An eddy-resolving ocean reanalysis using the 1/12° global HYbrid Coordinate Ocean Model (HYCOM) and the Navy Coupled Ocean Data Assimilation (NCODA) scheme

O.M Smedstad\textsuperscript{1}, E.J. Metzger\textsuperscript{2}, R.A. Allard\textsuperscript{2}, R. Broome\textsuperscript{1}, D.S. Franklin\textsuperscript{1} and A.J. Wallcraft\textsuperscript{2}

\textsuperscript{1}QinetiQ North America
\textsuperscript{2}Naval Research Laboratory

Layered Ocean Model Workshop
21-23 May 2013
Ann Arbor, Michigan
HYCOM/NCODA Ocean Reanalysis

- Of those ocean reanalyses performed to date, only a few have eddy-permitting resolution and none are capable of fully resolving oceanic mesoscale features (eddies and current meanders) across the globe.
- This project addresses the need for a long time period eddy-resolving ocean reanalysis.
- Funded by the DoD Modeling and Simulation Coordination Office (M&S CO).
- Goal to the sponsor: provide physically consistent environmental scenarios for planning, wargaming and scenarios to support the warfighter.
- Numerous other applications and research opportunities.
HYbrid Coordinate Ocean Model

Tri-pole latitudinal grid resolution (km)

- Curvi-linear grid: north of 47°N
- Mercator projection: 66°S to 47°N
- Uniform cylindrical: south of 66°S

- 32 hybrid coordinate surfaces, thermobaricity, $\sigma_2^*$
- K-Profile Parameterization (KPP) mixed layer model
- Monthly river runoff
- Surface salinity relaxation to U.S. Navy GDEM4 climatology
- Thermodynamic “energy loan” ice model
Atmospheric Forcing
NCEP Climate Forecast System Reanalysis (CFSR)

- Time frame: 1993-2012 (altimeter period)
- Horizontal resolution: 0.3125° gaussian
- Temporal resolution: 1-hourly
- QuikSCAT scaling
- Inputs:
  - Bulk-derived wind stress
  - Wind speed
  - Radiative fluxes
  - Thermal fluxes
  - Precipitation

Net Surface Shortwave (W/m²)
Surface Specific Humidity (kg/kg x 10²)
Precipitation (m/s x 10⁶)
Spin-up and Reanalysis Simulations

• Spin-up 1/12° non-assimilative global HYCOM with CFSR climatology (12 model years)
• Extend climatological spin-up with 1993-2012 1-hourly CFSR forcing using 1/12° non-assimilative global HYCOM
• Extend climatological spin-up with Oct 1992-2012 1-hourly CFSR forcing using 1/12° assimilative HYCOM/NCODA
  – Begin in Oct 1992, currently in May 2000
Navy Coupled Ocean Data Assimilation (NCODA)

Sequential Incremental Analysis Update (IAU) Analysis-Forecast-Analysis
NCODA analysis once per day that is incrementally inserted over a 6 hour window

Ocean/Ice Obs.
SST: GAC/LAC MCSST, GOES, Ship, Buoy
Profiles: XBTs, CTDs, Argo floats
Buoys: Fixed and drifting
Altimeter SSH anomaly
SSM/I sea ice concentration

Ocean QC

Innovations

3DVar

First Guess

HYCOM

3DVar - simultaneous analysis of ice concentration and 5 ocean variables: temperature, salinity, geopotential, layer pressure, and velocity (u,v)
Altimeter Observations

January 1, 1993

August 26, 1999

February 19, 2000
Observations to be Assimilated via NCODA
August 16 – September 16 1999

SSH Observations: 3-day data window
SST Observations: 24 hour data window
Profiles: 12-day data window

Modular Ocean Data Assimilation System (MODAS) used as vertical projection of the satellite altimeter observations.
Temperature Verification in the Pacific
August 1998 to August 1999
SST Mean Error

1999

19.1 vs NOAA OISST: Mean Error yr 1999
SST Skill Score

1998

19.1 vs NOAA OISST: Skill Score yr 1999
SSH Variability

Oct 92 – May 07 SSH variability based on T/P, ERS-1 and ERS-2 altimeters (from Collecte, Localisation, Satellites (CLS))
Mean SSH
1993-1999

Gulf Stream region

Kuroshio region
Kuroshio and Gulf Stream SSH with SST-based frontal analysis

Frontal analysis < 4 days old = white,
Frontal analysis ≥ 4 days old = black
Frontal analysis performed by the Naval Oceanographic Office
Mean SSH
Gulf of Mexico Region

1993

1994

1995

1996

1997

1998
Gulf of Mexico SSH and SST with SST-based frontal analysis

March 3 1999

Frontal analysis < 4 days old = white, analysis ≥ 4 days old = black
Frontal analysis performed by the Naval Oceanographic Office
Forced with 1 hourly CFSR winds and thermal forcing
Velocity Cross-section Across Luzon Strait
Sb-ADCP data (top) vs. 1/12° Global HYCOM (bottom) in the upper 300 m
Section along 120.75°E between Taiwan and Luzon

Sb-ADCP data from Liang et al. (2003, DSR Pt. II), 1991-2000
1993-1999 mean from HYCOM forced with 1 hourly CFSR winds and thermal forcing

Westward velocity:
- 40+ cm/s
- 30+ cm/s
Velocity Cross-section Along Luzon Strait
Sb-ADCP data (top) vs. 1/12° Global HYCOM (bottom) in the upper 300 m
Section along 21°N between 118.5°E and 124.0°E

Northward velocity of western core:
- 60+ cm/s
- 40+ cm/s

Sb-ADCP data from Liang et al. (2003, DSR Pt. II), 1991-2000
1993-1999 mean from HYCOM forced with 1 hourly CFSR winds and thermal forcing
Velocity Cross-sections East of Taiwan
Sb-ADCP data (top) vs. 1/12° Pacific HYCOM (bottom) in the upper 300 m
Sections at 22°N, 23°N, 24°N and 25°N

Sb-ADCP data from Liang et al. (2003, DSR Pt. II)
1993-1999 mean from HYCOM forced with 1 hourly CFSR winds and thermal forcing

Note how the two-core Kuroshio merges to a single jet in both the observations and HYCOM from the south to north along the Taiwan coast
WOCE PCM-1 Transport

From Johns et al. 2001
WOCE PCM-1 Transport

WOCE PCM-1 transport (black) via the adjusted geostrophic method from Johns et al. (2001) versus full water column transport from the global HYCOM/NCODA Ocean Reanalysis (red) using those model gridpoints between moorings M1 – M4. A ten day filter has been applied to both time series. The unfiltered mean and standard deviation for PCM-1 are 22.0 ± 4.8 Sv while that for global HYCOM is 23.7 ± 9.8 Sv. The correlation coefficient is 0.78.
Computational Requirements

• Computer time via the DoD High Performance Computing Modernization Office

• Currently integrating the ocean reanalysis on the Navy DoD Supercomputing Resource Center (DSRC) IBM iDataPlex

• Using 949 processors
  – Integrate up to 22 model days every 24 hrs of wall time
  – It will take ~8 months to integrate the remainder
Output and Storage

• HYCOM 3D native grid archive files (compressed):
  – Single hour: ~7 Gb
  – Saving 3-hourly output:
    • ~20 Tb / model year
    • ~340 Tb for the entire reanalysis

• HYCOM 3D constant .08° grid (±80° lat) netCDF files remapped to 40 z-levels (compressed):
  – Single hour: ~1.2 Gb
  – Saving 3-hourly output:
    • ~3.5 Tb / model year
    • ~59 Tb for the entire reanalysis

• Subset of the output will be placed on the hycom.org data server
  – When is still to be determined