An Ensemble Estimation of the Variability of Upper-ocean Heat Content over the Tropical Atlantic Ocean with Multi-Ocean Reanalysis Products

***Jieshun Zhu*[1]**, *Bohua Huang*[1,2], *and Magdalena A Balmaseda*[3]

[1]Center for Ocean-Land-Atmosphere Studies (COLA)

[2]Department of Atmospheric, Oceanic, and Earth Sciences

George Mason University (GMU)

[3] European Centre for Medium-Range Weather Forecasts (ECMWF)

HCA -- the averaged temperature anomalies in the upper 300m

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OUTLINES

- Six ODA products
- The uncertainty of HCA in the current ODAs
- Validation of an Ensemble ODA dataset

  - Leading EOF modes becoming more physically meaningful
  - Against the EOF maximizing signal-to-noise ratio (MSN EOF) (**common?**)
  - Against AVISO sea level dataset (**realistic?**)
  - Against PIRATA mooring dataset: five moorings

- Summary

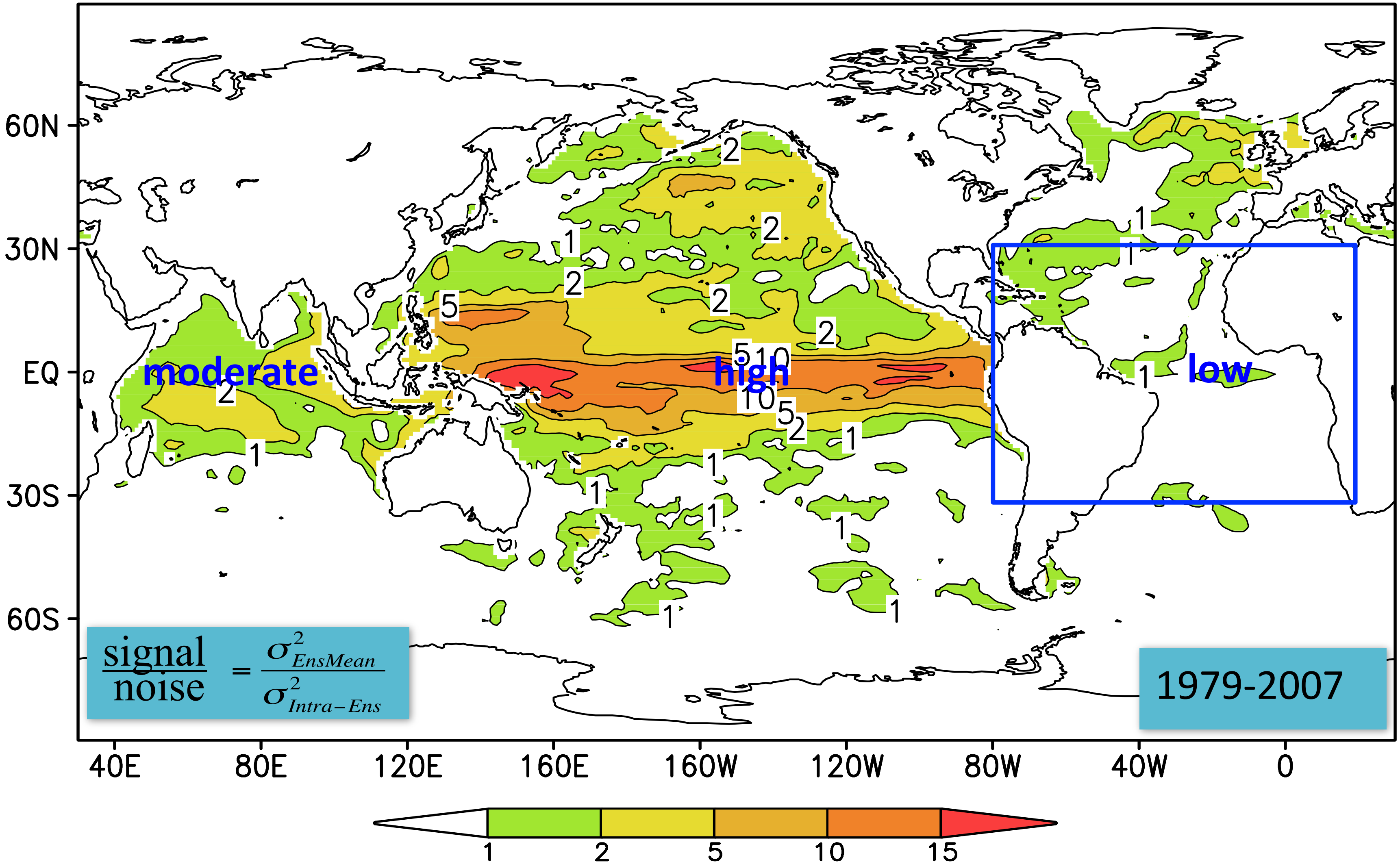
Multiple Ocean Analyses

Table 1 Brief summary of ocean state estimation systems

System and institution (reference)	Model and resolution	Method	Data	Period
ORA-S3, ECMWF, EU (Balmaseda et al. 2008)	HOPE 1X(0.3–1), 29 levels	3D OI with online bias correction	Altimeter (sea level anomalies and global trends), SST, T & S from XBT, CTD, Argo, TAO	1959–2009
COMBINE-NV ECMWF, EU (Balmaseda et al. 2010)	NEMO 1X(0.3–1) 42 levels	3D-VAR	EN3_v2a data set (including ocean station/CTD, XBT, Buoys, profilers inWOD05, GTSPP and ARGO)	1958–2008
GODAS, NCEP, USA (Behringer 2005)	MOM3 1X(0.3–1) 40 levels	3D-VAR	SST, T profiles from XBT, CTD, Argo, TAO	1979–2009
CFSR, NCEP, USA (Saha et al. 2010)	NCEP CFS2 (MOM4 0.5X(0.25–0.5) 40 levels)	Partially coupled data assimilation (3D-VAR for OM)	SST, T &S profiles from XBT, CTD, Argo, TAO	1979–2009
SODA 2.1.6, UM/TAMU, USA (Carton and Giese 2008)	POP 0.25X0.4, 40 levels	OI	Altimetry, satellite and in situ SST, T & S profiles from MBT, XBT, CTD, Argo and other float data, TAO and other buoys.	1958–2008
ECDA, GFDL, USA (Zhang et al. 2007)	GFDL CM2 (MOM4 1X(0.3–1), 50 levels)	Coupled data assimilation (ensemble kalman filter)	SST, T profiles from XBT, CTD, ARGO, TAO & S profiles from CTD, ARGO	1979–2007

- ***Different model systems***
- ***Different assimilation schemes***
- ***Slightly different observational inputs***

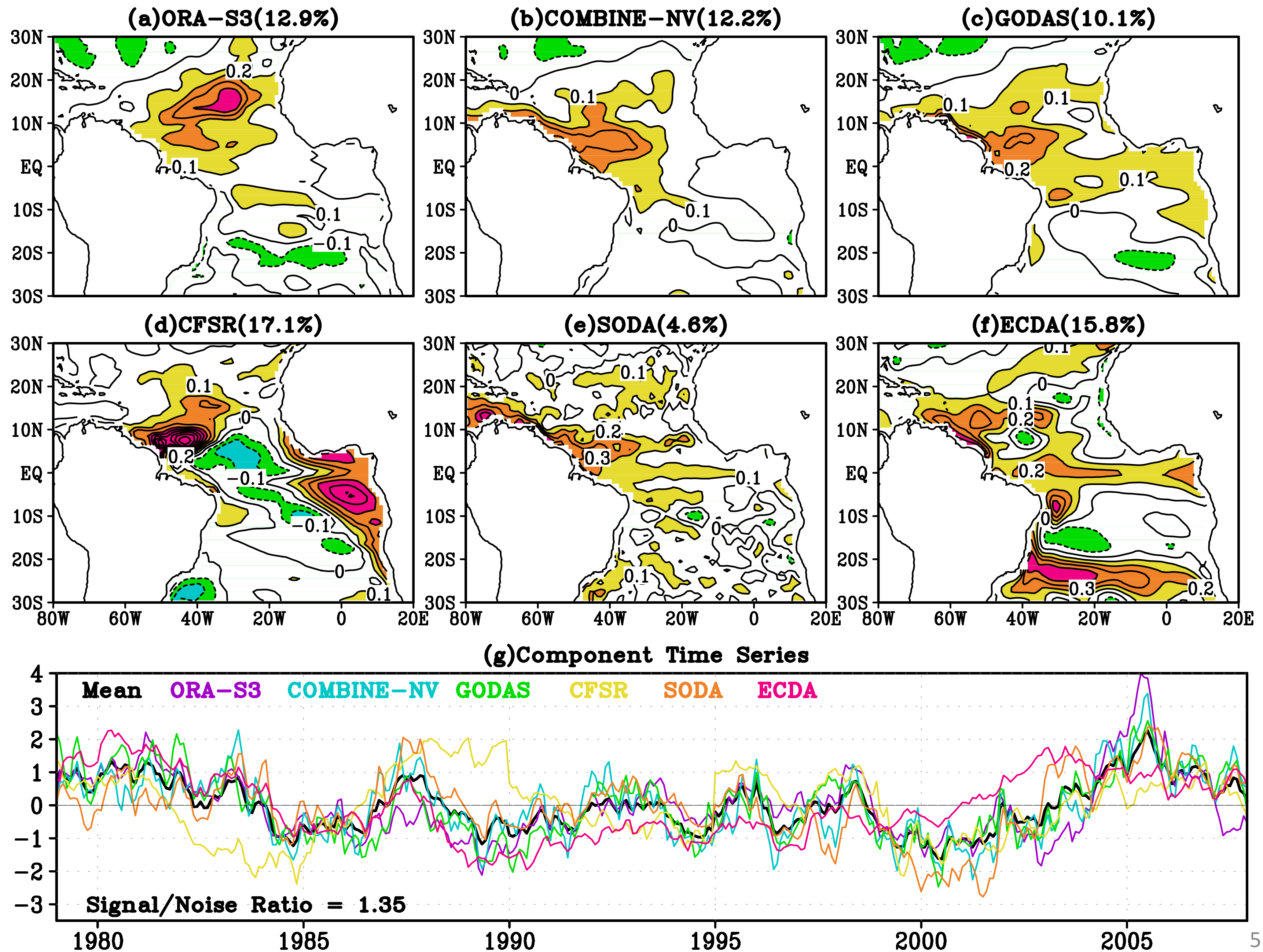
ODA Heat Content Uncertainty



$$\frac{\text{signal}}{\text{noise}} = \frac{\sigma^2_{EnsMean}}{\sigma^2_{Intra-Ens}}$$

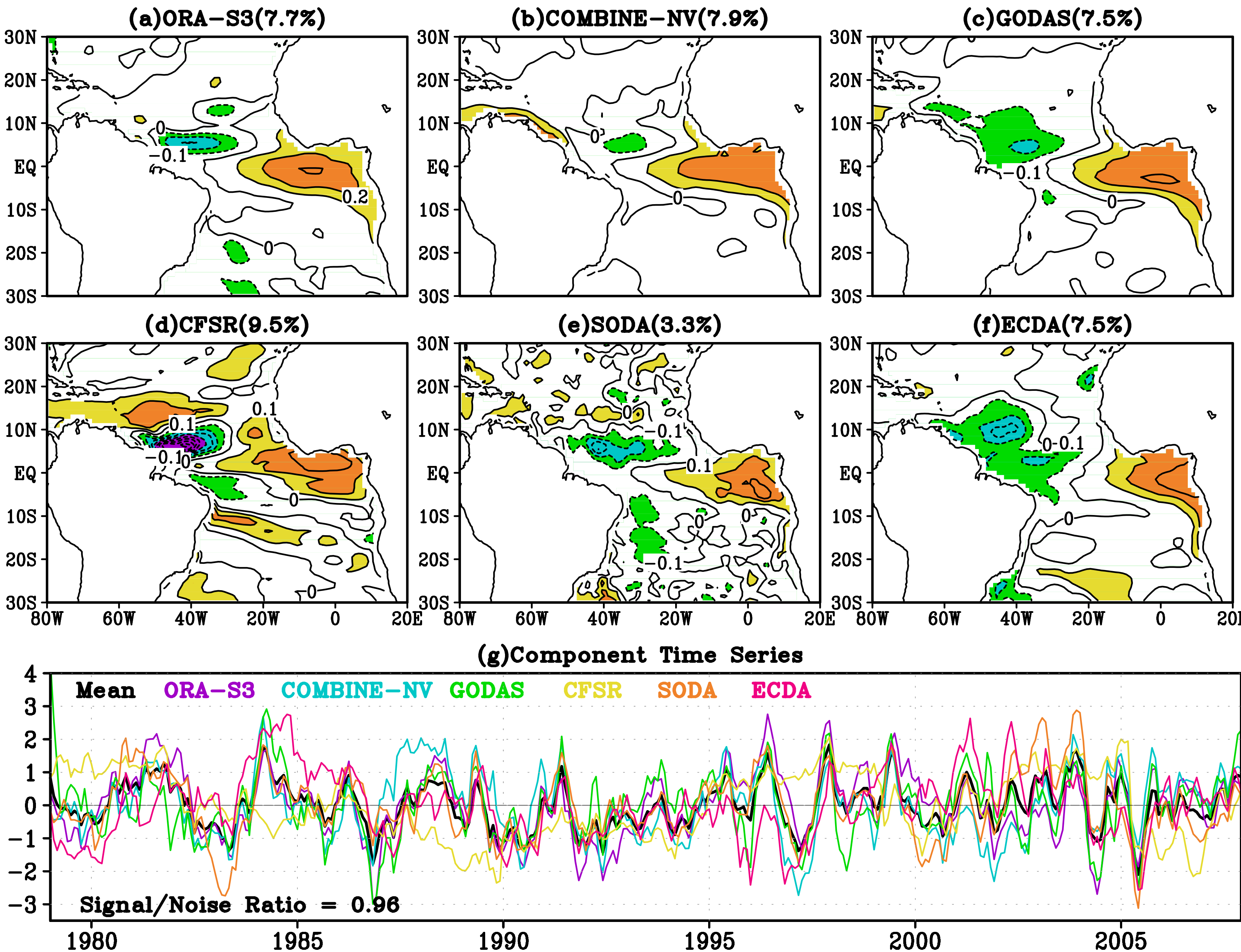
1979-2007

HCA: EOF1



(a)ORA-S3(12.9%)
(b)COMBINE-NV(12.2%)
(c)GODAS(10.1%)
(d)CFSR(17.1%)
(e)SODA(4.6%)
(f)ECDA(15.8%)
30N
20N
10N
EQ
10S
20S
30S
80W
60W
40W
20W
0
20E
(g)Component Time Series
Mean
ORA-S3
COMBINE-NV
GODAS
CFSR
SODA
ECDA
Signal/Noise Ratio = 1.35
1980
1985
1990
1995
2000
2005

HCA: EOF2


(a)ORA-S3(7.7%)
(b)COMBINE-NV(7.9%)
(c)GODAS(7.5%)
(d)CFSR(9.5%)
(e)SODA(3.3%)
(f)ECDA(7.5%)
30N
20N
10N
EQ
10S
20S
30S
80W
60W
40W
20W
0
20E
(g)Component Time Series
Mean
ORA-S3
COMBINE-NV
GODAS
CFSR
SODA
ECDA
Signal/Noise Ratio = 0.96
1980
1985
1990
1995
2000
2005

Problems: HCA spreads so significantly among different ODAs in the TA.

Questioning: results based on one ODA

1) How realistic is the characteristics of TAV derived from one of these reanalysis products?

2) How can we use analyses with this level of uncertainty to explain the physical processes of the TAV?

3) How much can we trust the predictions of TAV with dynamical forecast systems initialized from these analyses?

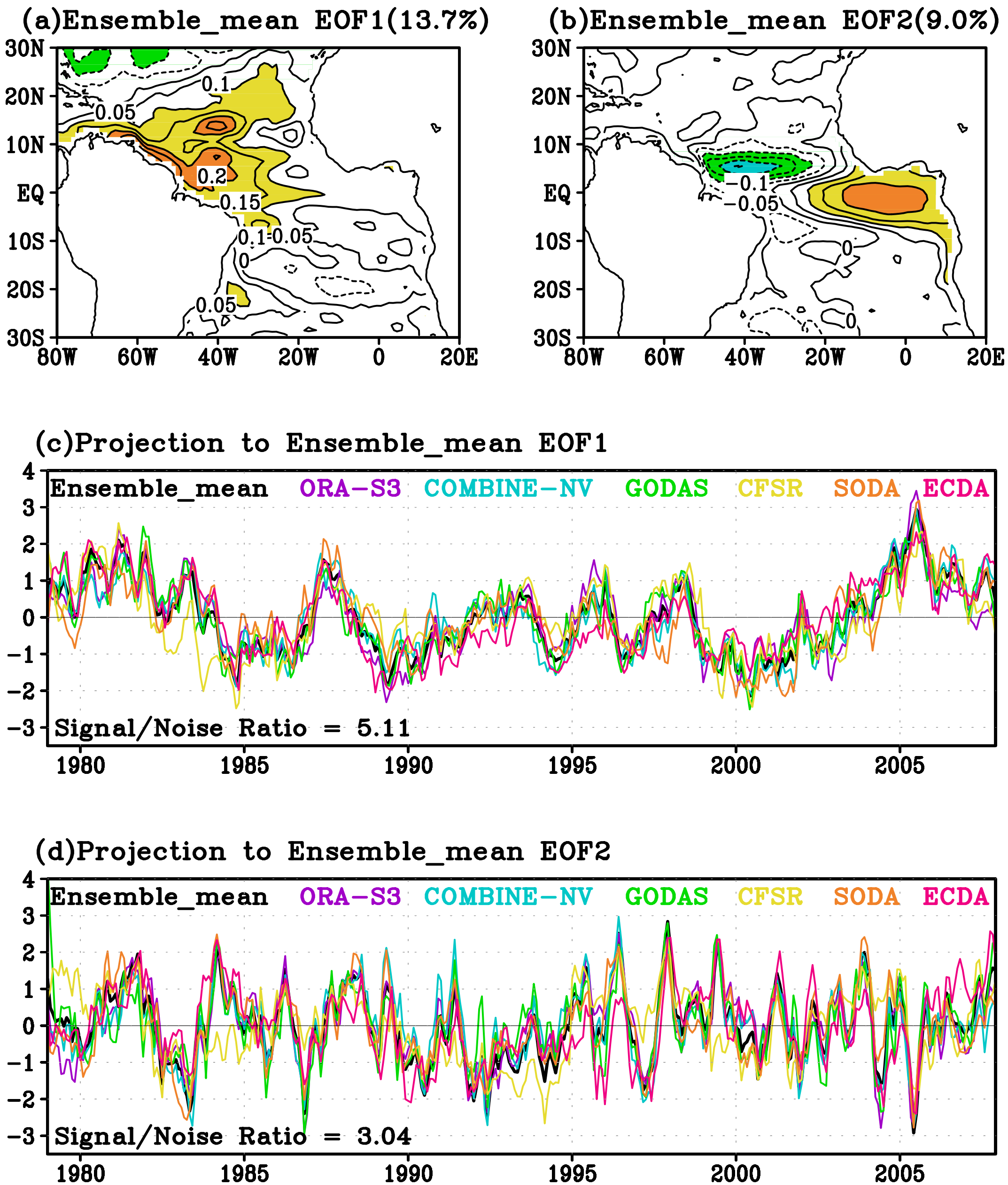
$$X_{total}=X_{signal}+X_{noise}$$

X_{signal} --- the interannual (or longer) variance in reality, which shows certain consistency among different reanalysis products due to similar ocean datasets assimilated into them.

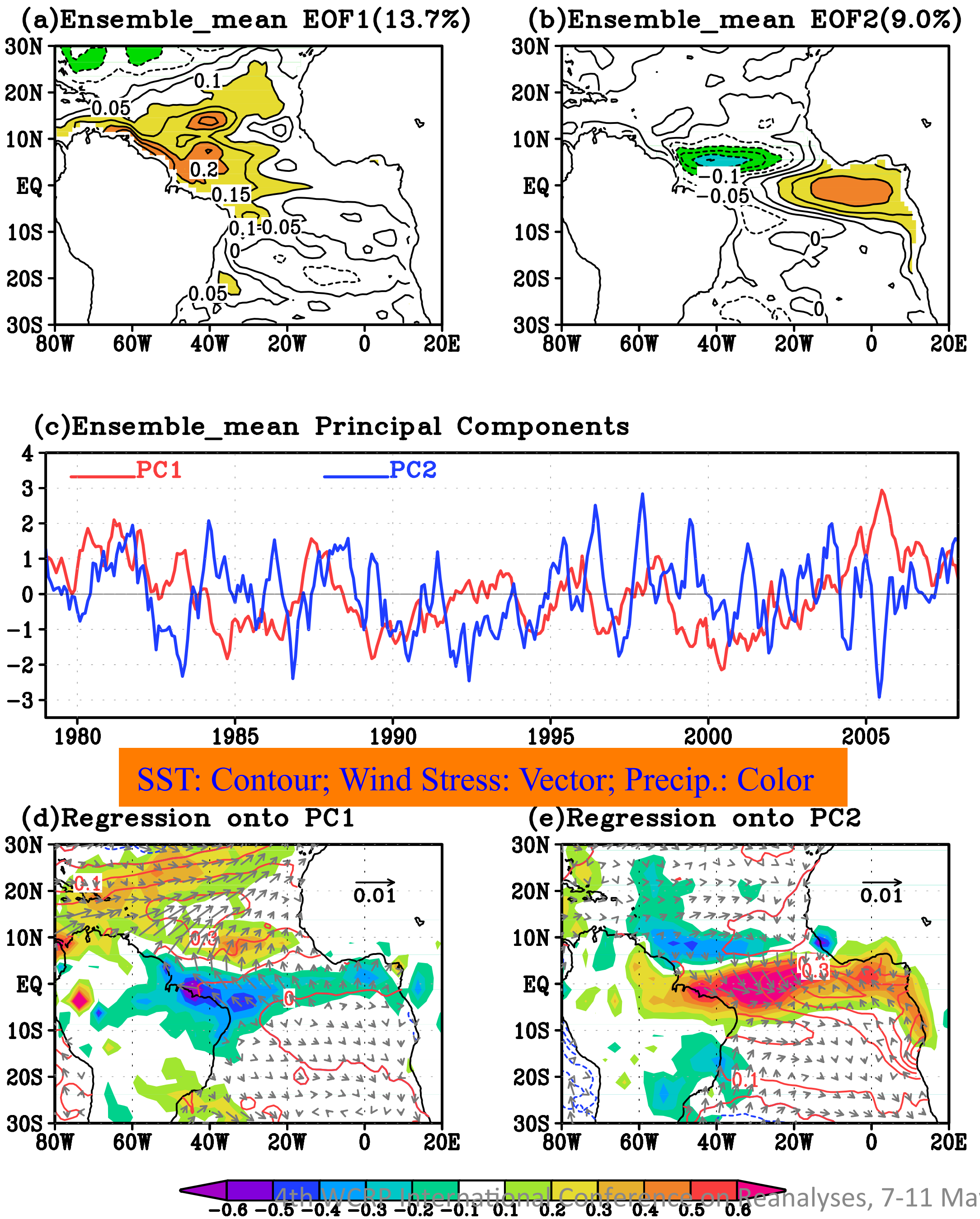
X_{noise} --- inherent in each individual product, which is associated with the errors in different atmospheric forcing, different ocean models, different assimilation schemes, and so on.

Claiming: Ensemble average of multiple ODAs is a useful method to improve estimating the changes of HCA.

Heat Content Anomaly

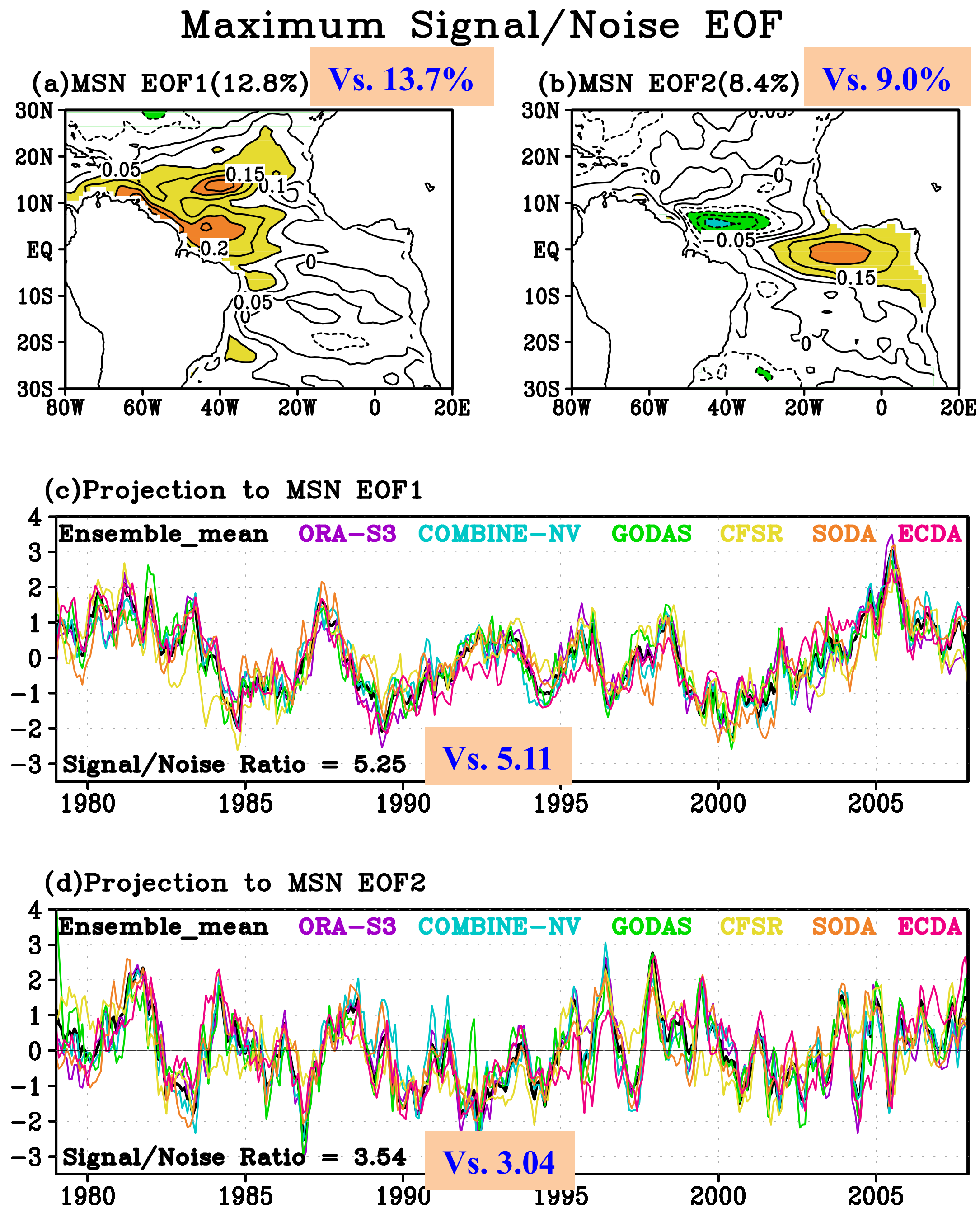


- **Ensemble average reduces noise effectively**
- **S/N ratio improves significantly**
- ***Signal exists in all analyses (masked by high internal noise)***



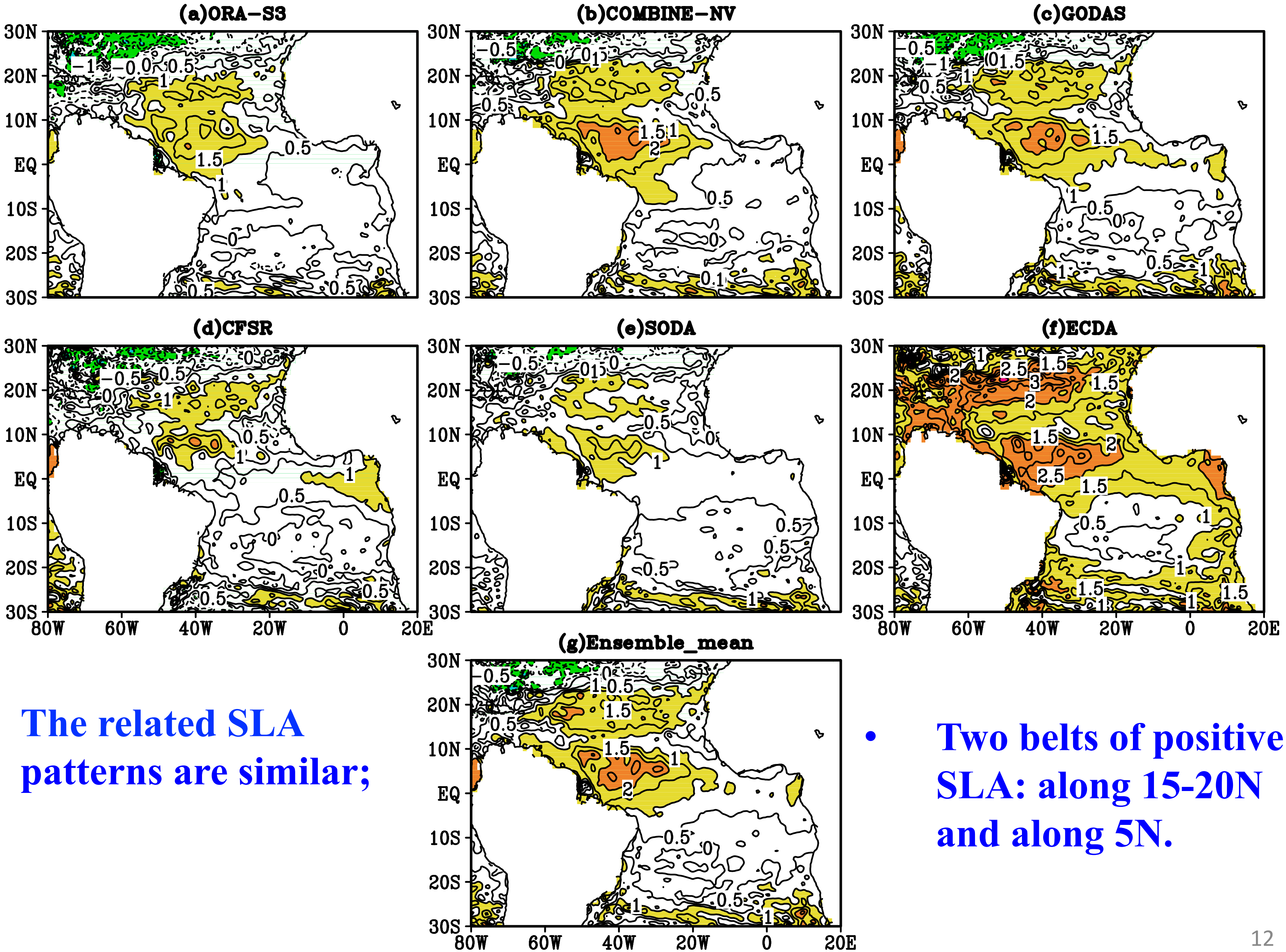
- **Leading EOF patterns become physically meaningful**

- **EOF1- Meridional mode**
- **EOF2- Zonal mode**



- **Prove that the noise in the Ensemble_mean analysis is reduced to an acceptable level.**

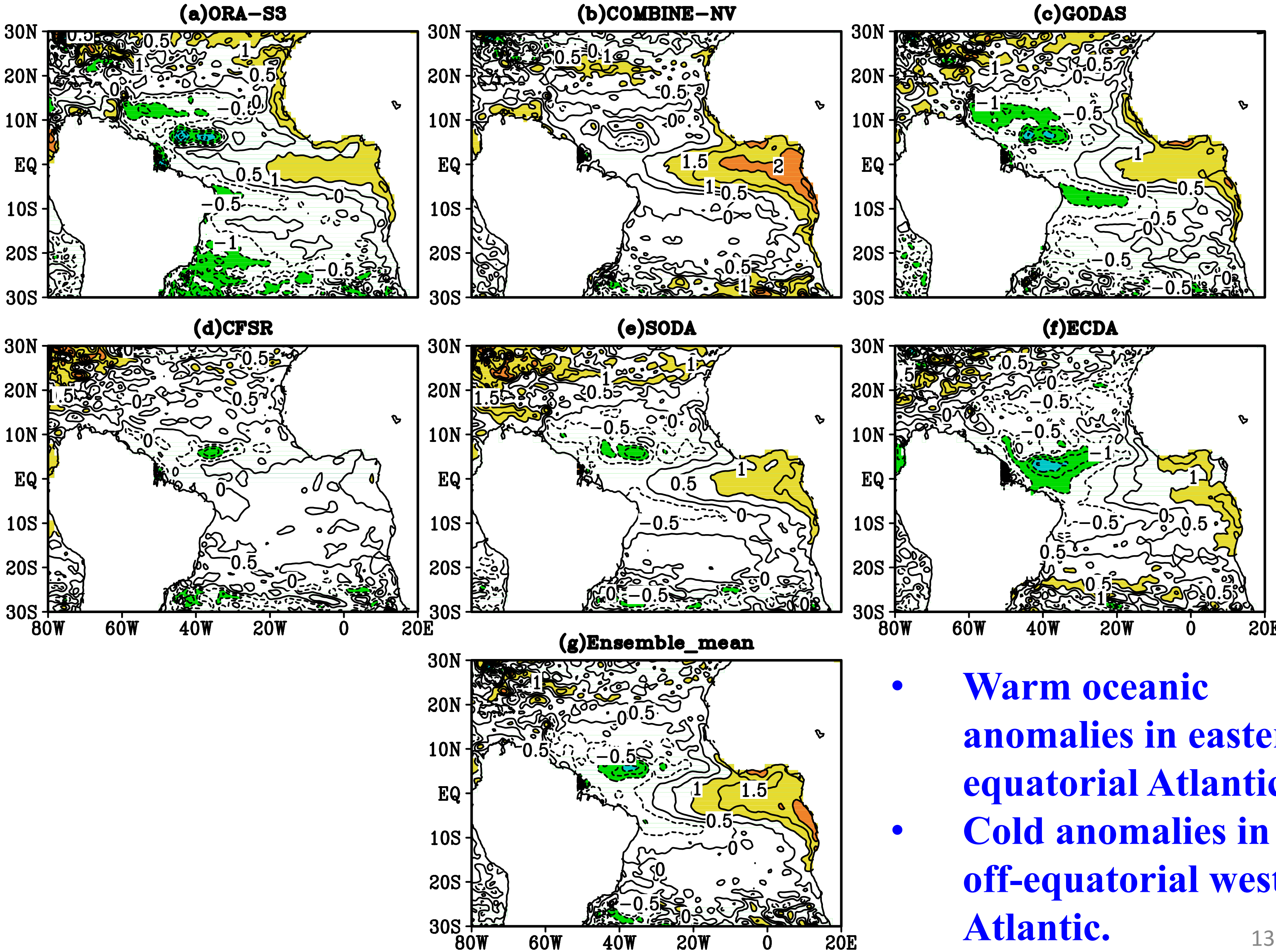
Regression Map of SLA onto PC1



- The related SLA patterns are similar;

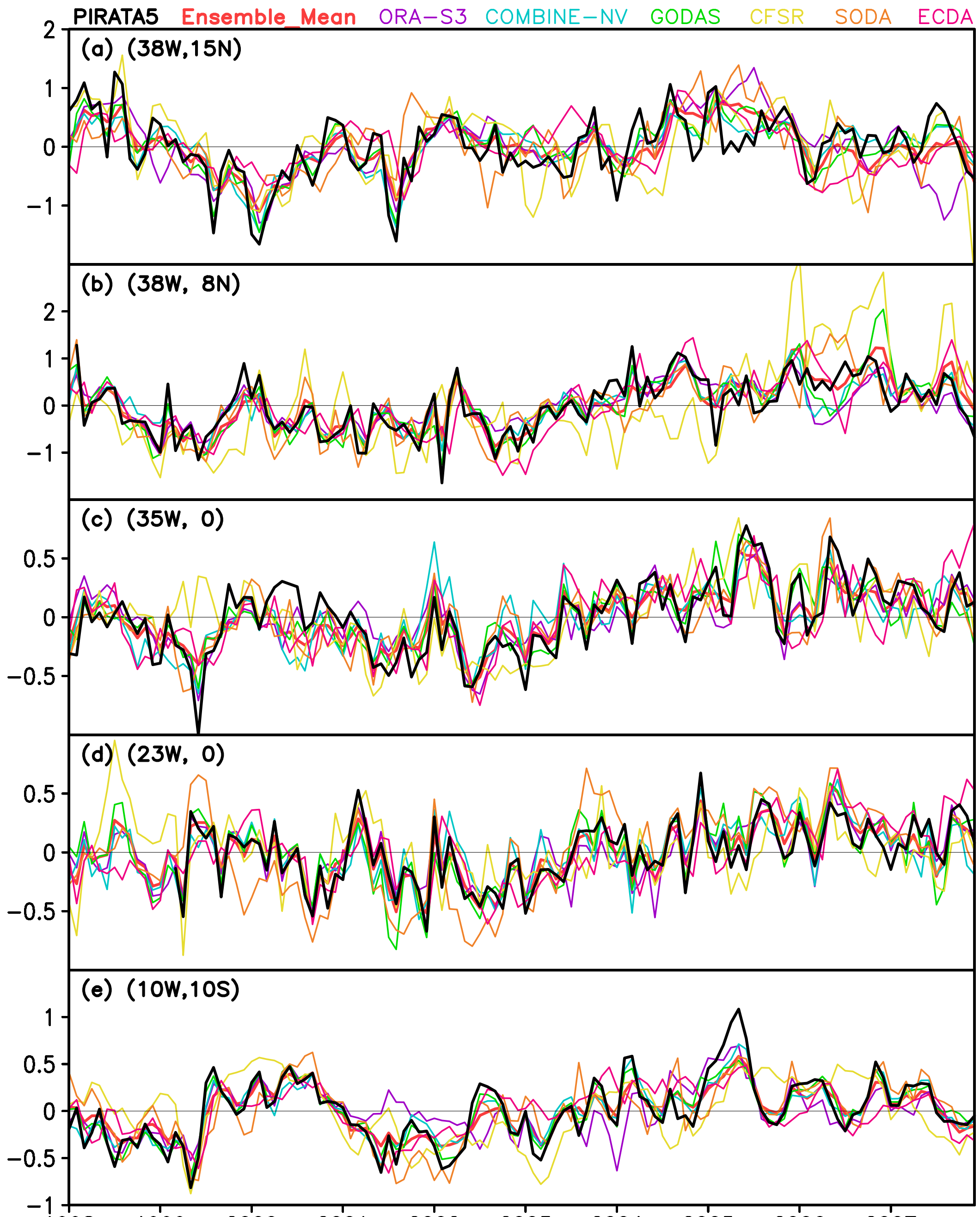
- Two belts of positive SLA: along 15-20N and along 5N.

Regression Map of SLA onto PC2



- **Warm oceanic anomalies in eastern equatorial Atlantic;**
- **Cold anomalies in the off-equatorial western Atlantic.**

HCA Time Series: vs. PIRATA



Quantitative Comparisons vs PIRATA moorings

Table 2 Anomaly correlations between the time series of HC anomalies from PIRATA mooring datasets and those from six ocean products and Ensemble_mean dataset

	Ensemble_Mean	ORA-S3	COMBINE-NV	GODAS	CFSR	SODA	ECDA
(38 W,15 N)	0.74	0.55	**0.81**	**0.83**	0.58	0.47	0.30
(38 W,8 N)	0.82	0.76	**0.86**	0.82	0.49	0.74	0.61
(35 W,0)	0.83	0.77	0.66	**0.84**	0.57	0.72	0.59
(23 W,0)	0.91	0.81	0.78	0.86	0.68	0.72	0.65
(10 W,10S)	0.90	0.71	**0.95**	**0.94**	0.54	0.71	0.64

The correlations lager than those in EM analysis are shown in boldface

Table 3 Same as Table 2 but for root mean square deviations (RMSDs)

	Ensemble_Mean	ORA-S3	COMBINE-NV	GODAS	CFSR	SODA	ECDA	Ensemble spread
(38 W,15 N)	0.37	0.51	**0.32**	**0.30**	0.53	0.55	0.57	0.29
(38 W,8 N)	0.34	0.38	**0.30**	0.37	0.87	0.44	0.53	0.36
(35 W,0)	0.17	0.20	0.24	0.17	0.28	0.22	0.27	0.15
(23 W,0)	0.11	0.16	0.17	0.15	0.21	0.27	0.23	0.16
(10 W,10S)	0.16	0.24	**0.12**	**0.12**	0.33	0.25	0.26	0.16

The ensemble spread among six ocean products is also shown in the last column. Units are °C. The RMSDs smaller than those in EM analysis are shown in boldface

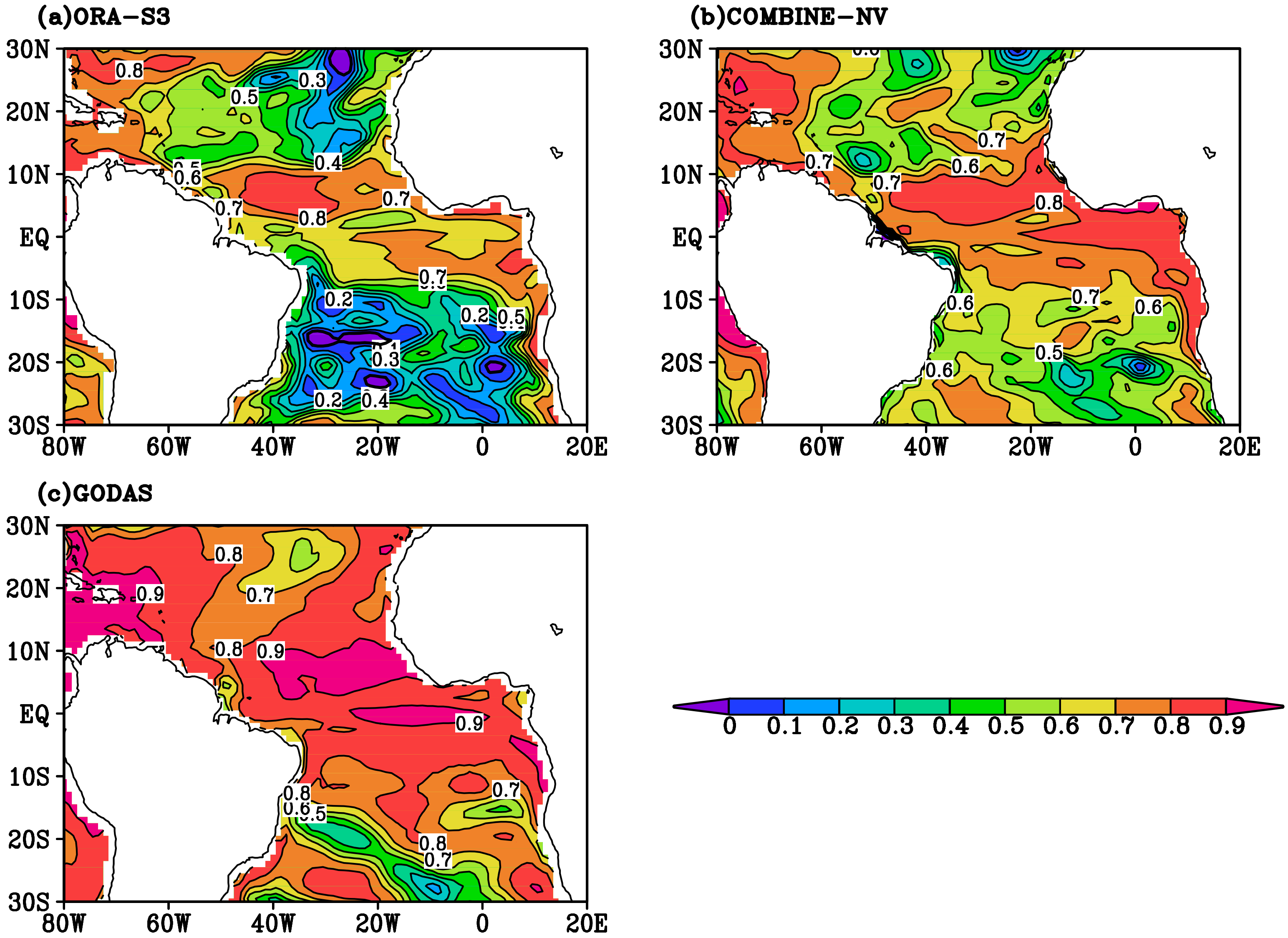
Summary

- **There is considerable uncertainty in HCA from different analyses, especially in the tropical Atlantic;**

- **Ensemble average of multiple ODAs is a useful method to improve estimating the changes of HCA.**

Zhu, J., B. Huang, and M. A. Balmaseda, 2012: ***Clim. Dyn.***, doi: 10.1007/s00382-011-1189-8 (published online)

Correlation: HCA vs. SLA



HCA Correlation: vs. Aviso