IMPROVEMENTS TO FATHOM, A SALINITY AND WATER QUALITY MODEL FOR FLORIDA BAY – LESSONS LEARNED FOR EVERGLADES RESTORATION PLUS…

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The FATHOM Model
Version 6.10
Outline of Presentation

• Overview of FATHOM salinity and water quality model

• Update on FATHOM calibration/verification (calver) project

• Use of FATHOM to evaluate sea level rise and climate change scenarios

“Essentially, all models are wrong, but some models are useful.”
Florida Bay Study Area

FLORIDA BAY

FRESHWATER INFLOWS

SHARK RIVER SLOUGH DISCHARGE

FLORIDA BAY
What is FATHOM?

• Dynamic, mass-balance salinity and water quality model of Florida Bay
• Accounts for water and solute budgets in each of 54 well-mixed basins
• Designed to investigate circulation, salinity, and water quality in response to
  – runoff
  – rainfall
  – evaporation
  – tides
  – boundary salinity
Cal/Ver Activities

• FATHOM was never formally calibrated or verified (cal/ver)

• Steps taken to accomplish cal/ver exercise
  – Assemble data
  – Improve models for western boundary salinity conditions
  – Improve freshwater input distribution along north shore
  – Improve basin exchange model (internal to FATHOM) – Manning’s N coefficient
Improved western boundary conditions regressions

New Models

• SERC25 = 37.25 - (1.47*p33_depth) - (0.02*T21lag2) - (2.31 * kwwatlevlag2), R² = 0.75 (0.65)
• SERC26 = 38.7 - (0.01*T21lag2) - (-1.91*kwwatlevlag2) - (1.5*p33_depth) - (1.62*P33_depthlag3), R² = 0.74 (0.6)
• SERC27 = 38.05 - (0.02*T21lag2) - (1.13*kwwatlevlag3) - (1.83*P33_depthlag1) + (1.08*kwwatlev), R² = 0.65 (0.55)
• SECR28 = 38.12 - (3.03*P33_depthlag2) + (0.50*vwndmialag1) - (0.33*vwndkwlag1), R² = 0.56 (0.42)

• Summary: 10 – 14% improvement in simulation of boundary conditions
Improvements to Freshwater Flows

- Original FATHOM: freshwater flows estimated from SFWMM flows
- Improved cal/ver version: freshwater flows estimated from SFWMM stage
- Less error in SFWMM stage output data compared to SFWMM flow output data
Discharge to Florida Bay Simulated from SFWMM Flows

Discharge to Florida Bay Simulated from SFWMM Stage (water levels)
Improved freshwater inputs
Modeling Issues with Observed and Model-Produced Flows

- Observed and model-produced data have negative (upstream) flows
- FATHOM cannot handle negative flows
- All negative flows are set equal to 0 before input to FATHOM
- Unavoidable and adds to model output error
Model Performance: East Bay Region

Manatee Bay

Barnes Sound

Blackwater Sound

Little Blackwater Sound
Model Performance: North Bay Region

Long Sound

Little Madeira Bay

Joe Bay

Salinity vs. Time (Jan-96 to Jan-00)
Model Performance: Northeast Region

Duck Key

Park Key

Butternut Key

Salinity vs. Time

- Black line: serc9
- Red line: cv6_125r-47

- Black line: obs
- Red line: FATHOM

Map of the Northeast Region with regions labeled: West, South, Central, Northeast, North Bay, East Bay.
Model Performance: Central Region

Terrapin Bay

Rankin Lake

Whipray Basin

Salinity

obs  FATHOM
Model Performance: South Region

Captain Key Basin

Porpoise Lake

Peterson Keys
Model Performance: Western Region

Rabbit Key Basin

Salinity Units

Jan-96 Jan-97 Jan-98 Jan-99 Jan-00

serc18 Basin-38

Johnson Key Basin

Salinity Units

Jan-96 Jan-97 Jan-98

serc17 FATHOM
Summary and Conclusions of Cal/Ver Exercise

- Boundary salinity models upgraded
- Input flows upgraded
- Manning N upgraded
- Negative flows still an issue
- Upgrades have significantly improved FATHOM output using SFWMM input data
Part 2: Simulating Sea Level Rise (SLR) and Climate Change (CC) Effects in Florida Bay using FATHOM

- Base Case, six SLR scenarios, and seven CC scenarios were examined
- Scenarios run for the period 1991-2002
- Modifications were made to bathymetry
  - Added accretion and infill effects
  - Added overspill from northern embayments to mangroves
  - Increased size of northern embayments
- Transitions from base to final scenario values not simulated – all changed elements are at steady-state values or patterns
Simulating Sea Level Rise (SLR) and Climate Change (CC) Effects in Florida Bay using FATHOM

• SLR scenarios:
  – Two step changes of sea level rise (1’ and 2’)
  – Six bathymetric responses in Florida Bay
  – Climate drivers and boundary conditions constant for the SLR scenarios

• The CC scenarios:
  – Conditions changed one at a time; sea level constant (no SLR)
  – Rainfall: +20%; -20%
  – Runoff: +20%; -20%
  – Evaporation: +15%
  – Boundary salinity: +5%; -5%
SLR Scenarios for FATHOM Simulations

Rainfall 1991 – 2002 Monthly observed at ENP sites at Tavernier, Flamingo and Royal Palm (5 regions)


Runoff 1991 – 2002 Monthly estimates using empirical water budget (EWB) approach based on canals, rivers and wetlands rainfall excess

Boundary salinity 1991-2002 Monthly estimates using observed SERC salinity and regressions with Shark River flows for missing values

Sea Level 1991 – 2002 Monthly average sea level observed at Key West (NOAA)

Tides 28 day cycle (repeated) of hourly tides based on NOAA primary and secondary sites

Base Case - Basin areas, shoal lengths and bathymetric profiles as in FATHOM version 6.1 documentation and MFL

A1 - Basin water areas constant - no overspill to land, no in-fill
Shoal water lengths constant - no overspill to land, no accretion

B1 - Basin water areas constant - no overspill to land, in-fill
Shoal water lengths constant – no overspill to land, accretion

C2 - Basin water areas expand - overspill to land, no in-fill
Shoal water lengths expand - overspill to land, no accretion

D2 - Basin water areas expand - overspill to land, in-fill
Shoal water lengths expand - overspill to land, accretion

E2 - Basin water areas expand - overspill to land, no in-fill
Inland bays (JB, LS, LM only) inundate upstream wetlands
Shoal water lengths expand - overspill to land, no accretion

F2 - Basin water areas expand - overspill to land, in-fill
Inland bays (JB, LS, LM only) inundate upstream wetlands
Shoal water lengths expand - overspill to land, accretion
Climate Change Scenarios for FATHOM Simulations

Base Case - Basin areas, shoal lengths and bathymetric profiles as in FATHOM documentation and MFL study

- **Rainfall** 1991 – 2002: Monthly observed at ENP sites at Tavernier, Flamingo and Royal Palm (5 regions)
- **Boundary salinity** 1991-2002: Monthly estimates using observed SERC salinity and regressions with Shark River flows for missing values
- **Sea Level** 1991 – 2002: Monthly average sea level observed at Key West (NOAA)
- **Tides** 28 day cycle (repeated) of hourly tides based on NOAA primary and secondary sites

**G1 & G2** - Rainfall +/- 20% - Increase/decrease applied uniformly to each monthly rainfall total over the simulation period

**H1** - Evaporation + 15% - Increase applied uniformly to each monthly evaporation total over the simulation period

**I1 & I2** - Runoff +/- 20% - Increase/decrease applied uniformly to each monthly runoff total over the simulation period

**J1 & J2** - Boundary salinity +/- 5% - Increase/decrease applied uniformly to each monthly boundary salinity value over the simulation period
# Results: SLR Scenarios – Average Salinity 1991-2002

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>FL Bay</th>
<th>FL Bay*</th>
<th>N</th>
<th>E</th>
<th>NE</th>
<th>C</th>
<th>S</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Basin water areas constant - no overspill to land, no in-fill. Shoal water lengths constant - no overspill to land, no accretion.</td>
<td>8.6%</td>
<td>21.2%</td>
<td>58.3%</td>
<td>10.4%</td>
<td>16.5%</td>
<td>-0.4%</td>
<td>-0.5%</td>
<td>-0.1%</td>
</tr>
<tr>
<td>B1</td>
<td>Basin water areas constant - no overspill to land, in-fill (0-1 ft). Shoal water lengths constant – no overspill to land, accretion (0-1 ft).</td>
<td>4.1%</td>
<td>10.8%</td>
<td>31.5%</td>
<td>3.7%</td>
<td>8.6%</td>
<td>-0.8%</td>
<td>-0.5%</td>
<td>0.0%</td>
</tr>
<tr>
<td>C2</td>
<td>Basin water areas expand - overspill to land, no in-fill. Shoal water lengths expand - overspill to land, no accretion.</td>
<td>13.5%</td>
<td>33.6%</td>
<td>93.6%</td>
<td>15.5%</td>
<td>24.6%</td>
<td>0.5%</td>
<td>-0.6%</td>
<td>-0.1%</td>
</tr>
<tr>
<td>D2</td>
<td>Basin water areas expand - overspill to land, in-fill (0-1 ft). Shoal water lengths expand - overspill to land, accretion (0-1 ft).</td>
<td>10.4%</td>
<td>25.9%</td>
<td>73.4%</td>
<td>9.4%</td>
<td>19.8%</td>
<td>0.8%</td>
<td>-0.4%</td>
<td>0.0%</td>
</tr>
<tr>
<td>E2</td>
<td>Basin water areas expand - overspill to land, no in-fill. Inland bays (JB, LS, LM only) inundate upstream wetlands. Shoal water lengths expand - overspill to land, no accretion</td>
<td>14.4%</td>
<td>36.1%</td>
<td>102.3%</td>
<td>16.0%</td>
<td>25.6%</td>
<td>0.5%</td>
<td>-0.5%</td>
<td>-0.1%</td>
</tr>
<tr>
<td>F2</td>
<td>Basin water areas expand - overspill to land, in-fill (0-1 ft). Inland bays (JB, LS, LM only) inundate upstream wetlands. Shoal water lengths expand - overspill to land, accretion (0-1 ft)</td>
<td>11.9%</td>
<td>30.3%</td>
<td>88.0%</td>
<td>10.5%</td>
<td>21.6%</td>
<td>0.9%</td>
<td>-0.2%</td>
<td>0.0%</td>
</tr>
</tbody>
</table>

* N, E, NE, and C only - no S or W
# Results: CC Scenarios – Average Salinity 1991-2002

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Description</th>
<th>FL Bay</th>
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<th>NE</th>
<th>C</th>
<th>S</th>
<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>Rainfall + 20% - Increase/decrease applied uniformly to each monthly rainfall total over the simulation period</td>
<td>-7.0%</td>
<td>-11.3%</td>
<td>-19.0%</td>
<td>-5.1%</td>
<td>-16.6%</td>
<td>-4.5%</td>
<td>-3.0%</td>
<td>-0.4%</td>
</tr>
<tr>
<td>G2</td>
<td>Rainfall - 20% - Increase/decrease applied uniformly to each monthly rainfall total over the simulation period</td>
<td>8.1%</td>
<td>13.5%</td>
<td>23.7%</td>
<td>5.4%</td>
<td>20.1%</td>
<td>4.7%</td>
<td>3.1%</td>
<td>0.4%</td>
</tr>
<tr>
<td>H1</td>
<td>Evaporation + 15% - Increase applied uniformly to each monthly evaporation total over the simulation period</td>
<td>8.4%</td>
<td>13.8%</td>
<td>23.4%</td>
<td>5.8%</td>
<td>19.8%</td>
<td>6.1%</td>
<td>3.2%</td>
<td>0.4%</td>
</tr>
<tr>
<td>I1</td>
<td>Runoff + 20% - Increase/decrease applied uniformly to each monthly runoff total over the simulation period</td>
<td>-4.3%</td>
<td>-8.0%</td>
<td>-15.7%</td>
<td>-4.2%</td>
<td>-9.3%</td>
<td>-2.7%</td>
<td>-1.1%</td>
<td>0.0%</td>
</tr>
<tr>
<td>I2</td>
<td>Runoff - 20% - Increase/decrease applied uniformly to each monthly runoff total over the simulation period</td>
<td>5.1%</td>
<td>9.9%</td>
<td>21.3%</td>
<td>4.7%</td>
<td>10.8%</td>
<td>2.8%</td>
<td>1.1%</td>
<td>0.0%</td>
</tr>
<tr>
<td>J1</td>
<td>Boundary salinity + 5% - Increase/decrease applied uniformly to each monthly boundary salinity value over the simulation period</td>
<td>5.0%</td>
<td>5.0%</td>
<td>4.9%</td>
<td>5.0%</td>
<td>4.9%</td>
<td>5.0%</td>
<td>5.0%</td>
<td>5.0%</td>
</tr>
<tr>
<td>J2</td>
<td>Boundary salinity - 5% - Increase/decrease applied uniformly to each monthly boundary salinity value over the simulation period</td>
<td>-5.0%</td>
<td>-5.0%</td>
<td>-4.9%</td>
<td>-5.0%</td>
<td>-4.9%</td>
<td>-5.0%</td>
<td>-5.0%</td>
<td>-5.0%</td>
</tr>
</tbody>
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Average Bay-wide Salinity Change - SLR Only

Salinity Change

Scenario

A1
B1
C2
D2
E2
F2
Average Salinity Change Bay-wide CC Only

Salinity Change

G1  G2  H1  I1  I2  J1  J2

-8% -5% -3% 0% 4% 6% 8%
## Results: SLR Average Residence Time

Change to residence time due to CC effects is very small (+/- 1 to 5%)

<table>
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<th>W</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Basin water areas constant - no overspill to land, no in-fill. Shoal water lengths constant - no overspill to land, no accretion.</td>
<td>-52%</td>
<td>-50%</td>
<td>-56%</td>
<td>-49%</td>
<td>-58%</td>
<td>-37%</td>
<td>-33%</td>
<td>3%</td>
</tr>
<tr>
<td>B1</td>
<td>Basin water areas constant - no overspill to land, in-fill (0-1 ft). Shoal water lengths constant – no overspill to land, accretion (0-1 ft).</td>
<td>-30%</td>
<td>-28%</td>
<td>-33%</td>
<td>-23%</td>
<td>-35%</td>
<td>-20%</td>
<td>-26%</td>
<td>-1%</td>
</tr>
<tr>
<td>C2</td>
<td>Basin water areas expand - overspill to land, no in-fill. Shoal water lengths expand - overspill to land, no accretion.</td>
<td>-70%</td>
<td>-66%</td>
<td>-74%</td>
<td>-68%</td>
<td>-77%</td>
<td>-46%</td>
<td>-43%</td>
<td>6%</td>
</tr>
<tr>
<td>D2</td>
<td>Basin water areas expand - overspill to land, in-fill (0-1 ft). Shoal water lengths expand - overspill to land, accretion (0-1 ft).</td>
<td>-55%</td>
<td>-49%</td>
<td>-58%</td>
<td>-42%</td>
<td>-66%</td>
<td>-31%</td>
<td>-38%</td>
<td>-1%</td>
</tr>
<tr>
<td>E2</td>
<td>Basin water areas expand - overspill to land, no in-fill. Inland bays (JB, LS, LM only) inundate upstream wetlands. Shoal water lengths expand - overspill to land, no accretion</td>
<td>-71%</td>
<td>-67%</td>
<td>-76%</td>
<td>-68%</td>
<td>-77%</td>
<td>-46%</td>
<td>-43%</td>
<td>6%</td>
</tr>
<tr>
<td>F2</td>
<td>Basin water areas expand - overspill to land, in-fill (0-1 ft). Inland bays (JB, LS, LM only) inundate upstream wetlands. Shoal water lengths expand - overspill to land, accretion (0-1 ft)</td>
<td>-56%</td>
<td>-51%</td>
<td>-63%</td>
<td>-43%</td>
<td>-66%</td>
<td>-31%</td>
<td>-38%</td>
<td>-1%</td>
</tr>
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Bay-wide Change in Residence Time from Base Case - SLR Scenarios
SLR and CC Summary and Conclusions

• SLR will:
  – increase salinity
  – reduce residence time

• Bay-wide, the salinity is expected to increase by 10-36% depending upon
  – ultimate amount of SLR (i.e. 1 ft increase or 2 ft increase)
  – the extent to which accretion and in-fill limit the amount of change

• Residence times anticipated to decrease by 30-70%, depending on the geologic factors.
SLR and CC: Summary and Conclusions

- Accretion and in-fill limit increase in salinity and decrease in residence times due to SLR
- Overspill to land and increase in size of nearshore embayments increase the % change in salinity
- Overspill to land and increase in size of nearshore embayments cause a larger decrease in % change in residence time
- CC increases or decrease salinity by ~12%
- Rainfall and evaporation have the largest CC effect on salinity — future trajectory of these 2 drivers is uncertain
SLR and CC: Summary and Conclusions

- Additional research using paleoecologic information may provide insight on the future trajectory for accretion and in-fill.
- This information can be used to understand the effect of SLR and CC on performance measures and targets that have been established for Everglades restoration.
Summary and Conclusions

- Largest changes to salinity and residence times are in North Region
- Less but significant change in Northeast and East Regions
- Slight change in Central Region
- Little change in the West and South Regions
THANKS!

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