What, how, and where can ocean salinity be an indicator of the ocean water cycle?

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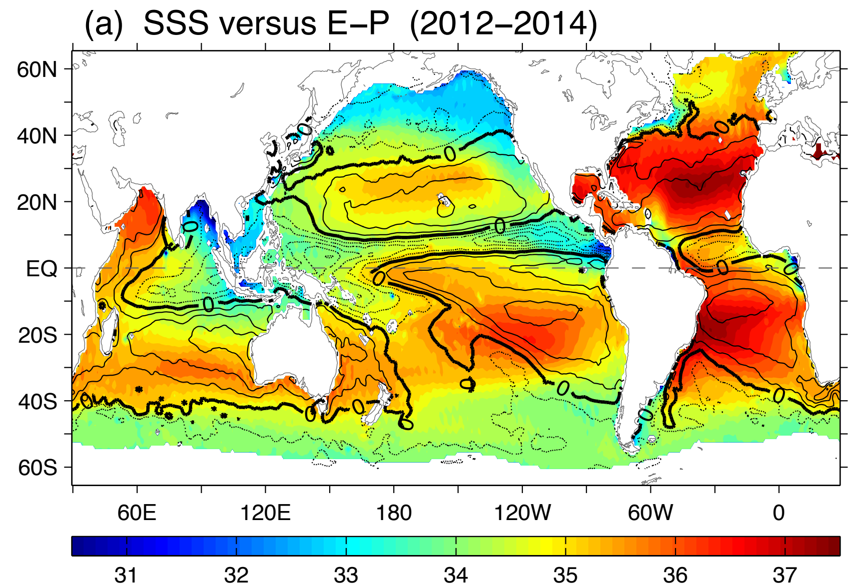
Main Questions:

- The use of sea surface salinity (SSS) as a measure of the ocean water cycle has long been suggested. But where and how this can be implemented?
- The relationship between SSS and E-P is not linear. Ocean dynamical processes play an important role in advecting & diffusing SSS anomalies. Is there any region where the influence of ocean processes on salinity is comparably small?

Aquarius SSS versus OAFlux - GPCP



Here we use 9 reanalyses to design and test the use of the ocean salinity as a measure of the uncertainty in the E-P products. Two questions are addressed:

(1) Are the uncertainties in the E-P products regime dependent? That is, are the E-P products most uncertain in the P-dominating regimes or E-dominating regimes?

(2) What aspects of uncertainties can be evaluated by salinity observations? That is, where ocean salinity variability is most sensitive to E-P, the P- or E- dominating regimes?

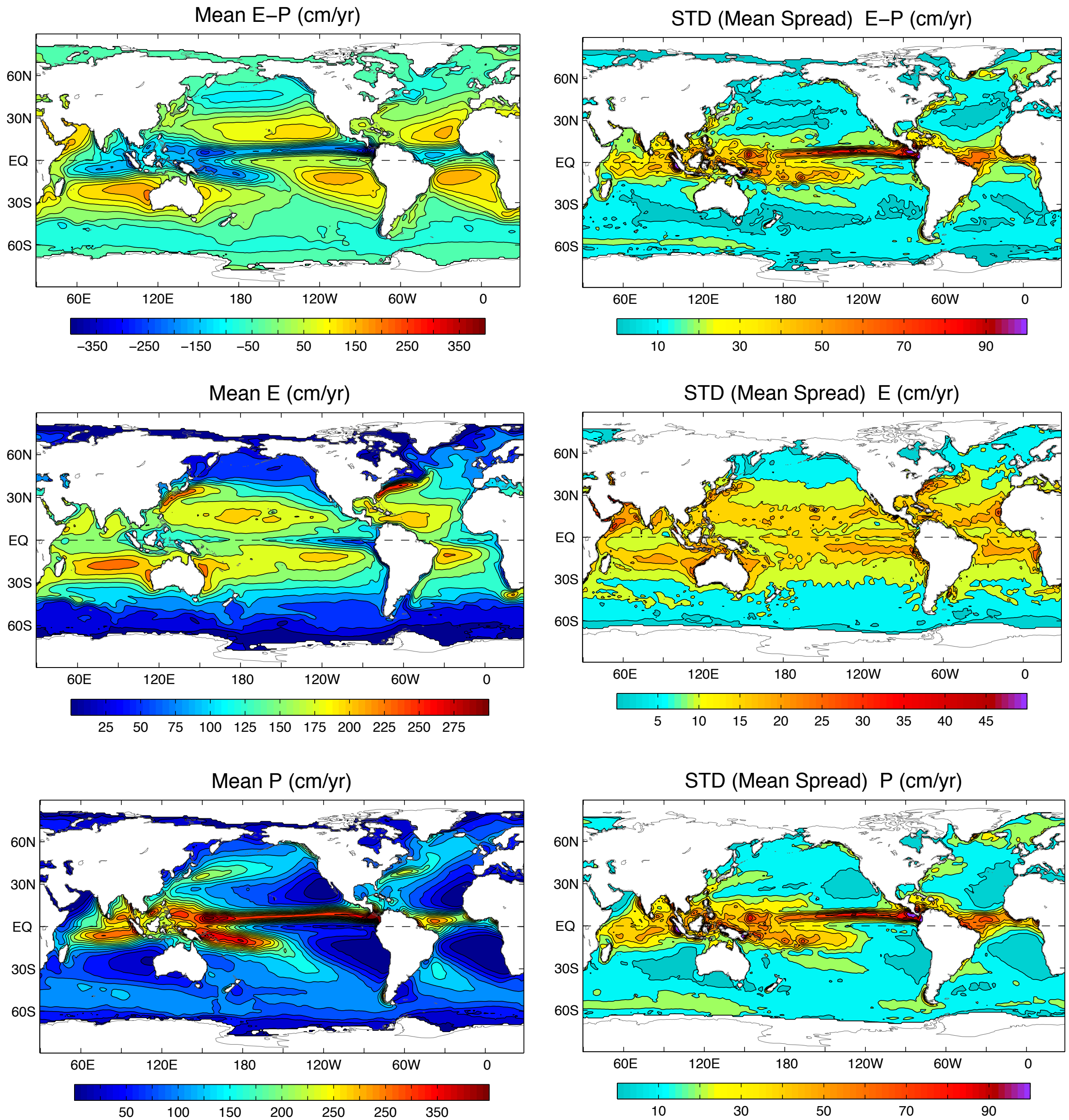
Product list: 9 reanalyses, 2 satellite-based

Atmospheric Reanalyses (E and P)							
Name	**Source**	**Period**	**Temporal Resolution**	**Spatial Resolution**	**Model Resolution**	**Data assimilation Scheme**	**Reference**
NCEP1	NCEP, NCAR	1948/01 onward	6 hourly	1.875°x1.875°	T62, 28 levels	3DVAR	Kalnay et al. (1996)
NCEP2	NCEP, DOE	1979/01 onward	6 hourly	1.875°x1.875°	T62, 28 levels	3DVAR	Kanamitsu et al. (2002)
CFSR	NCEP	1979/01 onward	hourly	0.5°x0.5°	T382, 64 levels	3DVAR	Saha et al. (2010)
ERA-40	ECMWF	1957/09 to 2002/08	6 hourly	1.125°x1.125°	T159, 60 levels	3DVAR	Uppala et al. (2015)
ERA-interim	ECMWF	1979/01 onward	6 hourly	0.7°x0.7°	T255, 60 levels	4DVAR	Dee et al. (2011)
ERA-20C	ECMWF	1900/01 to 2010/12	3 hourly	1.125°x1.125°	T159, 37 levels	4DVAR	Poli et al. (2013)
MERRA	NASA	1979/01 onward	3 hourly	0.5°x0.667°	0.5°x0.667°, 72 levels	Incremental Analysis Updates	Rienecker et al. (2011)
JRA-55	JMA	1958/01 onward	3 hourly	0.55°x0.55°	T319, 60 levels	4DVAR	Kobayashi et al. (2015)
20CR (v2c)	NOAA ESRL, CIRES CDC	1950/12 to 2011/12	6 hourly	2°x2°	T62, 28 levels	Ensemble Kalman Filter	Compo et al. (2011)

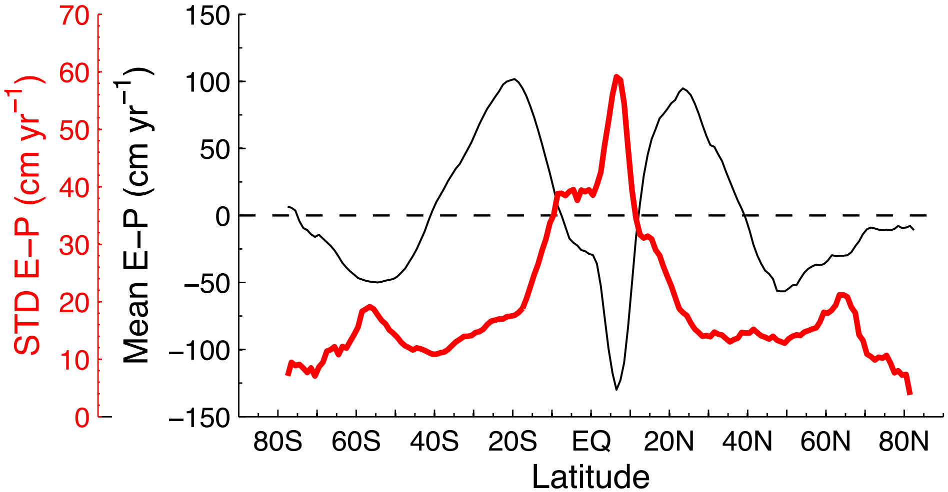
Satellite-based products							
Name	**Source**	**Period**	**Temporal Resolution**	**Spatial Resolution**	**Variable**	**Data Analysis Scheme**	**Reference**
OAFlux	WHOI	1958/01 onward	daily	1°x1°	E	Objective Synthesis	Yu et al. (2008)
GPCP	NASA	1979/01 onward	daily	2.5°x2.5°	P	Multi-sensor merging	Adler et al. (2003)
CMAP	NOAA	1979/01 onward	daily	2.5°x2.5°	P	Multi-sensor merging	Xie and Arkin. (1997)

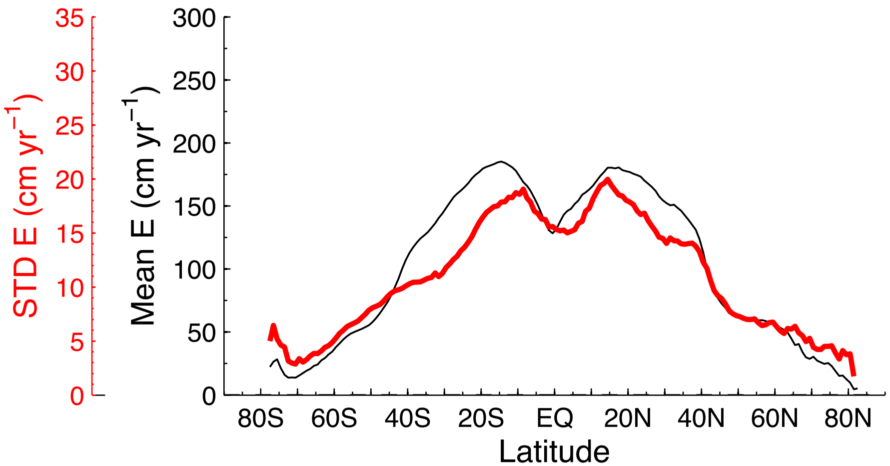
The study focuses on the period from 1979 to 2014.

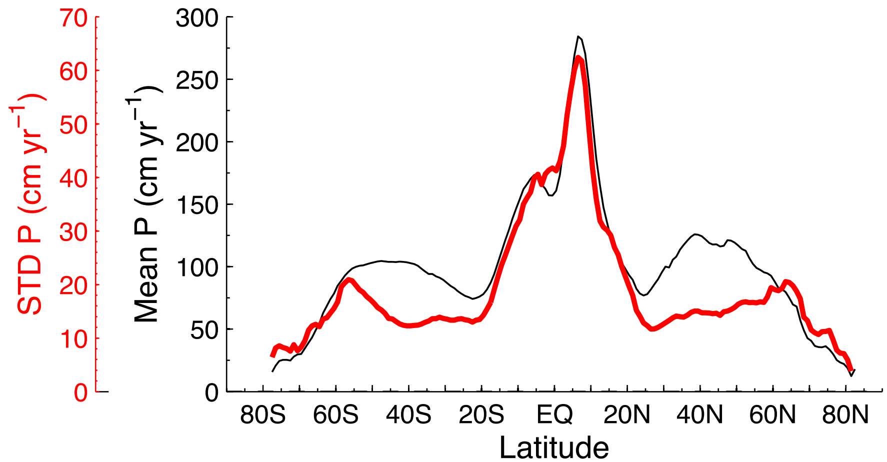
How and where do E-P products differ?
In tropical rain bands



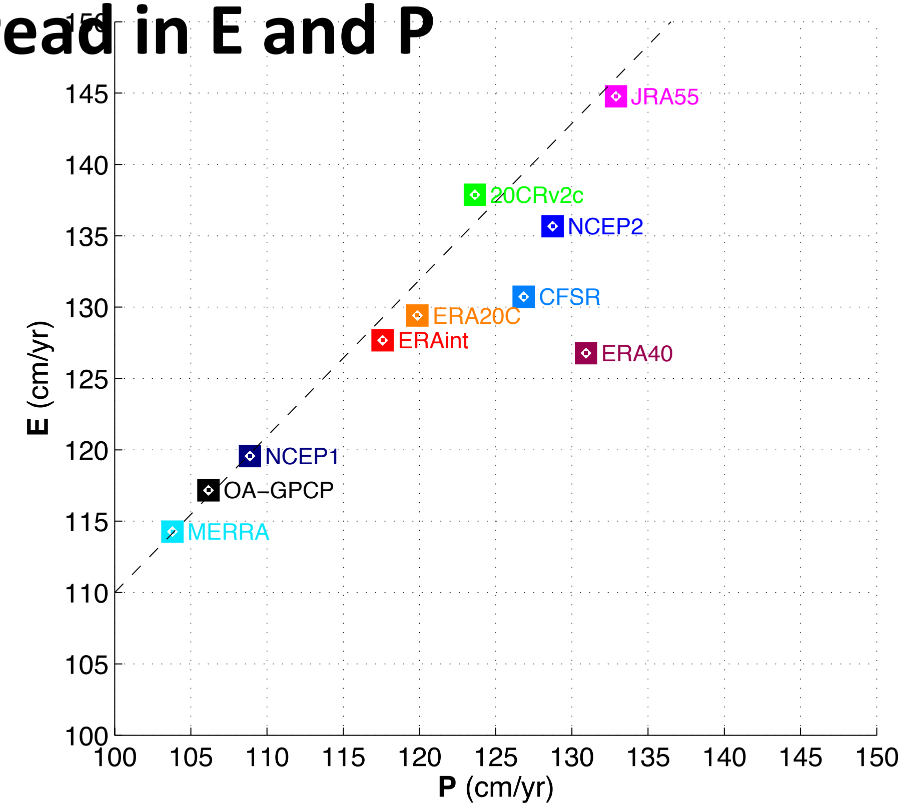
Zonally averaged time-mean vs spread: largest in tropical rain bands



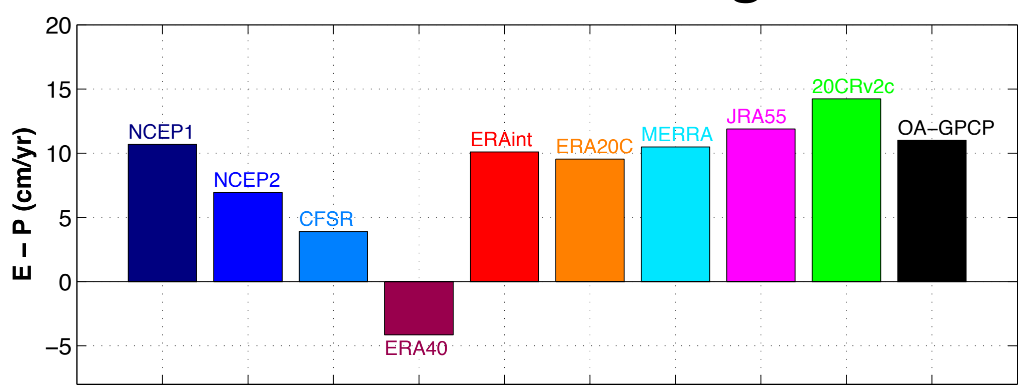




Spread in E and P



Global freshwater budgets

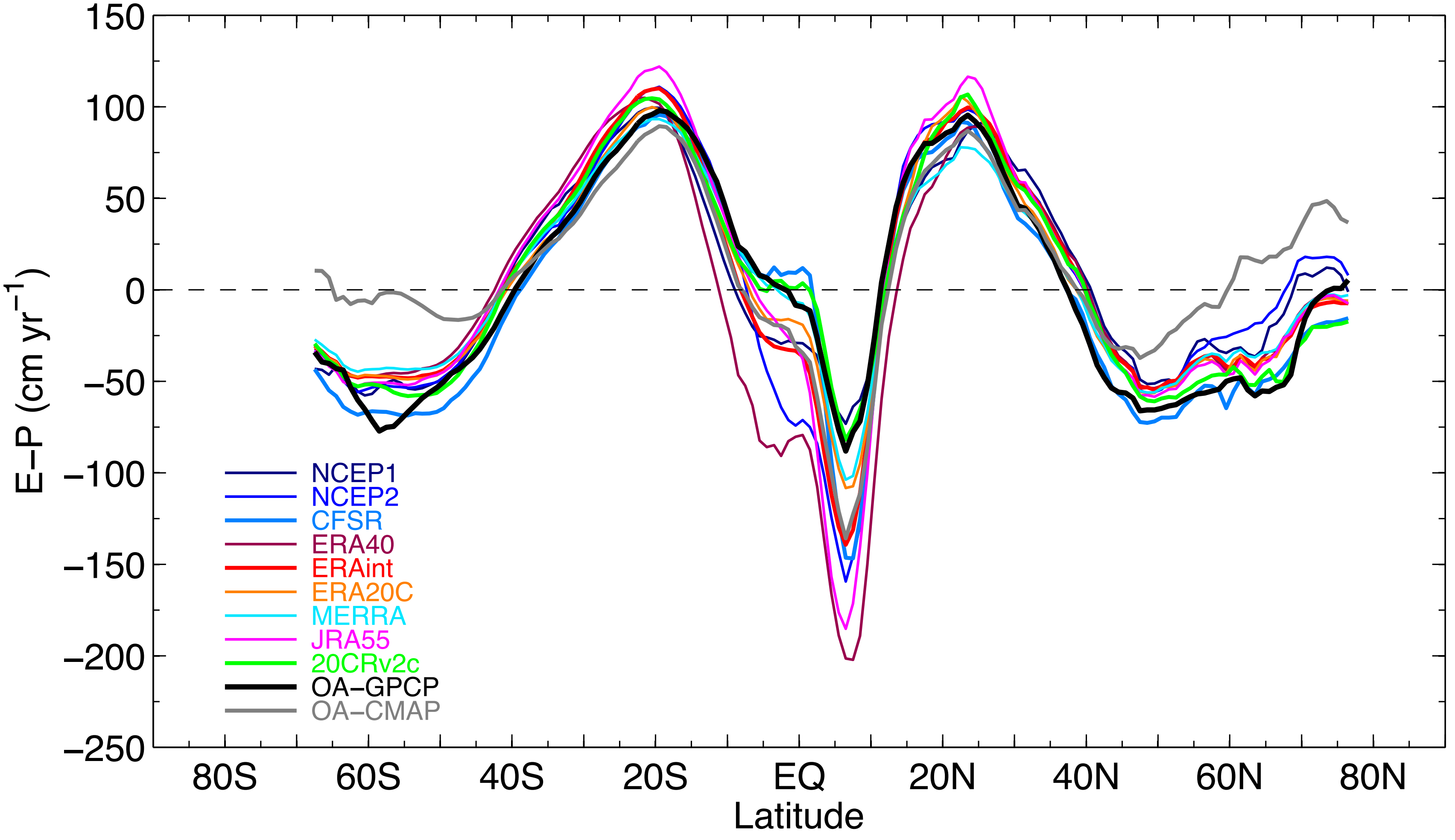


Global budgets of E-P, E and P, E/P ratio

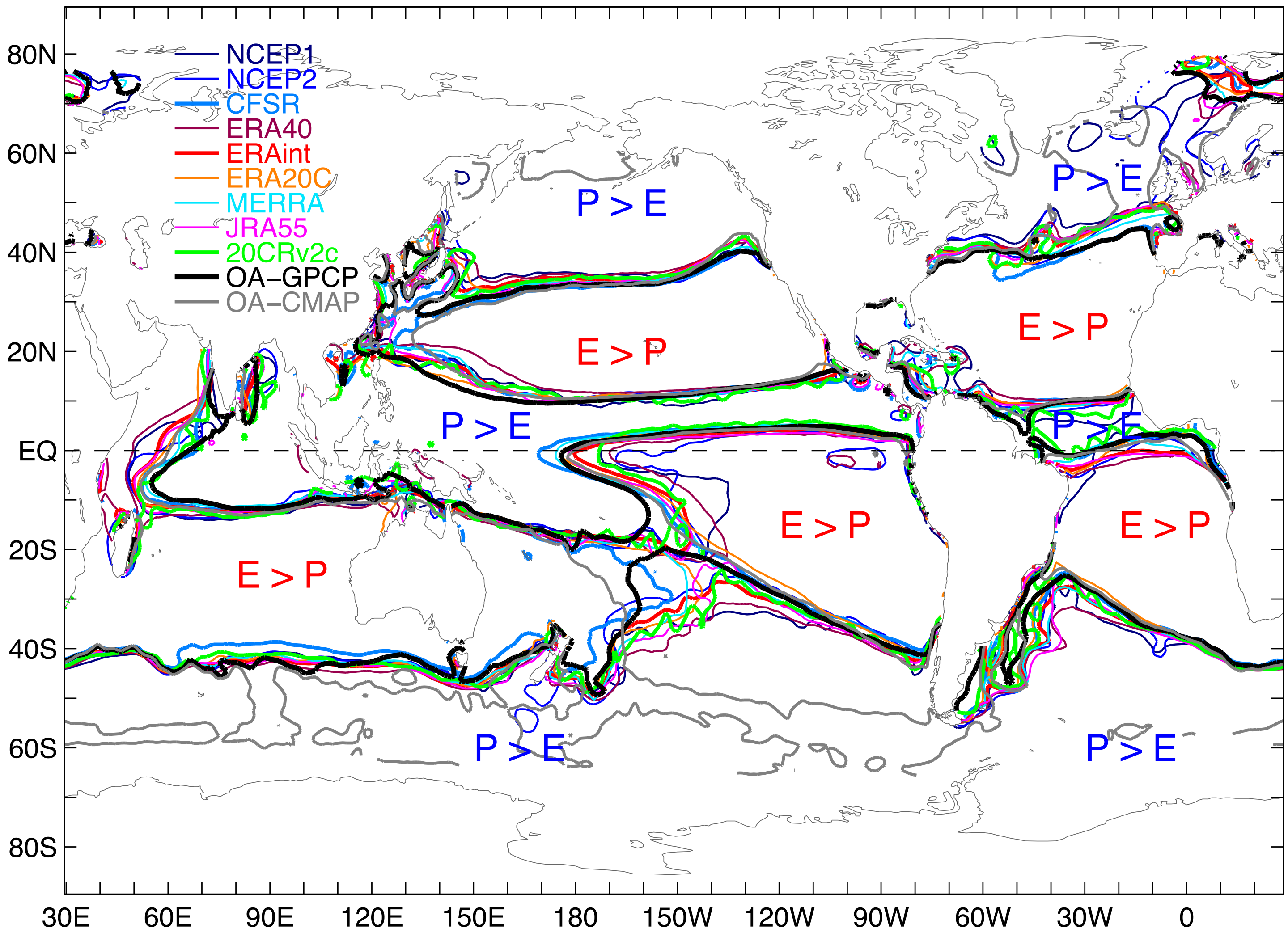
Products \ Properties	E	P	E-P	E/P	(E-P)/E*100 (%)
NCEP1	119.6	108.9	10.7	1.10	8.9
NCEP2	135.7	128.7	6.9	1.05	5.1
CFSR	130.7	126.8	3.9	1.03	3.0
ERA40	126.8	130.9	-4.2	0.97	-3.3
ERA-interim	127.7	117.6	10.1	1.09	7.9
ERA-20C	129.4	119.9	9.6	1.08	7.4
MERRA	114.3	103.8	10.5	1.10	9.2
JRA55	144.8	132.6	11.9	1.09	8.2
20CR	137.9	123.6	14.2	1.12	10.3
OAFlux/GPCP	117.2	106.2	11.0	1.10	9.4
OAFlux/CMAP	117.2	105.5	11.7	1.11	10.0
Ensemble Mean	127.5	117.4	10.1	1.09	7.9
STD (STD/Mean*100%)	10.2 (7.6%)	10.6 (9.2%)	2.8 (28.5%)	0.03 (2.5%)	2.2 (27.4%)

All have a similar E/P ratio

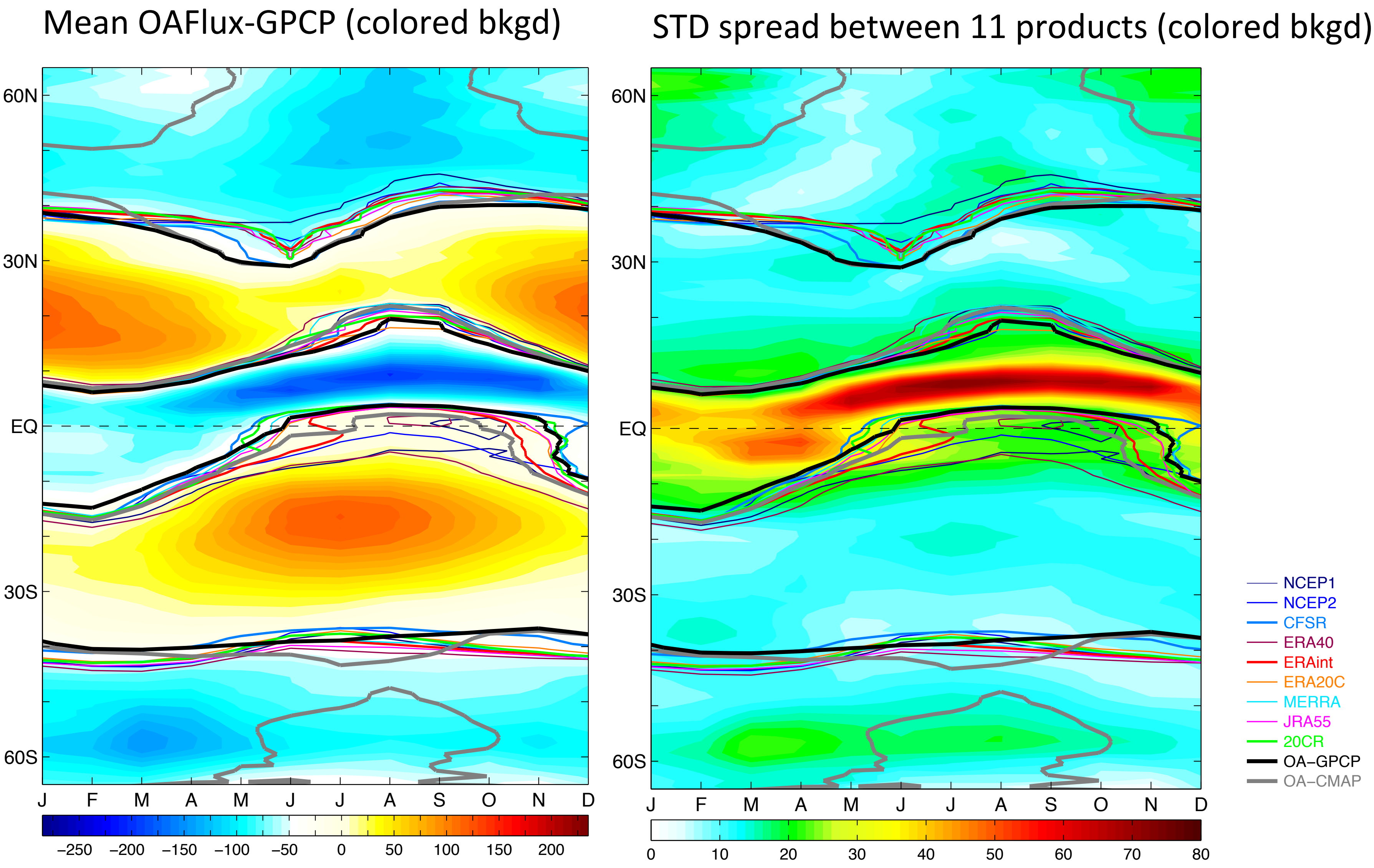
Product differences in zonal mean averages



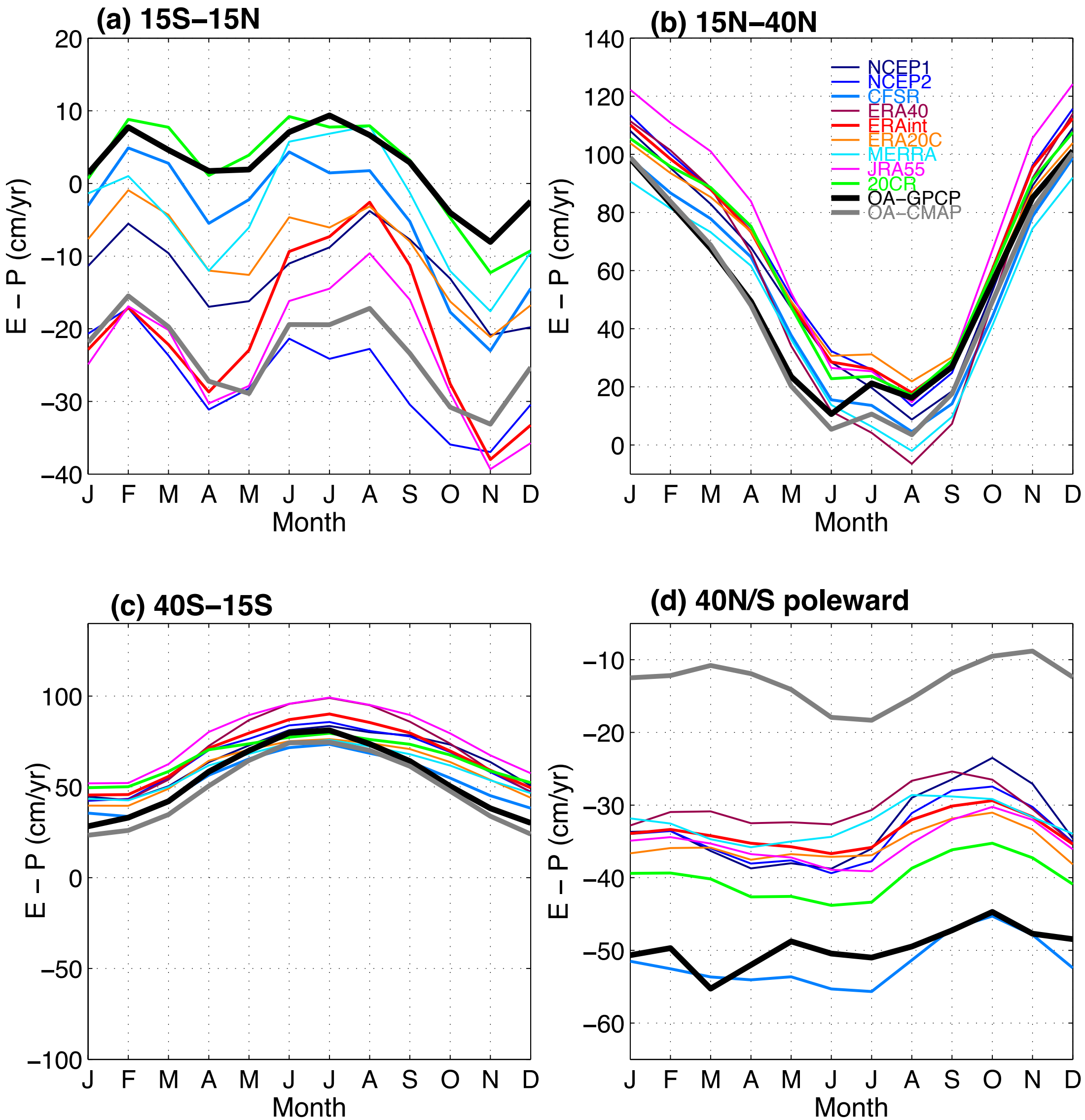
E-P zero lines



Seasonal variations of wet/dry zones

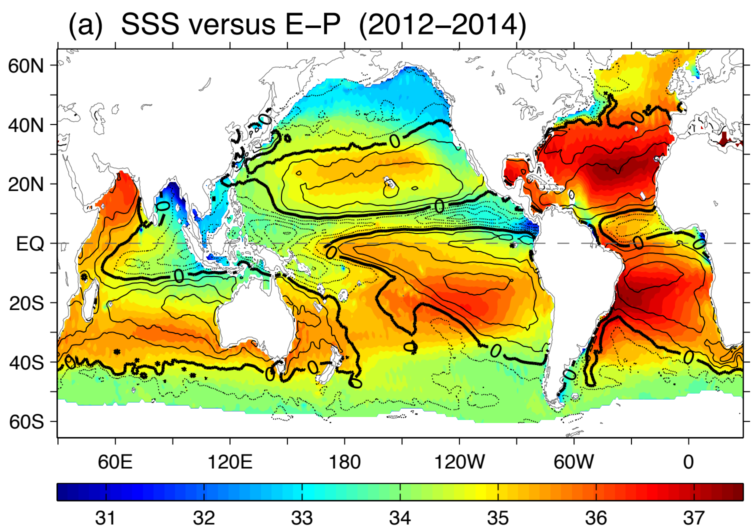


Seasonal variations of E-P in latitudinal bands

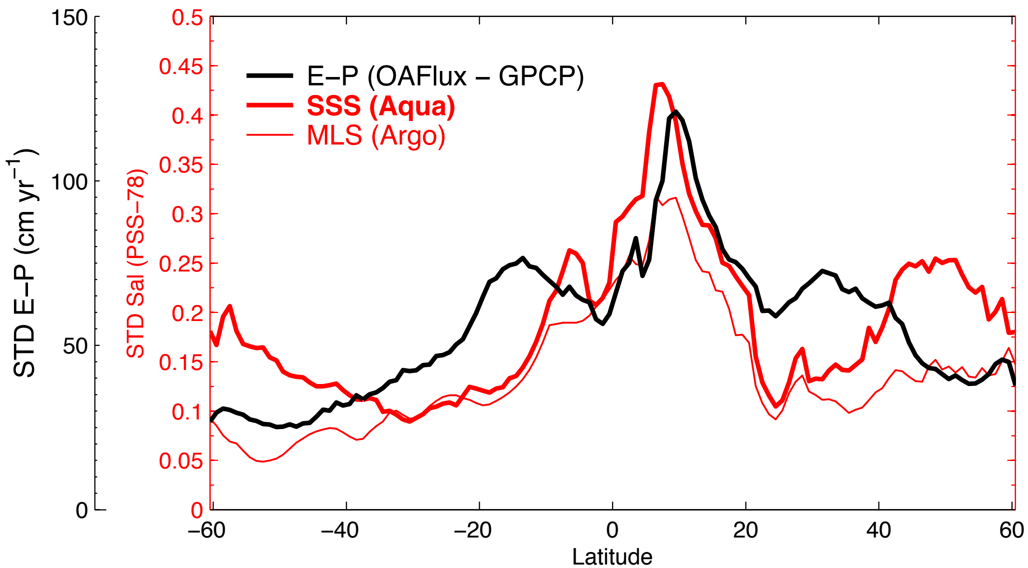


The E-P estimates are most uncertain in the tropical wet zone. In the high-latitude wet zones, the reanalyses tend to be comparable to each other.

Can Ocean salinity to help reduce the E-P uncertainty in the tropical wet zone?

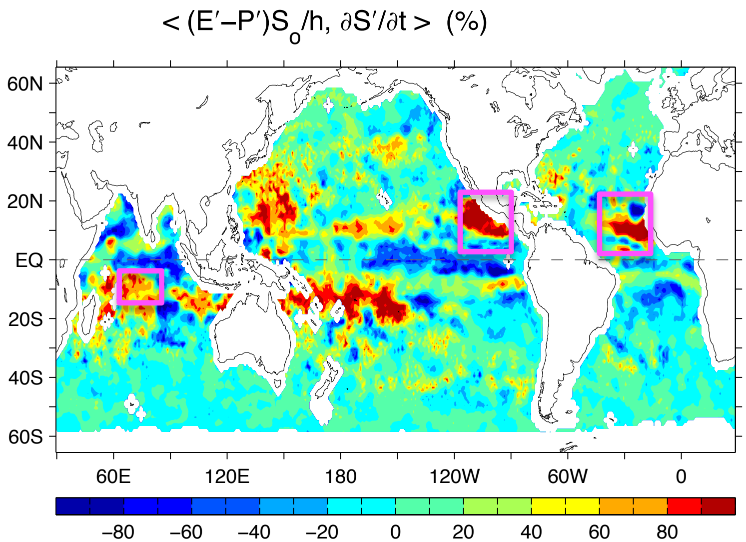


Seasonal STD

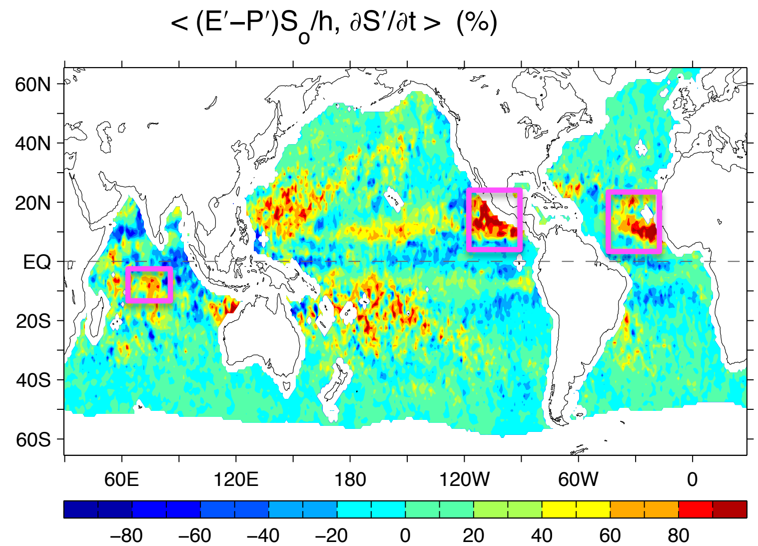


Percentage of SSS variability explained by E-P

Argo, OAFlux-GPCP



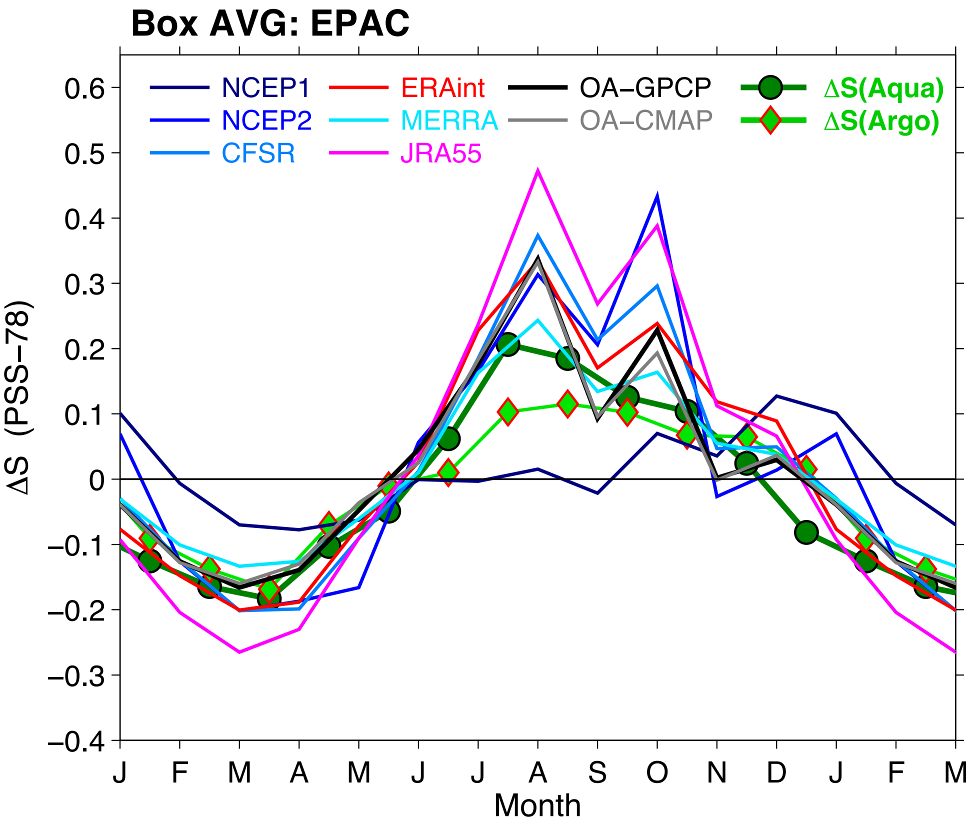
Aquarius, OAFlux-GPCP

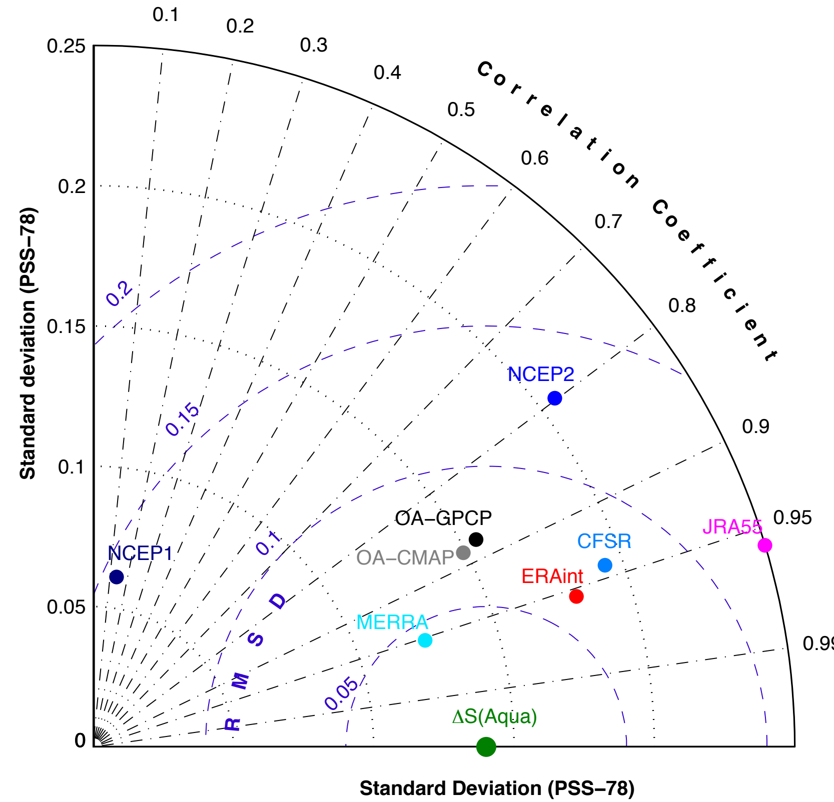


(Adapted from Yu 2011; 2014)

$$\frac{\partial S'}{\partial t} \approx \frac{S_0(E'-P')}{\bar{h}} - \bar{\mathbf{U}} \cdot \nabla S' - \mathbf{U}' \cdot \nabla \bar{S} - \frac{(\Gamma(w_e)(S-S_b))'}{\bar{h}} + \kappa \nabla^2 S' \qquad (1)$$

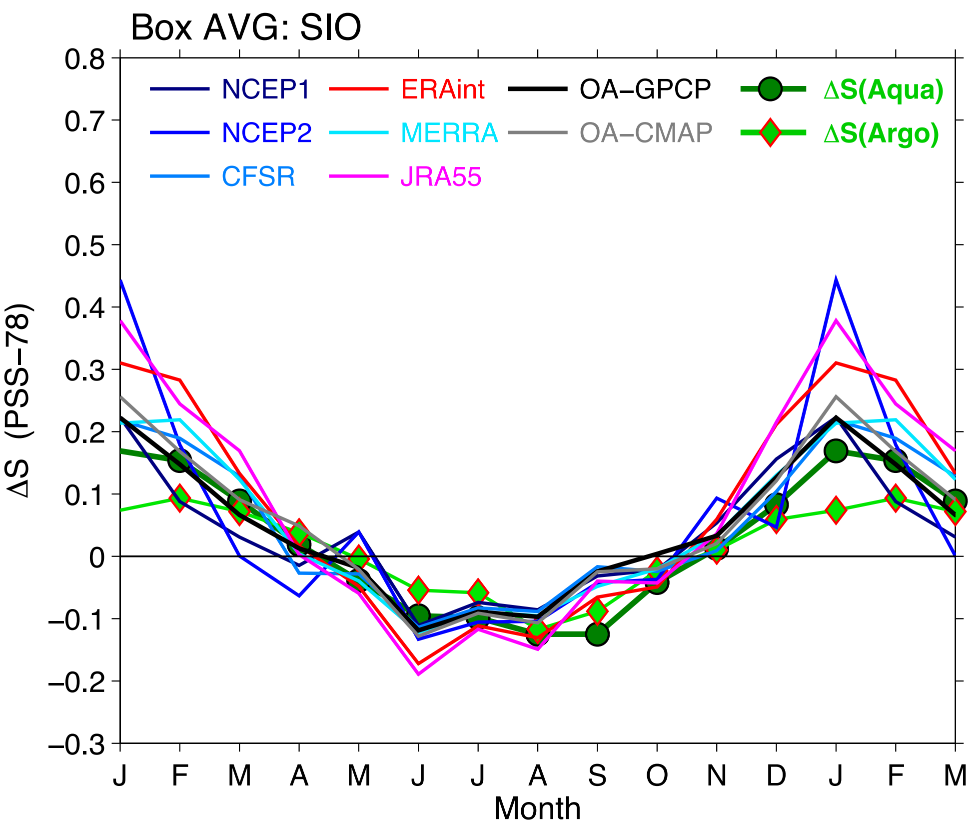
The eastern Pacific box

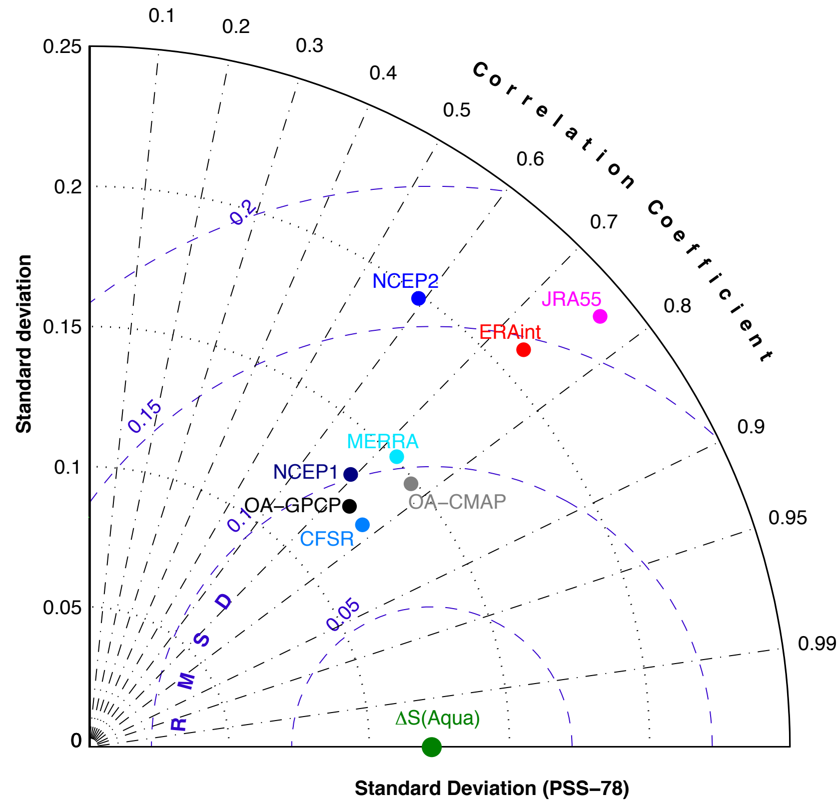




The seasonal STD produced by JRA55 and NCEP2 are above normal

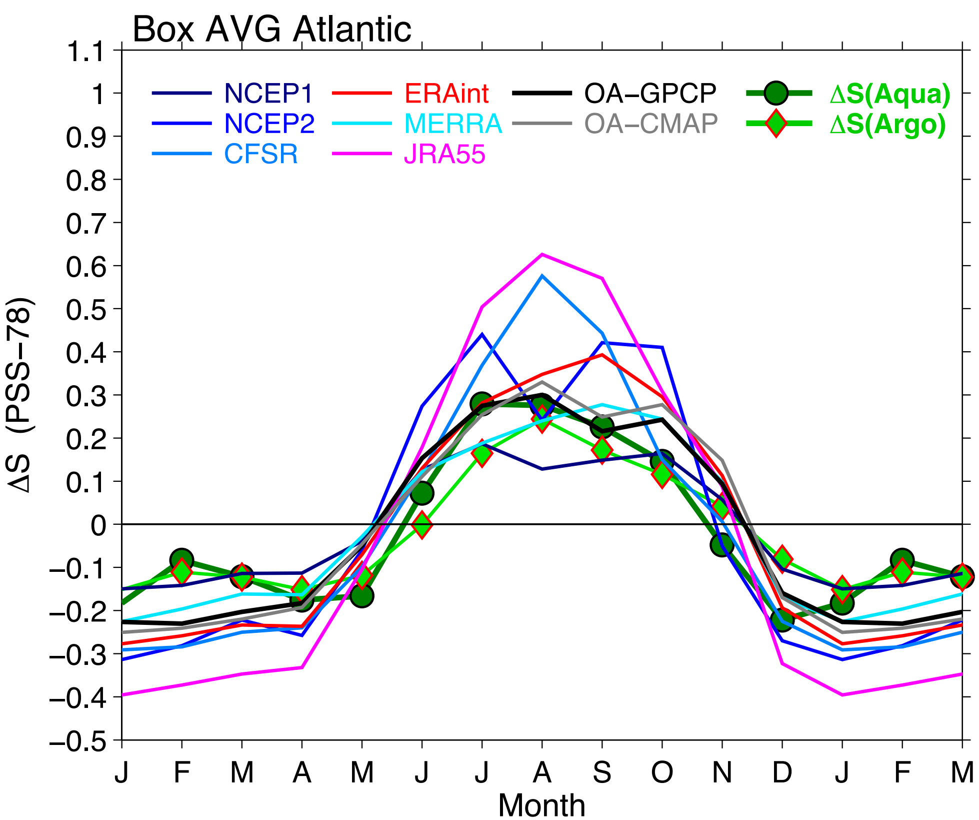
The southern IO box

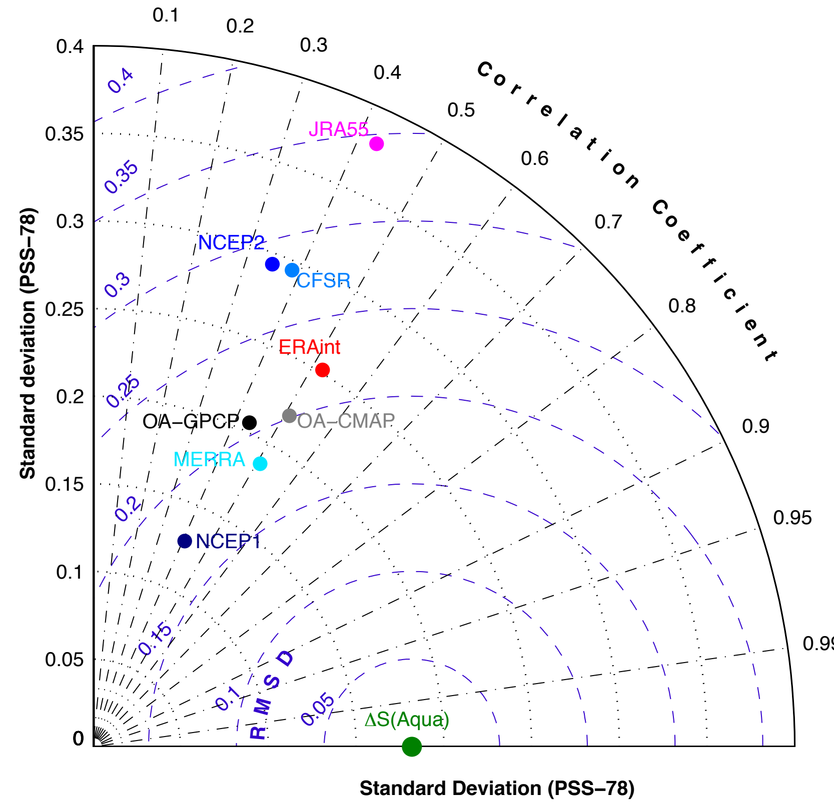




The seasonal STD produced by JRA55, NCEP2, and ERAinterim are above normal

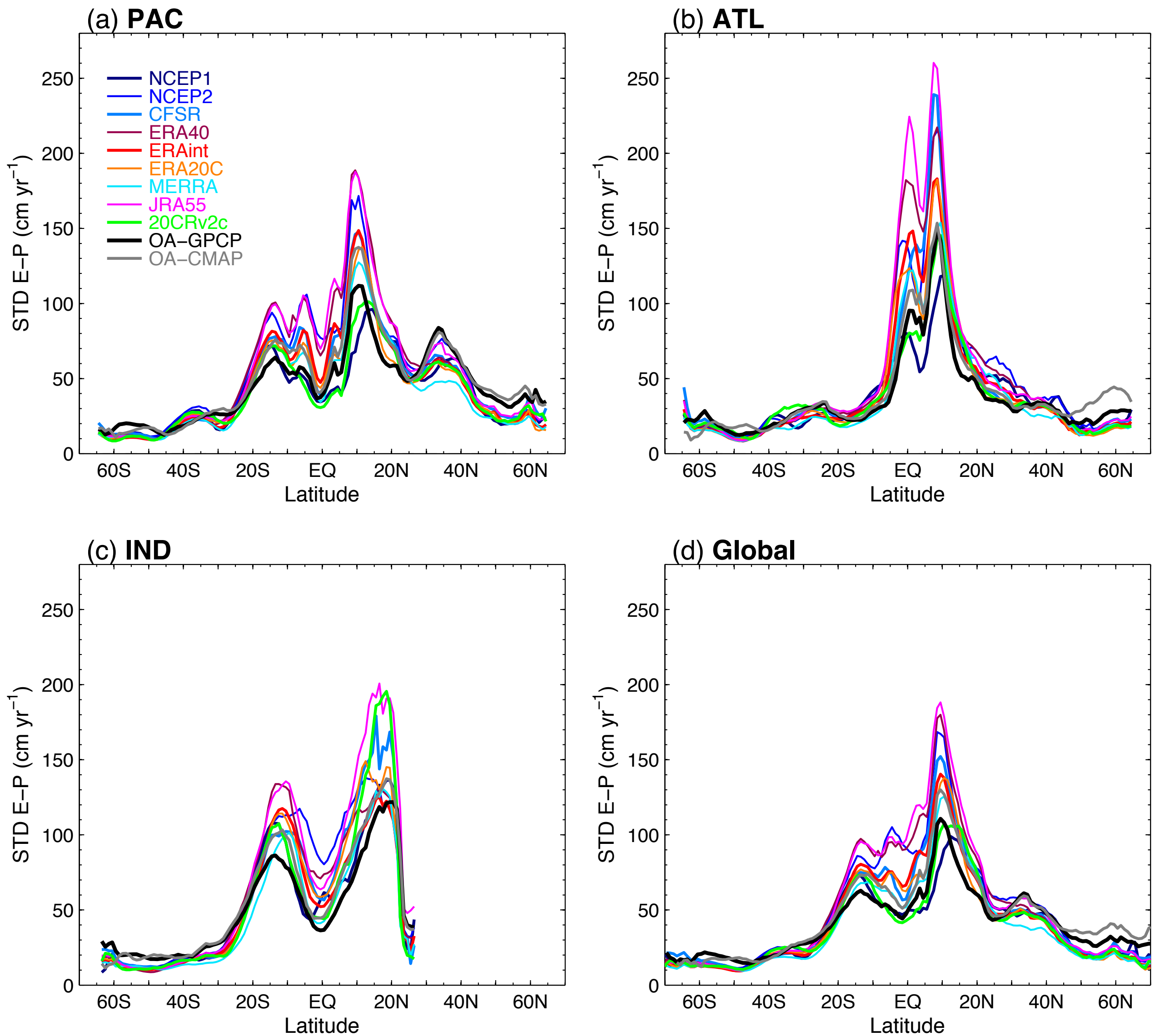
The eastern Atlantic box





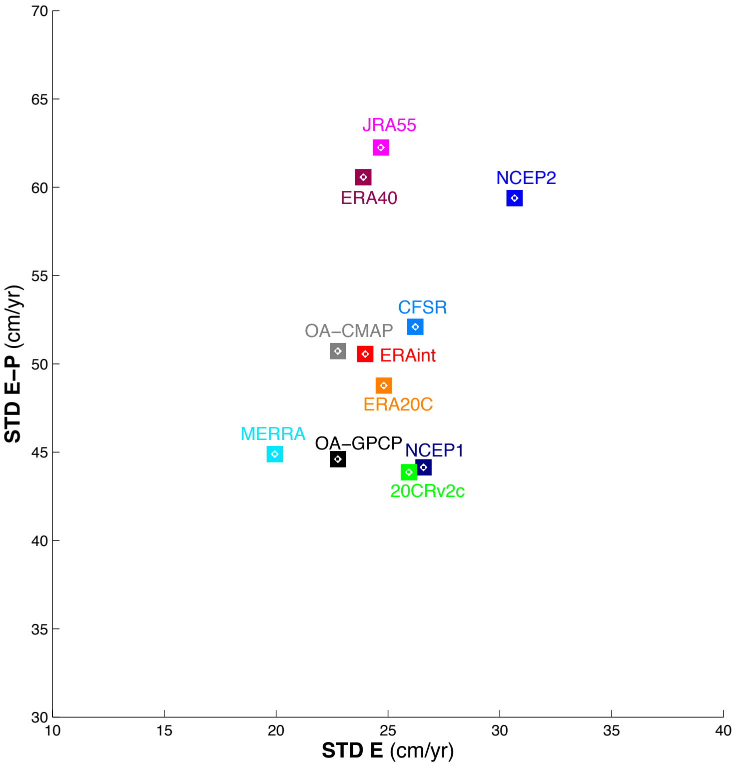
The seasonal STD produced by JRA55, NCEP2, and CFSR are above normal and poorly correlate with STD salinity.

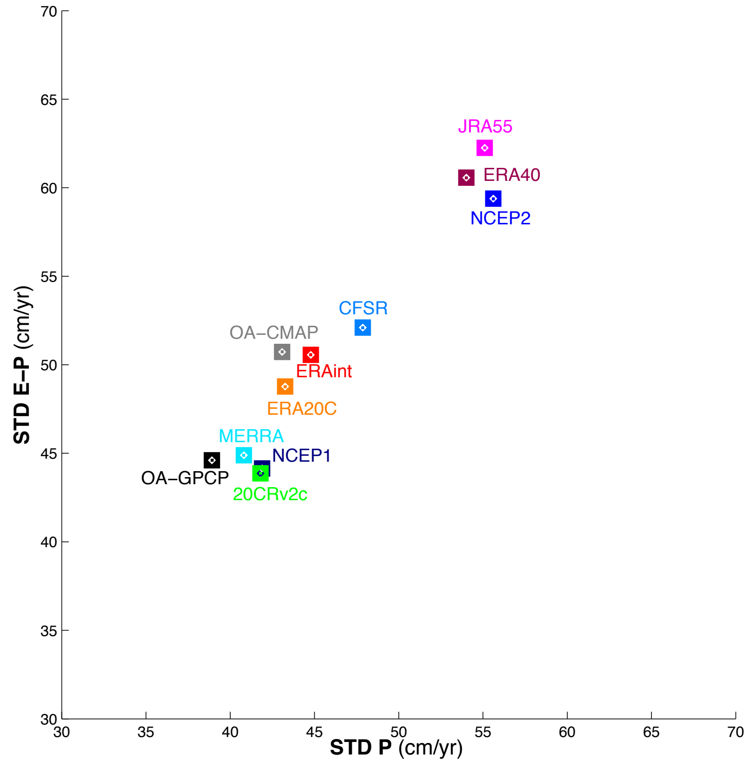
Seasonal STD E-P in three basins and global ocean



JRA55 and NCEP2 are persistently higher in all basins.

STD E, P versus E-P





The STD E-P does not depend on STD E:

- E variability is about half of STD P.
- Except for NCEP2, the spread in STD E is small between products.

The STD E-P depends near linearly on the STD P:

- Uncertainty in P dominates the global freshwater budgets and variability.
- JRA55, ERA40, and NCEP2 are outliners

Summary and conclusion

We designed and tested the use of the ocean salinity as a measure of the uncertainty in E-P by using 9 reanalyses and 2 satellite-based E-P products.

Major findings:

(1) The uncertainties in the E-P products are regime dependent, dominated by the uncertainties in P in the tropical wet zone.

(2) The zero E-P lines in the reanalyses are displaced more poleward when compared to satellite products, due primarily to the more spatially extended ITCZ rain belt in the reanalyses.

(3) The uncertainties in the tropical Precipitation can be evaluated by satellite SSS, showing that JRA55 and NCEP2 (and ERA40) overestimate the P variability.

(4) The uncertainty in P dominates the global freshwater budgets and variability. Models still have major difficulties in simulating the ITCZ rainfall strength and variability.

(5) If excluding NCEP2, ERA40, and JRA55, the global freshwater budgets from the 8-member ensemble are:

Global freshwater budgets based on 8 products

	Global Mean (cm/yr)	Seasonal STD (cm/yr)
E	123.5 ± 9.2 (7.5%)	23.9 ± 2.2
P	113.9 ± 8.9 (7.8%)	42.3 ± 2.7
E-P	9.6 ± 3.0 (31.3%)	46.7 ± 3.4