UPCOMING ADVANCEMENTS IN OCEAN DATA ASSIMILATION AT NCEP

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OCEAN DA COLLABORATIONS:

- NCEP/CPC/EMC: operational replacement from the MOM3 3DVar-GODAS to MOM6 Hybrid-GODAS (Sluka, Xue, Behringer)
- NCEP/EMC: ocean initialization for coupled HWRF/HYCOM forecasts (Dong, Mehra)
- NCEP/EMC: wave model initialization for CFSv3 (Flampouris)
- NCEP/EMC: sea-ice model initialization for CFSv3 (Wu, Vernieres, Grumbine, Saha)
- NRL-Stennis: 1/12º Global HYCOM-based Ocean-LETKF (Wei)
- NASA GMAO: MOM5 configuration of Ocean-LETKF (matching CFSR 1/2º resolution) to be use for MERRA2 Ocean reanalysis, coupled with Sea-Ice LETKF. (Vernieres)
- INCOIS (India; Paul, Reddy), and INPE (Brazil): ROMS-based Ocean-LETKF (Lima)
- INCOIS nested 1/4º MOM4p1-LETKF inside global 1/2º MOM4p1-LETKF (Rahaman)
SUMMARY

• Brief DA overview

• Advancements at NCEP

• Future trends in ocean DA

• Needs from Ocean Observing System development to support DA
BRIEF DA OVERVIEW
What is Data Assimilation?

Physical Atmosphere or Ocean

Observations

Data Assimilation

Computational Model

Improved estimate of the physical state
**MOST COMMON DA METHODS**

**Ensemble-based (EnKF)**
- Dynamically varying estimate of forecast error ("errors of the day")

**Variational**
- Climatological estimate of the forest error
  - Minimization
  - Iterative Solver

- xf
  - Xi
MOST COMMON DA METHODS

Ensemble-based (EnKF)

Dynamically varying estimate of forecast error ("errors of the day")

Variational

Minimization
Iterative Solver

Climatological estimate of the forest error

HYBRID

\( x_f \)

\( x_a \)
ADVANCEMENTS AT NCEP
21-YEAR HYBRID-GODAS REANALYSIS

Temperature and salinity (O-F) rmsd and bias reduced using the Hybrid-GODAS (5-day forecasts)

3-month moving averages

Pre-Argo Argo-Era
EQUATORIAL PACIFIC ADCP*

RMSD (cm/s)  Anomaly Correlation

Hybrid  3DVar

165E  170W  140W  110W

note: Hybrid-GODAS updates velocity field, 3DVar-GODAS does not.

*Acoustic Doppler Current Profilers
ASSIMILATION OF ADT ALTIMETRY

N. Atlantic

Assimilating:
Along-track Jason-2 & Cryosat2 plus gridded OSTIA SST

Baseline
MERRA-Ocean ADT

Assimilating:
After 1 month w/ daily analysis cycle

Thanks to: Guillaume Vernieres
GLOBAL DRIFTER PROGRAM (GDP) DATA

GOALS:
• Use drifter positions to improve near surface current estimates
• Update upper ocean T & S based on ensemble-derived error covariances
• Use GDP temperature measurements to bias-correct SST data

source: http://www.aoml.noaa.gov/phod/dac/index.php
SURFACE DRIFTERS - LAGRANGIAN DA

Depth: 15m

Depth: 105m

Thanks to: Luyu Sun, UMD
INVESTIGATION OF SOURCES OF UNCERTAINTY IN ENSEMBLE OCEAN DA

(After 1 month of model integration)

Spread on ocean surface – 06/Feb/2009

Thanks to: Leonardo Lima
INVESTIGATION OF SOURCES OF UNCERTAINTY IN ENSEMBLE OCEAN DA

(After 10 months of model integration)

Spread on ocean surface – 29/10/2009

SALT

TEMP

u

v

SSH

u and v Wind

Rad Fluxes (Short and Longwave)

Specific Humidity

Rain

Thanks to: Leonardo Lima
ASSIMILATION OF BIAS-CORRECTED SST INNOVATIONS

- highest correlations above MLD
- included a MLD calculation
- de-bias regional SST innovation
- split 2-layer localization

Thanks to: Leonardo Lima
ASSIMILATION OF BIAS-CORRECTED SST INNOVATIONS: RMSD

Temperature Profiles

Salinity Profiles

Regional average after 15 days assimilation
WAVE FORECAST BIAS CORRECTION USING NEURAL NETWORKS

- Ensemble Wave Data Assimilation (LETKF)
- Biased Corrected forecast (Neural Network)

Thanks to: Flampouris (DA) and Campos (NN)

Ensemble Spread over forecast lead times 0-10 days
COUPLED DATA ASSIMILATION
STRONGLY COUPLED DATA ASSIMILATION

Atmosphere

Land

Ocean

Sea Ice

Aerosol

EACH DOMAIN IS INFLUENCED BY OBSERVATION INNOVATIONS FROM ALL OTHER DOMAINS

Wave DA
Strongly Coupled LETKF

- Sharing of observational departures allows system to act as single **strongly coupled** system.
- Separate LETKF for each domain helps keep implementation simpler. **Ocean LETKF and Atmosphere LETKF can be developed independently.**


Data assimilation systems, normally separate “**weakly coupled DA**”

Thanks to Travis Sluka
EXPERIMENT SETUP WITH SPEEDY/NEMO COUPLED SYSTEM

SPEEDY-NEMO OSSE

Using the fast SPEEDY-NEMO (one year run takes only 12 hours on 1 core)

- Perfect model OSSE conducted using only atmospheric observations
- T30 atmosphere
- 2 degree ocean
- Coupling every 6 hours

Experiment parameters

- 40 ensemble members
- Localization: 1000km Hz
- Relaxation to prior spread: 90% for ocn 60% for atm

Thanks to Travis Sluka
**STRONGLY COUPLED DA REDUCES ERRORS** (vs. weakly coupled DA)

For example, assimilating only atmospheric observations leads to significant improvements in ocean:

- **Tropics**
- **MidLat - NH**
- **MidLat - SH**
- **Global**

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STRONGLY COUPLED DA REDUCES ERRORS (vs. weakly coupled DA)

Again, assimilating only atmospheric observations:

Upper 500m

Temperature

Pacific

Atlantic

Salinity

Time mean over last 5 years of 10-year experiment.
ATMOSPHERIC SURFACE VARIABLES
IMPROVED DUE TO MODEL FEEDBACKS

Error reduction due to strong coupling vs. weak coupling is reflected in atmosphere as well
FUTURE TRENDS IN OCEAN DA

• DA solutions that maintain balance between ocean and external forcing via **coupled analyses** (and improve fluxes that ultimately drive the forecast in the short-term)

• **Higher resolution models** and effectively **lower resolution** ‘top-heavy’ observing networks

• Incorporation of **new and underutilized observation types** (e.g. satellite gravity field data, in situ drifters/floats/gliders, surface winds, observed fluxes)

• Incorporation of **biogeochemistry** into ocean DA

• **Neural network / machine learning** pre- and post-processing within the DA cycling, and bias-correcting observations and model forecasts

• New DA methods to explicitly **analyze multiple spatial and temporal scales**
GENERAL NEEDS FROM OCEAN OBSERVATIONS TO SUPPORT DA

• Ideal Goal: maintain comparative resolution between feasible operational model resolutions and global observing system resolution

• Increased in situ observation coverage, including beneath sea ice, deep ocean currents, active dynamical regions like western boundary currents, southern ocean

• Redundant observing network design to calibrate and bias-correct measurements globally, improve agreement between different sources of measurements, and estimate errors of these measurements

• Improved observing of air-sea interface (fluxes), as well as Sealce-ocean, land-ocean, biogeochemical fluxes, etc. to help isolate model biases

• Co-located observations and observation-based estimates of cross-covariance relationships across domain boundaries (e.g. air-sea)
IN CONCLUSION

• Future advancements in ocean DA can be accelerated by active collaboration between observing, modeling, and DA communities

• Viable ocean model resolution is increasing faster than observing system resolution, which creates new challenges and requires:
  (1) new DA approaches (like coupled DA) and
  (2) more non-traditional observations to be included in ocean DA