A Review of CLIVAR GSOP and GODAE OceanView Ocean Reanalysis Intercomparison Project (ORA-IP)

Yan Xue and Xiaosong Yang

US CLIVAR Summit, August 4-6, 2015, Tucson, AZ

Overview

- **Ocean Reanalysis Intercomparison project (ORA-IP)** - Led by Magdalena Balmaseda
  - Organized by CLIVAR GSOP and GODAE OceanView
  - Initiated in 2011 after GODAE OceanView/CLIVAR GSOP workshop in Santa Cruz
  - Followed by workshop in 2012 in WHOI and in 2013 in ECMWF
  - A special issue of Climate Dynamics to be published in 2015
- **Real-Time Ocean Reanalysis Intercomparison Project (RT ORA-IP)** - Led by Yan Xue
  - Initiated in early 2014 after the TPOS 2020 Workshop in Scripps
  - Set up an experimental web site in summer 2014
- **EU COST project: Evaluating Ocean Syntheses (EOS) in 2015-2018**

ORA-IP Objectives

- **To estimate signal by ensemble mean and noise by ensemble spread**
- **To gain insight into the ocean variability and trends using an ensemble mean approach**
- **To measure progresses and identify deficiencies in ORA products**
- **To exploit ensemble ORA products**
  - For climate indicators
  - For model validation
  - For real-time monitoring
  - For initialization of coupled models

Courtesy of Magdalena Balmaseda

ORA-IP Products

- 6 Observation only
- 13 Low resolution
- 8 High resolution
- 4 Coupled DA
- 6 Long reanalyses, starting 1950's

Summary Paper:

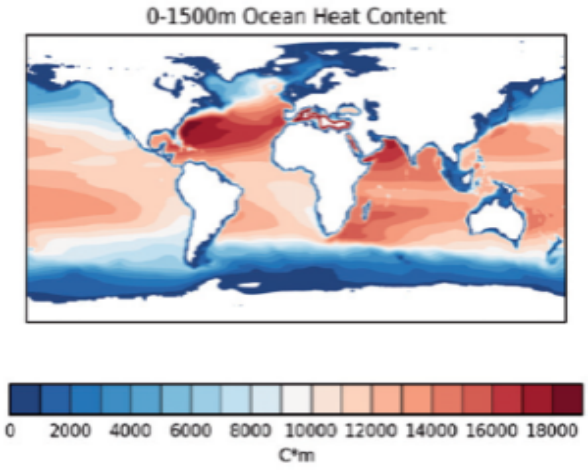
Balmaseda, M.A. et al., The Ocean Reanalysis Intercomparison project (ORA-IP) J.Op.Oceanogr. Volume 8, supplement 1, 9 June 2015

Product	Institution	Configuration	Control Method	Reference
1. ARMOR3D* (1993-2010)	CLS	1/3° no model	Optimal interpolation (T/S/SST)	Guinehut et al (2012), Mulet et al (2012)
2. CFSR (1980-2011)	NOAA NCEP	1/2° MOM4 coupled	3DVAR (T)	Saha et al (2010) Xue et al (2011)
3. CGLORS (1991-2011)	CMCC/INGV	1/2° NEMO3.2	3DVAR (SLA/T/SST/Ice)	Storto et al (2011)
4. ECCOJPL (1993-2011)	JPL/NASA	1° MITgcm	KF-KS (SLA/T)	Fukumori et al (2002)
5. ECDA (1993-2011)	GFDL/NOAA	1/3° MOM4 coupled	EnKF (T/S/SST)	Zhang et al (2007), Chang et al (2013)
6. EN3* (1950-2011)	UK Met Office	1° no model	Optimal interpolation (T/S)	Ingleby and Huddleston (2007)
7. GECCO2 (1948-2012)	University of Hamburg	1×1/3° MITgcm	4DVAR (SLA/SSH/T/S/SST)	
8. GLORYS2V1 (1993-2009)	Mercator Océan	1/4° NEMO3.1	SEEK (SLA/T/S/SST)	Ferry et al (2012)
9. GloSea5 (1993-2012)	UK Met Office	1/4° NEMO3.2	3DVAR (SLA/T/S/SST/ice)	Blockley et al (2014)
10. GMAO (1993-2011)	GSFC/NASA	1/2° MOM4p1	EnOI	Rienecker et al (2008)
11. GODAS (1980-2011)	NOAA NCEP	1×1/3° MOM3	3DVAR (SLA/T)	Behringer (2007)
12. K7	JAMSTEC/RIGC	1° MOM3	4DVAR (SLA/T/S/SST)	Masuda et al (2010)
13. MOVE-C (1993-2011)	MRI/JMA	0.3-1° MRI.COM2 coupled	3DVAR (SLA/T/S/SST)	Fuji et al (2009)
14. MOVE-CORE (1948-2007)	MRI/JMA	0.3-1° MRI.COM3	3DVAR (T/S/SST)	Fujii et al (2015)
15. MOVE-G2 (1993-2011)	MRI/JMA	0.3-1° MRI.COM3	3DVAR (SLA/T/S/SST)	Toyoda et al (2013)
16. NODC* (1955-2013)	NODC/NOAA	1° no model	Objective analysis (T/S)	Levitus et al (2012)
17. ORAS4 (1958-2009)	ECMWF	1° NEMO3	3DVAR (SLA/T/S/SST)	Balmaseda et al (2013), Mogensen et al (2012)
18. SODA (1950-2010)	University of Maryland/Texas A&M University	0.4×1/4° POP2.1	OI (T/S/SST)	Carton and Giese (2008)
19. UR025.4 (1989-2010)	University of Reading	1/4° NEMO3.2	OI (SLA/T/S/SST)	Haines et al (2012)

ORA-IP Achievement

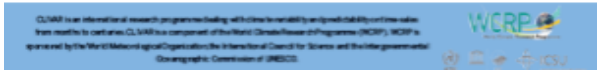
- **Steric Height (Andrea Storto)**
- **Surface Heat Fluxes (Maria Valdivieso)**
- **Salinity (Li Shi)**
- **Ocean Heat Content (Matt Palmer)**
- **Sea-Ice (Matthew Chevallier)**
- **Mixed Layer Depth (Takahiro Toyoda)**
- **AMOC (Alicia Karspeck)**
- **OSE for TPOS (Yan Xue)**

- **Sea Level (Fabrice Hernandez)**
- **D20 (Fabrice Hernandez)**



Special Issue Climate Dynamics in 2015

9 papers submitted so far
5 papers accepted so far

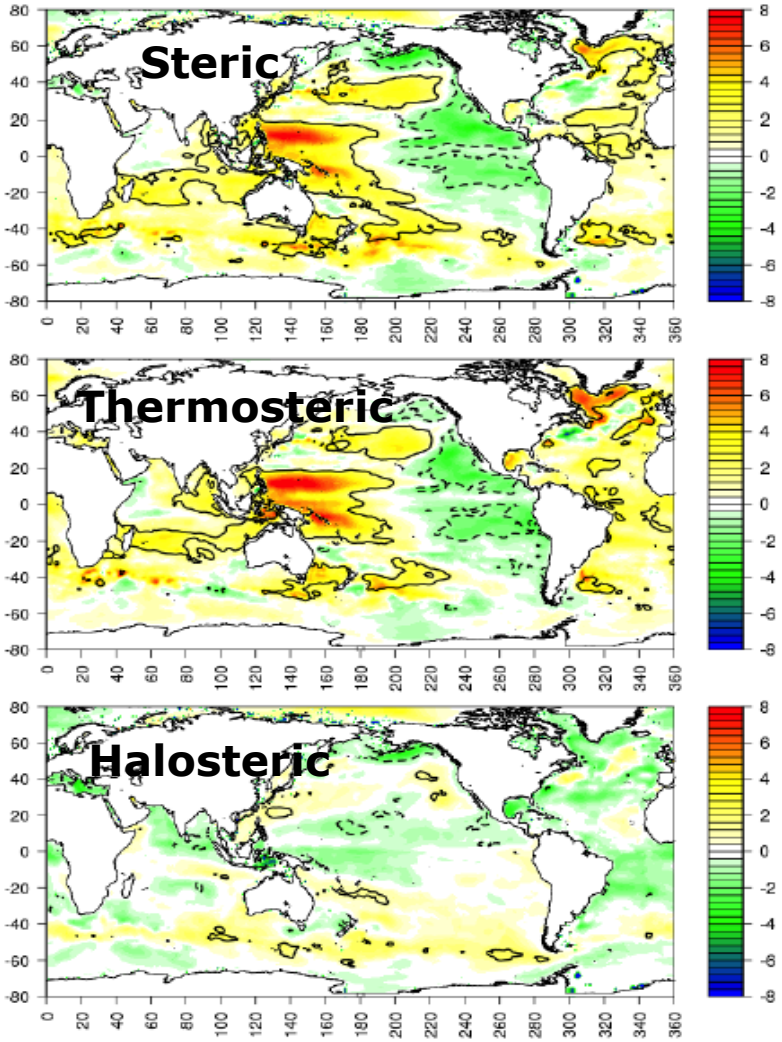


http://www.clivar.org/sites/default/files/documents/Exchanges64.pdf

ORA-IP: Steric Height

by Storto et al, Clim Dyn 2015, online

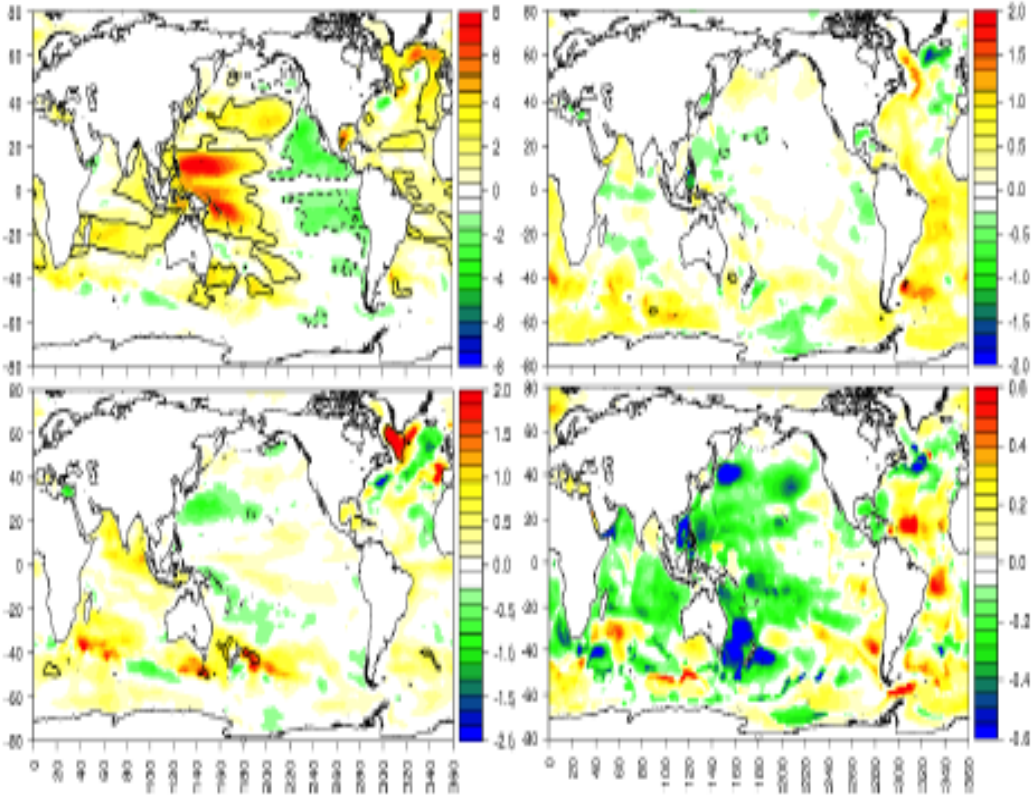
Linear Trend in 1993-2010 (Ensemble Mean)



Thermosteric SSH

0-700m

1500-4000m



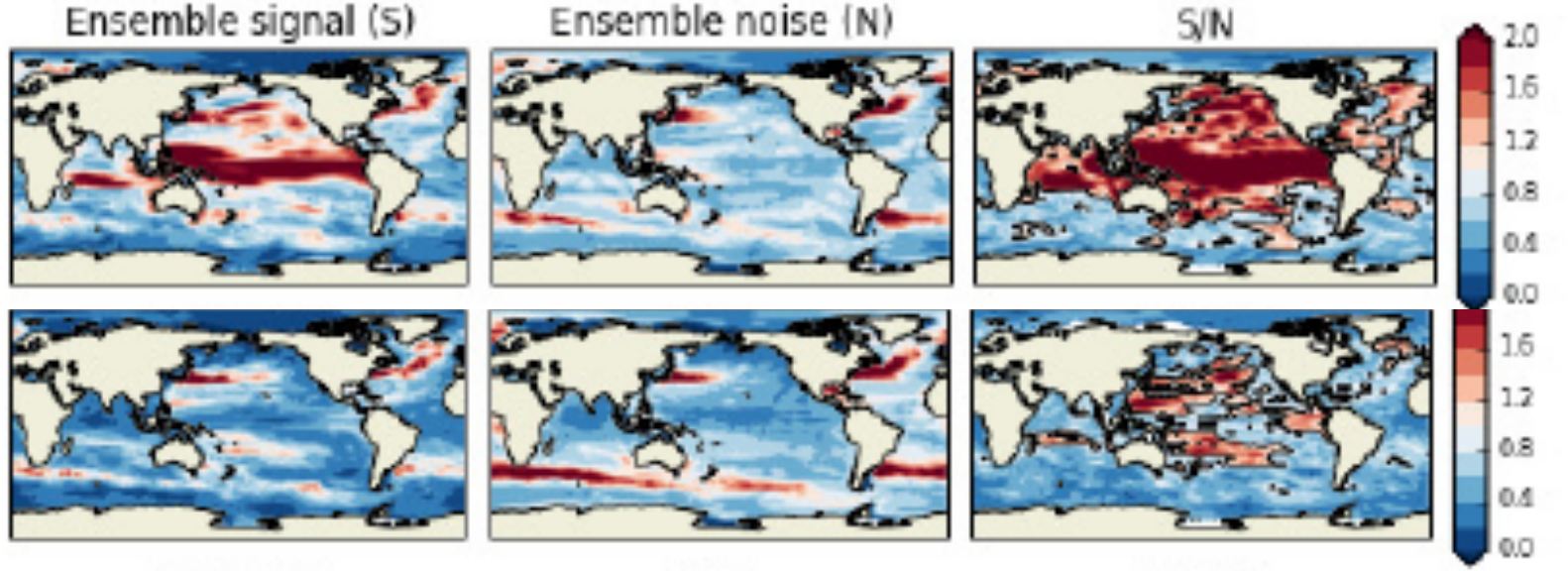
700-1500m

4000-bottom

ORA-IP: Heat Content

by Palmer et al, Clim Dyn 2015

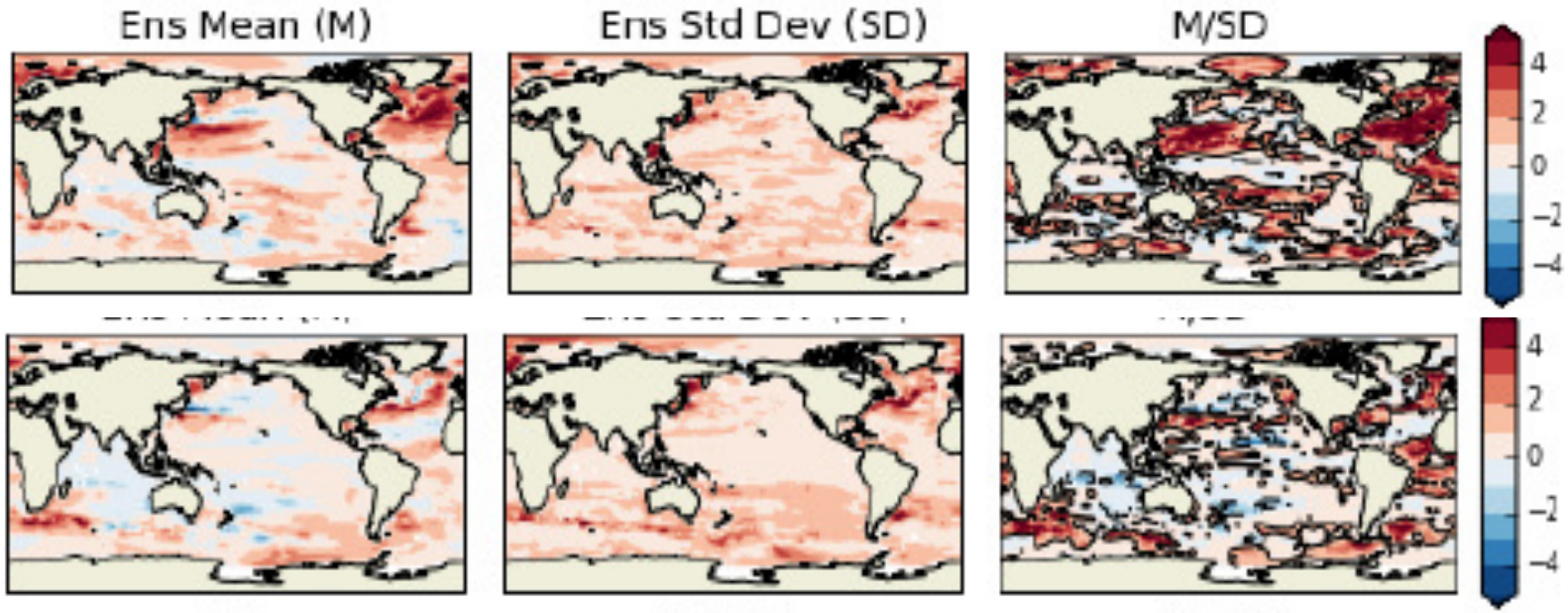
Interannual Variability (1993-2009)



0-300m

300-700m

Trend in 1970-2009



0-300m

300-700m

ORA-IP: Salinity

by Shi et al, Clim Dyn 2015

Fig. 5a

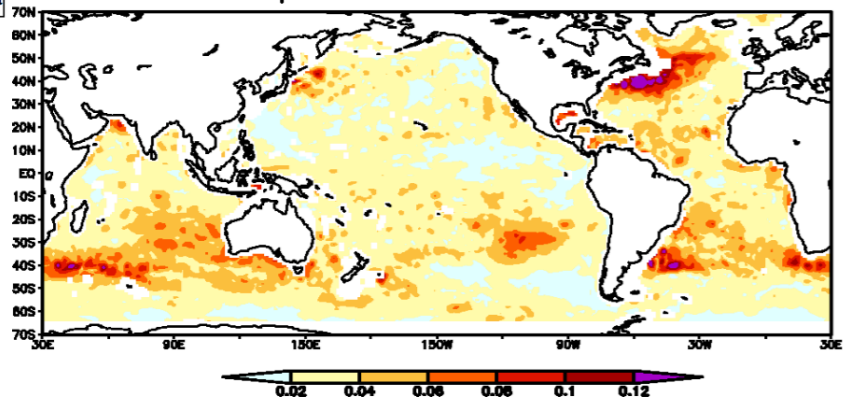


Fig. 5b

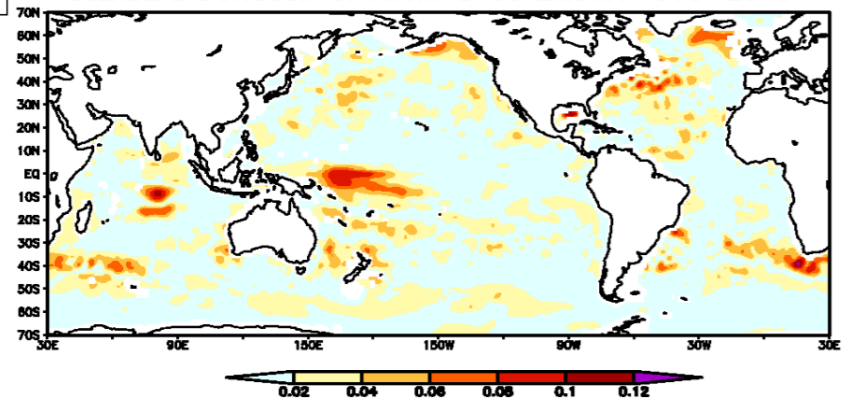
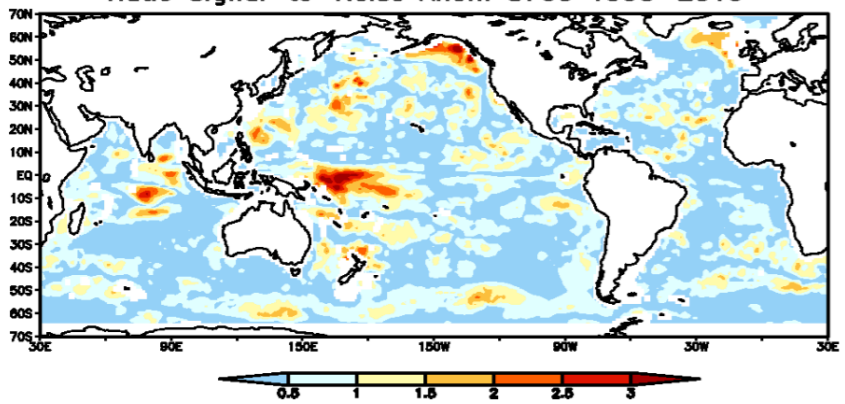


Fig. 5c



Correlation EMORA vs. EMOO

Fig. 10a

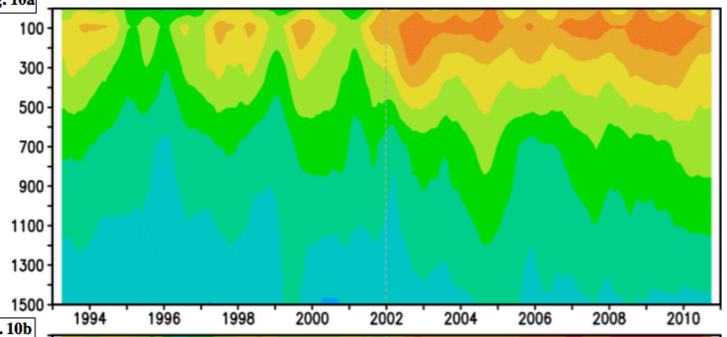


Fig. 10b

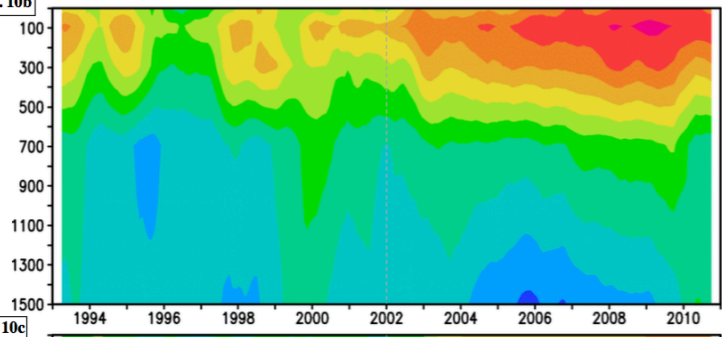
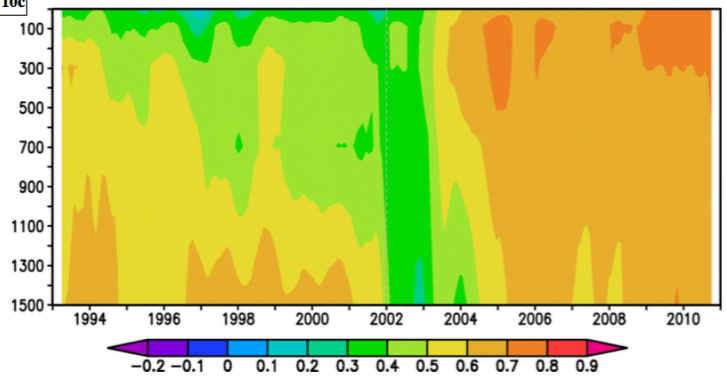


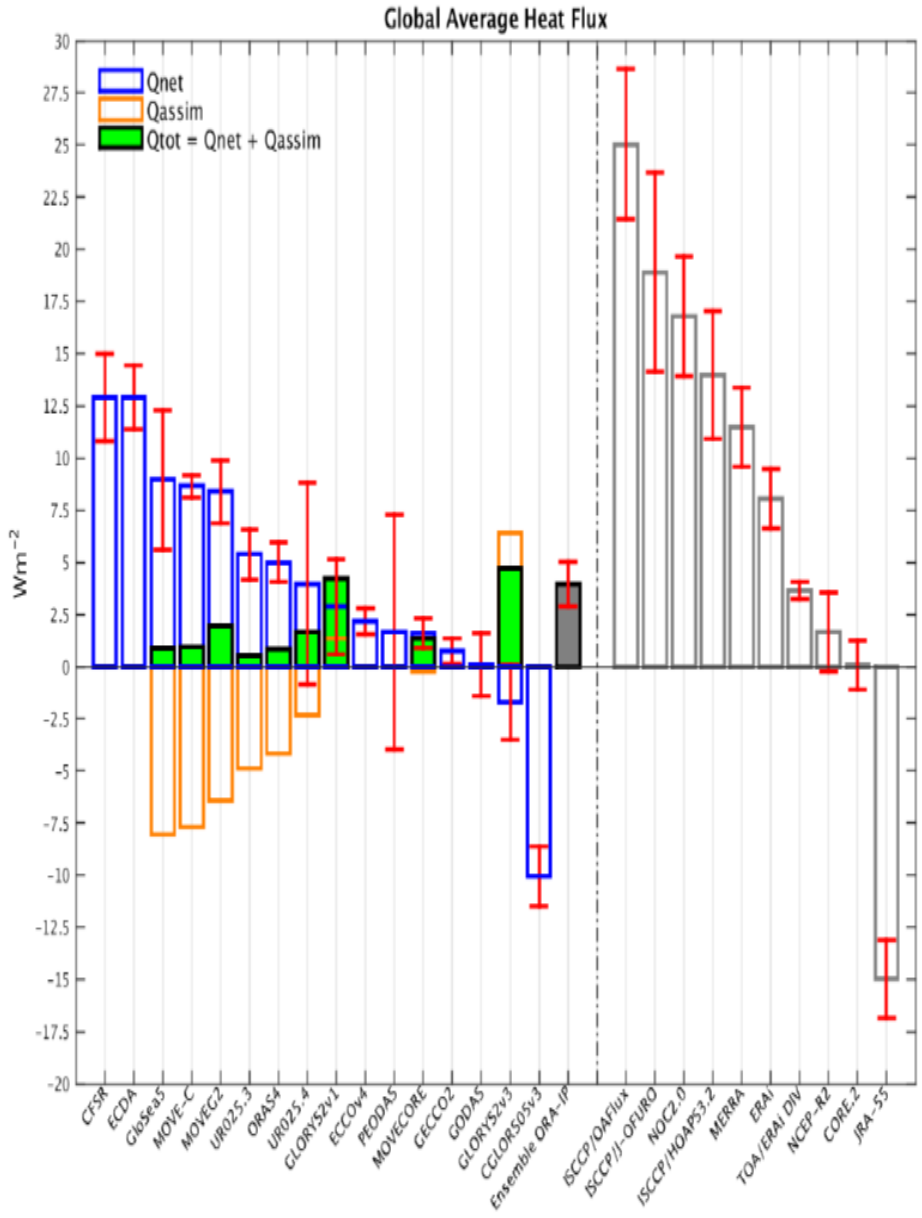
Fig. 10c



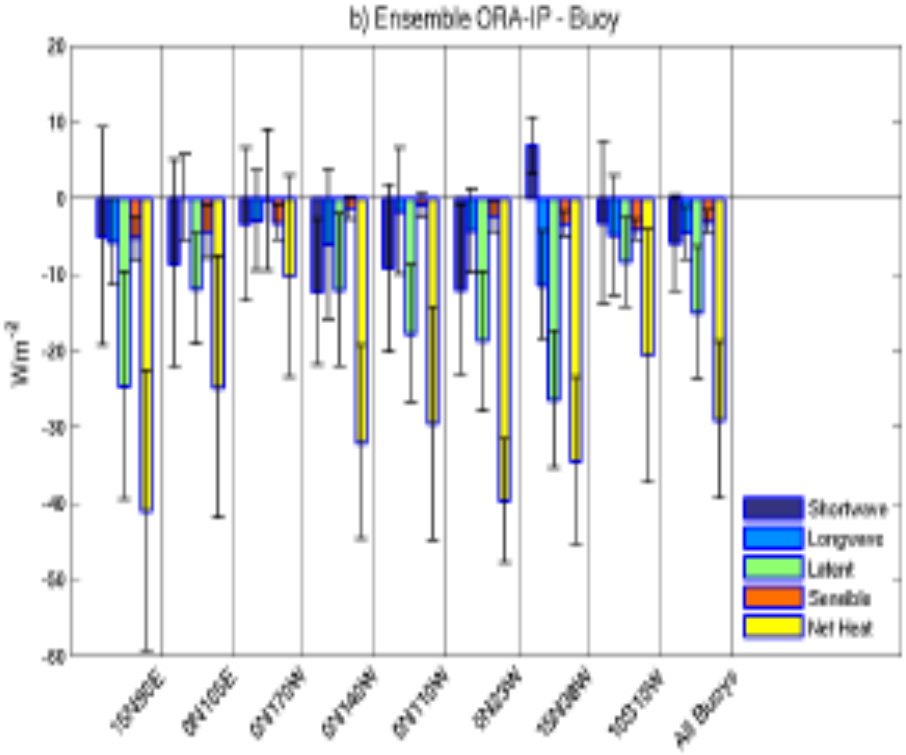
ORA-IP: Heat Fluxes

by Valdivieso et al, Clim Dyn 2015

Global Mean Net Surface Heat Fluxes

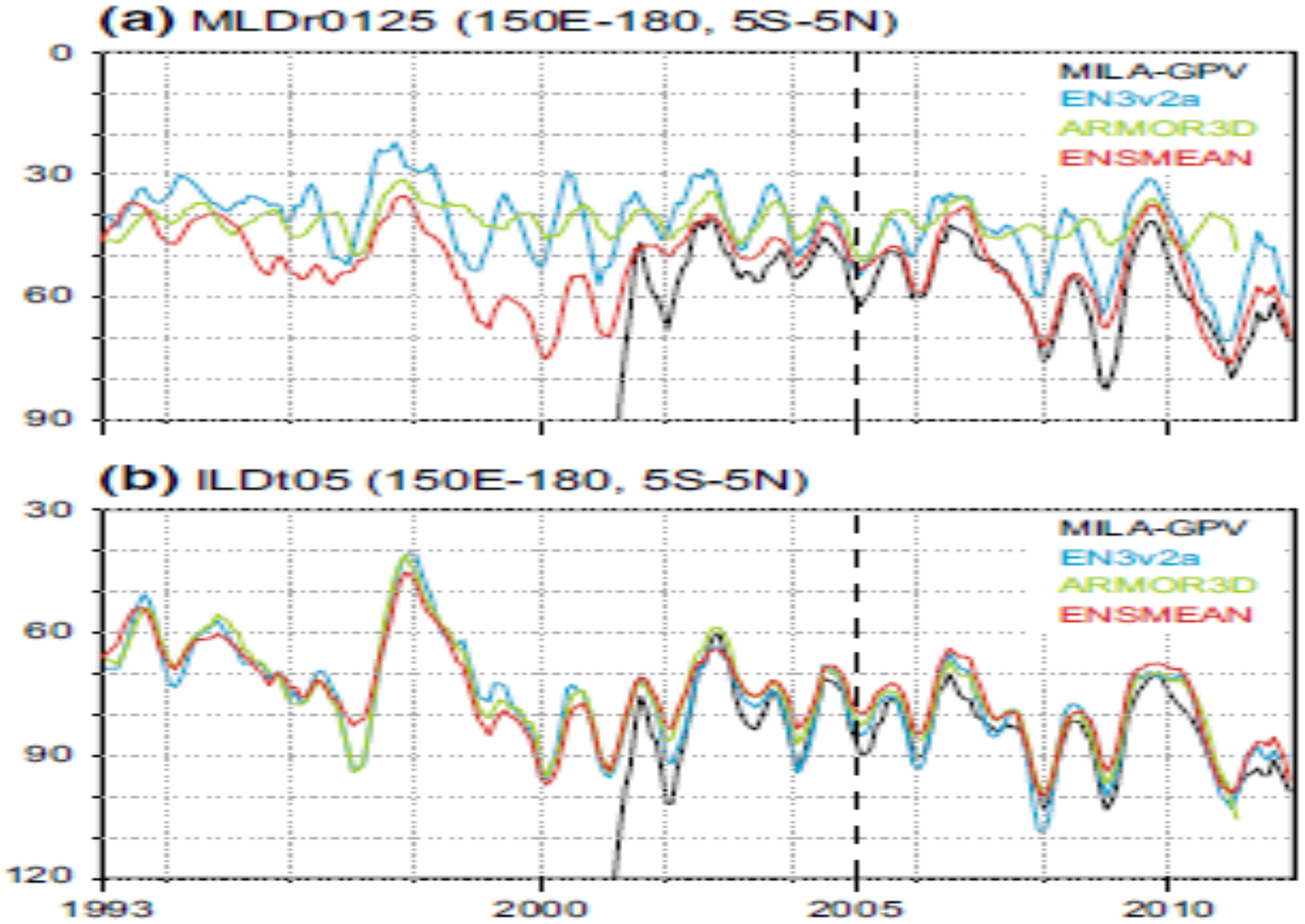


Mean Heat Fluxes: Ensemble - Buoy



ORA-IP: Mixed Layer Depth

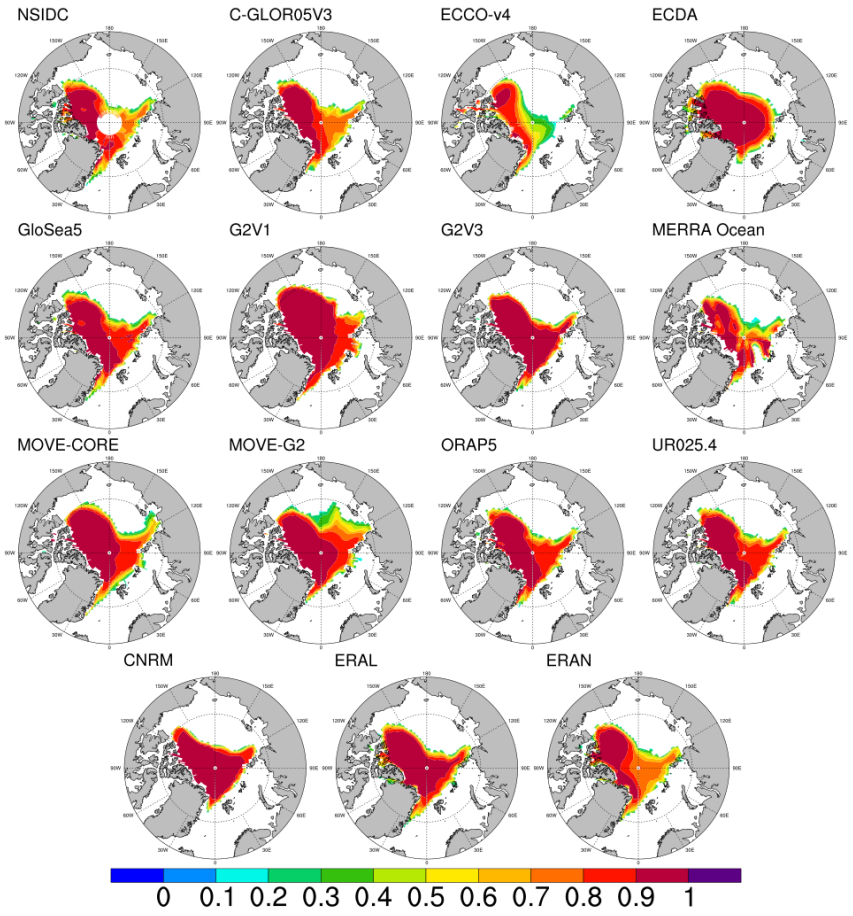
by Toyoda et al, Clim Dyn 2015



ORA-IP: Sea Ice

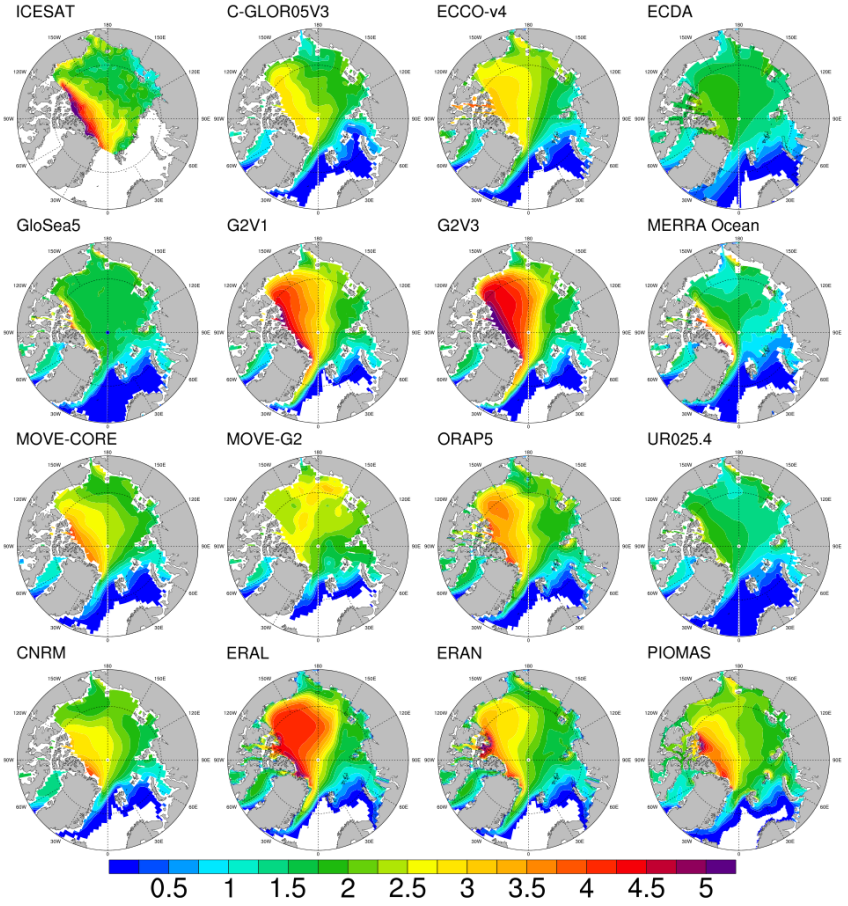
by Chevallier et al, Clim Dyn 2015

Sea Ice Concentration Sep 2007



NSIDC and ORA-IP

Sea Ice Thickness March 2007



IceSat and ORA-IP

ORA-IP Future Plan

- **Consolidation of the ORA-IP intercomparison (data publicly available, with version control)**
- **Promoting and extending the real-time monitoring**
- **Exchanging ocean reanalyses to assess the impacts of initial conditions in seasonal forecast**

Courtesy of Magdalena Balmaseda

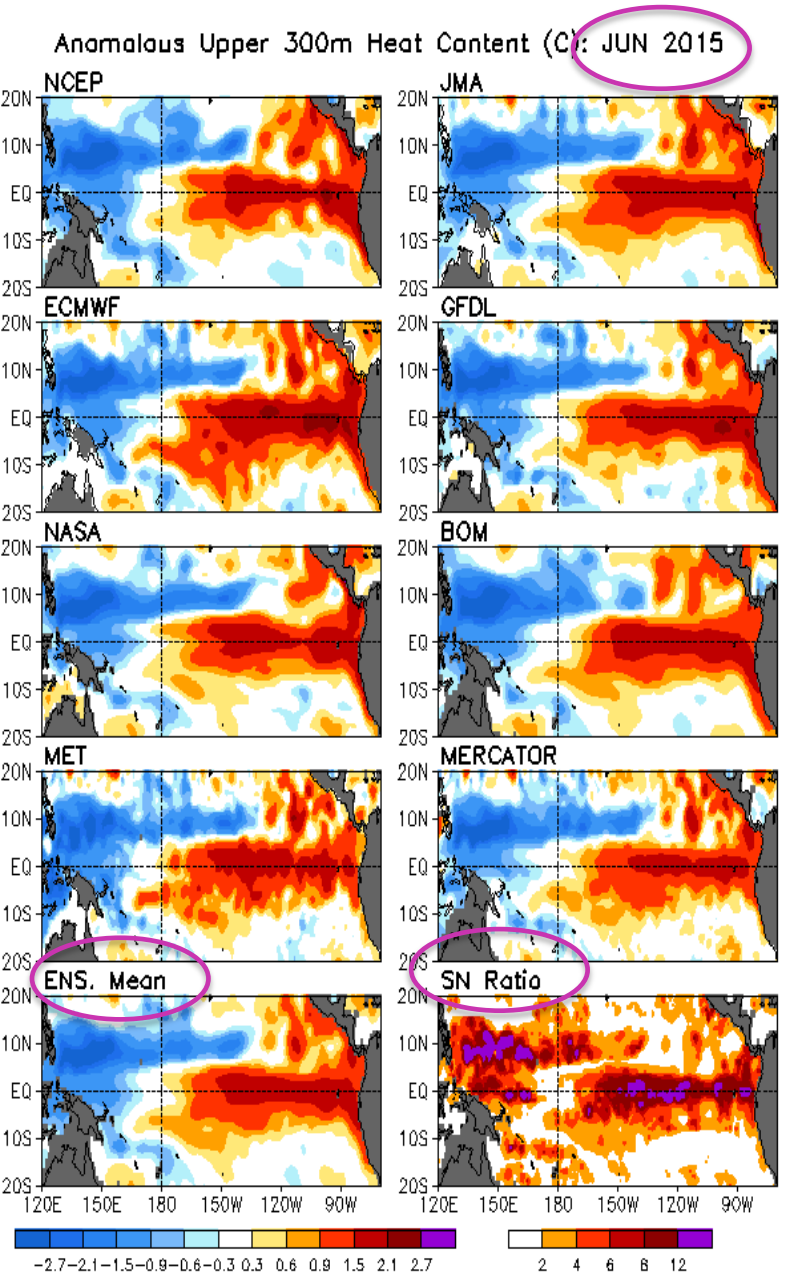
Real-Time ORA-IP

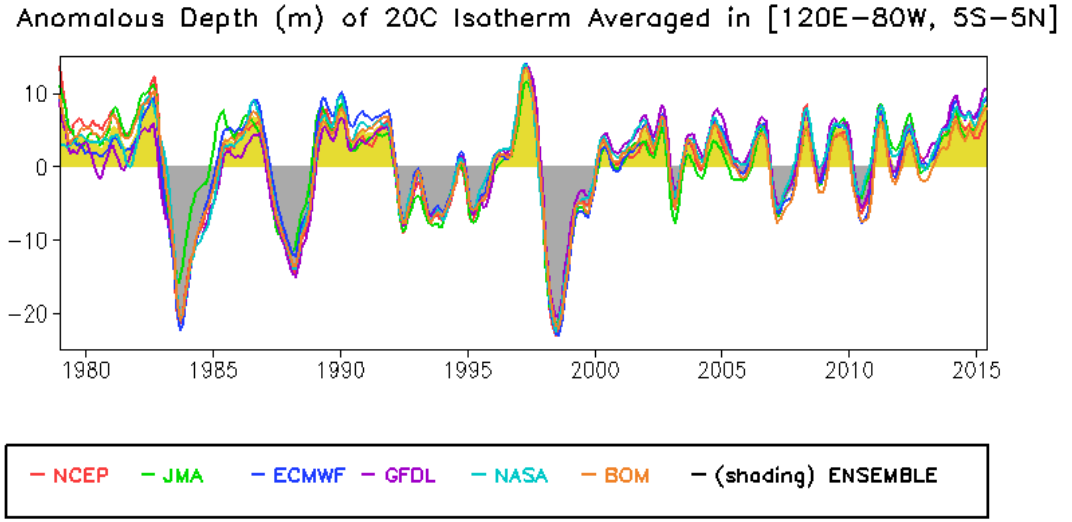
http://www.cpc.ncep.noaa.gov/products/GODAS/multiora_body.html

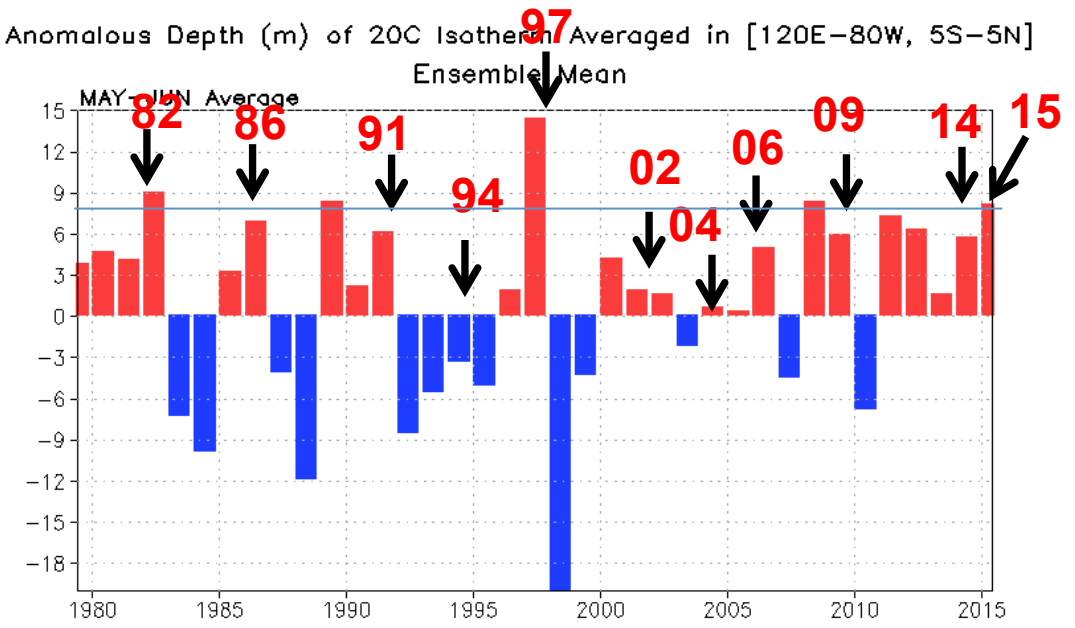
- **CPC leads the Real-Time Ocean Reanalyses Intercomparison Project coordinated by CLIVAR-GSOP and GODAE OceanView**
- **Assess uncertainties in temperature analysis of tropical Pacific in real time for ENSO monitoring and prediction**
- **Explore any connections between gaps in TAO observations and spreads among ensemble ORAs**
- **Articulate needs for sustained and enhanced ocean observations for TPOS2020**
- **Monitor signal-to-noise ratio and climate signals associated with ENSO, Pacific Decadal Oscillation, Indian Ocean Dipole, Tropical Atlantic Variability**

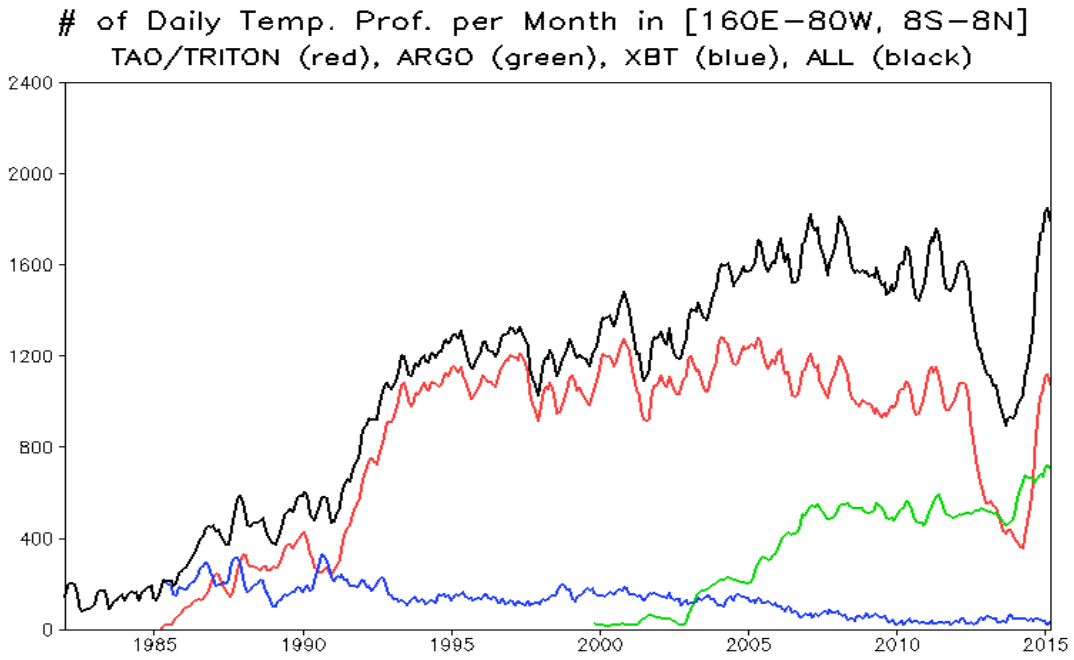
- **Acquired monthly temperature anomalies from eight centers (NCEP, ECMWF, JMA, BOM, GFDL, NASA, UK MET, MERCATOR)**
- **Update the ensemble ocean products on the 6th day of each month**

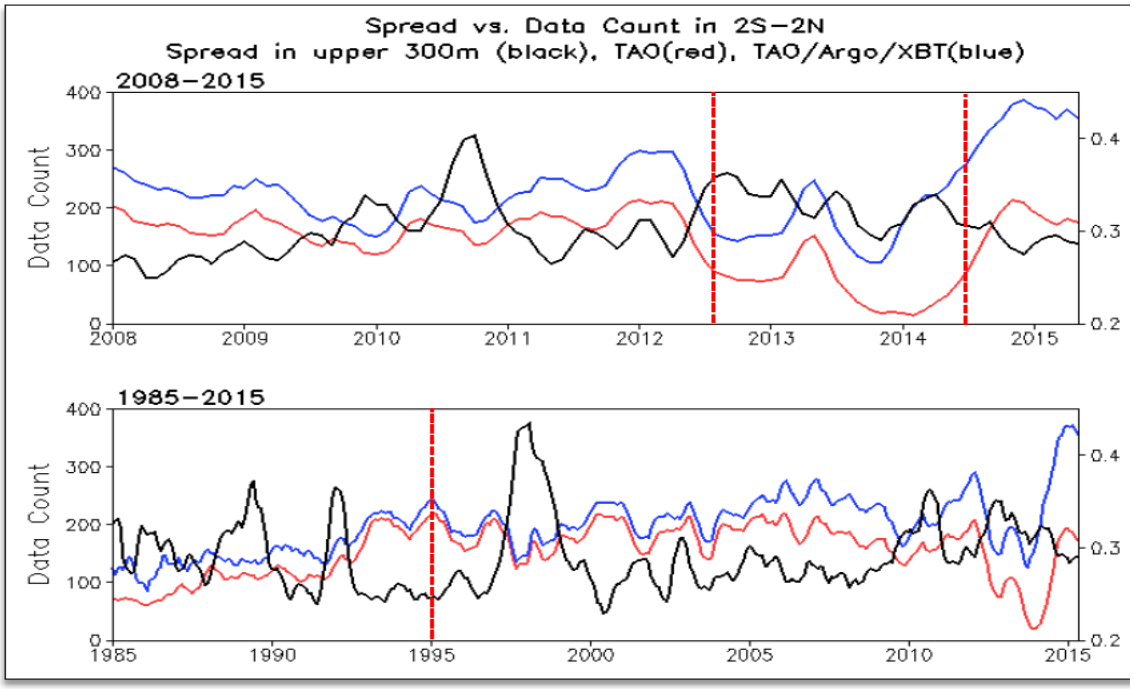
Monitoring ENSO











Spread vs. Data

Correlation in 1994-2015

- **0.46 (with TAO)**
- **0.37 (with ALL)**

EVALUATION OF OCEAN SYNTHESES

COST Action 1402

Jan 2015 – Dec 2018

http://www.eos-cost.eu

A COST Action to **improve the coordination** of European efforts in the evaluation of ocean syntheses:

- **better understanding of the value and use of ocean syntheses**
- **promote the use of ocean syntheses**

Chairs:
Aida Alvera-Azcárate (University of Liège, BE)
Keith Haines (University of Reading, UK)

WG 1: Preparation and harmonization of data : (Karina von Schuckmann, Simona Masina)
WG 2: Evaluation of ocean syntheses : (Andrea Storto, Antonio Turiel)
WG 3: Applications: from short-term predictability to climate studies : (G. Jordà, M. Valdivieso)
WG 4: Downscaling issues: from global to regional syntheses : (Marie Drévillon, Anna Brooke)

cost
EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

Earth System Science and Environmental Management

EUROPEAN SCIENCE FOUNDATION

GSOP Panel Priorities

- **Improve usability/accessibility of Ocean Reanalysis products**

- **Further evaluation of products**
  - **Do ensemble mean (signal) and ensemble spread (noise) have value?**
  - **Ocean heat (freshwater) content and budgets especially earth energy budget (cf. CLIVAR research focus)**
  - **Evaluation of transports, heat and freshwater (AMOC etc……..)**
  - **Monitoring observation minus analysis (O-A) of products**

- **Development of coupled data assimilation (and reanalysis) methods.**
  - **Key to use of surface variables : SST, SSS, Surface winds, Sea state…….**

- **Understanding the inter-model differences, and developing observational constraints for long-term sea level, ocean heat uptake and surface temperature rise.**

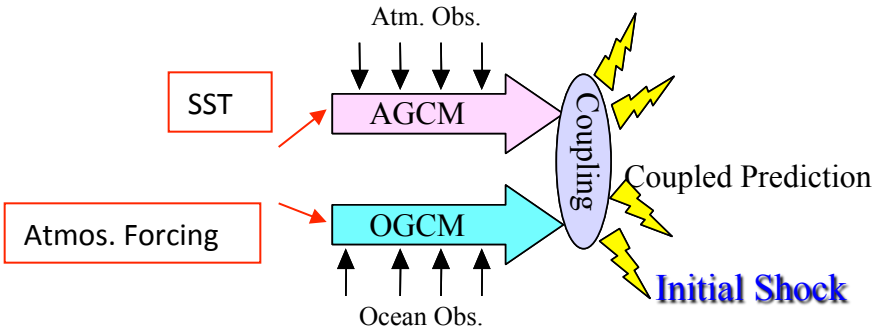
- **Understanding how internal variability manifests in regional sea level, ocean heat and freshwater storage and the implications for climate projections on decadal timescales.**

- **Using climate/ocean model simulations to evaluate the mapping methods employed to estimate past ocean heat uptake and sea level rise.**

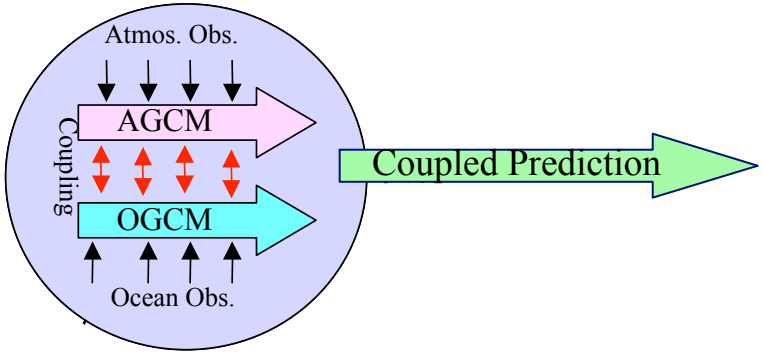
Courtesy of Magdalena Balmaseda

Development of Coupled Data Assimilation Systems

Ocean-alone System



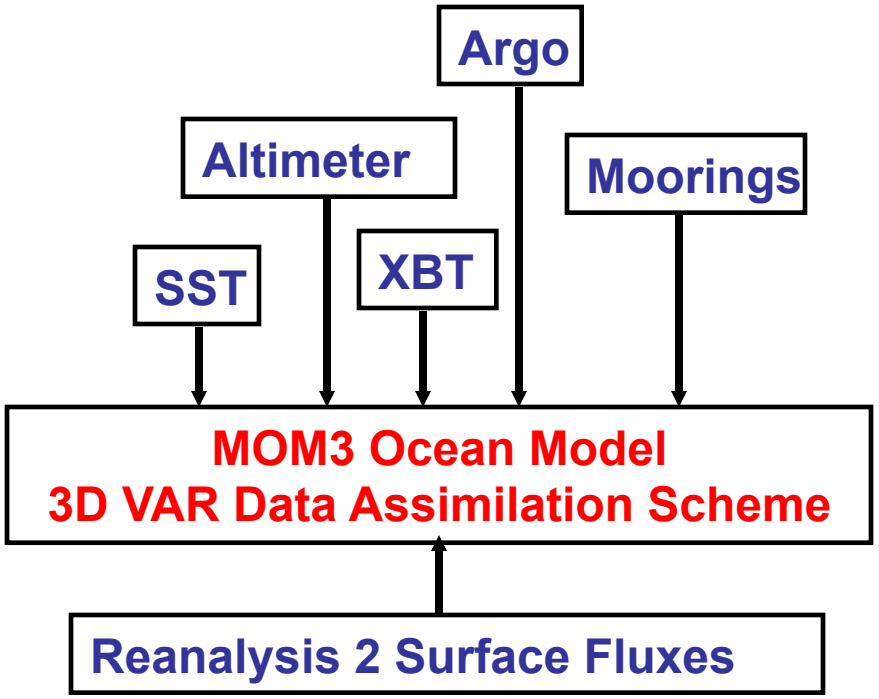
Coupled DA System



NCEP Ocean Data Assimilation Systems

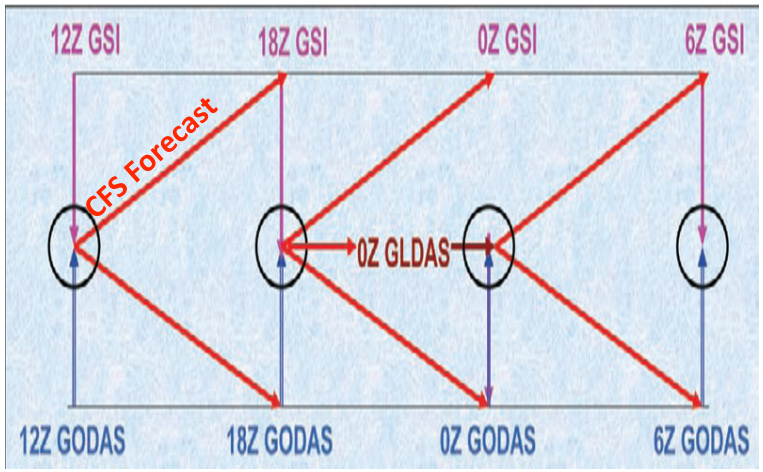
Ocean-alone → **Partially Coupled System**

Global Ocean Data Assimilation System
(GODAS, implemented in 2003)



Climate Forecast System Reanalysis
(CFSR, implemented in 2011)

Atmosphere Data Assimilation System
(T382L64 GSI)



Ocean Data Assimilation System
(MOM4 Ocean Model and 3D VAR)

Hybrid GODAS

- Hybrid Method:
  The **Hybrid-Gain** method of *Penny (2014)*
- EnKF Component:
  The **Local Ensemble Transform Kalman Filter (LETKF)** developed by *Hunt et al. (2007)* at the University of Maryland (UMD)
- Variational Component:
  NCEP's **operational 3DVar** used in the Global Ocean Data Assimilation System (GODAS) described by *Derber and Rosati (1989)* and *Behringer (2007)*

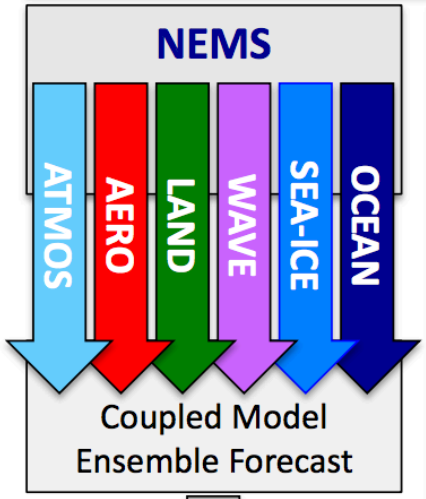
Penny, S.G., 2014: The Hybrid Local Ensemble Transform Kalman Filter. *Mon. Wea. Rev.*, **142**, 2139–2149. doi: http://dx.doi.org/10.1175/MWR-D-13-00131.1

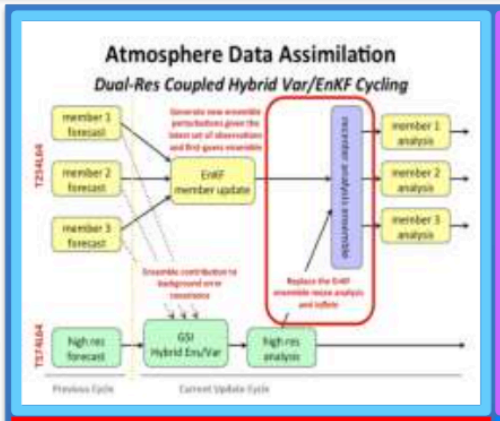
Hunt, B.R., E.J. Kostelich, and I. Szunyogh, 2007: Efficient Data Assimilation for Spatiotemporal Chaos: A Local Ensemble Transform Kalman Filter. *Physica D*, **230**, 112-126.

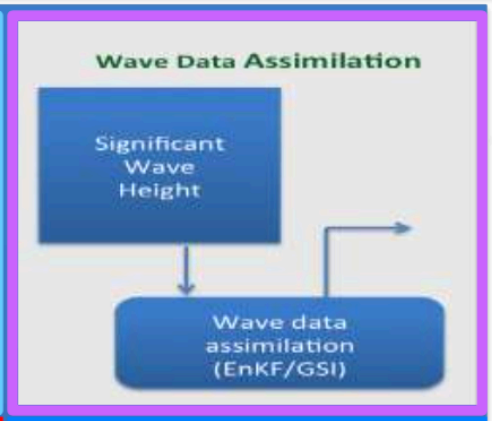
Derber, J. D., and A. Rosati, 1989: A global oceanic data assimilation system. *J. Phys. Oceanogr.*, **19**, 1333–1347.

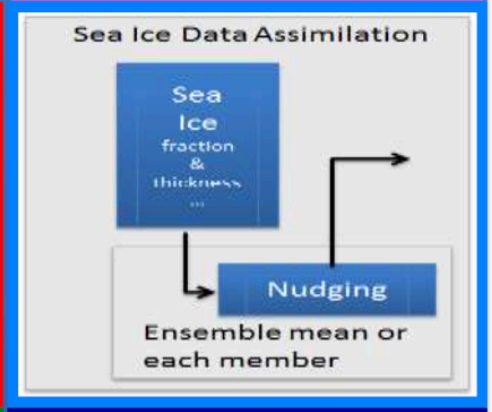
Behringer, D. W., 2007: The Global Ocean Data Assimilation System at NCEP. Preprints, 11th Symp. on Integrated Observing and Assimilation Systems for Atmosphere, Oceans and Land Surface, San Antonio, TX, *Amer. Meteor. Soc.*, 14–18.

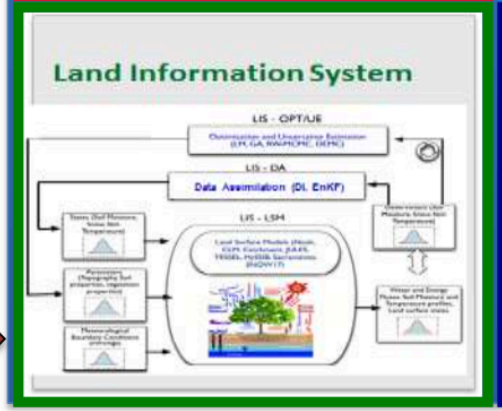
NCEP Coupled Hybrid Data Assimilation and Forecast System

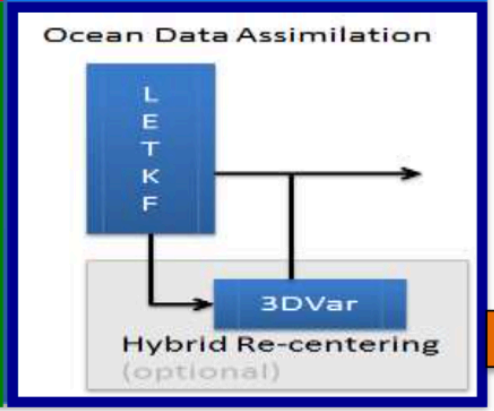


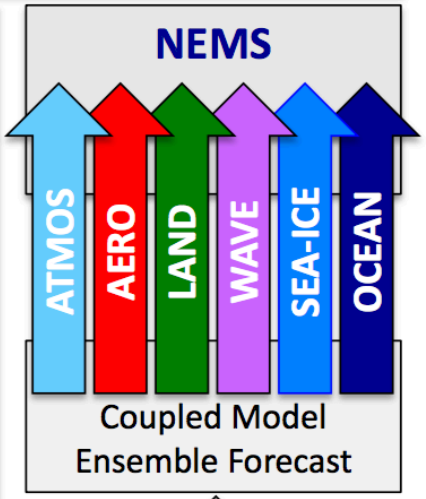












Coupled Ensemble Forecast (N members)

Coupled Ensemble Analysis (N Members)

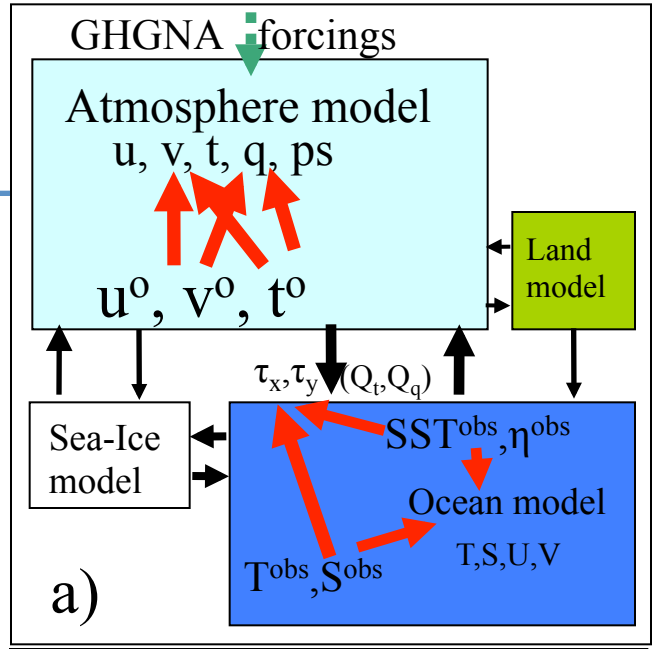
INPUT

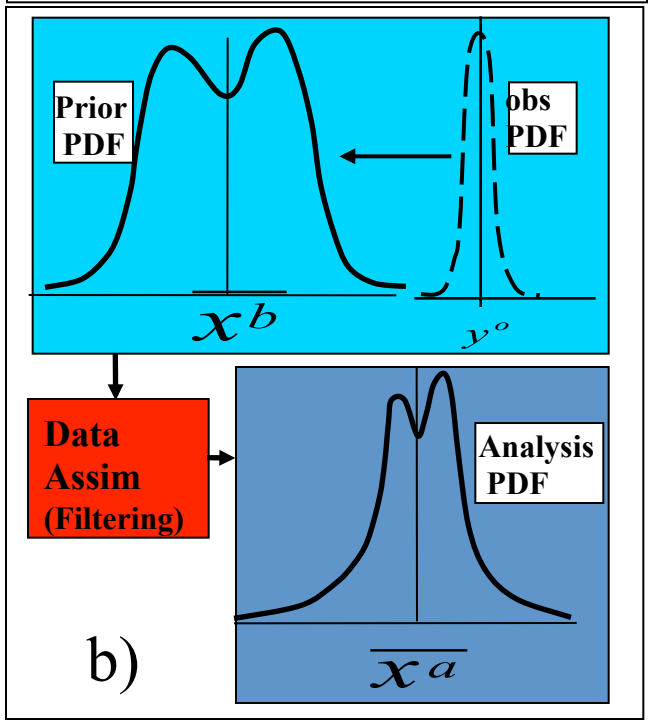
OUTPUT

GFDL ECDA system

Coupled Ensemble Data Assimilation estimates the *temporally-evolving probability distribution* of climate states under observational data constraint:

- ✓ Multi-variate analysis maintaining physical balances between state variables such as T-S relationship & geostrophic balance mostly
- ✓ All coupled components adjusted by observed data through instantaneously-exchanged fluxes
- ✓ Optimal ensemble initialization of coupled model with minimum initial shocks



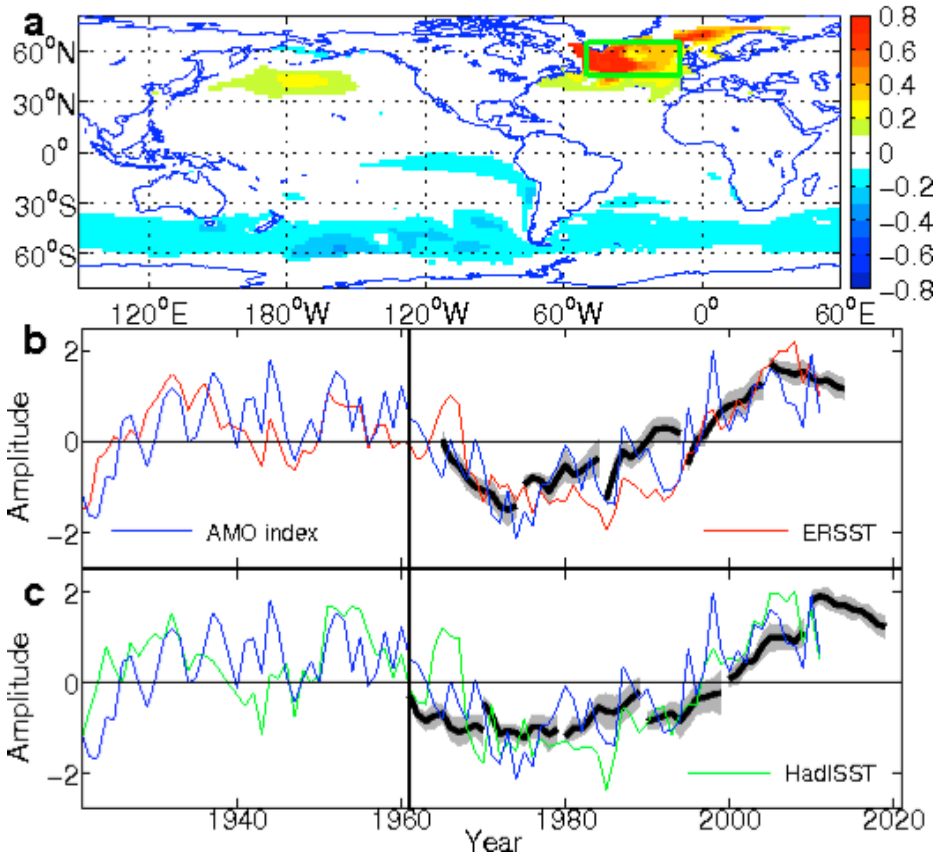


Coupled DA makes decadal climate prediction possible: predictable AMO-like internal SST pattern

I.C.: 1Jan., 1961-2012 from GFDL/ECDA

Leading predictable pattern

Time Series



- An inter-hemisphere dipole pattern
- Time series well correlated with AMO index
- Hindcasts following observations

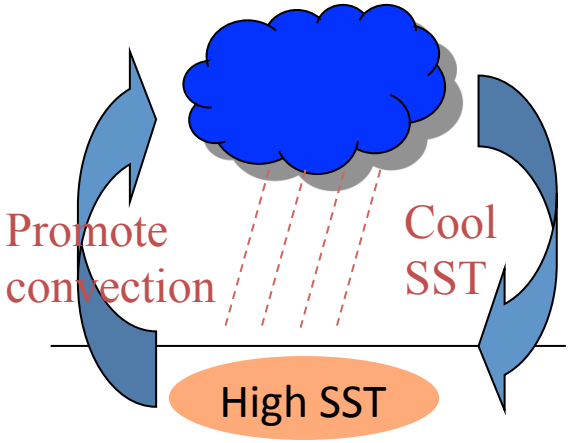
Yang et al. (2013, J. Clim.)

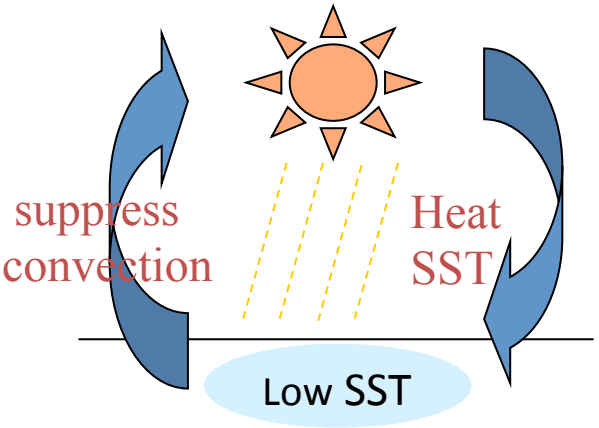
JMA Quasi Coupled Data Assimilation System (assimilating only ocean data)

・The negative feedback between SST and precipitation does not work in an AMIP Run, but is adequately reconstructed in the QCDA system

Fujii et al. 2009, http://dx.doi.org/10.1175/2009JCLI2814.1
Fujii et al. 2011, http://dx.doi.org/10.5772/30330

Negative feedback between SST and precipitation

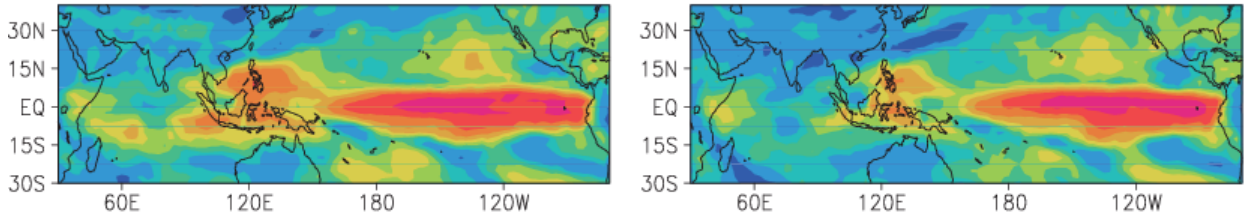




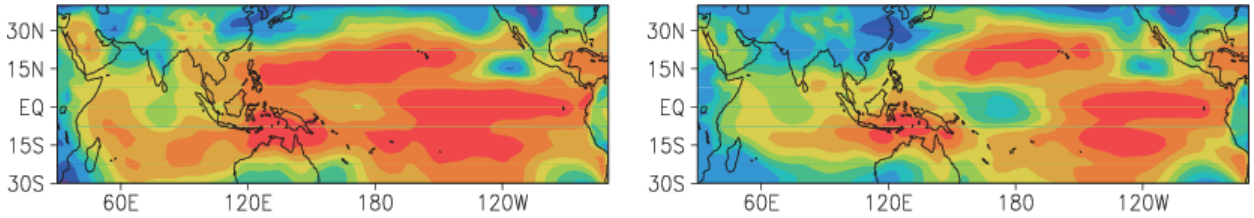
QCDA

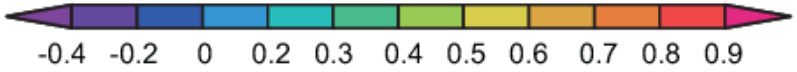
AMIP

ACC of OLR for all season (reference: NOAA-OLR)



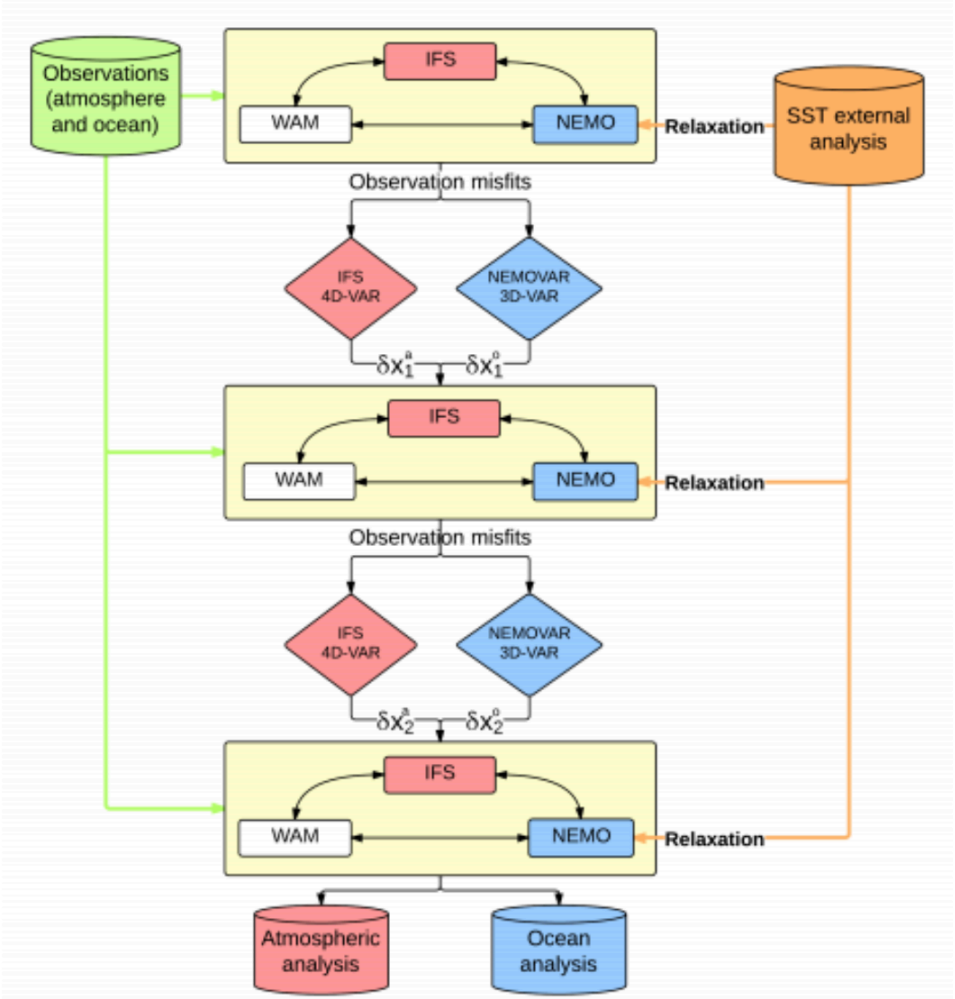
ACC of SLP for Jun.-Aug. (reference: JRA-25)





The CERA system

ECMWF



Incremental variational approach:

A common 24-hour assimilation window

Coupled model to compute observation misfits

Increments computed separately and in parallel

Separate background-error covariance model

Sea Surface Temperature:

SST relaxation scheme towards a daily SST analysis product

Model resolution:

Atmosphere: 1.125° horizontal grid with 137 levels

Ocean: 1° horizontal grid with 42 levels (first layer of 10 mete

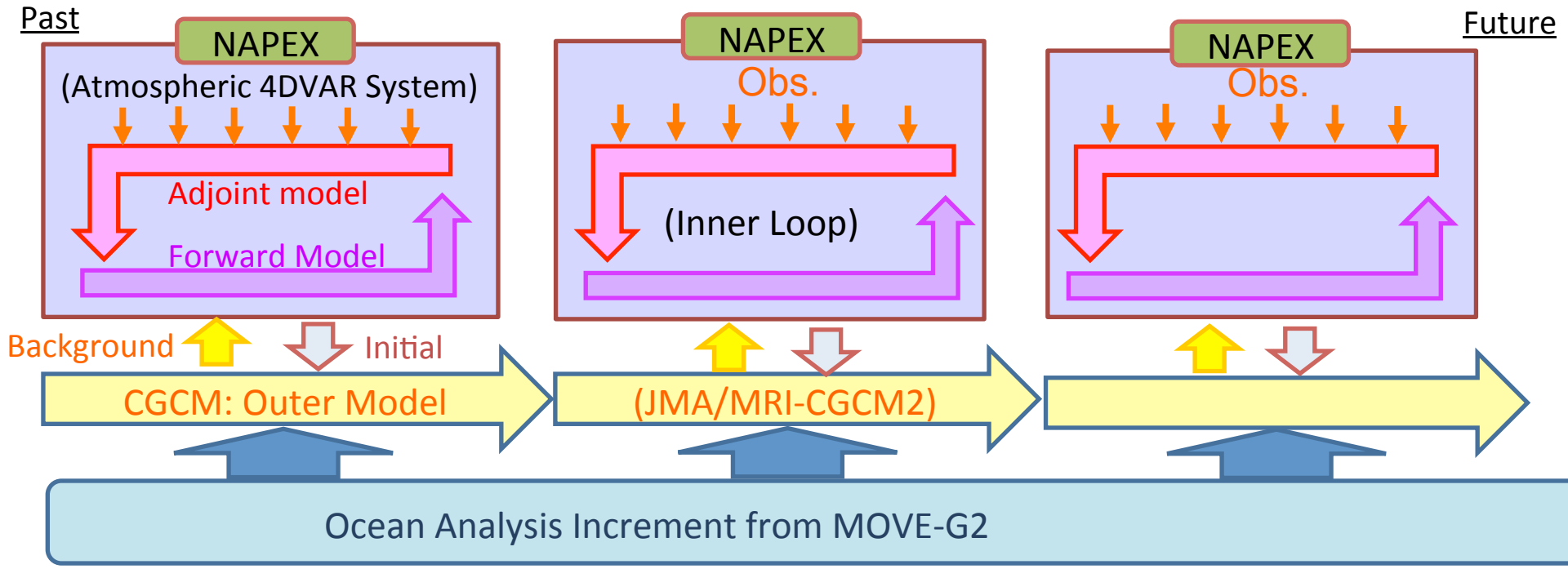
Wave: 1.5° horizontal grid

Experiments:

Run successfully on short recent periods

Laloyaux et al. 2015, CD

★Design of the new coupled DA system in JMA/MRI



- ✓ In the atmospheric analysis the CGCM is used as an outer model of the atmospheric 4DVAR system. (The background state required for integration of the adjoint model is generated by the CGCM.)
- ✓ Ocean analysis increment is calculated in the ocean analysis scheme, MOVE-G2 and applied to the CGCM.
- ✓ Atmospheric Analysis: every 6 hours. Ocean Analysis: every 10 days
- ✓ We plan to perform a 1-year reanalysis experiment in this year.

Summary of Coupled DA

- **Atmosphere and ocean data assimilation scheme usually runs separately**
- **Influence of ocean (atmosphere) data on the atmosphere (ocean) model is through coupled air-sea fluxes**
- **Most of coupled DA systems are in the early development stage and they are more expensive to run than ocean-alone DA systems**
- **It is unclear if coupled DA enhances ENSO forecast skill**

International Quality-Controlled Ocean Database

I Q u O D

Main goal

To construct the most complete, consistent and high quality subsurface ocean temperature (**EOV/ECV**) long-term database, with intelligent metadata and assigned uncertainty to each observation, and to freely distribute for use in ocean, climate and Earth system research science and applications of societal benefit.

Future plans to expand IQuOD effort to other EOVs/ECVs such as subsurface salinity, oxygen, etc.

How

- Key technical/scientific expertise and infrastructure resources from the international community will be globally-coordinated into a single best standard practice.
- Deliverables will be tailored in close cooperation/collaboration with end-users (e.g., observational, reanalysis/modelling communities and ocean/climate services).

Scientific/Implementation plan: under development.
Timeframe: 3-5 years (ultimately dependent on resources/funding)

Expected Outcomes

- **High quality subsurface ocean temperature database including intelligent metadata and uncertainty**

- **Applications of IQuOD products**
  - Ocean reanalyses
  - WMO GCOS Essential Climate and Ocean variables
  - CLIVAR Ocean Climate Indicators
  - CLIVAR Research Foci Initiatives (e.g., CONCEPT-HEAT)
  - WCRP Grand Challenge on Regional Sea Level Change and Coastal Impacts

- **Best practices for discovery/management of ocean observations and metadata**

- **Future efforts**
  Subsurface salinity observations and other ocean variables

IQuOD

www.iquod.org

CLIVAR Research Focus
"Consistency between planetary energy balance and ocean heat storage (CONCEPT-HEAT)"

Large uncertainties in estimates challenge our ability to infer an absolute measure of the Earth Energy Imbalance and its changes over time

An overarching goal is to bring together 7 climate research communities all concerned with the energy flows in the Earth's System:

- Atmospheric radiation
- Air-sea-fluxes
- Ocean Heat Content
- Ocean reanalysis
- Atmospheric reanalyses and NWP
- Climate models.
- Global sea level

to advance the understanding of the uncertainties through budget constraints and consistency studies

- Community white paper: von Schuckmann et al., 2015 (download at http://www.clivar.org)
- Planned workshop on energy flows through the climate system

(jointly with GSOP, ORA-IP, COST-EOS, ESA-OHF)