Status and Progress of NCODA Assimilation in HYCOM

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Outline:
Status of HYCOM/NCODA Assimilation Systems
Assimilation Verification Results
Model/Data Issues and Solutions
Analysis Covariance Consistency
Validation of Altimeter Assimilation Methods
Plans for Transition of MVOI to 3D-Var

Status HYCOM/NCODA Assimilation Systems

Global Model Assimilation

- hindcast run – November 2003 to May 2005 (as of last week)
- real-time run – December 2006 to present
- ~9 km grid resolution
- 24-hr update cycle
- assimilation only in Mercator part of grid (south of 47° N)

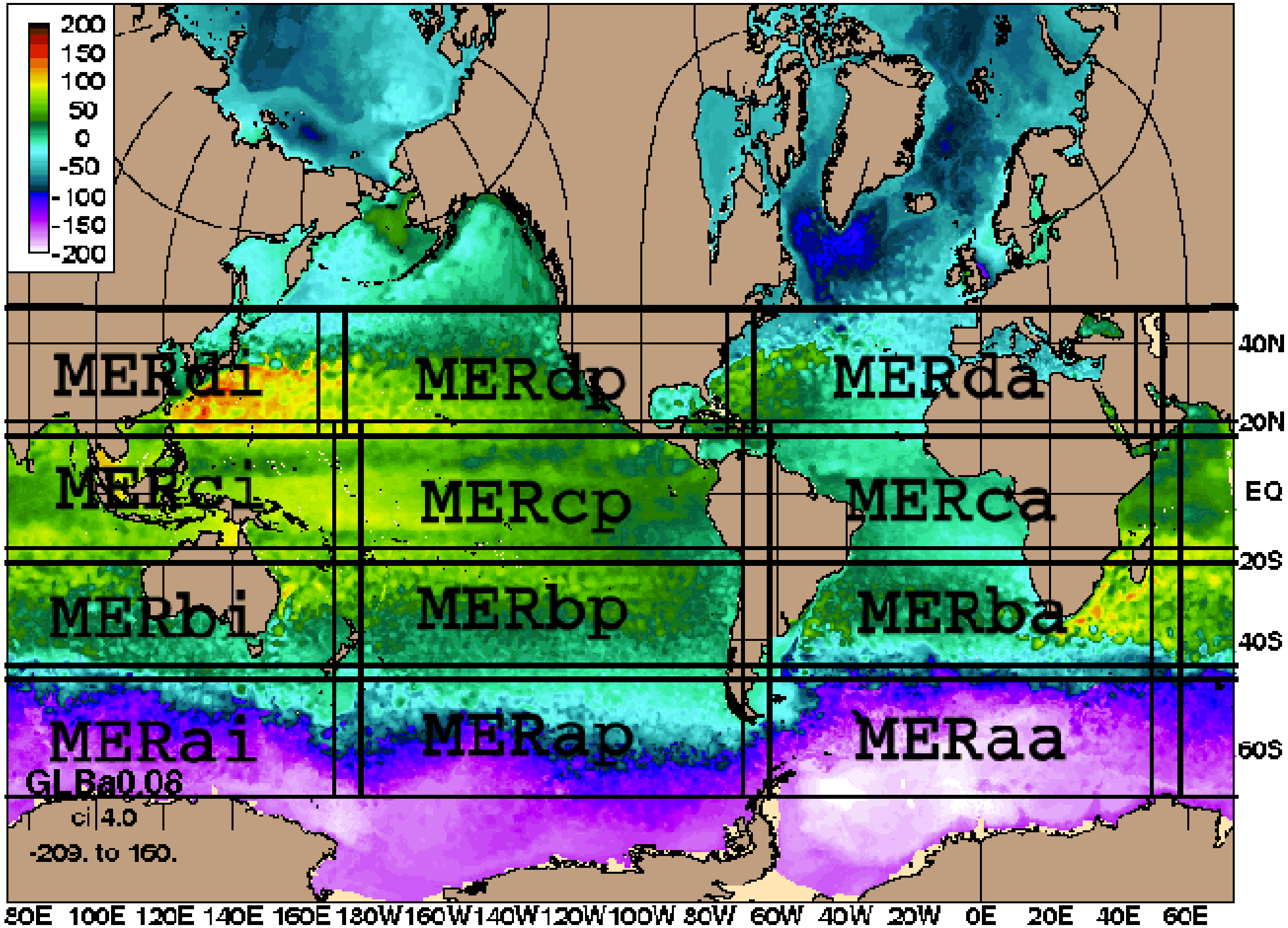
Gulf of Mexico Model Assimilation

- real-time run – August 2006 to present
- ~3 km grid resolution
- 24-hr update cycle

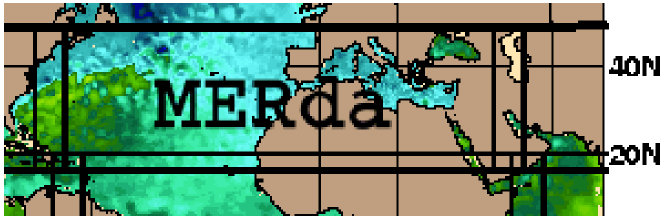
Both systems assimilate all operational sources of observations

- AVHRR GAC and GOES (GoM only) satellite SST, in situ SST, altimeter SSH, TS profiles (Argo, CTD, XBT), SSM/I sea ice

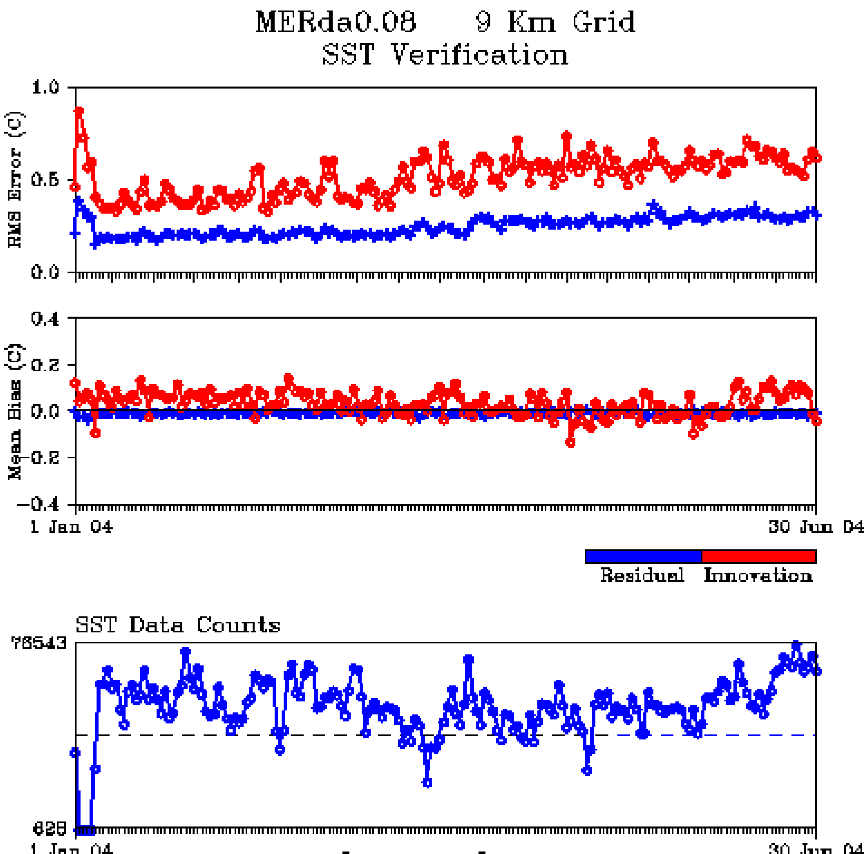
Global Model Assimilation Verification



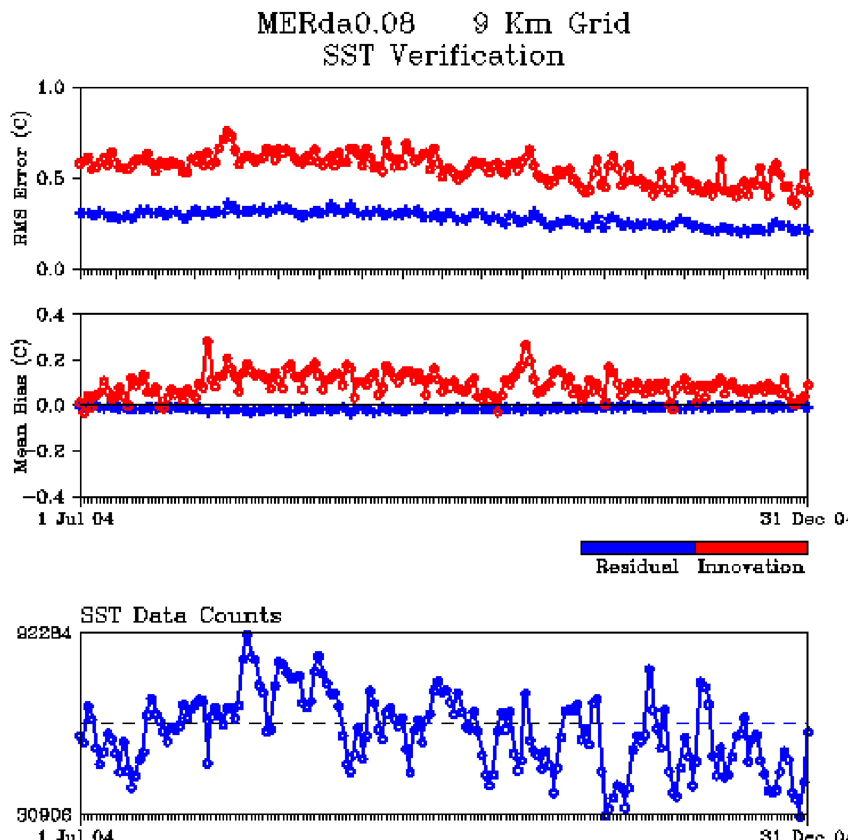
Analysis performed in 12 overlapping domains that define the Mercator part of the global grid



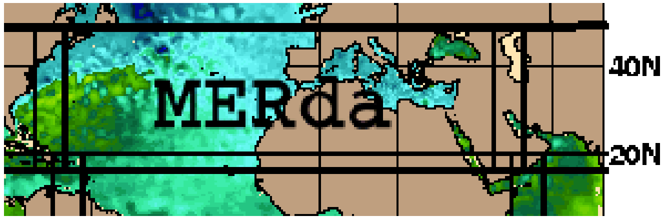
Global Model Assimilation 2004 SST Verification



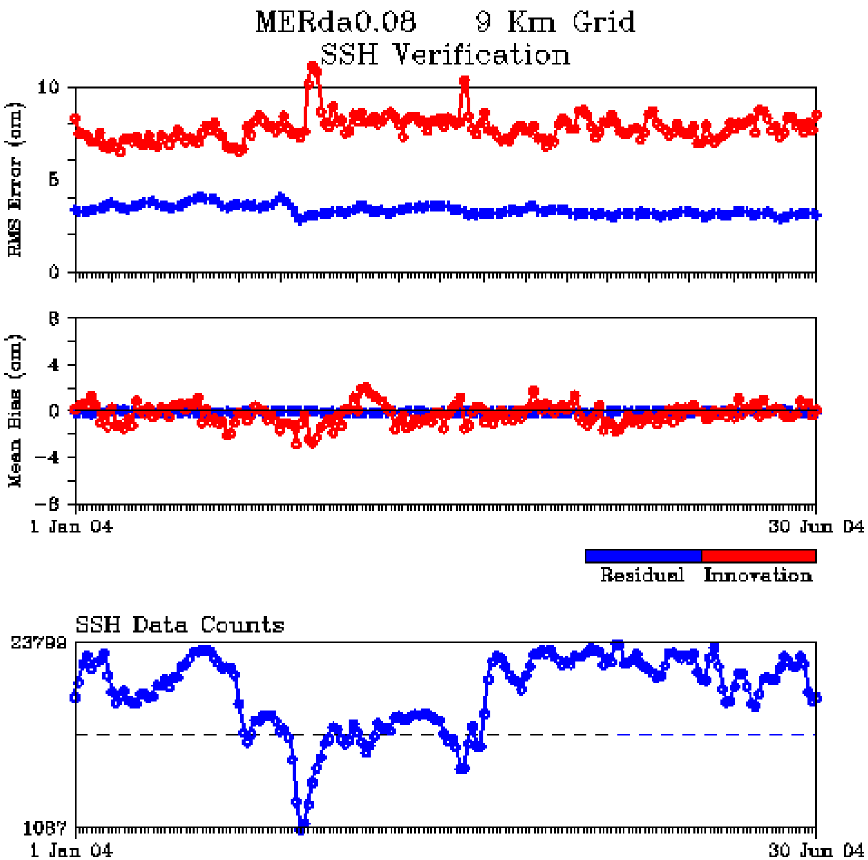
Jan – Jun



Jul – Dec



Global Model Assimilation
2004 SSH Verification



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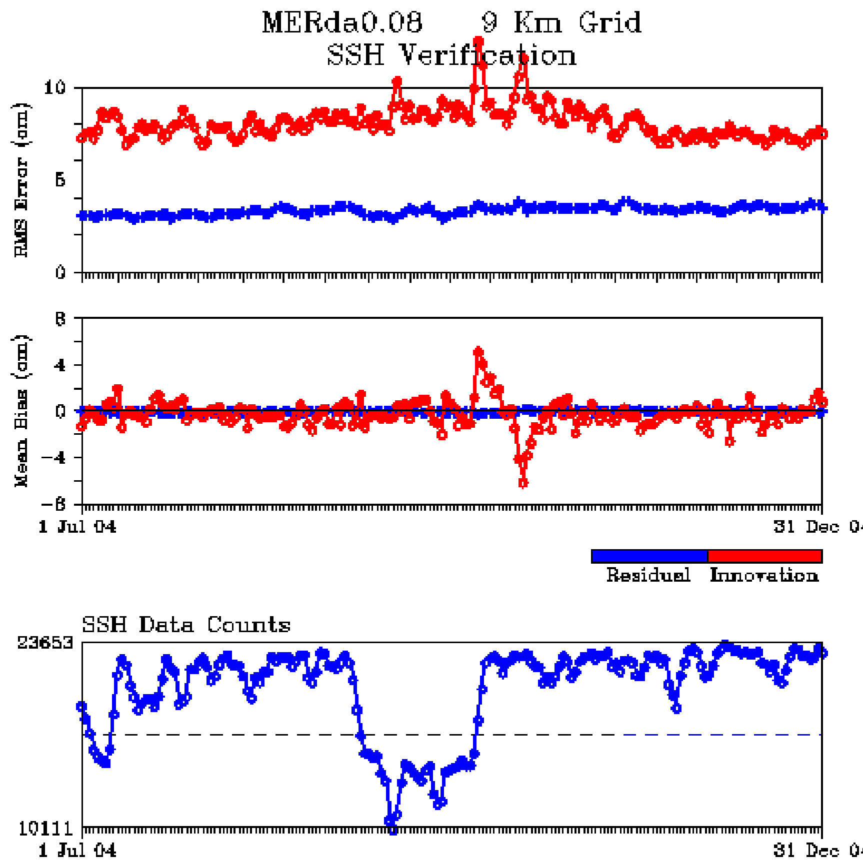
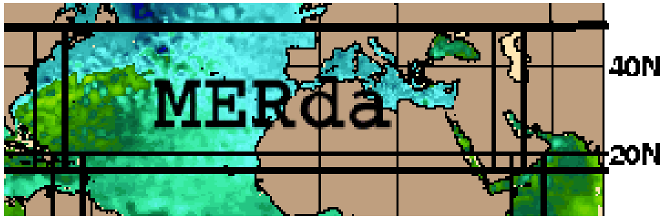
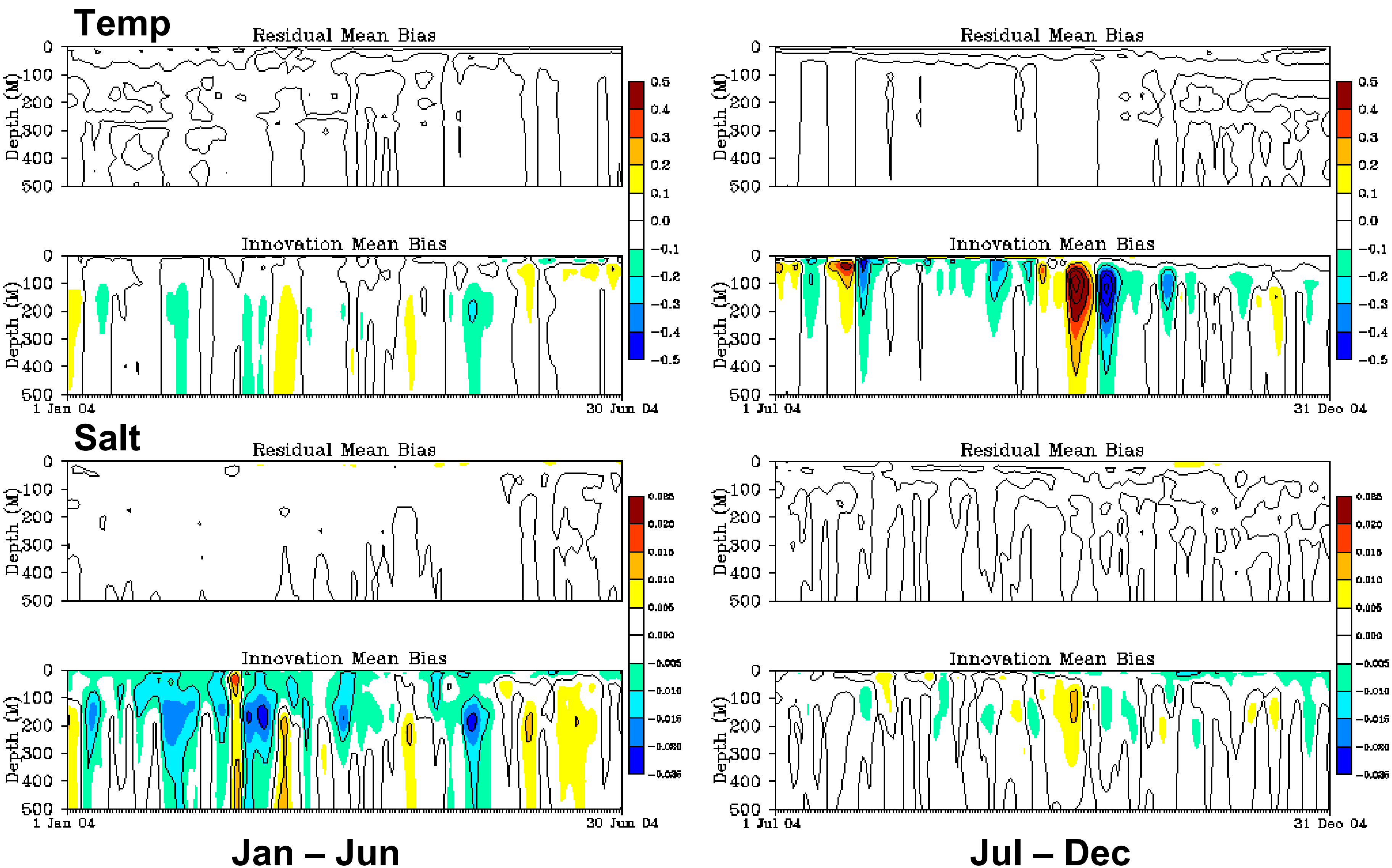
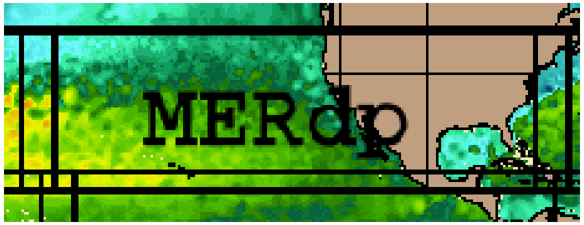


Jul – Dec

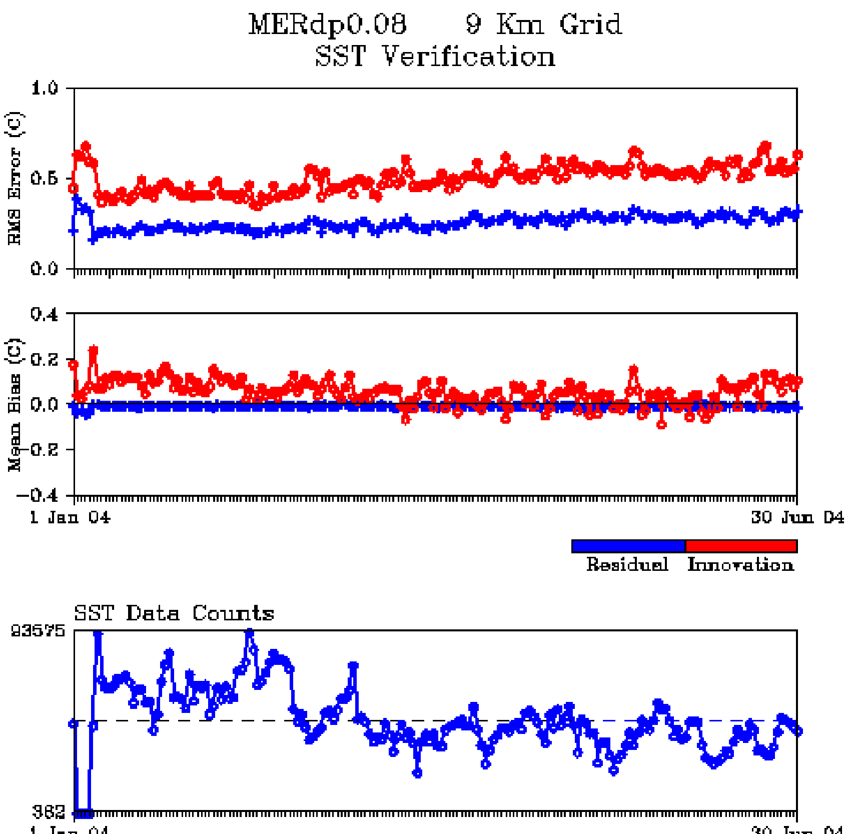


Global Model Assimilation 2004
Temperature/Salinity Mean Errors

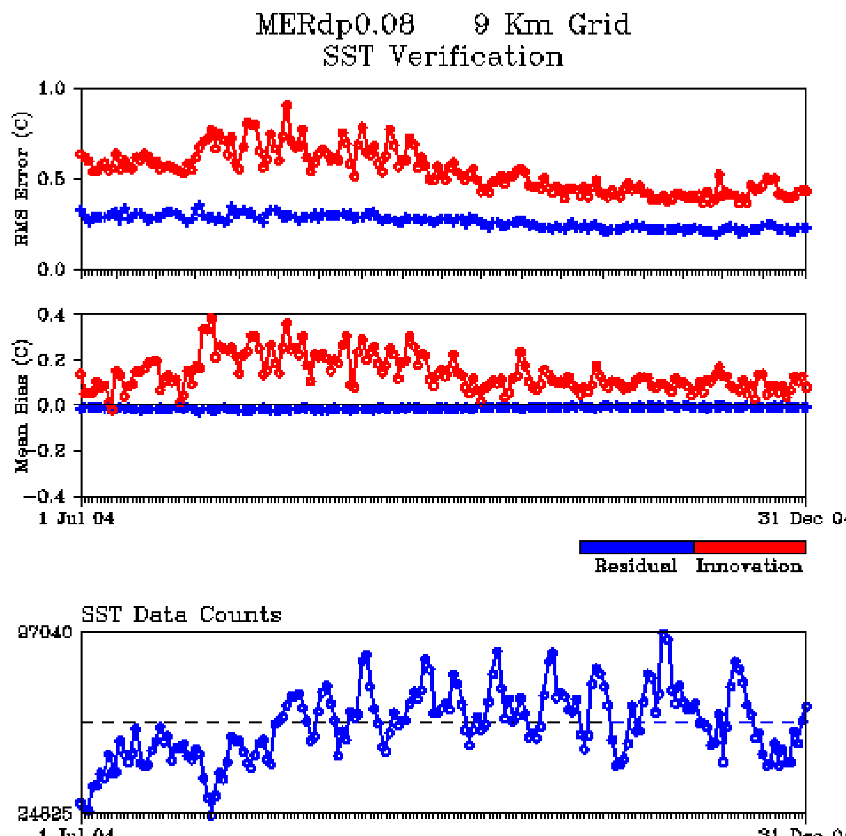




Global Model Assimilation 2004 SST Verification

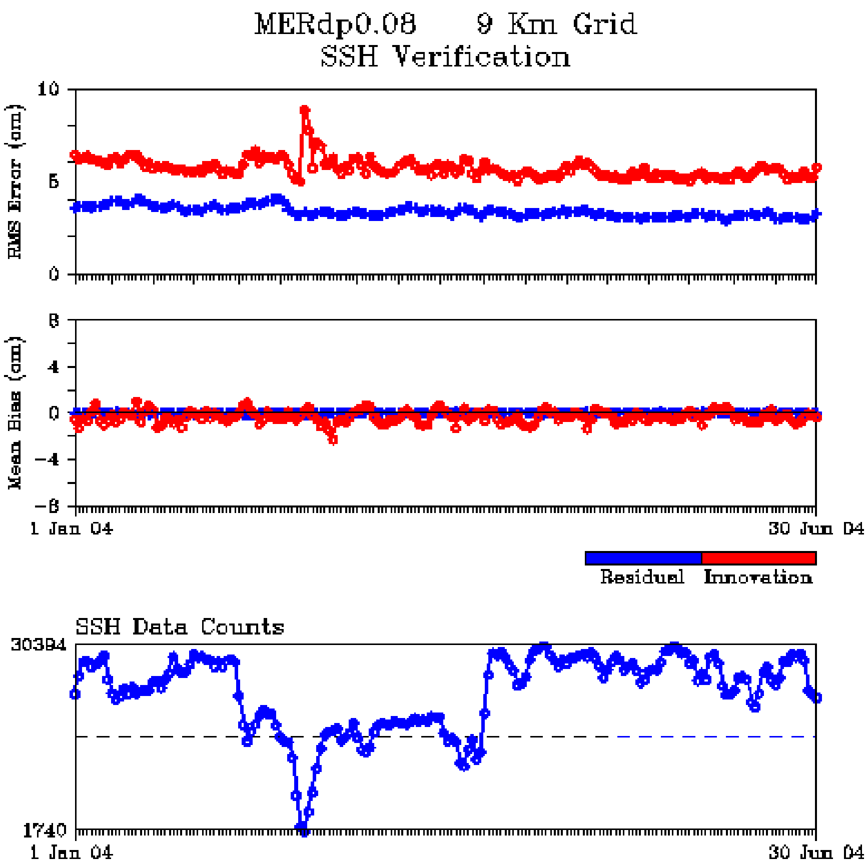


Jan – Jun

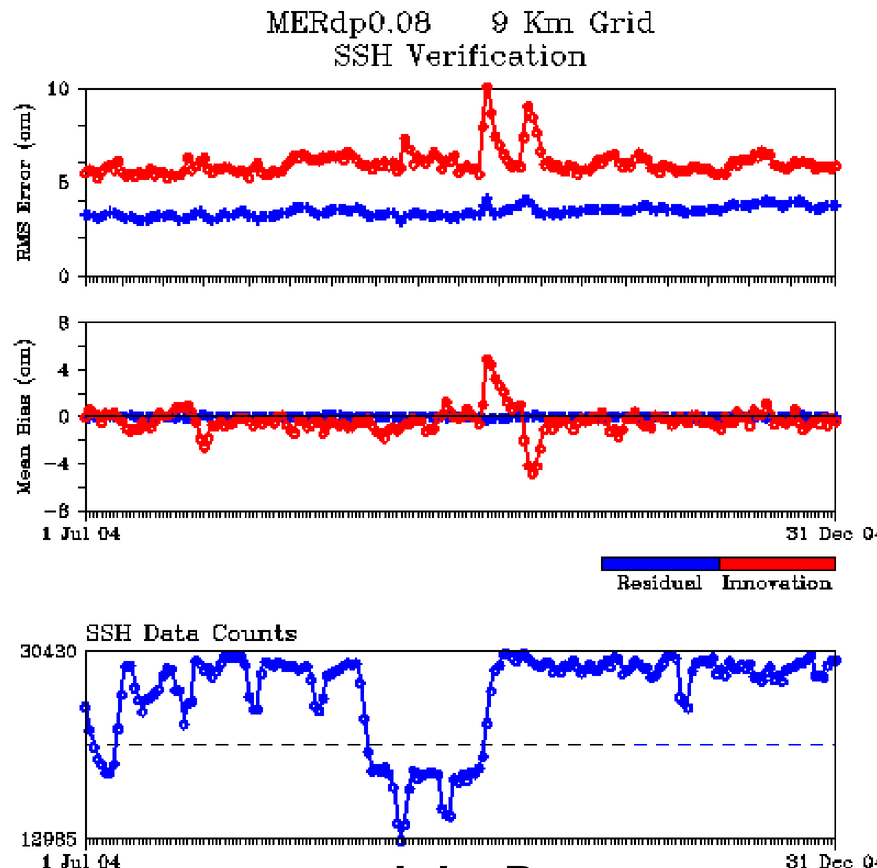


Jul – Dec

Global Model Assimilation
2004 SSH Verification



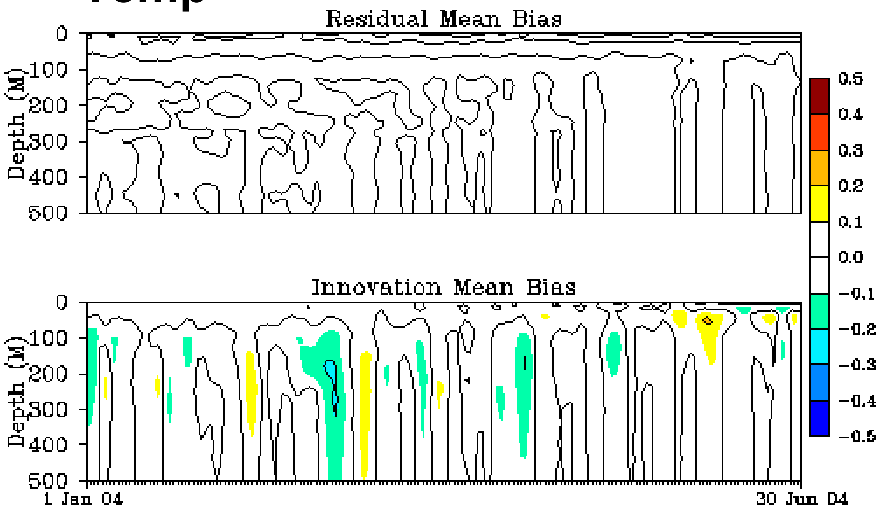
Jan – Jun

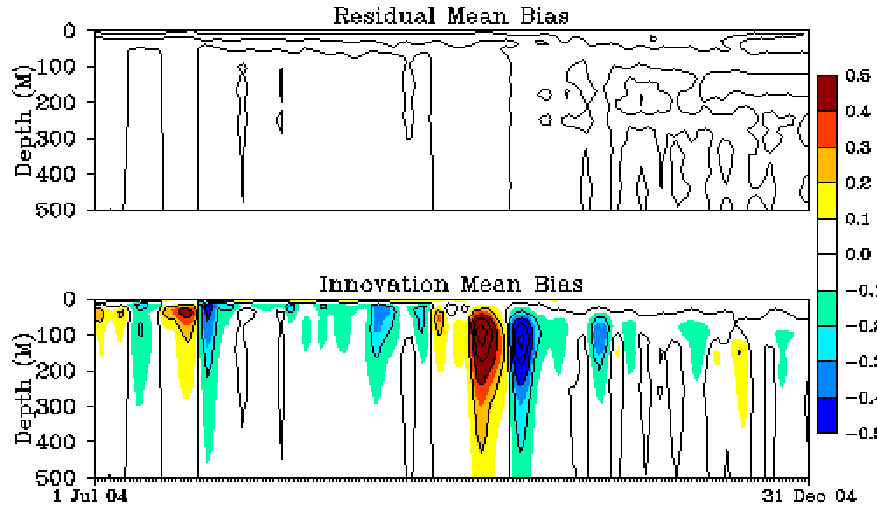


Jul – Dec

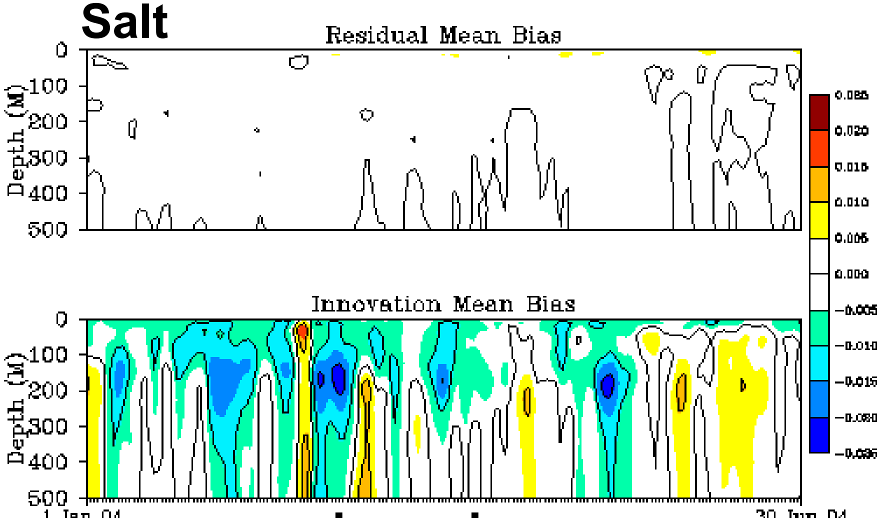
Global Model Assimilation 2004
Temperature/Salinity Mean Errors

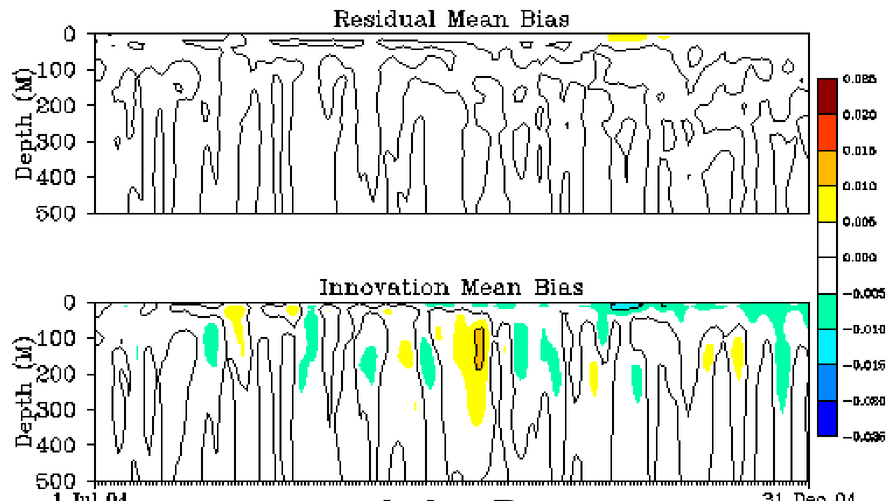
Temp





Salt





Jan – Jun **Jul – Dec**

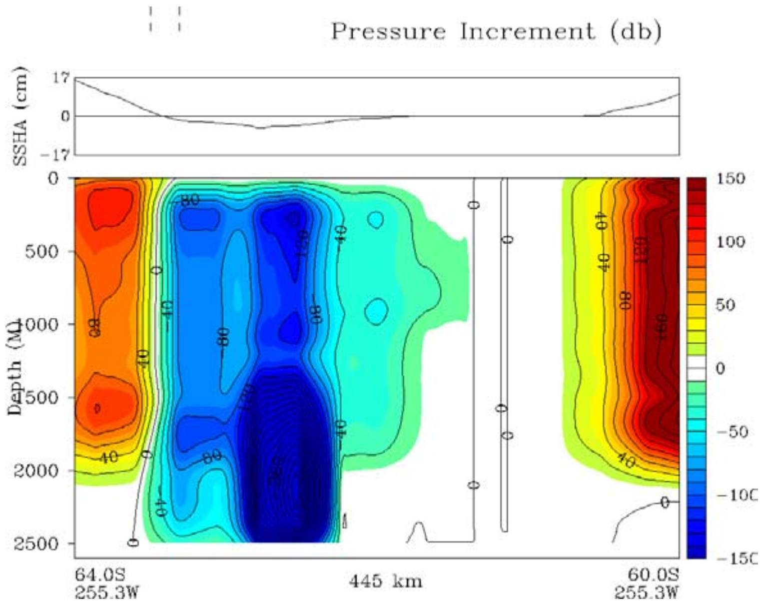
Summary 2004 Global Model Verification

- analysis residuals show consistent error reduction from 24-hr forecast
- analysis residuals unbiased, except for a small positive salinity bias (~0.01 PSU, < 50m) in tropical Pacific (MERcp) domain (not shown)
- SST bias increases in later half of 2004 - somewhat true in NW Atlantic (MERda) domain, especially true in NE Pacific (MERdp) domain
- SSH prediction errors dominated by GFO data issue during Sep/Oct
- salinity errors at depth spuriously large in first half of 2004 in NW Atlantic (MERda) and NE Pacific (MERdp) domains

Monitoring of assimilation error time series should be routine (NAVO?)

Need to understand cause – forcing errors, model drift, analysis error?

Model/Data Issues and Solutions



Cross section of layer pressure increments along 104.7°W from 64°S to 60°S   1 Dec 2004

Large layer pressure increments at depth

- tends to occur at high latitudes in weakly stratified water columns (also Med Sea)
- potential source(s) of problem:
  - assimilation of SSHA with large barotropic signals using Cooper Haines (CH) method
  - density inversions in model forecast
- solution to problem:
  - allow for weak model density inversions when computing layer pressure innovations
  - do not generate CH profile if Brunt-Vaisalla frequency of forecast profile is <1 cph
  - reject CH profile if residual of iterative fit to measured change in SSH is >1 cm

Model/Data Issues and Solutions

High Density SST Observations

- multiple sources SST data – AVHRR GAC/LAC, GOES, AMSR-E, AATSR, and soon METOP (potential for global 1 km data).
- large number of SST data increase analysis run time: post-multiplication step mapping from observation to grid space (matrix/vector operation).
- solution to problem:
    - perform 2D SST analysis using all data sources (HYCOM SST forecast first guess)
    - sample SST increments to select analyzed SST observations for 3D analysis
    - implemented in Gulf of Mexico HYCOM – decreased run time from 1.5 hrs to 11 min

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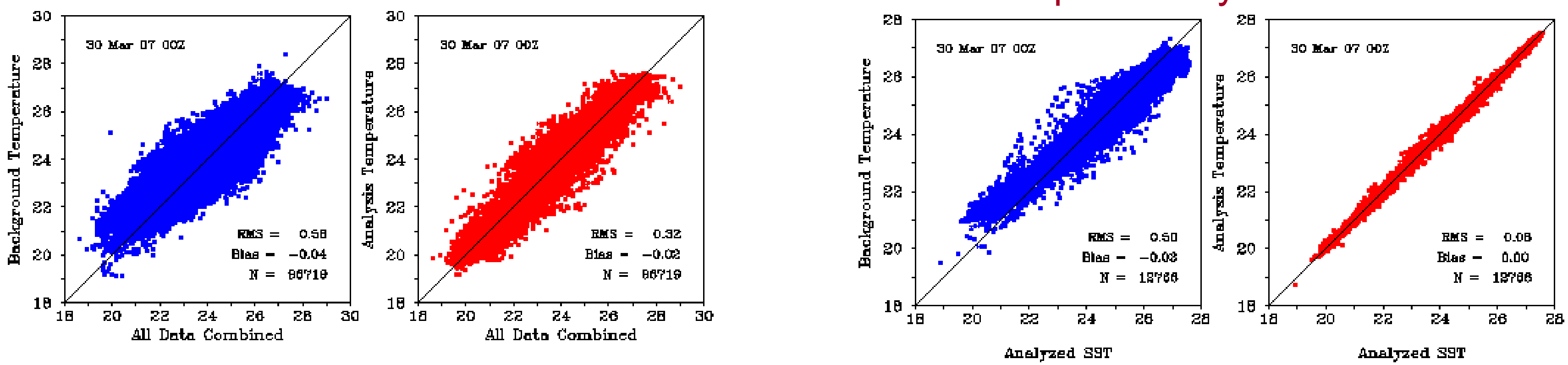
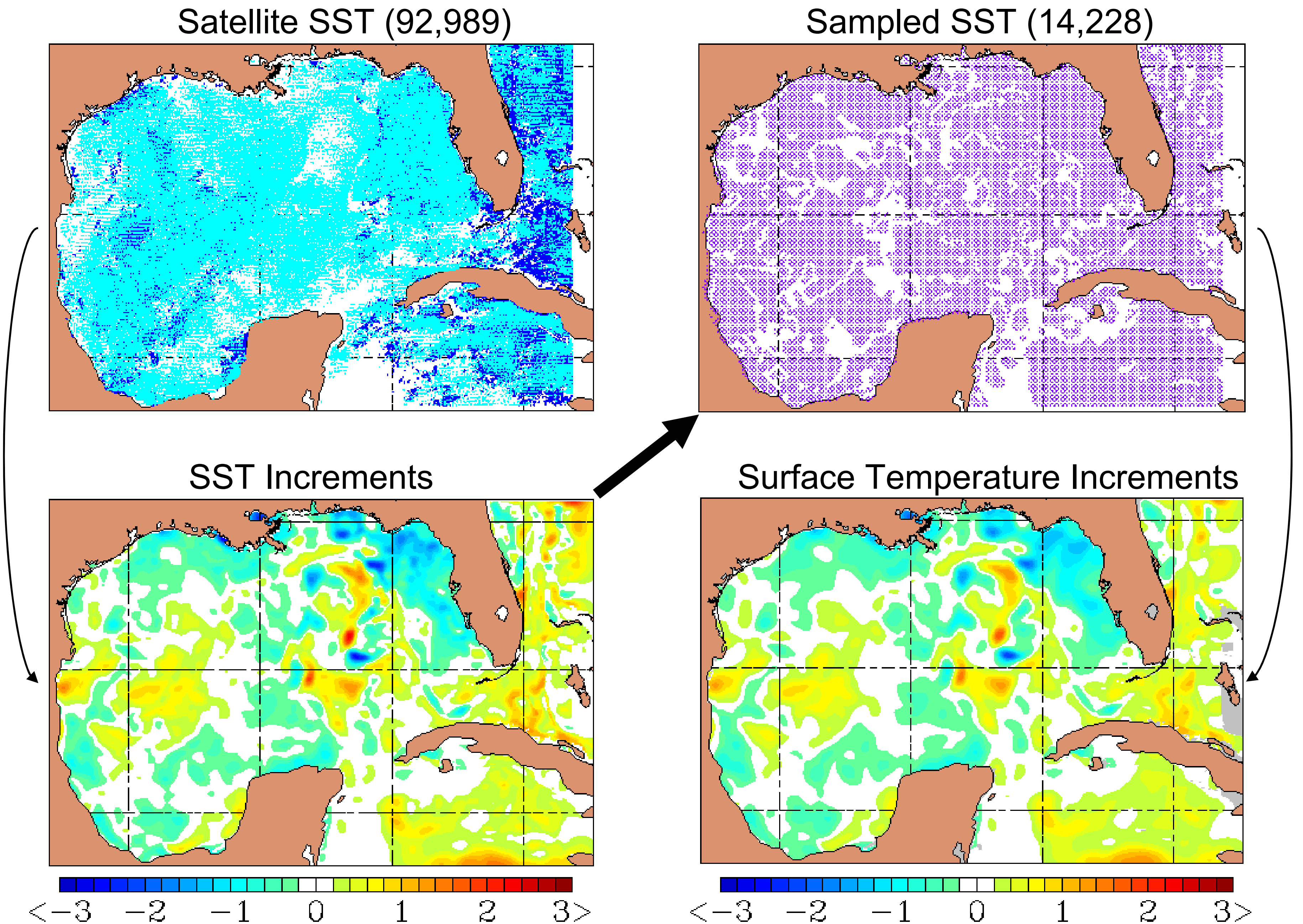
Forecast Innovation (blue) Analysis Residual (red)

Satellite SST Sampled Analyzed SST





Selection Criteria: δT 0.1 °C, sample every 4th grid node

Model/Data Issues and Solutions

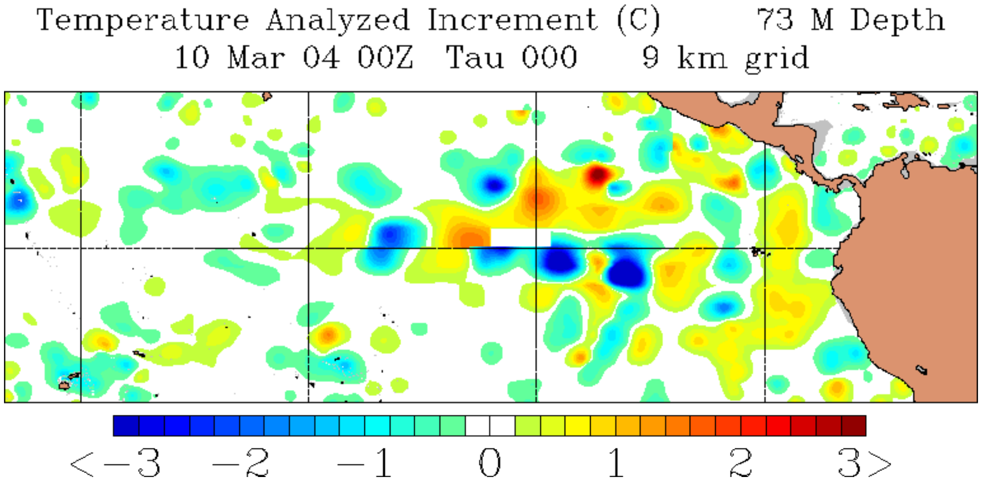
Dropped Analysis Volumes

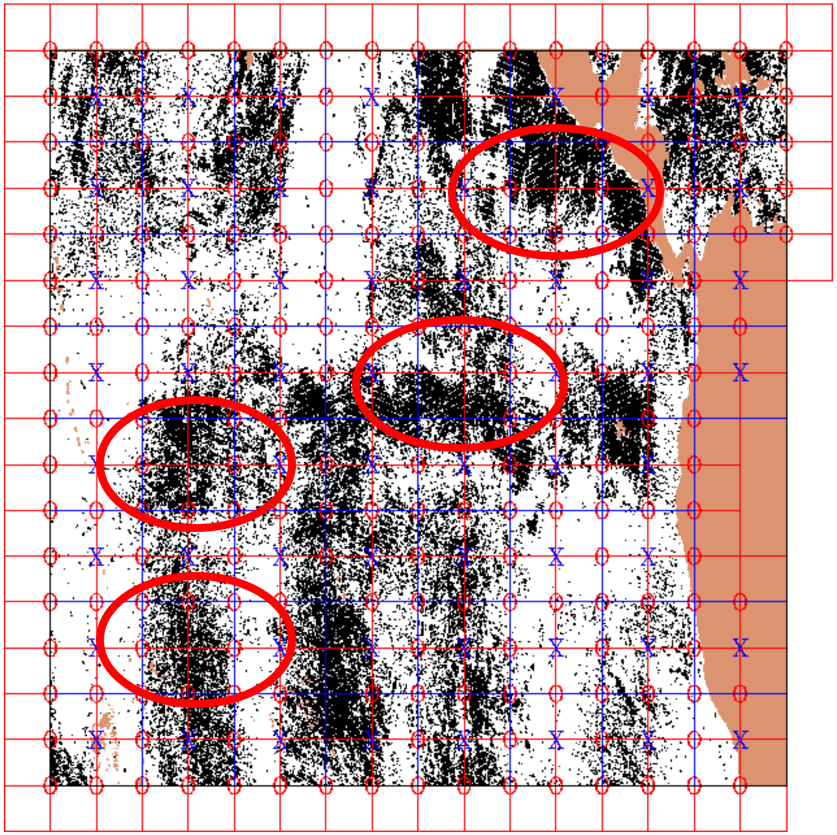
Effect of observation density and high resolution grid.

Processor work computed as product of number of data and number of grid points – used in load balancing algorithm.

Computed work value exceeded 32-bit integer – result is a negative number

Volume would be skipped (no work to do)





Analysis (X) and overlap volumes (o)

Ovals indicate missing volumes

Increments show discontinuities at missing volume edges

Analysis Covariance Consistency

$$J_{\min} = [y - H(x_b)]^T (HP_bH^T + R)^{-1} [y - H(x_b)]$$

P_b – background error covariance

y – observation vector

x_b – background

R – observation error covariance

H – linearized forward operator

$[y-H(x_b)]$ – innovation vector (d)

If P_b and R are specified consistent with the innovations, $Jmin/n_{obs} = 1$.

Note that the gain matrix $(HP_bH^T + R)^{-1}$ is the covariance of the innovations,

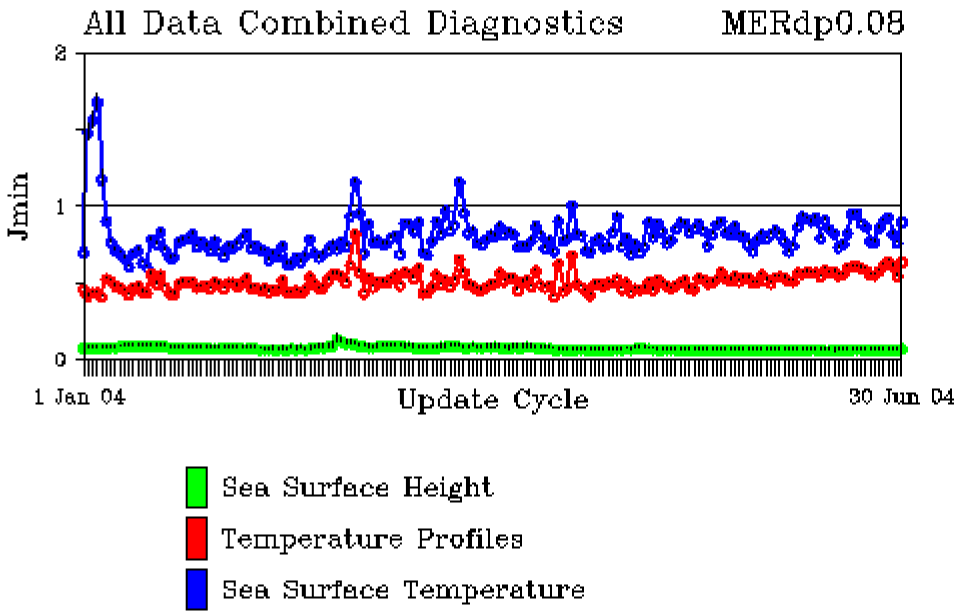
$$HP_bH^T + R = E(dd^T).$$

If Jmin > 1, specified errors are too small (or erroneous data assimilated).

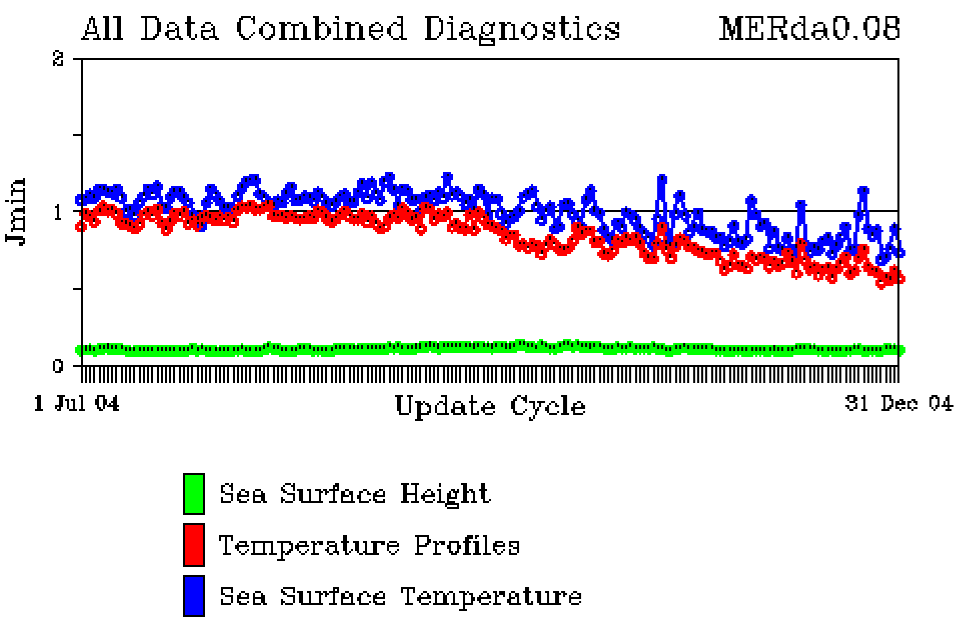
If Jmin < 1, specified errors are too large.

NCODA computes Jmin for all observing systems at each update cycle – used to monitor the background and/or observation error statistics.

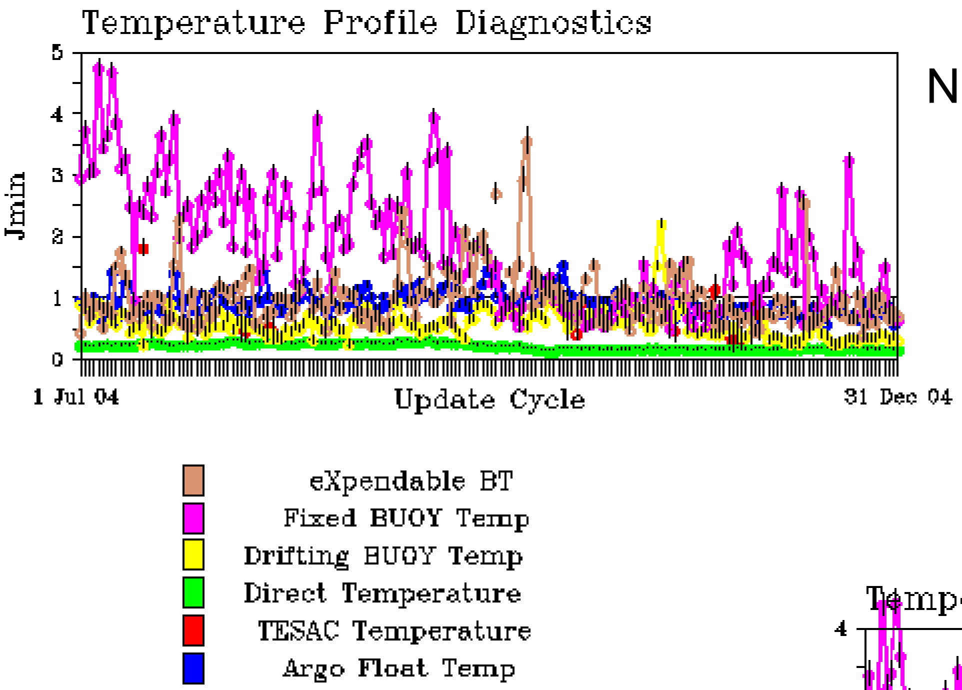
NE Pacific – Jan to Jun 2004



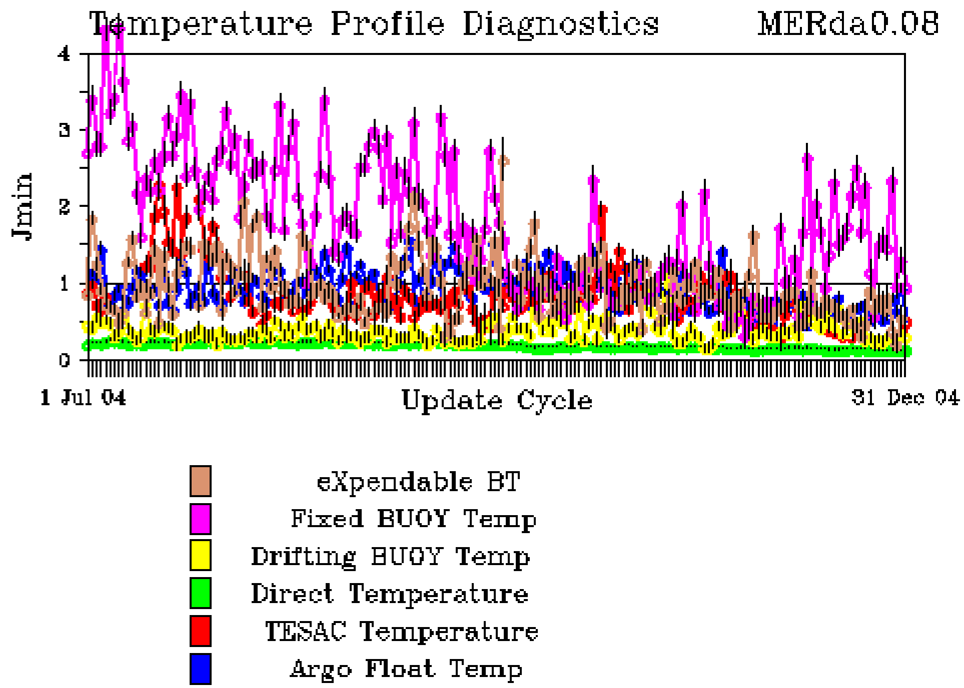
NW Atlantic – Jul to Dec 2004



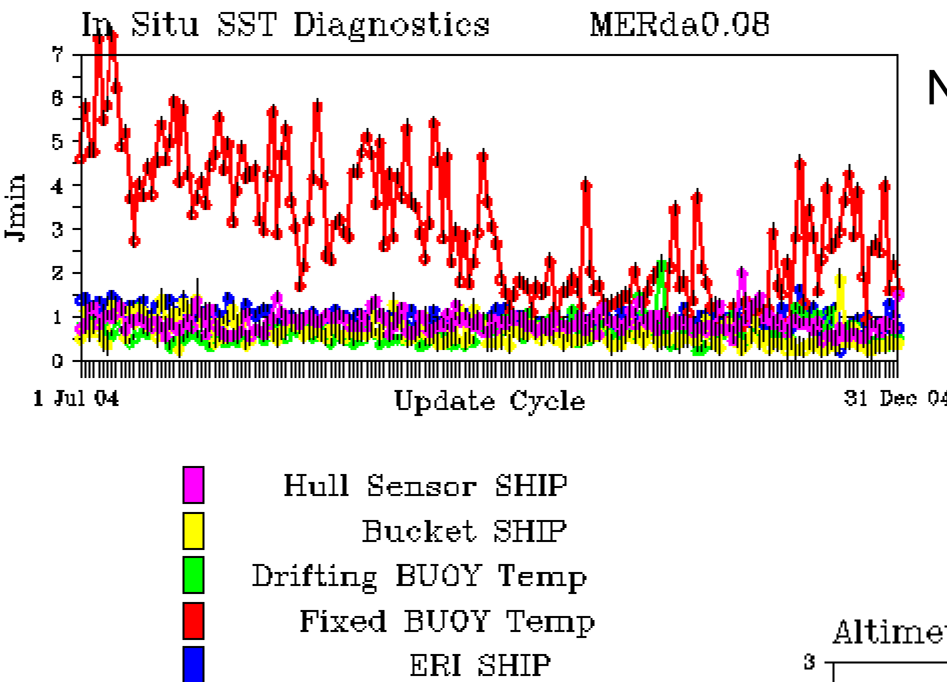
NE Pacific – Jul to Dec 2004



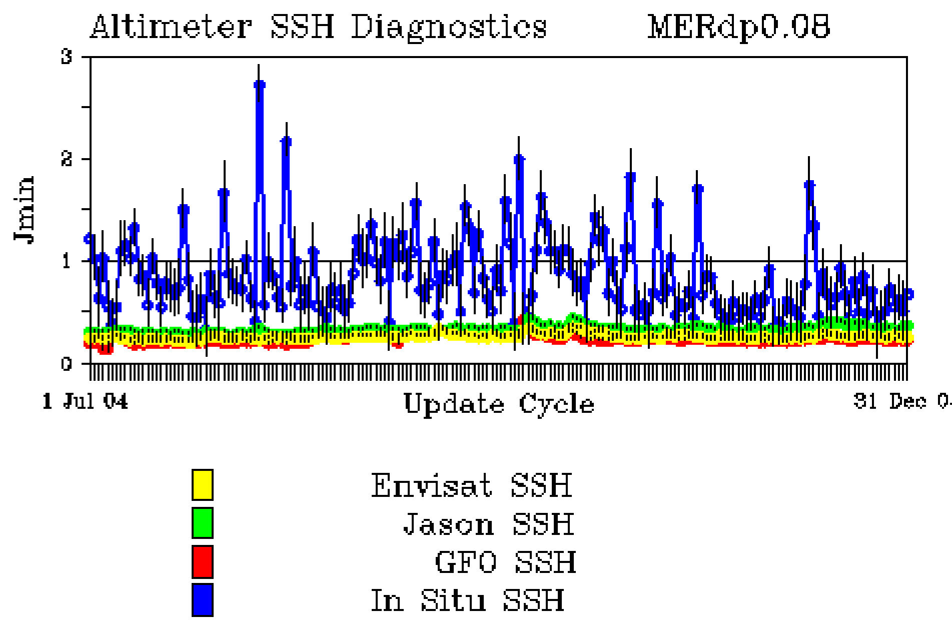
NW Atlantic – Jul to Dec 2004



NW Atlantic – Jul to Dec 2004



NE Pacific – Jul to Dec 2004



Summary Analysis Covariance Consistency

Possible Reasons for Discrepancies – Need for Tuning

SSH (Jmin << 1)

- background errors too large (assuming we know the measurement errors)
- correlated errors – true with the background (data used more than once); spatially correlated error may exist among observations (orbit error, etc)
- neglecting correlated error results in giving altimeter SSH data too large a weight in analysis

Fixed Buoy Observations (Jmin >> 1)

- prescribed observation errors are too small
- fixed buoy preprocessing (averaging hourly reports) creates erroneous data

Large Day-to-Day Fluctuations

- actual error in the forecast background likely to have significant variations
- specified background error covariance may be correct on average, but not in individual situations

Validation of Altimeter Assimilation Methods

Two Approaches in General Use

- Direct Method (Cooper Haines) – forecast model dependent
  - adjusts forecast density profile to be consistent with <u>change</u> in sea surface height from model forecast as measured by the altimeter
  - temperature and salinity adjustments are computed <u>simultaneously</u>, water mass properties on subsurface isopycnals are conserved
- Synthetic BT Method (MODAS) – forecast model independent
  - computes temperature at depth from SSHA using stored regressions of <u>climatological</u> temperature anomalies and dynamic height
  - salinity is computed from the synthetic (or float) temperatures using climatological <u>temperature-salinity</u> relationships

Both methods generate T(z) and S(z) using SSH and SST predictor variables

Altimeter Assimilation Validation Experiment

Compare T(z) and S(z) Profiles from SSH against Argo Profiles

Two Sources SSH predictor - *in situ* (Argo float) and altimeter

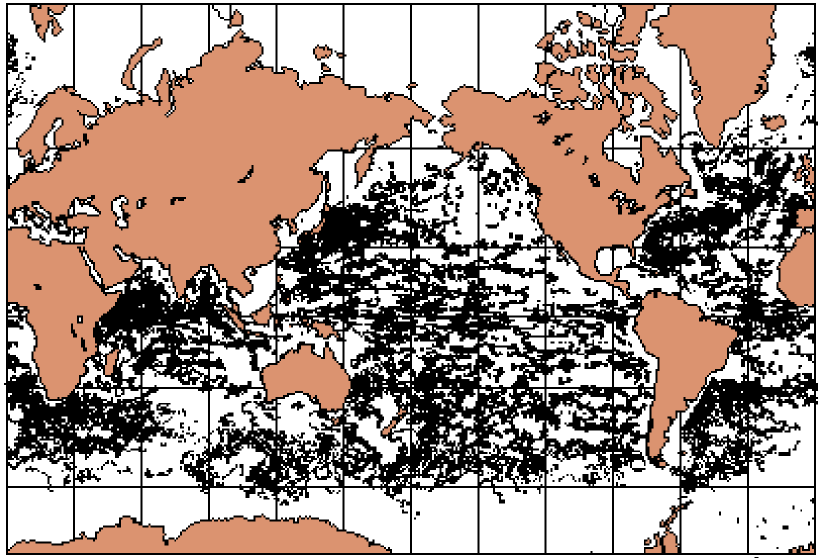
- Direct Method: (1) change of *in situ* SSH from successive float cycles
  (2) altimeter measured change of SSHA from float cycles
- Synthetic BT: (1) observed float SSHA
  (2) altimeter SSHA at float location and sampling time

SST predictor taken from shallowest pressure level of verifying float

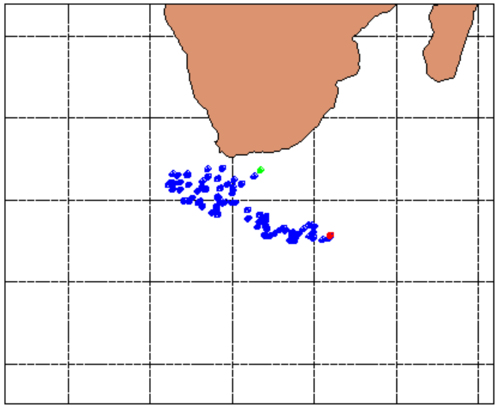
Metrics

1. Do derived TS profiles predict float TS profiles of cycle *N* better than simple persistence forecast of cycle *N* from cycle *N-1*?
2. Are solutions different when Argo *in situ* SSH is used as the predictor variable versus altimeter SSHA?
   - issue of non-steric effects in satellite altimeter observations
   - sensitivity of method to uncertainty in mapped altimeter SSHA data

Argo Float Observations 2003 - 2005



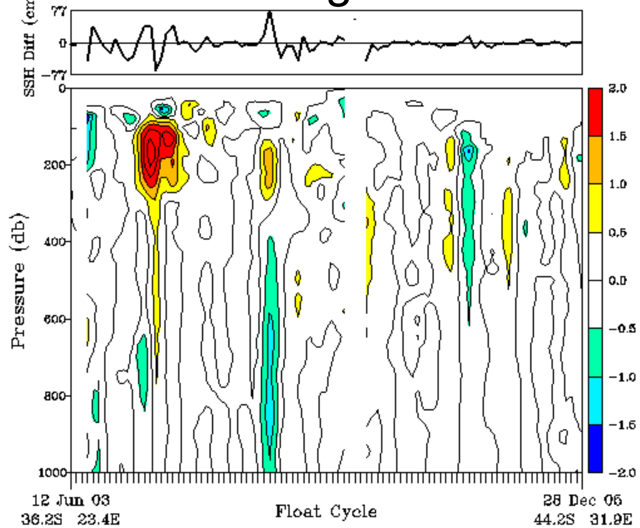
- float cycles retrieved from Monterey Argo GDAC;
  both R-mode and D-mode data used (no GTS DAC data)
- accept observed float pressure level if:
  - ascending profile, cycle number > 0
  - T,S QC code = 1 or 5, pressure QC code = 0 or 1
- inconsistencies found in R-mode QC codes (D-mode data OK)
- result: 2,080 call signs
  72,769 valid profiles (out of 86,338)
  10,636 delayed mode profiles



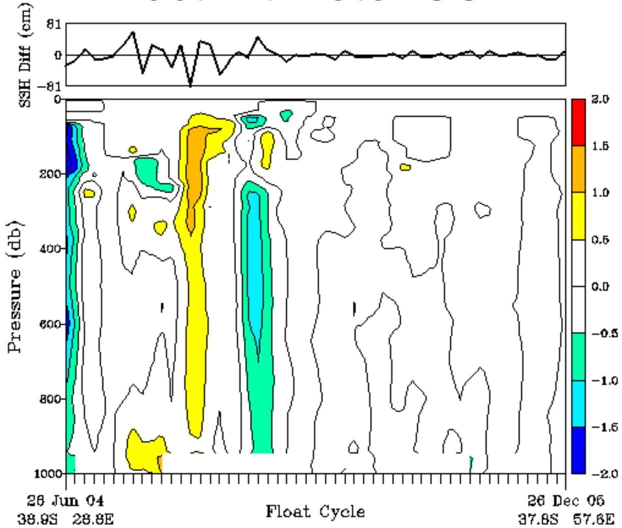
1900221

2 Jun 03 - 28 Dec 05

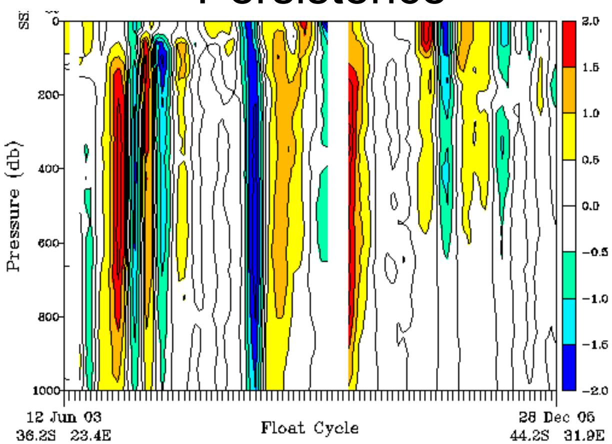
Direct Argo SSH



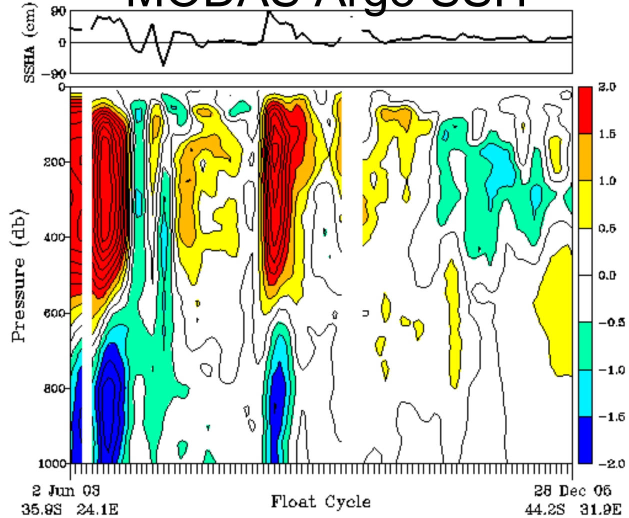
Direct Altimeter SSH



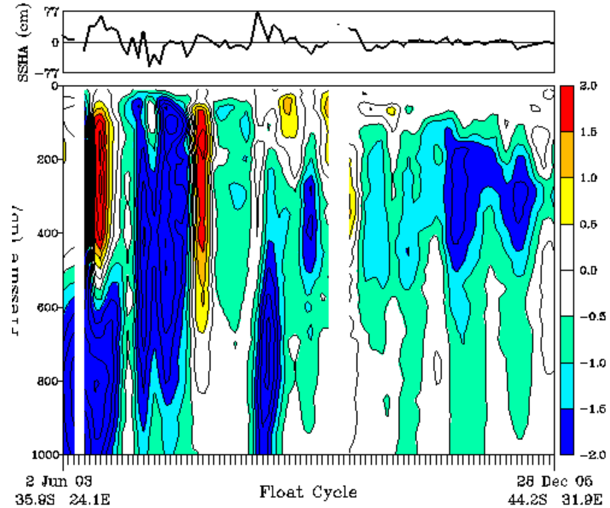
Persistence



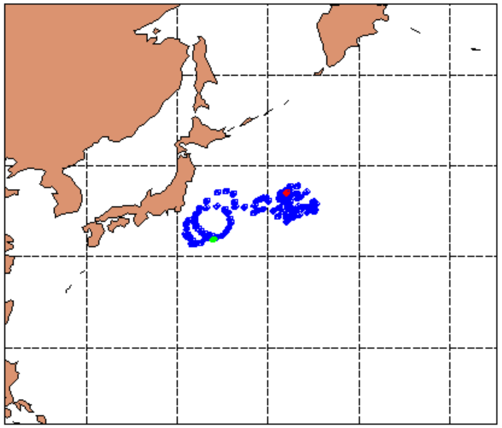
MODAS Argo SSH



MODAS Altimeter SSH



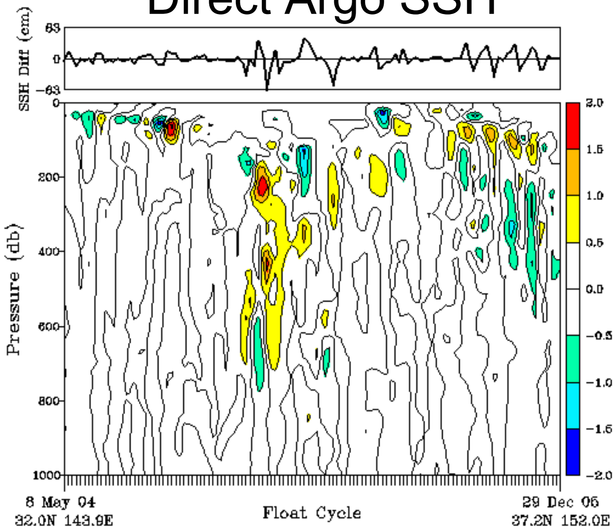
color slicing +/- 2°C



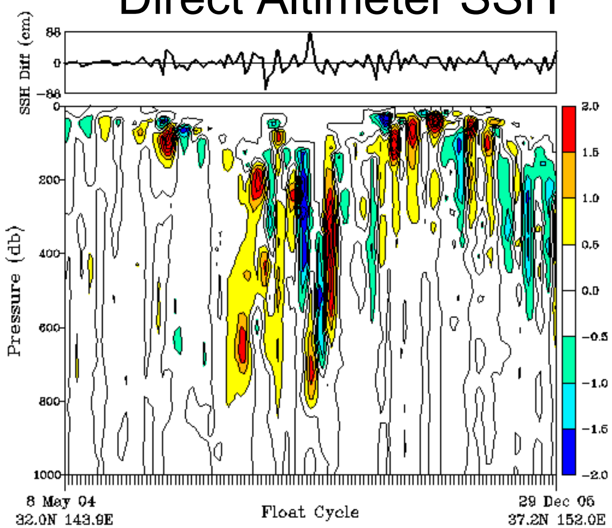
2900139

5 May 04 - 29 Dec 05

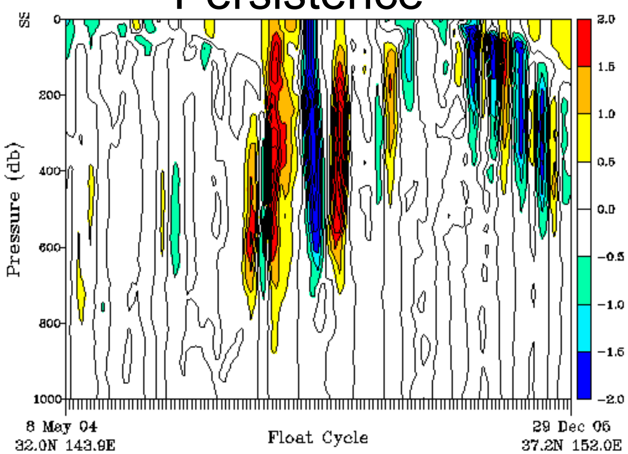
Direct Argo SSH



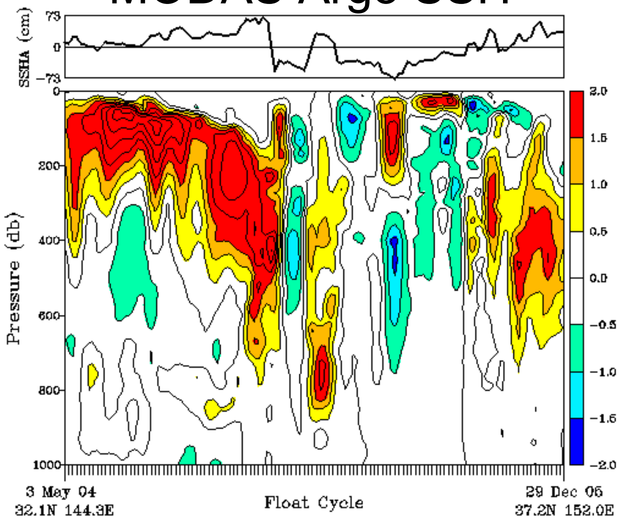
Direct Altimeter SSH



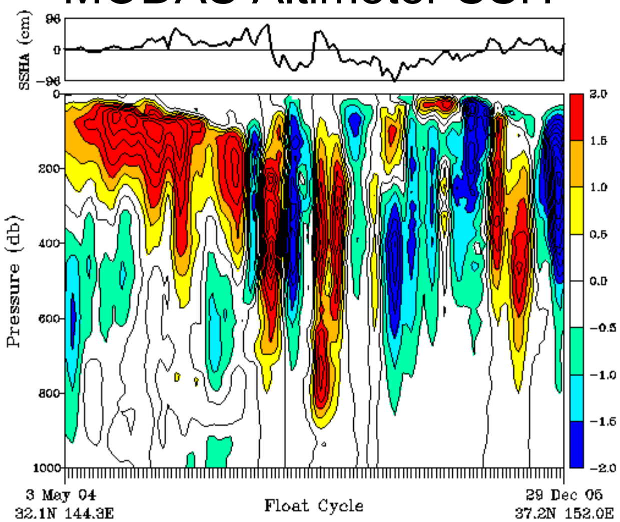
Persistence



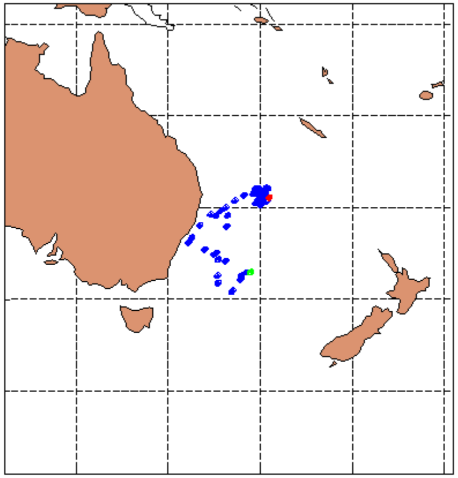
MODAS Argo SSH



MODAS Altimeter SSH



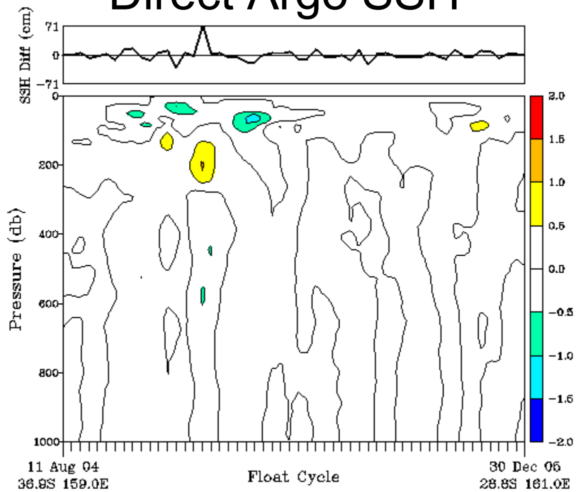
color slicing +/- 2°C



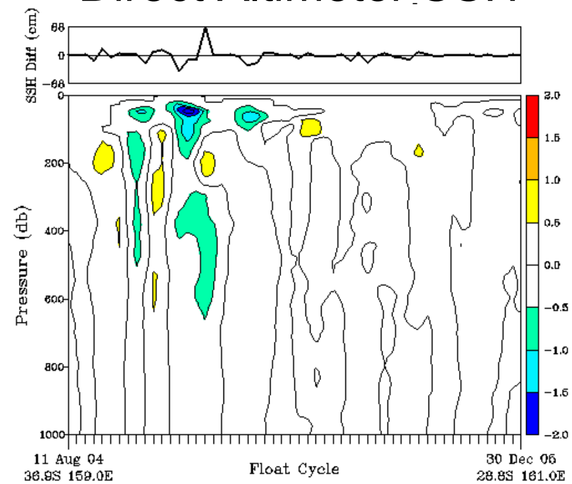
5900602

11 Aug 04 - 30 Dec 05

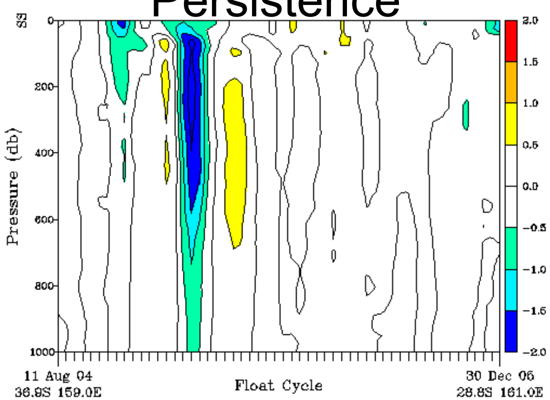
Direct Argo SSH



Direct Altimeter SSH

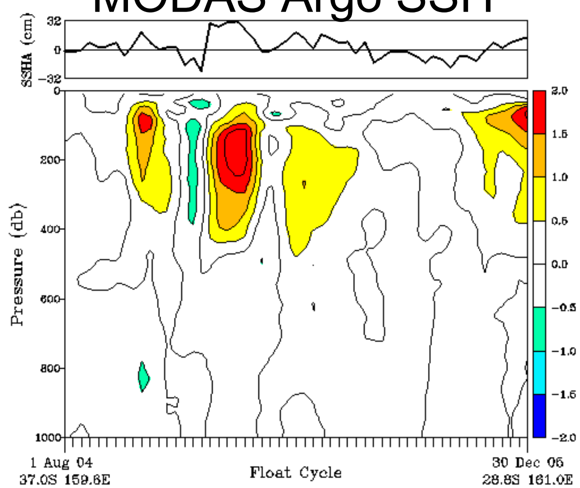


Persistence

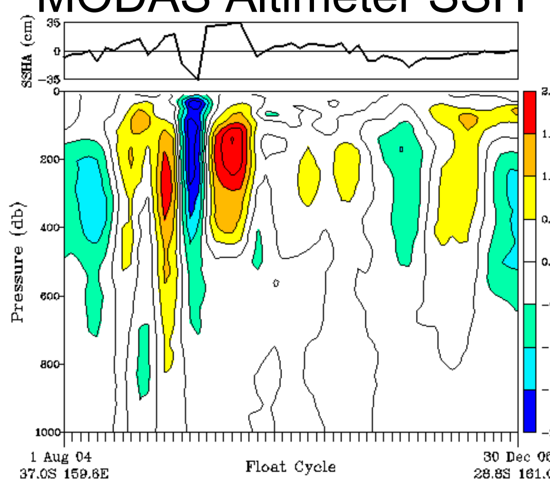


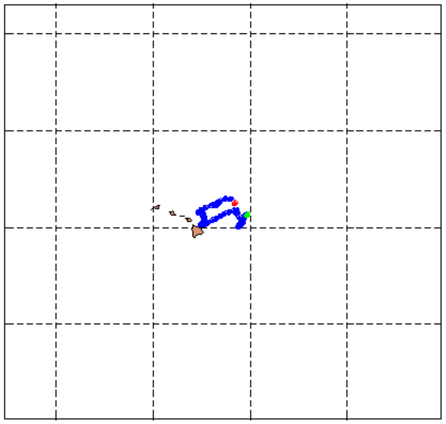
color slicing +/- 2°C

MODAS Argo SSH



MODAS Altimeter SSH

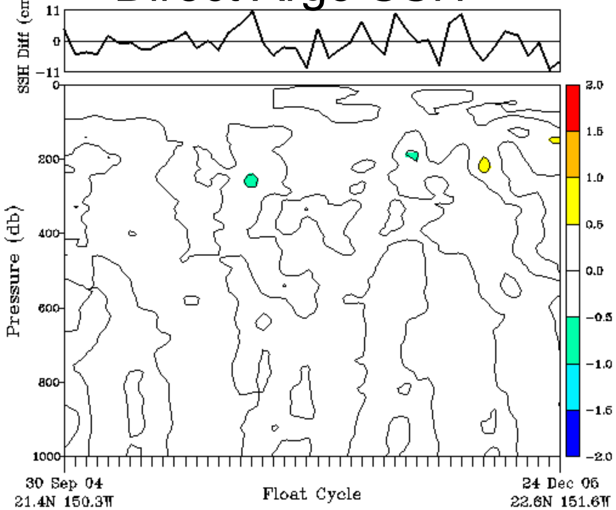




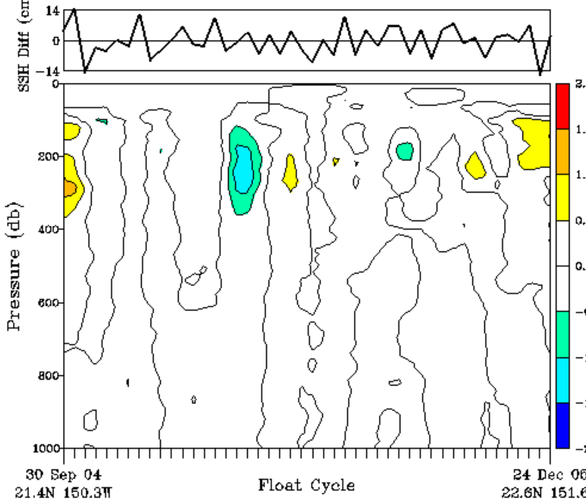
5900648

30 Sep 04 - 24 Dec 05

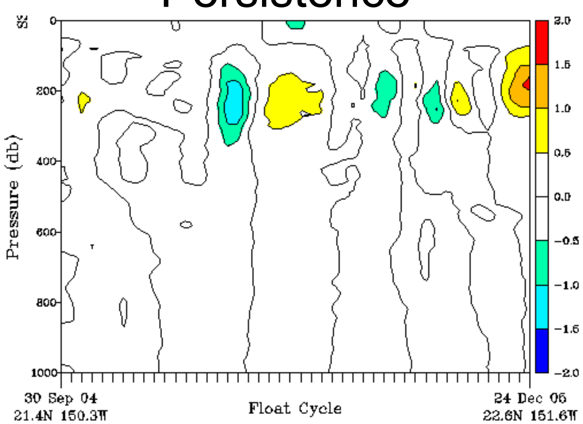
Direct Argo SSH



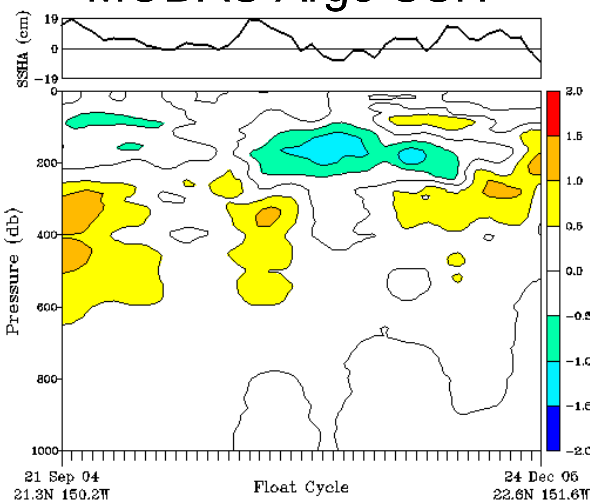
Direct Altimeter SSH



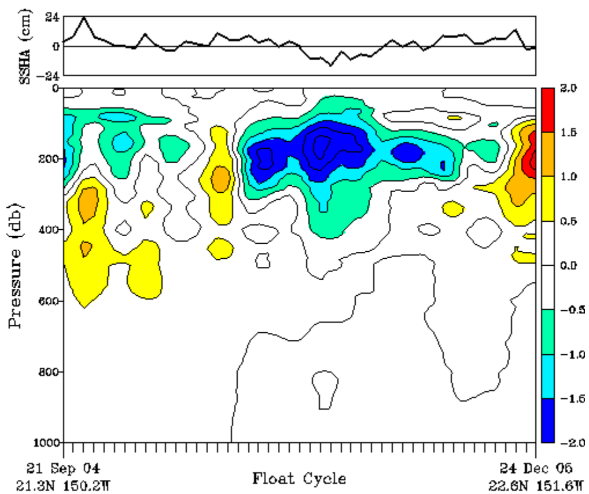
Persistence



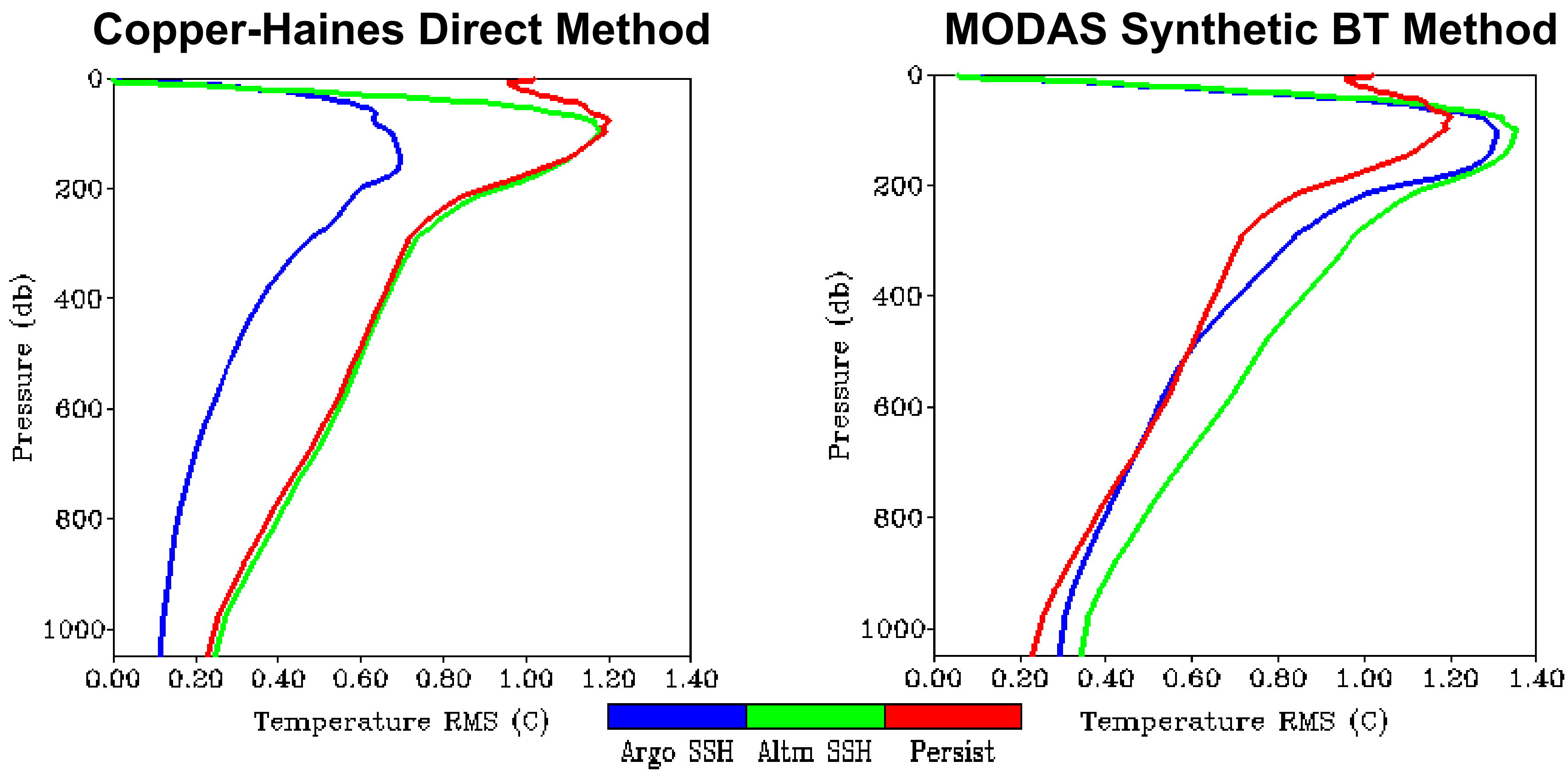
MODAS Argo SSH



MODAS Altimeter SSH



color slicing +/- 2°C



- Skill sensitive to source of SSH predictor variable - best results obtained with true steric height computed from Argo float profiles
- MODAS worst than persistence. Why? - use of a climate basis function (large variance to model), historical profile sampling limitations, salinity affects, etc.
- Direct method errors may be artificially low – previous Argo float represents perfect model forecast - issues of model forecast errors, model drift remain in operational application of the method.

Transition 3D-MVOI to 3D-Var

- funding in place for FY07 – FY09; work is on-going
- ocean 3D-Var based on NAVDAS (Roger Daley's 3D-Var for the atmosphere)
- advantages of 3D-Var are numerous
    - global solve – no more overlapping volumes (should run faster as a result)
    - greater flexibility for assimilating different observation data types
    - general framework for using more sophisticated background-error covariance models
- phased implementation approach planned
    - year 1: replace MVOI solver with 3D-Var solver (pre/post processing same)
    - year 2: relax horizontal and vertical gird restrictions, allow for non-separable vertical and horizontal correlations
    - year 3: incorporate new multivariate balance operators based on Anthony Weaver's work

END