TAYLOR ENGINEERING, INC.

Jupiter Inlet
Sediment Budget Update
TAC Meeting #3

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3/27/2024

JUPITER INLET DISTRICT

Overview

- Background & Project Goals
- Prior Studies
- Data Collection
- Longshore Transport Modeling
- Sediment Budget Update
- Recommendations
- Next Steps

Background

- Update sediment budget at Jupiter Inlet
- Sediment budget supports Inlet Management Plan
- Develop longshore transport (LST) model for sediment budget update
- Previous studies applied USACE 1966 LST estimate
  - 230,000 cy/year
  - Revisit LST with more recent wave conditions and numerical modeling

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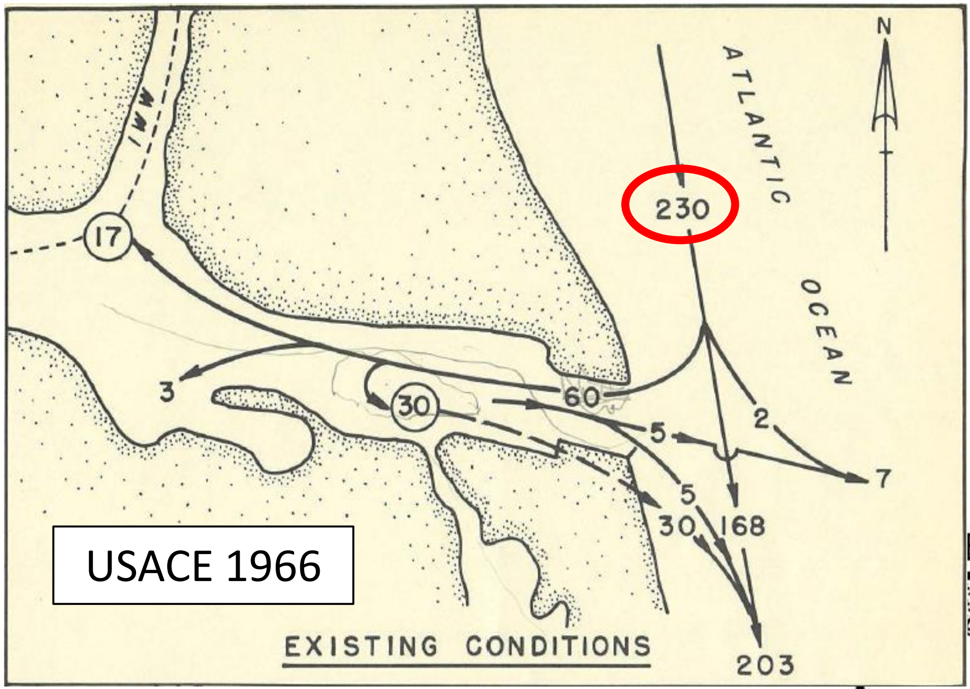
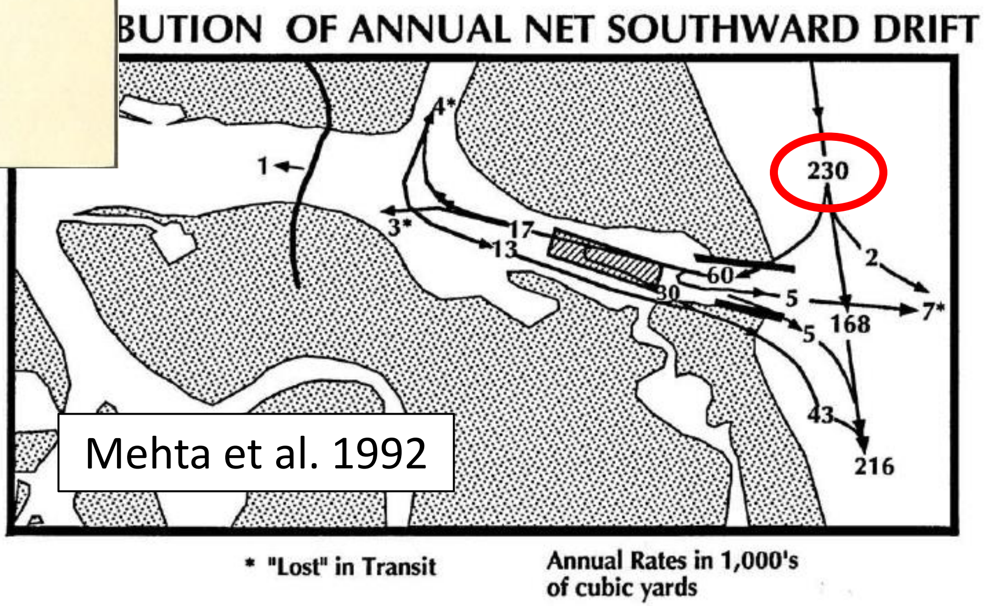
Prior Studies





Data Collection

- Topographic/bathymetric survey
  - February—April 2023
  - Beach profiles, ebb shoal, inlet
- Sediment samples
  - 72 grab samples for sieve analysis
    - Fine to medium-grained sand with varying amounts of shell and shell hash
  - 8 R-monuments
  - +10 ft to -30 ft-NAVD at 5 ft intervals
- Geodatabase

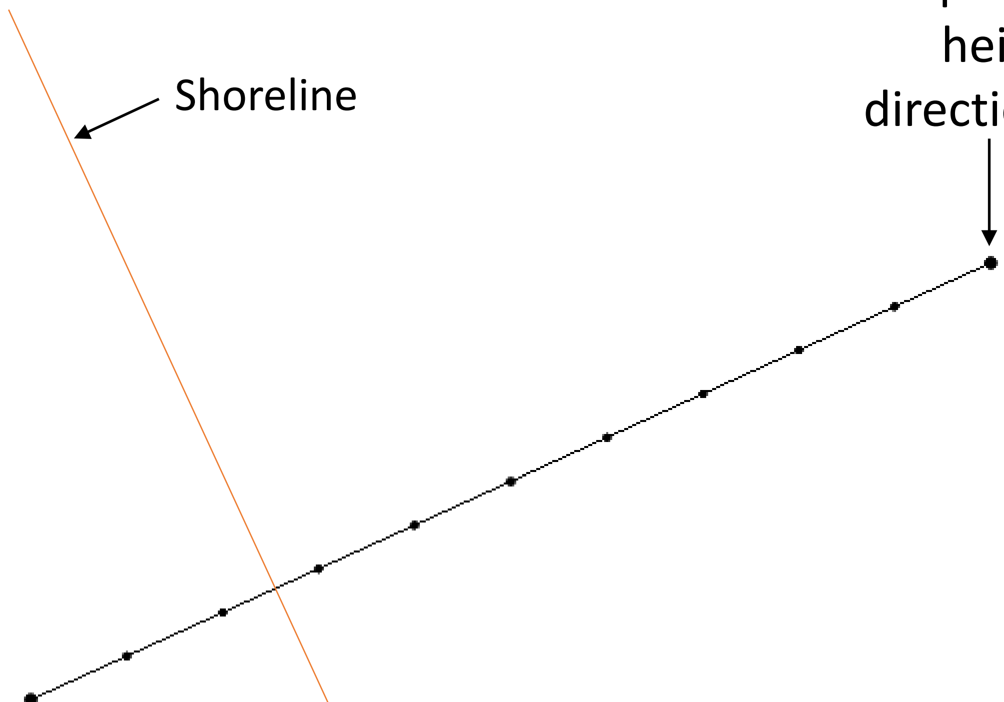
Longshore Transport Modeling

- Introduction
- MIKE Littoral Processes (LP) model
- Model Setup
- Sensitivity Testing
- Validation
- Production Run Results

Introduction

- Longshore transport (LST) rates constrain sediment budget equations
- Update LST rates with numerical model
  - Input wave climate from recent decades
- MIKE LP model propagates offshore waves along a cross-shore transect
  - Shoaling, refraction, breaking
  - Applies resulting wave-induced currents and setup to calculate sediment transport

Cross-shore Profile



Input hourly water level, wave height, wave period, wave direction at offshore profile point

Input at each profile point:

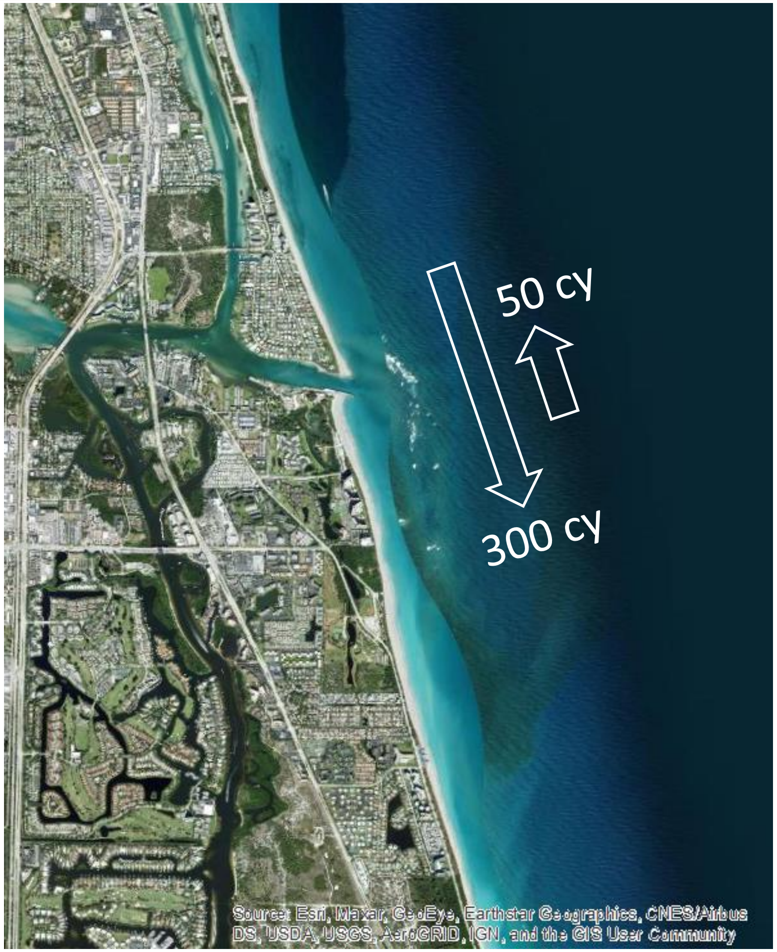
- Bed elevation (bathymetry)
- Sediment parameters

Hourly model output:

- Northward and southward longshore transport (littoral drift) in units of cubic meters

Introduction

- MIKE LP model calculates southward and northward directed LST
- Gross LST = N + S
  - 50 + 300 = 350 cy
- Net southward LST = S – N
  - 300 – 50 = 250 cy
- Net transport is directed southward within entire project area



MIKE Littoral Processes Model

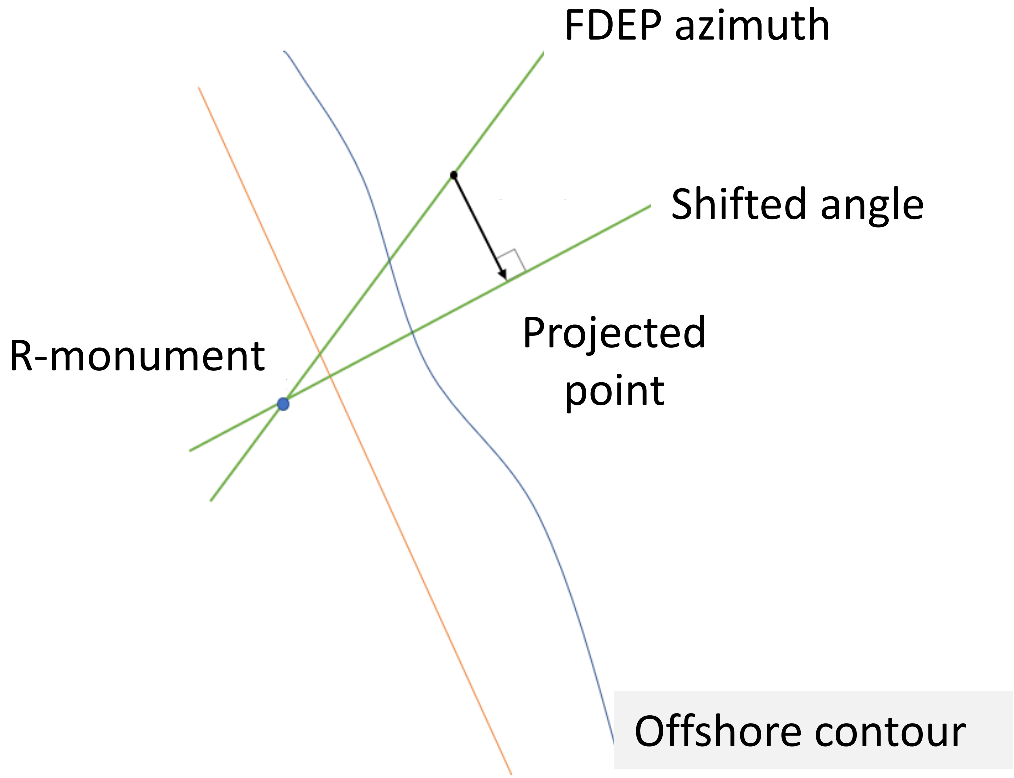
- Transect-based 1D model
  - No cross-shore transport, hardbottom, or morphodynamics
  - Study focuses on background longshore transport rates
- High computational efficiency
- Capture range of regional transport rates
  - Significant annual variability

Model Setup – Extents and Resolution

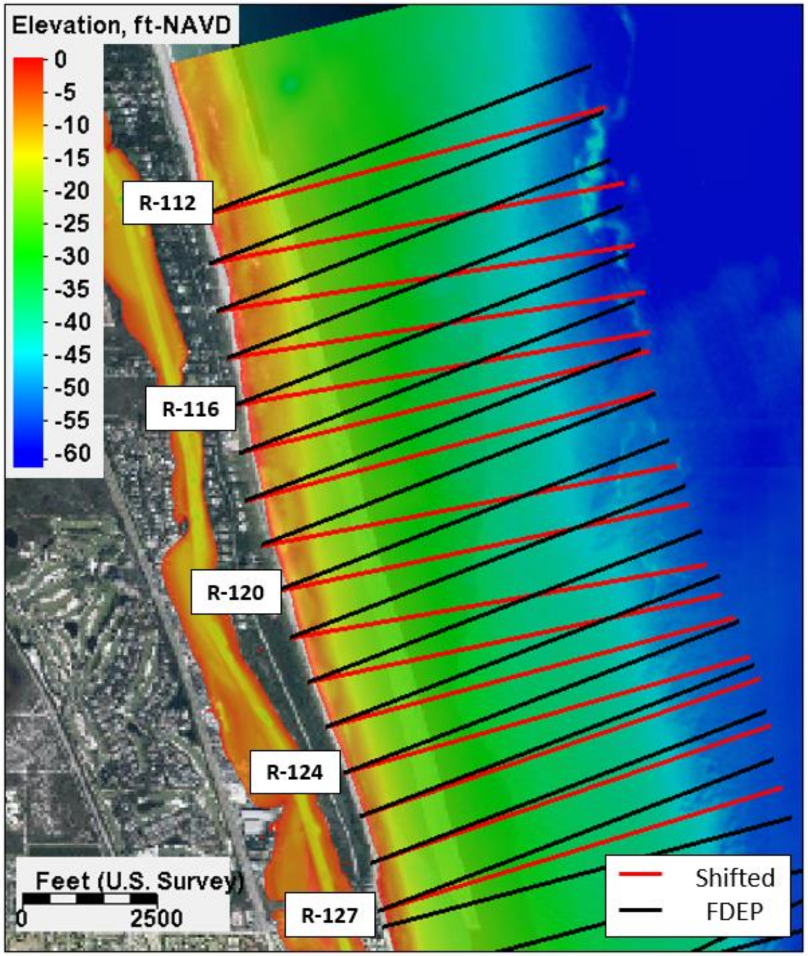
- Alongshore extents
  - 4.5 miles to north and 4.5 miles to south of the inlet
    - Martin County R-112 through Palm Beach County (PBC) R-36
  - Model all R-monuments except within inlet shadow
    - PBC R-8 through R-20
- Cross-shore profile (transect) layout
  - 800 points per profile
  - 10 ft point spacing
  - 60 ft depth contour

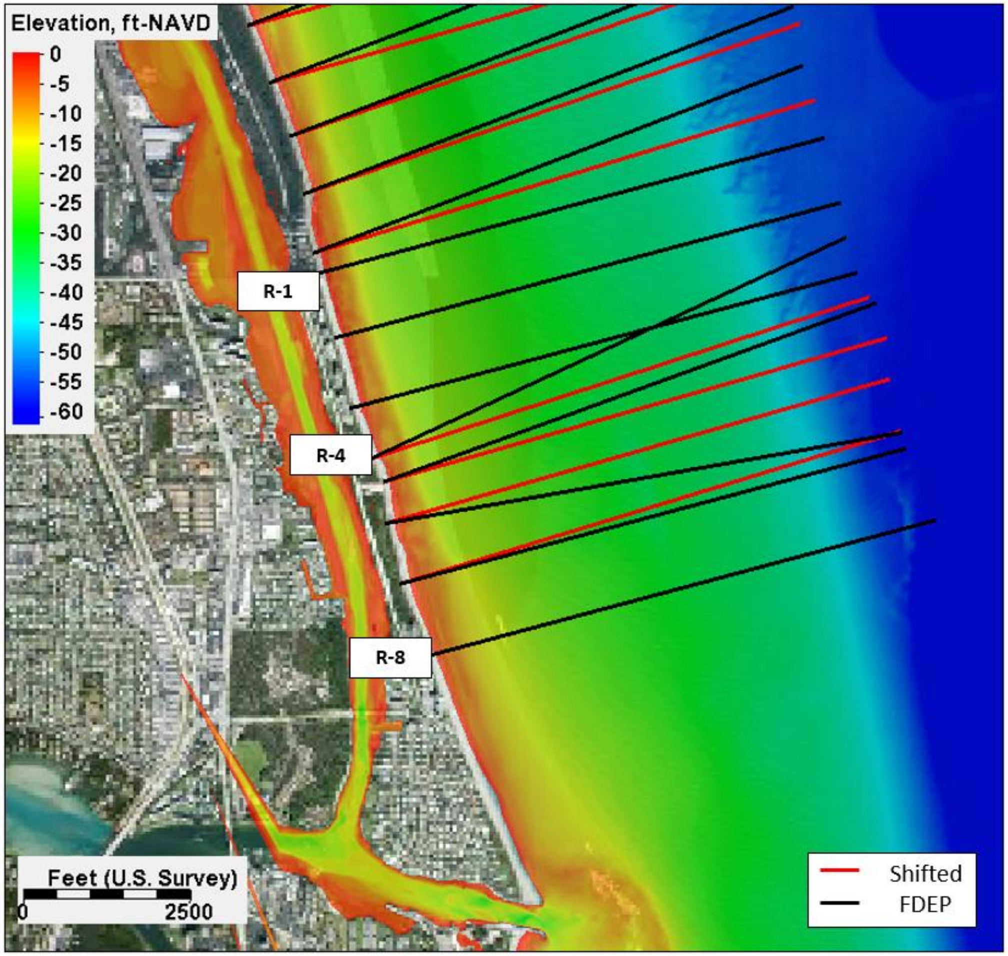
Model Setup

- Noticed that some R-monument azimuths not oriented to shore perpendicular
- Projected all survey data to comply with MIKE LP model requirement

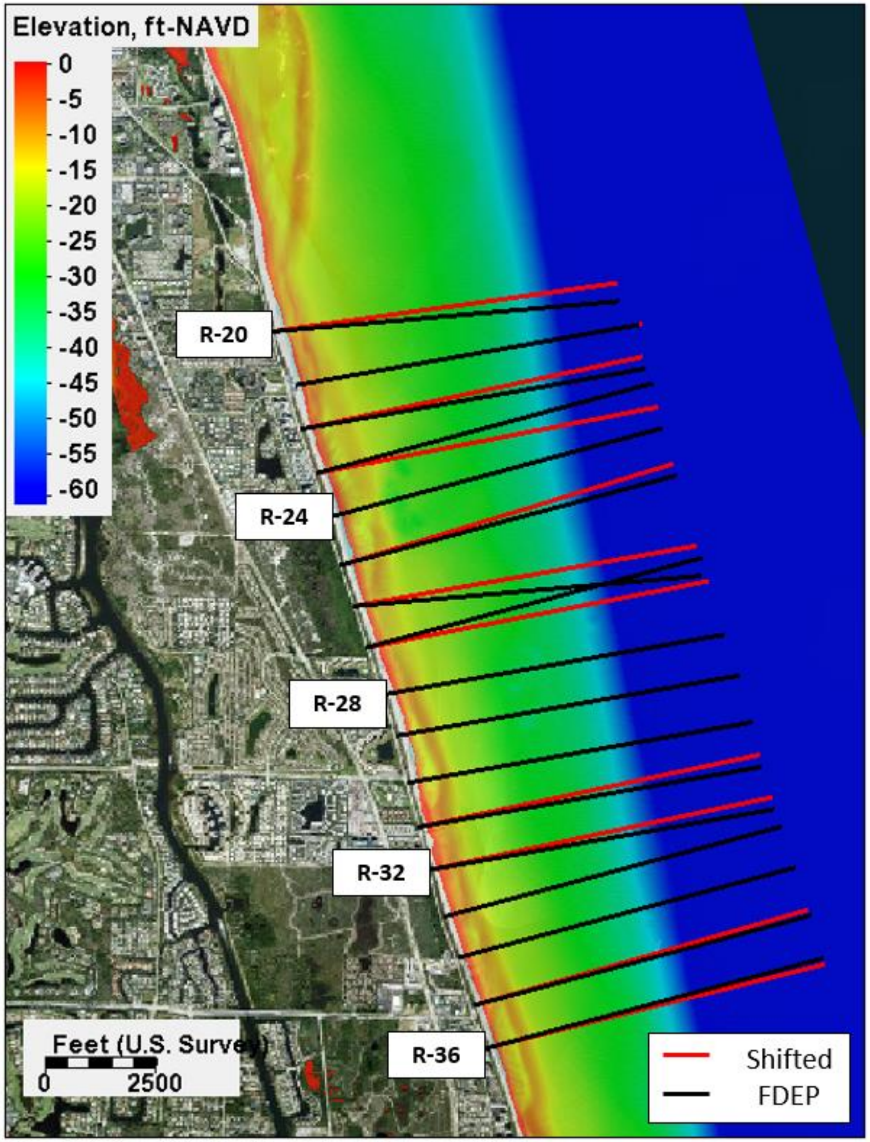


Model Setup


Elevation, ft-NAVD
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
R-112
R-116
R-120
R-124
R-127
Feet (U.S. Survey)
0
2500
Shifted
FDEP

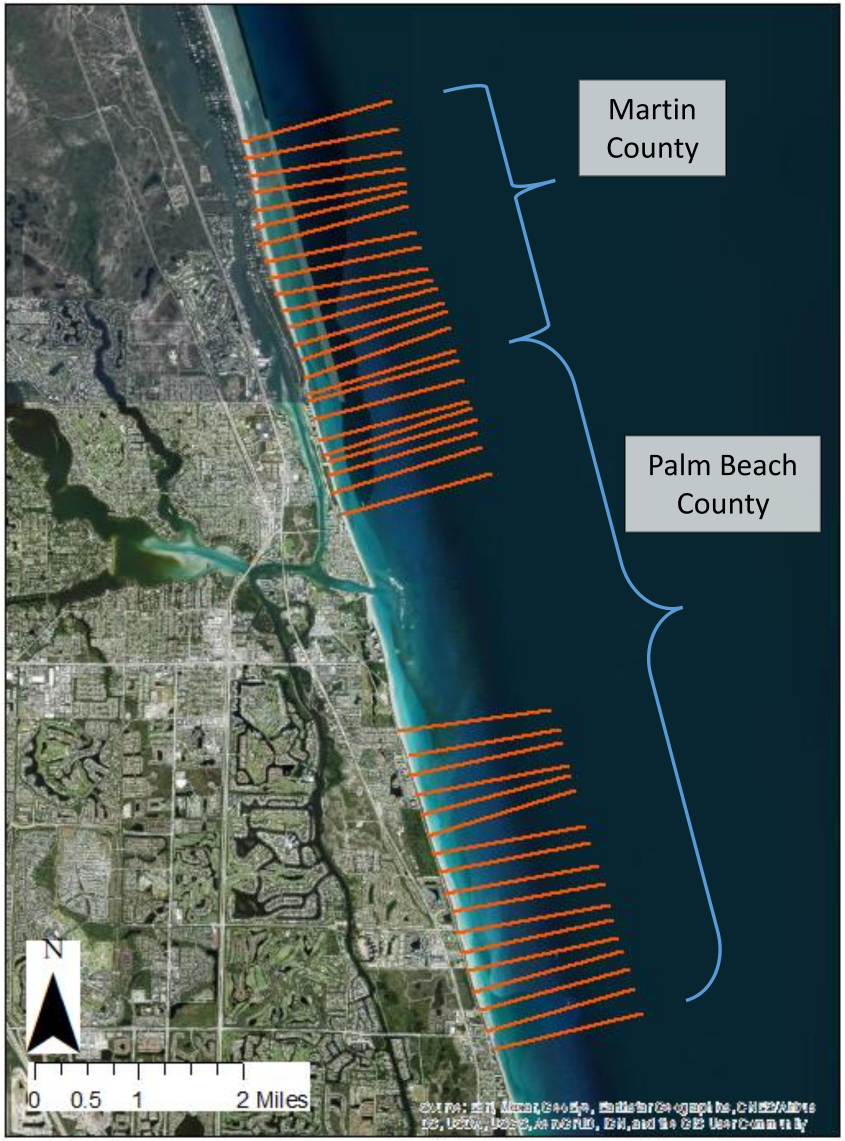

Elevation, ft-NAVD
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
R-1
R-4
R-8
Feet (U.S. Survey)
0
2500
Shifted
FDEP

Model Setup



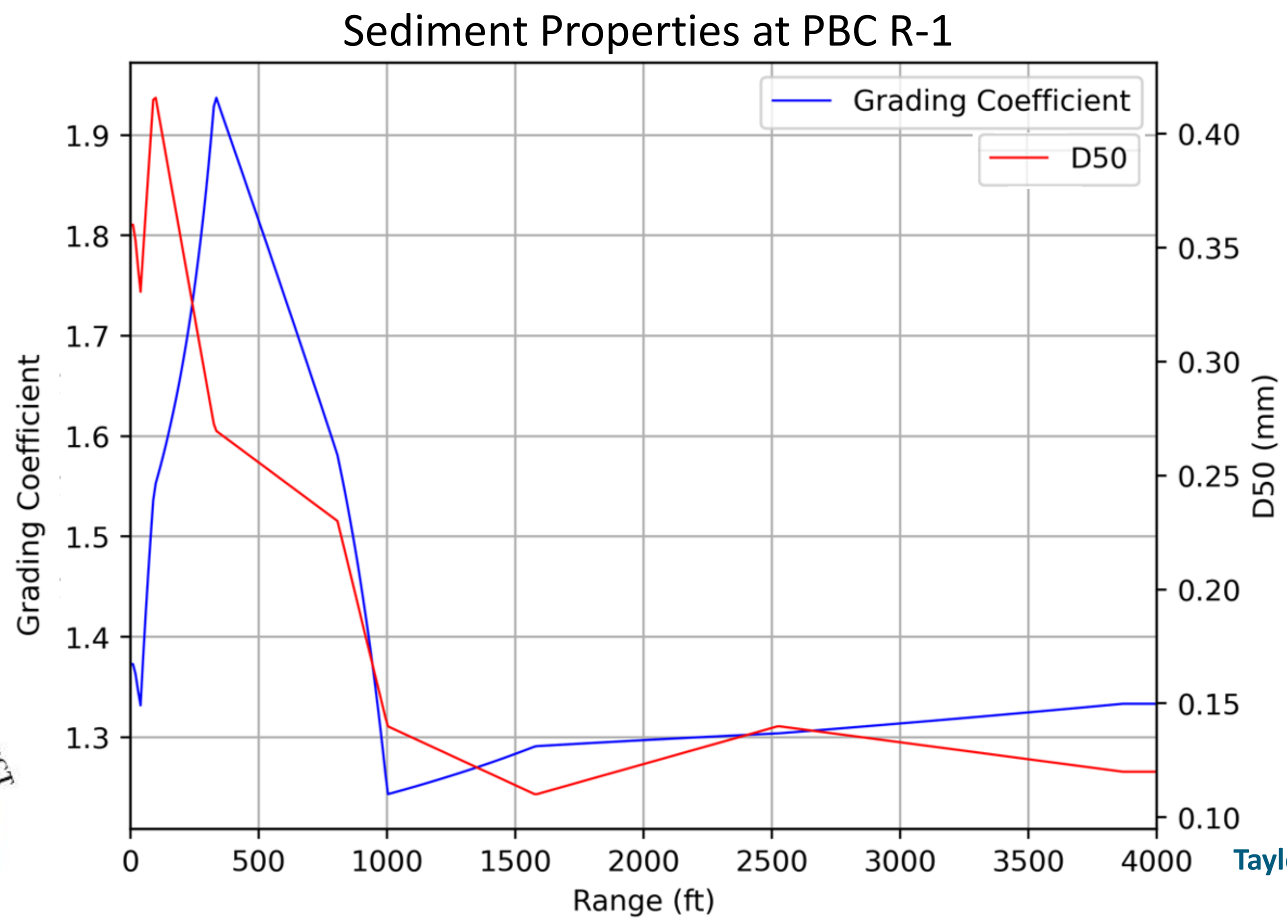
Elevation, ft-NAVD
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
R-20
R-24
R-28
R-32
R-36
Feet (U.S. Survey)
0
2500
Shifted
FDEP

Model Setup



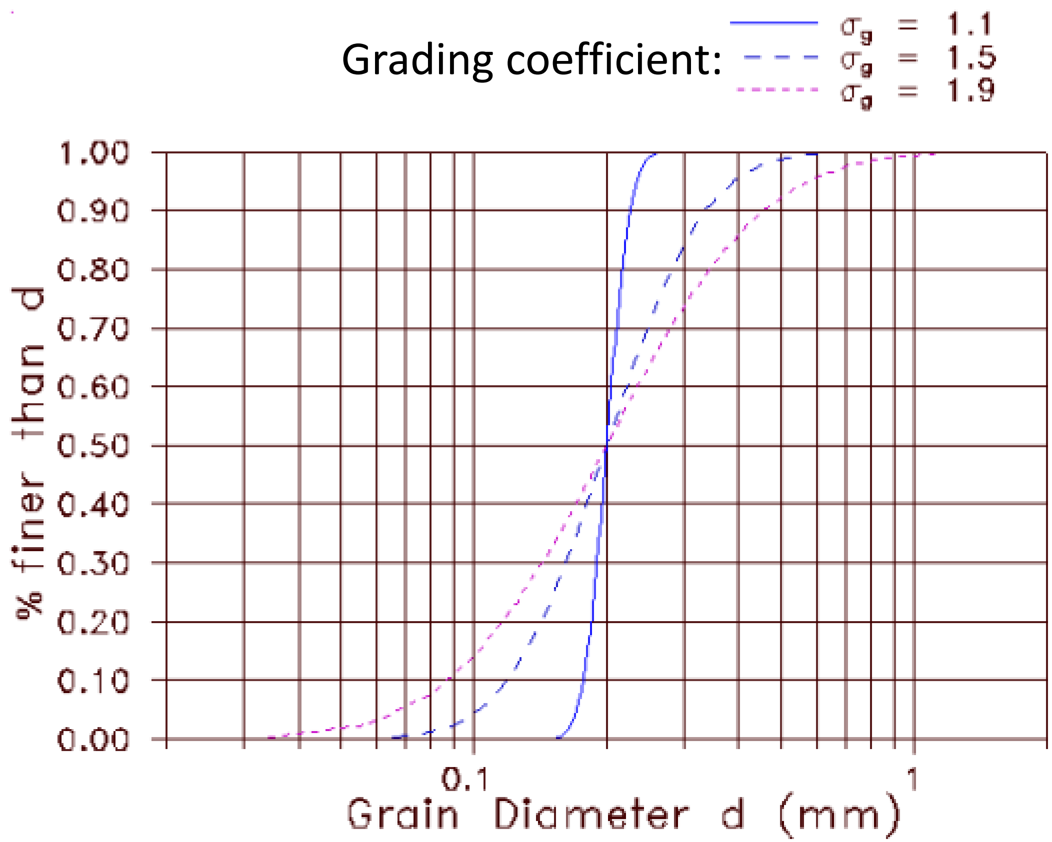
Model Setup – Sediment Properties

- Full particle size distribution curve at each sample
  - 9 samples per included R-monument



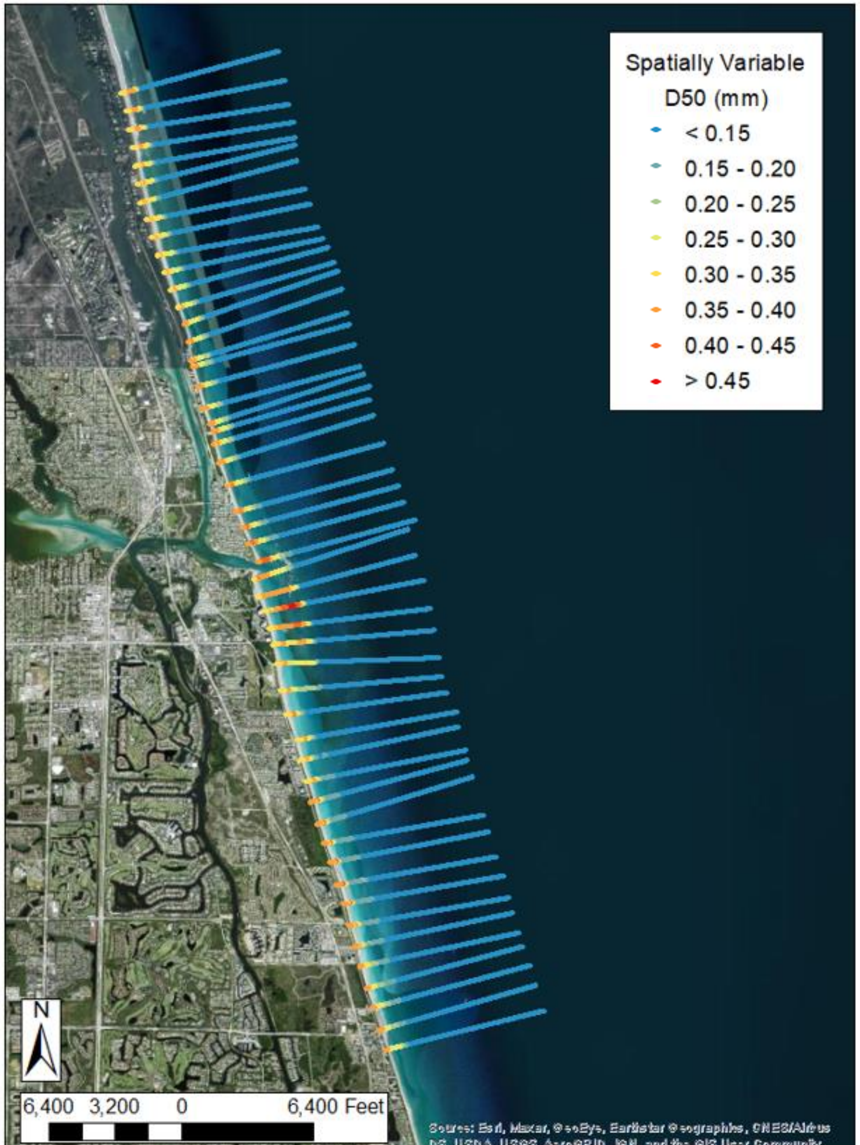
Model Setup – Sediment Properties

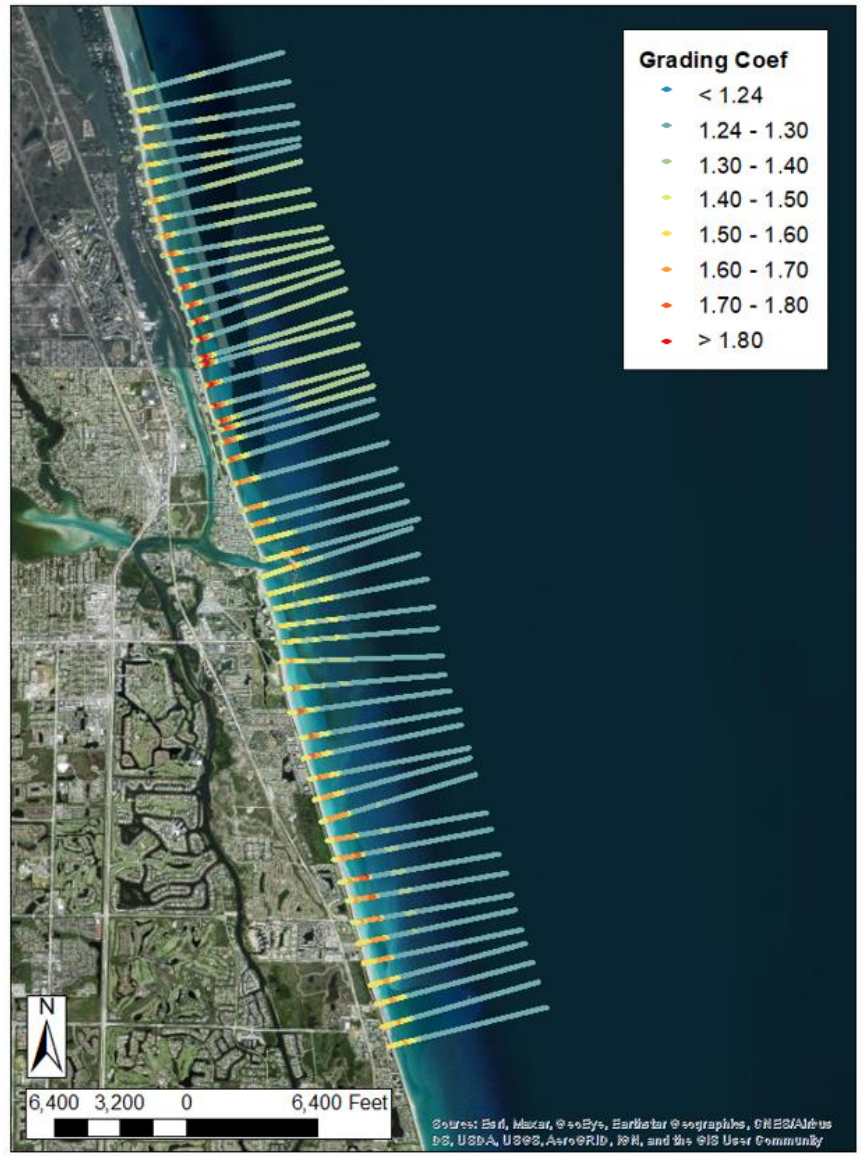
- Spatially variable D_{50} and grading coefficient $(D_{84}/D_{16})^{1/2}$



Source: MIKE LP Scientific Documentation

Model Setup – Sediment Properties





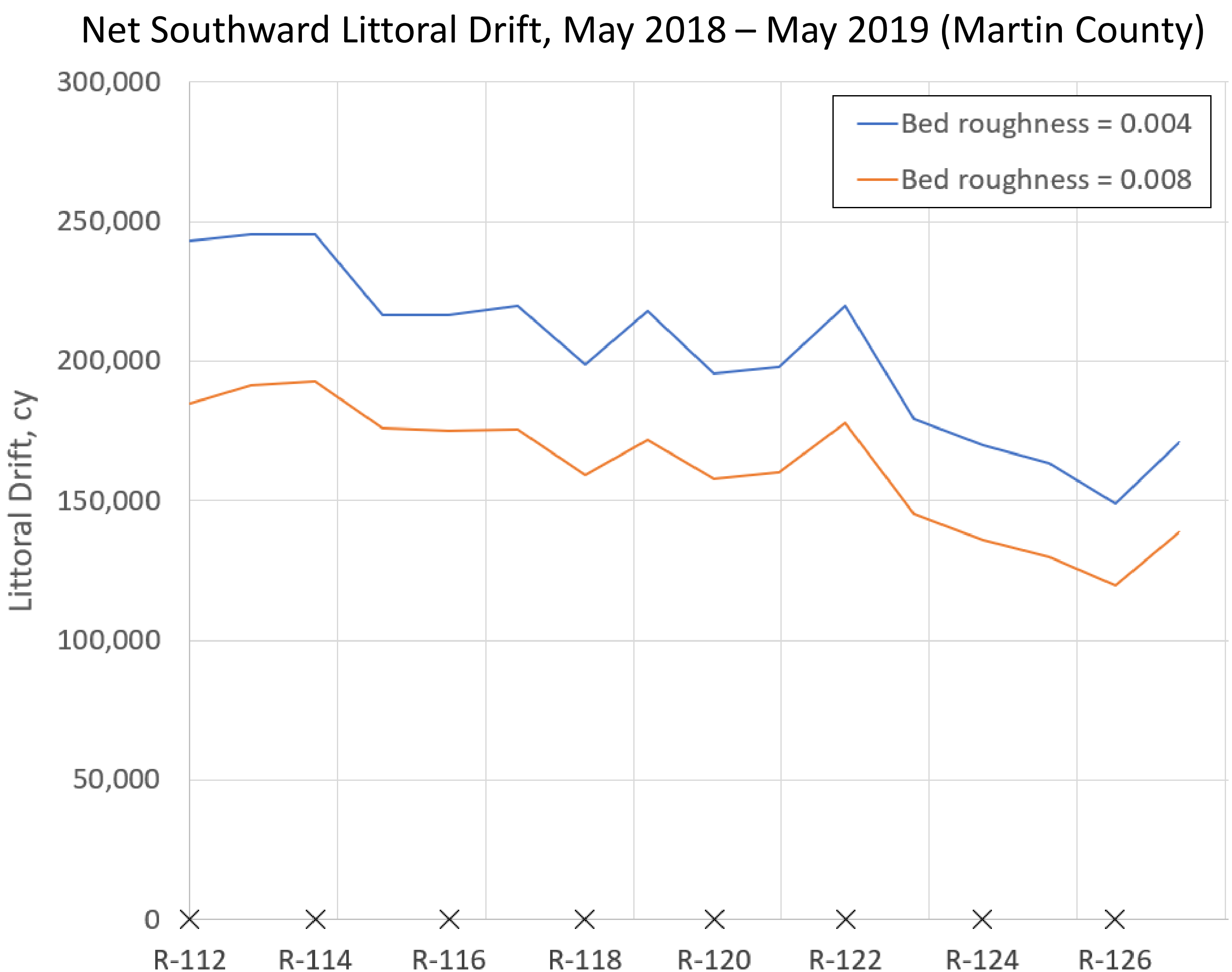
Model Setup – Input Data

- Bathymetry
  - Beach transect surveys
  - Post-hurricane bathymetric LiDAR
  - South FL FEMA Coastal FIS bathymetry applied offshore of beach transect surveys
- Hourly water levels
  - Lake Worth Pier NOAA tide gage
  - Trident Pier NOAA tide gage to fill gaps in record (adjusted tide amplitude)
- Hourly offshore wave conditions
  - USACE WIS hindcasts
  - Ft. Pierce NOAA NDBC buoy data to fill gaps in record

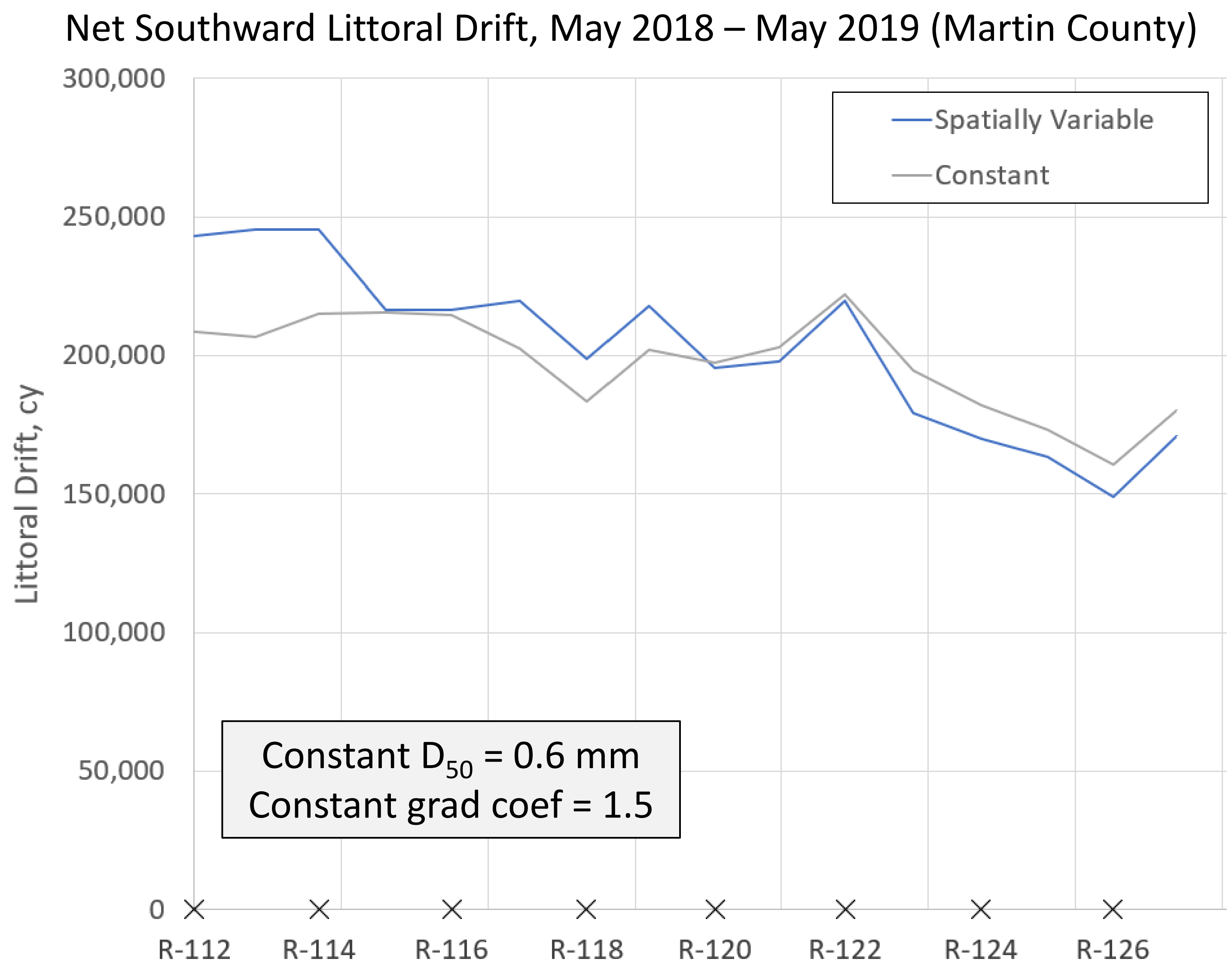
Sensitivity testing

- Bed roughness
- Sediment properties
- Wave model and parameters
  - Rayleigh vs. Battjes & Janssen (B&J)
  - B&J depth- and steepness-limited breaking
- Azimuth shift

Bed Roughness Sensitivity



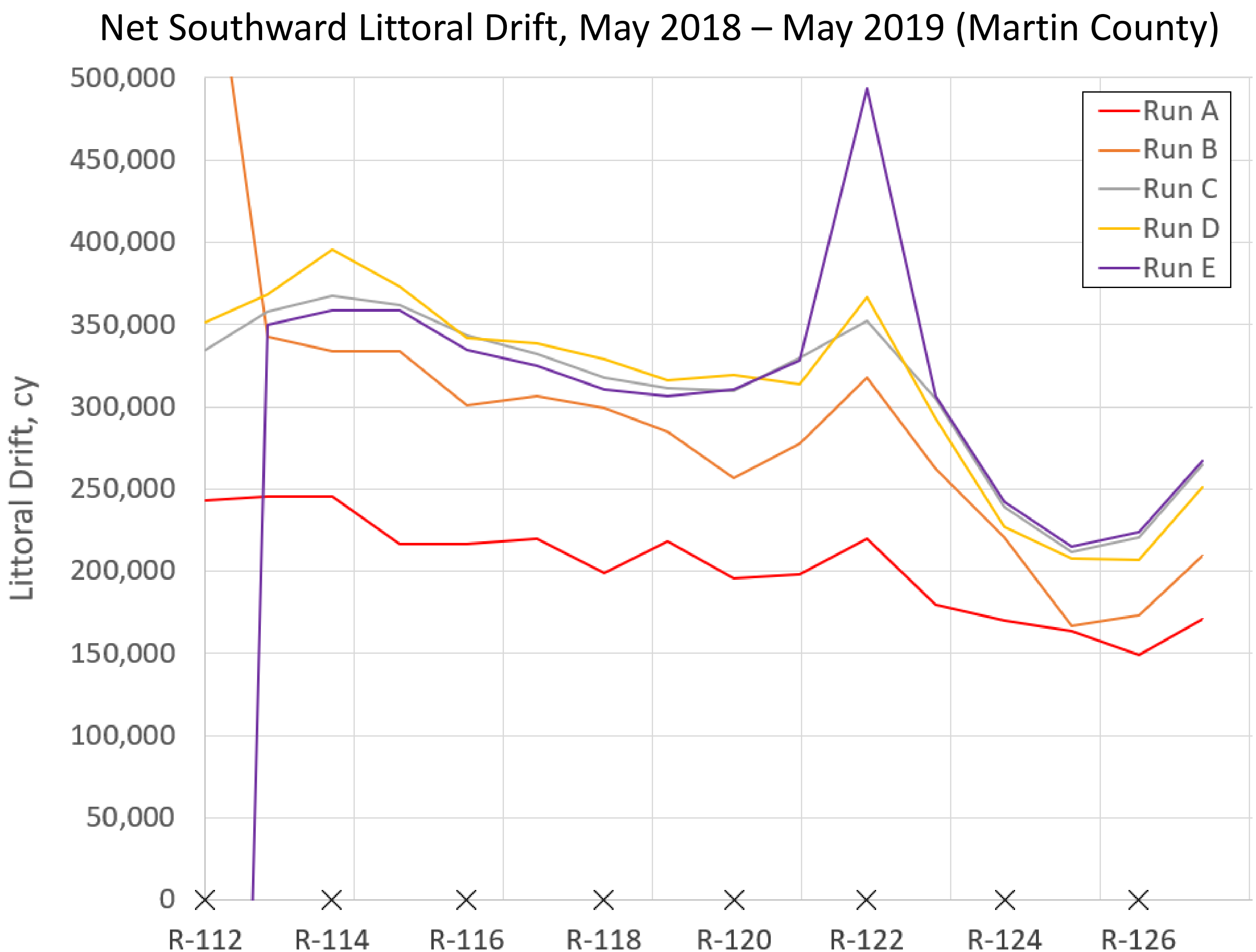
Sediment Properties Sensitivity Test



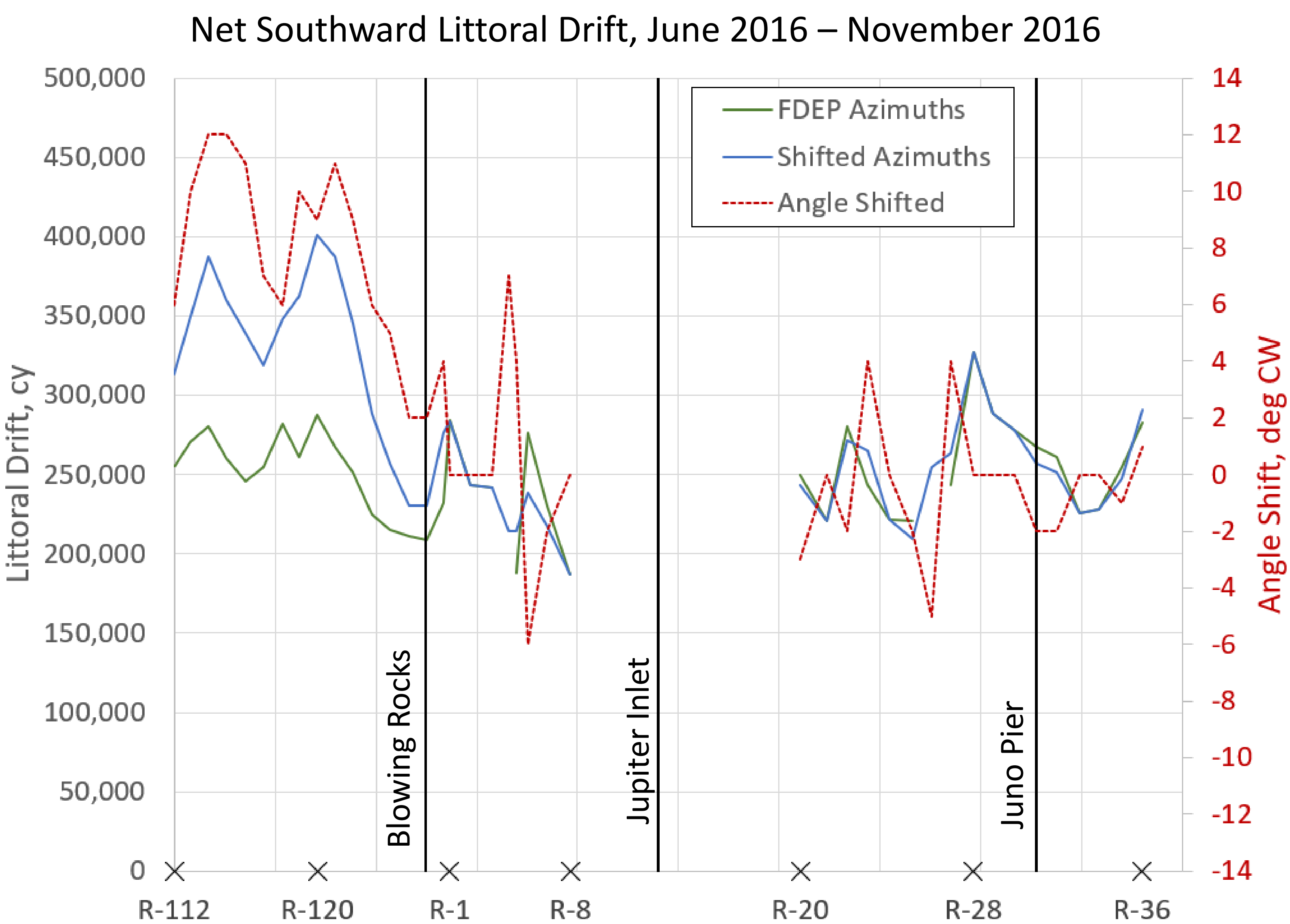
Wave Model Settings Sensitivity

Run	Wave Model	Dissipation Rate (default=1)	Depth-Limited Breaking (default=0.8)	Steepness-Limited Breaking (default=1)
A	Rayleigh	N/A	N/A	N/A
B	Battjes & Janssen	1	0.8	1
C	Battjes & Janssen	1	0.7	1
D	Battjes & Janssen	0.7	0.7	1
E	Battjes & Janssen	1	0.7	0.7

Wave Model Settings Sensitivity



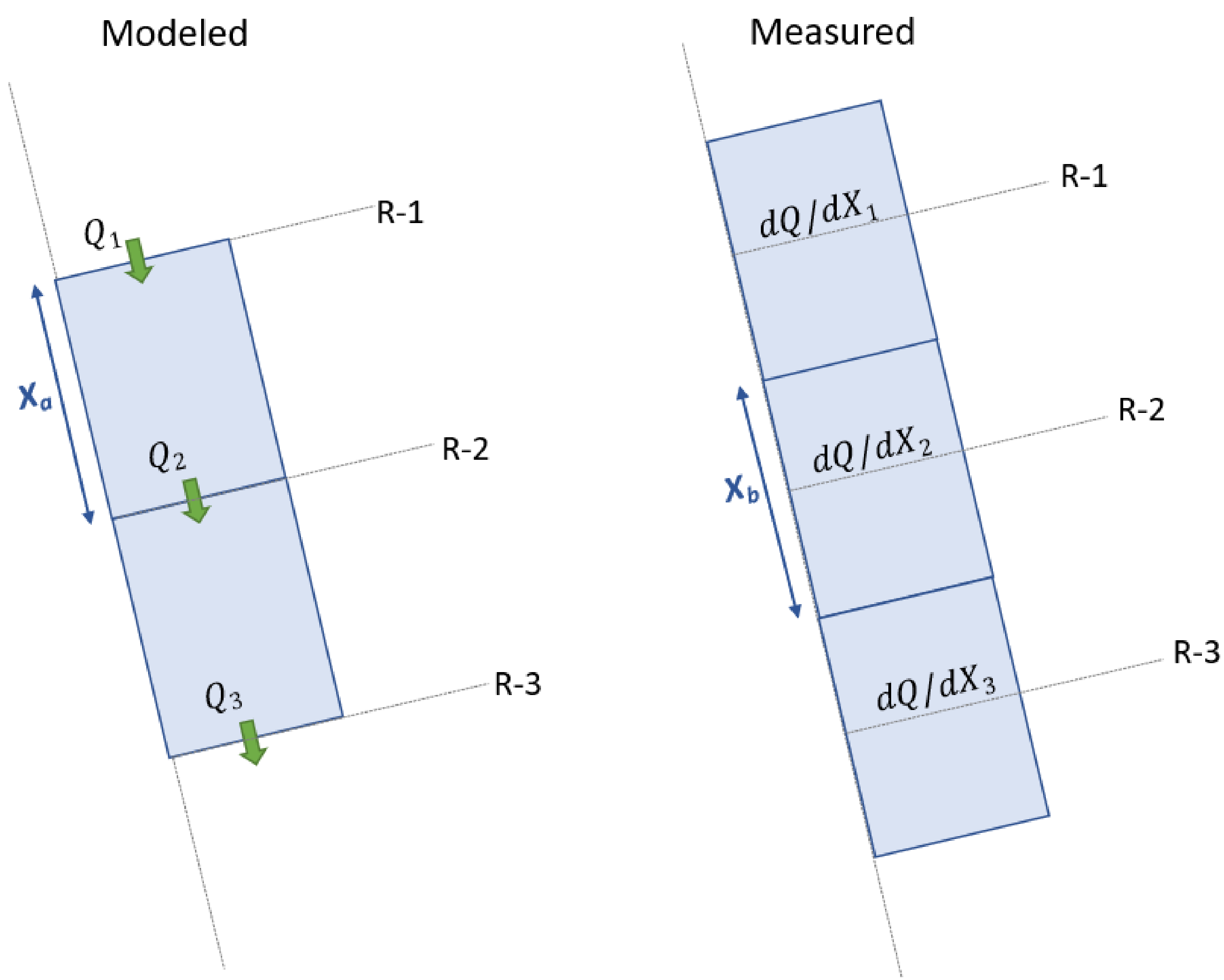
Azimuth Shift Sensitivity



Validation

- Compare modeled vs. measured data to establish model skill
- No directly measured LST available
  - Compare spatial gradient in LST → volume change
- Beach survey data clipped at offshore edge of littoral zone established by model results
  - Limit uncertainty in instrument vertical control
- Does the model reproduce alongshore volume change trends?

Validation



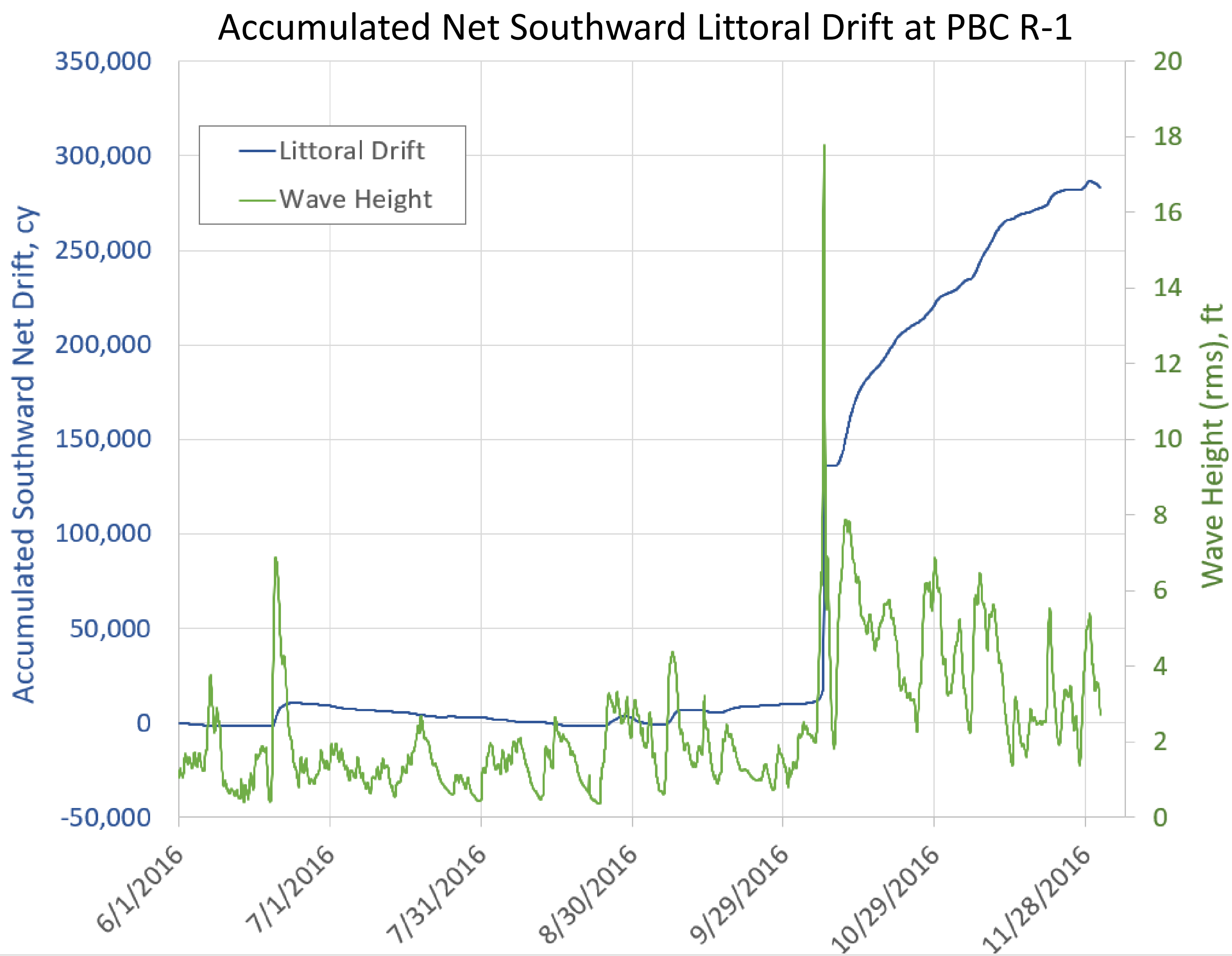
Accretion over X_a in cy = $Q_1 - Q_2$

Accretion over X_b in cy = $dQ/dX_2 * X_b$

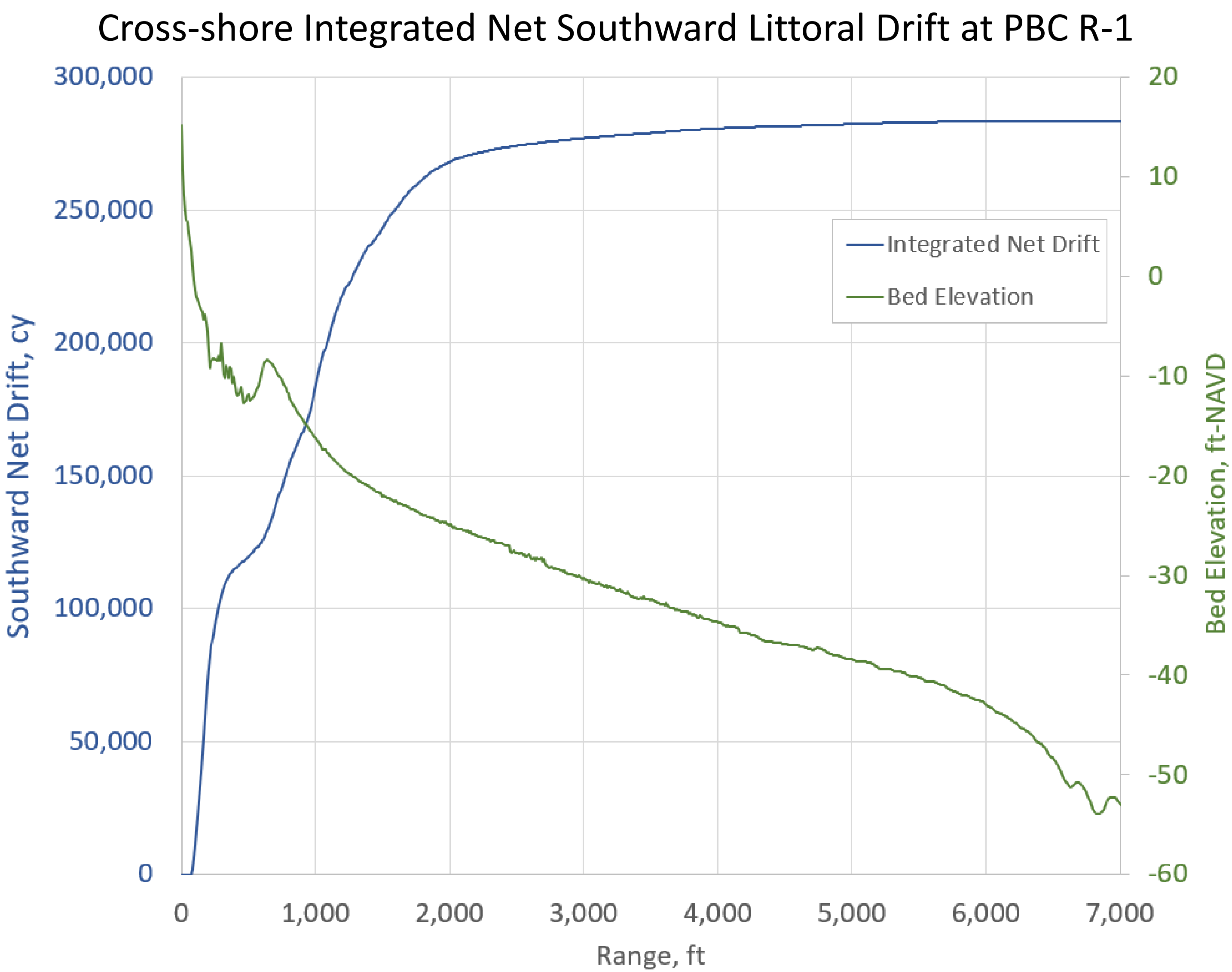
Validation

- Date selection considerations
  - Survey availability
  - Moderate wave energy
  - Avoid large nourishment events
- May 2016 to November 2016 – Hurricane Matthew
  - Martin and PBC
- May 2018 to May 2019
  - Martin only
- July 2019 to December 2019 – Hurricane Dorian
  - PBC only

Validation Results – May to Nov 2016



Validation Results – May to Nov 2016



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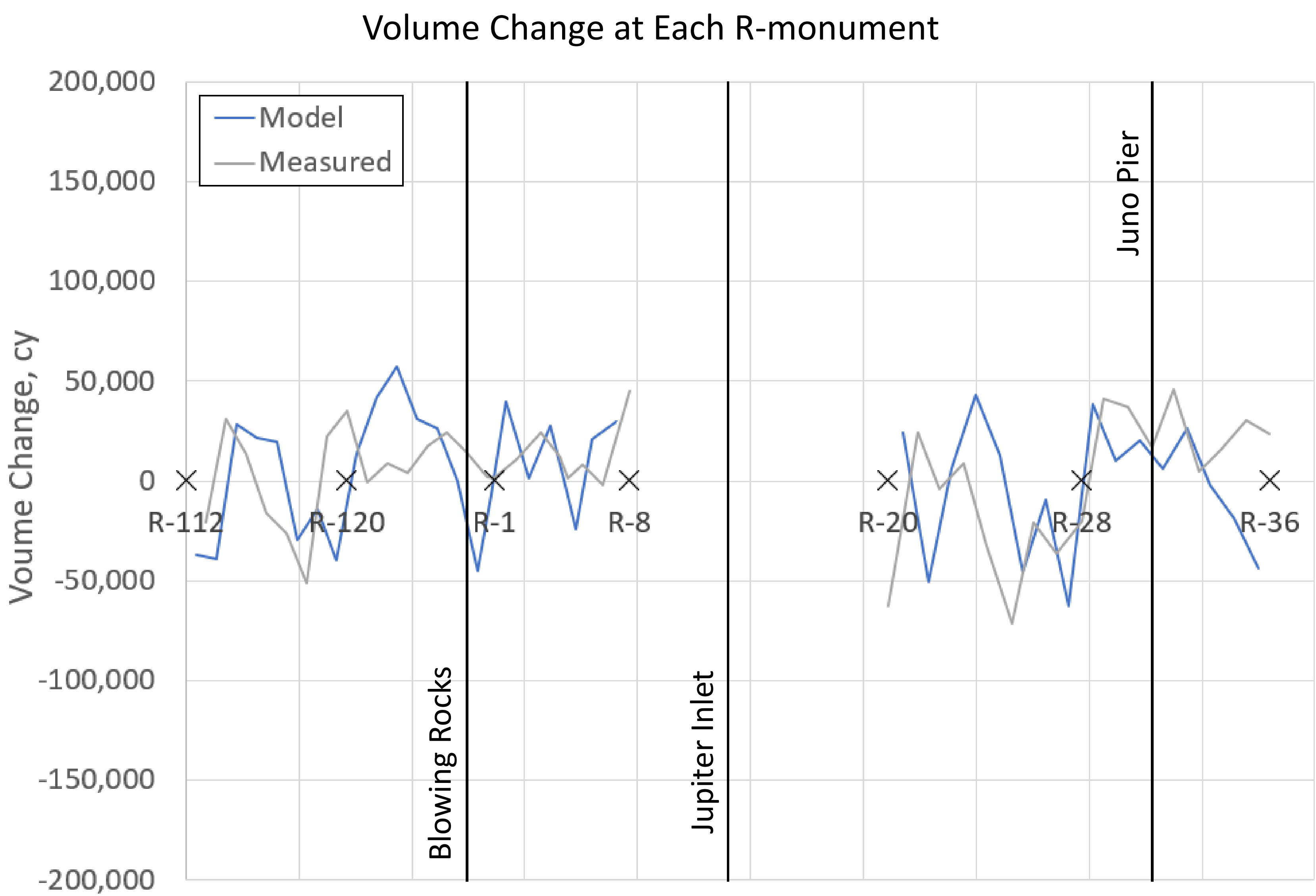

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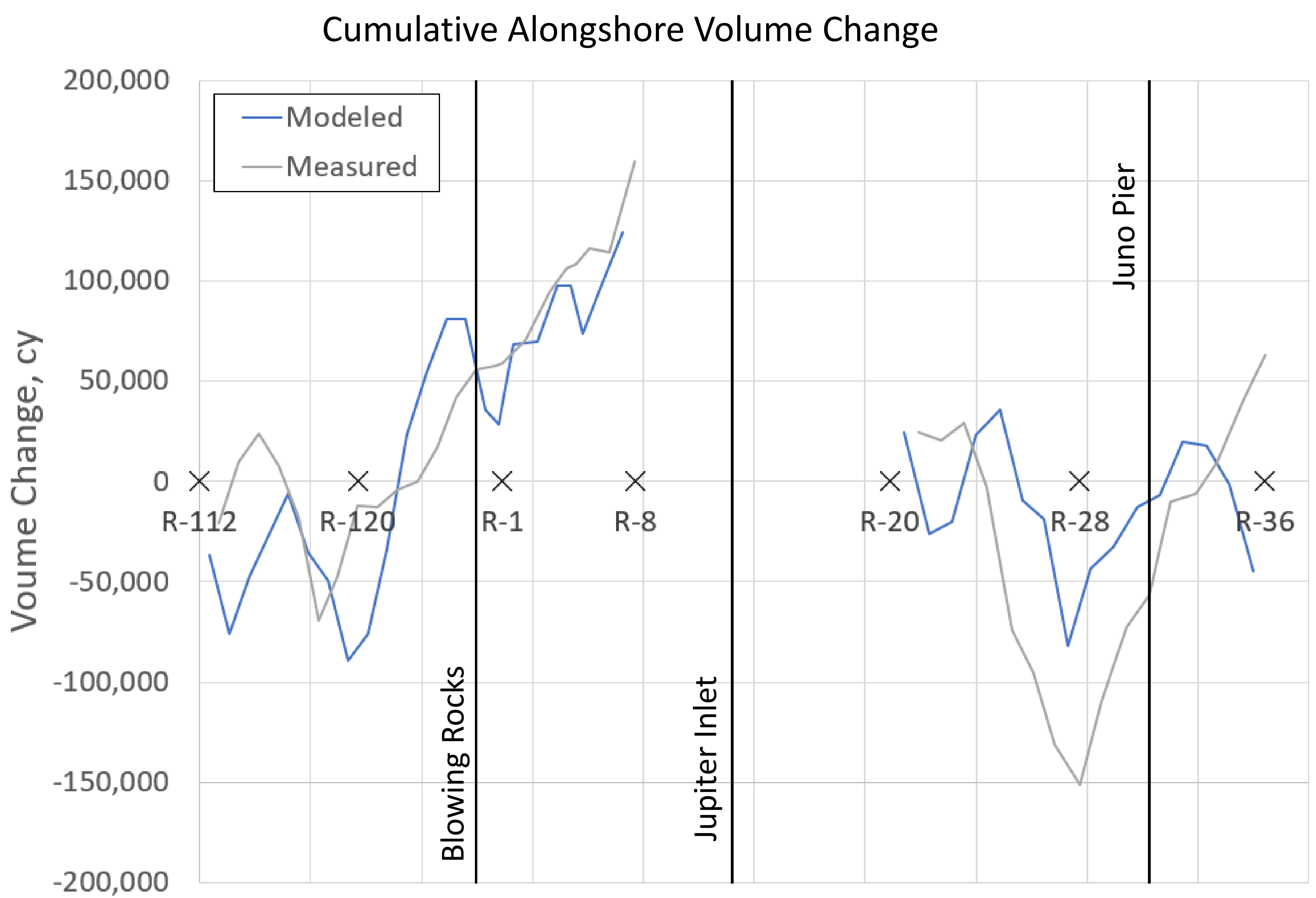
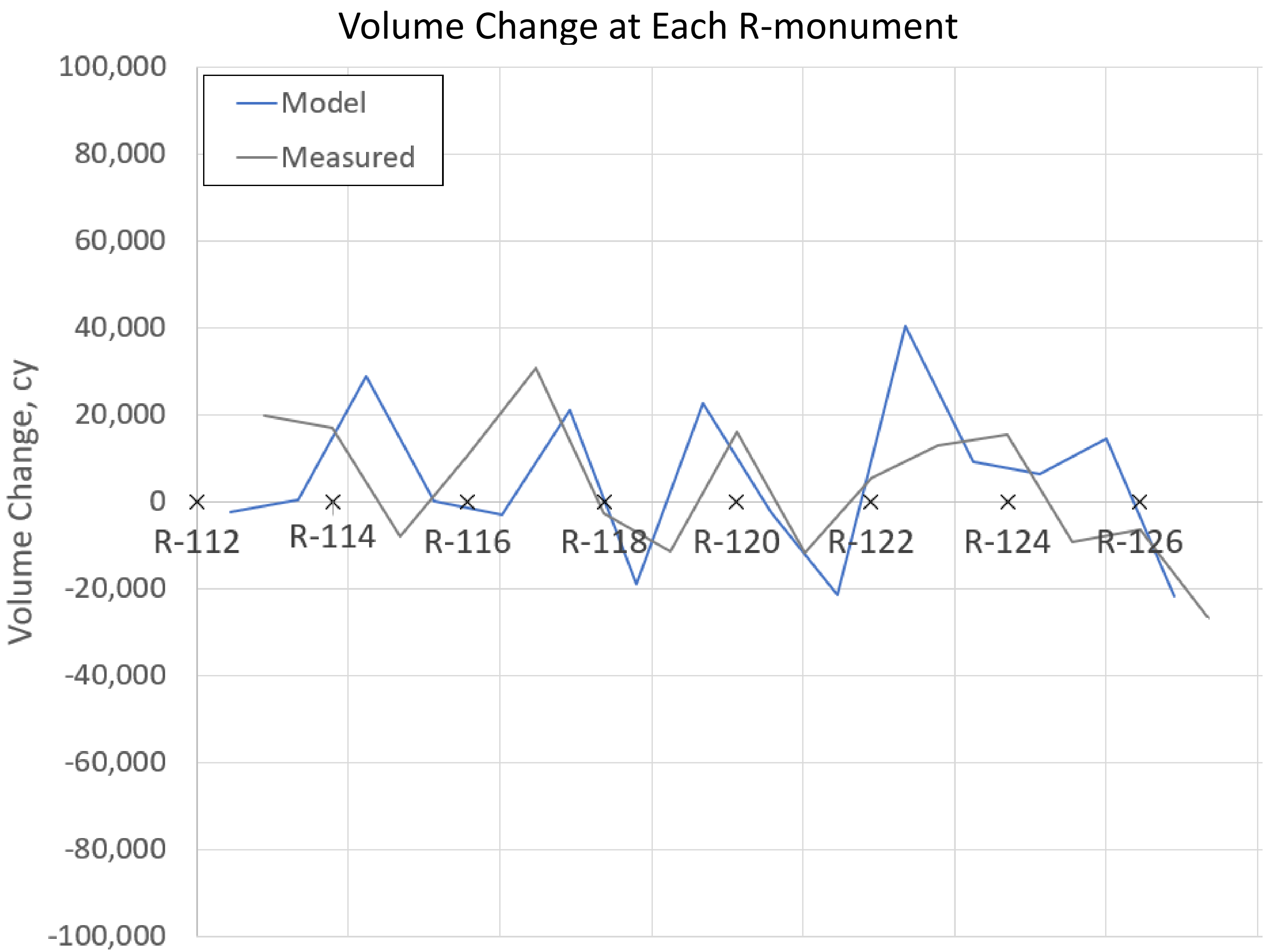
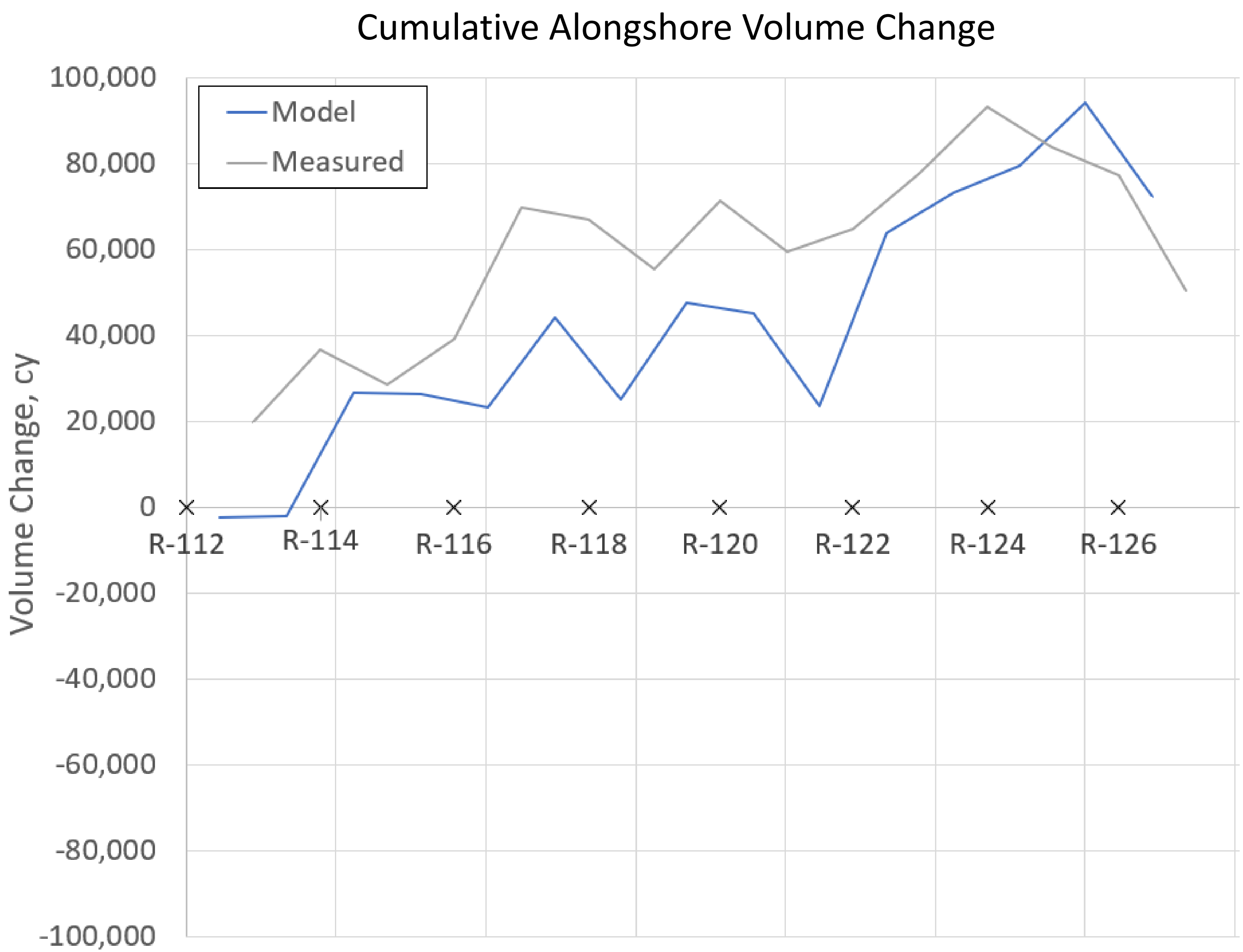


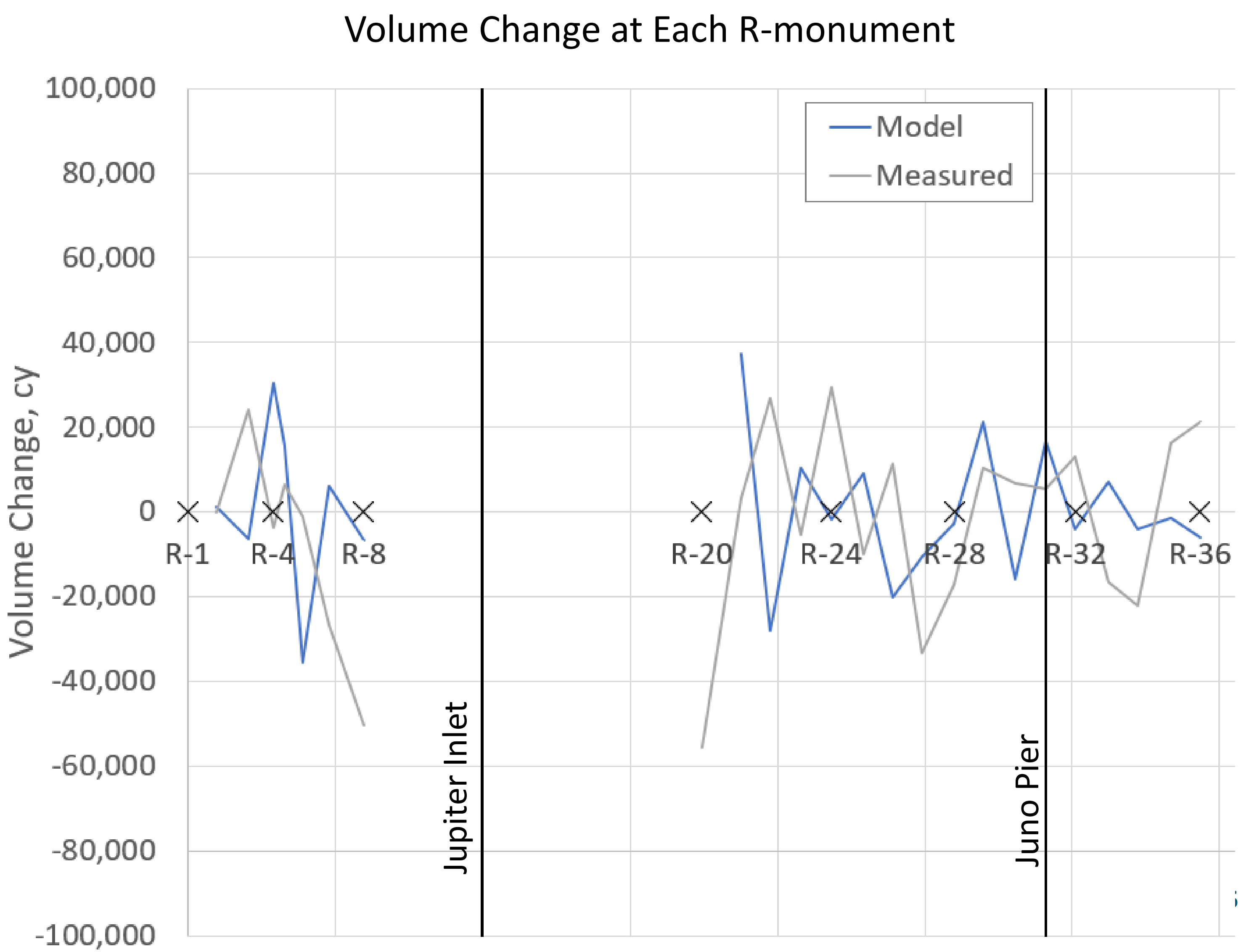
Validation Results – May 2018 to May 2019



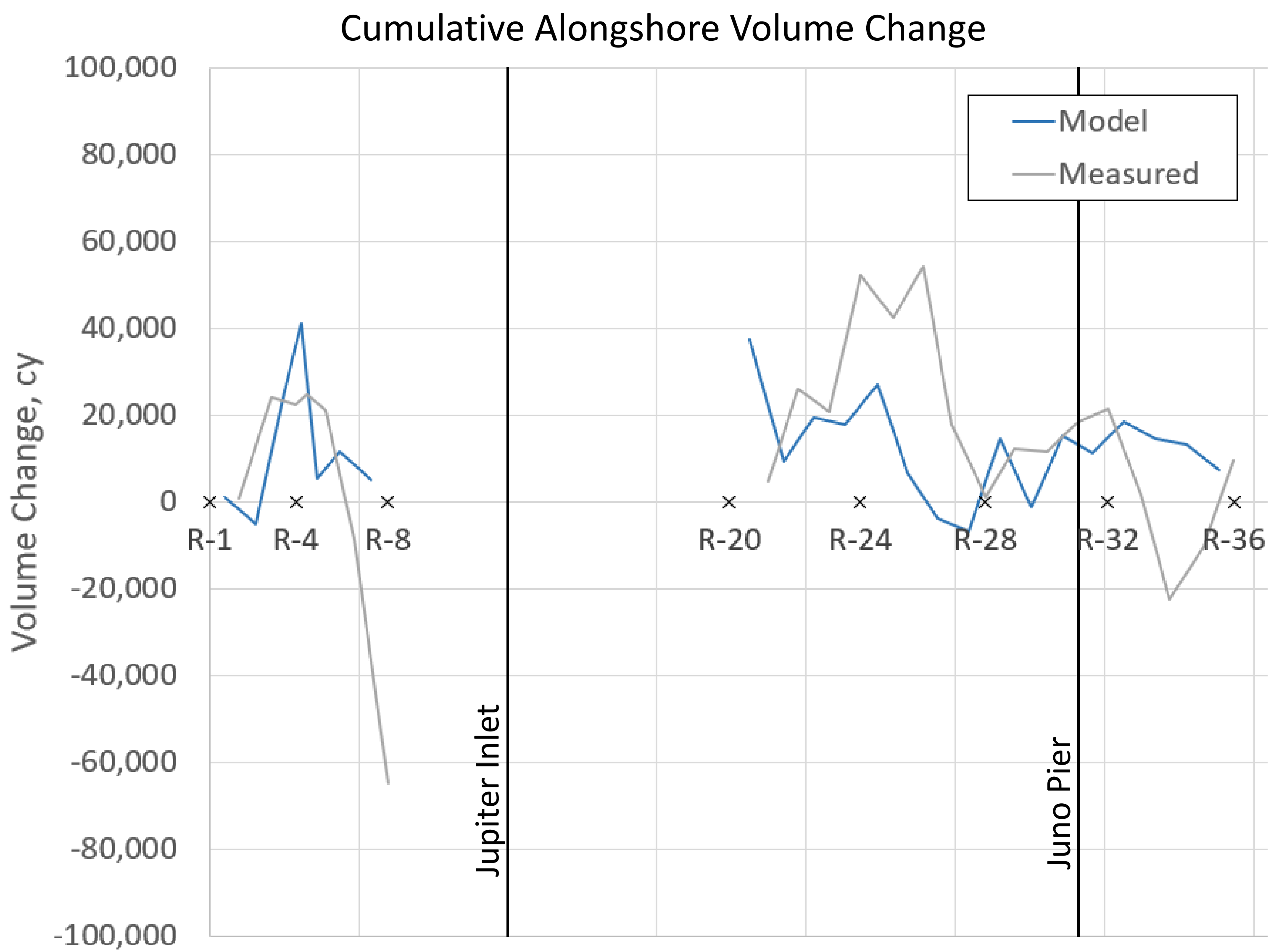
Validation Results – May 2018 to May 2019



Validation Results – Jul to Oct 2019



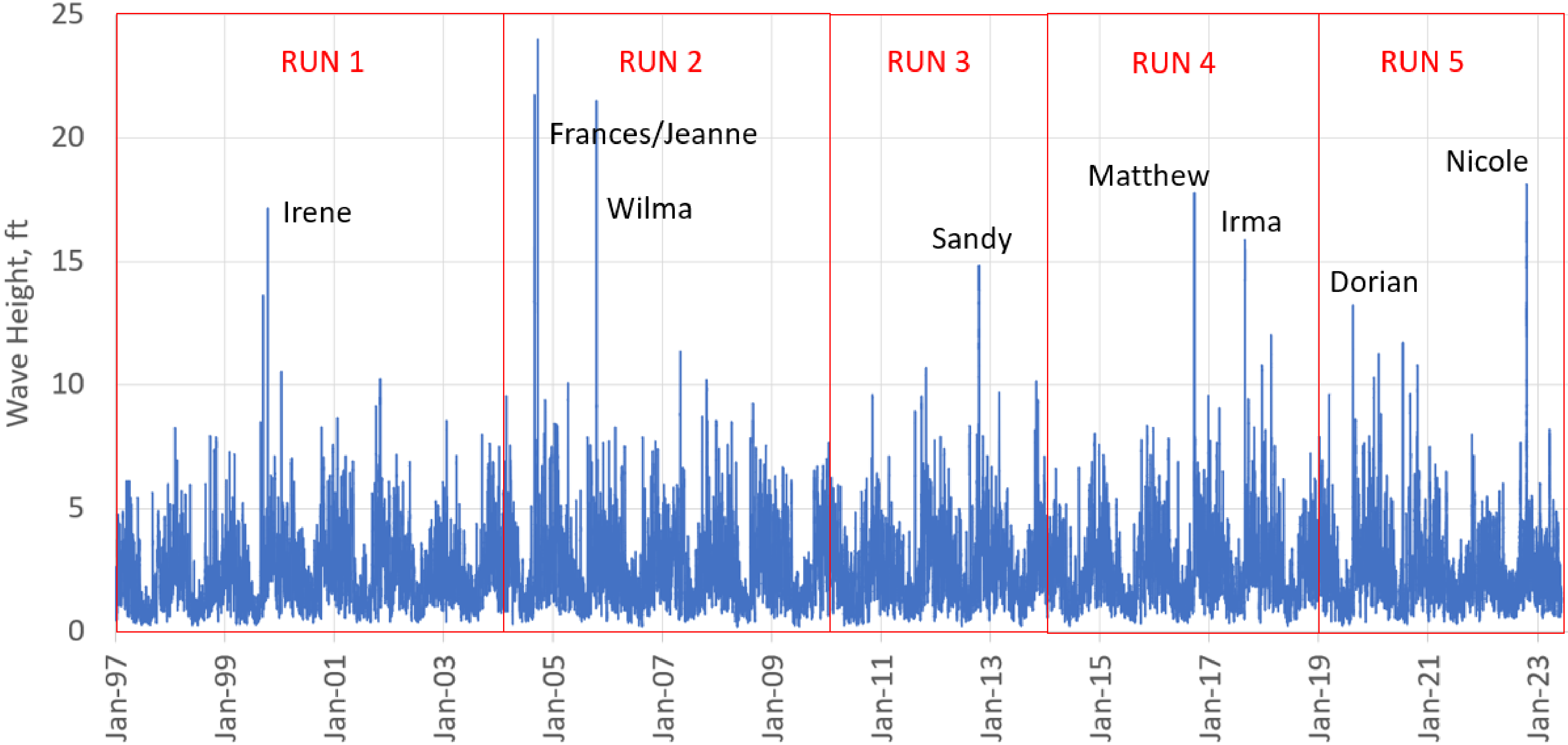
Validation Results – Jul to Oct 2019



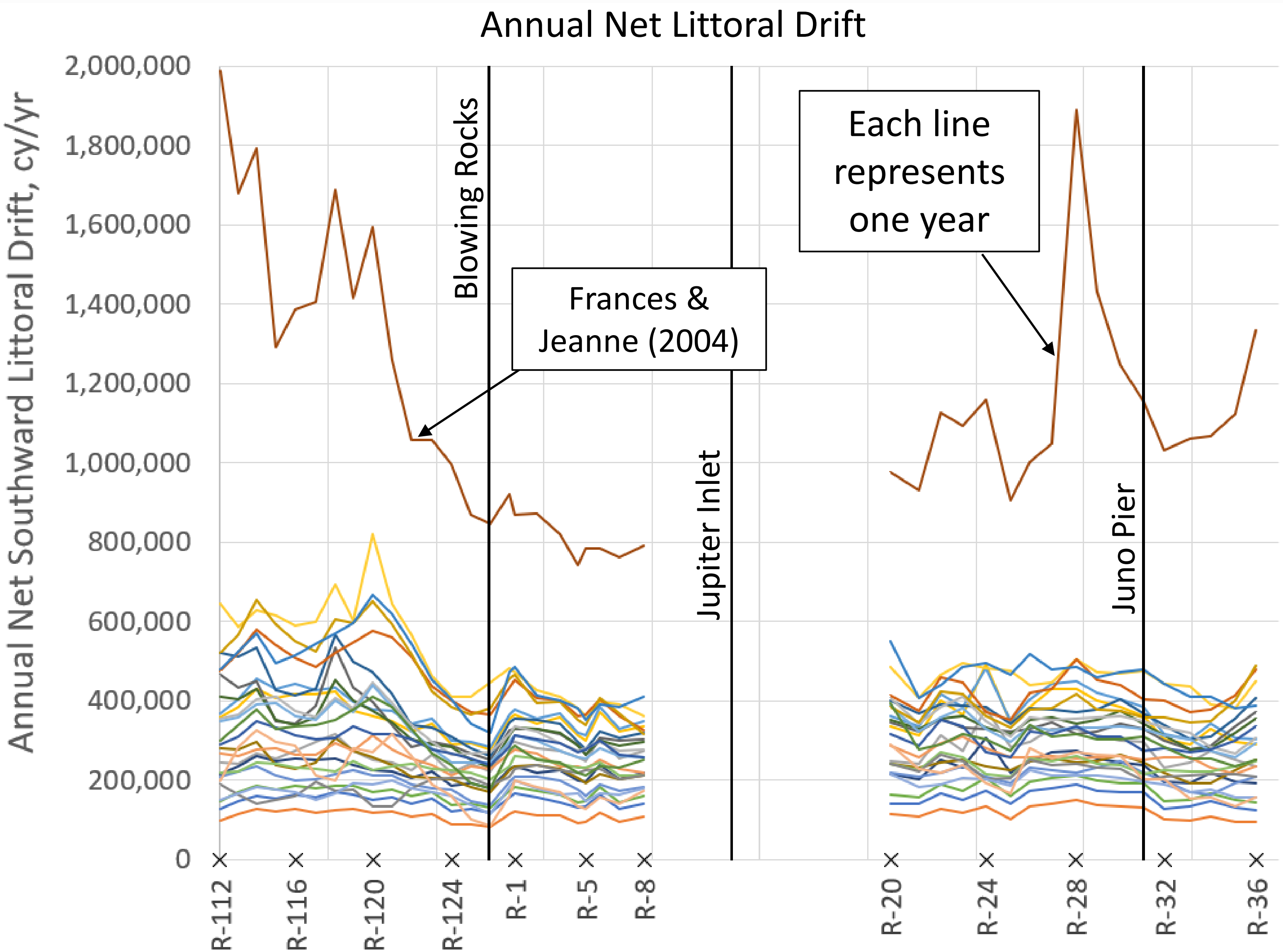
Production Runs

- Model LST from January 1, 1997—June 30, 2023
  - Jetty extension work completed in 1997
- Apply full calendar year results (1997—2022) for:
  - Annual average
  - Standard deviation
- Update bathymetry every ~5 years
  - Exact dates dependent on data availability

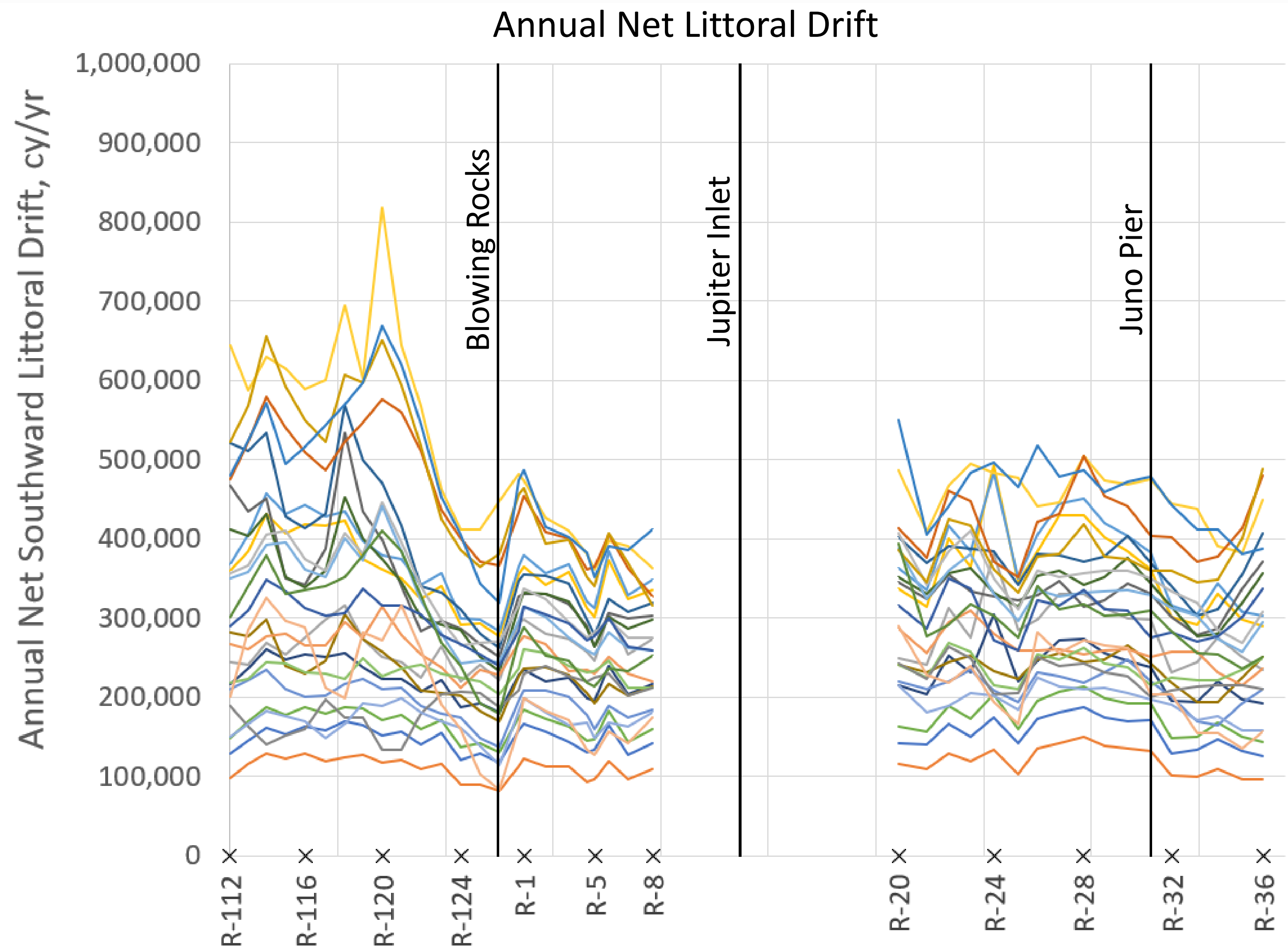
Production Run Dates



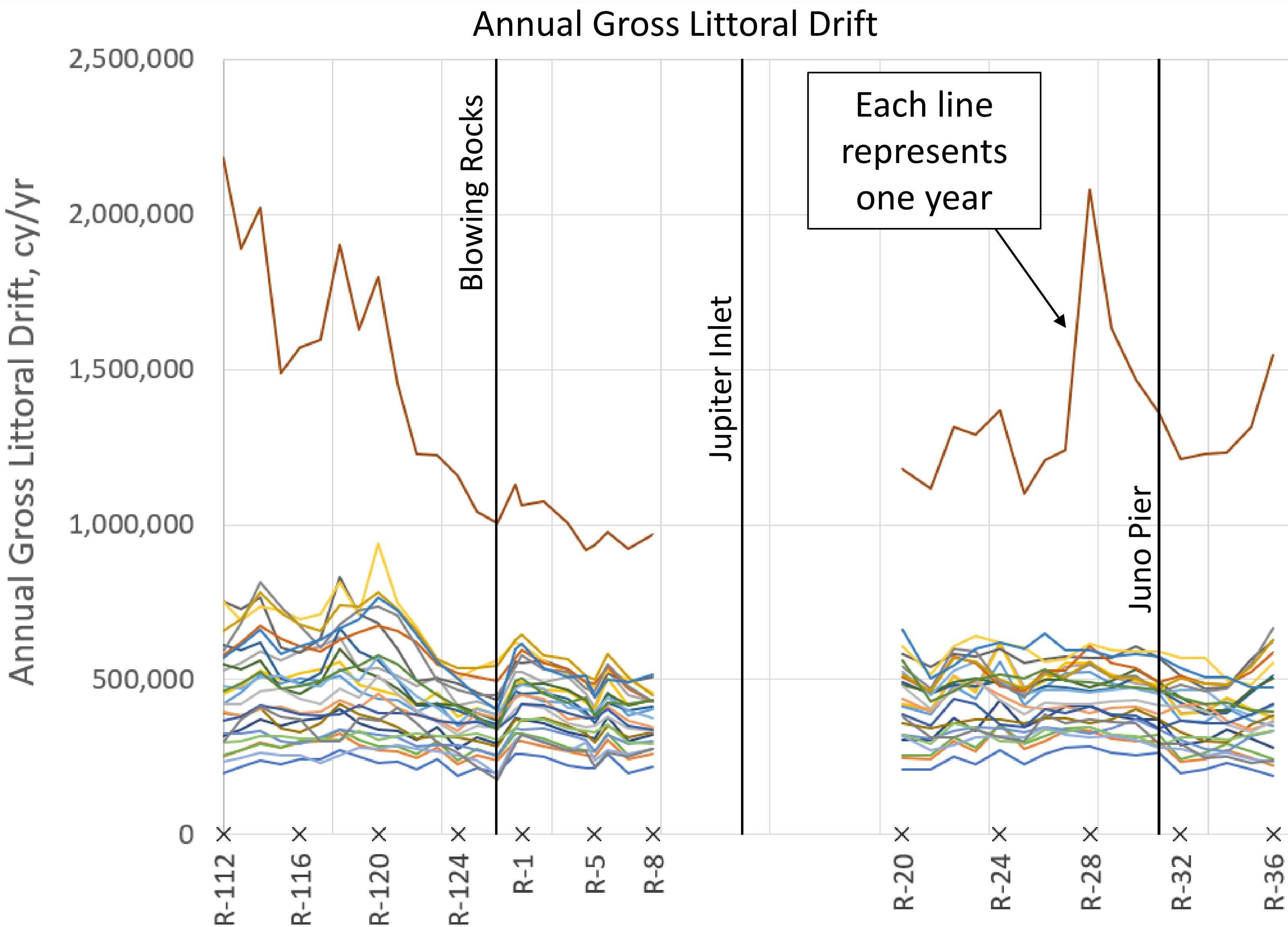
Production Run Results



Production Run Results (no 2004)



Production Run Results



Production Run Results – 1997 through 2022

Average and Standard Deviation of Annual Net Southward Littoral Drift

R-monument	Average (cy/yr)	Standard Deviation (cy/yr)	Average Without 2004 (cy/yr)	Standard Dev Without 2004 (cy/yr)
MC R-112	380,562	356,789	316,231	143,240
MC R-121	366,466	233,372	330,731	148,821
PBC R-1	322,406	148,430	300,565	100,152
PBC R-8	275,651	128,970	254,968	75,762
PBC R-20	336,498	167,376	310,901	106,939
PBC R-28	381,580	323,069	321,251	100,749
PBC R-36	320,248	233,318	279,631	109,661

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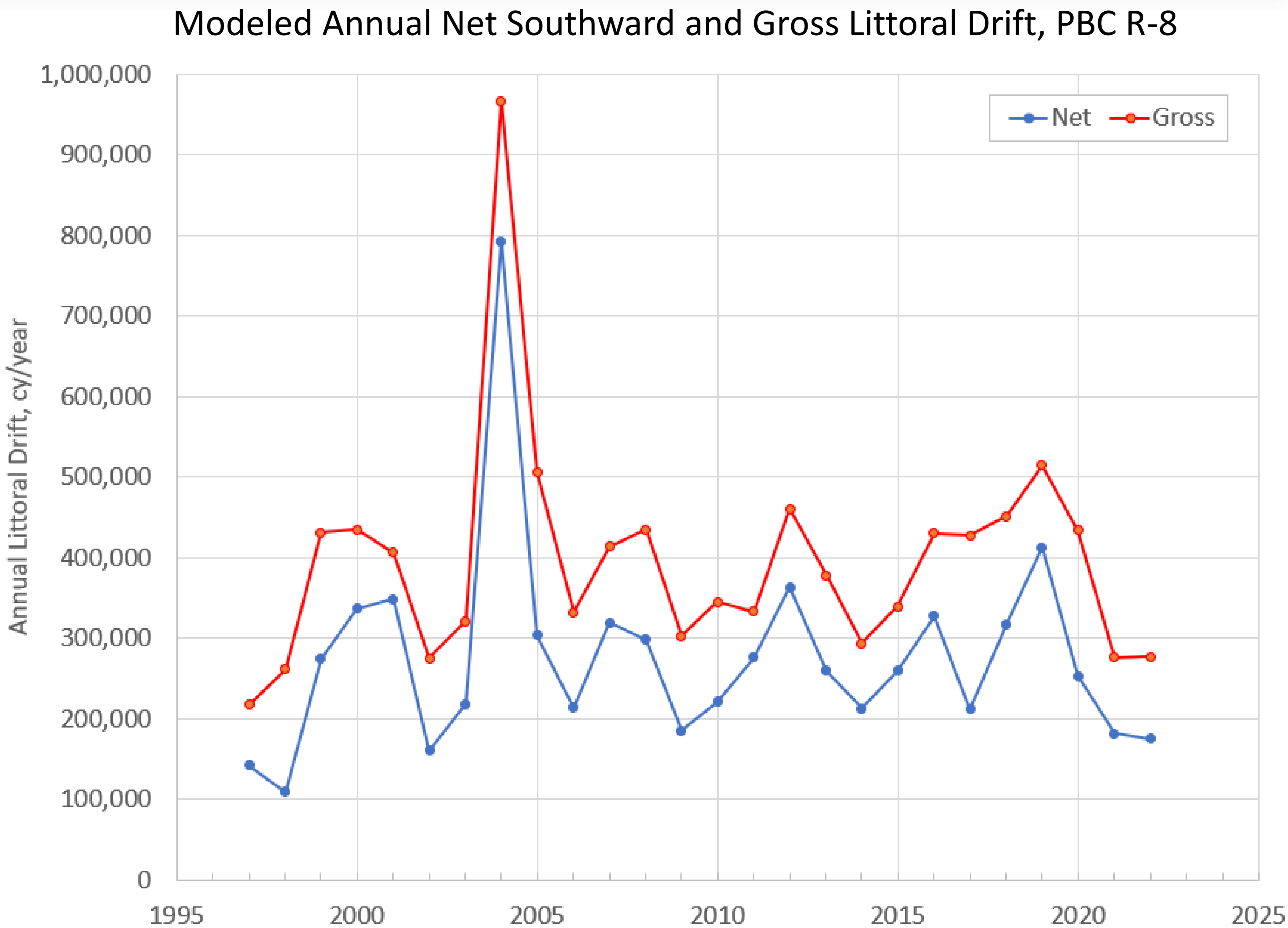
Production Run Results – 1997 through 2022

Modeled results relatively close to 1966 estimate!

Palm Beach County R-8	Transport	Annual Littoral Drift (Q), cy/yr	
		Average	Standard Deviation
USACE 1966	Net	230,000	90,000
MIKE LP Model, 1997-2022	Net	276,000	129,000
MIKE LP Model, 1997-2022	Gross	394,000	141,000

Production Run Results – 1997 through 2022



Sediment Budget

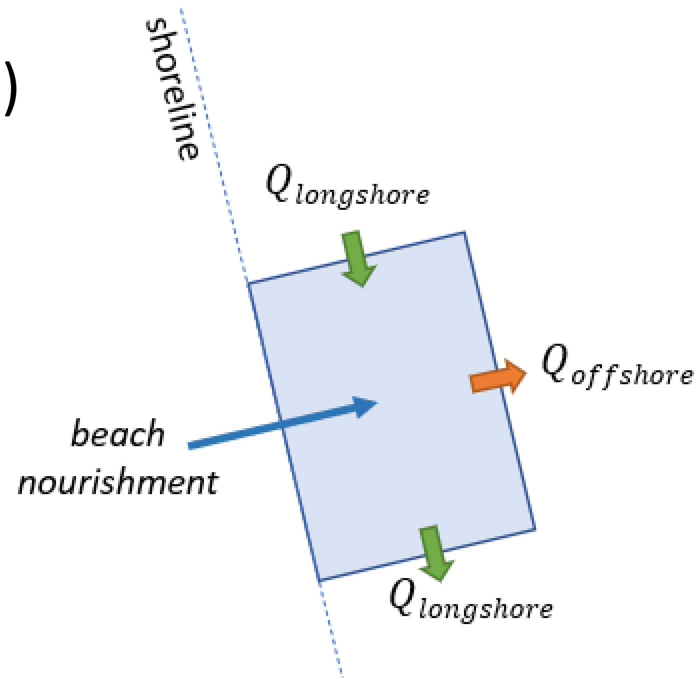
- Introduction
- Conceptual Model
- Input Data
- Results
  - September 2001—February 2023
  - July 2014—February 2023
- Average Annual Results
- Conclusions & Recommendations

Sediment Budget – Introduction

- Sediment budget guides decision-making related to managing the inlet and adjacent beaches
  - Requires accurate longshore transport rates
- Sediment budget update goals
  - How much sediment entering the inlet?
  - Offshore losses along the beaches?
  - Adequate annual bypassing?

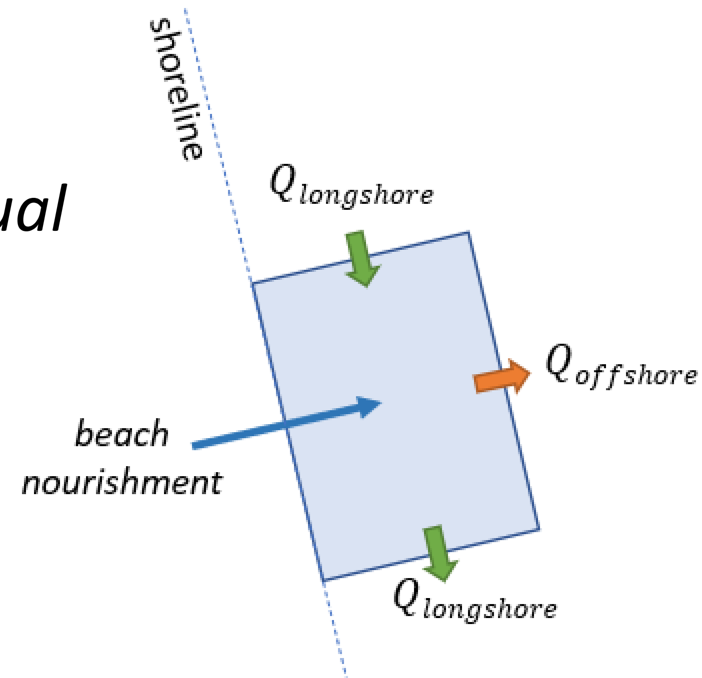
Sediment Budget – Introduction

- Mass balance of sediment sources and sinks applied within a control volume or *littoral cell*
- $\sum Q_{in} - \sum Q_{out} + P - R = \Delta V$
  - Q = sediment transport
  - P = placement (beach nourishment)
  - R = removal (dredging)
  - ΔV = volume change



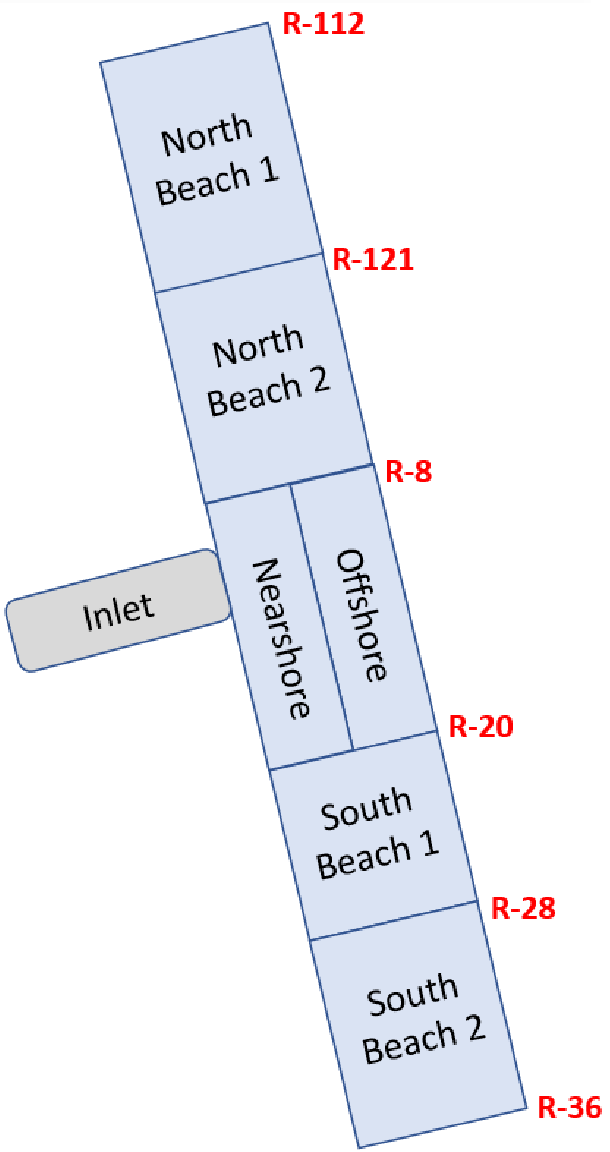
Sedimen Budget – Introduction

- $\sum Q_{in} - \sum Q_{out} + P - R = \Delta V$
- Typically...
  - P, R, ΔV known
  - Solve for an unknown Q term
- If solving for unknown term:
  - $\sum Q_{in} - \sum Q_{out} + P - R - \Delta V = residual$
- $Q_{offshore}$ represents residual



Conceptual Model Setup

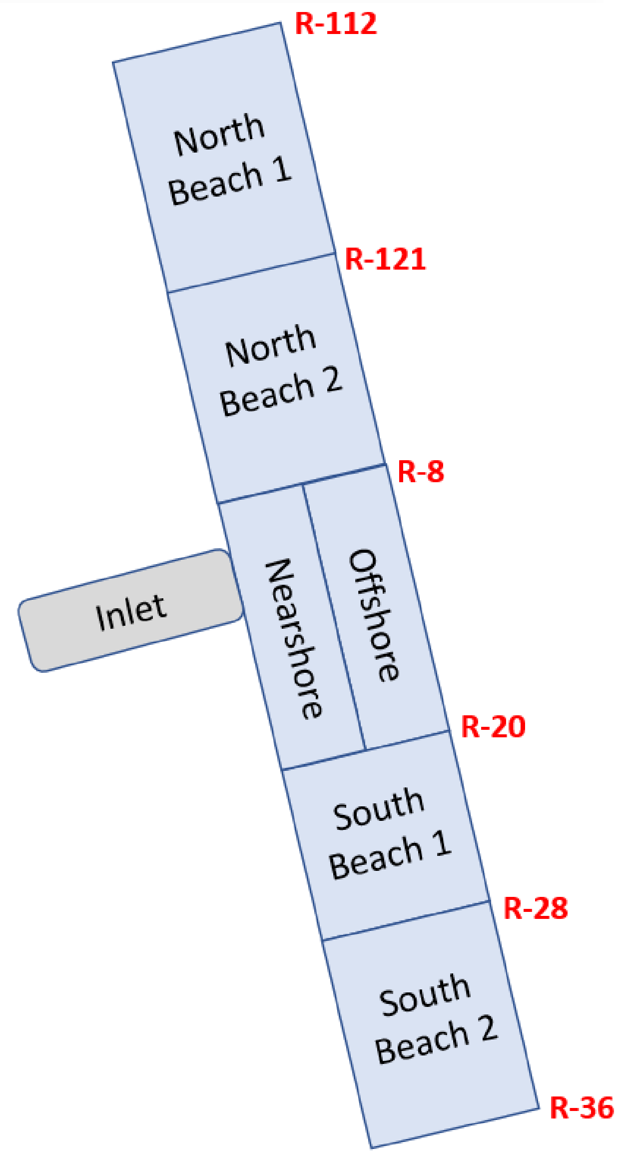
- Visual representation of control volumes
- Depth of closure guides delineation of littoral cells
  - Seaward edge of expected sediment movement
- Data availability guides selection of timeframes



Conceptual Model Setup

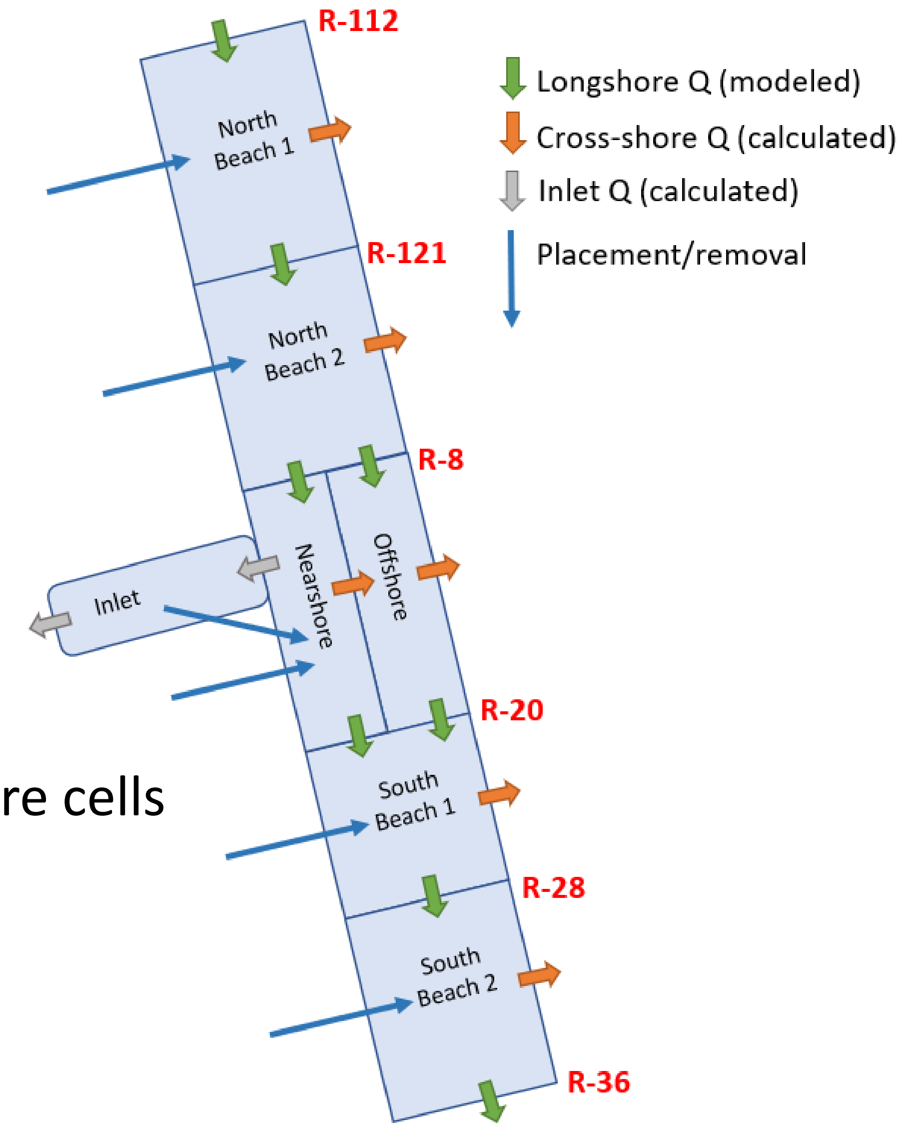
- Examine two timeframes
  - Sep 2001 – Feb 2023
  - Jul 2014 – Feb 2023
- Group R-monuments by depth of closure

Littoral Cell	Seaward Boundary (ft-NAVD)
North Beach 1	-30
North Beach 2	-35
Offshore	-35
South Beach 1	-30
South Beach 2	-35

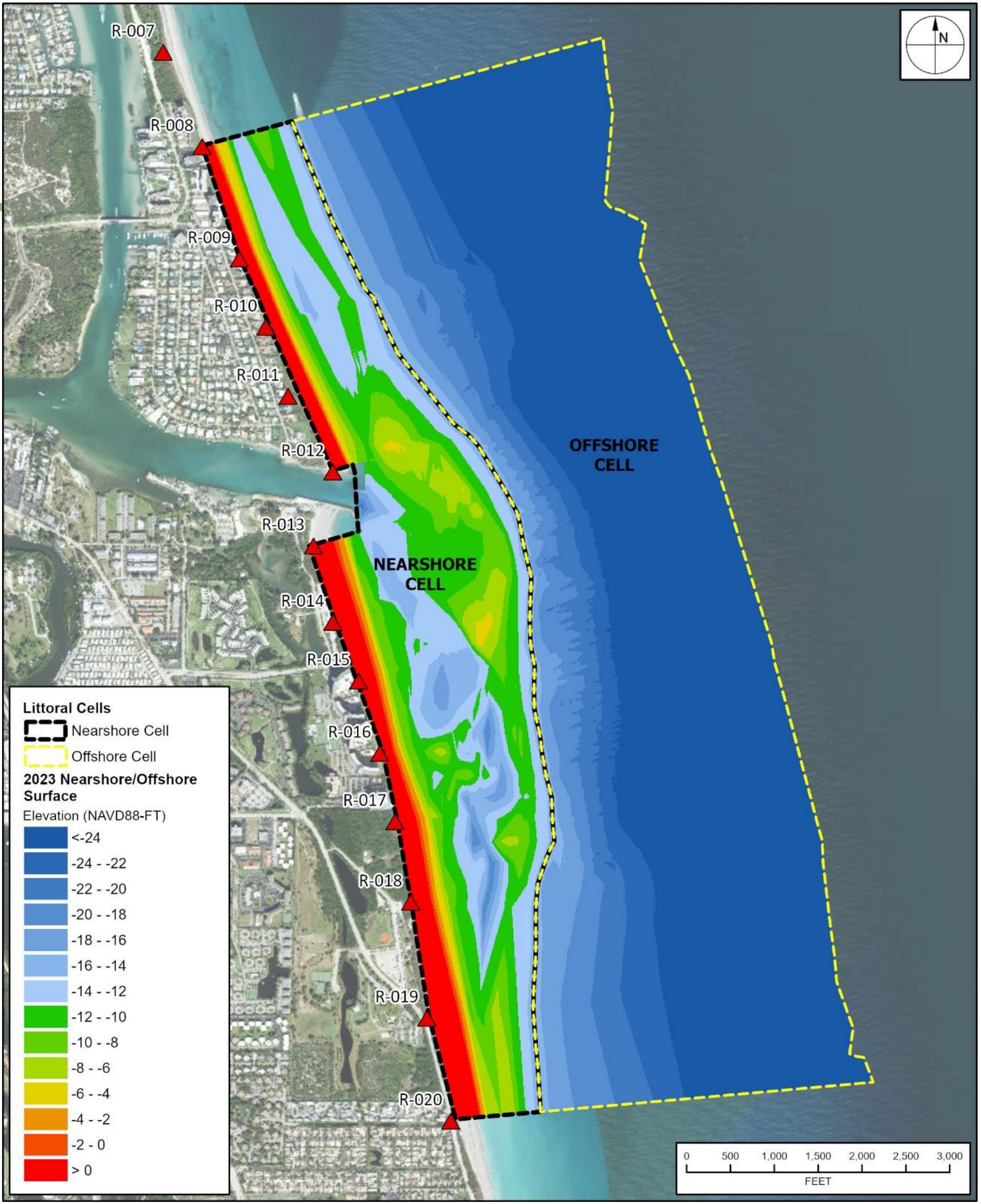


Conceptual Model Setup

- Inputs:
  - Q longshore from model
  - Beach nourishment records
  - Bypassing records
  - Surveyed volume change
- Assumption:
  - 4k cy/yr "lost" inside inlet
- Calculate:
  - Q into Inlet cell
  - Q between Nearshore/Offshore cells
  - Q offshore losses/gains



Cell Boundary



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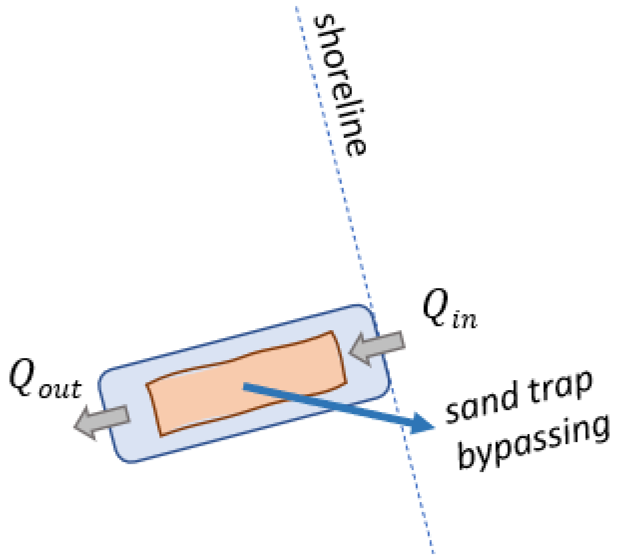
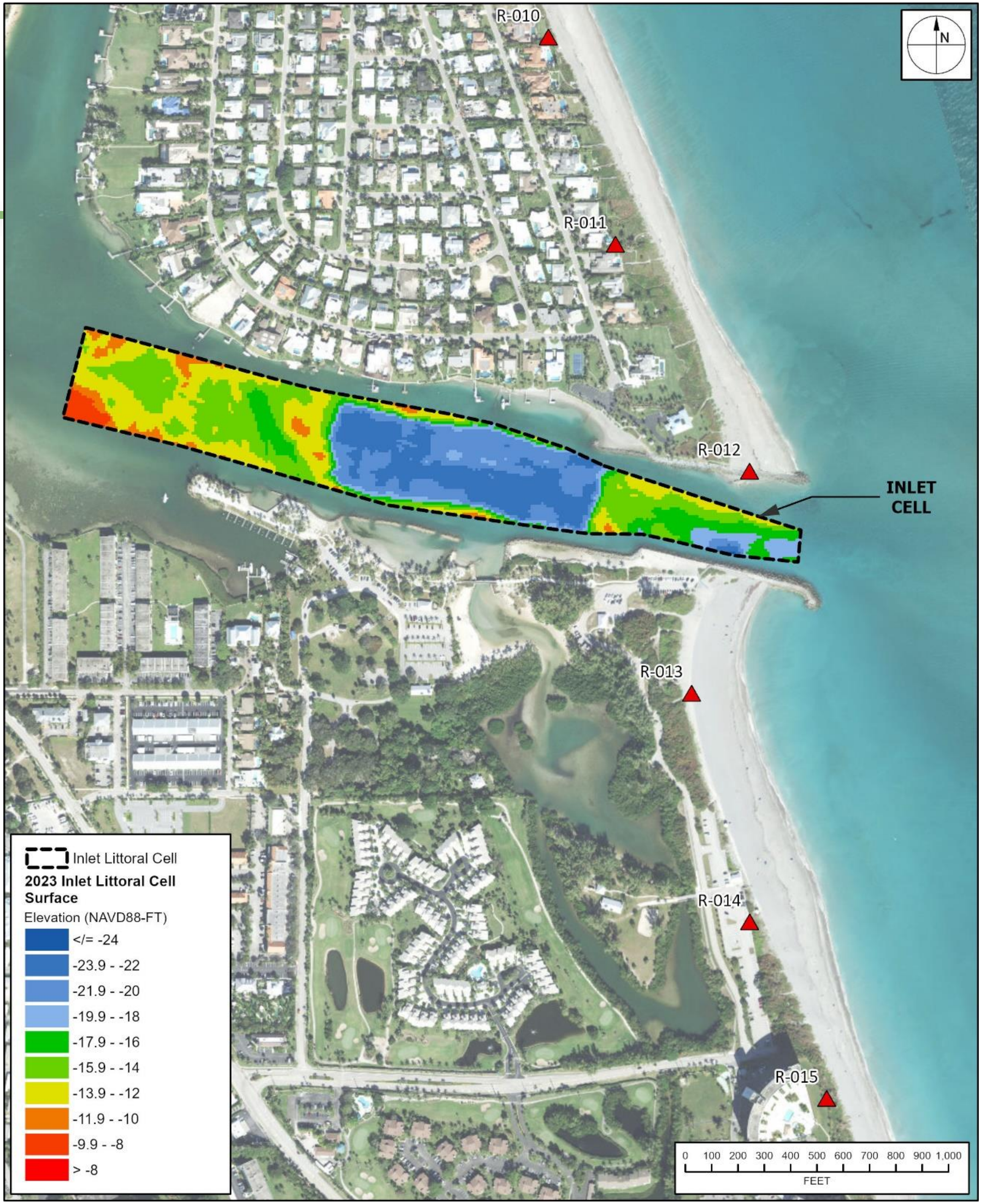
Inlet Littoral Cell

- Q_{out} = ∑ICWW bypassed + (4,000 cy/yr * number of years)
- $Q_{in} = Q_{out} + R + \Delta V$

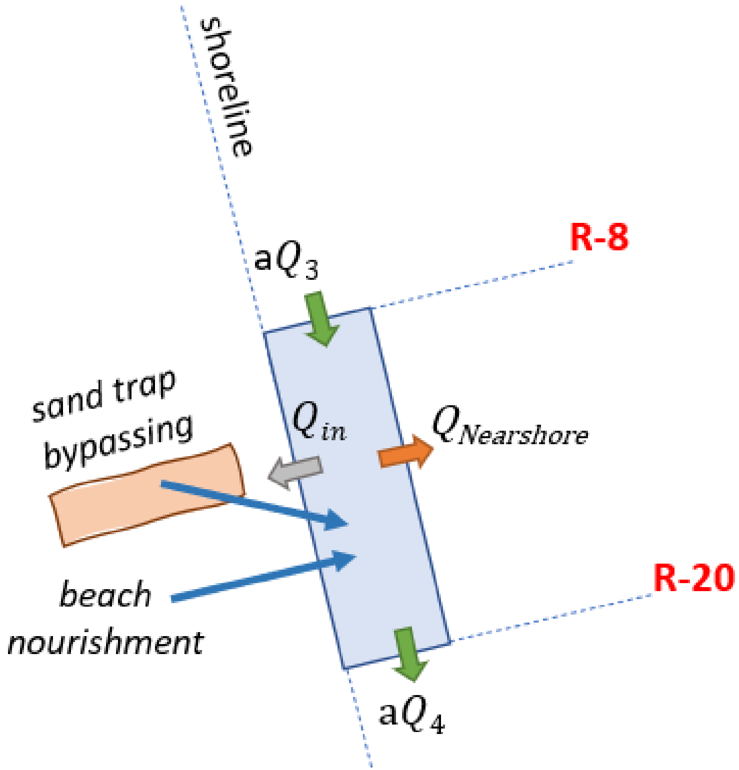


Inlet Littoral Cell



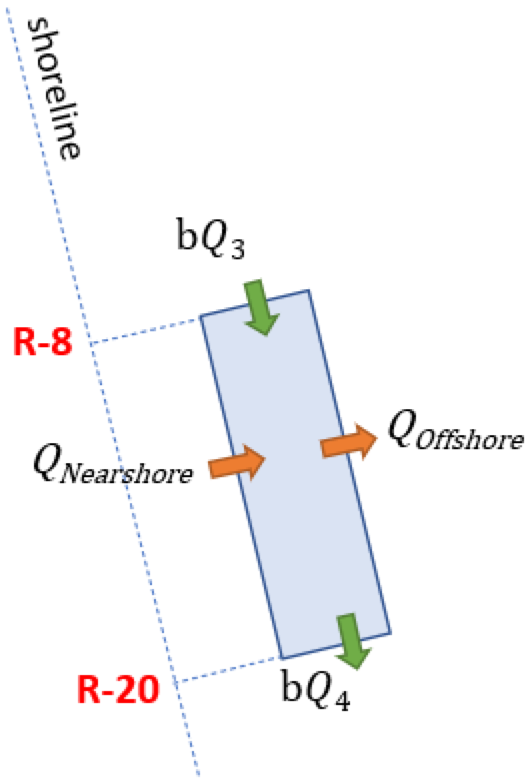
Nearshore Littoral Cell

- Q_{in} from Inlet littoral cell calculation
- Solve for $Q_{Nearshore}$
- Coefficient *a* from cross-shore distribution of LST



Offshore Littoral Cell

- $Q_{Nearshore}$ becomes an input term
- Solve for $Q_{Offshore}$
- Coefficient *b* from cross-shore distribution of LST



Results

Littoral Cell	Alongshore Length (ft)	Gains (+) or Losses (–) Across Seaward Edge (cy per linear ft per year)	
		Sep 2001 – Feb 2023	Jul 2014 – Feb 2023
North Beach 1	7,928	-2.5	3.6
North Beach 2	11,715	-15.7	-12.8
Nearshore	11,441	1.9	4.8
Offshore	11,441	-0.4	13.4
South Beach 1	8,495	-4.2	-9.8
South Beach 2	8,419	-20.4	-6.6

Results

Persistent offshore losses: North Beach 2 (Martin R-121 to PBC R-8)
South Beach 1 (PBC R-20 to R-28)
South Beach 2 (PBC R-28 to R-36)

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Results

Minor gains from Offshore cell to Nearshore cell (PBC R-8 to R-20)

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Results

Post-2014 significant recovery in Offshore (PBC R-8 to R-20)

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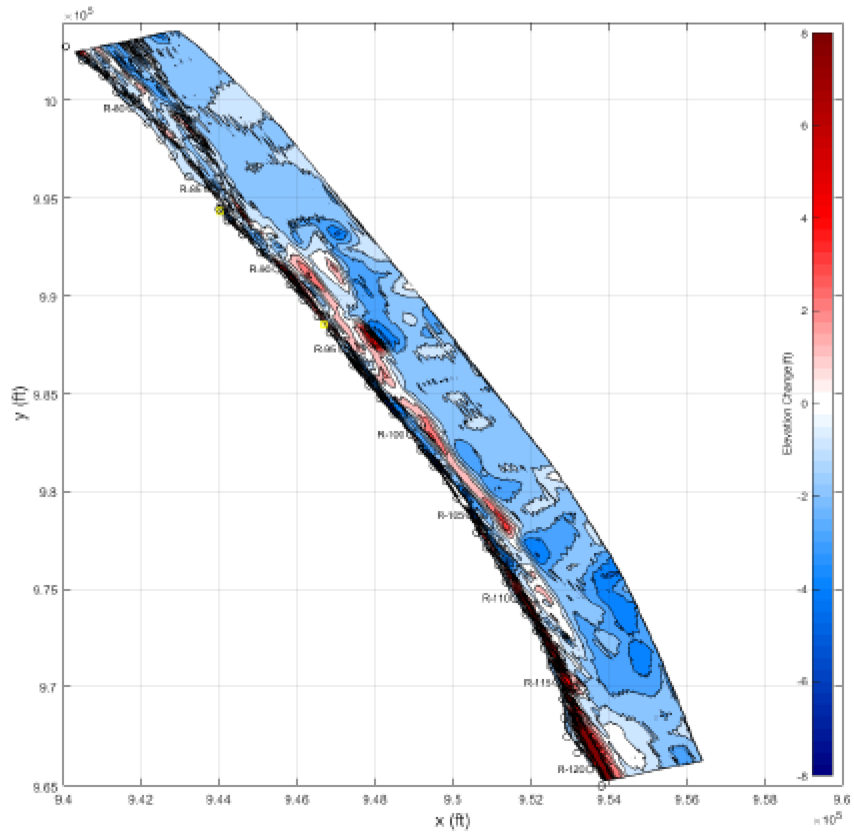
Results

Dr. David Kriebel 2020 – Jupiter Island

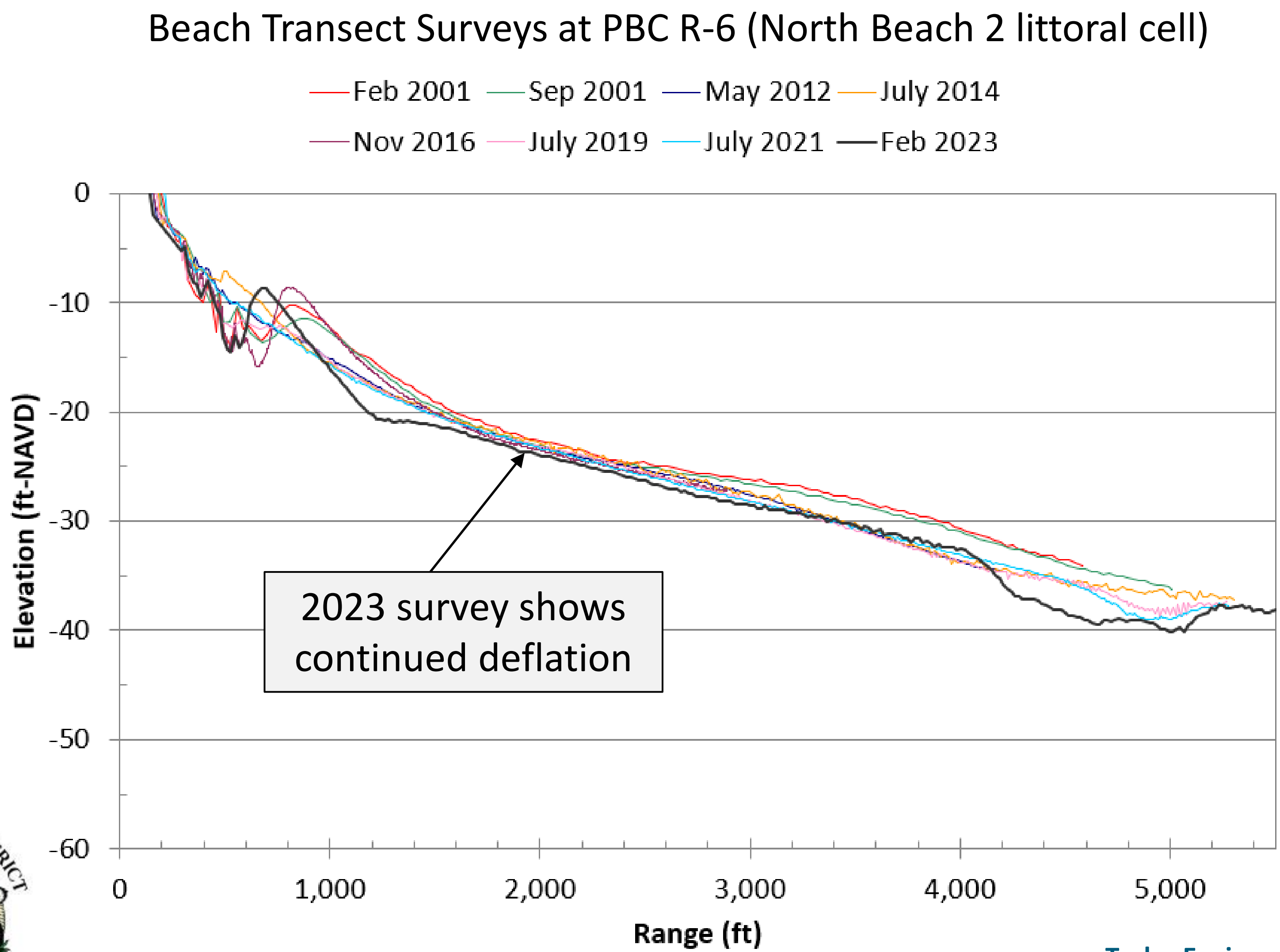
Independent Evidence of Offshore Losses

- GBA surveys for Town of Jupiter Island
  - Different dates, monuments, and surveyor
- Plot elevation change from 2001-2014
  - Blue shading is loss of elevation
  - Typical loss offshore is 1 to 2 ft
- Odroniec (2006) UF Masters Thesis
  - Noted lack of closure and offshore losses
  - Computed std dev in FDEP profiles
    - Found minimum std dev at 13 ft depth
- Beach profile data shows:
  - Most losses in depths greater than 13 ft
  - Most gains from monument to -13 ft



*We see the same “profile deflation” 2001-2014 with recovery at some R-monuments post-2014

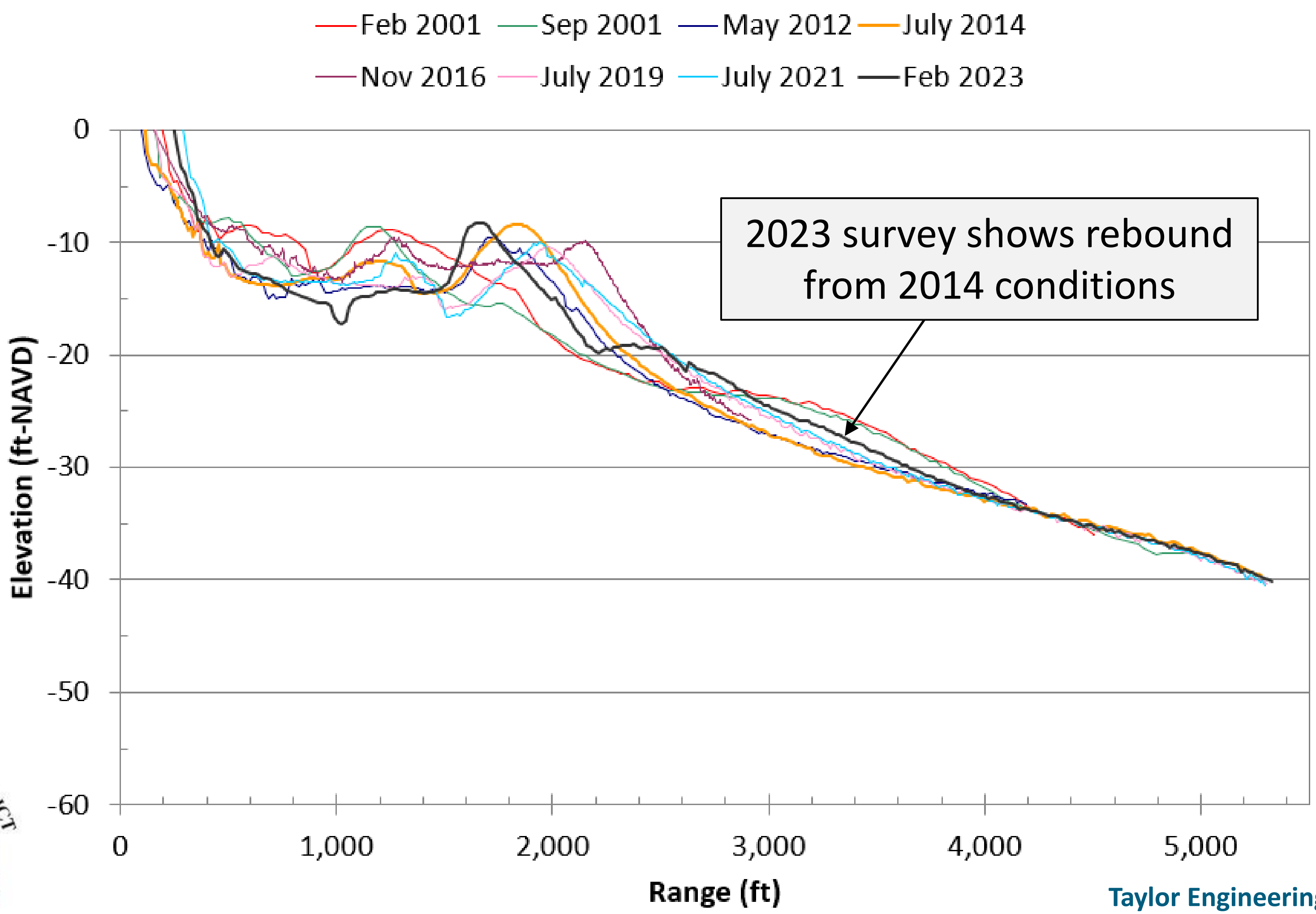
Results



Beach Transect Surveys at PBC R-6 (North Beach 2 littoral cell)
Feb 2001
Sep 2001
May 2012
July 2014
Nov 2016
July 2019
July 2021
Feb 2023
0
-10
-20
-30
-40
-50
-60
Elevation (ft-NAVD)
0
1,000
2,000
3,000
4,000
5,000
Range (ft)
2023 survey shows continued deflation

Results

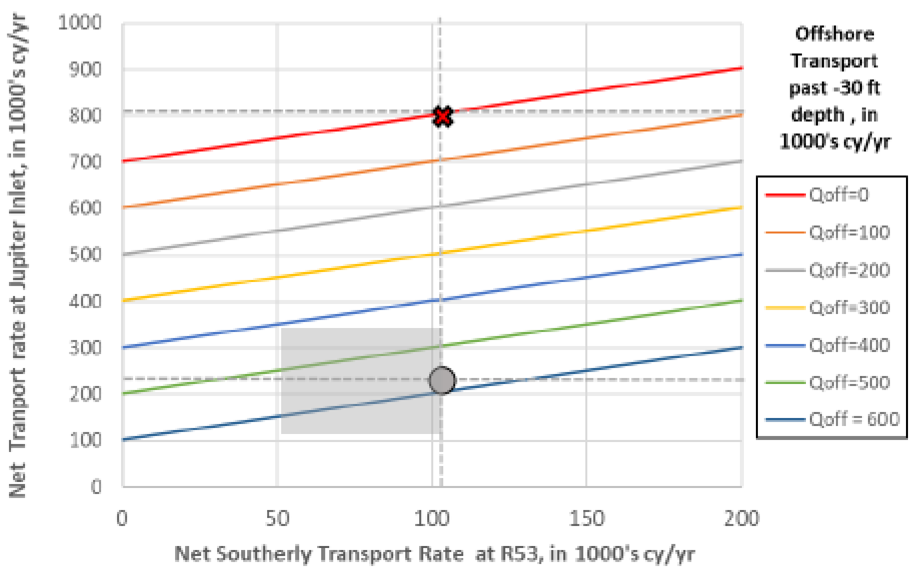
Beach Transect Surveys at PBC R-15 (Nearshore and Offshore littoral cells)



Results

Dr. David Kriebel 2020 – Jupiter Island

Family of Solutions for Island-Wide Sediment Budget



Use IMP's to narrow range of values

Option #1 adopting values from adjacent IMP's cannot be ruled out

Conclude that there must be large offshore volume losses!

$$Q_{in} + Q_{fill} - Q_{out} - Q_{off} = \Delta_{vol}$$

*500k cy ~ 8 cy/linear ft found by JI → similar to our results

Results

Source	Dates	R-8 Net Q Southward (cy/yr)	Net Q Into Inlet (cy/yr)	Percent of R-8 Q into Inlet
JID 2024	Sep 2001 - Feb 2023	289,993	85,046	29%
JID 2024	Jul 2014 - Feb 2023	257,309	79,890	31%
Mehta et al. 2007	1993-1998	230,000	75,900	33%

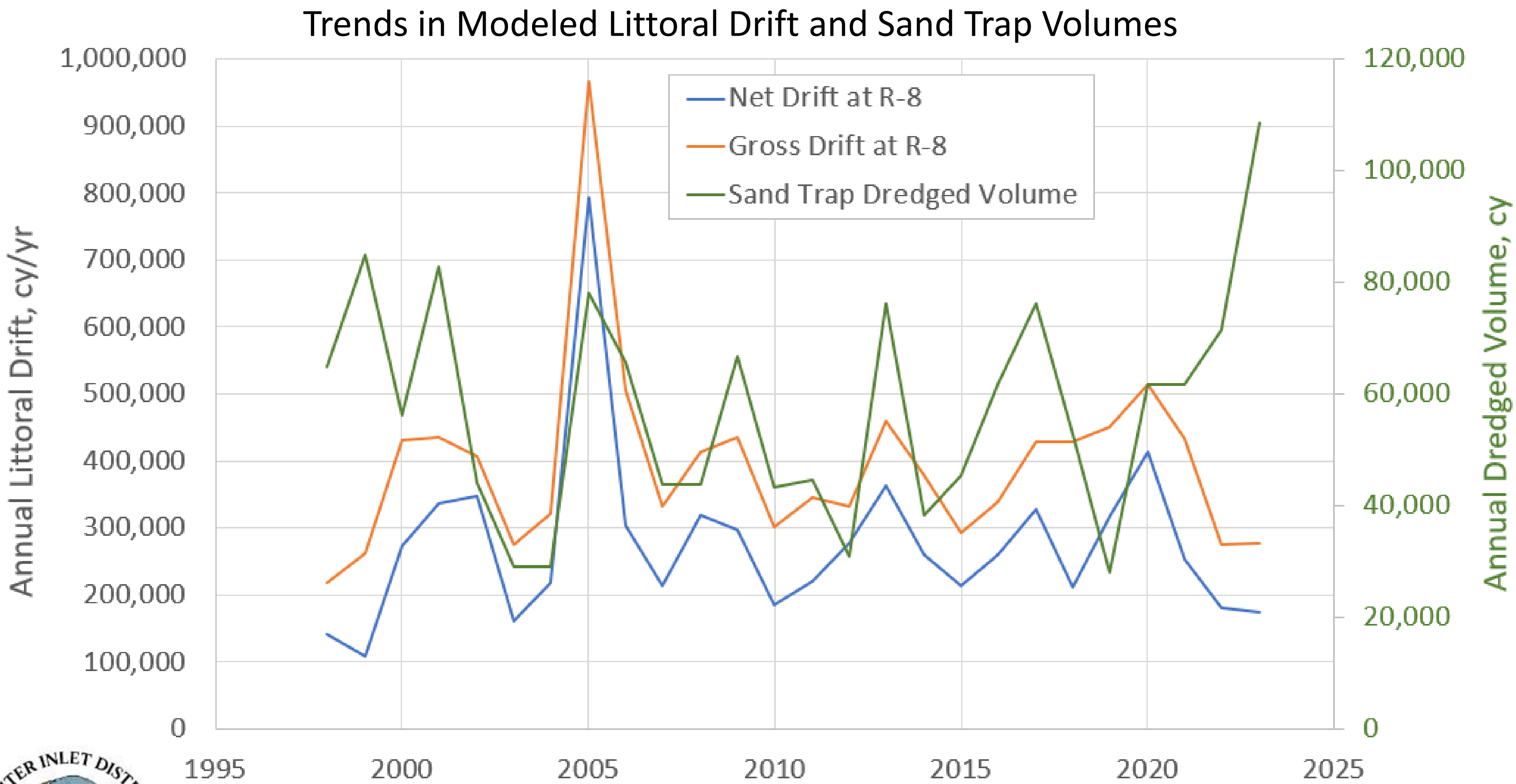
Results

Source	Dates	R-8 Gross Q (cy/yr)	Net Q Into Inlet (cy/yr)	Percent of R-8 Q into Inlet
JID 2024	Sep 2001 - Feb 2023	409,436	85,046	21%
JID 2024	Jul 2014 - Feb 2023	391,493	79,890	20%

Results

- Sensitivity tests for several input terms show limited impact on calculated offshore gains/losses
  - Modeled longshore $\sum Q_{in} - \sum Q_{out}$
    - 90%
    - 110%
  - Distribution of modeled Q to Nearshore vs. Offshore littoral cells
    - 75%:25%
    - 90%:10%
  - Losses within inlet complex
    - 7,000 cy/yr
    - 10,000 cy/yr

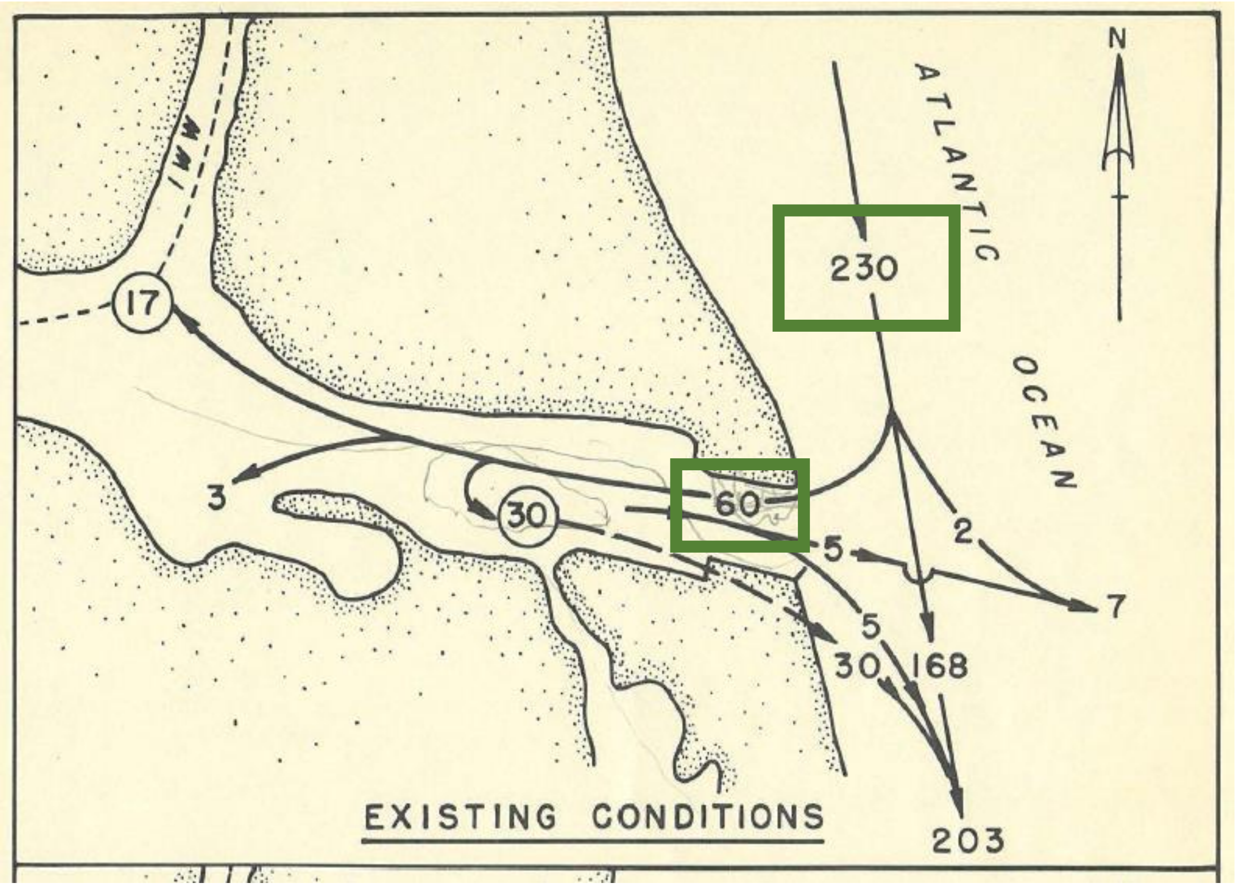
Results



Trends in Modeled Littoral Drift and Sand Trap Volumes
Net Drift at R-8
Gross Drift at R-8
Sand Trap Dredged Volume
Annual Littoral Drift, cy/yr
Annual Dredged Volume, cy
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
120,000
100,000
80,000
60,000
40,000
20,000
0
1995
2000
2005
2010
2015
2020
2025

Historical Comparison

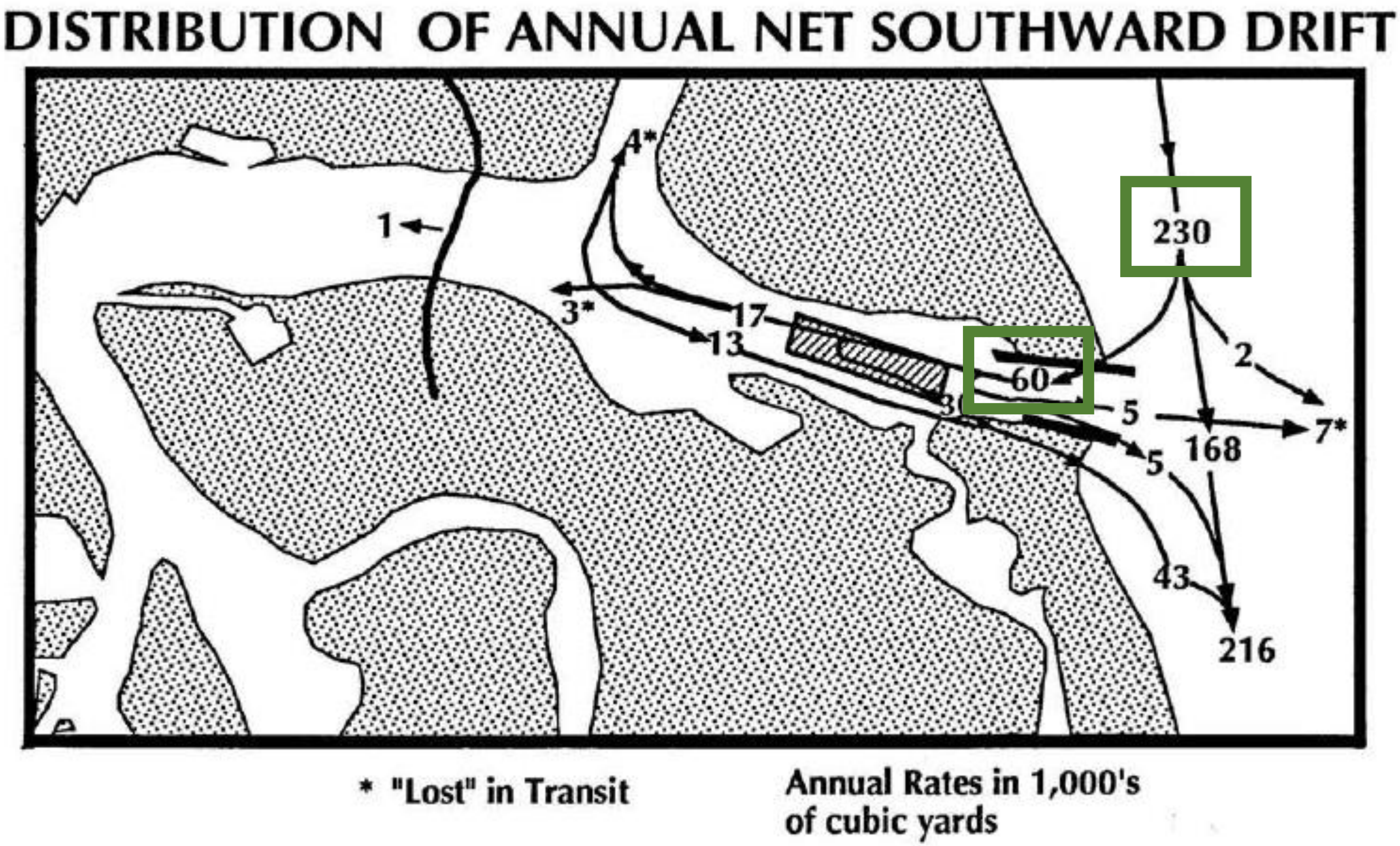
USACE 1966



Note: 60k cy represents gross transport into inlet, net = 50k

Historical Comparison

Mehta et al. 1992



Note: 60k cy represents gross transport into inlet, net = 50k

Historical Comparison

Sharma/Mehta 2007

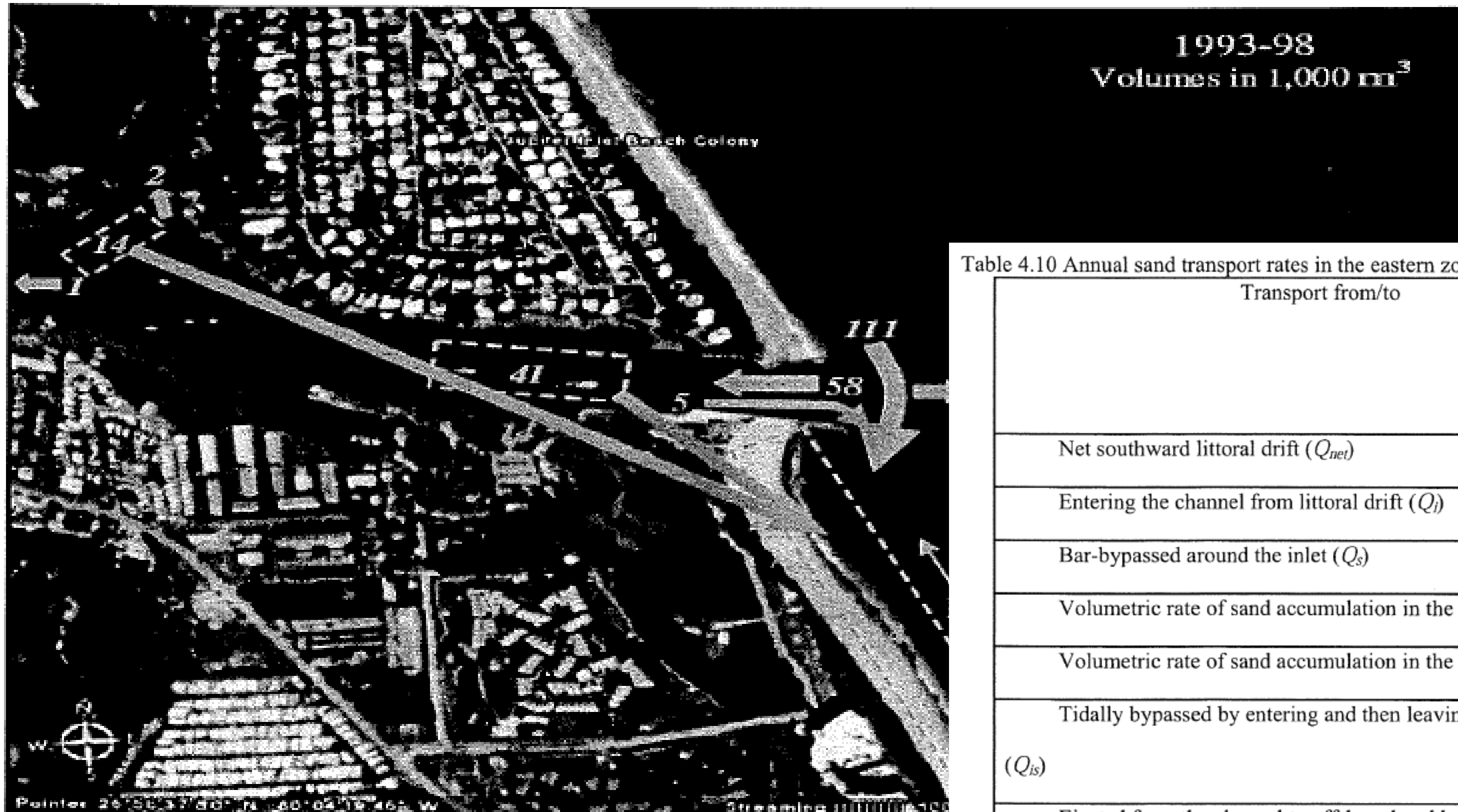


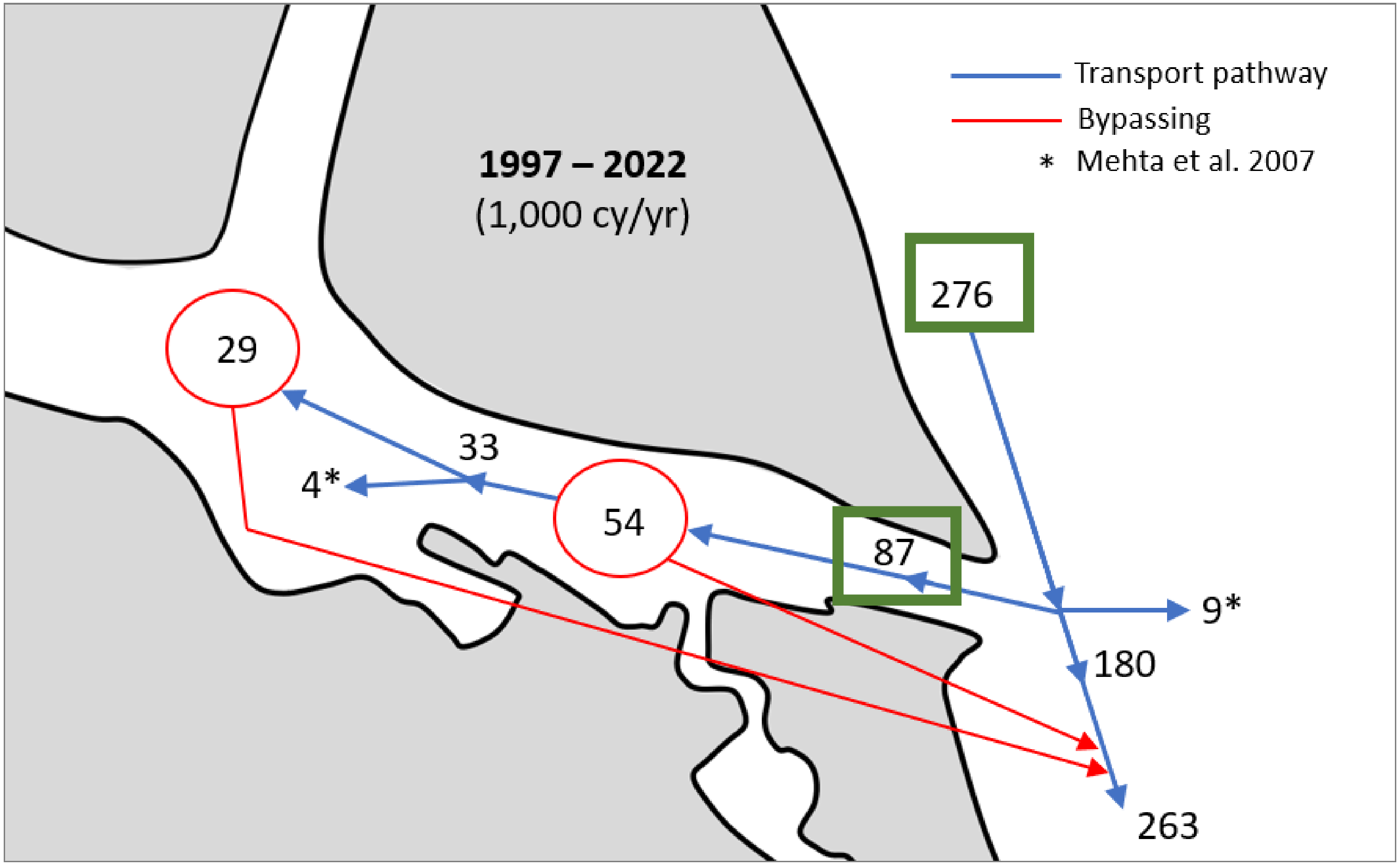
Figure 4.8 Components of eastern zone JID sand budget for 1993-199

Table 4.10 Annual sand transport rates in the eastern zone for 1993-1998 JID sand budget

Transport from/to	Volumetric rate (m^3/yr)
Net southward littoral drift (Q_{net}) **230k cy**	176,000
Entering the channel from littoral drift (Q_l) **76k cy**	58,000
Bar-bypassed around the inlet (Q_s)	111,000
Volumetric rate of sand accumulation in the ICWW (V_{ic})	14,000
Volumetric rate of sand accumulation in the trap (V_{st})	41,000
Tidally bypassed by entering and then leaving the channel (Q_{is})	5,000
Ejected from the channel to offshore by ebb flow (Q_j)	7,000
Transported to ICWW channels north and south of inlet(Q_{ic})	2,000
Transported to Central Embayment(Q_c)	1,000
Beach volume change rate downdrift of inlet (V_{dd})	4,000

Note: 76k cy (58k m^3) represents net transport

Historical Comparison



Note: 87k cy represents net transport into inlet

Historical Comparison

Transport Component (Volumes in 1,000 cy)	USACE 1966	Mehta et al. 1992	Sharma 2007 (1974-1986)	Sharma 2007 (1986-2002)	Mehta et al. 2007 (1993-1998)	Sharma 2007 (1998-2006)	JID 2024 (1997-2022)
Entering inlet (net)	50	50	73	70	76	79	87
Deposited in sand trap	30	30	42	44	54	52	54
Deposited in ICWW channel	17	13	27	22	18	24	29
Deposited in inlet complex	3	7	4	4	4	4	4*

*transport component applied from Mehta et al. 2007

Conclusions

- MIKE LP model and historical data analysis allowed for successful sediment budget update
  - Net southward Q at R-8 similar to prior estimate
  - Net percent Q into inlet similar to Mehta et al. 2007
- Nearshore/Offshore littoral cells show gains since 2014
  - Cross-shore distribution of sand not necessarily ideal

Conclusions

- Inlet littoral cell
  - ~30% of net southward Q and ~20% of gross Q deposits inside inlet complex
- Most beach littoral cells north and south of inlet show persistent offshore losses
  - Dr. Kriebel 2020 results for Jupiter Island (2001—2014) agree
  - Reports of "profile deflation" throughout east coast of Florida

Surveying Recommendations

- Ebb shoal
- Include PBC R-1 through R-12 in beach surveys
- Extend beach transect surveys farther offshore
  - ~6,000 ft
- When possible, collect beach, sand trap, and ebb shoal surveys within the same season
- Adjust R-monument azimuths

Next Steps

- Draft report
- Ebb shoal migration study
- Riverine study
- Updates to Inlet Management Plan

THANK YOU
Questions?