Regional Ocean Data Assimilation and Forecast Modeling using the NRL Coupled Ocean Data Assimilation System

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NRL Coupled Ocean Data Assimilation System

Advanced DA Technique Based on Optimal Estimation Theory

- oceanographic version of MVOI method used for decades in operational NWP systems: Lorenc (1981), Daley (1991)
- simultaneous analysis of five ocean variables: temperature, salinity, geopotential, and u-v velocity components (T, S, Φ, u, v)

Developed as Part of NRL Coupled Modeling Project

- Global System : Atm Forecast Model - NOGAPS
  Atm Data Assimilation - NAVDAS (3D VAR)
  Ocn Forecast Model - POP
  Ocn Data Assimilation - NCODA (3D MVOI)
- Regional System : Atm Forecast Model - COAMPS
  Atm Data Assimilation - NAVDAS (3D VAR)
  Ocn Forecast Model - NCOM
  Ocn Data Assimilation - NCODA (3D MVOI)

NRL Coupled Ocean Data Assimilation System

Flexible System

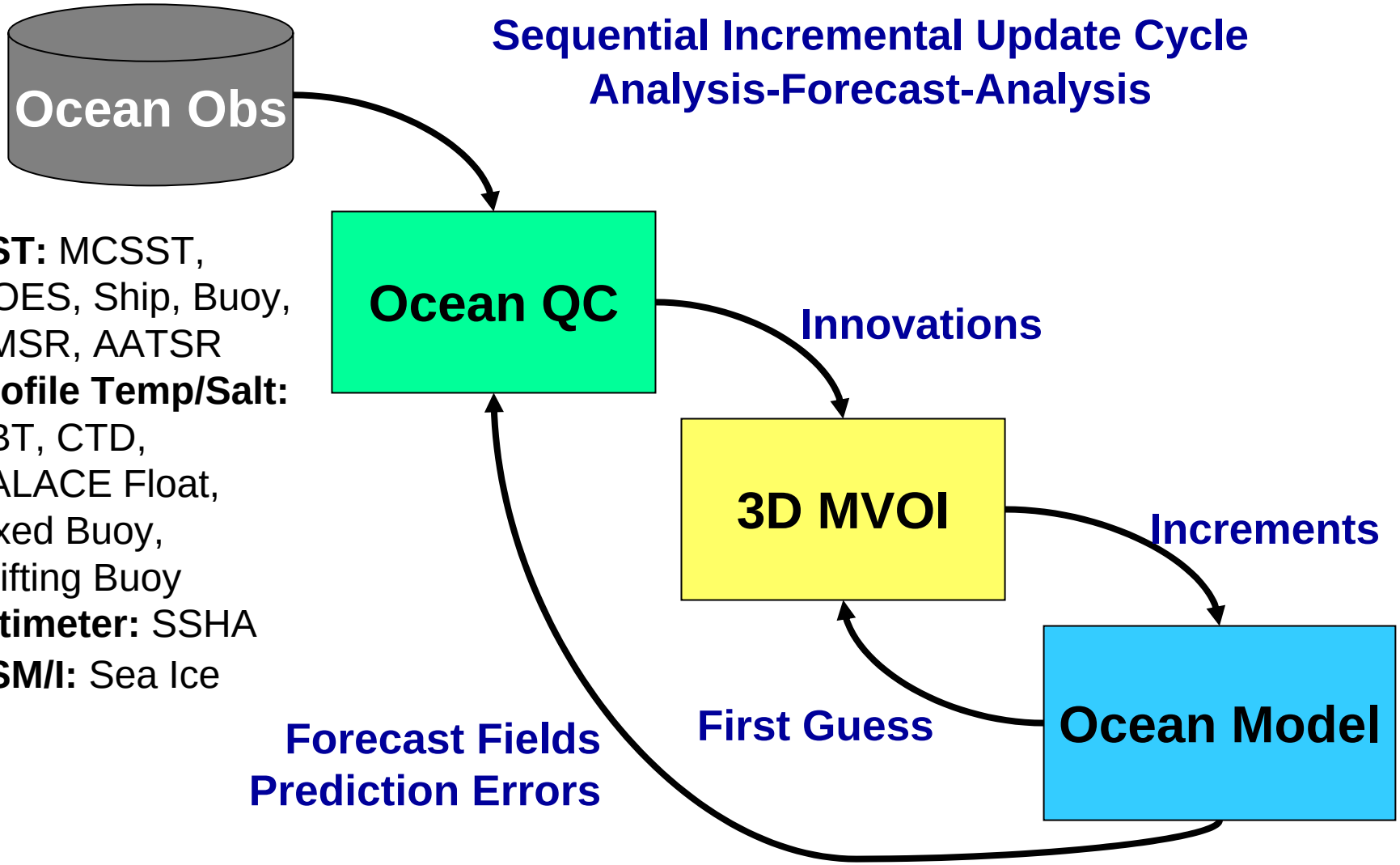
- performs multi-scale analyses on nested, successively higher resolution grids
- globally re-locatable
- initialize/update ocean forecast model or run stand-alone
  - 2D analyses of sea ice and SST (NWP boundary conditions)
  - 3D temperature and salinity analysis (geostrophic currents)
  - 3D MVOI sequential incremental update cycle

Designed as Complete End-to-End Analysis System

- data quality control
- analysis
- performance diagnostics

NRL Coupled Ocean Data Assimilation

Sequential Incremental Update Cycle
Analysis-Forecast-Analysis



SST: MCSST, GOES, Ship, Buoy, AMSR, AATSR
Profile Temp/Salt: XBT, CTD, PALACE Float, Fixed Buoy, Drifting Buoy
Altimeter: SSHA
SSM/I: Sea Ice

Forecast fields and prediction errors are used in the QC of newly received ocean observations

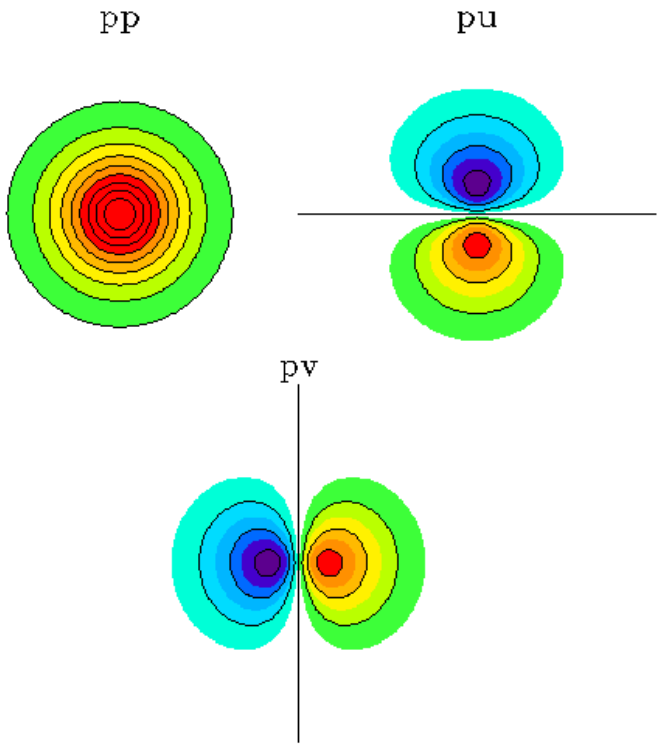
Error Covariances

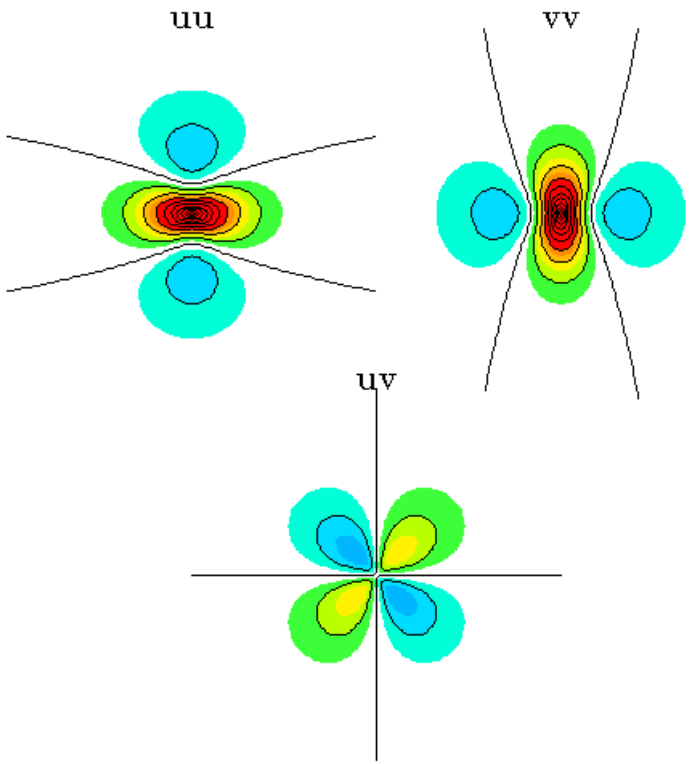
Separable Error Covariances : product of a variance and a correlation

- **Background Error Variances**
  - vary by position, depth and analysis variable
  - evolve with time, updated continuously using analyzed increments
- **Background Error Correlations**
  - total correlation product of a horizontal and a vertical correlation
  - horizontal correlations multivariate in mass and velocity
  - horizontal length scales non-homogenous and anisotropic
  - vertical correlations computed from background vertical density gradients, evolve with time
    - length scales large (small) when stratification weak (strong)

- **Error covariances include some limited 4-D capabilities**

Multivariate Horizontal Correlations



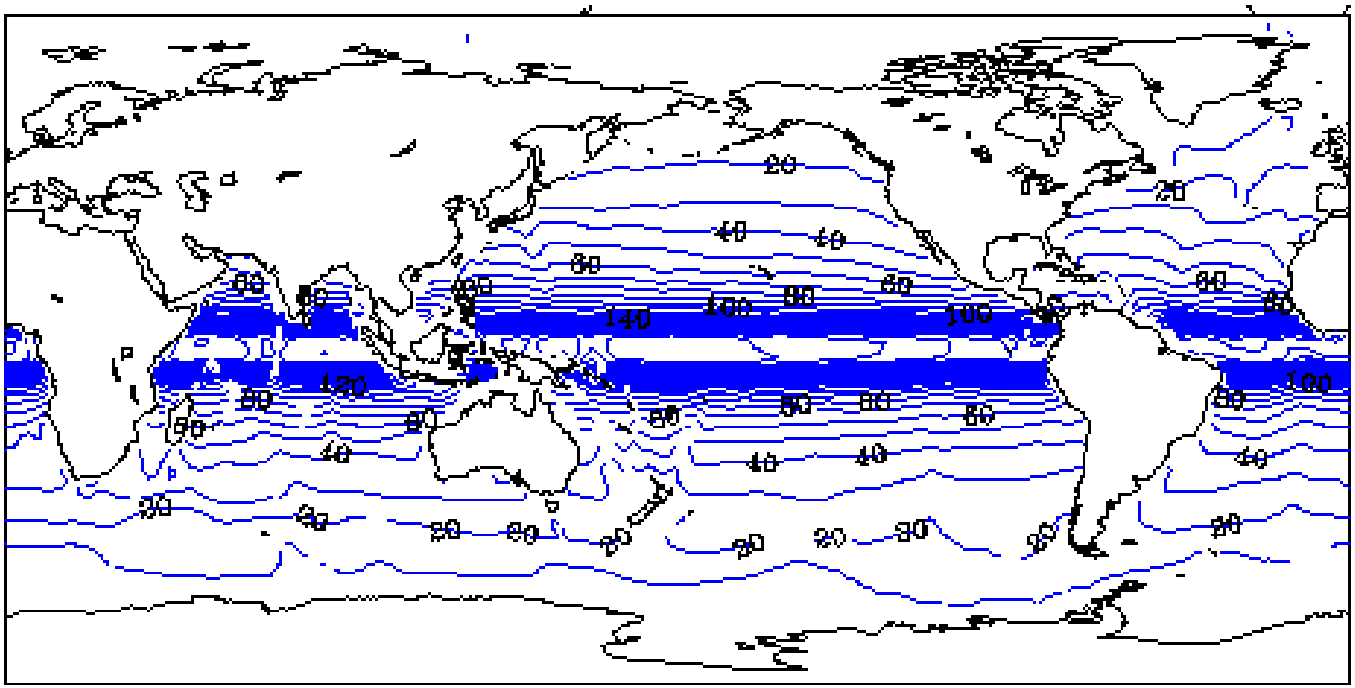


geopotential <ΦΦ> and velocity cross correlations <Φu>, <Φv>

u,v velocity <uu>, <vv> and cross correlations <uv>

warm colors show positive correlations - cool colors show negative correlations

Horizontal Correlation Length Scales



Default geopotential, temperature and salinity correlation length scales computed proportional to Rossby radius of deformation. ~10 km at poles >200 km at equator (Chelton et. al. (1998), J. Phys. Oceanogr. 28: 433-460)

Ocean Data Quality Control

- **real time**
- **fully automated**
- **routine, multiple data cuts per day, all data types**
- **performed in stages**
  - sensibility checks
  - gross error checks
  - consistency/cross validation checks
- **probabilistic framework**
  - outcome in form of probability of error
  - allows simple query capability
- **complex QC**
  - all QC procedures performed before decision to accept/reject
- **produces readily accessible quality controlled data sets**
  - QC data sets put on Monterey GODAE server in real-time

http://www.usgodae.org

Stages Ocean Data Quality Control

Stage I : sensibility checks

- land/sea boundary checks (400 m database resolution)
- location (speed) test for drifters and ship (aircraft) observations
- exact and near-dup duplicate tests

Stage II : gross error checks

- instrumentation error, vertical gradient, static stability checks
- cross variable checks (e.g. SST vs sea ice)
- background field checks using appropriate error variances
  - climate
  - previous analysis
  - model forecast
- buoy (float) sensor drift
- satellite SST large scale aerosol/dust bias detection
- SST diurnal warming events using NWP wind speeds and solar fluxes

Stage III : consistency checks

- innovation/cross validation error checks performed within analysis

Operational Ocean Observation Data Sources

- **AVHRR GAC/LAC Satellite SST** **~3,000,000 obs/day**
  - 8-km/2-km resolution (NOAA 16,17 day, night, relaxed day retrievals)
- **GOES Satellite SST** **~4,000,000 obs/day**
  - 12-km resolution (GOES 10,12 day, night retrievals)
- **Microwave SST** **~150,000 obs/day**
  - 20-km resolution **(TRMM, AMSRE)**
- ***In Situ* SST/SSS** **~15,000 obs/day**
  - surface ship, fixed and drifting buoys, CMAN, TRACKOB
- **Subsurface Temperature and Salinity Profiles** **~1500 profiles/day**
  - XBTs, CTDs (TESACS), PALACE floats
  - fixed buoys (TAO, PIRATA), thermistor chain drifting buoys
- **Sea Surface Height Anomaly (SSHA)** **~150,000 obs/day**
  - altimeter (GFO, Jason, ERS2, ENVISAT), XBTs, CTDs, PALACE Floats
- **Sea Ice Concentration** **~1,000,000 obs/day**
  - SSM/I (DMSP F13, F14, F15)

Approaches Altimeter SSHA Assimilation

1. **Direct method synthetic STDs**

   adjusts model density profile to be consistent with change in model forecast sea surface height measured by the altimeter

   temperature and salinity adjustments are computed simultaneously, water mass properties on subsurface isopycnals are conserved

2. **MODAS synthetic BTs**

   computes temperature at depth from SSHA using stored regressions of anomalies of climatological temperature and dynamic height

In both approaches, synthetic profiles are generated where the change in SSH exceeds altimeter measurement errors (~2-3 cm)

Synthetic profiles are assimilated with “real” observations, but unique observation errors are specified

Salinity Observation Data Sources

Multivariate method requires companion salinity for every temperature observation assimilated

- **observed temperature and salinity profiles (Argo floats, CTD) are directly assimilated**
- **salinity is derived from temperature-only profiles using regressions computed from historical TS profile observations**

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

bi-monthly regression coefficients (α) stored
on a global variable resolution grid (MODAS)

- **derived salinities are adjusted to ensure static stability throughout water column and neutral buoyancy in mixed layer**

NCODA Applications (QC, Analysis, Diagnostics)

Fleet Numerical Meteorology and Oceanography Center

- 2D sea ice SST analyses as lower boundary conditions for Navy global (NOGAPS) and regional (COAMPS) NWP - FY03
- global and regional stand-alone 3D analysis - FY04

Naval Oceanographic Office

- data assimilation component for SWAFS (POM) model - FY04

NOPP/GODAE

- data assimilation component for HYCOM model
- North Atlantic 1/12 deg resolution domain at NCEP - FY05
- global model domain at NAVOCEANO - FY06

NOPP/SST

- analysis component in project to produce 6-hourly global 10 Km SST analyses using all sources of SST (IR, MW, in situ)
- U.S. contribution to GODAE High Resolution SST Pilot Project (GHRSST)

NCODA Plans and Upgrades

- **wave model data assimilation (Wave Watch III) at FNMOC**
  - altimeter (buoy) significant wave height
  - adjustment wave model spectra using BMRC or NCEP methods

- **conversion to 3DVAR algorithm**
  - global solution, assimilate non-model variable observations
  - leverage NAVDAS solver (Daley and Barker - MWR)

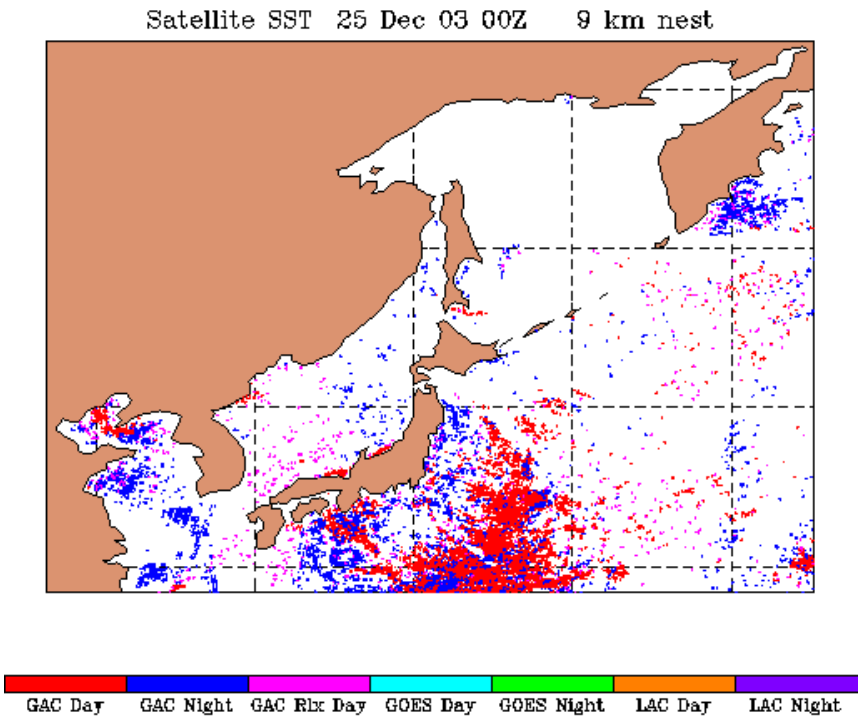
- **implement additional 4D capabilities in 3DVAR**
  - flow dependent correlations
  - non-separable background error correlations

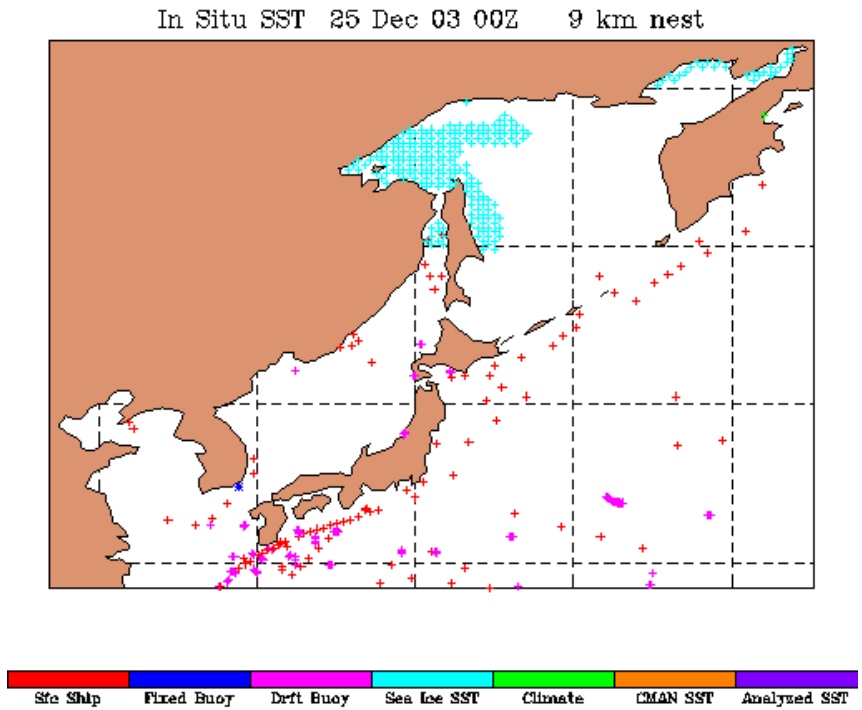
- **generalize analysis vertical coordinate**
  - z (POP)
  - sigma (SWAFS)
  - hybrid (HYCOM)

NCODA/SWAFS vs. SWAFS Operational Parallel Runs

- NAVOCEANO SWAFS forecast model (POM)
- NW Pacific domain, 7 Km x 9 Km grid resolution
- 24 hour update cycle
  - all observations within +/- 12 hrs analysis time
- initial conditions NAVO operational SWAFS run valid 23 Aug 2003
- NCODA analysis period from 23 Aug to 31 Dec 2003
- altimeter assimilation via MODAS synthetic temperature profiles
  - NCODA assimilation run
  - NAVO operational SWAFS run

NCODA Surface Observations 25 Dec 2003 00Z





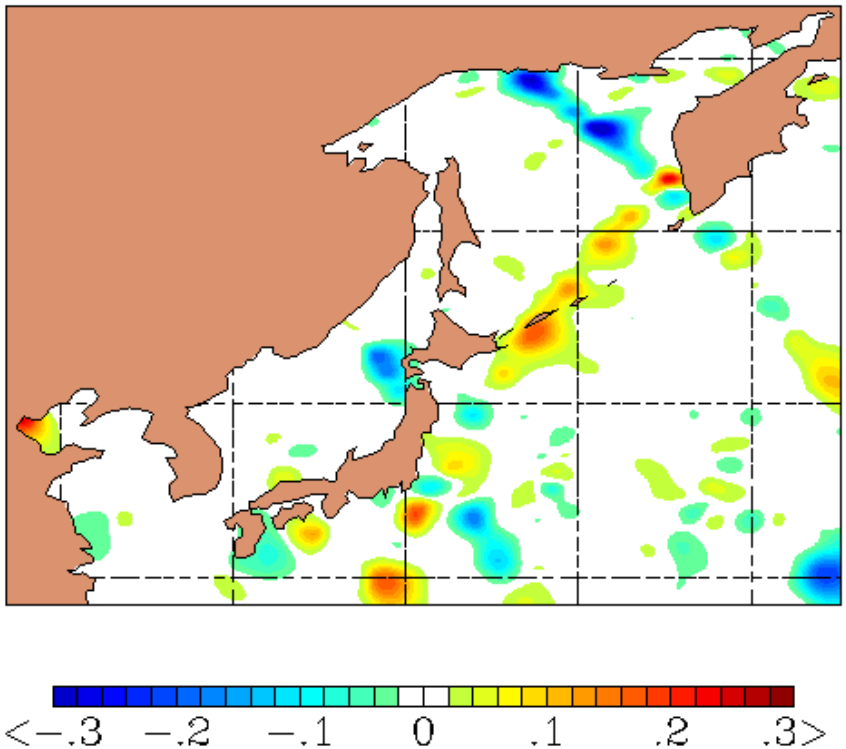
<u>Satellite SST Observations</u>

NOAA 16, 17 GAC day, night retrievals

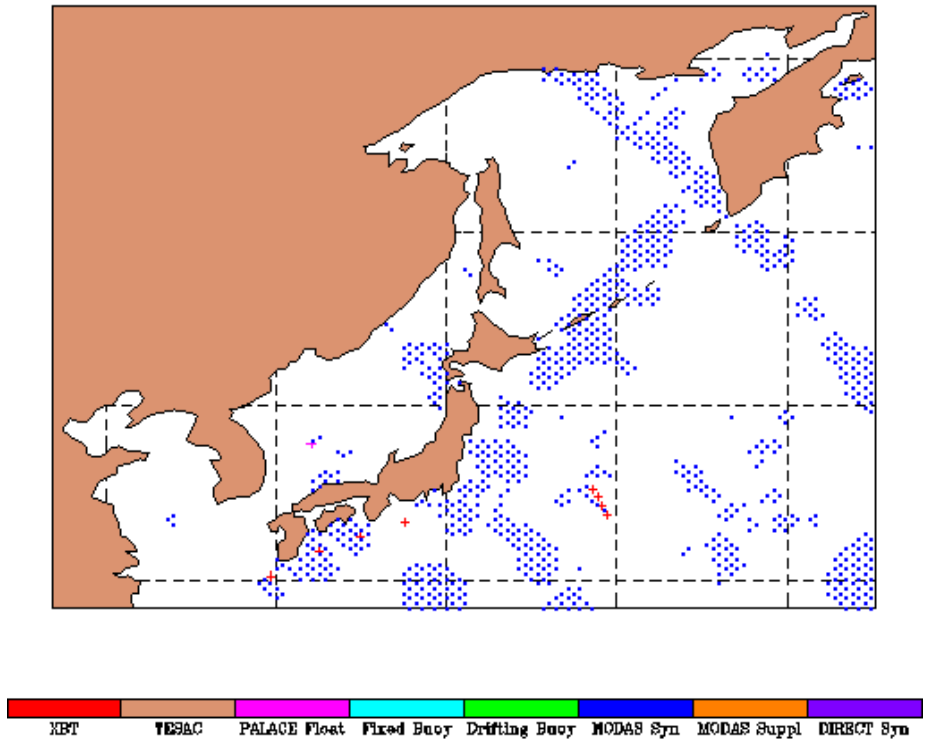
<u>In Situ SST Observations</u>

ship (ERI, hull contact), fixed buoys, drifting buoys, freezing sea water synthetic SSTs

NCODA Profile Observations 25 Dec 2003 00Z

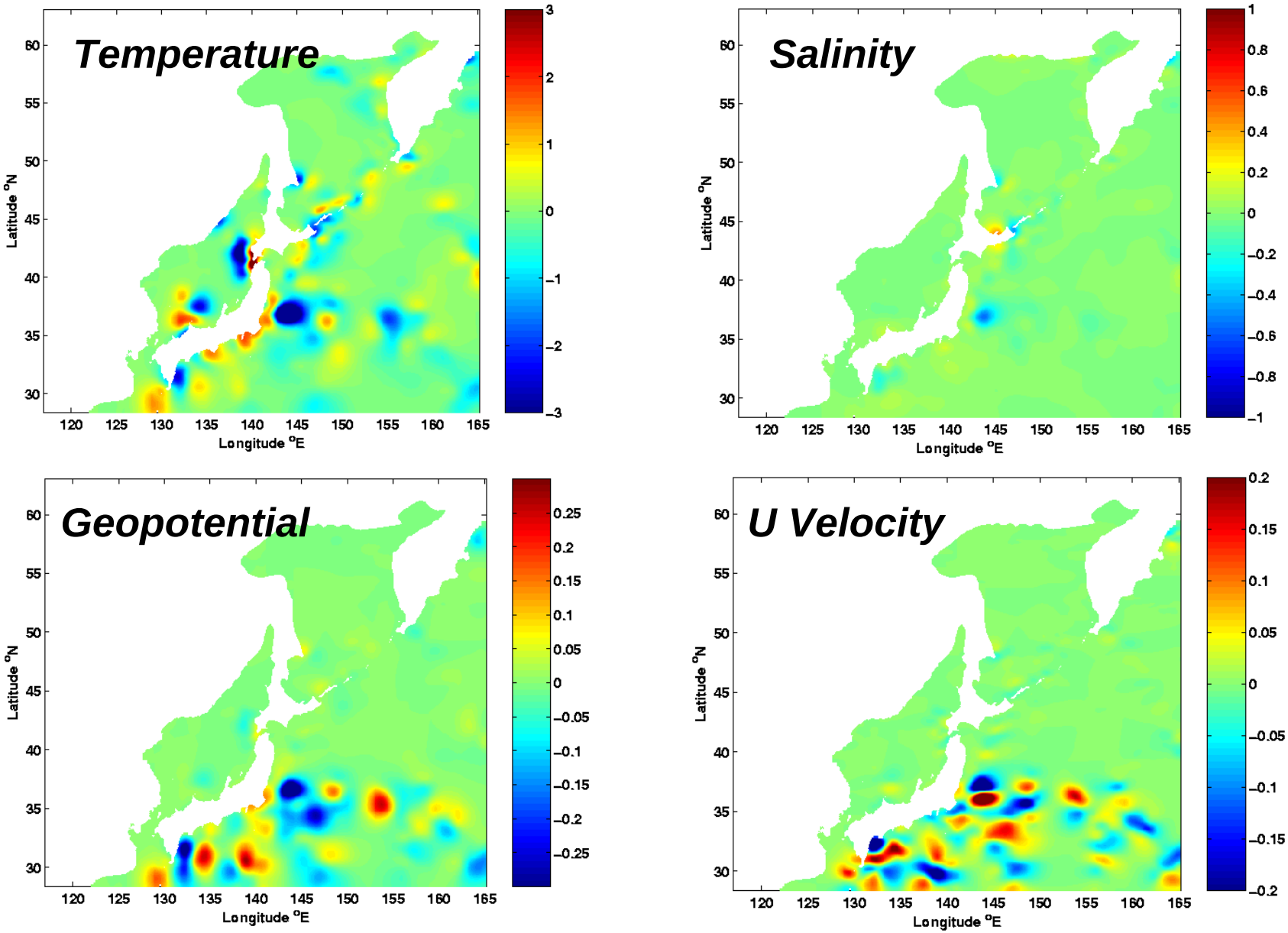


Analyzed change in SSH (cm) measured by satellite altimeters. Changes greater than +/- 2 cm are considered significant and are shown as color filled contours.

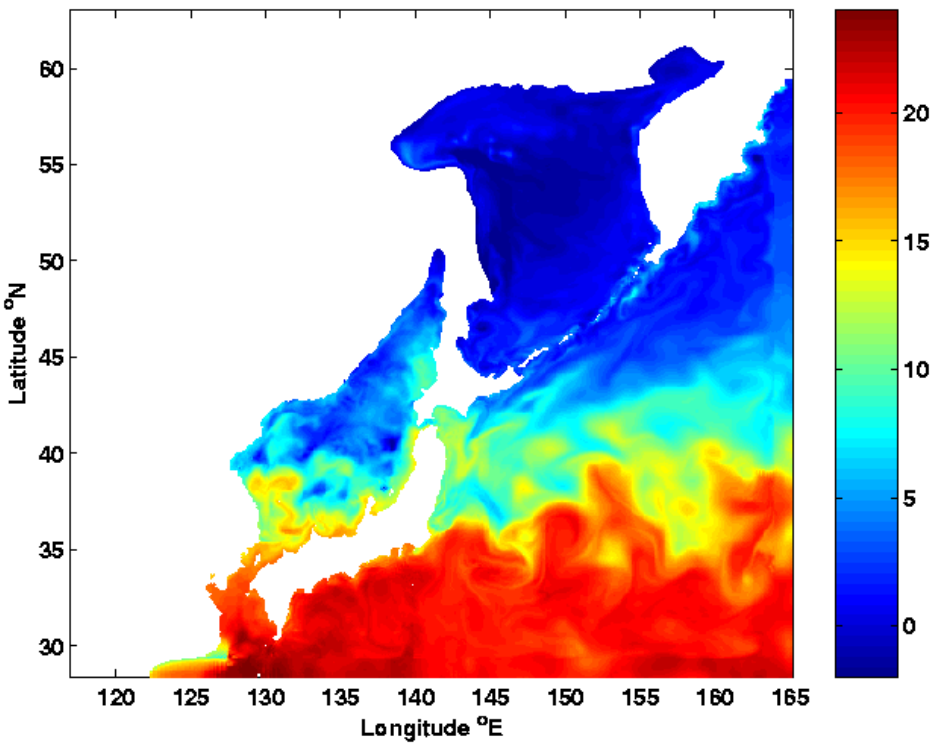


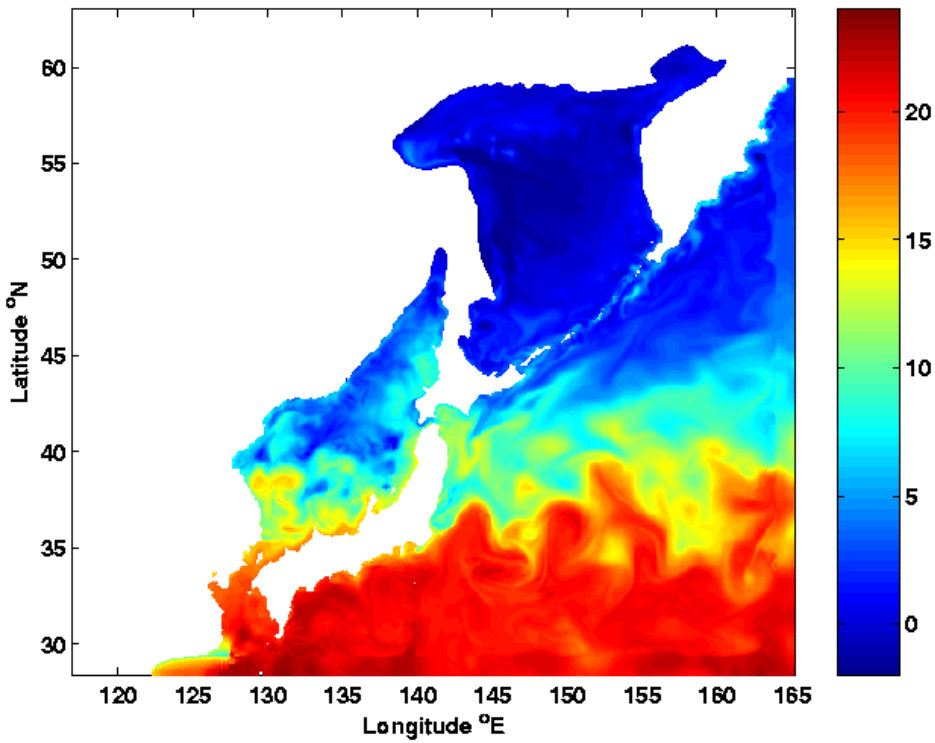
Sampling pattern of synthetic profiles (MODAS) to capture observed SSH changes. In situ profiles include XBTs, TESACs, Argo floats, Fixed buoys. Synthetic profiles are not generated near in situ profiles.

100 M Analyzed Increments 25 Dec 2003 00Z



100 M Temperature 25 Dec 2003 00Z

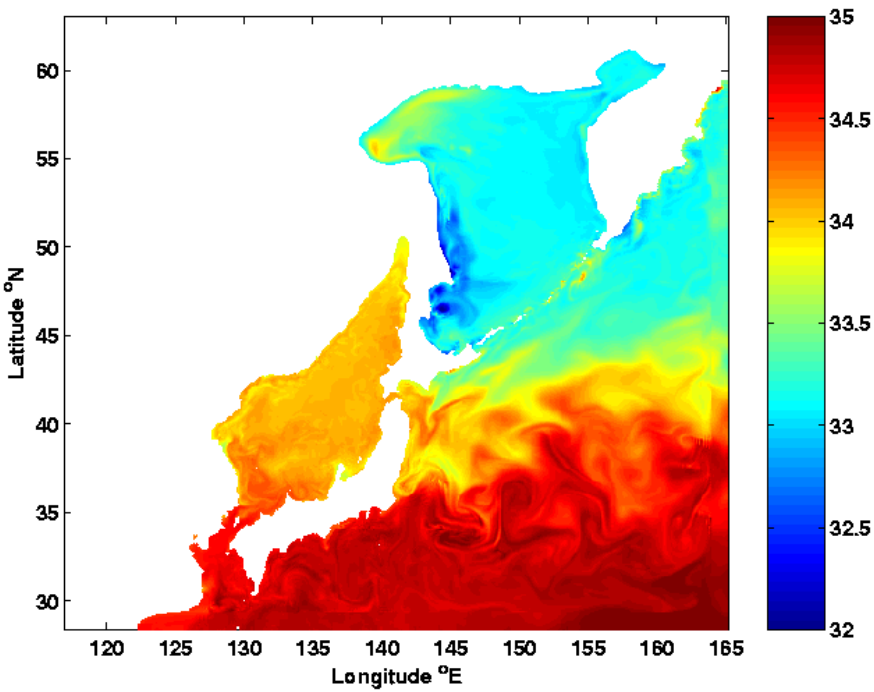


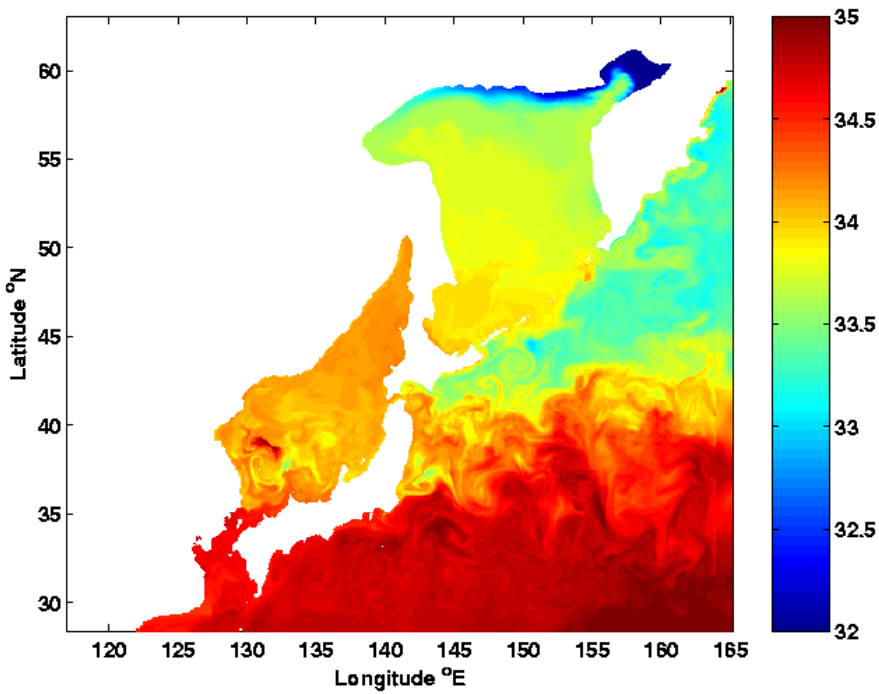


3D MVOI NCODA Assimilation Run

SWAFS Operational Run

100 M Salinity 25 Dec 2003 00Z

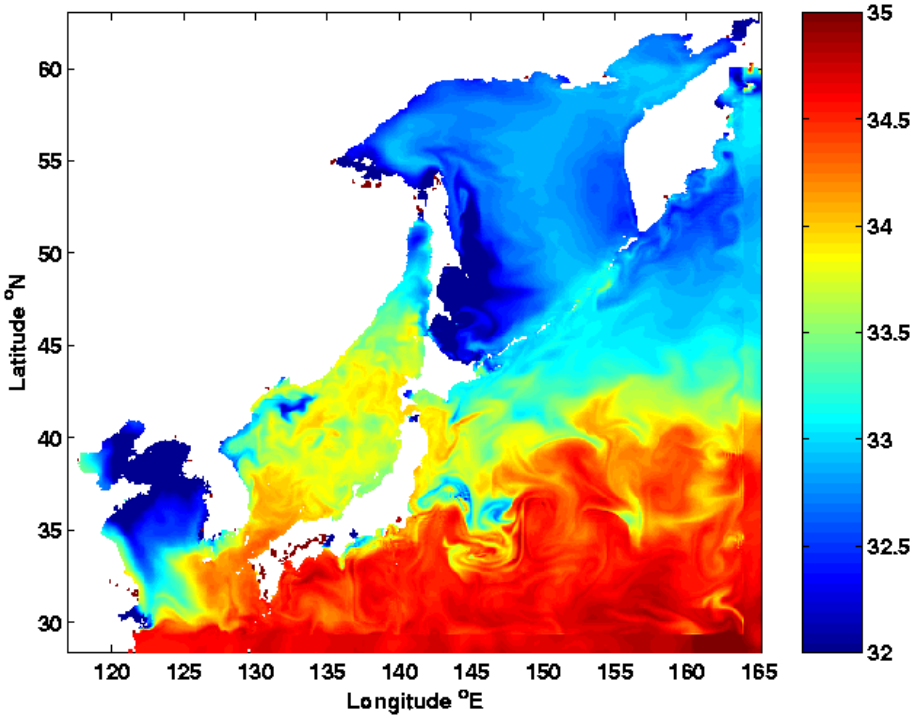


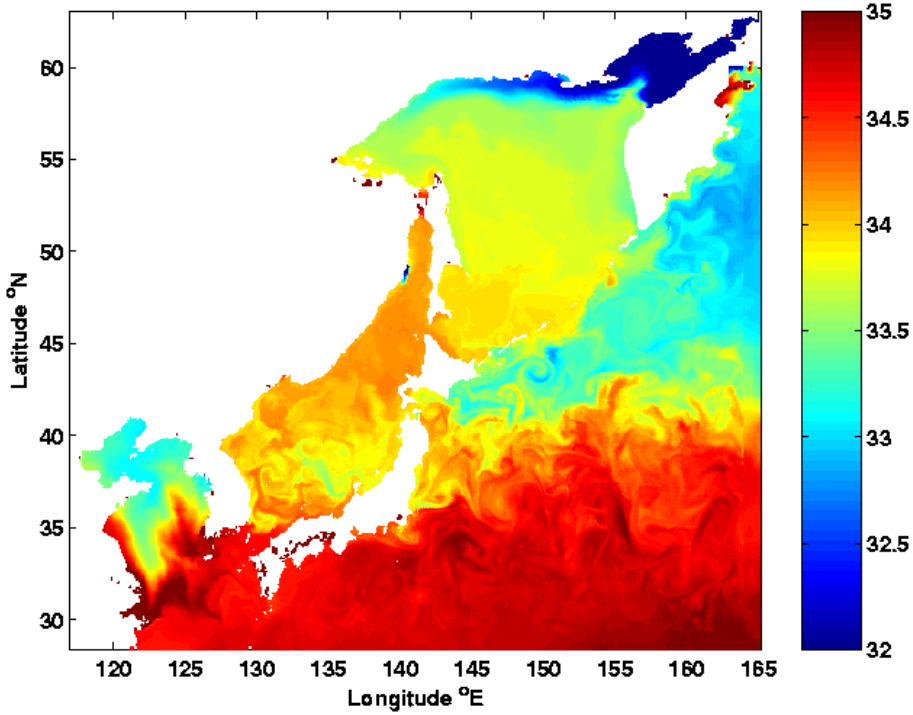


3D MVOI NCODA Assimilation Run

SWAFS Operational Run

Sea Surface Salinity 25 Dec 2003 00Z





3D MVOI NCODA Assimilation Run

SWAFS Operational Run