Final Report for Project

Technical support – Inter-model comparison for Corpus Christi Bay testbed

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Summary

We report results for Corpus Christi Bay circulation using OHSU's SELFE model (Zhang and Baptista 2008), as a part of the inter-model comparison exercise for this system. The time period chosen is two wet years (2000 and 2001), although we will focus on year 2000 as the data for 2001 is being withheld from modelers for "blind" comparison. Previously we have conducted model-data comparison for two dry years (1987 and 1988), and demonstrated that the model was able to capture the overall variation of salinity and temperature. However, comparisons were lacking for other hydrodynamic variables such as elevation and velocity, partly due to issues related to the observational data. Here we conduct a comprehensive model skill assessment using long-term data for elevation, salinity and temperature, as well as short time series of velocity data collected by TWDB scientists during the May 2000 survey. We show that the model is able to capture long-term trend of salinity and temperature, and is also accurate for elevation (both tidal and non-tidal components) and velocity.

1. Overall goal

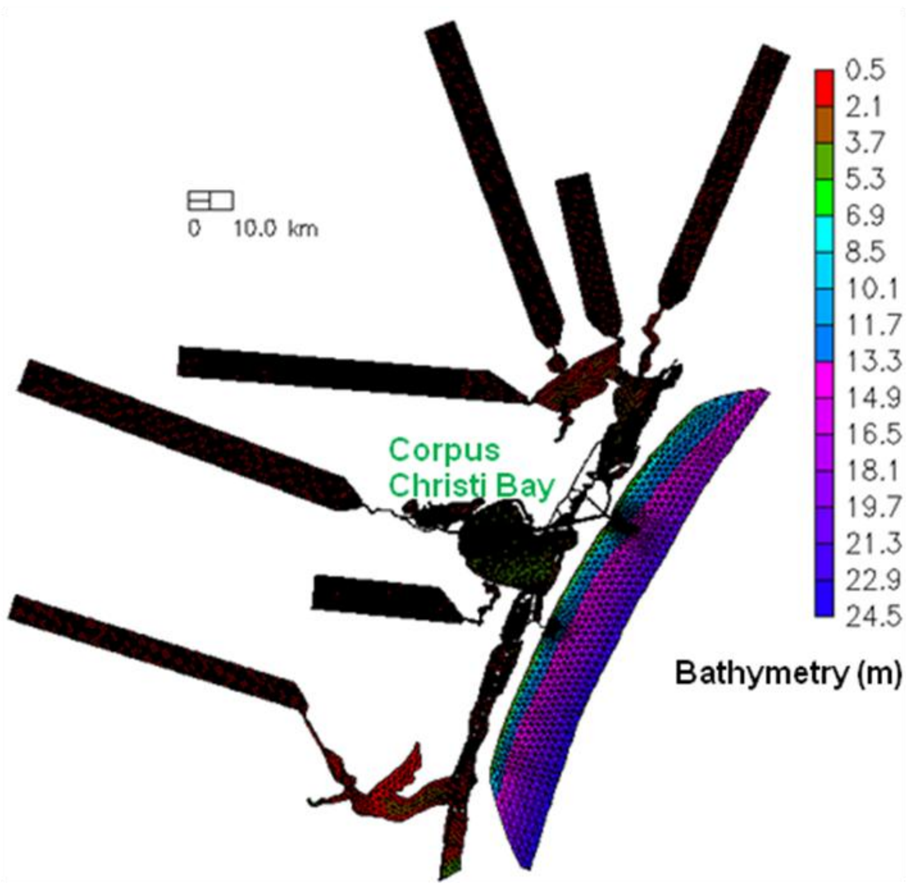
The main goal of the exercise is to study the long-term elevation, salinity and temperature trend in the Corpus Christi Bay system. There are 6 major tasks:

1) Develop a calibrated model of Corpus Christi Bay for the year 2000.
2) Conduct a vertical convergence study and choose an appropriate vertical resolution.
3) Compare Water Surface Elevation, Salinity and Temperature at all locations present in the data provided.
4) Run the model for the year 2001 using a) hotstart file from year 2000 run and b) common salinity initial condition file to be determined later.
5) Provide model outputs to TWDB in an agreed format to enable comparisons with 2001 Water Surface Elevation, Salinity and Temperature field data and for inter-model comparisons.
6) Provide 'best' calibrated model input files for inter-model speed comparison.

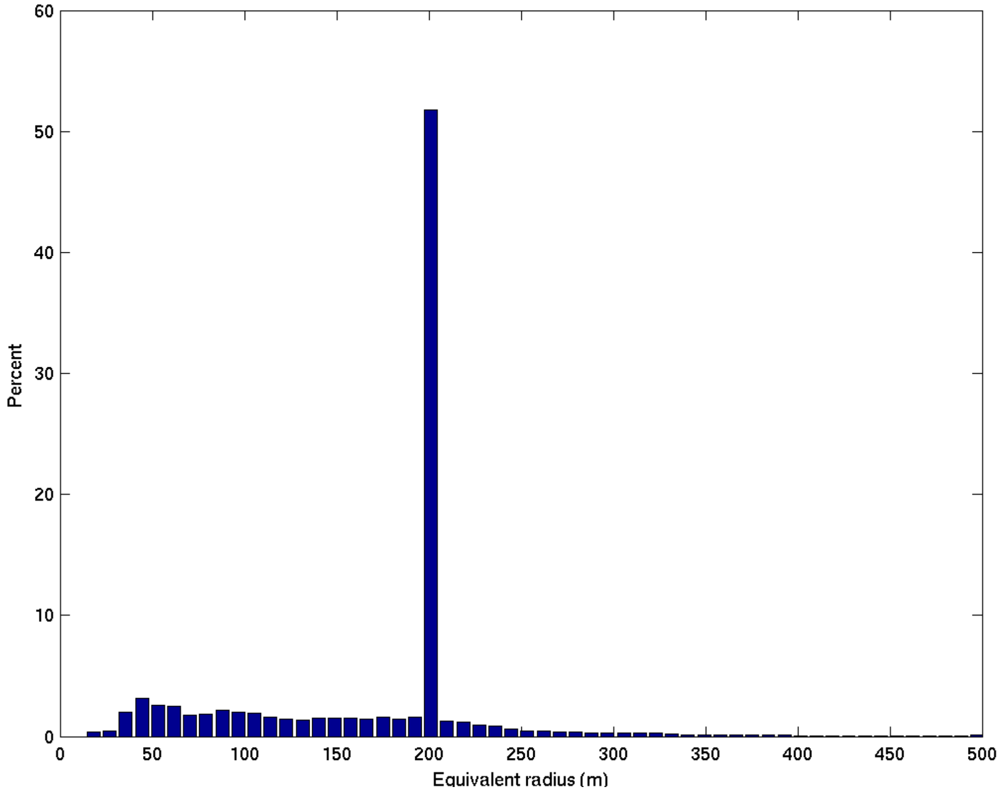
We will focus on Tasks 1-3 in this report.

2. Model domain

The model domain extends from Aransas Bay to the north, including a small part of Gulf of Mexico (GoM), Nueces Bay, Corpus Christi Bay, the upper Laguna Madre, and to just below Baffin Bay to the south (Fig. 1a). The system is generally very shallow (5m or less), and thus the effects of evaporation and precipitation are expected to play a significant role for salinity and temperature trend. In comparing the salinity at the Nueces River stations (Fig. 2ab), we found that the river boundaries are generally too close to the bays to impose freshwater flow (S=0PSU) there. Therefore we extended the river boundaries 30-80km in the upstream direction. Sensitivity tests revealed that the exact length of the added river portions is not important as long as it goes beyond of head of tide. A uniform depth of 2m is imposed at all river extensions, where a coarse ~500m resolution is used. This has more than doubled the total number of nodes from the original 10877 to 23286 (we didn't attempt to make the final grid as economical as possible by cutting down the extent of the added rivers). More than 80% of all elements in the final grid have an equivalent radius of 200m or less (Fig. 1b). The locations of field stations used in the following comparisons are shown in Fig. 2, including those occupied during the May 2000 intensive survey (Fig. 2c).

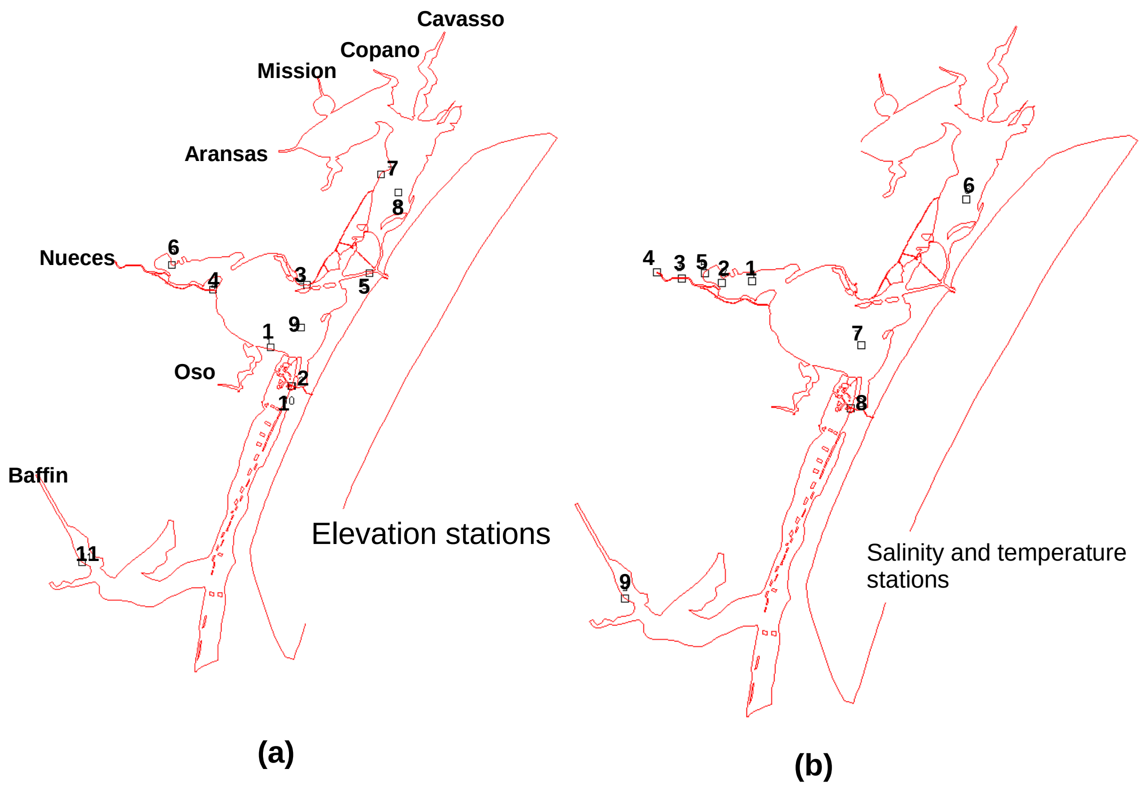


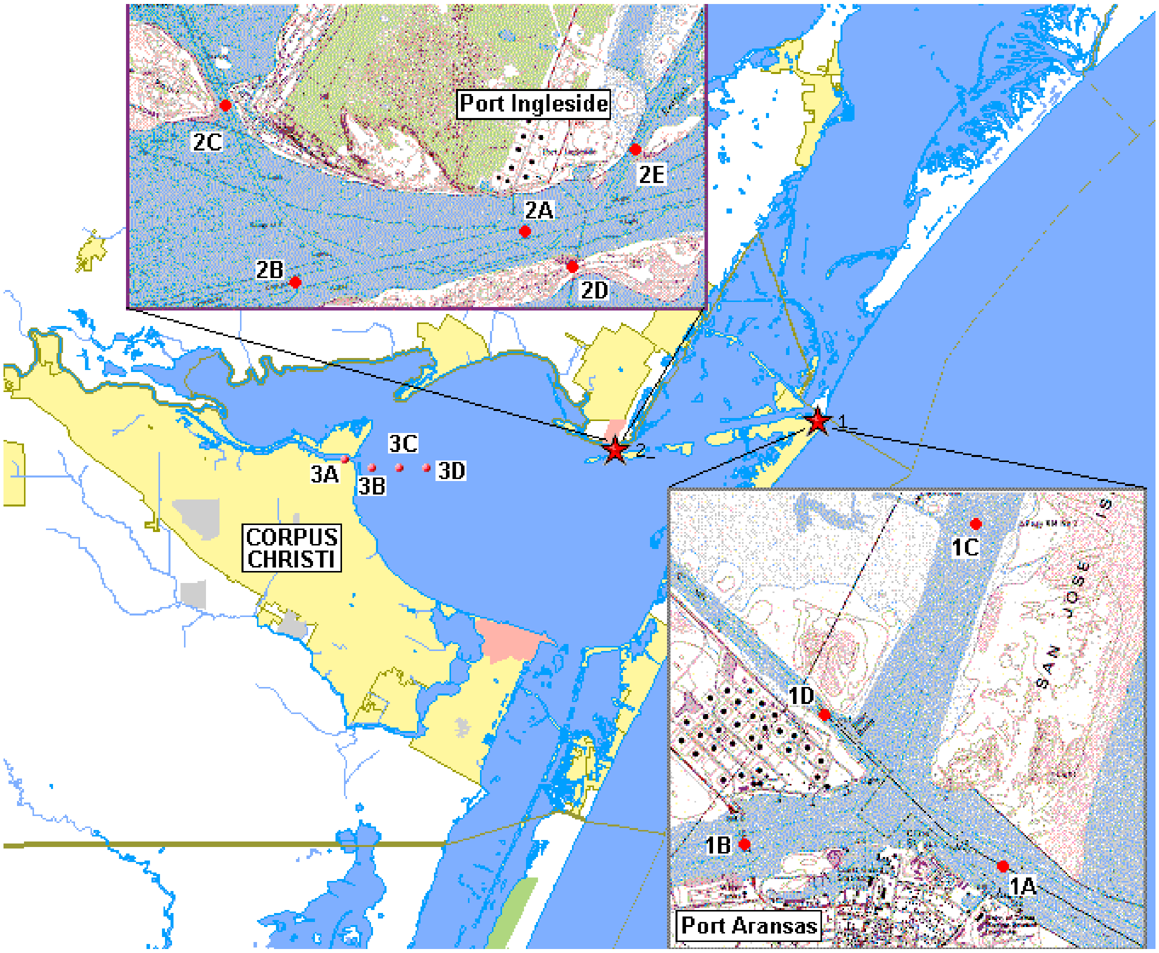
(a)



(b)

Fig. 1 (a) Model grid; (b) histogram of equivalent radius for each element in the grid.





(c)

Fig. 2 Station locations for (a) long-term elevation comparison; (b) long-term salinity and temperature comparison; and (c) May 2000 survey. The station numbers shown are used in the following figures.

3. Model forcings

At the rivers, powerplant intake and outflow and GoM boundaries, discharges or elevations are imposed. In addition, salinity values are also specified at rivers (S=0PSU), and at the GoM boundary. One thing we did differently from the previous study for 1988-9 is that we closed the boundaries at Intracoastal Water Way (ICWW) at Cabal, and at Cedar Bayou and Bludworth (i.e., land boundary there). The land boundary at Cabal has led to simplification of the way the atmospheric forcing is imposed; namely, we no longer need to ramp off the wind near the Cabal boundary. However, as discussed in Section 9, the closed boundary and the lack of freshwater discharge at Cedar Bayou and Bludworth causes problem for salinity at station 6 (Fig. 2b). At the air-water interface, evaporation and precipitation rates are applied, in addition to wind, air pressure, solar radiation, humidity, and longwave radiation. All time series boundary inputs and initial conditions were supplied by TWDB, except for the air pressure, solar radiation, humidity, and longwave radiation, which were instead taken from NCEP NARR (National Centers for Environmental Prediction's Regional Reanalysis product; http://www.cdc.noaa.gov/cdc/data.narr.html). The official version of SELFE (v3.0b) was modified to read in the time series for wind, evaporation and precipitation rates from the files supplied by TWDB instead of NARR files. Also the salinity and temperature conditions at power plant outflow points are set to the values at corresponding intake points inside the code, which is a non-standard part of the official version.

Year 2000 is considered a wet year for this system; flash flood occurred a couple of times during the year, with maximum flow rate reaching 300 m^3/s at Cavasso (Fig. 3). The freshwater discharge during the rest of the year is generally very small (<10 m^3/s).

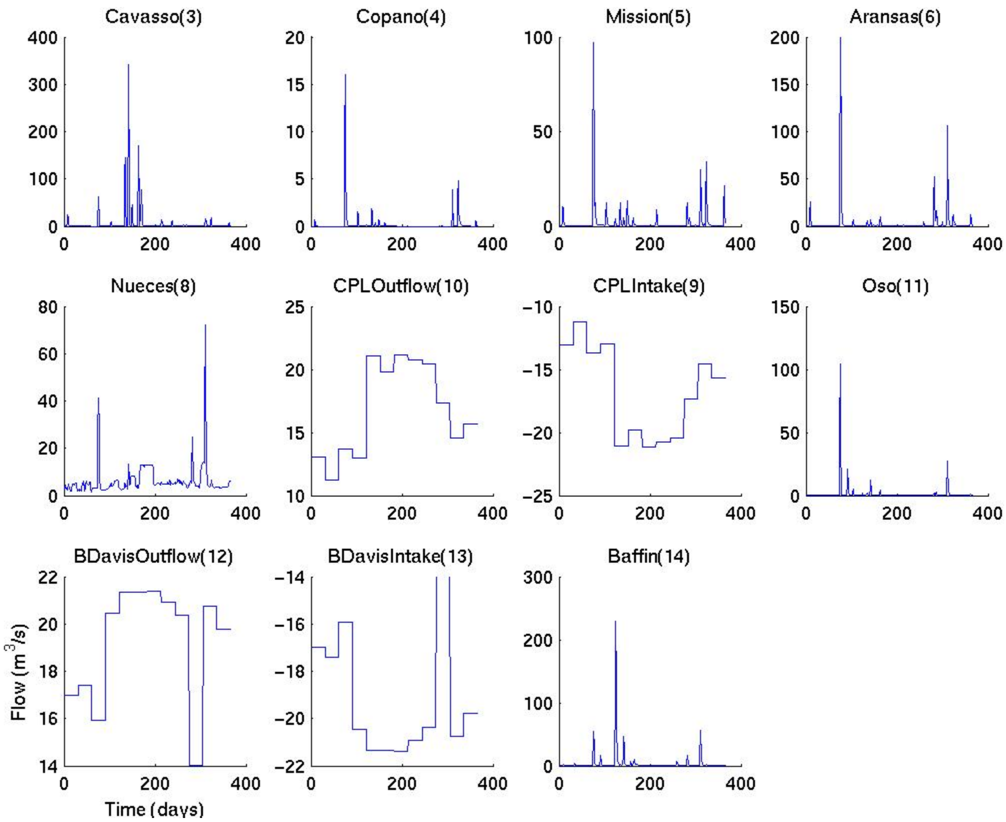
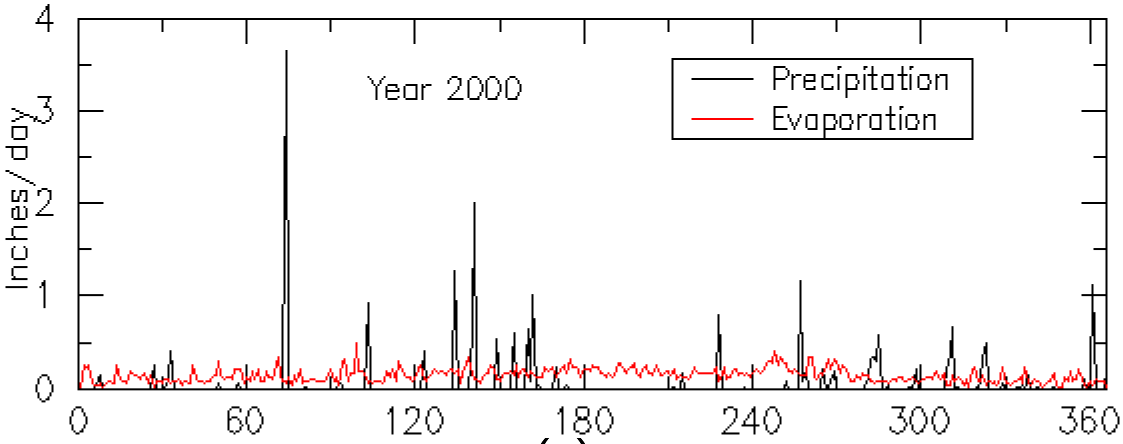


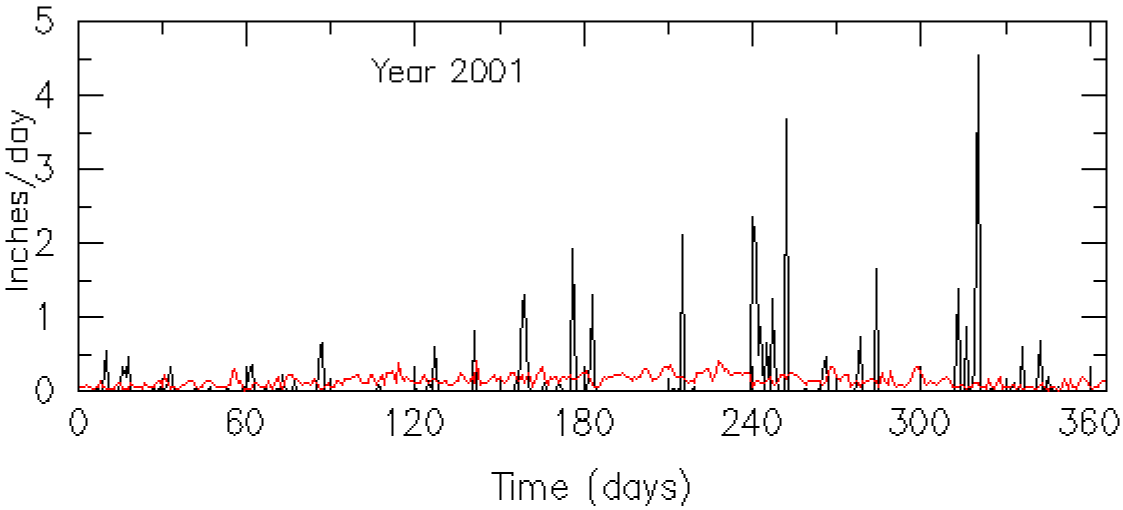
Fig. 3 Discharges at 7 rivers for year 2000 (see Fig. 2a), and 4 power plant intakes/outflows.

Associated with the flash flood is the heavy precipitation as shown in Fig. 4. The evaporation rate is generally more steady than the precipitation rate, and overall the system is dominated by evaporation (Fig. 4c). For the two years of concern, Fig. 4c indicates that year 2001 is wetter than 2000 especially for the 2nd half of the year. The timing of the flash flood should affect the salinity trend (Section 9).



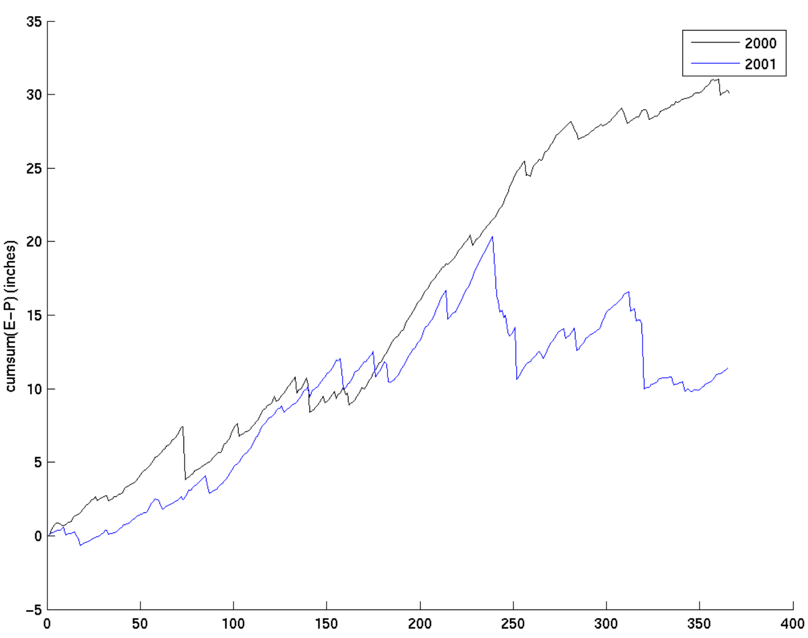
Year 2000
Precipitation
Evaporation
Inches/day
0
1
2
3
4
0
60
120
180
240
300
360

(a)



Year 2001
Inches/day
0
1
2
3
4
5
0
60
120
180
240
300
360
Time (days)

(b)



2000
2001
cumsum(E−P) (inches)
−5
0
5
10
15
20
25
30
35
0
50
100
150
200
250
300
350
400
Time (days)

(c)

Fig. 4 Rates of evaporation (E) and precipitation (P) for (a) 2000; (b) 2001. Cumulatively integrated E-P for the two years is shown in (c).

4. Observational data

The long-term data we have received from TWDB includes long-term time series of the elevation, salinity and temperature at several stations in various bays (Fig. 2ab). In addition, velocity data from May 5-7, 2000 field survey (Fig. 2c) is also used in the calibration effort. Note that some of the data has not been quality controlled or its length is too short for meaningful comparison (see below). Therefore not all data is used in the following comparisons.

5. Model set-up

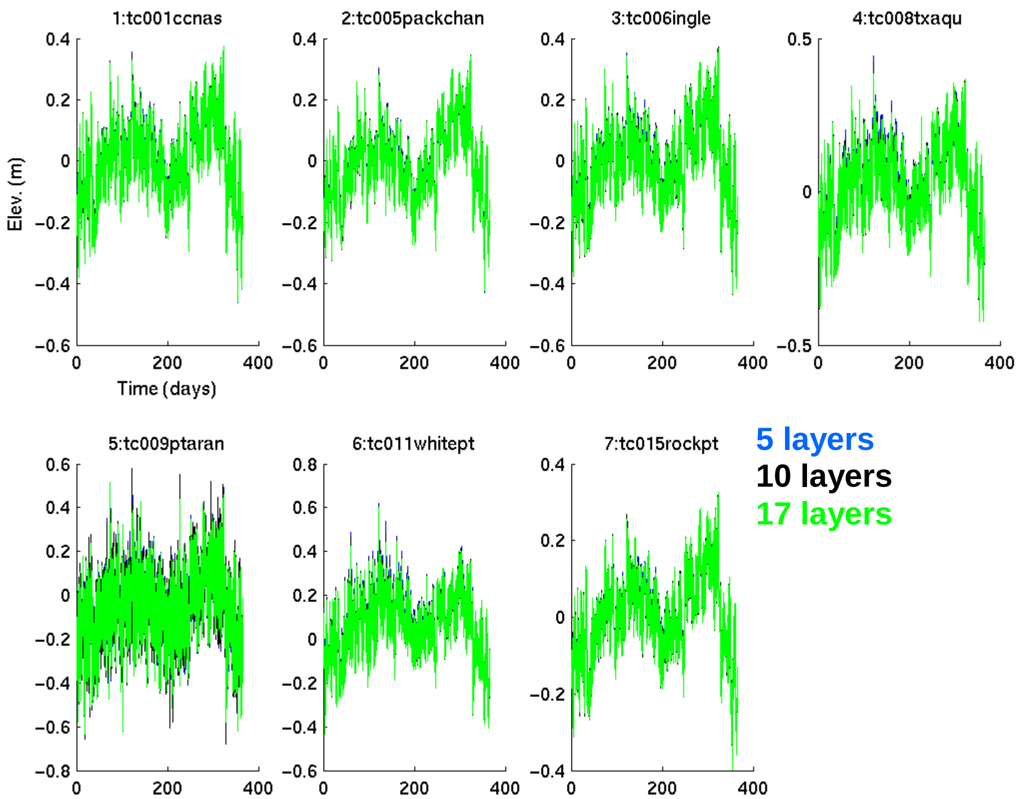
The version of the model SELFE we used is the current official web version v3.0b, with modifications that have been explained in Section 3. This version of SELFE is fully parallelized using MPI and domain decomposition. The horizontal grid consists of 23286 nodes and 41866 triangular elements, with the finest resolution of ~30m in some channels. After a convergence study with respect to the vertical grid resolution has been done (Section 6), we used a total of 5 terrain-following *S* layers in the vertical for the final simulation runs. A large time step of 60s was used, thanks to the superior stability for this semi-implicit model. A generic length-scale turbulence closure of *k-kl* (Umlauf and Burchard 2003), which is a modified Mellor-Yamada scheme and is implemented in the open-source GOTM library (gotm.net), was used to compute the viscosity and diffusivity. The air-water exchange of momentum and heat fluxes was calculated using Zeng's (1998) bulk aerodynamic theory. The 3D baroclinic model is computationally efficient; running on 7 CPUs of an Intel cluster with Rocks version 5.0, CPU clock speed of 2.66GHz and gigabit copper Ethernet network connection, it took about 4 days to complete a 1-year simulation.

A large part of the model uncertainties is associated with the external forcings. Since the system is strongly influenced by evaporation and precipitation, the use of a uniform evaporation and precipitation rate and spatially uniform wind is expected to introduce some errors in the model. Errors in model physics and numerics are responsible for the rest of model inaccuracies.

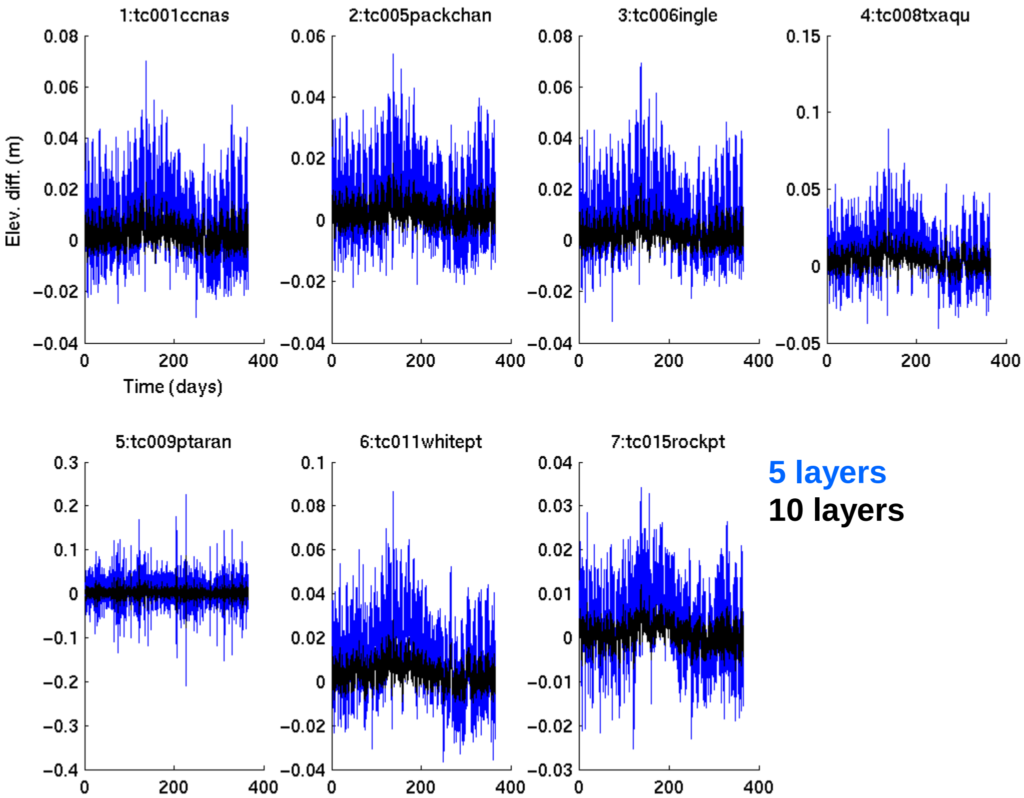
6. Convergence study with respect to the vertical grid resolution

Since the system is shallow throughout, only a few vertical layers may be required in a 3D model such as SELFE. To test the influence of vertical resolution on the results, we used 5, 10 and 17 *S* layers. Since the spacing constants in the *S* coordinate system remain the same for the three choices (h_c=6m, θ_b=1, θ_f=3), the vertical resolution in most part of the water column is approximately doubled and quadrupled when the number of *S* layers is increased from 5 to 10 to 17.

The influence of the vertical resolution on the calculated elevations, salinities and temperatures at various stations (Fig. 2ab) is shown in Figs. 5-7. Note that errors in the river discharge files were discovered a few times during the course of the project, and while the results shown in the following sections use the latest discharge values, the results presented here used the old discharge values. This is sufficient as we are only concerned with the convergence of the numerical model in this section. As can be seen from the comparison of Figs. 6a and 10, the changes in the discharges did not affect the results significantly, as the system is dominated by evaporation and precipitation. In all cases, the convergence is observed for those variables; the mean absolute differences between the results (for all stations) using 10 and 17 layers are merely 4.3mm, 0.45PSU, and 0.14^{o}C for elevation, salinity, and temperature respectively, which are only a small fraction of the mean signal. Even with only 5 layers, the differences are arguably not very large, as far as the long-term trend is concerned. Therefore in the following sections we use 5 layers for numerical efficiency.

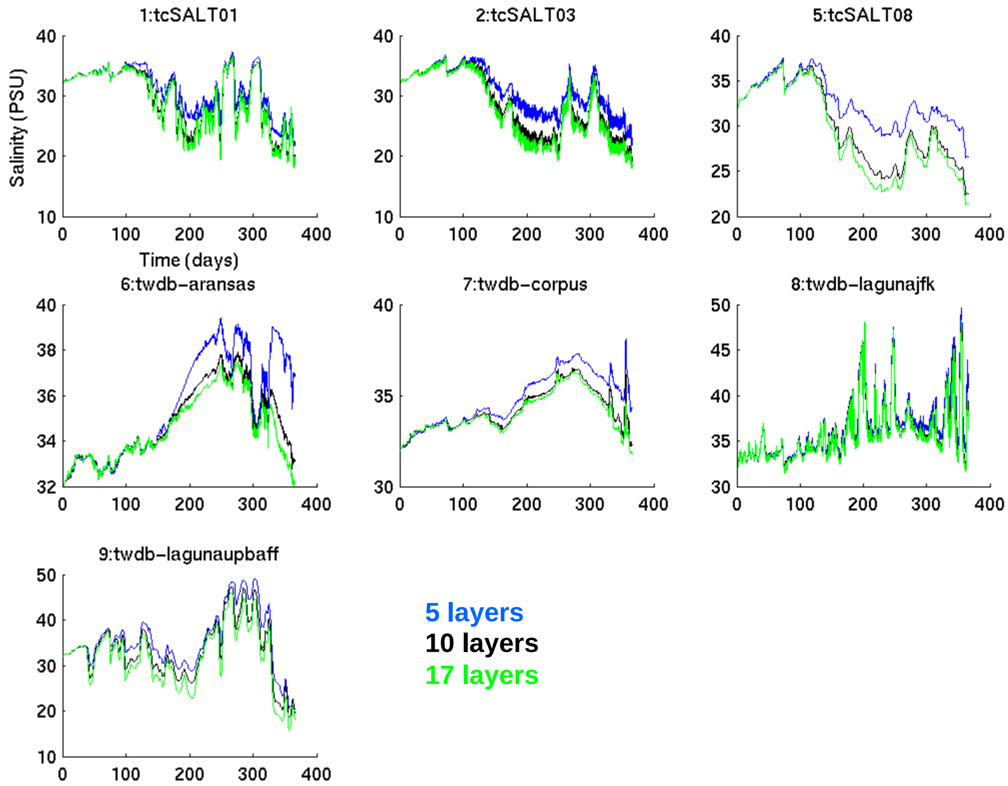


(a)

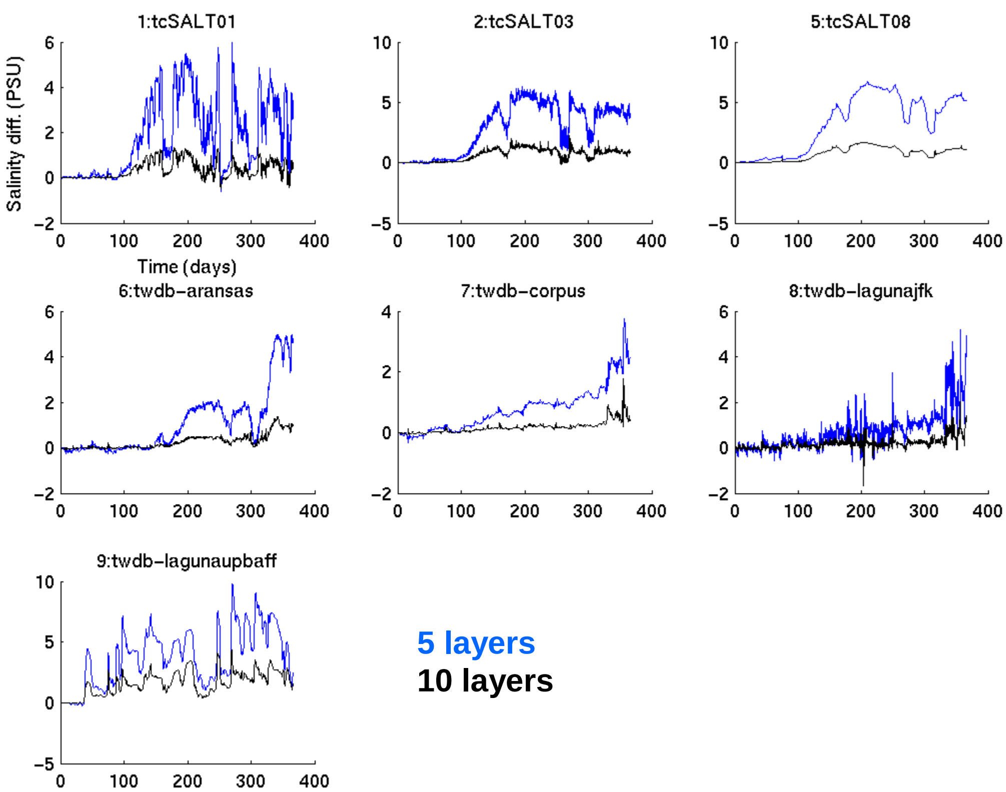


(b)

Fig. 5 Comparison of modeled elevations at 7 stations, with 5, 10, and 17 *S* layers in the vertical column. (a) Elevation time series; (b) differences of elevations using the results from 17 layers as the base. See Fig. 2a for station locations. Stations 8-11 were excluded because of the reason discussed in Section 7.

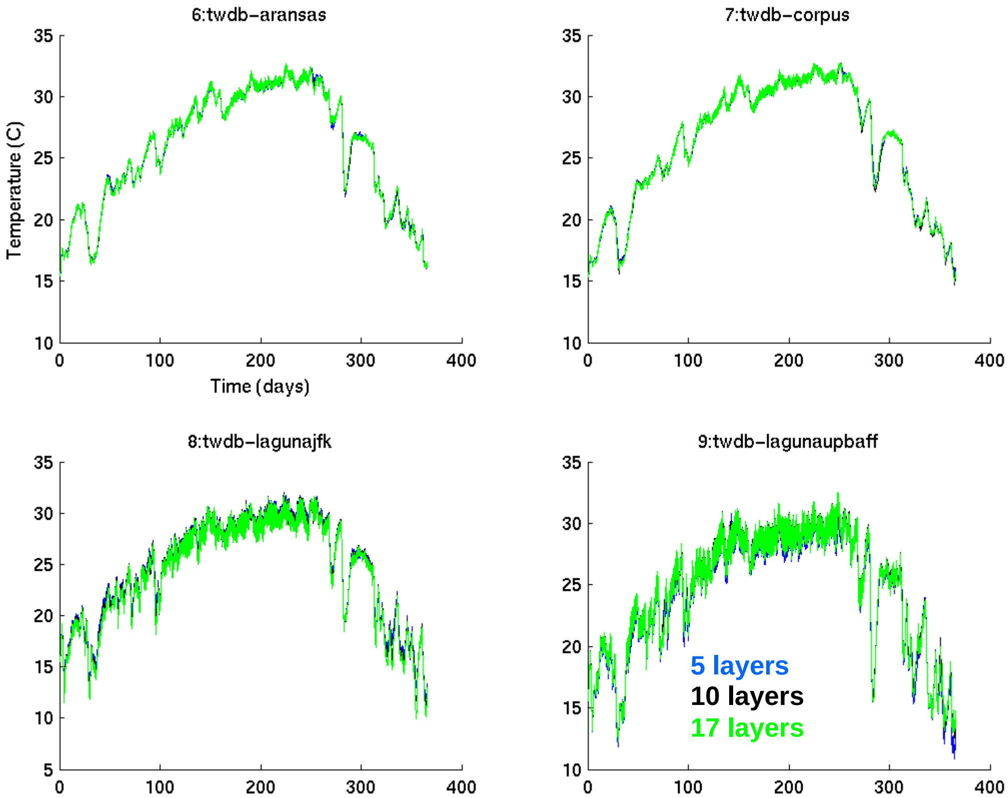


(a)

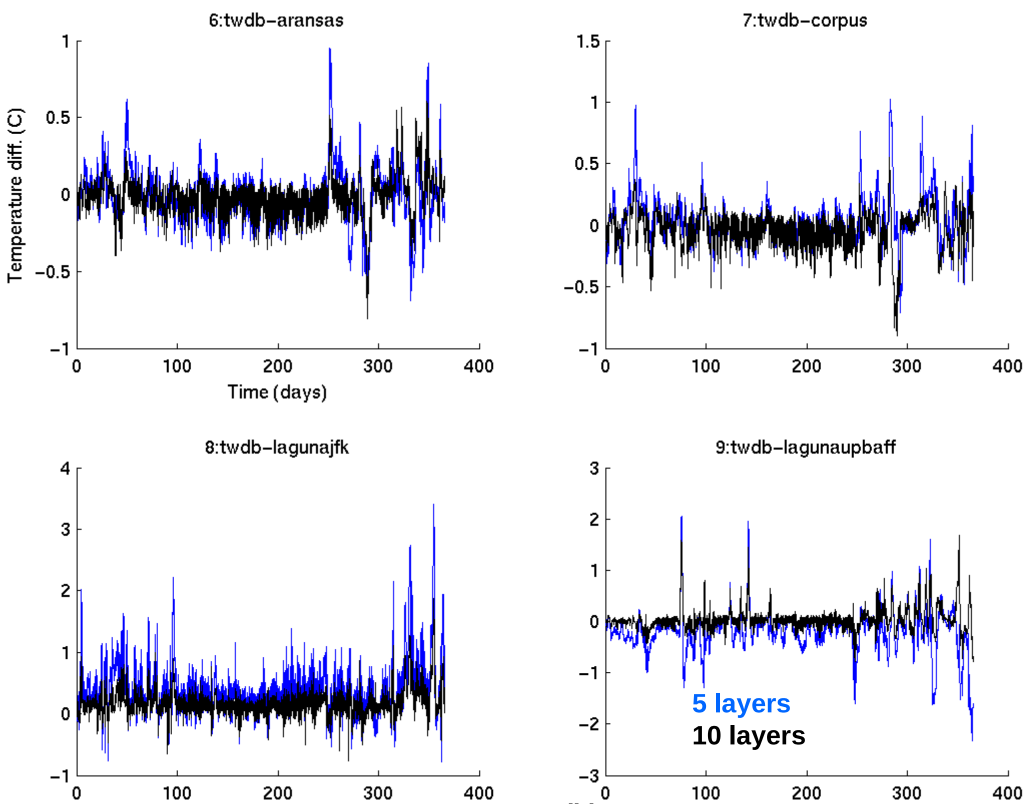


(b)

Fig. 6 Comparison of modeled salinities at 9 stations, with 5, 10, and 17 *S* layers in the vertical column. (a) Salinity time series; (b) differences of salinities using the results from 17 layers as the base. See Fig. 2b for station locations. Note that stations 3 and 4 are outside the domain and therefore excluded from the comparison.



(a)



(b)

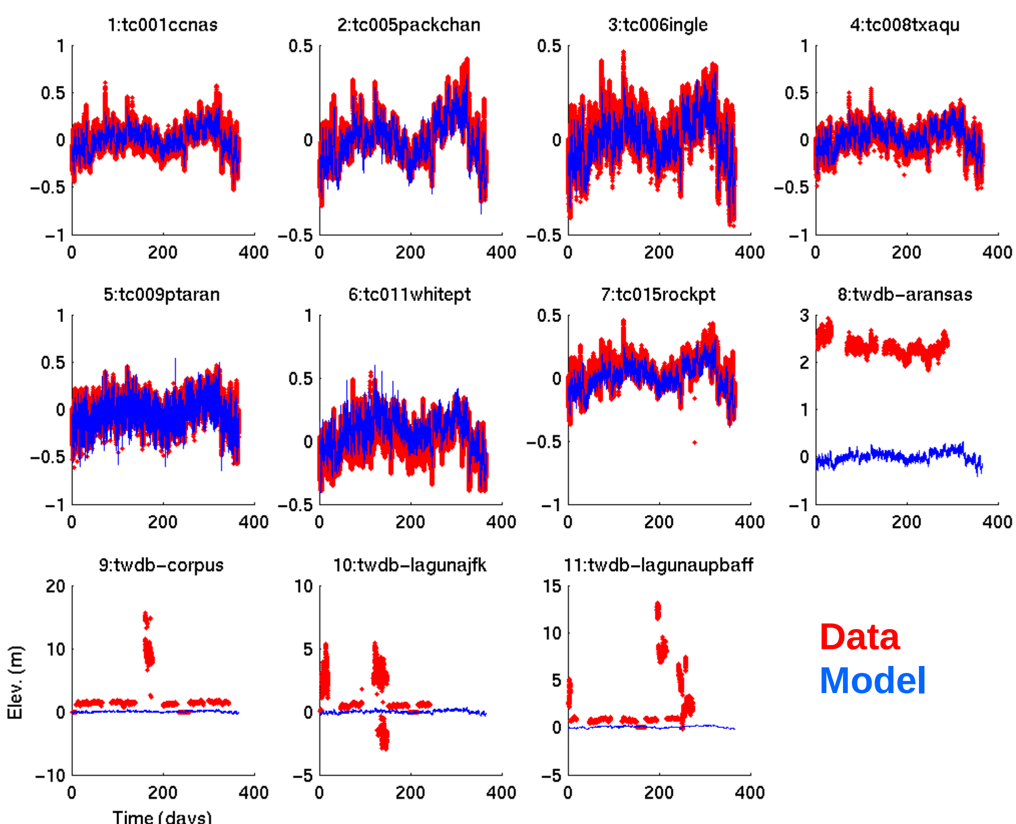
Fig. 7 Comparison of modeled temperatures at 4 TWDB stations (where data is available), with 5, 10, and 17 *S* layers in the vertical column. (a) Temperature time series; (b) differences of temperatures using the results from 17 layers as the base. See Fig. 2b for station locations.

7. Elevation

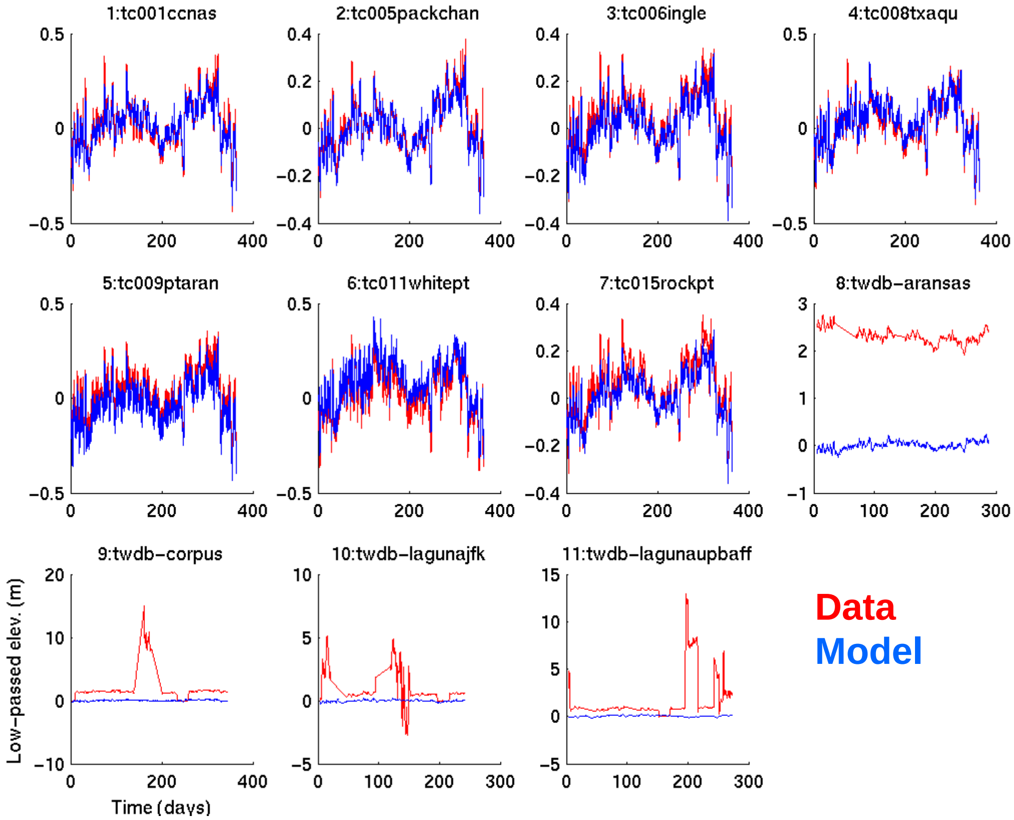
Long-term elevation data is available at 11 stations throughout the domain (Fig. 2a). For comparison with model results, we did tidal and low-pass filter analysis to examine the model performance at different frequencies. As shown in Fig. 8, the data at stations 8-11 seems to have quality issues, and therefore these stations are excluded in the discussions below.

The model generally captures the elevation very well. The root-mean-square errors (RMSEs) for the full and low-pass filtered signals are in the range of 3-8cm and 2-6cm respectively; the range of the mean model biases is -5 to 5cm for both signals (as the tidal signal contributes little to the mean). The sub-tidal variability due to the atmospheric and other forcings is well simulated by the model (Fig. 8b).

At tidal frequencies, the dominant signal comes from 2 diurnal constituents: O1 and K1 (Fig. 8c). The model-predicted amplitudes are in good agreement with the data; the largest error in amplitude is at station 7, where the local bathymetry errors may have played a role. The tidal phases are all very well predicted (over 90% within 0.1 degrees), even for the nonlinear high frequency M4. Overall, the model seems to have done a good job in capturing the variability of tidal and non-tidal signals from the shelf into rivers.



(a)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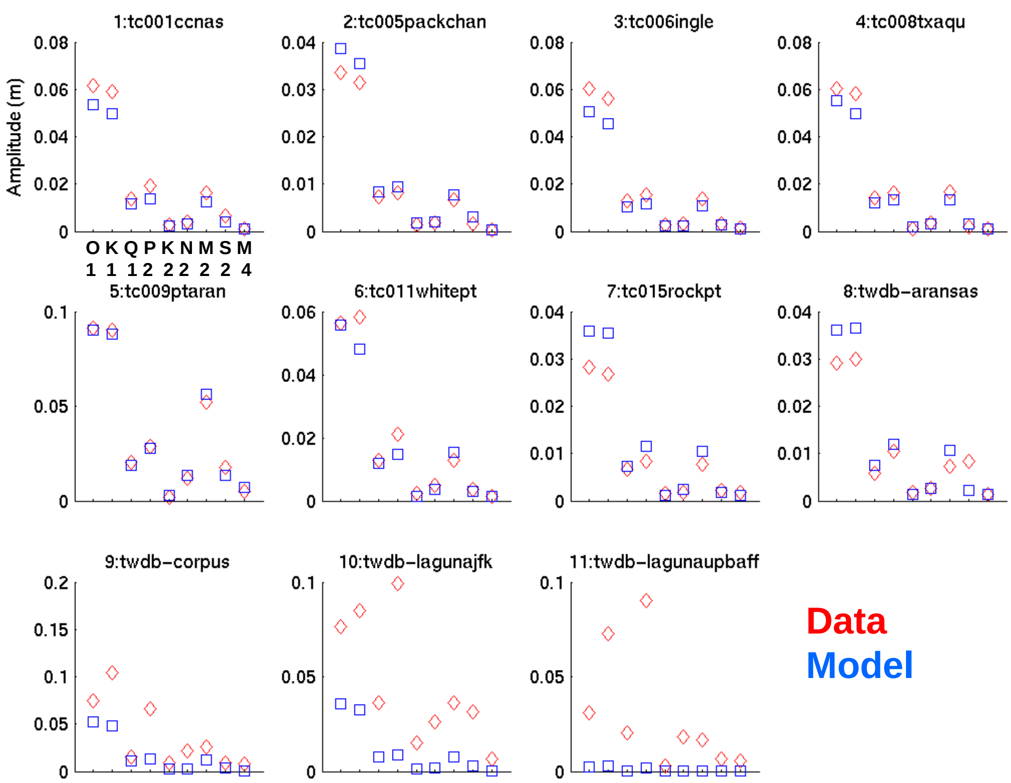
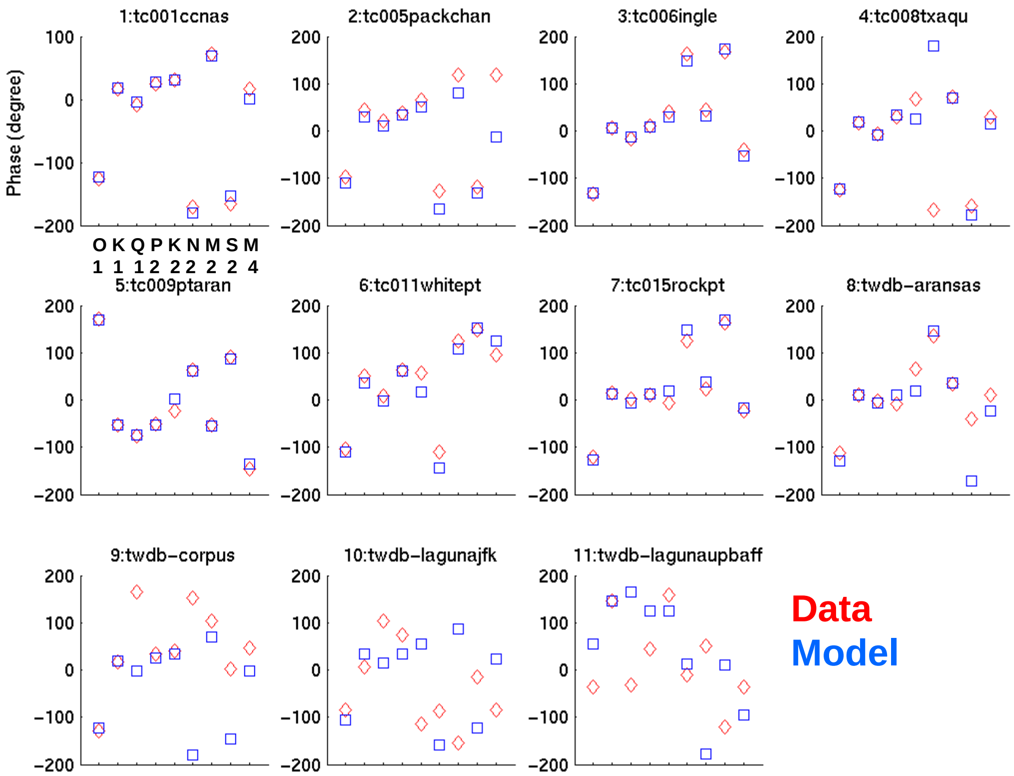
2:tc005packchan
3:tc006ingle
4:tc008txaqu
5:tc009ptaran
6:tc011whitept
7:tc015rockpt
8:twdb-aransas
9:twdb-corpus
10:twdb-lagunajfk
11:twdb-lagunaupbaff
Low-passed elev. (m)
Time (days)
Data
Model

(b)


1:tc001ccnas
2:tc005packchan
3:tc006ingle
4:tc008txaqu
Amplitude (m)
O K Q P K N M S M
1 1 1 2 2 2 2 2 4
5:tc009ptaran
6:tc011whitept
7:tc015rockpt
8:twdb-aransas
9:twdb-corpus
10:twdb-lagunajfk
11:twdb-lagunaupbaff
Data
Model

(c)



(d)

Fig. 8 Comparison of elevations at 11 stations (Fig. 2a). (a) Full signals; (b) 30-hour low-pass filtered signals; (c) tidal amplitudes; and (d) tidal phases. Note the problem with the data at stations 8-11 as can be seen in (a).

8. Velocity

The only velocity data available to us comes from the intensive 3-day survey May 5-7, 2000 by TWDB (Fig. 2c). The time series at several stations was discarded due to insufficient length. As the flow is mostly channelized at all stations, we compare the along-channel velocity at various depths throughout the water column at each station. The along-channel direction at each station is computed as that of the maximum variance in the data, and are shown in Fig. 9 as black lines in each panel. It can be seen that there is some variation of channel direction along the vertical column, even though the flow is not strongly stratified. The model-data comparison is quite good at all depths and stations, except at stations 2C and 3A (Figs. 9ef). Note that the large variation in the channel direction at station 3A may suggest possible problems with the data. The mean flow velocity is under-estimated at station 2C, which might be due to some localized processes missing in the model (e.g., local outflow). Overall, the model seems to be able to accurately capture both the amplitude and phase of the along-channel flow.

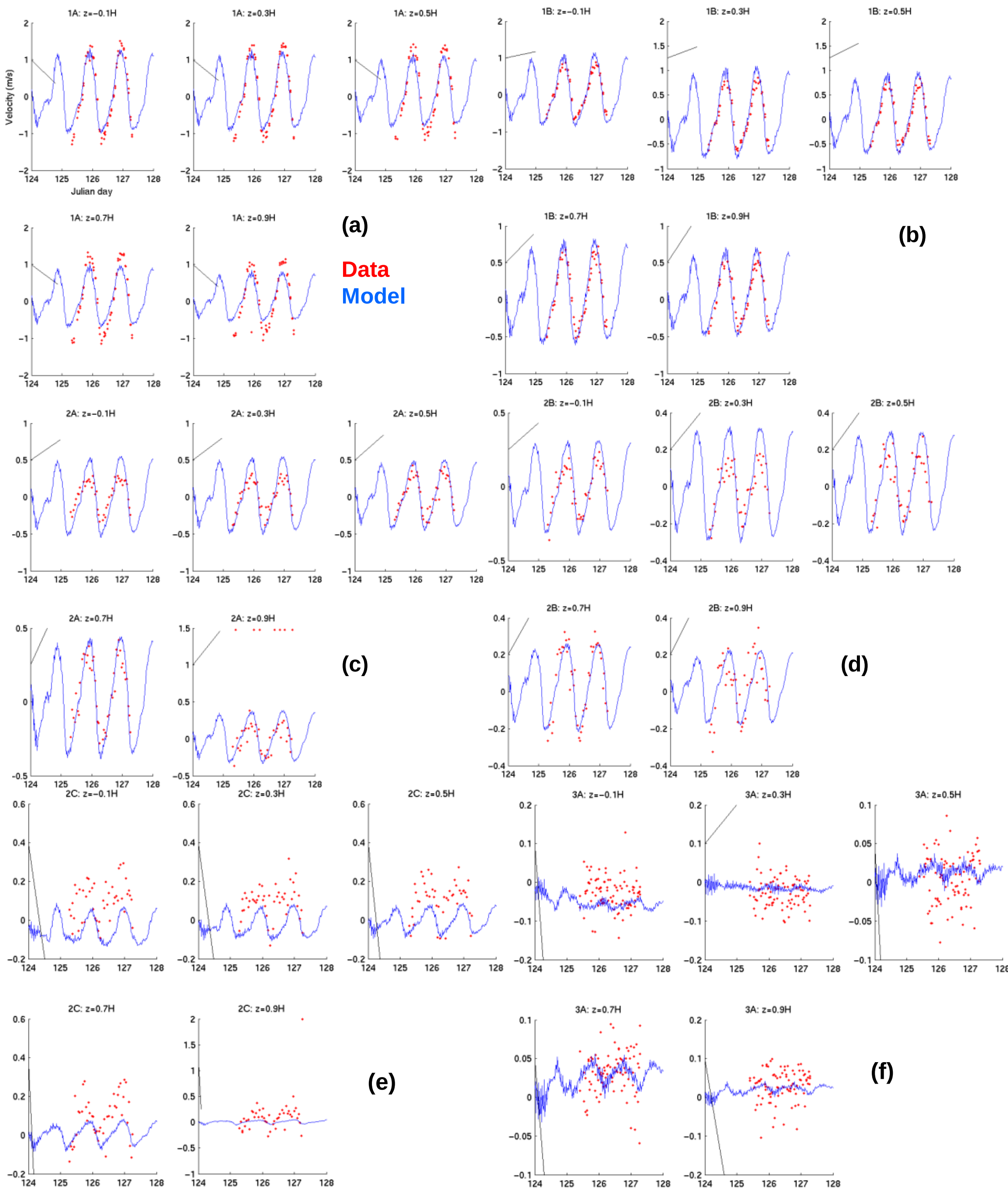


Fig. 9 Comparison of along-channel velocity at stations shown in Fig. 2c. The black lines indicate the channel angles. The vertical location where the comparison is made is shown for each panel; e.g., “1A: z=-0.1H” indicates that the measurement was made 10% of the total water depth from the surface at station 1A. Stations 1C, 1D, 2D, 2E, 3B, 3C, 3D have too few data for meaningful comparison.

9. Salinity

The largest model errors occur for salinity (Fig. 10). The model under-estimates the variability of the salinity in most stations. In addition, the mean biases at stations 2 and 5 reach 3-4 PSU; the smallest bias is found at station 1 (-0.01 PSU). Fig. 10 shows that the initial condition at station 9 is not accurate which has influenced errors there; however, the comparison gets better for the 2nd half of the year. The abrupt drop near the beginning of the year as seen in the data at station 8 is likely bogus as neither the river discharge nor the precipitation during this period supports such a drop (Figs. 3&4; one possibility, however, is that there may be some localized freshet there). The error in station 6 can be explained by Fig. 5a in the previous report (for years 1987-88). The lack of freshwater input at Cedar Bayou and Bludworth has led to much smaller variability in salinity.

Given all these uncertainties, the model seems to have done a reasonable job in capturing the long-term salinity trend; in fact, even at locations close to the Nueces River mouth (stations 1, 2 and 5) where the salinity pattern is most complex, the model bias is still much smaller than the mean signal; stations away from the River tend to have better accuracy, which suggests that the model may have errors in capturing the complex mixing process in the nearfield of the plume; further study with more detailed bathymetry and spatially varying evaporation and precipitation rates seems warranted. The range of RMSEs for all stations is 1-8PSU.

The comparison of the salinity profiles with CTD casts collected during May 4-7 2000 campaign is shown in Fig. 11. As expected, there is little vertical stratification in the system.

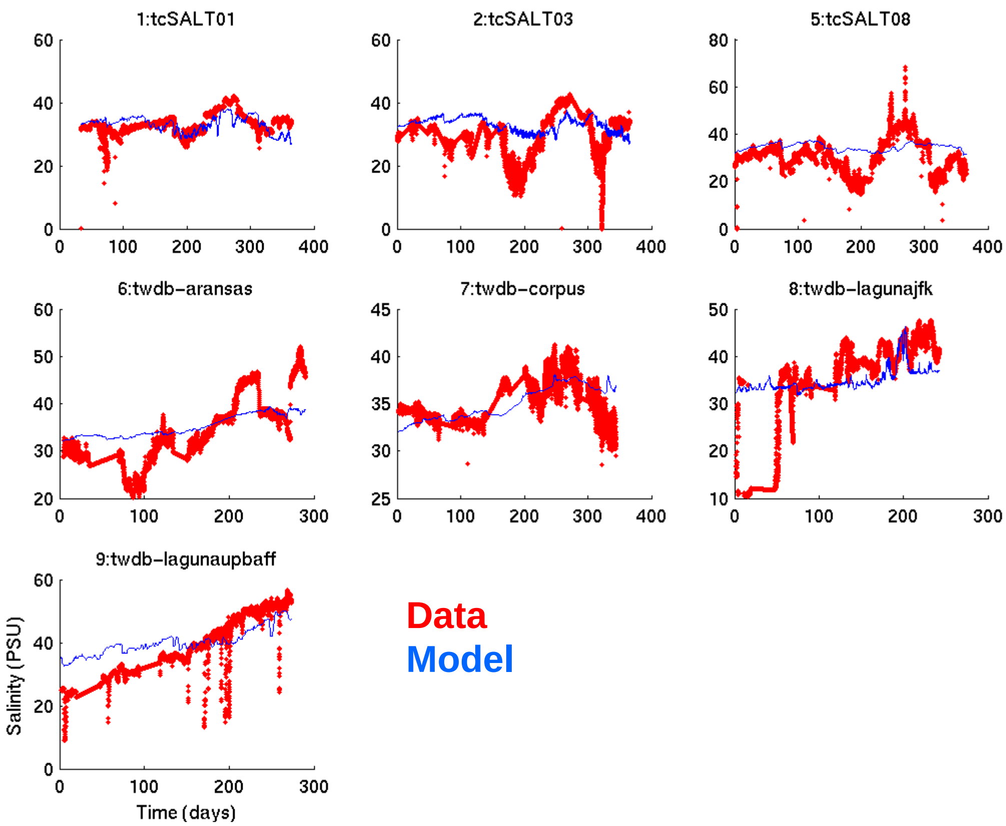
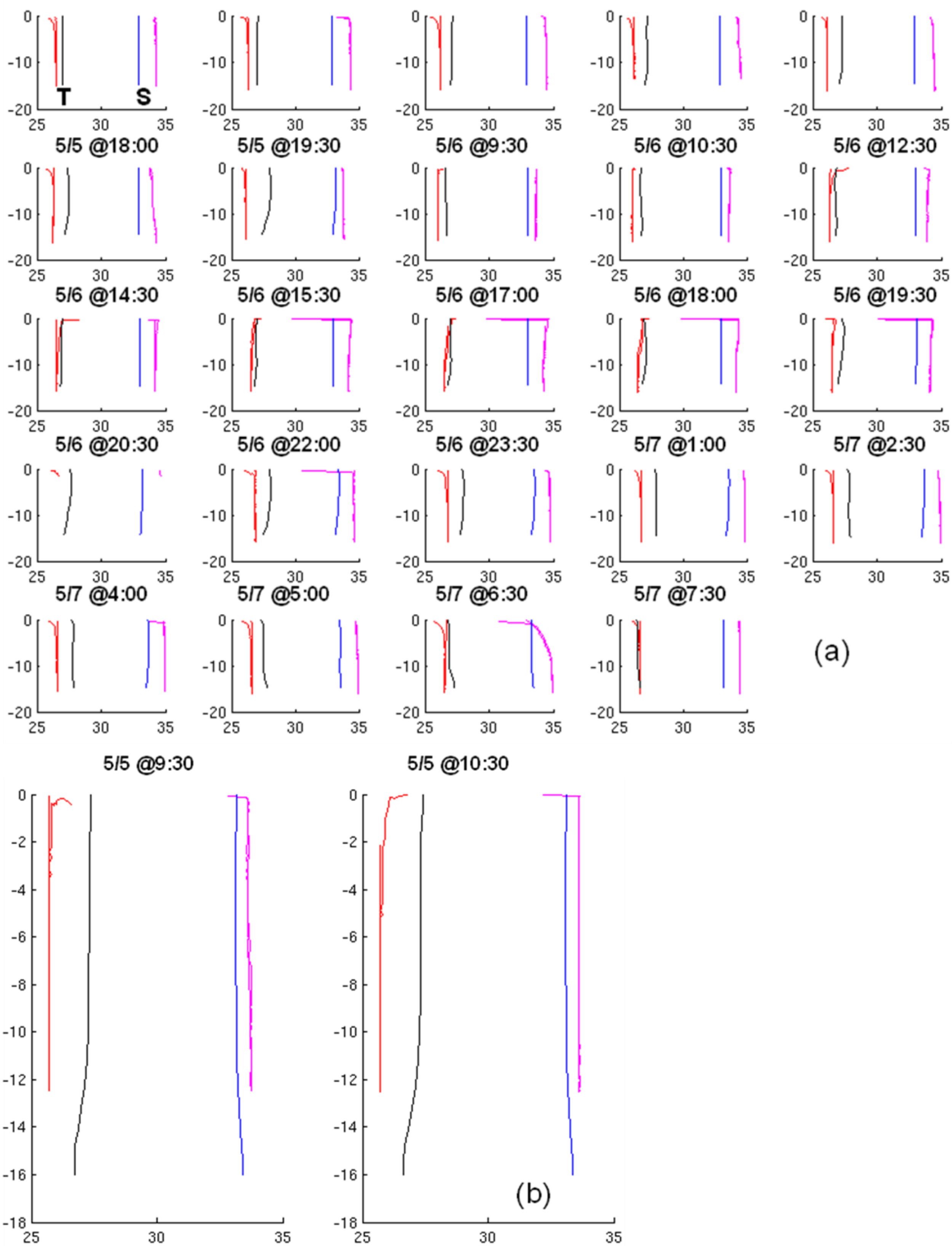


Fig. 10 Comparison of salinity at stations shown in Fig. 2b (stations 3 and 4 are too far outside the domain and thus excluded).


T
S
5/5 @18:00
5/5 @19:30
5/6 @9:30
5/6 @10:30
5/6 @12:30
5/6 @14:30
5/6 @15:30
5/6 @17:00
5/6 @18:00
5/6 @19:30
5/6 @20:30
5/6 @22:00
5/6 @23:30
5/7 @1:00
5/7 @2:30
5/7 @4:00
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(a)
5/5 @9:30
5/5 @10:30
(b)

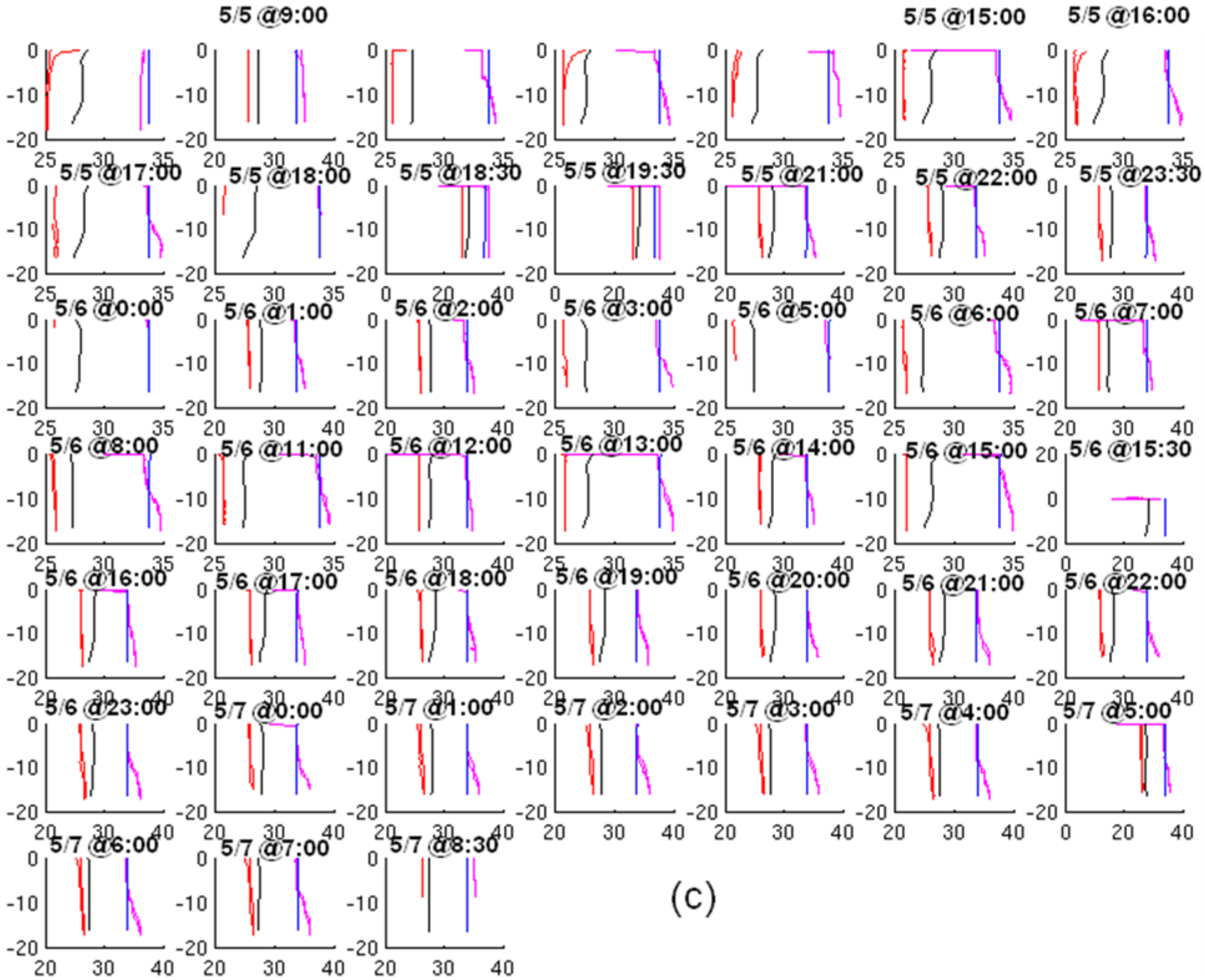

Fig. 11. Comparison of salinity and temperature profiles with CTD casts collected during May 4-7 campaign at 3 stations: (a) 1B; (b) 2A and (c) 3A. The data is in red (T) and magenta (S), and model results are in black and blue respectively.

10. Temperature

Of the 9 stations shown in Fig. 2b, only the 4 TWDB stations (6-9) have temperature data. Despite the uncertainties in the atmospheric forcing, the temperatures are robustly simulated by the model (Fig. 12). The mean model bias varies from -0.08 to 2^{o}C, largest at station 7. The RMSEs are in the range of 1-3^{o}C. Most importantly, the long-term temperature trend is very well captured by the model; in fact, the correlation coefficients at all 4 stations are above 0.9. Due to the lack of data, it remains to be seen if the modeled temperatures are accurate near the river mouths.

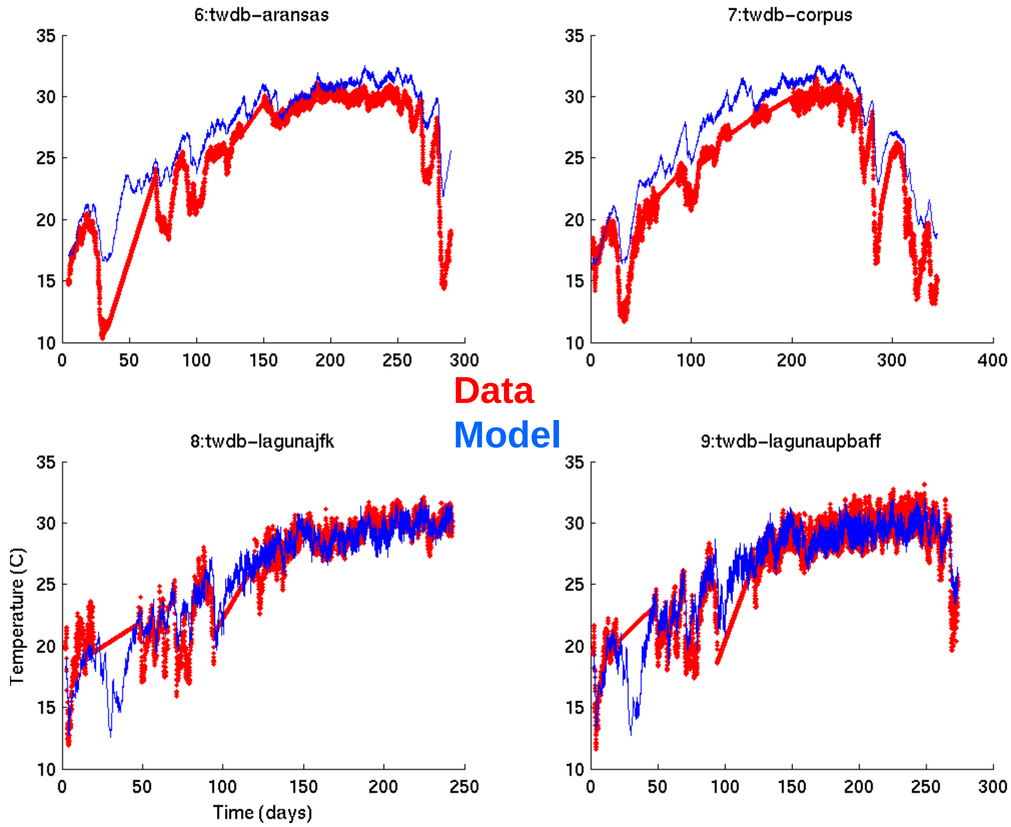

Fig. 12 Comparison of temperature at 4 TWDB stations shown in Fig. 2b.

11. Conclusion

We have successfully applied SELFE to the study of elevation, velocity, salinity and temperature trends in the Corpus Christi Bay region during a wet year (2000). Overall, the study suggests that SELFE is able to capture the long-term variability of elevation, salinity and temperature, subject to uncertainties in external forcings and boundary and initial conditions. The short-term variability of the velocity is also accurately simulated. Remaining issues are mostly related to salinity in the nearfield of the river plumes; detailed examination of local bathymetry and small-scale mixing processes should lead to further improvement of the model.

Technology transfer to TWDB

Upon completion of this project, OHSU will have transferred the following documents to TWDB:

1. This final report;
2. All input files for the final run of year 2000 and source code;
3. Results for year 2001.

References

Umlauf, L. and H. Burchard (2003) A generic length-scale equation for geophysical turbulence models. *J. Mar. Res.*, 6, pp. 235-265.

Zeng, X., M. Zhao and R. E. Dickinson (1998) "Intercomparison of bulk aerodynamic algorithms for the computation of sea surface fluxes using TOGA COARE and TAO data." *J. Clim.*, 11, 2628-2644.
Zhang, Y. and Baptista, A.M. (2008) "SELFE: A semi-implicit Eulerian-Lagrangian finite-element model for cross-scale ocean circulation", Ocean Modelling, 21(3-4), 71-96.