



FLORIDA BAY ASSESSMENT MODEL

VERSION 1.0 April 18, 2016

User Manual

South Florida Natural Resources Center

Everglades National Park



HYDROLOGIC MODEL MANUAL

SFNRC 2016:7-27

Cover picture shows false color satellite image of Florida Bay.

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South Florida Natural Resources Center
Everglades National Park
Homestead, Florida

National Park Service

U.S. Department of the Interior

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EXECUTIVE SUMMARY

No estimate is more in danger of erroneous calculations than those by which a man computes the force of his own genius.

– Samuel Johnson

Since all models are wrong the scientist cannot obtain a "correct" one by excessive elaboration. On the contrary following William of Occam he should seek an economical description of natural phenomena. Just as the ability to devise simple but evocative models is the signature of the great scientist so overelaboration and overparameterization is often the mark of mediocrity.

– George Box, (*Box, 1976*)

The Florida Bay Assessment Model (BAM) is a hydrological model specific to Florida Bay. Florida Bay is represented with 54 idealized basins and the physical basis is exceedingly simple, conservation of mass, thereby the suggestion of Box may find some satisfaction. Nonetheless, simplification and reductionism have dangers of their own, particularly when attempting to comprehend complexity as abounds in the natural world.

BAM attempts to balance the dimensional reduction of the physical description valued by Box with fidelity to the underlying complexities through use of the best available observational data describing the environment. BAM leverages a rich set of high-fidelity observational data within Florida Bay from the Marine Monitoring Network administered by Everglades National Park. Local tide predictions include all astronomical constituents, bathymetry is based on 30.5 cm depth resolution, and basin and shoal structure are specified from high-resolution GIS shapefiles.

BAM is also unique in that it is pure Python. Every aspect of the model is open, requiring no proprietary or special libraries or compilers. The source code is object-oriented, designed to be readable and extensible, fostering community involvement and empowering the user to mold the model to suit their own understanding of the underlying processes.

Dr. Johnson would no doubt question any claims of success and veracity regarding the usefulness of BAM, and as observed by Box, the hope is that BAM will provide an economical description, albeit not a correct one, of natural phenomena in Florida Bay.

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1 Introduction

The Florida Bay Assessment Model (BAM) is a 'basins' hydrological model of Florida Bay. It is mass-conservative and explicitly designed to assess water levels and salinities in 54 idealized basins representing Florida Bay. Basins are separated and connected by shoals, thereby the model conforms to a linked-node network hierarchy with basins as nodes and shoals as links. Interbasin fluxes are driven by hydraulic gradients developed across the shoals in response to water level elevations and are modeled with depth integrated velocity based on frictional flow from Manning's equation.

Each basin is forced with rainfall and evaporation. Basins on the Gulf of Mexico and Atlantic Ocean boundaries are also forced across the appropriate shoals with sea levels consisting of tidal variations and sea level changes. Coastal basins along the Everglades are forced with water levels determined from the Everglades Depth Estimation Network (EDEN) ([Telis et al., 2014](#)) with the shoal properties (length, width, depth) calibrated to match aggregate runoff from the FATHOM model ([Cosby et al., 2010](#)).

BAM can be considered a derivative work from FATHOM since it employs the same basic physical and domain representations, however, it is significantly different in several aspects. First, BAM uses contemporary, high-quality, high-temporal density observational data to drive model inputs and boundaries. These environmental forcings leverage the wealth of meteorological and hydrographic observations available from the Marine Monitoring Network administered by Everglades National Park. Tidal data are computed from local NOAA subordinate tide stations within Florida Bay containing all astronomical forcings including intrannual variations. The physical description of shoals linking the Everglades and Atlantic Ocean to Florida Bay have been updated to more accurately reflect existing flow paths. The reliance on high-quality, nearly continuous observational data to drive model inputs is a particular strength of BAM.

Second, BAM is pure Python. While this imposes an operational constraint since model runtimes are slower than a compiled binary image, it affords several advantages:

- Object oriented code facilitates clarity, scalability, extensibility and developer collaboration with modern programming language dictums.
- Adherence to modern programming standards and naming conventions results in code that is human readable and understandable, reducing the potential for software errors.
- Python dictionaries and native data containers simplify and clarify the processing of model data and objects.
- Cross-platform support. Any platform that runs Python can run BAM.
- No binaries and no dependence on special compilers or licensed third-party libraries.

Third, BAM outputs are not limited to specific time intervals, the output interval is user-controllable. Fourth, all BAM inputs/outputs are contained in ASCII comma delimited files imposing a uniform and accessible standard for model I/O enabling the evaluation of

alternative scenarios in a straightforward manner. Fifth, the graphical user interface is designed to allow interaction and querying of model results and parameters. Each basin and shoal in the model is accessible with a mouse click on the map, or from a list box. Integrated plotting facilities allow the comparison of model outputs from different runs. Sixth, the GUI is not required. BAM can be run in text-mode inside a terminal and is therefore easily controlled in batch mode by shell or other scripts. Seventh, all model controls are exposed through the command line interface which applies whether the GUI is used or not.

Lastly, BAM is open-source. This fosters transparency, allows community development, and empowers the individual to adjust and change any aspect of the model to suit their needs or conceptualizations.

1.1 Limitations

The physical basis is interbasin Mannings flow over shoals with conservation of mass. The simplified physical basis imposes several restrictions:

1. No wave propagation, stage/volume changes are instantaneous.
2. No diffusion/mixing, concentration equilibriums are instantaneous.
3. Mannings flow over deep or narrow shoals is not justifiable.
4. Water levels are not geodetic, but anomalies with respect to zero shoal depth.
5. Geomorphic bank and shoal changes over time are ignored.
6. The model is single layer. Groundwater exchange is either a component of aggregate runoff between basins or an imposed boundary condition.

The representation of basins, shoals and forcings is incomplete:

1. There are shoals with missing channels. For example, the Florida Keys are largely considered flow barriers, ignoring many channels.
2. Evaporation is a single daily timeseries applied to the entire domain.
3. Rainfall is estimated from a sparse set of daily timeseries.

2 Model Domain

BAM decomposes Florida Bay into 54 basins based on the geomorphology of the mangroves, buttonwood banks, and shoals separating individual basins (figure 1). Basin bathymetry is partitioned into 10 depth classes in 0.305 m (1 ft) increments following *Cosby et al.* (2010). There are 410 shoals linking the basins each characterized with a shoal width, land length (zero depth), and submerged lengths partitioned into the same 10 depth classes as the basins. Each shoal also has a Manning's friction coefficient applied over the shoal width, so that the shoal width is parallel to the interbasin flow path while the shoal lengths are perpendicular to the flow path.

Shoal data are derived from the work of *Cosby et al.* (2010), however a review of the shoals bordering domain boundaries with the Florida Keys and Everglades identified numerous deficiencies ignoring well-established flow paths between the boundaries and model basins. These shoals were adjusted and calibrated to produce water level dynamics inside the appropriate basins consistent with observed water level data.

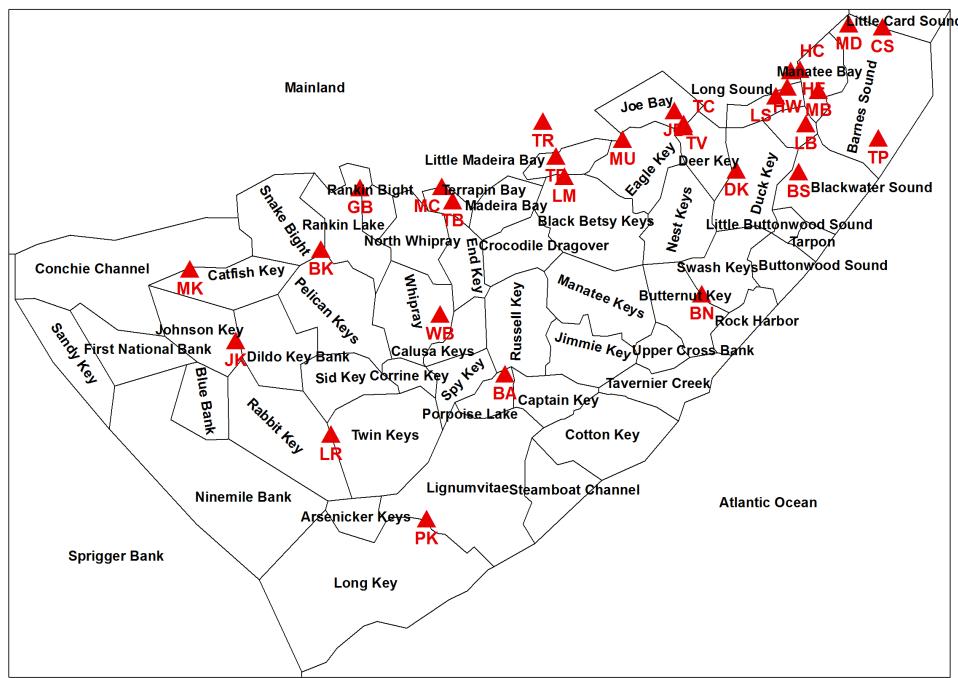


Figure 1.
BAM domain with basins and hydrographic stations (red).

3 Physical Representation

The physical basis of BAM is exceedingly simple. Mass-transport over shoals is governed by transport velocity v integrated over shoal depth and length

$$v = \sqrt{2g \frac{h_u - h_d}{1 + f}} \quad (1)$$

where h_u and h_d are upstream and downstream basin water levels, and f a friction factor

$$f = 2g n^2 w \rho^{-4/3} \quad (2)$$

where n is the Manning's coefficient, w the shoal width, ρ the shoal hydraulic radius and g the vertical acceleration. The module `hydro.py` contains all hydraulic computations.

The mass flux of dissolved substances over each shoal M (g) is calculated as the product of the concentration of the substance in the water C (g m^{-3}) and the water mass flux F ($\text{m}^3 \text{s}^{-1}$) across the shoal. The mass fluxes M are summed around the boundary of each basin, the net mass flux over all shoals is multiplied by the time step and, along with other inputs and outputs of mass during the time step, added to the mass in the basin at the beginning of the time step. The new mass is divided by the water volume to estimate the concentration at the end of the time step.

4 Input

BAM inputs are derived from a variety of sources, and with exception of Sea Level and Tide data are daily values specific to each basin in the domain. Sea Level is a monthly value applied to all Gulf and Ocean boundary basins, while Tides are interpolated to the model timestep from hourly tide data. Input data files and their periods of record are listed in table 1.

Variable	File	Start	End	Option
Rain	DailyRainFilled_cm_1999-9-1_2015-12-8.csv	1999-09-01	2015-12-08	-br
ET	PET_1999-9-1_2015-12-8.csv	1999-09-01	2015-12-08	-et
Tide	HourlyTide1990_2020.tar.gz	1990-01-01	2021-01-01	-bt
Sea Level	MSL_Anomaly.csv	1999-08-15	2015-12-15	-msl
Runoff	EDEN_Stage_OffsetMSL.csv	1999-09-01	2015-12-31	-bR
Flow	S197_Flow_1999-9-1_2016-3-31.csv	1999-09-01	2016-03-31	-bc
Salinity	DailySalinityFilled_1999-9-1_2015-12-8.csv	1999-09-01	2015-12-08	-sf
Stage	DailyStage_1999-9-1_2016-3-1.csv	1999-09-01	2016-03-01	-bs

Table 1. Input data files, period of record and command line option. Note that Salinity and Stage inputs are used for model output comparison, not as explicit model inputs. However, salinity timeseries can be imposed on basins with the --gaugeSalinity command line option.

The input files listed in table 1 are created from raw data with a series of R or Python scripts found in the etc/ directory. These files include

1. CreateRainData.R
2. CreateET.R
3. CreateTideData.py
4. CreateRegion.2.3.tide.R
5. EDEN_Stage.R
6. CreateSalinityData.R
7. Boundary.Salinity.R
8. CreateStageData.R

4.1 Basins

Basins and their associated observational data stations are listed in table 2. Basins numbered 5 - 58 are the 54 basins representing Florida Bay, basins 1 - 4 are not used. Basins 59 - 68 are boundary basins representing Gulf of Mexico and ocean boundaries, and basins 69 - 82 are boundary basins of the Everglades. Each of the boundary basins has a one-to-one mapping to a basin in the model domain as described in the appropriate section (Tides section 4.6, or Runoff section 4.5).

Basin	Name	Gauge	Basin	Name	Gauge
5	Barnes Sound	MD	44	Dildo Key Bank	None
6	Manatee Bay	MB	45	Tavernier Creek	None
7	Long Sound	LS	46	Butternut Key	BN
8	Little Blackwater Sound	LB	47	Duck Key	DK
9	Blackwater Sound	BS	48	Manatee Keys	None
10	Tarpon	None	49	Swash Keys	BN
11	Little Buttonwood Sound	None	50	Deer Key	TC
12	Nest Keys	None	51	Eagle Key	None
13	Joe Bay	TC	52	Steamboat Channel	None
14	Little Madeira Bay	LM	53	Arsenicker Keys	None
15	Black Betsy Keys	LM	54	Sid Key	None
16	Upper Cross Bank	None	55	Pelican Keys	None
17	Rock Harbor	None	56	Blue Bank	None
18	Buttonwood Sound	None	57	First National Bank	None
19	Jimmie Key	None	58	Sandy Key	None
20	Cotton Key	None	59	Gulf Tide 1	Gulf_1
21	Captain Key	None	60	Gulf Tide 2	Gulf_2
22	Russell Key	None	61	Gulf Tide 3	Gulf_3
23	Crocodile Dragover	None	62	Gulf Tide 4	Gulf_4
24	Madeira Bay	None	63	Ocean Tide 5	Ocean_5
25	Terrapin Bay	None	64	Ocean Tide 6	Ocean_6
26	End Key	None	65	Ocean Tide 7	Ocean_7
27	Calusa Keys	None	66	Ocean Tide 8	Ocean_8
28	Spy Key	None	67	Ocean Tide 9	Ocean_9
29	Porpoise Lake	BA	68	Card Sound Tide 10	Ocean_10
30	Lignumvitae	PK	69	EVER to Snake Bight	S15
31	Long Key	None	70	EVER to Rankin Lake	S16
32	Twin Keys	LR	71	EVER to Rankin Bight	S16
33	Corrine Key	None	72	EVER to North Whipray	S16
34	Whipray	WB	73	EVER to Terrapin Bay	S17
35	North Whipray	None	74	EVER to Madeira Bay	S17
36	Rankin Bight	None	75	EVER to Little Madeira Bay	S18
37	Rankin Lake	GB	76	EVER to Eagle Key	S19
38	Rabbit Key	LR	77	EVER to Joe Bay	S20
39	Johnson Key	JK	78	EVER to Deer Key	S21
40	Catfish Key	MK	79	EVER to Long Sound	S22
41	Snake Bight	BK	80	EVER to Manatee Bay	S22
42	Conchie Channel	None	81	EVER to Conchie Channel	S15
43	Ninemile Bank	None	82	EVER to Barnes Sound	S22

Table 2. BAM basin numbers, names and observational data/boundary stations.

The basin parameter file defines mappings between basins and observational gauges, as well as boundary basins and their input timeseries. This file is specified with the `-bp` [`--basinParameter`] option (default: `Basin_Parameters.csv`).

The basin shapefile is specified with the `-bn` [`--basins`] option (default: `data/GIS/FLBayBasins`).

Bathymetry is described in the `-bd` [`--basinDepth`] file (default: `Basin_Area_Depth.csv`).

Initial values of basin variables are set from the `-bi` [`--basinInit`] file (default:

`Basin_Initial_Values.csv`). However, for basins where observations are available the `-si` [`--salinityInit`] option (default: `yes`) will override the initial salinity values set from `basinInit` with observed data.

4.2 Shoals

Shoals are links between basins, and the objects where mass transport is quantified. The structure of the model is dictated by the basin-shoal linkage in the `-sp` [`--shoalParameters`] file (default: `Shoal_Parameters.csv`).

The shoals shapefile is specified with the `-s` [`--shoals`] option (default: `data/GIS/FathomLines`).

Shoal bathymetry and width is defined in the `-sl` [`--shoalLength`] file (default: `Shoal_Length_Depth.csv`). Mannings friction coefficients are also specified in the `shoalLength` file.

The user can override the Mannings coefficients specified in `shoalParameters` with the `-sm` [`--shoalManning`] option (default: `None`). Use of this option will set the Mannings coefficient for all shoals in the model to the single specified value.

4.3 Rain

Rain input is based on observational data from the Marine Monitoring stations show in figure 1. Since data coverage is not continuous, a resampling scheme is used to estimate surrogate values for missing data at each station. Data from each station is first partitioned into rain observations for each day of the year over the period of record. Data for a missing day is reconstructed by randomly sampling from the partitioned data for that day over all years. This preserves the seasonal distribution of rainfall while allowing for natural variability.

Observed and reconstructed rain at the stations in eastern Florida Bay is shown in figure 2, and for the western basins in figure 3.

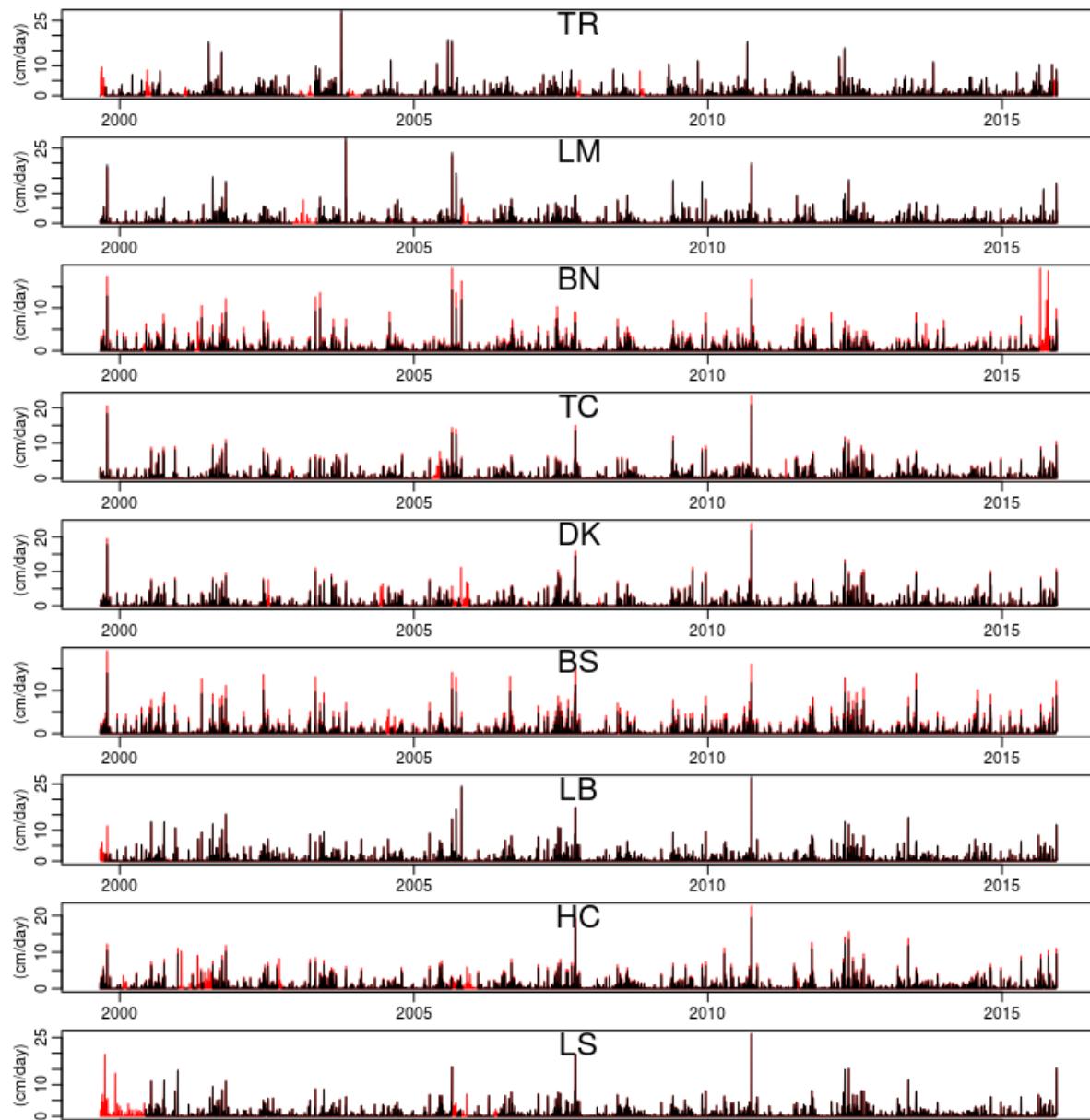


Figure 2. East Florida Bay observed rain (black) and reconstructed rain (red).

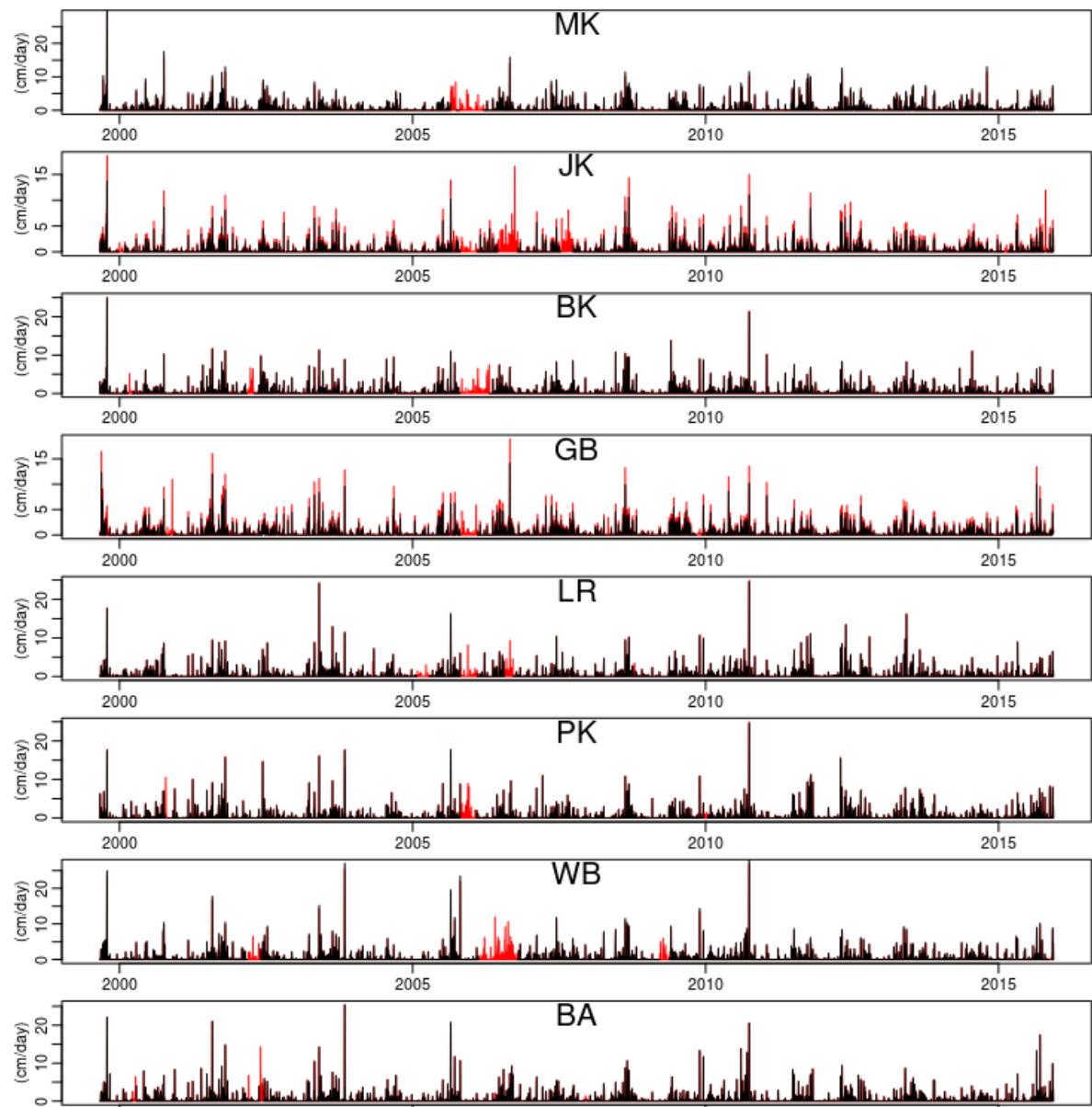


Figure 3. West Florida Bay observed rain (black) and reconstructed rain (red).

Estimation of total rain over basins tens to hundreds of square kilometers in area is notoriously challenging based on sparse, point measurements. To afford user control over selection and effective areal input of rain, a mapping of basin to rain gauge stations is specified in the basin parameters (`-bp`, `--basinParameter`) file. An excerpt of the basin parameter file is shown here:

Basin,	Name,	Rain Gauge,	Rain Scale,	Gauge
8,	Little Blackwater Sound,	[LS LB BS],	[3 2 3],	LB
9,	Blackwater Sound,	[DK BS LB],	[2 3 2],	BS
10,	Tarpon,	[BS BN DK],	[2 2 1],	None
11,	Little Buttonwood Sound,	[BS BN DK],	[1 2 2],	None

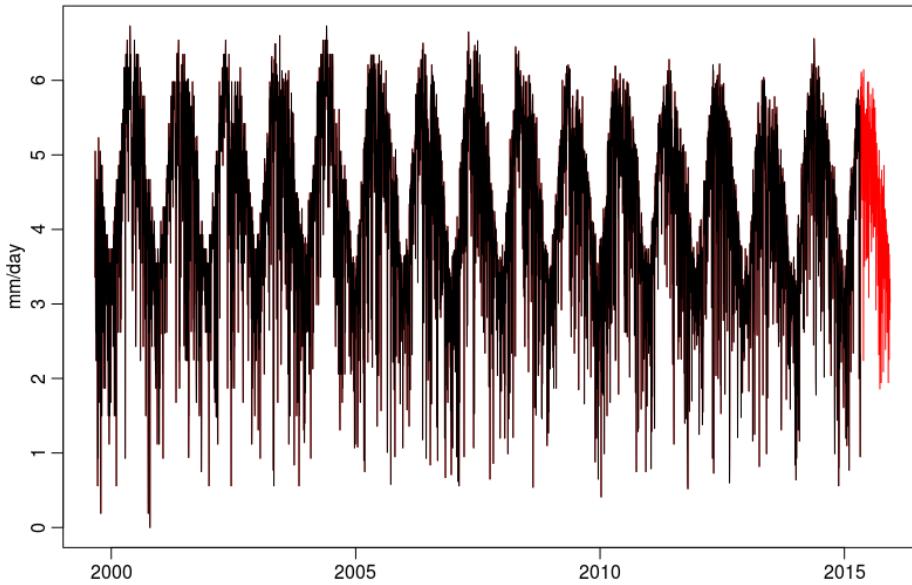
The Rain Gauge column defines a list of rain gauges aggregated to produce the input rainfall for a basin. The Rain Scale is a corresponding list of scale factors applied to each rain gauge data value in the gauge list. This allows complete control over the basin rain input, and has been found to give good spatial smoothing to compensate for the fact that point measurements of rain are often insufficient to represent total rain volumes over a large areal extents.

The rain input file is specified with the `-br` `--basinRain` option, and has a default value of `DailyRainFilled_cm_1999-9-1_2015-12-8.csv`. Rain inputs can be disabled by specifying the `-nr` `--noRain` option, which has a default value of `False`.

4.4 ET

Evapotranspiration (ET) data are obtained from the South Florida Water Management District (SFWMD) measuring stations at Joe Bay in the C-111 basin (JBTS_C111), structure S331 in the L31N basin (S331W_L31NS), and a three station average in water conservation area 3A of the WCA3A basin (3AS3WX_WCA3). Note that these basins are not in Florida Bay.

A single timeseries is created by taking the maximum value of the three data sets for any given day which covers most data gaps. The remaining gaps are reconstructed with a resampling scheme where the data are partitioned into samples for each day of the year over the period of record and missing data randomly drawn from the samples for a specific yearday. Figure 4 plots the resultant ET data which is applied to all basins in the model.

**Figure 4.**

SFWMD observed ET (black) and reconstructed ET (red).

To provide user control over the magnitude of ET, the `-es [--ET scale]` command line option applies a scale factor to the data shown in figure 4.

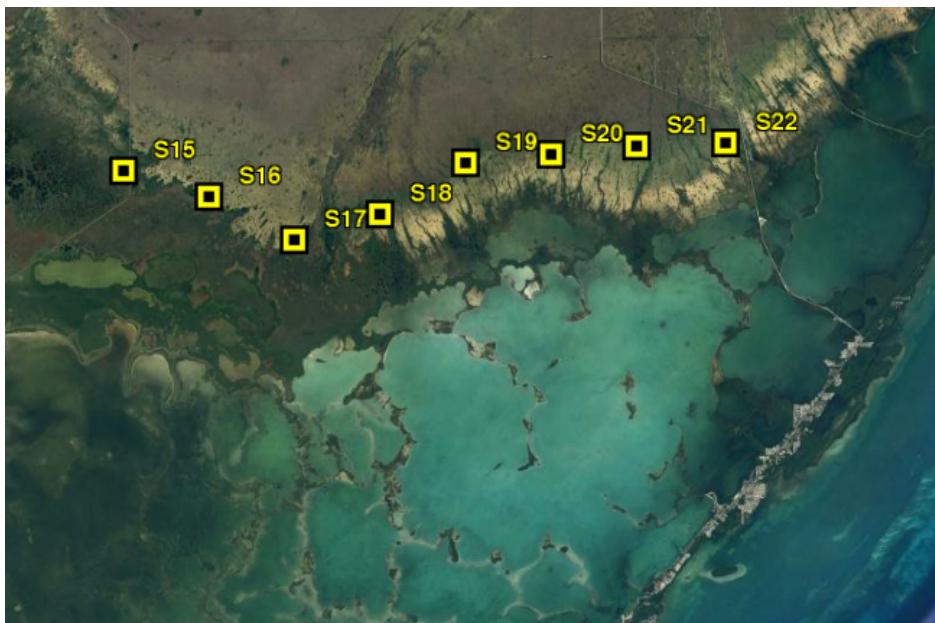
The ET input file is specified with the `-et [--ET]` option, and has a default value of `PET_1999-9-1_2015-12-8.csv`. ET inputs can be disabled by specifying the `-ne [--noET]` option, which has a default value of `False`.

4.5 Everglades Runoff

The BAM convention for basin runoff is that positive runoff corresponds to flow leaving the basin, while negative runoff quantifies flow entering the basin.

A hydraulic head relationship exists between water levels in the southern Everglades and freshwater runoff into coastal basins as expressed in strong negative correlations between Everglades water level and coastal basin salinity ([Tabb, 1967](#); [Kelble et al., 2007](#)). BAM uses this relationship to estimate integrated Everglades runoff (streamflow, sheetflow and groundwater) into the coastal basins with the same shoal hydraulics driving all other inter-basin flows. Shoal parameters are calibrated to match runoff values determined by FATHOM ([Cosby et al., 2010](#)) in section 10.

Upstream basins representing the Everglades have water levels determined by values extracted from the Everglades Depth Estimation Network (EDEN) at eight stations shown in figure 5 and table 3. These water levels are converted from NAVD to water level anomalies with respect to Florida Bay mean sea level over the period 2008 - 2015.

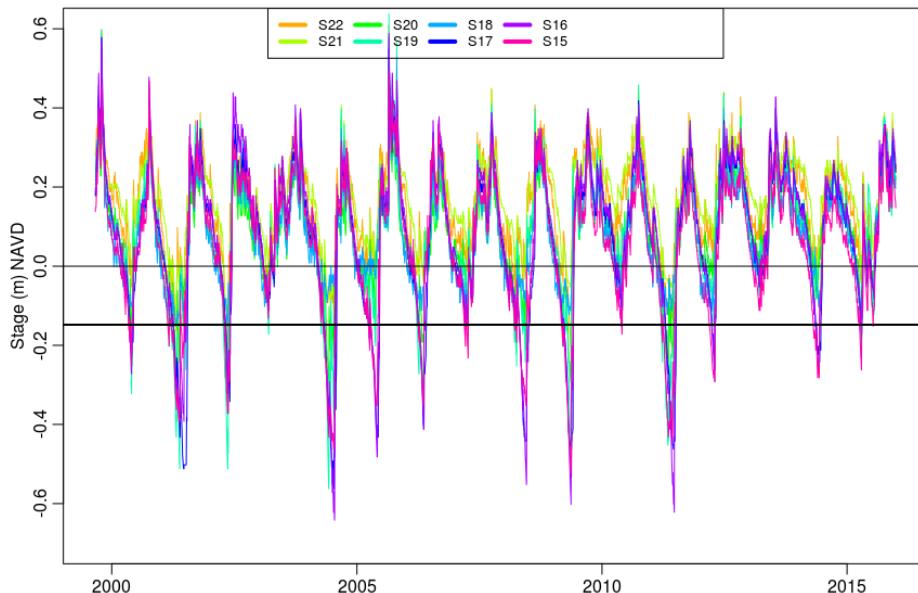
**Figure 5.**

Eight stations in the southern Everglades where EDEN stage is extracted to provide hydraulic forcings for runoff into the coastal basins.

Station	UTM North	UTM East	Zone	Longitude	Latitude
S15	2794000	520000	17	-80.801379	25.262235
S16	2792500	525000	17	-80.751752	25.248614
S17	2790000	530000	17	-80.702158	25.225945
S18	2791500	535000	17	-80.652480	25.239383
S19	2794500	540000	17	-80.602747	25.266350
S20	2795000	545000	17	-80.553075	25.270723
S21	2795500	550000	17	-80.503400	25.275079
S22	2795700	55200	17	-80.451747	25.276703

Table 3. Coordinates of EDEN stations providing Everglades stage to drive runoff.

Water levels at the EDEN stations are shown in figure 6 exhibiting the expected seasonal uniformity, as well as deeper dry-season minima along the western bay.

**Figure 6.**

EDEN stage at eight stations in the southern Everglades. Mean sea level (2008-2015) is shown by the line at -14.8 cm.

The EDEN stage file used to drive runoff is specified with the `-bR [--basinStageRunoff]` option with a default value of `EDEN_Stage_OffsetMSL.csv`. The mapping of EDEN stage values to coastal basins and the corresponding shoals is specified with the `-bS [--basinStageRunoffMap]` with a default of `Basin_Runoff_Boundary.csv`. Runoff from the hydraulic stage relationship can be disabled with the `-nR [--noStageRunoff]` option which has a default of `False`. An example of the EDEN stage to coastal basin runoff mapping file is shown below.

Source_Basin	EDEN	Dest_Basin	Dest_Name	Shoals
82,	S22,	5,	Barnes Sound,	[373]
80,	S22,	6,	Manatee Bay,	[333 334]
79,	S22,	7,	Long Sound,	[336 337 338 339 340 341 342 343]
77,	S20,	13,	Joe Bay,	[348 358 359 360]
75,	S18,	14,	Little Madeira Bay,	[168 169 170 171 172 173 174]
74,	S17,	24,	Madeira Bay,	[149 150 151]
73,	S17,	25,	Terrapin Bay,	[142 143 144]
72,	S16,	35,	North Whipray,	[126 127]
71,	S16,	36,	Rankin Bight,	[135]
70,	S16,	37,	Rankin Lake,	[136 137 138 139 140 141]
69,	S15,	41,	Snake Bight,	[24 25 26]
78,	S21,	50,	Deer Key,	[346 347]
76,	S19,	51,	Eagle Key,	[356 357]
81,	S15,	42,	Conchie Channel,	[6 7 8 9 10]

4.6 Tides

Tidal variations are a primary driver of hydraulic fluxes throughout Florida Bay. In order to accurately estimate basin water levels and thereby the associated mass transports between basins BAM uses local, hourly tidal estimates as the foundation for tidal boundary conditions. These estimates are computed from NOAA subordinate station harmonic constituents at the stations listed in table 4. The resultant tidal data contain all astronomical forcings, but do not include variations of secular sea level rise, annual or interannual cycles from ocean currents and atmospheric teleconnections. Those are accounted in section 4.7.

Name	Station ID
Cape Sable, East Cape, Florida	TEC4165
Long Key, western end, Florida	8723899
Lignumvitae Key, NE side, Florida Bay, Florida	8723824
Snake Creek, Hwy. 1 bridge, Windley Key, Florida	8723787
Tavernier Creek, Hwy. 1 bridge, Hawk Channel, Florida	8723748
Garden Cove, Key Largo, Florida	8723622
Little Card Sound bridge, Florida	8723534

Table 4. NOAA subordinate tide stations where tides are calculated along the gulf and ocean boundaries.

Timeseries for the stations in table 4 are generated by the `CreateTideData.py` and `CreateRegion.2.3.tide.R` programs.

Basins numbered 59 - 68 are tidal boundary basins, each one connected to a Florida Bay basin as specified in the `shoalParameters` file and shown in table 5.

Name	Basin	Name	Basin	Shoals
Conchie Channel	42	Gulf_1	59	23
Sandy Key	58	Gulf_2	60	22 370
Ninemile Bank	43	Gulf_3	61	45 371
Long Key	31	Gulf_4	62	70
Long Key	31	Ocean_5	63	64 65 66 67 68
Long Key	31	Ocean_6	64	61 62 63 239 237
Lignumvitae	30	Ocean_6	64	237
Steamboat Channel	52	Ocean_7	65	240
Cotton Key	20	Ocean_7	65	241 242
Tavanier Creek	45	Ocean_8	66	271 272 273 274
Rock Harbor	17	Ocean_8	66	288
Buttonwood Sound	18	Ocean_9	67	289 290
Tarpon	10	Ocean_9	67	309
Blackwater Sound	9	Ocean_9	67	310
Barnes Sound	5	Ocean_9	67	365 366
Barnes Sound	5	Ocean_10	68	362 363

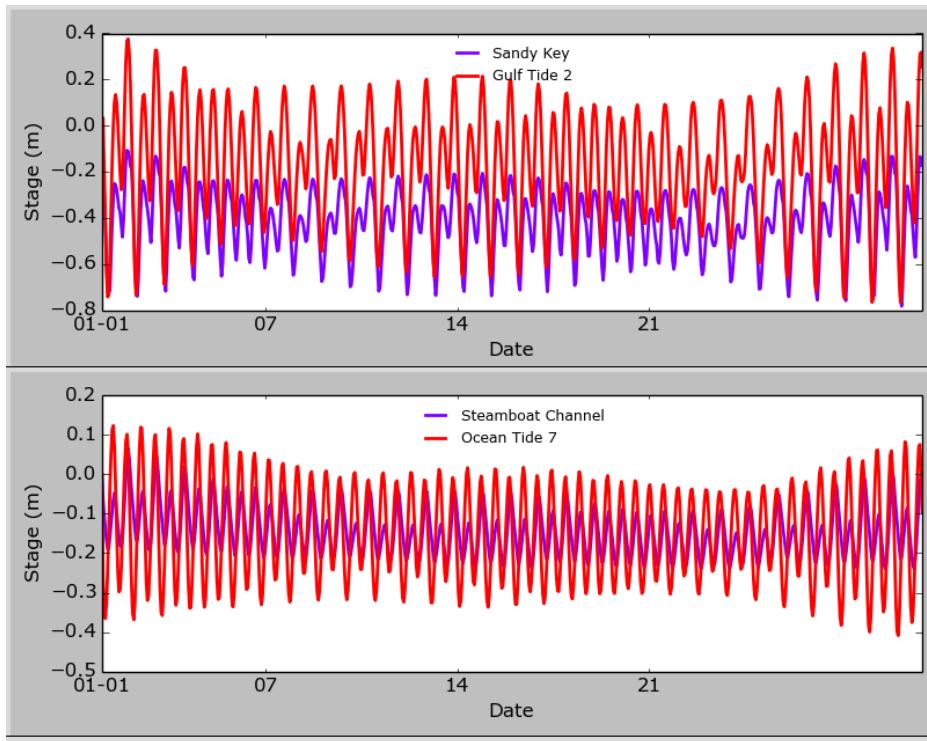
Table 5. Tide boundary basin and shoal mapping.
Boundary basin names corresponds to the basin Gauge listed in table 2.

There are no NOAA stations along western Florida Bay between Cape Sable and Long Key. Examination of tidal response at these two stations shows that tides at Long Key are delayed 6 - 8 hours and attenuated by a factor of 2.7 - 3 in relation to Cape Sable. To estimate tidal responses between these two points it is assumed that northern region tides are 2/3 the amplitude and 3 hours delayed from Cape Sable, while the southern region is 4/3 the amplitude and 3 hours prior to Long Key. These amplitude and phase modulations are performed in `CreateRegion.2.3.tide.R` producing the tidal forcings for the `Gulf_2` and `Gulf_3` boundaries. A graphical comparison shows that these assumptions give a reasonable transitional tidal response between Cape Sable and Long Key.

The mapping between boundary basin tidal heights and tidal timeseries is specified in the `-bt --basinTide` file (default: `Basin_Tide_Boundary_2010_2015.csv`). If the `-nt [--noTide]` option (default: `False`) is activated, no tidal data are applied at the boundaries.

BAM interpolates hourly tidal timeseries to the model timestep at runtime based on cubic spline fits to the hourly data. The cubic splines are generated during model initialization and this process can be time consuming. Two approaches are used to minimize this delay. First, the spline generations are parallel processed with up to 4 processors (if available). Second, subsets of hourly tidal data can be specified in the `basinTide` file that correspond to the model simulation period, say 2010-1-1 to 2015-12-31 instead of the entire model period of record.

An example of tidal boundary data and the corresponding basin response is depicted in figure 7.

**Figure 7.**

Tidal boundary conditions (red) and corresponding basin water levels (blue) for the period 2010-1-1 through 2010-1-31.

4.7 Sea Level

Tidal data are local and derived from astronomically-forced harmonic constituents fit to water level observations. As such, they do not include sea level response to regional ocean currents, atmospheric teleconnections or secular sea level rise. To address this the `-msl [--seasonalMSL]` file (default: `MSL_Anomaly.csv`) specifies a regional mean sea level anomaly timeseries superimposed on the tidal boundary data. Regional sea levels are not applied if the `-nm [--noMeanSeaLevel]` option (default: `False`) is activated.

The default regional sea levels in `MSL_Anomaly.csv` are determined from monthly mean sea level data at the three long-term, primary NOAA tide stations listed in table 6. Monthly mean sea levels published by NOAA have the annual seasonal cycle removed, and are with respect to the current (1983 - 2001) National Tidal Datum Epoch (NTDE) determination of mean sea level at each station.

Station	CO-OPS ID	Verified Data	NAVD (m)	MSL (m)
Virginia Key	8723214	1994 - 2016	3.698	3.431
Vaca Key	8723970	1973 - 2016	1.182	0.931
Key West	8724580	1954 - 2016	1.928	1.662

Table 6. Long-term, primary NOAA tide gauges. MSL is the NTDE mean sea level datum elevation, and NAVD the North American Vertical Datum elevation.

To represent total mean sea level the annual seasonal cycle at each station is added to the published monthly sea levels and converted to the NAVD datum. The three stations are then averaged to estimate a regional mean sea level timeseries on a common datum (RMS

deviation of 1.7 cm).

Finally, the mean sea level timeseries is converted from the NAVD datum reference to mean sea level in Florida Bay over the 2008-2015 period. This is necessary since BAM operates on water level anomalies rather than a geodetic reference. The reference mean sea level in Florida Bay is determined from an average of daily mean water levels at stations LM, PK and MK over 2008-2015 smoothed with a 30-day moving average. The resultant sea level signal is shown in figure 8.

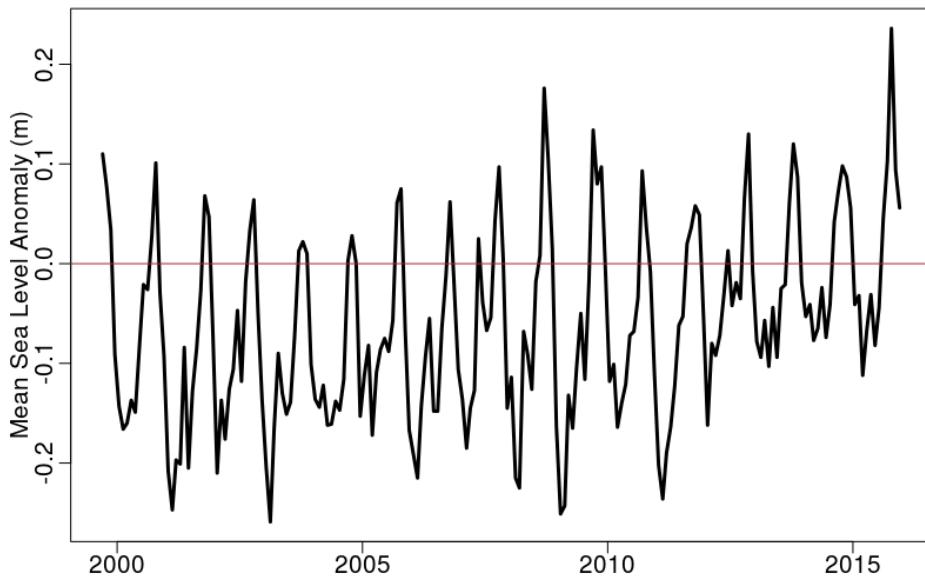


Figure 8.

Mean sea level anomaly with respect to the 2008-2015 mean sea level in Florida Bay (-14.8 cm NAVD).

4.8 Basin Boundary Conditions

Tidal and Everglades boundary basins impose water levels that interact with basins along the periphery of Florida Bay. There are also two methods to impose stage or flow boundaries onto interior basins: fixed boundary conditions impose a constant stage or flow, dynamic boundary conditions impose values from a timeseries.

Warning: Stage boundary conditions are imposed at the start of each timestep. Currently, the basin water level is then updated according to changes in volume from mass transport.

Warning: Dynamic timeseries flow values are assumed to be in units of $\text{ft}^3 \text{s}^{-1}$. Fixed timeseries flow values are specified in units of $\text{m}^3 \text{s}^{-1}$.

4.8.1 Fixed Boundary Conditions

Fixed boundary conditions are enabled with the `-fb` [`--fixedBoundaryConditions`] option (default: `False`). When enabled, the forcings are specified in the `-bf` [`--basinFixedBCFile`]

file (default: `Basin_Fixed_Boundary_Condition.csv`). An example of a `basinFixedBCFile` is shown below:

```
Basin, Name,      Type, Value
56,     Blue Bank, flow, 1000
```

Type can have the value `stage` or `flow`. If Type is `flow` then at each model timestep the flow Value ($\text{m}^3 \text{s}^{-1}$) is multiplied by the model timestep interval converting the flow into a volume (m^3). This volume is added to the basin at the beginning of the timestep.

If Type is `stage` then at each model timestep the basin water level is set to the stage Value at the beginning of the timestep. This does not prevent the basin water level from being updated at the end of the timestep in response to mass transport.

4.8.2 Dynamic Boundary Conditions

Dynamic boundary conditions are enabled by default, and can be disabled with the `-nb` [`--noDynamicBoundaryConditions`] option (default: `False`). When enabled, forcings are specified in the `-bc` [`--basinBCFile`] file (default: `Basin_Boundary_Condition.csv`). An example of a `basinBCFile` is shown below:

```
Basin, Name,      Type, File
6,     Manatee Bay, flow, data/Boundary/S197_Flow_1999-9-1_2016-3-31.csv
```

Type can have the value `stage` or `flow`. If Type is `flow` then at each model timestep the flow value obtained from File is multiplied by 0.028317 to convert it from $\text{ft}^3 \text{s}^{-1}$ to $\text{m}^3 \text{s}^{-1}$. The resulting value is multiplied by the model timestep interval to convert the flow to a volume (m^3). This volume is added to the basin at the beginning of the timestep.

If Type is `stage` then at each model timestep the basin water level is set to the stage value obtained from the File at the beginning of the timestep. This does not prevent the basin water level from being updated at the end of the timestep in response to mass transport.

4.9 Salinity

Salinity is a primary output of the model and is not required as input to estimate basin salinities. However, high-quality, long-period salinity available from marine monitoring stations afford several advantages to model operation and evaluation. First, salinity in the gulf and ocean boundary basins exert an important influence on salinities inside the bay. Boundary salinity and runoff may be the most important exogenous variables for coastal basin salinity and good model results require accurate boundary salinities.

Second, observed data can be used to initialize basin salinities with the `-si` [`--salinityInit`]

option. Third, basin salinities can be imposed from observed timeseries with the `-gs` [`--gaugeSalinity`] option. If `-gs` is specified then all basins with salinity gauges listed in the `basinParameter` `-bp` file will have observed salinities imposed. Finally, the database of observed salinities allows the user to plot observed data against model output for evaluation and comparison purposes.

Salinity on the Gulf of Mexico boundary has significant variability in comparison to open ocean seawater. Here, the Florida Shelf has a wide, flat and shallow bathymetry, with a generally weak, northerly countercurrent to the Loop current. This allows hypersaline conditions to develop during times of high evaporation and weak circulation. The shelf also receives freshwater runoff from the Shark River and Everglades distributaries, and significant subtropical rain events can also contribute to hyposaline conditions. Boundary salinity for this domain is computed from a 4-gauge average of daily mean salinity at the stations MK, JK, LR, PK, which has an overall standard deviation of 1.7 g/kg over the period September 1, 1999 to December 31, 2015 (N = 5943).

On the Atlantic side salinity is less variable than the Florida Shelf, but still ranges considerably in comparison to open ocean values. The Lignumvitae basin (station PK) in southern Florida Bay is a predominantly marine environment with significant exchange with the Atlantic, and we use a six-month lowpass filter applied to the PK station salinity to represent Atlantic boundary salinities.

Observed salinities are specified in the `-sf` [`--salinityFile`] file (default: `DailySalinityFilled_1999-9-1_2015-12-8.csv`). Boundary salinities are also included in this file with boundary data 'gauges' specified in the `basinParameter` file (for example: `Ocean_1` and `Gulf_1`).

Salinity observations are not continuous thereby a resampling scheme is used to estimate values of missing data at each station. Data from each station is first partitioned into observations for each day of the year over the period of record. Data for a missing day is reconstructed by randomly sampling from the partitioned data for that day over all years.

4.10 Basin Water Level

Basins water levels are computed according to mass conservation of water across shoals along with contributions from rainfall, ET, runoff and fixed boundary conditions. Exceptions are the gulf, ocean and Everglades boundary basins where water levels are imposed from tidal, sea level data and EDEN data.

Since basin water levels provide the hydraulic potential for interbasin mass transfer, the availability of high-quality, long-period observational water levels is useful in the evaluation of model development and performance. The graphical user interface provides graphical comparison of observed and modeled water levels.

The water level data file is defined with the `-bs` [`--basinStage`] option

(default: DailyStage_1999-9-1_2016-3-1.csv).

4.11 Wind

Wind is currently not used.

5 Output

Model output is exclusively in UTF-8 encoded comma-delimited variable (.csv) files. Each basin in the model has a file created based on the basin name, for example `Long Sound.csv`.

Basin output variables can be selected in the graphical user interface, default variables are `Salinity`, `Stage`, `Flow`, `Volume`, `Rain`, `Evaporation`, `Runoff`.

The output directory is defined by the `-bo [--basinOutput]` option with default: `home_dir/BAM.out` where `home_dir` is the value of the `HOME` environment variable if it is defined, otherwise the current working directory.

Messages generated during a model run are written to the `RunInfo.txt` file in the model output directory.

Currently, no shoal output is created.

6 Model Execution

BAM is a Python 3 application. The model entry-point is the function `main()` in `bam.py` which is invoked by simply executing `bam.py` as a shell command. To execute the model without the graphical user interface specify the `-ng` [`--noGUI`] option.

6.1 Installation

In addition to Python 3, several community modules such as SciPy are needed. Installation notes can be found in the docstring of the `Notes.py` module and can be accessed from the Python console:

```
>>> import Notes
>>> help( Notes.InstallationNotes )

returns:

InstallationNotes()
    Installation:

    sudo apt-get install python3
    sudo apt-get install python3-tk
    sudo apt-get install tk-dev
    sudo apt-get install libffi-dev # for cairocffi/matplotlib.backends
    sudo apt-get install python3-pip
    sudo pip3    install cairocffi # for matplotlib.backends
    sudo pip3    install numpy
    sudo pip3    install scipy
    sudo pip3    install matplotlib
    sudo pip3    install pyshp      # https://github.com/GeospatialPython/pyshp
    sudo pip3 install git+https://github.com/uqfoundation/dill.git@master
    sudo pip3 install git+https://github.com/uqfoundation/multiprocess.git@master

    Editor: gedit
    sudo apt-get install gedit
```

6.2 Command line options

All model control parameters can be set with command line arguments. Important options for run control:

```
-p PATH, --path PATH      : Top level path of BAM: -p /opt/hydro/models/PyBAM/
-t TIMESTEP, --timestep : TIMESTEP timestep (s): -t 360
-S START, --start START : Start date time: -S "2010-01-01 00:00"
-E END, --end END       : End date time:   -E "2010-01-01 08:00"
-oi OUTPUTINTERVAL, --outputInterval OUTPUTINTERVAL :
                           Time interval (hr) of output data: -oi 1
-bo BASINOUTPUTDIR, --basinOutput BASINOUTPUTDIR :
                           Directory to write basin outputs: -bo /home/jpark/BAM.out
```

6.2.1 All options

Issuing the command `./bam.py -h` will list all arguments.

```
> ./bam.py --help
usage: bam.py [-h] [-p PATH] [-t TIMESTEP] [-S START] [-E END]
              [-vt VELOCITY_TOL] [-it MAX_ITERATION] [-bn BASINSHAPEFILE]
              [-bd BASINDEPTH] [-bp BASINPARAMETERS] [-bi BASININIT]
              [-bt BASINTIDE] [-br BASINRAIN] [-bc BASINBCFILE]
              [-bf BASINFIXEDBCFILE] [-bo BASINOUTPUTDIR]
              [-br BASINSTAGERUNOFF] [-bs BASINSTAGERUNOFFMAP]
              [-bs BASINSTAGE] [-et ET] [-es ET_SCALE] [-s SHOALSHAPEFILE]
              [-sp SHOALPARAMETERS] [-sl SHOALLENGTH] [-sm SHOALMANNING]
              [-sf SALINITYFILE] [-msl SEASONALMSL] [-si SALINITYINIT] [-gs]
              [-e EDITOR] [-r RUNID] [-rf RUNINFOFILE] [-oi OUTPUTINTERVAL]
              [-mi [MAPINTERVAL [MAPINTERVAL ...]]] [-L STAGELEGENDBOUND]
              [-P SALINITYLEGENDBOUND] [-fb] [-nb] [-nr] [-ne] [-nR] [-nt]
              [-nm] [-ng] [-D] [-DA]
```

Bay Assessment Model

optional arguments:

```
-h, --help            show this help message and exit
-p PATH, --path PATH  Top level path of BAM: -p /opt/hydro/models/PyBAM/
-t TIMESTEP, --timestep TIMESTEP
                      timestep (s): -t 360
-S START, --start START
                      start date time: -S "2010-01-01"
-E END, --end END      End date time: -E "2010-01-02"
-vt VELOCITY_TOL, --velocity_tolerance VELOCITY_TOL
                      velocity iteration tolerance (m/s): -vt 0.0001
-it MAX_ITERATION, --max_iteration MAX_ITERATION
                      velocity iteration limit: -it 3000
-bn BASINSHAPEFILE, --basins BASINSHAPEFILE
                      Basins shape file: -bn data/GIS/FLBayBasins
-bd BASINDEPTH, --basinDepth BASINDEPTH
                      Basin area depth input file: -bd
                      data/init/Basin_Area_Depth.csv
-bp BASINPARAMETERS, --basinParameter BASINPARAMETERS
                      Basin parameters input file: -bp
                      data/init/Basin_Parameters.csv
-bi BASININIT, --basinInit BASININIT
                      Basin initial state variable input file:-bi
                      data/init/Basin_Initial_Values.csv
-bt BASINTIDE, --basinTide BASINTIDE
                      Basin tide boundary data files: -bt
                      data/Boundary/Basin_Tide_Boundary_2010_2015.csv
-br BASINRAIN, --basinRain BASINRAIN
                      Daily rain data file: -br
                      data/Rain/DailyRainFilled_cm_1999-9-1_2015-12-8.csv
-bc BASINBCFILE, --basinBCfile BASINBCFILE
                      Basin boundary condition data files: -bc
                      data/Boundary/Basin_Boundary_Condition.csv
-bf BASINFIXEDBCFILE, --basinFixedBCfile BASINFIXEDBCFILE
                      Basin fixed boundary condition data files: -bf
                      data/Boundary/Basin_Fixed_Boundary_Condition.csv
-bo BASINOUTPUTDIR, --basinOutput BASINOUTPUTDIR
                      Directory to write basin outputs: -bo
                      /home/jpark/BAM.out
```

```

-bR BASINSTAGERUNOFF, --basinStageRunoff BASINSTAGERUNOFF
    Daily runoff EDEN stage data file: -bR
    data/Runoff/EDEN_Stage_OffsetMSL.csv
-bS BASINSTAGERUNOFFMAP, --basinStageRunoffMap BASINSTAGERUNOFFMAP
    Mapping of EDEN stage to basin: -bS
    data/Boundary/Basin_Runoff_Boundary.csv
-bs BASINSTAGE, --basinStage BASINSTAGE
    Daily stage data file: -bs
    data/Stage/DailyStage_1999-9-1_2016-3-1.csv
-et ET, --ET ET      PET data file: -et data/ET/PET_1999-9-1_2015-12-8.csv
-es ET_SCALE, --ET scale ET_SCALE
    Scale factor on global ET: -es 2
-s SHOALSHAPEFILE, --shoals SHOALSHAPEFILE
    Shoals shape file: -s data/GIS/FathomLines
-sp SHOALPARAMETERS, --shoalParameters SHOALPARAMETERS
    Shoal to basin mapping file:-sp
    data/init/Shoal_Parameters.csv
-sl SHOALLENGTH, --shoalLength SHOALLENGTH
    Shoal width and length depth input file:-sl
    data/init/Shoal_Length_Depth.csv
-sm SHOALMANNING, --shoalManning SHOALMANNING
    Manning friction for all shoals: -sm 0.1
-sf SALINITYFILE, --salinityFile SALINITYFILE
    Daily salinity data file: -sf data/Salinity/DailySalin
    ityFilled_1999-9-1_2015-12-8.csv
-msl SEASONALMSL, --seasonalMSL SEASONALMSL
    Seasonal MSL: -msl data/Tide/MSL_Anomaly.csv
-si SALINITYINIT, --salinityInit SALINITYINIT
    Initialize basin salinity from gauge data.
-gs, --gaugeSalinity  Impose basin gauge salinity where available.
-e EDITOR, --editor EDITOR
    Editor: -e gedit
-r RUNID, --runID RUNID
    Run ID for output files: -r RunID
-rf RUNINFOFILE, --runInfoFile RUNINFOFILE
    File for model run messages: -rf RunInfo.txt
-oi OUTPUTINTERVAL, --outputInterval OUTPUTINTERVAL
    Time interval (hr) of output data: -oi 1
-mi [MAPINTERVAL [MAPINTERVAL ...]], --mapInterval [MAPINTERVAL [MAPINTERVAL ...]]
    Time interval of display refresh in (days) and [(hr)]:
    -mi 1 [0]
-L STAGELEGENDBOUND, --stageLegend STAGELEGENDBOUND
    Stage legend bound on map: -L 0.5
-P SALINITYLEGENDBOUND, --salinityLegend SALINITYLEGENDBOUND
    Salinity legend bound on map: -P 50
-fb, --fixedBoundaryConditions
    Enable fixed boundary conditions for basins.
-nb, --noDynamicBoundaryConditions
    Disable basin dynamic boundary conditions.
-nr, --noRain
    Disable rain inputs.
-ne, --noET
    Disable ET inputs.
-nR, --noStageRunoff
    Disable EDEN stage runoff inputs.
-nt, --noTide
    Disable tidal boundary inputs.
-nm, --noMeanSeaLevel
    Disable mean sea level inputs.
-ng, --noGUI
    Disable GUI.
-D, --DEBUG
-DA, --DEBUG_ALL

```

7 Graphical User Interface

The graphical user interface (GUI) is enabled by default (figure 9). The GUI can be disabled with the `-ng --noGUI` option. The GUI Map updates a color-coded representation of basin stage or salinity during a run at intervals specified by the `-mi [--mapInterval]` option (default: 1 day, 0 hours). Since the function which executes a model run (`Model.Run()`) is not exposed to the GUI main loop, there is currently no user interaction processed during a model run. This may change in future versions.

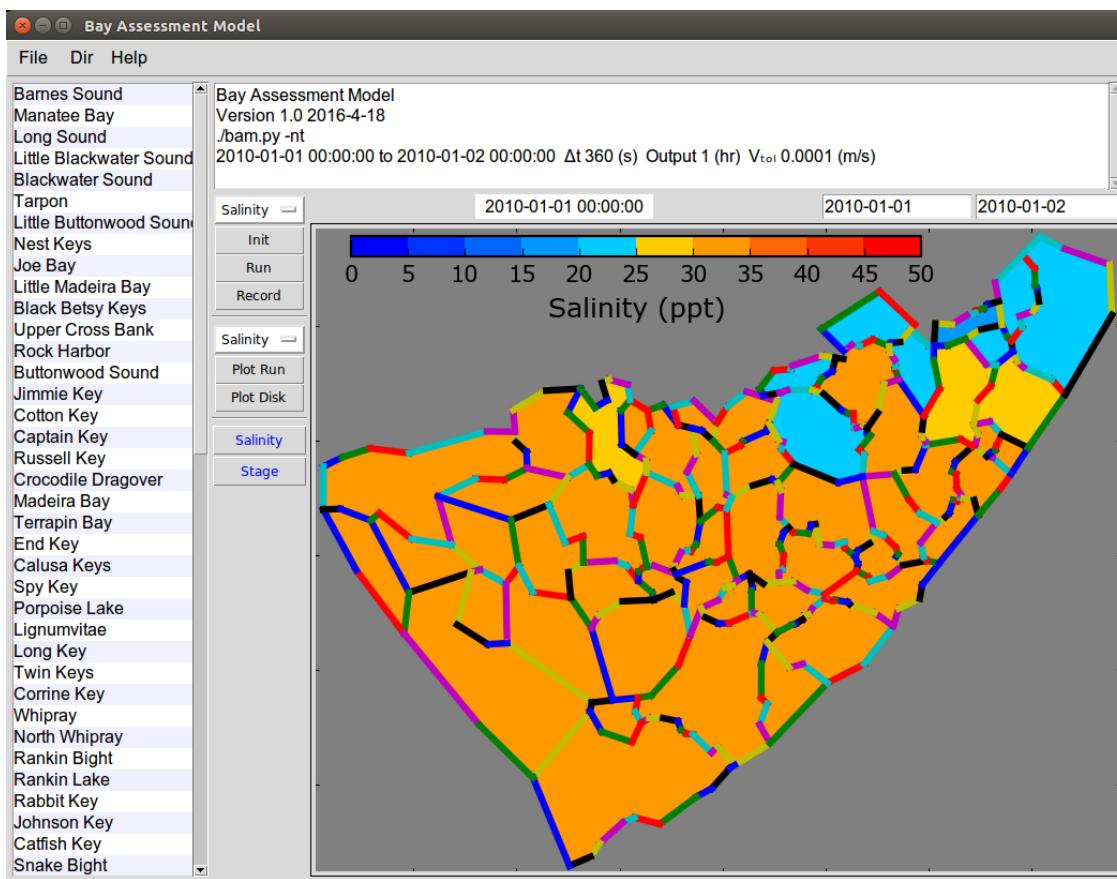


Figure 9.
BAM graphical user interface.

The main window is divided into 6 sections:

1. Menu bar
2. Basin listbox
3. Message window
4. Run and Plot controls
5. Time display and entry boxes
6. Map

each described below.

7.1 Menu

7.1.1 File : Init

The **File : Init** menu opens a dialogue box allowing the user to select a file to initialize basin variables. The default is `Basin_Initial_Values.csv`.

7.1.2 File : Edit

File : Edit opens a dialogue box allowing the user to specify a file to be edited. The editor which is invoked is specified with the `-e [--editor]` option (default: `gedit`).

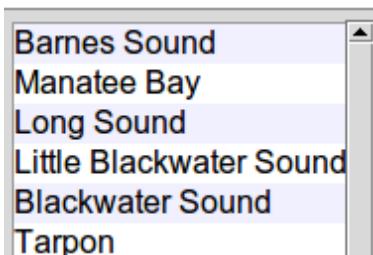
7.1.3 Dir : Plot Disk

The **Dir : Plot Disk** menu opens a dialogue box specifying the directory location of output data files to be plotted when the **Plot Disk** button is pressed. The default is either the previous value of this dialogue selection, or the value of the `HOME` environment variable if defined, or the current working directory.

7.1.4 Dir : Output

Dir : Output opens a dialogue box specifying the directory location to write output data files. The default is either the previous value of this dialogue selection, or the value of the `HOME` environment variable if defined, or the current working directory.

7.2 Basin listbox



The basin listbox allows the user to select any combination of basin objects with the mouse. Single basins are also selected if clicked on the map. When a basin is selected its current information is printed in the message window. The basin listbox is also used to select basins for plot commands.

7.3 Run and Plot

These selectors and buttons control the map display and plotting options.



The top selector allows for either salinity or stage color graduations to be displayed on the map.

The **Init** button calls the model initialization function for the current model start, stop times and run options.

Run initiates model execution.

Record raises a pop-up window of check button selectors to specify which basin variables will be written to output.

The middle selector specifies the basin variable to be plotted.

Plot Run plots the currently selected variable from the model run for all basins selected in the basin list box.

Plot Disk plots the currently selected variable from the archive directory specified in the **Dir : Plot Disk** menu for all basins selected in the basin list box.

Salinity plots observed salinity data for basins selected in the basin list box where data is available.

Stage plots observed water level data for basins selected in the basin list box where data is available.

7.4 Message window

```
Bay Assessment Model
Version 1.0 2016-4-18
./bam.py -nt
2010-01-01 00:00:00 to 2010-01-02 00:00:00 Δt 360 (s) Output 1 (hr) Vtol 0.0001 (m/s)
```

The message window is a text box displaying messages and information on model objects. Messages generated during a model run are written to the `RunInfo.txt` file in the model output directory.

7.5 Time



Current model time is displayed above the map in a message box. Two text entry boxes are located on the right above the map. The text entry on the left can be used to set the model simulation start time, the text entry on the right to set the model simulation end time.

Simulation start and stop times can also be set with the `-S [--start]` and `-E [--end]` command line options.

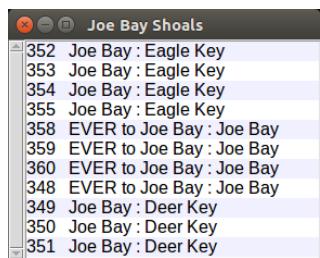
Two formats are supported for time entry: `YYYY-MM-DD` and `YYYY-MM-DD HH:MM`.

7.6 Map

The map is an interactive display of two GIS shapefiles, the basins shapefile (`-bn [--basins]` default: `FLBayBasins`) and the shoals shapefile (`-s [--shoals]` default: `FathomLines`).

The map will display color graduations of basin state variables salinity or stage as specified with the selector (section 7.3). Shoals are shown with a random color assignment to allow easy visualization.

Left-mouse-click on a basin will select the basin in the basin list box and will display current basin state variables in the message box. Left-mouse-click on a shoal will display current shoal state variables in the message box.



Right-mouse-click on a basin will present a list box with all shoals associated with the basin. Selecting a shoal in the list box will display current shoal state variables in the message box.

8 Mass Balance Check

To check mass balance turn off all normal inputs and specify a fixed flow (-fb [--fixedBoundaryConditions]) into Blue Bank with 1000 m³/s, t = 1 s timestep and all shoal Mannings coefficients of 0.1. The -bf [--basinFixedBCFile] file would be:

```
Basin, Name,      Type, Value
56,   Blue Bank, flow, 1000
```

The command line:

```
./bam.py -t 1 -E "2010-1-1 08:00" -nt -nm -ne -nr -nR -nb -fb -si 'n' -sm 0.1
```

Blue Bank should then equilibriate at 8 hours to:

```
Blue Bank : dt = 1 s
Stage: 0.01 (m)
Salinity: 17.77 (g/kg)
Volume: 0.0425 (km^3)
Shoal Flux: 1000.0 (m^3/s)
```

Independent mass balance calculations and verification are detailed in etc/Notes.txt.

9 Salinity Check

Salinity computations can be checked with a fixed flow (-fb [--fixedBoundaryConditions]) into Blue Bank with 1000 m³/s, t = 1 s timestep and all shoal Mannings coefficients of 0.1. Initial salinity in Blue Bank and surrounding basins is 35 (g/kg). With the command line:

```
./bam.py -t 1 -E "2010-1-1 08:00" -nt -nm -ne -nr -nR -nb -fb -si 'n' -sm 0.1
```

Blue Bank should produce output:

Time	Salinity(ppt)	Stage(m)	Volume(m ³)	Flow(m ³ /dt)	Salt mass	Computed
2010-01-01 00:00:00	35	0	42277036.502	NA	1475257188737	35.00
2010-01-01 00:00:01	34.999	0	42278036.502	0	1475257188737	35.00
2010-01-01 00:00:02	34.998	0	42278968.321	68.182	1475254809583	35.00
2010-01-01 00:00:03	34.998	0	42279873.768	94.553	1475251510312	35.00
2010-01-01 00:00:04	34.997	0	42280759.225	114.543	1475247513617	35.00
...						
2010-01-01 07:59:56	17.774	0.01	42500628.472	1000	753148504363	17.77
2010-01-01 07:59:57	17.774	0.01	42500628.472	1000	753130783484	17.77
2010-01-01 07:59:58	17.773	0.01	42500628.472	1000	753113063021	17.77
2010-01-01 07:59:59	17.773	0.01	42500628.472	1000	753095342976	17.77
2010-01-01 08:00:00	17.773	0.01	42500628.472	1000	753077623348	17.77

Salt mass and Computed salinity are from independent spreadsheet calculations. Salinity verification can be found in etc/BlueBankSalinity-Q+1000cms_dt1.ods.

10 Runoff Calibration

Runoff from the Everglades to coastal basins is determined by the relative water level elevation between the Everglades and coastal basins. This allows for both positive and negative runoff between the Everglades and coastal basins. Shoal properties of the coastal basins (length, width, depth) have been calibrated to match aggregate runoff from the FATHOM model (*Cosby et al.*, 2010) over the rainy seasons of 2001, 2002 and 2003, the three years of overlap between BAM and FATHOM. Plots shown below compare the calibrated basin runoff and FATHOM values. It should be noted that FATHOM values are strictly negative (no flow is allowed from the coastal basins into the Everglades) and are available at only 1 point per month.

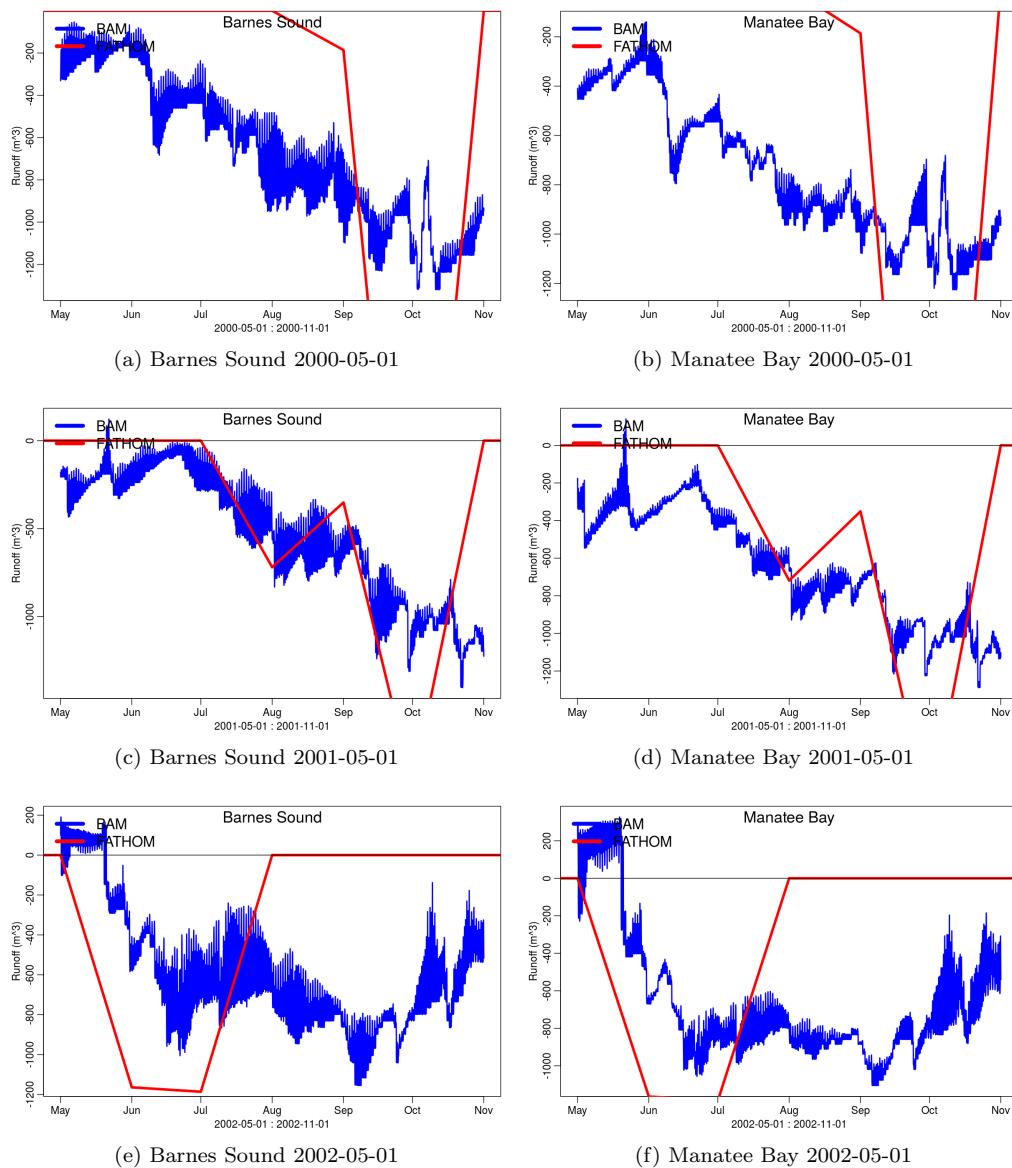


Figure 10. Barnes Sound and Manatee Bay Runoff

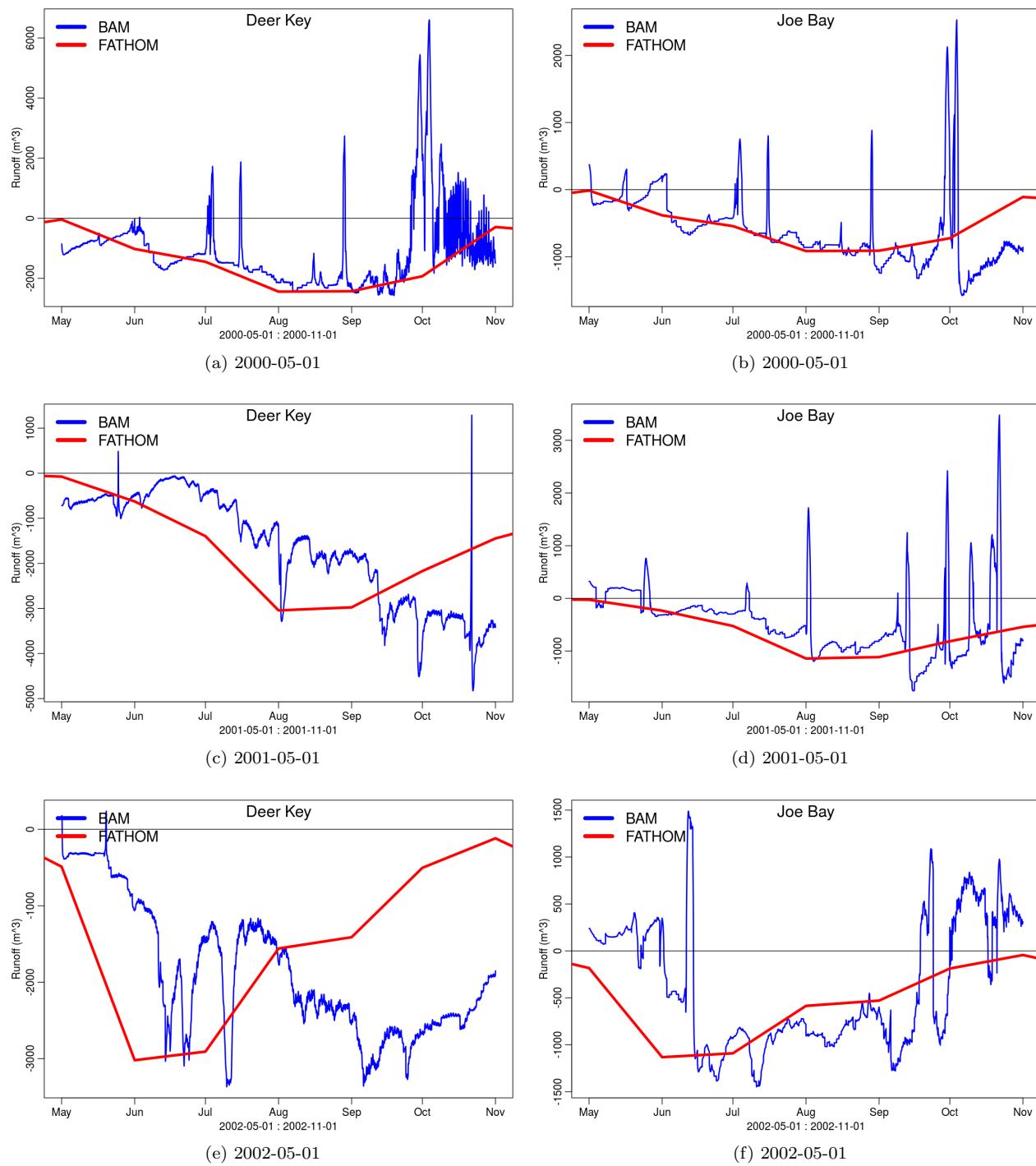


Figure 11. Deer Key and Joe Bay Runoff

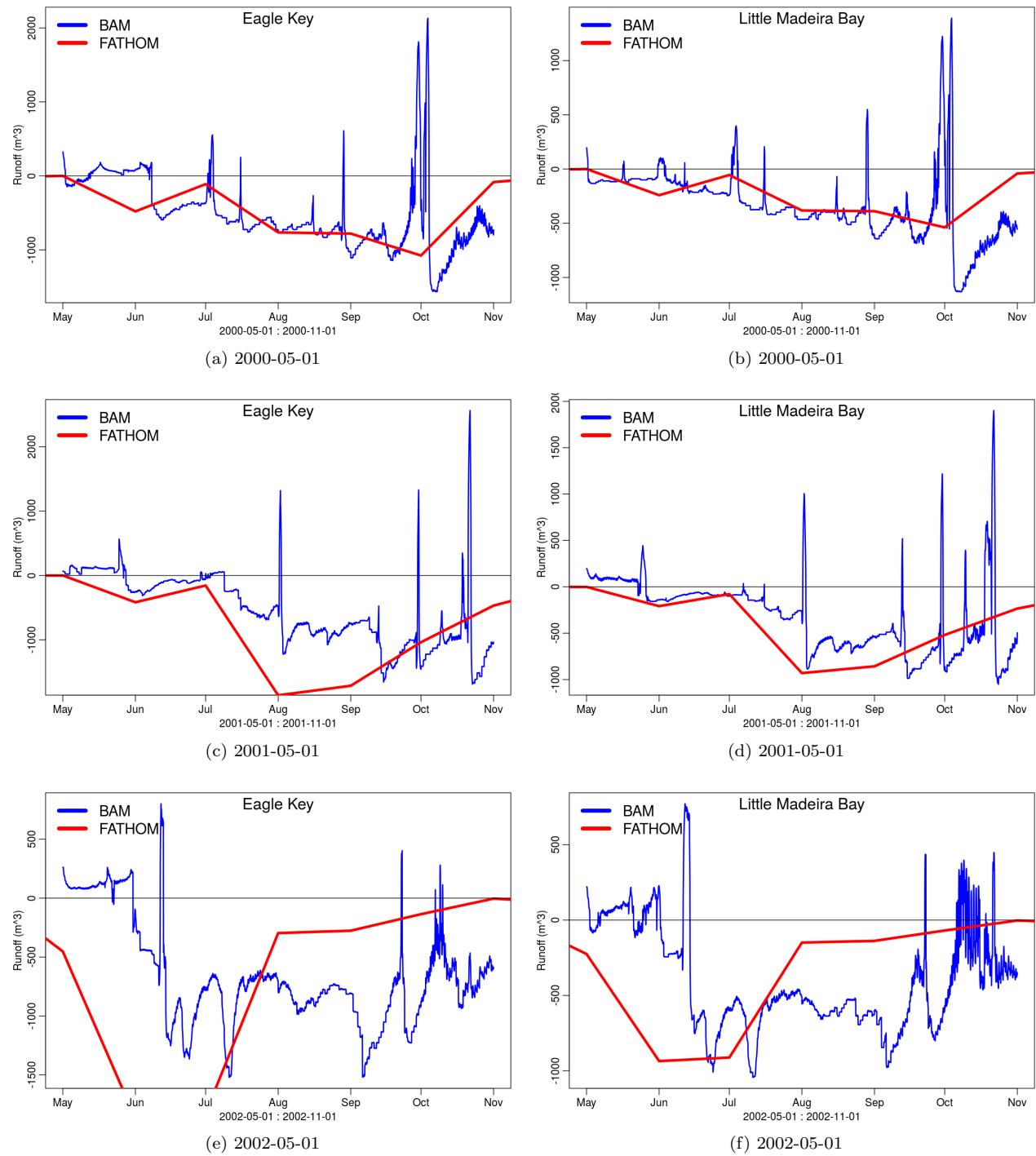


Figure 12. Eagle Key and Little Madeira Bay Runoff

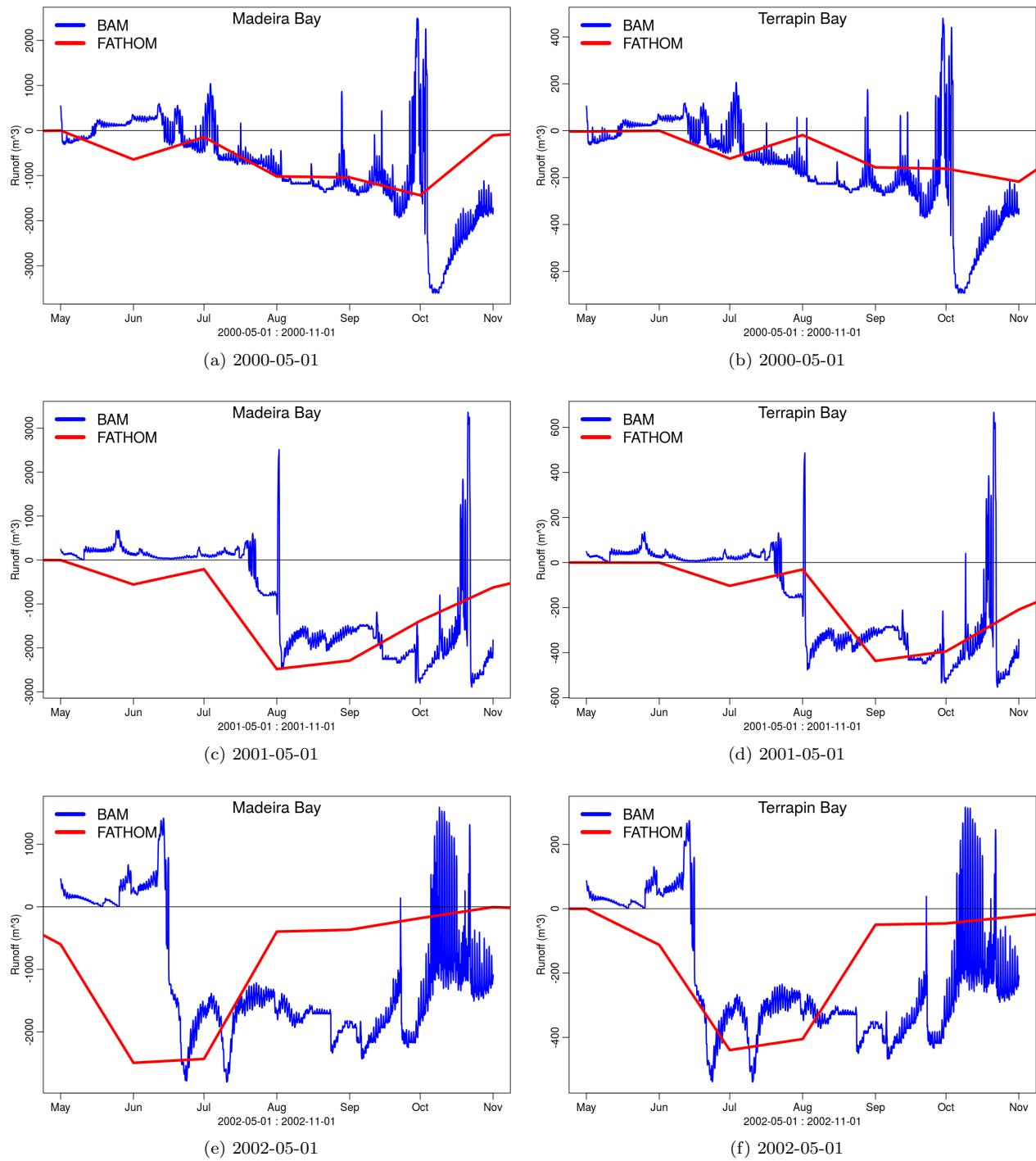


Figure 13. Madeira Bay and Terrapin Bay Runoff

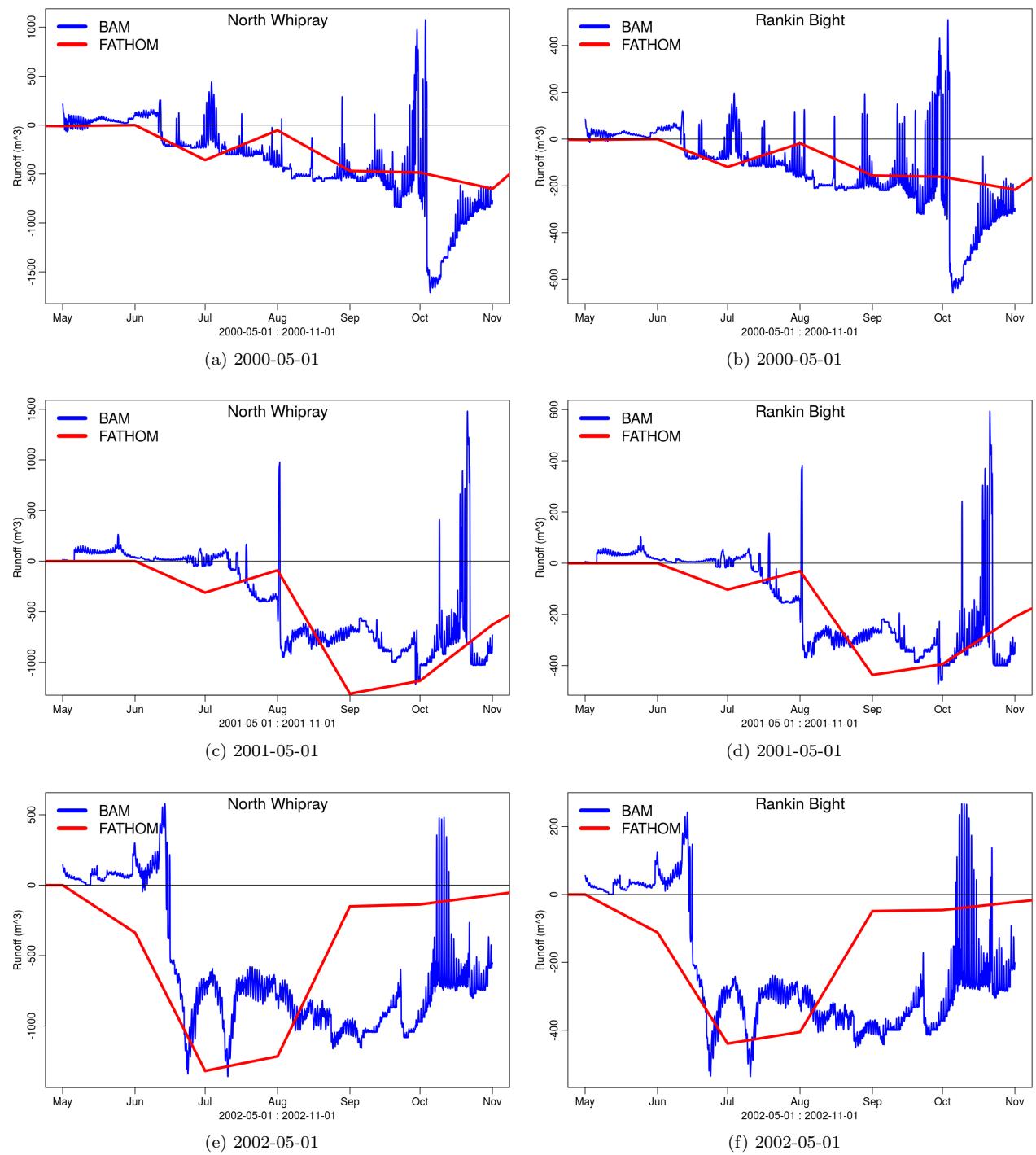


Figure 14. North Whipray and Rankin Bight Runoff

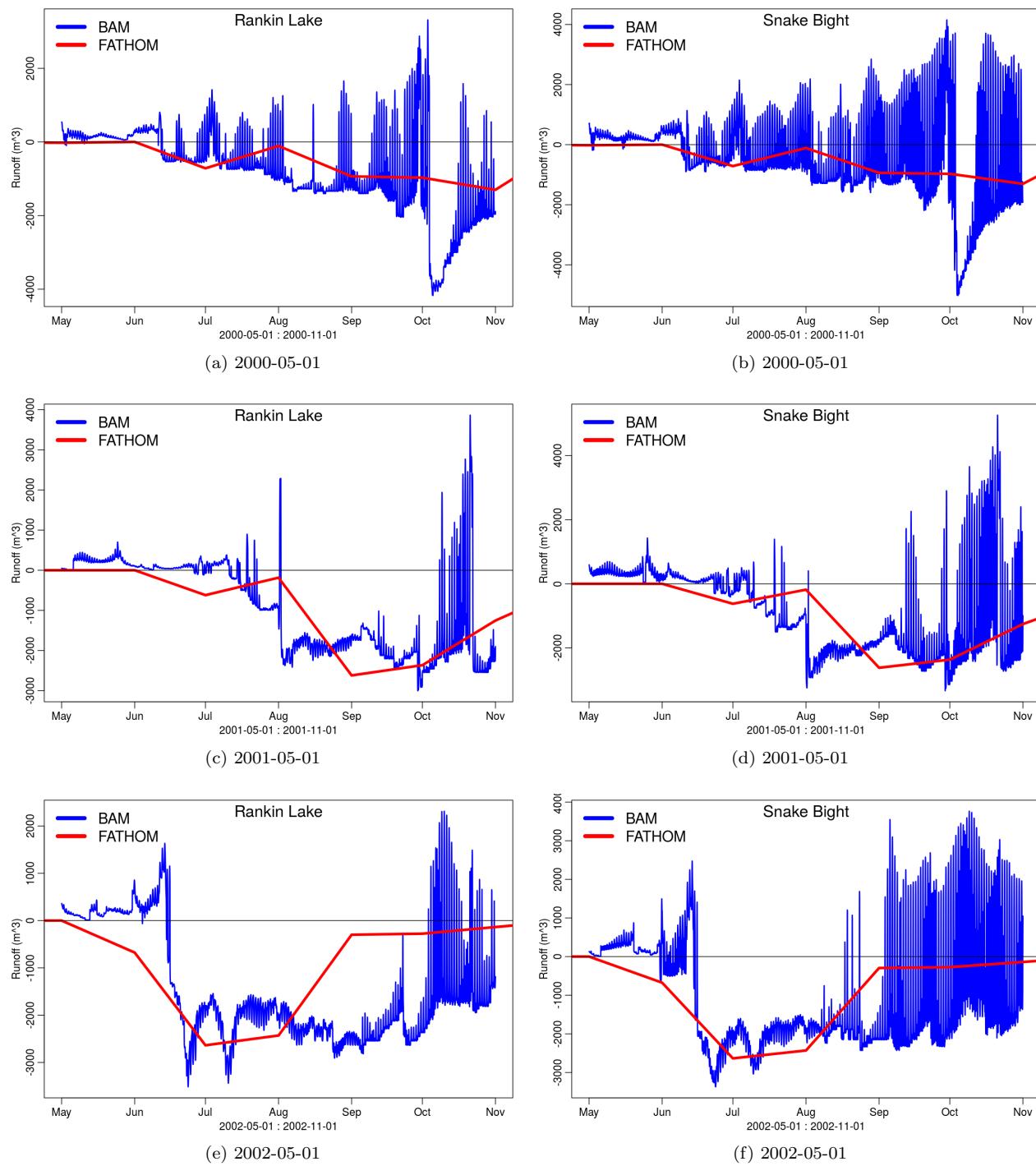


Figure 15. Rankin Lake and Snake Bight Runoff

11 Stage Comparison

Interbasin mass transport is driven by hydraulic potential between basins. Accurate water level simulation is a core competency for good model performance. This section presents comparisons of basin water levels computed by BAM (blue) and the associated marine monitoring station point-observations (red) over the period 2010-1-1 to 2015-12-1.

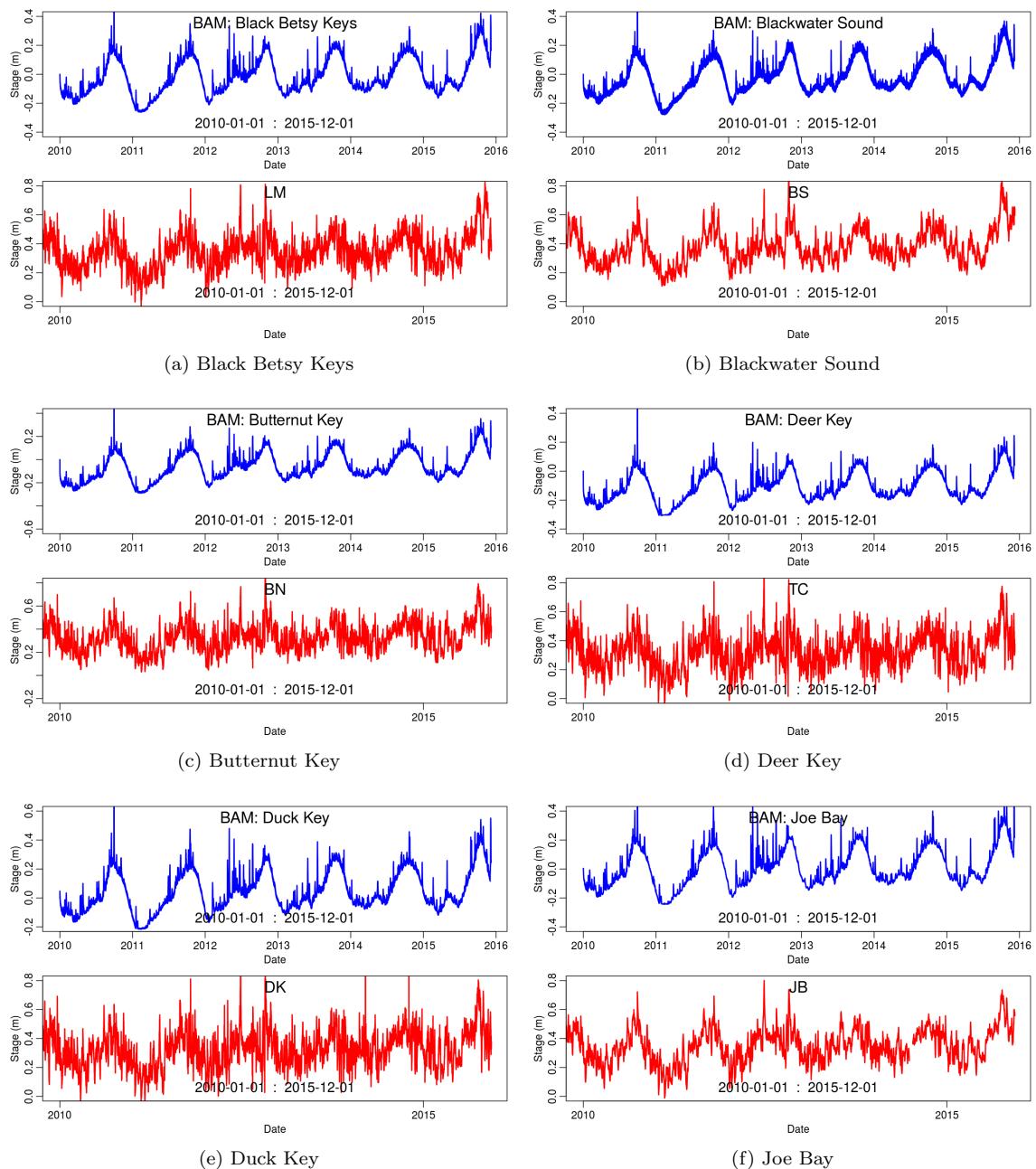


Figure 16. Water level comparisons: Black Betsy Keys, Blackwater Sound, Butternut Key, Deer Key, Duck Key and Joe Bay.

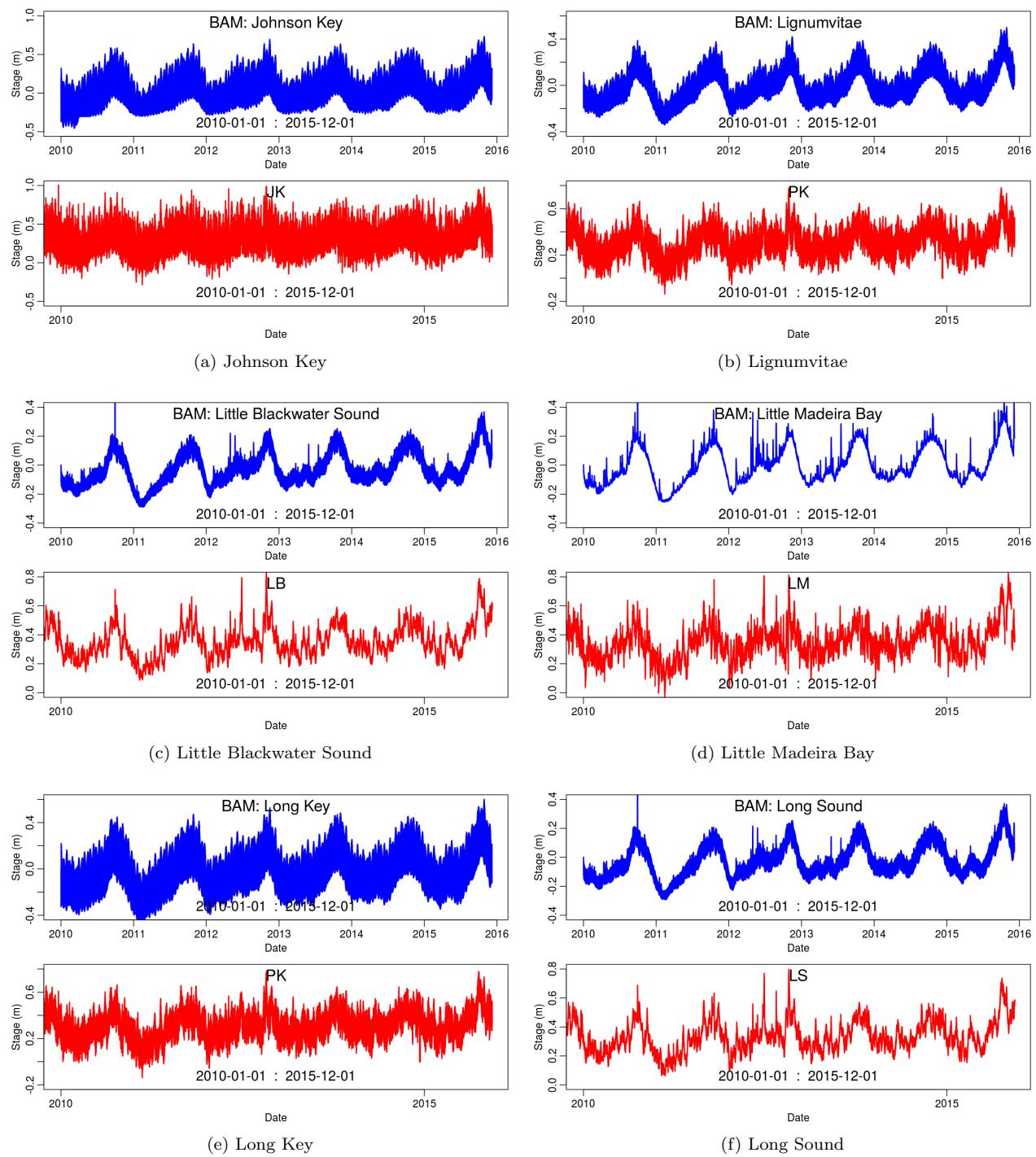


Figure 17. Water level comparisons: Johnson Key, Lignumvitae, Little Blackwater Sound, Little Madeira Bay, Long Key and Long Sound.

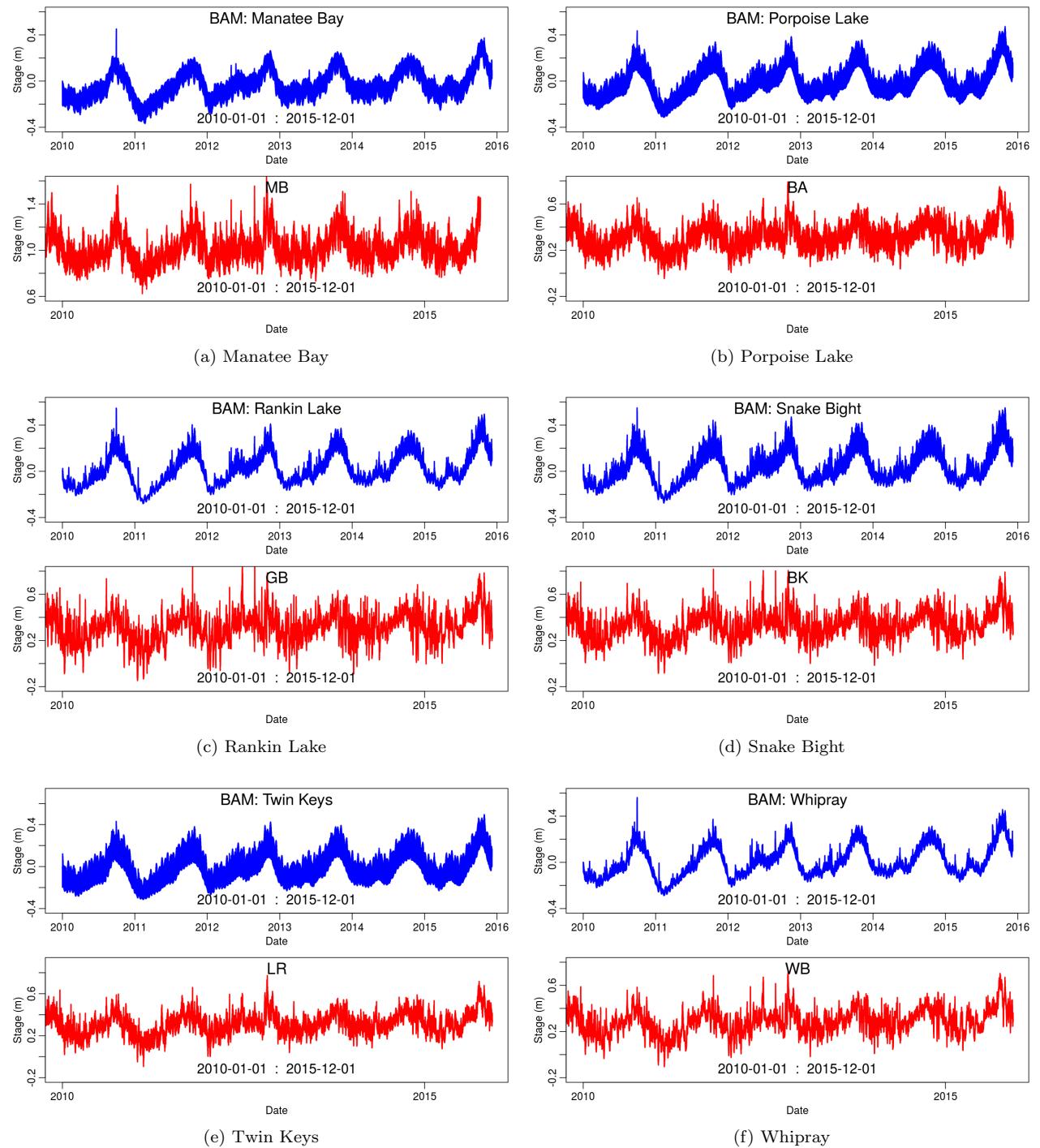


Figure 18. Water level comparisons: Manatee Bay, Porpoise Lake, Rankin Lake, Snake Bight, Twin Keys and Whipray.

12 Salinity Comparison

Salinity comparisons for the period 1999-9-1 to 2015-12-7 are shown in figure 19. Top panel is BAM output, bottom panel observed data.

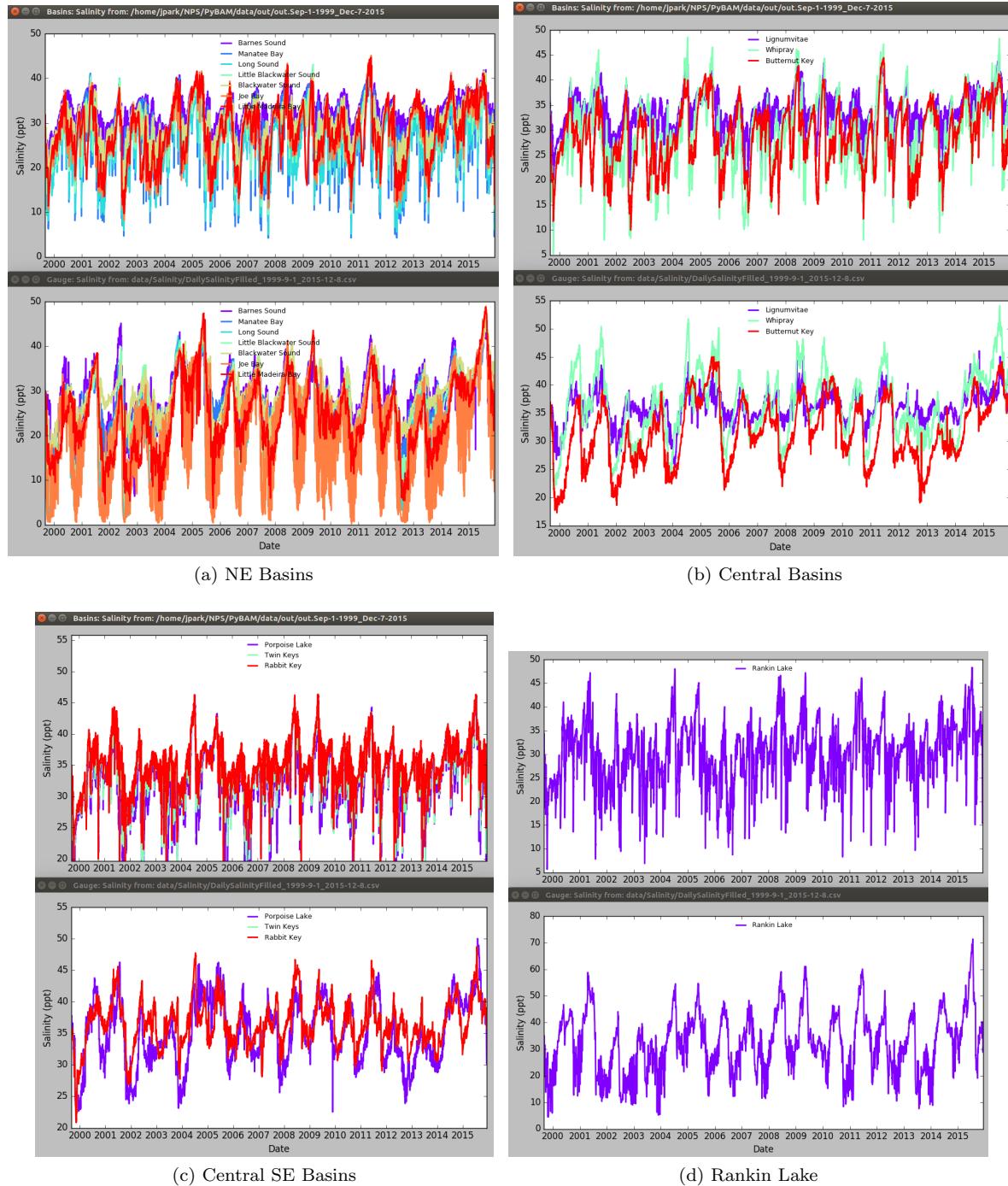
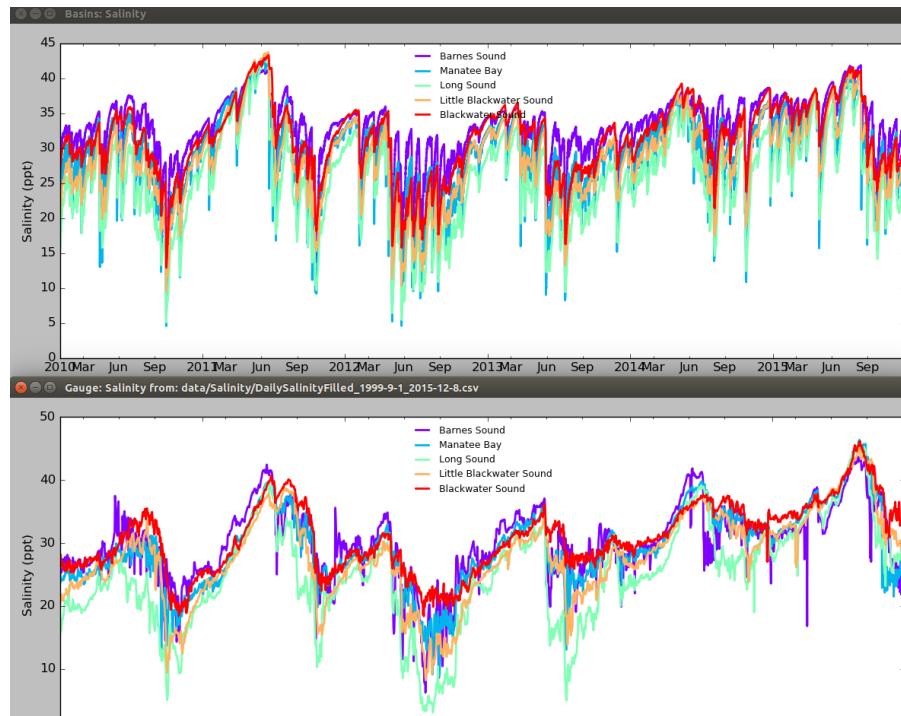
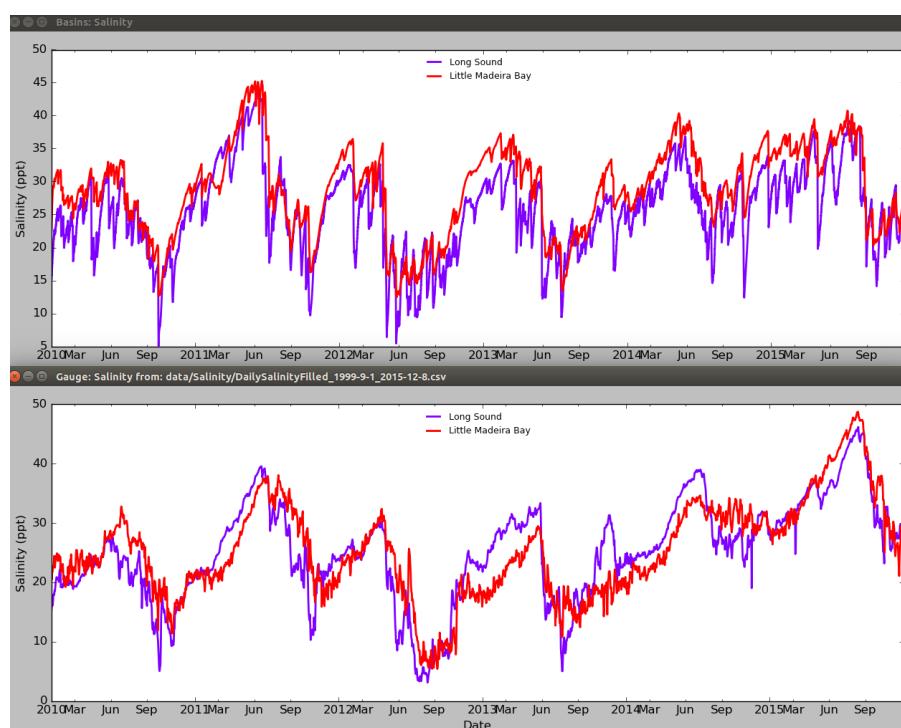


Figure 19. Salinity comparisons 1999-9-1 to 2015-12-7.

Salinity comparisons for the period 2010-1-1 to 2015-12-7 are shown in figure 19. Top panel is BAM output, bottom panel observed data.

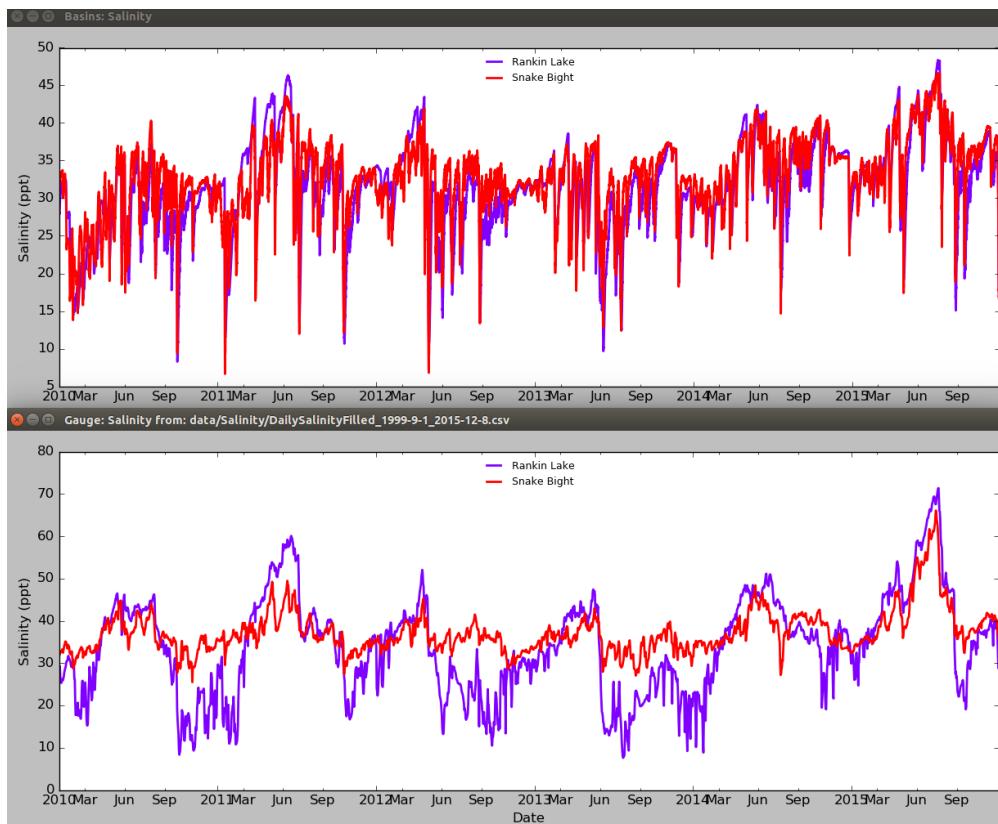


(a) NE Basins



(b) N Basins

Figure 20. Salinity comparisons 2010-1-1 to 2015-12-7.



(a) NW Basins

Figure 21. Salinity comparisons 2010-1-1 to 2015-12-7.

Salinity comparisons over the rainy seasons of 2000, 2001, and 2002 are shown below. Top panels are BAM output, bottom panels observed salinity. BAM values are basin-wide, observations are point measurements, and not necessarily in the same basin as the BAM output. In some cases multiple observations from adjacent basins are shown.

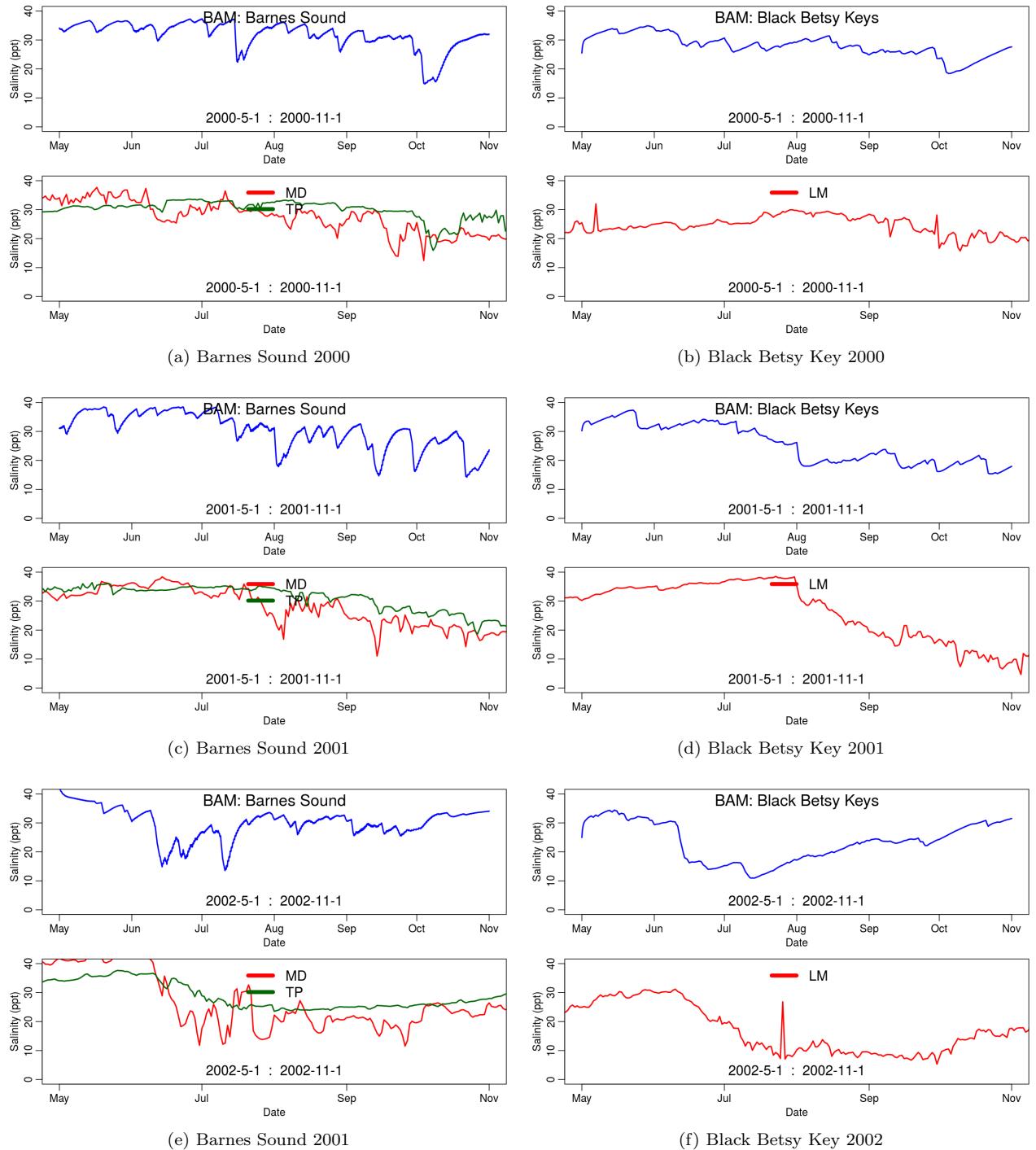


Figure 22. Salinity comparisons at Barnes Sound and Black Betsy Key 2000-2002.

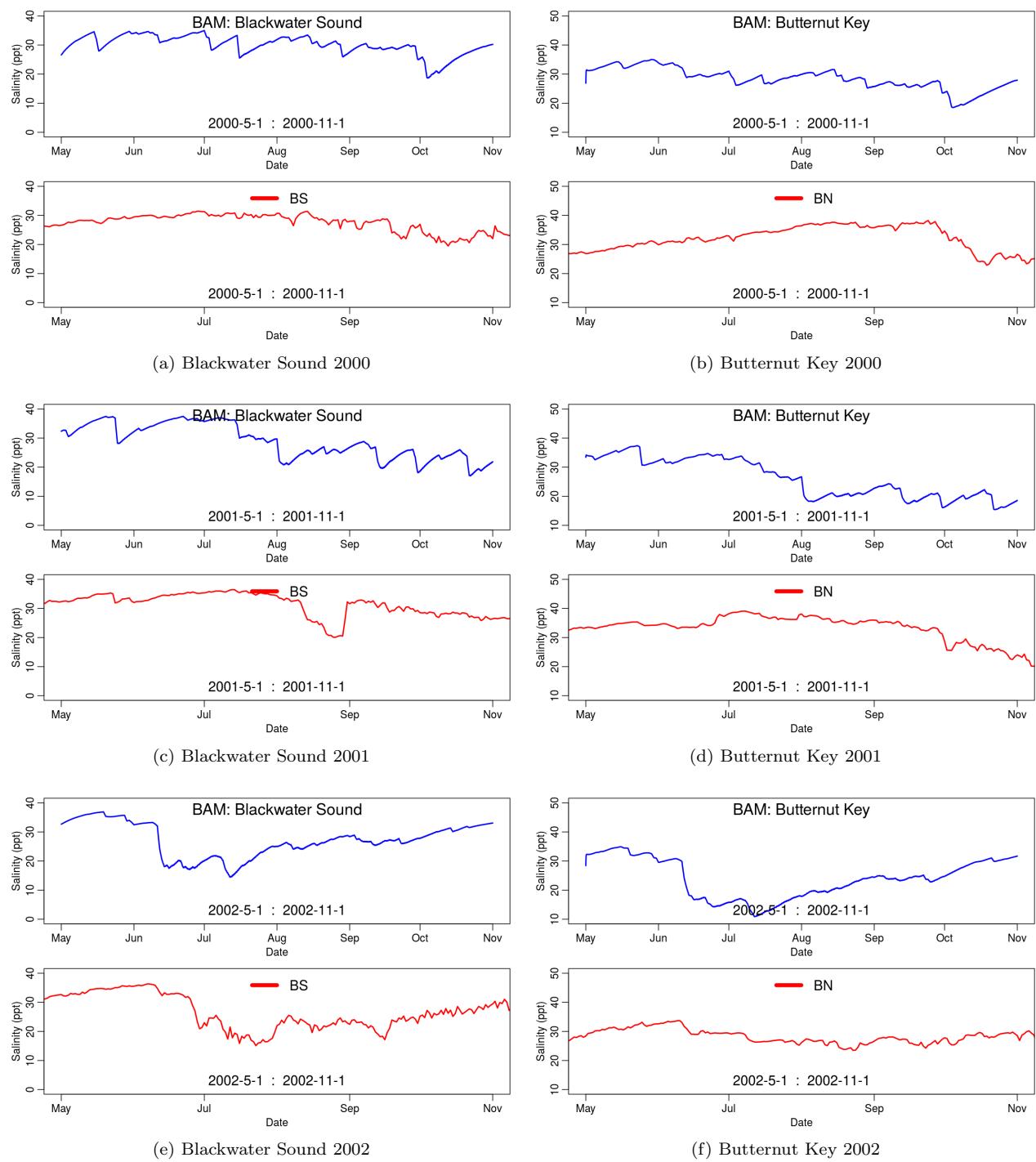


Figure 23. Salinity comparisons at Blackwater Sound, and Butternut Key 2000-2002.

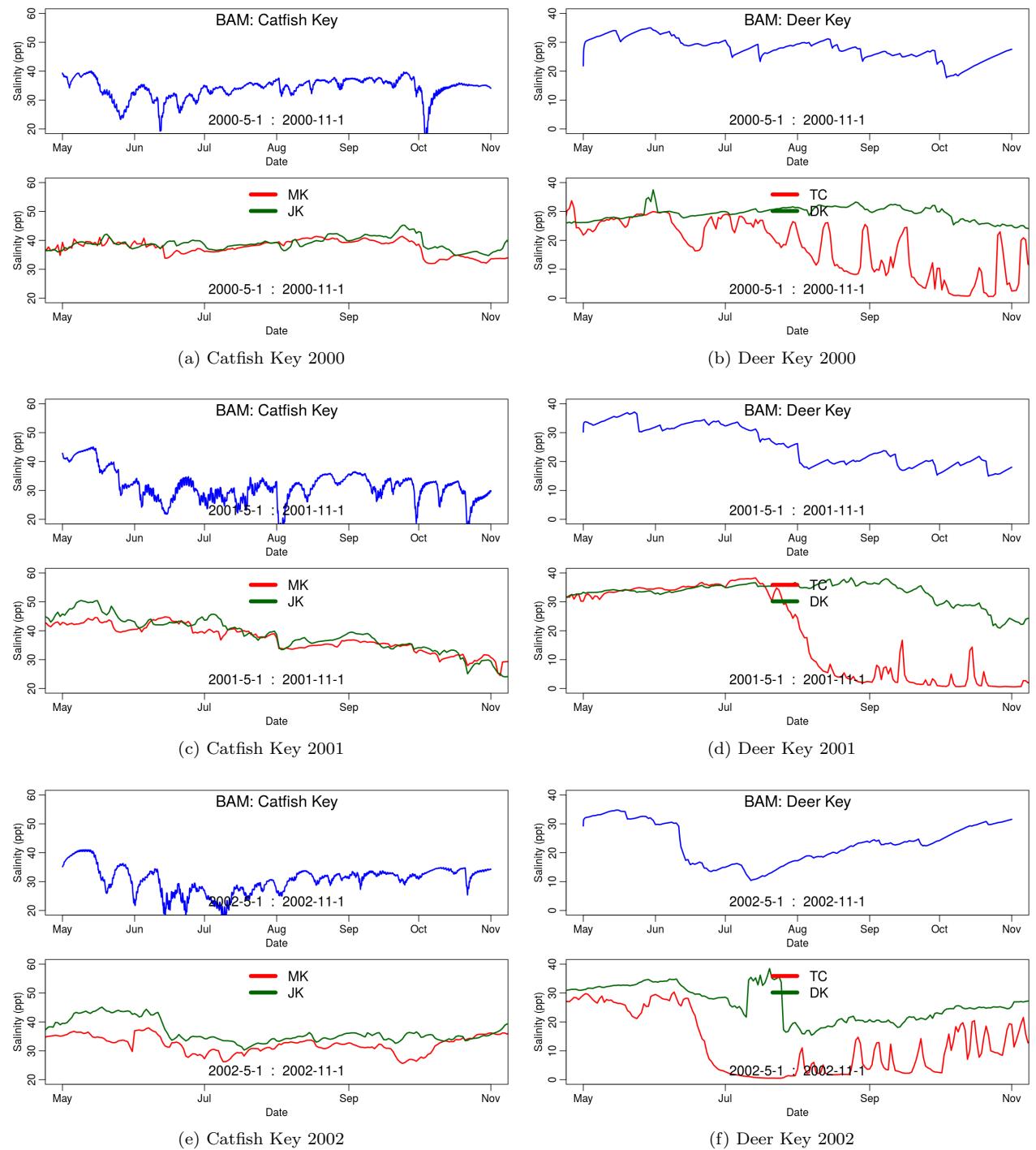


Figure 24. Salinity comparisons at Catfish Key and Deer Key 2000-2002.

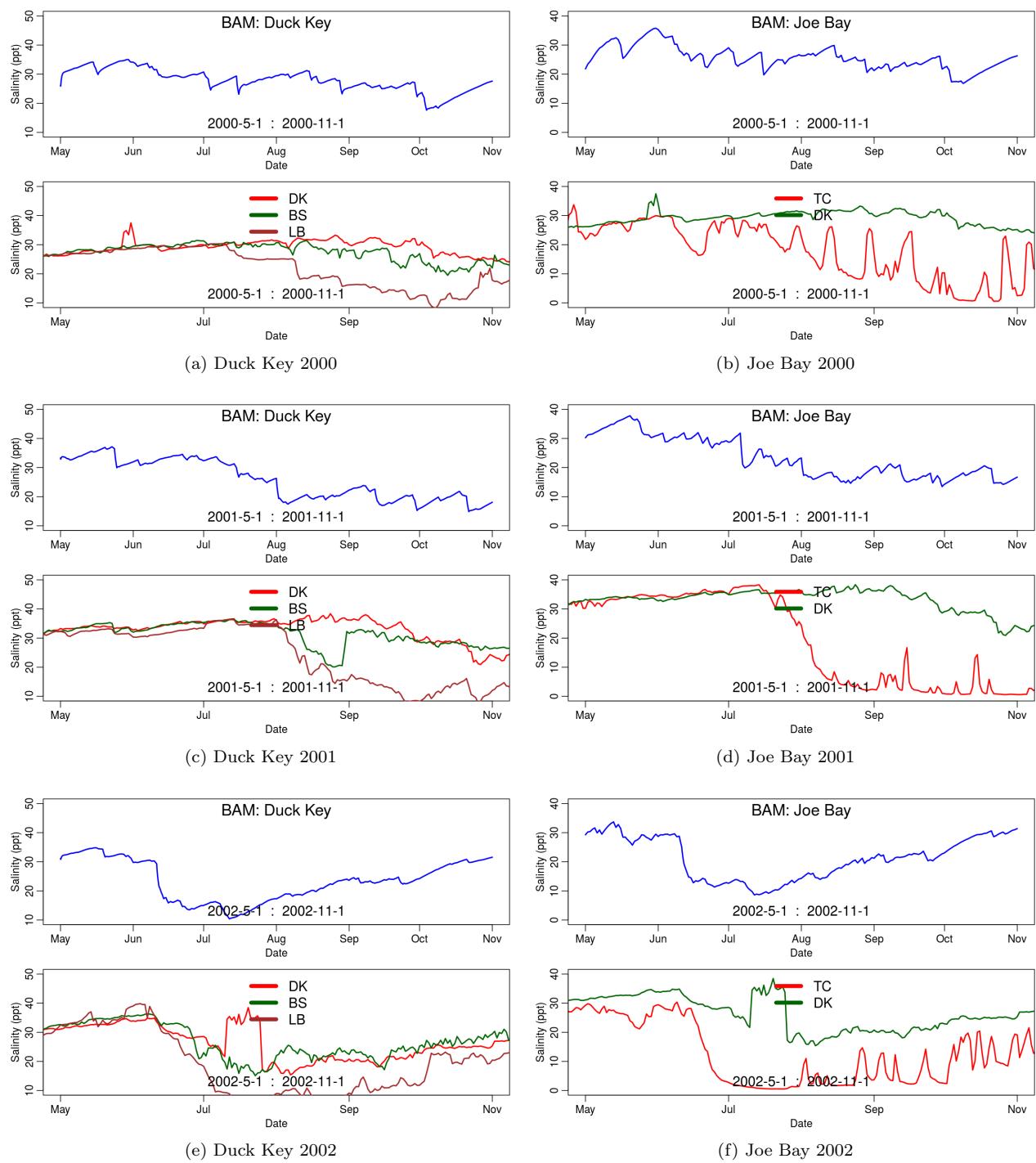


Figure 25. Salinity comparisons at Duck Key and Joe Bay 2000-2002.

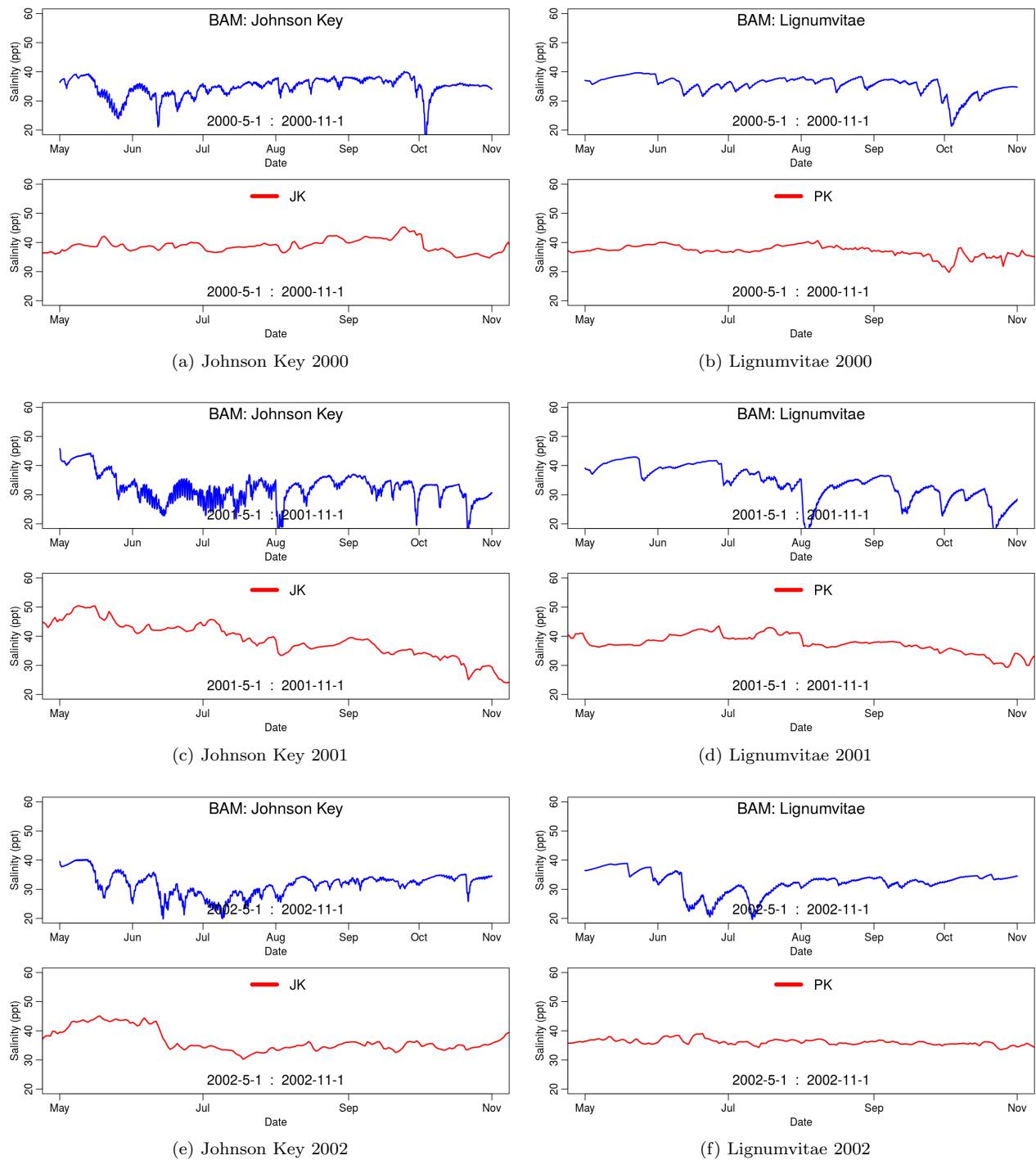


Figure 26. Salinity comparisons at Johnson Key and Lignumvitae 2000-2002.

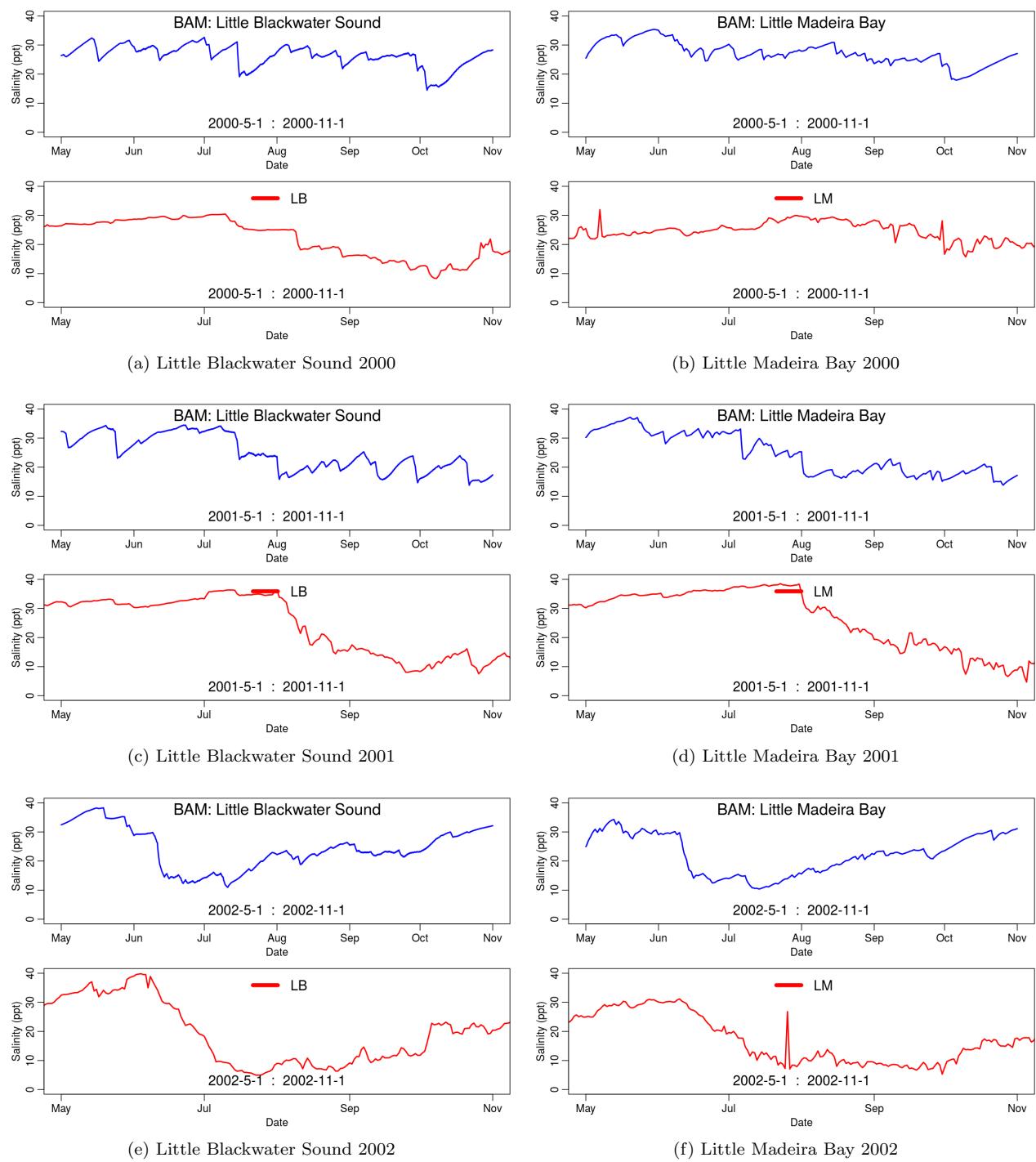


Figure 27. Salinity comparisons at Little Blackwater Sound and Little Madeira Bay 2000-2002.

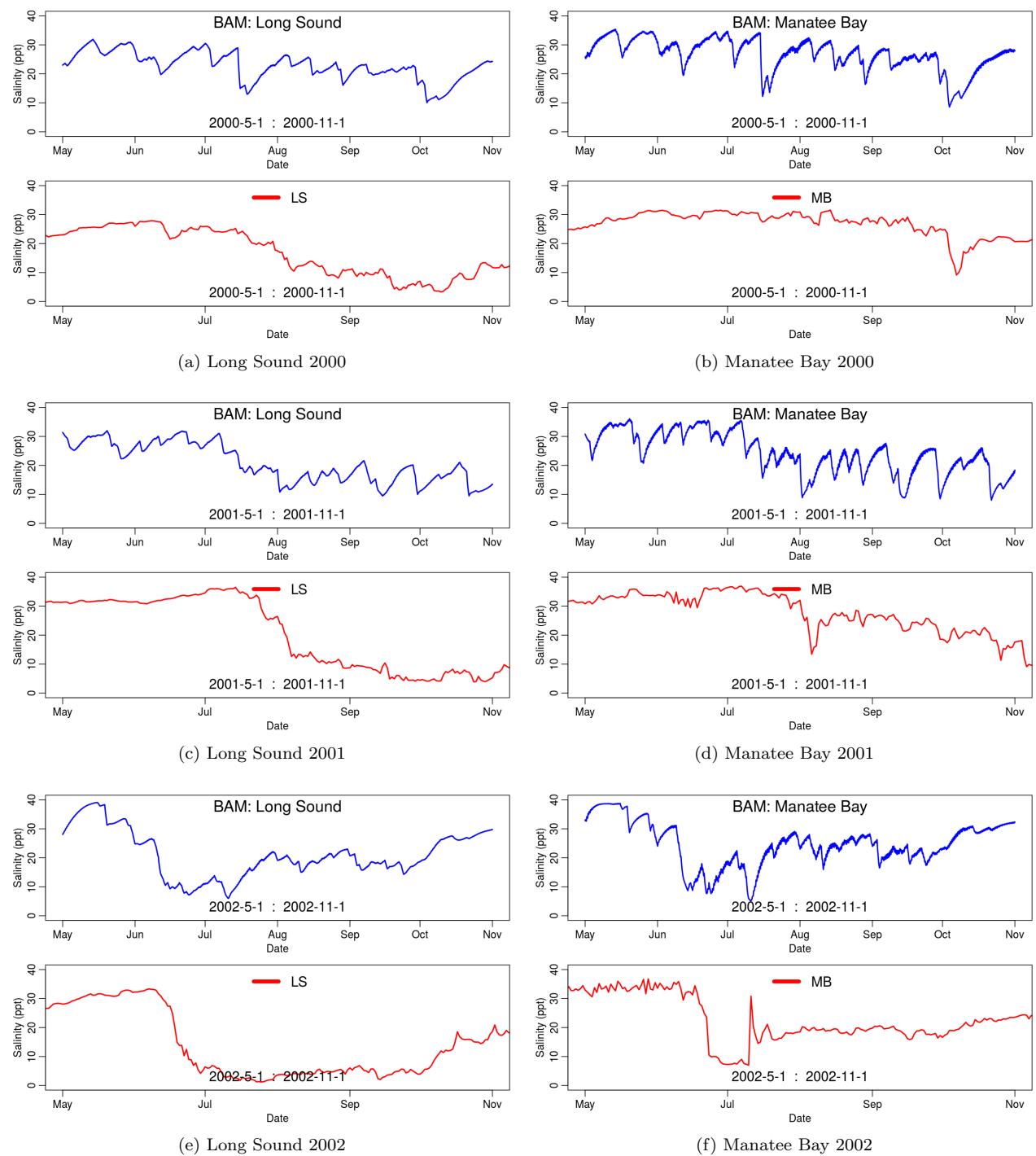


Figure 28. Salinity comparisons at Long Sound and Manatee Bay 2000-2002.

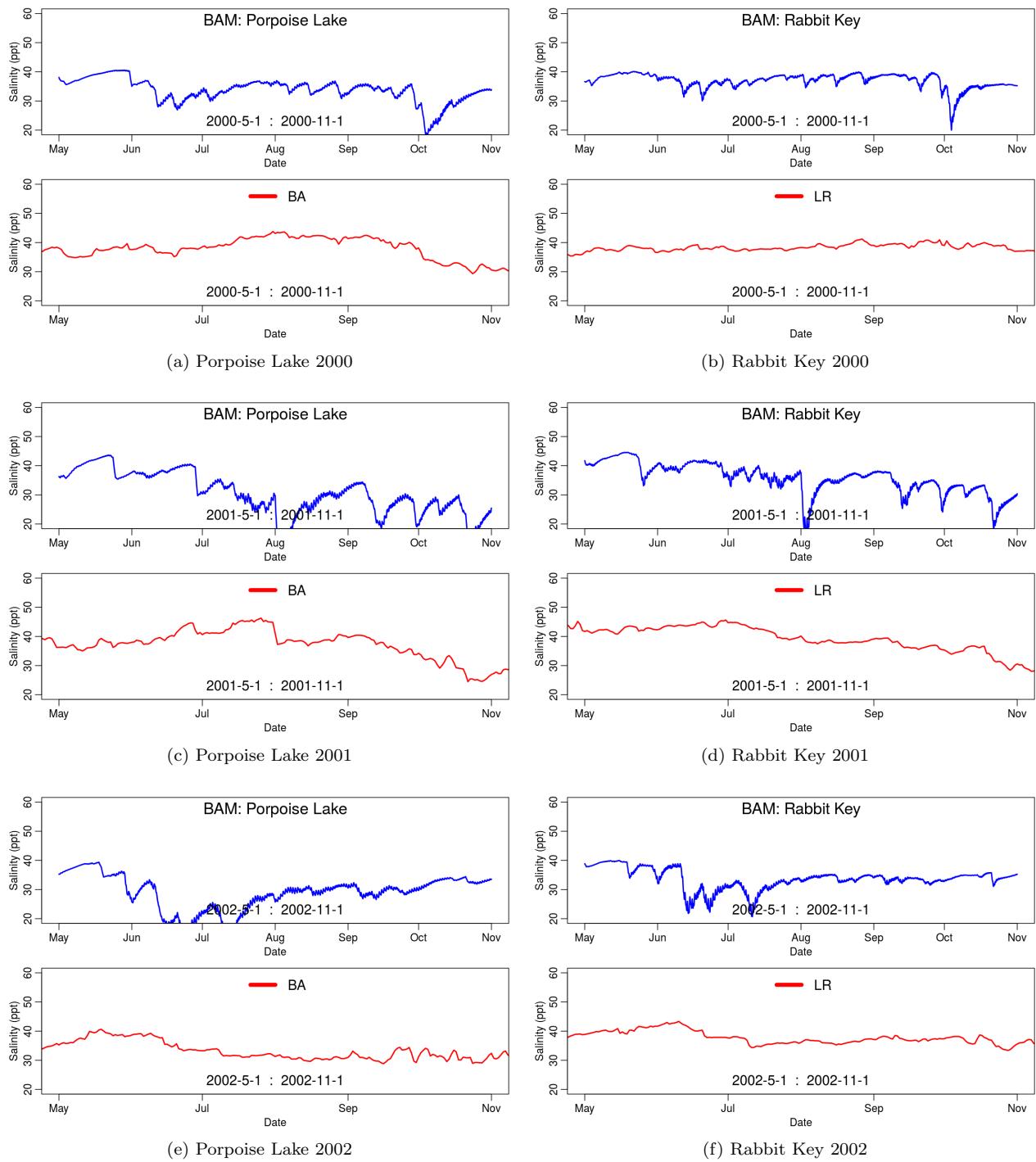


Figure 29. Salinity comparisons at Porpoise Lake and Rabbit Key 2000-2002.

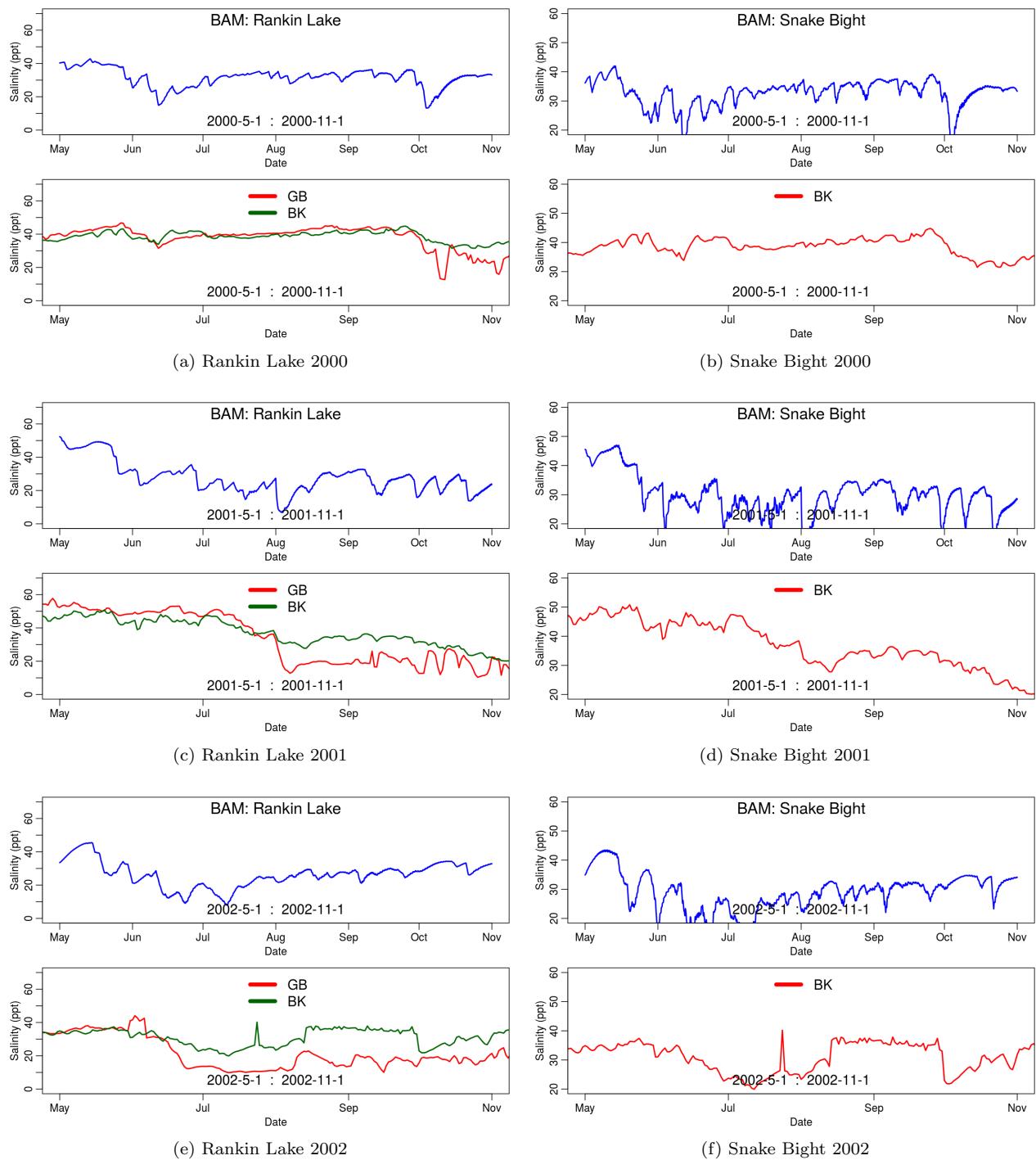


Figure 30. Salinity comparisons at Rankin Lake and Snake Bight 2000-2002.

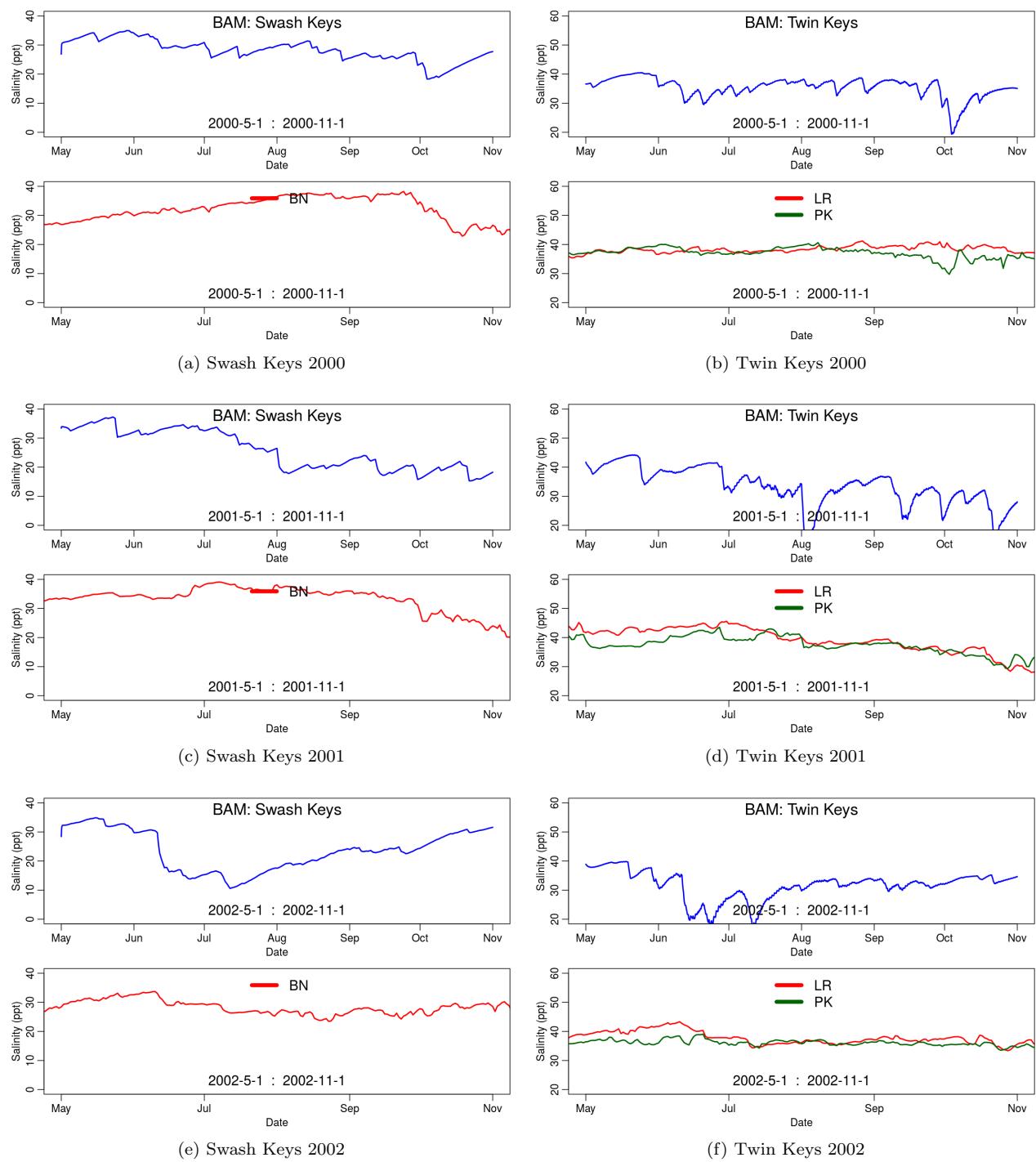


Figure 31. Salinity comparisons at Swash Keys and Twin Keys 2000-2002.

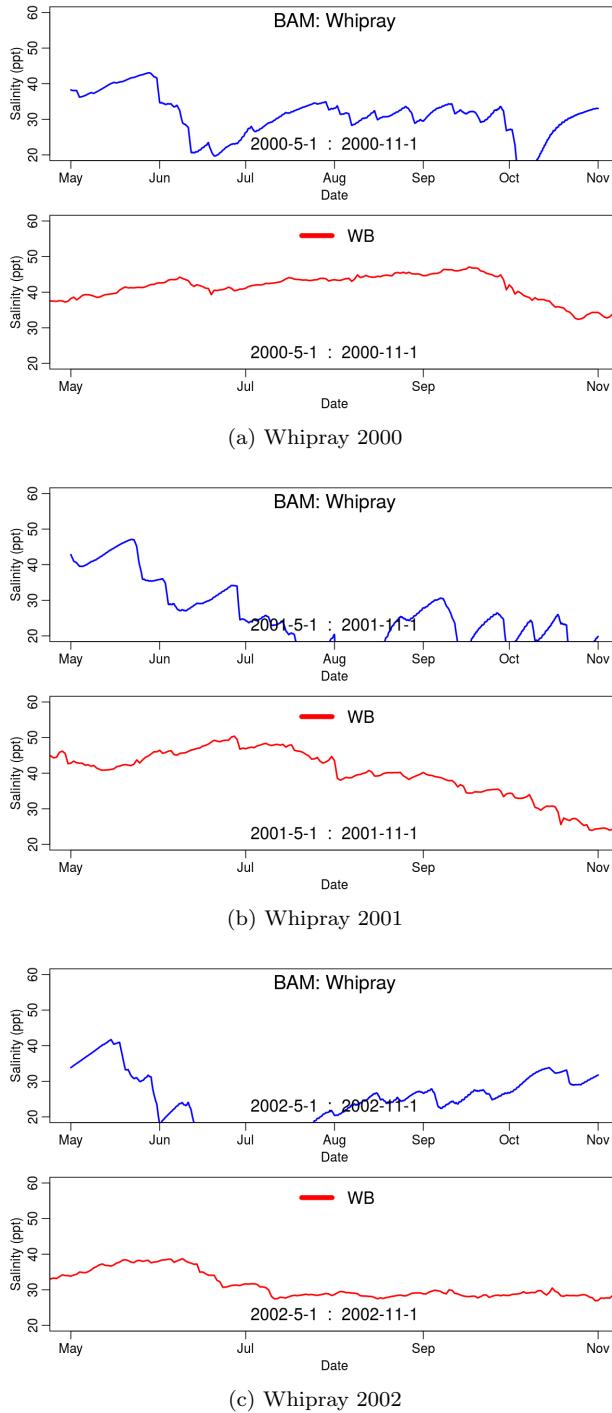


Figure 32. Salinity comparisons at Whipray 2000-2002.

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