NRL Multivariate Ocean Data Assimilation System Overview

Jim Cummings

NRL Multivariate Ocean Data Assimilation

DA Technique Based on Optimal Estimation Theory

- oceanographic version of MVOI method widely used in NWP systems (Daley, 1991)
- simultaneous analysis of five ocean variables: temperature, salinity, geopotential, and u-v velocity components (T, S, Φ, u, v)
- multivariate in mass and velocity

Observation Space Formulation

$$x_a = x_b + P_b H^T (H P_b H^T + R)^{-1} [y - H(x_b)]$$

where $\mathbf{x_a}$ = analysis, $\mathbf{x_b}$ = background

$\mathbf{P_b}$ = background error covariance, $\mathbf{R}$ = observation error covariance

$\mathbf{H}$ = forward operator (spatial interpolation in 3 dimensions)

$\mathbf{(x_a - x_b)}$ = analyzed increment

$\mathbf{[y-H(x_b)]}$ = innovation vector (synoptic T, S, u, v observations)

NRL Multivariate Ocean Data Assimilation

Flexible System

- global or regional applications
- supports re-locatable, multi-scale analyses on nested, successively higher resolution grids
- used to initialize/update ocean forecast model or run stand-alone
- interfaced to multiple ocean forecast models
  - Hybrid Coordinate Ocean Model (HYCOM)
  - Navy Coastal Ocean Model (NCOM)
  - Wavewatch III wave forecast model (WW3)

Designed as Complete End-to-End Analysis System

- fully automated ocean data quality control
- multivariate analysis
- performance diagnostics package

NRL Multivariate Ocean Data Assimilation

Operational Applications

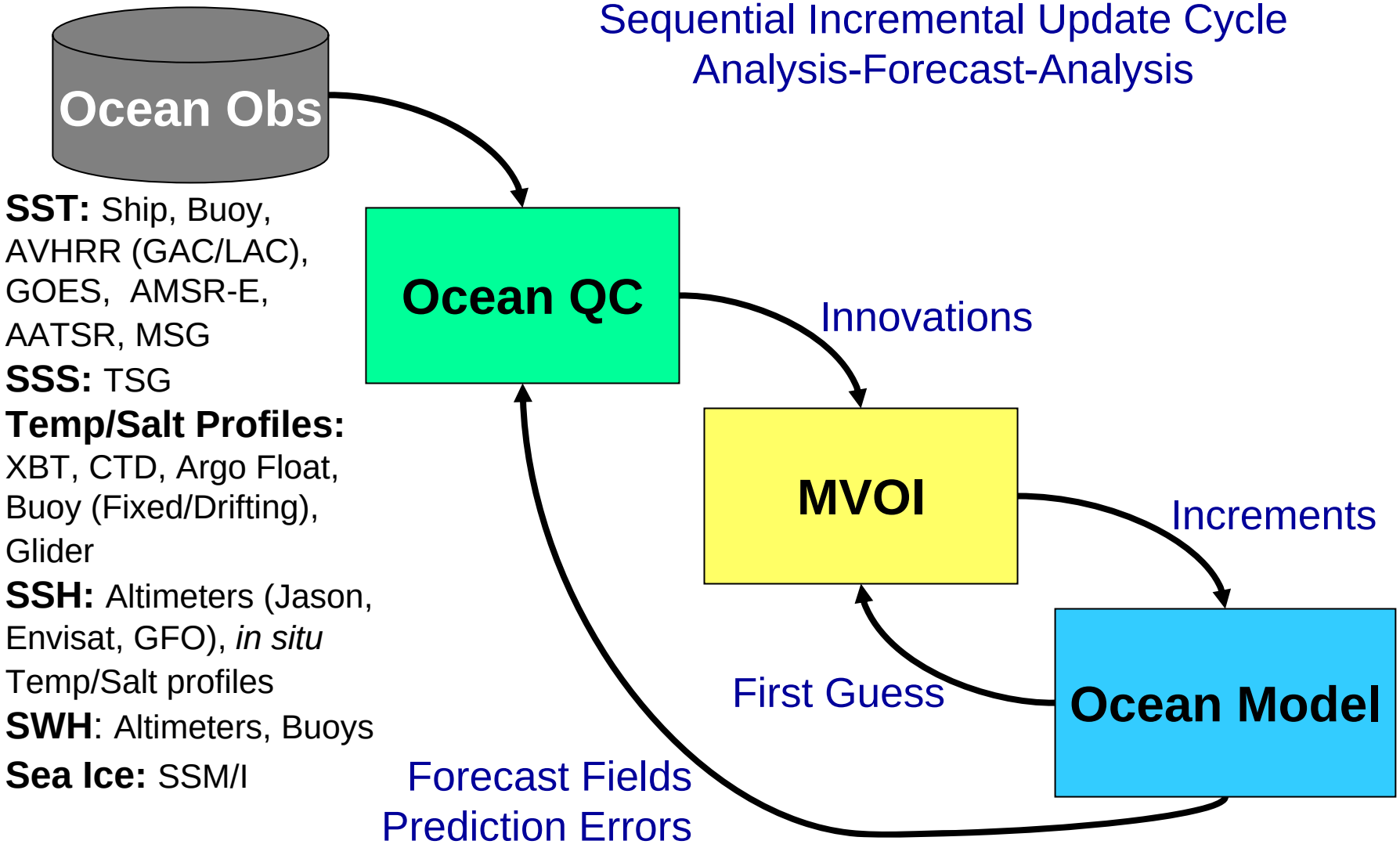
- SST and sea ice analyses as LBCs for COAMPS and NOGAPS NWP models at FNMOC
- global and regional 3D analysis-only runs at FNMOC and NAVOCEANO

Pre-Operational Applications

- MVOI cycling with global HYCOM (NOPP/GODAE project)
- MVOI cycling with regional HYCOM and NCOM (various NRL and NOPP/CODAE projects)
- ensemble-based adaptive sampling project with ocean gliders
- assimilation altimeter SWH in global Wavewatch III at FNMOC

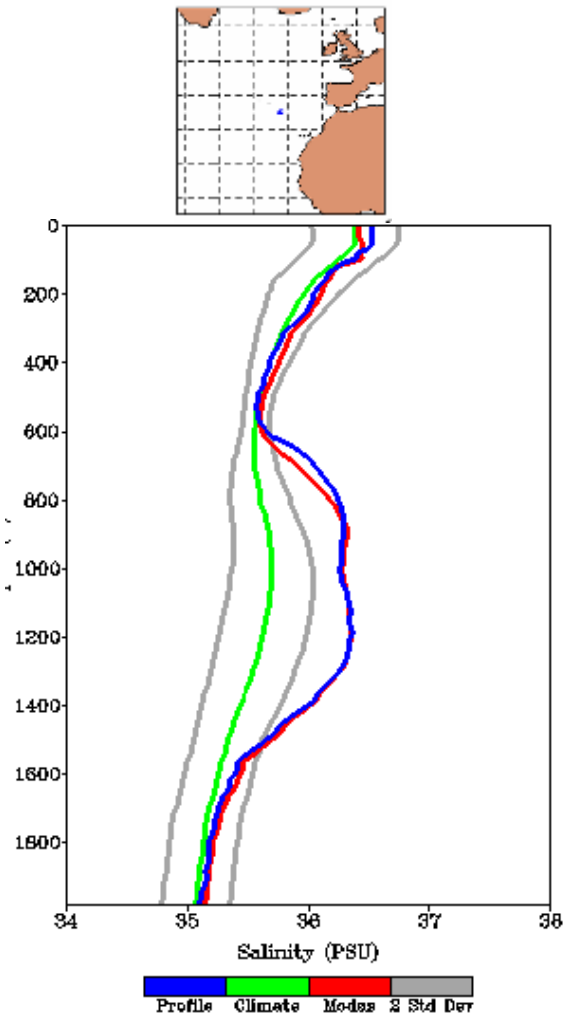
NRL Ocean Data Assimilation

Sequential Incremental Update Cycle
Analysis-Forecast-Analysis



Model forecast fields and prediction errors are being evaluated for use in the QC of newly received ocean observations

Salinity Observation Data Sources



- observed salinity (Argo, CTD) is directly assimilated
- salinity is derived for temperature-only profiles using MODAS historical TS relationships (bi-monthly, global)

$$S_{i,k}(T) = \bar{S}_{i,k} + \alpha_{i,k}(T - \bar{T}_{i,k})$$

$$\alpha_{i,k} = \Sigma b_{i,j}(T_{j,k} - \bar{T}_{i,k})(S_{j,k} - \bar{S}_{i,k}) / \Sigma b_{i,j}(T_{j,k} - \bar{T}_{i,k})^2$$

$$b_{i,j} = \exp(-((x_j - x_i)/L_x)^2 - ((y_j - y_i)/L_y)^2 - ((t_j - t_i)/L_t)^2)$$

- derived salinity values are put through the automated QC procedures in same way as an observed salinity

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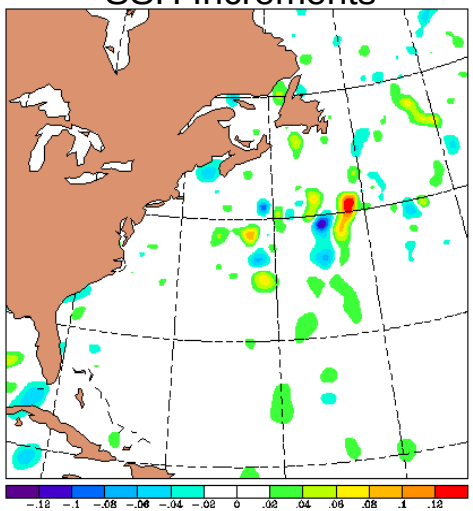
MODAS salt profile derived from Argo float temperature in MEDDY (red) - verifying Argo salt profile in blue – MODAS does a good job predicting MEDDY salinities

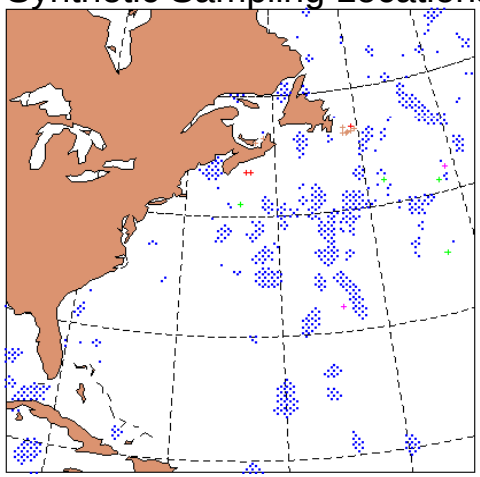
Altimeter SSH Assimilation

Synthetic T/S profiles generated using one of two approaches: Synthetics are assimilated in the MVOI as an observing system

SSH Increments



Synthetic Sampling Locations



1. Direct method (modified form of Cooper Haines)

- adjusts model density profile to be consistent with measured change in model forecast SSH (creates T/S innovations)
- observation errors set to forecast error variance plus residual error from iterative fit of density adjustment

2. MODAS synthetic BT method

- computes temperature at depth from SSHA using stored regressions of climate anomalies of temperature and dynamic height
- salinity is then computed from synthetic temperatures
- observation errors are set to stored regression residuals

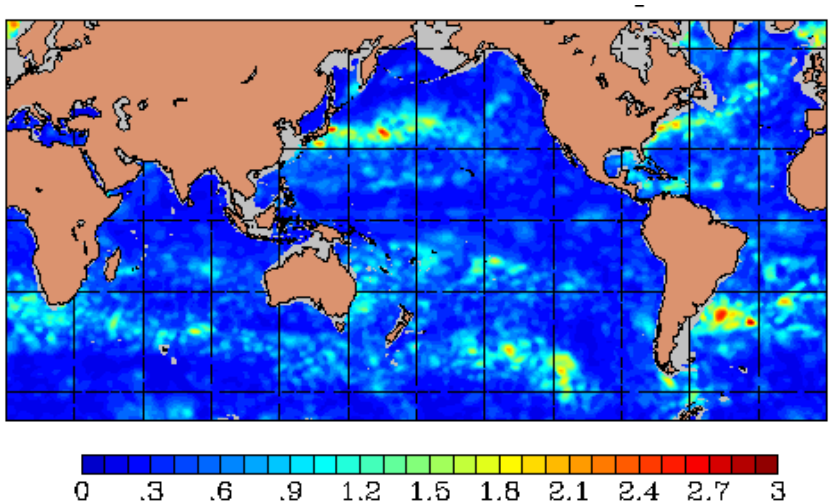
synthetic profiles are generated where analyzed change in SSH exceeds altimeter measurement errors (~2 cm)

Background Error Covariances

Separable formulation: product of a variance and a correlation

Error Variances

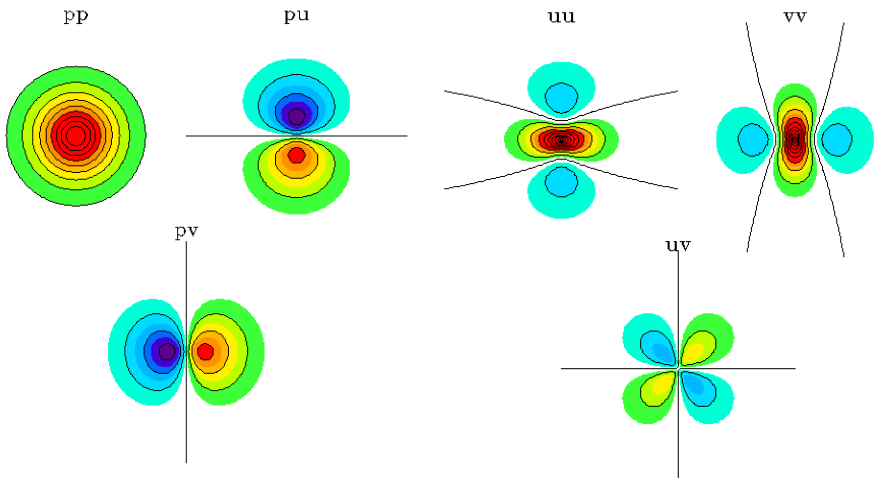
- vary by position, depth and analysis variable
- evolve with time, updated continuously using analyzed increment fields
- error growth parameterization used in long term absence of observations
  - function of age of data on grid and innovation temporal autocorrelations
  - evolves to climate or free running model errors in limit of no data



400 M temperature background error standard deviation (°C) from FNMOC global analysis

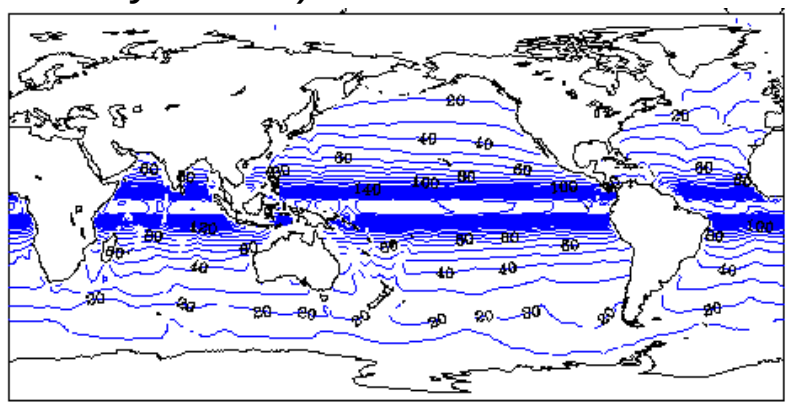
Background Error Correlations

Separable formulation: product of a horizontal and a vertical correlation

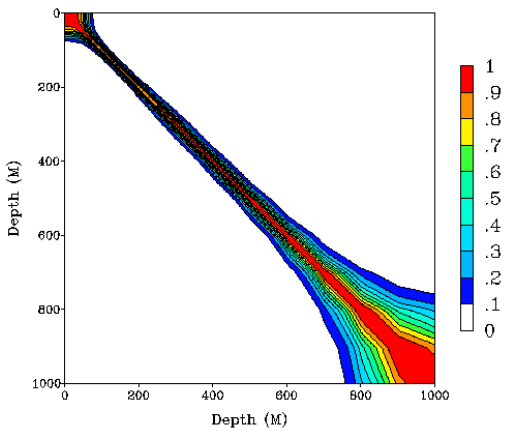


geopotential and velocity **u,v velocity**

Horizontal correlations are multivariate in velocity and geopotential - length scales depend on location (default is Rossby radius)



Rossby Radius Deformation (km)

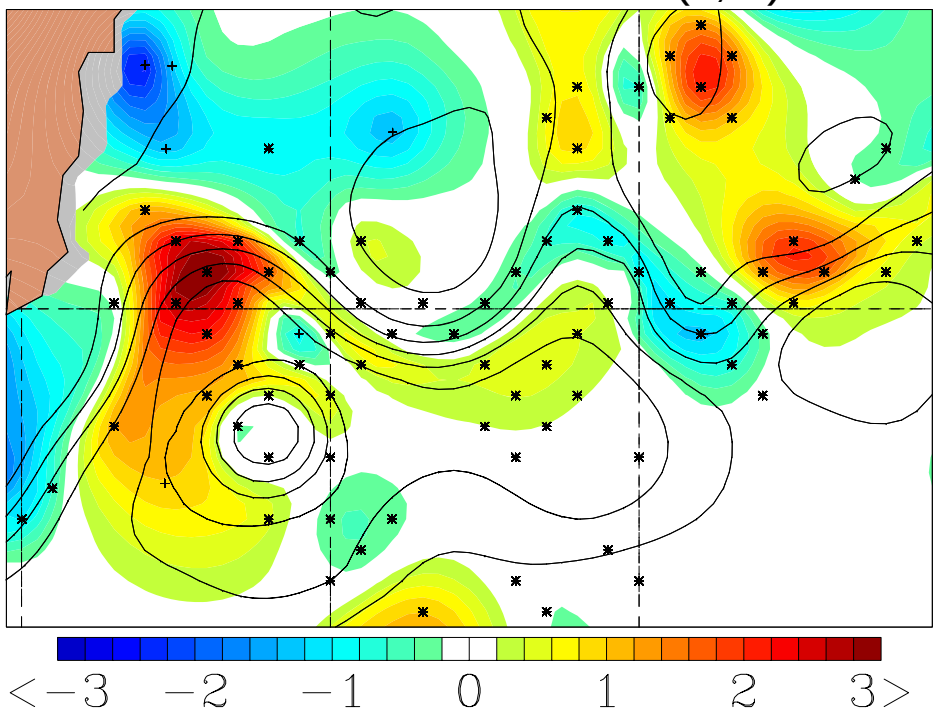


Vertical correlation length scales are computed from background vertical density gradients - correlations evolve with time but do not vary with location

scales are large (small) when stratification is weak (strong)

Flow Dependent Error Correlations

Temperature Increments at 100 M (color)
Forecast Surface Height (lines)
Observation Locations (∗, +)



flow scale, h_s = 0.2

Note increments stretched along Kuroshio front and decorrelation in cold eddy south of the Kuroshio

MVOI correlations modified to incorporate flow dependence from forecast surface height.

$$C = C_h C_v C_f$$

C_h – horizontal correlation
C_v – vertical correlation
C_f – flow dependent correlation

Small (large) values of flow dependence scalar (h_s) produces strong (weak) flow dependence

Observation Error Variances

- sum of measurement error (ε_i), representation error (ε_r), and data age error (ε_τ)
- measurement errors are from data provider or table look-up
  - satellite SST measurement errors computed from buoy match-ups
  - *in situ* measurement errors function of instrument type
- satellite representation error function of resolution of model (r_g), resolution of observing system (r_o), and background horizontal gradient (∇_b)

$$\varepsilon_r = \nabla_b \cdot (r_o / r_g) \qquad r_o > r_g$$

- profile representation error function of mesoscale variance (σ_t) and uncertainty associated with internal wave activity (vertical gradient used as proxy)

$$\varepsilon_r = \kappa_t \sigma_t + \lambda_t \cdot (dT \cdot dz^{-1})$$

  - κ_t and λ_t are determined empirically for temperature and salinity
- data age error a function of observation time (τ_o), time correlation scale (τ_c), and observation depth (z_o) relative to maximum depth of time correlation (z_c)

$$\varepsilon_\tau = \varepsilon_i \cdot (\tau_o \cdot \delta) / \tau_c$$

$$\delta = 1 - z_o / (z_o + z_c)$$

- observation error variances tuned based on J_{min} statistics

  $J_{min} << 1$ variances too large, $J_{min} >> 1$ variances too small (or bad data)

Projects Underway and Present Developments

Projects Underway – Present Developments

- Conversion to 3D-Var assimilation system based on NAVDAS
  - natural development pathway from MVOI
  - global solution, no data selection
  - direct assimilation of observations with (weak) nonlinearities in the observation operator
  - non-separable covariances (horizontal and vertical)
  - vertical flow dependence (isopycnal coordinates)
  - new balance operators (based on Anthony Weaver's work)
- Development of 4D-Var assimilation based on NAVDAS-AR
  - focus on Navy Coastal Ocean Model (NCOM) in limited domains
- Adaptive Sampling
  - incorporation of ensemble covariances in assimilation (so called hybrid approach)

Projects Underway – Present Developments

- Assimilation of new observing systems
  - glider T/S data and METOP, MSG, AMSR-E and MTSAT SST
- Diagnostics and automated tuning of error covariances
- Wave Model assimilation of altimeter SWH
  - Global and regional Wavewatch III assimilation at FNMOC
  - evaluation of alternative wave model updating strategies
- Global and regional HYCOM/NCODA NOPP/GODAE transitions
  - real-time demonstration later this year (2007)
- Development and implementation of adaptive QC methods
- Improvement in pre-processing functions
  - adaptive data thinning to handle large amounts of satellite observations
  - bias detection/correction

END