Ocean reanalysis at the GMAO

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Overview of MERRAOcean (1978–present)

• Models
• Ocean observing system
• Assimilation methodology
• Some diagnostics

Current development

• Modeling/DA:
  o SST (Santha)
  o Wave (Matt, Santha)
  o ¼ degree Ocean modeling (Yuri)
  o Carbon fluxes (Watson, Cecile)
• New observing systems:
  o SSS (Aquarius Ludovic, Emanuel, Santha, ...)
  o Sea-Ice Freeboard (CryoSat, OIB, ... Nathan Kurtz)
  o GRACE
  o Reconstructed Sea-level
Ocean: MOM4p1 (½ degree tripolar ocean grid resolution, 40 vertical levels)

Sea-Ice: CICE (Los Alamos National Laboratory)

Atmosphere: Fortuna 2.5 constrained to MERRA

Ex: 2012 minimum sea-ice extent
In-situ obs count as a function of depth [obs/month]
Ocean Sea-Ice Observing System

Distribution of *In-situ* observations

Mostly Temperature profiles, very few Salinity measurements
Assimilation methodology: EnOI

Static ensemble from EOFs of hindcast anomalies \((T, S, U, V, SSH, \ldots)\)

**iODAS** (Keppenne, 2008)

\[
X_a - X_b = \rho PH^T (H \rho PH^T + R)^{-1} (Y_o - HX_b)
\]

Background state

Observations

Analysis increment applied to MOM and CICE using IAU (Bloom et al., 1995)
Use covariances from static background error to:

- Estimate $S$ from $T$ observations
- Estimate Ocean density from altimeter
Sea level anomaly as a predictor of the 3D ocean temperature

Assimilation methodology: EnOI

Sea level anomaly (SLA) DEC 1997

Temperature anomaly DEC 1997 (Celsius)

Projection of SLA onto the 3D Ocean Temperature using Covariances estimated from the joint EOFs of the GEOS5 coupled system

Sea level anomaly as a predictor of the 3D ocean temperature.
Diagnostics: RMS of OMF

Temperature [°C]

0-300 m

300-1000 m

Salinity [psu]

0-300 m

300-1000 m
**Diagnostics: Overturning circulation (RAPID array)**

**AMOC stream function in MERRA Ocean**

![Graph showing AMOC stream function with depth and latitude axes.](image)

**Sv**

**Transports at 26.5N:**

- Total
- Florida strait
- Ekman
- Mid-Ocean
- AMOC

*Source: NASA/JPL-Caltech*
Current development

- **Modeling/DA:**
  - SST (Santha, Ricardo)
  - Wave (Matt, Santha)
  - $\frac{1}{4}$ degree Ocean modeling (Yuri)
  - Carbon fluxes (Watson, Cecile)

- **New observing systems:**
  - SSS (Aquarius Ludovic, Emanuel, Santha, …)
  - Sea-Ice Freeboard (CryoSat, OIB, … Nathan Kurtz)
  - GRACE
  - Reconstructed Sea-level
Current Atmospheric DAS configuration: Skin SST ≈ Bulk SST.

New system:
Skin SST = Bulk SST +
- Diurnal warming – Cool skin +
- Ana Increment

Positive Impact on 5 day forecast

Analysis Increment:
- All surface-sensitive IR
- including 3 AVHRR channels
- MW (GMI, AMSR-2) in-progress

Bulk SST is from UKMO OSTIA
Weakly coupled system:
Skin SST = Ocean surface T + Diurnal warming – Cool skin + Atmos Ana Increment
Ocean surface T:
Model T + Ocean Ana Increment

NOAA-PMEL Ocean Climate Stn. PAPA “reference” mooring
High quality, frequent obs since ~1950
University of Miami Wave Model (UMWM)

Validation: Comparison with WaveWatch III
Configuration:

AGCM: 0.50 cube sphere, 72 vertical levels;

OGCM: 1/4 tripolar, 50 vertical levels (MOM5).

¼ degree Ocean model for the next seasonal prediction system
Yuri Vikhliaev (0.25 deg Ocean) and Christian Keppenne (0.1 deg Ocean)
½ degree Ocean model for the next seasonal prediction system
$\frac{1}{4}$ degree Ocean model for the next seasonal prediction system
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$\frac{1}{4}$ degree Ocean model for the next seasonal prediction system
¼ degree Ocean model for the next seasonal prediction system
$\frac{1}{4}$ degree Ocean model for the next seasonal prediction system
1/4 degree Ocean model for the next seasonal prediction system
Quarter-Degree

Half-Degree

Kuroshio Current: 200001

Kuroshio Current: 200007

(m/s)

Komori et al., 2003
Quarter-Degree

Half-Degree

(m/s)
¼ degree Ocean model for the next seasonal prediction system
Existing Product:
- Ocean pCO₂ and CO₂ fluxes from the NOBM-Poseidon
- Publicly available at carbon.nasa.gov for 2003-2012
- Current pCO₂ and CO₂ fluxes show agreement with in situ data
- Different reanalysis forcing data produce flux estimates within 20% globally

Development:
- pCO₂ and CO₂ fluxes from the NOBM using Modular Ocean Model (both offline using Carbon Tracker data and online using GEOS-5)
- Assimilation of both chlorophyll and Particulate Inorganic Carbon
New observing systems: L2 Aquarius SSS

Overview of SAC-D/Aquarius observation scheme (image credit: NASA, CONAE)

\[ T_b = e(T, S, \text{Freq}, ...) I \]

\[ \frac{T_b}{T} = e(\text{SSS}, \text{SST}, \text{Freq}, ...) \]

Tb Estimated from the 3 Aquarius radiometer operating at 1.4Ghz

NOAA OISST (Reynolds)
New observing systems: L2 Aquarius SSS

Correction of the L2 SSS

$k=1,\ldots,6$ (instrument and orbit type)
New observing systems: L2 Aquarius SSS
BIAS

Before
New observing systems: L2 Aquarius SSS BIAS

ANN: Aquarius-Argo

Beam 1

Beam 2

Beam 3

Ascending

Descending

AFTER

[psu]
New observing systems: L2 Aquarius SSS

RMSD
New observing systems: L2 Aquarius SSS RMSD

ANN: RMS AQ-OBS

Beam 1

Beam 2

Beam 3

Ascending

Descending

AFTER
New observing systems: L2 Aquarius SSS
DA experiments

OMF = *In-situ* bulk S - S from 24 hr lead Forecast
New observing systems: Monthly average estimate of Sea Ice Thickness

Nathan Kurtz
Analysis methodology:
Ensemble (62 members) Kalman Smoother to assimilate monthly mean

\[ X_a = X_b + \rho PH^T (H \rho PH^T + R)^{-1} (Y_o - HX_b) \]

New observing systems: Monthly average estimate of Sea Ice Thickness
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Cov(+, sea-ice thickness 2012 Oct 1)

Single observation of monthly mean sea-ice thickness.
New observing systems: Monthly average estimate of Sea Ice Thickness

Cov(+, sea-ice thickness Oct 15 2012)

Single observation of monthly mean sea-ice thickness.
New observing systems: Monthly average estimate of Sea Ice Thickness

Cov(+, sea-ice thickness Nov 1 2012)

Single observation of monthly mean sea-ice thickness.
New observing systems: Monthly average estimate of Sea Ice Thickness
bottom pressure retrieval?

\[ \frac{\partial \rho}{\partial t} = U_{Earth}^{12} + U_{N-body}^{12} + U_{tides}^{12} + U_{Ocean}^{12} + U_{Atmo}^{12} + U_{Hydro}^{12} + U_{Ion-lt}^{12} + \epsilon \]

From GMAO
New observing systems: ~Monthly average reconstructed Sea Level
Richard Ray, Scott Luthcke, Briant Loomis, Brian Beckley, Frank Lemoine

Use statistical reconstruction
To constrain the 3D ocean T