SST Jan-Dec 2001

Current GODAS

¼° MOM6-3DVar

Upgrading CPC operational ocean Monitoring to use Hybrid-GODAS

Steve Penny (NCEP/UMD)

Yan Xue (NCEP-CPC)

James Carton (UMD)

Dave Behringer (NCEP-EMC)

Travis Sluka (NCEP-CPC /UMD)

CURRENT GODAS

(**G**lobal **O**cean **D**ata **A**ssimilation **S**ystem)

Used operationally at NCEP for CFS (0.5˚ MOM4) and **ocean monitoring at CPC** (1˚ MOM3)

- 1x1 degree GFDL MOM3 ocean model forced by R2 fluxes
- Model space 3DVar following Derber and Rosati (1989), diffusion operator for hz bg err covariance
- Assimilates insitu T profiles, with synthetic salinity calculated from climatological relationships
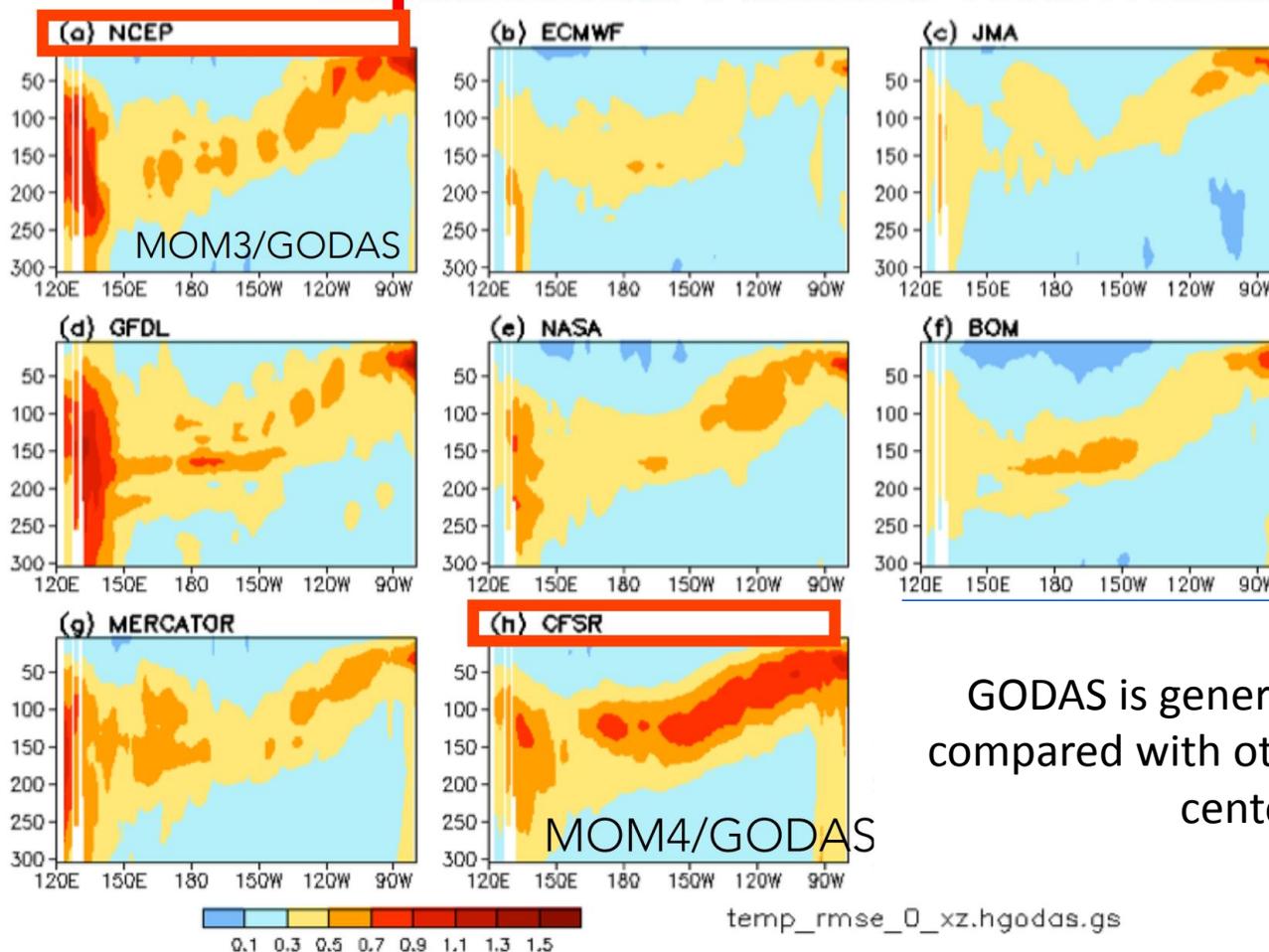
Shortfalls compared with other current operational centers

- No sea ice model
- 1 degree resolution (vs ½ or ¼)
- Univariate bkg err T/S covariance
- Does not assimilate Argo salinity, altimetry

GODAS Temperature Anomaly (0°N), 2017 May 03

unit: °C
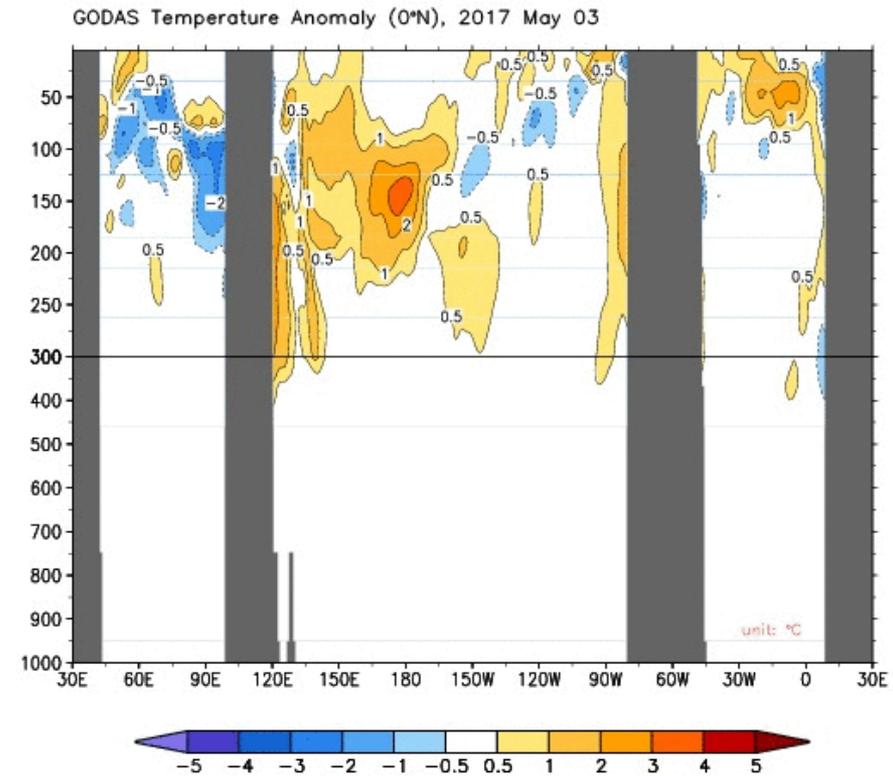
# CURRENT GODAS COMPARISON

Equatorial Pacific Thermocline

MOM3/GODAS

MOM4/GODAS

RMSD of anomaly correlations versus ensemble mean

GODAS is generally an outlier compared with other operational centers

temp_rmse_0_xz.hgodas.gs

HYBRID GODAS

Main objective is to transition a 3DVar/EnKF "Hybrid-GODAS" to operational level.

A Hybrid-GODAS demonstration project (Penny, 2015) with the ½ degree MOM4p1 configuration used by CFSR showed marked improvement in T/S RMSD and bias, as well as currents with a hybrid 3DVar/EnKF
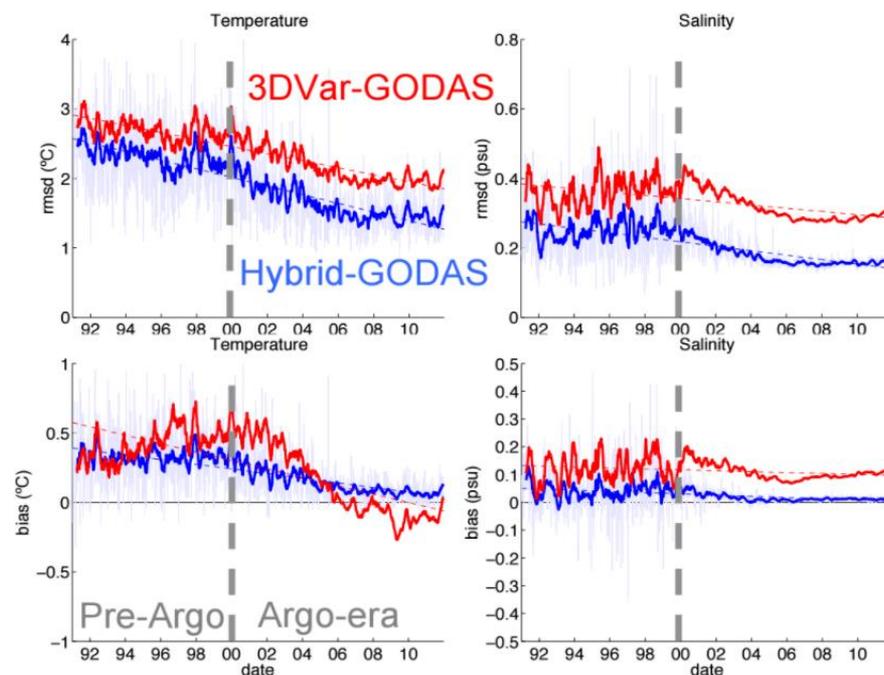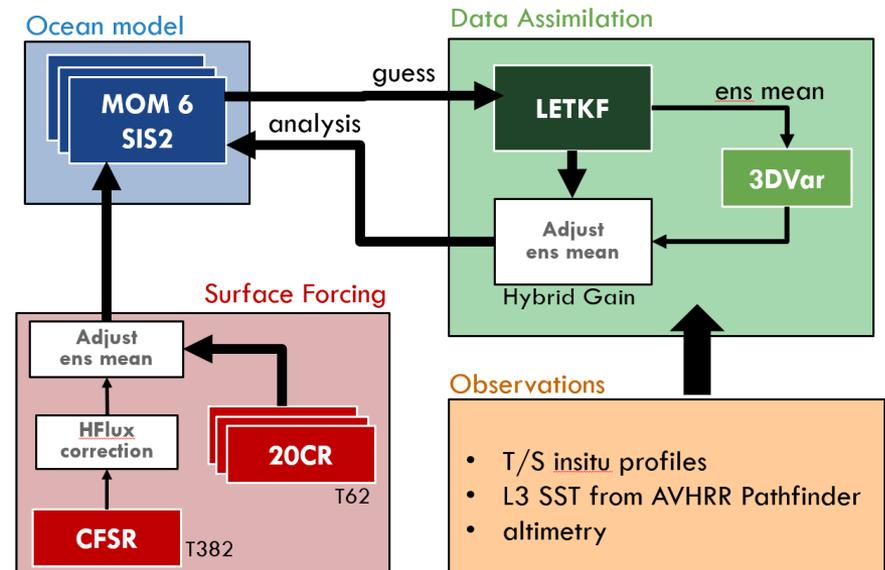
Penny et al, 2015

GODAS UPGRADE OVERVIEW

Deliverables:

- transition of Hybrid-GODAS demonstration to an operational system for CPC ocean monitoring

- argo era (2000-2014), and 1979- present reanalysis

System upgrades:

examination and upgrade of all components of GODAS system:

- **ocean model** - higher resolution, latest MOM6 model

- **surface forcing** – CFSR fluxes with shortwave and net heat flux corrections

- **data assimilation** - (3dvar -> hybrid gain)

- **observations** - expanded observation set (direct assim of SST, altimetry, insitu T/S)

Ocean model

MOM 6
SIS2

guess

Data Assimilation

LETKF

ens mean

3DVar

analysis

Adjust
ens mean

Hybrid Gain

Surface Forcing

Adjust
ens mean

HFlux
correction

20CR

T62

CFSR   T382

Observations

- T/S insitu profiles
- L3 SST from AVHRR Pathfinder
- altimetry

MOM6 OCEAN MODEL

Ocean model

MOM 6
SIS2

Major upgrade of ocean model to MOM6 / SIS2
(sea ice simulator)
(vs MOM3/4 and no ice model)

Arbitrary Lagrangian Eulearian Method (ALE) allows for
any vertical coordinate and no vertical CFL limit on
timestep / resolution

75 vertical levels z*, with option of hybrid vertical
coordinates, 2m resolution at surface
(vs 40 lvl, 10m at surface)

¼ degree, eddy permitting, same configuration
used by GFDL for CMIP6 runs
(vs 1 or ½ degree)

Much work has gone into MOM6 to
improve parameterizations and reduce
model bias

ρ coords.

σ coords.

z coords.
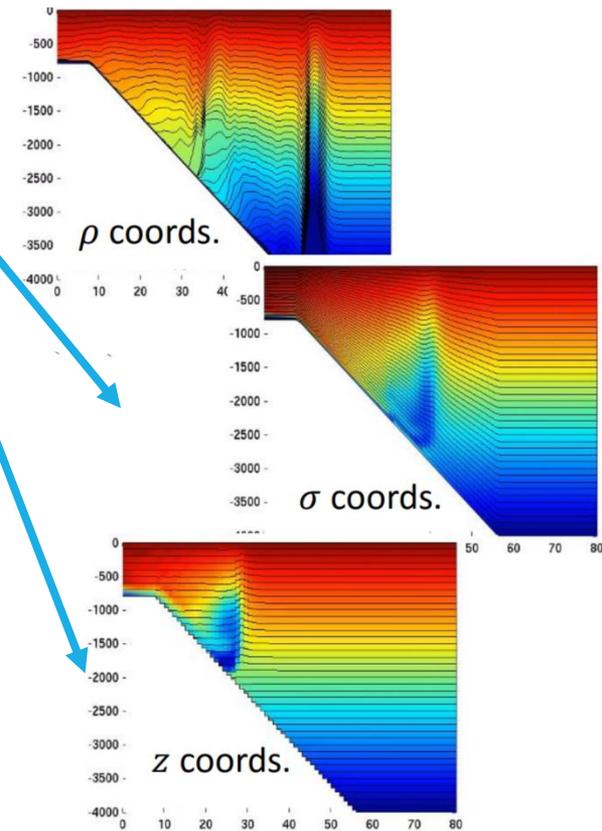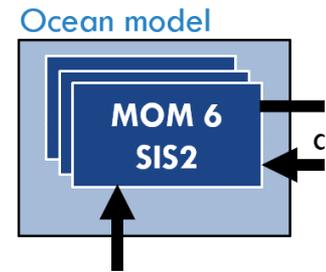
SURFACE FLUXES

Bulk flux parameterization using **CFSR** (T382) daily surface fields (DSW, DLW, 2m T/q, 10m U/V, Ps)

Ensemble perturbations are obtained from the 56 member 20th Century Reanalysis, **20CR** (T62)

Special attention is given to downward shortwave (DSW) and net heat flux given 1) the model's thin surface levels and 2) no relaxation to analyzed SST product
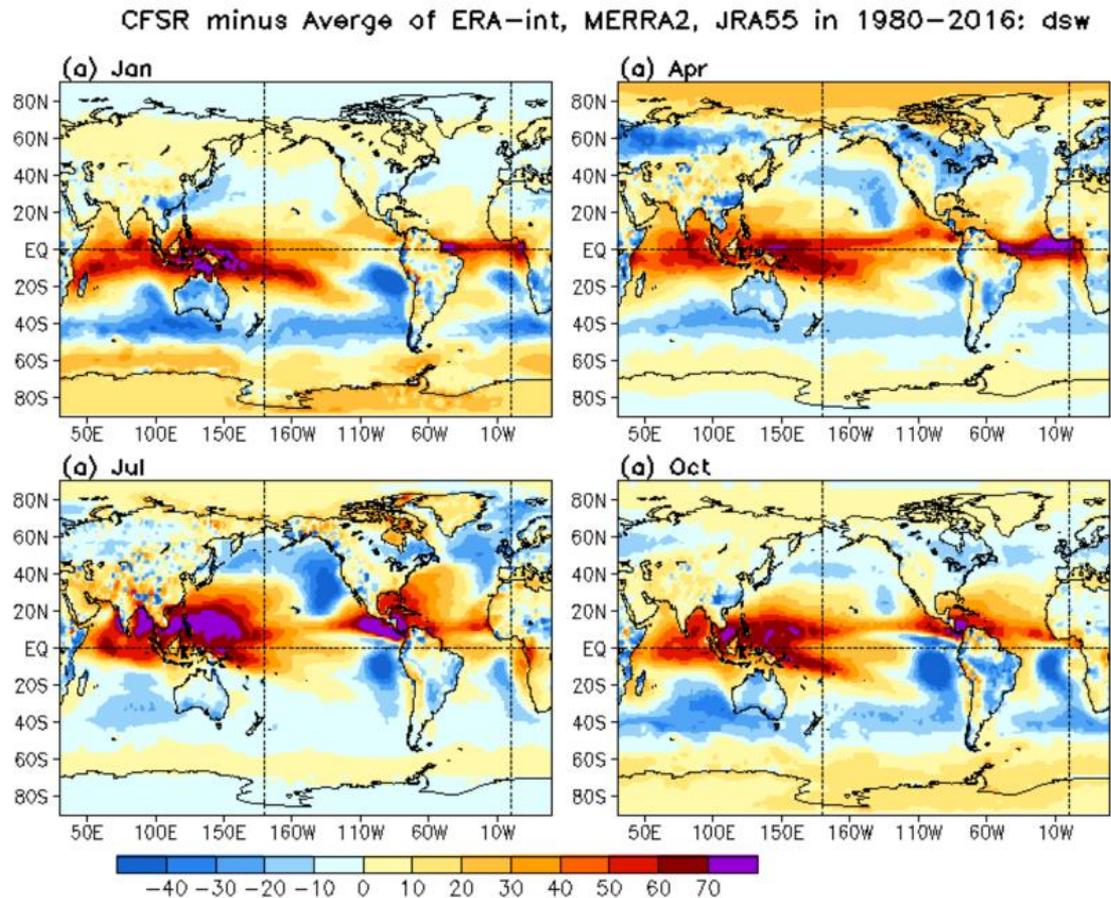

Fluxes corrected by:

1. replacing CFSR DSW climatology with CORE

2. heat flux correction based on analysis increment bias (Carton)
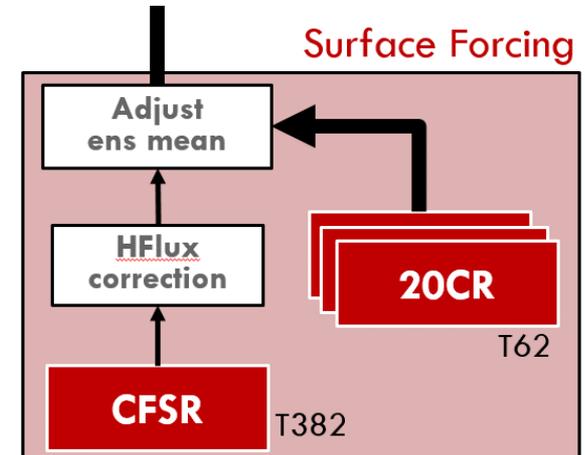
CFSR DSW BIAS

Large biases in CFSR
shortwave radiation
compared to other
products
(up to 70 W/m² in tropics)

We replace CFSR's DSW
climatology with DSW
climatology from NCAR
CORE

CFSR minus Averge of ERA-int, MERRA2, JRA55 in 1980-2016: dsw

NET HEAT FLUX CORRECTION

Fluxes from various reanalysis product vary greatly:

A climatological net het flux correction algorithm used for SODA uses **analysis increment bias** from a data assimilation run to calculate a **climatological heat flux adjustment**

Results in significantly reduced background error bias, data assimilation system doesn't have to work as hard **(very important to the EnKF)**

Temperature AI over mixed layer

Native Fluxes   **Corrected Fluxes**
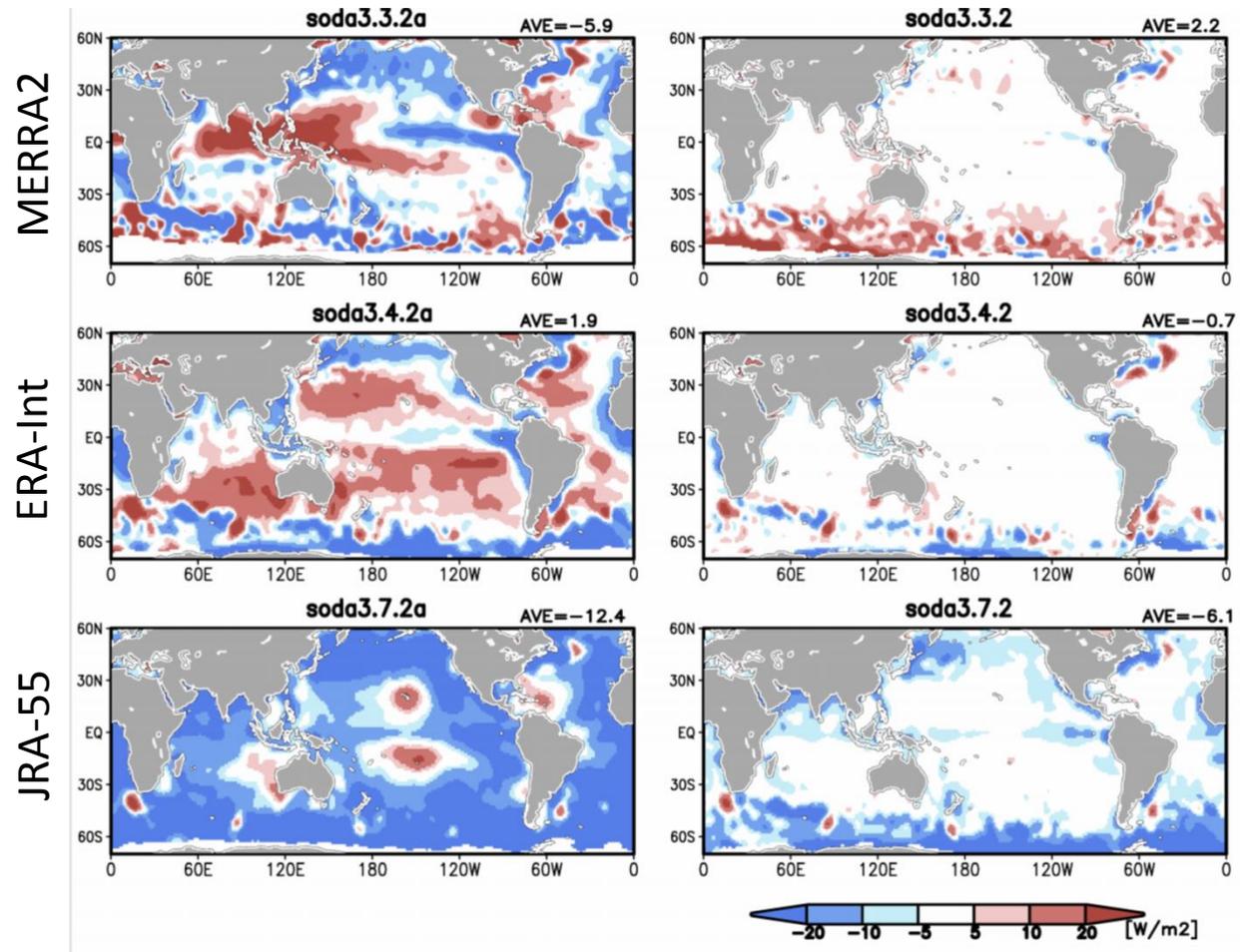
MODEL FREE RUN PERFORMANCE

T RMSD compared to EN4

- MOM6 free run with DSW correction is superior to that without DSW correction

- MOM6 free run with DSW correction also outperforms SODA 3.3.0 (MOM5 with MERRA2 forcing) free run

- ¼° MOM6 simulates the deep ocean T/S structure much better than ½° MOM4 and ¼° MOM5
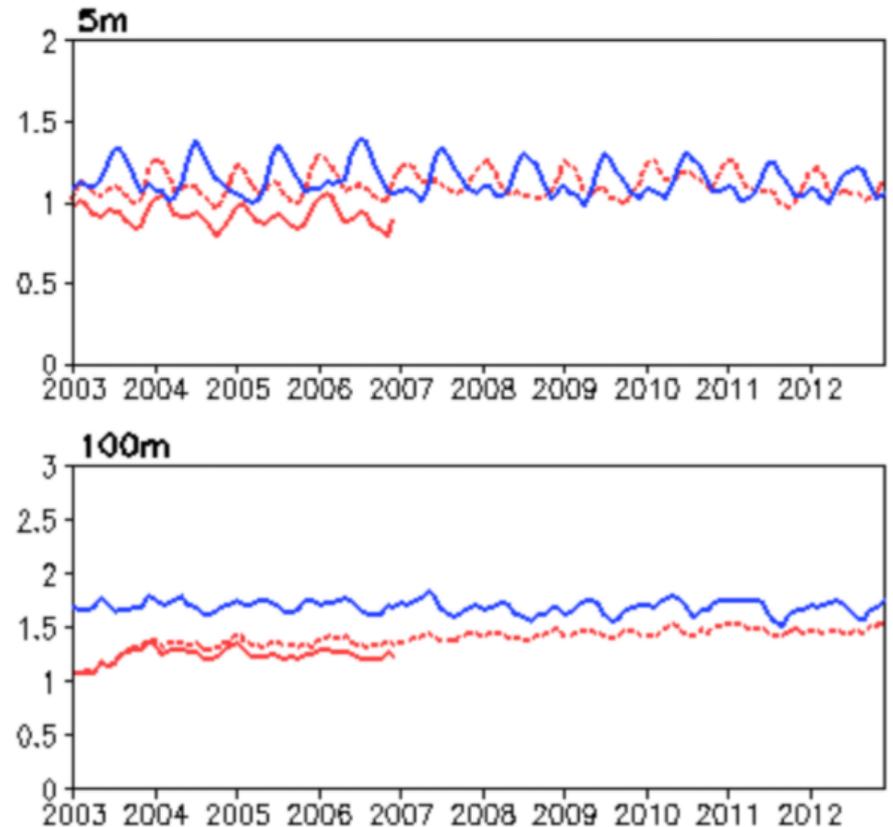
MOM5/MERRA2   **MOM6/CFSR**   corrected **(-----)**
uncorrected **(- - -)**

HYBRID GAIN DA SYSTEM

Hybrid Gain combining EnKF and 3DVar

LETKF
(local ensemble transform Kalman filter)

Dynamic estimation of **multivariate** background error covariance via an ensemble

Ocean-LETKF already used and tested within NCEP/ NRL / NASA

Observation space 3DVar

Helps with model biases that EnKF is unable to correct

Data Assimilation

Hybrid Gain

guess → LETKF → ens mean → 3DVar → Adjust ens mean → analysis
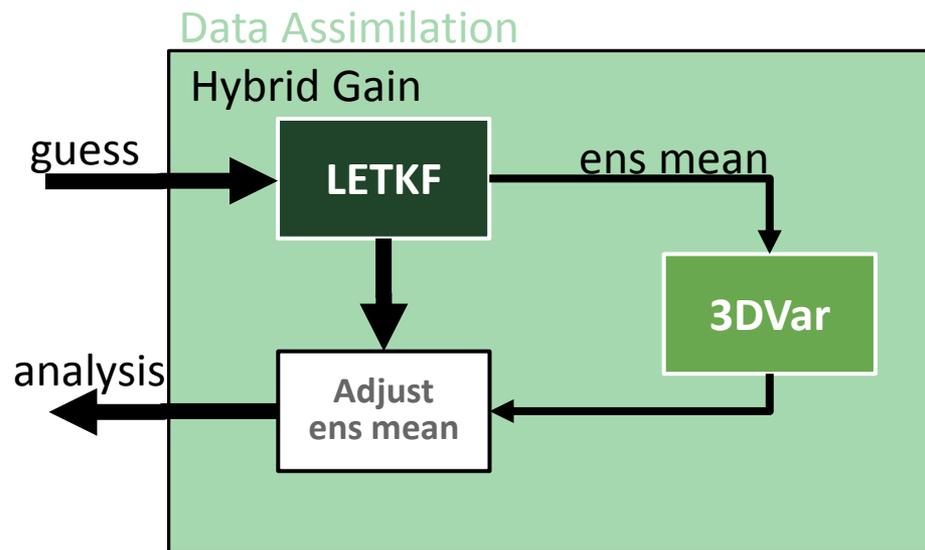
* Most work of past several months focused on 3DVar upgrade

OBSERVATION SPACE 3DVAR

Current GODAS 3DVar

- model space 3dvar

$$\left[\mathbf{B}^{-1} + \mathbf{H}^T\mathbf{R}^{-1}\mathbf{H}\right]\delta\mathbf{x} = \mathbf{H}^T\mathbf{R}^{-1}\delta\mathbf{y}$$

- **univariate** T/S bg err covariance
- does not scale well computationally

Upgraded 3DVar

- observation space 3dvar

$$\left[\mathbf{HBH}^T + \mathbf{R}\right]\mathbf{z} = \delta\mathbf{y}$$
$$\delta\mathbf{x} = \mathbf{BH}^T\mathbf{z}$$

- Solver highly influenced by Navy's NCODA
- much faster given sparsity of ocean obs
- Allows for computationally more expensive bg err covariance

Phase 1, univariate T/S bg err covariance

Phase 2, multivariate (T/S/SSH/U/V) bg err cov via static ensemble from leading modes of prior LETKF reanalysis members

UPGRADED 3DVAR – PHASE 1

As with NCODA, vertical correlation distance dynamically determined from **vertical density gradient** of background.

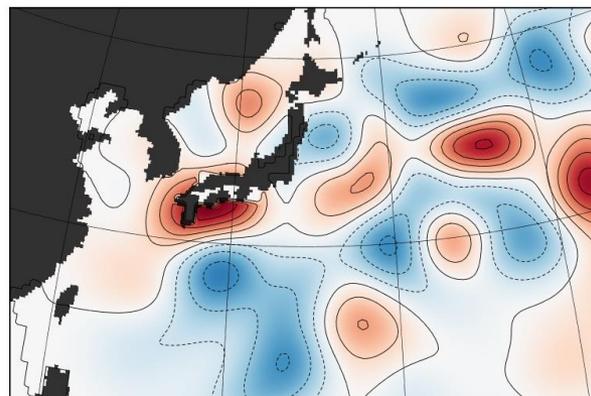- Allows surface obs to impact entire mixed layer

Horizontal correlations contain a dynamic component from **SSH/SST gradient tensor**

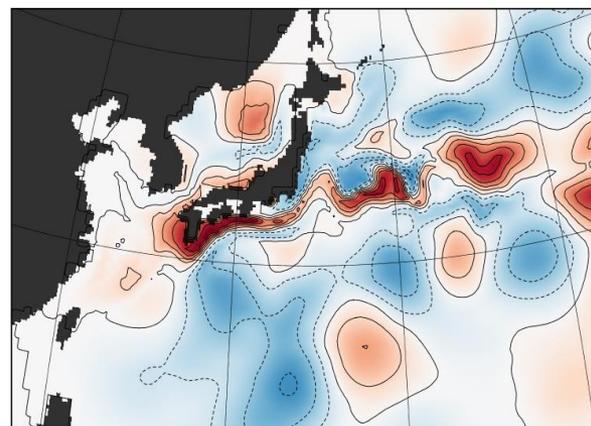- better performance at boundary currents

Observations kept at observed locations

- QC can keep more observations (current GODAS has to remove all single level observations)

Temperature analysis increment (5m)

Standard isotropic hz correlations

With SSH gradient tensor

UPGRADED 3DVAR – PHASE 2

Univariate covariance model replaced with **multivariate covariance** model

Leading modes of EOF decomposition from a previous LETKF run
(using Randomized SVD method Following Halko et al. (2011) for PCA of large datasets)

Provides full model state correlations (T/S/SSH/U/V), and a straightforward approach for assimilating altimetry

Example leading modes from 1 month of calculations (still being processed... final modes will be from 21 years of data)
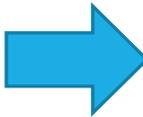
- Warm western Indian ocean
- Cold/salty eastern Indian ocean
- Warm western Pacific
- Cold upwelling eastern Pacific
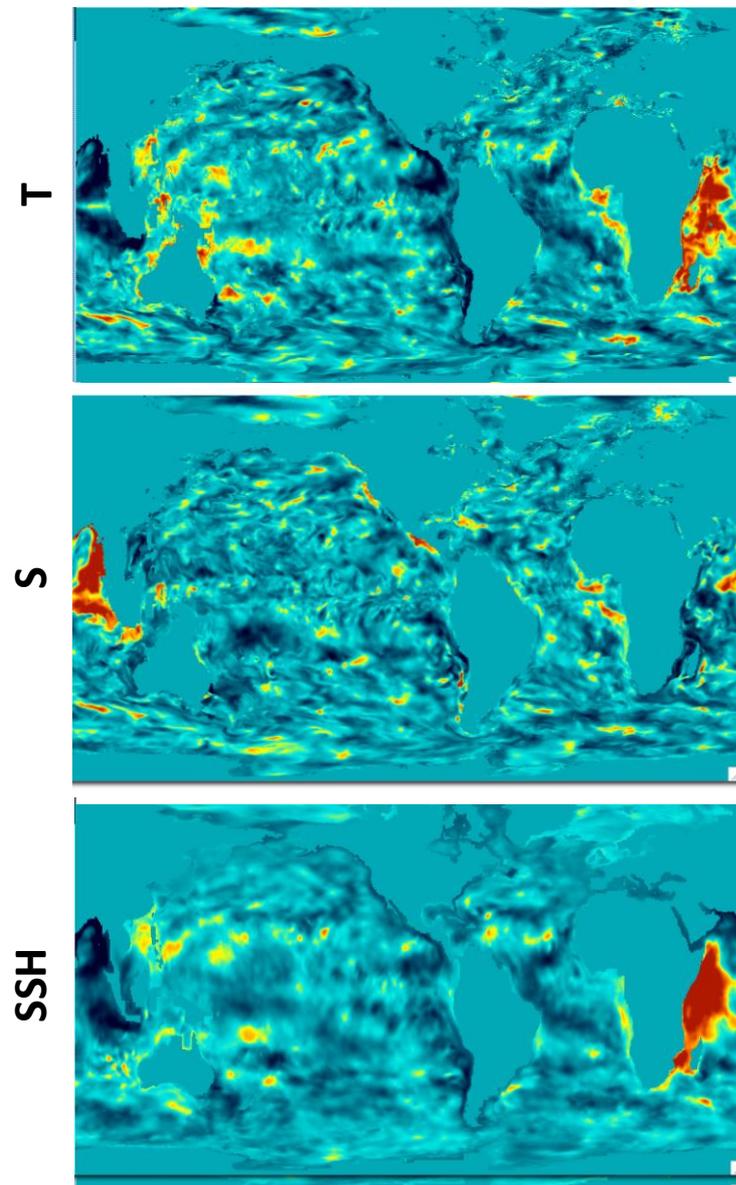
INITIAL 3DVAR- PHASE 1 RESULTS

Phase1of 3DVar development should have results **comparable** with current GODAS
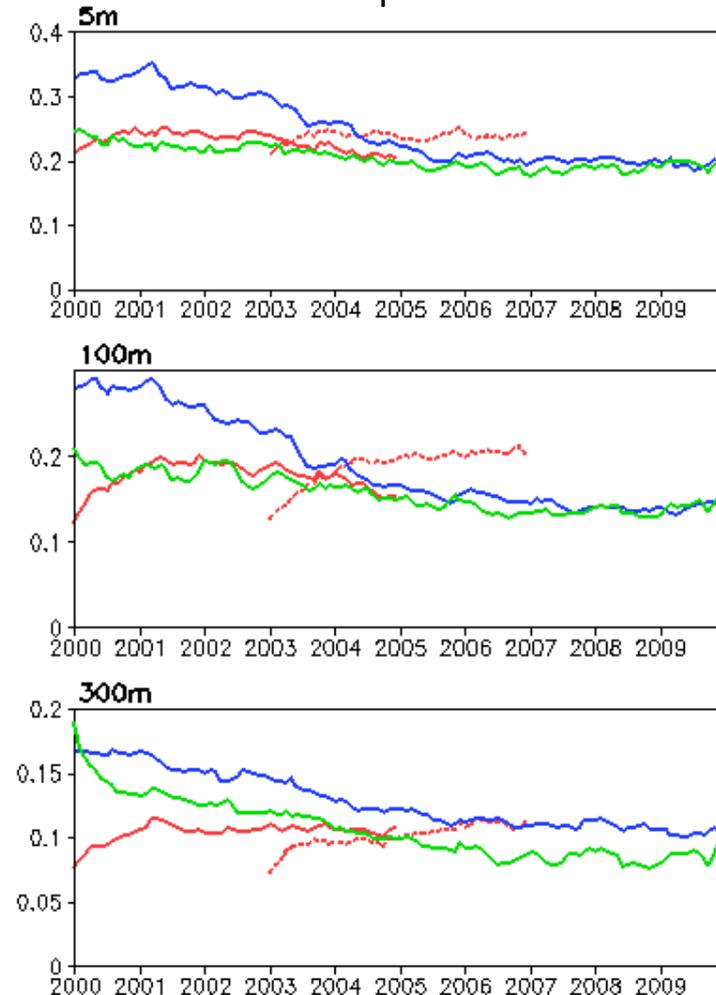
First run of the new 3DVar is encouraging given system has not been tuned yet.
(Underperforming at depths likely due to a vt loc distance bug to be fixed next)

Greater improvements will be achieved when combining with LETKF for **hybrid** system reanalysis, and with 3dvar phase 2 upgrade utilizing **multivariate** covariance and altimetry obs
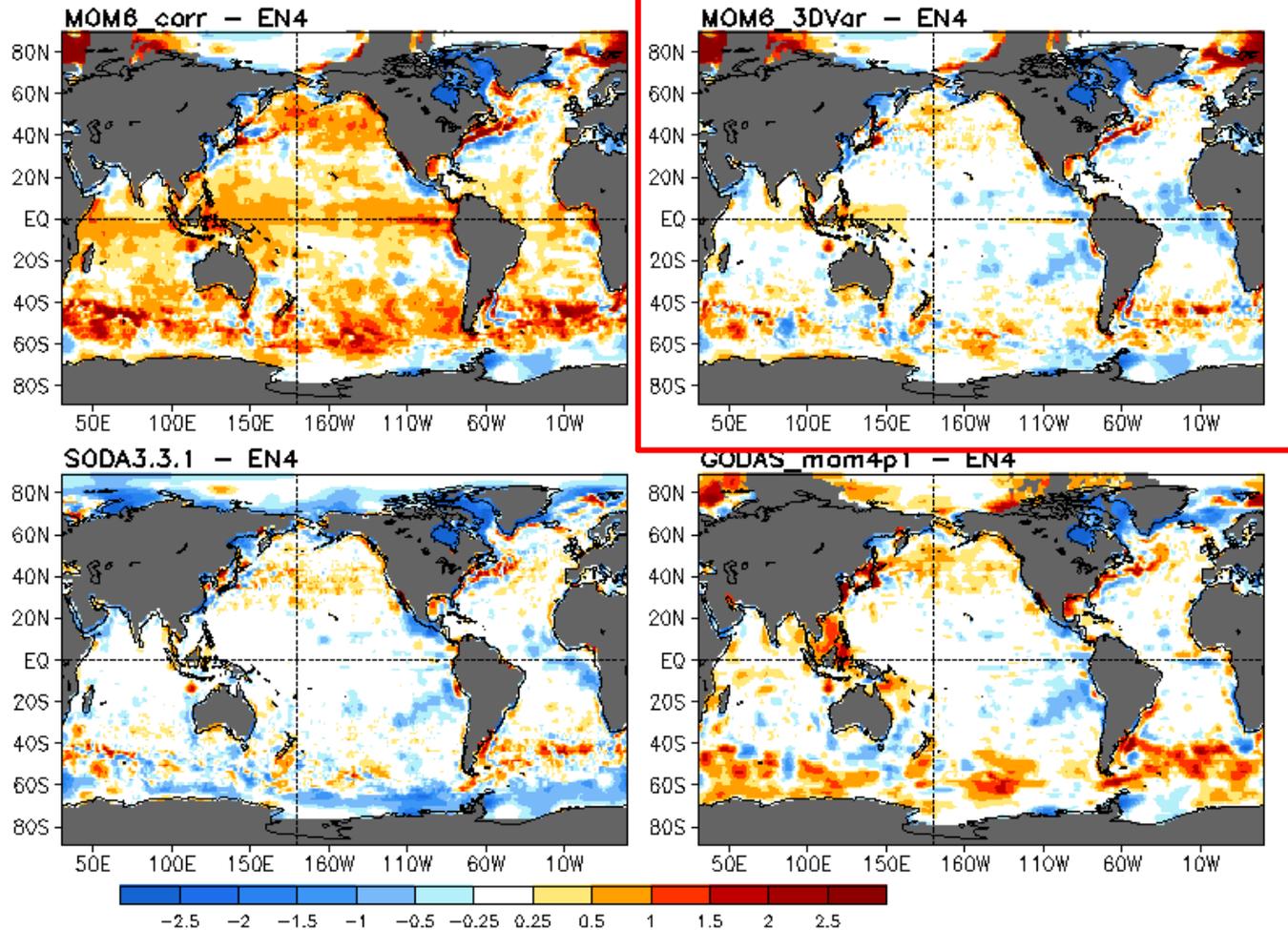
S RMSD compared with EN4

MOM6 3DVar (Free run dashed)
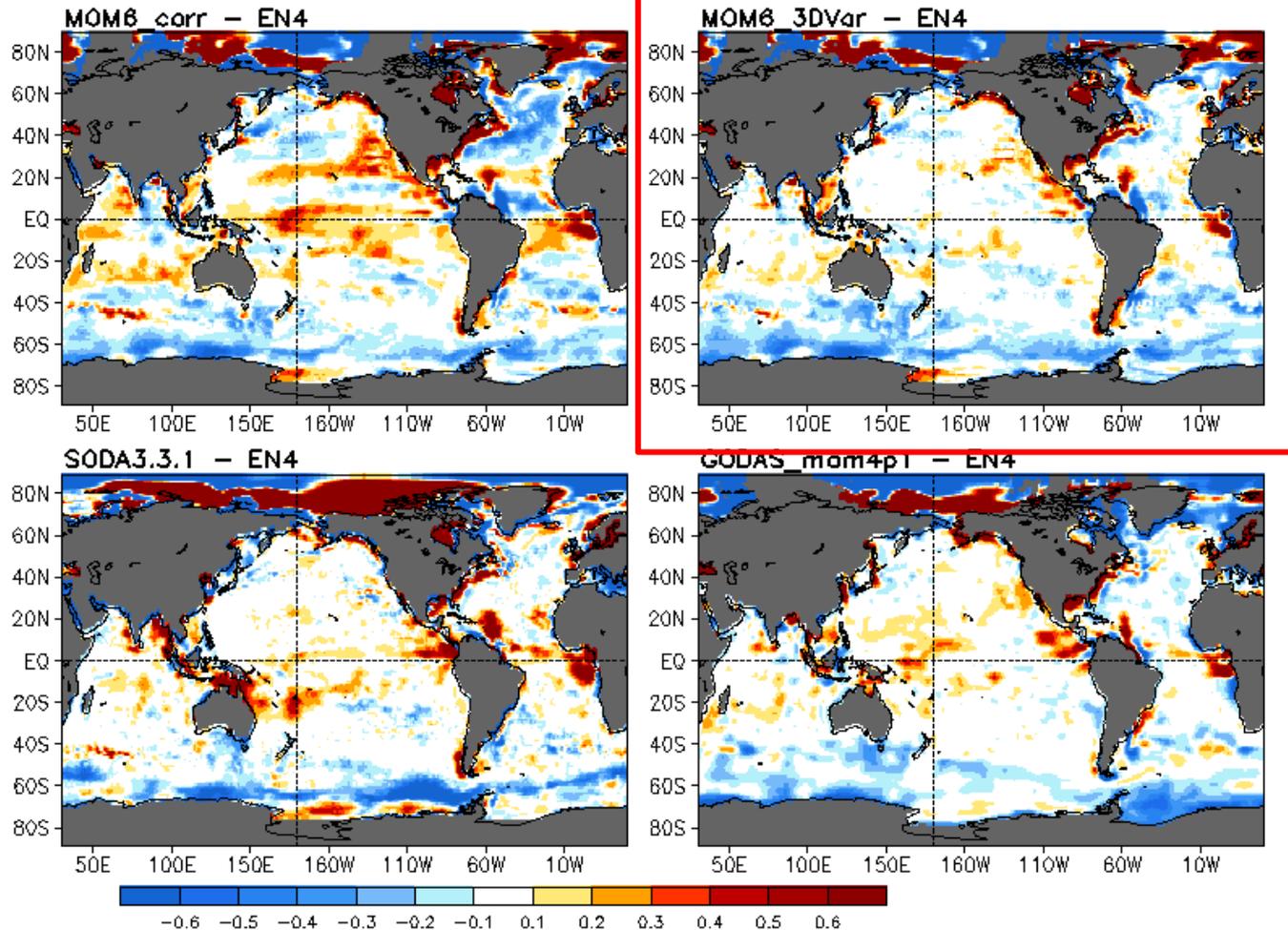**SODA 3.3.1   GODAS MOM4p1**

INITIAL 3DVAR- PHASE 1 RESULTS

Temp at 5m averaged in jan2004-dec2004 (C)

INITIAL 3DVAR- PHASE 1 RESULTS

Salt at 5m averaged in jan2004-dec2004 (PSU)

HYBRID-GODAS PROJECT STATUS

0. MOM6/Flux verification

Still being analyzed, but positive results

1. Observation space 3DVar (argo era, 2000-2014)
    Observations: T/S profiles, AVHRR night time SST
    Univariate T/S covariances

Currently Running

2. Hybrid-GODAS reanalysis (argo era)
    Observations: T/S profiles, SST, altimetry (LETKF only)
    Up to 56 member ensemble
    Forcing from 20CR recentered on CFSR

3. Upgraded 3DVar reanalysis (1979-present)
    Multivariate covariance derived from hybrid reanalysis
    Heat flux correction based on analysis increment bias in previous run