Recent Developments in the Navy Coastal Ocean Model and its application as the ocean component in regional coupled forecast models

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Outline

- **Motivation**
- **NCOM**
- **RELO**
- **COAMPS**
- **Applications**

  Kuroshio Extension

  Ligurian Sea

  Adriatic Sea

Objectives

- Develop a limited area air-sea model system for research, operation and forecasting
- Validate the forecast system in coastal and open ocean regions
- Test over open ocean in presence of strong ocean fronts and under extreme conditions
- Comparison of coupled versus "uncoupled" COAMPS - what is gained by air-sea coupling?

Navy Coastal Ocean Model
NCOM

Approach used for NCOM development

Use well-established ocean-modeling physics and numerics:

Basic physics and numerics of POM.

Combined sigma/z-level vertical grids and partial bottom cells

Implicit treatment of free surface

Options:

2^{nd} or 4^{th} order pressure gradient calc and Coriolis term interpolation

2^{nd} or 3^{rd} order advection of horizontal and vertical advection of scalars and momentum advection

spatial filtering of vertical buoyancy gradients (checkerboard removal)

Code structure consistent with COAMPS.

Flexible, includes nesting

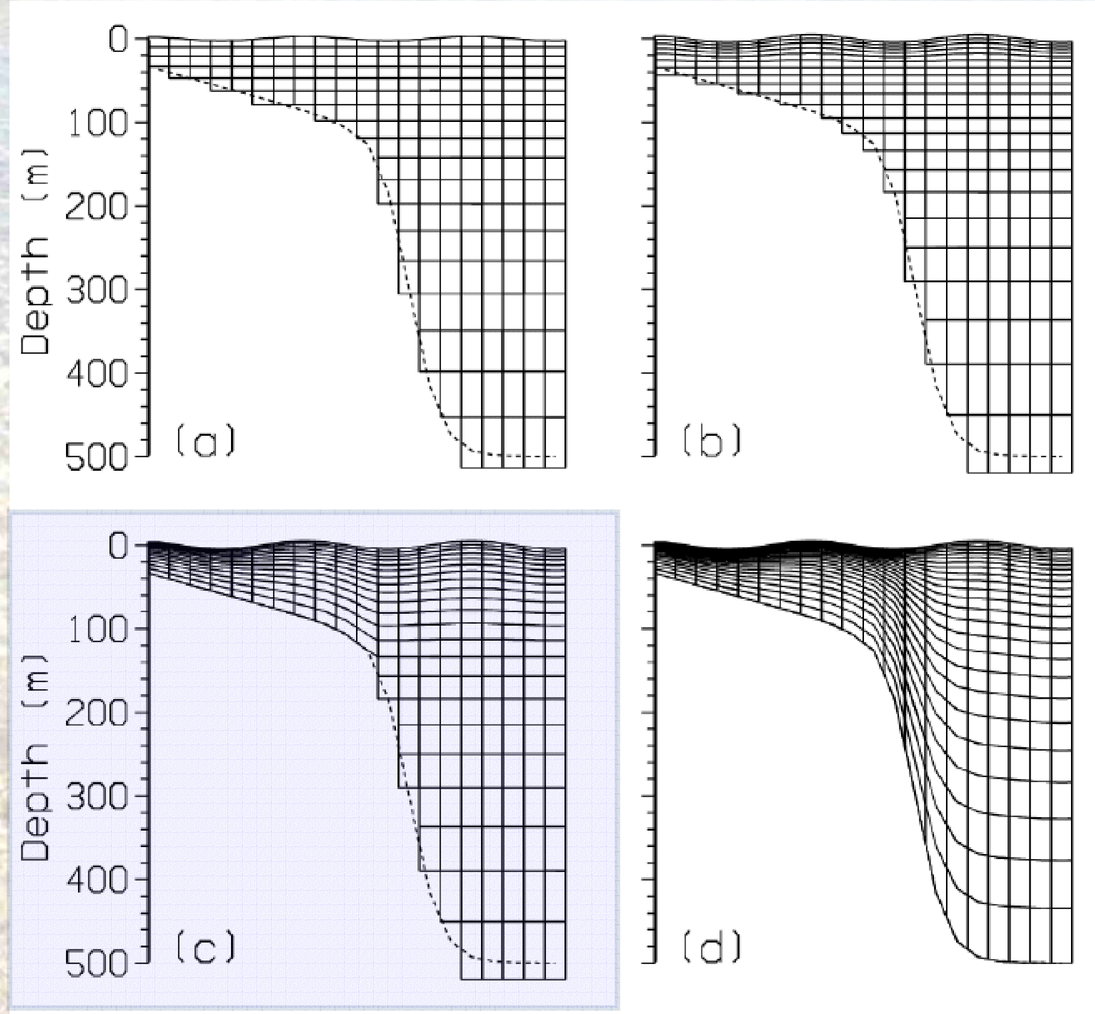
Scalable and efficient on a variety of computers.

Incorporate improvements and additional capabilities when needed or determined to be worthwhile.

Different ways the sigma/z-level grid can be set up

The model uses sigma coordinates in the upper layers and z-levels (i.e, constant-depth levels) in the lower layers. The depth at which the grid changes from sigma to z-level can be set by the user.

The grid can be set up with:
(a) single sigma layer at surface,
(b) several sigma layers at the surface (useful if the surface elevation changes are large relative to the vertical grid resolution used near the surface),
c) sigma layers to the bottom in the shallow water and z-levels in the deeper water, and
(d) sigma coordinates all the way to the bottom everywhere.



GNCOM: 19 s-layers in upper 137 m and 21 z-layers from 137 m to 5500 m

Model Physics

Primitive equation	Incompressible	Free surface
Hydrostatic	Boussinesq	C-grid

Grid-cell Re or Smagorinsky horizontal mixing.

Mellor-Yamada Level 2 or 2.5 vertical mixing

Quadratic bottom drag.

Source term for river and runoff inflows.

Forcing with atm pressure and local tidal potential.

Penetrating solar radiation (2-band model for Jerlov types)

4-component bio model

Flux BC provides TKE from wave breaking

Options for wave forcing:

- Wave radiation stress.
- Advection by Stokes drift.
- Parameterization of Langmuir mixing (Kantha and Clayson 2004).
- Increased bottom drag in shallow water due to wave motions.

Parameterization of Enhanced Vertical Mixing by Langmuir Cells and the Stokes Drift Current

Add additional term to the TKE eqn of MYL2.5 turbulence model to parameterize shear production of TKE from the interaction of the Stokes drift current with the wind-driven current (Kantha and Clayson, 2004).

Shear production term in TKE equation due to mean model velocity (U, V)

Km*{ (dU/dz)**2 + (dV/dz)**2 }   Km = vertical mixing coefficient

Kantha and Clayson (2004) parameterization of additional shear production due to Stokes drift current (Us, Vs)

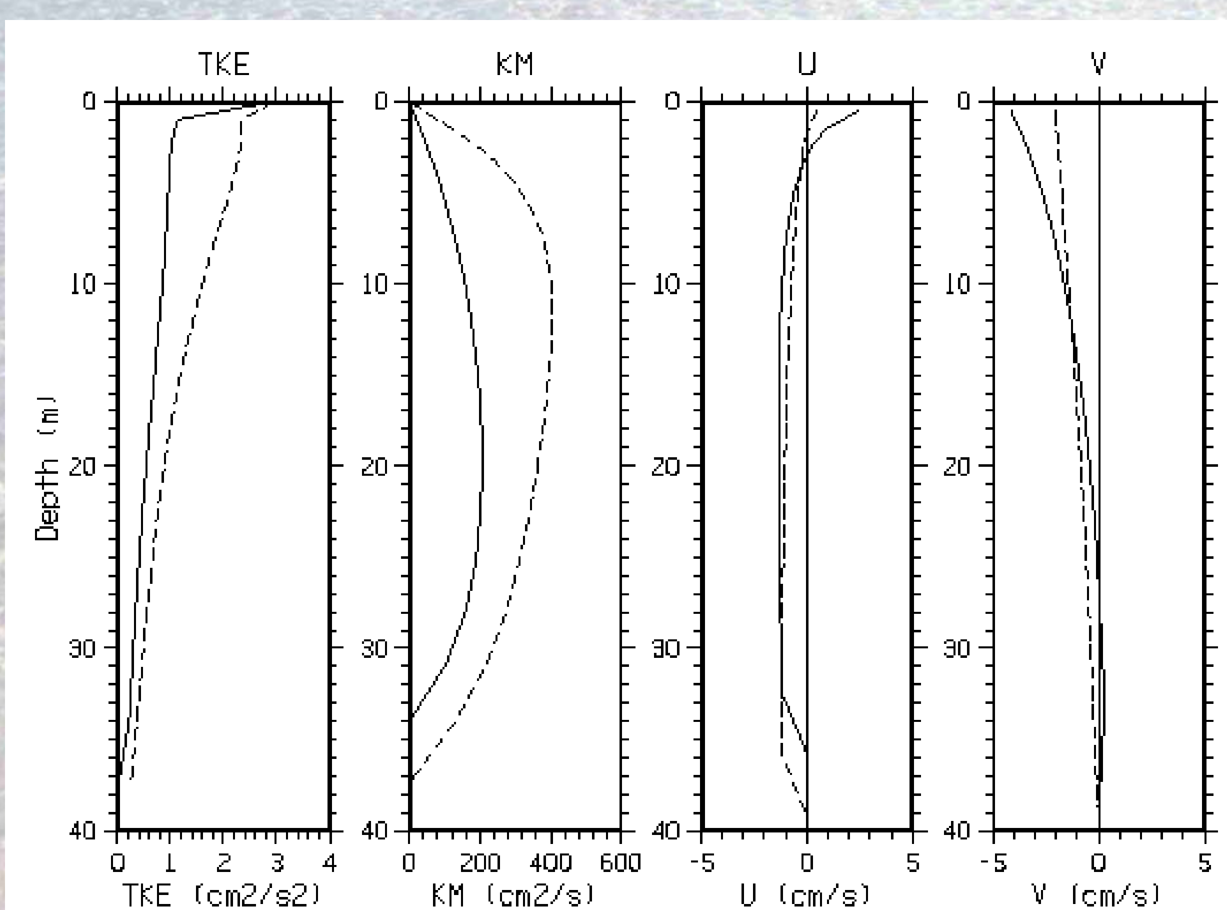
Km*{ dU/dz*d(Us)/dz + dV/dz*d(Vs)/dz }

Modification of Kantha and Clayson parameterization to avoid negative values

Km*{ |dU/dz*d(Us)/dz + dV/dz*d(Vs)/dz | }

Comparison of profiles for test case for simulations without (solid) and with (dashed) enhanced vertical mixing

Use modification of Kantha and Clayson (2004) parameterization



Test case by McWilliams et al (1997) for LES simulation of LC; also Kantha and Clayson (2004)

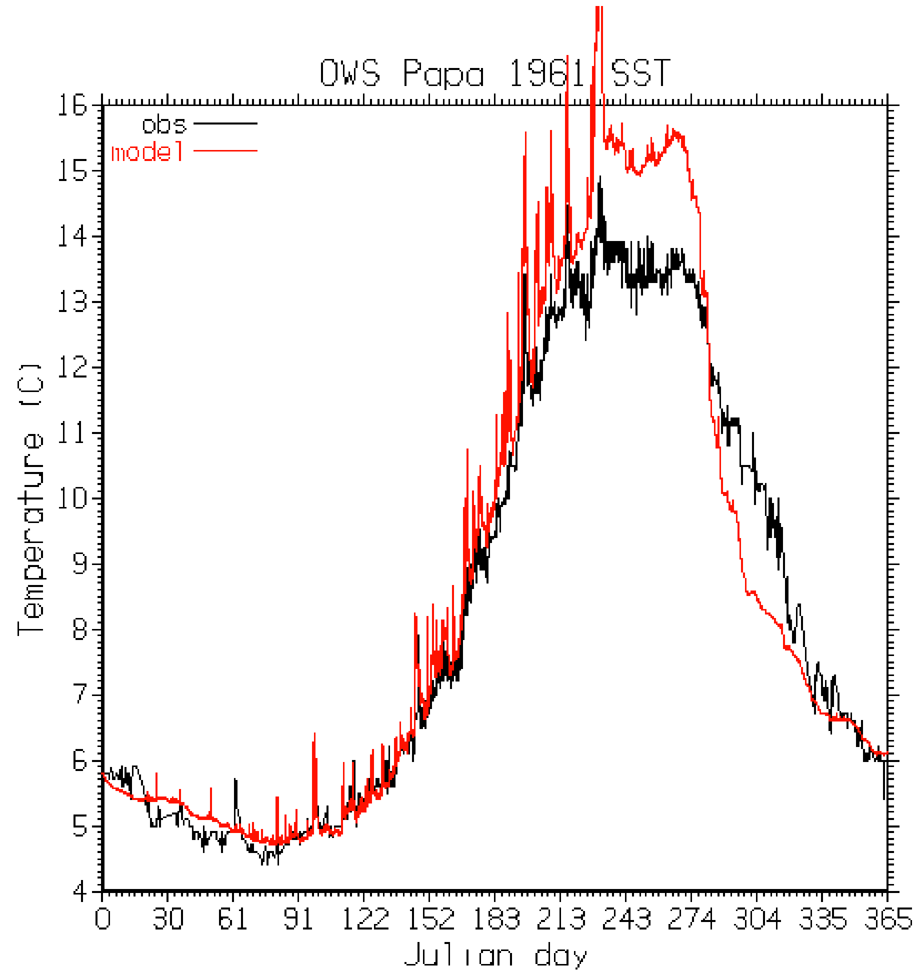
Wind speed = 5 m/s
Wind stress = 0.037 Pa (u_*= 0.006 m/s)
Initial mixed-layer depth = 33 m
Coriolis parameter = 0.0001 1/s (43.3 N)
Surface wave amplitude = 0.8 m
Surface wave period = 6 s
Surface Stokes drift current Us(0) = 0.068 m/s
Langmuir Number = sqrt[u_*/Us(0)] = 0.297

Note: model velocity profiles (U,V) do NOT include Stokes drift current.

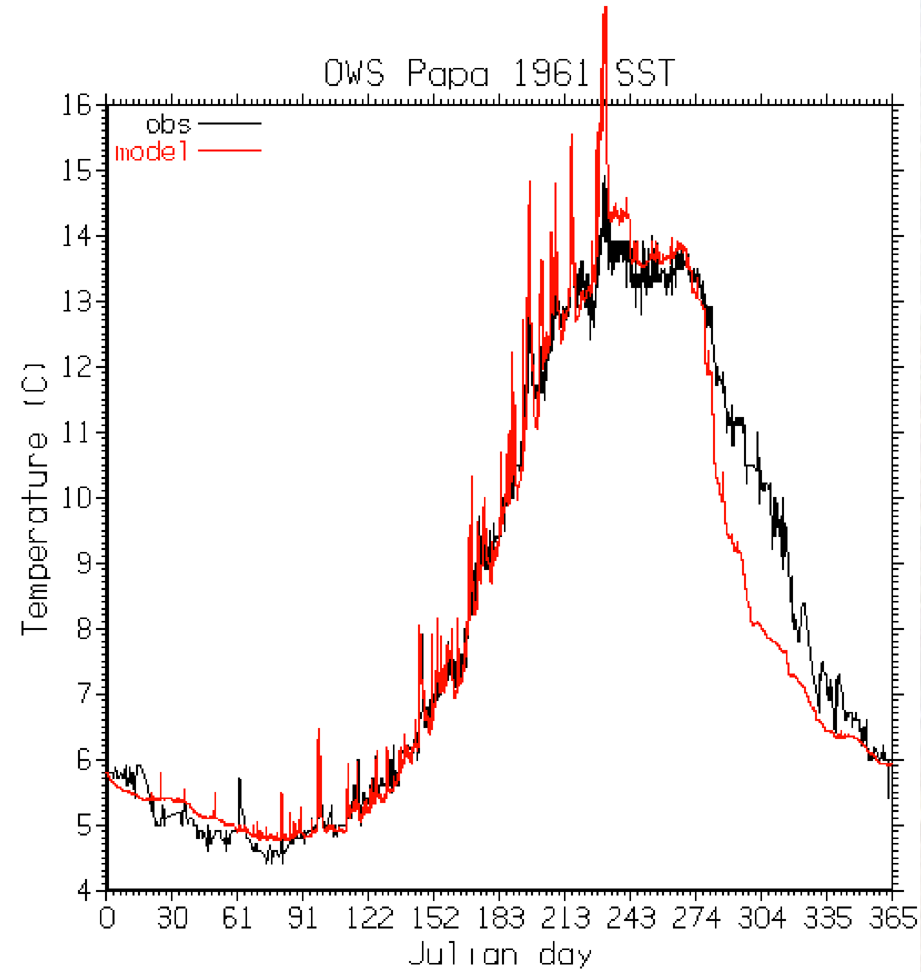
Comparison of simulations at OWS Papa without and with enhanced mixing by Stokes drift current

Plots show simulated (red) and observed (black) SST

Without enhanced mixing



With enhanced mixing

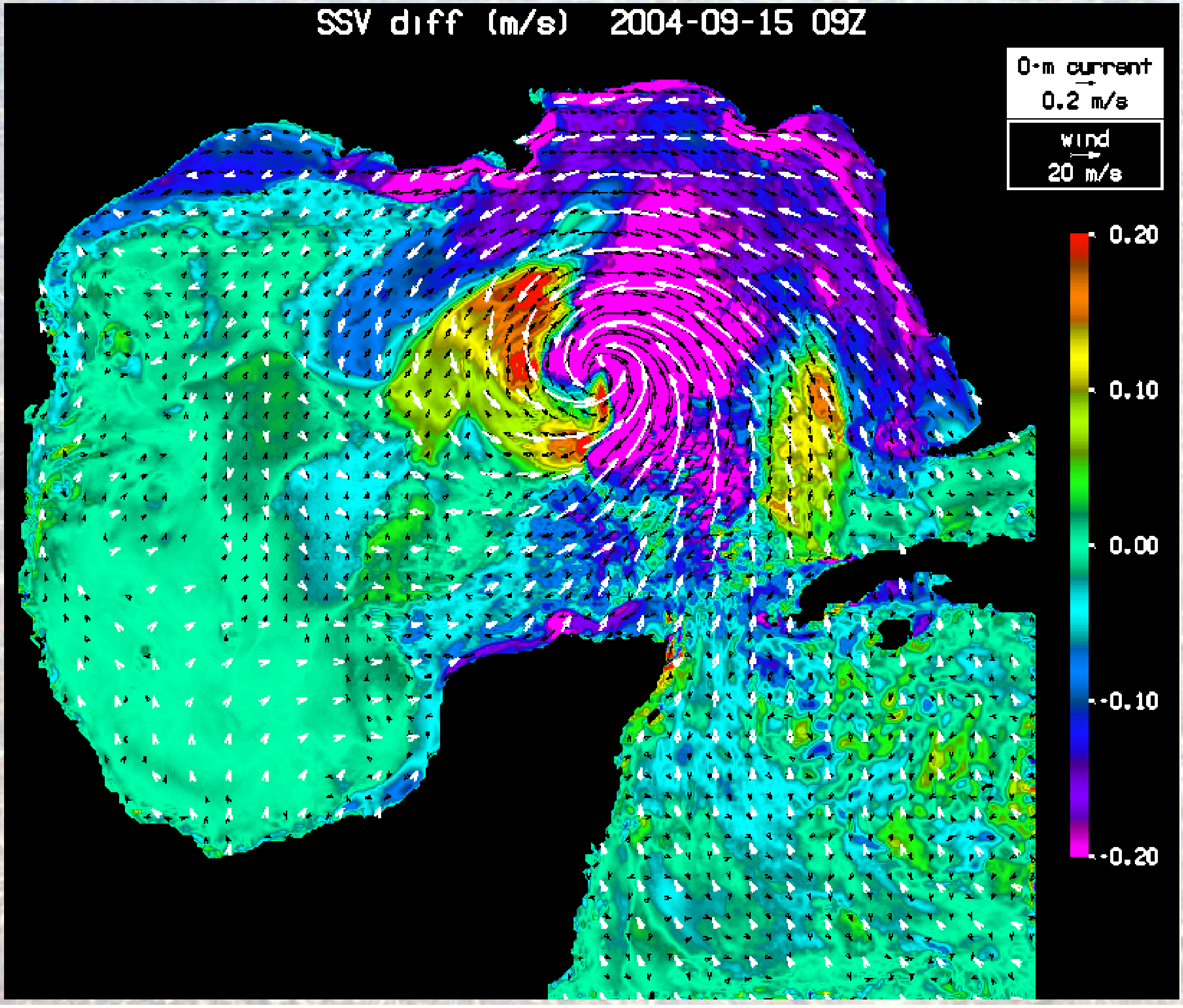


Difference of NCOM surface current for runs with full wave forcing (WaveWatch 3) and no wave forcing

Surface currents in this plot do NOT include Stokes drift current

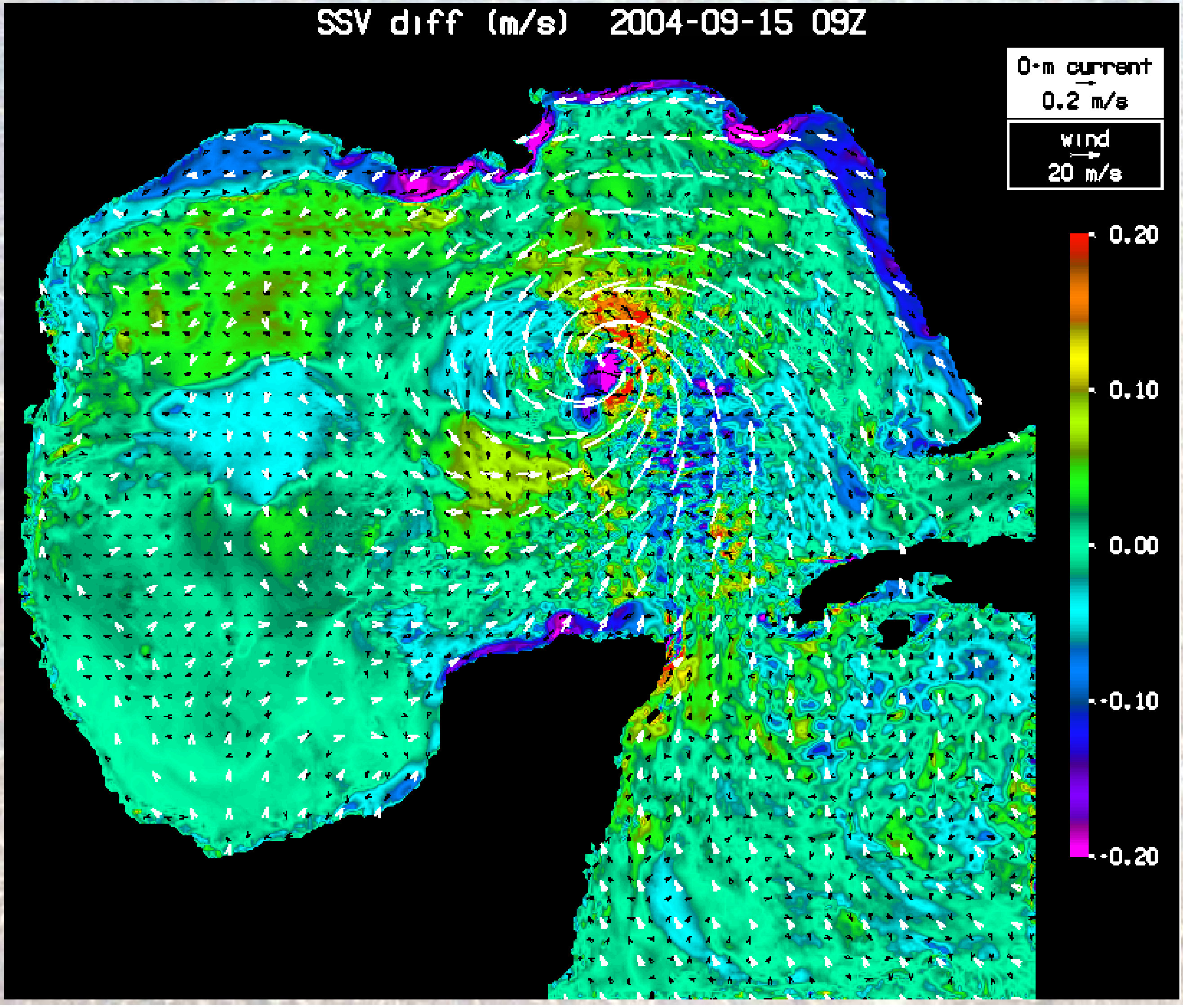
Hurricane Ivan

9 km res. COAMPS forcing



Difference of model surface current for runs with full wave forcing and no wave forcing

Surface current for run with wave forcing includes Stokes drift current



RELOcatable System

RELO NCOM/NCODA

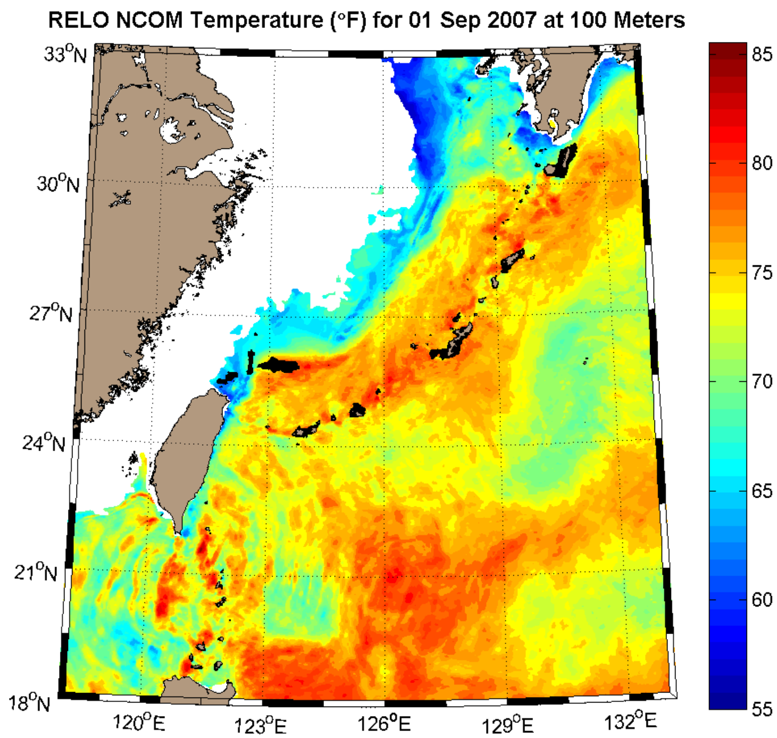
NCODA - NRL Coupled Ocean Data Assimilation - Cummings, QJRMS, 2005

NCOM - Navy Coastal Ocean Model – Barron, et al., Ocean Modelling, 2006

COAMPS - Coastal Ocean Atmosphere Mesoscale Prediction System

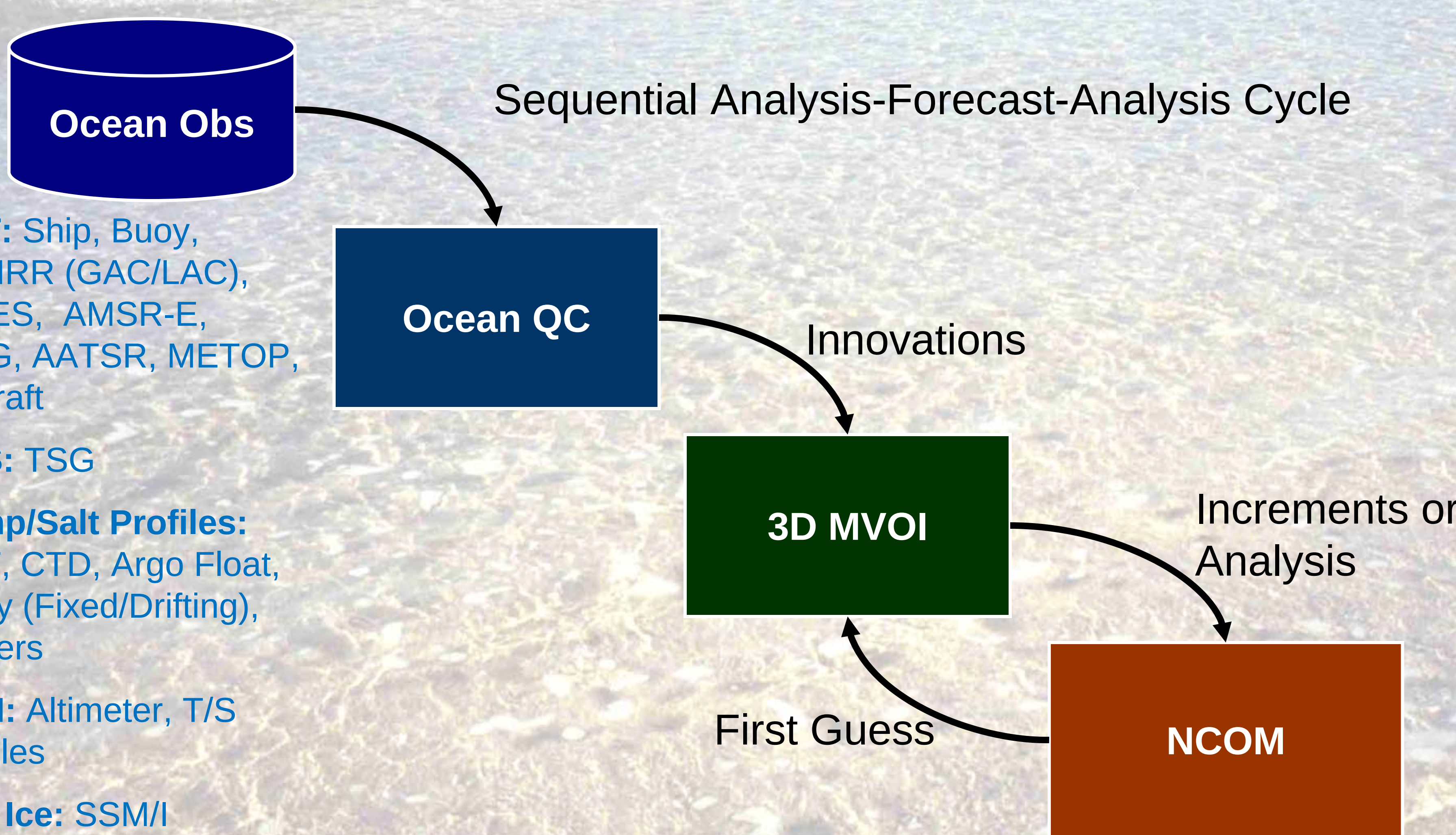
3km grid / 49 T levels
COAMPS 15km forcing
Lateral BCs by G-NCOM
OSU OTIS tides (global/regional)
NRL DBDB2' bathymetry
NRL global river database
Assimilates data from
- Satellites (SST, SSH)
- *In situ* obs (XBTs, CTDs, floats, buoys, gliders, ships)

3D Forecasts to 72 hours
- T, S, currents, elevation
- Acoustic properties for Navy applications



Daily plot of temperature at 100m during September 2007.

RELO Ocean Data Assimilation



SST: Ship, Buoy, AVHRR (GAC/LAC), GOES, AMSR-E, MSG, AATSR, METOP, Aircraft

SSS: TSG

Temp/Salt Profiles: XBT, CTD, Argo Float, Buoy (Fixed/Drifting), Gliders

SSH: Altimeter, T/S profiles

Sea Ice: SSM/I

RELO Parent/Child Nesting

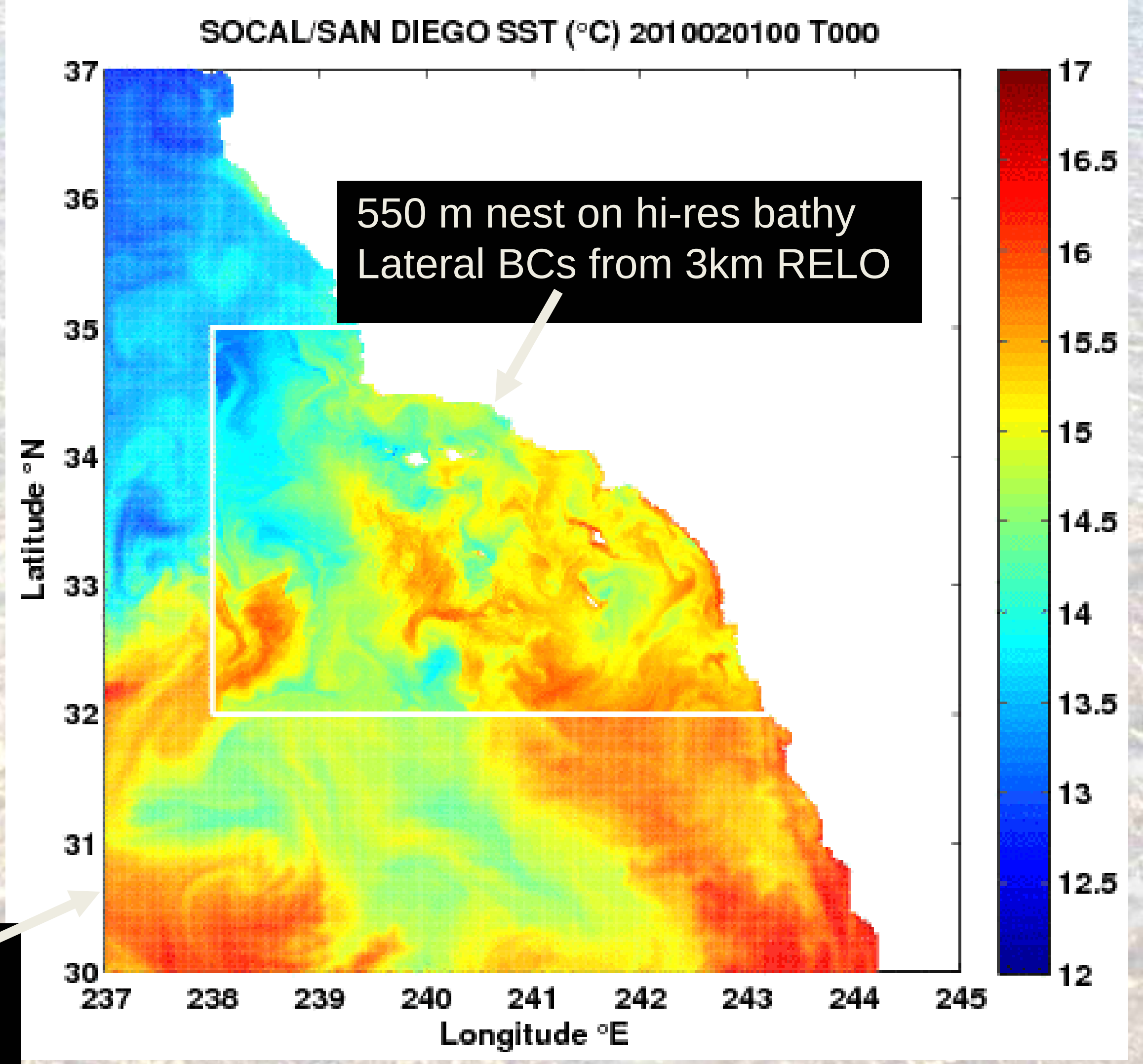
Simple one-way nesting between parent and dependent child nest

Advantages:

- No restriction on grid ratio
- Independent data assimilation
- Flexibility with adding tides

Disadvantage:

- No two-way feedback
  in analysis or forecast
- Frequent storage of parent



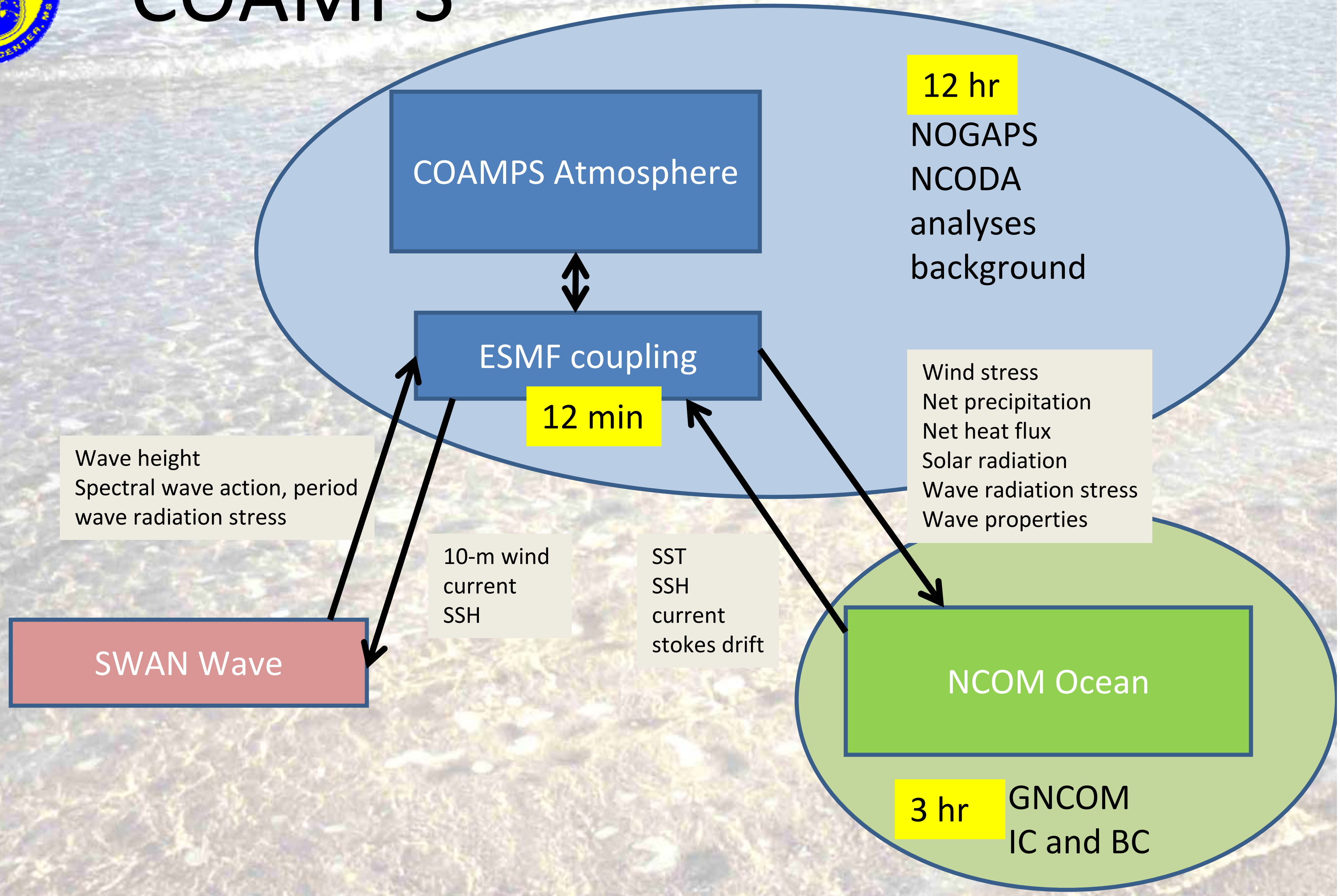
3km grid / 49 T levels
NRL DBDB2' bathymetry
Lateral BCs by G-NCOM
OSU OTIS tides

Timeseries of 0-72h surface temperature forecast starting 01 Feb 2010.

Coupled Ocean/Atmosphere Mesoscale Prediction System COAMPS

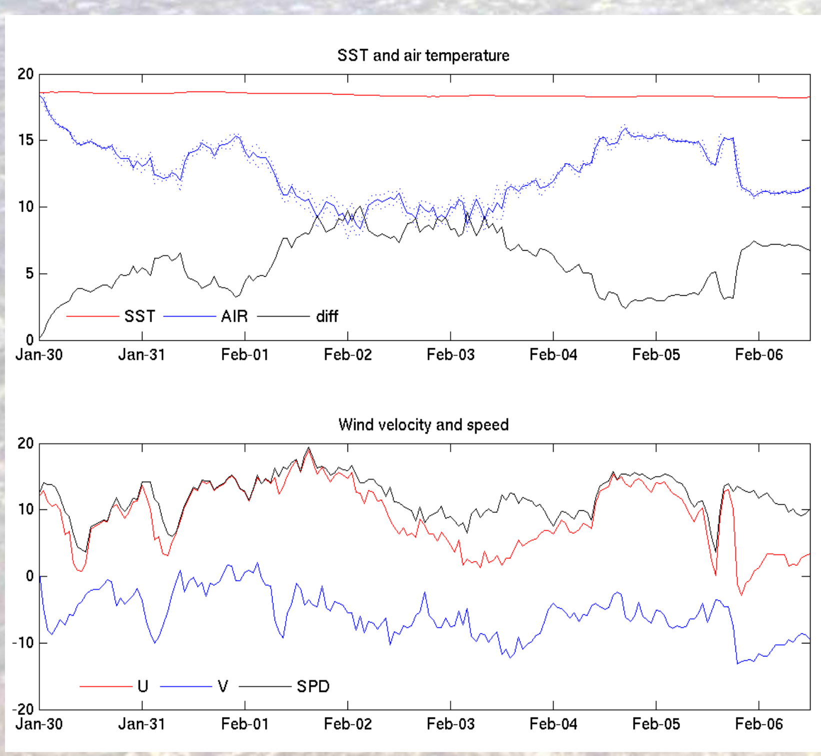
Coupled atmosphere-ocean-wave model

COAMPS ®


12 hr
NOGAPS
NCODA
analyses
background
COAMPS Atmosphere
ESMF coupling
12 min
Wind stress
Net precipitation
Net heat flux
Solar radiation
Wave radiation stress
Wave properties
Wave height
Spectral wave action, period
wave radiation stress
10-m wind
current
SSH
SST
SSH
current
stokes drift
SWAN Wave
NCOM Ocean
3 hr
GNCOM
IC and BC

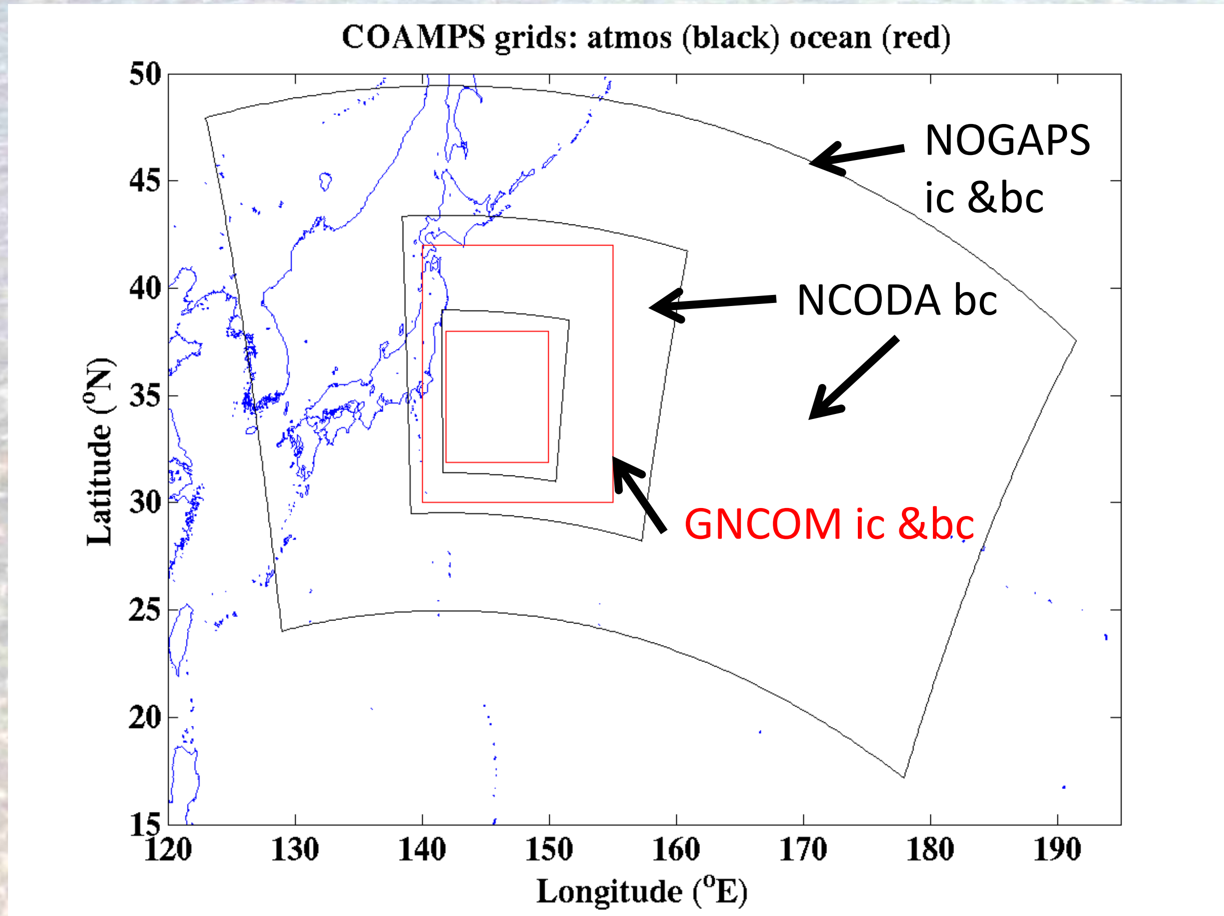
Cold Air Outbreak February 1, 2005

KEO buoy surface observations

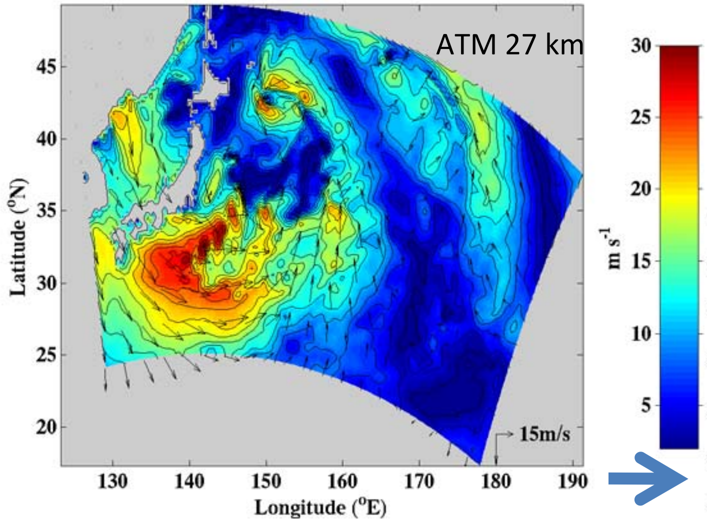


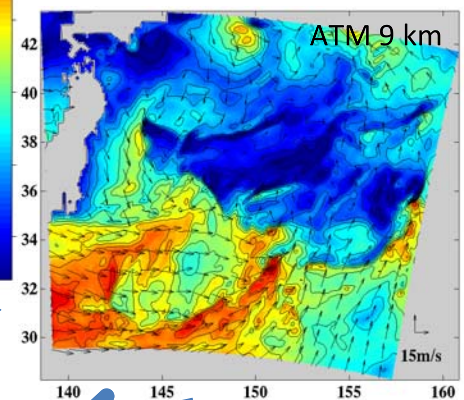
Position 144.6°E, 32.4°N

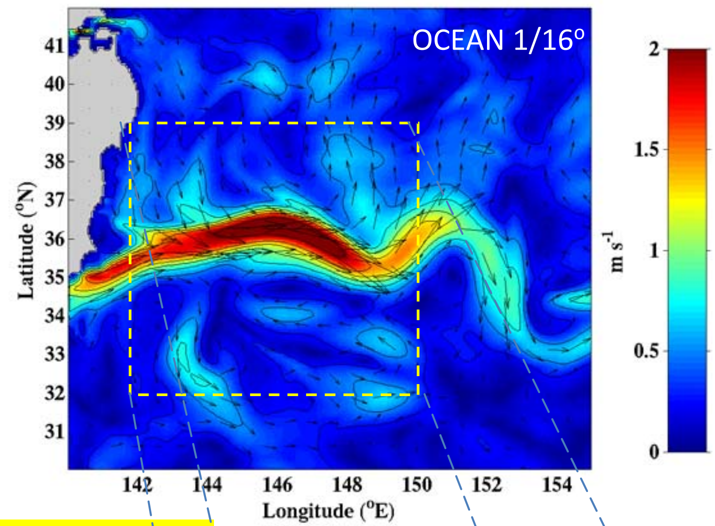
Nested grids



KESS coupled COAMPS grids





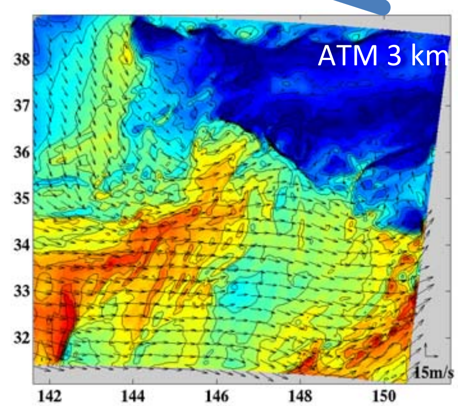


COAMPS ATM models

Lambert conformal projection
40 levels

3 nests: 27 km, 9 km and 3 km

12 hour cycling with data assimilation



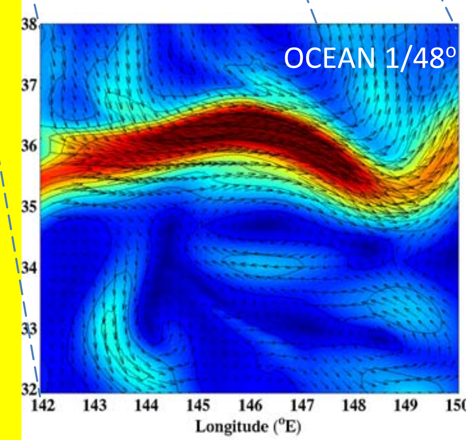
NCOM models

Spherical coordinates
50 levels (35 sigma)
rivers and 8 tidal components

Nest 1: 1/16º NCOM
241 x 193 x 50 grid

Nest 2: 1/48º NCOM
385 x 289 x 50 grid

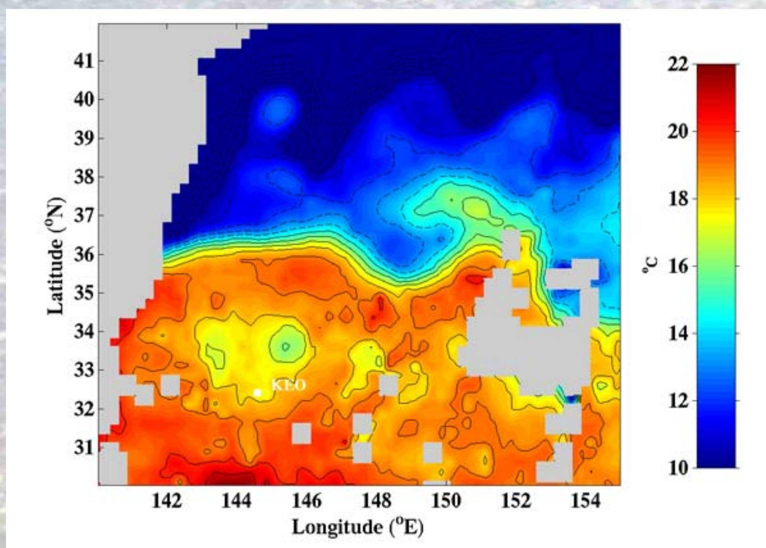
IC and BC from
East-Asian Seas 1/16º NCOM



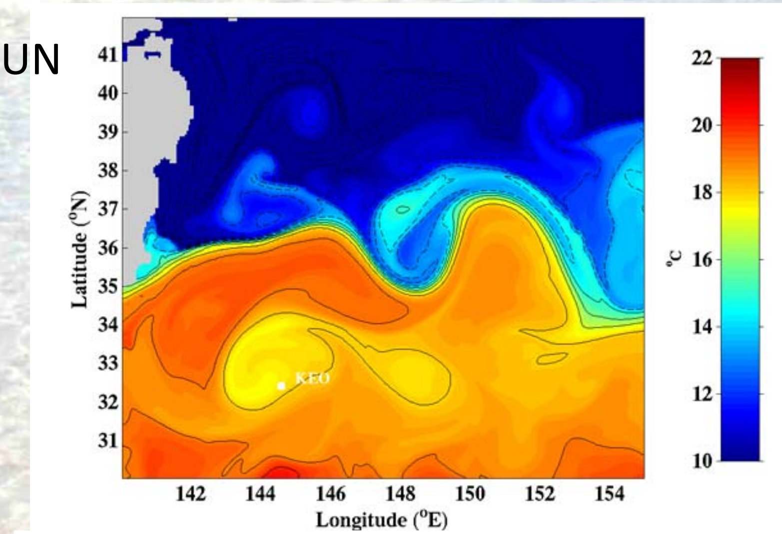
Ocean conditions: Sea Surface Temperature

Feb 01, 2005

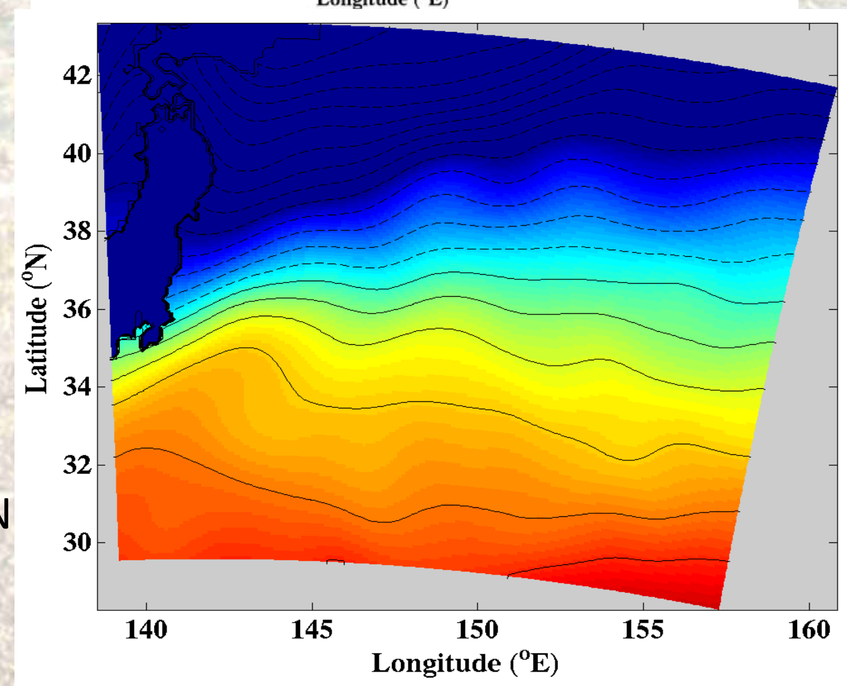
AMSR-E OBSERVATION



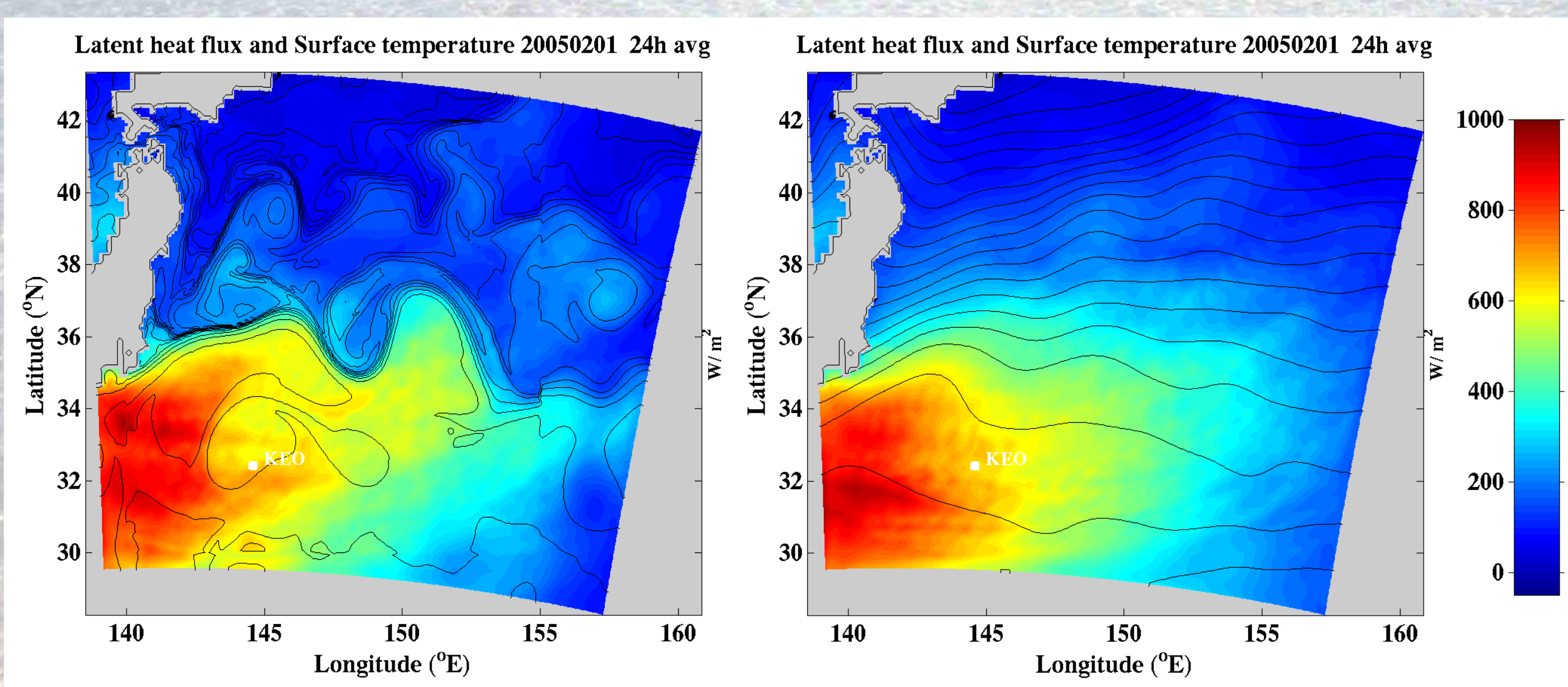
COUPLED RUN



UNCOUPLED RUN



Coupled or uncoupled COAMPS ?
9 km grid solutions

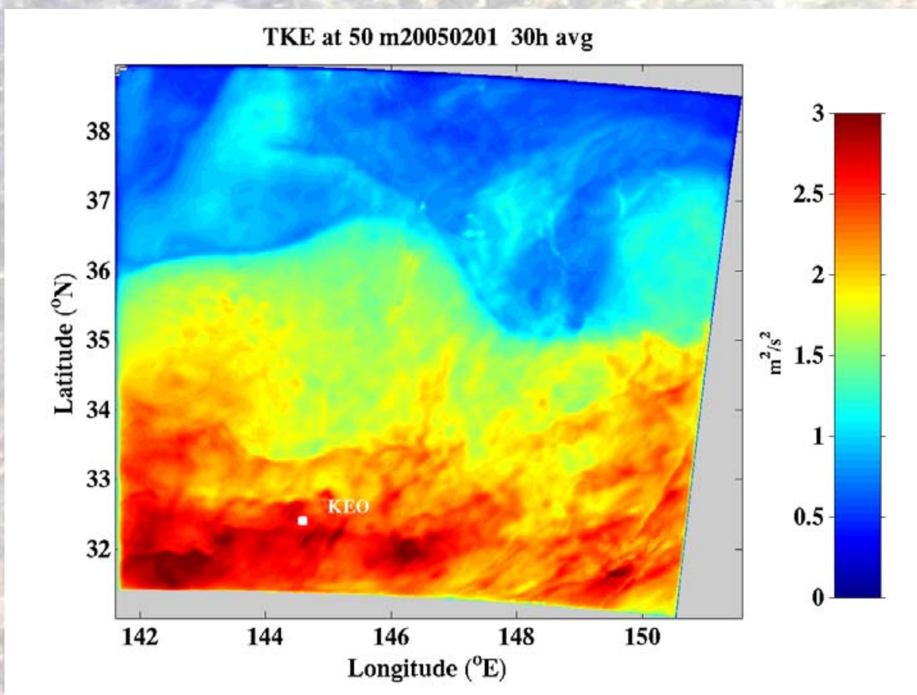


COUPLED UNCOUPLED

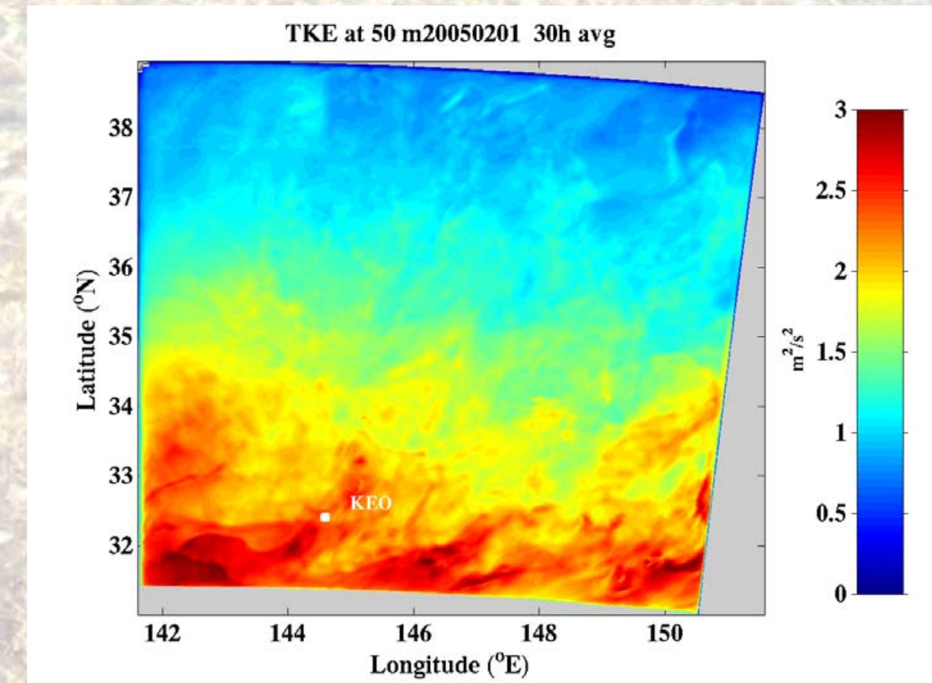
Feedback to Atmosphere:

Turbulent kinetic energy in the PBL

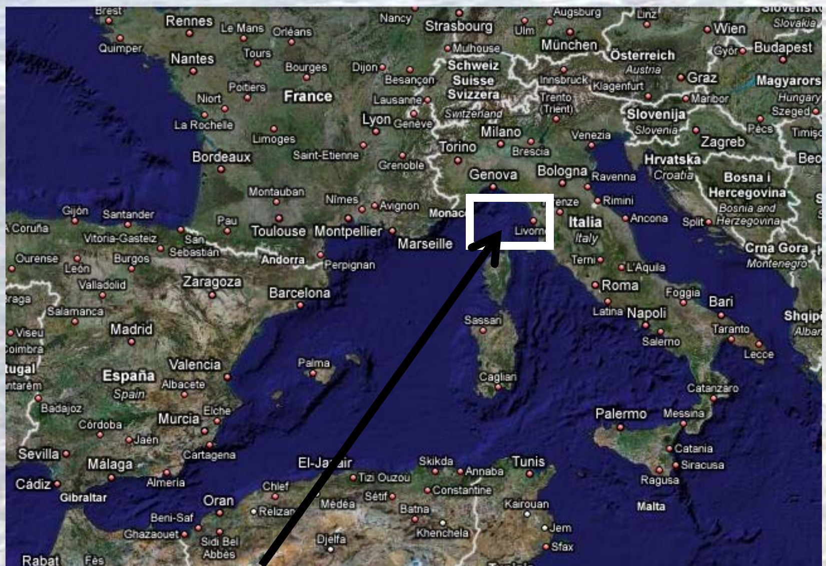
COUPLED



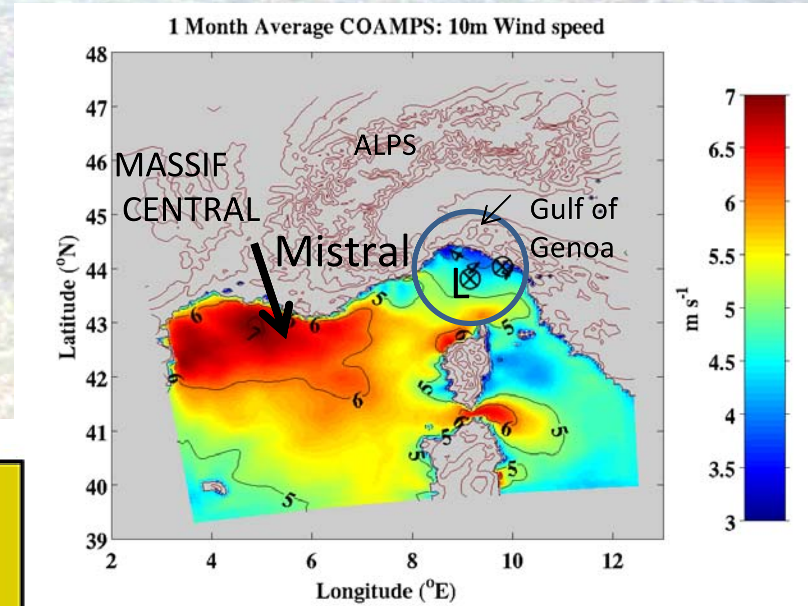
UNCOUPLED

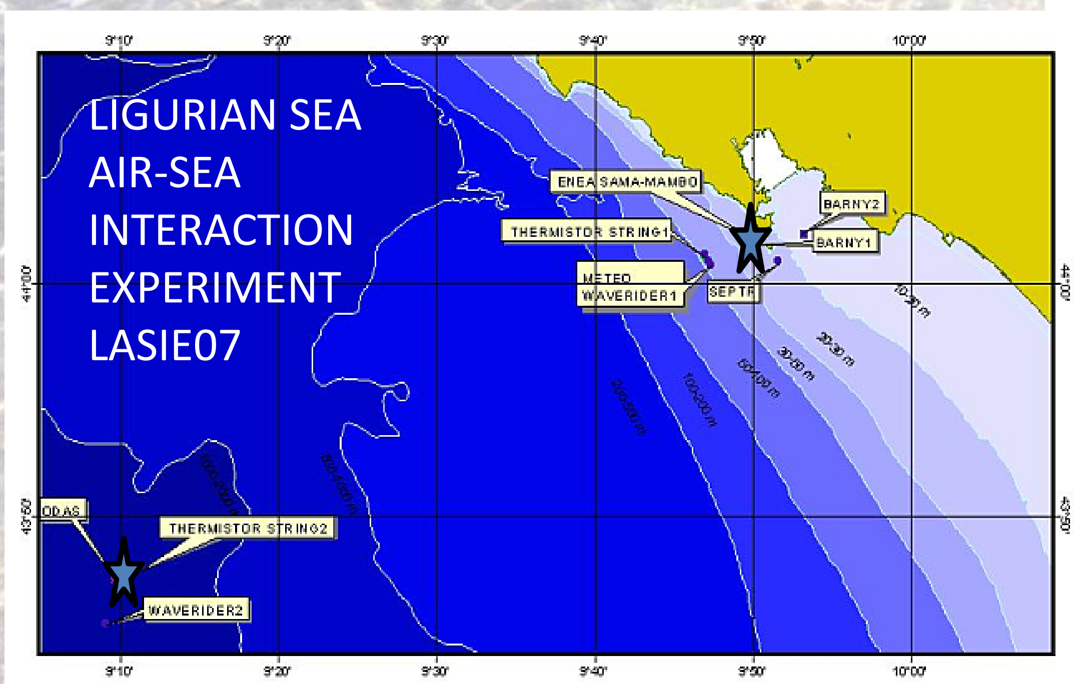


Ligurian Sea June 2007



Events of interest: Alpine Lee cyclogenesis and strong winds in summer

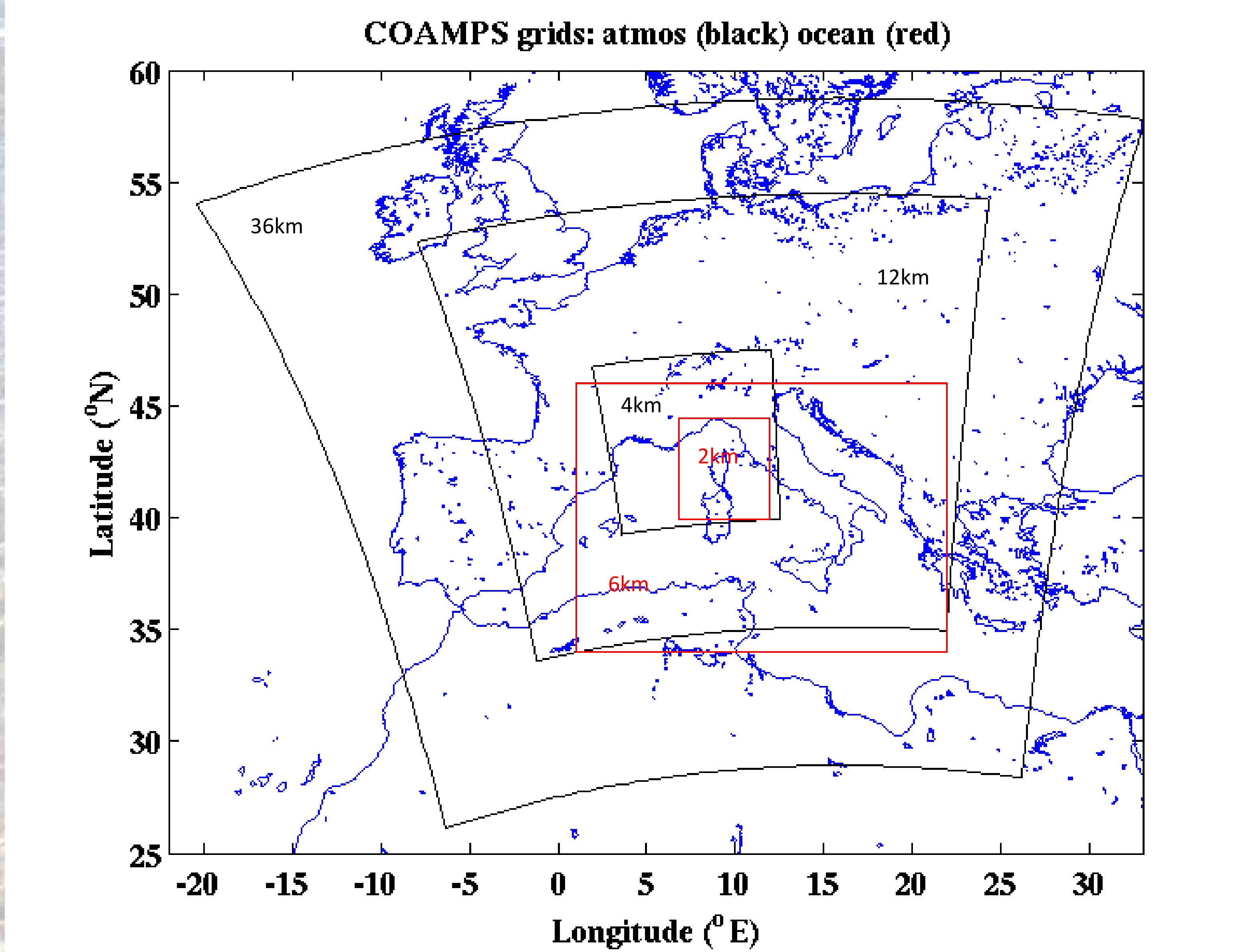




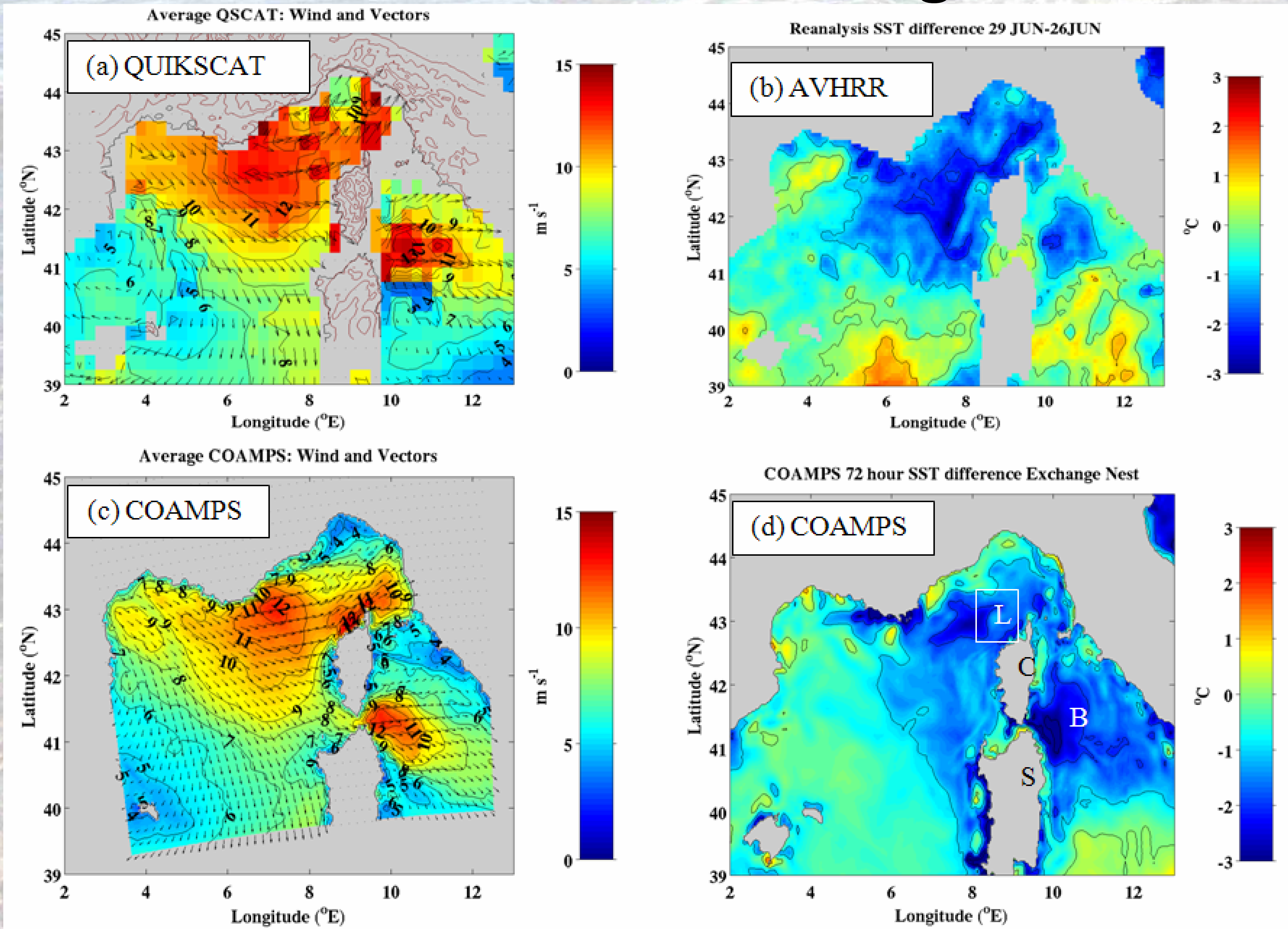
Data: LASIE07 (June/July 2007, PI: Joao Teixiera). Over 300 ocean profiles, 100 radiosondes, 2 surface met moorings, wave buoys, drifters, ADCP, thermistor moorings.

Aim: to better understand coupled boundary layer processes.

Model nests

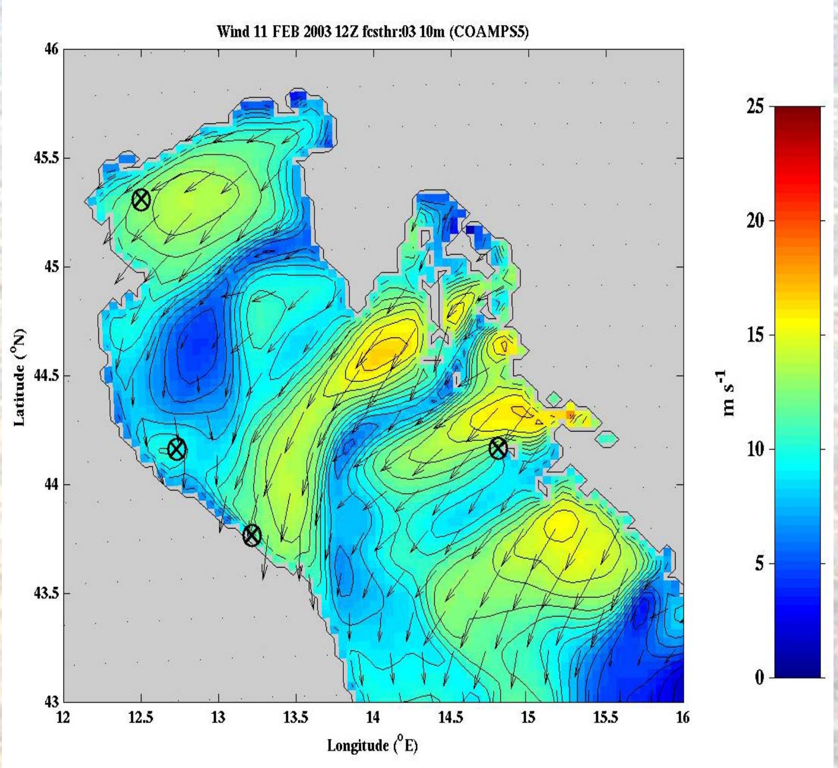

COAMPS grids: atmos (black) ocean (red)
36km
12km
4km
2km
6km
Latitude (⁰N)
Longitude (⁰ E)
60
55
50
45
40
35
30
25
-20
-15
-10
-5
0
5
10
15
20
25
30

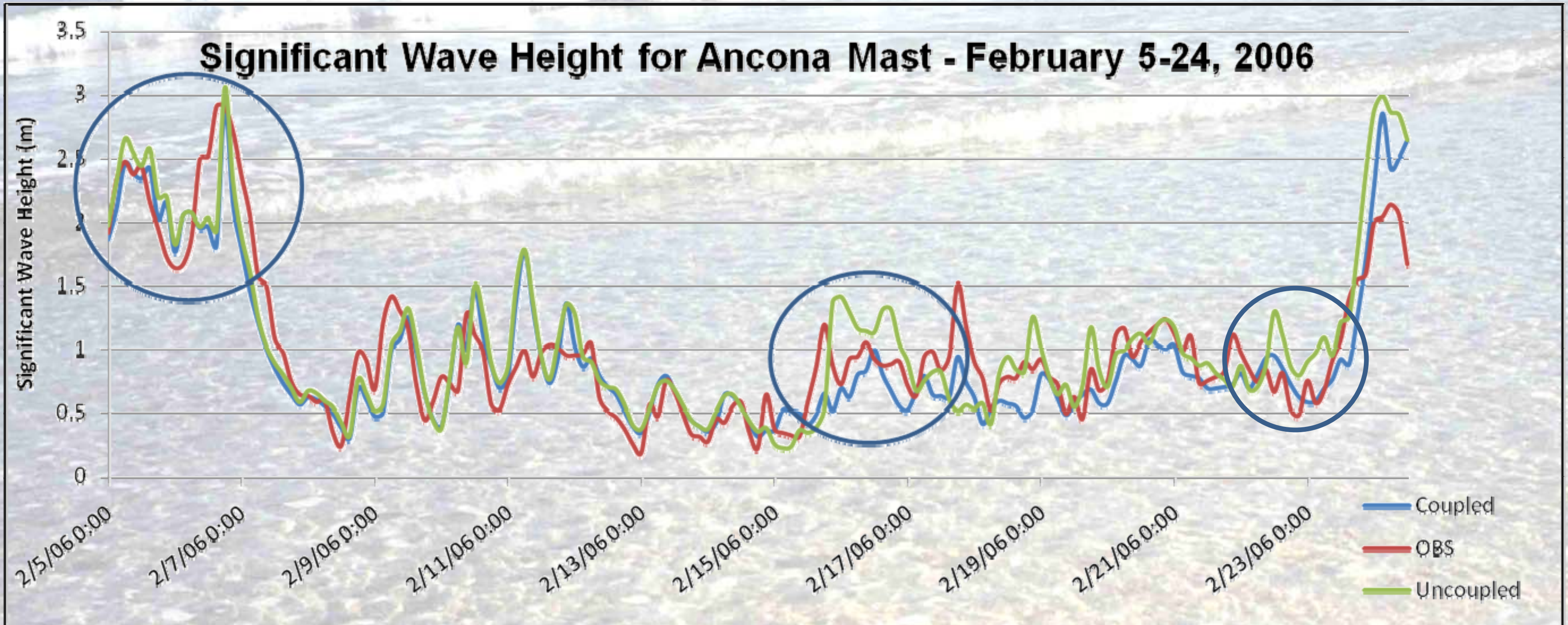
Winds and SST change

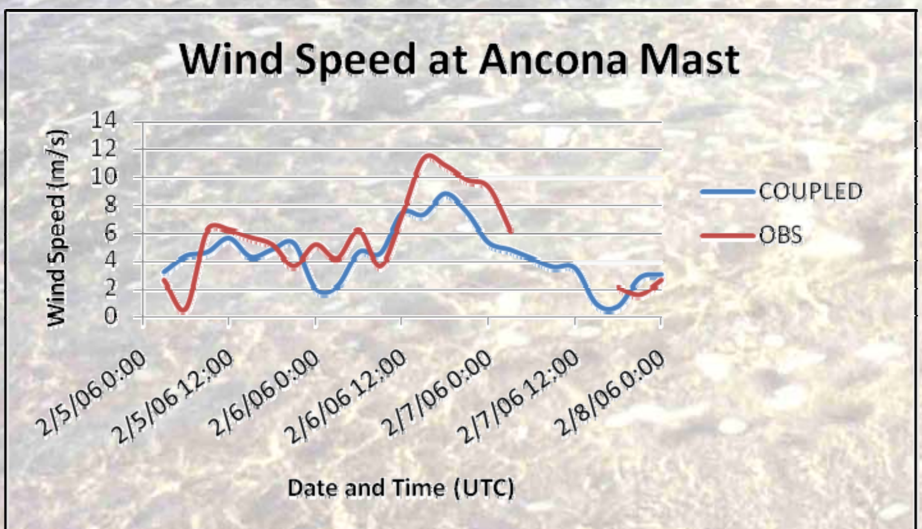


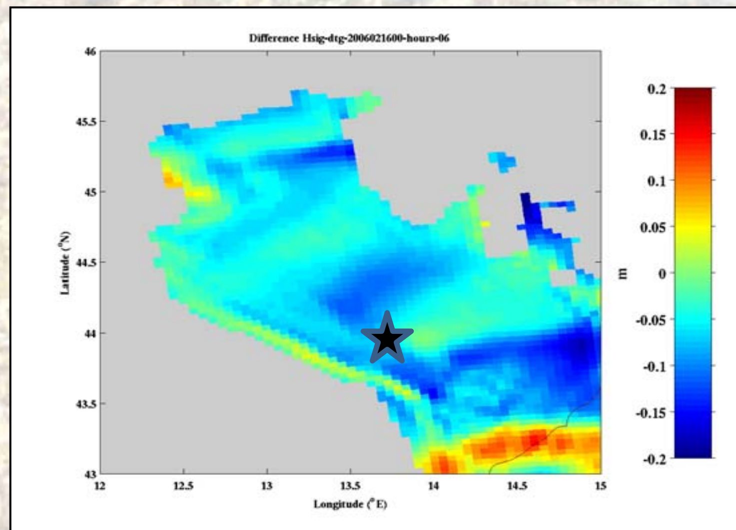
Adriatic Sea Bora Event, Feb 2006

- Bora: Downslope windstorms that occur in the Dinuric Alps that are categorized by their synoptic setting
  - northeasterly wind direction (perpendicular to Diurnic Alps)
  - cyclonic or anticyclonic depending on synoptic wind situation
  - subjective bora identification in literature
  - Pullen et al. (2003, 2007) examined air/sea coupling for several bora events in February 2003.









COUPLED: Mean Bias: -0.05 m Correlation: 0.88 RMSE: 0.29

UNCOUPLED: Mean Bias: 0.06 m Correlation: 0.85 RMSE: 0.34

CONCLUSIONS

NCOM has been modified to accept wave radiation stress as forcing and to include Stokes drift currents.

Wave effects enhance vertical mixing in the ML when the Kantha-Clayson mixing parameterization of LC is used

RELO provides an efficient venue for setting up a regional NCOM including data assimilation based on NCODA

NCOM coupled to COAMPS provides more realistic air-sea interaction in the open ocean and in coastal areas than run without an active ocean model

Coupled COAMPS-NCOM-SWAN model improves wave forecast over standalone wave models

Effects of waves on ocean currents

- Stokes drift current (SDC):
  - Advection of model fields
  - Calculation of continuity (calculation of vertical velocity)
  - Coriolis term
  - Calculation of bottom drag
  - Vertical mixing in the surface mixed layer
- Wave-radiation stress due to horizontal gradients of the energy of the surface waves.
- Enhancement of bottom drag coefficient in shallow water due to wave orbital motions near bottom.
- Enhanced vertical mixing due to Langmuir cells (LCs) and Langmuir turbulence.
- Note that vertical mixing within the ocean model does NOT mix the SDC because of short time scale of the SDC relative to time scale of turbulent mixing.

Feedback to Atmosphere:

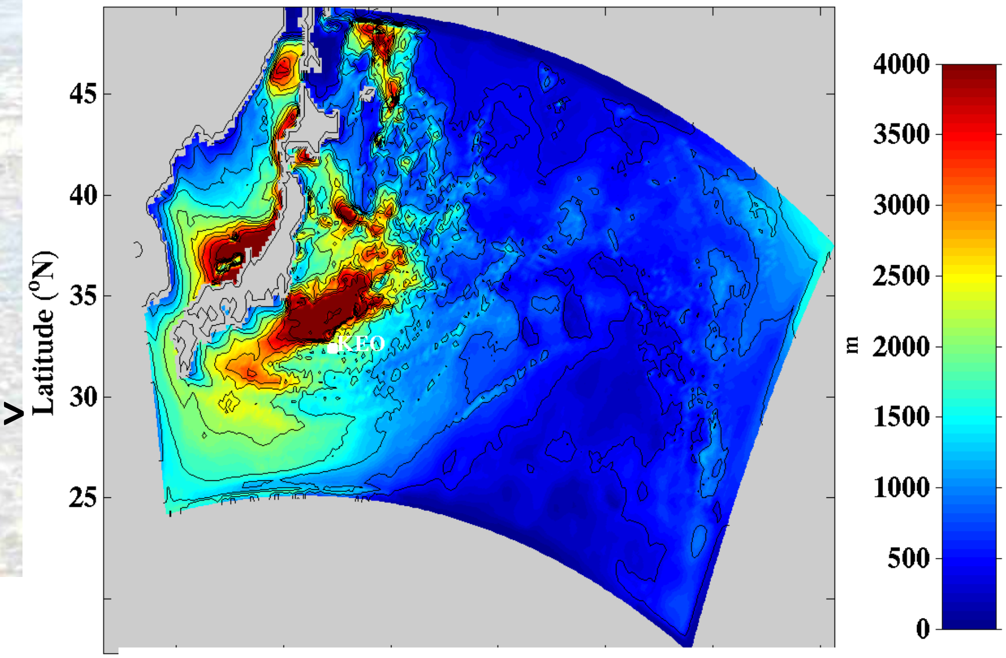
High Sea Surface Temperature =>

High Latent heat Flux =>

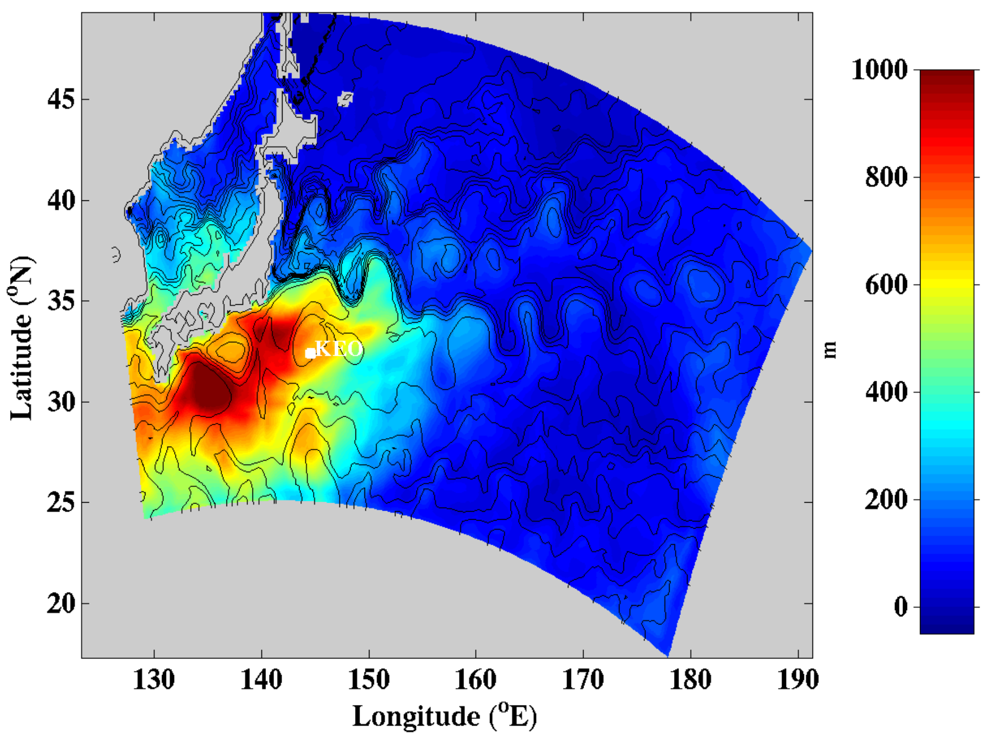
High Planetary Boundary Layer Height =>

Rain bands

PBL height 20050201 24h avg



Latent heat flux and Surface temperature 20050201 24h avg



Total precip 2005020100 12 hours