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CHESAPEAKE BAY OPERATIONAL FORECAST SYSTEM: SKILL ASSESSMENT FOR 2001 AND IMPROVEMENTS

Silver Spring, Maryland
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noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Coast Survey Development Laboratory

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ABSTRACT

The Chesapeake Bay Operational Forecast System (CBOFS) model has now been running for nearly two years in an operational mode. The operational system consisting of scripts and programs which access local databases, internet data and local data streams has been refined to a stable and robust system. During these last two years the emphasis has been placed on operational status while development of the model itself has been frozen to avoid unnecessary complications. In the summer of 2001 the system was deemed operational and results were released to the public. Now we turn our attention once again to the quality of the water level predictions and the capability of the hydrodynamic model itself. This note describes the model skill exhibited during the year 2001 and several changes designed to improve the model performance.

A new error assessment shows that CBOFS worked slightly better in 2001 than in 1998 for which the original error assessment technical report was done (Gross, 2000). A selective analysis of the worst case errors revealed that the upper bay high water errors were often associated with NW winds. It is believed that NW winds are under-measured at the Thomas Point wind sensor since it is in the lee of the coast for NW winds. Increasing the amplitude of NW winds produces better model results for these events. Unfortunately the correction slightly degrades performance for lighter wind times.

Analysis of the mean model nowcast error at Chesapeake Bay Bridge Tunnel (CBBT) revealed a routine bias of 10% of non-tidal water level. In the present system the nowcast open boundary water level condition is produced by applying a phase and amplitude correction to the total water level observed at CBBT. It is hypothesized that the separation of the long period subtidal water and tidal water level components before application of the amplitude and phase shifts to the tidal component will correct the bias error.

It is recommended that the correction to the Thomas Point winds and the correction for the boundary condition specification of the water levels at the Chesapeake Bay Bridge Tunnel be incorporated in the CBOFS.

1. INTRODUCTION

Daily plots of the Chesapeake Bay Operational Forecast System (CBOFS) (Gross, Bosley and Hess, 2000) model nowcasts and 24 hour forecasts sometimes give the false impression of large errors, a conclusion which might be a perception problem. A careful analysis of the actual errors over the past year reveal that the model is still operating within the NOS accepted error bounds put forth in the 1999 skill assessment (Gross, 2000; NOS, 1999). However, there are a few simple techniques which could be applied to improve the model, especially for upper bay high water events. It is clear that the model does not do well during some large storm events. There is no doubt that the absolute errors of more than 10 cm difference of model verses observation is more likely during a storm event. However, as a percentage of non-tidal water level, the errors during events are only of order 10%. Still it would be good to identify any consistent biases and take steps to reduce these biases.

One continuing error bias appears to be caused by the wind field used for nowcasts. During nowcasts the wind field for the upper bay is based on the winds observed at the Thomas Point Lighthouse (CMAN station id. TPLM2). This is one of the very few wind stations over the water in Chesapeake Bay. However, it appears that it might be too close to land, giving a low wind whenever the wind blows from the landward direction (NW). Thus it will be seen that modeled water levels in the upper bay are too high when the wind is blowing from the NW. The wind is not strong enough in the model to blow the water level down and drain the upper bay. A method to correct this is presented below.

In the forecasts, it is obvious that the offshore water level prediction for the next 24 hours is responsible for most of the forecast errors in the lower bay. The Meteorological Development Laboratory's Extra-Tropical Storm Surge (MDL ETSS, formerly referred to as TDL), model is used to give forecasts which often have a 10 cm error. A more careful method of conjoining the ETSS forecasts with the nowcast and observation data can provide a slightly better forecast by taking advantage of persistence. Persistence (and ETSS predictions) in the non-tidal water level has almost no skill beyond 30 hours, but within the range of 0-18 hours can be used to improve the model results slightly.

The National Weather Service changed the forecast wind field model from the Eta-22 model to the Eta-12 model in fall of 2001. The new model shows every indication that it will be an improvement. Wind fields clearly show a speed-up over the water in the bay, a feature which was highlighted during the Coastal Marine Demonstration Project (Szilagyi *et al.*, 2000) when the 4km Regional Atmospheric Modeling System (RAMS) model was run. However the CBOFS model was calibrated with the old Eta-32 wind model and it would seem reasonable to assume a new calibration with the new wind field is necessary. With only a few months of data we have only preliminary indications of how the calibration should be changed. Direct comparisons of the Eta winds to observations reveal that the wind speed gain factor of 1.2 identified years ago in the Eta-32 results is still present and no changes to the calibration are recommended at this time. We do plan to revisit this question after accumulating a year's worth of runs using Eta-12.

This report summarizes the first year of the operational CBOFS. Operational procedures and lessons learned are first presented. The updated skill assessment statistics for operational nowcasts and forecasts of the year 2001 are presented. Little significant difference is seen between 2001 and the 1998 statistics of the previous report. Next an analysis of the Thomas Point wind will reveal a logical method of applying a correction. Skill assessment statistics will be presented for the modified nowcast model. Little difference in the gross statistics result, but the apparent improvement in the small group of NW wind events justifies this modification. An analysis of the new Eta winds will show that no changes in calibration are justified. A correction to the non-tidal water level forcing in nowcast mode is demonstrated. Finally the problem with the ETSS forecast water levels is presented. A simple persistence technique is presented which gives a small improvement to the model.

2. 24X7 OPERATIONAL SUCCESSES AND FAILURES

A full year of running in the operational mode has shown that the system is quite robust. For most of the year the model ran four times a day, everyday with no operator intervention. There were, however, several failures from which we have learned valuable lessons in operational model maintenance. When problems or changes occurred which required substantial action by the model programmers, notes were added to the files /CBOFS/execlog/CHANGES.txt or /CBOFS/execlog/FailureExamples.txt. These comments are based on those notes.

A common failure mode for the model was a hardware failure in the field of one of the instruments upon which the model relies for real-time observation data. The model suffers a complete shutdown only when the Chesapeake Bay Bridge Tunnel (CBBT) water level gauge is inaccessible or broken for more than a few hours. Otherwise it continues to run in somewhat degraded form when, for instance, one of the wind sensors is unavailable, or a short drop out of CBBT water level data occurs, or there is a delayed Eta wind forecast.

The CBBT water level data stream was interrupted during the year for a variety of reasons. Once the Chesapeake Bay data acquisition computer shut down and required a manual reboot. Once the CO-OPS PUFFF file format for CBBT was altered. This required reprogramming some of the data re-formatting software.

A malfunctioning wind gauge at CBBT somehow produced several hours of 50 m/s winds which the quality control checks failed to catch. An additional quality control speed limiter of 25 m/s was programmed into the genwind_2obsB.f program to prevent this in the future. A format field in mecca21.f was overrun at the same time. The format was expanded to allow 25 m/s winds.

A wind blew straight up the James River for long enough to drive the modeled water level to an unphysically high value. The mecca21.f code detects such a high water and halts. Because such events only cause high water at the heads of rivers, which have very small volume, the event does not produce problems anywhere else in the grid. An alteration to the mecca21.f code was implemented to allow higher water levels before halting. The previous limiting value of 3.0m was increased to 5.0m.

In May 2001, CO-OPS IT people changed the IP addresses of all of their machines. Because some of the CBOFS scripts used IP addresses, this caused wide spread failures. The scripts now use symbolic names. It is hoped that the IT people will inform CBOFS personnel of similar changes in advance and not make them on Fridays preceding long weekends.

OSO changed some of the files listed for the TPLM2 station. Changes were made to account for the new record formats.

On Nov. 26, 2001, NCEP switched from the old Eta-22 wind model to a new Eta-12 model. This required the ODAAS scripts to be changed to sub-sample the new grid. A new windwieghts file for genwind_bin.f90 was created for the new grid.

Once, the computer hard disk drive became full due mainly to graphics files. The problem was solved by archiving the files to CDROM and deleting them from the hard disk to free up space. This is one of several yearly maintenance tasks required to keep CBOFS running. A yearly maintenance list should be created. A script should be written to move all the files for archiving to a single place to be ready to be written to the CD. This problem may be more critical in the future. Now that CBOFS is running four times a day, it produces about 1.7 Gigabytes of graphics files per year. That will nearly fill up the available disk space every year.

NCEP changed some of their computer access codes. This caused the ODAAS system to fail and no forecast winds were available. The problem was solved by some phone calls to NCEP. The people running our data sources need to inform us when they make changes which can impact our operations, like changing the security codes on their computers.

Occasional slow-ups of the data acquisition from the NWLON water level data base threw off the timing of our programs and delayed graphics. This threw an unnecessary CORMS error flag. No action was necessary as the graphics do run and are posted to the web, but just a few minutes late. To accommodate similar slow downs in the future a larger time window is provided for the graphics programs to finish before a CORMS error flag is thrown.

There are ten discrete events listed above. Most of these required only a few hours of time to analyze, debug and implement the necessary changes. The large exception was the NCEP change to Eta-12 which involved several people for several days. It appears that during 2001 only 40 hours, or so, of operational maintenance was required.

In retrospect very few of these incidents could have been anticipated. Perhaps better communication with the CO-OPS IT staff and the NCEP IT staff would help. But to both groups our needs are fairly minor and remembering to contact us about possible CBOFS interactions with every networking and data formatting task would be difficult. On the other hand the CORMS system caught all of these events and action to correct the problems was taken within 24 hours or less.

To help prevent a few of the predictable problems a text document, /CBOFS /docs /YEARLY_TASKS, has been added to the /CBOFS/docs directory, which describes the various house keeping and file maintenance tasks which must be performed through out the year.

3. SKILL ASSESSMENT STATISTICS

The nowcast and forecast skill assessment statistics are presented for the year 2001. Tables 1-6 are nearly identical in format to appendix A of the 1998 Skill Assessment report (Gross, 2000). (A description of the data processing used to produce these assessment tables is provided in the appendix. The particular statistics are described in the appendix . The statistics DPO and DNO, duration of positive and negative outliers have been condensed to their summation, DO, duration of outliers. This is convenient as throughout all of these 2001 tests DO=0.0.) A slight improvement over the 1998 statistics is probably attributable to the rather calm weather of 2001. Fewer big storm events occurred in 2001. At CBBT, the location closest to the mouth of the bay, the standard deviation of the error is only 2.3 cm at nowcast. The error quickly grows with the forecast hour, reaching 8 cm at 6 hours and plateaus at 8-10 cm for 12-24 hours. The upper bay locations, like Baltimore, have about 8 cm standard deviation at zero hour, but do not grow until hour 18 when the standard deviation of the error surpasses 10 cm.

To prepare the forecast skill assessment statistics the particular forecast hour must be isolated from the rest of the data. Using Matlab this is done with:

```
% Forecast 0,6,12,18 hour numbers.
for fhour = [0,6,12,18];
Cf=Cfore18;
l = find(Cf.hour>(fhour-.5) & Cf.hour<(fhour+.5));
Cf.H=Cf.H(l,:);Cf.jday=Cf.jday(l);
disp(['Forecast Hour',int2str(fhour)])
skillassesstable(Cf,Obs,Obstideonly,2:12);end
```

The model was rerun for the year 2001 in hindcast mode by constructing a single continuous time series of the forcing functions using the reworked and more thoroughly quality controlled data from the NWLON database. The skill assessment statistics are given in Table 6. They look somewhat degraded compared to the operational Nowcast statistics, Table 1. This is actually because several storm events interrupted the operational run and thus the storm data are not part of the operational run statistics. However the differences are slight and are not statistically significant. In the next sections the model is rerun with alterations to the forcing functions. The statistics of these test runs should be compared directly to the "re-run" nowcast statistics (Table 6).

Table 1: Skill Assessment Statistics for the Operational Nowcast

Station	SM	RMSE	SD	NOF	CF	POF	DO	WOF	5%	median	95%
	m	m	m	%	%	%	h	%	m	m	m
cbbt	-0.004	0.024	0.023	0.0	100.0	0.0	0	0.0	-0.040	-0.007	0.037
hamp	0.013	0.058	0.056	0.0	98.0	0.1	0	0.0	-0.071	-0.002	0.098
kipt	0.011	0.040	0.039	0.0	99.7	0.0	0	0.0	-0.051	0.004	0.073
glou	0.002	0.062	0.061	0.0	98.7	0.1	0	0.0	-0.100	-0.001	0.092
lewi	0.004	0.062	0.062	0.0	97.6	0.0	0	0.0	-0.095	-0.007	0.105
colo	-0.003	0.096	0.096	0.1	89.8	0.5	0	0.1	-0.153	-0.011	0.154
solo	0.000	0.075	0.075	0.0	94.7	0.1	0	0.0	-0.114	-0.009	0.132
camb	0.011	0.107	0.107	0.2	85.1	0.3	0	0.0	-0.159	0.003	0.182
anna	0.004	0.081	0.081	0.0	93.2	0.4	0	0.2	-0.120	-0.008	0.148
balt	0.010	0.085	0.084	0.0	92.2	0.4	0	0.3	-0.118	-0.000	0.158
tolc	0.012	0.086	0.085	0.0	92.0	0.4	0	0.2	-0.122	0.003	0.158

SM: series mean. RMSE: root mean square error. SD: Standard deviation. NOF: Negative outlier frequency is percent of time error is more than 0.3m to the negative. CF: Central Frequency is percent of time the error is inside ±0.3m. POF: Positive Outlier Frequency is percent of time error is more than 0.3m to the positive. DO: Maximum Duration of Outliers is cumulative time when the error is more than 0.3m or less than -0.3m for a continuous duration of 24 hours. This is the sum of the DPO and DNO, duration of postive and negative outlier statistics of NOS 1999. WOF: Worst case Outlier Frequency is percent time predicted water level higher than observed by 0.3m and the astronomical tidal prediction is closer to the observed. median(%50), and 5% and 95%: Points of the cumulative probability distribution of water level error.

Table 2: Skill Assessment Statistics for the 06 forecast hour

Station	SM	RMSE	SD	NOF	CF	POF	DO	WOF	5%	median	95%
	m	m	m	%	%	%	h	%	m	m	m
cbbt	0.043	0.100	0.091	0.3	87.0	0.3	0	0.0	-0.125	0.043	0.179
hamp	0.058	0.117	0.101	0.3	83.6	1.5	0	0.0	-0.114	0.062	0.215
kipt	0.054	0.108	0.093	0.3	86.8	0.9	0	0.0	-0.120	0.057	0.198
glou	0.029	0.106	0.102	0.6	86.3	0.6	0	0.0	-0.165	0.039	0.171
lewi	0.016	0.067	0.065	0.0	97.6	0.0	0	0.0	-0.100	0.016	0.120
colo	0.001	0.097	0.097	0.0	89.5	0.3	0	0.0	-0.142	0.003	0.156
solo	0.006	0.072	0.072	0.0	96.3	0.0	0	0.0	-0.102	-0.003	0.130
camb	0.004	0.102	0.102	0.3	86.5	0.0	0	0.0	-0.152	-0.008	0.179
anna	0.002	0.076	0.076	0.0	93.3	0.0	0	0.0	-0.117	-0.003	0.133
balt	0.006	0.094	0.093	0.6	90.1	0.3	0	0.0	-0.146	-0.002	0.160
tolc	0.008	0.083	0.083	0.3	91.5	0.0	0	0.0	-0.118	0.003	0.151

Table 3: Skill Assessment Statistics for the 12 forecast hour

Station	SM	RMSE	SD	NOF	CF	POF	DO	WOF	5%	median	95%
	m	m	m	%	%	%	h	%	m	m	m
cbbt	0.027	0.106	0.103	0.6	86.0	1.2	0	0.0	-0.173	0.032	0.186
hamp	0.034	0.115	0.110	0.6	82.7	1.5	0	0.0	-0.152	0.037	0.195
kipt	0.040	0.110	0.103	0.3	85.3	1.5	0	0.0	-0.147	0.045	0.203
glou	0.038	0.111	0.104	0.9	86.5	1.2	0	0.0	-0.132	0.040	0.191
lewi	0.032	0.090	0.085	0.0	90.4	0.0	0	0.0	-0.128	0.037	0.158
colo	0.011	0.096	0.096	0.0	89.5	0.0	0	0.0	-0.158	0.022	0.151
solo	0.031	0.093	0.088	0.3	88.9	0.3	0	0.0	-0.136	0.030	0.158
camb	0.040	0.125	0.118	0.9	79.0	0.9	0	0.0	-0.153	0.038	0.223
anna	0.009	0.091	0.091	0.9	92.7	0.3	0	0.0	-0.139	0.006	0.129
balt	-0.005	0.105	0.105	1.5	88.6	0.6	0	0.3	-0.170	-0.005	0.142
tolc	-0.001	0.101	0.101	1.5	90.1	0.3	0	0.0	-0.159	-0.002	0.140

Table 4: Skill Assessment Statistics for the 18 forecast hour

Station	SM	RMSE	SD	NOF	CF	POF	DO	WOF	5%	median	95%
	m	m	m	%	%	%	h	%	m	m	m
cbbt	0.035	0.114	0.109	0.6	84.3	1.5	0	0.0	-0.153	0.039	0.199
hamp	0.054	0.131	0.119	0.6	77.3	2.3	0	0.0	-0.165	0.053	0.234
kipt	0.052	0.120	0.109	0.6	80.8	1.8	0	0.0	-0.145	0.057	0.211
glou	0.030	0.117	0.113	0.9	83.0	1.2	0	0.0	-0.168	0.033	0.198
lewi	0.015	0.094	0.093	0.6	89.9	0.0	0	0.0	-0.144	0.021	0.154
colo	0.021	0.105	0.103	0.6	87.5	0.6	0	0.0	-0.140	0.020	0.181
solo	0.008	0.099	0.099	0.6	88.4	0.6	0	0.3	-0.150	0.008	0.166
camb	0.015	0.124	0.123	0.6	77.8	0.9	0	0.0	-0.175	-0.001	0.204
anna	0.022	0.107	0.105	1.2	88.1	0.9	0	0.3	-0.149	0.023	0.178
balt	0.028	0.125	0.122	1.5	84.2	1.8	0	0.3	-0.161	0.027	0.217
tolc	0.037	0.120	0.114	1.2	85.5	1.5	0	0.3	-0.151	0.039	0.204

Table 5: Skill Assessment Statistics for the 24 forecast hour

Station	SM	RMSE	SD	NOF	CF	POF	DO	WOF	5%	median	95%
	m	m	m	%	%	%	h	%	m	m	m
cbbt	0.025	0.110	0.107	0.9	85.0	0.9	0	0.0	-0.153	0.026	0.184
hamp	0.043	0.127	0.120	0.9	77.5	2.0	0	0.0	-0.168	0.041	0.222
kipt	0.047	0.117	0.107	0.3	83.3	2.1	0	0.0	-0.125	0.046	0.203
glou	0.033	0.128	0.123	1.2	79.5	2.3	0	0.0	-0.170	0.031	0.208
lewi	0.036	0.113	0.107	0.6	85.7	0.6	0	0.0	-0.140	0.038	0.210
colo	0.026	0.120	0.117	0.6	82.5	1.2	0	0.3	-0.160	0.030	0.222
solo	0.047	0.122	0.113	0.3	80.0	1.5	0	0.0	-0.149	0.049	0.240
camb	0.057	0.143	0.131	0.3	67.9	2.4	0	0.0	-0.172	0.056	0.253
anna	0.028	0.118	0.115	0.6	80.8	1.5	0	0.6	-0.167	0.027	0.218
balt	0.023	0.135	0.133	1.2	77.1	2.3	0	0.9	-0.208	0.023	0.209
tolc	0.035	0.129	0.124	0.6	80.2	2.3	0	0.3	-0.181	0.037	0.219

Table 6: Skill Assessment Statistics for the Re-Run Nowcast

Station	SM	RMSE	SD	NOF	CF	POF	DO	WOF	5%	median	95%
	m	m	m	%	%	%	h	%	m	m	m
cbbt	-0.003	0.025	0.025	0.0	100.0	0.0	0	0.0	-0.042	-0.006	0.039
hamp	0.014	0.054	0.053	0.0	98.2	0.0	0	0.0	-0.063	0.005	0.101
kipt	0.013	0.040	0.038	0.0	99.7	0.0	0	0.0	-0.047	0.008	0.076
glou	0.003	0.060	0.060	0.0	98.8	0.0	0	0.0	-0.095	0.002	0.095
lewi	0.006	0.063	0.063	0.0	97.5	0.0	0	0.0	-0.094	-0.004	0.110
colo	0.000	0.097	0.097	0.0	89.3	0.6	0	0.1	-0.151	-0.008	0.161
solo	0.004	0.076	0.076	0.0	94.6	0.1	0	0.0	-0.112	-0.006	0.138
camb	0.014	0.108	0.107	0.2	84.7	0.4	0	0.0	-0.156	0.006	0.184
anna	0.009	0.082	0.082	0.0	92.7	0.4	0	0.2	-0.113	-0.004	0.155
balt	0.015	0.086	0.085	0.0	91.8	0.5	0	0.4	-0.112	0.005	0.163
tolc	0.018	0.088	0.086	0.0	91.5	0.5	0	0.3	-0.114	0.007	0.166

4. THOMAS POINT WIND CORRECTIONS

An evaluation of the water level errors from the nowcast runs of 2001 can be presented in several forms. The clearest form is the time series of the detided observed and modeled water levels at each station and their differences (Figs. 1 and 2). Nowcast water levels near the mouth of the bay are always more accurate than those in the Northern bay because the model uses an open boundary condition based on observed water level at the mouth of the bay. However time series of errors at the Baltimore station show greater variance and apparently large errors during low water events. Since low water events are associated with Nor'easter storms it was thought that the model's response to the wind could be a problem. The wind direction plot of Fig. 2 includes colored dots whenever the error at Baltimore is large. The dots are always found in the NW wind quadrant. The largest errors occur when winds from the NW are not strong enough to blow down the water level. The errors are not occurring during North or Northeast winds, but rather only during Northwest winds.

Figure 3 demonstrates the correlation of large errors with the wind direction. The figure portrays all of the Thomas Point wind vectors for the year as dots surrounding the origin, indicating the amplitude and direction the wind is blowing toward. The green dots are times when the water level errors are less than 0.2m in magnitude (absolute value). Red dots mark wind vectors when the model water level is higher than the observation by more than 0.2m. Blue dots indicate when the model water level is lower than observation by more than 0.2m . The clustering of blue dots to the South East indicates that when wind blows from the NW, a direction which should drive the water level down, the model is not going down strongly enough. It is hypothesized that the wind measurement at Thomas Point of a NW wind is an under-measurement because the station is immediately in the lee of the shore for NW winds. Wind speeds over water are faster than over land and thus the wind throughout the rest of the northern Chesapeake bay is probably faster than the Thomas Point measurement indicates.

Additional nowcast runs of the CBOFS model were conducted with Thomas Point winds increased when blowing from the NW. A correction function was constructed to give a smooth increase in the wind speed when blowing from the NW (Fig.4). The factor is a function of the wind direction, θ:

$$A = 1.0 * (1 + \beta * exp(-((\theta - \theta_o)/\alpha).^2));$$

The correction is scaled by $\beta = 0.20$, centered around the $\theta_o = 315°N$ direction with an angular spread given by $\alpha = 36°$. Figure 5 shows the same plot of wind vectors color coded by magnitude of error in water level. With a 20% increase in the NW winds many of the largest errors are decreased and fewer blue dots are evident in the Tolchester and Baltimore plots. The effect of this correction is only strongly felt by the largest wind events from the NW which does not occur very often.

The overall skill assessment statistics are almost unchanged, but most are slightly improved by applying this correction (Table 7 compares to uncorrected case Table 6). The error bars at Baltimore and Tolchester were skewed toward positive values with 5% of errors lower than -.112m and 5% greater than 0.163m at Baltimore. With the 20% correction to Thomas Point winds the outlier errors are more evenly distributed from -0.125m to +0.131m. The 20% correction has been applied to the operational CBOFS system.

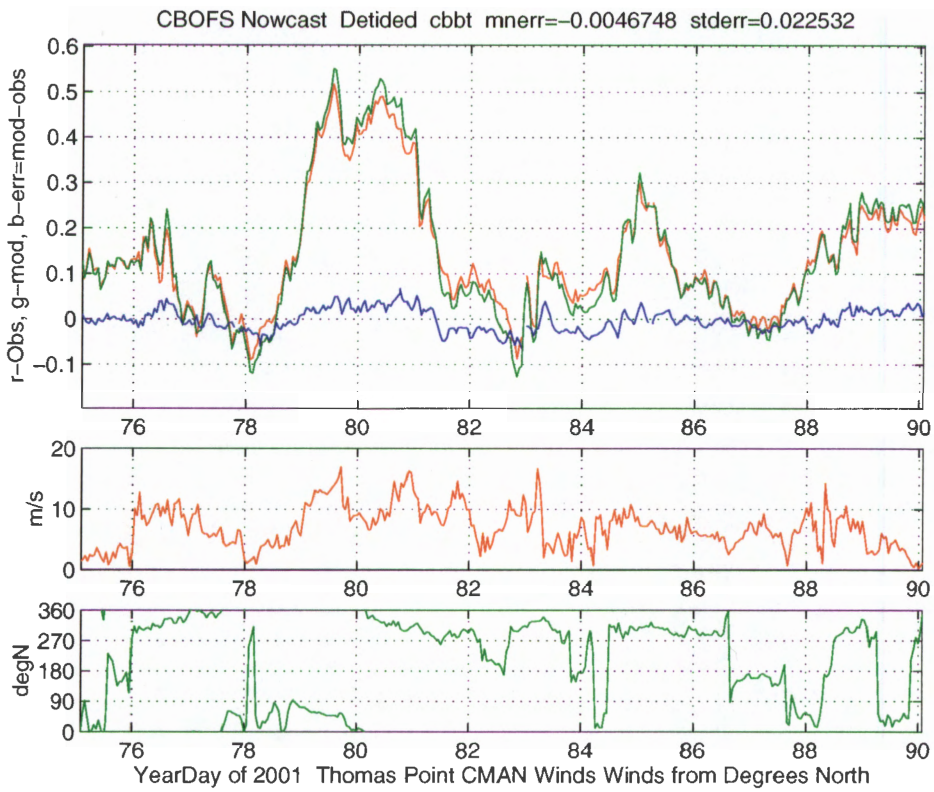

Figure 1: Uppermost subplot depicts the detided observed (red) and nowcast (green) modeled water levels at CBBT and their difference, the error (blue). Lower subplots depict the speed (red) and direction (green) of the observed wind at CBBT.

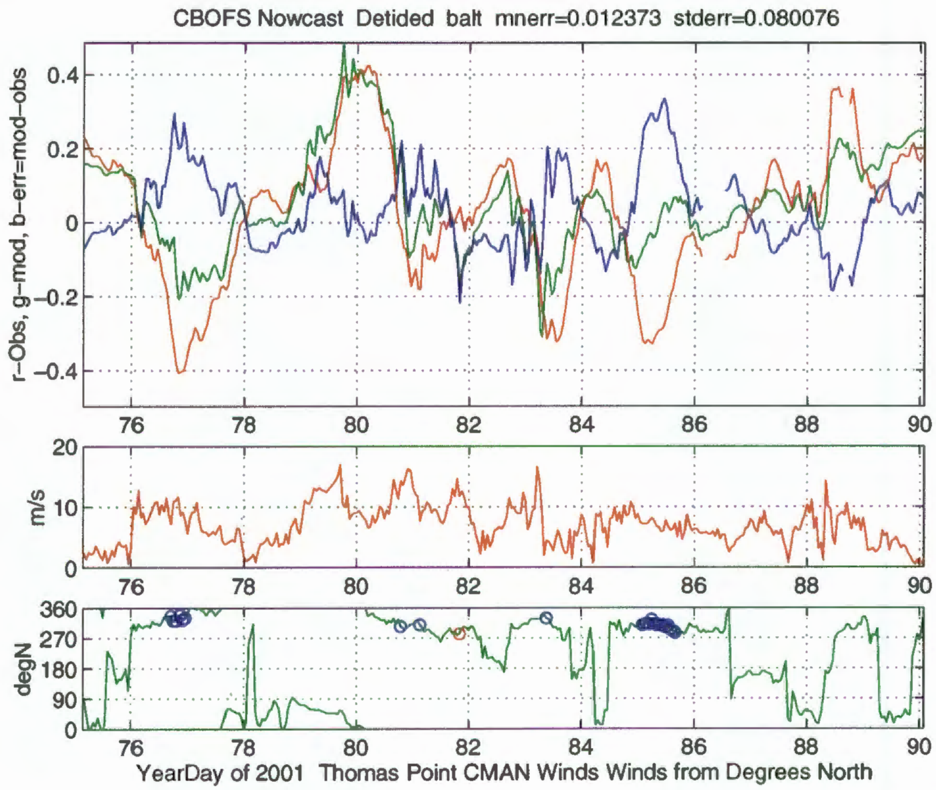

Figure 2: Uppermost subplot depicts the detided observed (red) and nowcast (green) modeled water levels at Baltimore and their difference, the error (blue). Lower subplots depict the speed (red) and direction (green) of the observed wind at Thomas Point Light. Blue dots on the wind direction plot indicate moments when the error at Baltimore is large. The preponderance of blue dots are found when the wind blows from the NW.

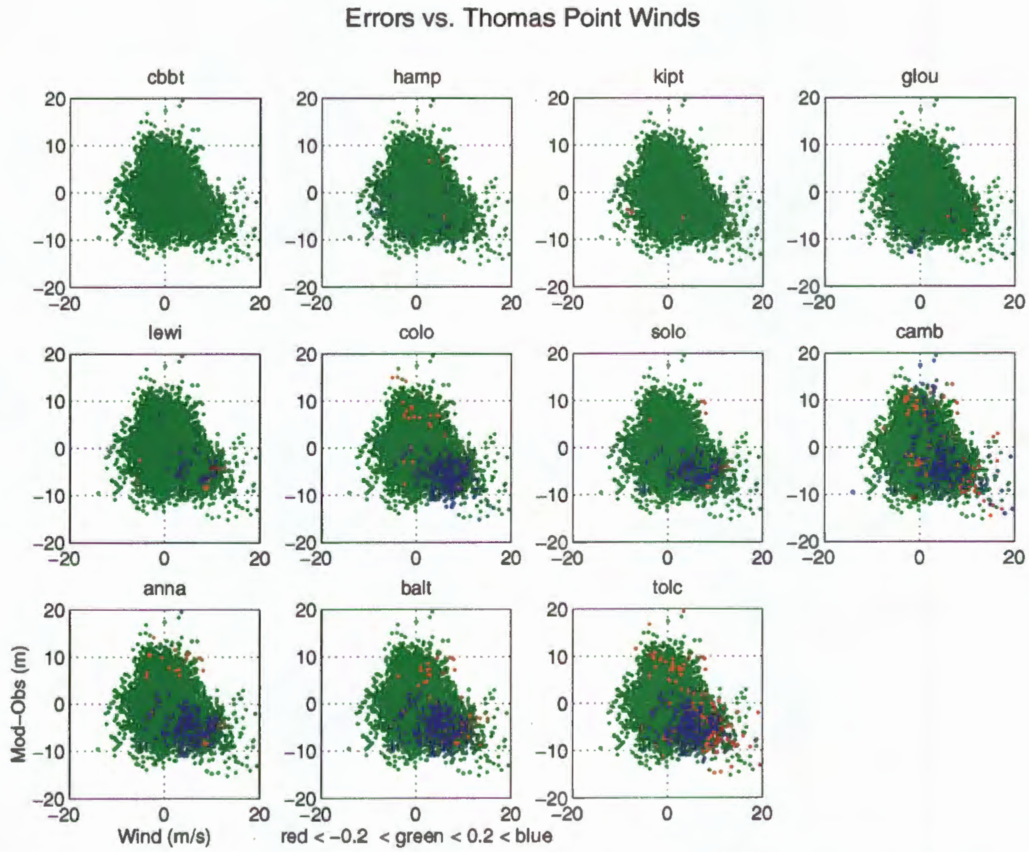

Figure 3: Colored dots plotted at the end of wind vectors (wind blows from center of plots toward the dot). Red indicates water level errors when model is lower than the observation (at the station) by more than 0.2m. Blue indicates water level errors when model is higher than the observation by more than 0.2m. Green dots are when magnitude of the error is smaller than 0.2m.

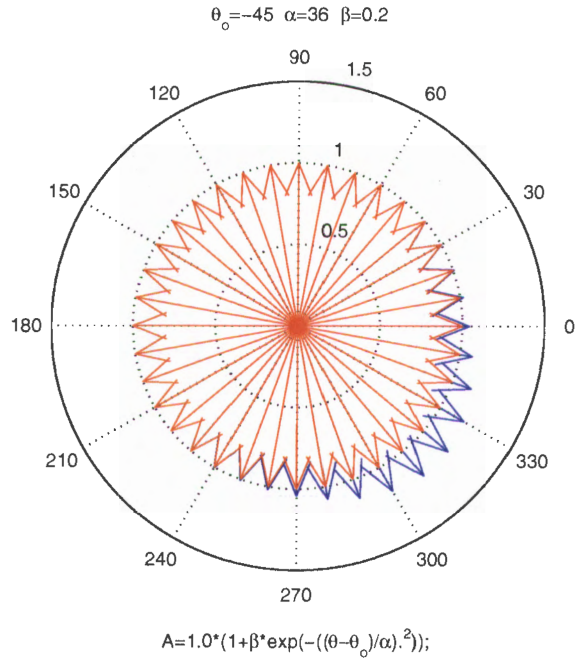

Figure 4: The wind vector blowing from the NW is amplified. The red unit vector represents an unaffected wind vector. The corrected vectors in blue are smoothly increased when blowing from the NW.

Table 7: Skill assessment statistics when Thomas Point Winds are augmented by 20% when blowing from the NW.

Station	SM	RMSE	SD	NOF	CF	POF	DO	WOF	5%	median	95%
	m	m	m	%	%	%	h	%	m	m	m
cbbt	-0.003	0.026	0.025	0.0	100.0	0.0	0	0.0	-0.042	-0.007	0.039
hamp	0.014	0.055	0.053	0.0	98.1	0.0	0	0.0	-0.063	0.005	0.102
kipt	0.012	0.040	0.038	0.0	99.7	0.0	0	0.0	-0.048	0.008	0.077
glou	0.002	0.060	0.060	0.0	98.8	0.0	0	0.0	-0.096	0.002	0.095
lewi	0.003	0.060	0.060	0.0	98.3	0.0	0	0.0	-0.095	-0.006	0.101
colo	-0.003	0.094	0.094	0.0	90.2	0.4	0	0.1	-0.152	-0.010	0.149
solo	0.000	0.073	0.073	0.0	95.6	0.0	0	0.0	-0.113	-0.007	0.126
camb	0.012	0.106	0.105	0.2	85.7	0.3	0	0.0	-0.155	0.004	0.180
anna	0.003	0.075	0.075	0.0	94.6	0.1	0	0.1	-0.115	-0.007	0.132
balt	0.003	0.081	0.081	0.3	93.4	0.1	0	0.1	-0.125	-0.002	0.131
tolc	0.011	0.080	0.079	0.0	93.2	0.1	0	0.1	-0.117	0.004	0.143

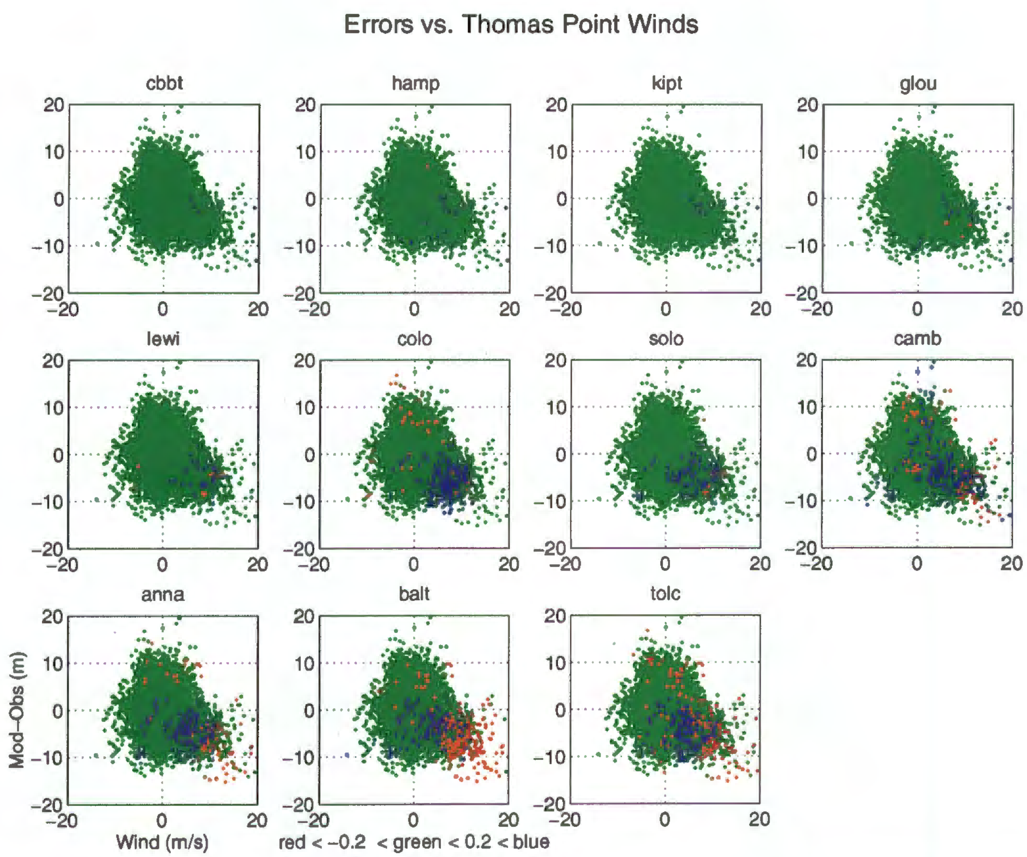

Figure 5: Same plot as Figure 3 except with Thomas Point winds increased by 20% when coming from off land, i.e. NW winds.

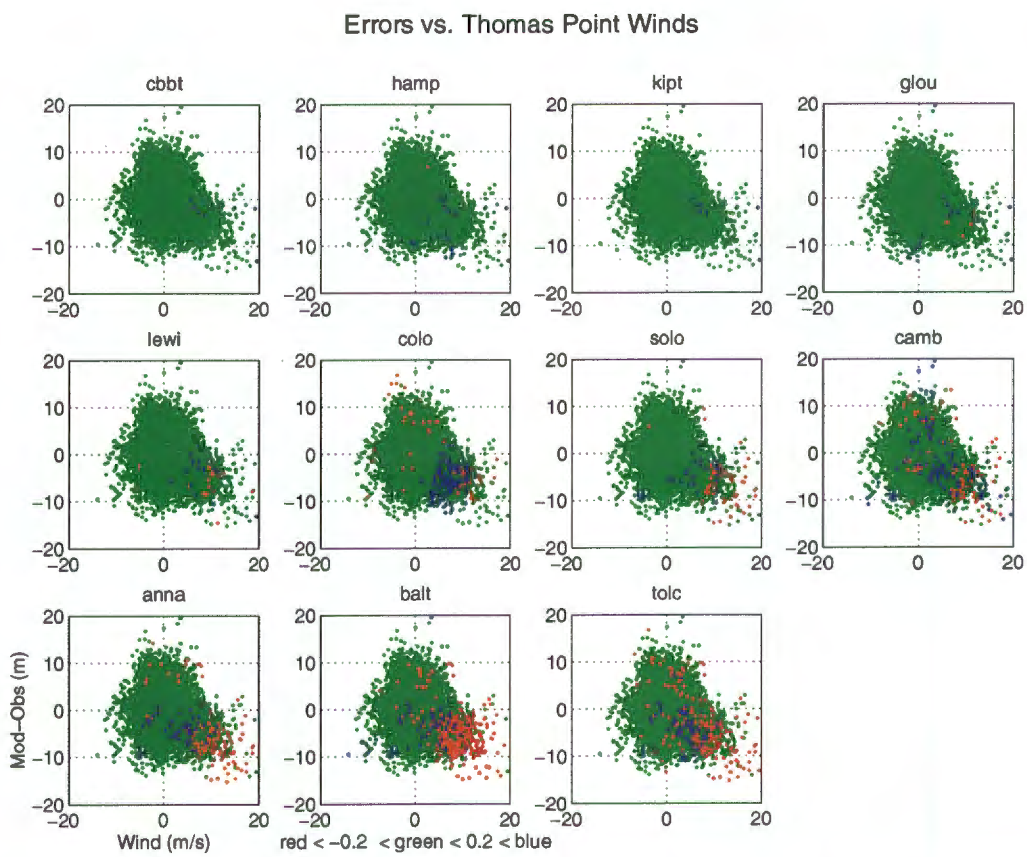

Figure 6: Same plot as Figure A except with Thomas Point winds increased by 30% when coming from off land, i.e. NW winds.

5. A COMPARISON OF ETA WINDS WITH OBSERVATIONS

The Eta-32 wind fields were found to be too light in comparison to the observation data at TPLM and CBBT and a correction factor was applied in the operational CBOFS system (Gross *et al*, 2000). However Eta-22 and Eta-12 have not been tested. Now with a year of Eta-22 and Eta-12 results an updated comparison between the models and wind observations can be performed. The genwind_bin.f90 program applied a 1.2 factor to the Eta winds based upon the Eta-32 calibration. The CBOFS output file contains the winds at CBBT, TPLM and an intermediate point, Rappahanock. The nowcast file has unscaled CBBT and TPLM winds. These data were analyzed with the assumption that (aside from the 1.2 factor) the winds output into the CBOFS files are the same as the observations or the Eta model. The wind speeds and directions were converted to complex values:

$$U + iV = SPEED * exp(i * (90 - DIRECTION) * \pi/180)$$

(See description in Matlab routine windcompdir.m.) A least squares fit of the complex wind vectors between Eta and observations was performed. The results in Fig. 7 show the scatter between the Obs and Eta as the red dots and the fit as green dots. The plots are by components U and V. Since the fit includes some rotation angle correction the green dots are not in a simple straight line. (They would be if I could render a four dimensional plot.) Because the correlation coefficient is not close to unity the least squares regression of x on y gives a different slope from the regression of y on x. No obvious reason favors the observations over the Eta winds as the dependent variable. Therefore the slope and intercept given below are the average of the two possible regressions. The relationships show that the Eta winds are too small by about 15% at CBBT and 30% at TPLM.

$$CBBTW_{eta} = (0.8685 + 0.0713i)W_{obs} - 0.3427 + 0.0067i$$

$$TPLMW_{eta} = (0.7452 - 0.1777i)W_{obs} - 0.2431 + 0.3339i$$

$$RappW_{eta} = (1.1136 - 0.0299i)W_{obs} - 0.4197 + 0.0485i$$

The absolute values of the slopes, 0.87 and 0.77, have inverses of 1.15 and 1.30 which are similar to the 1.2 factor used previously with Eta-32. Rappahanock's is smaller at 1.11 = 1/0.90. The angular correction for CBBT is only 4.7 degrees but for TPLM it is -13.4 degrees. The correlation coefficients reflect the complex rotation and are $R^2 = [0.8216 + 0.0695i; 0.7772 - 0.1849i; 0.8456 - 0.0206i]$for CBBT, TPLM and Rapp respectively.

It is difficult to see in these plots whether there is a bias in the misfit of the TPLM observations to Eta due to direction. One might suspect that the NW wind effect mentioned before is manifest in the -13.4 degree rotation and 1.30 amplitude ratio. Plots were done with winds

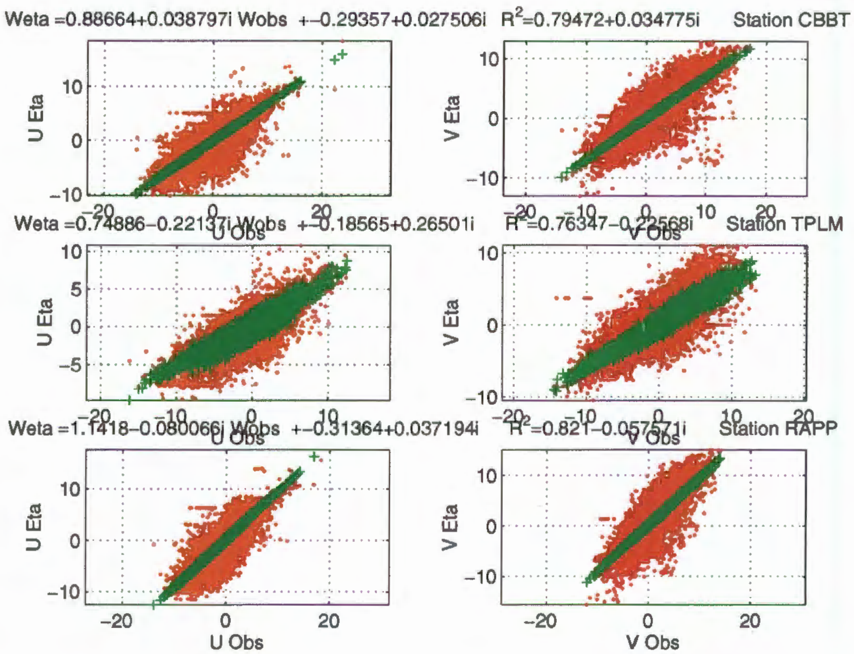

Figure 7: Comparison of Eta model vs. observed surface winds at CBBT, TPLM, and Rappahanock. Real corresponds to E-W winds component, Imag to N-S component. Red dots are the data comparison. Green dots are the least squares estimate of Eta winds based on the observed winds. The non-straight line nature of the green dots indicates an angular rotation of the observed winds to obtain the least squares estimates of eta winds.

only, blowing from each of the four quadrants, NE, SE, SW, and NW. The TPLM slopes were

```
NE   0.8202 - 0.1576i    =0.8352 e(i -10.8767  degrees)
SE   0.6715 - 0.1634i    =0.6911 e(i -13.6763  degrees)
SW   0.8200 - 0.0922i    =0.8252 e(i  -6.4153  degrees)
NW   0.9382 - 0.2103i    =0.9615 e(i -12.6342  degrees)
```

(The mean of these slopes is not 0.77 because of the unequal number of points in the different quadrants.) SE is the most different in magnitude, but NW is most different in rotation. The conclusion that observed TPLM winds from the NW should be multiplied by 1.20 to correct for the windward land effect is opposed here. The one direction where the correction between Eta and TPLM is smallest is the NW.

It is difficult to use this comparison of Eta to observations to conclude strongly that the multiplier coefficient for Eta should be changed. The correction factor for CBBT should perhaps be 1.15 while for TPLM 1.30 might be better. However the interpolated value at Rapp would use a smaller value, 1.11. The correlation of observed wind with Eta winds will probably never be much better than 0.8, indicating a basic uncertainty in the difficult to measure or model surface winds over an estuary. Since there is no conclusive evidence contradicting the use of the 1.2 factor, no changes in use of the Eta winds will be implemented.

6. CBBT NON-TIDAL WATER LEVEL CORRECTIONS

CBBT water level observations are used to force the outer boundary water level of the model. The observed water levels are re-scaled and phase shifted to account for the frictional degradation and time lag when the tidal wave propagates the three grid cell lengths from the outer ocean to the CBBT location. The correction was:

$$H_{ocean}(T) = 1.134 H_{CBBT}(T + 0.2833 hour)$$

The multiplication factor is applied to both the non-tidal and the astronomical tide. There is evidence that the non-tidal component of the water level reconstructed by the model at CBBT is too large by approximately 10% (Fig. 8). To correct this effect a test was run where the CBBT water level was separated into the tidal and non-tidal components by subtracting the NOAA tidal constituent reconstructed tide from the observations. Only the tidal component is scaled and time shifted.

$$H_{ocean}(T) = 1.134 H_{CBBT}^{tidal}(T + 0.2833 hour) + H_{CBBT}^{NON-tidal}(T)$$

The time series of percentage error shown in Fig. 8 is reduced in the corrected run Fig. 9. The effect on the skill assessment statistics is good at CBBT and lower bay locations. Surprisingly the effect at the upper bay locations is actually noticeable, improving the standard deviation by almost 0.5cm. The skill assessment statistics are improved almost everywhere, Table 8, in comparison to the uncorrected model statistics Table 6. This correction to the model was implemented.

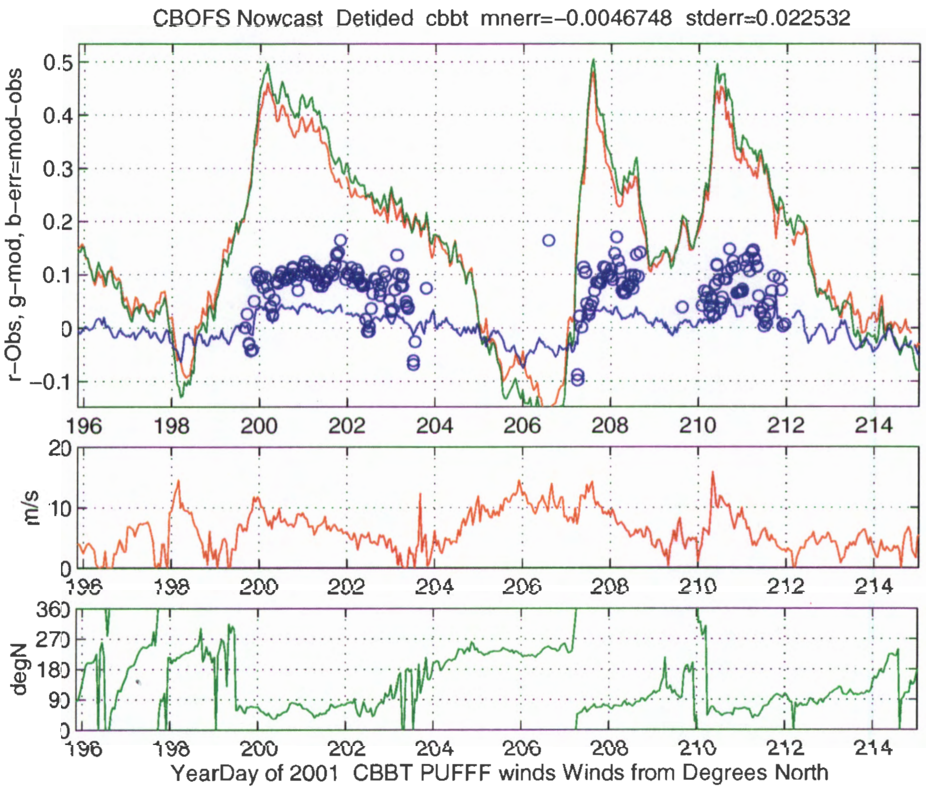

Figure 8: The top plot depicts the detided observed (red) and nowcast (green) modeled water levels at CBBT and their difference, the error (blue). The blue circles are the percentage error. The errors are clustered near 10%. CBBT Wind speed and direction are depicted in the lower panels.

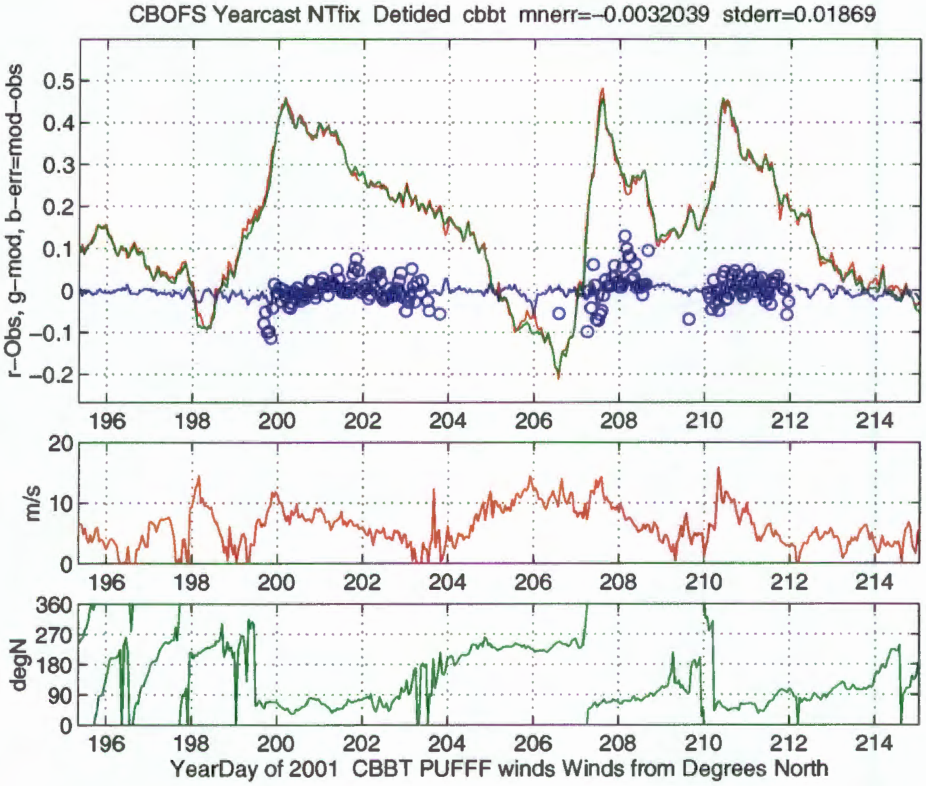

Figure 9: The top plot depicts the detided observed (red) and nowcast (green) modeled water levels at CBBT and their difference, the error (blue). The blue circles are the percentage error. The new method of transferring CBBT water levels is used here. The errors are now clustered about 0% and much smaller than 10%. CBBT Wind speed and direction are depicted in the lower panels.

Table 8: Skill Statistics when CBBT boundary condition is corrected.

Station	SM	RMSE	SD	NOF	CF	POF	DO	WOF	5%	median	95%
	m	m	m	%	%	%	h	%	m	m	m
cbbt	-0.003	0.018	0.018	0.0	100.0	0.0	0	0.0	-0.032	-0.005	0.022
hamp	0.014	0.048	0.046	0.0	99.1	0.0	0	0.0	-0.054	0.006	0.091
kipt	0.012	0.032	0.029	0.0	100.0	0.0	0	0.0	-0.035	0.010	0.059
glou	0.003	0.054	0.054	0.0	99.6	0.0	0	0.0	-0.086	0.002	0.086
lewi	0.005	0.057	0.057	0.0	98.3	0.0	0	0.0	-0.088	-0.003	0.094
colo	0.000	0.092	0.092	0.0	91.2	0.5	0	0.1	-0.142	-0.007	0.150
solo	0.004	0.070	0.070	0.0	95.7	0.0	0	0.0	-0.106	-0.004	0.124
camb	0.013	0.104	0.103	0.2	86.6	0.2	0	0.0	-0.152	0.007	0.174
anna	0.009	0.077	0.077	0.0	93.8	0.3	0	0.2	-0.107	-0.002	0.143
balt	0.015	0.081	0.080	0.0	93.0	0.3	0	0.3	-0.108	0.007	0.151
tolc	0.018	0.083	0.081	0.0	92.6	0.3	0	0.2	-0.111	0.008	0.153

7. EXTRA TROPICAL STORM SURGE MODEL

The outer water level boundary condition must transition from the observation-based value described in the previous section to the forecast value provided by the daily runs of the MDL-ETSS model. To avoid crashing the model the transition must be done smoothly with a zero hour correction to the ETSS value with perhaps a ramp-up time (T_{ramp}) to the full ETSS value. Several methods of performing the transition and ramp may be modeled:
Model 1:

$$H_{bc}(T) = (H_{obs}(T_o) - H_{ETSS}(T_o))\left(1 - \frac{T - T_o}{T_{ramp}}\right) + H_{ETSS}(T)$$

Model 2:

$$H_{bc}(T) = \left[1 - \frac{T - T_o}{T_{ramp}}\right] H_{obs}(T_o) + \frac{T - T_o}{T_{ramp}} H_{ETSS}(T)$$

Both models after T_{ramp}:

$$H_{bc}(T) = H_{ETSS} \qquad for \quad T > T_o + T_{ramp}$$

The first BC formulation method immediately changes with the dH_{ETSS}/dt and slowly rids itself of the initial offset mismatch. The second method brings in the variation due to H_{ETSS} slowly, allowing the constant offset of H_{obs} to persist. A third method uses the first method with the T_{ramp} infinitely long so that the mean offset of H_{obs} is used throughout the forecast period. This third method is desirable if the ETSS model has a poorly defined non-zero mean due, perhaps, to seasonal variation, unresolved SSA, SA tides or tidal epoch variability.

Time variation of the error for the three methods is examined in Figure 10. The errors are presented as a cloud of errors spreading with increasing forecast hour. At the zero forecast hour, T_o, all correction methods necessarily have zero error, as they are forced to $H_{obs}(T_o)$. The rate of growth of error will vary with persistence accuracy and ETSS accuracy. Fig. 10 shows the growth of error with forecast hour for the raw ETSS in subplot A. This has a bad initial error reflecting the mismatch with the real observations. Subplot B is a pure persistence forecast, it uses only the observation at hour 0 and no additional information. Subplot C uses the continuous offset method to correct the ETSS. Subplot D ramps out the offset and uses full ETSS model variation. Subplot E ramps out the offset and ramps in the time variation of the ETSS model.

The worst case is the uncorrected ETSS model. The persistence only model shows how valuable the initial observation is. By a small degree the best model is the persistence of initial observation with full ETSS, subplot C. This takes advantage of the long term variation in the offset correction to ETSS while allowing the 24 hour variation of ETSS to describe events. All models have basically no predictive ability at 24 hours where the variation of errors is equal to the variation of the subtidal water level signal ($\sigma = 12.7cm$). It is recommended that the CBOFS use the persistence of initial observation with full ETSS.

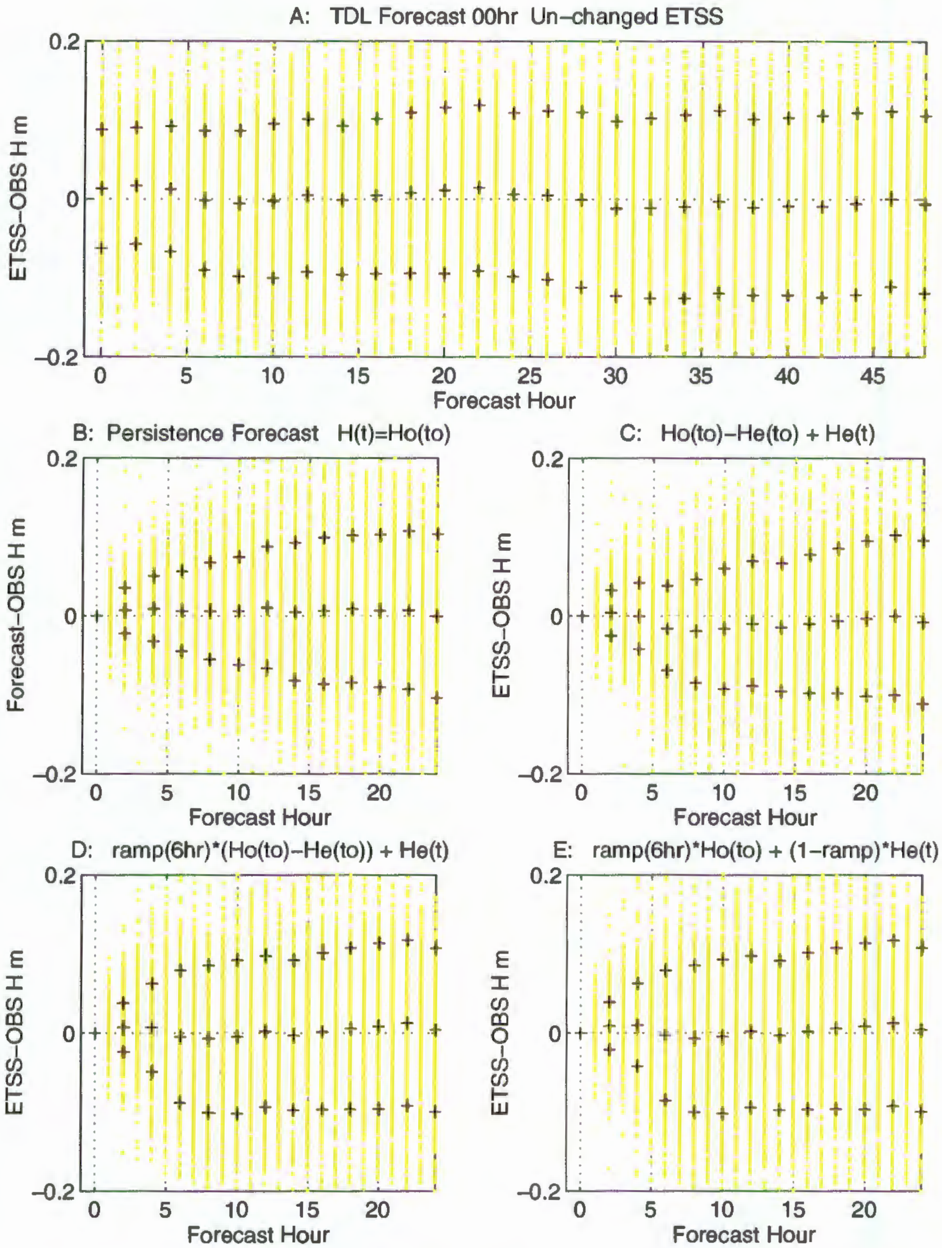

Figure 10: The errors of the water forecast model plotted verses forecast hour. The yellow dots are the individual errors, the crosses are the mean and ± standard deviations of the errors for each forecast hour. A: raw ETSS, B: Pure persistence of an observation from forecast hour 0, C: ETSS corrected by a constant offset at hour 0 which is then persisted for the next 24 hours. D: ETSS corrected at hour 0 then the correction is ramped away across the next six hours. E: ETSS corrected at hour 0 then the correction is ramped away across the next six hours while ETSS is ramped up.

8. SUMMARY

The run analysis of the previous sections identify the best method of handling input forcing data. Thomas Point Winds should be amplified in the NW quadrant; Eta winds are to be left alone with their current 1.2 multiplier; the CBBT non-tidal water level correction should be implemented; the ETSS model should use the persisted zero hour offset correction, rather than a ramp. Changes to the gentidenew.f program addressed the CBBT and ETSS issues. Changes to genwind_obs.f addressed the TPLM directional amplification. These changes were implemented in Feb. 2002.

CBOFS' first year of operations have gone well. Only a few operational changes to the system were necessary and nothing large is anticipated. The 2001 skill assessments are not appreciably different from the 1999 statistics upon which CBOFS was declared accurate enough to be made operational.

Three modeling changes have been identified which will improve the accuracy of the CBOFS model. The correction for the Thomas Point Light winds when blowing from the NW will improve NW wind event response and is shown not to degrade the performance at other times. The alteration to the handling of the CBBT water level forcing is a natural correction and improved performance of the nowcasts at all stations. The ETSS forecast data will be corrected using the constant persistence mode for the 0 hour forecast offset with no ramp. These three changes were implemented in Feb. 2002 and have become part of the operational system.

The skill statistics for the nowcast with both the CBBT water level forcing change and the TPLM wind directional change, Table 9, are better than the original (compare to Re-Run Nowcast, Table 6):

Table 9: Skill Statistics with both the CBBT B.C. and the TPLM wind speed fixed.

Station	SM	RMSE	SD	NOF	CF	POF	DO	WOF	5%	median	95%
	m	m	m	%	%	%	h	%	m	m	m
cbbt	-0.003	0.019	0.018	0.0	100.0	0.0	0	0.0	-0.033	-0.005	0.023
hamp	0.014	0.049	0.047	0.0	99.1	0.0	0	0.0	-0.054	0.006	0.092
kipt	0.012	0.032	0.030	0.0	100.0	0.0	0	0.0	-0.035	0.010	0.060
glou	0.002	0.055	0.055	0.0	99.6	0.0	0	0.0	-0.087	0.002	0.085
lewi	0.003	0.054	0.054	0.0	99.0	0.0	0	0.0	-0.090	-0.004	0.085
colo	-0.003	0.089	0.089	0.0	92.0	0.3	0	0.1	-0.144	-0.009	0.139
solo	0.000	0.067	0.067	0.0	96.7	0.0	0	0.0	-0.107	-0.005	0.113
camb	0.011	0.102	0.101	0.1	87.3	0.2	0	0.0	-0.150	0.005	0.168
anna	0.002	0.070	0.070	0.0	95.9	0.0	0	0.0	-0.110	-0.005	0.121
balt	0.003	0.077	0.077	0.3	94.4	0.1	0	0.1	-0.123	0.001	0.118
tolc	0.011	0.076	0.075	0.0	94.5	0.1	0	0.1	-0.114	0.006	0.132

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Zervas, C. 1999. Tidal current analysis procedures and associated computer programs. **NOAA Technical Report** NOS CO-OPS 0021, 101 pp.

APPENDIX: MATLAB PROCESSING

1. Matlab Data Structures

The figures in this paper were created with a library of Matlab routines created specifically for this paper. They all work upon the primary data sources of the time series of water level at each of the eleven test stations throughout the Bay (plus the outer B.C. labeled ocean). (1 ocean, 2 CBBT, 3 Hampton Roads, 4 Kiptopeke, 5 Gloucester Point, 6 Lewisetta, 7 Colonial Beach, 8 Solomons Island, 9 Cambridge, 10 Annapolis, 11 Baltimore, 12 Tolchester.) The nowcast and forecast model output time series and observation data from the NWLON data bases are placed into Matlab structures. All structures share these attributes:

```
>> Cnow
Cnow =
           H: [9874x12 double]
        jday: [9874x1 double]
        hour: [9874x1 double]
          ho: [1x12 double]
   caselabel: 'CBOFS Nowcast'
   stationid: [12x4 char]            Four letter abbr. for stations
```

The variable "hour" represents the hour into either the nowcast or forecast of the particular point. So Nowcast hour usually spans 0:12 and forecast hour spans 0:24. The four overlapping forecast data sets are separated by the starting hour, Cfore00, Cfore06, Cfore12, Cfore18. Obs.hour is degeneratively equal to 0.

Wind time series for Thomas Point and CBBT are in separate structures of somewhat similar style:

```
WindTP =
        jday: [8833x1 double]
           U: [8833x1 double]        Eastward positive
           V: [8833x1 double]        Northward positive
          UV: [8833x1 double]        Complex notation U+iV
       speed: [8833x1 double]
         dir: [8833x1 double]        Direction From (degrees North)
   caselabel: 'Thomas Point CMAN Winds'
```

Some of the time series have been tidally decomposed using the routine detide.m. This calculates the 37 constituents according to the remove and reduce method of NOS (Zervas 1999). The tideonly and detide structures are created and stored.

All of the relevant structured data can be found in:

```
>> load /usr/home/tgross/matlab/CBOFS/ALL2001.mat
>> whos
  Name                 Size              Bytes  Class
  Cfore00              1x1              753222  struct array
  Cfore06              1x1             1406662  struct array
  Cfore12              1x1              769222  struct array
  Cfore18              1x1             1409382  struct array
  Cnow                 1x1             1717690  struct array
  Cnowdetide           1x1             1728488  struct array
  Cnowtideonly         1x1             1728492  struct array
  Obs                  1x1            10047700  struct array
  Obsdetide            1x1            10058498  struct array
  Obstideonly          1x1            10058502  struct array
  WindCBBT             1x1              495548  struct array
  WindTP               1x1              495562  struct array
  periods             37x1                 296  double array
  perlabel            37x4                 296  char array
```

The hindcast re-runs of the model and the experimental tests of different boundary forcing methods are stored in similar structures. Test cases include:

```
Cyear                  Simple One Year Rerun
Cyeardetide
Cyeartideonly
Cyearnt                Test of Non-Tidal CBBT method
Cyearntdetide
Cyearnttideonly
Cyearp1      Test with 10% NW TPLM wind increase
Cyearp1detide
Cyearp1tideonly
Cyearp2      Test with 20% NW TPLM wind increase
```

```
Cyearp2detide
Cyearp2tideonly
Cyearp3      Test with 30% NW TPLM wind increase
Cyearp3detide
Cyearp3tideonly
Cyearnt             Test of CBBT Non-Tidal scaling correction
Cyearntdetide
Cyearnttideonly
Cyearboth           Nowcast rerun with both TPLM wind and CBBT corrections.
```

2. Matlab Display Tools

2.1. sliderzoom(Obs,Cnow,WindTP)

sliderzoom displays time series of Observation and Model water levels with the difference. It also displays the wind speed and direction. A second window is created with a choice box to switch the station displayed. Slider bars are provided for changing the view point of the plots. A narrow time window can be created (say 7 days) and the window can be slid back and forth throughout the year.

auxiliary plotting routines sliderzoom is a fairly complicated piece of Matlab GUI programming. In addition to standard Matlab routines it also requires: errwinddirsub.m, makeLui.m, subzoom.m, plotdir.m, fillnan.m, fixnan.m, dayaxis.m,julian.m, gregorian.m, suptitle.m

2.2. highlowevents(Obs,Cnow,WindTP,highlow,errange)

highlowevents creates the wind vector scatter plots colored by the amplitude of the error. highlow defines high or low water events by plotting only the wind and errors occurring when the water level is above or below the median water level by highlow meters. Probability density plots are also created.

elevenpolarerror(Obs,Clow,Wind,errrange) elevenpolarerror is called by highlowevents. It creates the eleven vector/error plots.

elevencumprobs(Obs,highlowrange) elevencumprobs is called by highlowevents. It creates the eleven cumulative probability plots of water level.

2.3. elevenploterr(Cfore06,Obs)

Does eleven plots of error as a function of forecast hour.

errdepend(err(:,k),A.hour(lA),Xdbin,L,0) Does the single plot of error as a function of forecast hour.

2.4. [Ctideonly, Cdetide] = detide(C,periods,istations)

Fits the tidal constituents listed in periods to the water levels in the C structure. Creates two new structures with all of the attributes of C, with detided and with just the tide reconstructed. Essentially C = Ctideonly + Cdetide.

tidefit.m, tidemake.m, tidalconst.m Tidal decomposition and reconstruction routines. tidefit.m does a discrete least squares fit of the tidal harmonics, so it can use gappy or unevenly spaced data. Rather slow, but quite robust and does return the NOS constituents. tidemake uses the output of tidefit with a time array to recreate a tideonly time series of height. tidalconst just provides the periods in hours of the usual 37 constituents.

2.5. windcompdir.m

[X,Y,P,W]=windcompdir(Cnow,Cfore18,[0 360]); This extracts the observation winds from the Cnow file and the Eta winds from the Cfore file and compares them with a complex least squares regression. The Cnow and Cfore files keep data for TPLM, CBBT and the interpolated station Rappahanock. Plots of the comparisons are output. The comparisons may be restricted to a directional range by changing [0 360] to, for instance, [270 360]. Also outputs graphs of the the complex lag correlations. The lag correlations do not work properly if the time series are chopped up by specifying a directional range of other than [0 360]. Used to create Fig. 7.

leastsqs.m Performs least squares regression of x on y and y on x. Outputs the linear fit lines and the average slope, intercept of the two regressions.

2.6. tdlcases.m

tdlcases(TDL00,Obsdetide,Tramp) creates plots of the errors of the TDL water level forecasts as a function of forecast hour. It also synthesizes the several cases of ways of correcting the 0 hour water level and persisting the correction with a ramp of Tramp hours. Used to create Fig. 10.

2.7. skillassess.m

[SM, RMSE, SD, NOF, CF, POF, DO, WOF, errbar] = assessjuly(Hmod, Hobs, Hastro, T, h1, h2, w, hr, per); [SM, RMSE, SD, NOF(h2), CF(h1), POF(h2), DO(h2,hr), WOF(w), errbar(per)] Provides the skill assessment statistics from the model assessment tech report (NOS 1999). SM series mean. RMSE root mean square error (includes SM). SD Standard deviation (root mean square error with the mean removed). NOF(h2) Negative outlier frequency is percent of time error is more than h2 to the negative. CF Central Frequency is percent of time the error is inside $\pm$h1, POF Positive Outlier Frequency is percent of time error is more than h2 to the positive. DO: Maximum Duration of Outliers is cumulative time when the error is more than 0.3m or less than -0.3m for a continuous duration of at least 24 hours. This is the sum of the DPO and DNO, duration of postive and negative outlier statistics of NOS 1999. WOF(w) Worst Case Outlier Frequency is percent time predicted water level higher than observed by w and the Astronomical tidal prediction is closer to the observed (Astro tides are better during a low water event.) errbar is the median(%50), and $\pm(100 - per)/2\%$ points of the cumulative error probability distribution. The model assessment tech report prescribes values for the tests of h1=0.15m, h2=0.30m, w=0.30m, hr=24hours, per=90%.

skillassesstable.m Loops skillassess through the eleven stations and prints results out in a table.

3. Files of Data and Matlab Routines

The data for the CBOFS 2001 are contained in Matlab MAT files. These are binary files used by Matlab to reconstruct Matlab run session and aid in loading speed. The observation data and the operational model runs are in ALL2001.mat. The nowcasts were reran for the year using cleaned up data. These are in Cyearnormal.mat. The re-runs of the model with the altered wind fields are in Cyearw31536p3.mat and Cyearw31536p2.mat.

MAT-files in the directory /usr/home/tgross/matlab/CBOFS ALL2001.mat CyearNTfix.mat Cyearw31536p3.mat Cyearw31536p2.mat Cyearbothchanges.mat TDL.mat

These mat files are tarred together in CBOFS2001mat.tar

All of the above mentioned Matlab scripted routines are in the tar file CBOFS2001matscripts.tar. All of these scripts are in the tar: sliderzoom.m, errwinddirsub.m, makeLui.m, subzoom.m, plotdir.m, fillnan.m, fixnan.m, dayaxis.m, julian.m, gregorian.m, suptitle.m, highlowevents.m, elevenpolarerror.m, elevencumprobs.m, elevenploterr.m, errdepend.m, detide.m tidefit.m, tidemake.m, tidalconst.m skillassess.m, skillassesstable.m .