Aquarius Data Release V2.0 Validation Analysis

Gary Lagerloef, Aquarius Principal Investigator
H. Kao, ESR
And Aquarius Cal/Val Team

Understanding the Interaction Between Ocean Circulation, the Water Cycle, and Climate by Measuring Ocean Salinity

Aquarius/SAC-D

Analysis period: 8/25/2011-11/25/2012

Cal-Val Virtual Workshop WebMeeting *29-30 January /2013*

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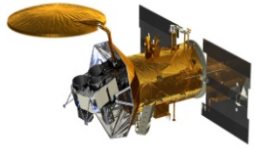
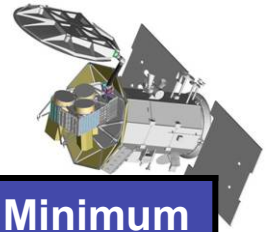
Outline



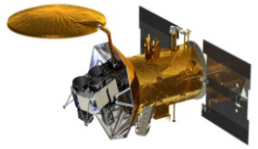
- V1.3.9 data is precursor test run for V2.0; Results shown for V1.3.9
- Contrast changes from V1.3
- Analyses cover the period Sep 2011 – Dec 2012 (16 months)
- Global buoy difference maps and statistics
- HYCOM model – buoy comparisons
- Triple Point analysis for global error
- Time series of global buoy differences
- Monthly maps – buoy differences and seasonal biases
- Ascending – descending sides of the orbit, more seasonal bias
- Seasonal error analysis & minimum mission requirement.

Baseline and Minimum Mission



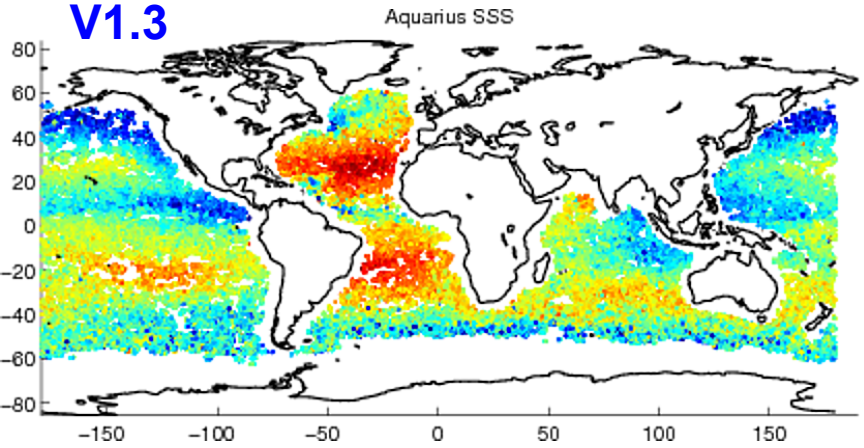
	Level 1 Science Mission Requirement	Baseline Mission	Minimum Mission
1	The Aquarius Mission shall collect the space-based measurements to retrieve Sea Surface Salinity (SSS) with global root-mean-square (rms) random errors and systematic biases no larger than 0.2 psu on 150 km by 150 km scales over the ice-free oceans	?	?
2	SSS Averaging Interval	1 Month	3 Months
3	Mission Duration	At least 3 Years	At least 1 Year
4	Deliver data products to a NASA Distributed Active Archive Center (DAAC). Level 1a Reconstructed Unprocessed Instrument Data Level 1b Calibrated Sensor Units Level 2 Derived Geolocated SSS Level 3 Time-space averaged SSS on a standard Earth Projection		Yes

Comparison to Argo Buoys

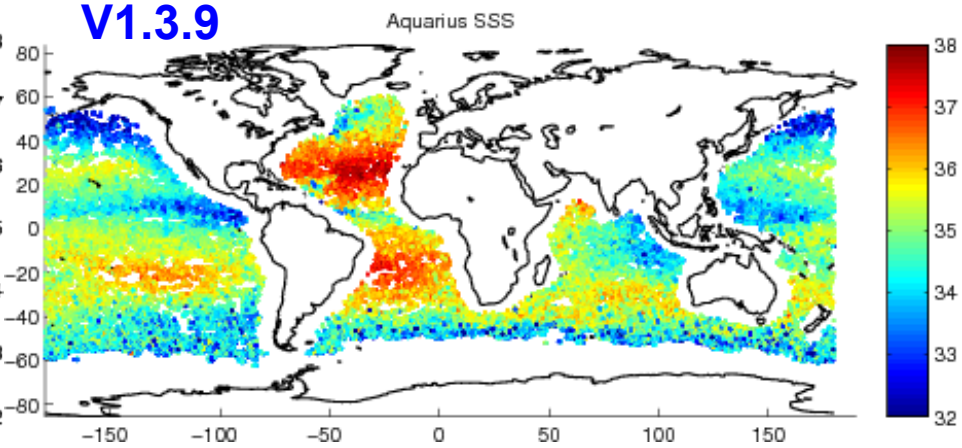


Aquarius salinity at buoy location & time

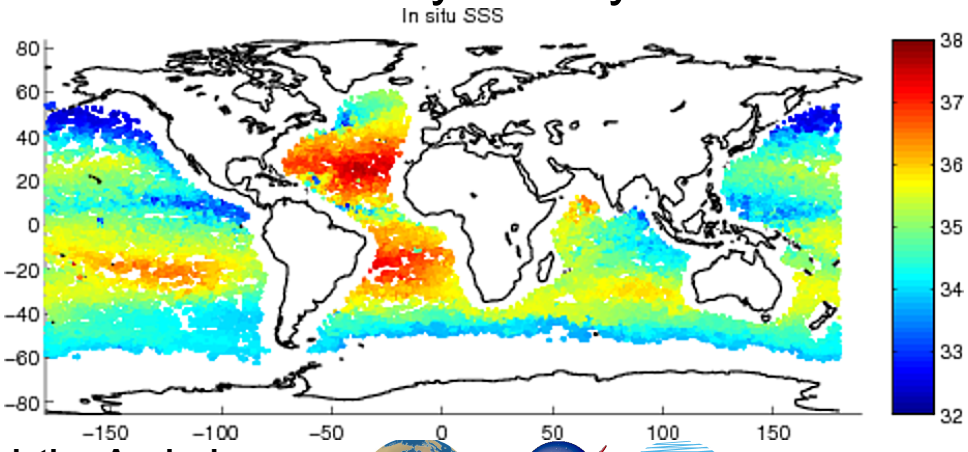
V1.3



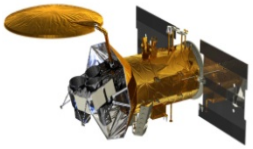
V1.3.9



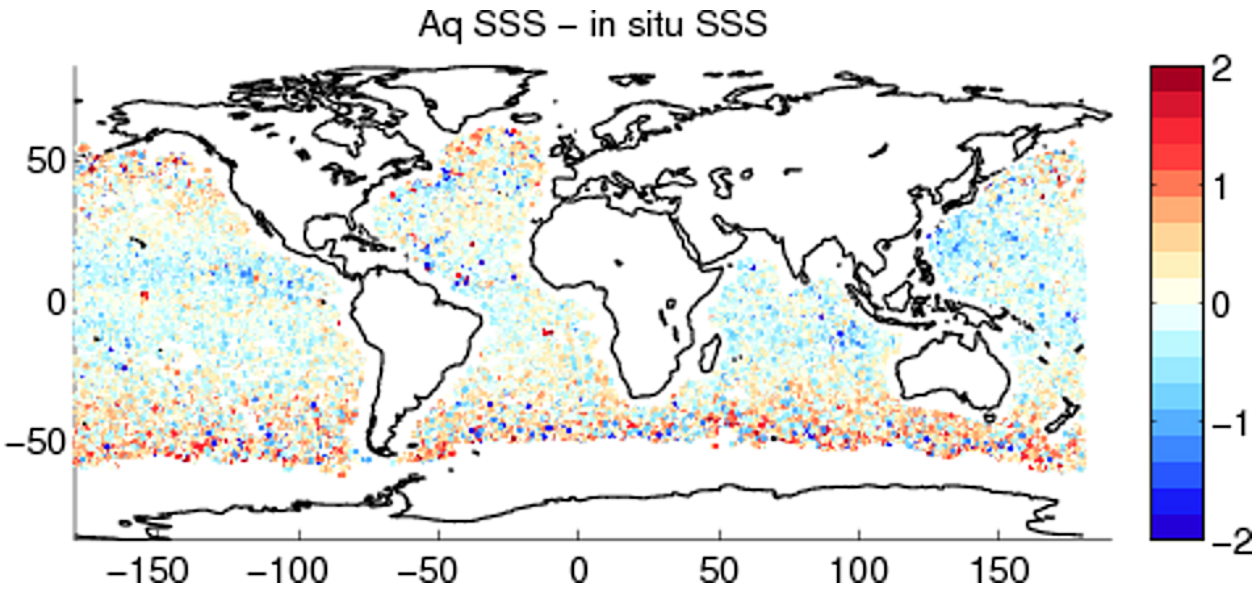
Buoy salinity



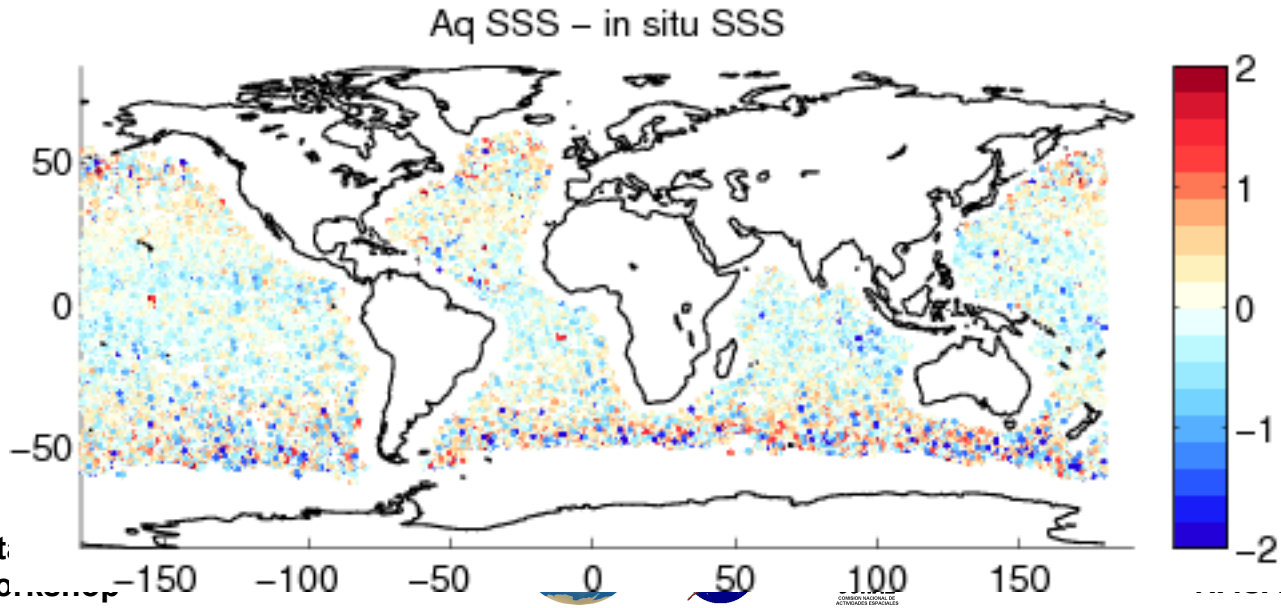
Aquarius – Argo Difference



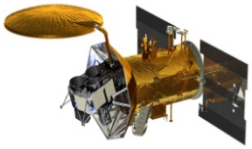
V1.3



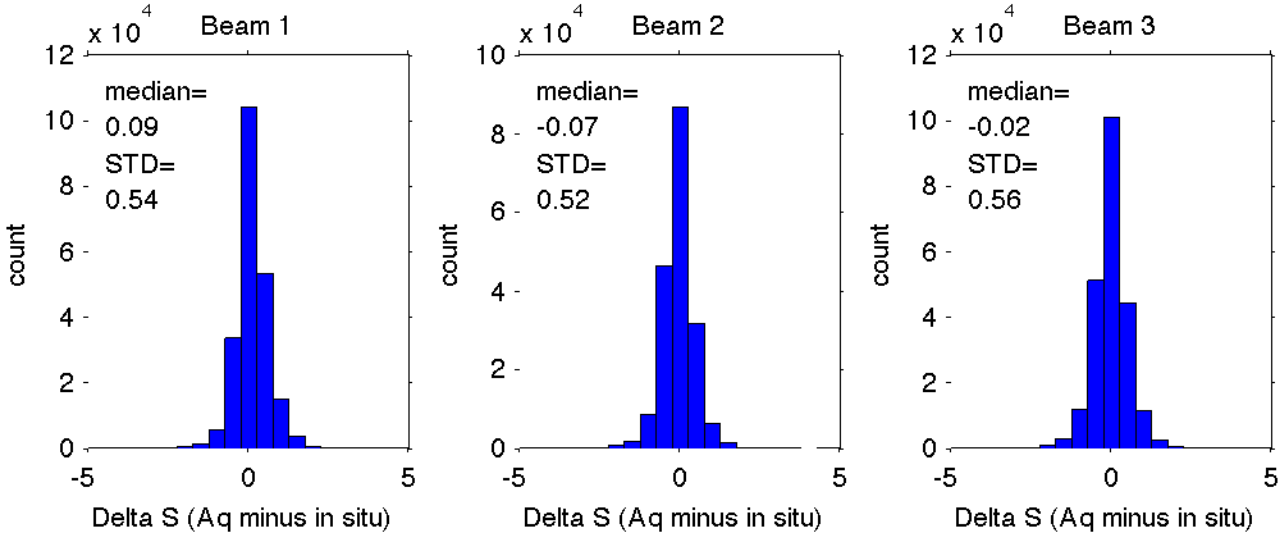
V1.3.9



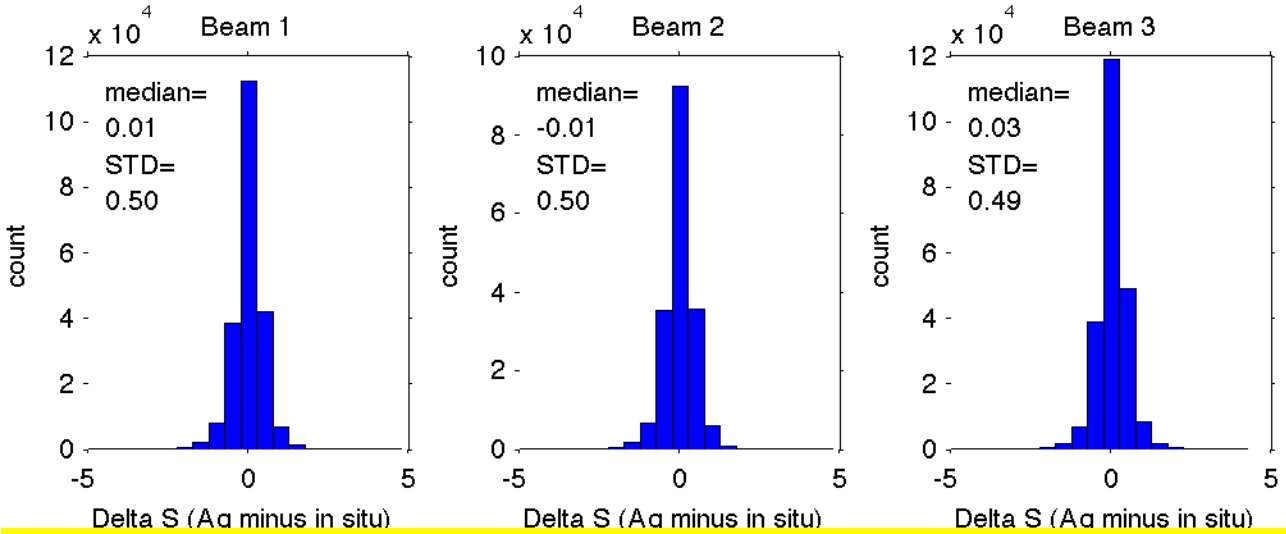
Aquarius – Argo Histograms



V1.3

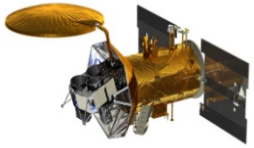


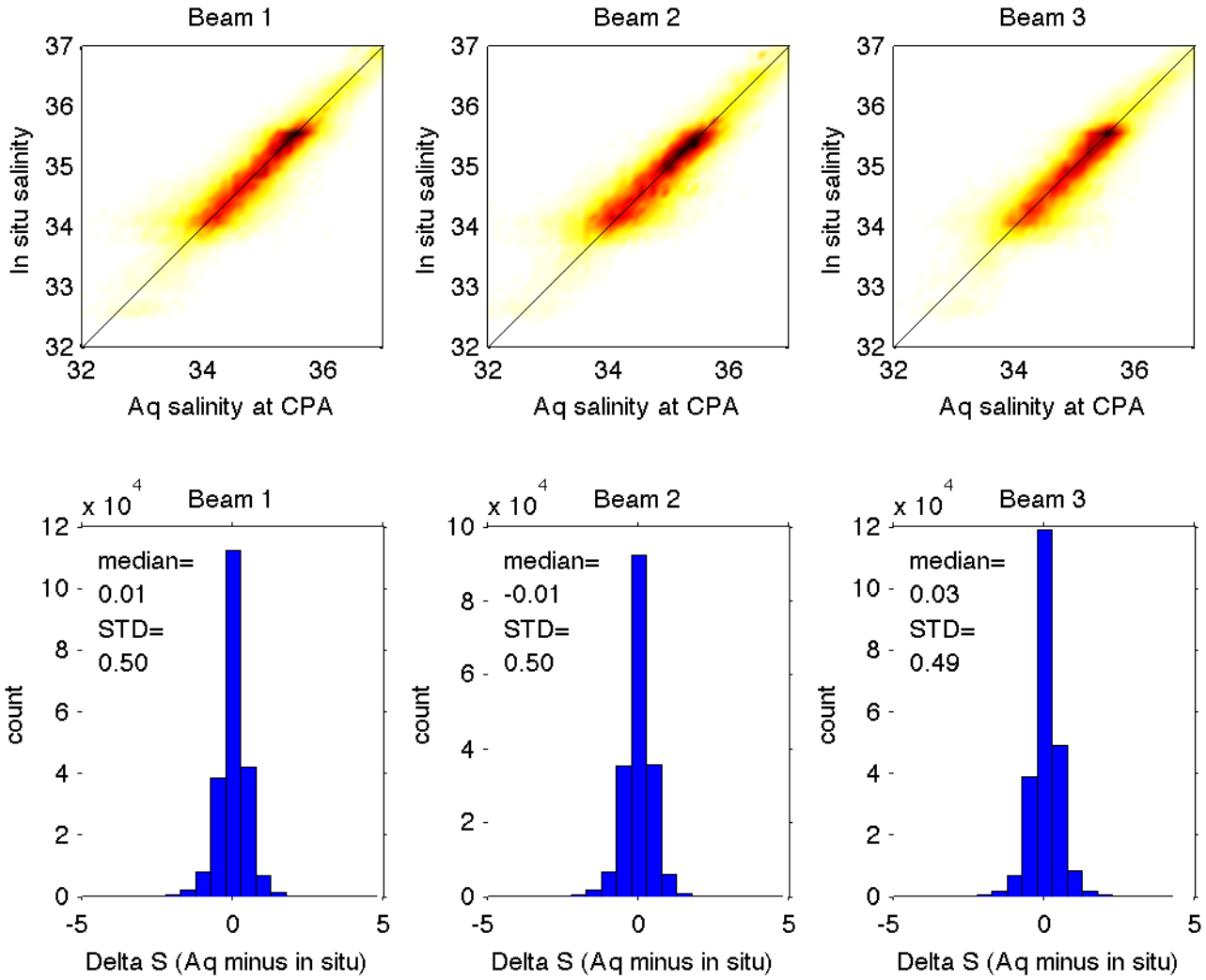
V1.3.9



SST > 5C, windspeed <15m/s, Land and ice fraction < 0.0005

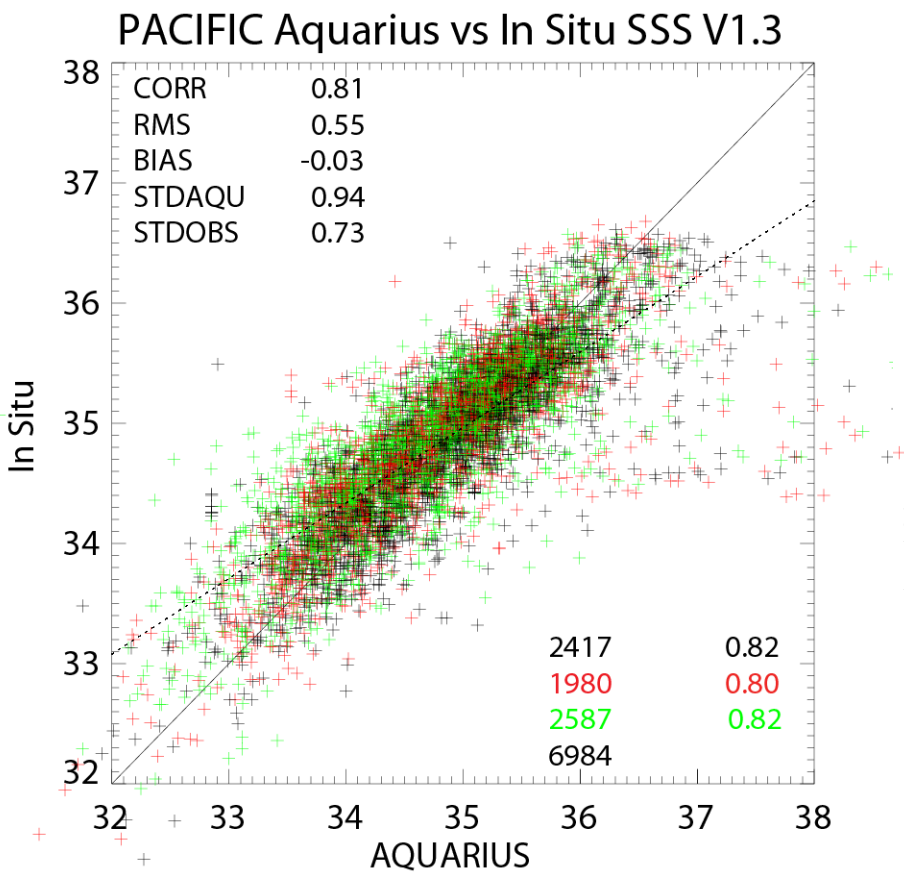
V1.3.9 Scatter Plots

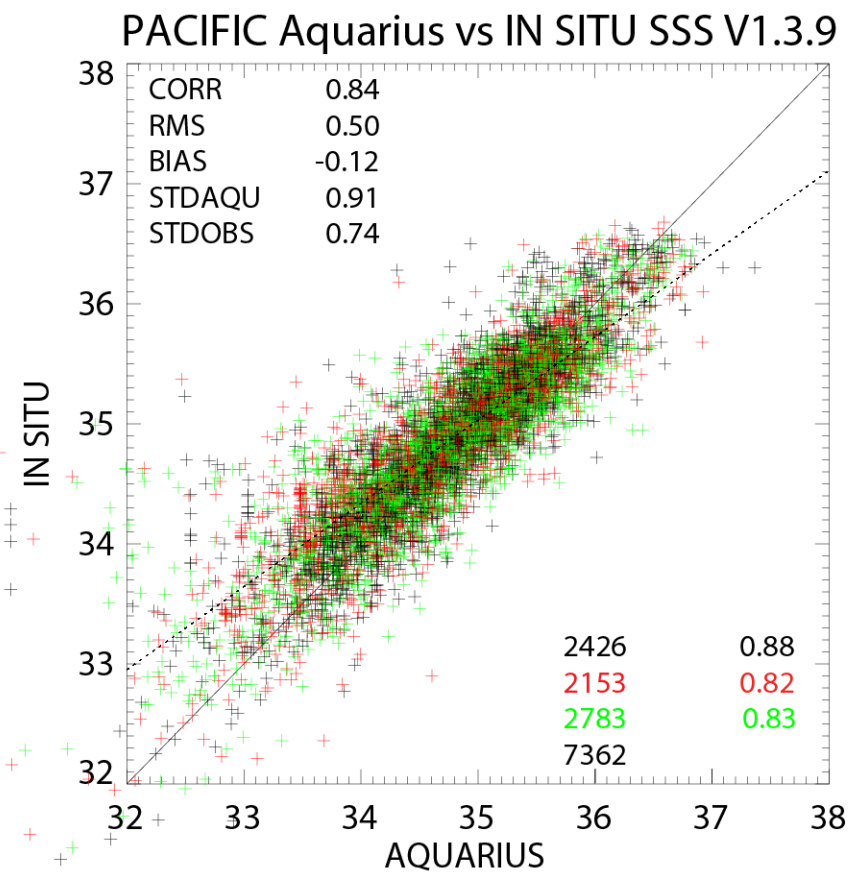




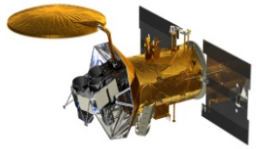
Eric Hackert, et al, ESSIC

Pacific Ocean Statistics



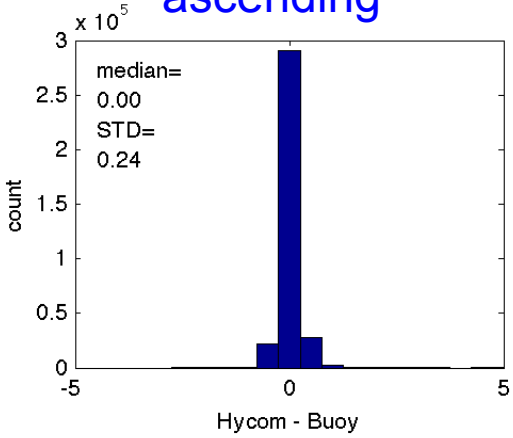


HYCOM – in situ SSS

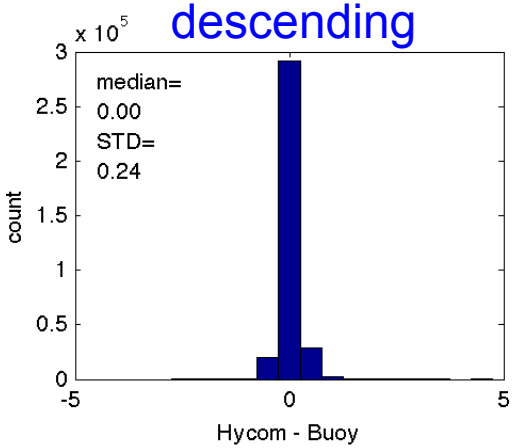


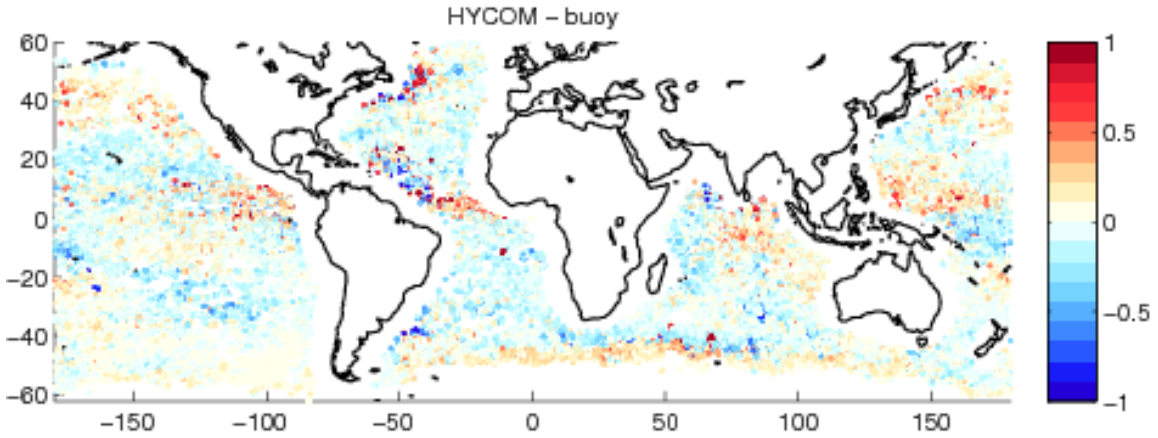
Note the considerable large scale systematic differences between HYCOM and the buoys (V1.3.9 data with HYCOM position offset corrected)

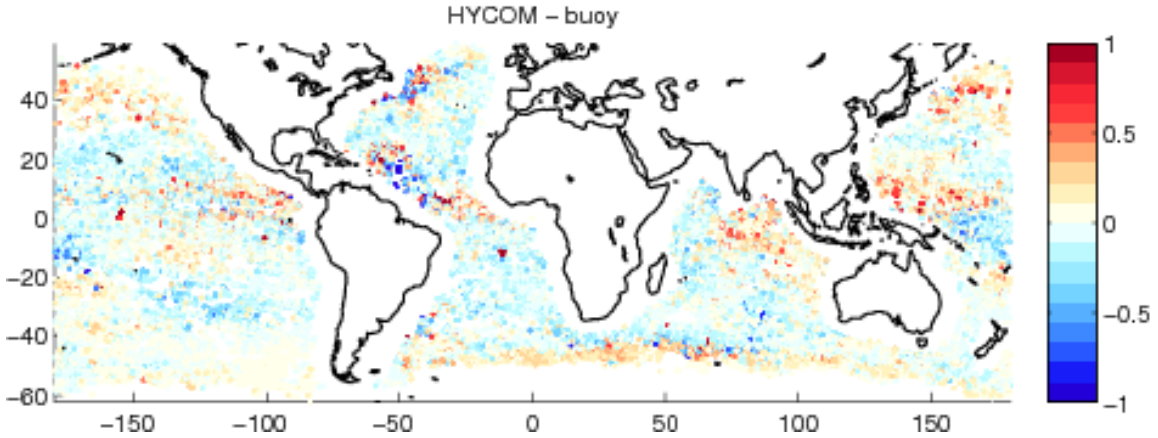
ascending



descending







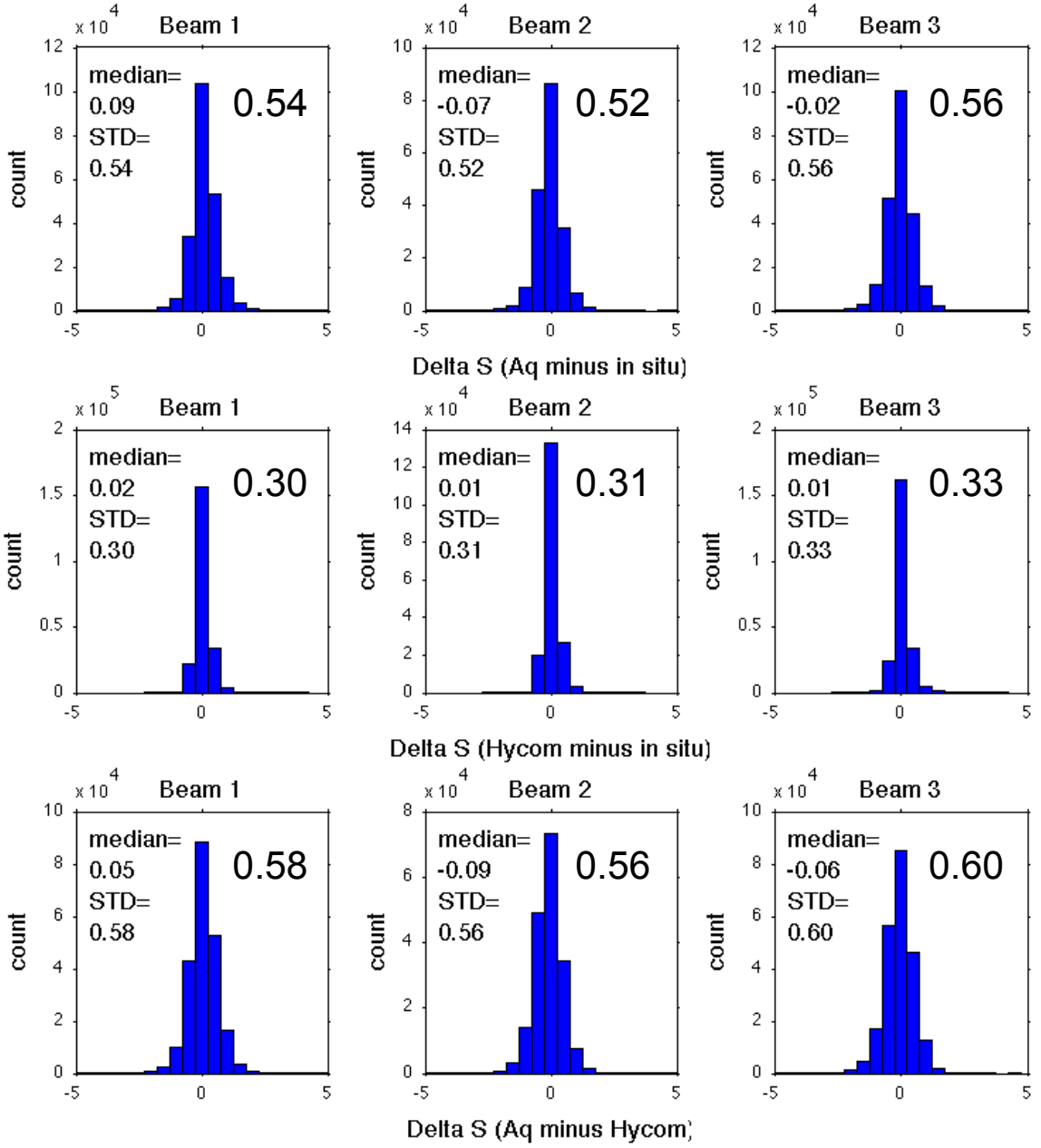
Summary of 3 co-located differences

Aq – in situ

dSSS V1.3
8/25/2011-11/25/2012
Matchup Specifications
land and ice frac < 0.0005
SST > 5C,
windspeed <15m/s

HYCOM – in situ

Aq – HYCOM



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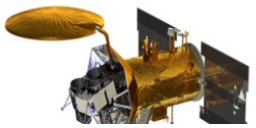


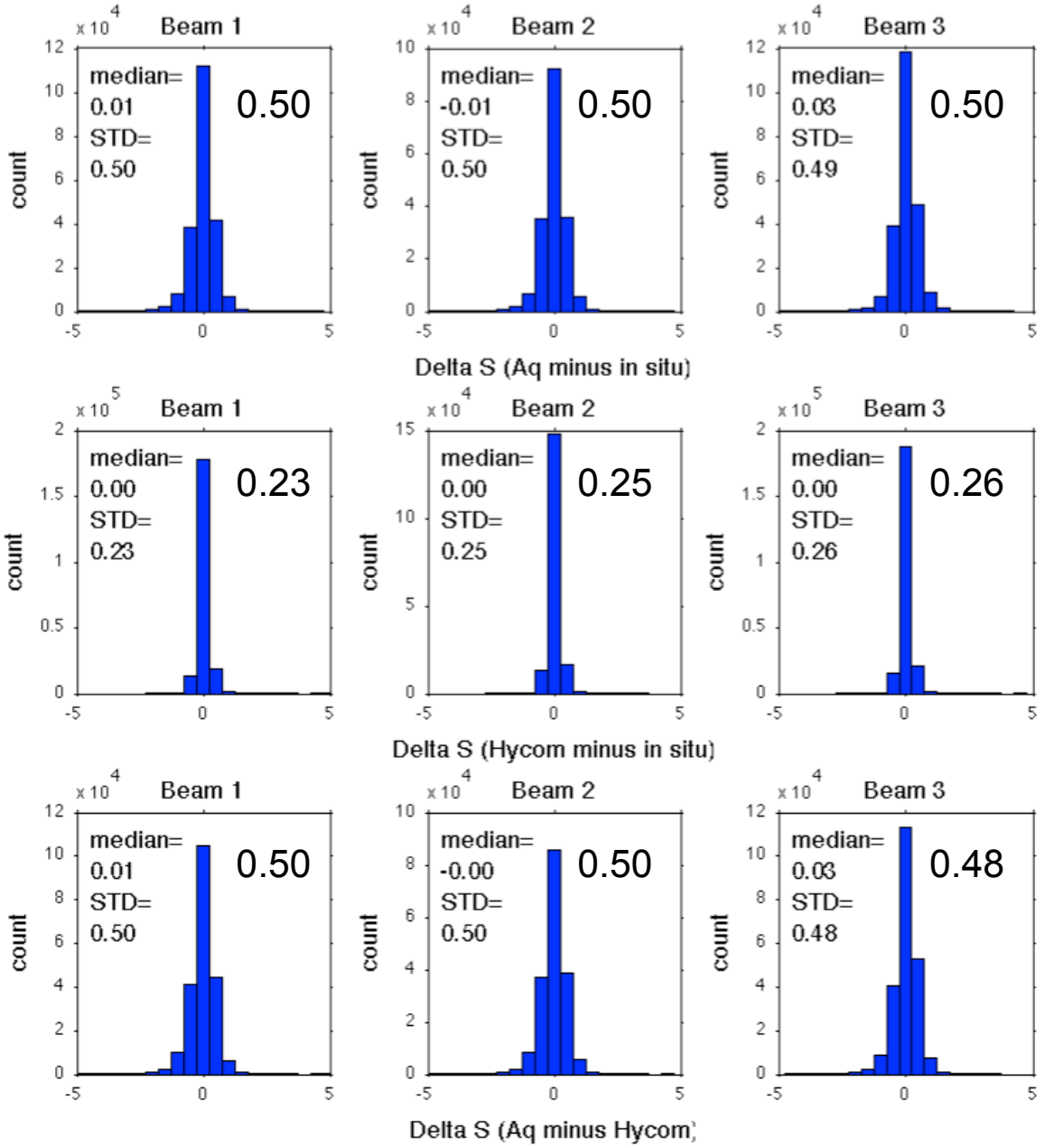
Aq – in situ

dSSS V1.3.9
8/25/2011-11/25/2012
Matchup Specifications
land and ice frac < 0.0005
SST > 5C,
windspeed <15m/s

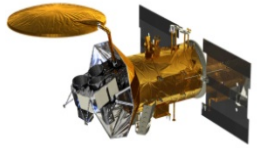
HYCOM – in situ

RMSE = sqrt(Bias^2 + STD^2)

Aq – HYCOM



Triple point uncertainty estimate of Aquarius and validation data



The satellite salinity measurement S_S and the *in situ* validation measurement S_V are defined by:

$$S_S = S \pm \varepsilon_S$$

$$S_V = S \pm \varepsilon_V$$

where S is the true surface salinity averaged over the Aquarius footprint area and microwave optical depth in sea water (~ 1 cm). ε_S and ε_V are the respective satellite and *in situ* measurement errors relative to S. The mean square of the difference ΔS between S_S and S_V is given by:

$$\langle \Delta S_{SV}^2 \rangle = \langle \varepsilon_S^2 \rangle + \langle \varepsilon_V^2 \rangle \quad (1)$$

where $\langle\ \rangle$ denotes the average over a given set of paired satellite and *in situ* measurements, and $\langle \varepsilon_S \varepsilon_V \rangle = 0$.

Likewise, define HyCOM salinity interpolated to the satellite footprint as $S_H = S \pm \varepsilon_H$, and mean square differences

$$\langle \Delta S_{HV}^2 \rangle = \langle \varepsilon_H^2 \rangle + \langle \varepsilon_V^2 \rangle \quad (2)$$ HyCOM vs in situ validation data

$$\langle \Delta S_{SH}^2 \rangle = \langle \varepsilon_S^2 \rangle + \langle \varepsilon_H^2 \rangle \quad (3)$$ Satellite vs HyCOM

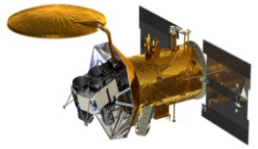
Equations (1)-(3) comprise three equations with three variables given by:

$$\langle \varepsilon_S^2 \rangle = \{\langle \Delta S_{SV}^2 \rangle + \langle \Delta S_{SH}^2 \rangle - \langle \Delta S_{HV}^2 \rangle\} /2 \quad (4)$$ satellite measurement error

$$\langle \varepsilon_H^2 \rangle = \{\langle \Delta S_{SH}^2 \rangle + \langle \Delta S_{HV}^2 \rangle - \langle \Delta S_{SV}^2 \rangle\} /2 \quad (5)$$ HyCOM measurement error

$$\langle \varepsilon_V^2 \rangle = \{\langle \Delta S_{SV}^2 \rangle + \langle \Delta S_{HV}^2 \rangle - \langle \Delta S_{SH}^2 \rangle\} /2 \quad (6)$$ In situ validation measurement error

Triple Point Analyses: V1.3 & V1.3.9



- Aquarius RMSE is reduced (~0.52 -> 0.46 psu)
- HYCOM RMSE is significantly reduced in V1.3.9 matchup because of the correction in V1.3.9 for the HYCOM latitude offset that was in earlier versions
- Now HYCOM RMSE is consistent with buoy RMSE
- The Aquarius rms error remains ~ 0.46 psu because of the spurious seasonal cycle

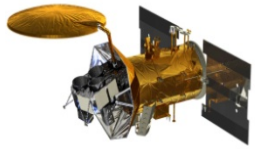
V1.3

	Beam 1	Beam 2	Beam 3
Aquarius RMSE	0.52	0.50	0.53
Hycom RMSE	0.25	0.27	0.28
Insitu RMSE	0.16	0.16	0.17
Theoretical monthly RMSE if all errors are uncorellated			
Monthly RMSE (8 samples worst case) psu	0.19	0.18	0.19

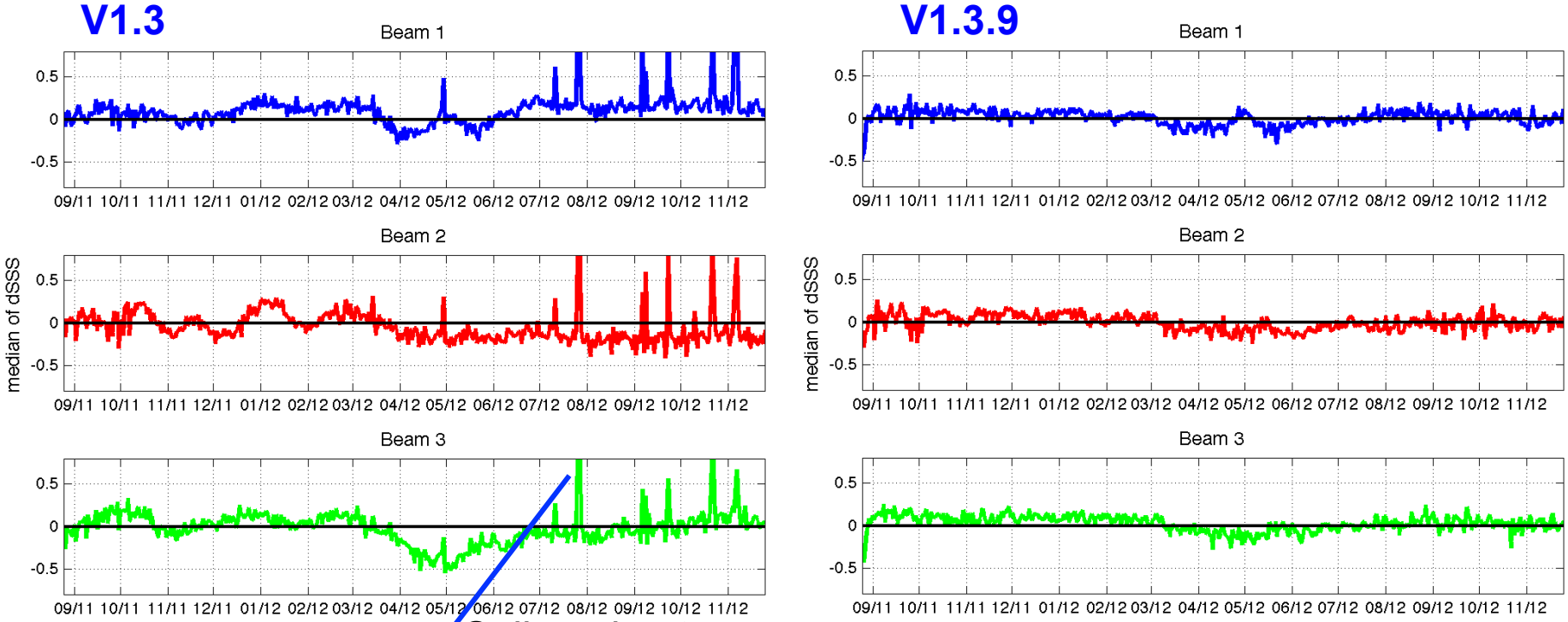
V1.3.9

	Beam 1	Beam 2	Beam 3
Aquarius RMSE	0.47	0.47	0.45
Hycom RMSE	0.16	0.18	0.17
Insitu RMSE	0.16	0.18	0.20
Theoretical monthly RMSE if all errors are uncorellated			
Monthly RMSE (8 samples worst case) psu	0.17	0.17	0.16

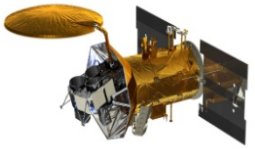
Quasi-monthly calibration variations



V1.3 data has transient quasi-monthly calibration errors. These are removed in V1.3.9 as we study the partition of the sources between instrument the model error.



Aq V1.3 – buoy, Monthly ESR L3 data

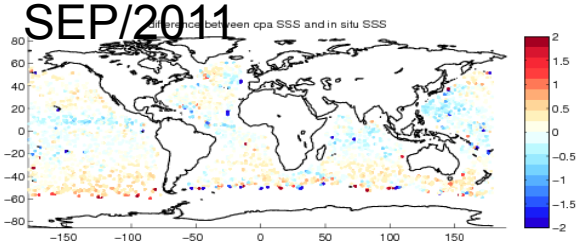


Monthly global RMSE is ~0.50 mainly due to spatial and temporal geographically correlated errors

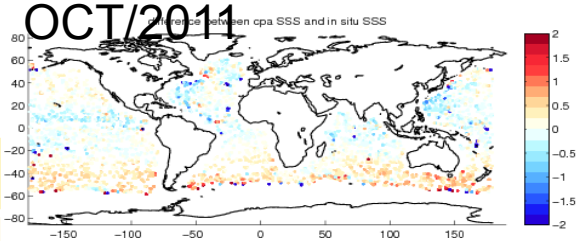
ESR gridding
land and ice frac < 0.0005
Buoy SST>5C, radius=150km

	median	STD
SEP/11	0.08	0.46
OCT/11	0.08	0.44
NOV/11	-0.02	0.54
DEC/11	0.06	0.54
JAN/12	0.10	0.50
FEB/12	0.10	0.50
MAR/12	-0.03	0.42
APR/12	-0.23	0.46
MAY/12	-0.21	0.42
JUN/12	-0.08	0.45

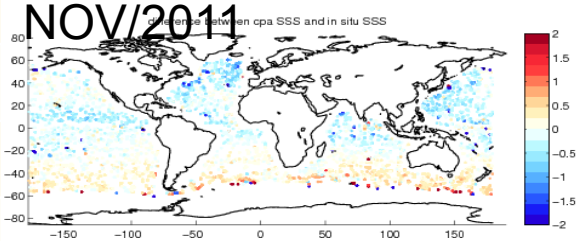
SEP/2011



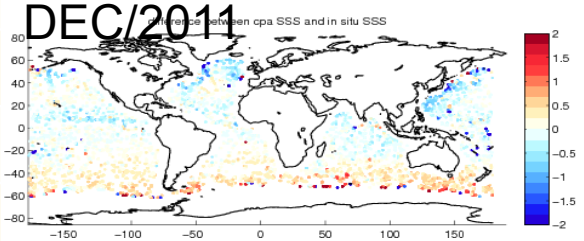
OCT/2011



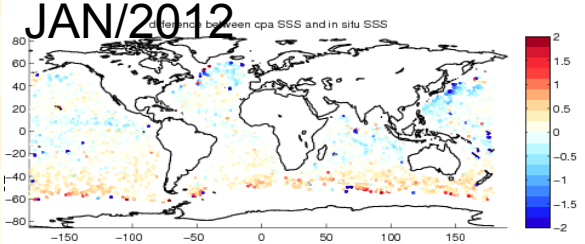
NOV/2011



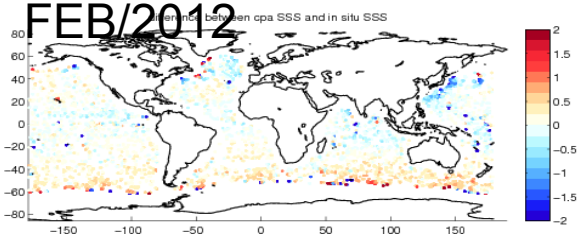
DEC/2011



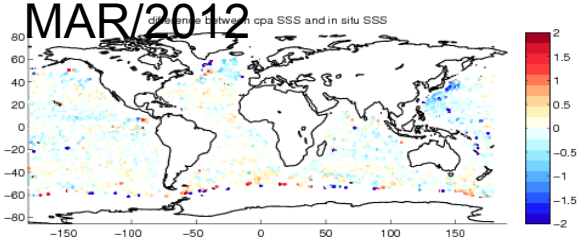
JAN/2012



FEB/2012



MAR/2012



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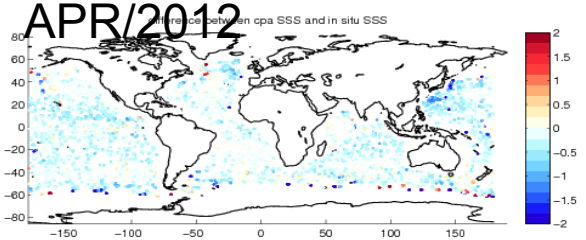
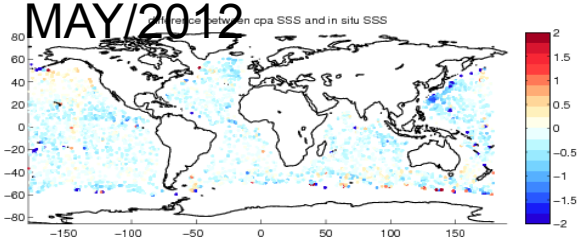
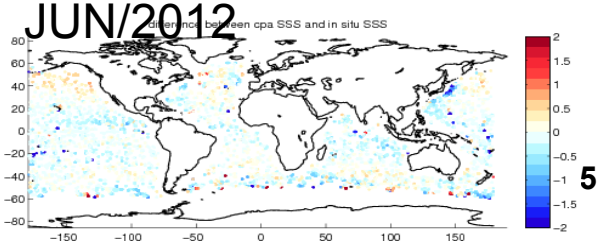


MAY/2012

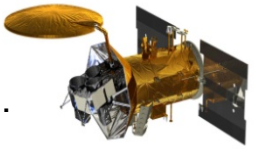


JUN/2012



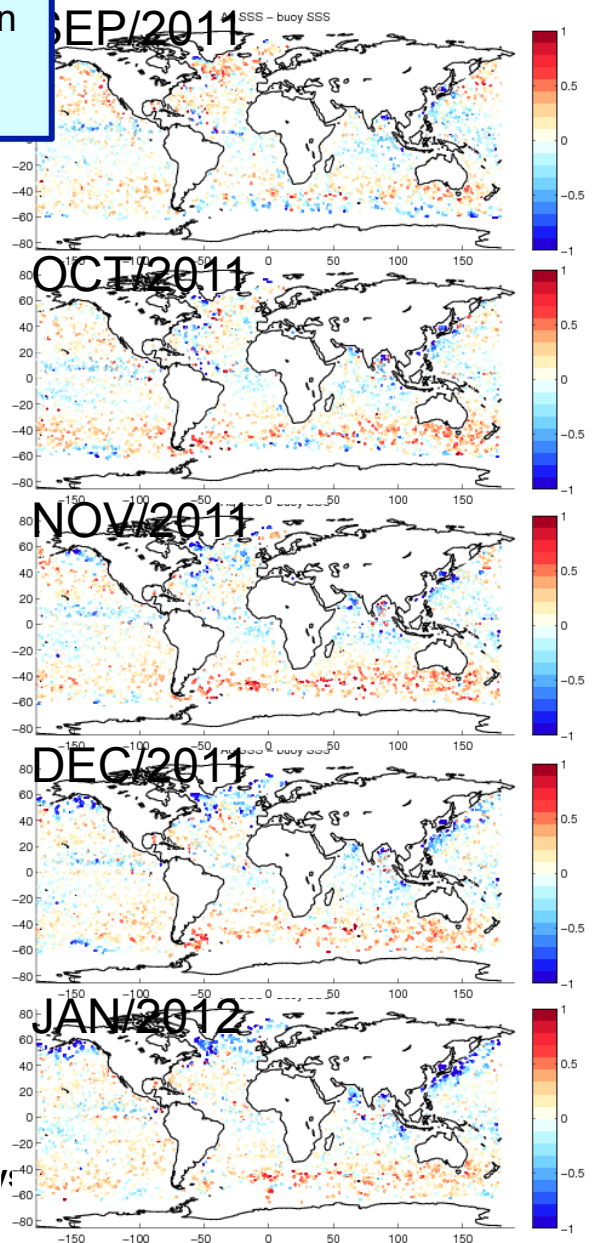
Aq V1.3.9 – buoy, Monthly ESR L3 data

Median and STD calculation exclude SST<5C, but the maps on the right include all data.



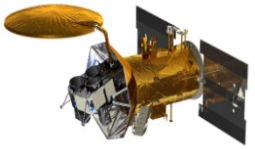
Monthly global RMSE is much less than V1.3, but geographically correlated errors remain (lower range color scale)

	median	STD
SEP/11	0.07	0.30
OCT/11	0.07	0.33
NOV/11	0.07	0.35
DEC/11	0.05	0.35
JAN/12	0.06	0.35
FEB/12	0.02	0.37
MAR/12	-0.10	0.33
APR/12	-0.13	0.31
MAY/12	-0.11	0.31
JUN/12	-0.07	0.33
JUL/12	-0.03	0.34
AUG/12	-0.03	0.36
SEP/12	-0.01	0.29



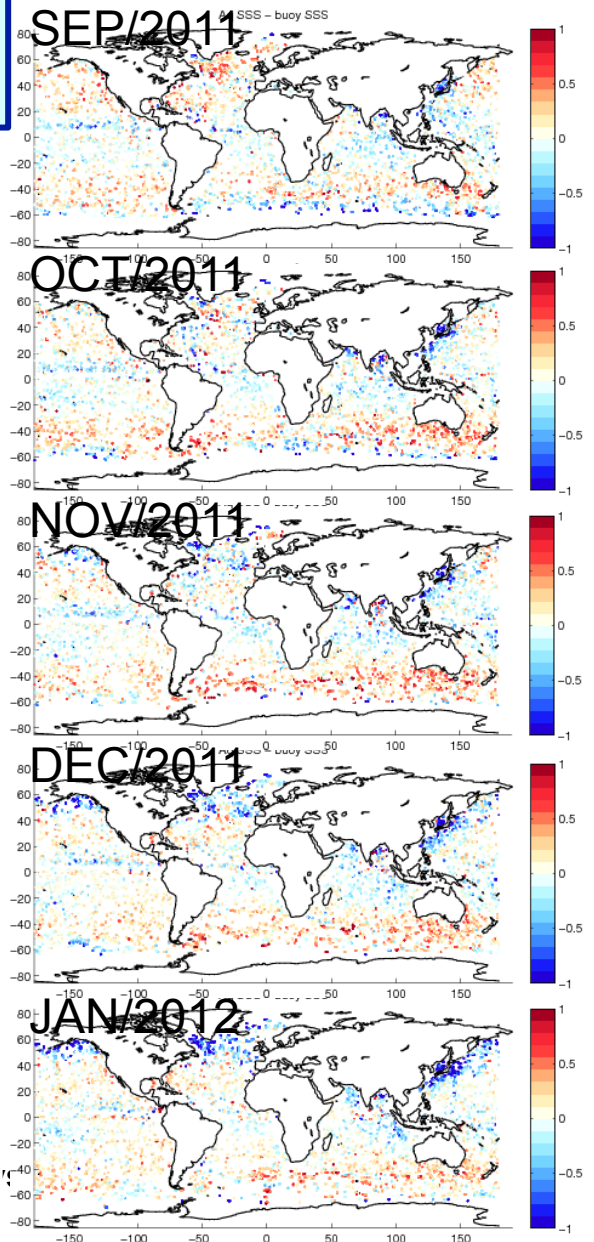
AQUARIUS/SAC-D

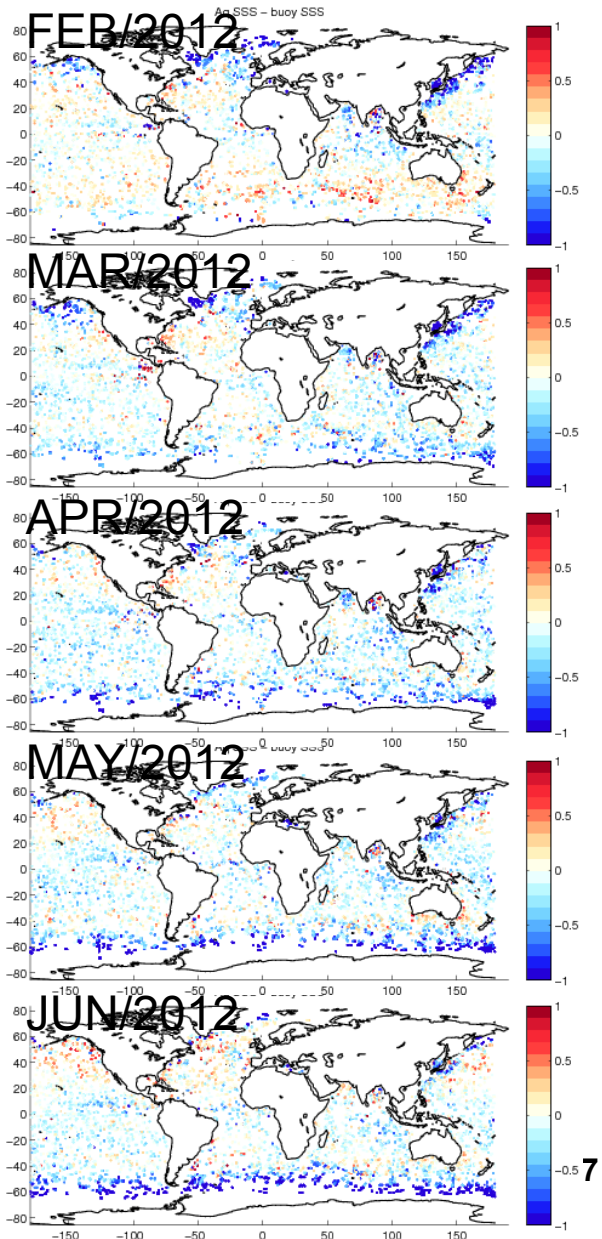
Aq V1.3.9 – buoy, Monthly L3 data from ADPS



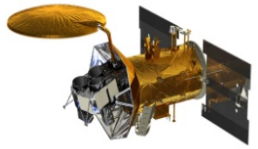
ADPS gridding
land_frac <0.02; ice_frac <0.005
Higher AQ-buoy STD

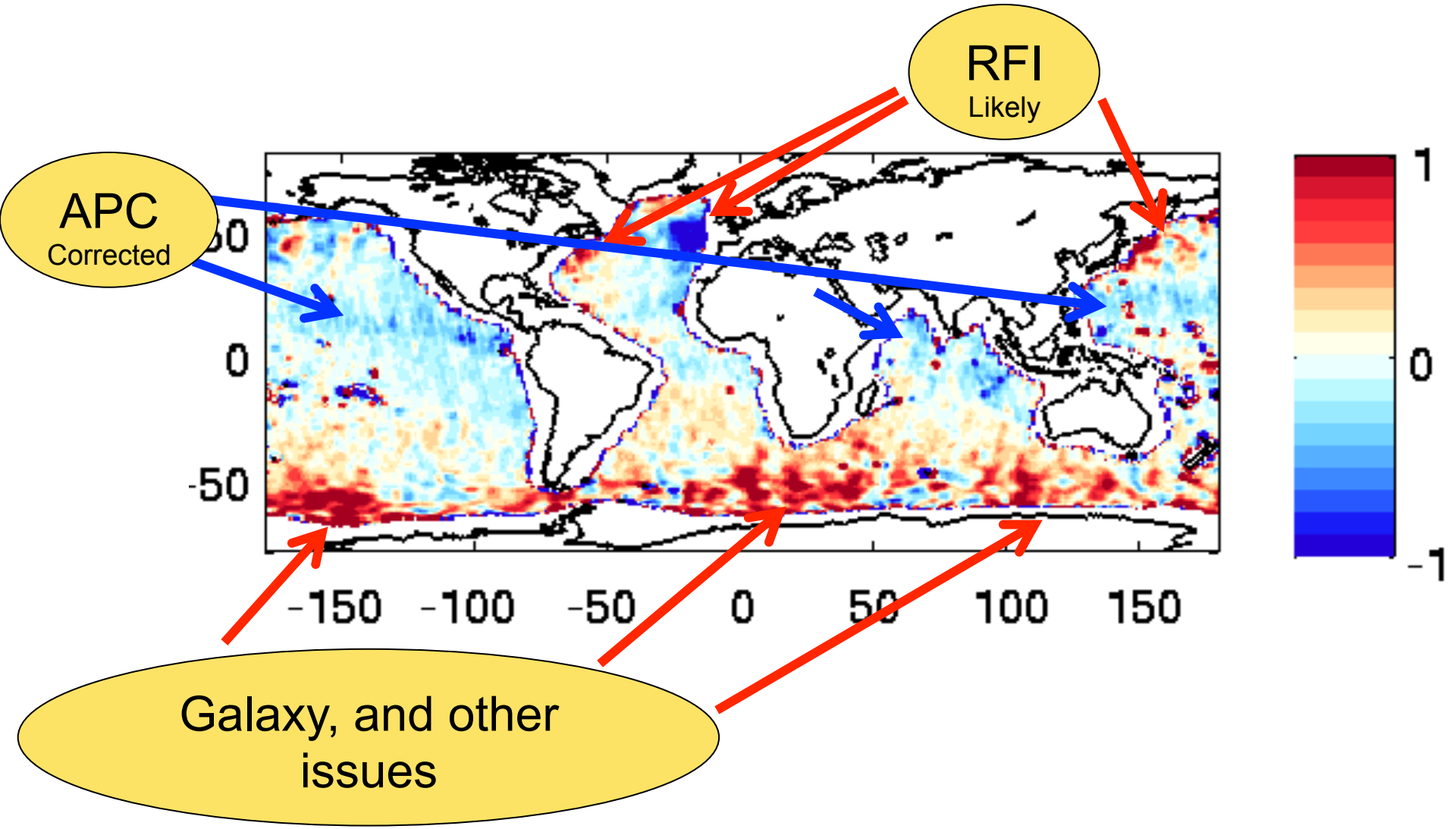
	median	STD
SEP/11	0.07	0.37
OCT/11	0.07	0.37
NOV/11	0.06	0.37
DEC/11	0.05	0.38
JAN/12	0.05	0.40
FEB/12	0.02	0.41
MAR/12	-0.10	0.37
APR/12	-0.14	0.37
MAY/12	-0.11	0.36
JUN/12	-0.07	0.37
JUL/12	-0.03	0.37
AUG/12	-0.01	0.36
SEP/12	0.01	0.35



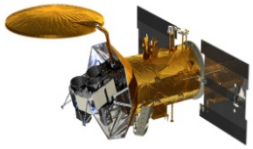


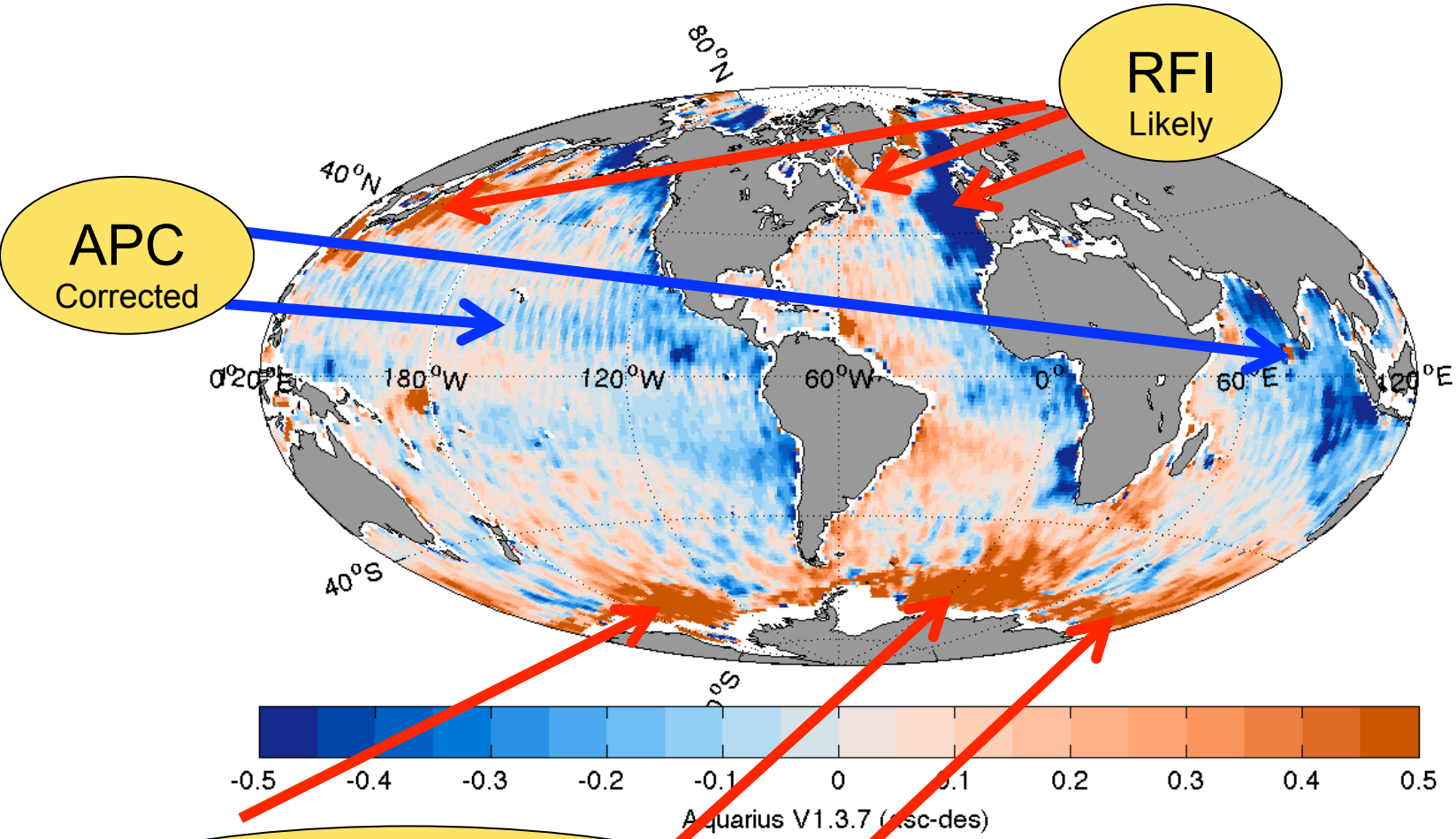
10 month averaged V1.3 Ascending – Descending



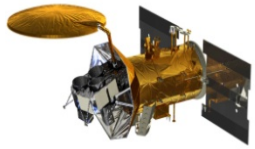


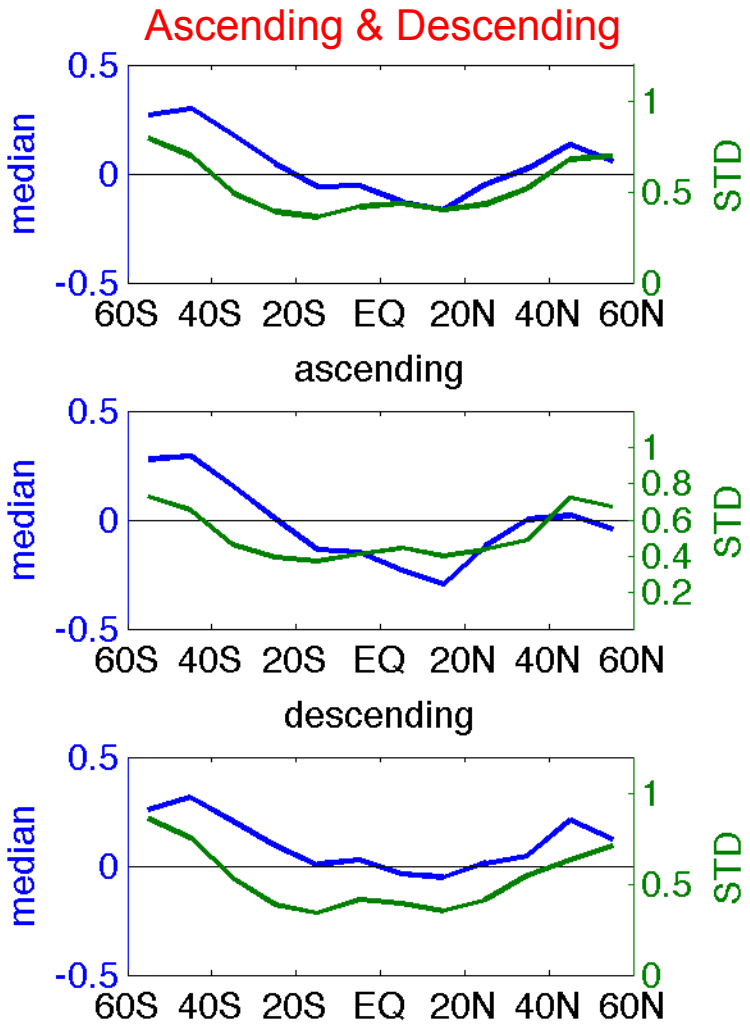
10 month averaged V1.3.7 Ascending – Descending





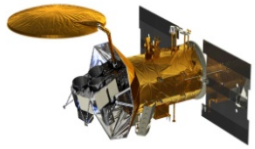
Aq V1.3 – buoy, by Latitude

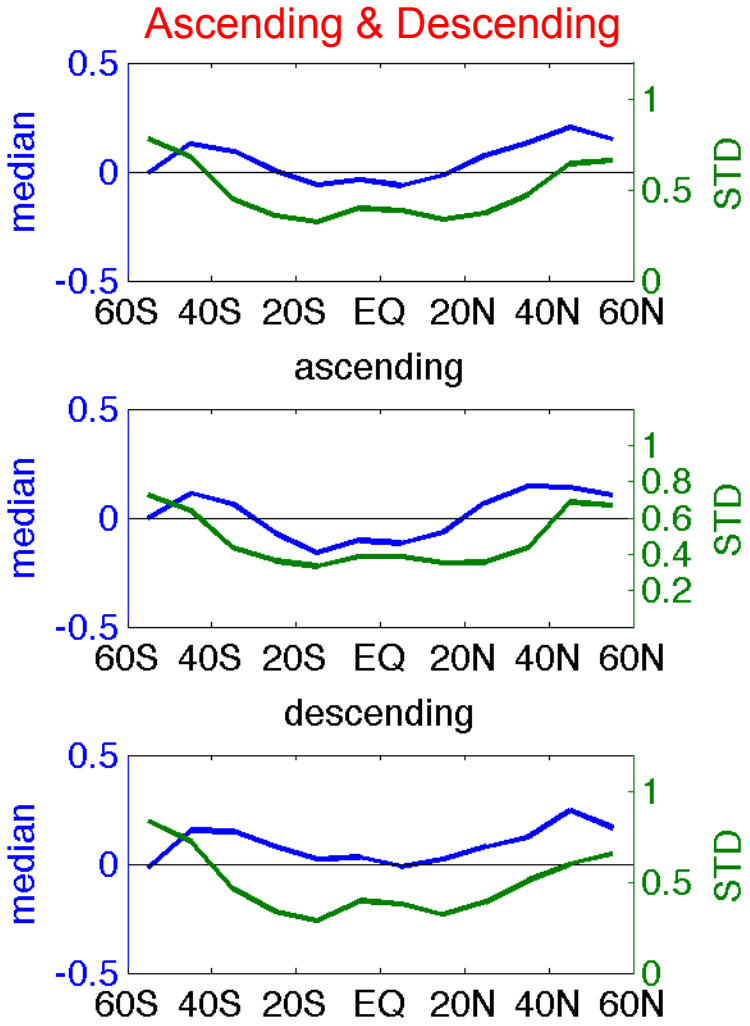




STD	both	ascend	descen
50-60N	0.70	0.67	0.71
40-50N	0.68	0.72	0.63
30-40N	0.52	0.49	0.55
20-30N	0.43	0.44	0.41
10-20N	0.40	0.40	0.35
0-10N	0.44	0.45	0.39
10S-0	0.42	0.41	0.41
10-20S	0.36	0.37	0.34
20-30S	0.39	0.39	0.39
30-40S	0.49	0.46	0.53
40-50S	0.70	0.65	0.76
50-60S	0.79	0.73	0.86

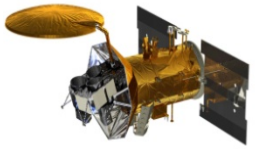
Aq V1.3.9 – buoy, by Latitude (STD)

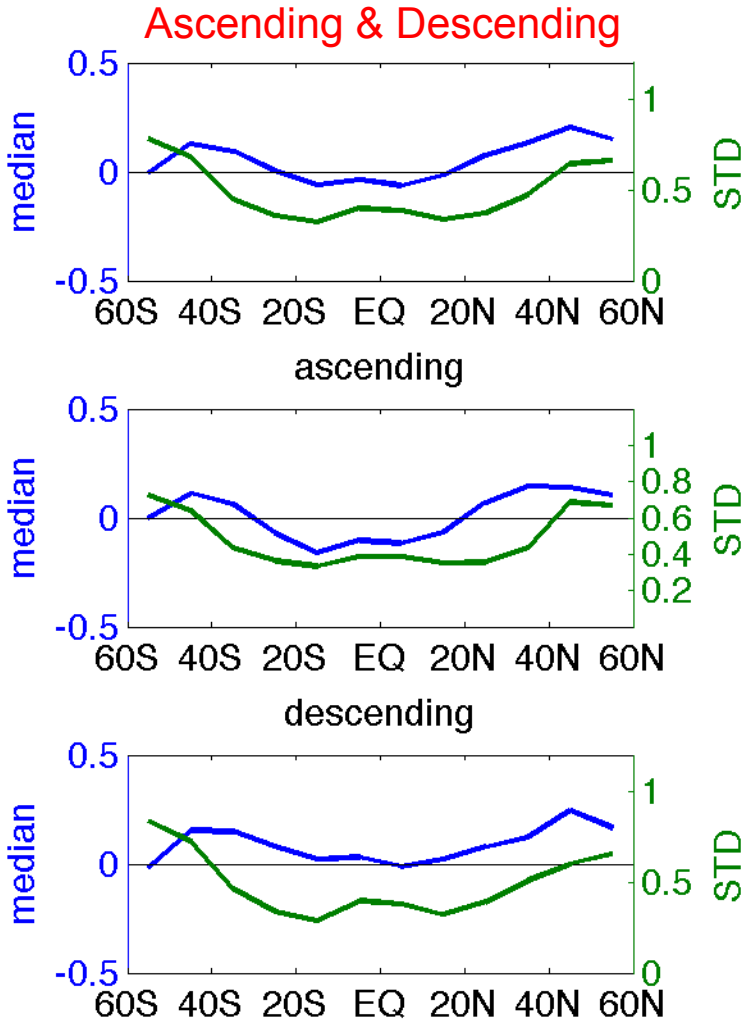




STD	both	ascend	descen
50-60N	0.66	0.67	0.65
40-50N	0.64	0.69	0.60
30-40N	0.47	0.43	0.51
20-30N	0.37	0.35	0.39
10-20N	0.34	0.35	0.32
0-10N	0.39	0.39	0.38
10S-0	0.40	0.39	0.40
10-20S	0.32	0.34	0.29
20-30S	0.36	0.36	0.34
30-40S	0.45	0.43	0.46
40-50S	0.68	0.64	0.72
50-60S	0.78	0.72	0.84

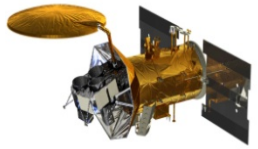
Aq V1.3.9 – buoy, by Latitude (BIAS)



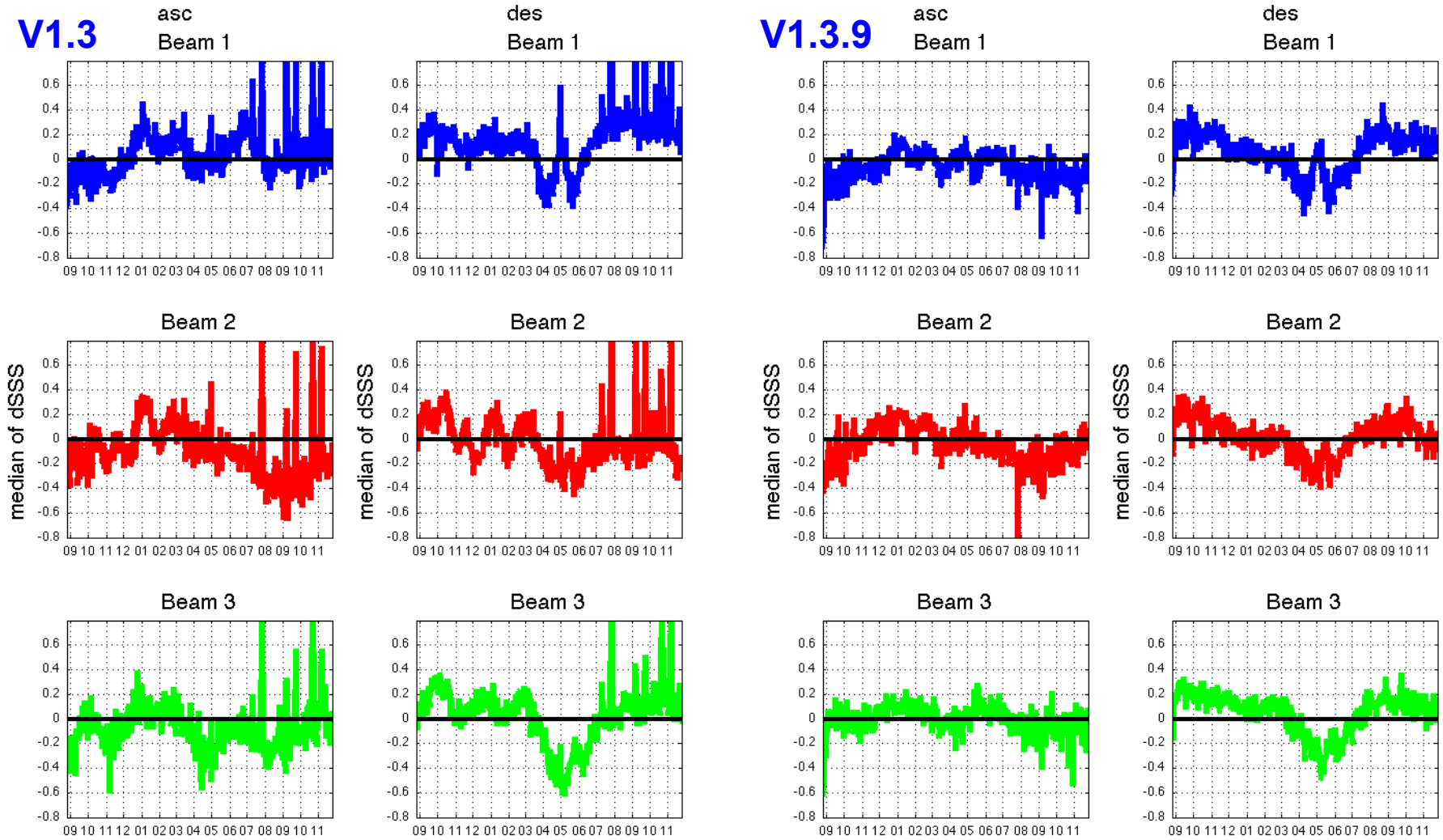


BIAS	both	ascend	descen
50-60N	0.15	0.11	0.17
40-50N	0.20	0.14	0.24
30-40N	0.13	0.15	0.12
20-30N	0.07	0.07	0.08
10-20N	-0.01	-0.07	0.02
0-10N	-0.06	-0.12	-0.01
10S-0	-0.04	-0.11	0.03
10-20S	-0.06	-0.16	0.02
20-30S	0.01	-0.07	0.08
30-40S	0.10	0.06	0.15
40-50S	0.13	0.11	0.16
50-60S	-0.01	0.00	-0.02

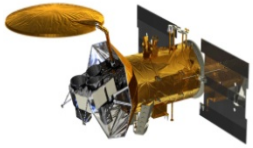
Ascending and Descending trends



V1.3 trends are different for ascending and descending. Likely sources are antenna coupling, galaxy reflection and others

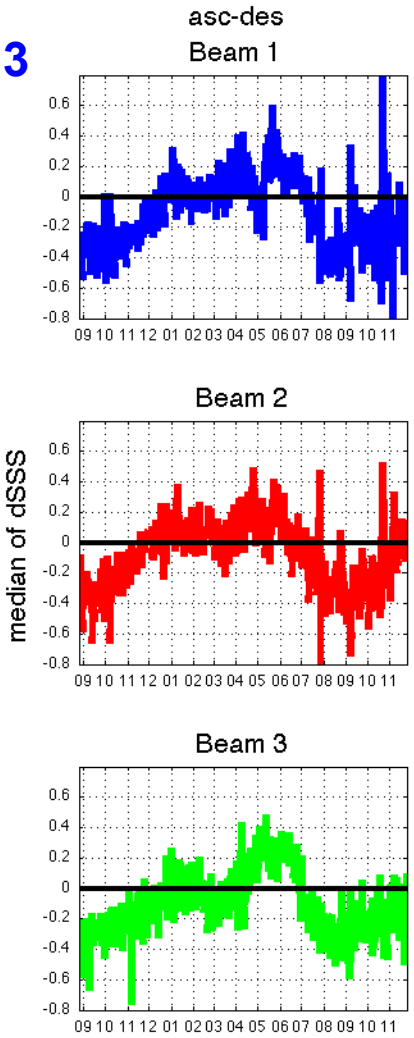


Ascending and Descending trends

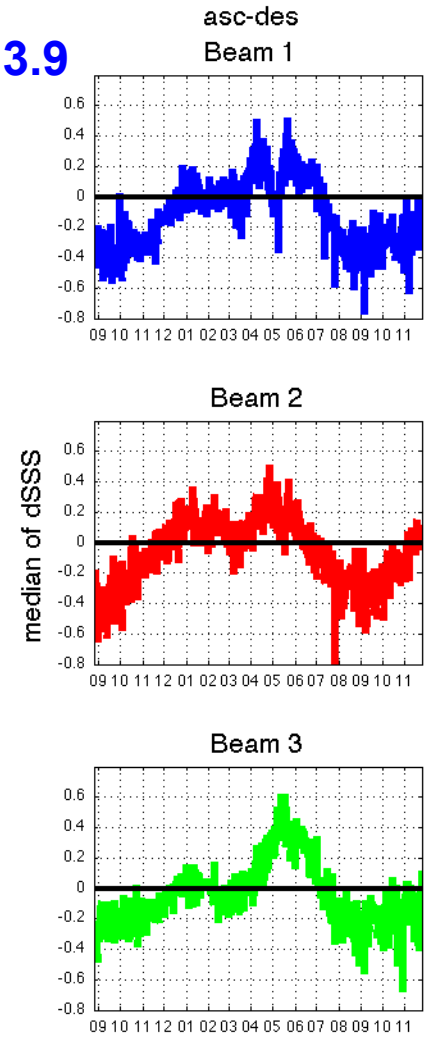


V1.3 trends are different for ascending and descending. Likely sources are antenna coupling, galaxy reflection and others

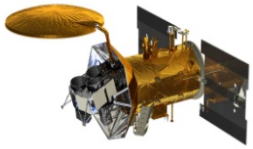
V1.3

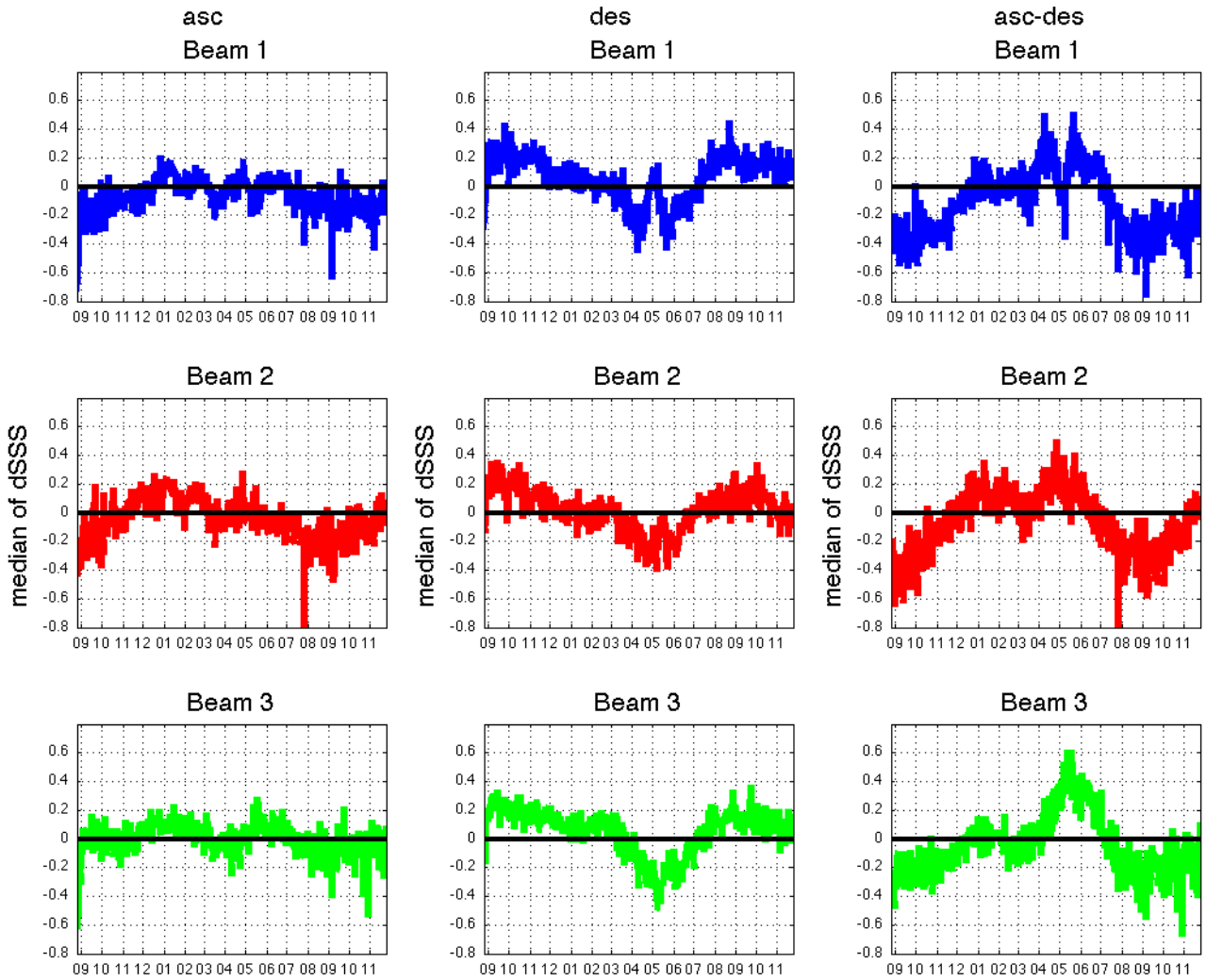


V1.3.9

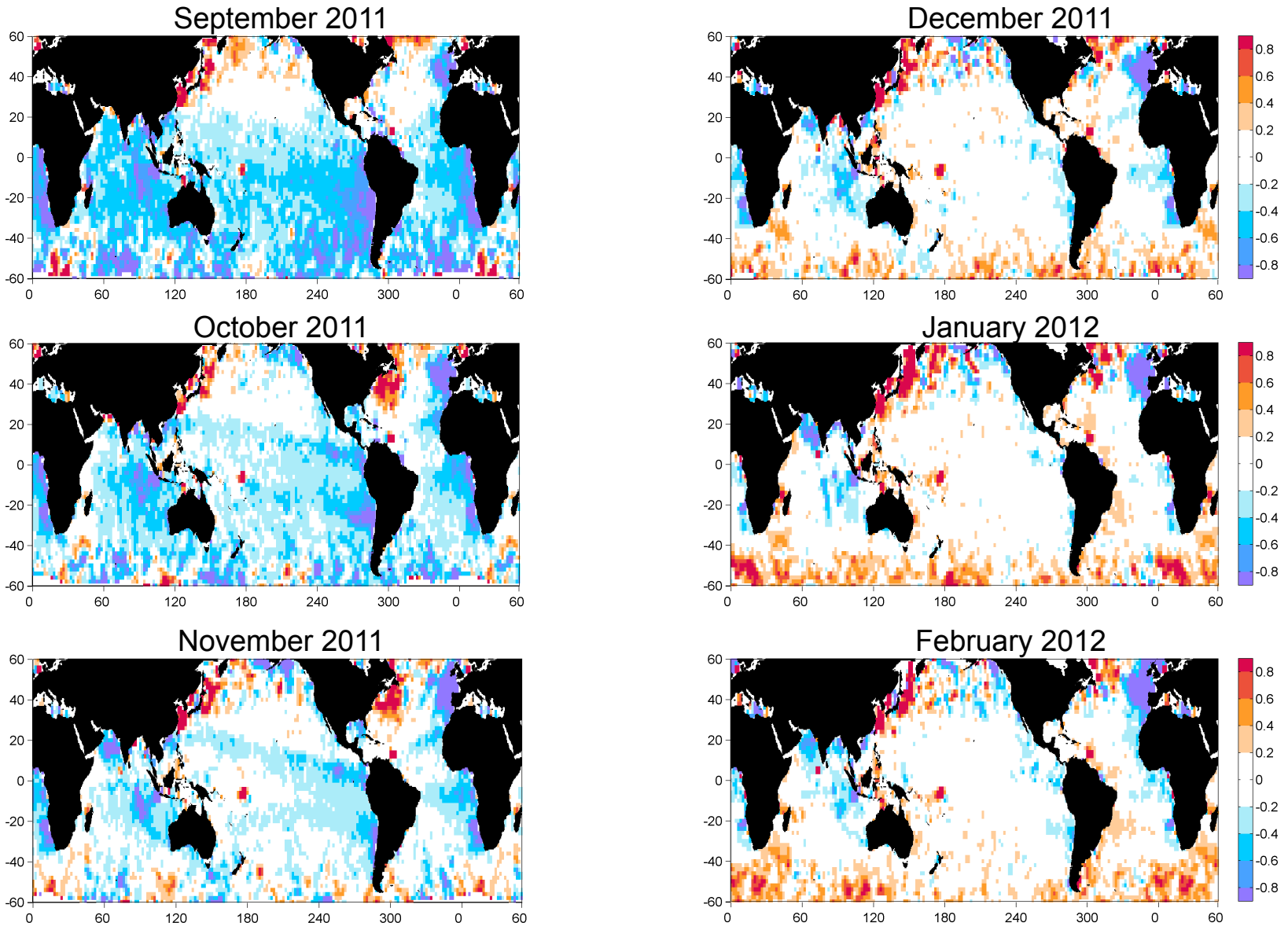


V1.3.9 Buoy Match-up Timeseries





Ascending-Descending Differences (V1.3.9)

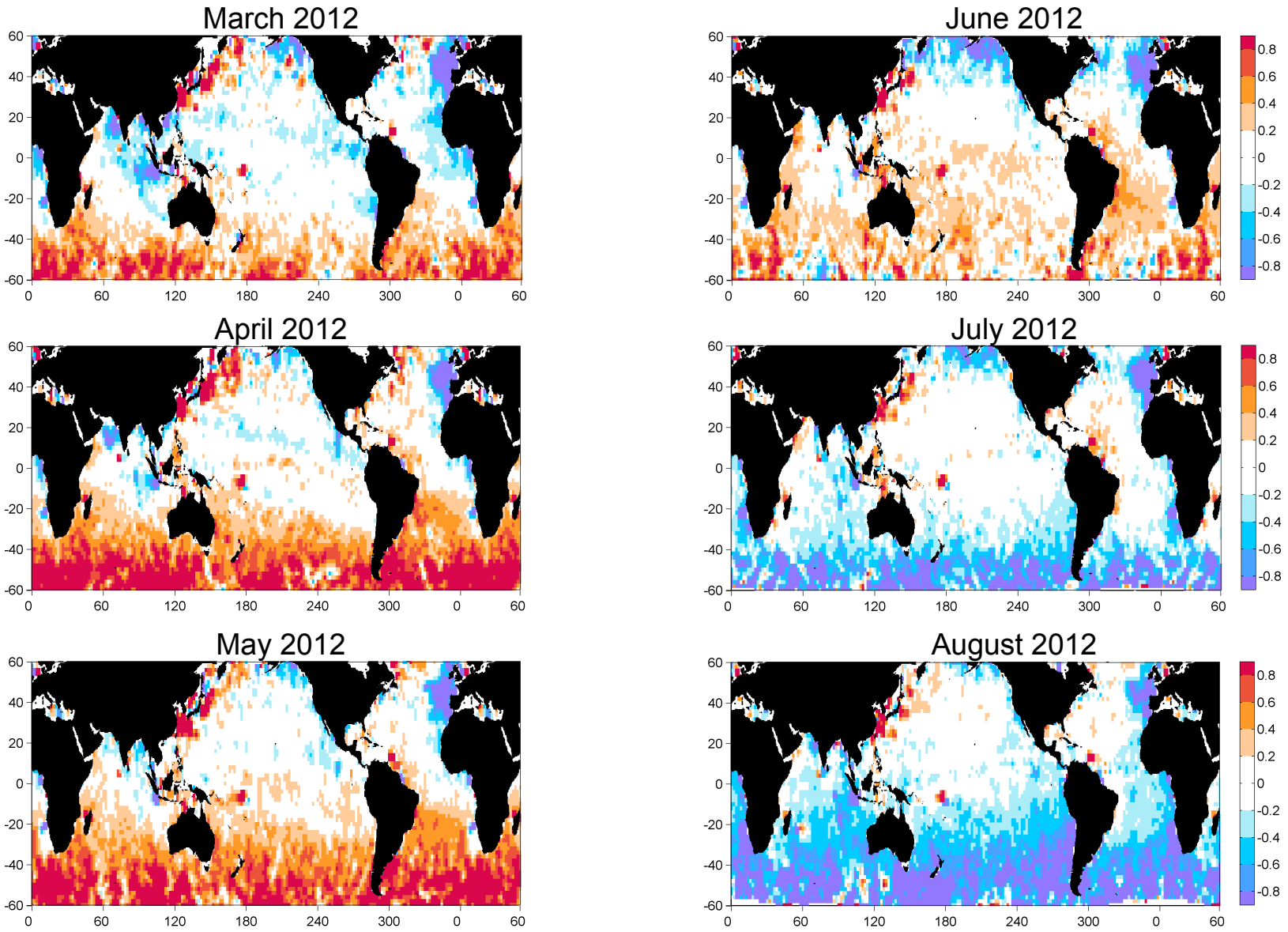


O. Melnichenko & P. Hacker; U. Hawaii

The difference between ascending and descending SSS. Monthly fields of SSS were constructed by bin-averaging raw Aquarius data (either ascending or descending) within 4° x 4° bins centered on a global grid with the grid spacing of 2°.

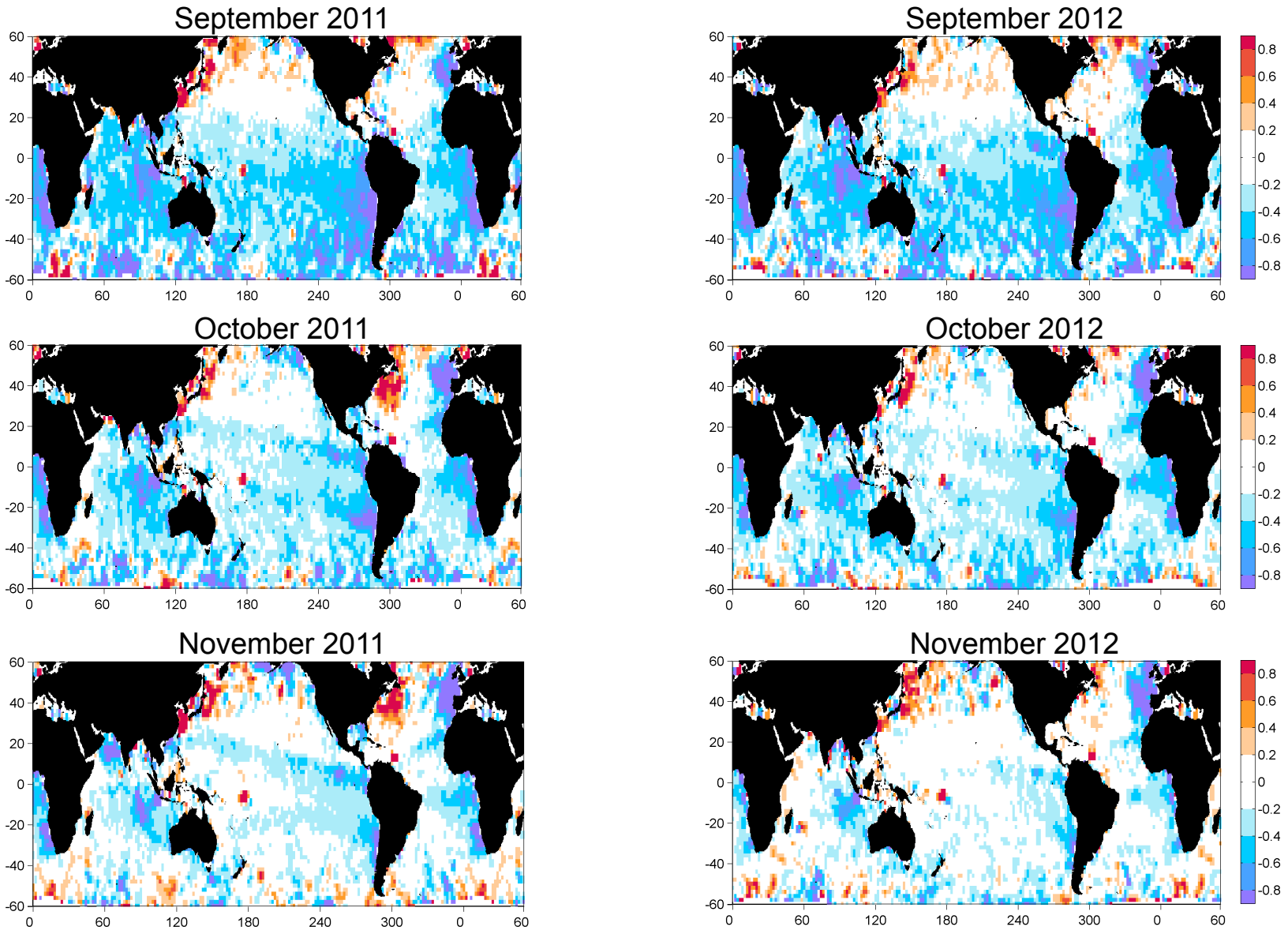
Ascending-Descending Differences (V1.3.9)

O. Melnichenko & P. Hacker; U. Hawaii



The difference between ascending and descending SSS. Monthly fields of SSS were constructed by bin-averaging raw Aquarius data (either ascending or descending) within 4° x 4° bins centered on a global grid with the grid spacing of 2°.

Ascending-Descending Differences (V1.3.9)

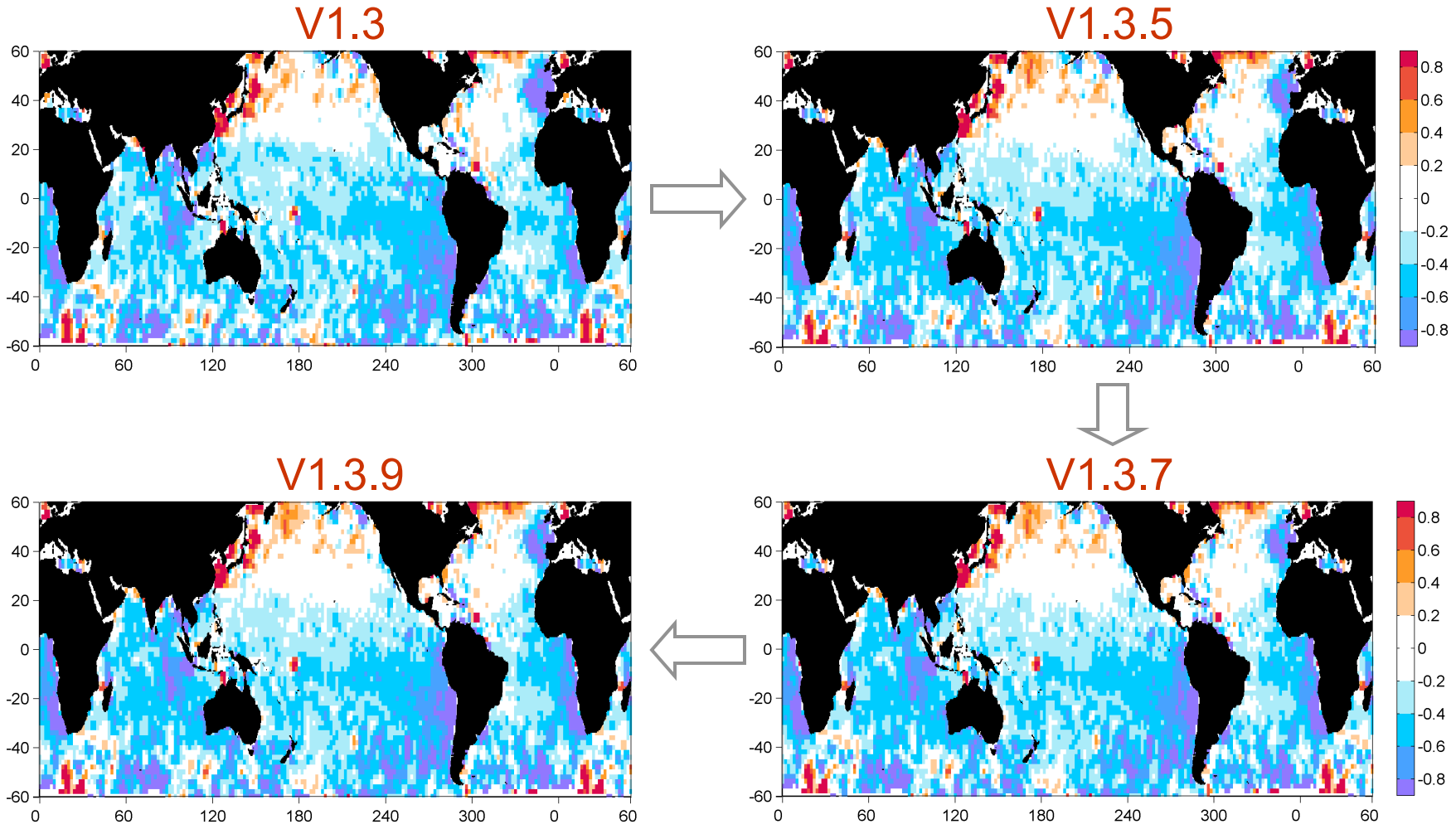


O. Melnichenko & P. Hacker; U. Hawaii

The difference between ascending and descending SSS. Monthly fields of SSS were constructed by bin-averaging raw Aquarius data (either ascending or descending) within 4° x 4° bins centered on a global grid with the grid spacing of 2°.

Ascending-Descending Differences

September 2011

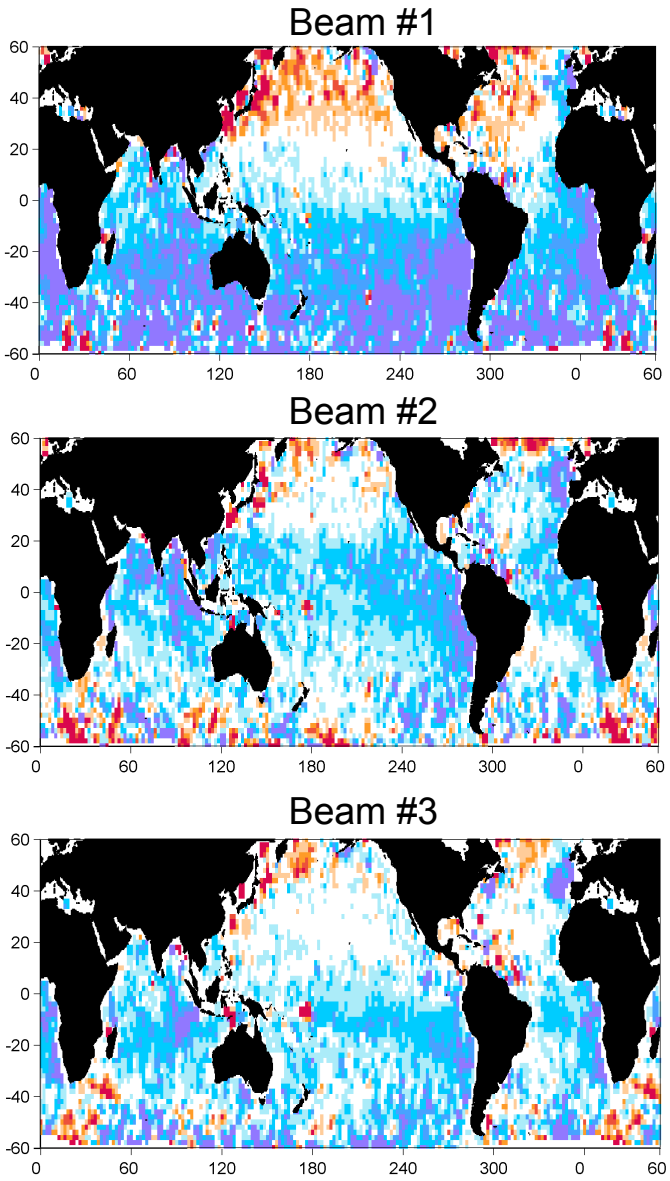


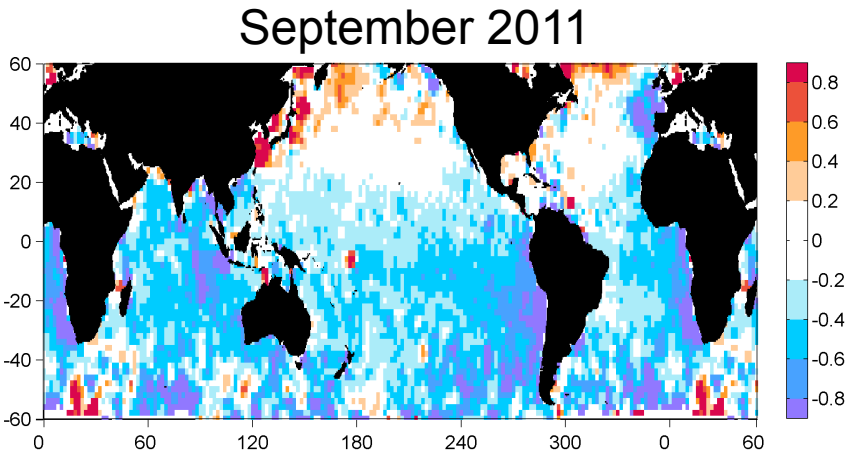
O. Melnichenko & P. Hacker; U. Hawaii

The difference between ascending and descending SSS. Monthly fields of SSS were constructed by bin-averaging raw Aquarius data (either ascending or descending) within 4° x 4° bins centered on a global grid with the grid spacing of 2°.

Ascending-Descending Differences (V1.3.9)

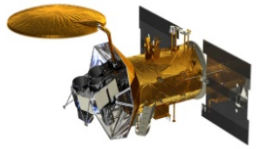
O. Melnichenko & P. Hacker; U. Hawaii





Monthly fields of SSS were constructed by bin-averaging raw Aquarius data (either ascending or descending) within 4° x 4° bins centered on a global grid with the grid spacing of 2°.

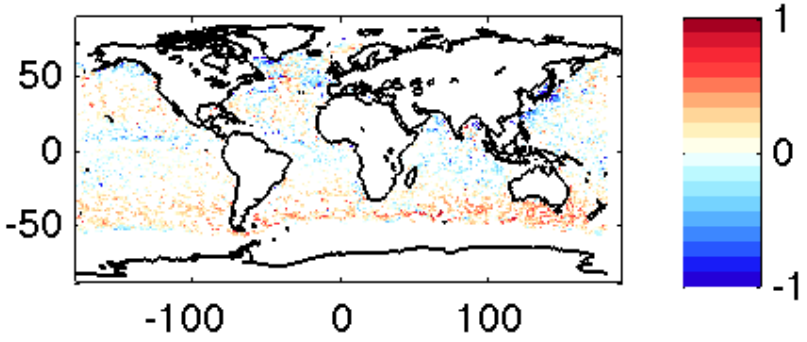
Three-month (seasonal) average buoy differences, V1.3.9



Clearly evident seasonal error variation

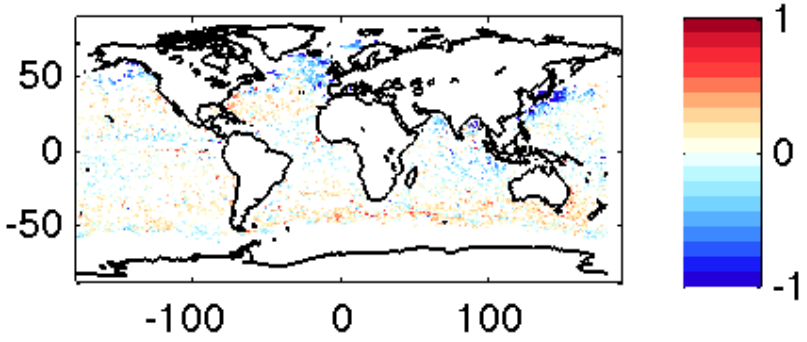
SON

09/21/2011 - 12/20/2011



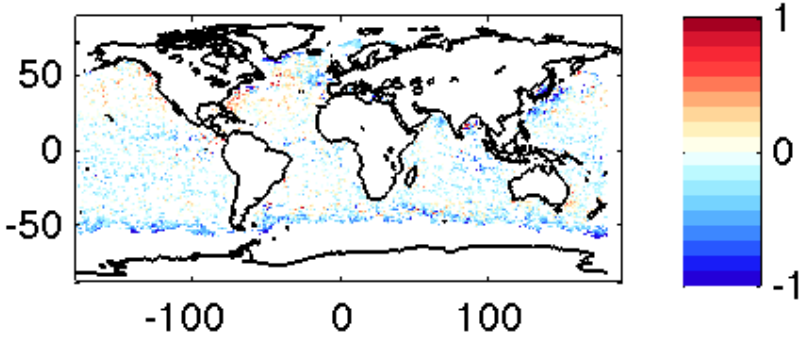
DJF

12/21/2011 - 03/20/2012



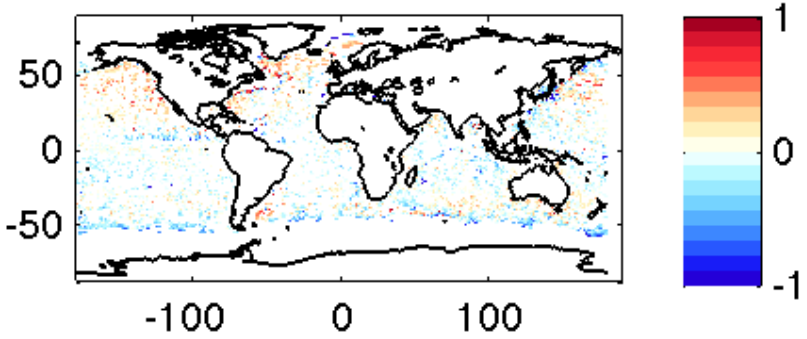
MAM

03/21/2012 - 06/20/2012

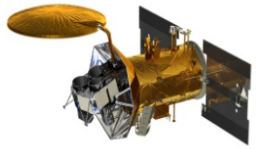


JJA

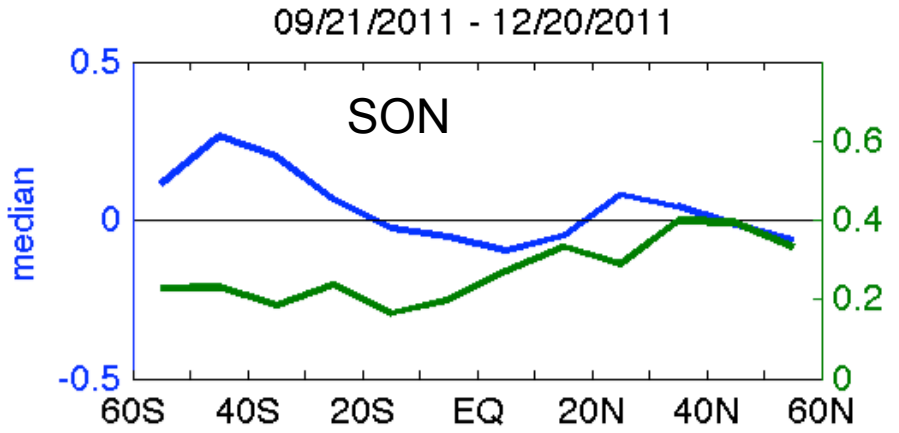
06/21/2012 - 09/20/2012

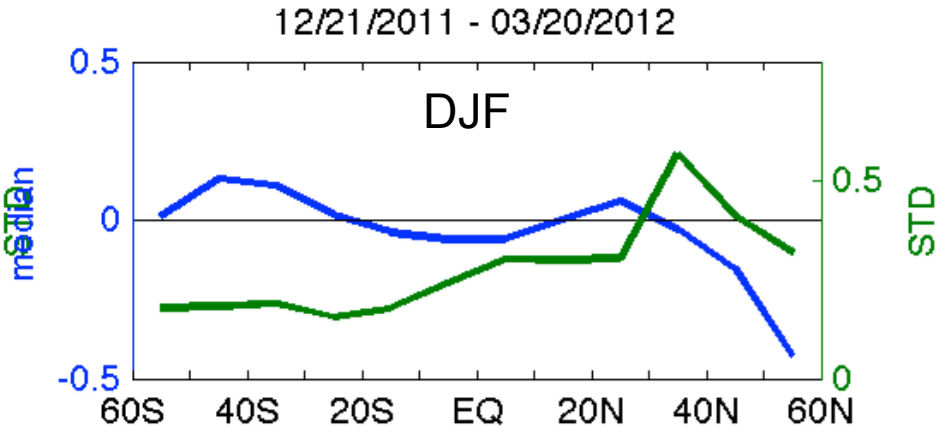


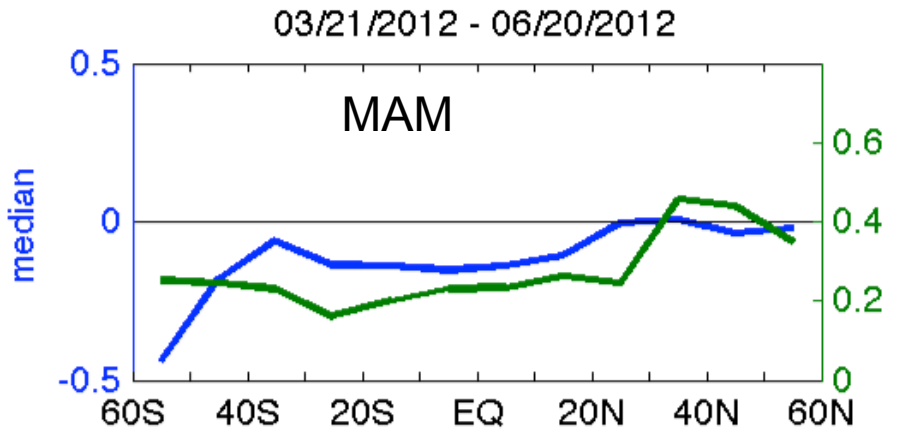
Three-month (seasonal) average buoy differences, V1.3.9

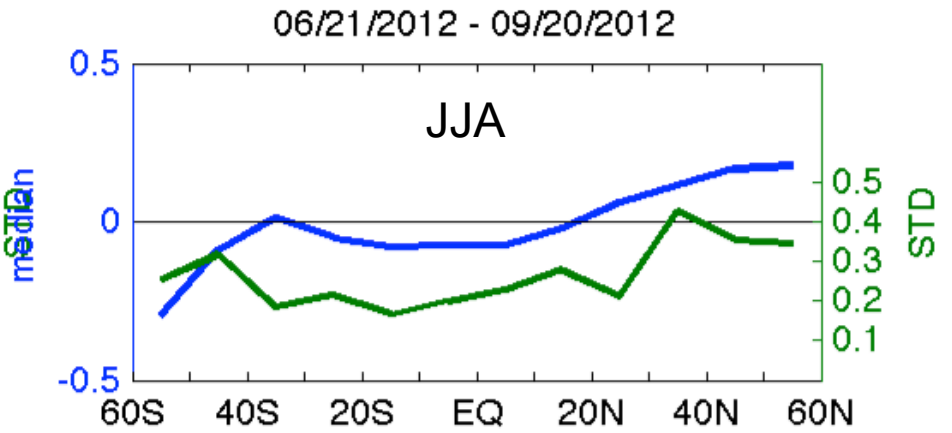


Clearly evident seasonal error variation

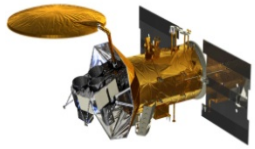








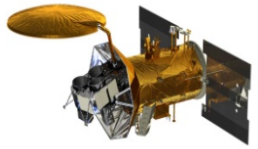
Aq V1.3.9 – buoy (averaged around L3 grid), by Latitude (L3)



For seasonal means, about 25% of the latitude bands have both bias and std within 0.2 psu.

Latitude	SON Bias	SON STD	DJF Bias	DJF STD	MAM Bias	MAM STD	JJA Bias	JJA STD
50-60N	-0.06	0.33	-0.43	0.32	-0.02	0.35	0.18	0.35
40-50N	-0.01	0.39	-0.15	0.41	-0.04	0.44	0.17	0.35
30-40N	0.04	0.40	-0.03	0.57	0.01	0.46	0.11	0.43
20-30N	0.08	0.29	0.06	0.30	0.00	0.24	0.06	0.21
10-20N	-0.05	0.33	0.00	0.30	-0.11	0.26	-0.02	0.28
0-10N	-0.09	0.27	-0.06	0.30	-0.14	0.24	-0.08	0.23
10S-0	-0.05	0.20	-0.06	0.24	-0.15	0.23	-0.07	0.20
10-20S	-0.02	0.16	-0.04	0.18	-0.14	0.20	-0.08	0.17
20-30S	0.06	0.24	0.02	0.16	-0.14	0.16	-0.05	0.22
30-40S	0.20	0.18	0.11	0.19	-0.06	0.23	0.01	0.19
40-50S	0.26	0.24	0.13	0.18	-0.18	0.24	-0.09	0.32
50-60S	0.11	0.23	0.01	0.18	-0.44	0.25	-0.30	0.25

Aq V1.3.9 – buoy (averaged around L3 grid), by Latitude (L3)

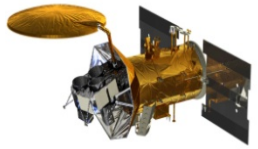


STD: STD of Aq – buoy difference
STDb: STD of buoy data

$STDa = sqrt(STD^2 - STDb^2)$ = STD of Aquarius

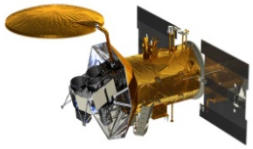
Latitude	SON			DJF			MAM			JJA		
	BIAS	STD	STDb	BIAS	STD	STDb	BIAS	STD	STDb	BIAS	STD	STDb
0-10	-0.07	0.24	0.04	-0.06	0.27	0.03	-0.15	0.23	0.03	-0.07	0.21	0.06
11-20	-0.04	0.26	0.05	-0.02	0.25	0.06	-0.12	0.23	0.06	-0.05	0.23	0.07
21-30	0.07	0.26	0.06	0.04	0.24	0.07	-0.08	0.21	0.06	-0.01	0.22	0.07
31-40	0.15	0.30	0.08	0.08	0.40	0.07	-0.04	0.33	0.07	0.04	0.30	0.08
41-50	0.22	0.31	0.12	0.10	0.29	0.12	-0.16	0.30	0.11	-0.04	0.34	0.10
51-60	0.04	0.30	0.15	-0.04	0.28	0.15	-0.34	0.35	0.14	-0.14	0.39	0.12

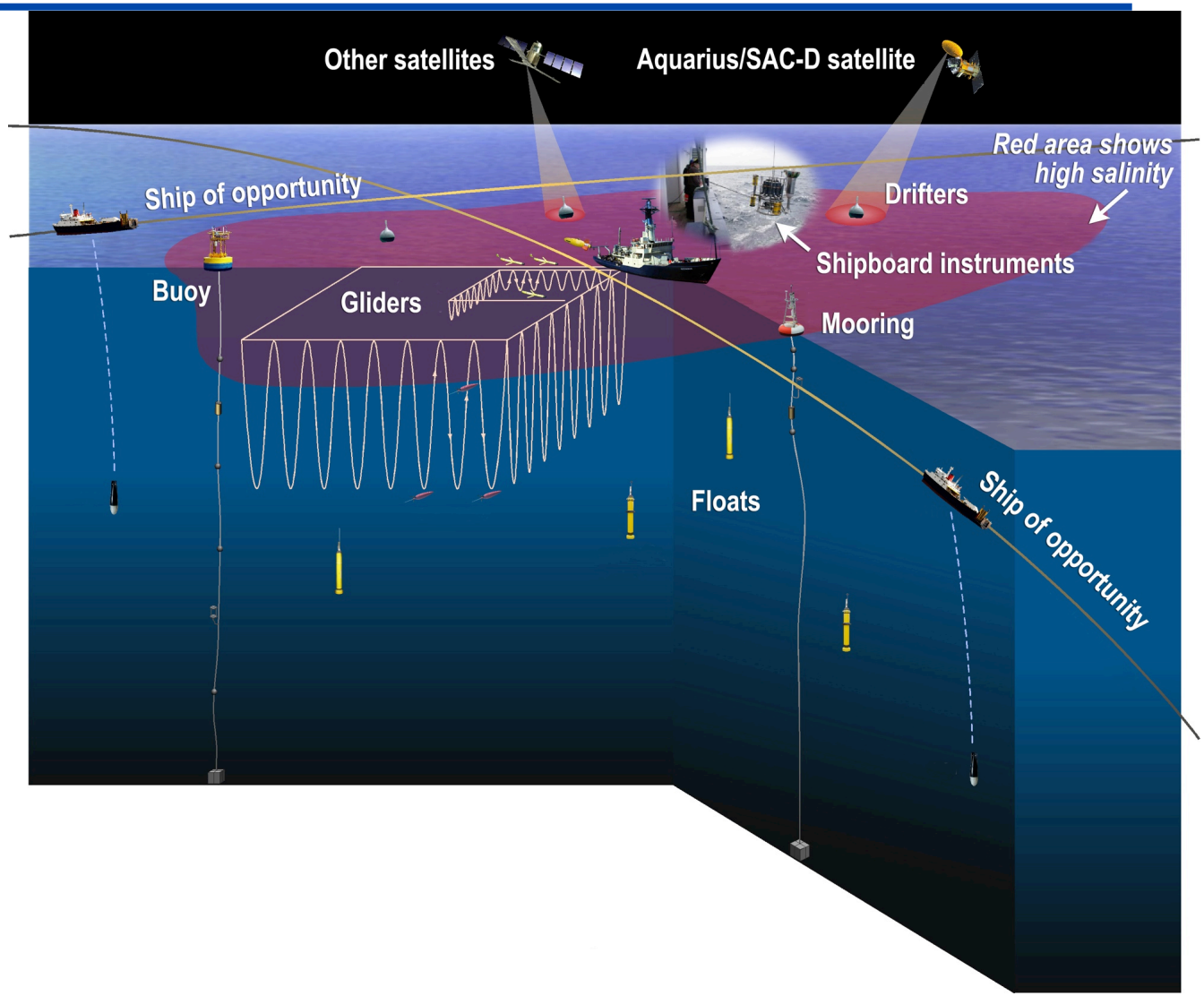
Seasonal Error Estimates Compared with Minimum Mission Requirements



Minimum Mission Seasonal Salinity Error (psu)		SON	DJF	MAM	JJA
Latitude Range	Allocation (psu)	STDa	STDa	STDa	STDa
0-10	0.15	0.24	0.27	0.24	0.24
11-20	0.16	0.26	0.24	0.26	0.26
21-30	0.16	0.25	0.23	0.25	0.25
31-40	0.18	0.29	0.39	0.29	0.29
41-50	0.21	0.29	0.26	0.29	0.29
51-60	0.24	0.26	0.24	0.26	0.26
61-70	0.26				
Global RMS	0.20	0.26	0.28	0.27	0.27

SPURS Cruise Sep-Oct 2012



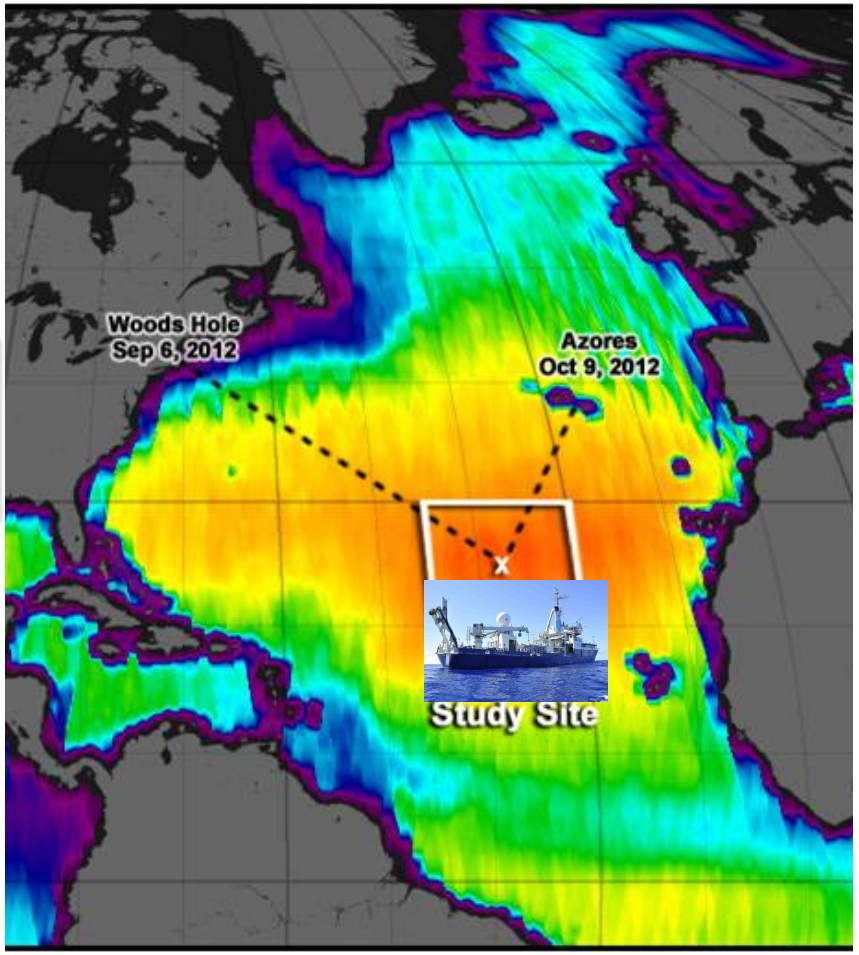


SPURS

Salinity Processes in the Upper Ocean Regional Study

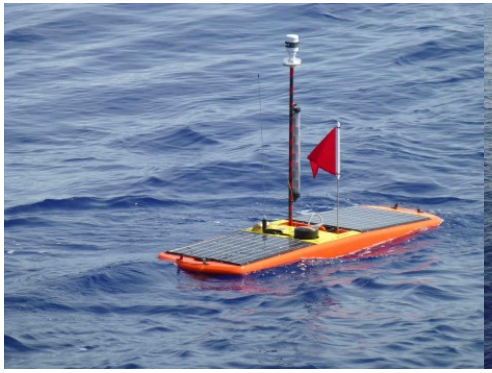
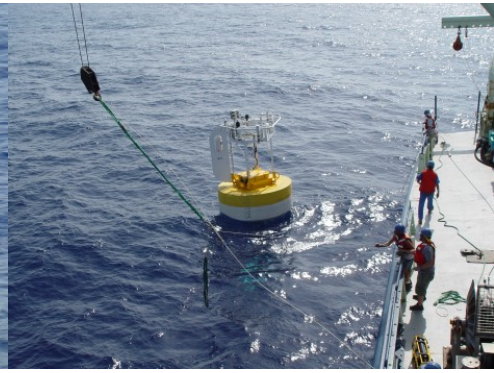
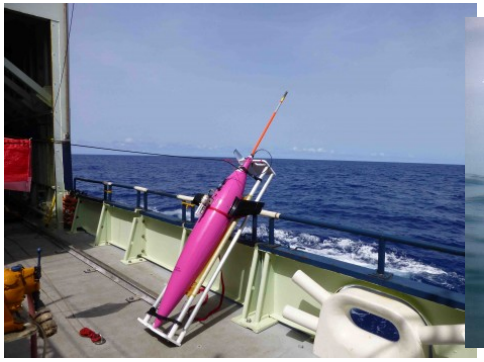
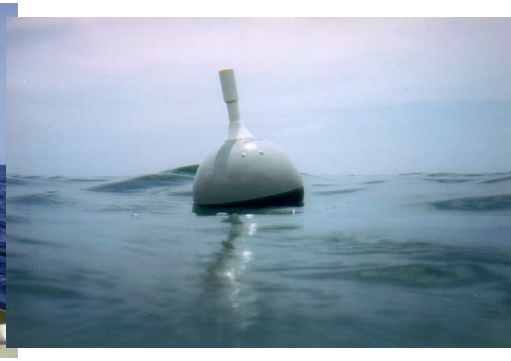
SPURS plans 5 cruises during Sept. 2012 – Sept. 2013

1. Thalassa/France-2012 (8/16 - 9/13)
2. Knorr/US-2012 (9/6 – 10/9)
3. Sarmiento/Spain-2013 (3/14 – 4/20)
4. Endeavour/US-2013 (3/14 – 4/14)
5. US Cruise-2013 (Sept.)

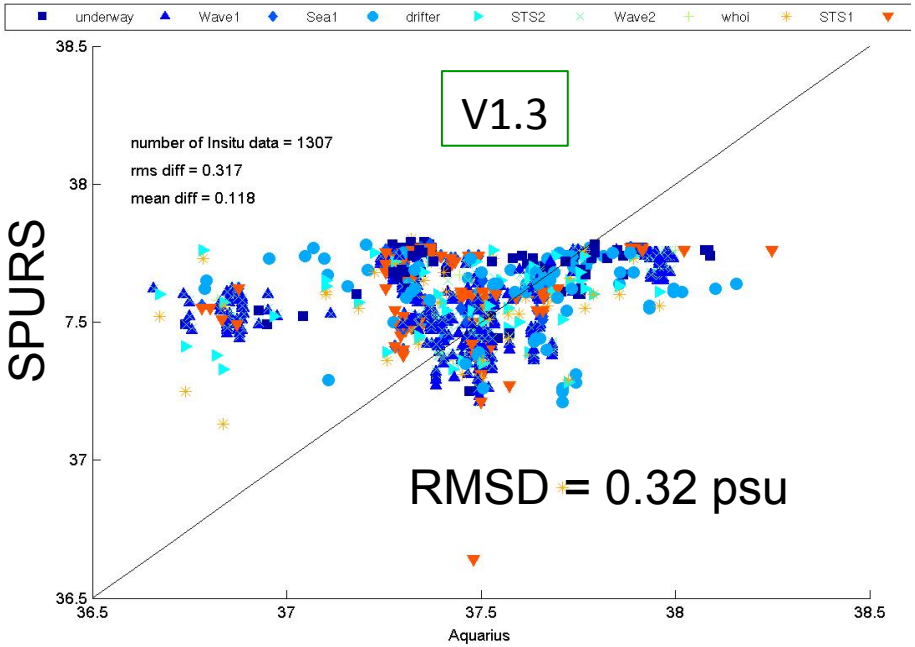


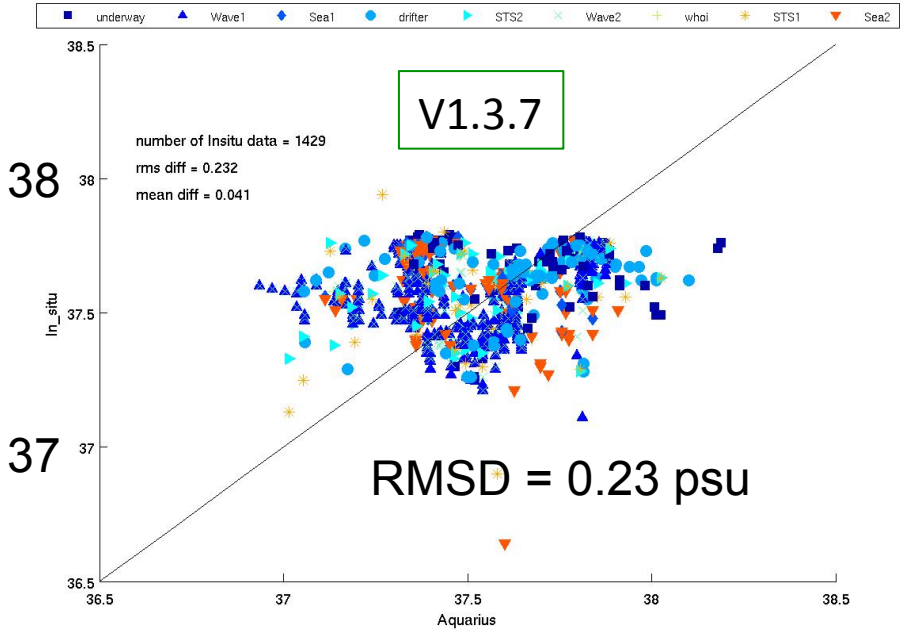
SPURS Salinity Data Depth (in meters)

- Waveglider-1: 0.2
- Drifter: 0.6
- WHOI mooring: 1
- STS Float-1: 0-2
- STS Float-2: 2-15
- Seaglider-1: 0-2
- Seaglider-2: 2-15
- Underway: 5
- Waveglider-2: 6

SPURS-Aquarius Matchup
6 Sep – 9 Oct 2012

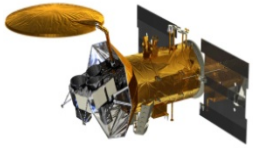




AQUARIUS

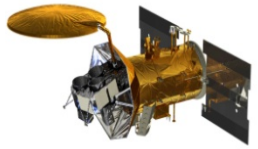
Let SPURS RMSE = 0.15,
Then Aquarius RMSE=sqrt($.23^2$ - $.15^2$)=0.17 psu

Summary



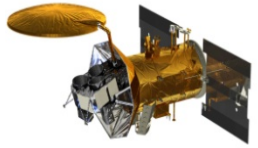
- Global RMSE, for the entire 16-months together, ~0.46 psu (triple point analysis, point measurements, no averaging)
- Monthly mean RMSE approximately 0.33 psu
- Significant annual error cycle and geographic error patterns, >0.5 psu amplitude, especially in southern hemisphere.
- Ascending-descending annual cycle bias, mostly in the descending side of the orbit (6am)
- **Beware of making any conclusions about the annual cycle in the data**
- Three-month average gridded fields global RMSE ~ 0.27 psu; Minimum Mission Requirement = 0.20 psu
- SPURS RMSD (1-month) ~0.23 psu, RMSE(Aquarius) ~0.17 psu

Baseline and Minimum Mission - Status



	Level 1 Science Mission Requirement	Baseline Mission	Minimum Mission
1	The Aquarius Mission shall collect the space-based measurements to retrieve Sea Surface Salinity (SSS) with global root-mean-square (rms) random errors and systematic biases no larger than **0.2 psu** on 150 km by 150 km scales over the ice-free oceans	0.33	0.27
2	SSS Averaging Interval	1 Month	3 Months
3	Mission Duration	At least 3 Years	At least 1 Year
4	Deliver data products to a NASA Distributed Active Archive Center (DAAC). Level 1a Reconstructed Unprocessed Instrument Data Level 1b Calibrated Sensor Units Level 2 Derived Geolocated SSS Level 3 Time-space averaged SSS on a standard Earth Projection		Yes

Version Summary



- V1.3: Operational since April 2012, uses deflection ratio (DR) calibration, has ~0.5 degree pointing offset
- V1.3.2: August 2012. Early updates of several parts of code to correct for pointing offset, introduces a new model for the antenna gain pattern, new land corrections and roughness model.
- V1.3.4: September 2012: Introduces an exponential calibration drift correction for long-term drift. Quasi-monthly calibration "wiggles" still prevalent.
- V1.3.5: September 2012: Some corrections to V1.3.4 code; V1.3.5 released to science team for evaluation
- V1.3.7: December 2012: Separate instrument Calibration Wiggles from Geophysical error
- V1.3.9: Correct for reference salinity (HYCOM) latitude offset