean OBS

NCODA

DATABASE

GDEM MODAS DBDBV DBDB2 OSUITide Rivers

Ocean Setup

GOFS

Ocean Setup

WAVE Setup

SWAN/WW3

CICE

COAMPS®

Hydrology

LSM

ESMF/NUOPC

CONNECTOR

GLOBE WWS Clim

NCODA QC

obs, remote sensing, text

NAVGEM

Atmosphere Setup

Atmosphere OBS

Ocean Setup

Atmos BC (Analysis)

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SST, SSH ICE, PROF SHIP, GLDR

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GDEM MODAS DBDBV DBDB2 OSUITide Rivers

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WAVE Setup

SWAN/WW3

CICE

COAMPS®

Hydrology

LSM

ESMF/NUOPC

CONNECTOR
LIS is a comprehensive, interoperable land surface modeling and data assimilation framework.

- Includes the support for:
  - A large suite of land surface models (Noah, CLSM, VIC, JULES, CLM, ...)
  - Data assimilation algorithms (EnKF, EnKS)
  - Remote sensing data products (SMAP, SMOS, AMSR2, ASCAT, GRACE, MODIS, VIIRS, ...)

- Includes computational subsystems for optimization, forward modeling and uncertainty estimation.
Implementation of WRF-Hydro for Naval Applications

WRF-HYDRO’s configuration for COAMPS-LIS-HYDRO is similar to the National Water Model.

COAMPS-LIS-WRF-Hydro
Coupled Ocean/Atmosphere Mesoscale Convective System (COAMPS®)

Table 1 atmos-CICE exchange fields
1. Land surface type
2. sea level pressure
3. surface wind U (10m)
4. surface wind V (10m)
5. air temp (2m)
6. Water vapor mixing ratio (2 m)
7. surface downward short wave flux
8. surface downward longwave flux
9. surface total precipitation
10. relative humidity (2m) *
11. surface net shortwave flux *
12. surface net longwave flux *
13. surface albedo *
14. ground surface temperature (i.e., sea surface temperature)*
15. surface latent heat flux *
16. surface sensible heat flux *
17. surface stress *
* variables may not be actually needed, but are included
Coupled COAMPS-LIS-HYDRO Forecasting System

ESMF NUOPC Caps for COAMPS, LIS and WRF-HYDRO

Complete milestones
- V0.3 – one-way coupled ATM-LND-HYD
- V0.4 - two-way coupled ATM-LND w/ one-way coupled LND-HYD
- V0.5 - two-way coupled ATM-LND w/ two-way coupled LND-HYD
- V0.6 - all six feedbacks turned on, allowing direct interactions between WRF-Hydro and atmosphere
- V0.7 – Integrate with generalized microphysics & LND ensemble perturbations

Near Future Plan
- Evaluate water cycle budget diagnostics for high-resolution coupled experiments
- Refine linkage of hydrology-microphysics within COAMPS/WRF-Hydro framework
- Prototype testing and evaluation of generalized re-locatable COAMPS-OS capability
  - second OCONUS test case – Luzon (Philippine) flood case
- Leverage land and hydrology community advancements (upgrades of LIS and WRF-Hydro in COAMPS-Hydro coupled system)

The land model is typically called as a subroutine of the atmosphere. After introducing LIS as an external land component, a customized NUOPC Connector was created to couple nest-to-nest. Supported connector operations (can be applied in series).
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

- Cold start 72-h forecast (from 2011082600)
- 3-nests (27-km; 9-km; 3-km)
- LSM: NOAH v3.4
- Two experiments:
  1. “lis” :
     - Initial soil state= Global ~47-km AFWA LIS fields interpolated to COAMPS grid
     - Surface parameters (e.g., soil, vegetation types, terrain, etc.) from COAMPS initialization (USGS-based)
  2. “ldt” :
     - Initial soil state= LIS_HIST file (From Sujay Kumar, NASA-GSFC)
     - Surface parameters (e.g., soil, vegetation types, terrain, etc.) from LDT lis_input file (MODIFIED_IGBP_MODIS_NOAH-based) (from Kumar, NASA-GSFC)
     - Validation using NRL verify against radiosonde and surface (land, ship, buoy) observations
     - ~2h CPU for 72-h fcst on DSRC haise (240 proc)
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

72-h forecasts from 2011082600 for nest 3 (3-km)

Hourly precipitation (mm h⁻¹)
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

72-h forecasts from 2011082600 for nest 3 (3-km)

10-cm soil moisture (vol fr)
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)
72-h forecasts from 2011082600 for nest 3 (3-km)
10-cm soil temperature (°C)
Nest 3 subset (3-km) LIS experiment
72-h accumulated precipitation (in)

Nest 3 subset (3-km) LDT experiment
72-h accumulated precipitation (in)

Observed
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)
COAMPS Nest-3 (3-km) near-surface statistics (against land, ship, buoy data)

“LDT” is generally too warm and dry.
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)
COAMPS Nest-3 (3-km) 72-h forecast vertical statistics (against radiosonde data)

“LDT” is generally too warm and dry in boundary layer.
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

COAMPS Nest-3 (3-km) 10-cm soil moisture (vol frac): Analysis valid 2011082600

- Soil generally drier domain-wide for “ldt”, as compared to “lis”.

Difference ("lis" – “ldt”)
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

COAMPS Nest-3 (3-km) 10-cm soil moisture (vol frac): 72-h fcst valid 2011082900

Difference ("lis" – “ldt”)

- Soil generally drier domain-wide for “ldt”, as compared to “lis”.

![Map of soil moisture differences](image)
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

COAMPS Nest-3 (3-km) 10-cm soil temperature (K): Analysis valid 2011082600

Difference ("lis" – "ldt")

- Soil generally warmer domain-wide for "ldt", as compared to "lis".
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

COAMPS Nest-3 (3-km) 10-cm soil temperature (K): 72-h fcst valid 2011082900

• Soil generally warmer domain-wide for “ldt”, as compared to “lis”.

Difference (“lis” – “ldt”)
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

COAMPS Nest-3 (3-km) 2-m air temperature (K): 72-h fcst valid 2011082900

- Air temperature bias similar to soil temperature.
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)
COAMPS Nest-3 (3-km) near-surface time series: Tidewater, NC
Observations: NRCS National Water and Climate Center

Air temperature (°C)

Forecast hour

COAMPS 2-m air temperature (°C)

LIS
LDT

Tidewater, NC
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

COAMPS Nest-3 (3-km) near-surface time series: Tidewater, VA

Observations: NRCS National Water and Climate Center

Air temperature (°C)

Forecast hour

Tidewater, NC

COAMPS 2-m air temperature (°C)

LIS

LDT

Forecast hour
COAMPS-LIS Soil Moisture Forecast Movie

Large change of soil moisture fraction following the Hurricane Irene forecast track
Red line: COAMPS forecast track
Magenta line: Best track
Day 2-3 COAMPS-LIS 20 – 100 m Soil Liquid Fraction Forecast
COAMPS-LIS Soil Temperature Forecast Movie

LIS soiltemp1, 2011-08-26T12
Day 2-3 COAMPS-LIS 20 m – 100 m Soil Temperature Forecast
Implementation of WRF-Hydro for Naval Applications

- one-way coupling of COAMPS-LIS-WRF-Hydro
- Initiated setup of hurricane Irene test case
- Initiated setup of Luzon Island
Surface Runoff Movie

Large surface water runoff following the Hurricane Irene forecast track
Red line: COAMPS forecast track
Magenta line: Best track
Subsurface Runoff Movie

Increased subsurface runoff in the Cape Cod and Delaware Estuary Watersheds
Summary

Key Findings

• To couple LIS and WRF-Hydro with COAMPS via the ESMF NUOPC connectors at every nest time step require us to:
  • move the coupling of the land surface to the end of physics loop
  • develop customized NUOPC nest-to-nest connectors
  • modify COAMPS surface variables to use a much higher-resolution LIS inland water mask (LIS includes lake models)
• COAMPS precipitation is sensitive to the microphysical collection and aerosol concentration in the new generalized microphysics
• The COAMPS-LIS-WRF HYDRO preliminary results are encouraging

Expected Broader Implications

• Provides new capability of hydrology forecast – new battlespace information for coastal Marine Operation
• Improvement of the atmosphere land surface prediction and its feedback to the atmosphere BL
Future Plan

- Refine linkage of hydrology-microphysics within COAMPS/WRF-Hydro framework
- Evaluate water cycle budget diagnostics for high-resolution coupled experiments
- Prototype testing and evaluation of generalized re-locatable capability
  - second flood test case over Luzon, Philippine
- Leverage land and hydrology community advancements
  (upgrades of LIS and WRF-Hydro in COAMPS-Hydro coupled system)
Idealized two-moment COAMPS® Hurricane Prediction

Hurricanes appear to pre-condition the orographic rainfall environment prior to landfall through aerosol transport.

The challenge will be to reliably predict these conditions or other cloud/aerosol interactions in complex mesoscale situations:
- Account for source/sink terms
- Include 3-D initialization (NAAPS)
Modified scheme shifts the main rainband slightly eastward.

Control-Modified (mm)
Precipitation timing, intensity, and total accumulations are sensitive to changes in the sedimentation algorithm. Such changes may alter:
- Downdraft & cold pool dynamics
- Modeled updraft dynamics
- Land/Sea/Hydrology coupling
- Basin-wide precipitation

Precipitation sensitivity in idealized 3-D COAMPS thunderstorm simulations

- $\Delta x = 2000m$
- $\Delta z = 10-50m$ ($z < 7$ km)

$\Delta$precip $\sim 35\%$
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

72-h forecasts from 2011082600 for nest 3 (3-km)

10-m winds (m s$^{-1}$)
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

72-h forecasts from 2011082600 for nest 3 (3-km)

2-m relative humidity (%)
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

72-h forecasts from 2011082600 for nest 3 (3-km)

2-m air temperature (°C)
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)

COAMPS Nest-3 (3-km) near-surface time series: Tidewater, VA

Observations: NRCS National Water and Climate Center

- 24-h = 0.59 in
- 48-h = 5.41 in
- 72-h = 6.52 in

Erroneous?
COAMPS HYCCAP Case Study: Hurricane Irene (Aug 2011)
COAMPS Nest-3 (3-km) near-surface time series: Tidewater, VA
Observations: NRCS National Water and Climate Center

COAMPS accumulated precipitation (in)

SCAN soil moisture (%)
Tidewater, VA

24-h = 0.59 in
48-h = 5.41 in
72-h = 6.52 in

Erroneous?
Implementation of LIS for Naval Applications

- COAMPS-LIS simulations were conducted to generate initial conditions for Hurricane Irene (Aug 2011) case study.
- Noah LSM (v 3.3) was configured over a 3-nested domain, using high resolution vegetation (MODIS) and soils (STATSGO; 1km) parameters.
- The COAMPS and NLDAS2 meteorology was used to drive the LSMs.
- The test domain and initial condition data are used to test/validate a two-way coupled COAMPS-LIS.

NLDAS2-LIS soil moisture forecast