Coastal monitoring using UAS to track changes in beach morphology: Waikīkī, Hawai‘i

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Committee Members:
Chip Fletcher (chairperson), Tiffany Anderson, & Scott Rowland

Coastal Geology Group
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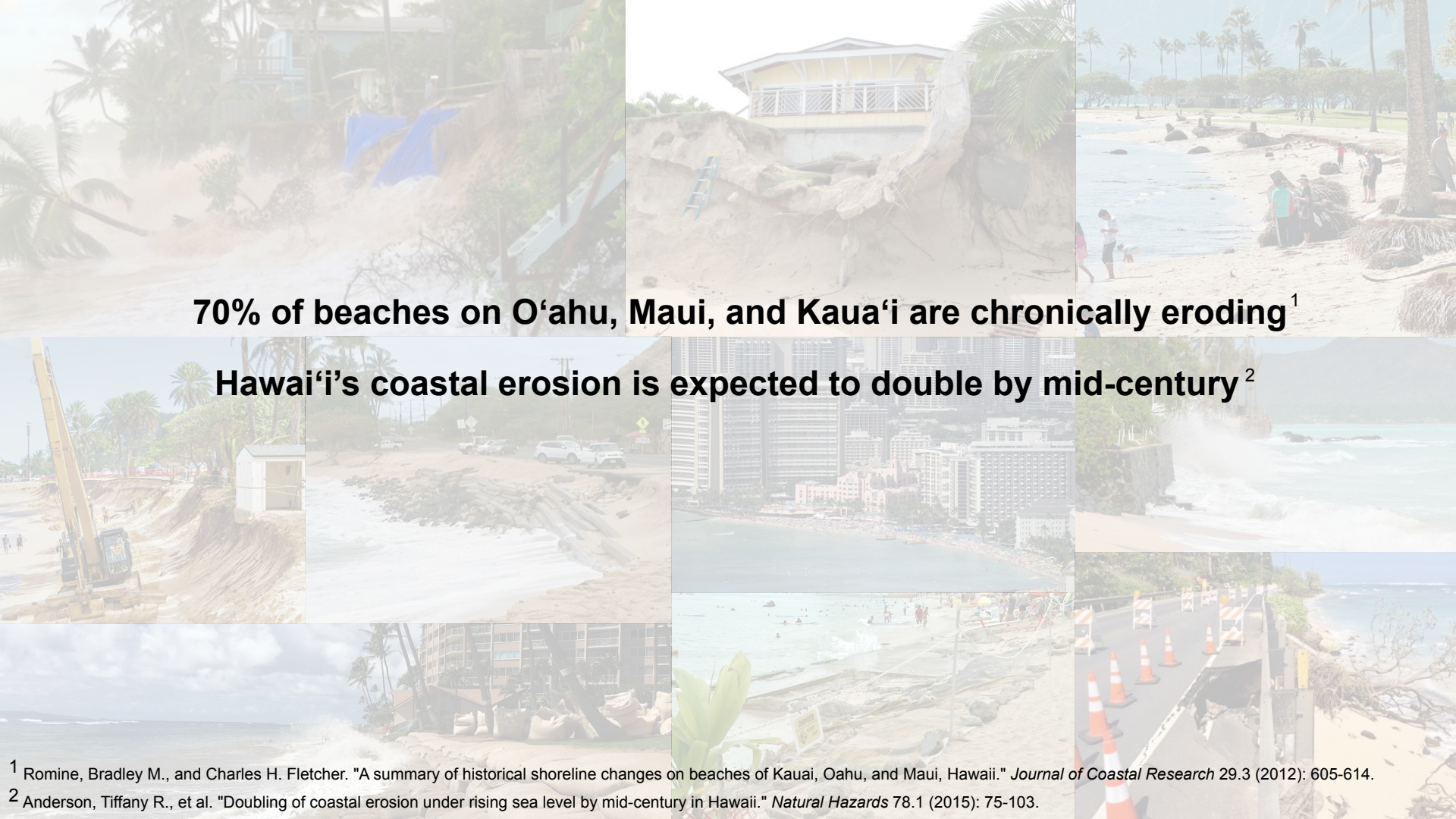
School of Ocean and Earth Science and Technology
University of Hawai‘i at Mānoa

DANGER



70% of beaches on O‘ahu, Maui, and Kaua‘i are chronically eroding[1]

Hawai‘i’s coastal erosion is expected to double by mid-century[2]

[1] Romine, Bradley M., and Charles H. Fletcher. "A summary of historical shoreline changes on beaches of Kauai, Oahu, and Maui, Hawaii." *Journal of Coastal Research* 29.3 (2012): 605-614.

[2] Anderson, Tiffany R., et al. "Doubling of coastal erosion under rising sea level by mid-century in Hawaii." *Natural Hazards* 78.1 (2015): 75-103.

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A **need** for cost-efficient tools for effective, empirically-based coastal management

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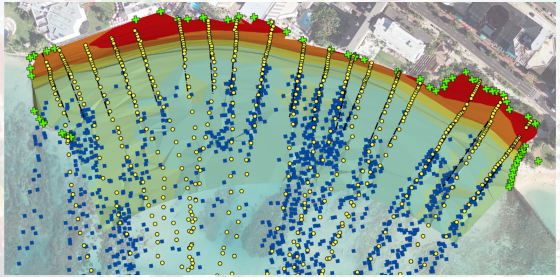
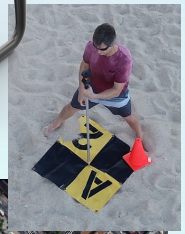
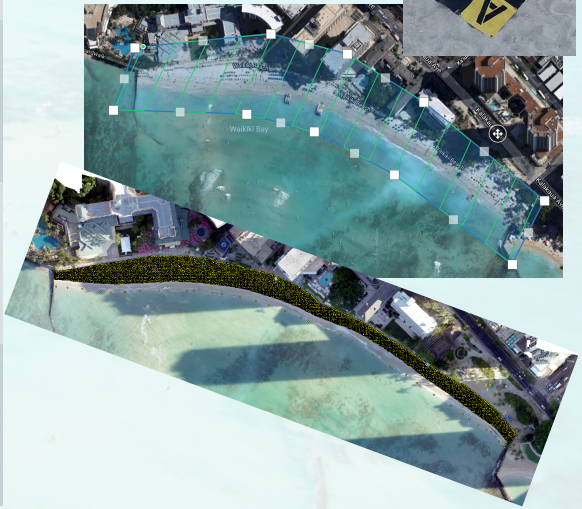
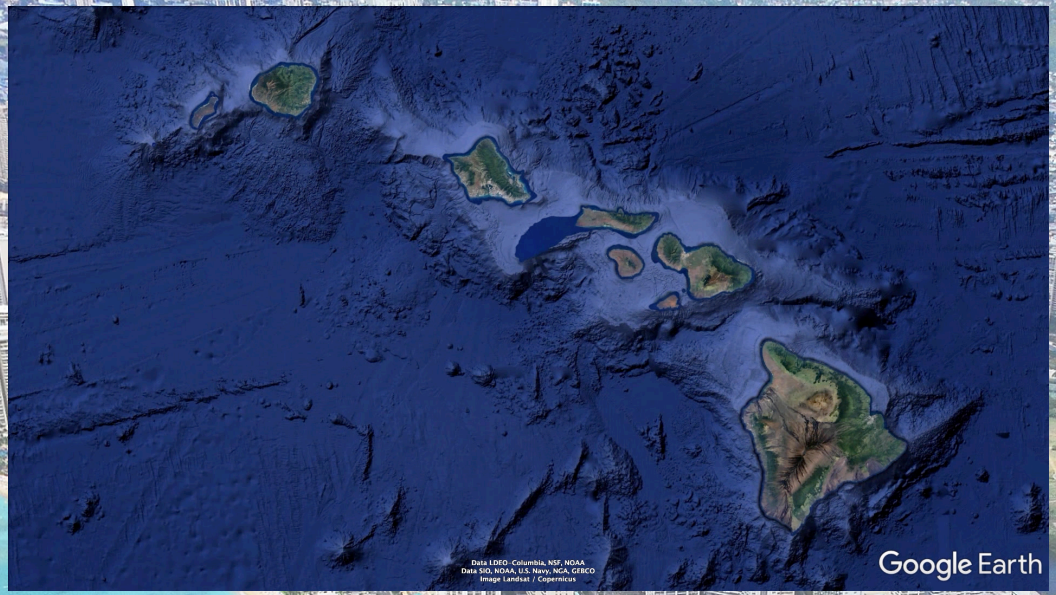


Total Station and Rod	Unmanned Aerial Systems
~8 hours in the field	~1 hour in the field
Difficult in crowded conditions, relies on line of sight	Bird's eye view
Undersampled	High resolution (~3 cm/pix)
Nearshore data	Limited to subaerial beach
Costly and specialized	Inexpensive, readily available, easy to use, variety of data products





Royal Hawaiian Beach



- Completely human-engineered system
- Economic importance - $2.2 billion/year
- Culturally significant

- Compartmentalized littoral cell

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- Chronically eroding - consistent loss of subaerial beach year to year

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- Bi-directional wave climate - summer southerly swells, trade-wind waves during winter

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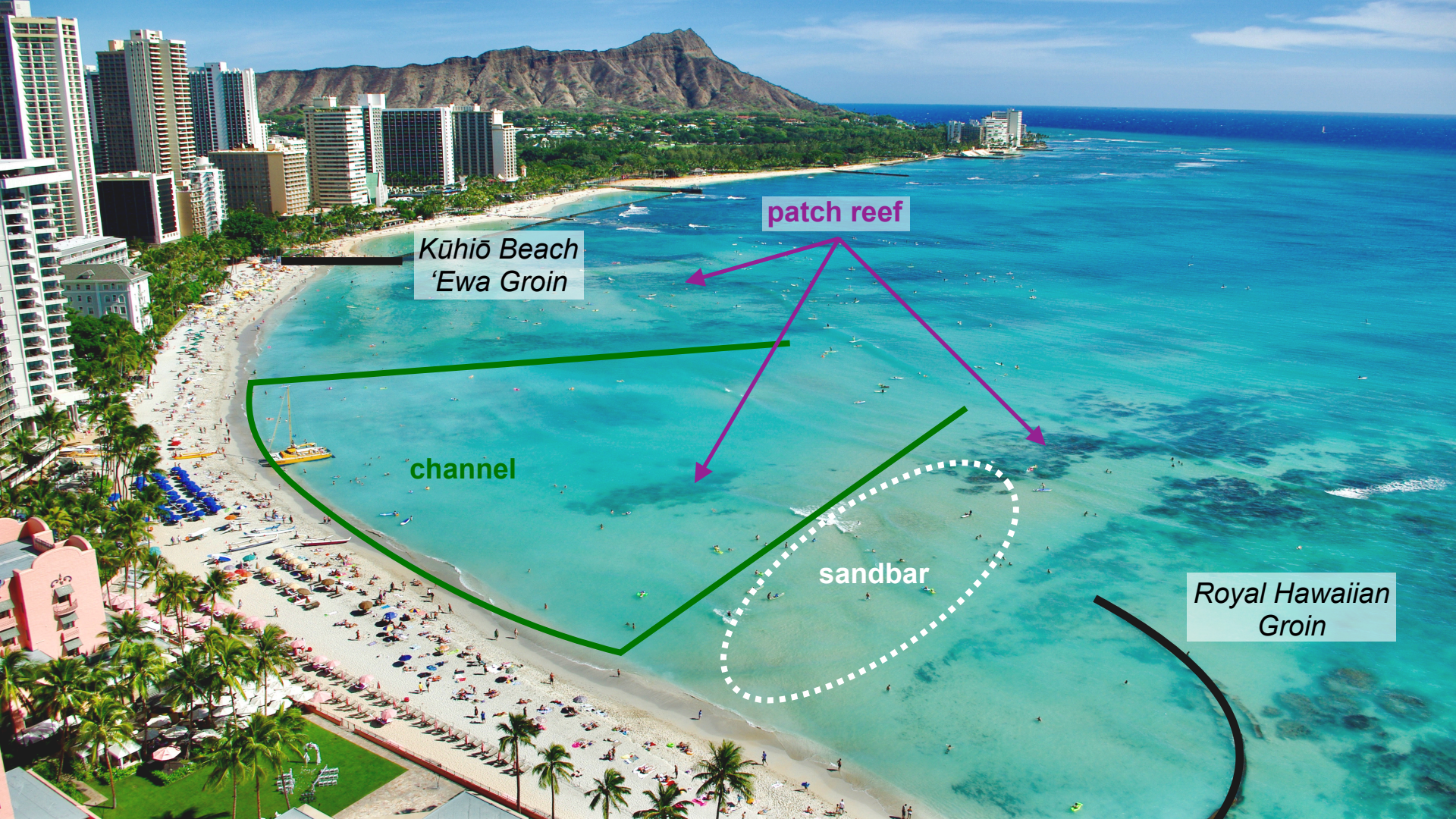
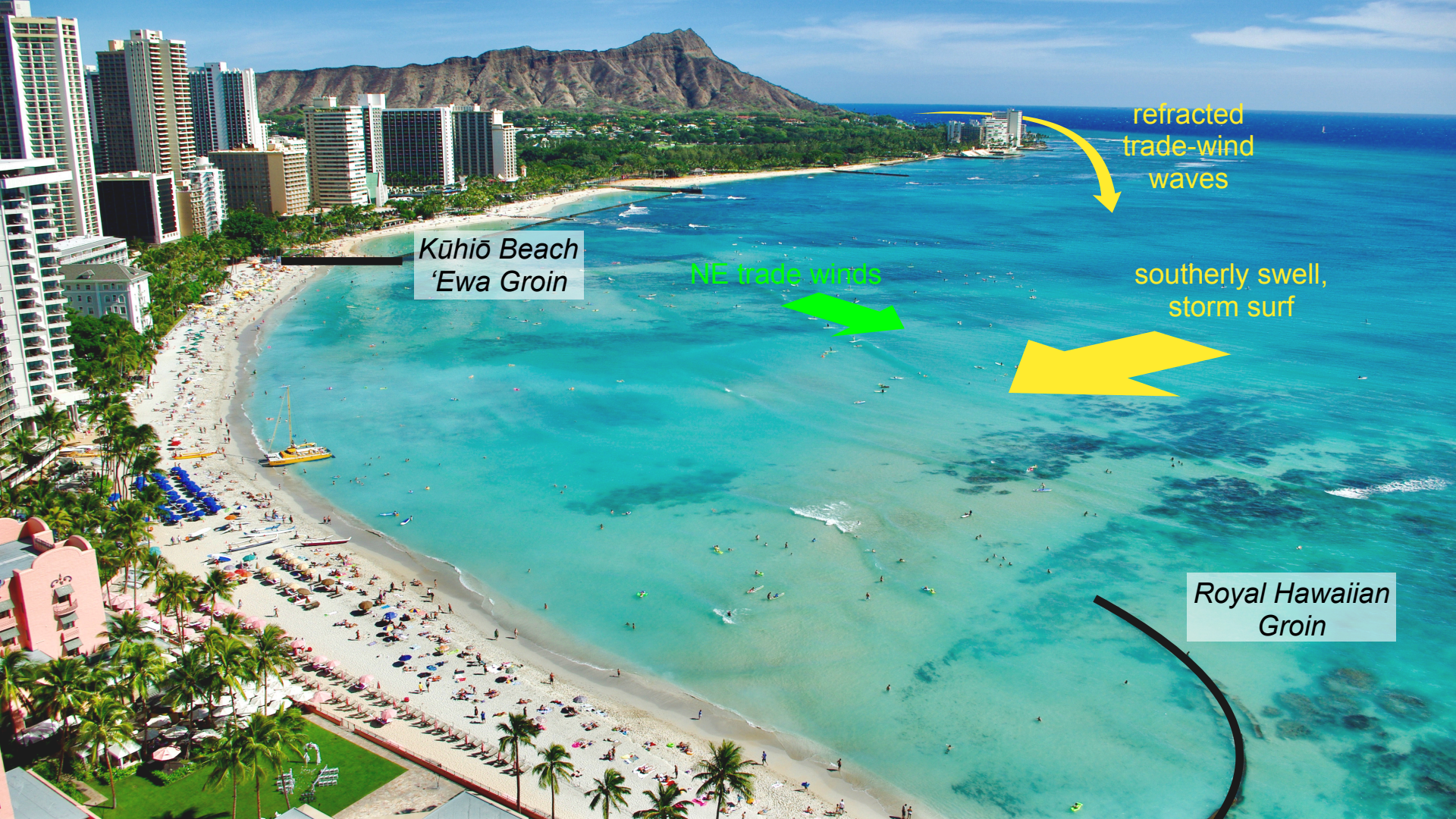
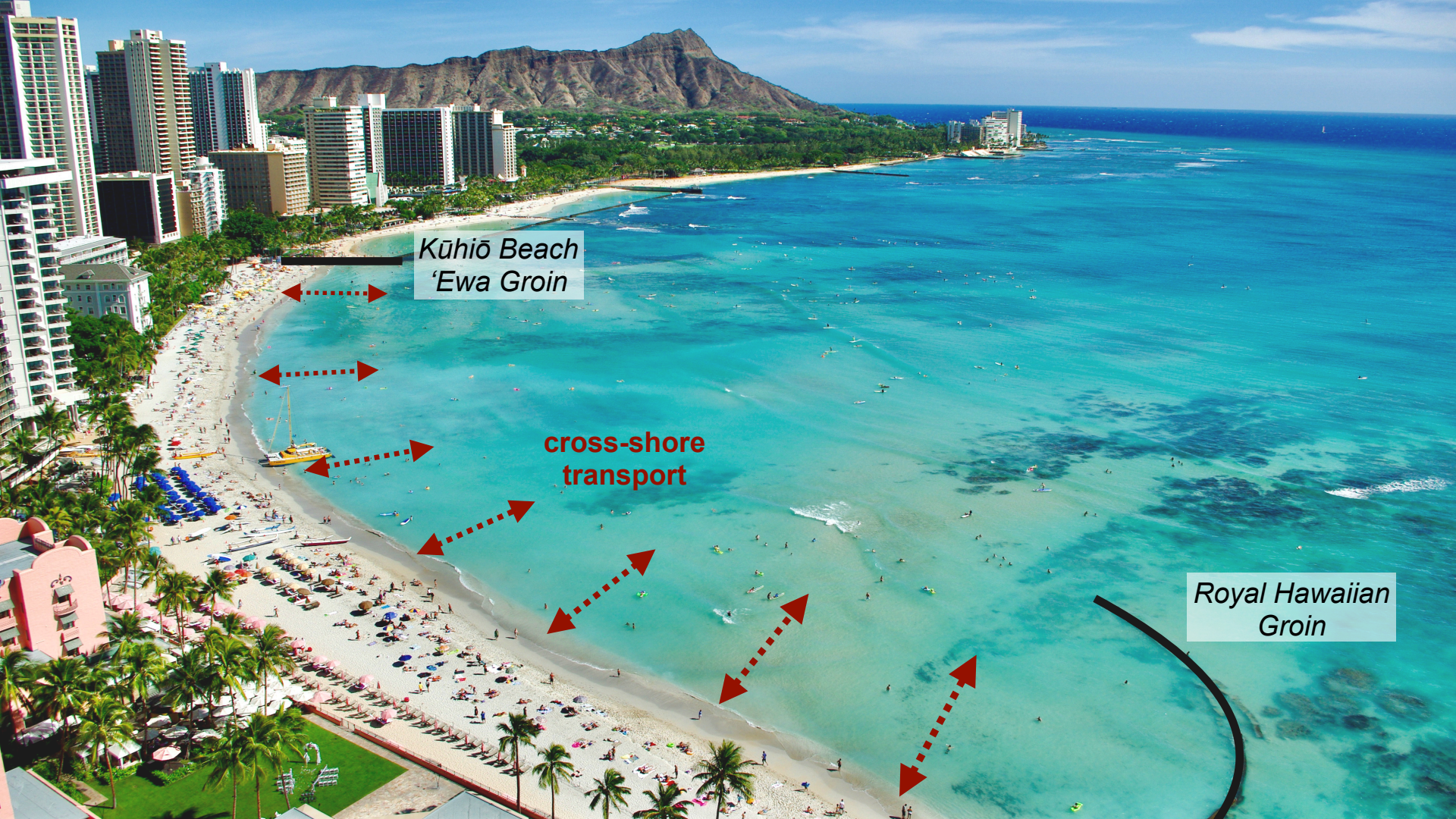
- Chronically eroding - consistent loss of subaerial beach year to year
- Bi-directional wave climate - summer southerly swells, trade-wind waves during winter
- Weekly surveys for 8 months (April - November 2018)

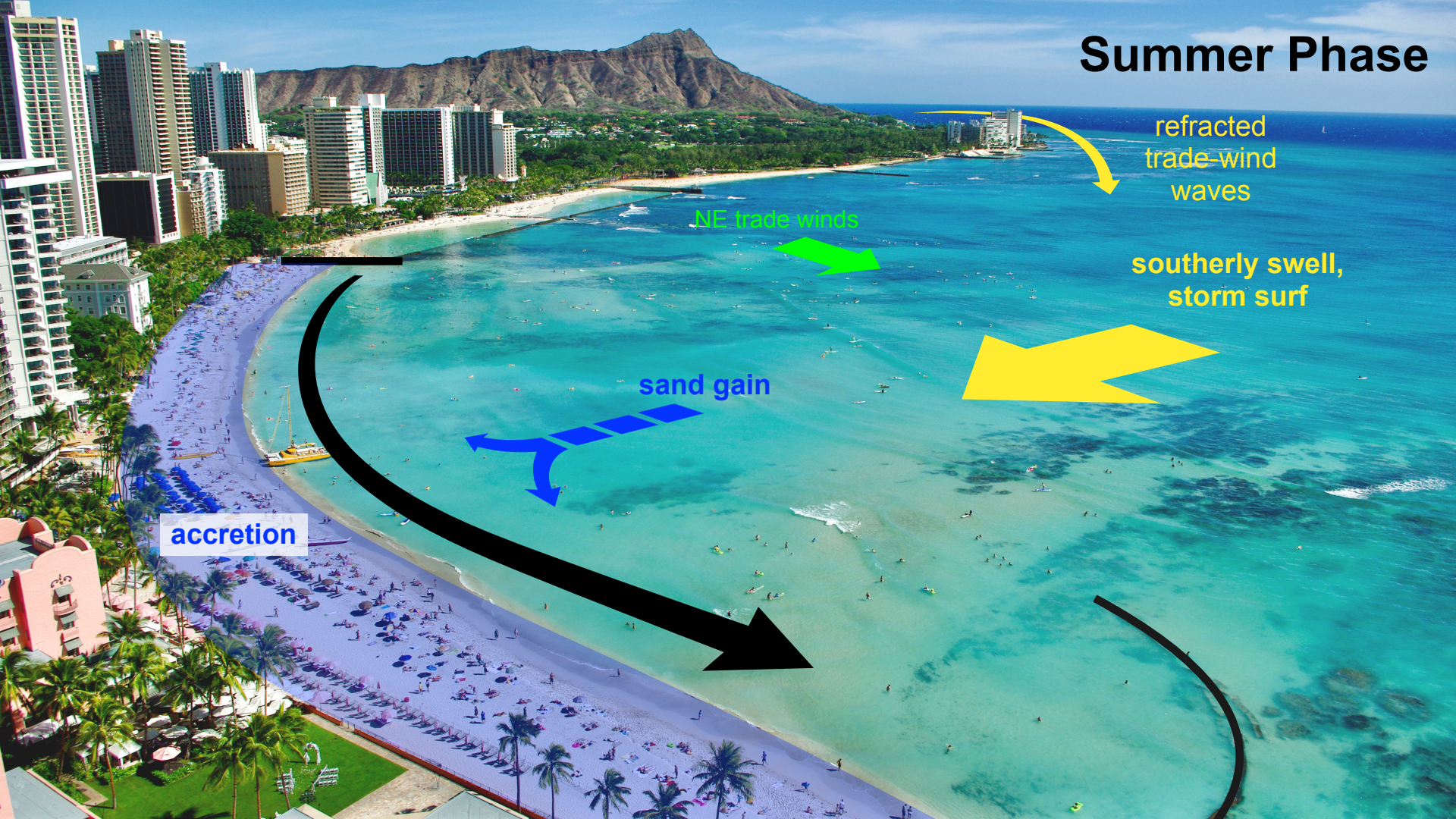
Kūhiō Beach
'Ewa Groin
Royal Hawaiian
Groin

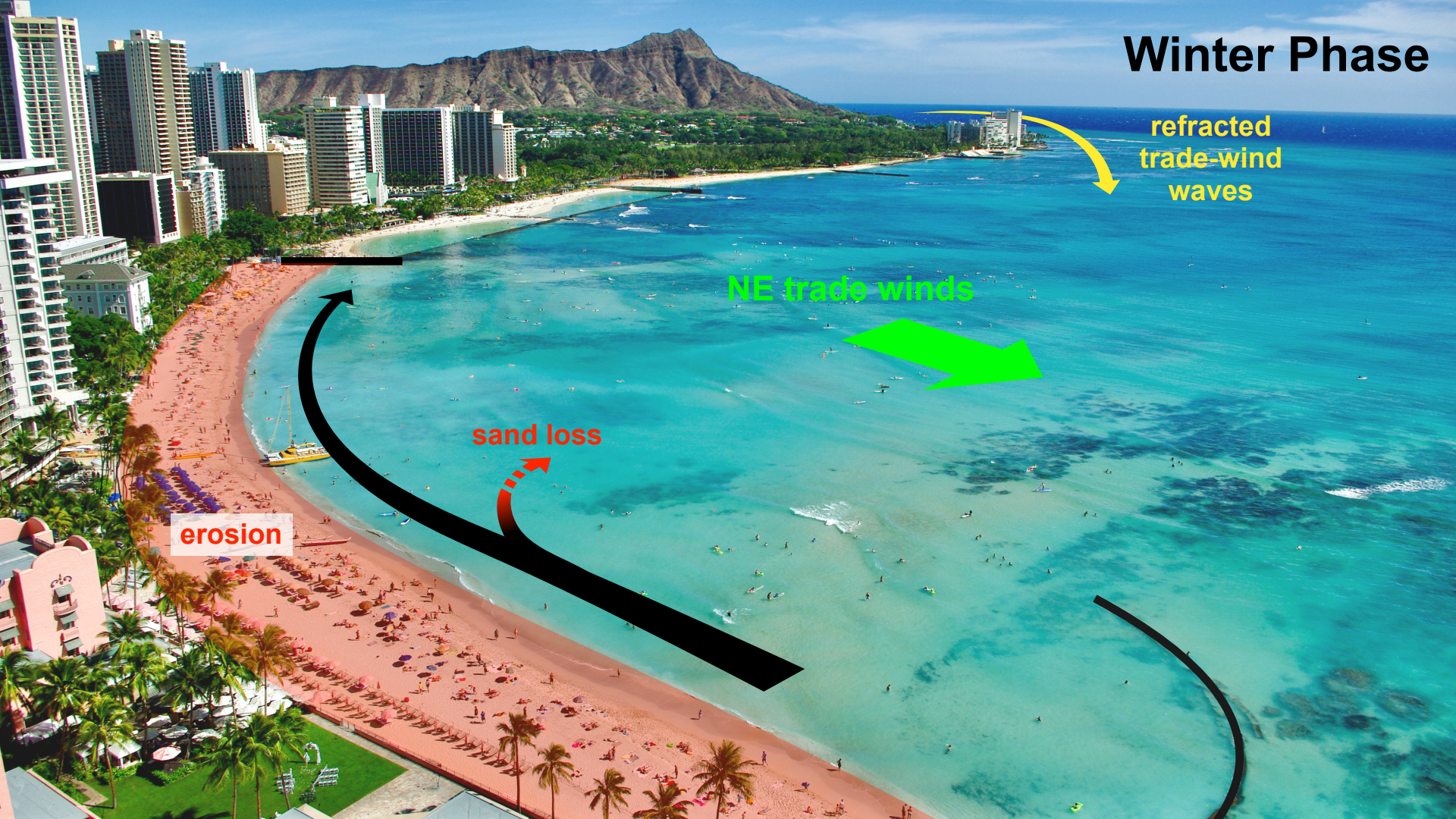

patch reef
Kūhiō Beach
'Ewa Groin
channel
sandbar
Royal Hawaiian
Groin


refracted
trade-wind
waves
Kūhiō Beach
'Ewa Groin
NE trade winds
southerly swell,
storm surf
Royal Hawaiian
Groin

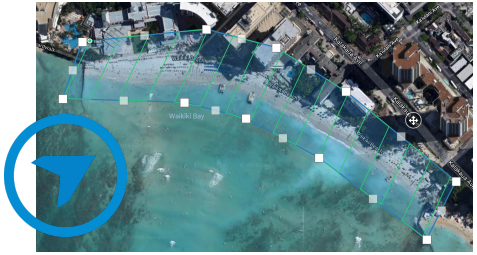
Kūhiō Beach
'Ewa Groin
longshore
transport
Royal Hawaiian
Groin

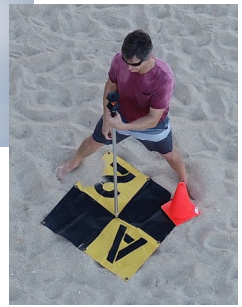

Kūhiō Beach
'Ewa Groin
cross-shore
transport
Royal Hawaiian
Groin


Summer Phase
refracted trade-wind waves
NE trade winds
southerly swell, storm surf
sand gain
accretion

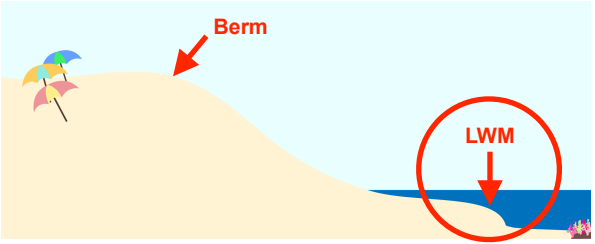

Winter Phase
refracted trade-wind waves
NE trade winds
sand loss
erosion

Data Collection ----▶ Post-Processing ----▶ Data Analysis





- Flight plan
- Aerial survey
- Ground survey



- Error reduction
- Point cloud and orthomosaic generation

- Noise reduction
- “Bare earth” extraction

rapidlasso

- Digital elevation model (DEM)
- Masking, smoothing, organizing

ArcGIS

- Beach width
- Surface variability
- Surface area and volume

- Empirical Orthogonal Function analysis (sediment transport processes)

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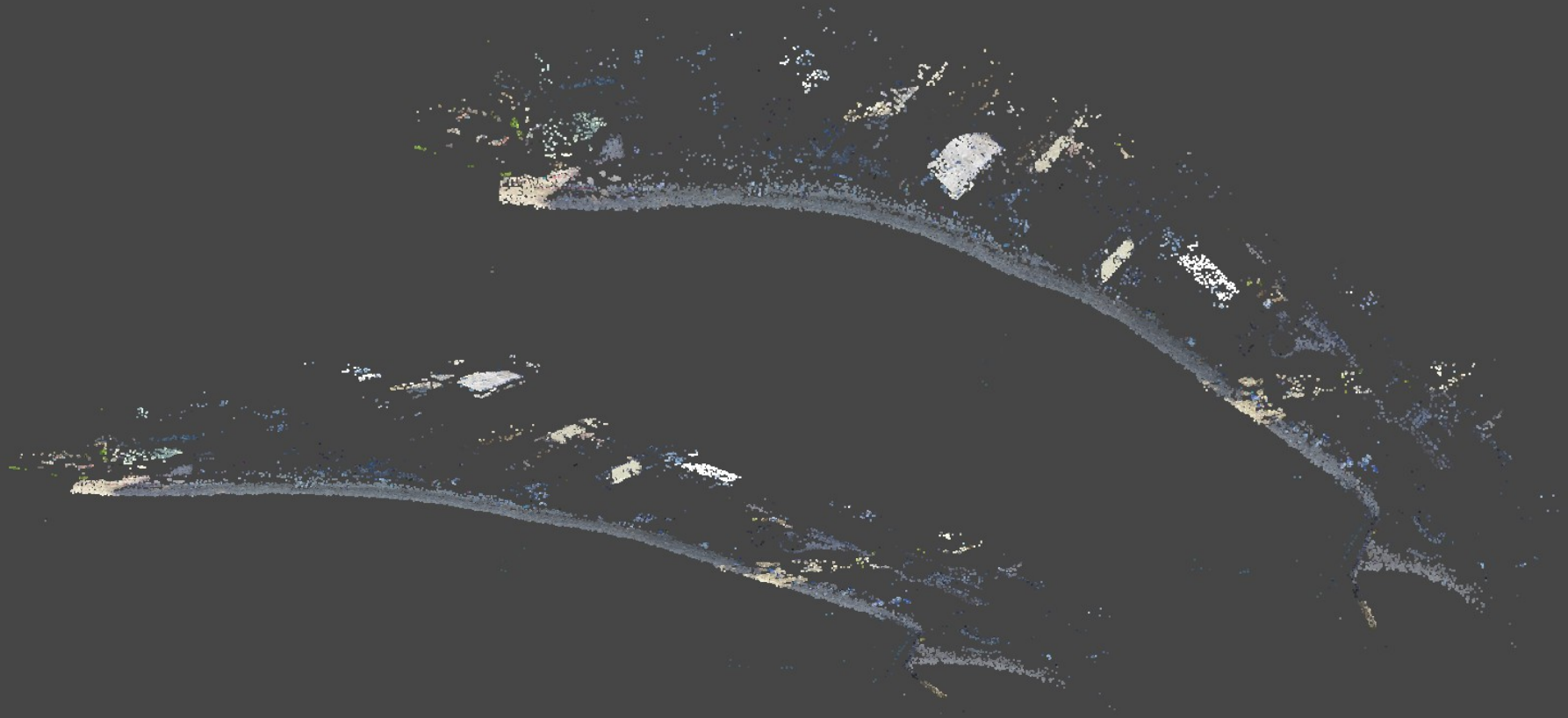
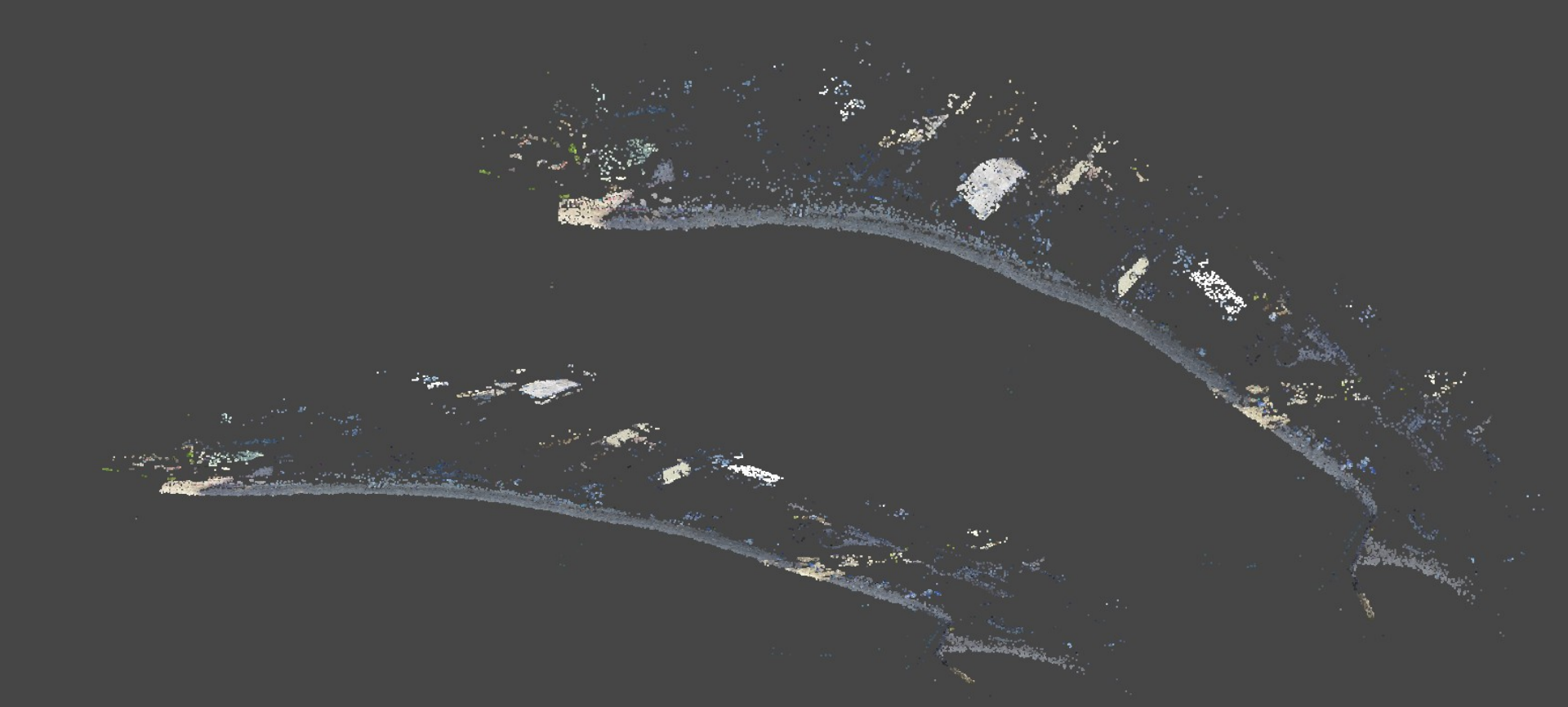
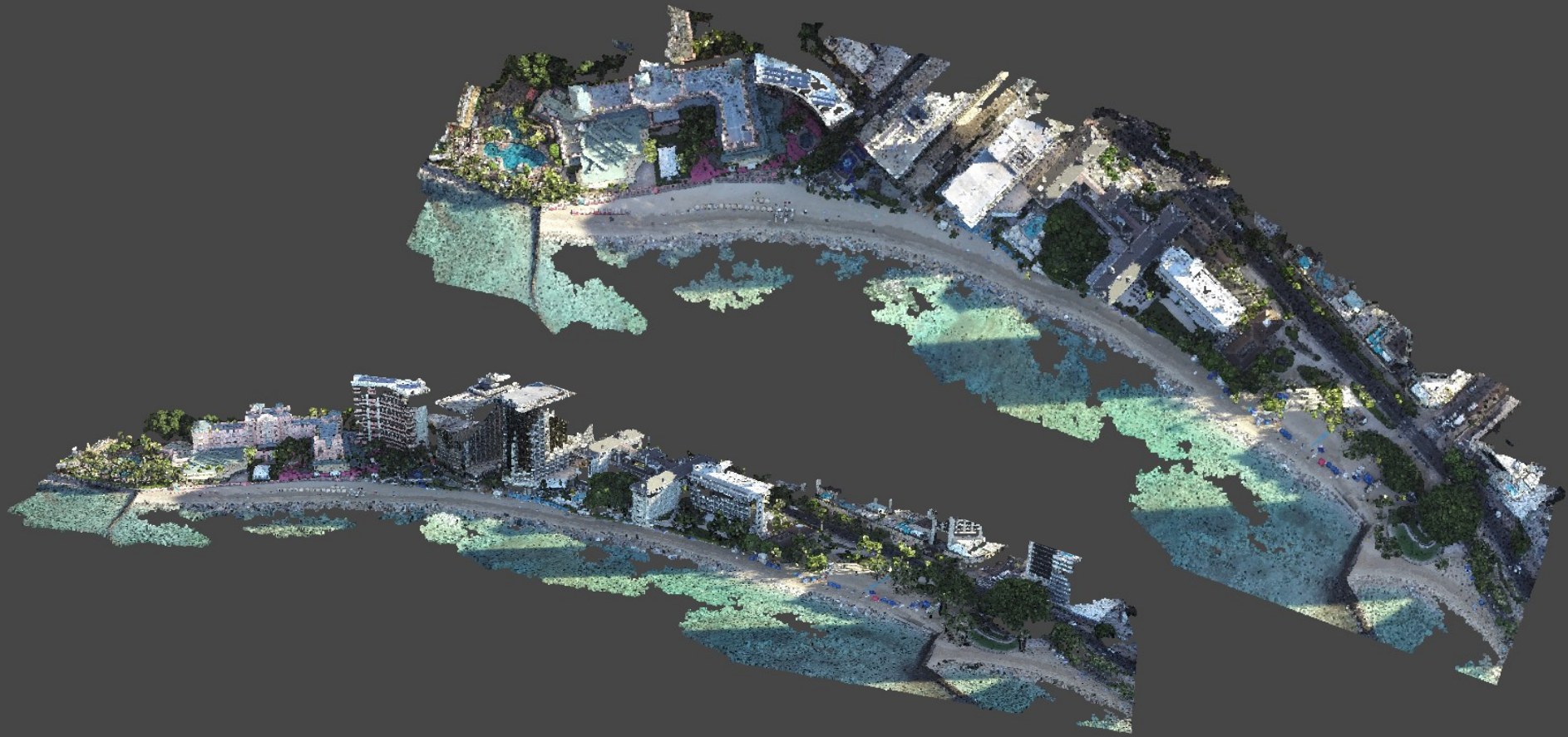


Sparse Cloud - Rudimentary 3-D model based off of common points across photos



Iterative error analysis to delete the least accurate points based on uncertainty parameters



Dense Cloud - Robust point cloud based off most accurate points of the sparse cloud

Orthomosaic - Geometrically corrected mosaic of photos

04/12/2018

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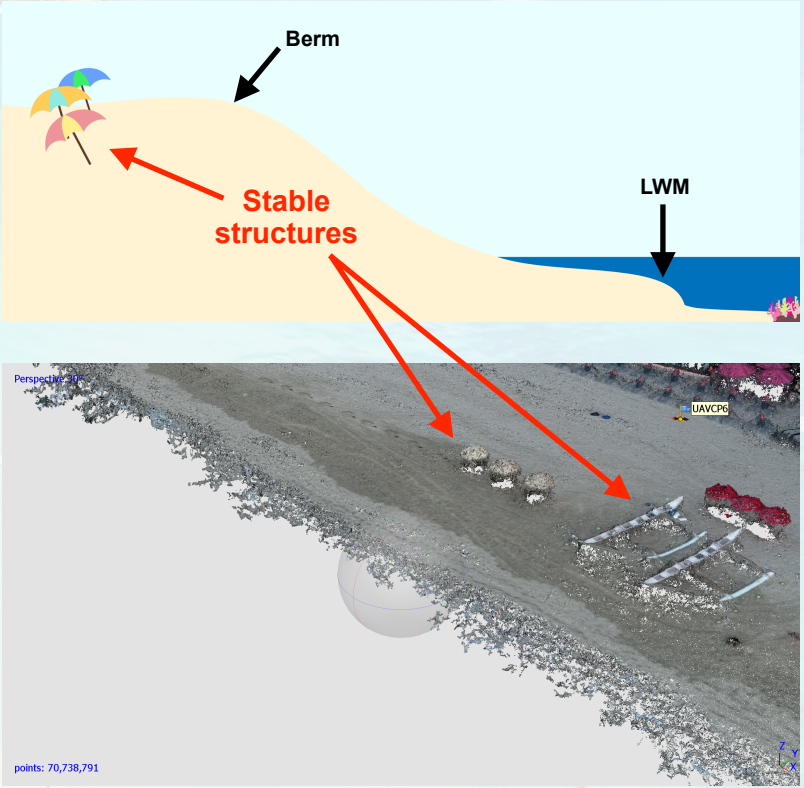
Dense Cloud Processing: LAStools

- Stable structures on the beach require removal

```
for /d %%i in (%IN_DIR%\*) do (

    cd "%%i"
    echo Current directory: %%i

    IF EXIST "%IN_DIR%\mask_Beach.shp" (
        lasclip -i *.laz ^
                -poly %IN_DIR%\mask_Beach.shp ^
                -odix _clip -olaz ^
                -cores %NUM_CORES%
    ) ELSE (
        ECHO Polygon for clipping not found. No clippin
    )

    rmdir temp /s /q
    mkdir temp

    rmdir temp\tiles_raw /s /q
    mkdir temp\tiles_raw
    echo Created clean tiles_raw folder in temporary di

    IF EXIST "*_clip.laz" (
        lastile -i *_clip.laz ^
                -tile_size 100 -buffer 20 -flag_as_withheld ^
                -epsg %COOR_SYS% ^
```

rapidlasso



Dense Cloud Processing: LAStools

- Stable structures on the beach require removal
- Wave run-up/saturated sand at the foreshore results in noise

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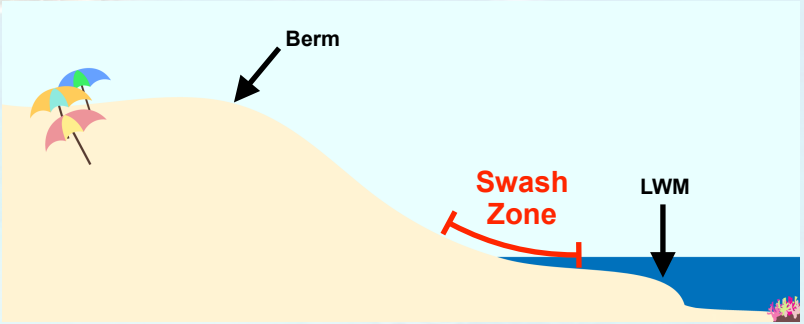
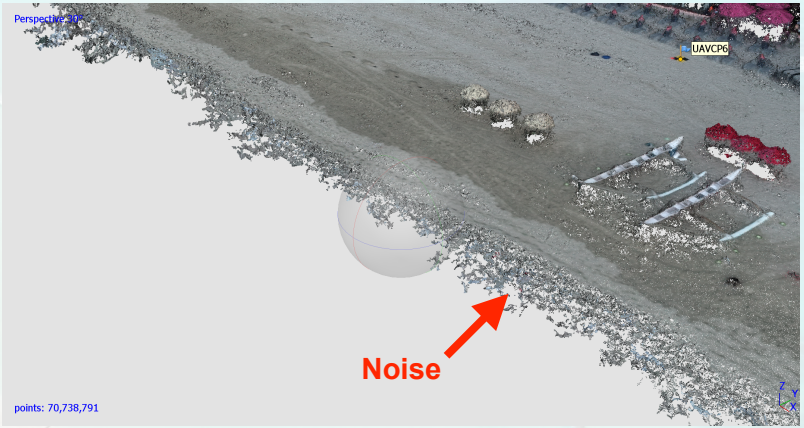
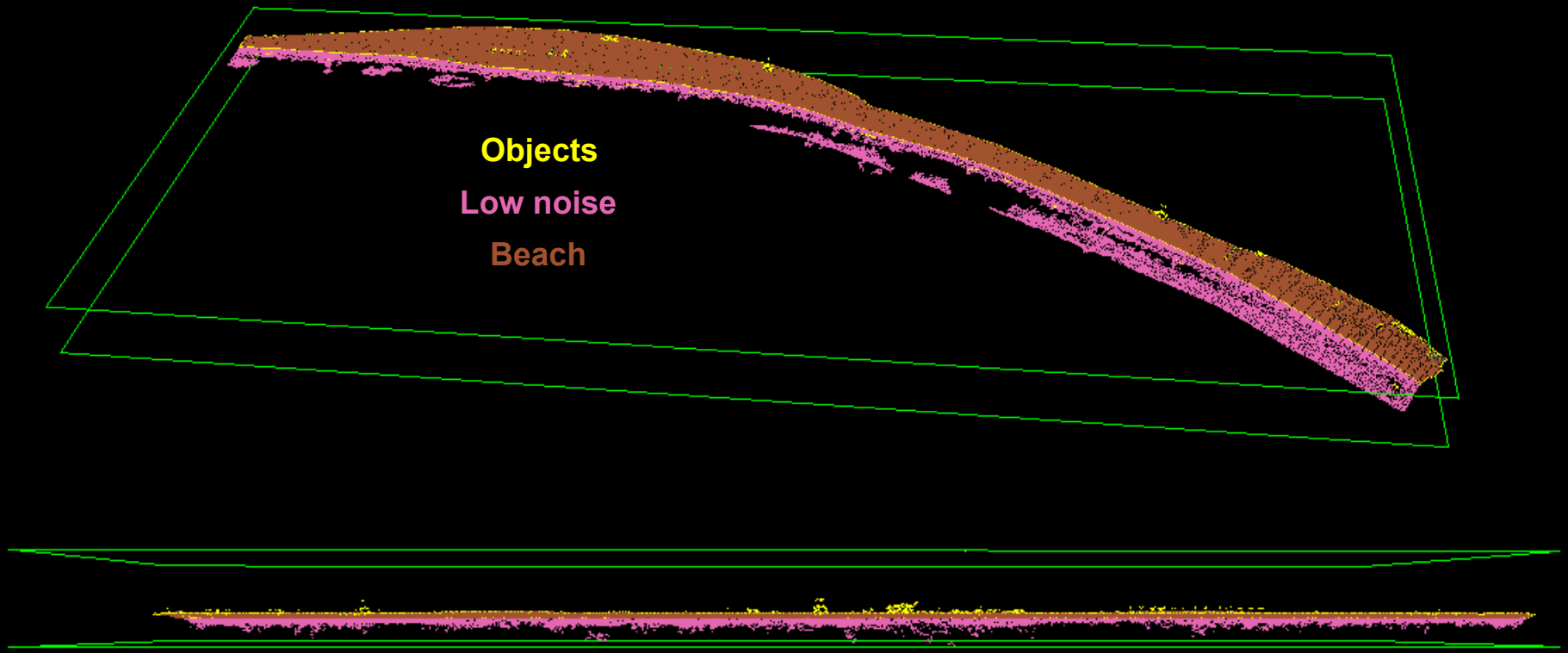
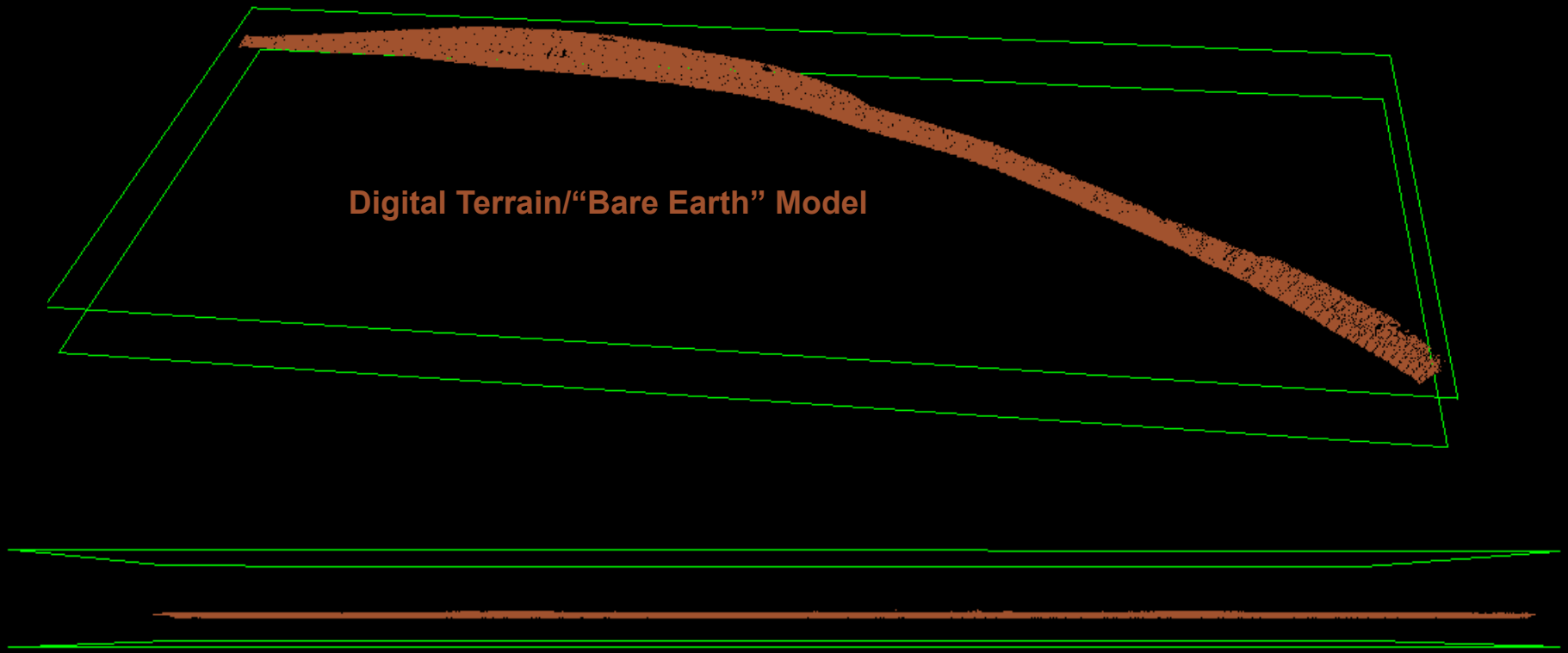





Objects
Low noise
Beach


Digital Terrain/“Bare Earth” Model

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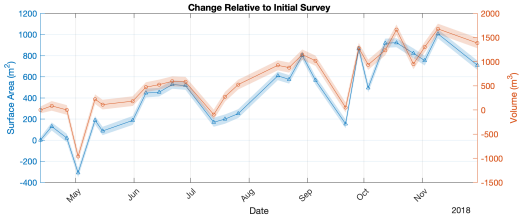
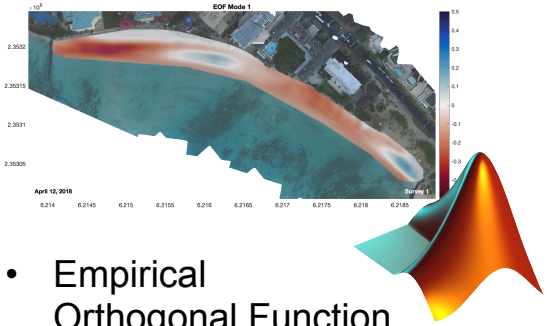




- Empirical Orthogonal Function analysis (sediment transport processes)

Uncertainty

- Surface interpolation uncertainty determined through separate field survey
- Compared ~230 measured points to post-processed surface
  - Mean difference = 0.007 meters
    - No observed spatial correlations
    - Errors are randomly distributed about a mean of zero

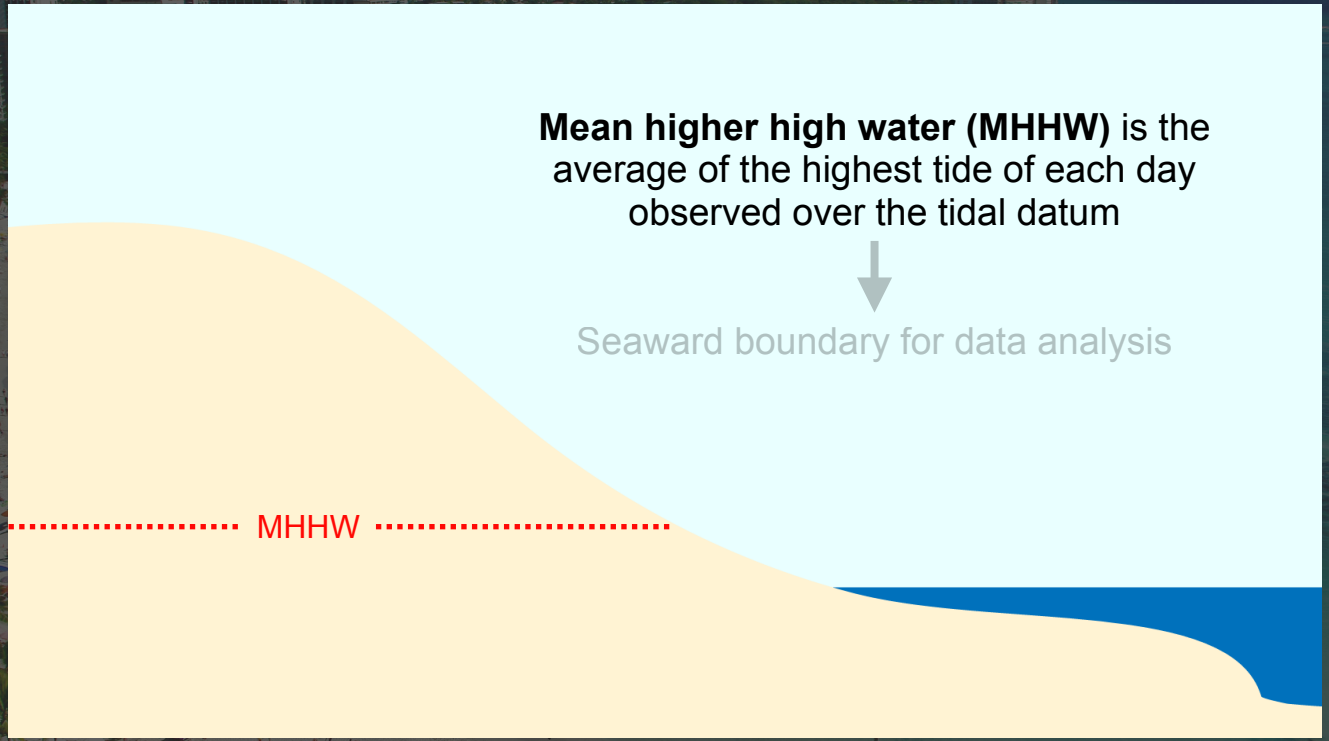
Standard Deviation of the Mean:

$$\sigma_\mu = \frac{\sigma}{\sqrt{n}}$$

σ Standard Deviation of the Errors

n Number of measured points

Surface Area and Beach Width Uncertainty

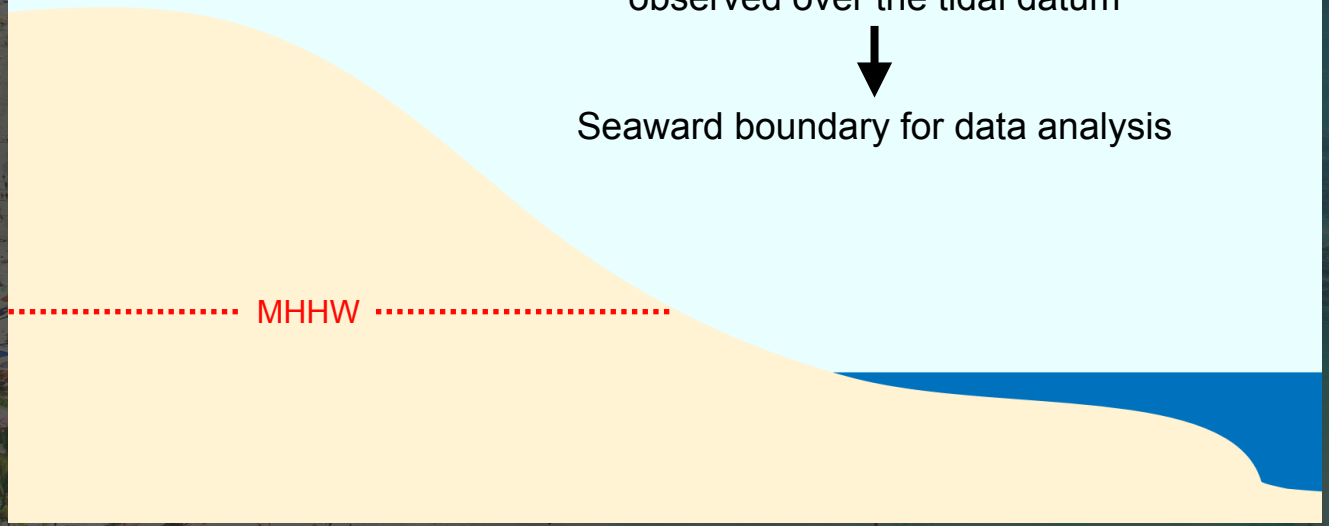


Surface Area and Beach Width Uncertainty

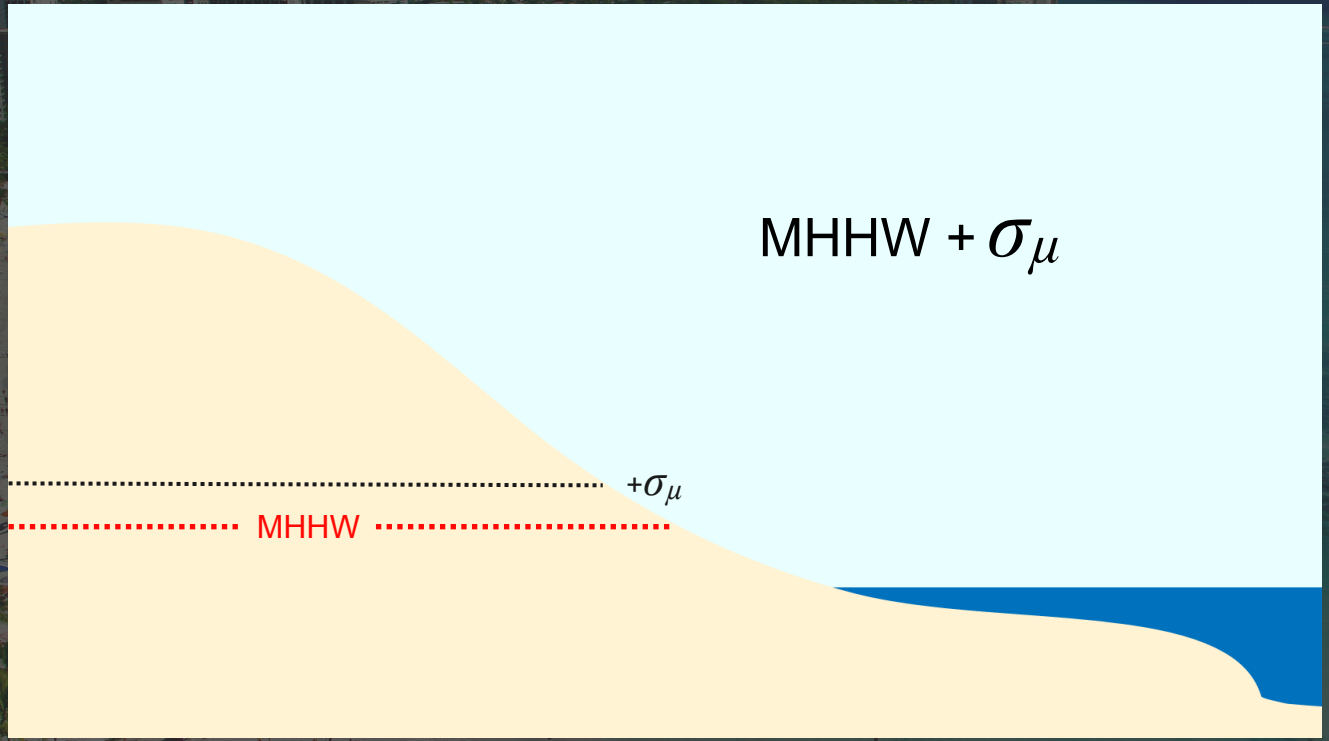
Mean higher high water (MHHW) is the average of the highest tide of each day observed over the tidal datum

↓

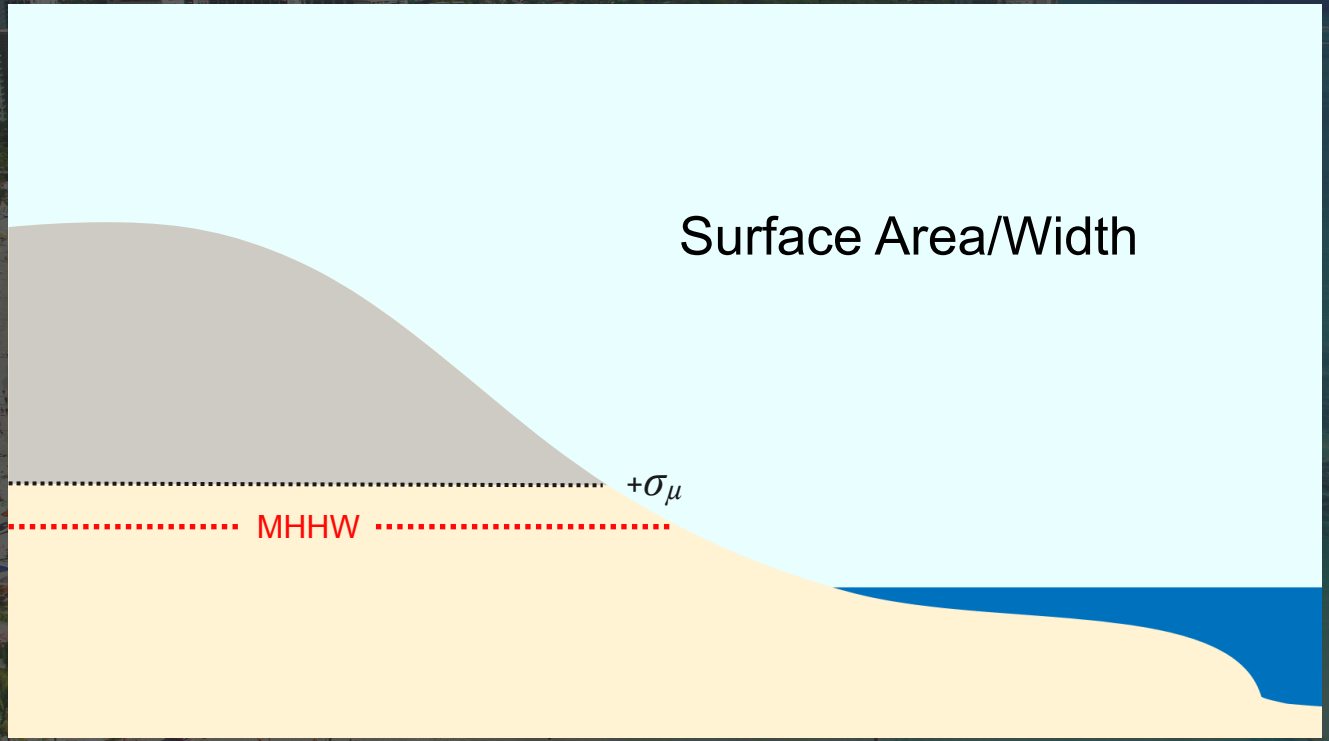
Seaward boundary for data analysis



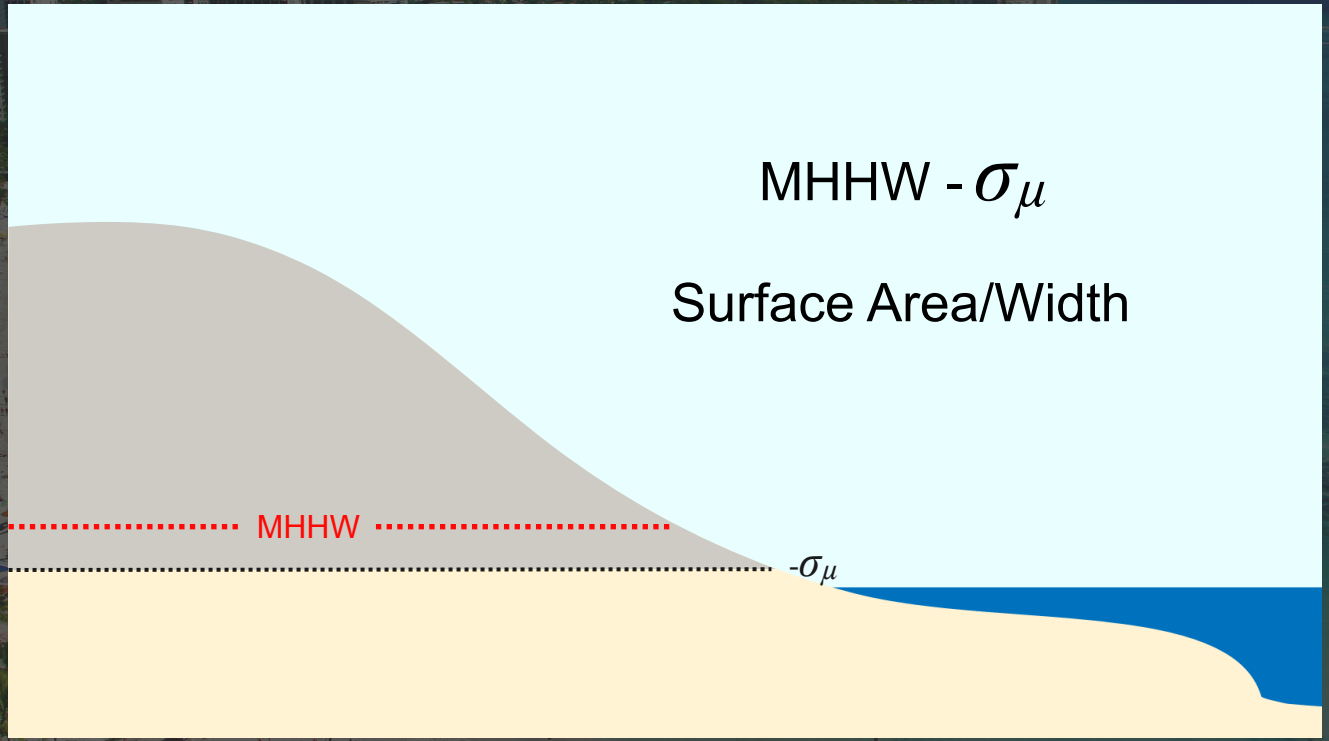
Surface Area and Beach Width Uncertainty



Surface Area and Beach Width Uncertainty

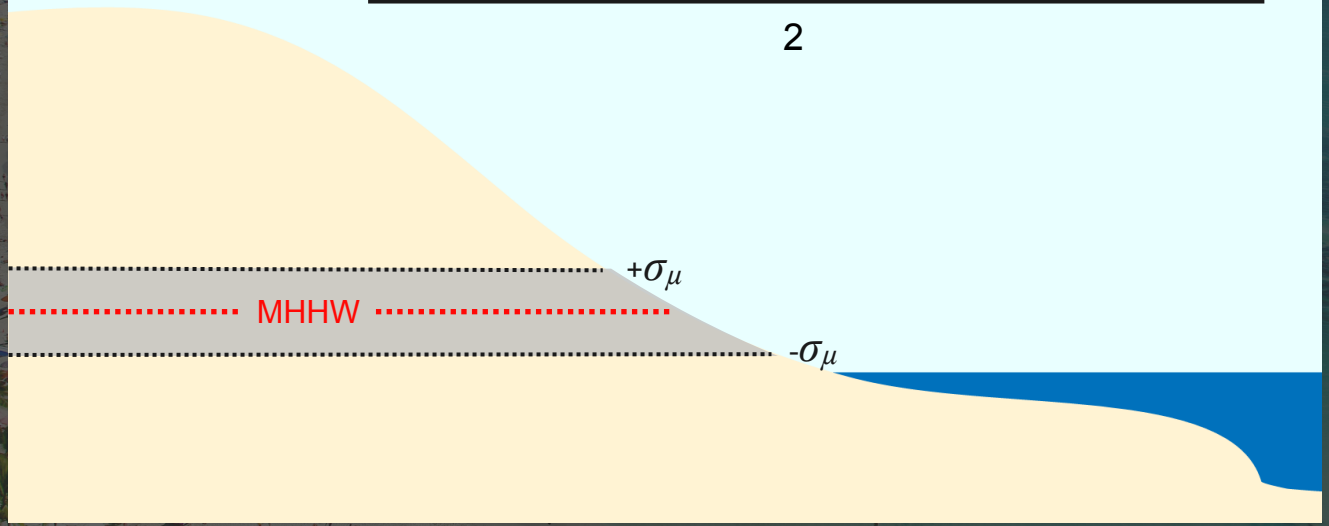


Surface Area and Beach Width Uncertainty



Surface Area and Beach Width Uncertainty

$$\frac{\text{(larger surface area/width - smaller surface area/width)}}{2}$$



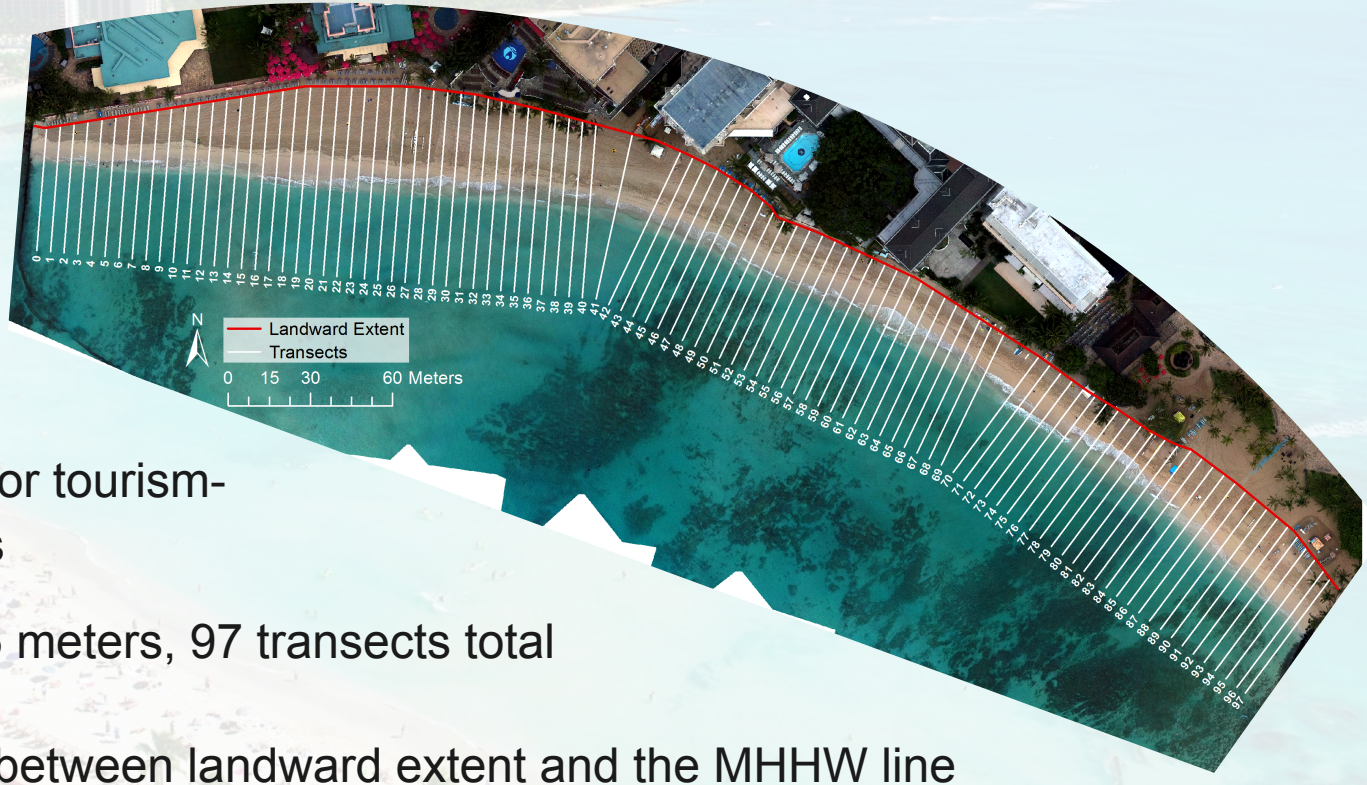
Volume Uncertainty

$$U_{vol_j} = A_j \sigma_\mu$$

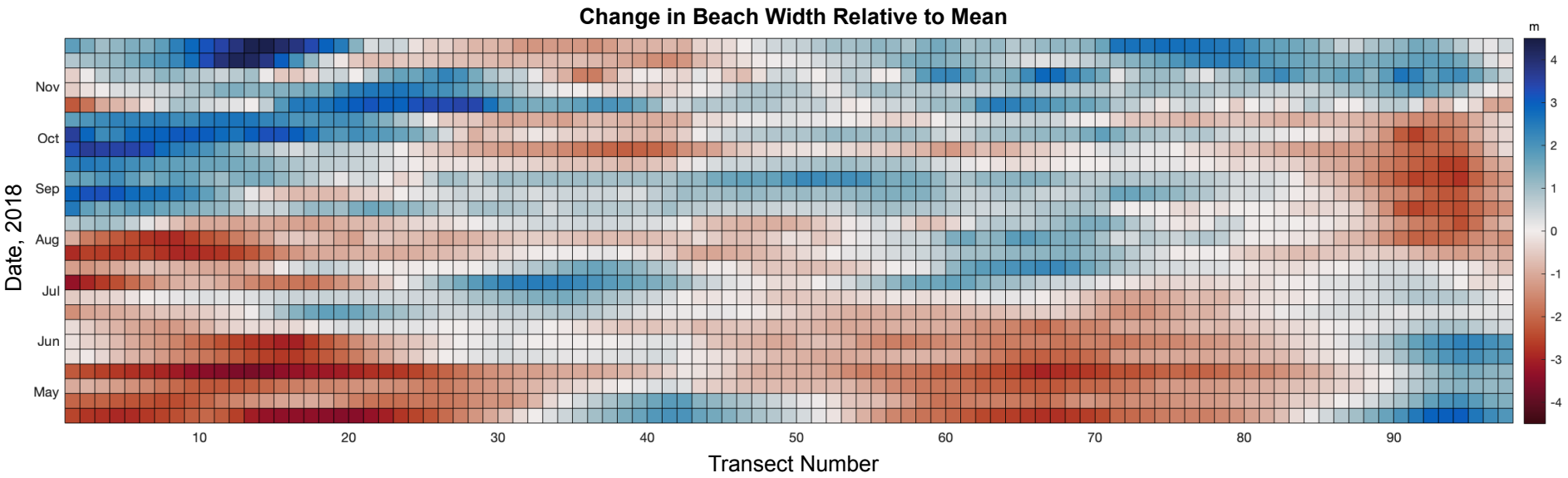
A_j j^{th} area of footprint

σ_μ Standard Deviation of the Mean

Results & Discussion: Beach Width



- Important metric for tourism-centered beaches
- Transects every 5 meters, 97 transects total
- Width = distance between landward extent and the MHHW line


Change in Beach Width Relative to Mean
Date, 2018
Nov
Oct
Sep
Aug
Jul
Jun
May
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40
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60
70
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90
Transect Number
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2
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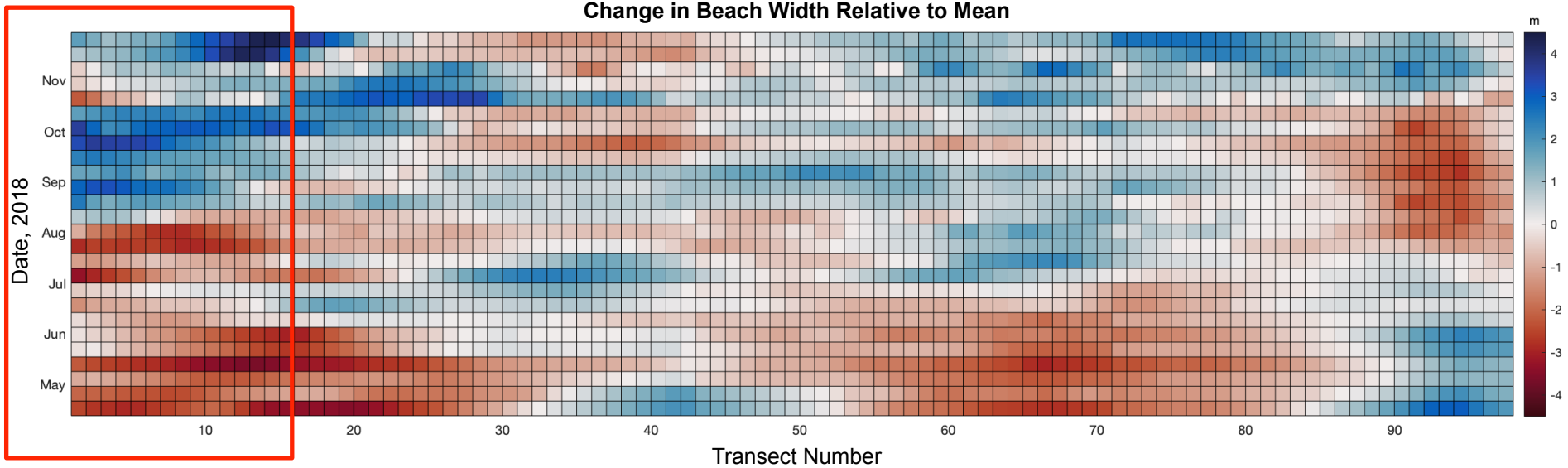
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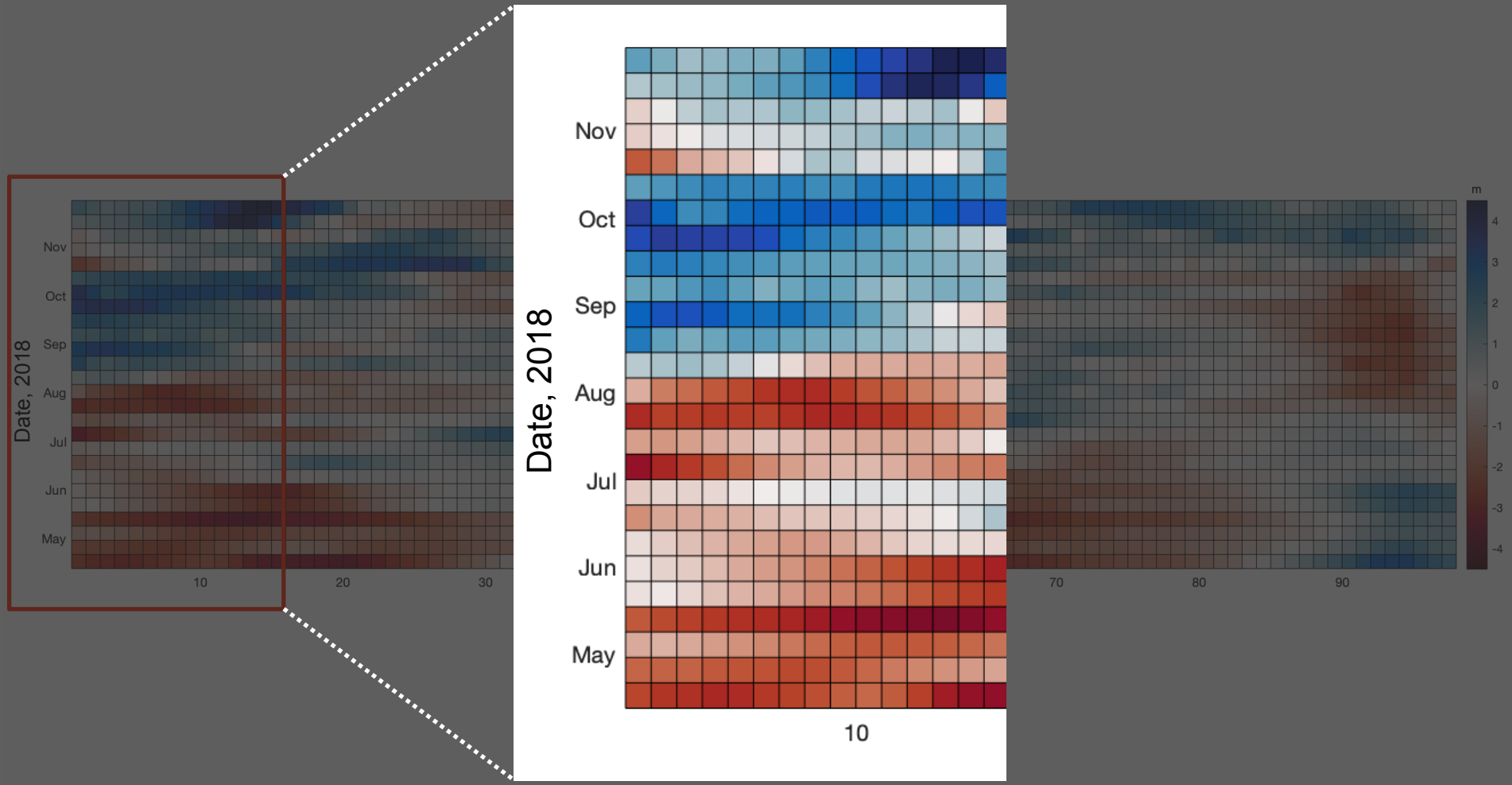
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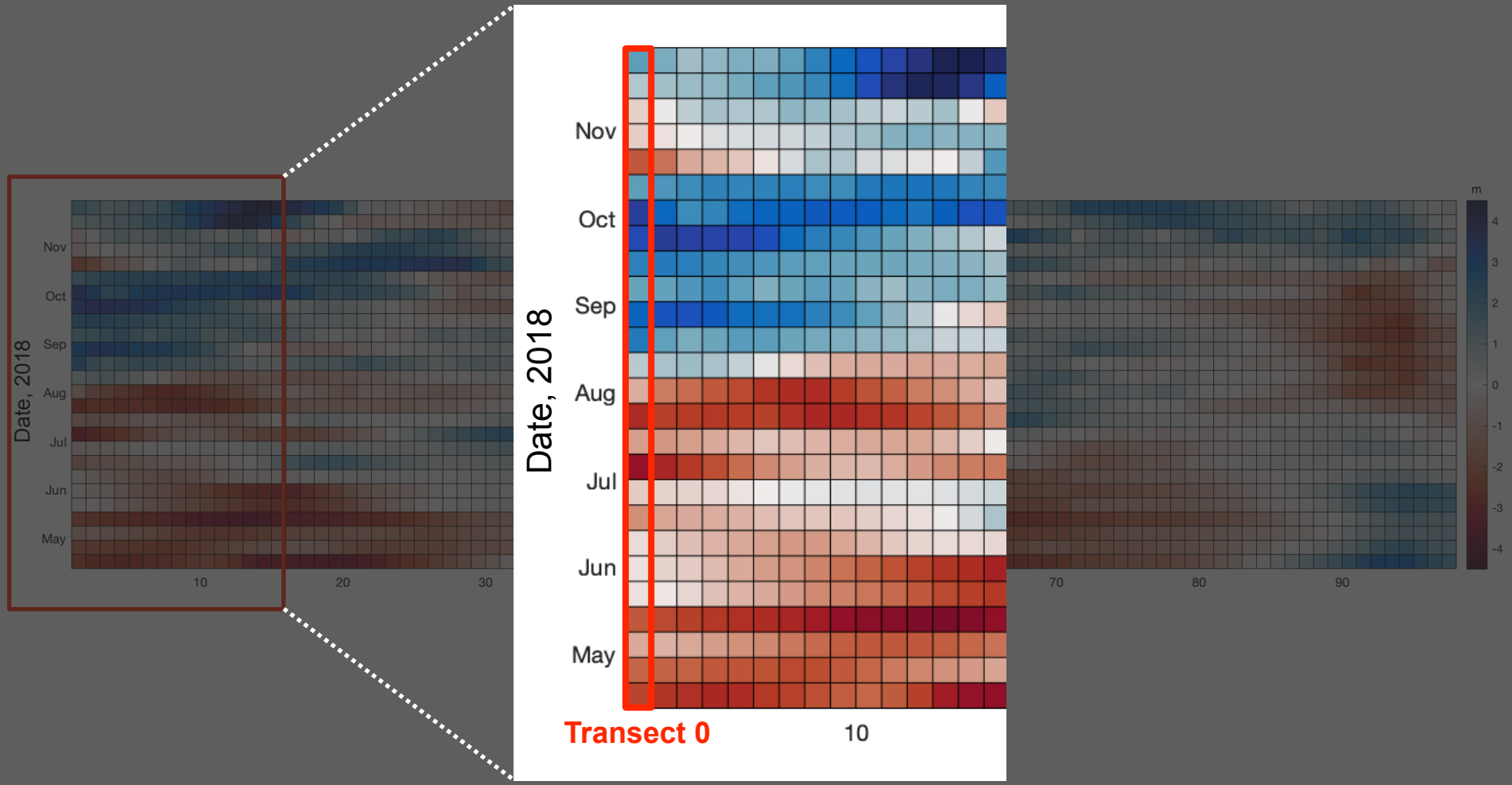
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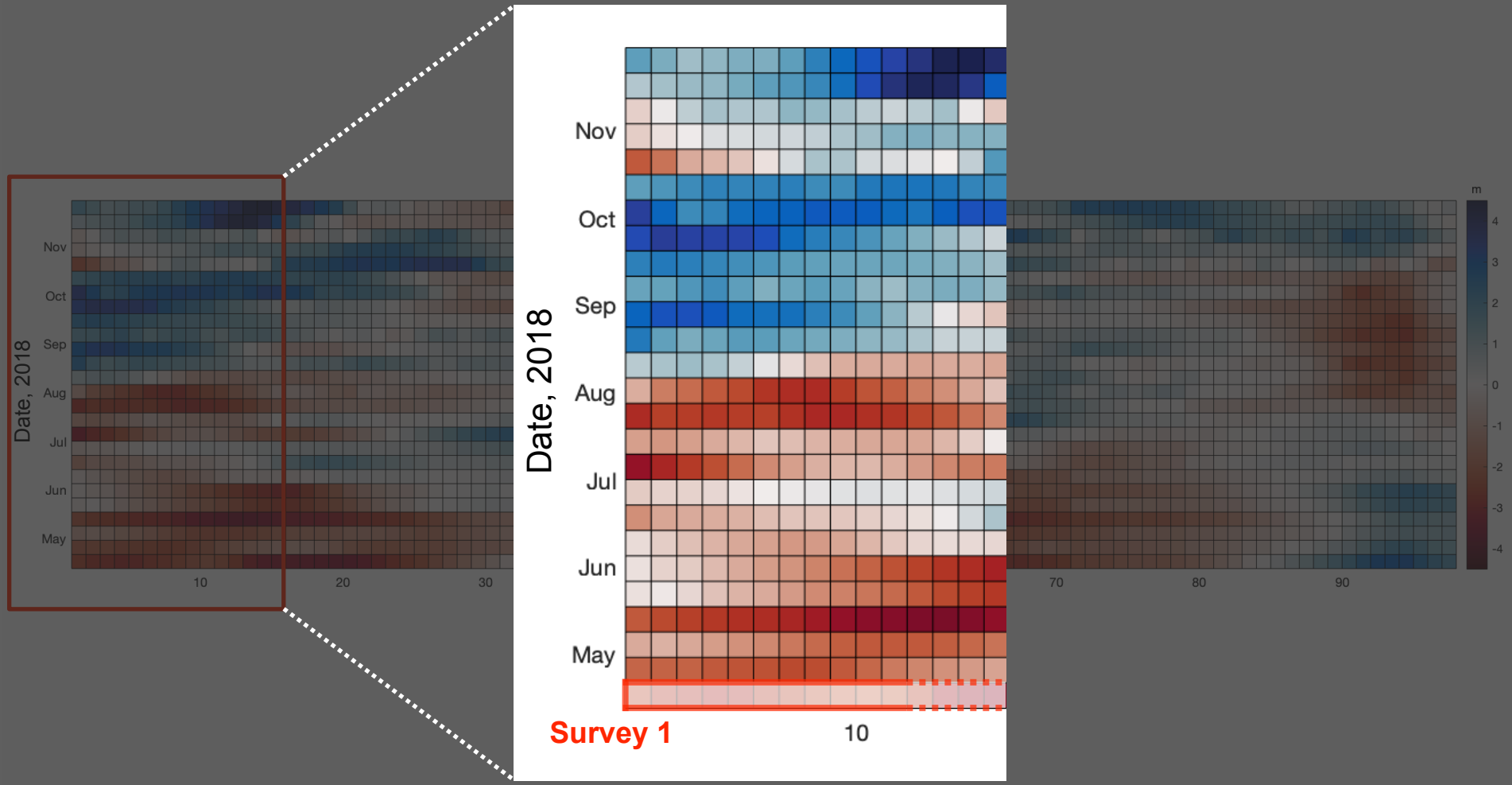
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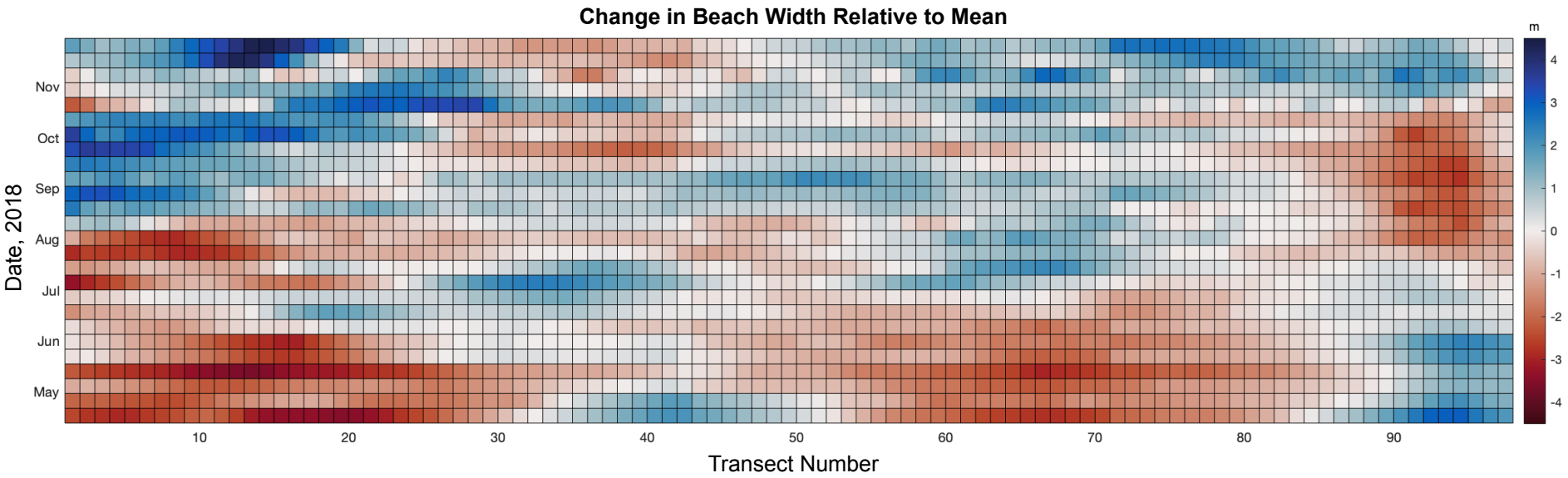
Survey 1
10

West **East**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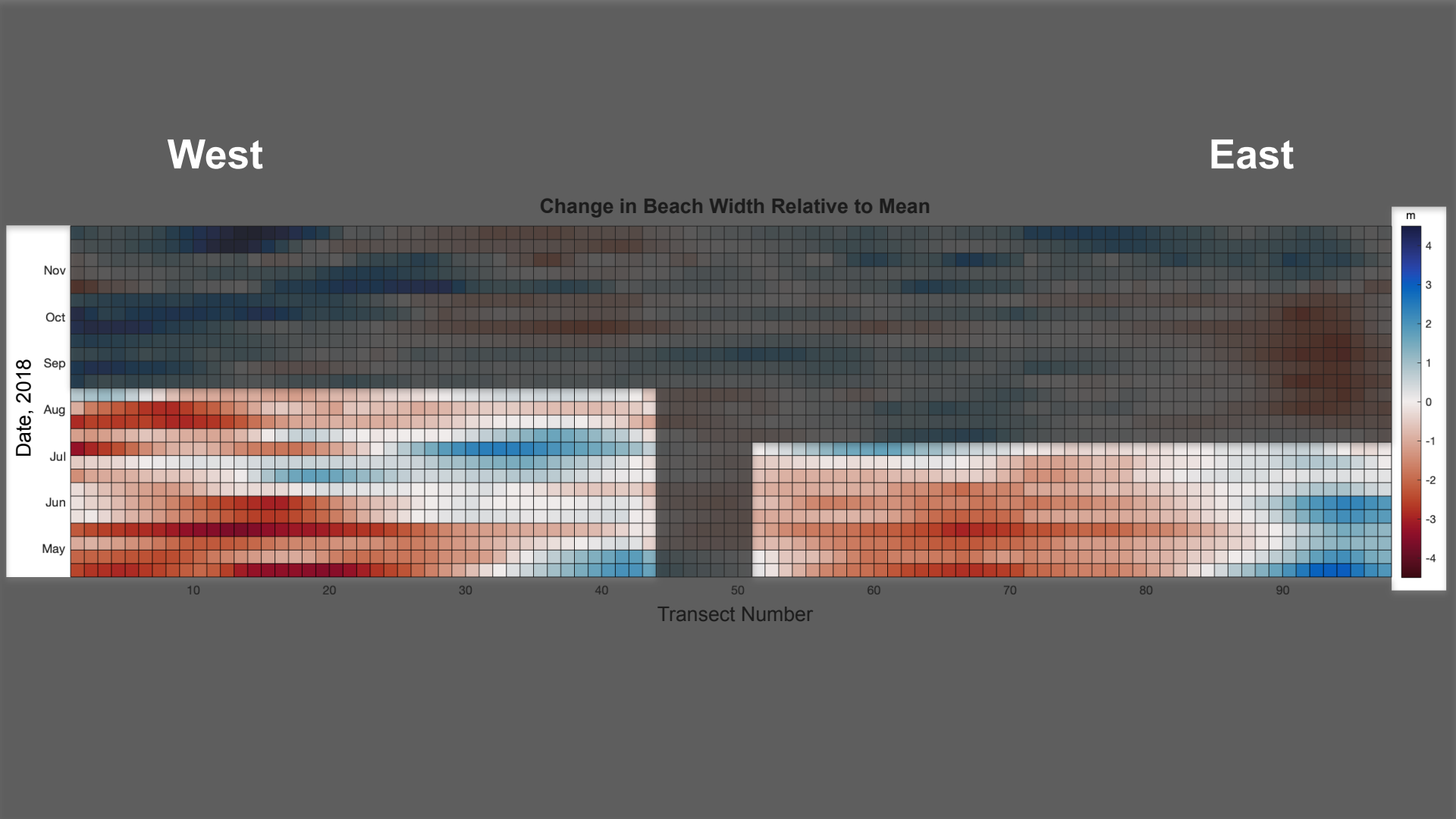
West
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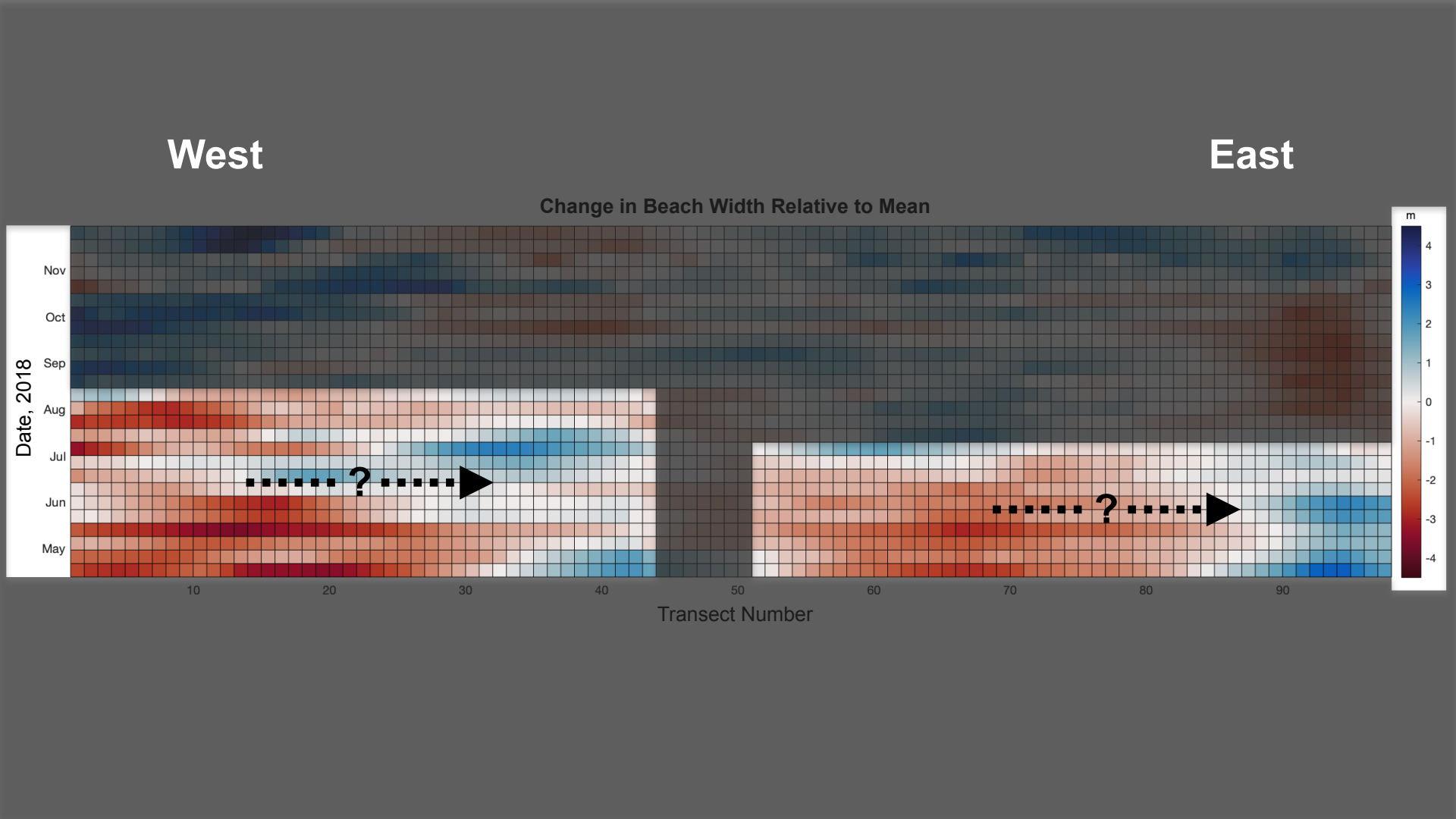
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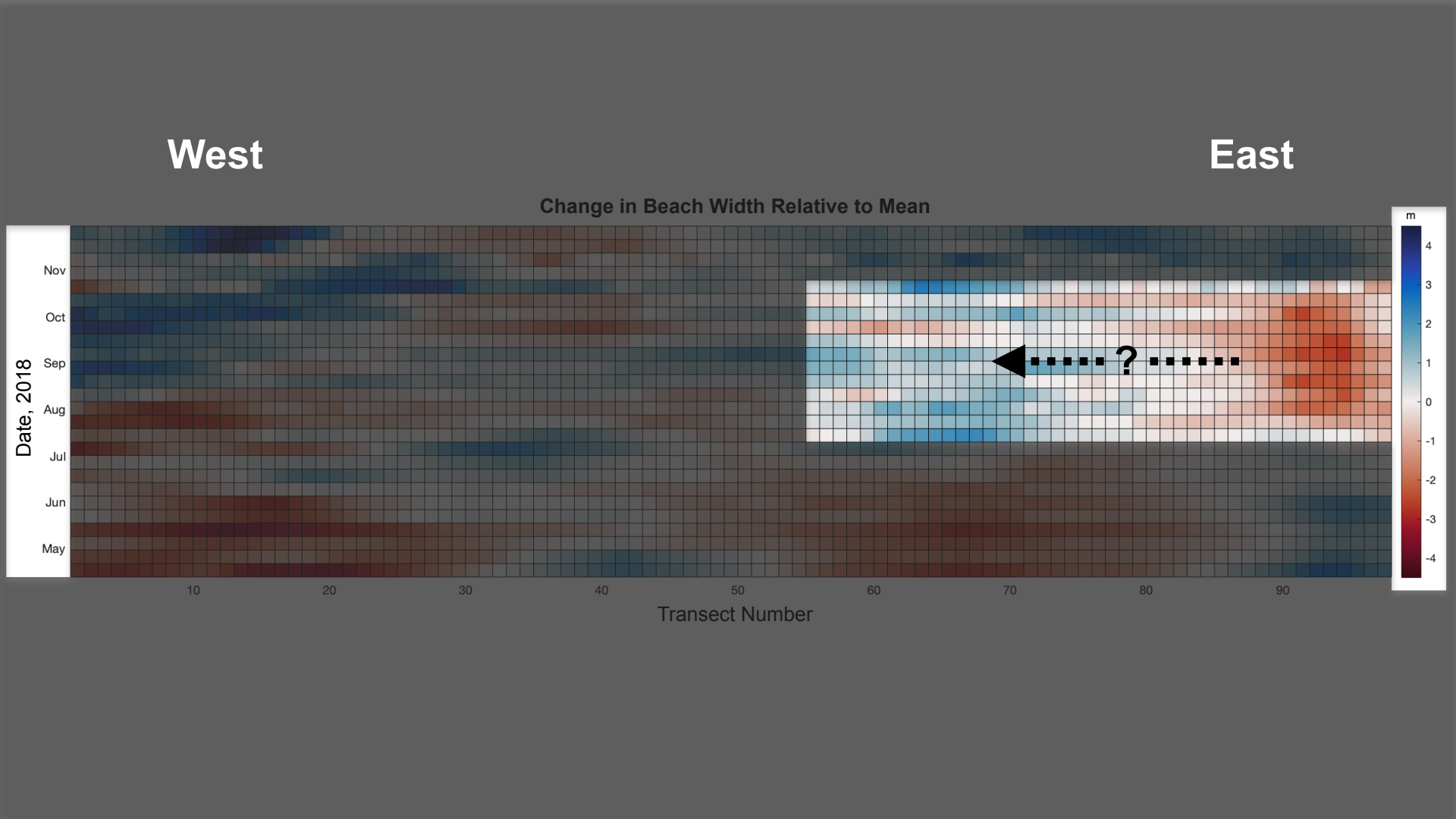
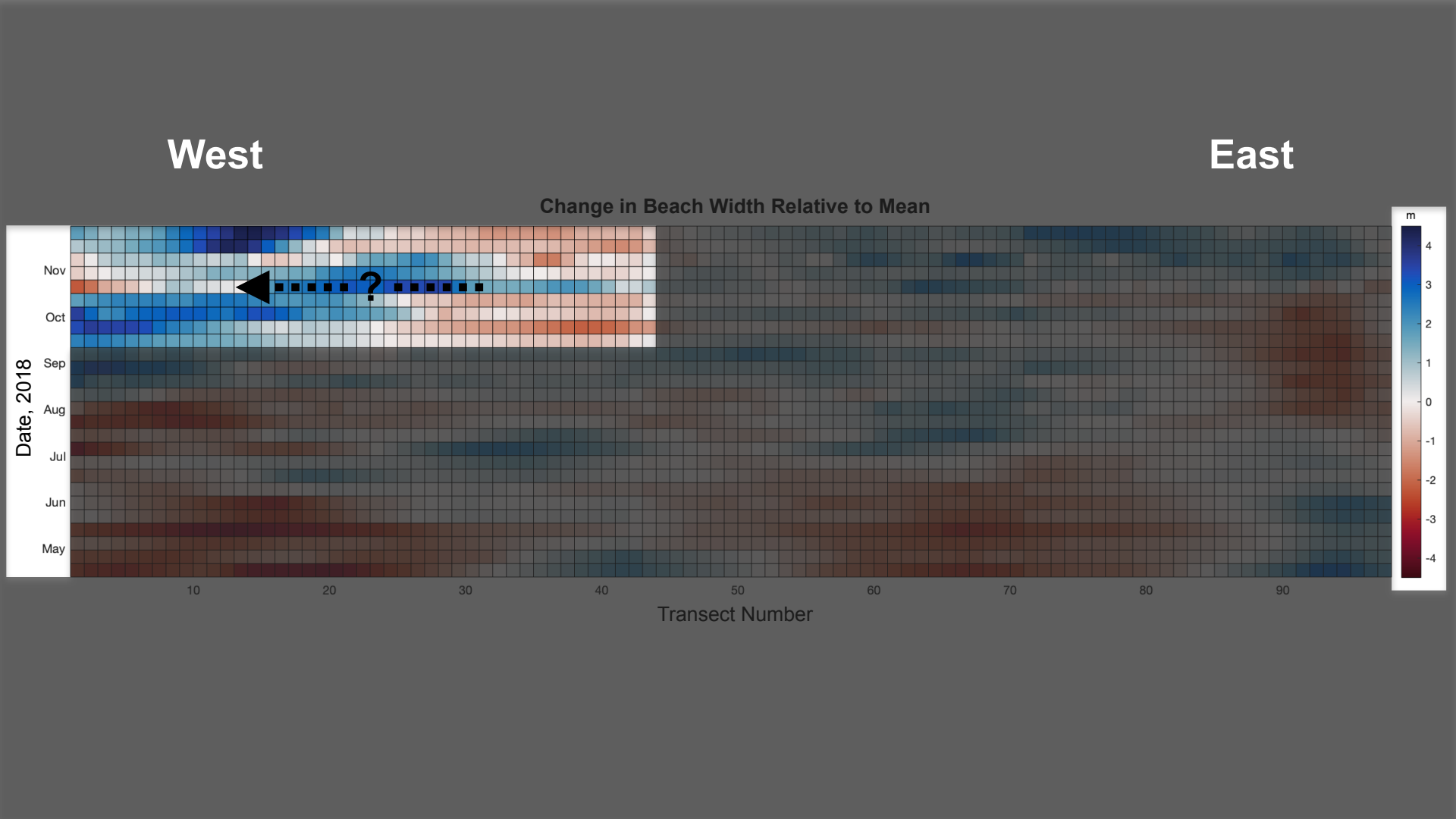
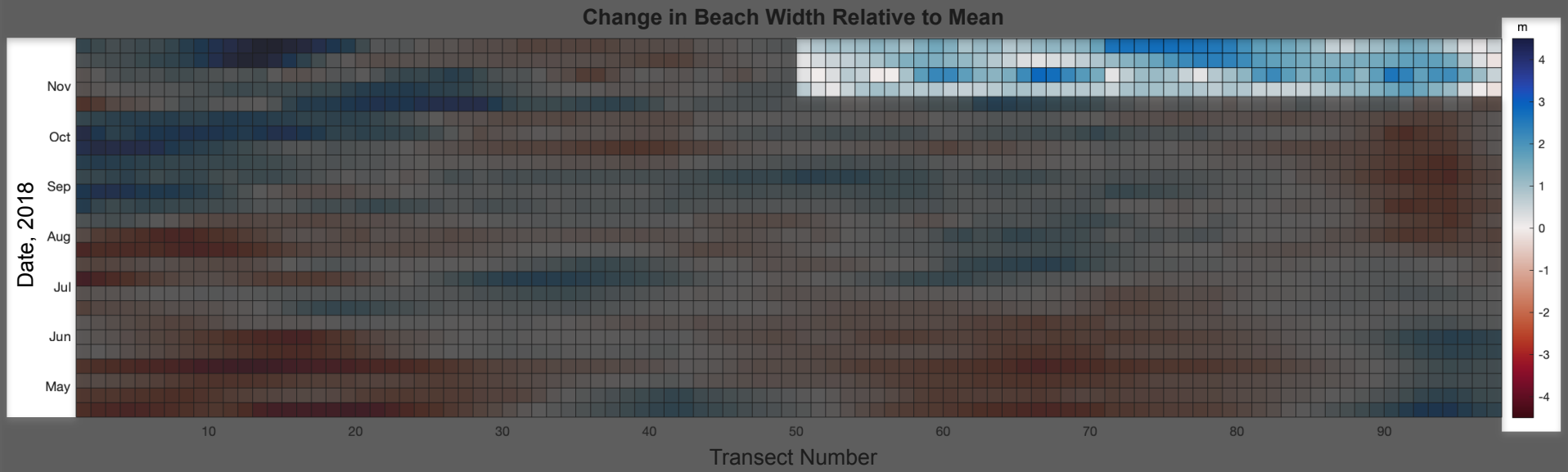
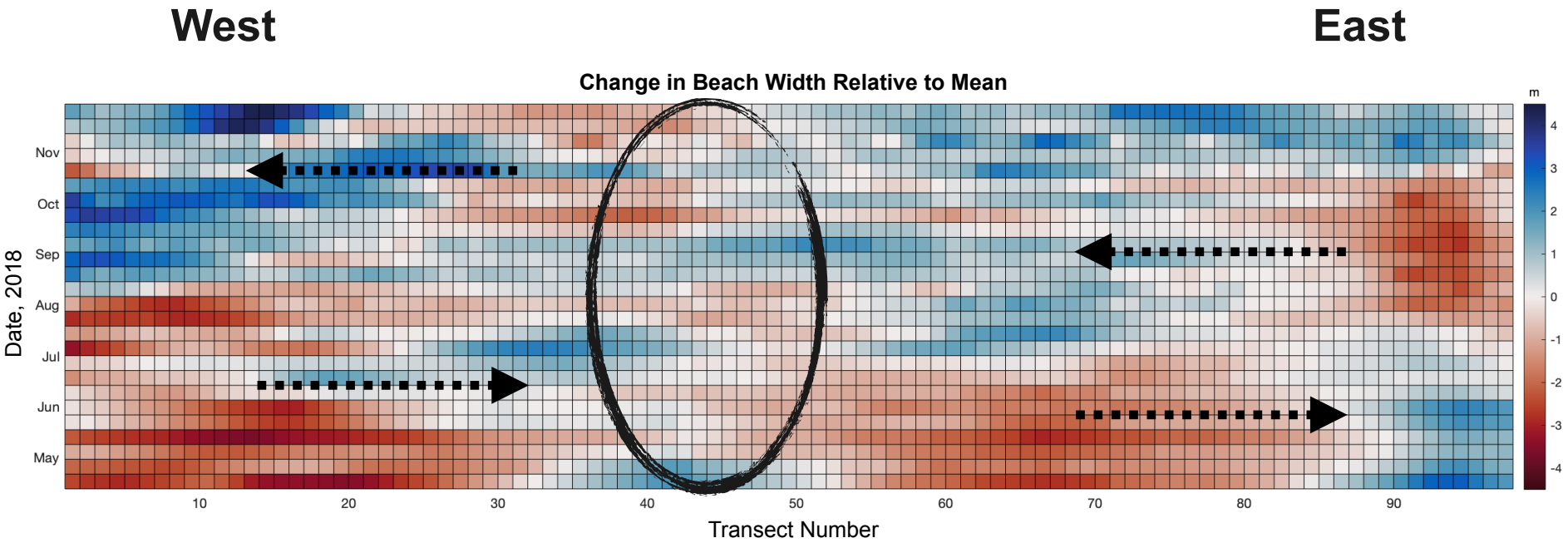
20
30
40
50
60
70
80
90
Transect Number
m
4
3
2
1
0
-1
-2
-3
-4


West
East
Change in Beach Width Relative to Mean
Date, 2018
Nov
Oct
Sep
Aug
Jul
Jun
May
?
10
20
30
40
50
60
70
80
90
Transect Number
m
4
3
2
1
0
-1
-2
-3
-4


West
East
Change in Beach Width Relative to Mean
Date, 2018
Nov
Oct
Sep
Aug
Jul
Jun
May
?
10
20
30
40
50
60
70
80
90
Transect Number
m
4
3
2
1
0
-1
-2
-3
-4

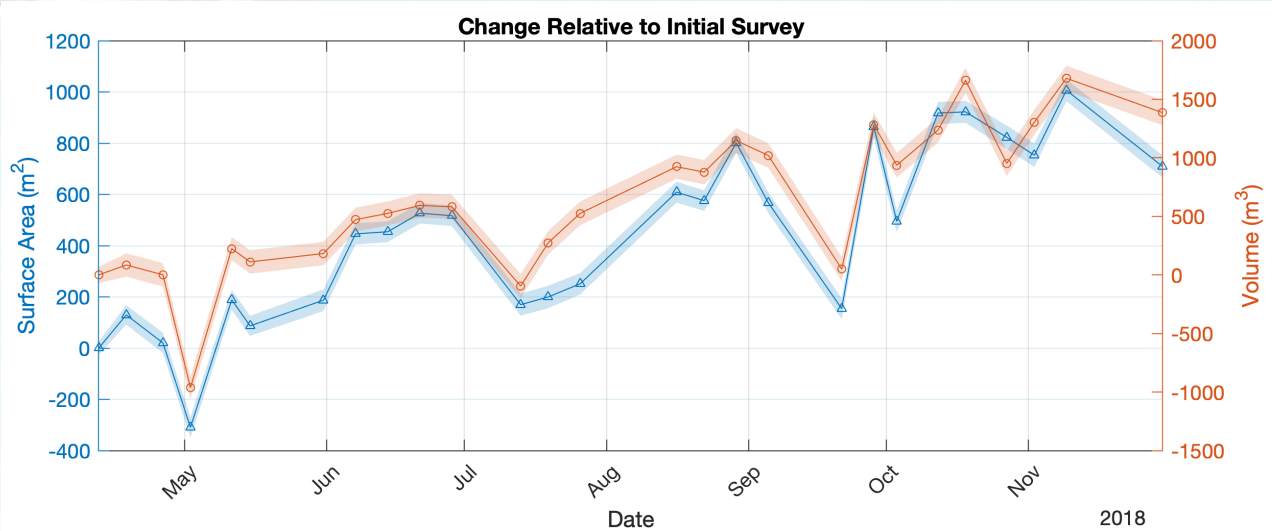
West East


Change in Beach Width Relative to Mean
Date, 2018
Nov
Oct
Sep
Aug
Jul
Jun
May
10
20
30
40
50
60
70
80
90
Transect Number
m
4
3
2
1
0
-1
-2
-3
-4


West
East
Change in Beach Width Relative to Mean
m
4
3
2
1
0
-1
-2
-3
-4
Nov
Oct
Sep
Aug
Jul
Jun
May
Date, 2018
10
20
30
40
50
60
70
80
90
Transect Number

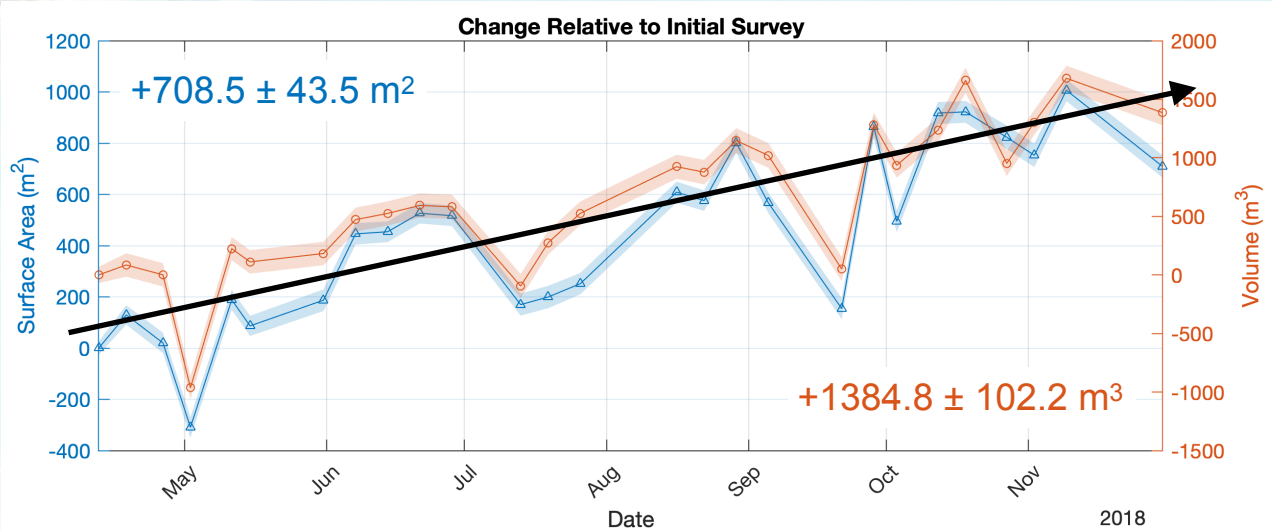
Results & Discussion: Surface Area & Volume

- Correlate variations in surface area and volume with conditions



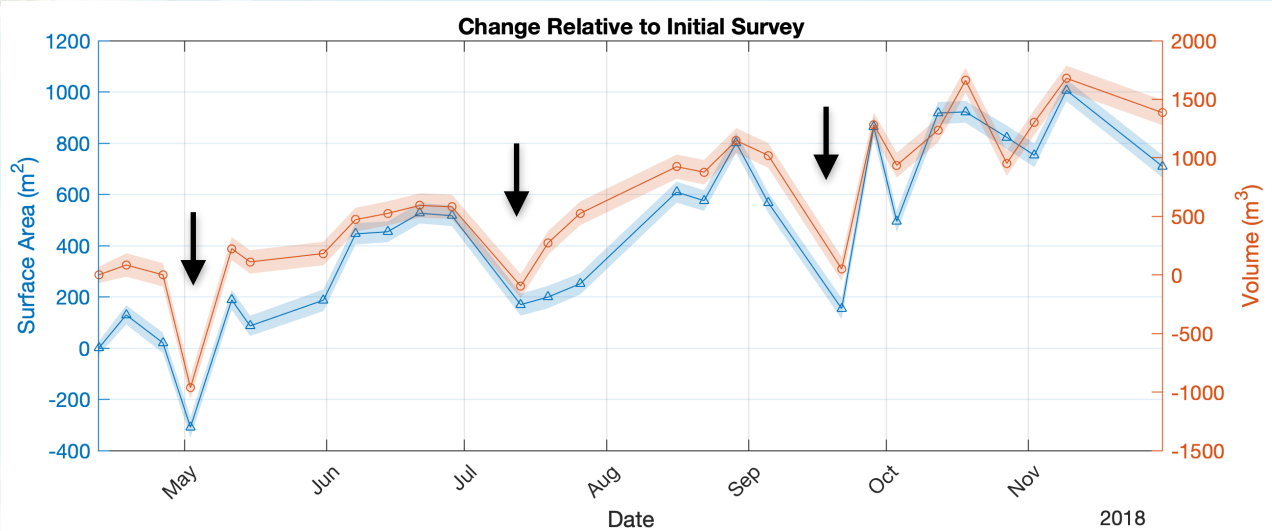
Results & Discussion: Surface Area & Volume

- Correlate variations in surface area and volume with conditions
- Overall increase in both surface area and volume



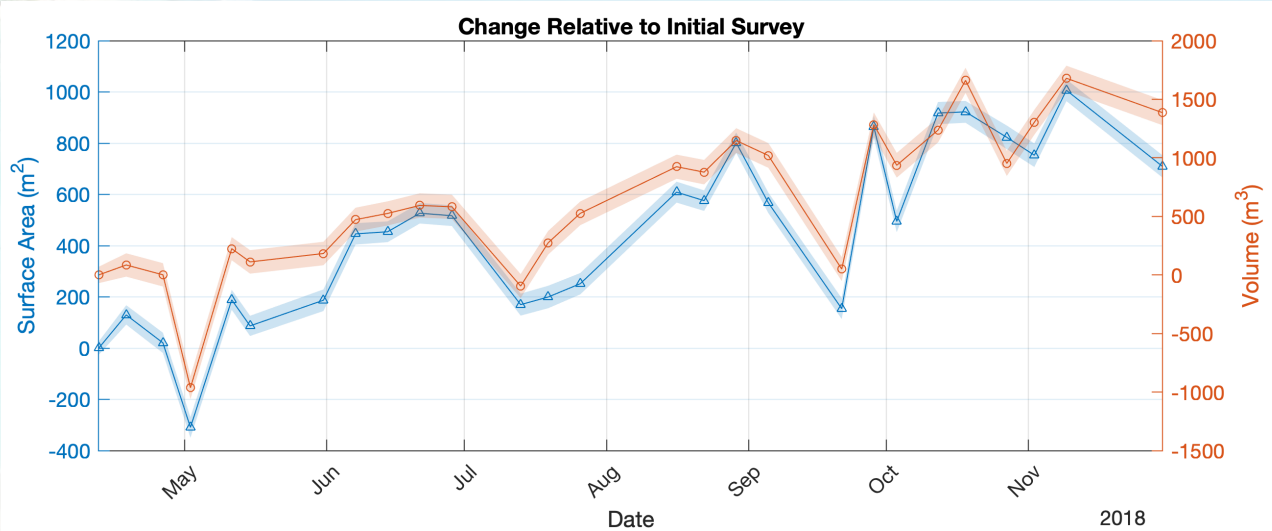
Results & Discussion: Surface Area & Volume

- Correlate variations in surface area and volume with conditions
- Overall increase in both surface area and volume
- Several erosion/recovery events



Results & Discussion: Surface Area & Volume

- Correlate variations in surface area and volume with conditions
- Overall increase in both surface area and volume
- Several erosion/recovery events
- Beach volume behavior relative to surface area



Results & Discussion: Surface Area & Volume

- Correlate variations in surface area and volume with conditions
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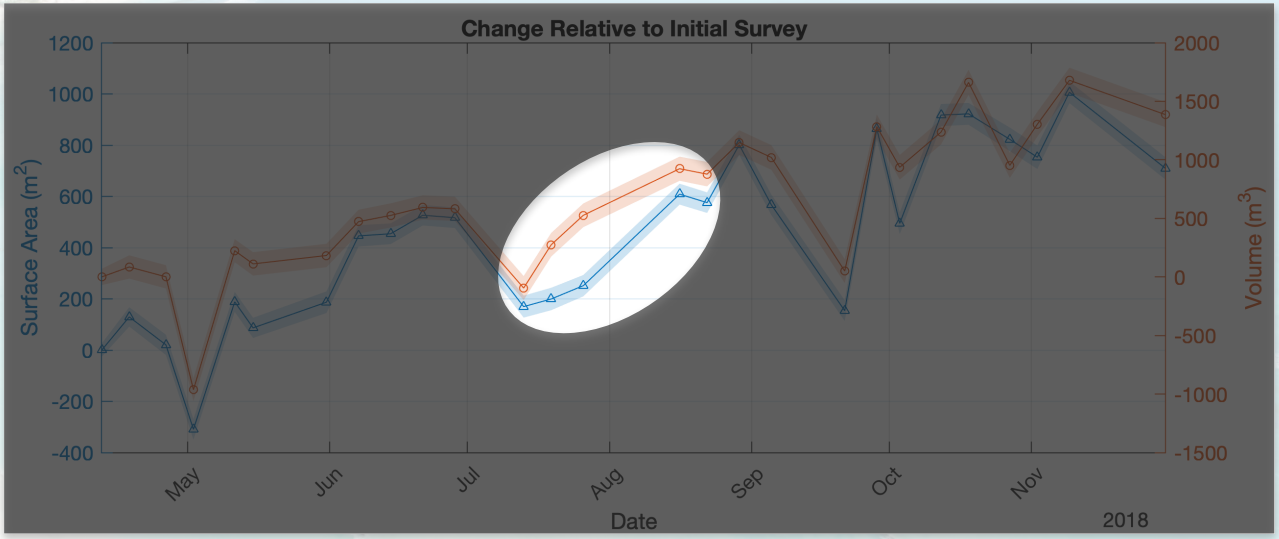
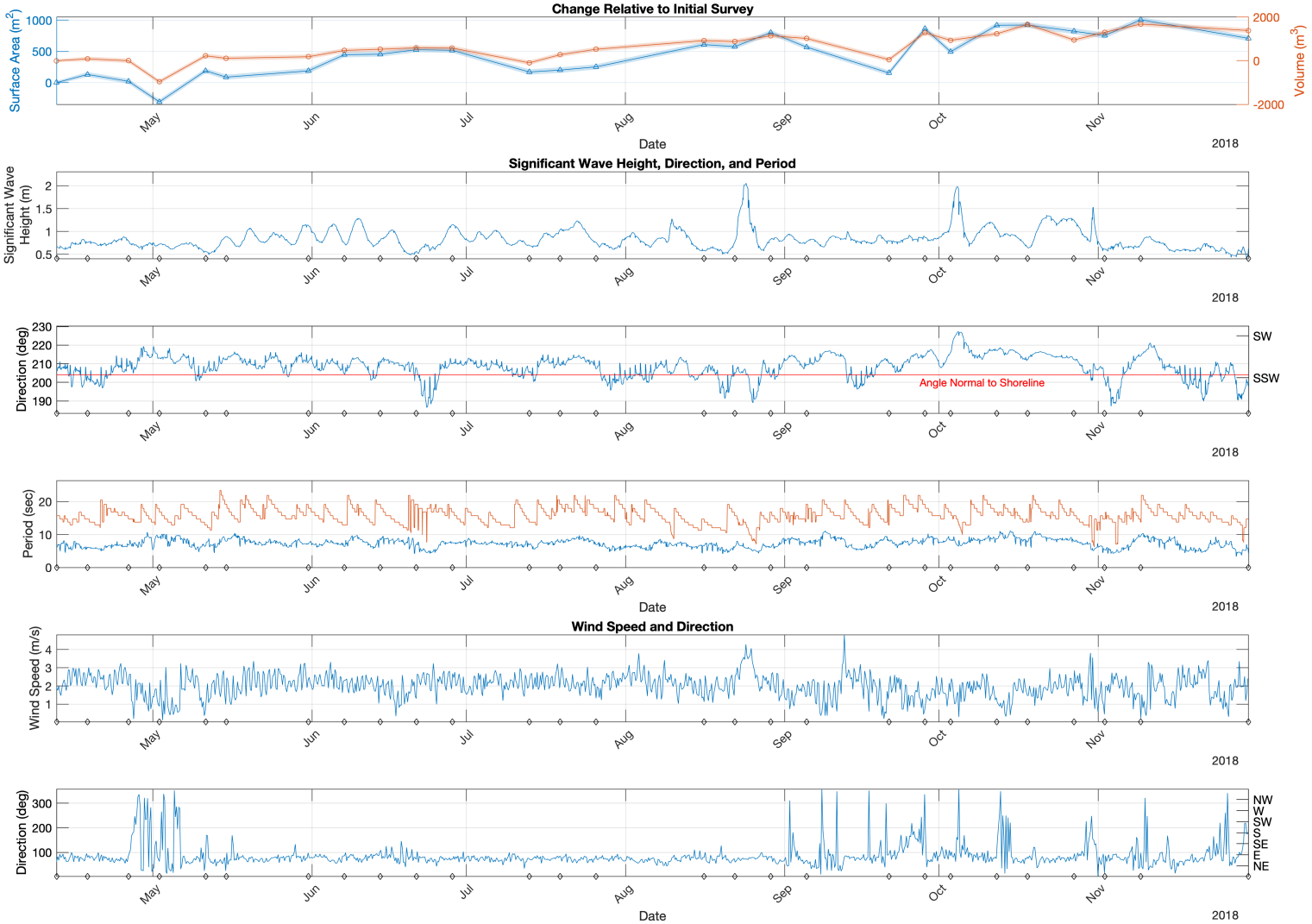
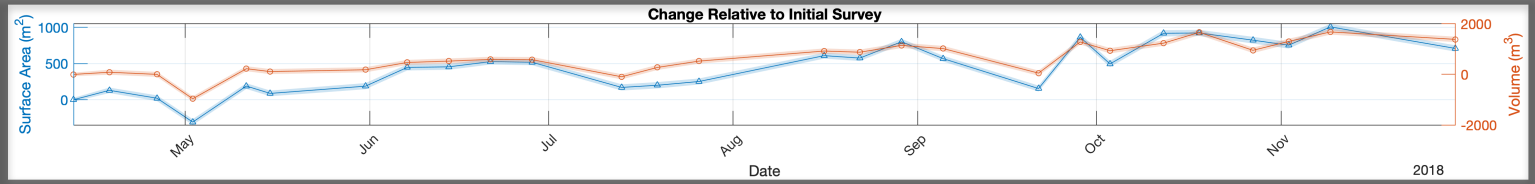
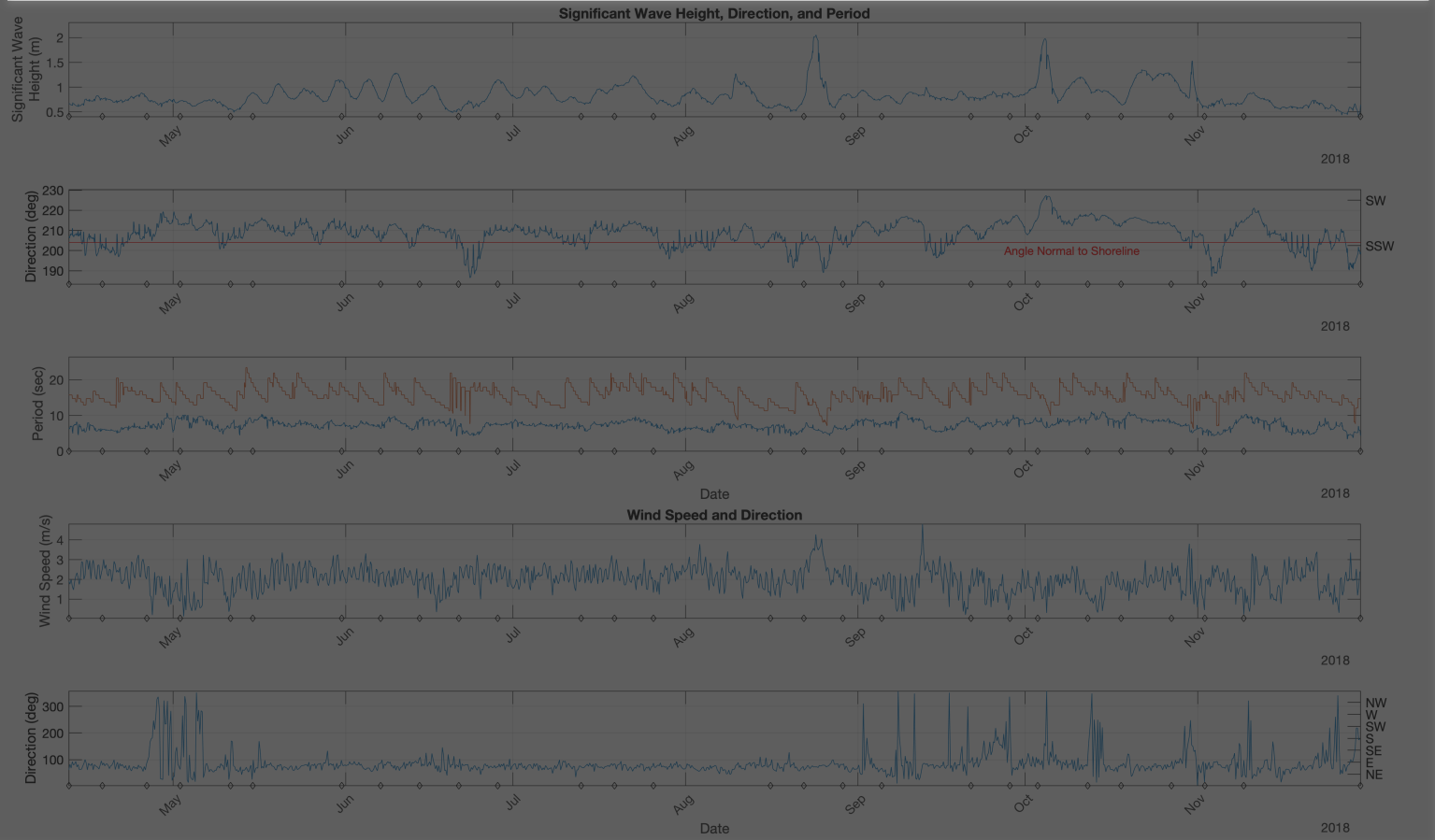



Change Relative to Initial Survey
Surface Area (m^2)
Volume (m^3)
1000
500
0
2000
0
-2000
May
Jun
Jul
Aug
Sep
Oct
Nov
Date
2018
Significant Wave Height, Direction, and Period
Significant Wave Height (m)
2
1.5
1
0.5
Direction (deg)
230
220
210
200
190
SW
SSW
Angle Normal to Shoreline
Period (sec)
20
10
0
Wind Speed and Direction
Wind Speed (m/s)
4
3
2
1
Direction (deg)
300
200
100
NW
W
SW
S
SE
E
NE

Surface Area (m²)
Volume (m³)

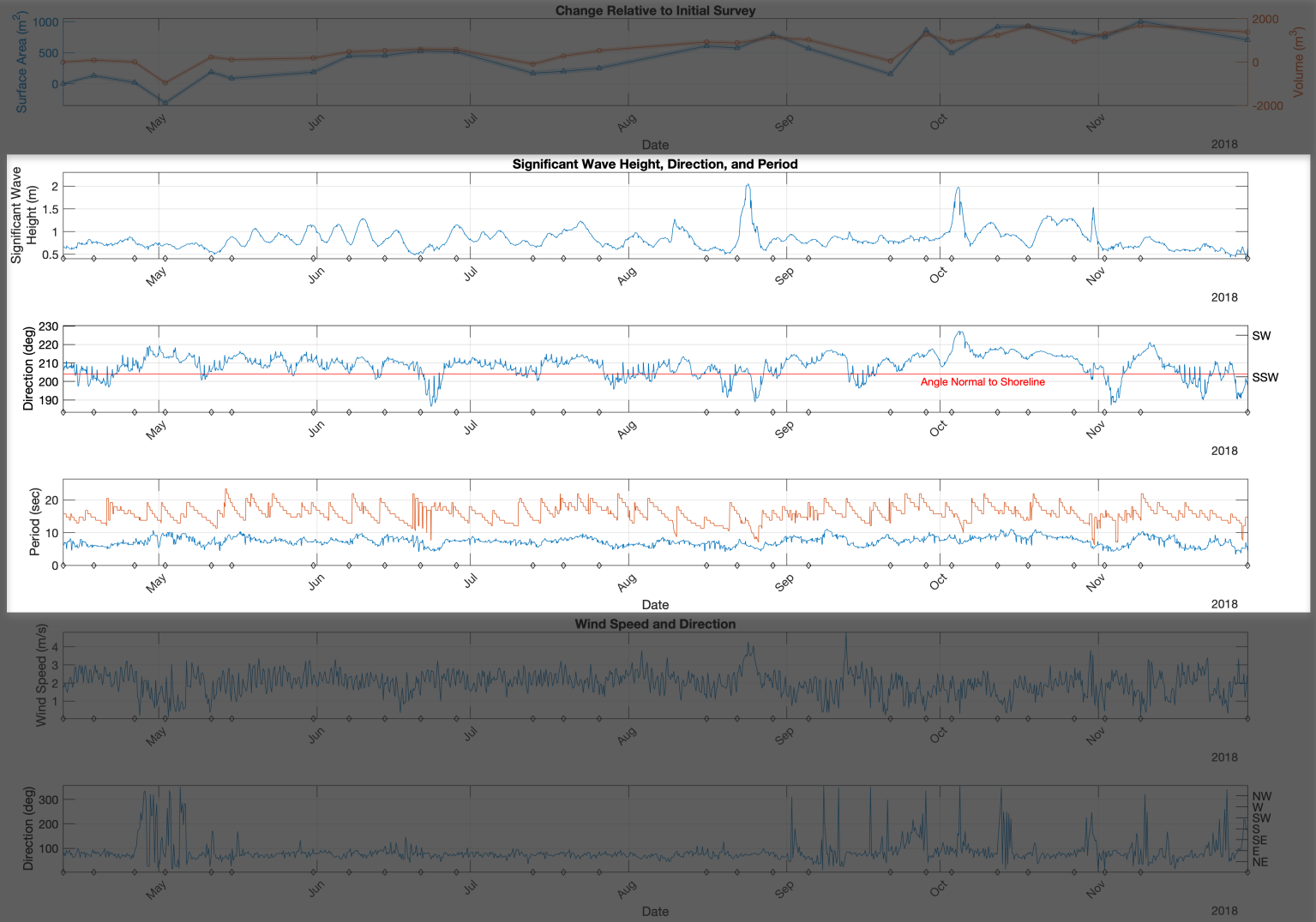




Significant Wave Height (m)

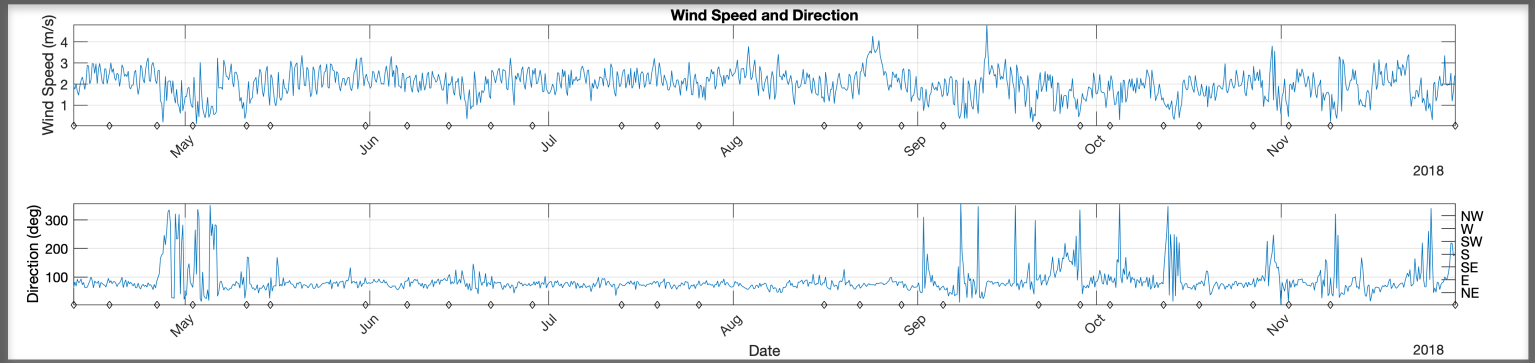
Direction (deg)

Period (sec)

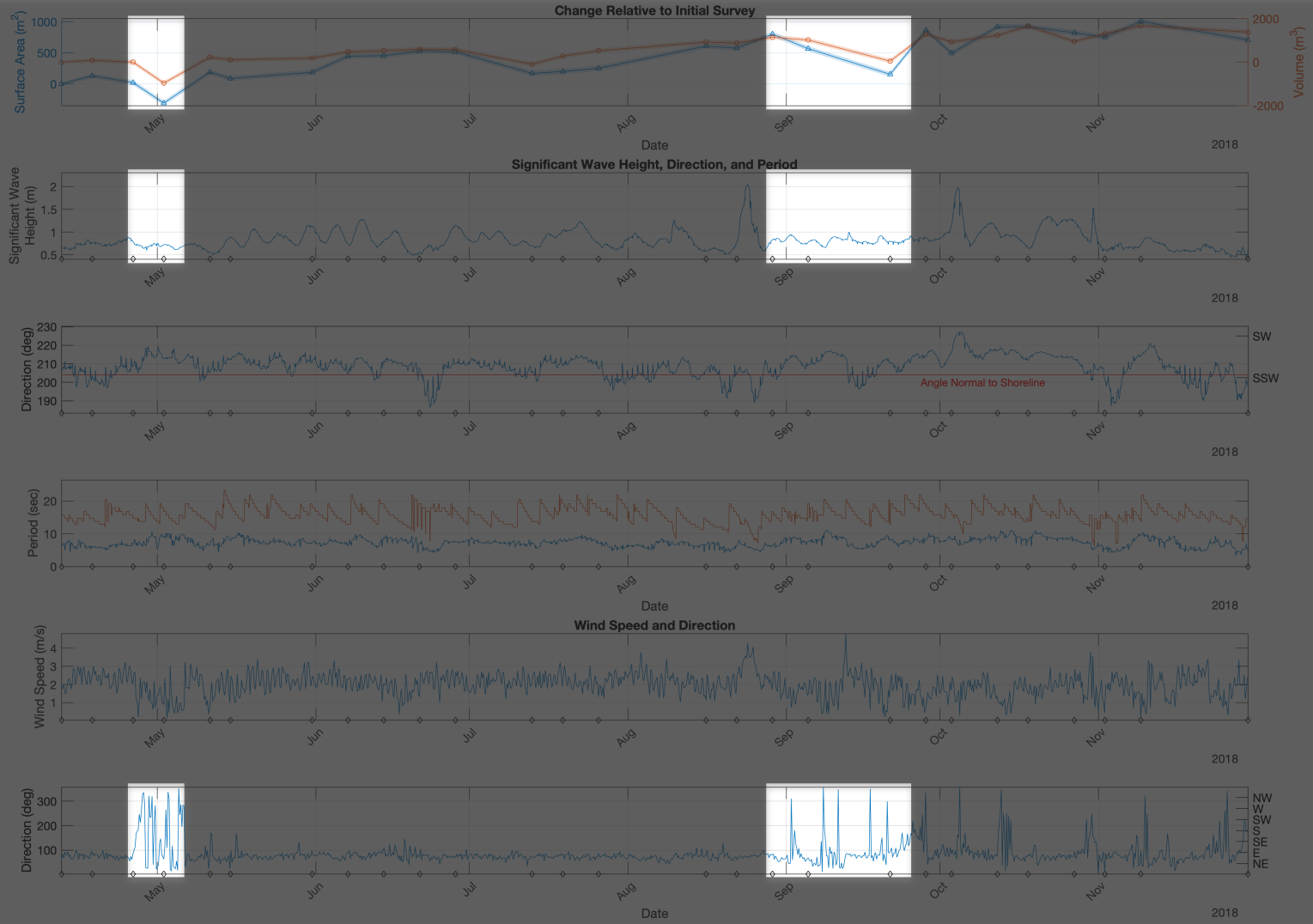


Speed (m/s)

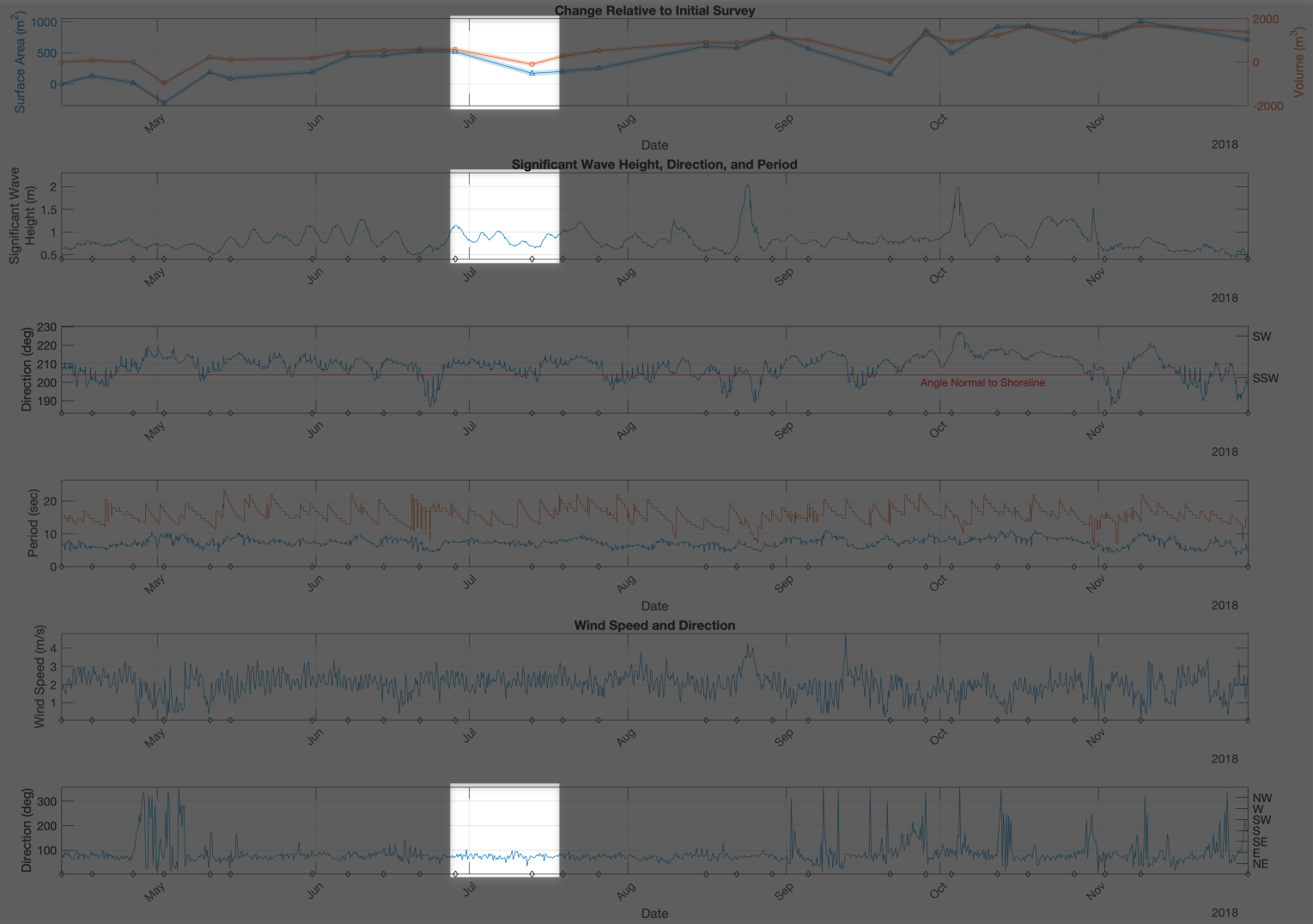
Direction (deg)



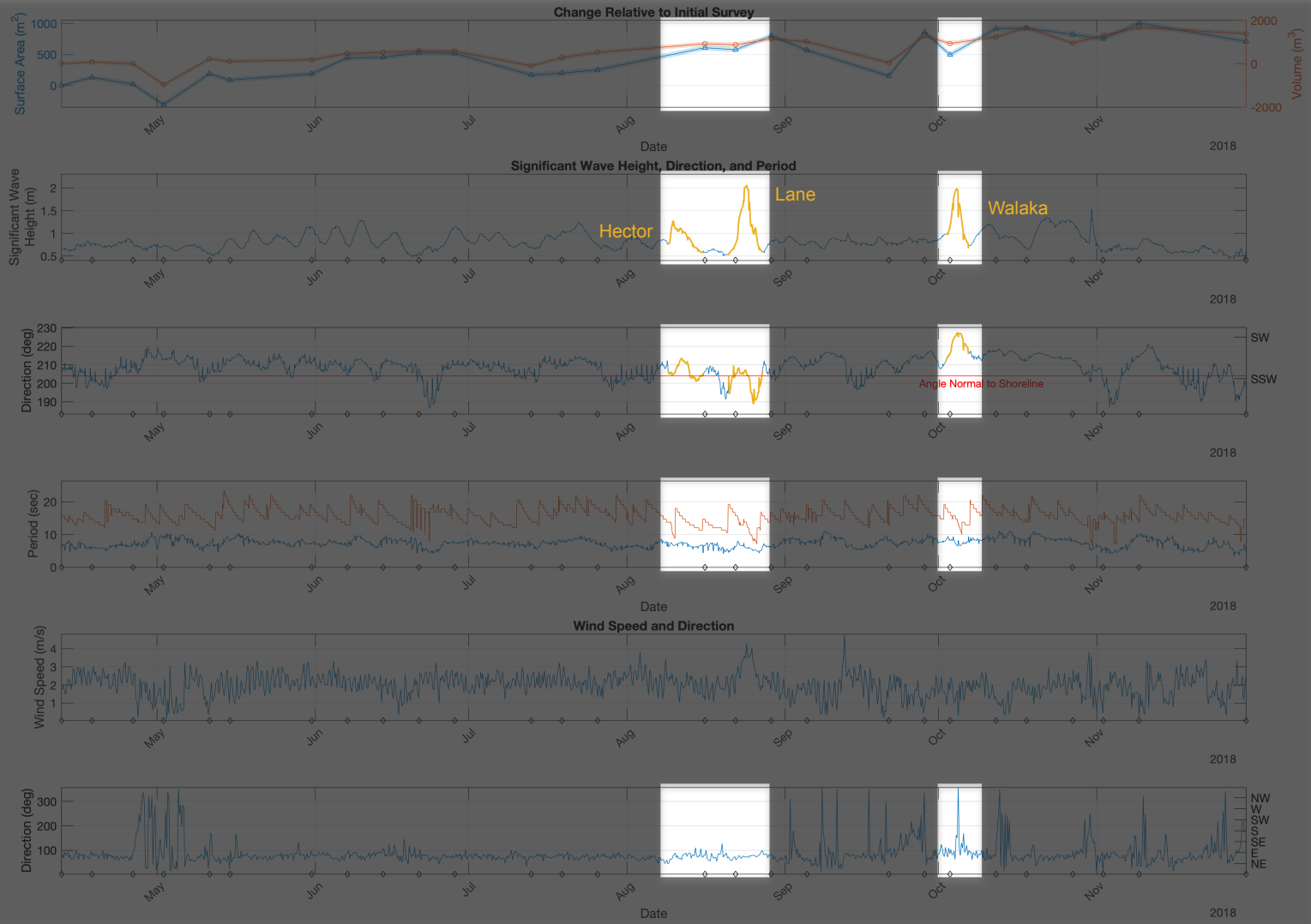
These erosion events seem to correlate with periods of little wave energy and irregularities of the trade winds



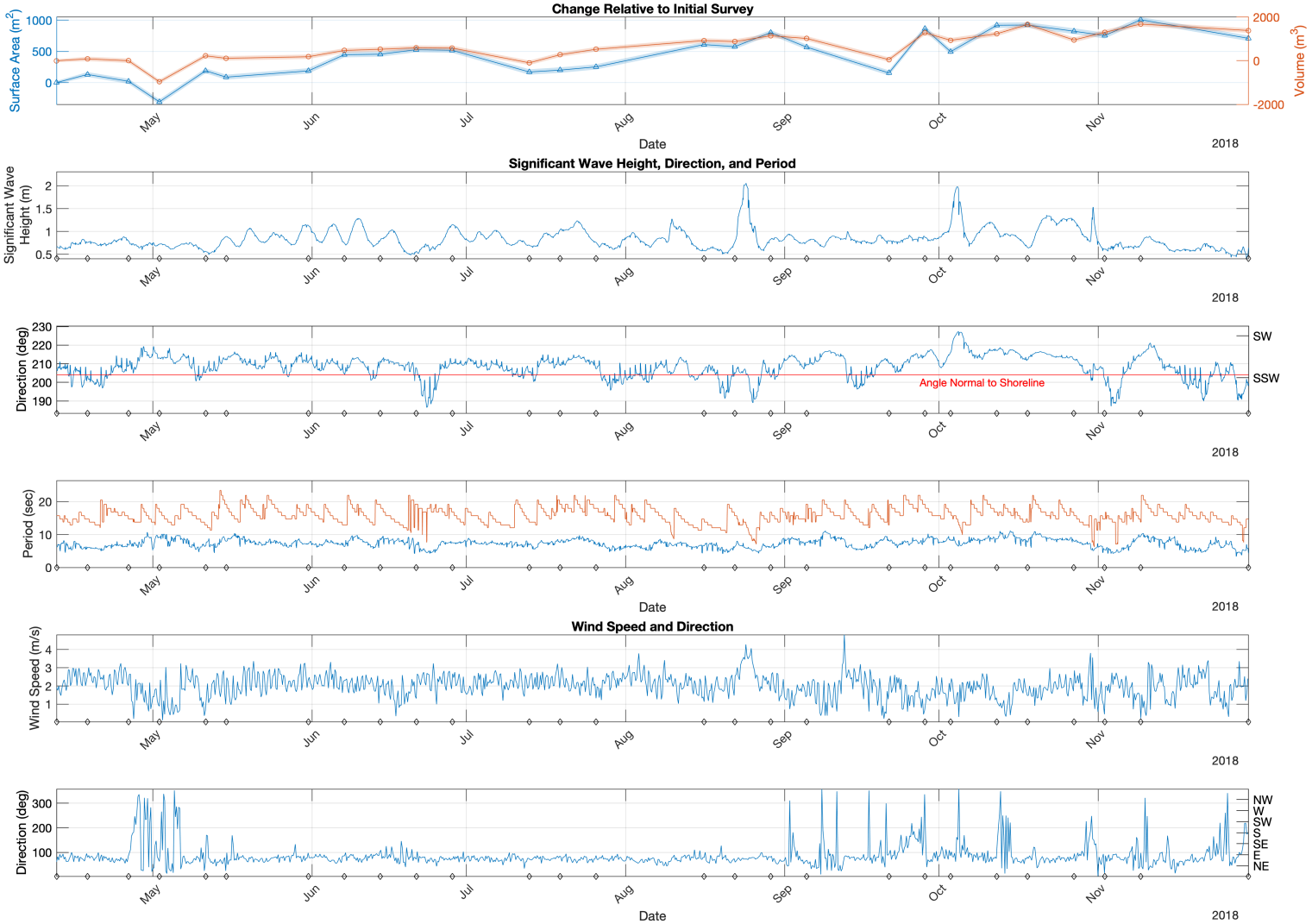
This erosion event seems to correlate with more energetic SSW swells and a regular NE trade wind pattern



Hurricanes generating short period swell of varying directions do not interrupt prior trends nor cause erosion

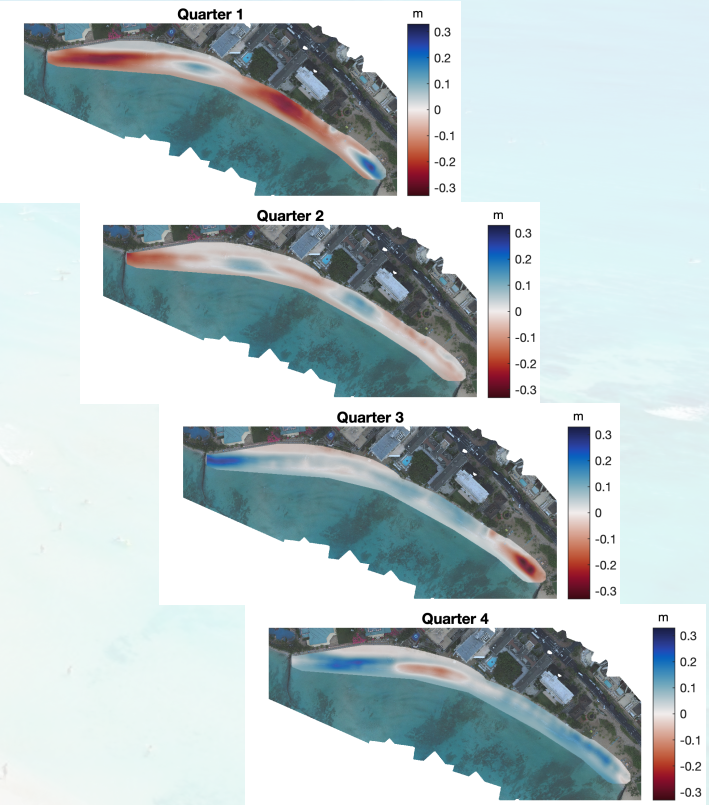


A complex system that is directionally sensitive to wind and waves

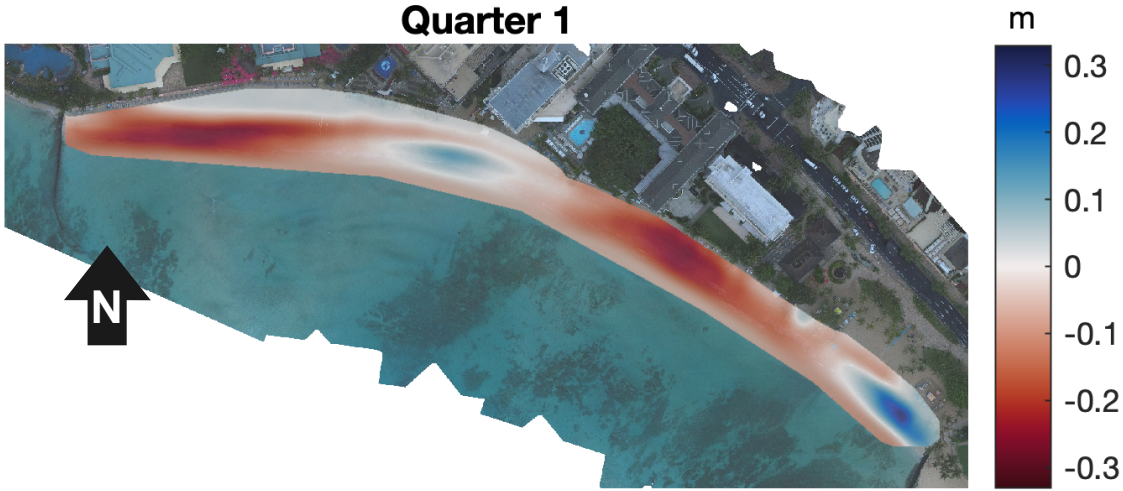


Results & Discussion: Surface Variability

- Add another dimension
- Get an understanding of how the surface varies through time
- De-mean, divide time series into quarters, and average
    - Quarters are arbitrary
    - Each quarter is characterized by of an event/series of events



- The beginning of the active swell season (summer phase)
- Q1 beach state predominately below mean elevation
- Above mean elevation at central beach, east end



April 12, 2018 - May 31, 2018

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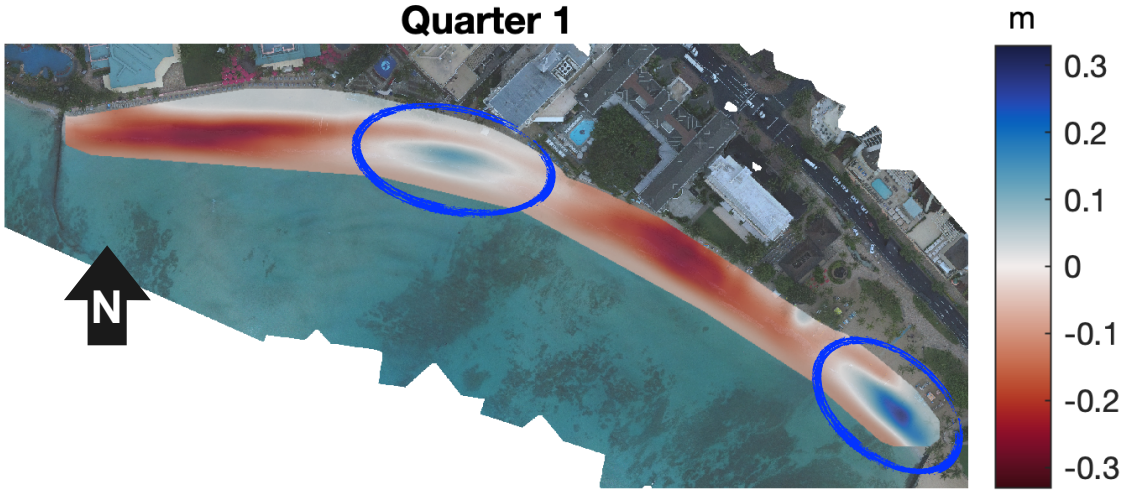
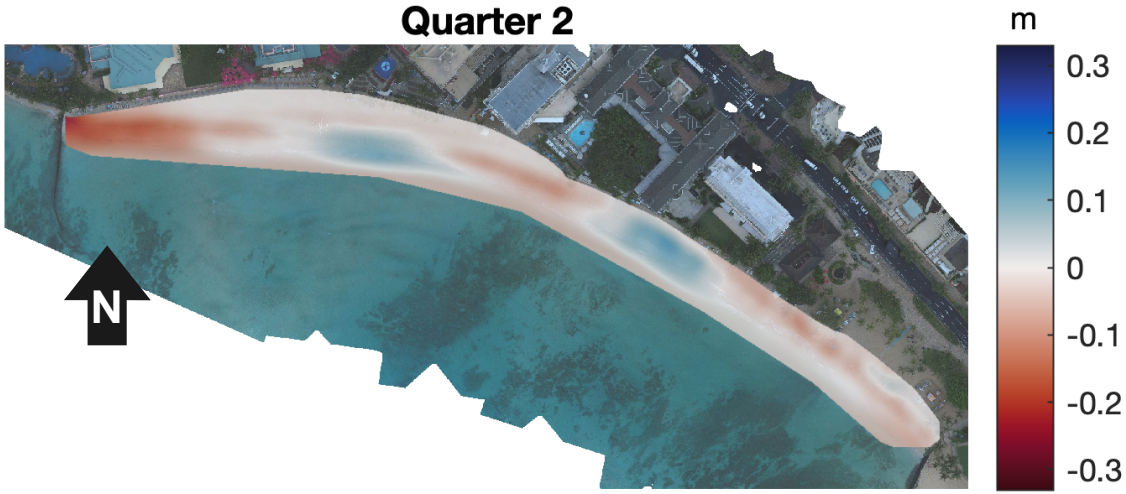
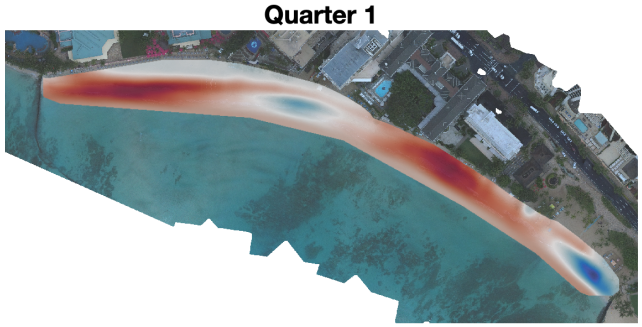


April 12, 2018 - May 31, 2018

- Southerly swell in full swing
- Accretion at central beach
- Erosion at east end of beach



June 7, 2018 - July 26, 2018



April 12, 2018 - May 31, 2018

- Southerly swell in full swing
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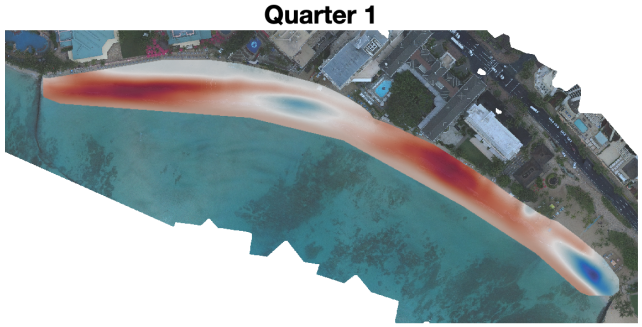
June 7, 2018 - July 26, 2018



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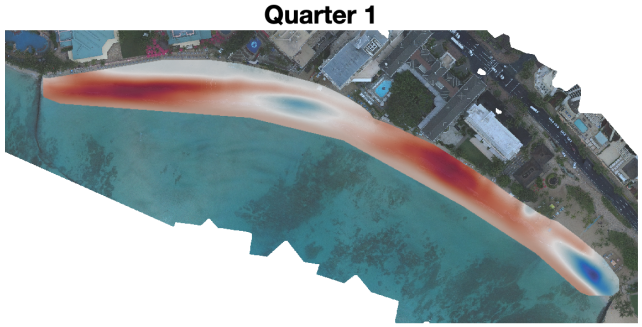
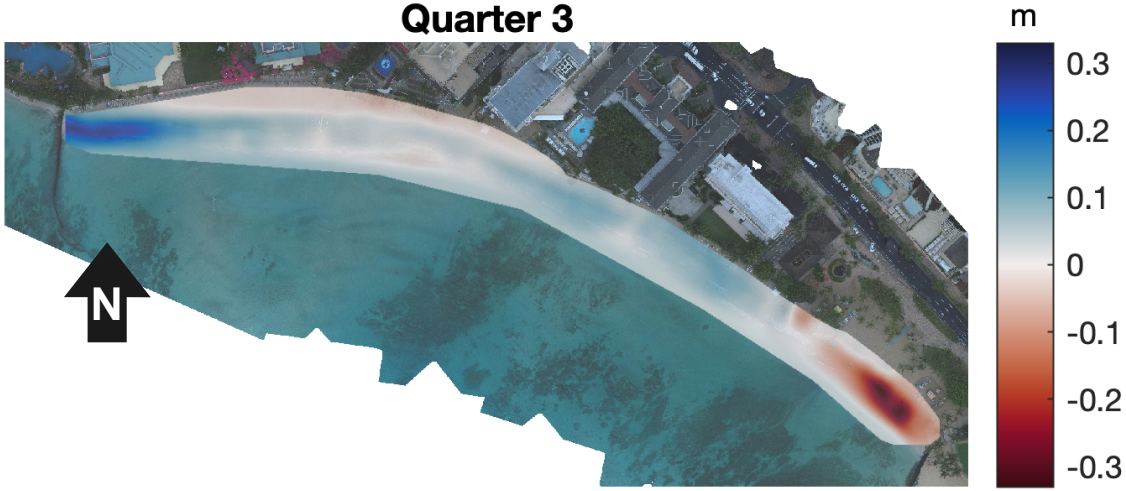


April 12, 2018 - May 31, 2018

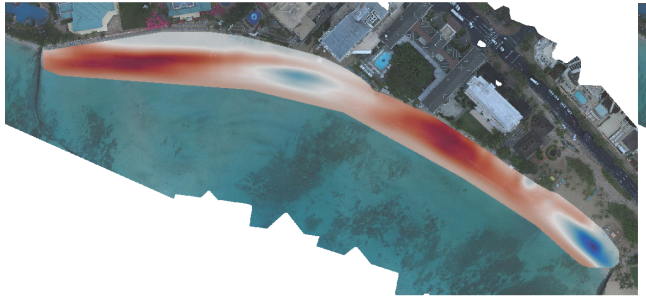
- Hurricane swells (Hector, Lane, Walaka)
- Accretion at west end
- Erosion at east end
- General accretion

Quarter 3



August 16, 2018 - October 3, 2018

Quarter 1



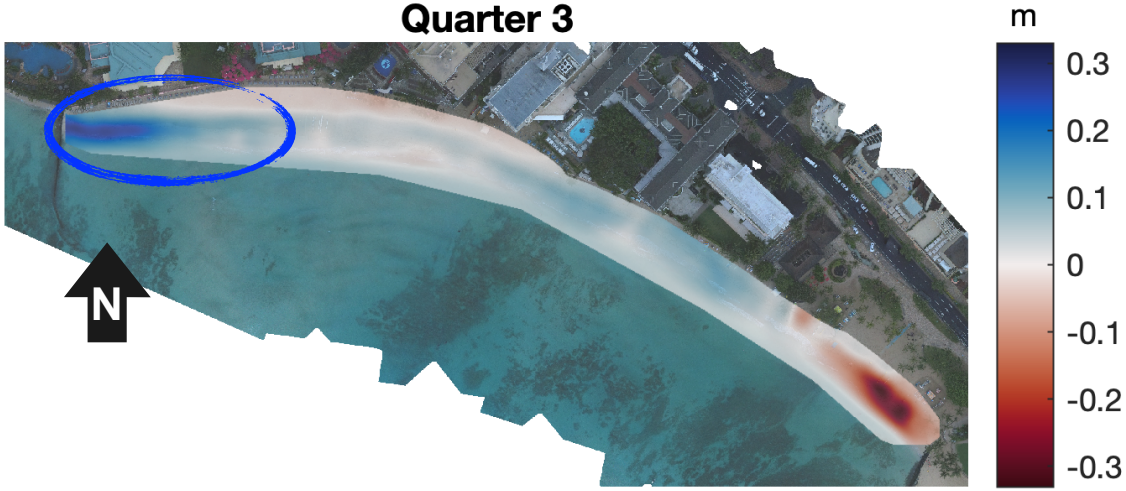
April 12, 2018 - May 31, 2018

Quarter 2

June 7, 2018 - July 26, 2018

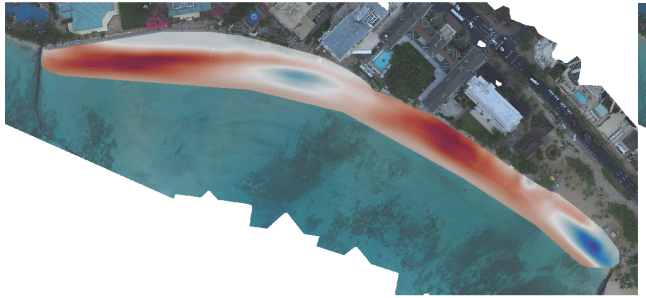
- Hurricane swells (Hector, Lane, Walaka)
- Accretion at west end
- Erosion at east end
- General accretion

Quarter 3



August 16, 2018 - October 3, 2018

Quarter 1



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Quarter 3

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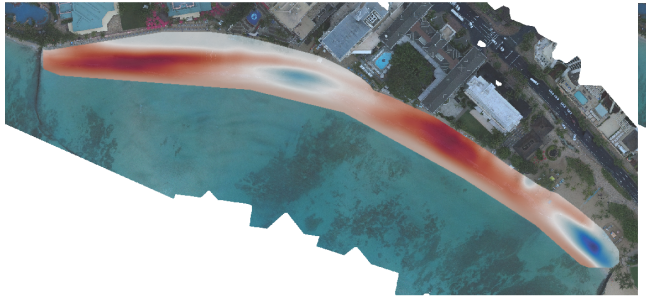

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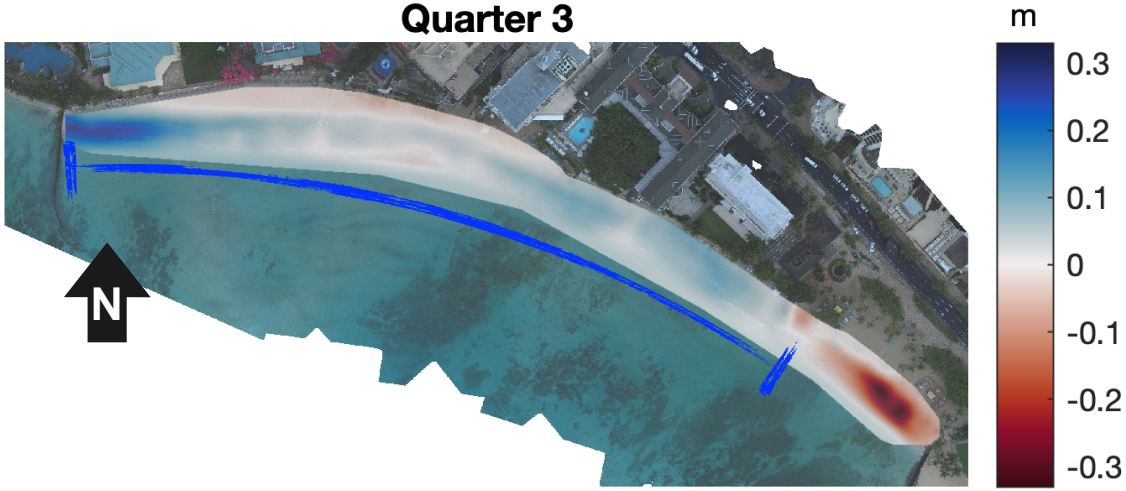
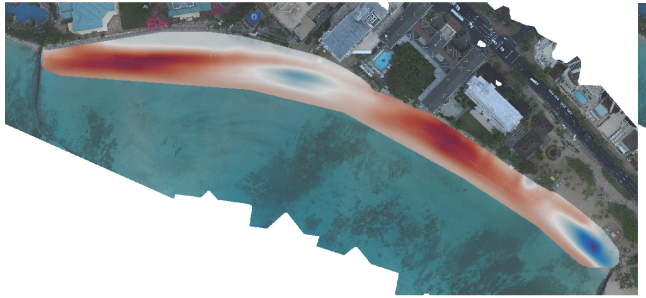
Quarter 3



August 16, 2018 - October 3, 2018

Quarter 1



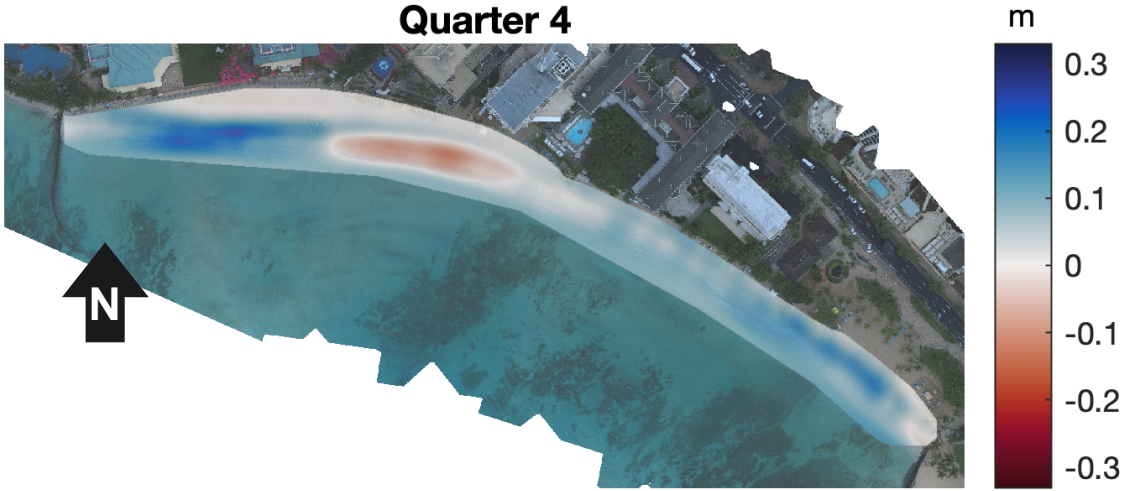
April 12, 2018 - May 31, 2018

Quarter 2

June 7, 2018 - July 26, 2018

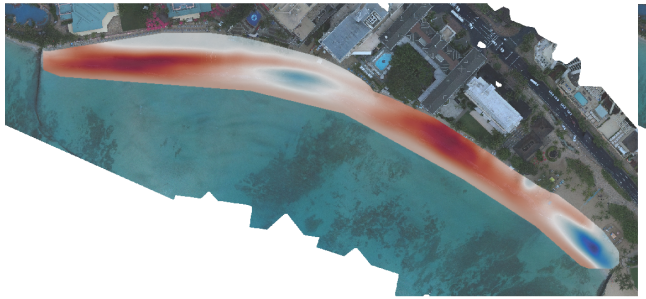
- Final south swells before winter phase begins
- General accretion
- Erosion hotspot at east end dissipates
- Erosion at central beach

Quarter 4



October 12, 2018 - November 30, 2018

Quarter 1



April 12, 2018 - May 31, 2018

Quarter 2

June 7, 2018 - July 26, 2018

Quarter 3

August 16, 2018 - October 3, 2018

- Final south swells before winter phase begins
- General accretion
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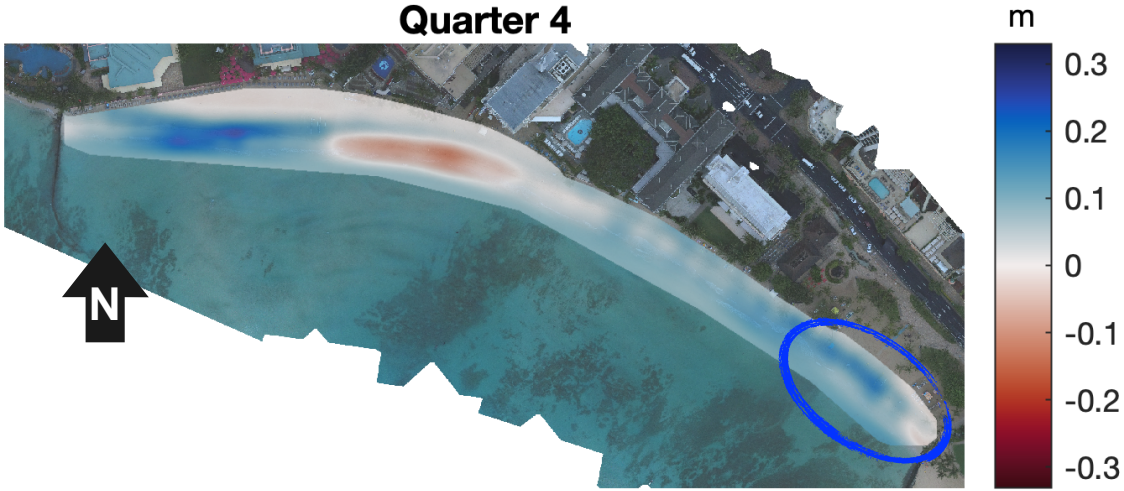
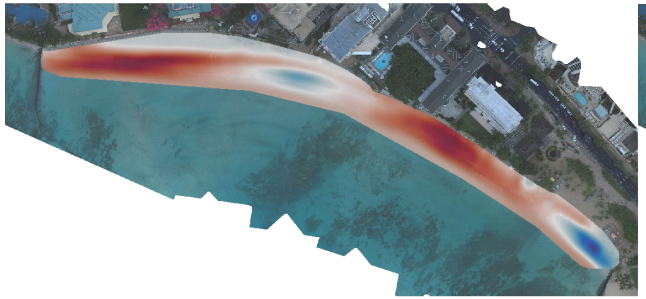
- Erosion at central beach

Quarter 4



October 12, 2018 - November 30, 2018

Quarter 1



April 12, 2018 - May 31, 2018

Quarter 2

June 7, 2018 - July 26, 2018

Quarter 3

August 16, 2018 - October 3, 2018

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- General accretion
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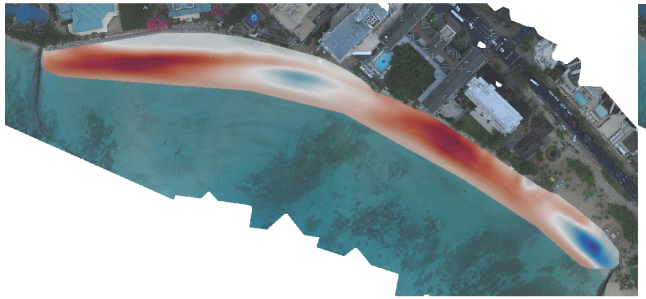
- Erosion at central beach

Quarter 4

October 12, 2018 - November 30, 2018

Quarter 1



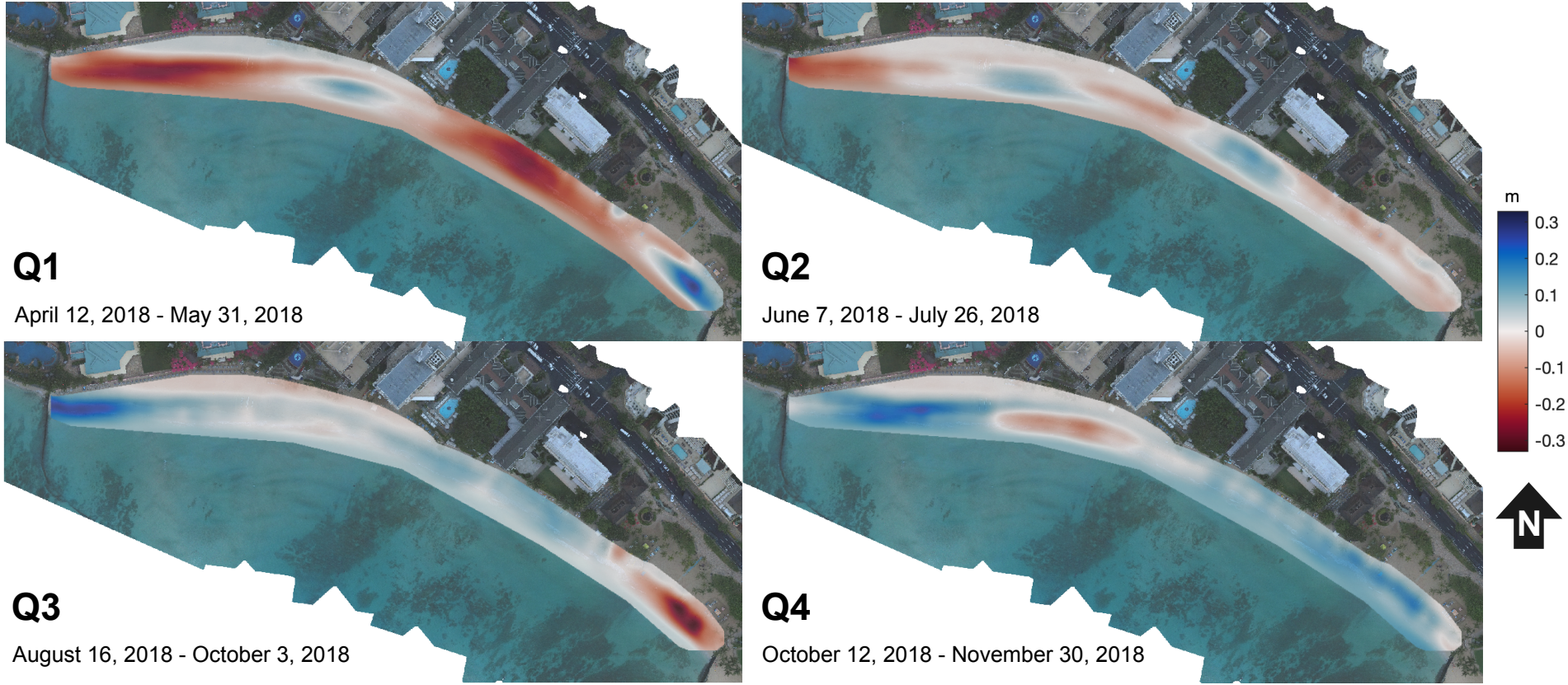
April 12, 2018 - May 31, 2018

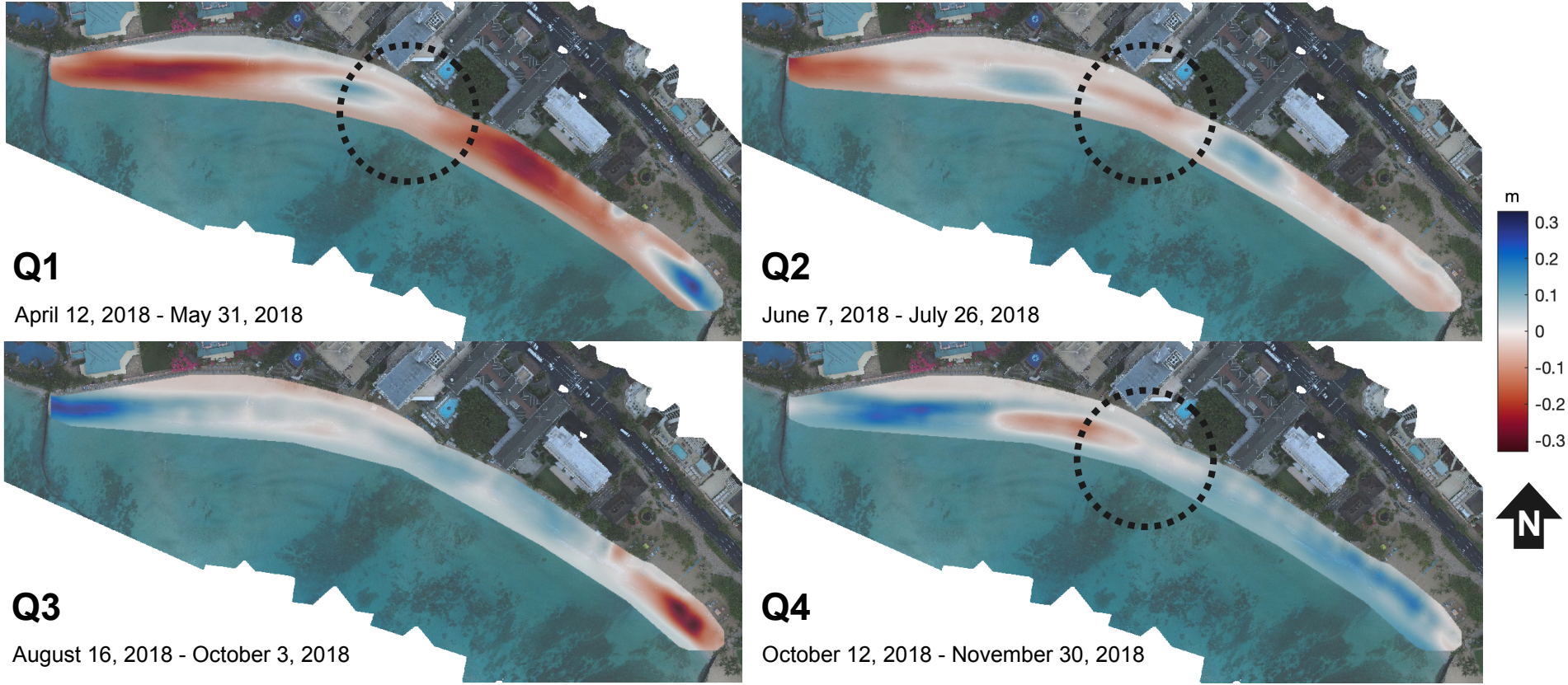
Quarter 2

June 7, 2018 - July 26, 2018

Quarter 3

August 16, 2018 - October 3, 2018


Q1
April 12, 2018 - May 31, 2018
Q2
June 7, 2018 - July 26, 2018
Q3
August 16, 2018 - October 3, 2018
Q4
October 12, 2018 - November 30, 2018
m
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
N


Q1
April 12, 2018 - May 31, 2018
Q2
June 7, 2018 - July 26, 2018
Q3
August 16, 2018 - October 3, 2018
Q4
October 12, 2018 - November 30, 2018
m
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
N

Results & Discussion: EOF Analysis

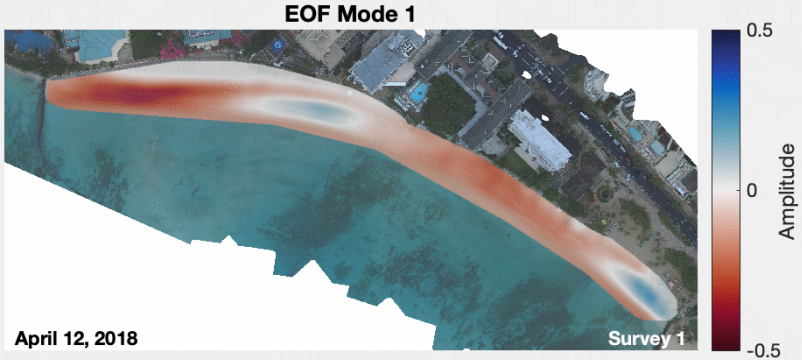
- Empirical Orthogonal Function (EOF) analysis is used to study spatial modes (i.e. patterns) of variability and how they change with time
  - Gives a measure of the ‘importance’ of each pattern
  - Not based on physical principles, but mathematically orthogonal (independent) modes can be interpreted as such
- Gives insight into sediment transport behavior
- These patterns can be correlated to specific conditions and/or events

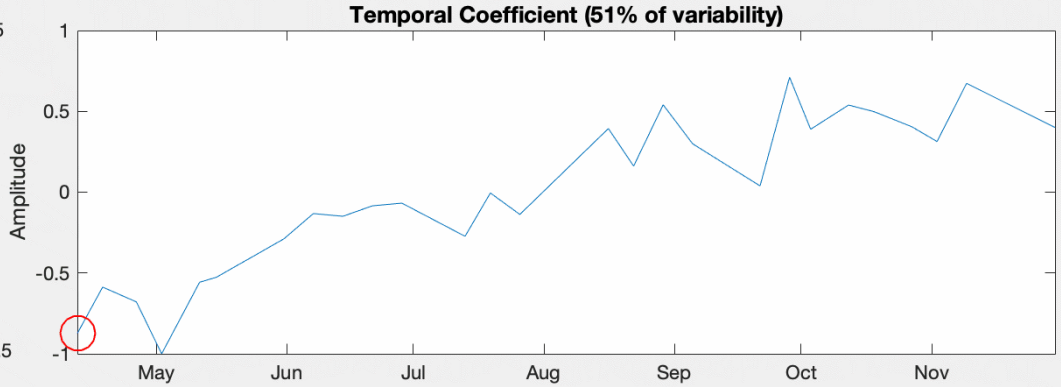
Mode 1 (51% variability): Congruent Transport, Two “Subcells”

Longshore transport - cross-shore exchange?

2 subcells

Directionality of sand transport is consistent in both cells





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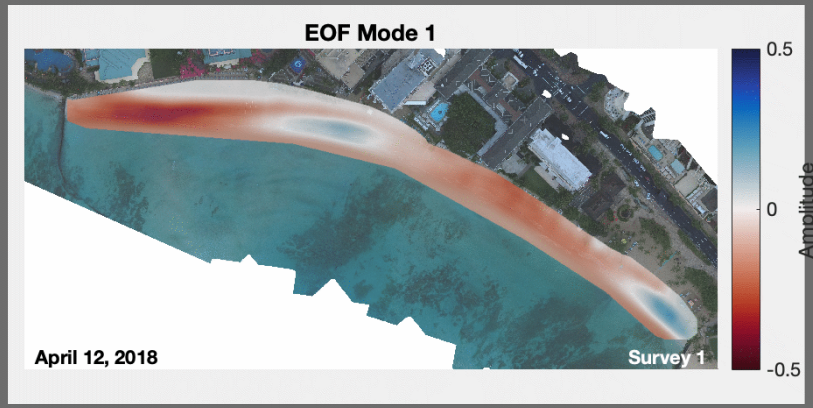

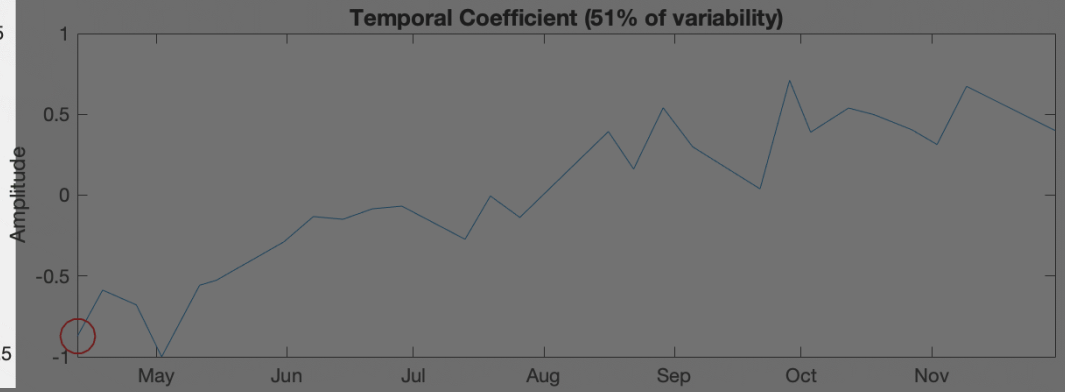

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Longshore transport - cross-shore exchange?

2 subcells

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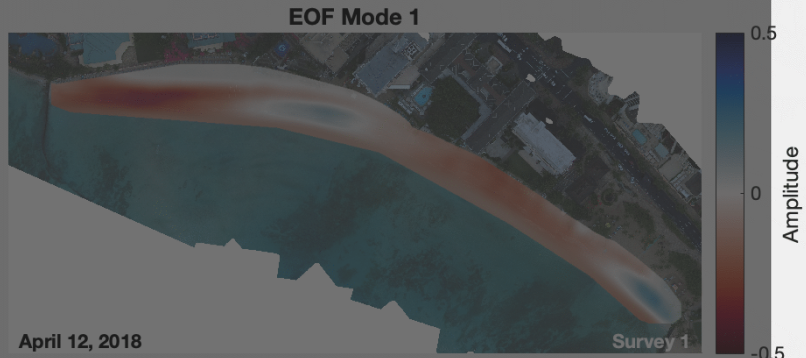

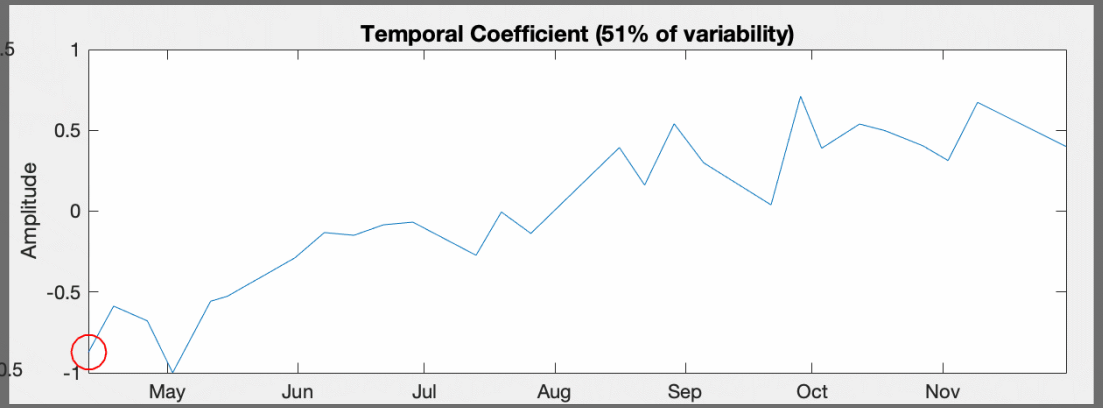

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Longshore transport - cross-shore exchange?

2 subcells

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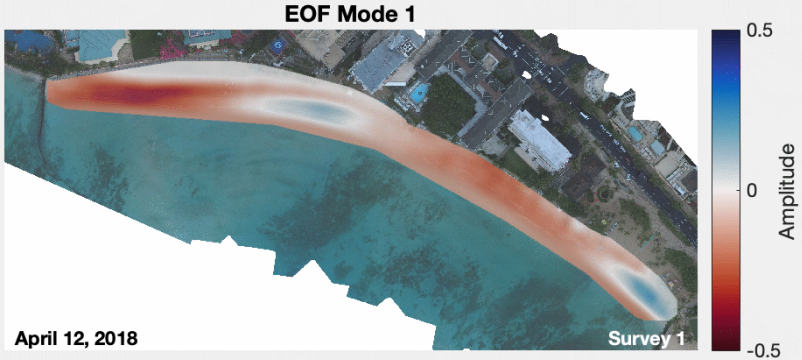

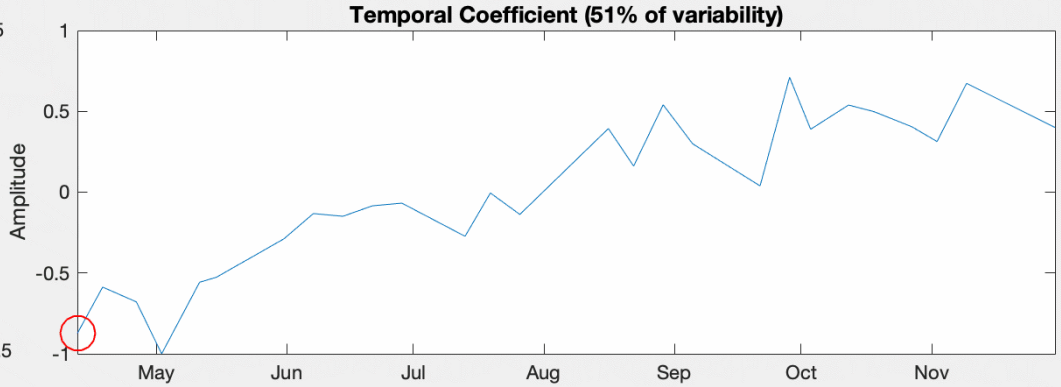

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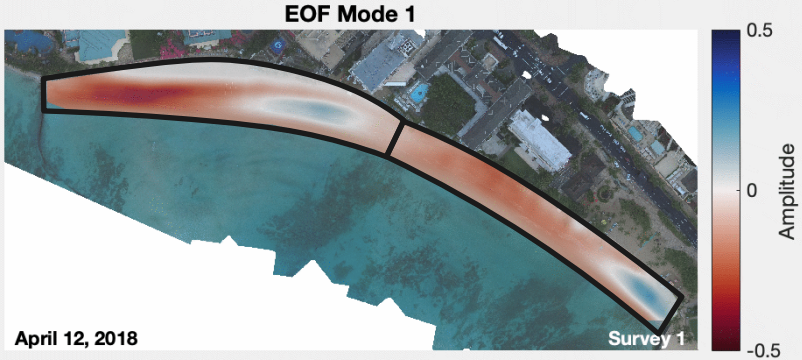

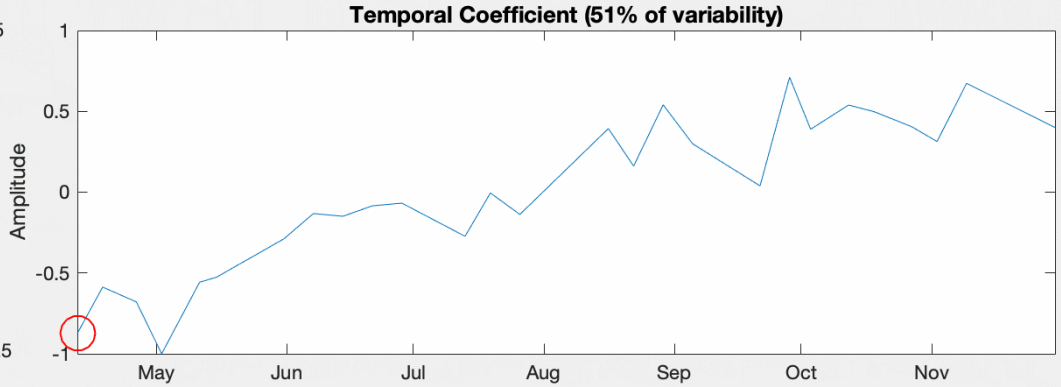

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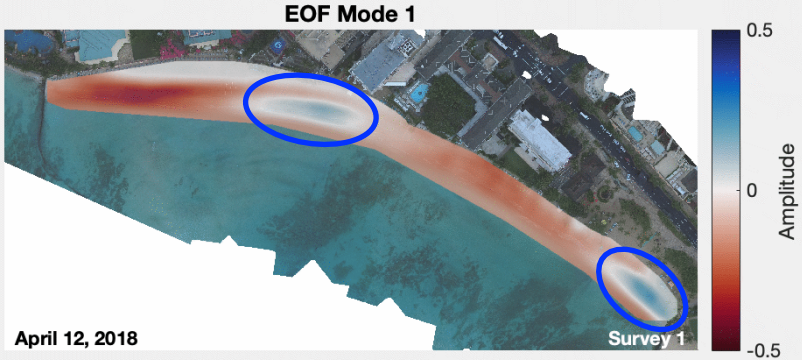

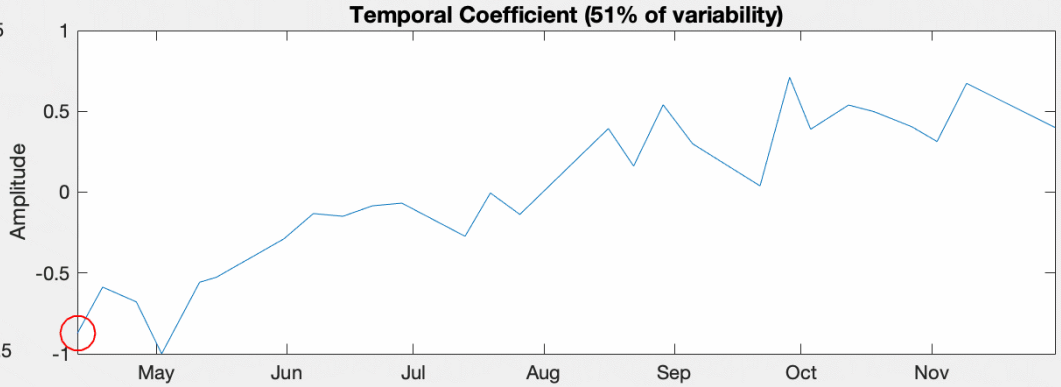

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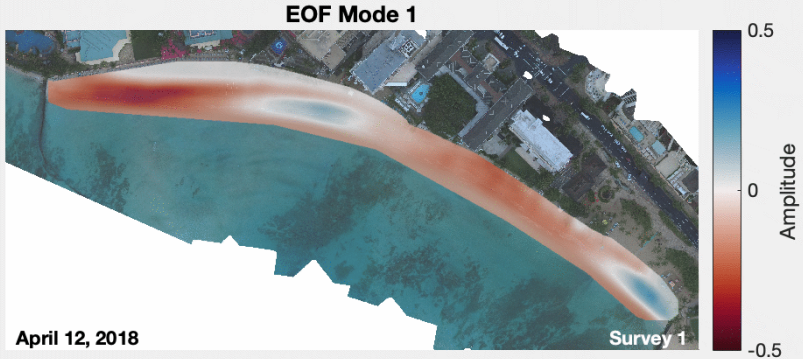

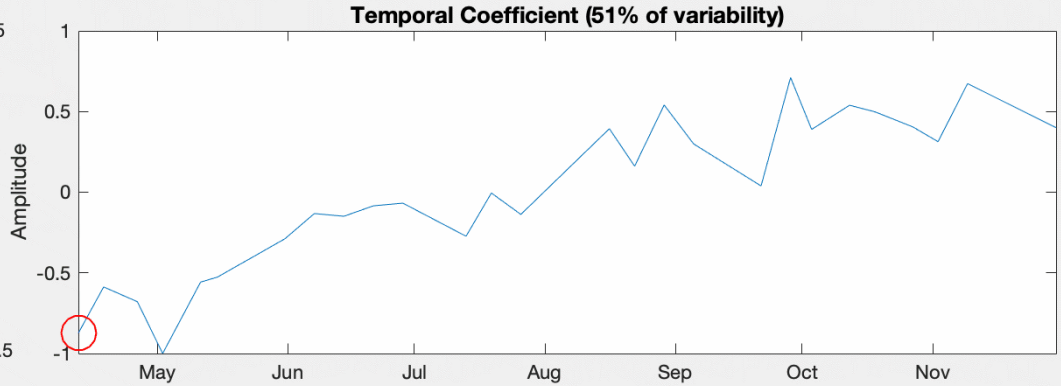

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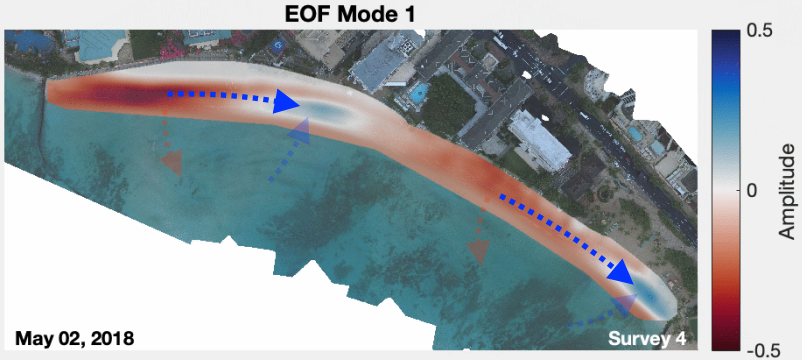

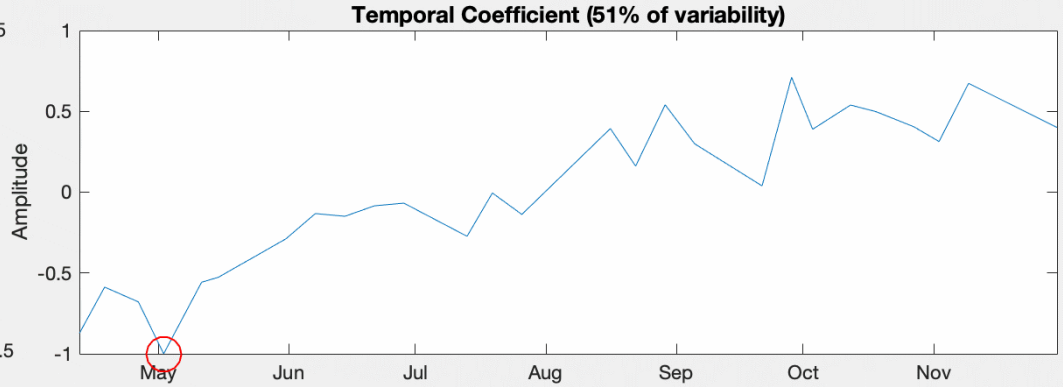

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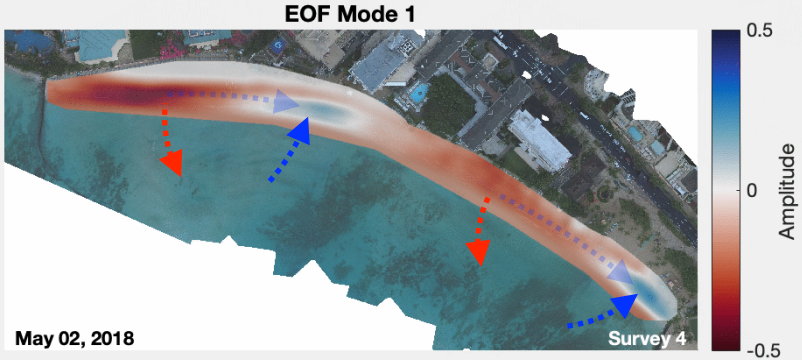

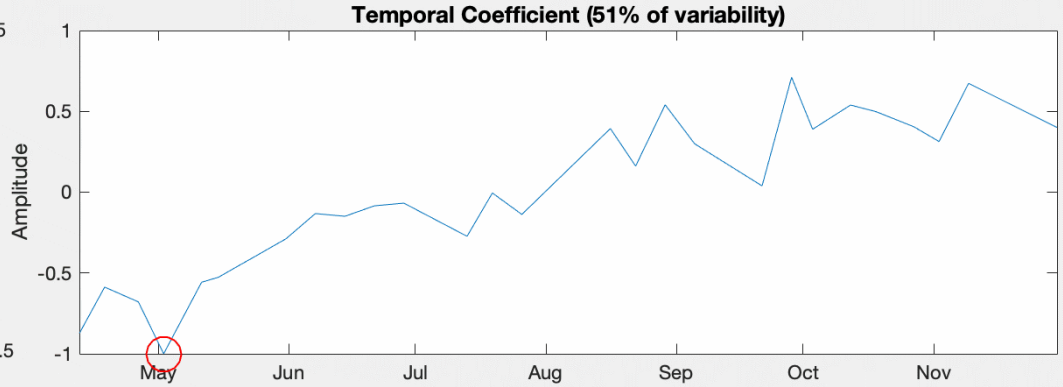

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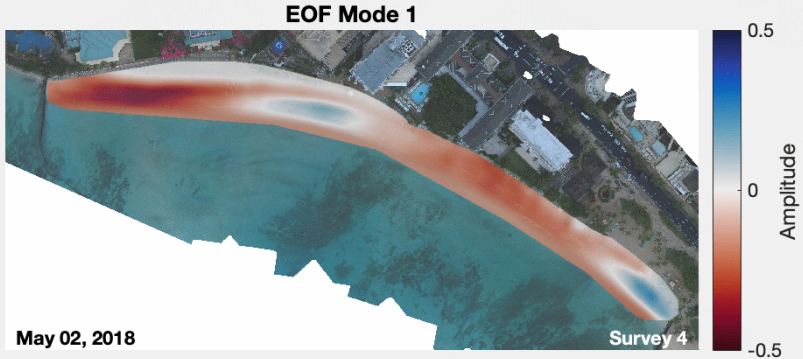

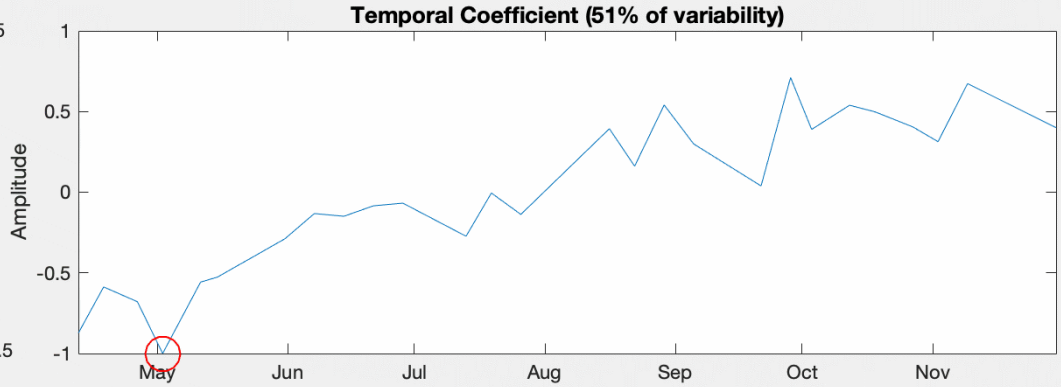

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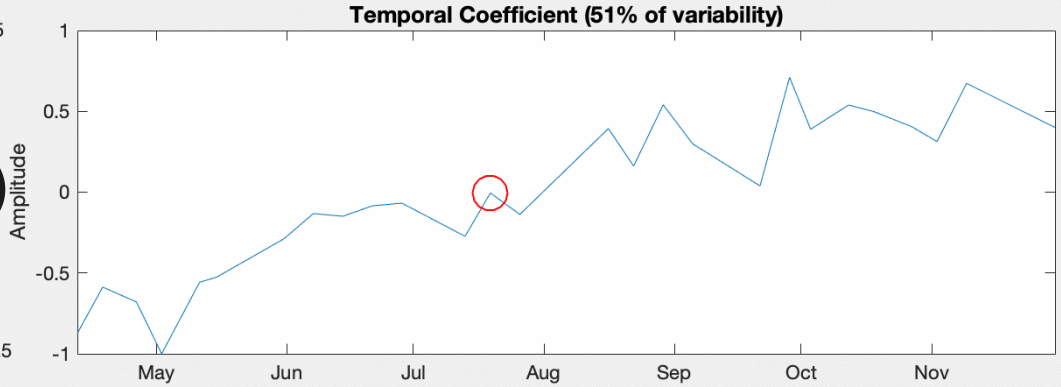

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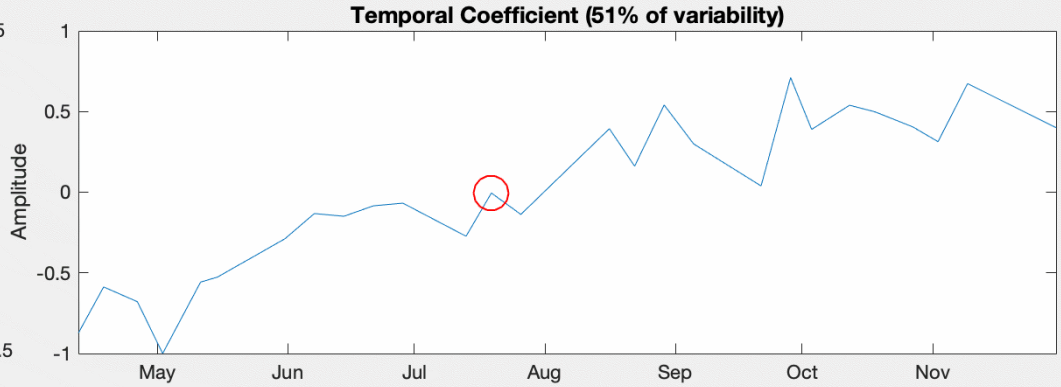

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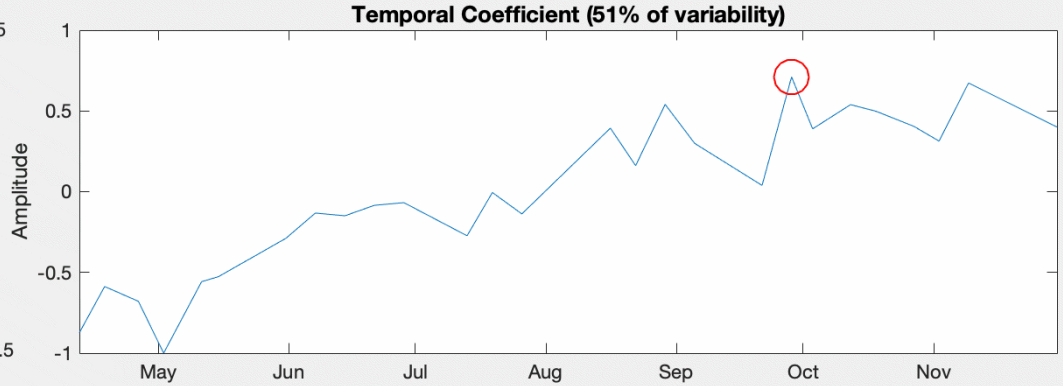

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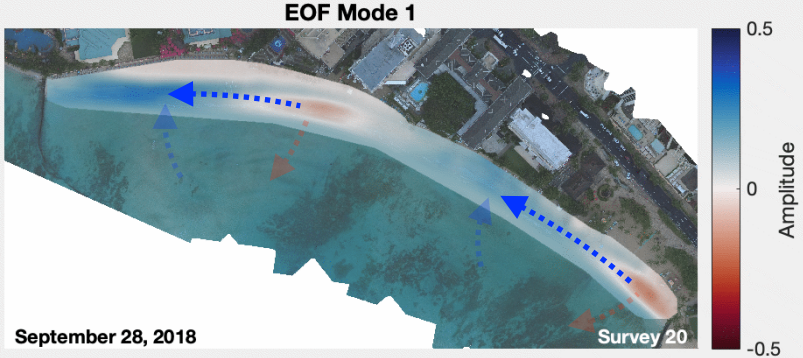

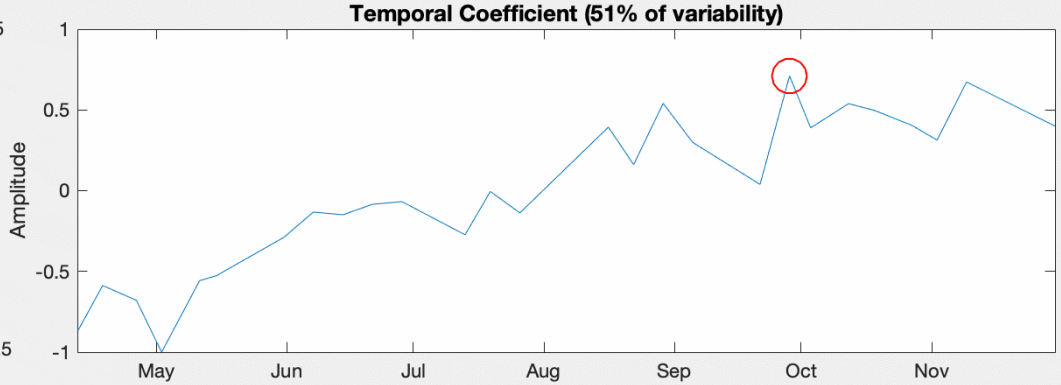

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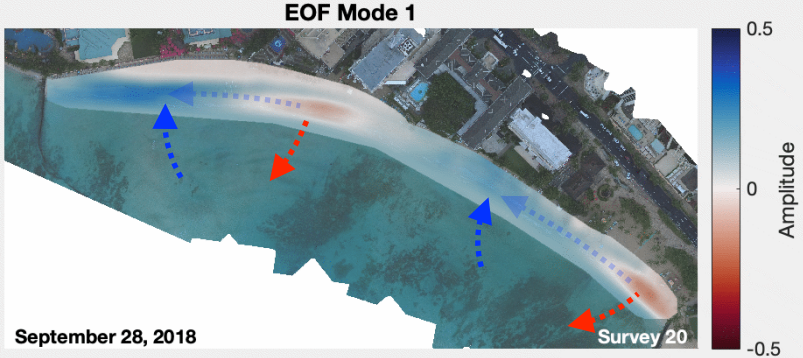

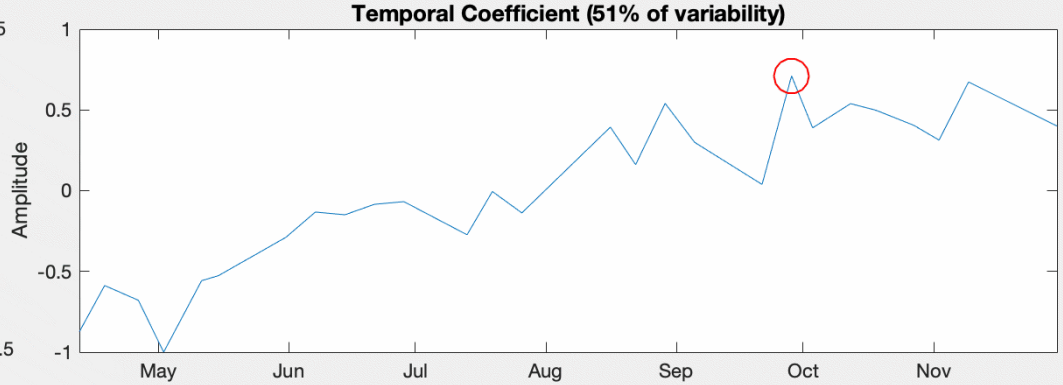

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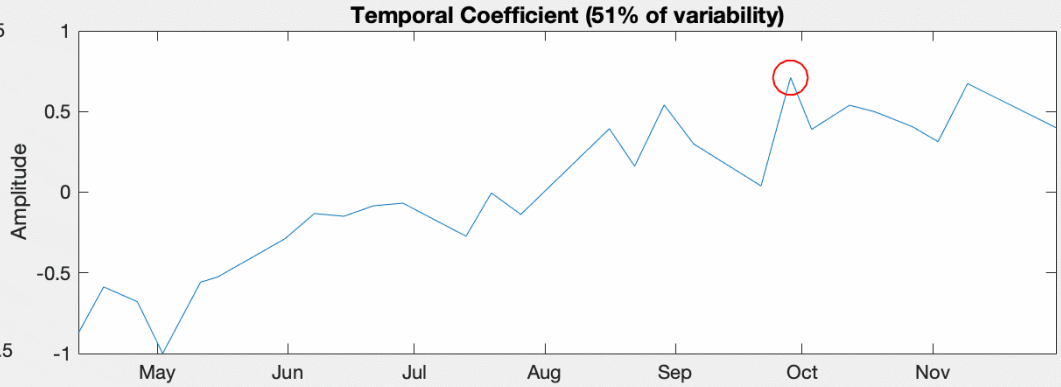

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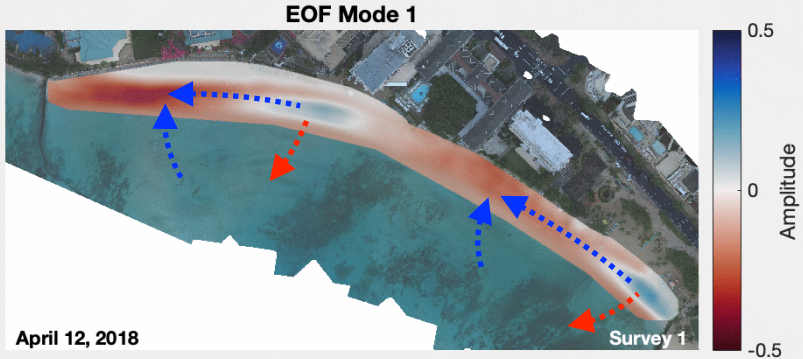

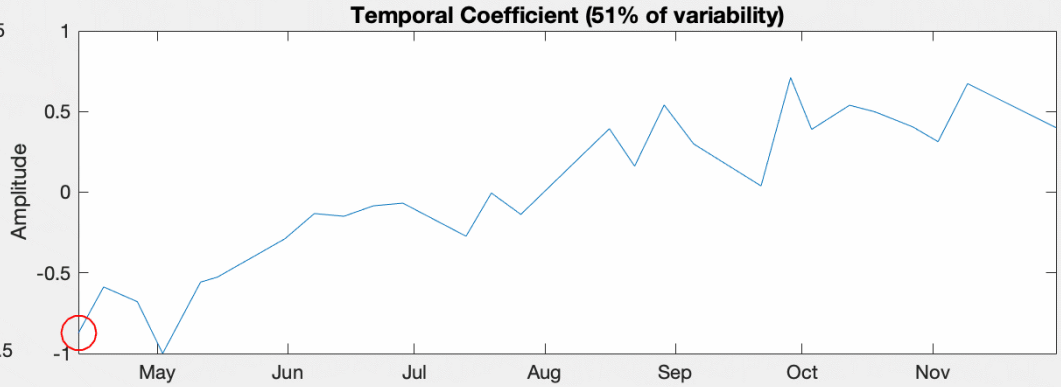

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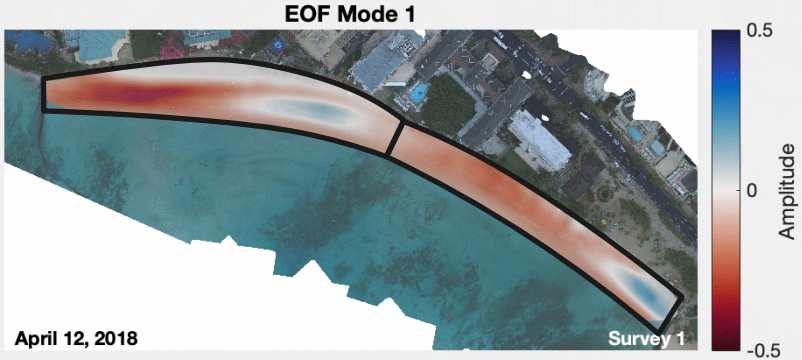

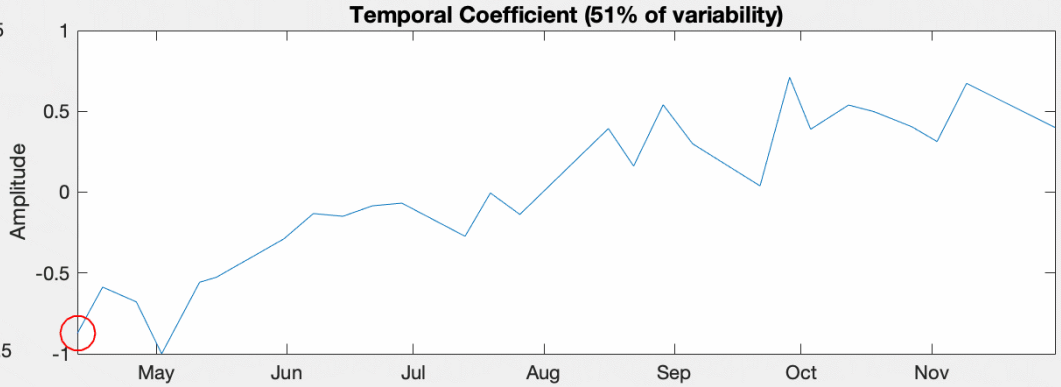

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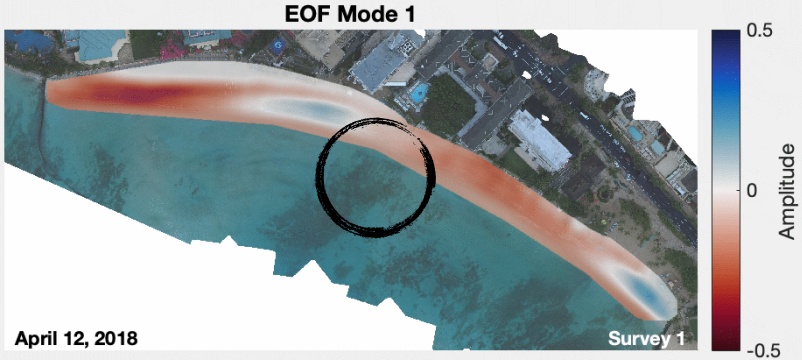

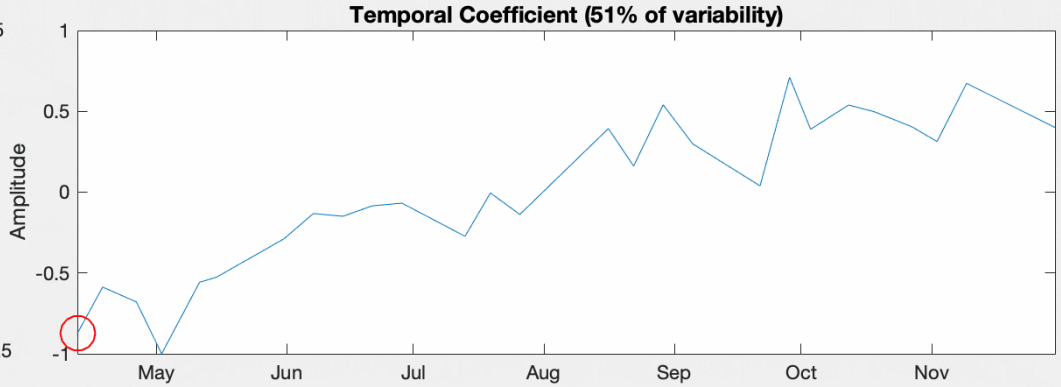

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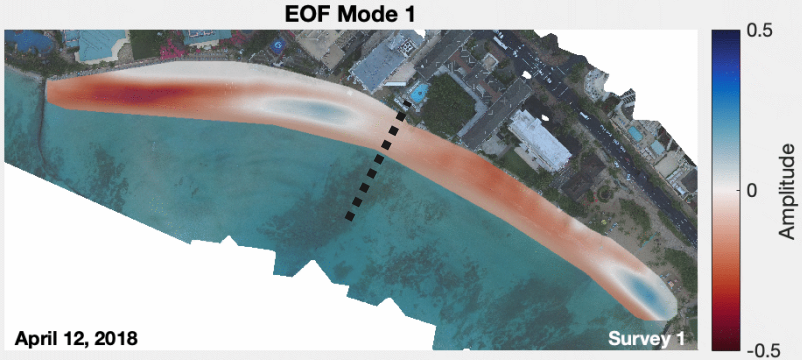

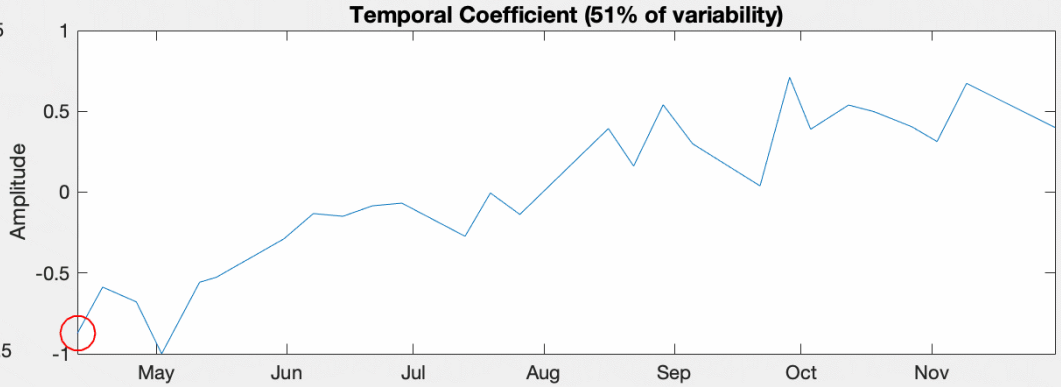

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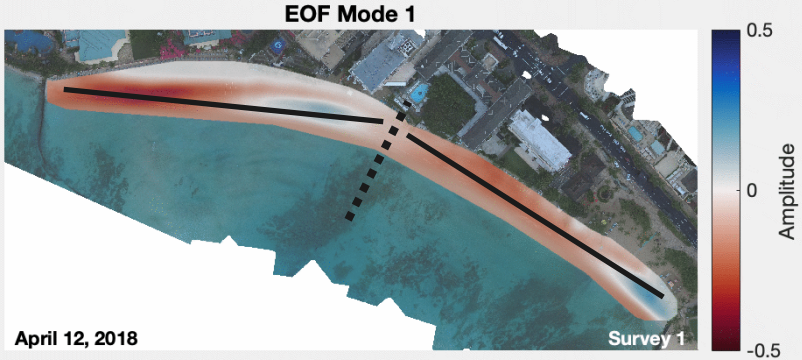

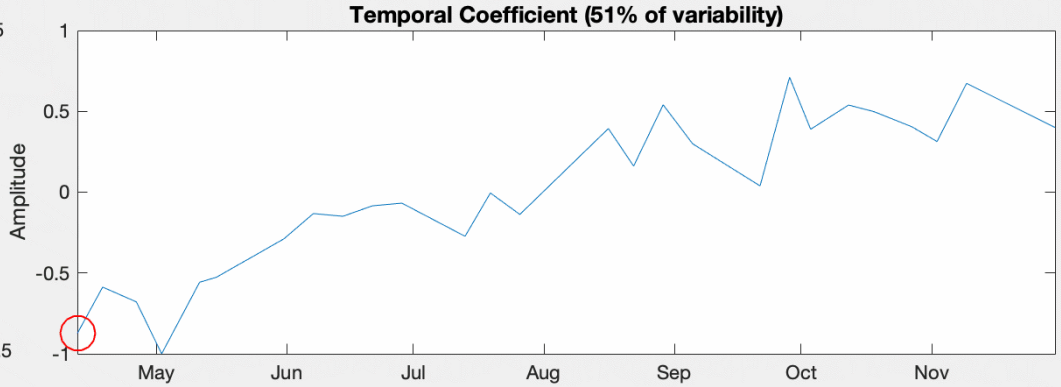

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Again, 2 subcells within greater system

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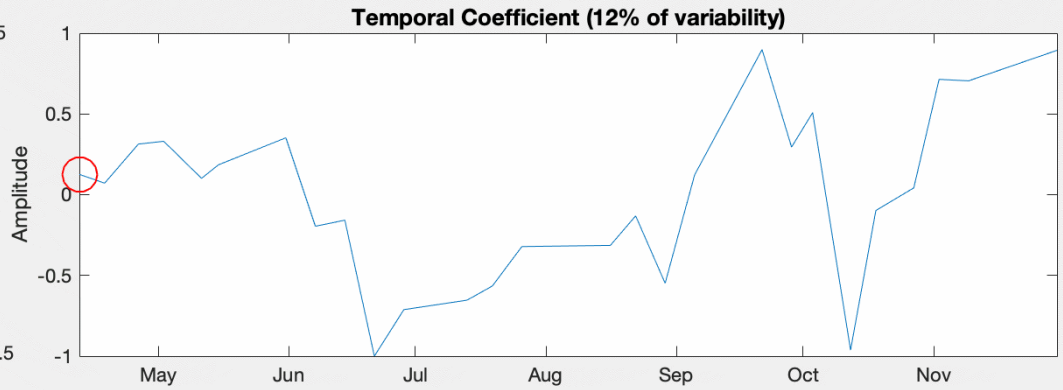

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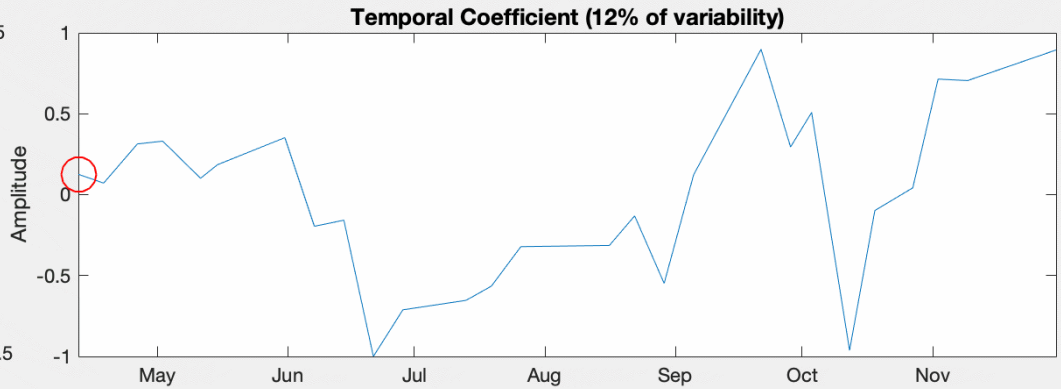

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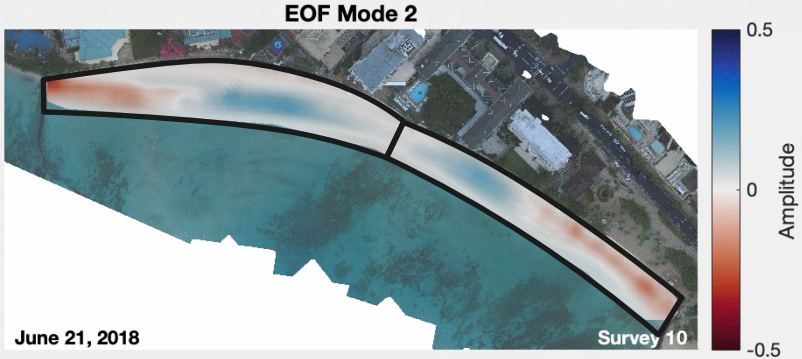

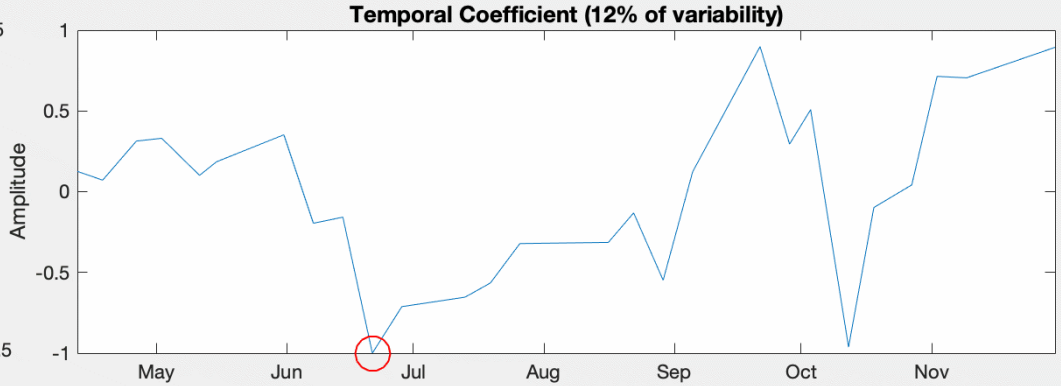

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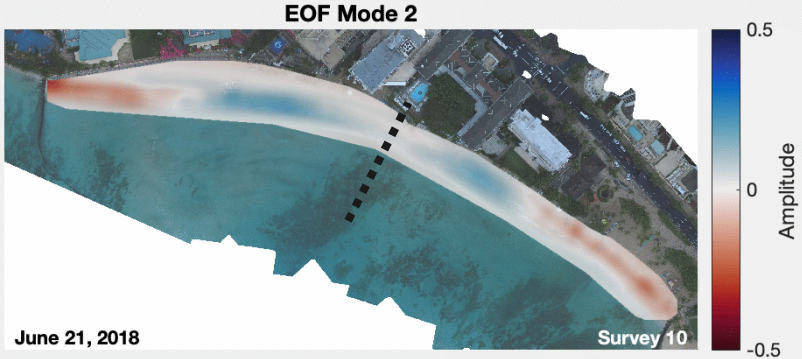

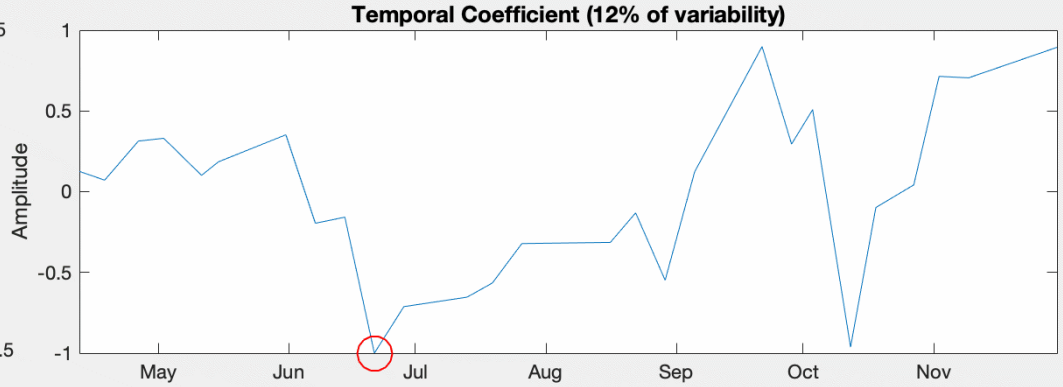

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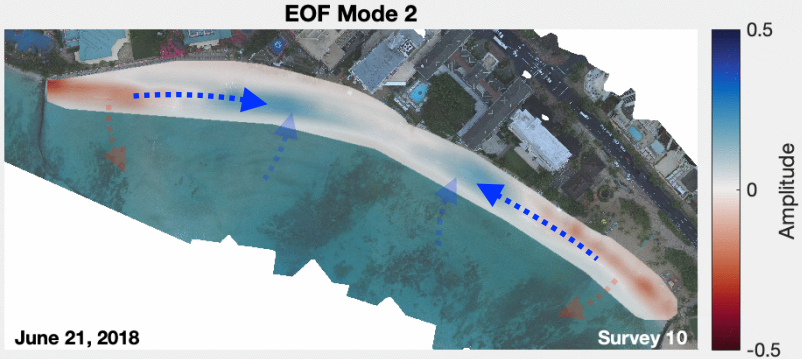

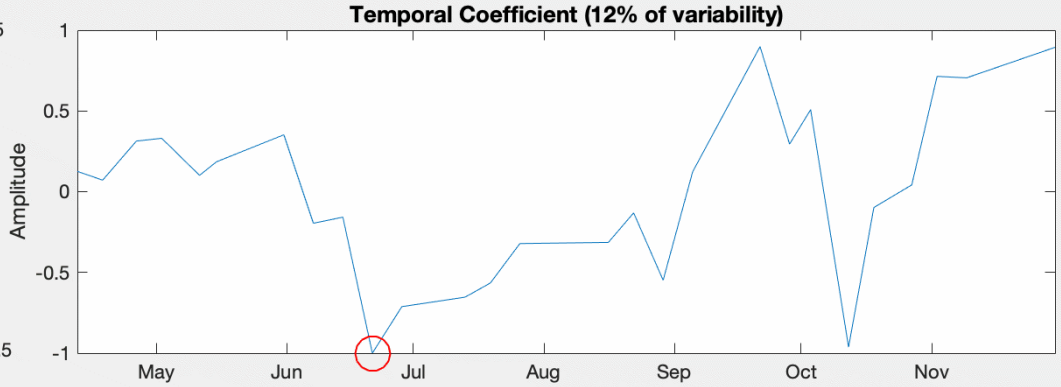

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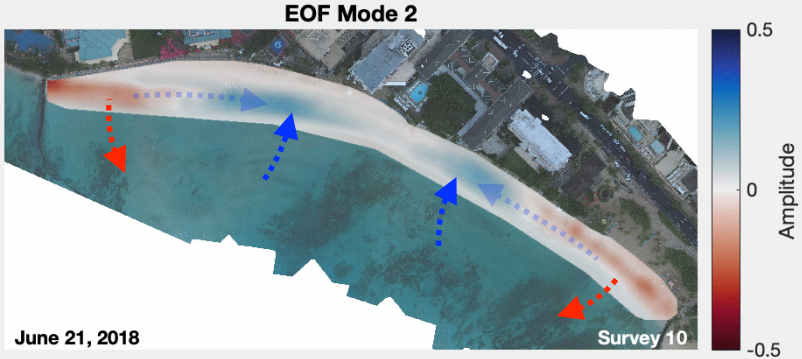

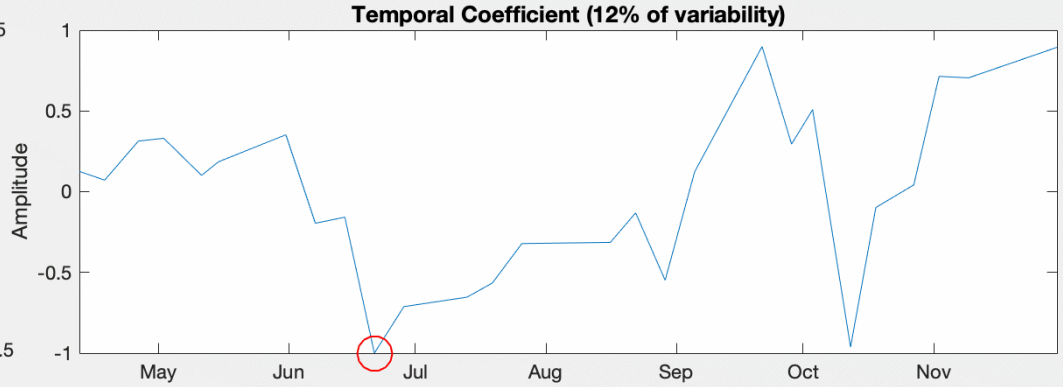

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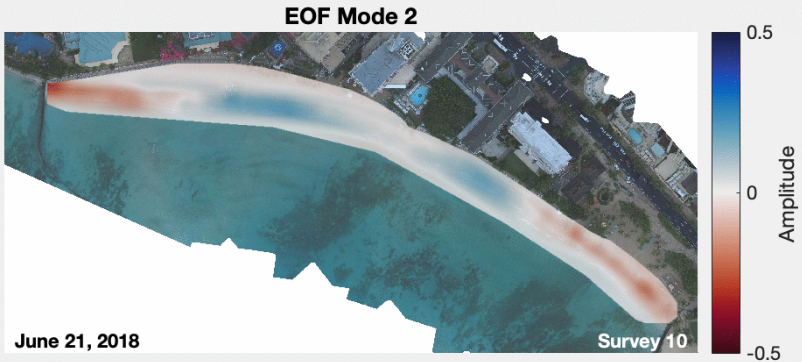

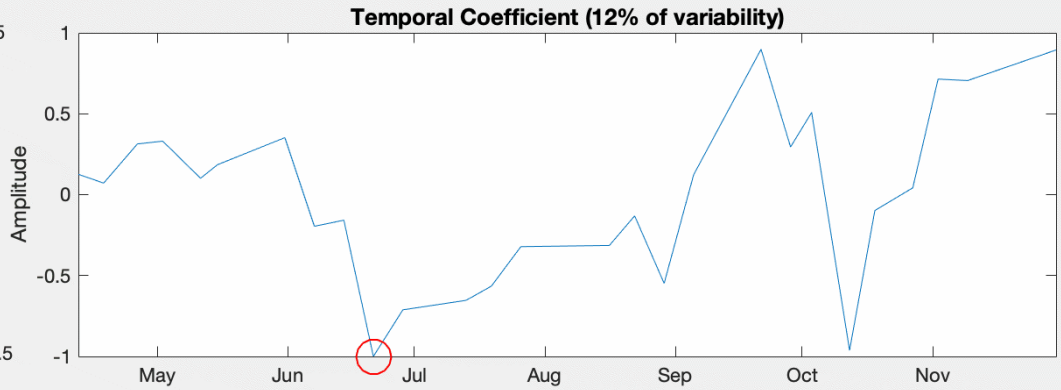

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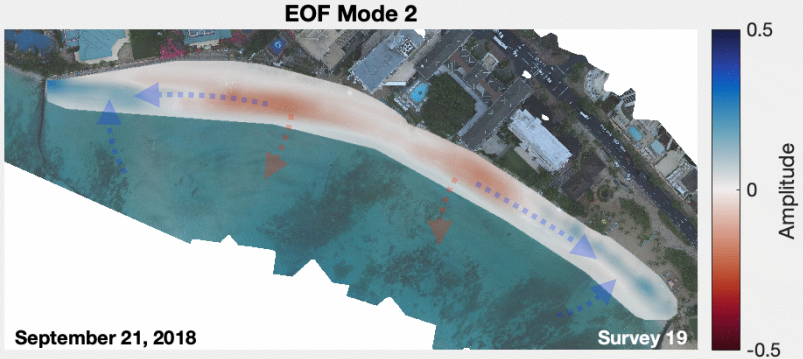

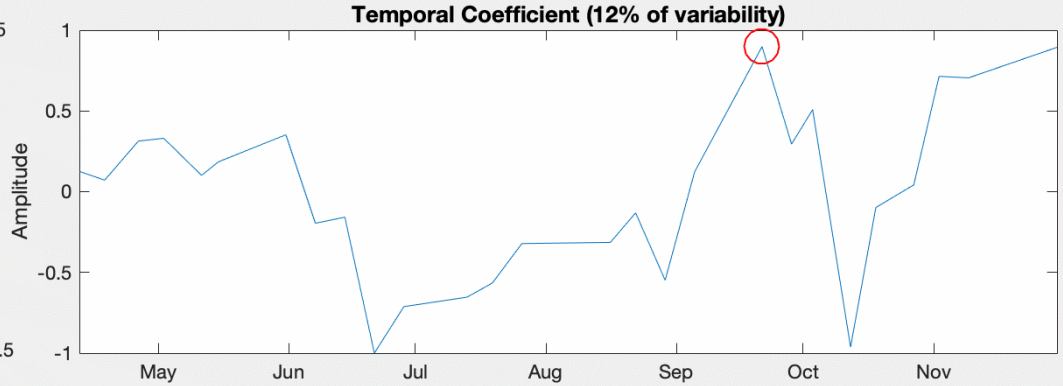

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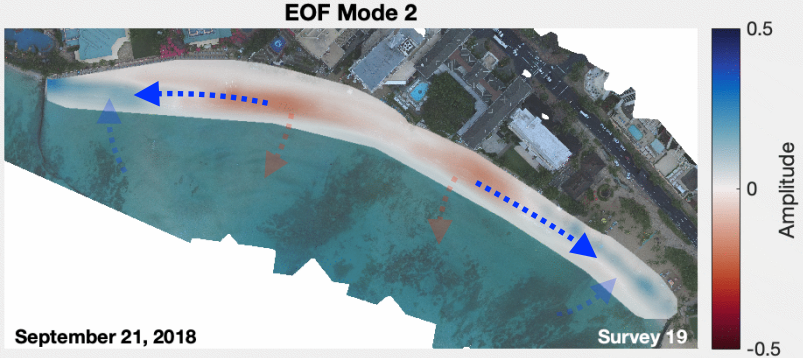

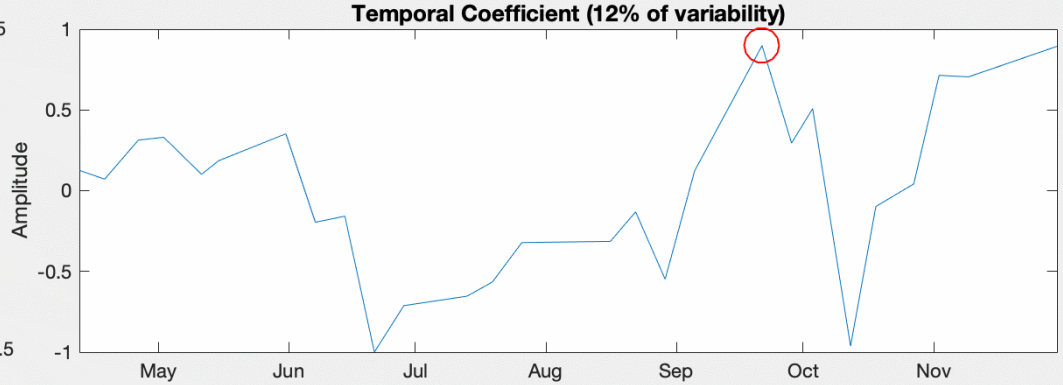

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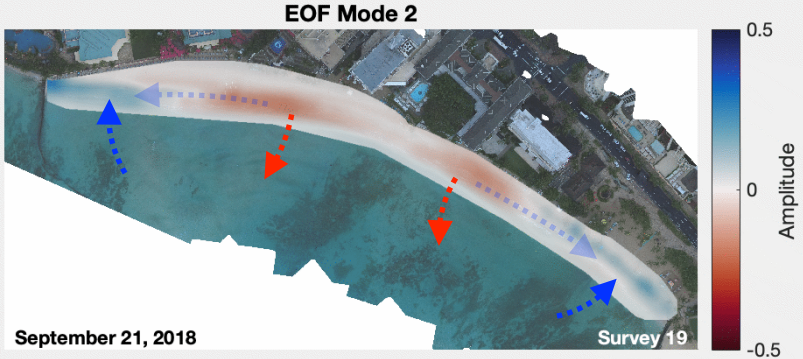

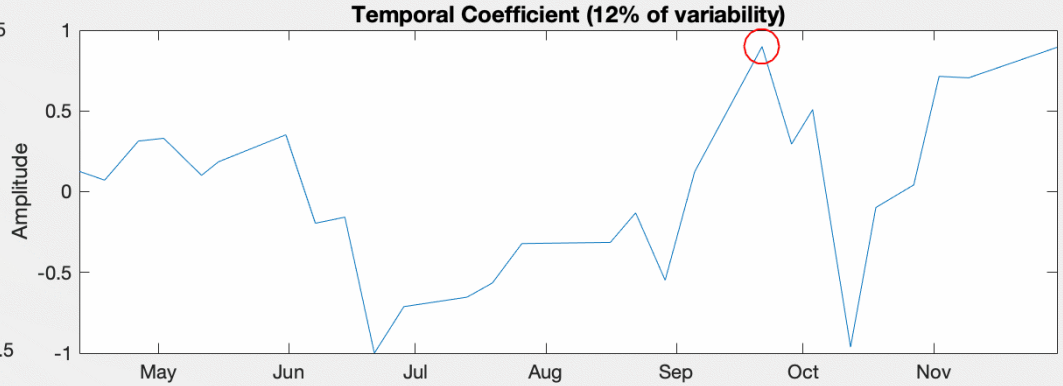

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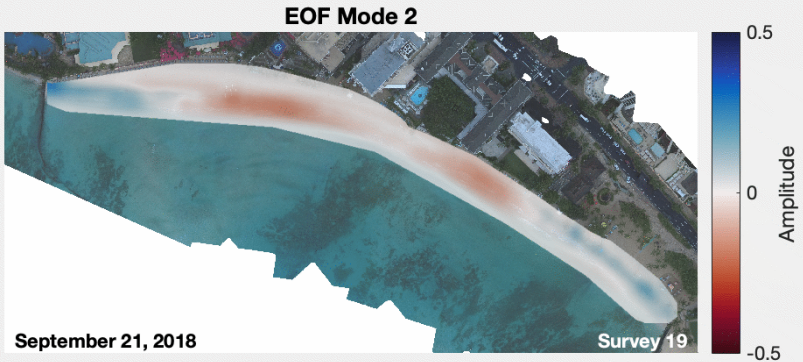
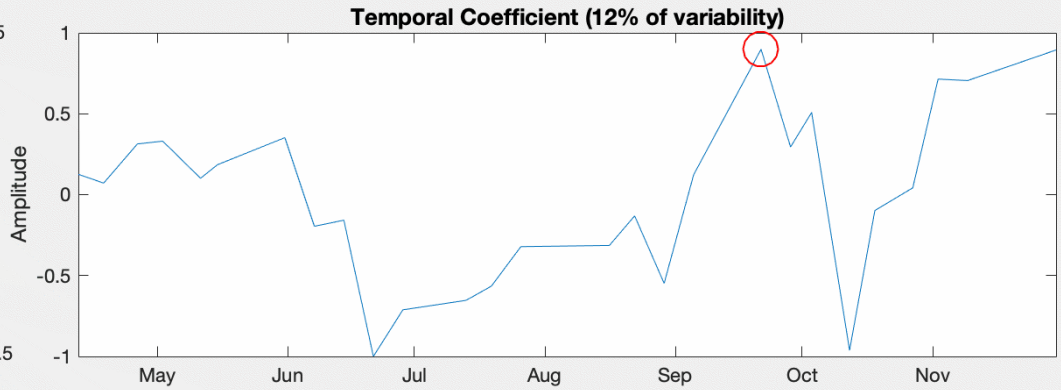
Nearshore sink/source? (Habel et al., 2016)





Mode 2 (12% variability): Non-congruent Transport, Two Subcells

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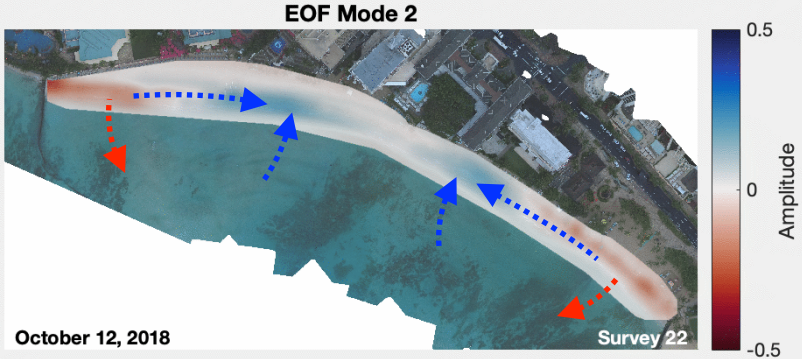

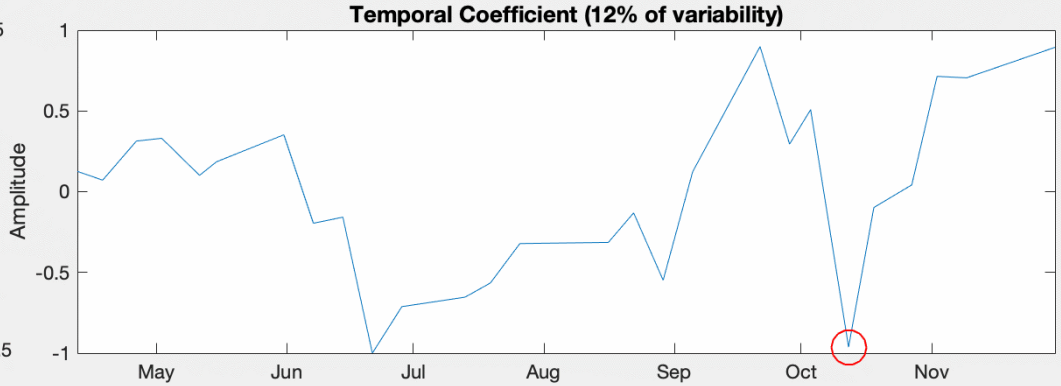

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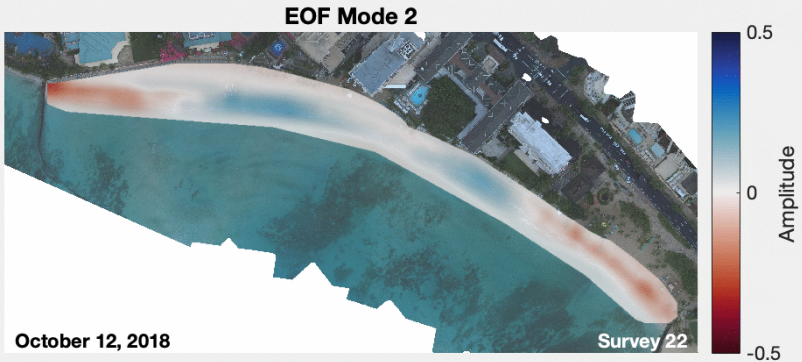

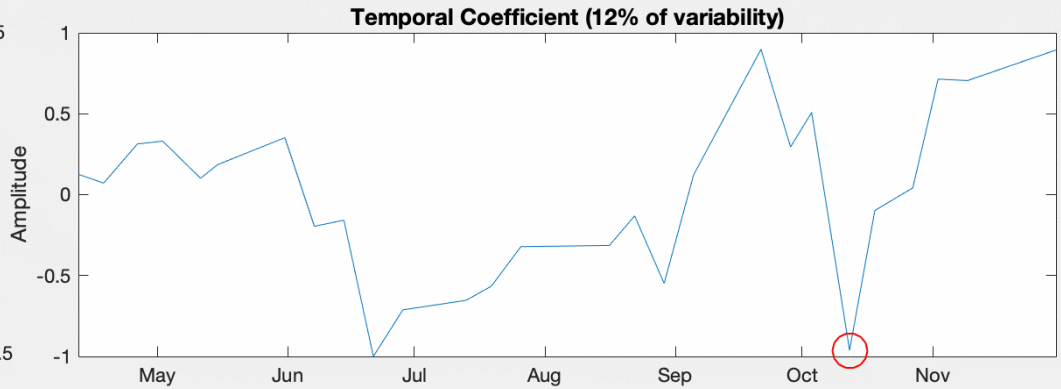

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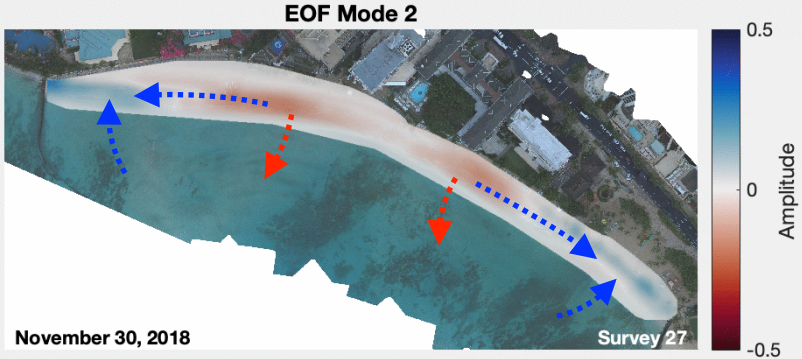
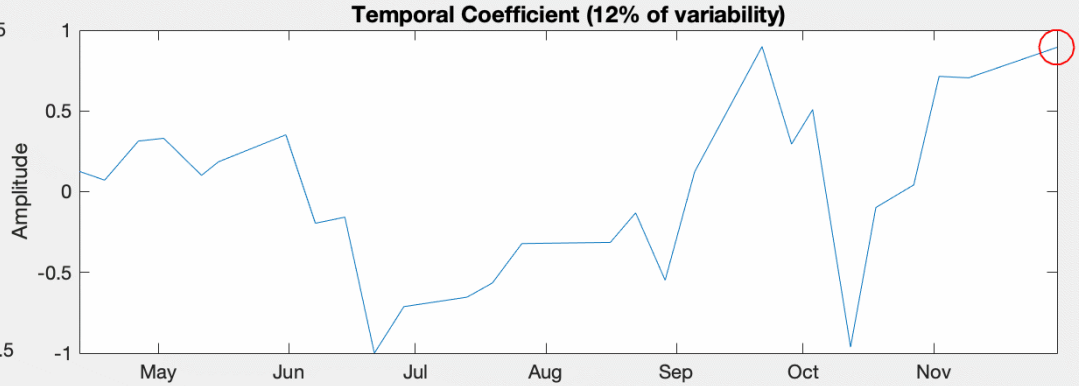
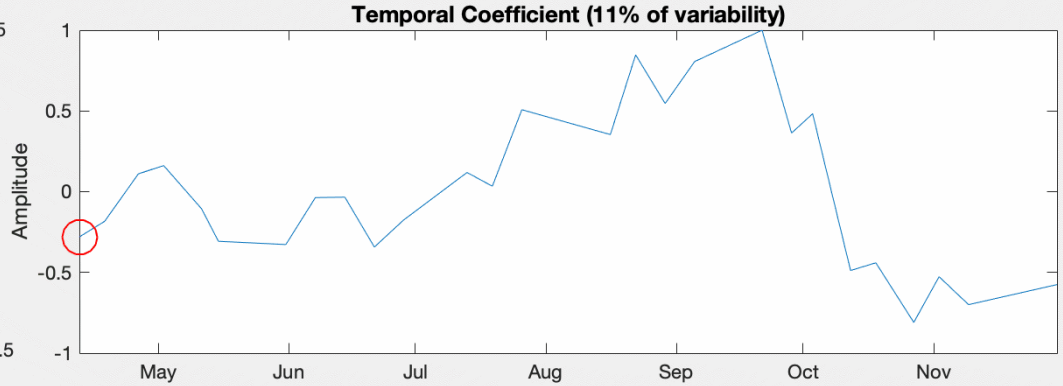




Mode 3 (11% variability): Terminal Cross-shore Transport

Opposing cross-shore transport at ends of the beach

Central beach remains stable



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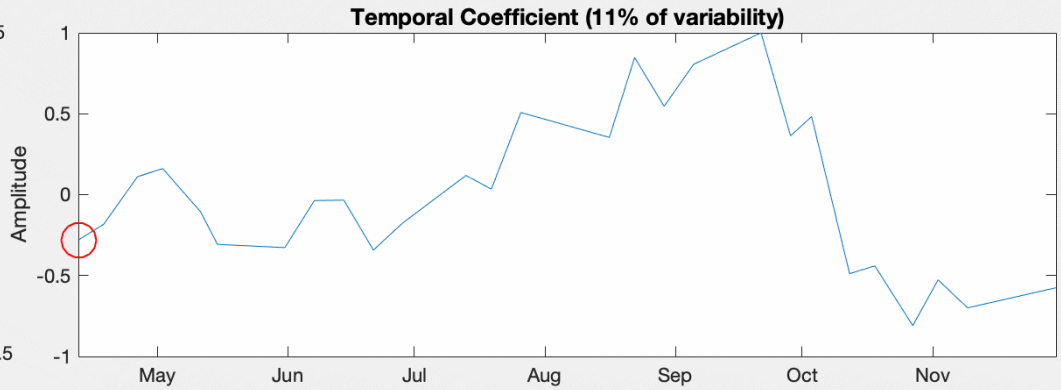

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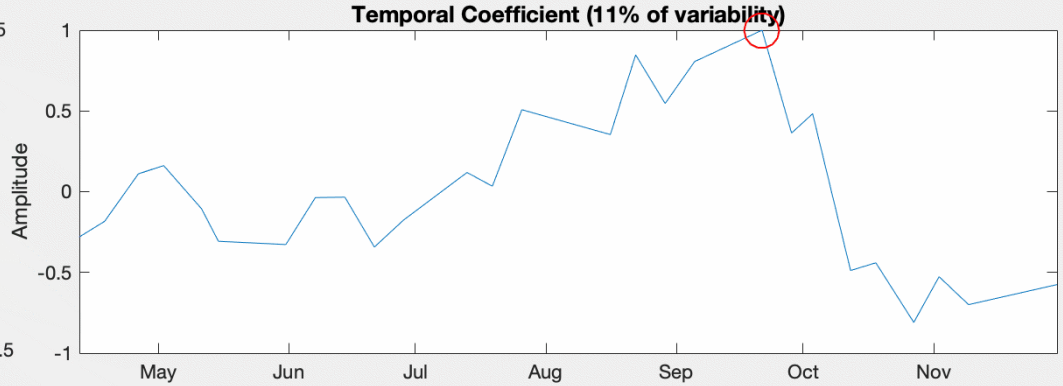

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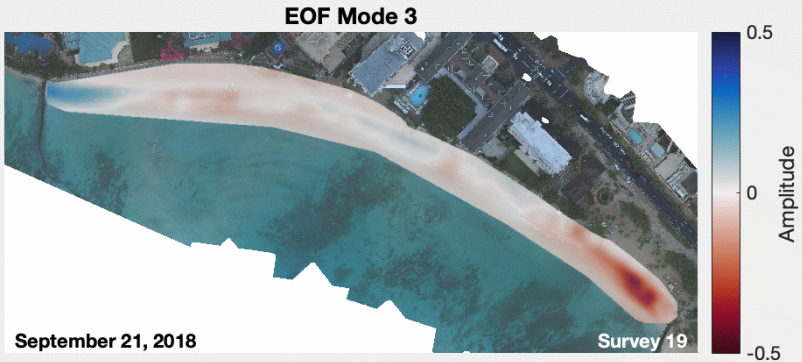

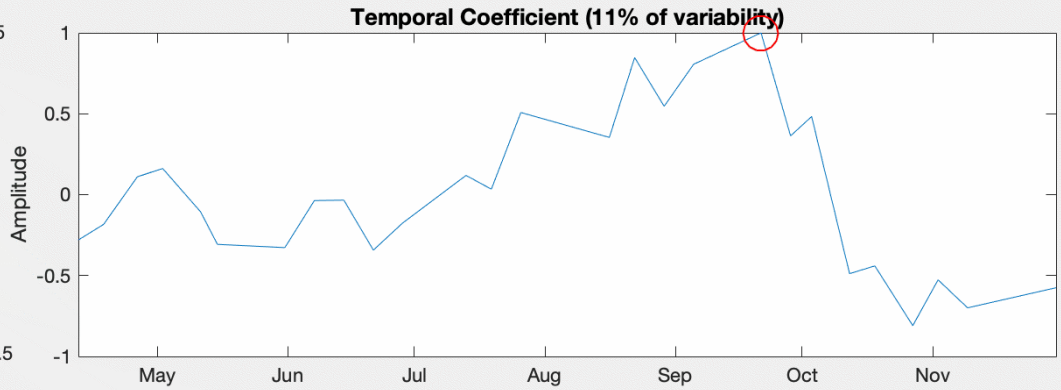

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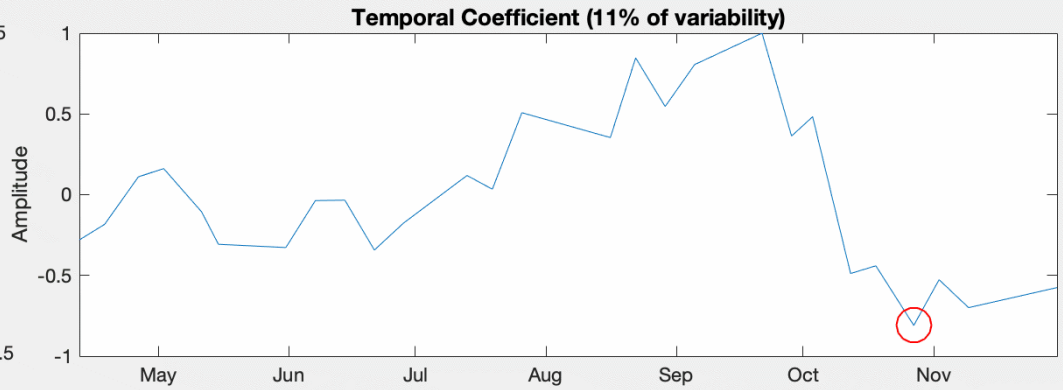

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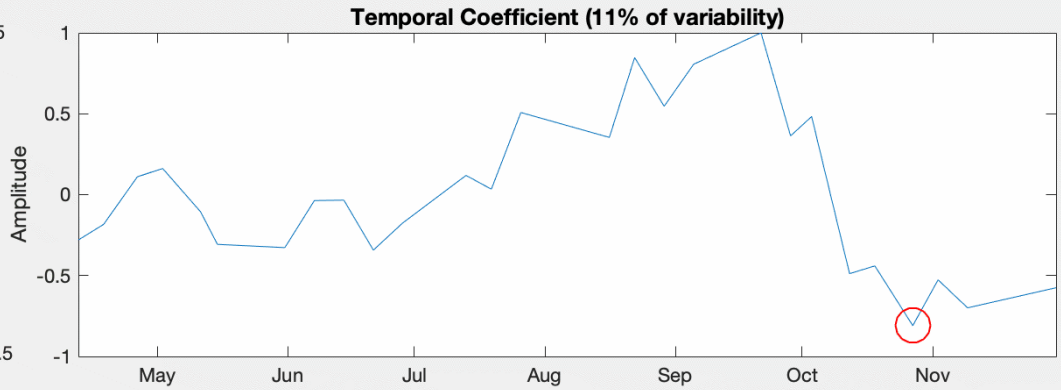
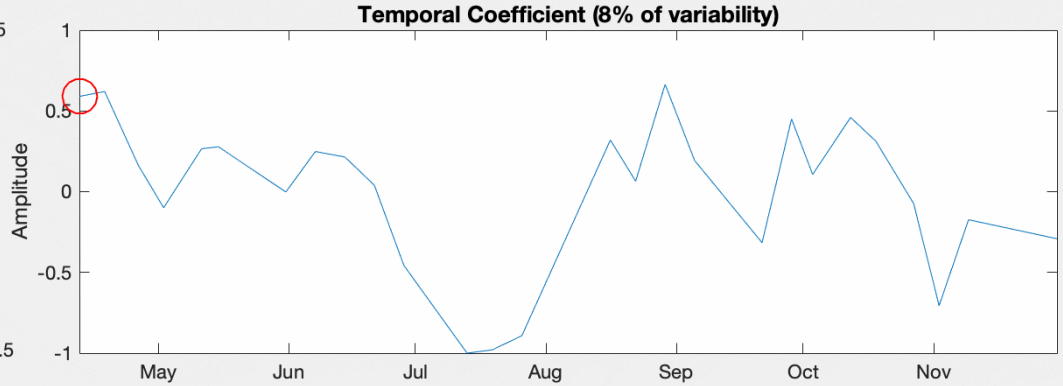


Mode 4 (8% variability): East/West Rotation

East and west subcells inflate/deflate

May be indicative of longer term seasonal rotation of beach



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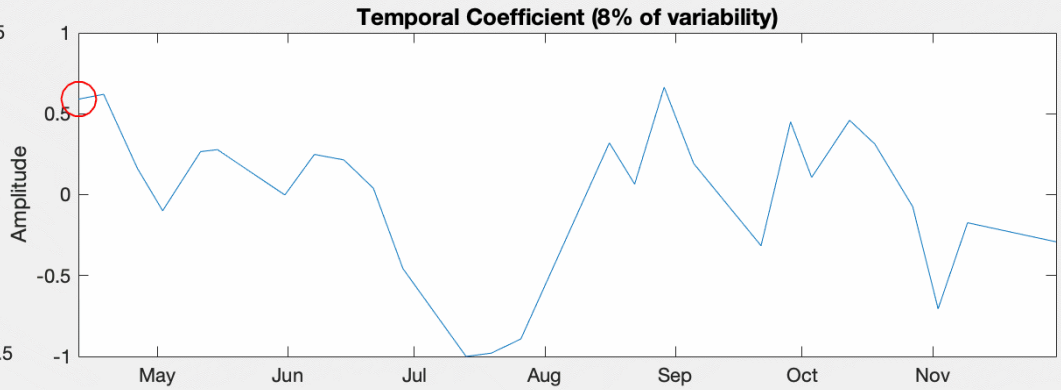

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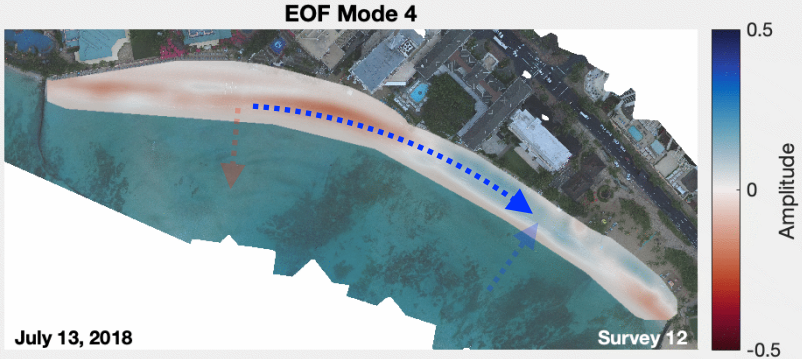

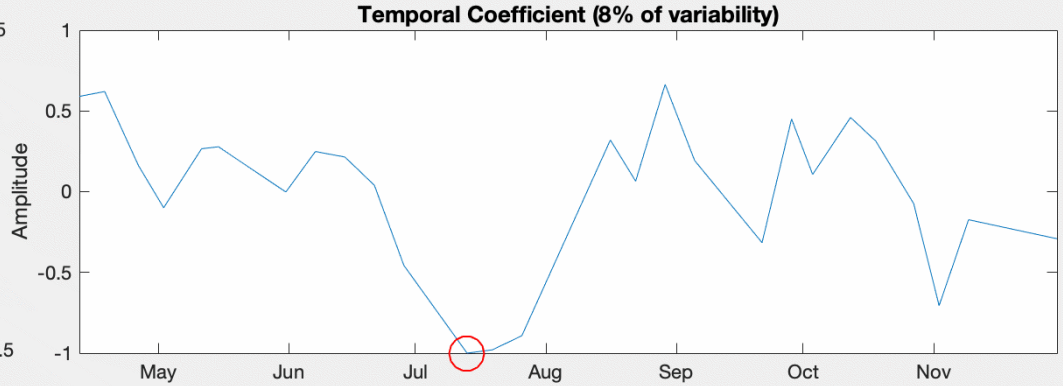

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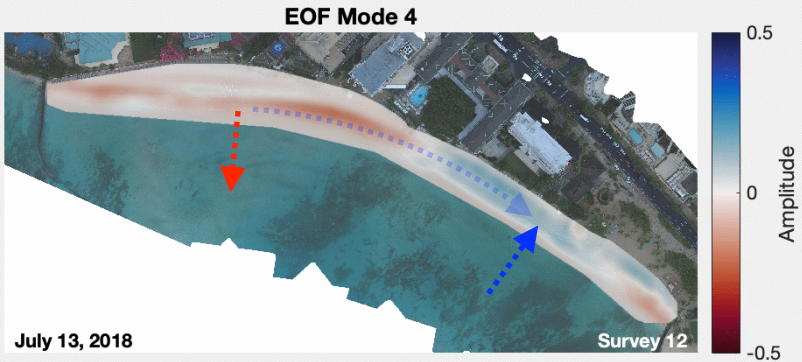

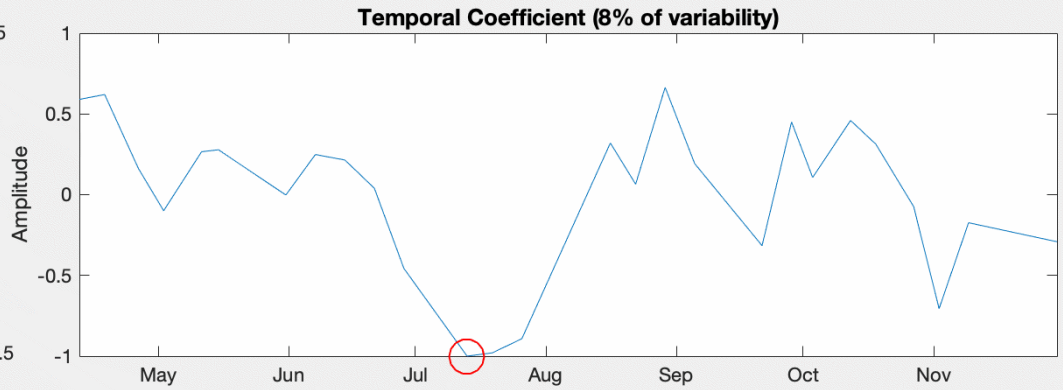

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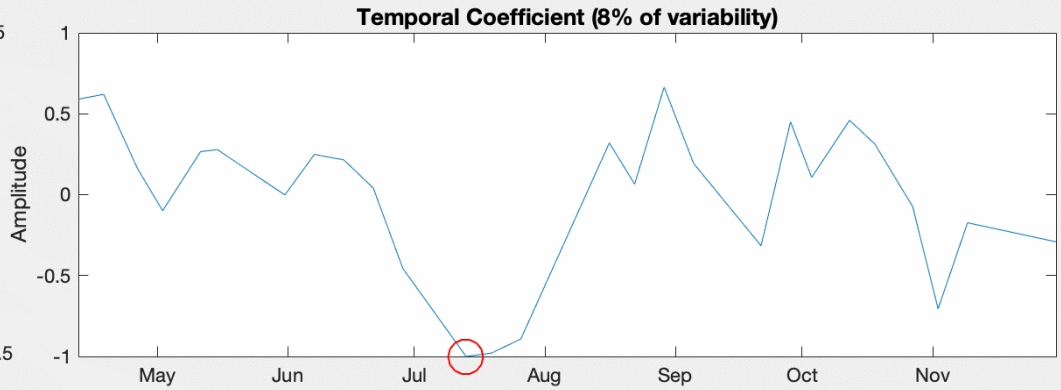

Management Implications

- Frequent beach monitoring allows us to understand beach behavior in greater detail
  - Identifying erosion & accretion hotspots
  - Inform management
  - Assess management strategies

Photo: CGG/Anna Mikkelsen

Takeaways - Royal Hawaiian Beach

- Overall increase in surface area and volume over study period
  - Attributed to swell activity and active hurricane season

- Not-so-clear association between beach response and marine forcing's interaction with nearshore bathymetry
  - Subcell behavior

- Limitations being addressed in current research
  - Continuation of time-series
  - Bathymetry
  - Wave data - Kilo Nalu Observatory, pressure sensors

Takeaways - sUAS and Coastal Monitoring

- UAS capable of providing high-resolution, near-real time, actionable results
  - Valuable data for management

- Ability to capture smaller scale beach dynamics

- Efficient - reduces hours in the field
  - Survey with greater frequency
  - Operational flexibility

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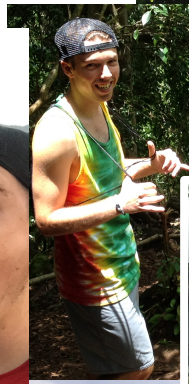

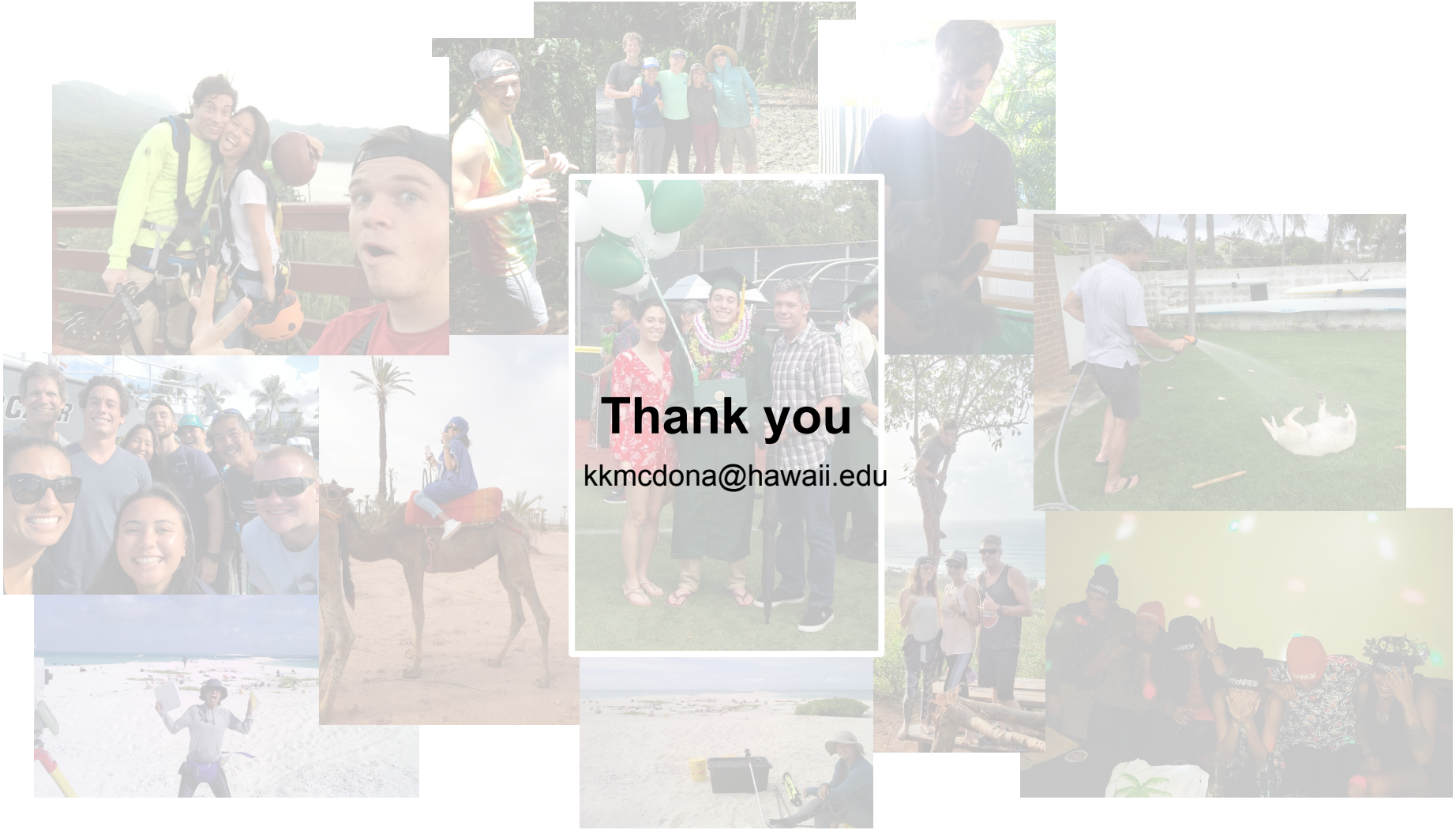

Thank you

kkmcdona@hawaii.edu