Synthesis and Assimilation Systems - Essential Adjuncts to the Global Ocean Observing System

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Overview

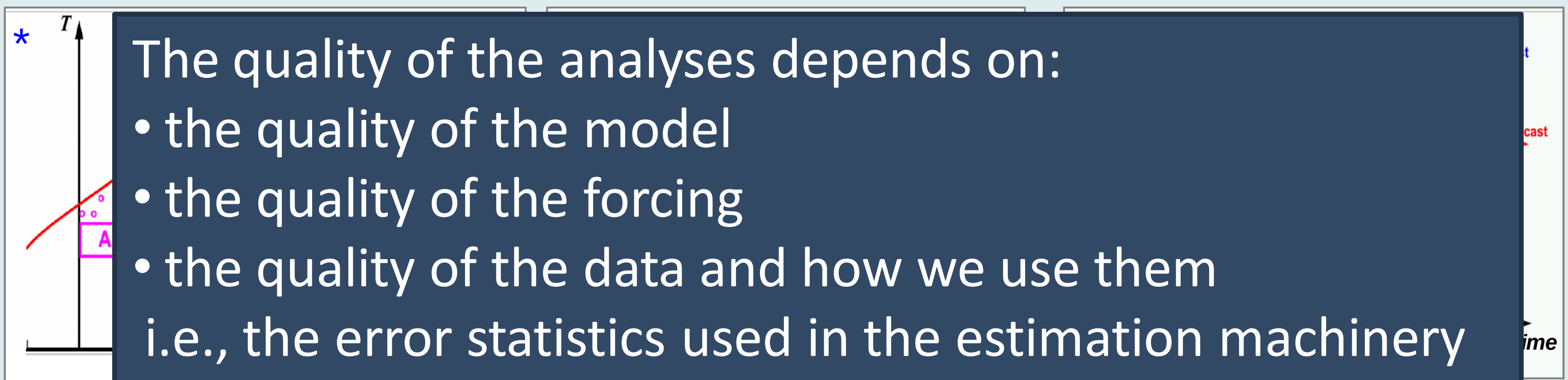
- **Current global synthesis efforts**
  - Real-time operational oceanography
  - State estimation for climate applications
  - Impact of the global ocean observing system
- **Challenges**
  - The Observing System
  - Modeling and Assimilation
  - Surface Forcing
- **Prospects for the future**
  - Integrated Earth System Analyses
  - Analyses and models in observing system design
  - Monitoring the ocean and the observing system
- **Recommendations**

Early drivers: Support for naval applications and seasonal forecasts

GODAE and CLIVAR: major advances through international cooperation, connections with the observationalists and with users

Now: ocean state estimation on a routine basis
Surface fluxes from various sources: atmospheric reanalyses or RT NWP analyses

A variety of estimation methods:
- Optimal interpolation (OI), asymptotic Kalman filters, 3DVar
- Ensemble methods – state-dependent error estimates
- Smoothers: 4Dvar; Kalman smoothers



The quality of the analyses depends on:
- the quality of the model
- the quality of the forcing
- the quality of the data and how we use them

i.e., the error statistics used in the estimation machinery

* ECMWF graphic
* Graphic from Rolf Reichle

RT operational oceanography - Le Traon *et al*., Oke *et al*. & GODAE08 papers

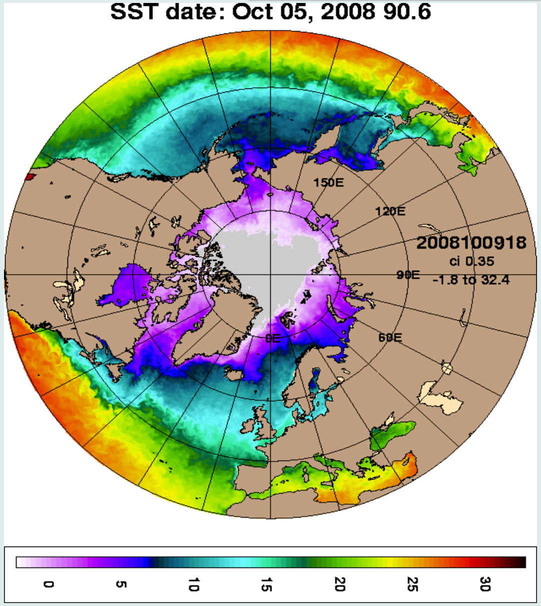
Systems:

- global, 1/10° or finer horizontal grid spacing
- community ocean models (NEMO, HYCOM,…)

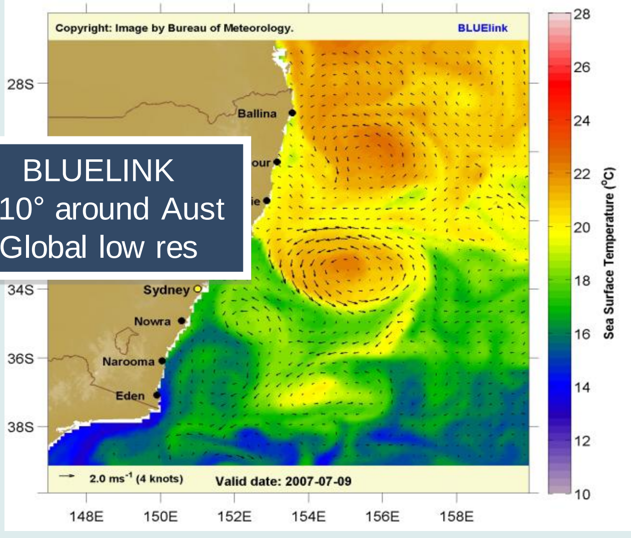
Many applications:

- monitoring and prediction of marine pollution
- safety and effectiveness of operations at sea
- Naval operations
- ocean information for NWP forecasts

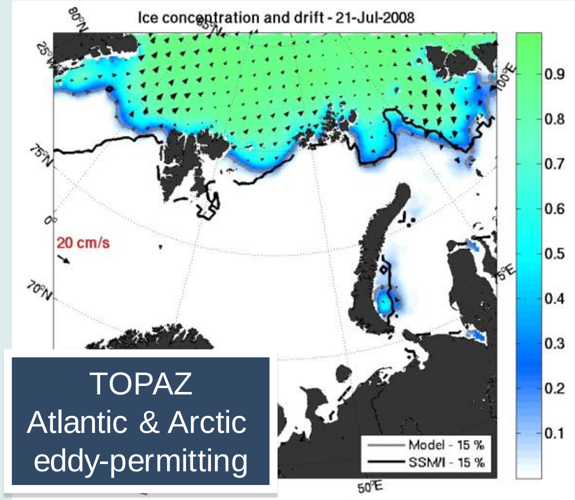
HYCOM/NCODA
1/12° global



BLUELINK
1/10° around Aust
Global low res



TOPAZ
Atlantic & Arctic
eddy-permitting



From Dombrowsky et al. (2008) GODAE Symposium

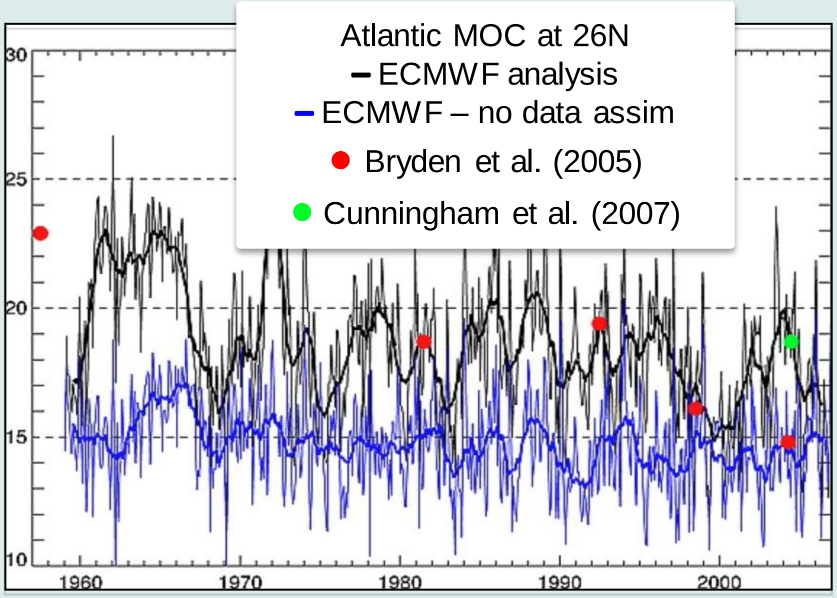
Climate applications – Lee *et al*., Balmaseda *et al*., Stammer *et al.,* Xue *et al.*

Systems:

- global, 1/4° or coarser horizontal grid spacing
- comparisons of many metrics: http://www.clivar.org/organization/gsop/gsop.php

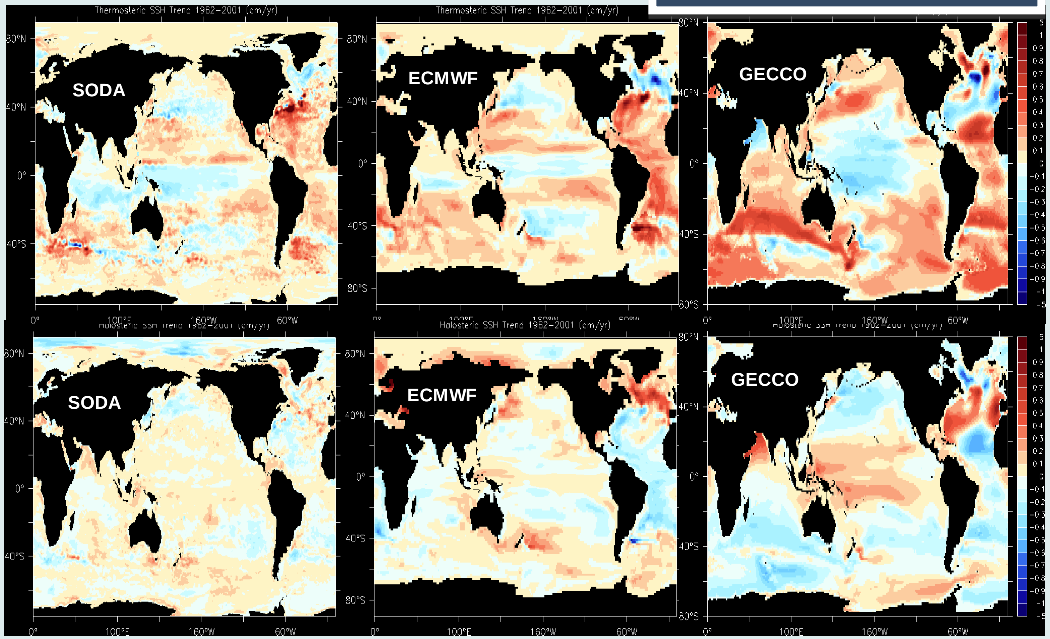
Many applications:

- monitoring climate indices
- initialization of climate forecasts
- reanalyses to inform diagnostics of Earth's climate



From Lee et al. CWP

SSH trends 1962-2001 *
Thermosteric (upper)
Halosteric (lower)



** Note these analyses did not use corrected XBT data*

From Stammer et al. CWP

Observations assimilated:

SSH (anomalies) from altimeters; gravity for geoid and

SST (Sea-ice concentration) (Oce

Temperature profiles from XBTs/CTDs, the GTMBA, A

Salinity profiles from Argo

Cross-validation: CTD salinity, current me

No Observation System is redundant!

Operational ocean forecasting critically depends on altimeter, Argo and SST observations

Altimeter → **mesoscale variability**

Argo T/S → **stratification, heat content, <u>only</u> constraint on salinity**

SST → **mixed layer properties**

Oke et al. CWP

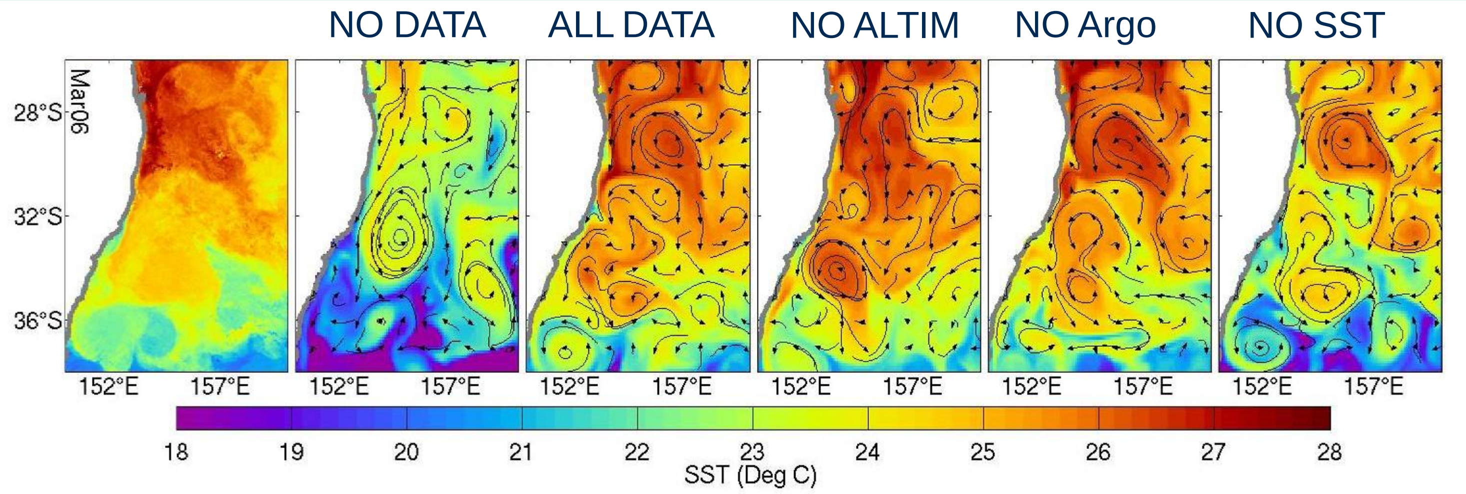
Seasonal Prediction

- Moorings, altimeter data, Argo are complementary
- GTMBA: the backbone; provide high frequency data; *continuity important for forecast calibration*
- Altimeter: the only OS contributing skill in the N. Subtrop. Atlantic skill; backbone away from TAO/Triton
- Argo is the only OS contributing skill in the Indian Ocean (in ECMWF system)
- SST: important for mixed layer and for AGCM

see Magdalena Balmaseda's presentation

Decadal Prediction

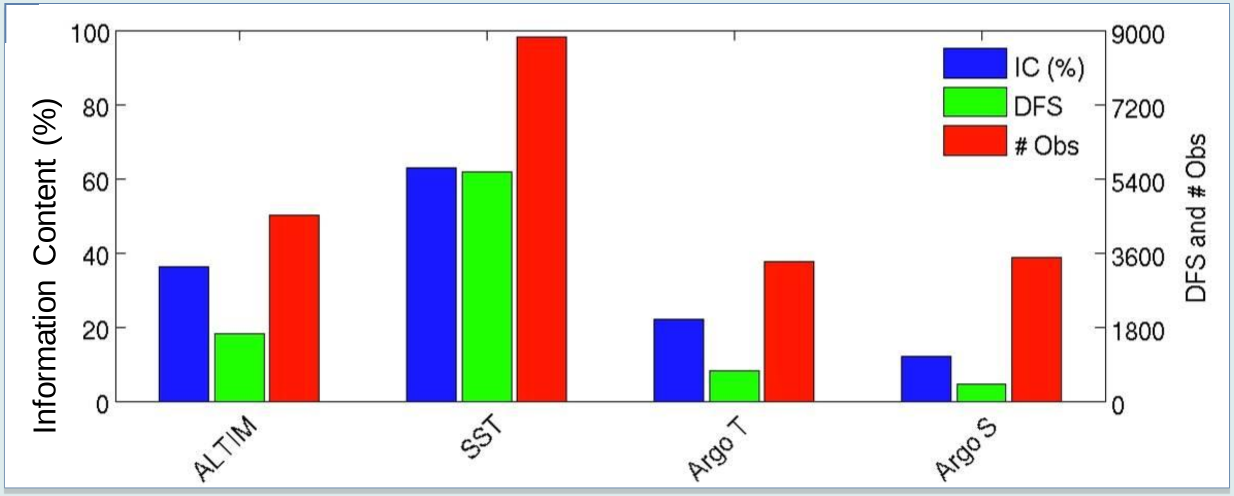
- Data outside the tropical oceans; deep data? homogeneous? Long time series important



1/10º Bluelink system

6-month long OSEs starting December 2005

Oke and Schiller (GRL, 2007)

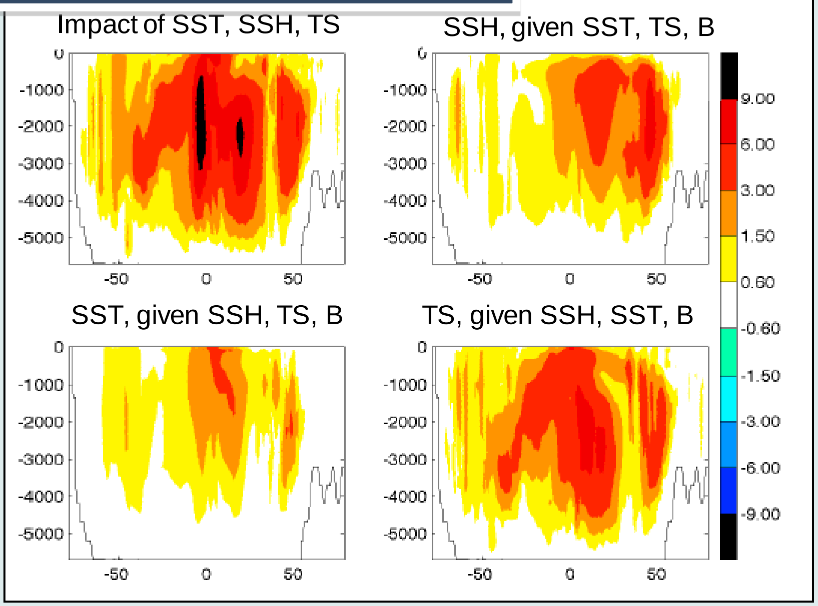


A single estimate from 1/1/2007

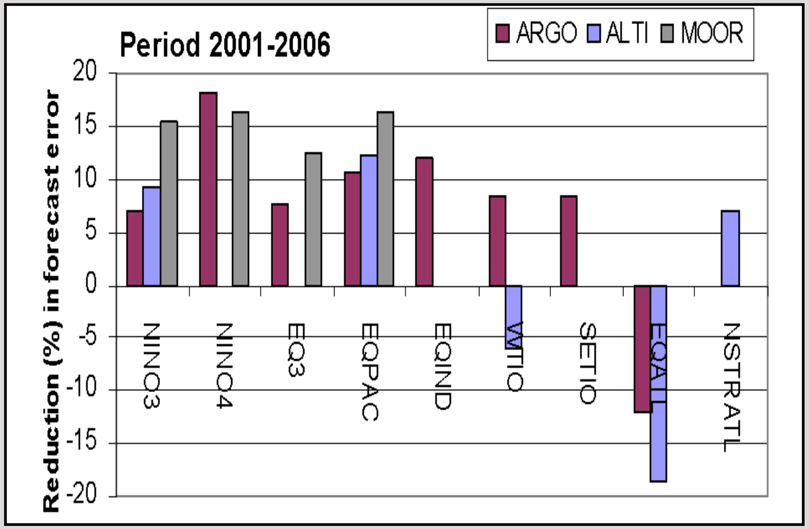
Australian Region

From Oke et al. (2008) GODAE Symposium & Oke et al. CWP

Impact of the observing system on MOC (Sv) in the ECCO system RMS differences for 2006



Heimbach et al. CWP; Forget et al. (2009)

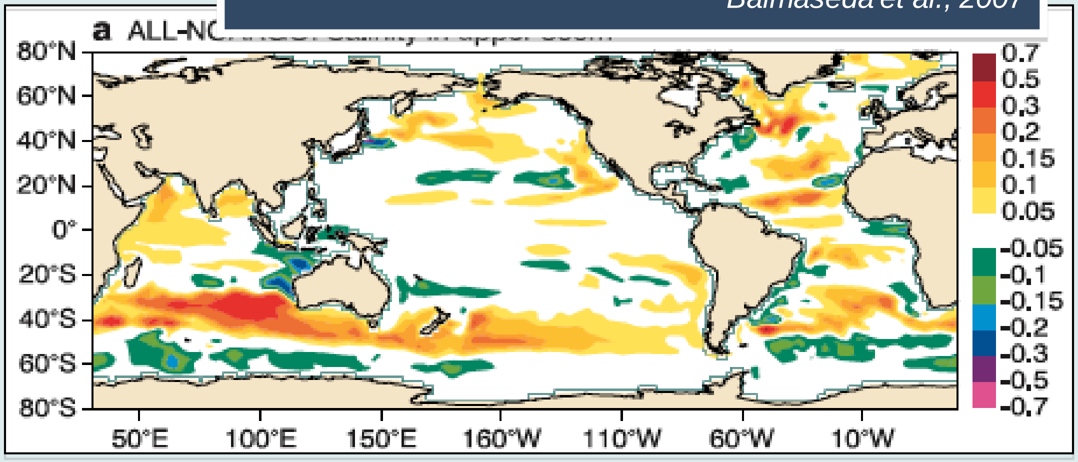


ECMWF S3 (1-7 mo forecast)

Balmaseda & Anderson (2009)

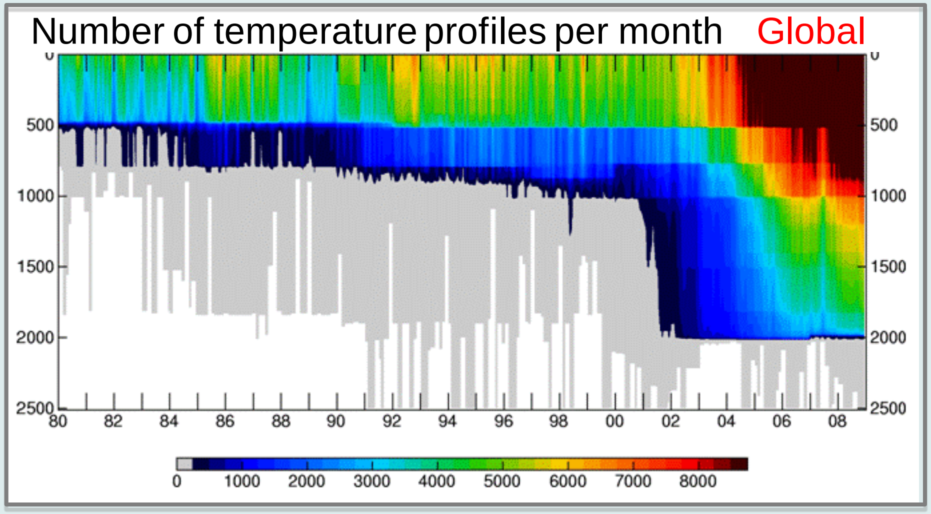
ECMWF S3
- Impact of Argo on av. salinity in upper 300m

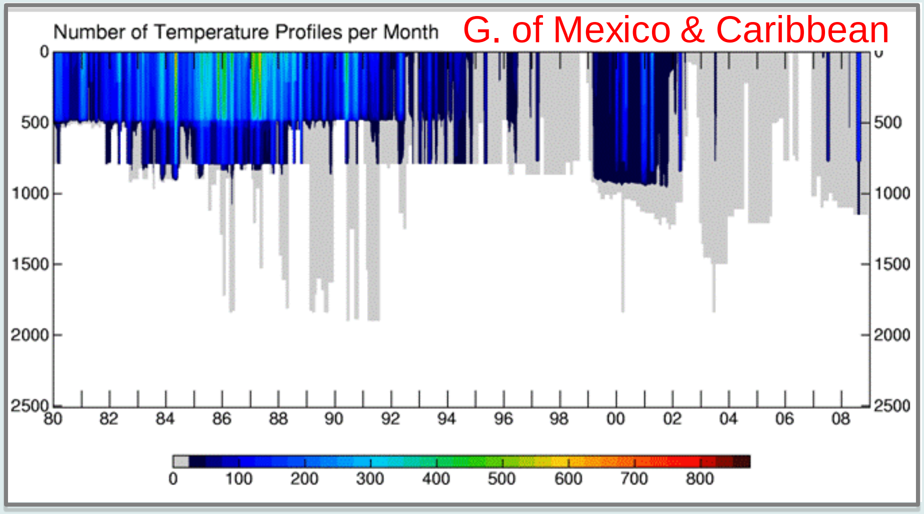
Balmaseda et al., 2007



- Argo: Biggest impact in less well-observed regions (Indian, S. Atlantic, S. Pacific, Southern Ocean)
- Argo salinity also improves estimated temperature

  Smith and Haines (2009)
- T impact on S can differ from S data impact on S *Balmaseda et al. (2007)*

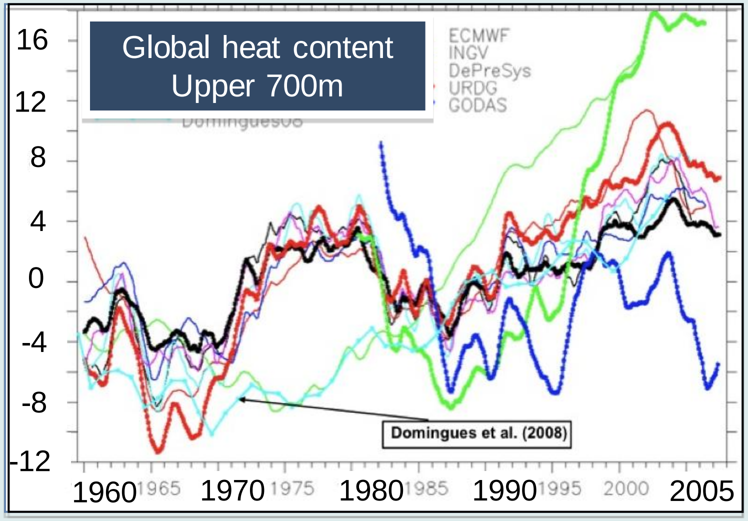


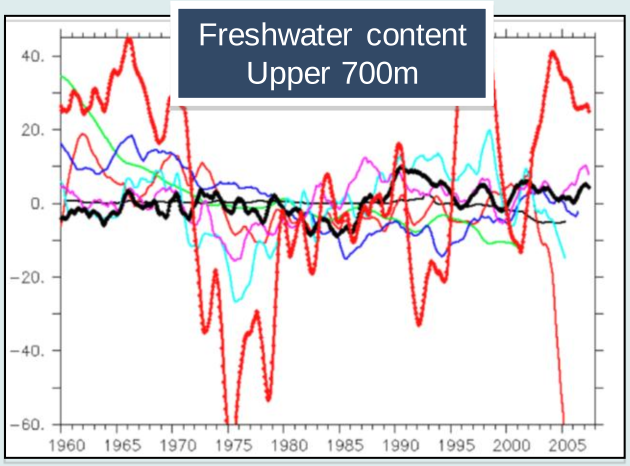


Courtesy David Behringer

- Uneven observational coverage in space and time
- Deep ocean and ice covered regions are poorly observed.
- OS in marginal seas is declining
- OS in coastal areas needs attention

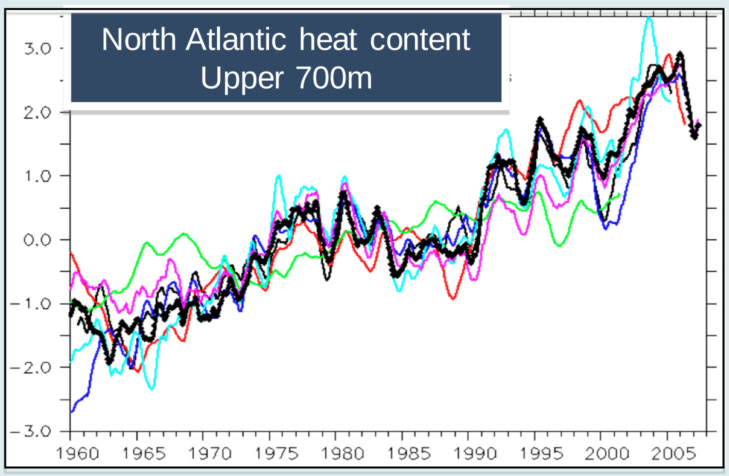
Carson and Harrison (2008):
- 50-year trends over most of the ocean are not significant at 90% CL.
- At 50 m, only 30% of the ocean has a significant trend with 90% CL.
- The percentage decreases significantly with depth.





Issues:

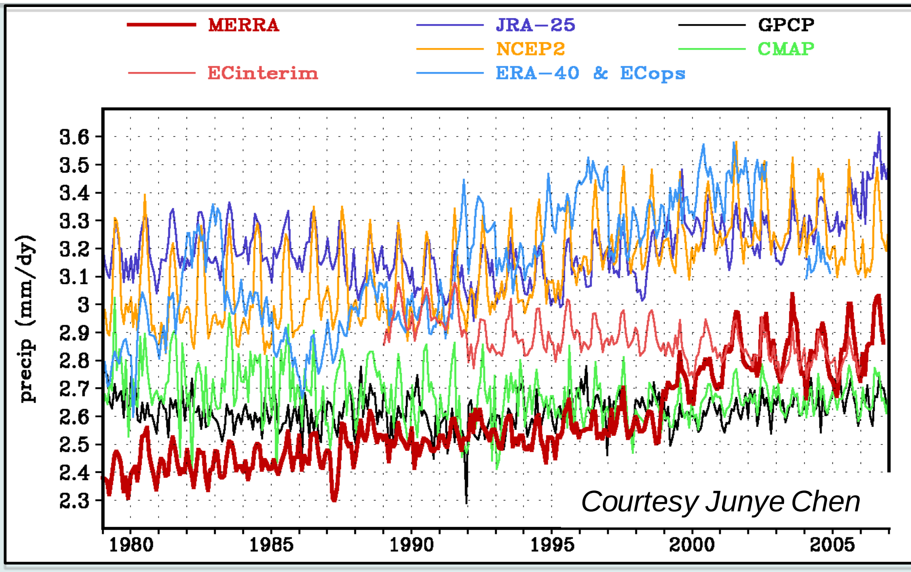
- Error statistics – both model and observations
- Reliable estimates of uncertainty in the analyses
- Understanding the analysis differences: controlled experiments – same data, QC, forcing, ….
- Model and forcing biases – esp. important in the early periods
- Treatment of salinity in the pre-Argo era
- Corrections to data bases (e.g., XBT, Argo) – need for continual updates to re-analyses & careful documentation
- Constraining the (sub)mesoscale in coastal models



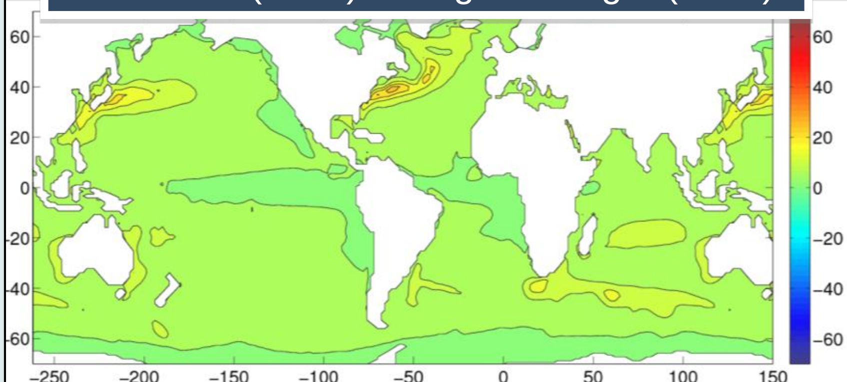
From Stammer et al. CWP

** Note these analyses did not use corrected XBT data*

Global Mean Precipitation Rate from Reanalyses



Δ Turb. Heat Flux (Wm^{-2}): Fairall et al (2003) – Large & Yeager (2008)



Courtesy Bernard Barnier

http://gmao.gsfc.nasa.gov/merra

- Ocean community has tackled the task of improving surface forcing itself (CORE, DRAKKAR, OAFlux)
- Satellite observations – essential for air-sea fluxes (esp. scatterometer and precipitation)
- *In situ* surface measurements - calibration of satellite-derived fluxes; evaluation of NWP and reanalysis flux estimates

- NWP centres should continually improve analyses, reduce the impact of changing observing systems (reduce model biases), provide estimates of uncertainty.

Studies of climate change and decadal variability must resolve changes in the net heat flux of few Wm^{-2} per decade (Bindoff et al., 2007), Expected improvements in ocean state estimation in the next 10 years:

- Reduced model biases
    - Increased model resolution (both horizontal and vertical)
    - Improved parameterizations
- Improvements in NWP analyses and re-analyses ⇒ improved forcing products
- Improved error covariance modeling – the basis of the estimation procedure
- Improved RT and DM QC for input data streams
- Easy access to data bases with appropriate metadata ⇒ all data will be available to be assimilated

Emerging generation: “coupled” analyses or
Integrated Earth System Analyses

- State estimates consistent across components
- Current efforts target improved initialization of climate forecasts

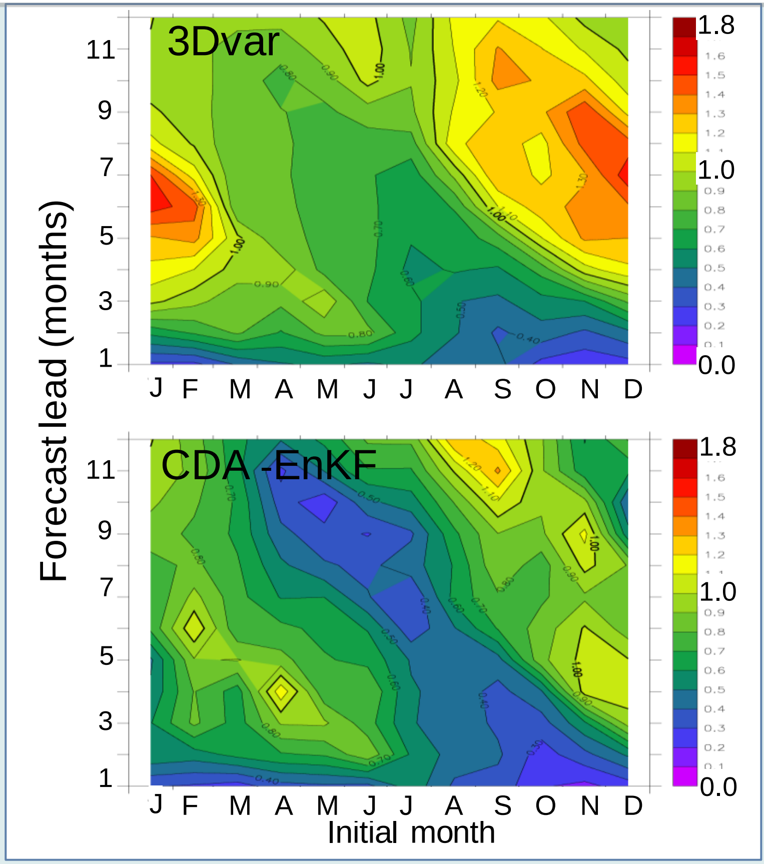
Some current examples:

3DVar (NCEP)	EnKF (GFDL, GMAO)
4DVar (FRGC/JAMSTEC)	Kalman Filter (LEGI/CNRS)

- Future: atmosphere-ocean-land-sea-ice-chemistry-biology

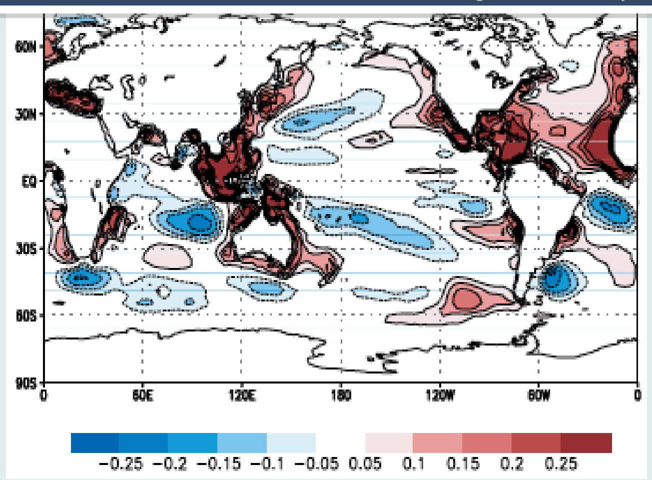
GFDL CDA - EnKF
- Impact on Forecast Niño-3 SST anomalies
- RMS as a fn of initial time and forecast lead

Courtesy Tony Rosati



FRCGC – 4DVar
- Estimating drag coefficient
- log (α_E) – multiplies Louis drag coeff.

From Sigiura et al. (2008)



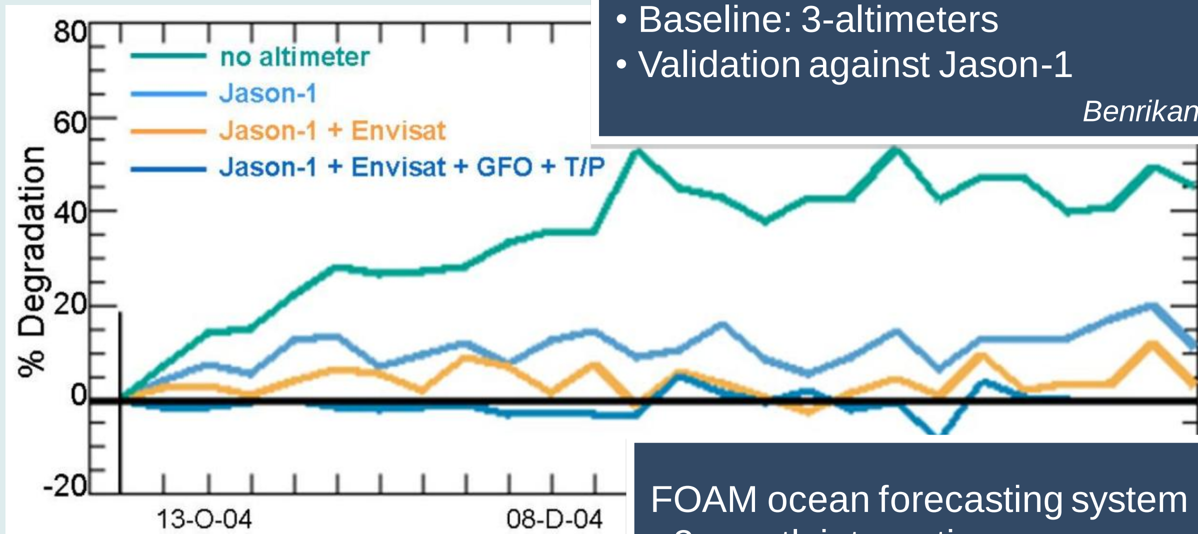
$$E = \rho \alpha_E C_E |\mathbf{v}| (q_{sat} - q)$$

Assimilation: a contribution to observing system design

- All 4 altimeters add to skill
- Impact from 1st altimeter is the largest
- Mesoscale dynamics in NE Atl constrained better by altimeters than in NW Atl
- NRT data from 4 altimeters ≡ delayed mode data from 2 altimeters
- Q: Will SWOT be able to replace 4 altimeters??
- Future: OSSEs (GODAE OceanView) & new diagnostic tools

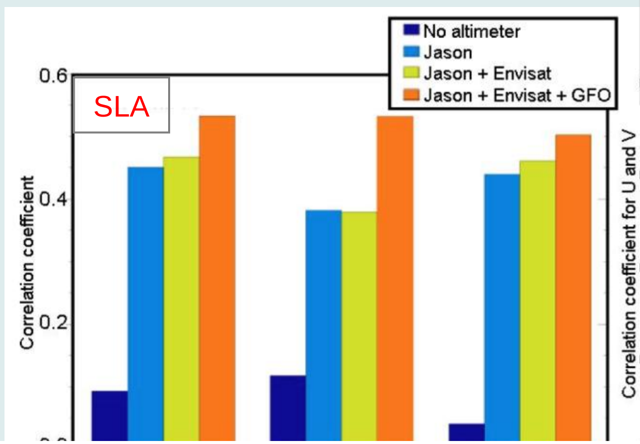
Mercator ocean forecasting system – N. Atl.
- 7-day forecasts using all available data
- Baseline: 3-altimeters
- Validation against Jason-1

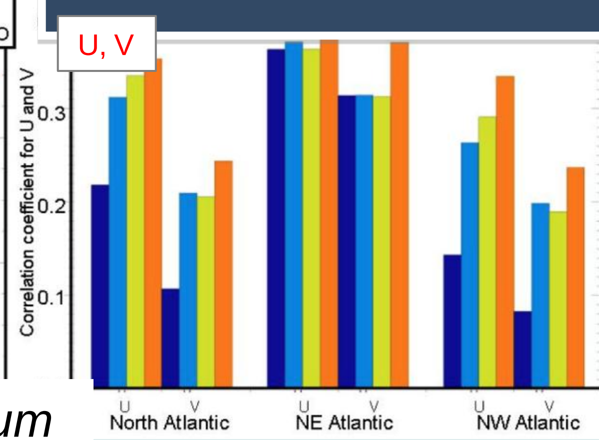
Benrikan et al., 2009



FOAM ocean forecasting system – N. Atl.
- 3-month integrations
- comparisons against assimilated SLA and velocities from drifting buoys (indept data)

Martin et al., 2007





See Oke et al. paper from GODAE Symposium

Recommendations

Observations

- **Sustain the existing GOOS:**
  Argo, Tropical Moored Buoy Arrays, altimetry, gravity, MW and IR-based SST, ocean colour, and MW-based sea-ice concentration.

- **Enhance Global Tropical Moored Buoy Arrays:**
  Complete RAMA.
  Maintain PIRATA enhancements to establish impacts on seasonal forecasts.

- **Develop new observing systems:**
  Sea-ice thickness and sea surface salinity from space
  Wide-swath altimetry (SWOT)
  Biogeochemical Argo

- **Address under-sampling of the ocean:**
  Extend the observing system to include full-depth Argo-type measurements.
  Sample boundary currents, transports through key regions, marginal seas, ice-covered oceans
  Add observations east of 95°W to correct model biases in the far eastern Pacific.

Recommendations

External Forcing

• **Continue to advance satellite measurements for air-sea flux estimates**

scatterometer winds, precipitation

• **Expand the surface flux reference network under OceanSITES and the ship-based measurement program**

especially in higher latitudes and in areas with severe weather conditions

• **Improve estimates of land freshwater input to the ocean:**

ice melting, river runoff, ground water seepage

The input data streams

• **Define uncertainties in data sets:**

instrument and systematic errors

ocean observations and surface flux products

• **Improve QC, including the development of standards for QC tests.**

• **Provide metadata with each observation - heritage and history of corrections.**

• **Target digitization of historical data sources to fill gaps in poorly sampled periods and regions.**

Recommendations

Assimilation/Synthesis Systems

- **Maintain ocean state estimation as an integral part of the ocean observing and information system.**

    Use assimilation systems and tools as routine mechanisms to evaluate and design the GOOS

- **Improve assimilation/synthesis products:**

    Improved assimilation approaches
    Improved ocean general circulation models
    Better estimates of data sampling (representation) errors

- **Characterize the uncertainties in each synthesis product**

    Needed for a multi-model ensemble state estimate

- **Undertake a concerted comparison effort to understand the differences between analysis products:**

    Use the same data and forcing.
    Expand analysis diagnostics: innovations, residuals, details of data impacts

- **Atmospheric reanalyses should be continually improved and updated**

- **Advance dynamically consistent coupled atmosphere/ocean/sea-ice estimation:**

    A consistent view of Earth's climate variability
    Improve the initialization for coupled climate predictions

Grazie mille *!*

Particolarmente a tutti i miei coautori *!*