Assessing statistical climate variability from the TAO buoy array

NGI Project File Number: 12-NGI2-24

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• The objective is to determine the statistical oceanographic variability in the upper 500 meters of the Central Pacific Ocean over the past two decades.

• A statistical analysis of equatorial Pacific data for 65 TAO/TRITON sites was performed to facilitate NDBC QC algorithms.

• ENSO relationships to TAO data for possible QC inclusion

• Data analyzed:
    i. longwave radiation
    ii. downwelling shortwave radiation
    iii. precipitation
    iv. surface meteorology values (air temperature, wind speed and direction, air pressure, surface water temperature, relative humidity)
    v. subsurface salinity
    vi. subsurface water temperature.

• Most products are embedded in PowerPoints or Excel files, and are generated using a combination of Microsoft's Visual Basic for Application (VBA) code, GMT, R, and shell scripts.

• Data plots include:
    i. Box plots and whiskers
    ii. Histograms
    iii. Temporal scatterplots
    iv. Statistical tables (lifetime, and monthly)

• ENSO relationships to Niño 3, Niño 3.4, Niño 4 Southern Oscillation Index (SOI), the Trans-Niño Index (TNI), and the Oceanic Niño Index (ONI):
    i. Overlays of El Niño Climate Indices on temporal scatterplots
    ii. Correlation matrix
    iii. Scatterplots of variables for $r>|0.7|$, with regression equation, confidence intervals, and prediction intervals
    iv. Spatial plots of ENSO teleconnection correlations, including depth patterns

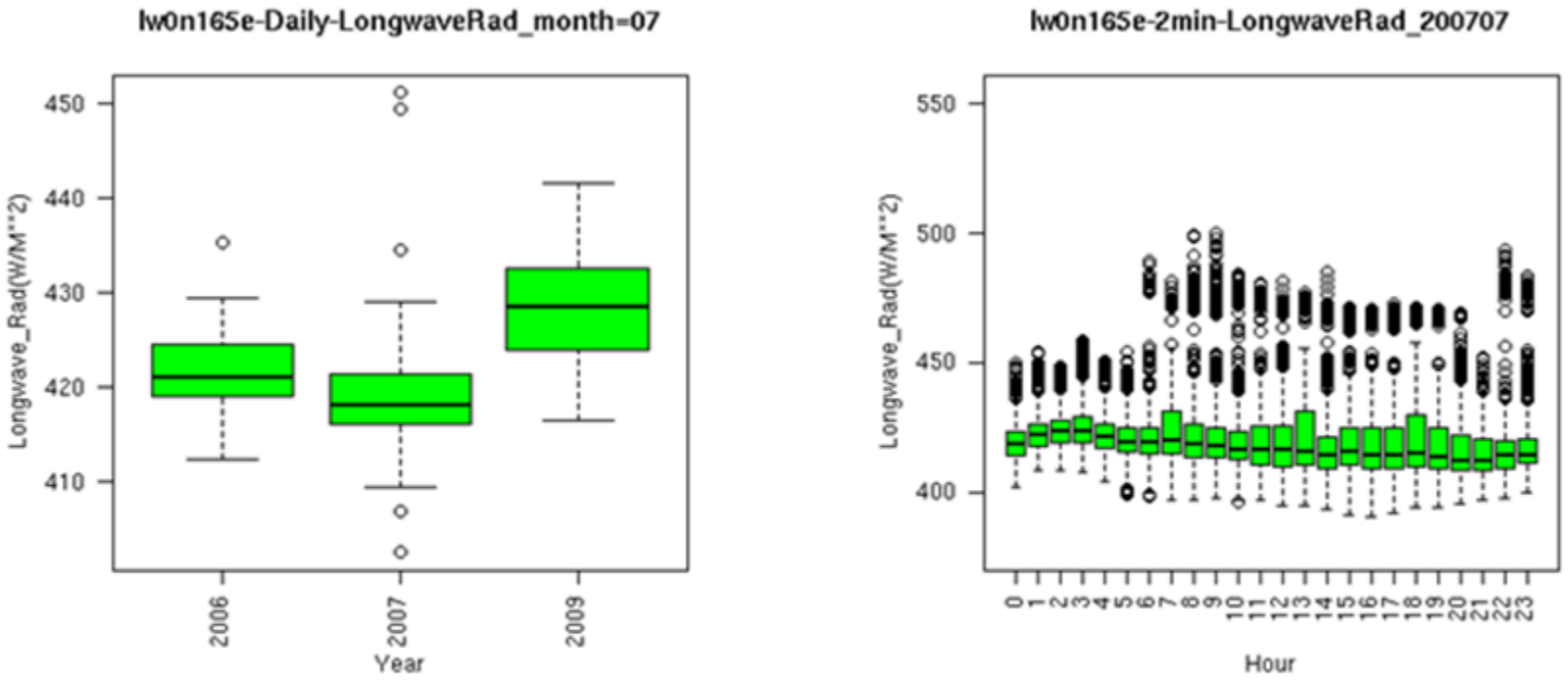


Figure 3. Example of longwave radiation box and whisker plots for the buoy located on the equator at 165°E. An instance of daily observations with year on x axis for July is shown on the left, and two-minute observations with hour on x axis for July 2007 is shown on the right. The box ranges are from the 25th to 75th percentiles, known as the interquartile range, with a line depicting the median. The arms of the box plot extend out to all observations within 1.5 times the interquartile range above the 75th percentile, and the same distance below the 25th percentile. Points outside those bands are outliers.

(11 buoys for longwave, 23 for shortwave)

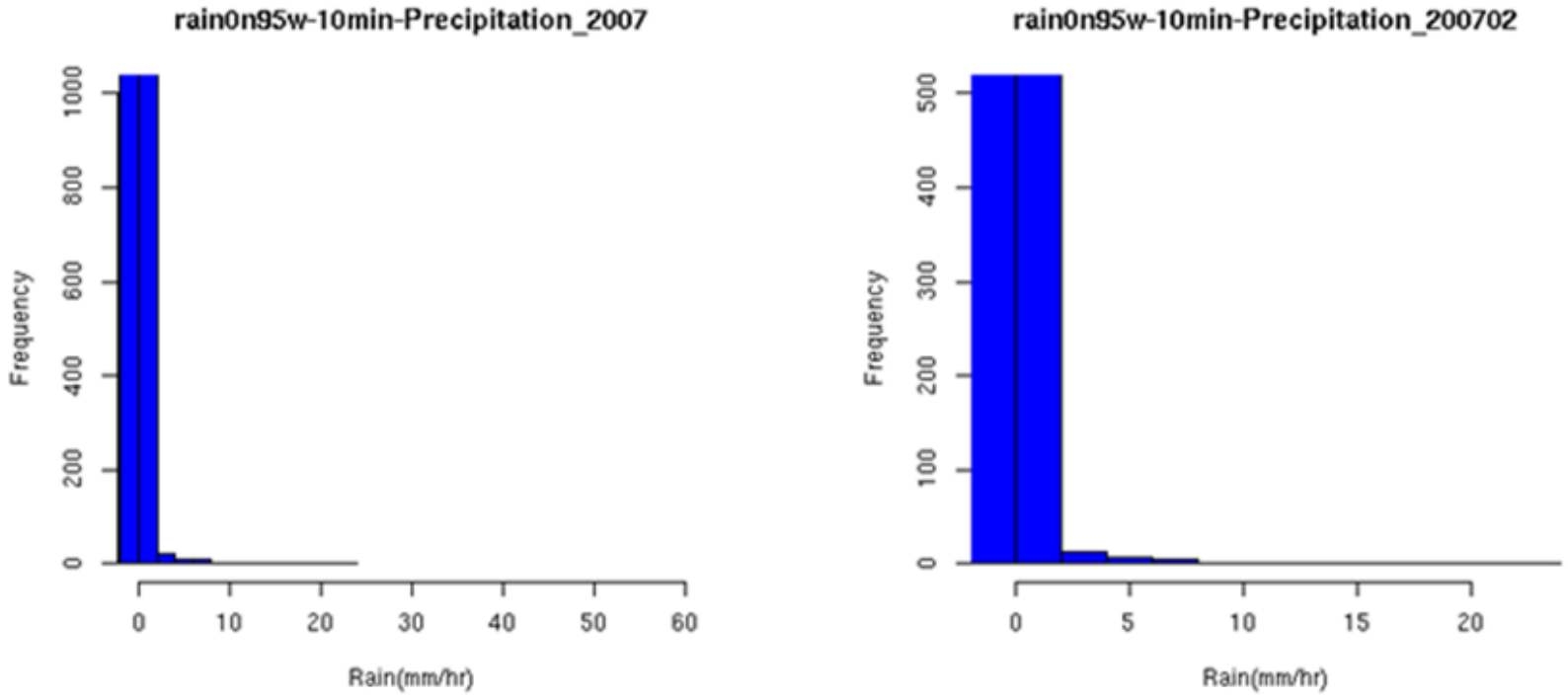
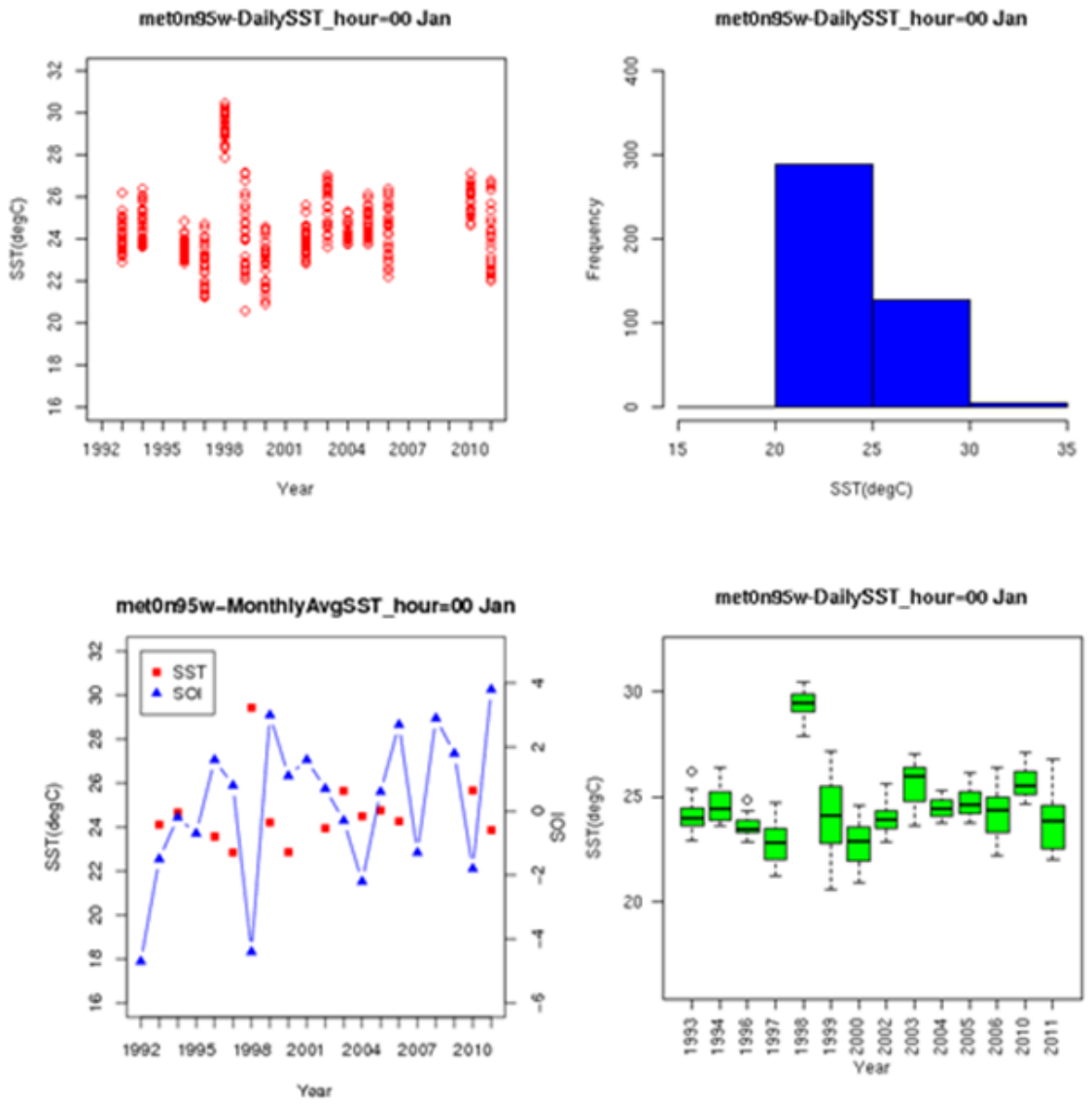


Figure 4. Example of histogram plots for rain rate (mm h^{-1}) in ten-minute intervals for the buoy located on the equator at 95°W. An instance of annual data distribution in 2007 is shown on the left, and February 2007 shown on the right. Note the contaminated negative values.

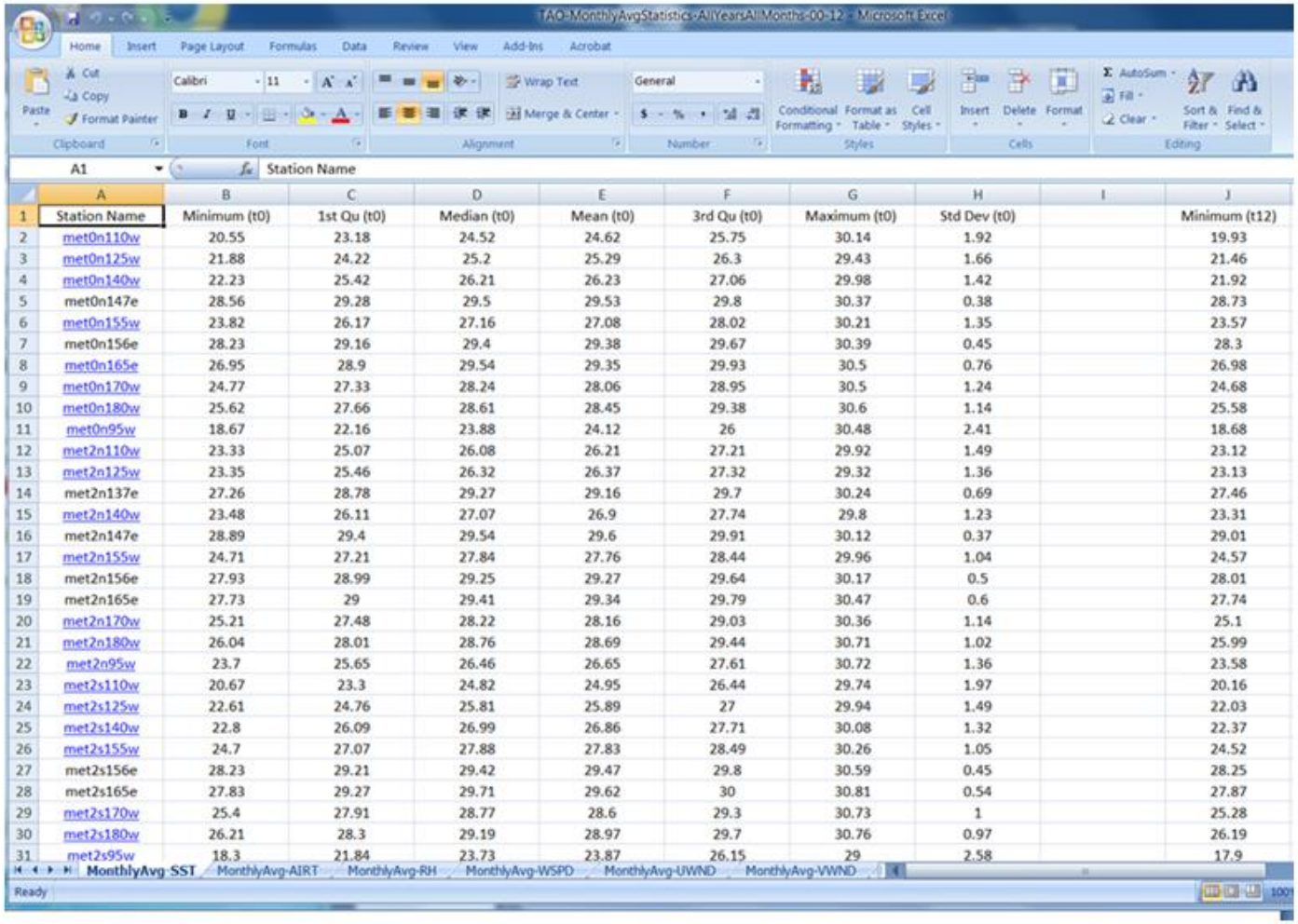
(28 buoys)



(65 buoys)

Figure 9. Examples of different types of monthly surface analysis plots for the equatorial buoy located at 95°W, all valid for 00 UTC SST data in January. Top left: Scatterplot for daily value on y axis and year on the x axis. Bottom left: Scatterplot of monthly averages of the data in the top left, superimposed with a trend line for a climate index (in this case, the Southern Oscillation Index, or SOI). Top right: histogram of frequency tallies versus SST. Bottom right: same dataset as in top left, but a box and whisker plot. Note how SOI and monthly mean SST are somewhat inversely correlated, but as will be seen, the correlation is a modest -0.26 (Fig. 10).

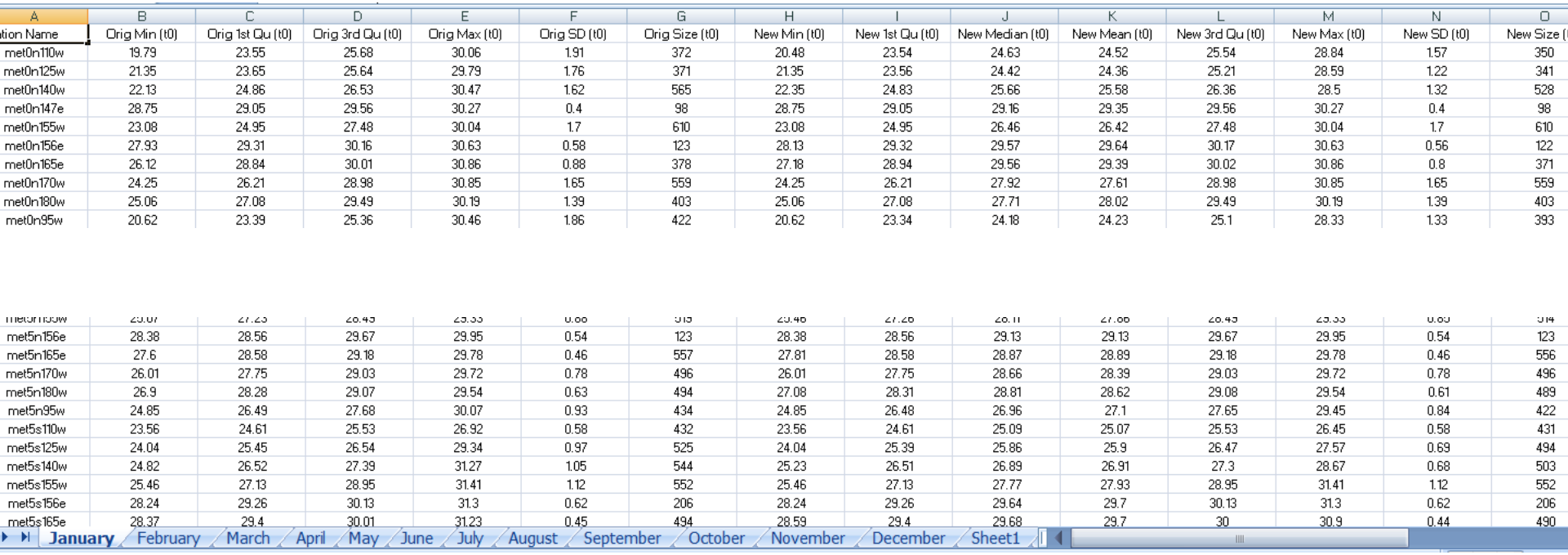
Statistics for lifetime of each buoy, per variable



Station Name	Minimum (t0)	1st Qu (t0)	Median (t0)	Mean (t0)	3rd Qu (t0)	Maximum (t0)	Std Dev (t0)		Minimum (t12)
met0n110w	20.55	23.18	24.52	24.62	25.75	30.14	1.92		19.93
met0n125w	21.88	24.22	25.2	25.29	26.3	29.43	1.66		21.46
met0n140w	22.23	25.42	26.21	26.23	27.06	29.98	1.42		21.92
met0n147e	28.56	29.28	29.5	29.53	29.8	30.37	0.38		28.73
met0n155w	23.82	26.17	27.16	27.08	28.02	30.21	1.35		23.57
met0n156e	28.23	29.16	29.4	29.38	29.67	30.39	0.45		28.3
met0n165e	26.95	28.9	29.54	29.35	29.93	30.5	0.76		26.98
met0n170w	24.77	27.33	28.24	28.06	28.95	30.5	1.24		24.68
met0n180w	25.62	27.66	28.61	28.45	29.38	30.6	1.14		25.58
met0n95w	18.67	22.16	23.88	24.12	26	30.48	2.41		18.68
met2n110w	23.33	25.07	26.08	26.21	27.21	29.92	1.49		23.12
met2n125w	23.35	25.46	26.32	26.37	27.32	29.32	1.36		23.13
met2n137e	27.26	28.78	29.27	29.16	29.7	30.24	0.69		27.46
met2n140w	23.48	26.11	27.07	26.9	27.74	29.8	1.23		23.31
met2n147e	28.89	29.4	29.54	29.6	29.91	30.12	0.37		29.01
met2n155w	24.71	27.21	27.84	27.76	28.44	29.96	1.04		24.57
met2n156e	27.93	28.99	29.25	29.27	29.64	30.17	0.5		28.01
met2n165e	27.73	29	29.41	29.34	29.79	30.47	0.6		27.74
met2n170w	25.21	27.48	28.22	28.16	29.03	30.36	1.14		25.1
met2n180w	26.04	28.01	28.76	28.69	29.44	30.71	1.02		25.99
met2n95w	23.7	25.65	26.46	26.65	27.61	30.72	1.36		23.58
met2s110w	20.67	23.3	24.82	24.95	26.44	29.74	1.97		20.16
met2s125w	22.61	24.76	25.81	25.89	27	29.94	1.49		22.03
met2s140w	22.8	26.09	26.99	26.86	27.71	30.08	1.32		22.37
met2s155w	24.7	27.07	27.88	27.83	28.49	30.26	1.05		24.52
met2s156e	28.23	29.21	29.42	29.47	29.8	30.59	0.45		28.25
met2s165e	27.83	29.27	29.71	29.62	30	30.81	0.54		27.87
met2s170w	25.4	27.91	28.77	28.6	29.3	30.73	1		25.28
met2s180w	26.21	28.3	29.19	28.97	29.7	30.76	0.97		26.19
met2s95w	18.3	21.84	23.73	23.87	26.15	29	2.58		17.9

Figure 7. Portion of spreadsheet showing statistical metrics for the lifetime of the each buoy, based on monthly averages. Spreadsheet tabs exist for SST, air temperature, wind speed, zonal wind, and meridional wind. Statistical metrics include minimum, 1st quartile, median, mean, 3rd quartile, maximum, and standard deviation. Columns B through H are for 00 UTC, while columns J through P are for 12 UTC (cutoff in figure). Each station is listed in Column A, and if it's highlighted in blue, the station has at least one moderate to strong correlation to a climate index (when r>|0.7|) with the surface variable. Clicking on these highlighted names will open a PowerPoint with correlation metrics, discussed in Figure 8.

Statistics for each month per buoy, one spreadsheet per variable



ation Name	Orig Min (t0)	Orig 1st Qu (t0)	Orig 3rd Qu (t0)	Orig Max (t0)	Orig SD (t0)	Orig Size (t0)	New Min (t0)	New 1st Qu (t0)	New Median (t0)	New Mean (t0)	New 3rd Qu (t0)	New Max (t0)	New SD (t0)	New Size (t
met0n110w	19.79	23.55	25.68	30.06	1.91	372	20.48	23.54	24.63	24.52	25.54	28.84	1.57	350
met0n125w	21.35	23.65	25.64	29.79	1.76	371	21.35	23.56	24.42	24.36	25.21	28.59	1.22	341
met0n140w	22.13	24.86	26.53	30.47	1.62	565	22.35	24.83	25.66	25.58	26.36	28.5	1.32	528
met0n147e	28.75	29.05	29.56	30.27	0.4	98	28.75	29.05	29.16	29.35	29.56	30.27	0.4	98
met0n155w	23.08	24.95	27.48	30.04	1.7	610	23.08	24.95	26.46	26.42	27.48	30.04	1.7	610
met0n156e	27.93	29.31	30.16	30.63	0.58	123	28.13	29.32	29.57	29.64	30.17	30.63	0.56	122
met0n165e	26.12	28.84	30.01	30.86	0.88	378	27.18	28.94	29.56	29.39	30.02	30.86	0.8	371
met0n170w	24.25	26.21	28.98	30.85	1.65	559	24.25	26.21	27.92	27.61	28.98	30.85	1.65	559
met0n180w	25.06	27.08	29.49	30.19	1.39	403	25.06	27.08	27.71	28.02	29.49	30.19	1.39	403
met0n95w	20.62	23.39	25.36	30.46	1.86	422	20.62	23.34	24.18	24.23	25.1	28.33	1.33	393
met5n156e	28.38	28.56	29.67	29.95	0.54	123	28.38	28.56	29.13	29.13	29.67	29.95	0.54	123
met5n165e	27.6	28.58	29.18	29.78	0.46	557	27.81	28.58	28.87	28.89	29.18	29.78	0.46	556
met5n170w	26.01	27.75	29.03	29.72	0.78	496	26.01	27.75	28.66	28.39	29.03	29.72	0.78	496
met5n180w	26.9	28.28	29.07	29.54	0.63	494	27.08	28.31	28.81	28.62	29.08	29.54	0.61	489
met5n95w	24.85	26.49	27.68	30.07	0.93	434	24.85	26.48	26.96	27.1	27.65	29.45	0.84	422
met5s110w	23.56	24.61	25.53	26.92	0.58	432	23.56	24.61	25.09	25.07	25.53	26.45	0.58	431
met5s125w	24.04	25.45	26.54	29.34	0.97	525	24.04	25.39	25.86	25.9	26.47	27.57	0.69	494
met5s140w	24.82	26.52	27.39	31.27	1.05	544	25.23	26.51	26.89	26.91	27.3	28.67	0.68	503
met5s155w	25.46	27.13	28.95	31.41	1.12	552	25.46	27.13	27.77	27.93	28.95	31.41	1.12	552
met5s156e	28.24	29.26	30.13	31.3	0.62	206	28.24	29.26	29.64	29.7	30.13	31.3	0.62	206
met5s165e	28.37	29.4	30.01	31.23	0.45	494	28.59	29.4	29.68	29.7	30	30.9	0.44	490

January | February | March | April | May | June | July | August | September | October | November | December | Sheet1

[all data][outliers removed]

00Z is for columns B-O
12Z is for columns Q-AD

El Nino relationships

MonthlyAvgCICorrelation.SST.00, for met0n95w

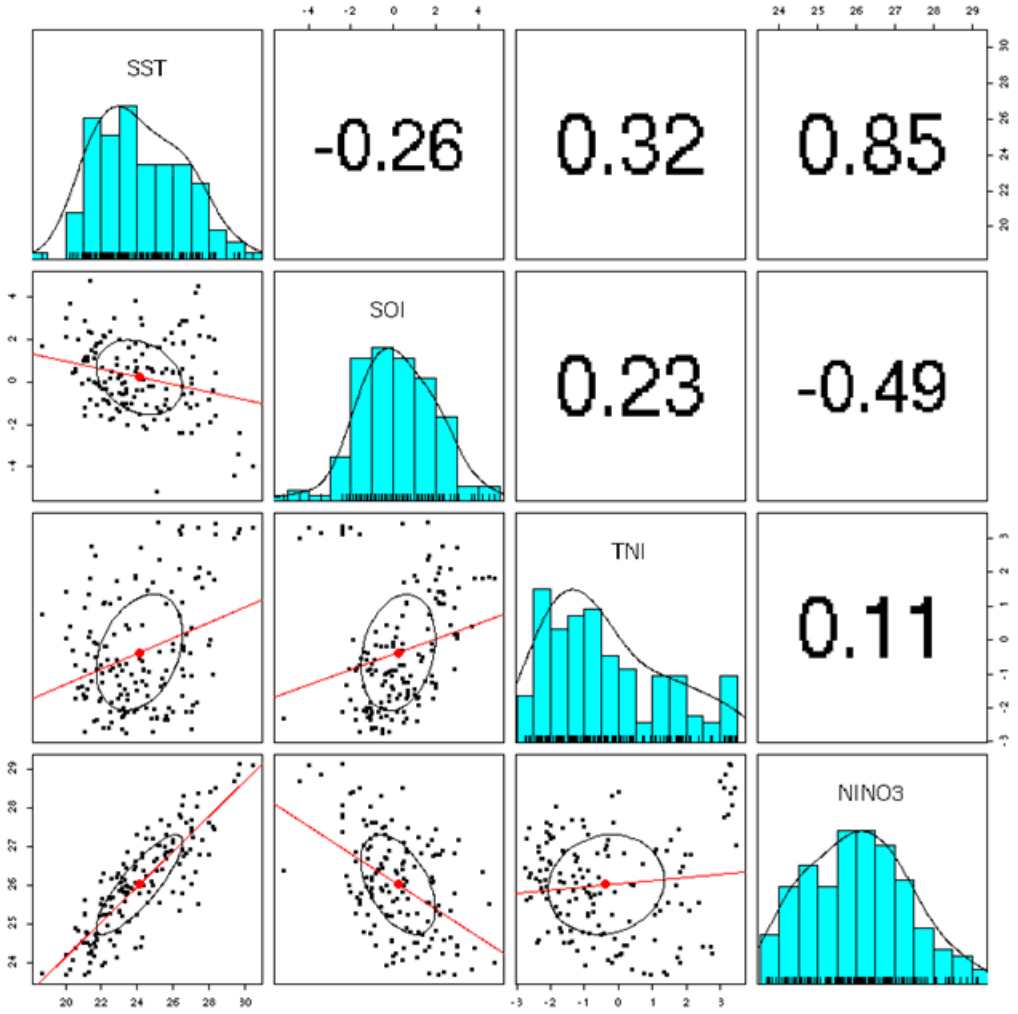
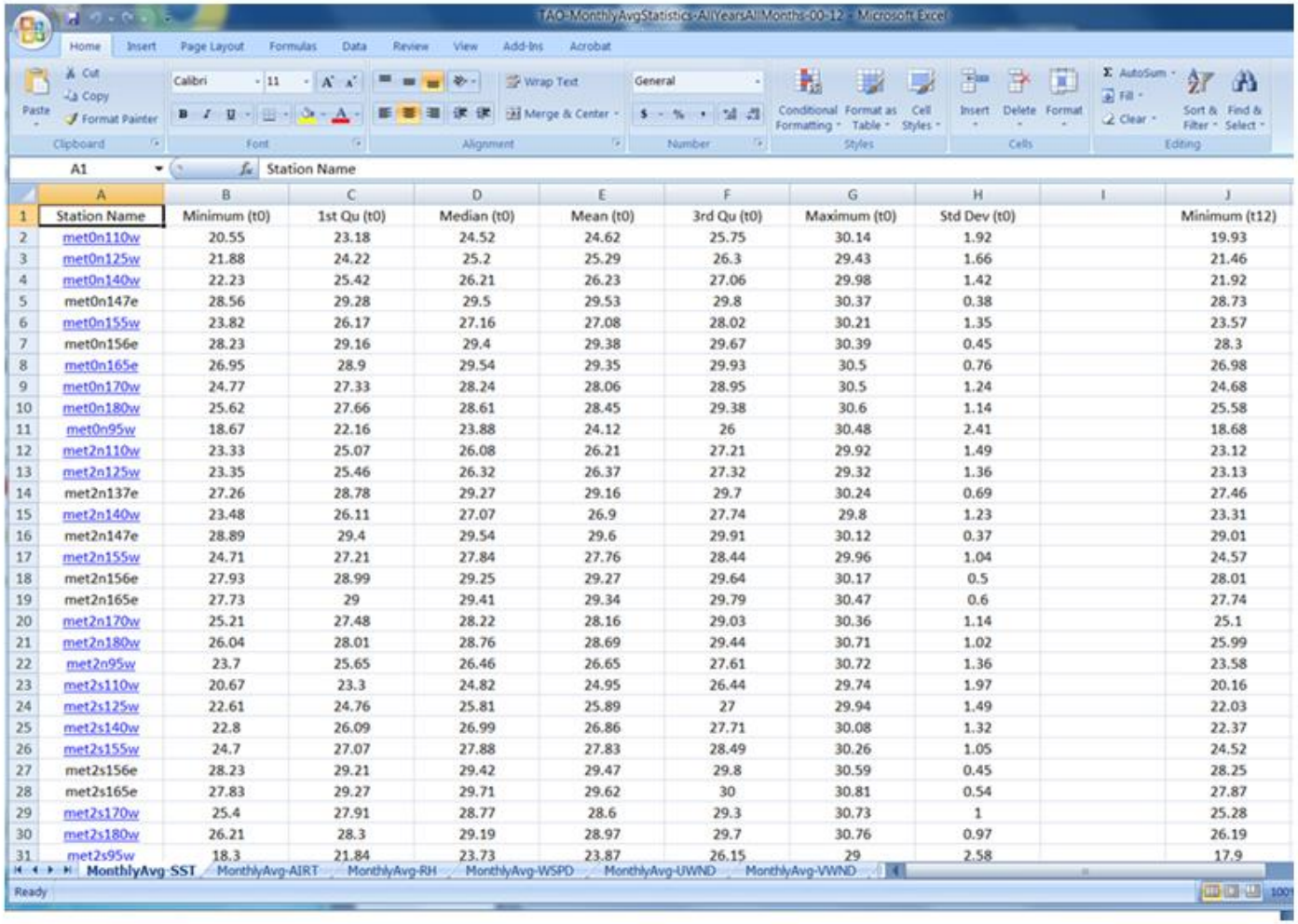


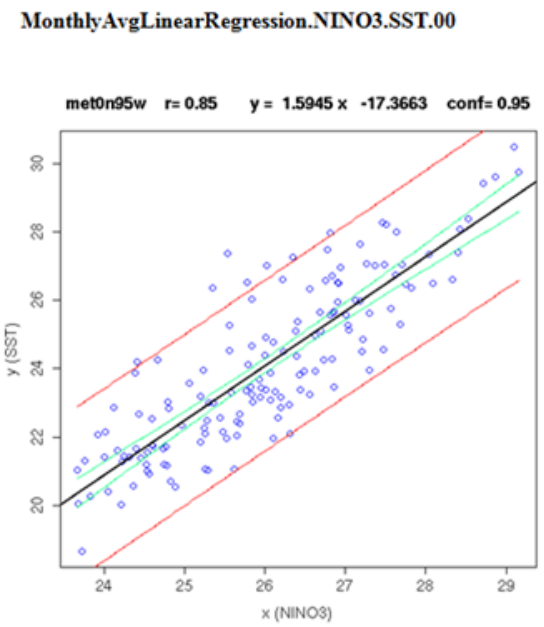
Figure 10. Correlation matrix for the equatorial buoy located at 95°W, valid for 00 UTC monthly averaged SST data. Scatterplots are shown in lower left of matrix for all pairs of datasets, and include a regression line and correlation ellipse. In general, the narrower the ellipse, the stronger is the relationship. Histograms of the relationship are shown along the matrix diagonal, with a curve to qualitatively ascertain if the association is Gaussian. The correlation coefficient of all pairs is shown in the upper right of the matrix. When available, overlapping Niño regions and/or ONI will also be shown in other columns.

Statistics for lifetime of each buoy, per variable



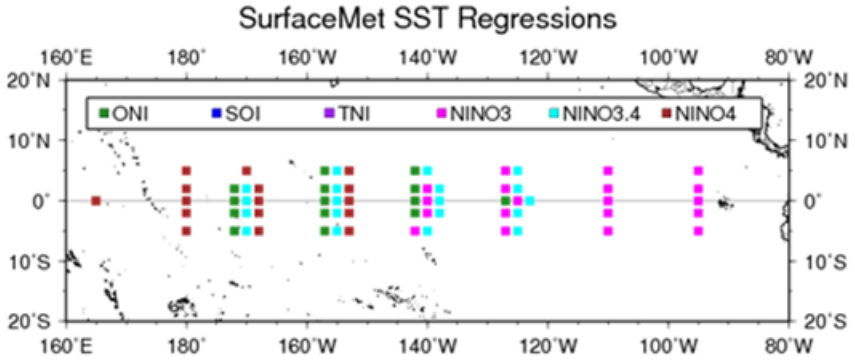
Station Name	Minimum (t0)	1st Qu (t0)	Median (t0)	Mean (t0)	3rd Qu (t0)	Maximum (t0)	Std Dev (t0)		Minimum (t12)
met0n110w	20.55	23.18	24.52	24.62	25.75	30.14	1.92		19.93
met0n125w	21.88	24.22	25.2	25.29	26.3	29.43	1.66		21.46
met0n140w	22.23	25.42	26.21	26.23	27.06	29.98	1.42		21.92
met0n147e	28.56	29.28	29.5	29.53	29.8	30.37	0.38		28.73
met0n155w	23.82	26.17	27.16	27.08	28.02	30.21	1.35		23.57
met0n156e	28.23	29.16	29.4	29.38	29.67	30.39	0.45		28.3
met0n165e	26.95	28.9	29.54	29.35	29.93	30.5	0.76		26.98
met0n170w	24.77	27.33	28.24	28.06	28.95	30.5	1.24		24.68
met0n180w	25.62	27.66	28.61	28.45	29.38	30.6	1.14		25.58
met0n95w	18.67	22.16	23.88	24.12	26	30.48	2.41		18.68
met2n110w	23.33	25.07	26.08	26.21	27.21	29.92	1.49		23.12
met2n125w	23.35	25.46	26.32	26.37	27.32	29.32	1.36		23.13
met2n137e	27.26	28.78	29.27	29.16	29.7	30.24	0.69		27.46
met2n140w	23.48	26.11	27.07	26.9	27.74	29.8	1.23		23.31
met2n147e	28.89	29.4	29.54	29.6	29.91	30.12	0.37		29.01
met2n155w	24.71	27.21	27.84	27.76	28.44	29.96	1.04		24.57
met2n156e	27.93	28.99	29.25	29.27	29.64	30.17	0.5		28.01
met2n165e	27.73	29	29.41	29.34	29.79	30.47	0.6		27.74
met2n170w	25.21	27.48	28.22	28.16	29.03	30.36	1.14		25.1
met2n180w	26.04	28.01	28.76	28.69	29.44	30.71	1.02		25.99
met2n95w	23.7	25.65	26.46	26.65	27.61	30.72	1.36		23.58
met2s110w	20.67	23.3	24.82	24.95	26.44	29.74	1.97		20.16
met2s125w	22.61	24.76	25.81	25.89	27	29.94	1.49		22.03
met2s140w	22.8	26.09	26.99	26.86	27.71	30.08	1.32		22.37
met2s155w	24.7	27.07	27.88	27.83	28.49	30.26	1.05		24.52
met2s156e	28.23	29.21	29.42	29.47	29.8	30.59	0.45		28.25
met2s165e	27.83	29.27	29.71	29.62	30	30.81	0.54		27.87
met2s170w	25.4	27.91	28.77	28.6	29.3	30.73	1		25.28
met2s180w	26.21	28.3	29.19	28.97	29.7	30.76	0.97		26.19
met2s95w	18.3	21.84	23.73	23.87	26.15	29	2.58		17.9

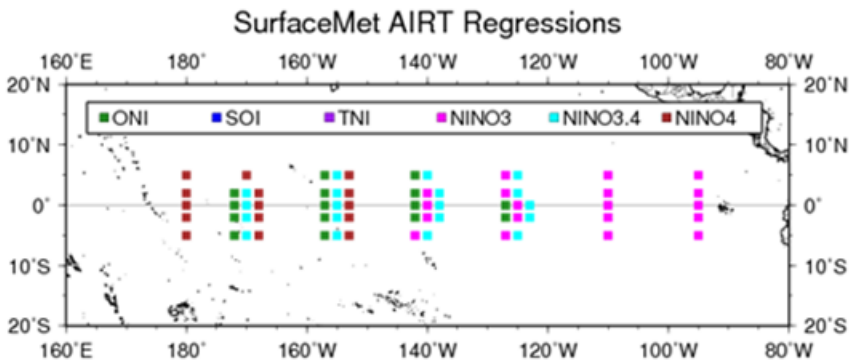
Figure 7. Portion of spreadsheet showing statistical metrics for the lifetime of the each buoy, based on monthly averages. Spreadsheet tabs exist for SST, air temperature, wind speed, zonal wind, and meridional wind. Statistical metrics include minimum, 1st quartile, median, mean, 3rd quartile, maximum, and standard deviation. Columns B through H are for 00 UTC, while columns J through P are for 12 UTC (cutoff in figure). Each station is listed in Column A, and if it's highlighted in blue, the station has at least one moderate to strong correlation to a climate index (when r>|0.7|) with the surface variable. Clicking on these highlighted names will open a PowerPoint with correlation metrics, discussed in Figure 8.

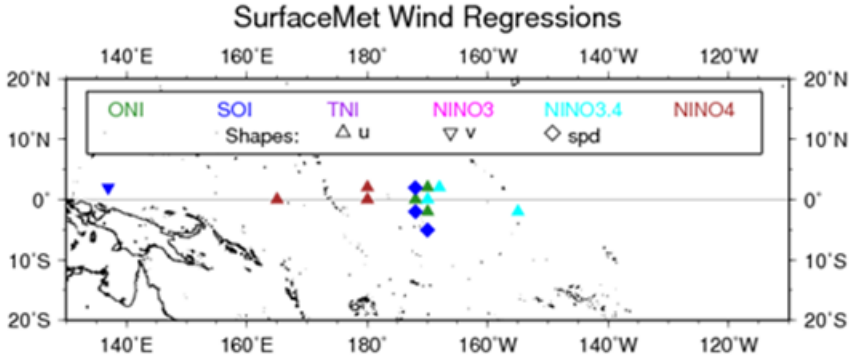


x (NINO3)	fitted y (SST)	Lower Prediction	Upper Prediction
22.6	18.66837	16.11382	21.22291
22.8	18.98726	16.43922	21.53530
23.0	19.30615	16.76424	21.84806
23.2	19.62504	17.08888	22.16120
23.4	19.94393	17.41314	22.47472
23.6	20.26282	17.73702	22.78862
23.8	20.58171	18.06051	23.10292
24.0	20.90060	18.38361	23.41760
24.2	21.21949	18.70632	23.73267
24.4	21.53839	19.02863	24.04814
24.6	21.85728	19.35056	24.36400
24.8	22.17617	19.67208	24.68025
25.0	22.49506	19.99321	24.99690
25.2	22.81395	20.31395	25.31396
25.4	23.13284	20.63428	25.63140
25.6	23.45173	20.95421	25.94925
25.8	23.77062	21.27375	26.26750
26.0	24.08951	21.59288	26.58615
26.2	24.40841	21.91161	26.90520
26.4	24.72730	22.22994	27.22465
26.6	25.04619	22.54787	27.54450
26.8	25.36508	22.86541	27.86475
27.0	25.68397	23.18254	28.18540
27.2	26.00286	23.49927	28.50645
27.4	26.32175	23.81561	28.82789
27.6	26.64064	24.13155	29.14973
27.8	26.95954	24.44710	29.47197
28.0	27.27843	24.76225	29.79460
28.2	27.59732	25.07702	30.11762
28.4	27.91621	25.39139	30.44103
28.6	28.23510	25.70538	30.76482
28.8	28.55399	26.01898	31.08900
29.0	28.87288	26.33220	31.41357
29.2	29.19177	26.64504	31.73851

Figure 8. Example of a PowerPoint image initiated by clicking on "met0n95w" in Row 11 in Fig. 7. This shows all correlations in which r>|0.7|. In this case, the equatorial buoy located at 95°W has a correlation coefficient of 0.85 between SST and the Niño 3 region at 00 UTC. The corresponding linear regression equation is $SST = 1.5945\ Niño3 - 17.3663$. The green line on the scatterplot on the left shows the confidence interval at the 95% confidence level. The red lines indicate the prediction level. A table showing the database range of Niño 3 values is shown in the first column, the linear regression computed value of SST in column 2, and the confidence level range in columns 3 and 4. These 4 columns can provide quality control guidance if an observation is highly correlated to ENSO patterns. In this example, SST at 12 UTC also possessed strong correlations to Niño 3, and was contained in Slide 2 of the PowerPoint (not shown). Some buoys can be moderately to highly correlated to multiple climate indices or regions, such as the buoy at 2°N and 170°W in which SST is correlated to ONI, Niño 3, and Niño 3.4 (not shown).







Air and water temperature generally correlated best with their respective Niño regions, as well as ONI in the western half (consistent with its ONI Niño 3.4 definition)

Most wind correlations occur in the center of the domain from 180°W to 170°W, with correlations to their respective Niño regions, SOI, or ONI. The correlations are for wind speed or zonal wind, with only a single meridional wind value correlated to SOI on the far western edge of the domain. It is likely that physical relationships regarding ongoing ENSO events with these wind variables exist, and should be explored in follow-up research.

Figure 12. All buoys in which the correlation are r>|0.7|, color-coded for ONI, SOI, TNI, Niño 3, Niño 3.4, and Niño 4. Side by side symbols indicate multiple climate indices are r>|0.7|.

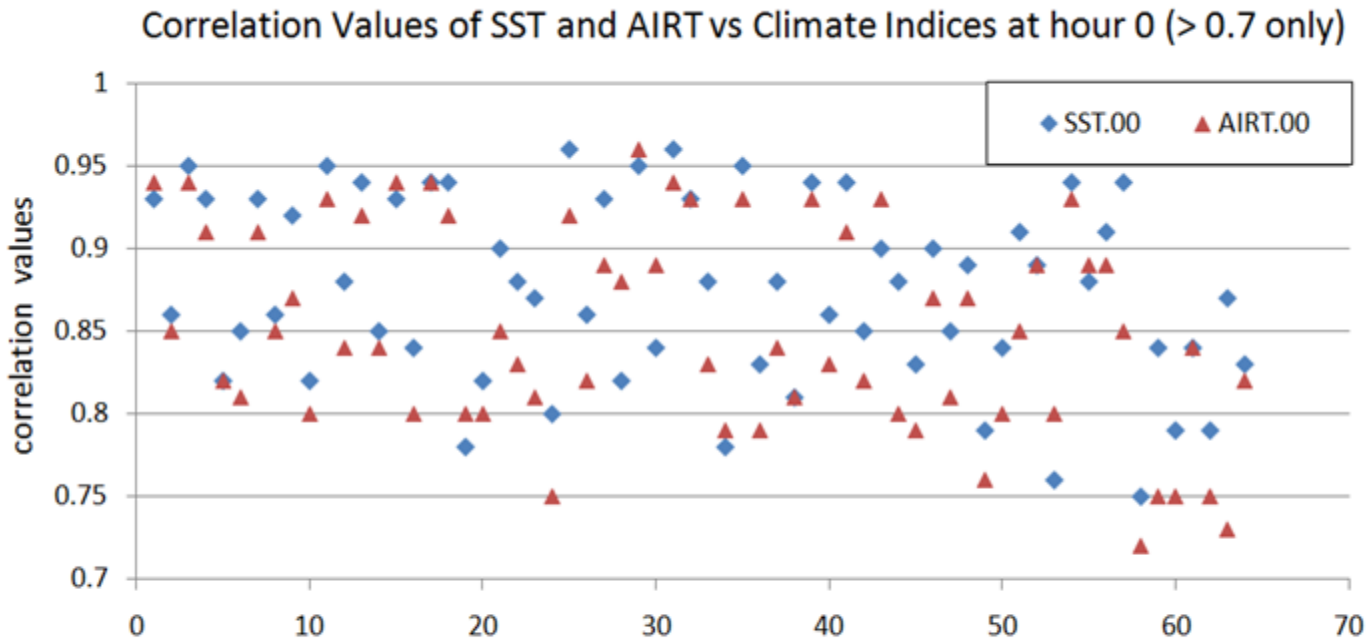


Figure 6. Comparison of 00 UTC SST and air temperature correlations for the 63 cases when r>|0.7|. On average, $(\overline{r_{SST}} - \overline{r_{Tair}})$=0.02, indicating that SST has 2% higher correlation on average than air temperature. $r_{SST} > r_{air}$ in 54 of the 64 cases. 12 UTC gives similar results (not shown).

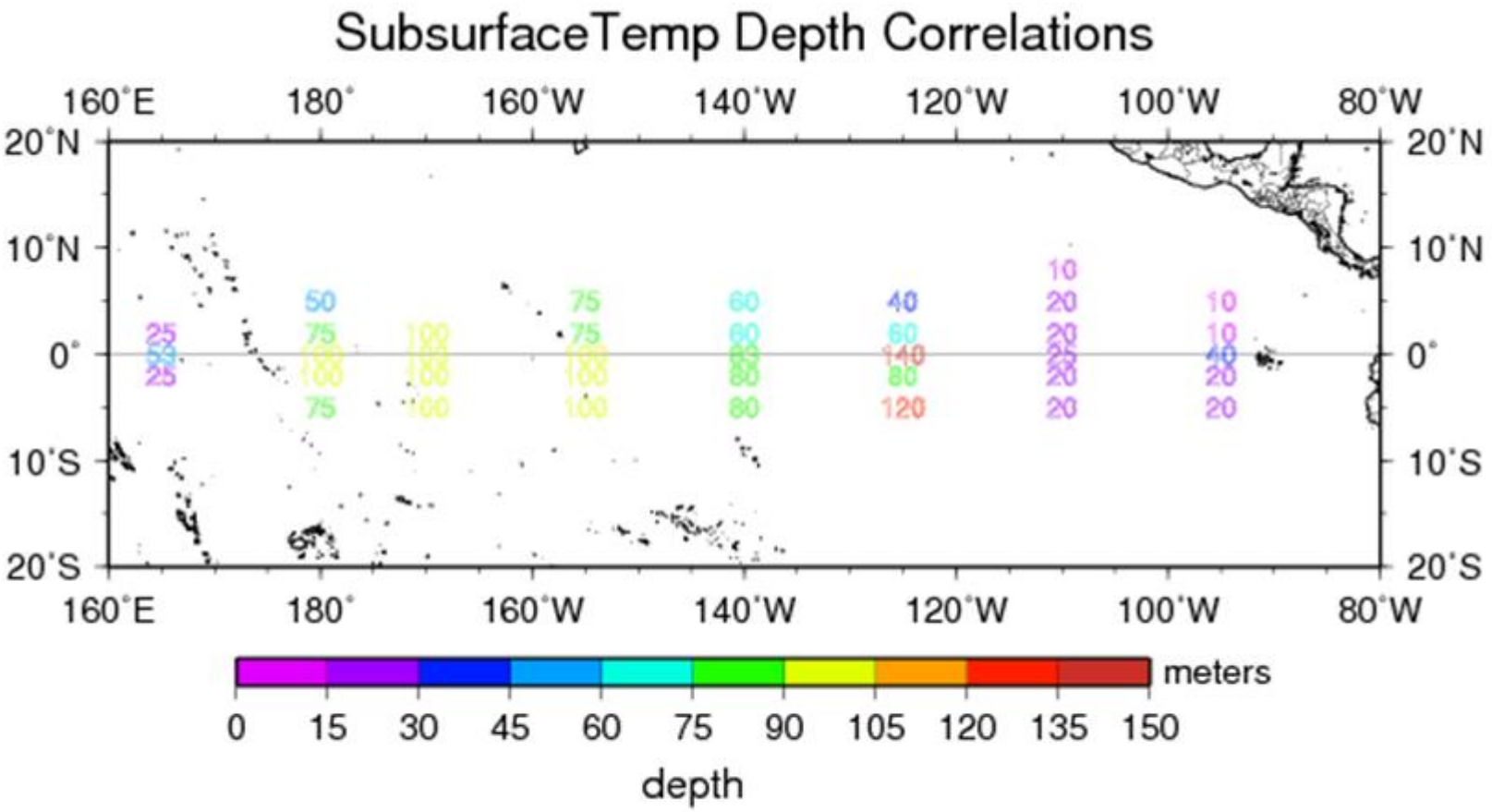


Figure 13. Color-coded depths at which the correlations reach r>|0.7|.

The ENSO signal penetrates deepest at the equator, from 125°W to 140 m. From 180°W to 140°W, the ENSO signal reaches from 50 to 105 m. The ENSO correlation is shallow on the far eastern and western edge of the TAO domain.

Other ENSO tidbits

- ONI's correlation with SST is on average 0.08 less than the peak Niño region correlation
- No correlations with air or water temperature met the r>|0.7| threshold for SOI or TNI
- No RH-ENSO relationship was noted based on the r>|0.7| threshold except for a single buoy located at 125°W and 0°N (r=-0.72 with ONI)
- No TNI relationship is found with RH, wind, or salinity.
- Some ENSO correlations are seen with salinity profiles, but in most cases the data sample is limited so the significance of the relationship is unclear. Example for 140°W, 0°N is shown below. The threshold was met down to 60 m.

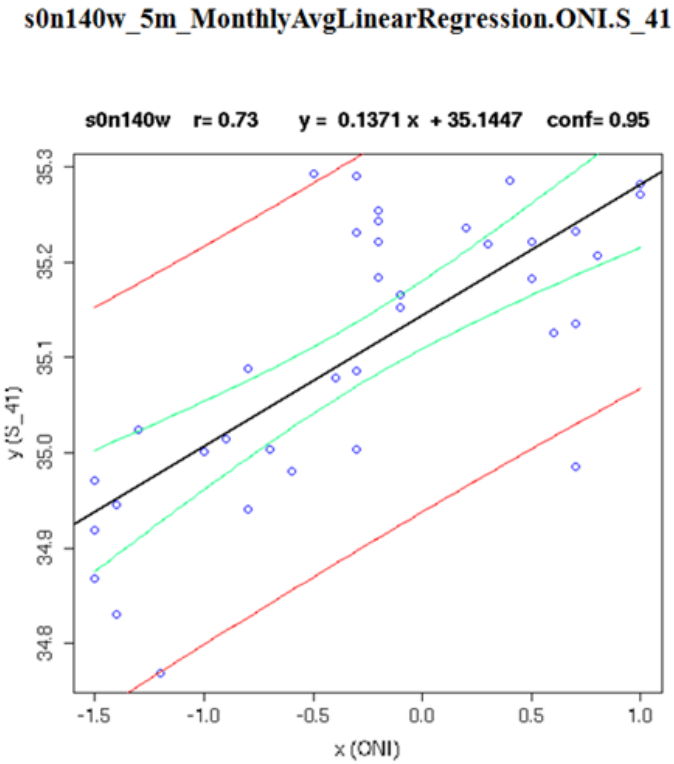


Figure 14. As in Fig. 8, but an example of a salinity correlation to ONI for the equatorial buoy located at 140°W. Note that the sample size is smaller, though.