Evaluation of satellite-derived coupling between surface wind and SST frontal zones using moored buoys in the Gulf Stream and eastern equatorial Pacific

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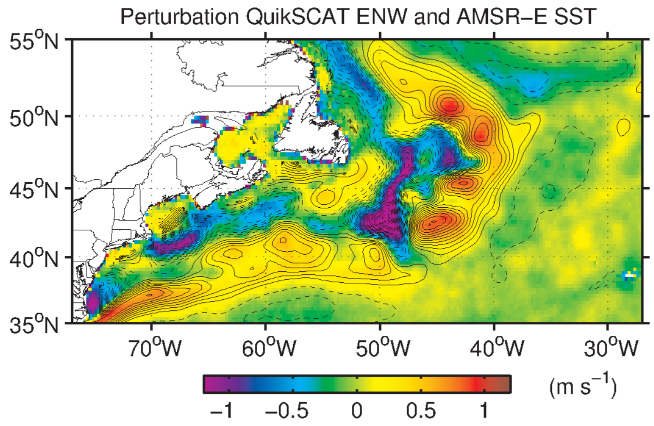
Purpose

- Evaluate satellite observations of the surface wind response to SST frontal zones [length scales of O(10-1000 km)] using moored buoy observations
- How does the SST-induced responses of surface stratification and actual near-surface wind speed contribute to the 10-m equivalent neutral wind speed (ENW) responses to SST fronts? Stratification can be highly variable spatially as winds blow across SST fronts.

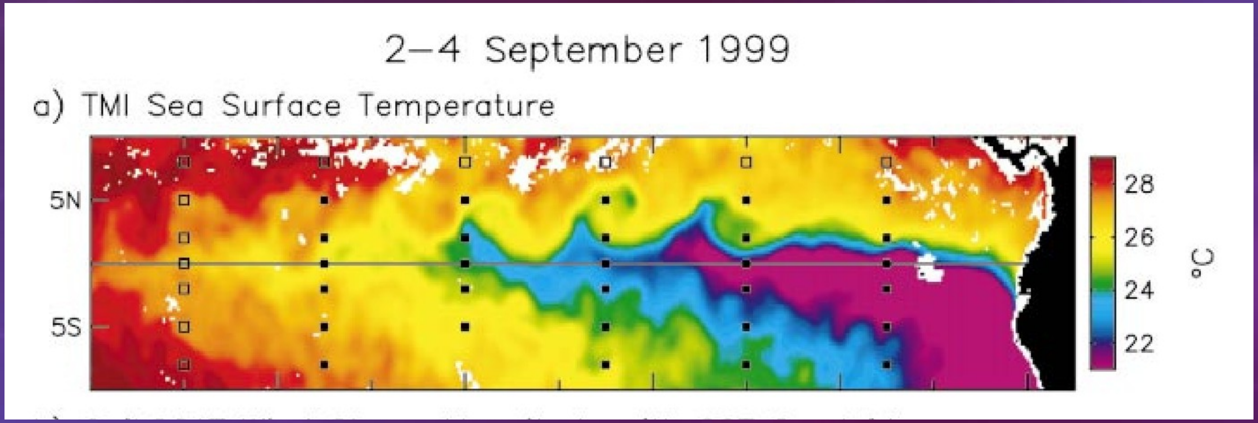
Motivation



7-yr mean spatially high-pass filtered QuikSCAT ENW (colors) and AMSR-E SST (contours)

Mesoscale features of QuikSCAT ENW and surface stress are highly correlated with those of AMSR-E SST

Motivation



Tropical instability waves are a dominant source of SST variability within several degrees of the equator in the eastern Pacific

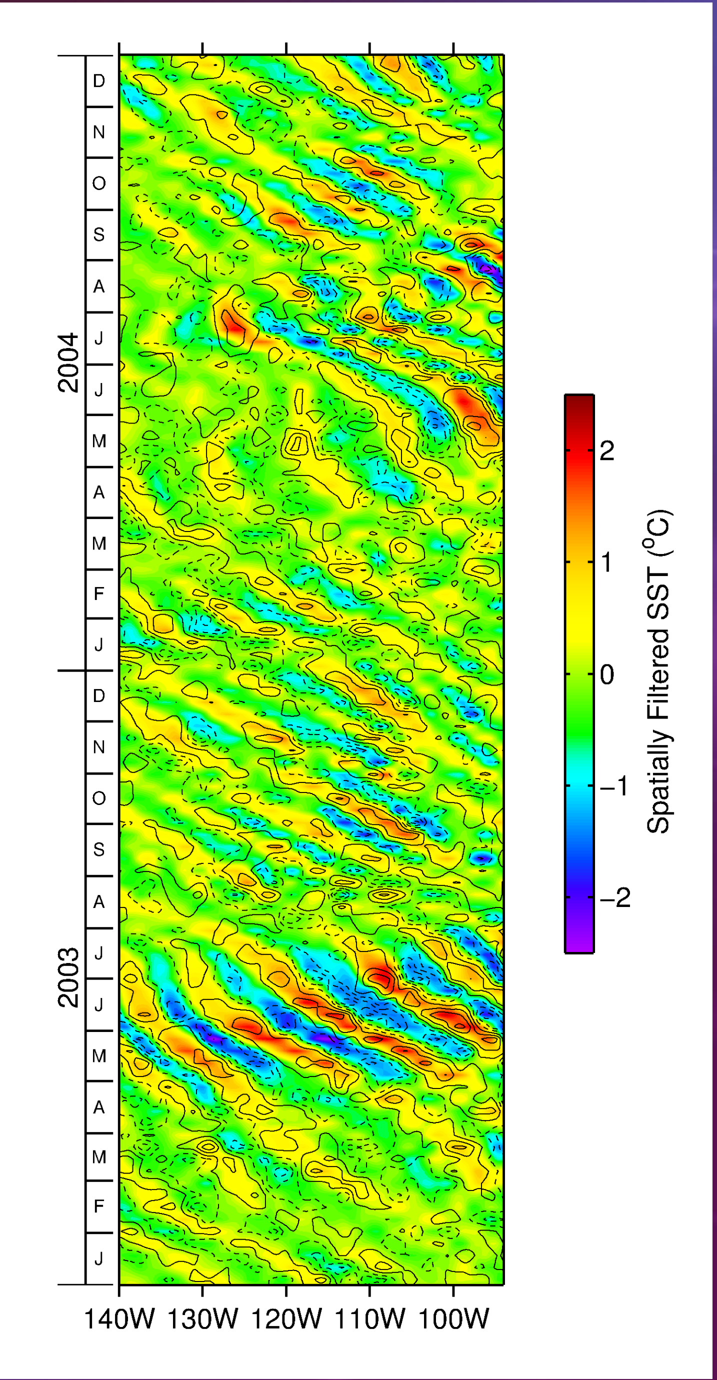
TIWs propagate westward at roughly 50 cm/s and have wavelengths of between 1000 and 3000 km

Time-longitude transect along 1°N for 2-year period

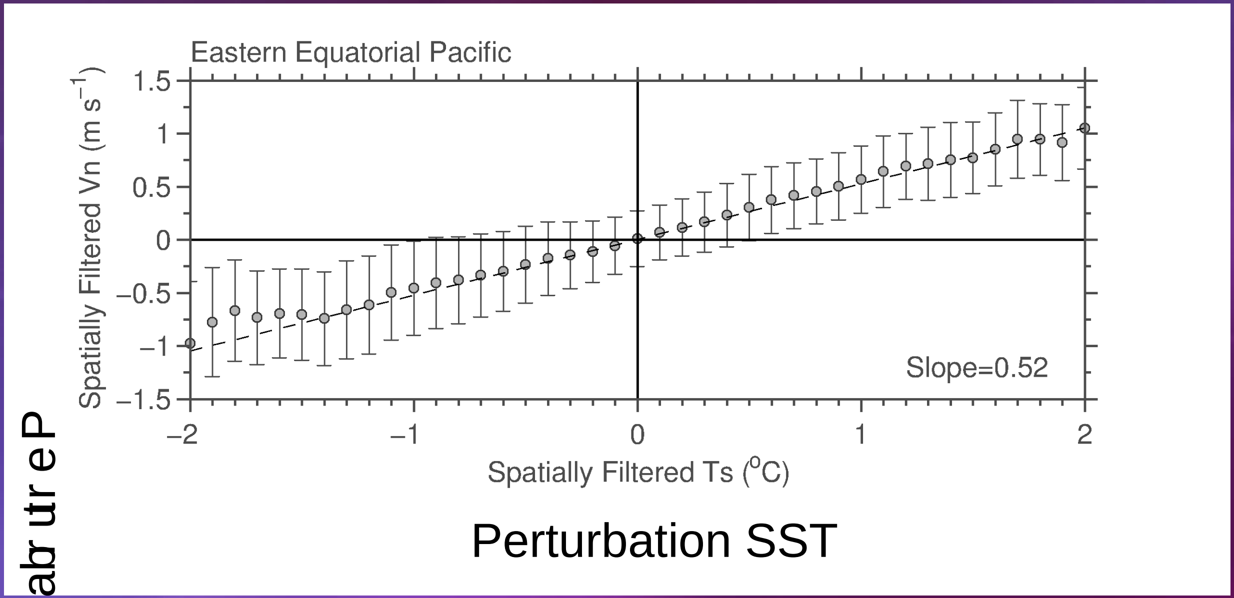
Spatially filtered:

AMSR-E SST (colors)

QuikSCAT ENW (contours)



QuikSCAT ENW and AMSR-E SST statistical analysis in the eastern equatorial Pacific

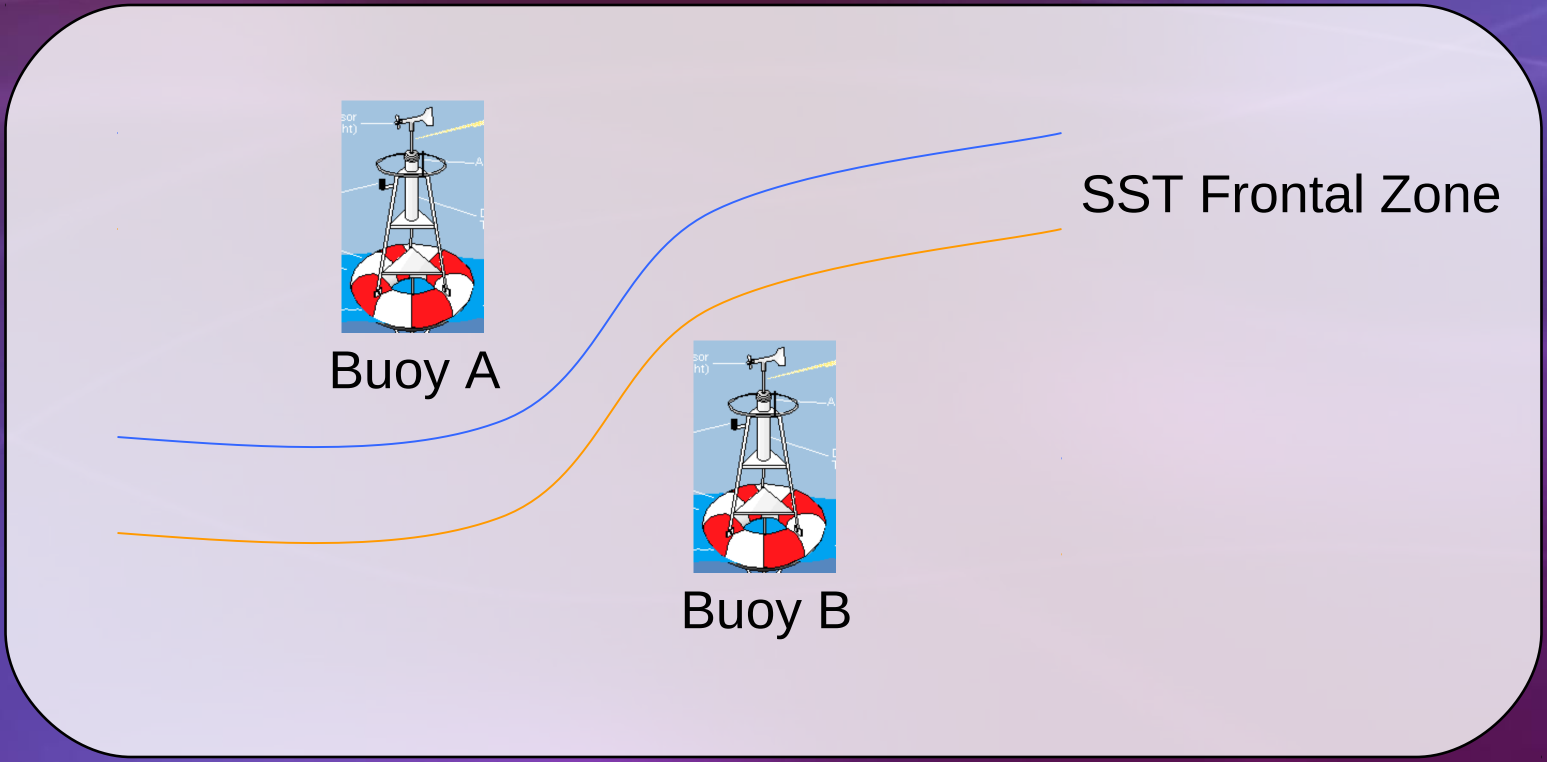


Spatially-filtered ENW perturbations are related linearly to SST

Physics behind wind-SST interactions on the oceanic mesoscale

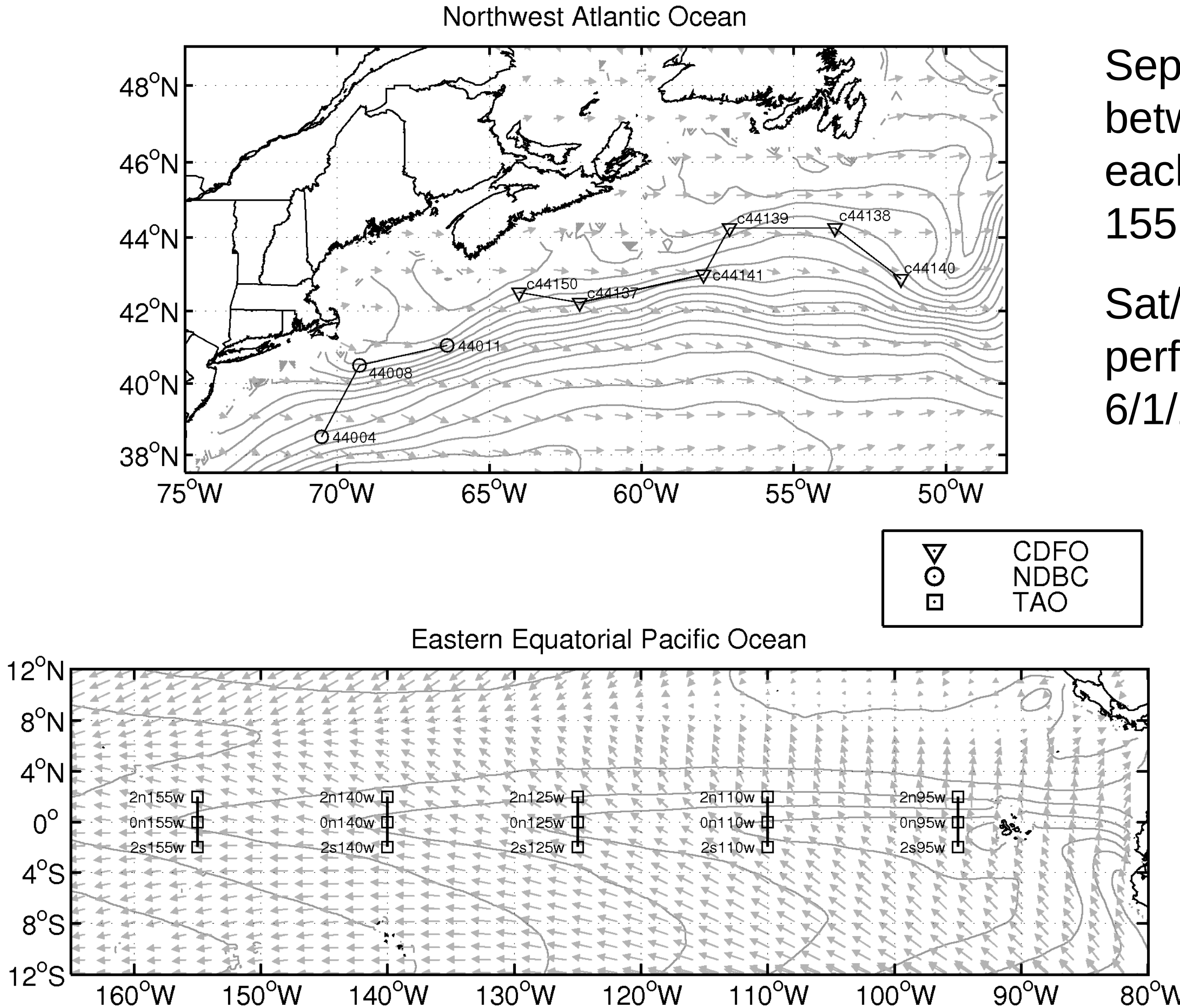
1) SST-induced hydrostatic pressure gradients generated by cross-frontal boundary layer temperature and depth changes (locally low surface pressure over warm water and higher SLP over cooler water; e.g., Lindzen and Nigam 1987; Hashizume et al. 2001; Small et al. 2003JCLI, 2005JGR)
2) Cross-frontal boundary height changes in an equilibrium regime well downwind of front (e.g., Samelson et al. 2006; Spall 2007)
3) Secondary circulations (e.g., Hsu 1984; Wai and Stage 1989)
4) SST-induced modulation of vertical turbulent momentum transport from aloft to the surface (e.g., Sweet et al. 1981; Wallace et al. 1989; Hayes et al. 1989)
5) SST-induced modulation of surface layer vertical profile of horizontal wind by cross-frontal changes of surface buoyancy fluxes (e.g., Friehe et al. 1991; Liu et al. 2007)
6) Surface drag (tau/H) balancing SST-induced pressure driven flow (Small et al. 2005; O’Neill et al. 2010)
7) Baroclinic modification of pressure gradients, vertical shear, and turbulent mixing in the surface layer and throughout the depth of the boundary layer

Methodology



Test the hypothesis that the wind speed difference $V_{10B}-V_{10A}=\delta V_{10}$ depends on the SST difference $T_{SB}-T_{SA}=\delta T_S$

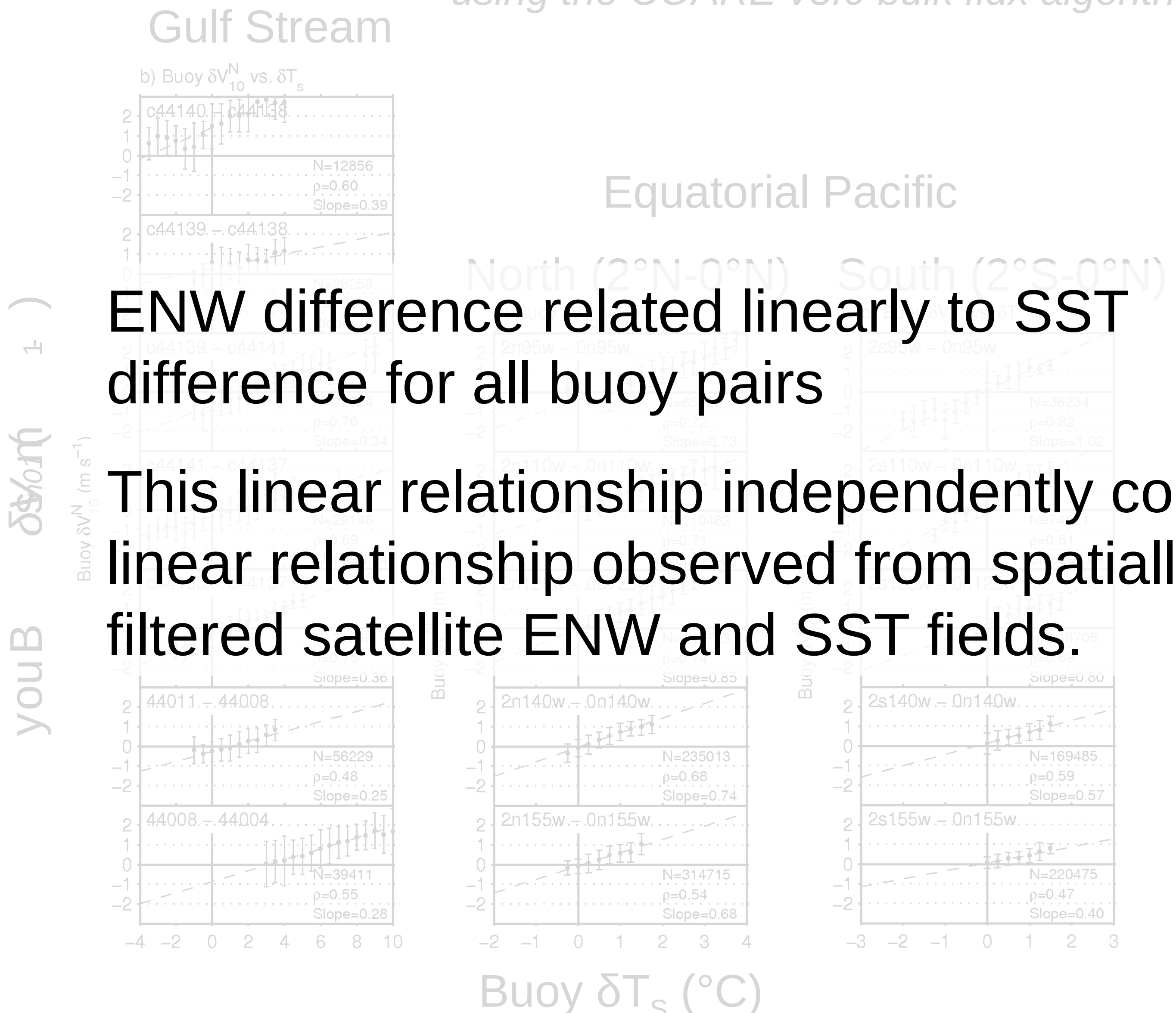
17 buoy pairs in the Gulf Stream and eastern equatorial Pacific



Separation distances between buoys in each pair are between 155 and 343 km

Sat/buoy evaluation performed for period 6/1/2002-7/31/2009

ENW computed according to Liu and Tang (1996) using the COARE v3.0 bulk flux algorithm



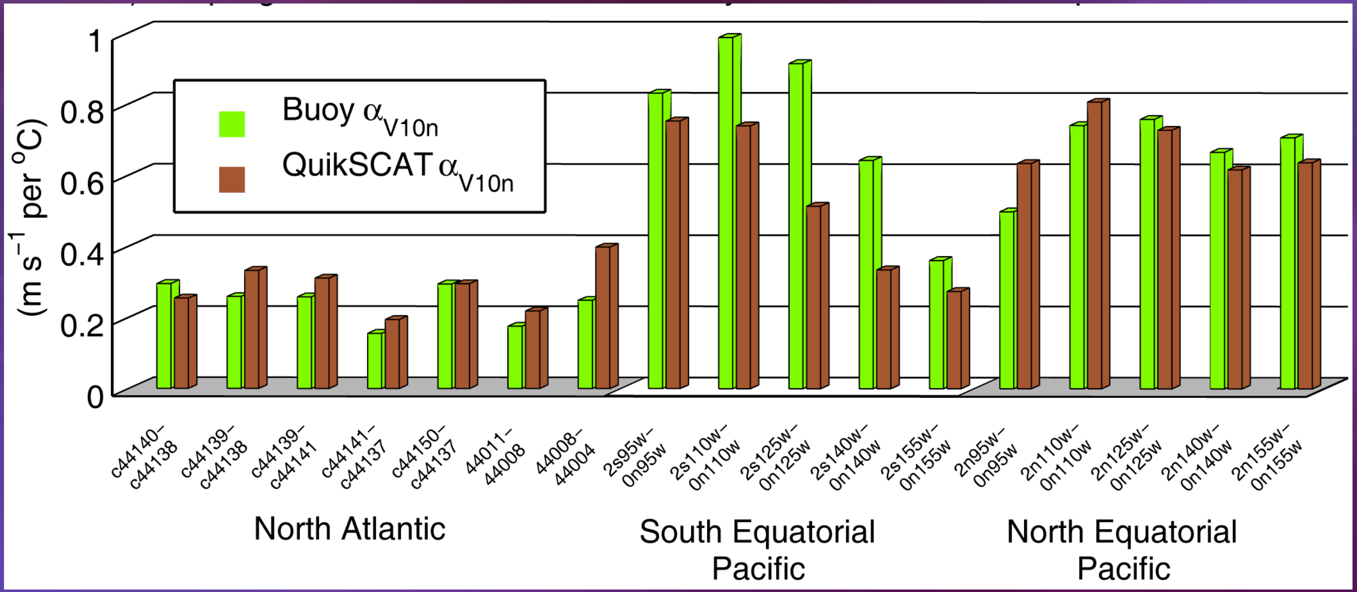
ENW difference related linearly to SST difference for all buoy pairs

This linear relationship independently confirms linear relationship observed from spatially-filtered satellite ENW and SST fields.

Satellite-buoy evaluation procedure

- Collocated buoy and QuikSCAT ENWs that are within +/- 30 minutes
- Bilinearly interpolated QuikSCAT ENW to buoy positions
- Removed rain-flagged QuikSCAT ENW
- Linearly interpolated AMSR-E SST to QuikSCAT observation times and buoy positions
- Considered ENW range of 2-20 m/s
- Apply 10-day running mean to collocated wind and SST time series

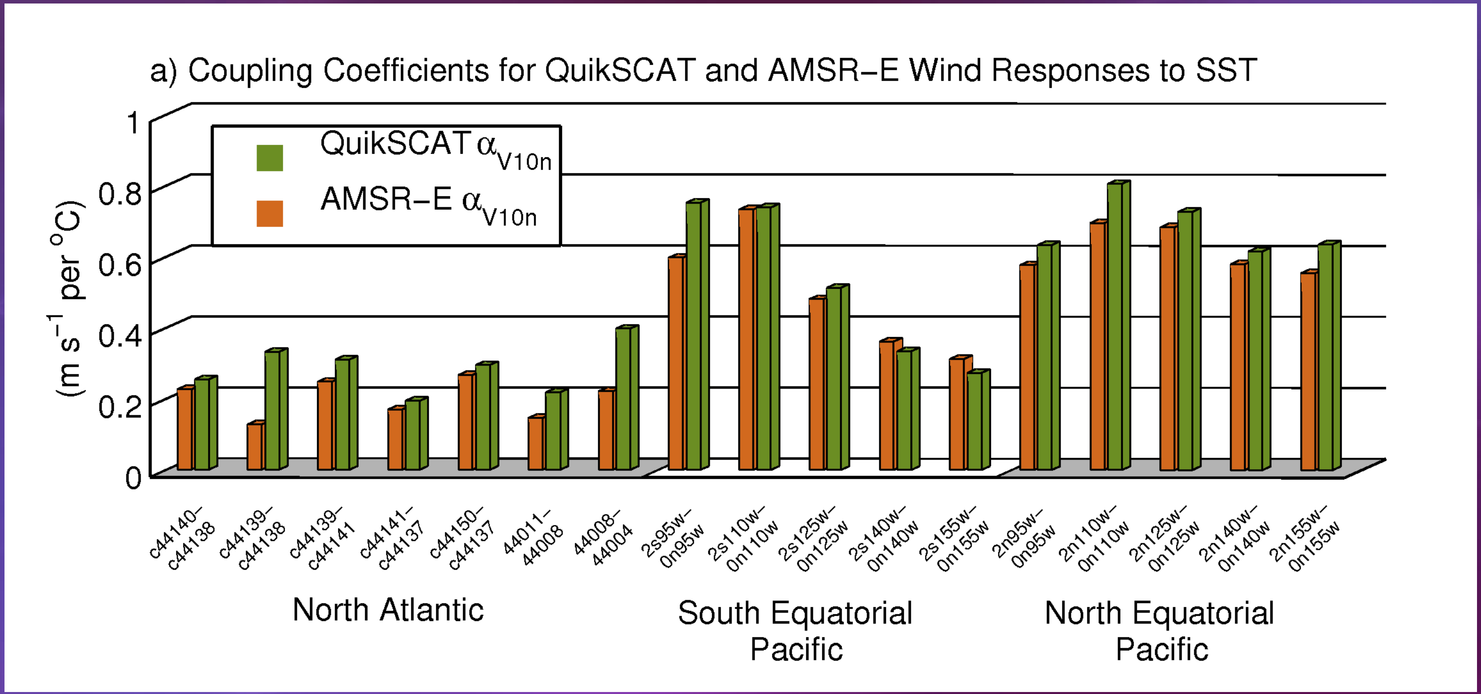
Comparison between buoy and satellite ENW responses to SST



QuikSCAT ENW and AMSR-E SST

Response of 10-m ENW from QuikSCAT similar for most buoy pairs, although biased low over the south equatorial Pacific.

Comparison between QuikSCAT and AMSR-E ENW responses to SST



Using AMSR-E ENW produces a very similar result, including the low bias in the SEP.

Summary statistics of evaluation of the satellite wind-SST response

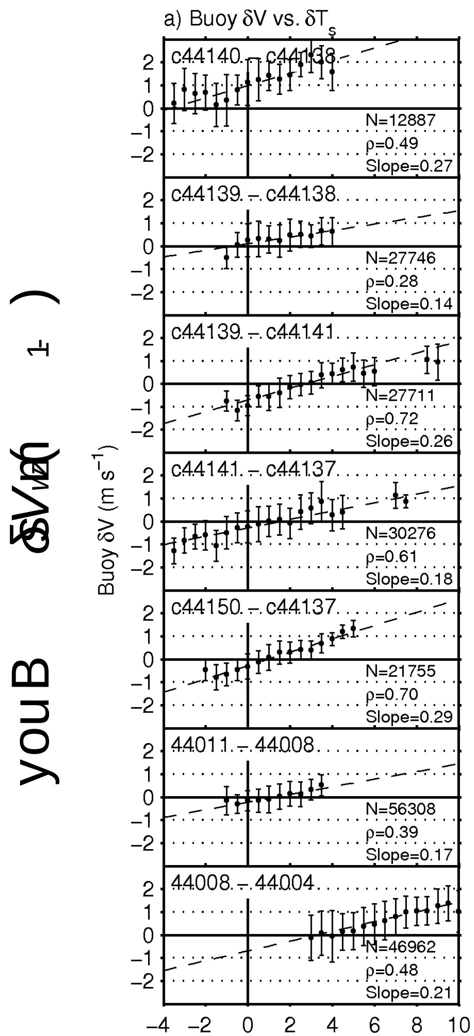
	QuikSCAT/Buoy			AMSR-E/Buoy		
	Mean Diff.	RMS Diff.	Norm. Diff.	Mean Diff.	RMS Diff.	Norm. Diff.
Gulf Stream	0.04	0.07	17%	−0.08	0.08	−25%
S. Eq. Pac.	−0.23	0.26	−31%	−0.18	0.20	−28%
N. Eq. Pac.	0.01	0.07	2%	−0.06	0.08	−9%
All 17 Buoy Pairs	−0.05	0.15	−10%	−0.11	0.13	−21%

TABLE 6. Mean, root-mean square (RMS), and normalized mean differences of $\alpha_{\delta V_{10n}}$ computed from the QuikSCAT and AMSR-E estimates relative to the collocated buoy estimates as listed in Table 5. The normalized mean differences of $\alpha_{\delta V_{10n}}$ are expressed as a percentage of the mean differences of $\alpha_{\delta V_{10n}}$ relative to the buoy-mean $\alpha_{\delta V_{10n}}$ for each region listed in Table 5. The statistics were computed for all 17 buoy pairs and separately for the 7 buoy pairs over the Gulf Stream, and the 5 each over the south and north equatorial Pacific. The mean differences were computed as the satellite $\alpha_{\delta V_{10n}}$ minus the buoy $\alpha_{\delta V_{10n}}$. The mean and RMS differences are in units of m s^{-1} per °C.

Buoy-measured wind speed differences are correlated positively with and related linearly to the SST differences.

No height or stability corrections applied to buoy wind measurements.

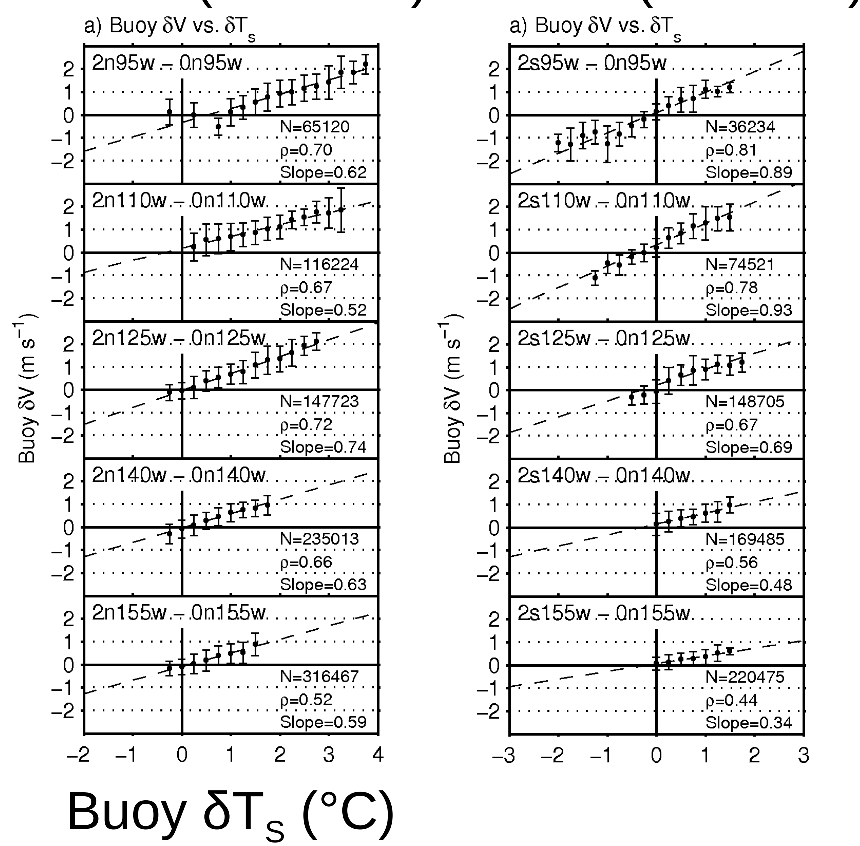
Gulf Stream



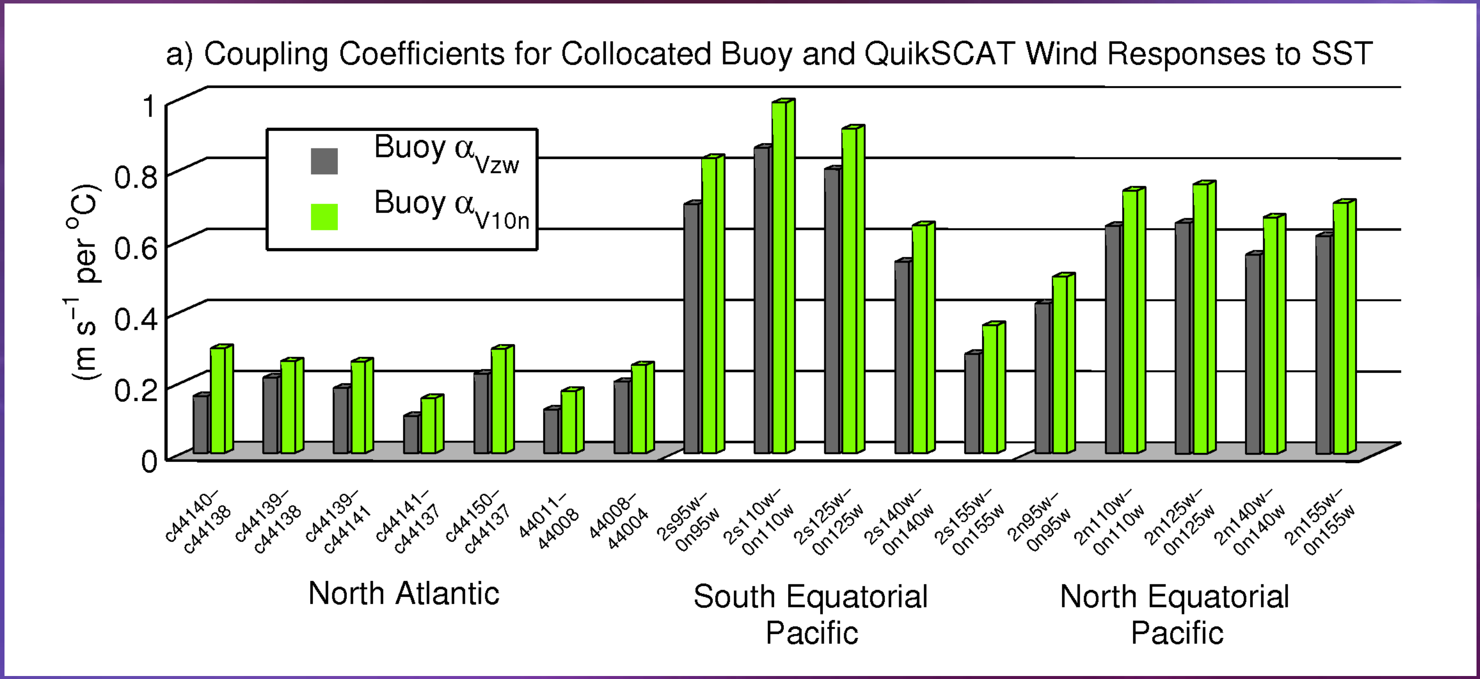
Equatorial Pacific

North (2°N-0°N)

South (2°S-0°N)



Comparison of buoy wind speed and ENW responses to SST



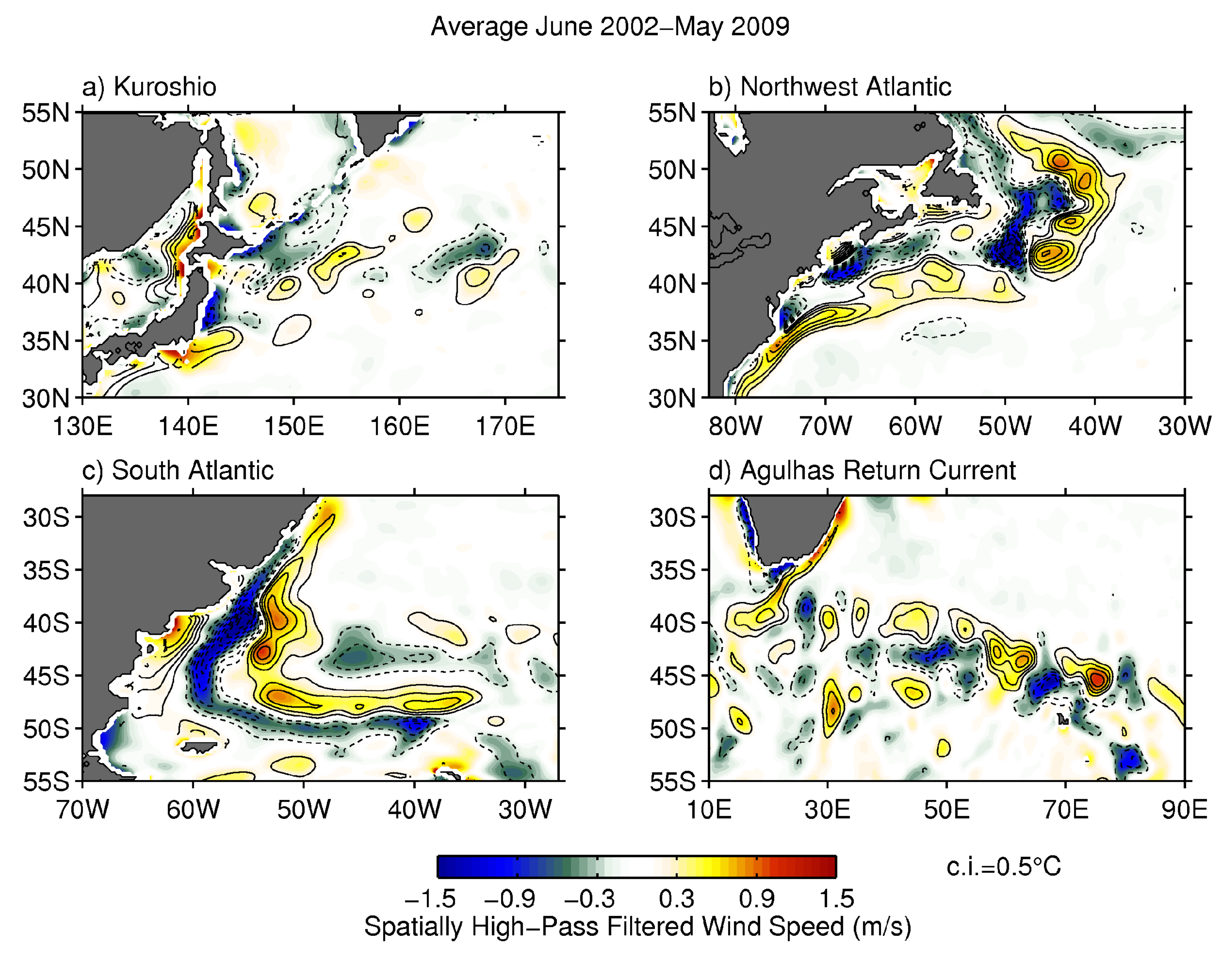
- Response of ENW V10n to SST is only about 10-30% larger than the response of the actual wind speed Vzw to SST

- Buoy ENW response to SST is caused mainly by the response of the actual near-surface wind speed to SST rather than near-surface stratification

Summary

- SST-induced response of QuikSCAT ENW similar to most buoy pairs, although biased low over the south equatorial Pacific (between the equator and 2°S)
- SST-induced response of the ENW can be interpreted principally as a response of the actual near-surface wind speed to SST
  - SST-induced changes to surface layer stratification make relatively small contributions to ENW and stress responses to spatially-varying SST
- Manuscript submitted to Journal of Climate

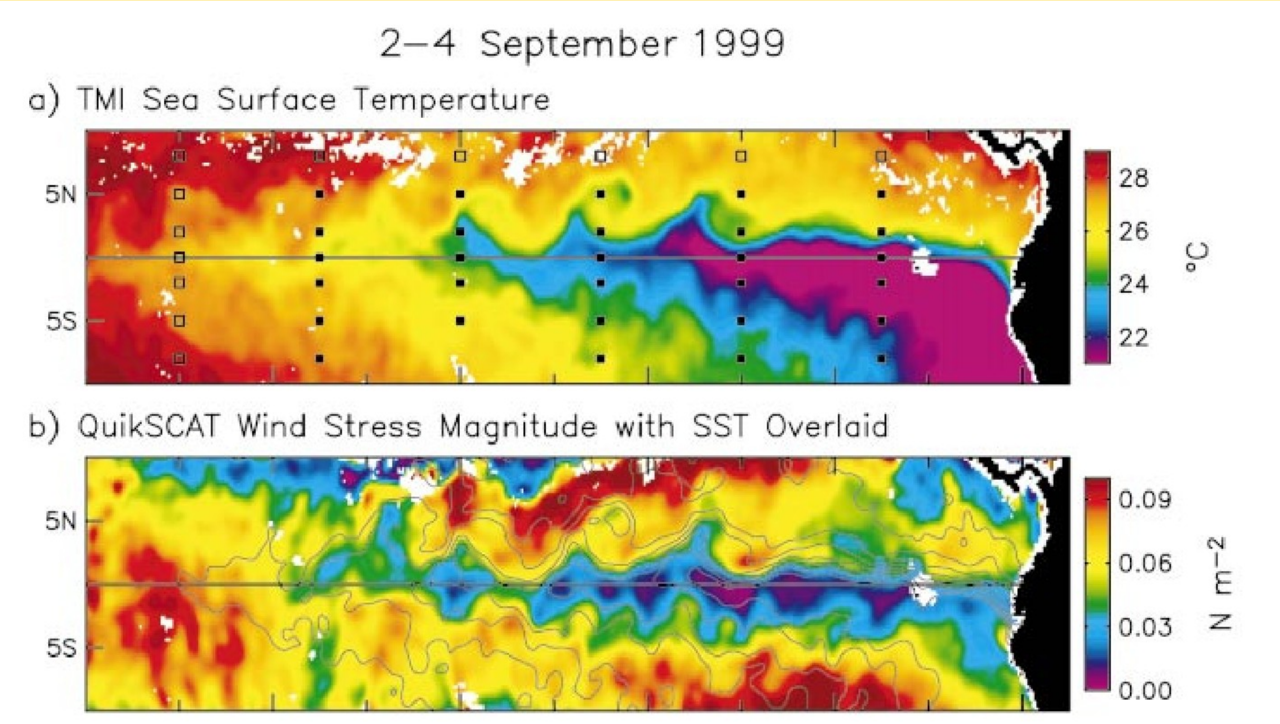
Buoy Pair	δL (km)	N	ρ δV_{z_w}-δT_s	$\alpha_{\delta V_{z_w}}$ (m s^{-1} $^\circ$C^{-1})	$\alpha_{\delta V_{10n}}$ (m s^{-1} $^\circ$C^{-1})	$\alpha_{\delta\lvert\boldsymbol{\tau}\rvert}$ $\times 10^{-2}$ (N m^{-2} $^\circ$C^{-1})
c44140-c44138	232.0	8790	0.48	0.28 ± 0.12	0.35 ± 0.15	0.94 ± 0.56
c44139-c44138	275.5	24306	0.27	0.14 ± 0.05	0.16 ± 0.07	0.68 ± 0.26
c44139-c44141	155.6	23709	0.71	0.25 ± 0.03	0.33 ± 0.04	1.06 ± 0.14
c44141-c44137	343.0	29171	0.61	0.18 ± 0.04	0.24 ± 0.05	0.85 ± 0.21
c44150-c44137	167.2	21357	0.70	0.29 ± 0.06	0.37 ± 0.07	1.29 ± 0.28
44011-44008	234.8	55496	0.39	0.18 ± 0.03	0.27 ± 0.04	0.66 ± 0.14
44008-44004	246.3	39479	0.48	0.20 ± 0.02	0.27 ± 0.02	0.90 ± 0.07
Gulf Stream Mean				0.22	0.28	0.91
2s95w-0n95w	222.4	35947	0.82	0.88 ± 0.07	1.00 ± 0.08	1.54 ± 0.12
2s110w-0n110w	222.4	74452	0.78	0.91 ± 0.12	1.07 ± 0.13	1.87 ± 0.26
2s125w-0n125w	222.4	147222	0.62	0.68 ± 0.08	0.78 ± 0.09	1.32 ± 0.18
2s140w-0n140w	222.4	168119	0.49	0.44 ± 0.09	0.53 ± 0.10	1.14 ± 0.25
2s155w-0n155w	222.4	219113	0.39	0.26 ± 0.08	0.31 ± 0.09	0.86 ± 0.20
South Eq. Pac. Mean				0.63	0.74	1.35
2n95w-0n95w	222.4	64963	0.69	0.64 ± 0.05	0.75 ± 0.06	1.15 ± 0.09
2n110w-0n110w	222.4	108710	0.60	0.50 ± 0.08	0.63 ± 0.09	1.23 ± 0.15
2n125w-0n125w	222.4	147209	0.71	0.72 ± 0.07	0.82 ± 0.08	1.71 ± 0.17
2n140w-0n140w	222.4	232585	0.64	0.59 ± 0.08	0.69 ± 0.09	1.53 ± 0.21
2n155w-0n155w	222.4	312945	0.50	0.54 ± 0.08	0.62 ± 0.09	1.56 ± 0.22
North Eq. Pac. Mean				0.60	0.70	1.44
Mean of all Buoy Pairs				0.45	0.54	1.21



Colors are spatially high-pass filtered QuikSCAT wind speed

Contours of filtered AMSR-E SST with c.i.=0.5°C (solid=warm, dashed=cool)

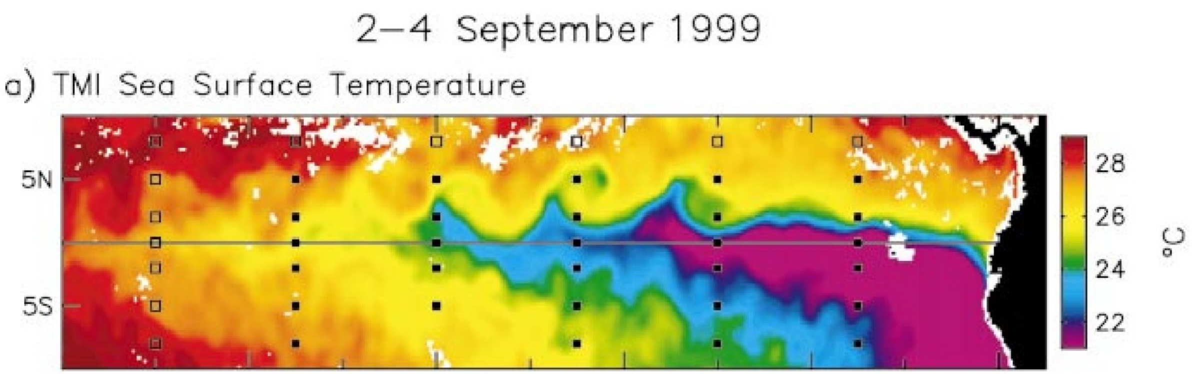
Wind-SST interaction over the eastern Pacific cold tongue as observed from satellite



From Chelton et al. (2001; *J. Climate*), which corroborated satellite studies by Xie et al. (1998), Liu et al. (1998), and Hashizume et al. (2001).

Wind stress magnitude is reduced over the TIW cold cusps compared to the surrounding warmer water

Wind-SST interaction over the eastern Pacific cold tongue as observed from satellite



Tropical Instability Waves (TIWs)

- Wavelengths of 1000-2000 km
- Westward phase speeds of ~0.5 m s^{-1}
- Typically active between September thru March
- Are usually more well-defined north of the equatorial cold tongue

From Chelton et al. (2001; *J. Climate*), which corroborated satellite studies by Xie et al. (1998), Liu et al. (1998), and Hashizume et al. (2001).

Buoy-QuikSCAT comparison statistics

		QuikSCAT/Buoy V_{10n}			
	Buoy	N	Corr.	Bias	RMS
Gulf Stream	c44137	2255	0.96	0.22	1.33
	c44138	2131	0.96	0.21	1.25
	c44139	2280	0.95	0.26	1.31
	c44140	915	0.94	0.47	1.42
	c44141	1882	0.95	0.07	1.38
	c44150	1460	0.96	−0.13	1.19
	44004	2780	0.96	0.11	1.10
	44008	3723	0.96	−0.05	1.16
	44011	3430	0.97	0.17	1.09
Eq. Pacific	2s95w	475	0.87	−0.11	0.86
	0n95w	1611	0.93	−0.42	0.82
	2n95w	782	0.91	−0.30	0.87
	2s110w	824	0.89	−0.11	0.76
	0n110w	1403	0.88	−0.42	1.02
	2n110w	1427	0.92	−0.62	0.96
	2s125w	2677	0.91	−0.25	0.77
	0n125w	2162	0.86	−0.21	0.96
	2n125w	1227	0.91	−0.63	0.98
	2s140w	1782	0.92	−0.26	0.73
	0n140w	2524	0.91	−0.31	0.78
	2n140w	2232	0.90	−0.61	1.00
	2s155w	2306	0.93	−0.45	0.82
	0n155w	2660	0.90	−0.29	0.85
	2n155w	2850	0.91	−0.50	0.93

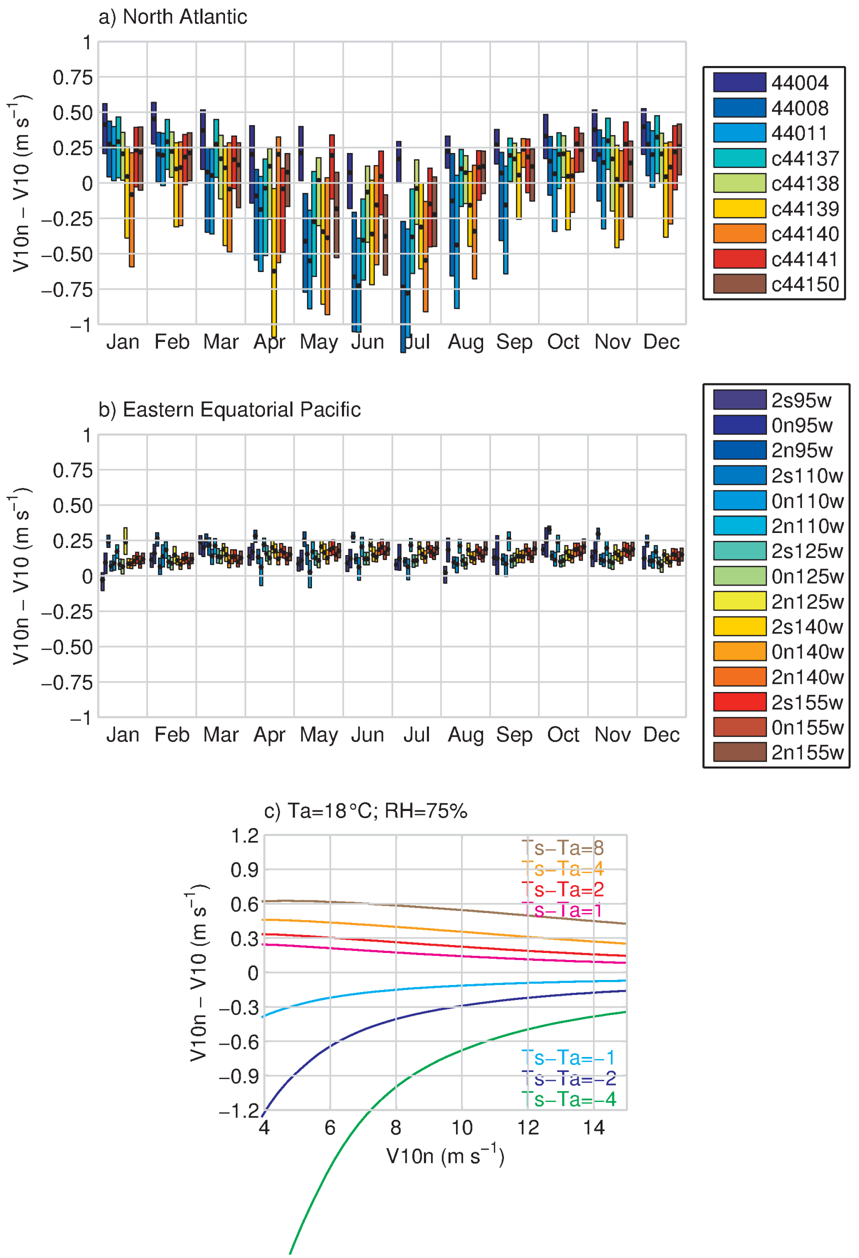
RMS differences larger over Gulf Stream – 1.09 to 1.42 m s^{-1}

RMS differences between 0.76 to 1.02 m s^{-1}

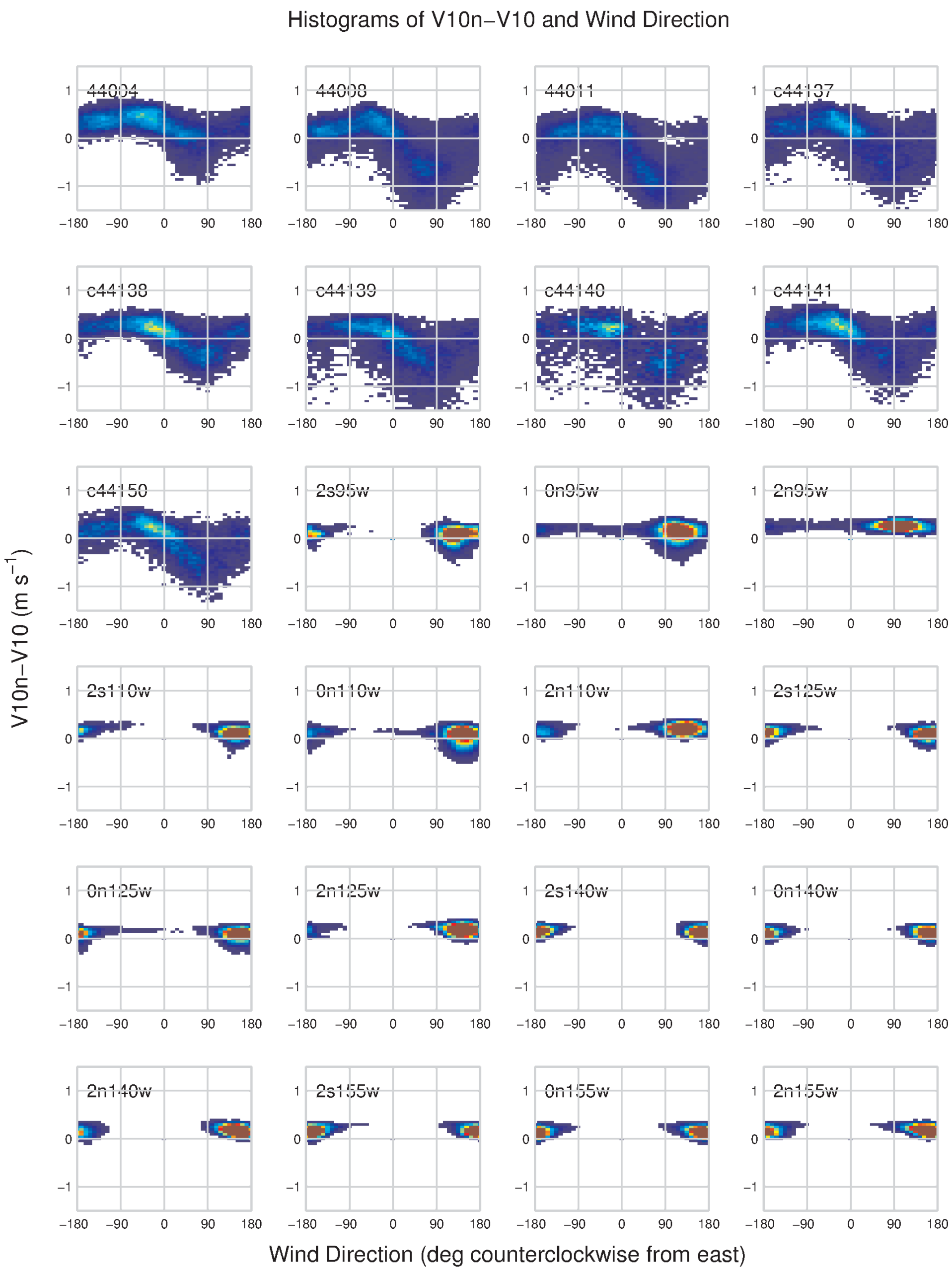
QuikSCAT winds biased low over eq. Pacific

Buoy-AMSR-E SST comparison statistics

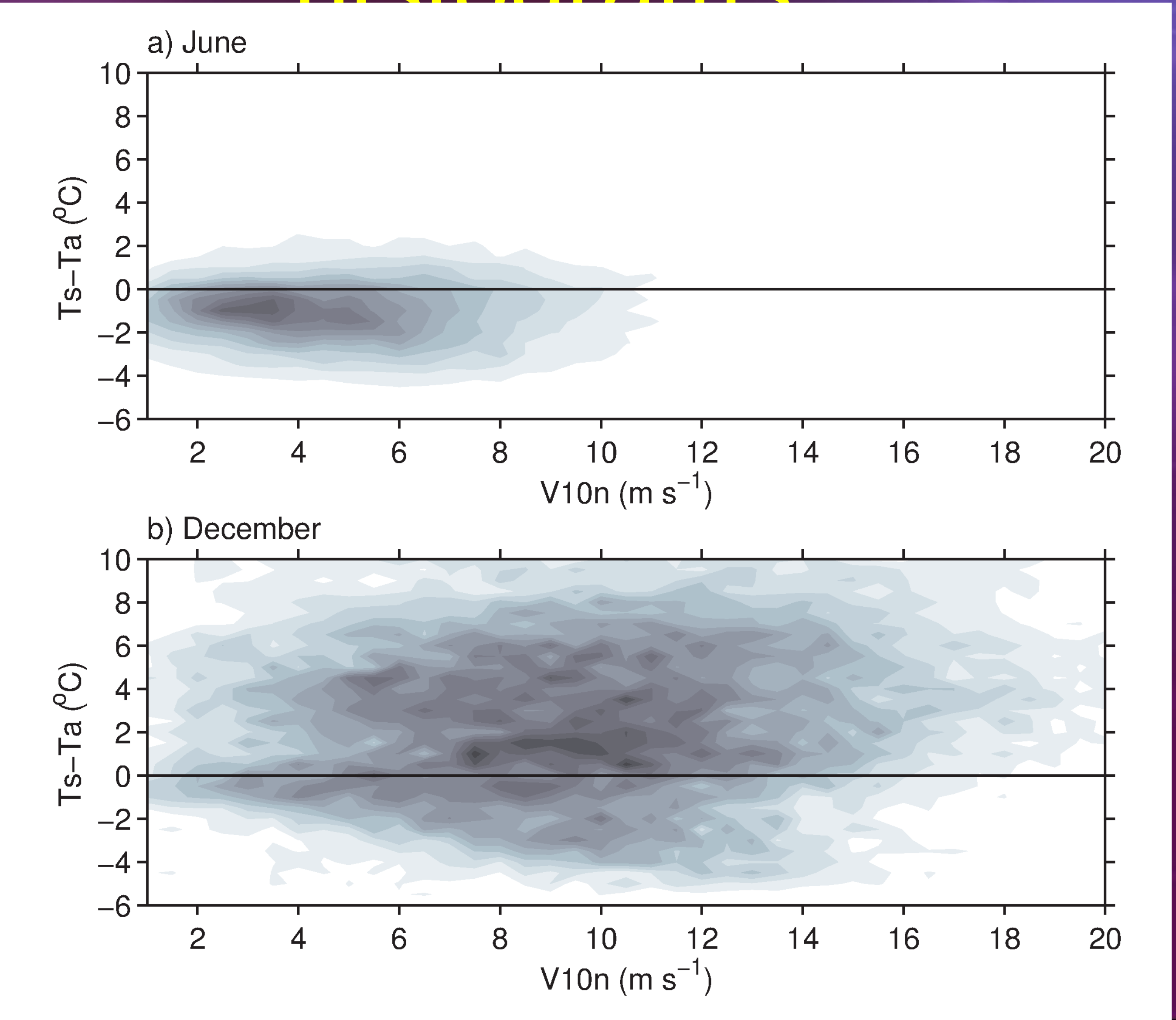
Buoy	AMSR-E/Buoy SST N	Corr.	Bias	RMS
c44137	2333	0.98	0.51	1.35
c44138	1750	0.98	0.04	0.94
c44139	2099	0.98	0.36	1.16
c44140	966	0.96	0.16	1.57
c44141	1929	0.98	0.41	1.49
c44150	1459	0.98	0.06	1.06
44004	2324	0.97	0.31	1.43
44008	3249	0.97	0.31	1.30
44011	2722	0.97	1.15	1.67
2s95w	1434	0.99	−0.27	0.43
0n95w	1420	0.96	−0.12	0.57
2n95w	1328	0.94	−0.11	0.51
2s110w	881	0.99	−0.26	0.34
0n110w	1630	0.96	−0.19	0.47
2n110w	1719	0.98	−0.16	0.36
2s125w	2610	0.98	−0.25	0.36
0n125w	1545	0.95	−0.10	0.44
2n125w	1531	0.95	−0.10	0.44
2s140w	2072	0.96	−0.16	0.30
0n140w	2172	0.97	−0.21	0.32
2n140w	1954	0.96	−0.14	0.31
2s155w	1978	0.97	−0.11	0.28
0n155w	2704	0.98	−0.20	0.31
2n155w	2247	0.97	−0.15	0.31

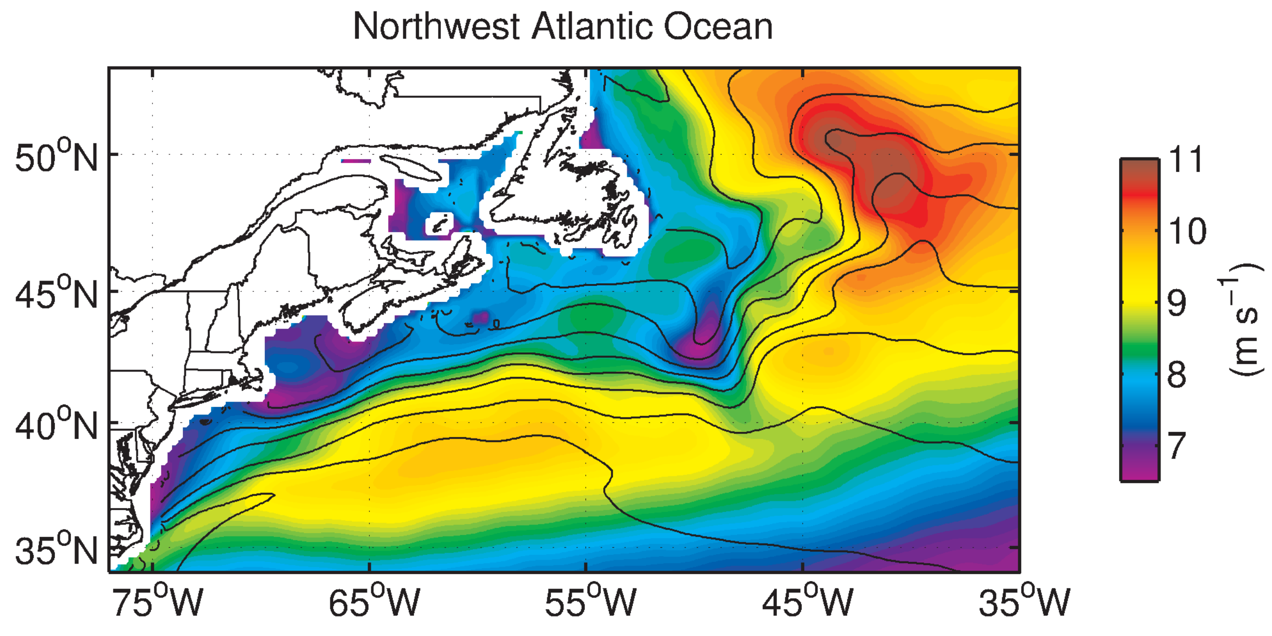


a) North Atlantic
V10n – V10 (m s−1)
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
44004
44008
44011
c44137
c44138
c44139
c44140
c44141
c44150
b) Eastern Equatorial Pacific
2s95w
0n95w
2n95w
2s110w
0n110w
2n110w
2s125w
0n125w
2n125w
2s140w
0n140w
2n140w
2s155w
0n155w
2n155w
c) Ta=18°C; RH=75%
Ts−Ta=8
Ts−Ta=4
Ts−Ta=2
Ts−Ta=1
Ts−Ta=−1
Ts−Ta=−2
Ts−Ta=−4
V10n (m s−1)


Histograms of V10n−V10 and Wind Direction
44004
44008
44011
c44137
c44138
c44139
c44140
c44141
c44150
2s95w
0n95w
2n95w
2s110w
0n110w
2n110w
2s125w
0n125w
2n125w
2s140w
0n140w
2n140w
2s155w
0n155w
2n155w
V10n−V10 (m s−1)
Wind Direction (deg counterclockwise from east)

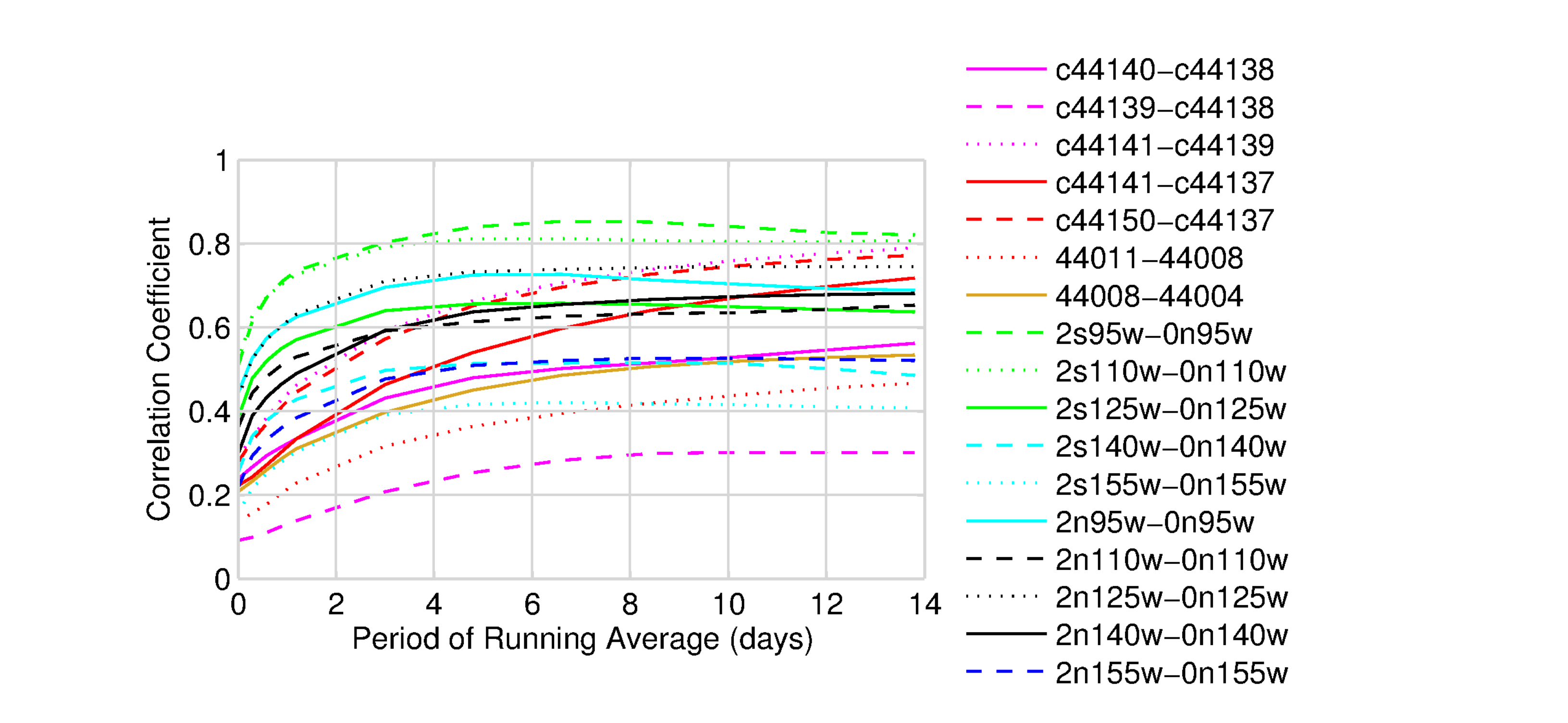
Gulf Stream V10n-V10 histograms



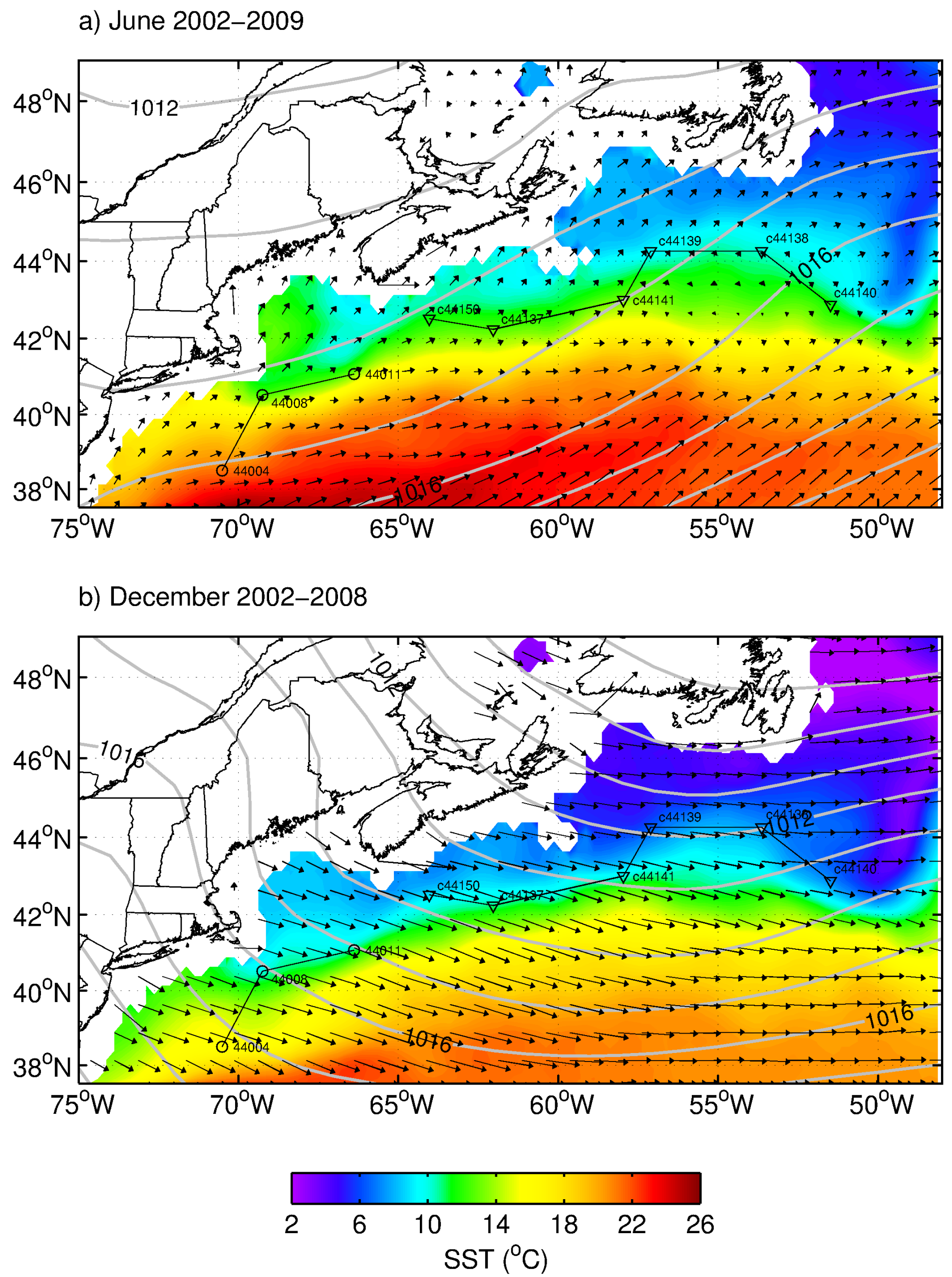


Northwest Atlantic Ocean
50°N
45°N
40°N
35°N
75°W
65°W
55°W
45°W
35°W
11
10
9
8
7
(m s⁻¹)

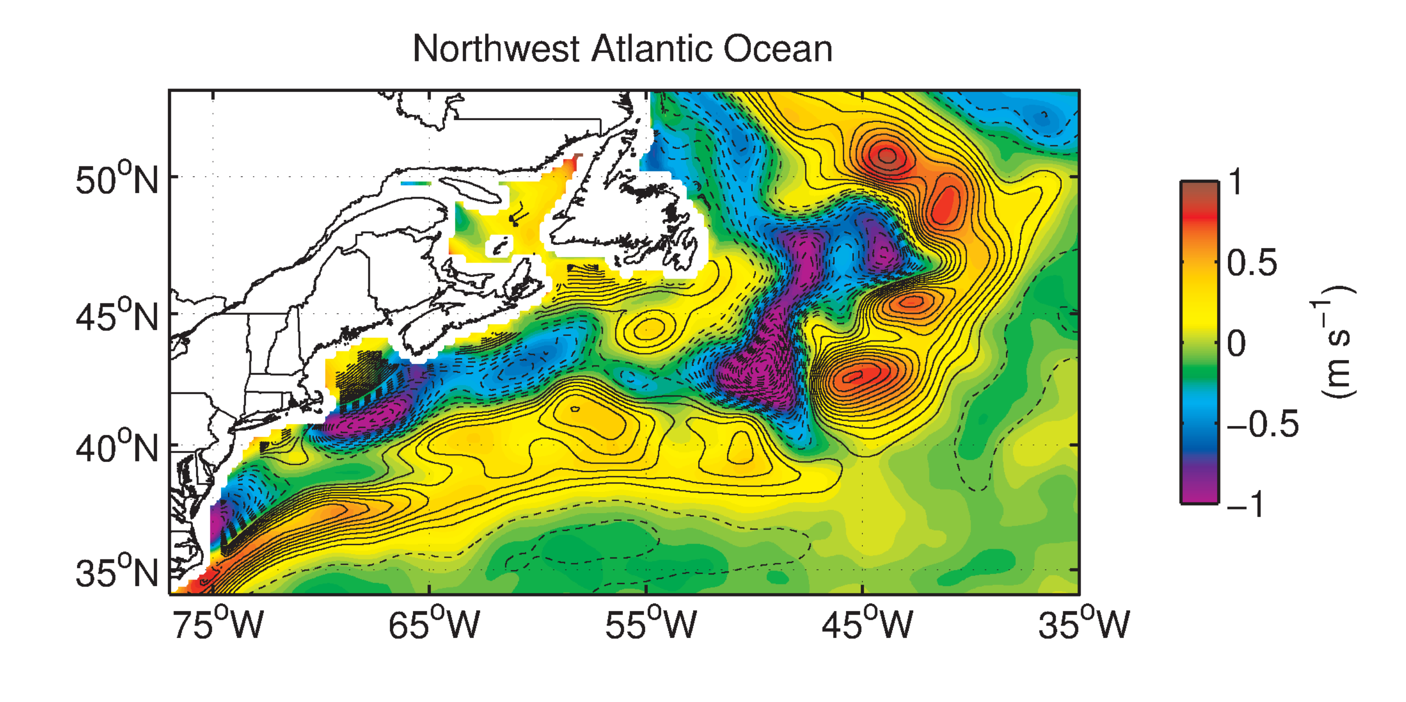
Correlation coefficient between buoy δVzw and δTs



Buoy Pair	$\alpha_{\delta V_{zw}}$		$\alpha_{\delta V_{10n}}$		$\alpha_{\delta\lvert\boldsymbol{\tau}\rvert} \times 10^{-2}$		Median $\widetilde{V}_{10n}$		Median $\widetilde{\rho}_a$	
	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr	May-Oct	Nov-Apr
c44140-c44138	0.18	0.26	0.21	0.29	0.50	0.90	6.4	8.8	1.22	1.26
c44139-c44138	0.20	0.25	0.24	0.31	0.47	1.22	6.3	9.1	1.22	1.26
c44139-c44141	0.23	0.23	0.37	0.30	0.98	1.28	6.3	9.0	1.22	1.27
c44141-c44137	0.21	0.19	0.27	0.25	0.55	1.12	6.2	9.1	1.21	1.27
c44150-c44137	0.33	0.29	0.41	0.34	1.07	1.32	5.6	8.6	1.22	1.27
44011-44008	0.17	0.18	0.27	0.25	0.44	0.72	4.7	8.3	1.22	1.27
44008-44004	0.21	0.24	0.29	0.29	0.67	1.14	5.7	8.7	1.20	1.25
Mean	0.22	0.23	0.29	0.29	0.67	1.10	5.9	8.8	1.22	1.26


a) June 2002–2009
1012
1016
48°N
46°N
44°N
42°N
40°N
38°N
75°W
70°W
65°W
60°W
55°W
50°W
c44139
c44138
c44140
c44141
c44150
c44137
44011
44008
44004
b) December 2002–2008
1012
1016
48°N
46°N
44°N
42°N
40°N
38°N
75°W
70°W
65°W
60°W
55°W
50°W
c44139
c44138
c44140
c44141
c44150
c44137
44011
44008
44004
2
6
10
14
18
22
26
SST (°C)

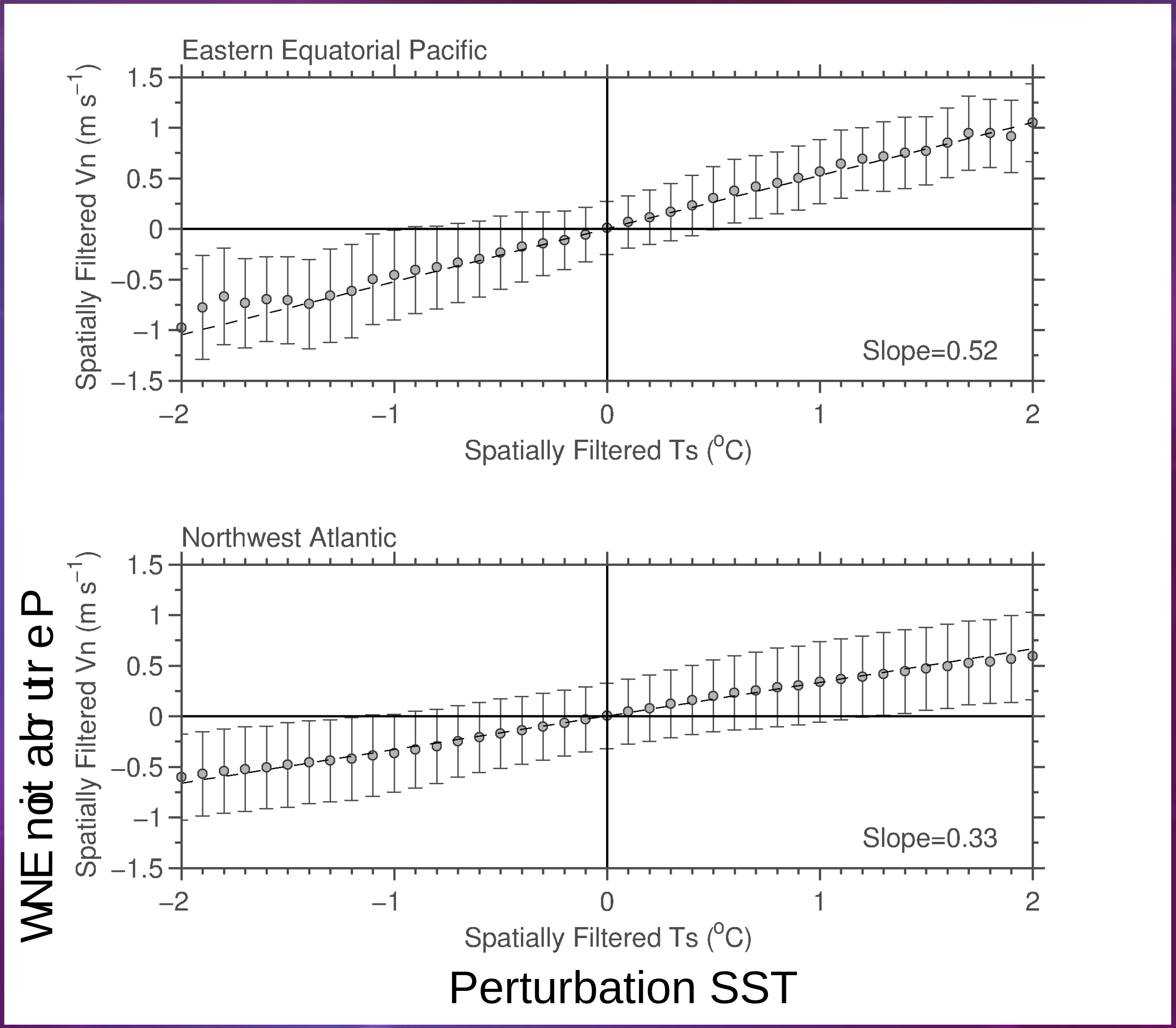
Motivation



7-yr mean spatially high-pass filtered QuikSCAT ENW (colors) and AMSR-E SST (contours)

Mesoscale features in ENW are highly correlated with those of SST

QuikSCAT ENW and AMSR-E SST statistical analysis



Spatially-filtered ENW is related linearly to SST

	QuikSCAT/Buoy V_{10n}				AMSR-E/Buoy V_{10n}				AMSR-E/Buoy SST			
Buoy	N	Corr.	Bias	RMS	N	Corr.	Bias	RMS	N	Corr.	Bias	RMS
c44137	2255	0.96	0.22	1.33	2359	0.94	0.06	1.39	2333	0.98	0.51	1.35
c44138	2131	0.96	0.21	1.25	1777	0.92	0.14	1.54	1750	0.98	0.04	0.94
c44139	2280	0.95	0.26	1.31	1841	0.93	0.20	1.46	2099	0.98	0.36	1.16
c44140	915	0.94	0.47	1.42	963	0.89	0.50	1.79	966	0.96	0.16	1.57
c44141	1882	0.95	0.07	1.38	1888	0.94	0.02	1.38	1929	0.98	0.41	1.49
c44150	1460	0.96	−0.13	1.19	1467	0.94	−0.25	1.32	1459	0.98	0.06	1.06
44004	2780	0.96	0.11	1.10	1885	0.95	0.05	1.16	2324	0.97	0.31	1.43
44008	3723	0.96	−0.05	1.16	2856	0.95	−0.25	1.31	3249	0.97	0.31	1.30
44011	3430	0.97	0.17	1.09	2508	0.95	0.01	1.22	2722	0.97	1.15	1.67
Total	20856	0.96	0.13	1.22	17544	0.94	0.02	1.37	18831	0.97	0.42	1.36
2s95w	475	0.87	−0.11	0.86	283	0.87	0.00	0.81	1434	0.99	−0.27	0.43
0n95w	1611	0.93	−0.42	0.82	950	0.91	−0.18	0.78	1420	0.96	−0.12	0.57
2n95w	782	0.91	−0.30	0.87	610	0.92	−0.13	0.80	1328	0.94	−0.11	0.51
2s110w	824	0.89	−0.11	0.76	626	0.88	0.06	0.75	881	0.99	−0.26	0.34
0n110w	1403	0.88	−0.42	1.02	1250	0.87	−0.11	0.95	1630	0.96	−0.19	0.47
2n110w	1427	0.92	−0.62	0.96	1087	0.92	−0.45	0.89	1719	0.98	−0.16	0.36
2s125w	2677	0.91	−0.25	0.77	2201	0.91	−0.08	0.72	2610	0.98	−0.25	0.36
0n125w	2162	0.86	−0.21	0.96	1413	0.86	0.03	0.92	1545	0.95	−0.10	0.44
2n125w	1227	0.91	−0.63	0.98	1083	0.91	−0.41	0.83	1531	0.95	−0.10	0.44
2s140w	1782	0.92	−0.26	0.73	1614	0.92	−0.17	0.65	2072	0.96	−0.16	0.30
0n140w	2524	0.91	−0.31	0.78	2172	0.89	−0.12	0.74	2172	0.97	−0.21	0.32
2n140w	2232	0.90	−0.61	1.00	1816	0.89	−0.40	0.90	1954	0.96	−0.14	0.31
2s155w	2306	0.93	−0.45	0.82	1866	0.94	−0.32	0.73	1978	0.97	−0.11	0.28
0n155w	2660	0.90	−0.29	0.85	2195	0.90	−0.11	0.80	2704	0.98	−0.20	0.31
2n155w	2850	0.91	−0.50	0.93	2117	0.91	−0.33	0.90	2247	0.97	−0.15	0.31
Total	26942	0.91	−0.38	0.88	21283	0.90	−0.20	0.81	27225	0.97	−0.17	0.40