Beach Change and Sand Transport along the Southern California Coast

March 21st, 2024

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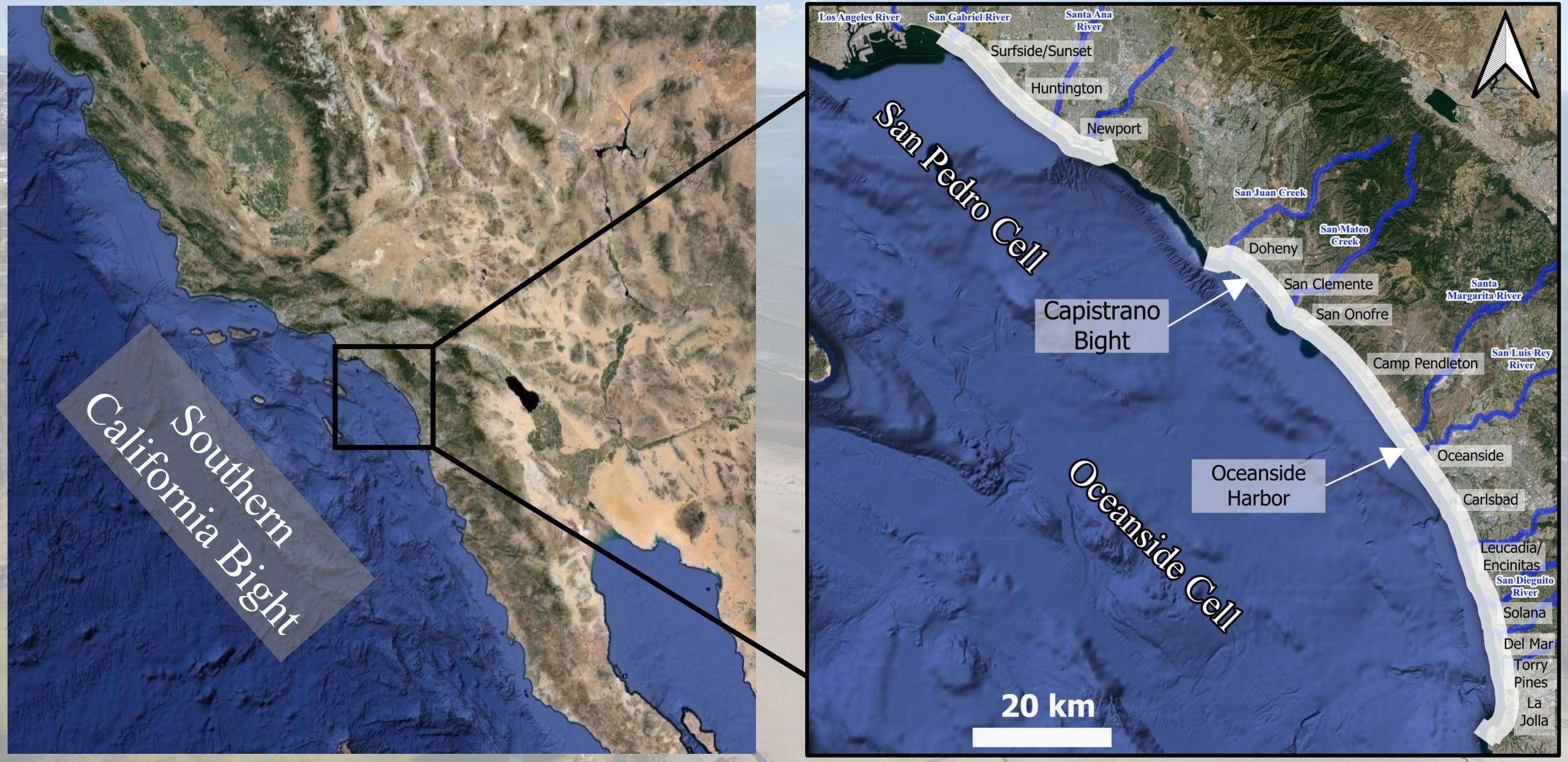
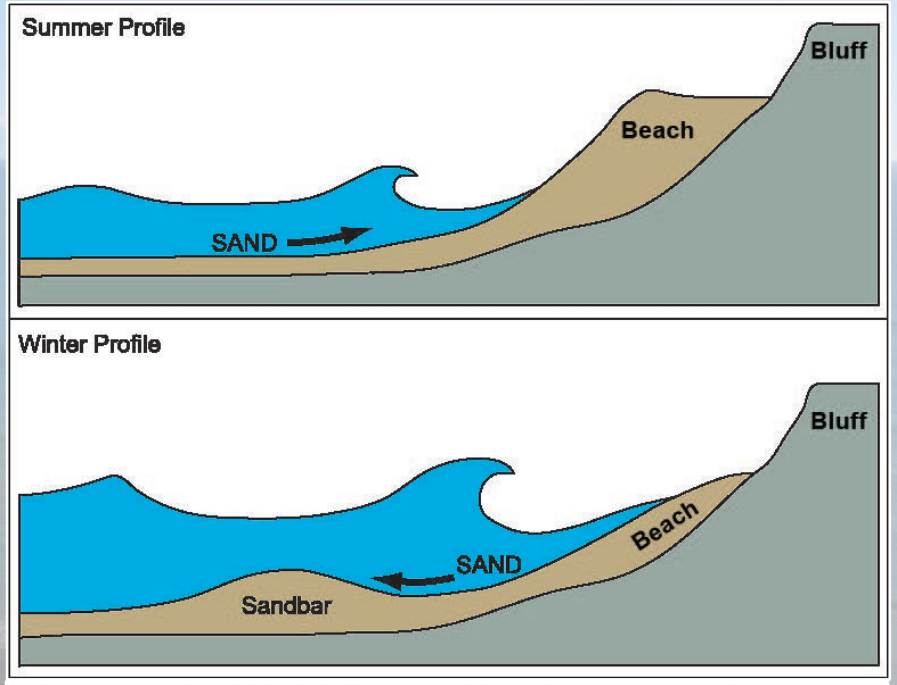
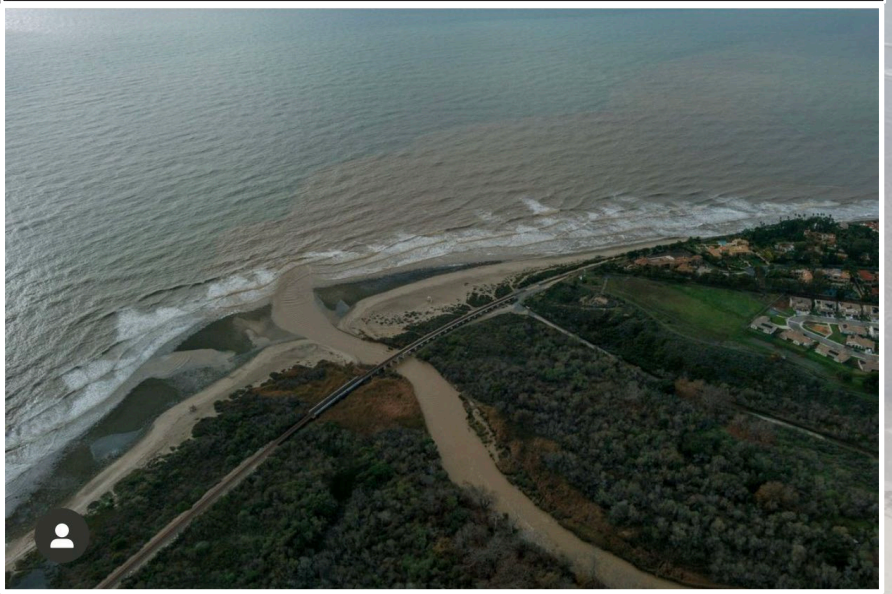

Southern California Bight
Los Angeles River
San Gabriel River
Santa Ana River
Surfside/Sunset
Huntington
Newport
San Pedro Cell
San Juan Creek
San Mateo Creek
Doheny
San Clemente
Capistrano Bight
Santa Margarita River
San Onofre
Camp Pendleton
San Luis Rey River
Oceanside
Oceanside Harbor
Carlsbad
Oceanside Cell
Leucadia/ Encinitas
San Dieguito River
Solana
Del Mar
Torry Pines
La Jolla
20 km

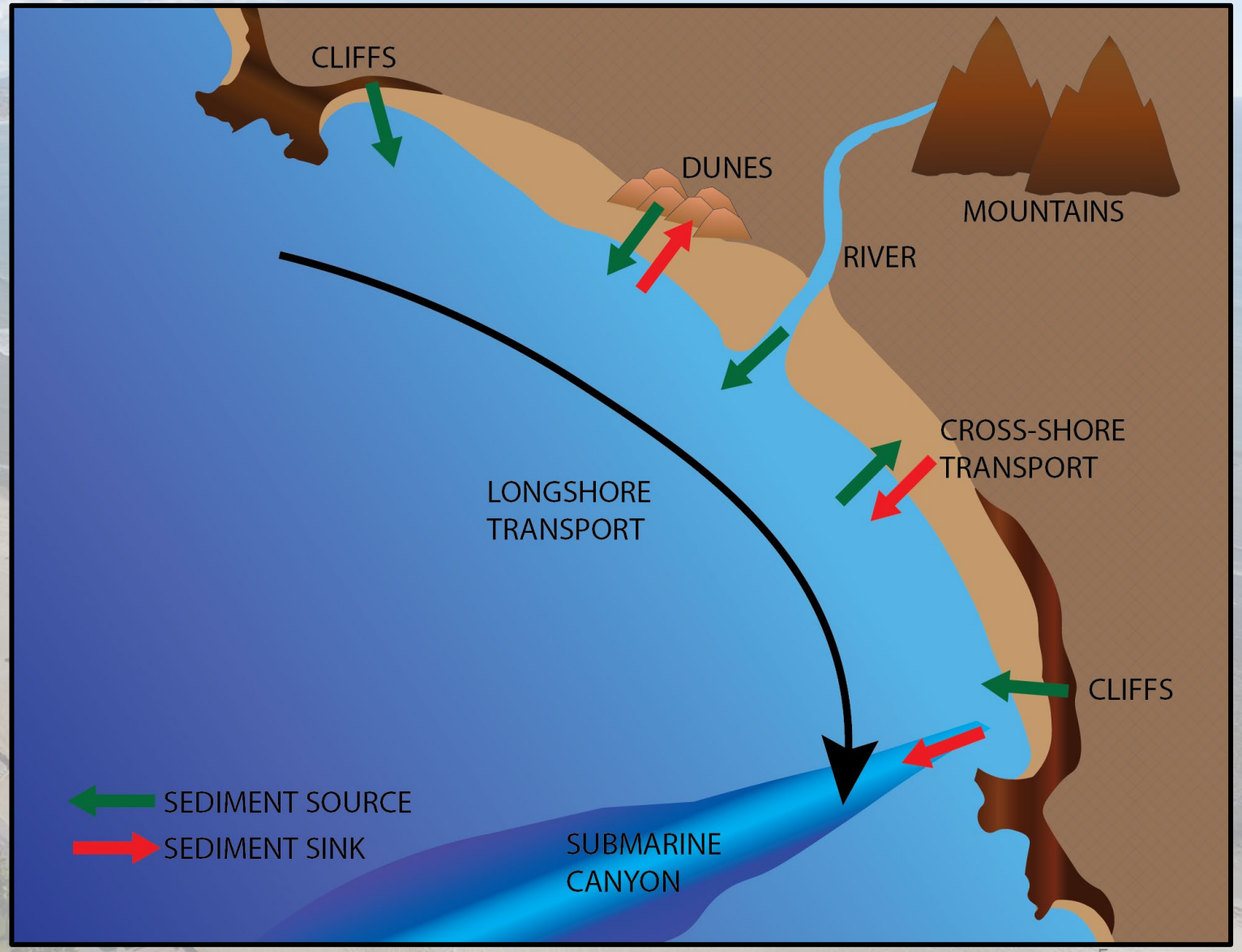
What drives beach width changes?

- Seasonal differences in wave energy
  - Yates 2009
- Interannual changes in wave energy/direction: El Nino/La Nina
  - Vos 2023
- Changes in sand supplies from rivers and cliff erosion
  - Flick 1993, Patsch 2006
- Gradients in longshore transport (divergence of drift)
  - Komar 1970

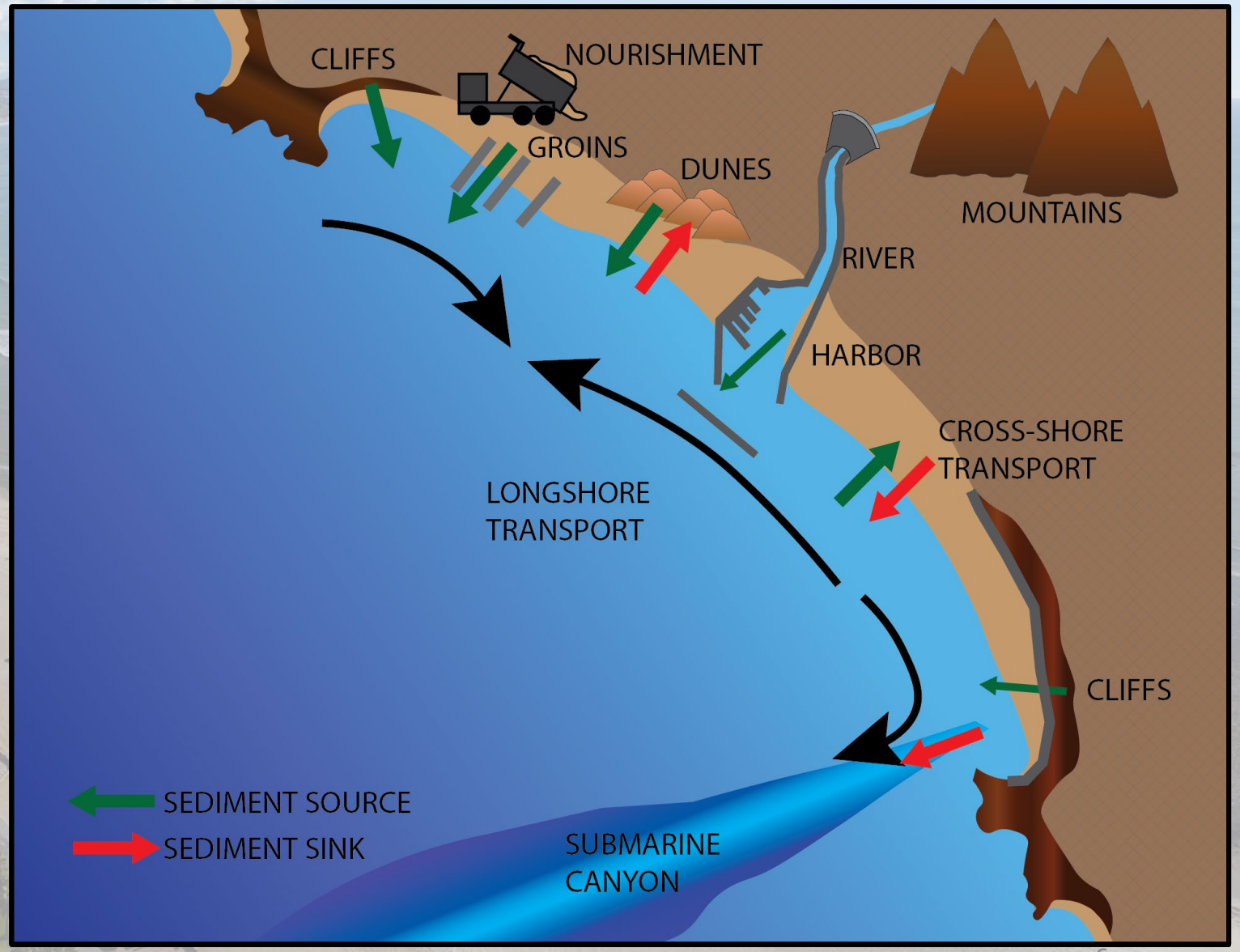




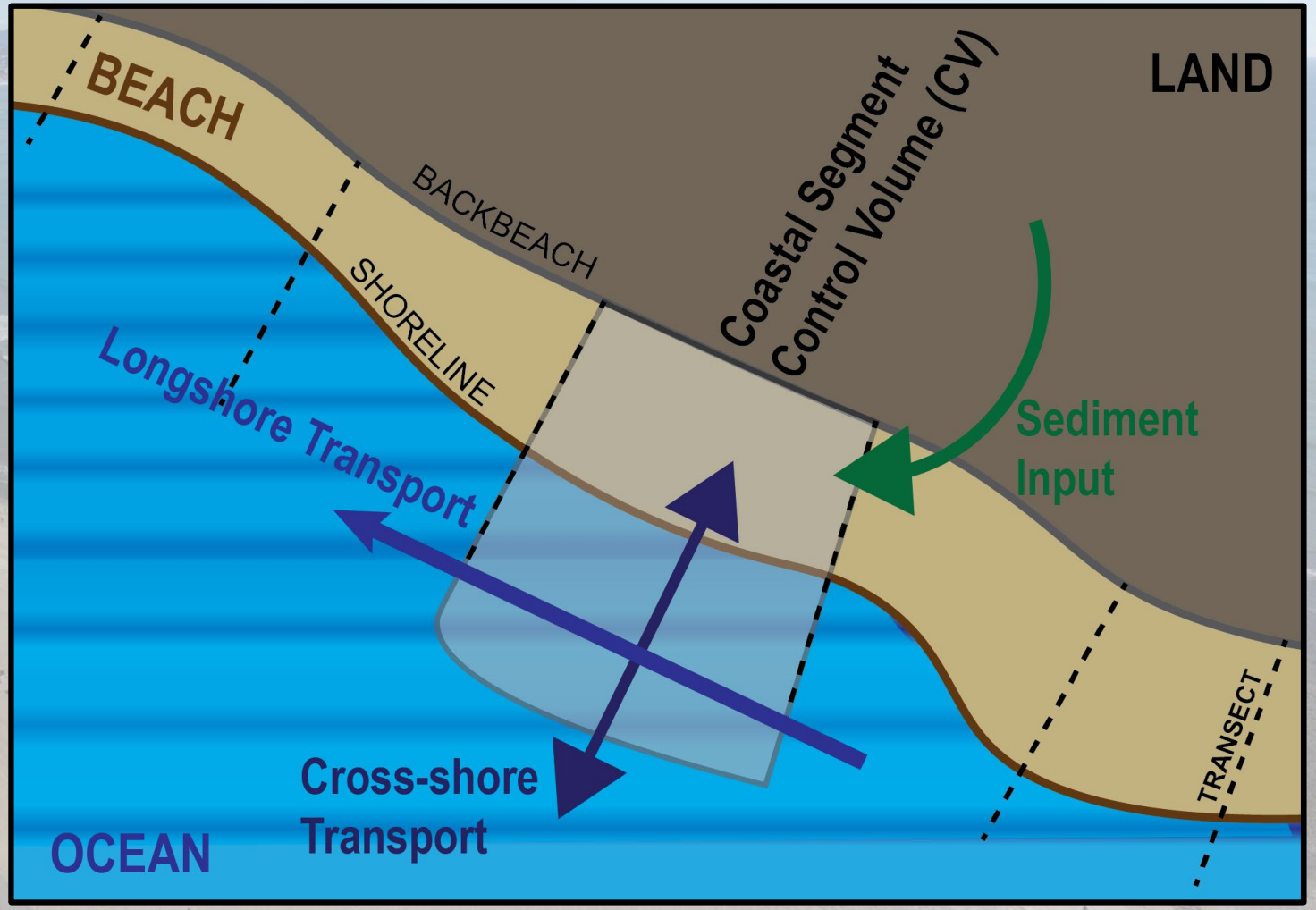
- Beach change can be interpreted in the context of a littoral cell



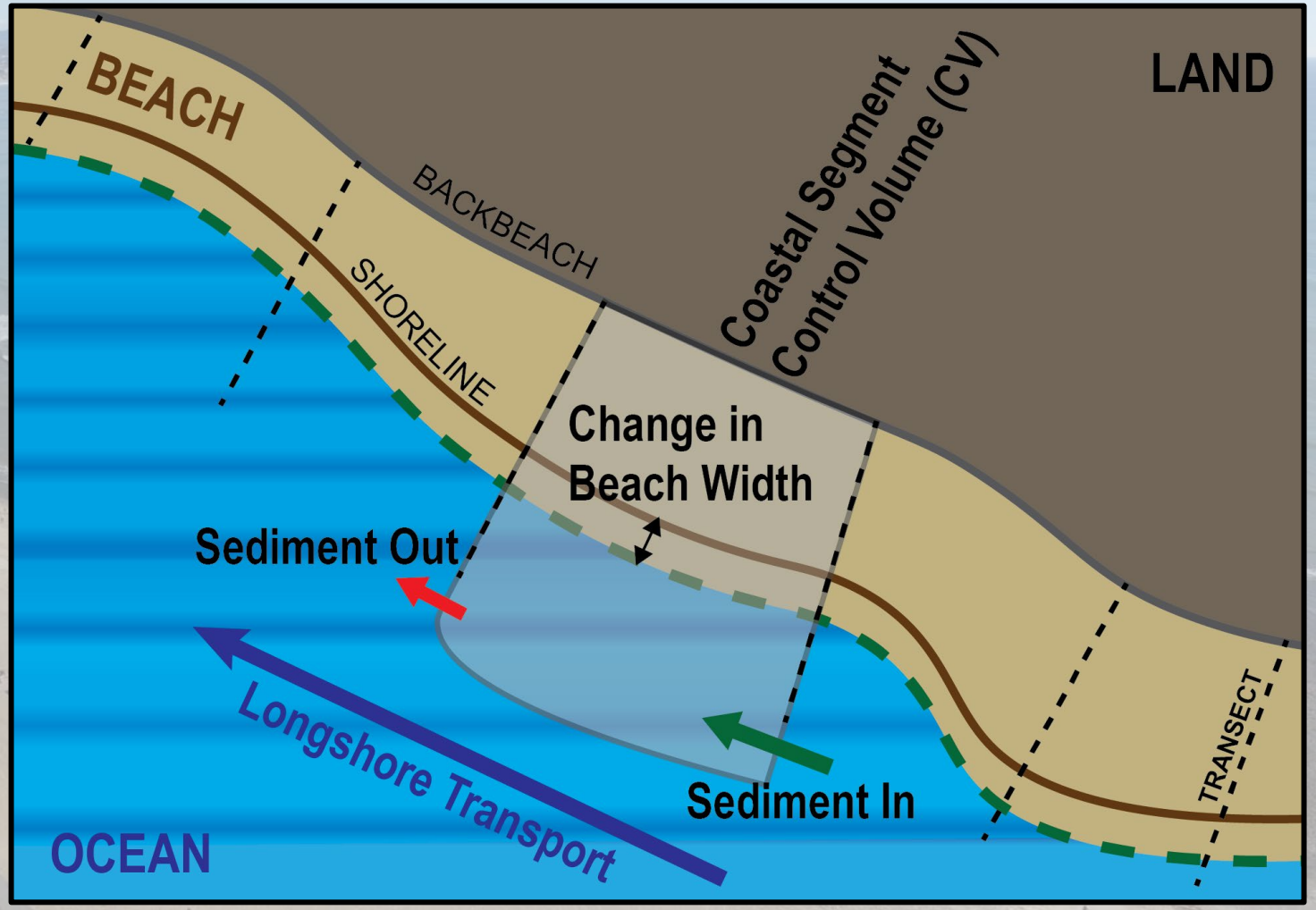
- Sediment movement impacted by environment and infrastructure



- Littoral segments support sediment budgets (mass balance).



- Littoral segments support sediment budgets (mass balance).
- Spatial differences in longshore transport drive beach width changes
- Divergence of Drift (DoD) = spatial differences in longshore transport

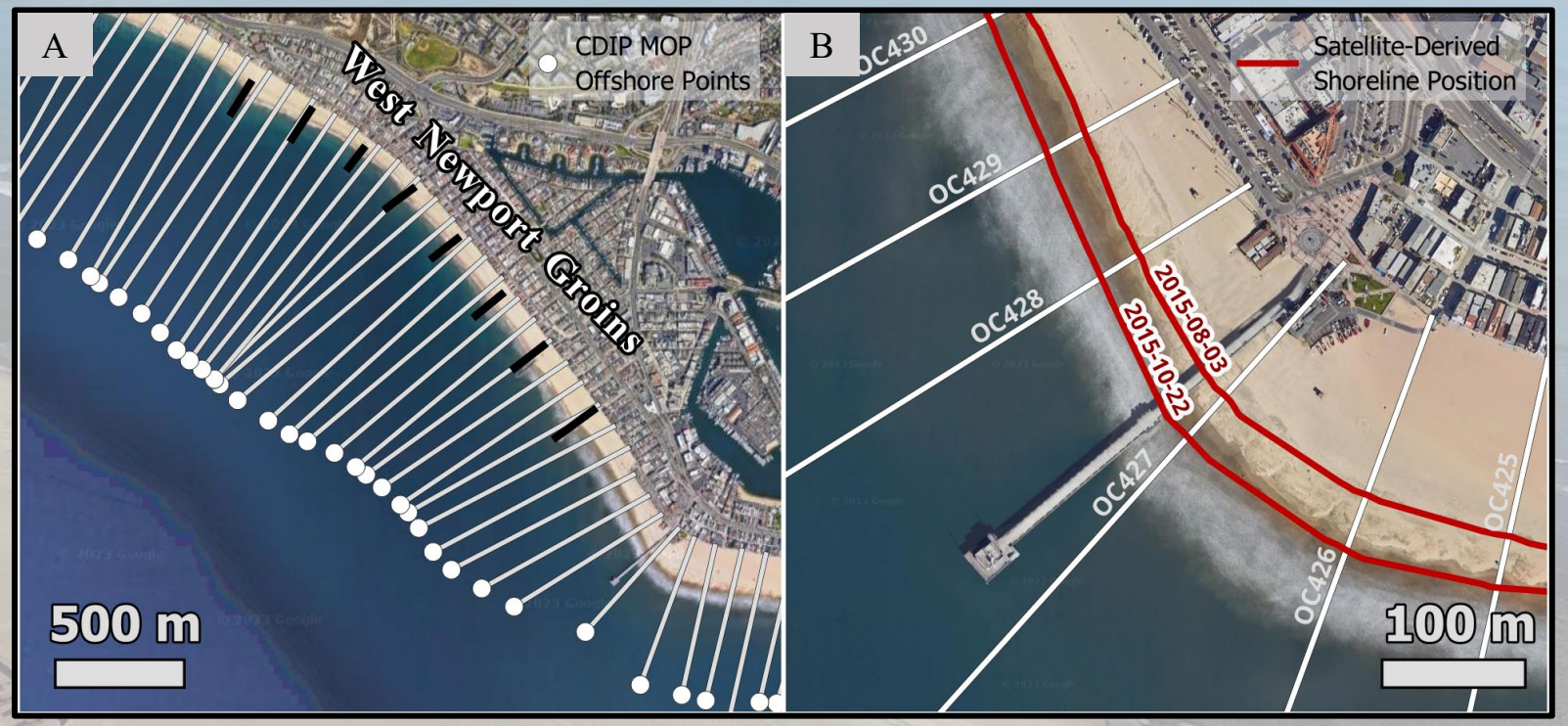


Data Sources for Beach Analyses

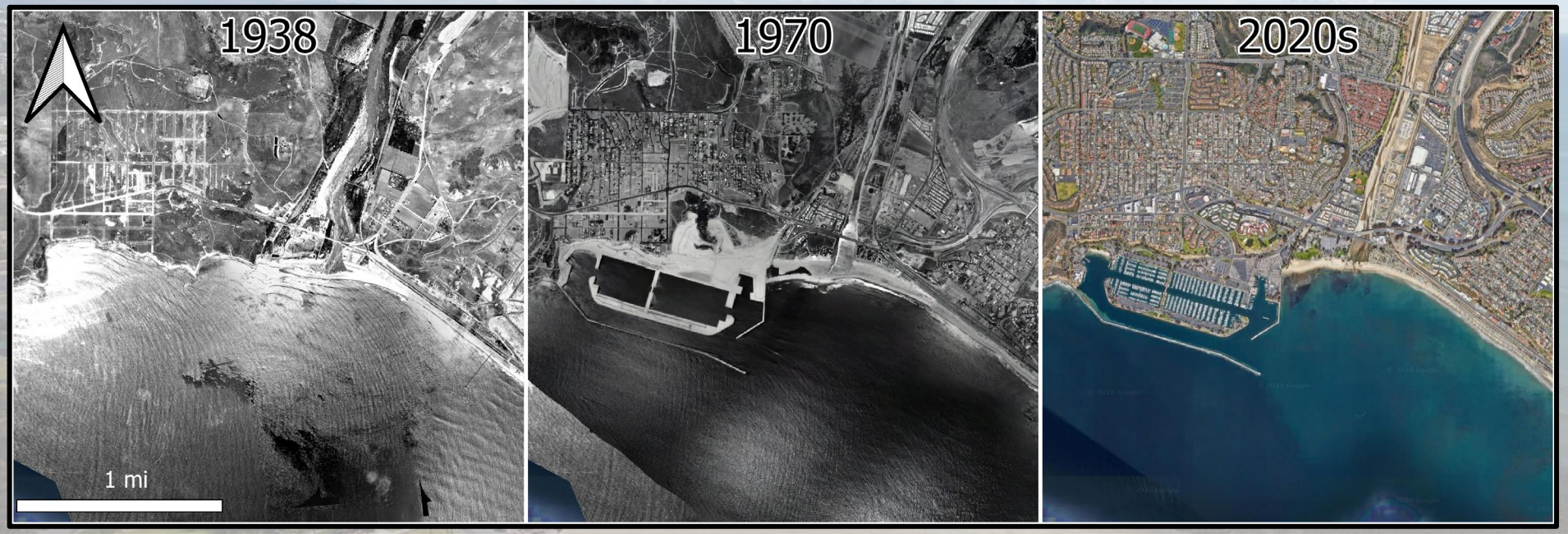
Historical Aerial Imagery
- Historical imagery offers insights into coastal changes during the 20th century

Satellite-derived beach widths
- Monthly to sub-monthly shoreline positions (Vos 2019)

Wave data
- CDIP MOP data (modeled wave height, period, direction), hourly, every 100m at 10m isobath (O'Reilly 2016)

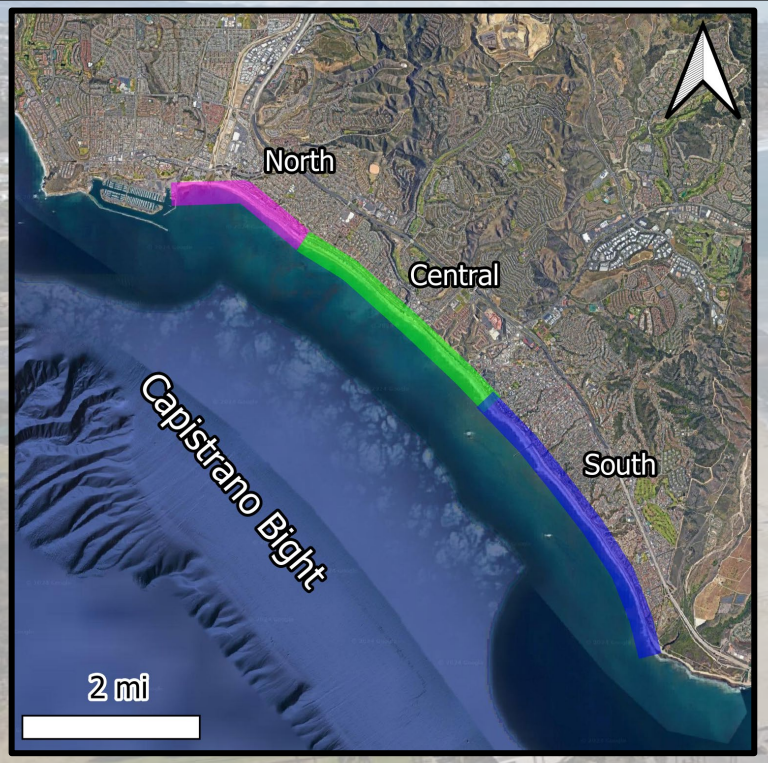


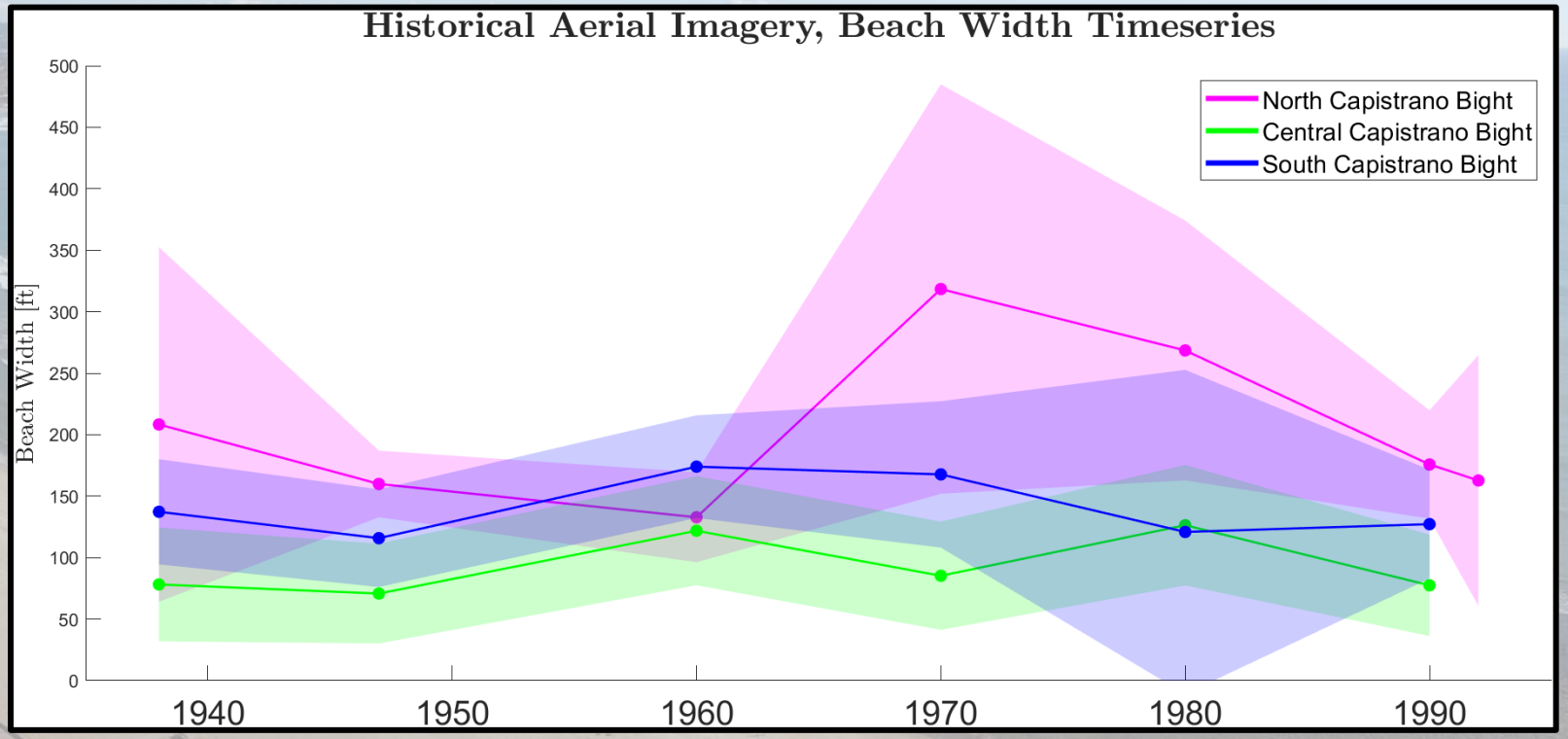
Historical Perspective (1938-1991)



- During the 20th century, the southern California coastline and adjacent watersheds rapidly transformed with urbanization
- Extensive nourishment projects occurred during the middle part of the last century, but rates have declined in recent decades

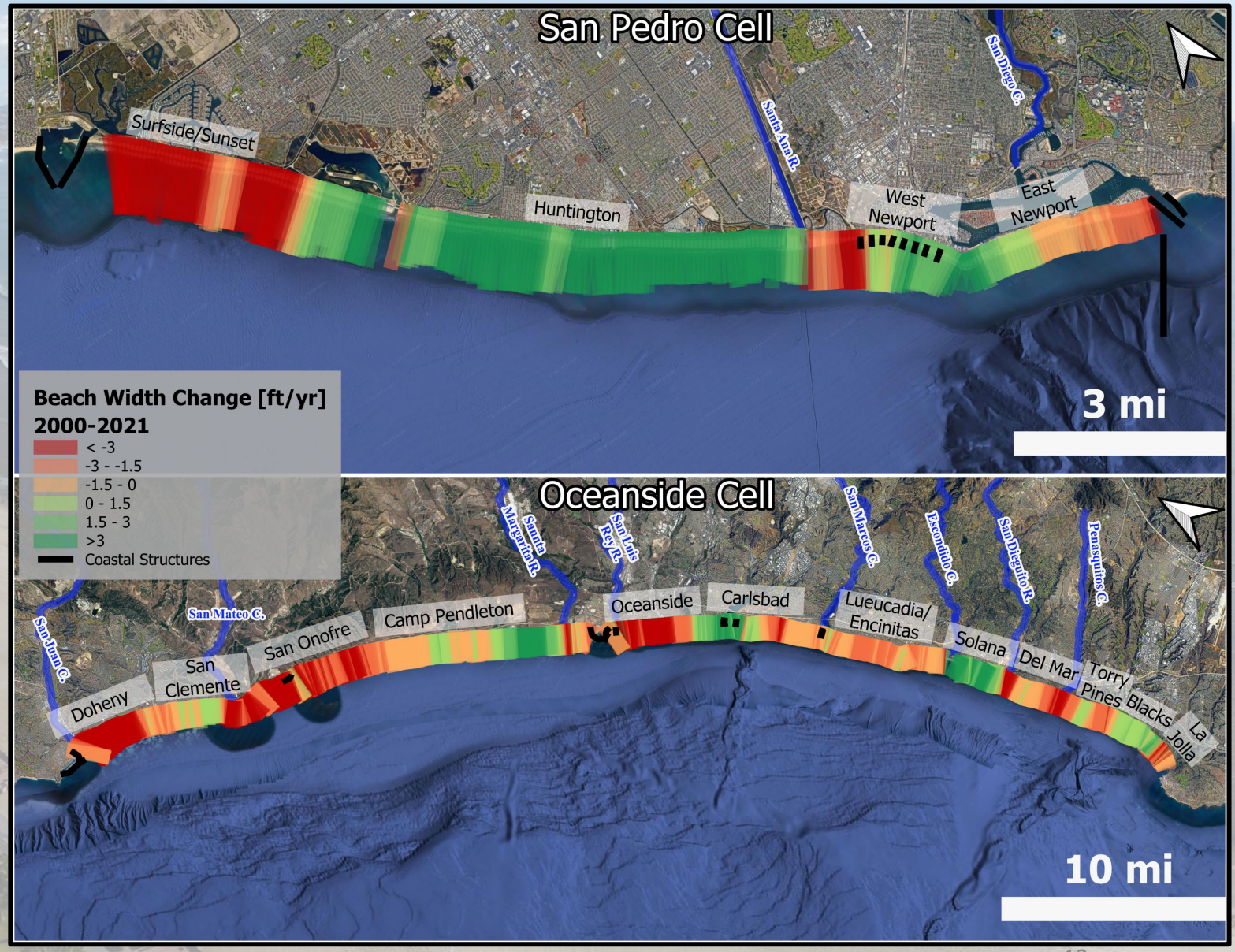
Historical Perspective (1938-1991)



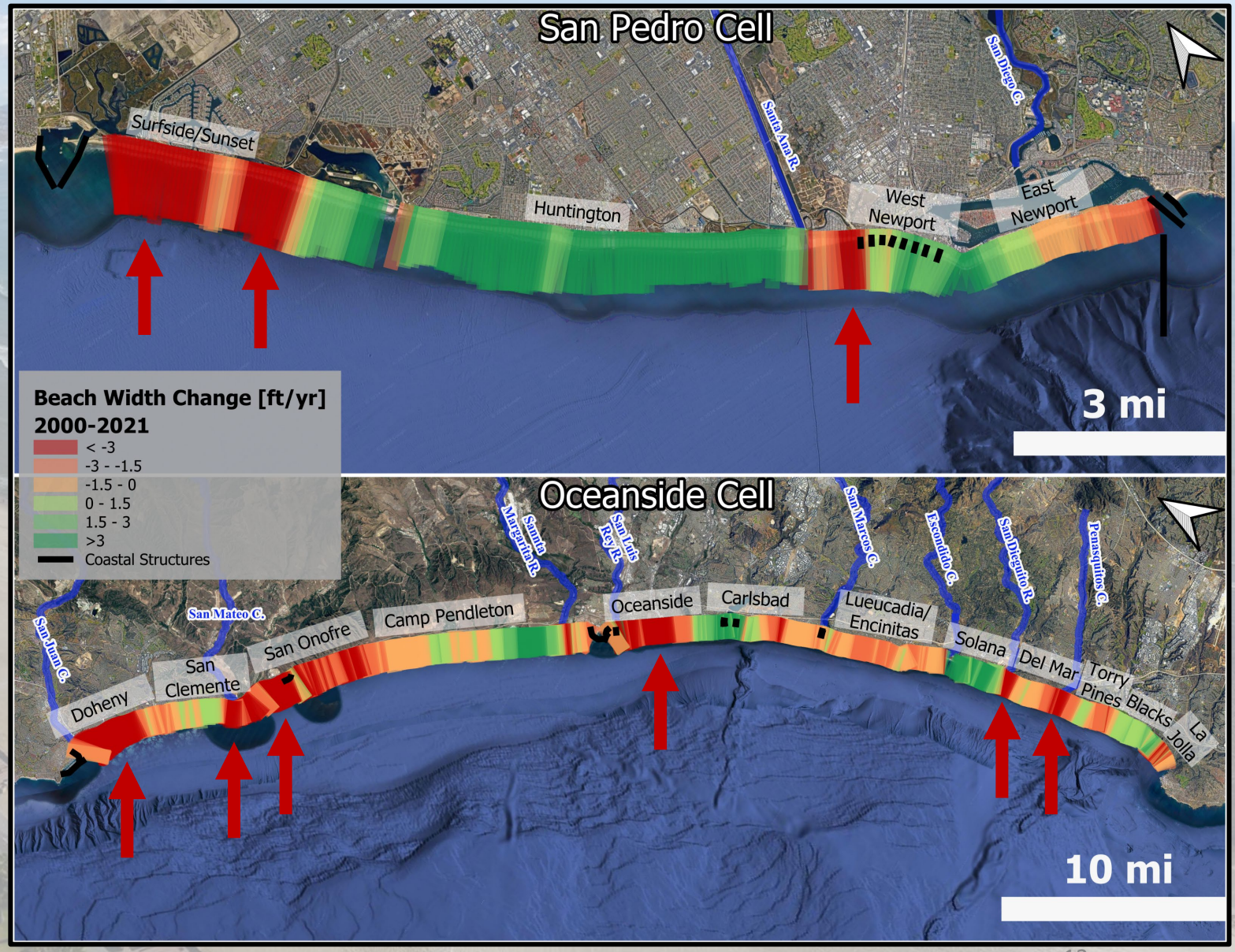


- Historical aerial imagery shows beach widths were relatively stable during the 20th century
- Northern beaches widen from nourishment (~2.2 million cubic yards from Dana Point Harbor) and eventually return to pre- 1970 levels, suggesting about 20 years of benefit

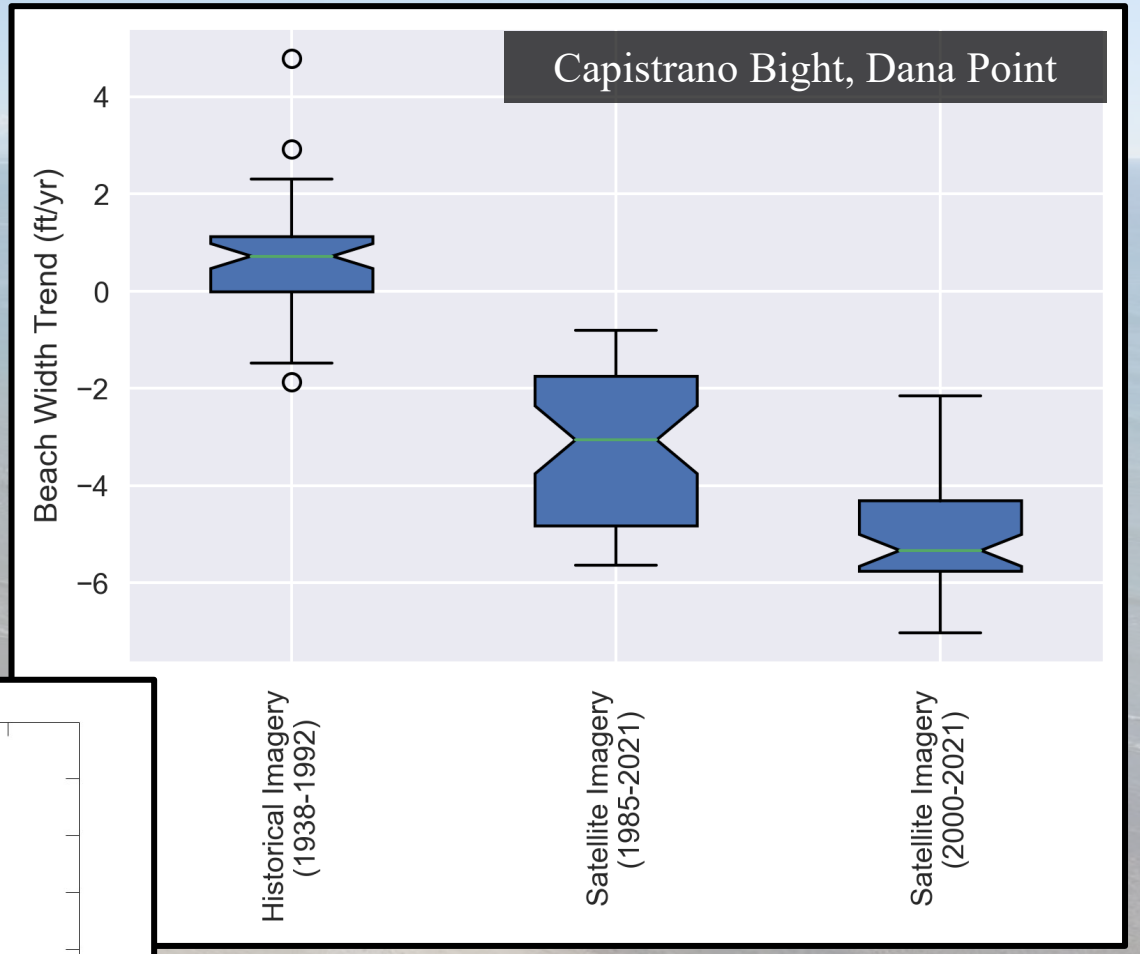
- Beach width trends based on satellite-derived beach width data
- While many beaches have been eroding since 2000, some beaches have been growing

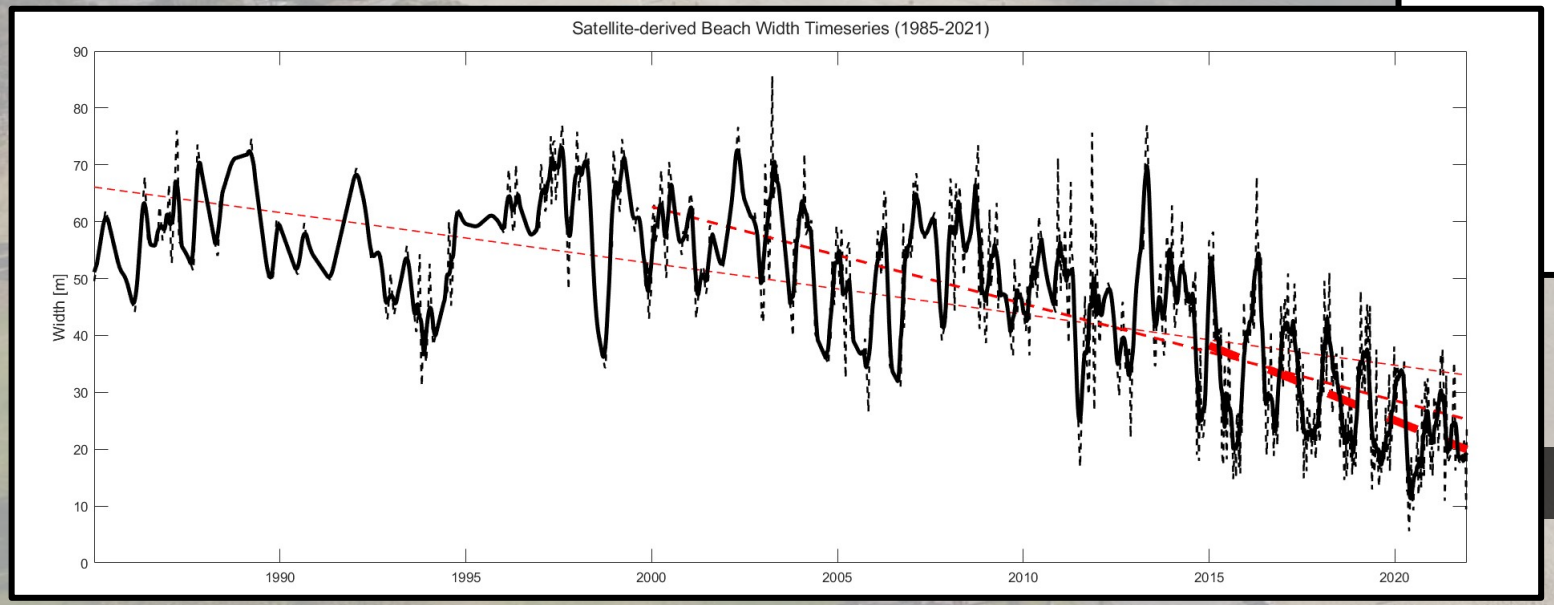


- Data reveals erosion hot spots



Evidence of accelerating beach loss





Cyprus Shores, San Clemente

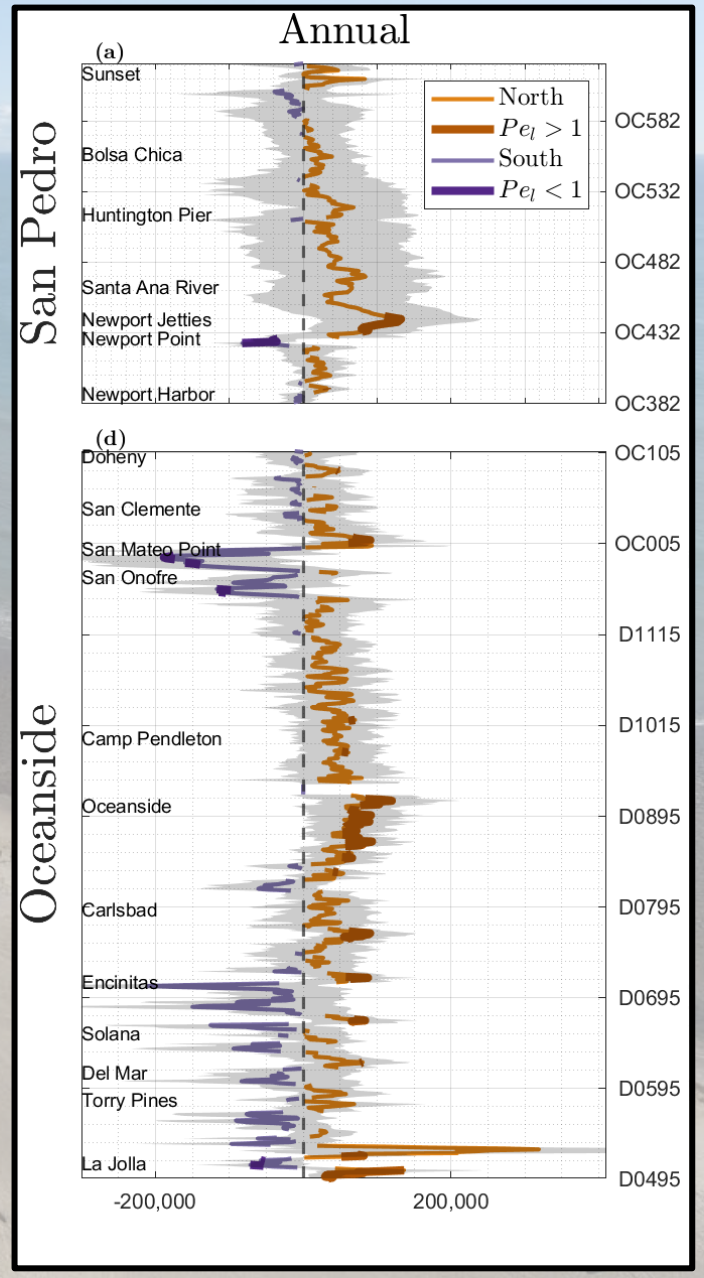
- Potential longshore transport estimated using CDIP MOP data & CERC equation between 2000-2021

$$Q = K\gamma\sqrt{gH_b^5}\sin(2\theta_b)$$

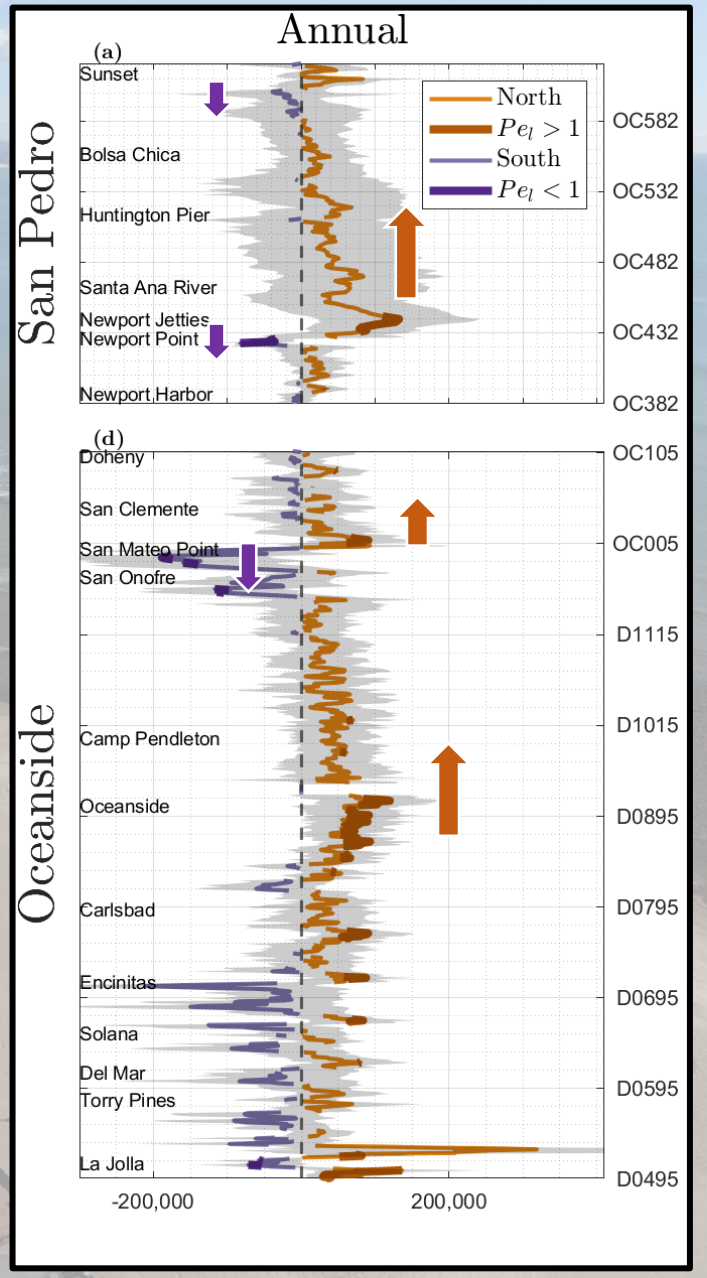
- Peclet Number captures ratio of mean and standard deviation in transport

$$Pe = \frac{\mu_Q}{\sigma_Q}$$

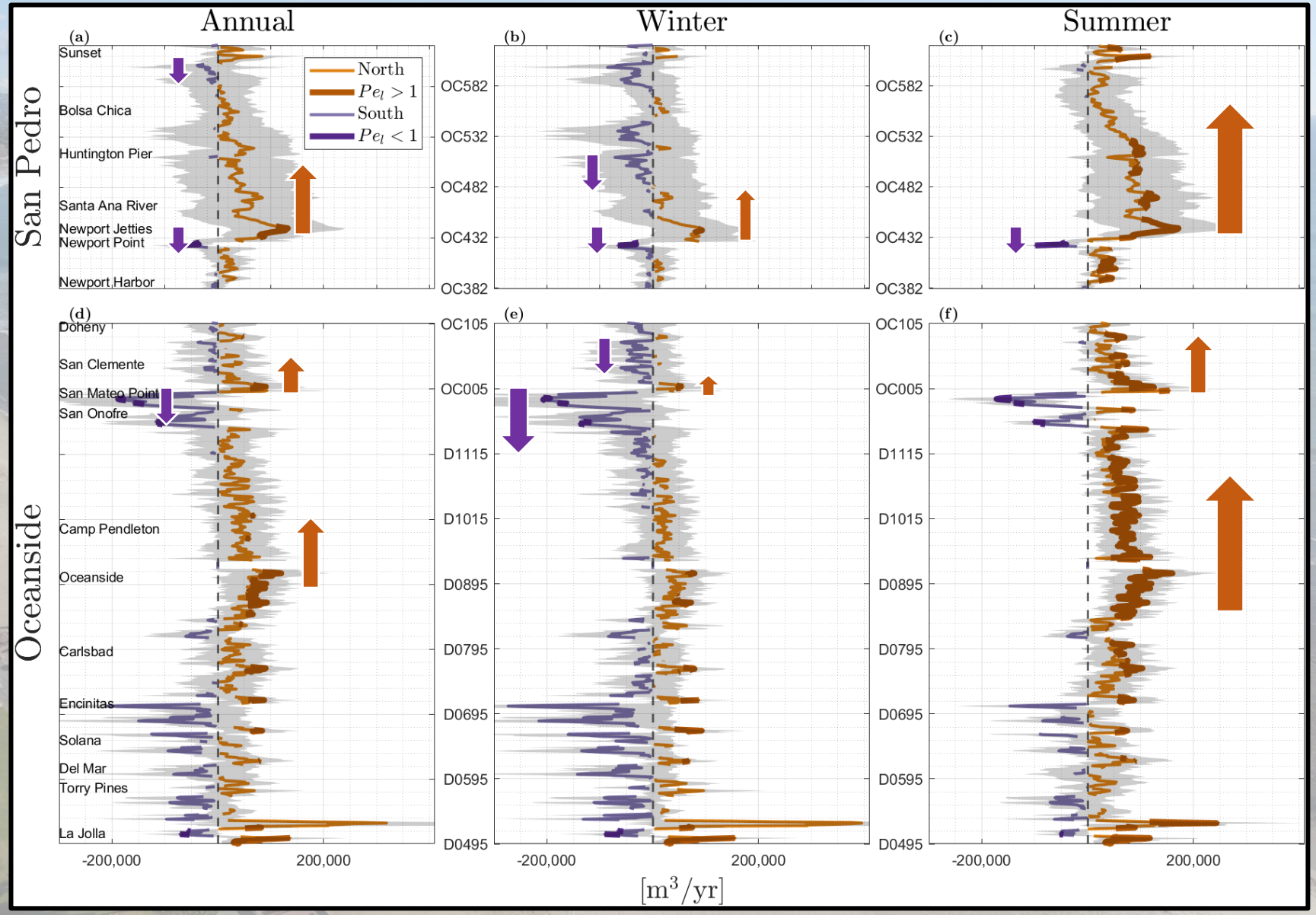
- $Pe > 1$ – Dominated by Advection
- $Pe < 1$ – Dominated by Diffusion



- Potential longshore transport estimated using CDIP MOP data & CERC equation between 2000-2021
- Longshore transport direction changes along the coast, with more northward transport than southern transport (on average)
- Most beaches are more diffusive than advective

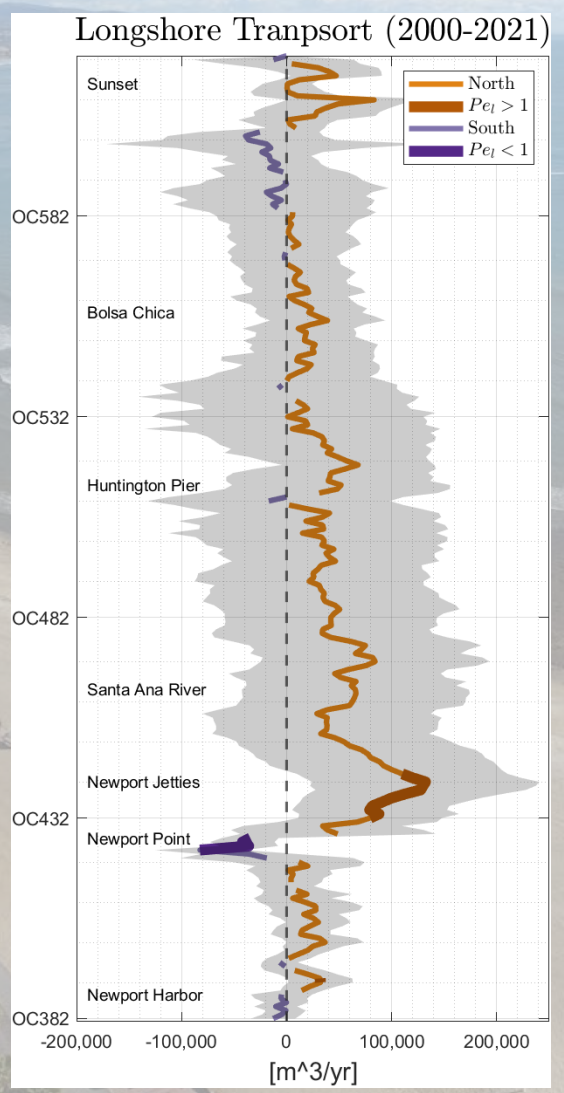


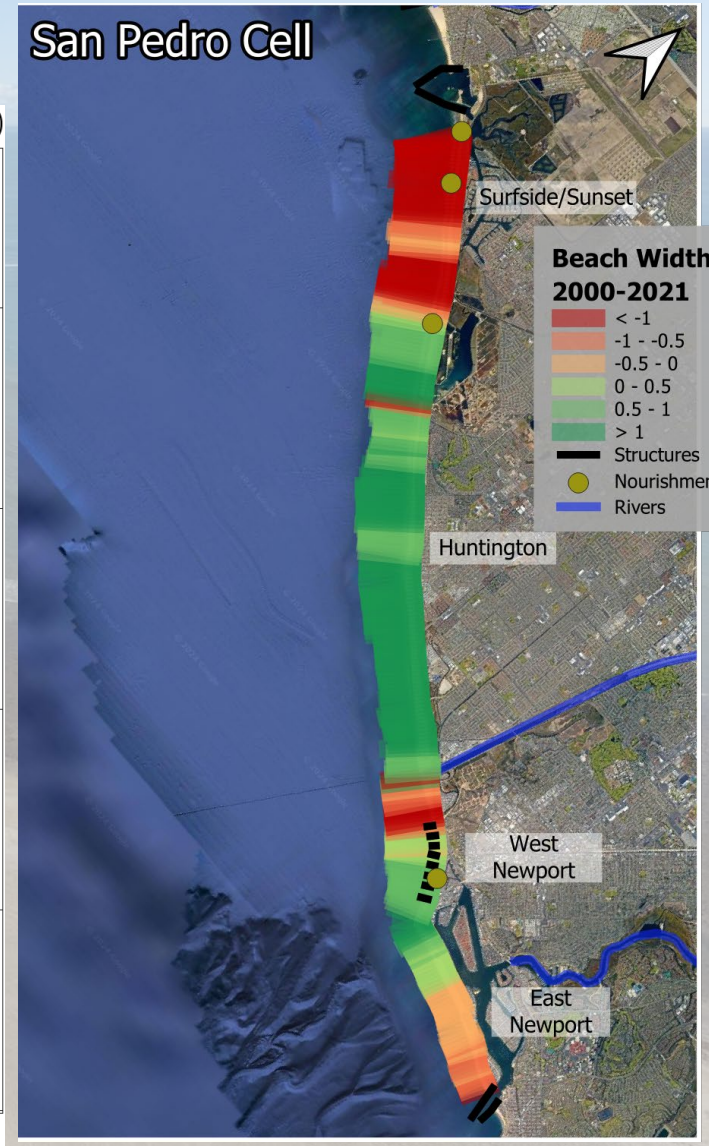
- The mean transport direction reverses seasonally in many locations
- Transport is more southerly in the winter, and northerly in the summer



San Pedro Cell

- Do spatial differences in longshore transport (DoD) explain beach change?

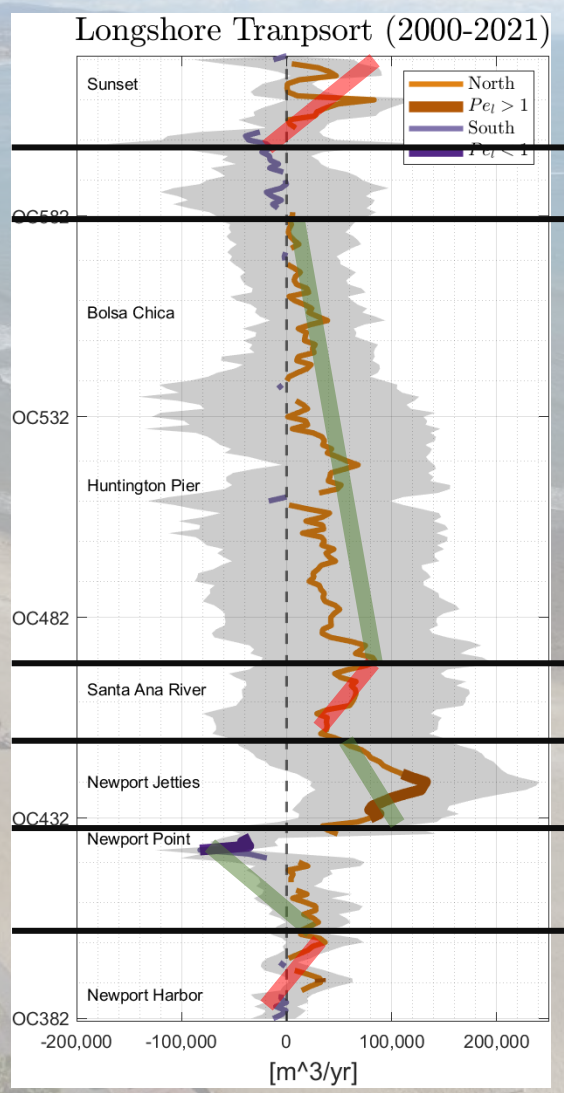


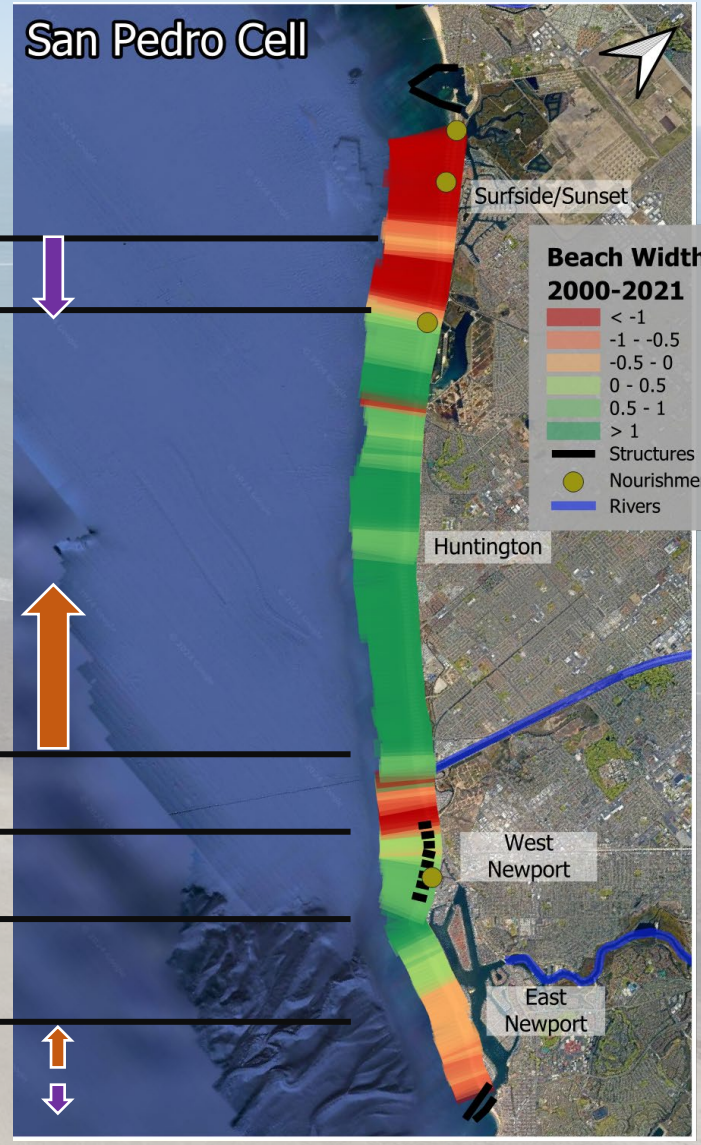


For more details see paper by Kahl et al. (2024)

San Pedro Cell

- Do spatial differences in longshore transport (DoD) explain beach change?
- Spatial structure of longshore transport informs segment boundaries





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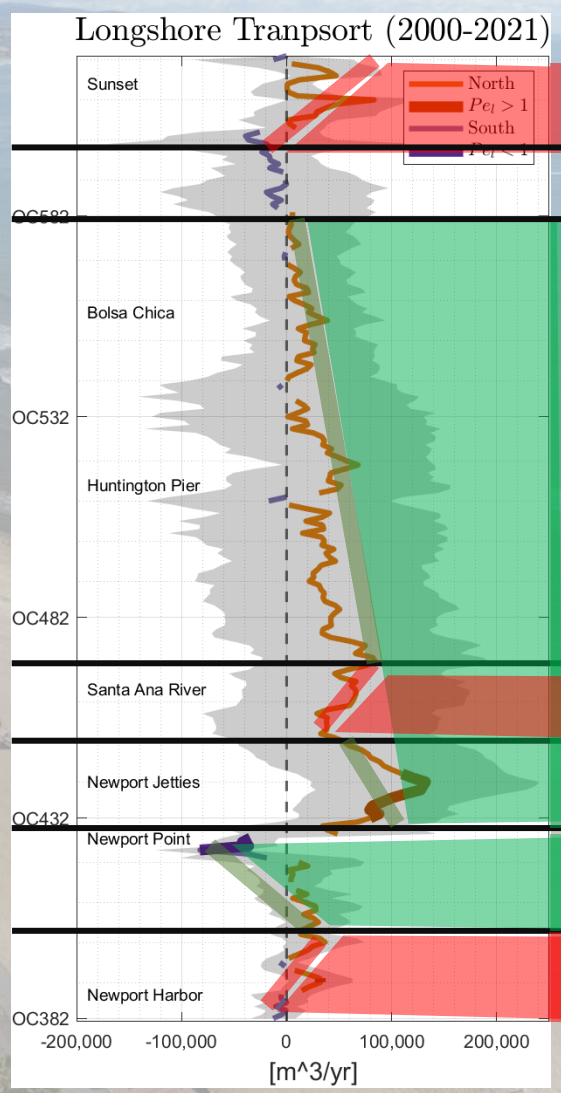
San Pedro Cell

- Do spatial differences in longshore transport (DoD) explain beach change?
- Spatial structure of longshore transport informs segment boundaries
- 93% of beaches either widen or narrow consistent with DoD



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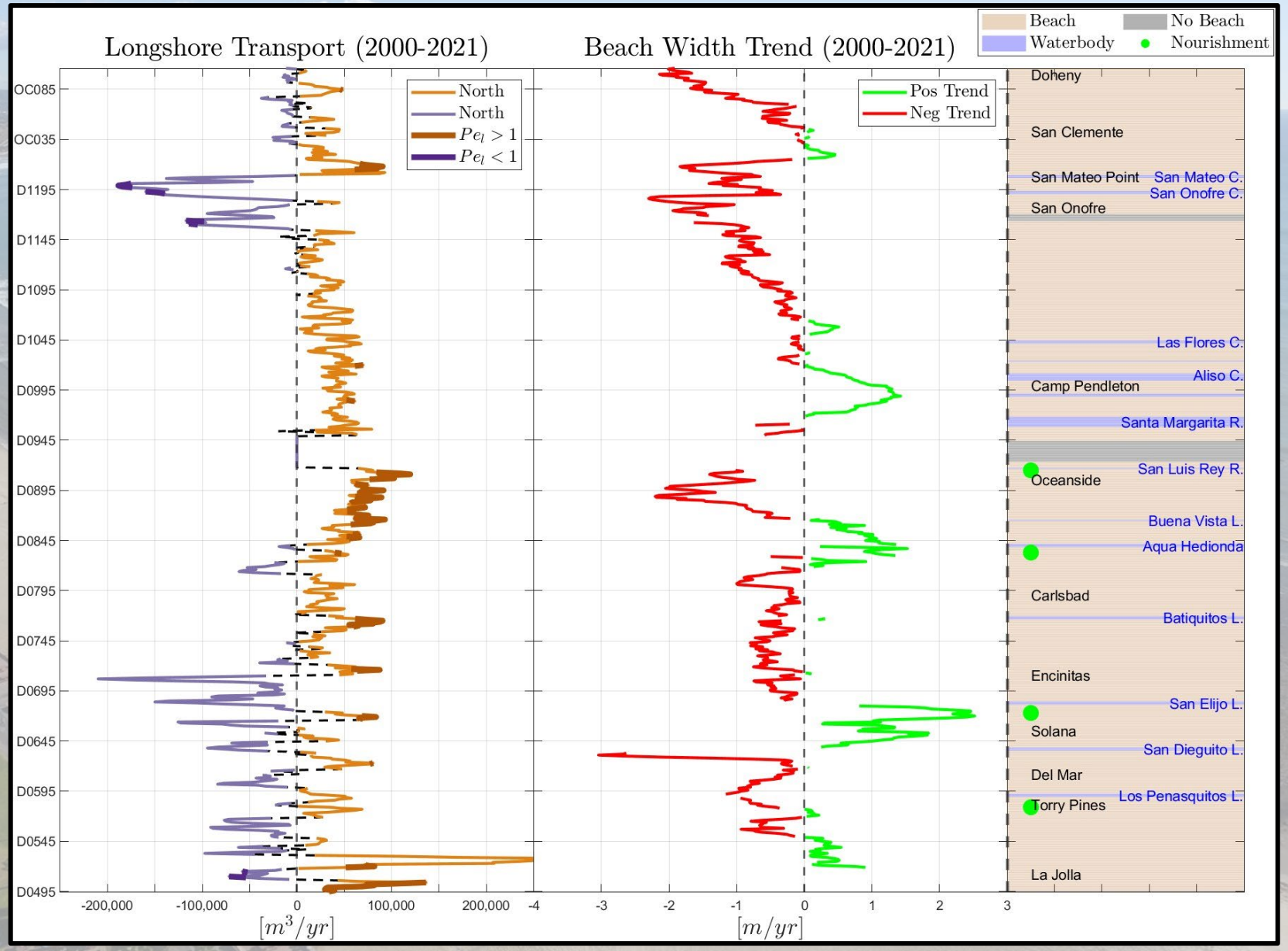
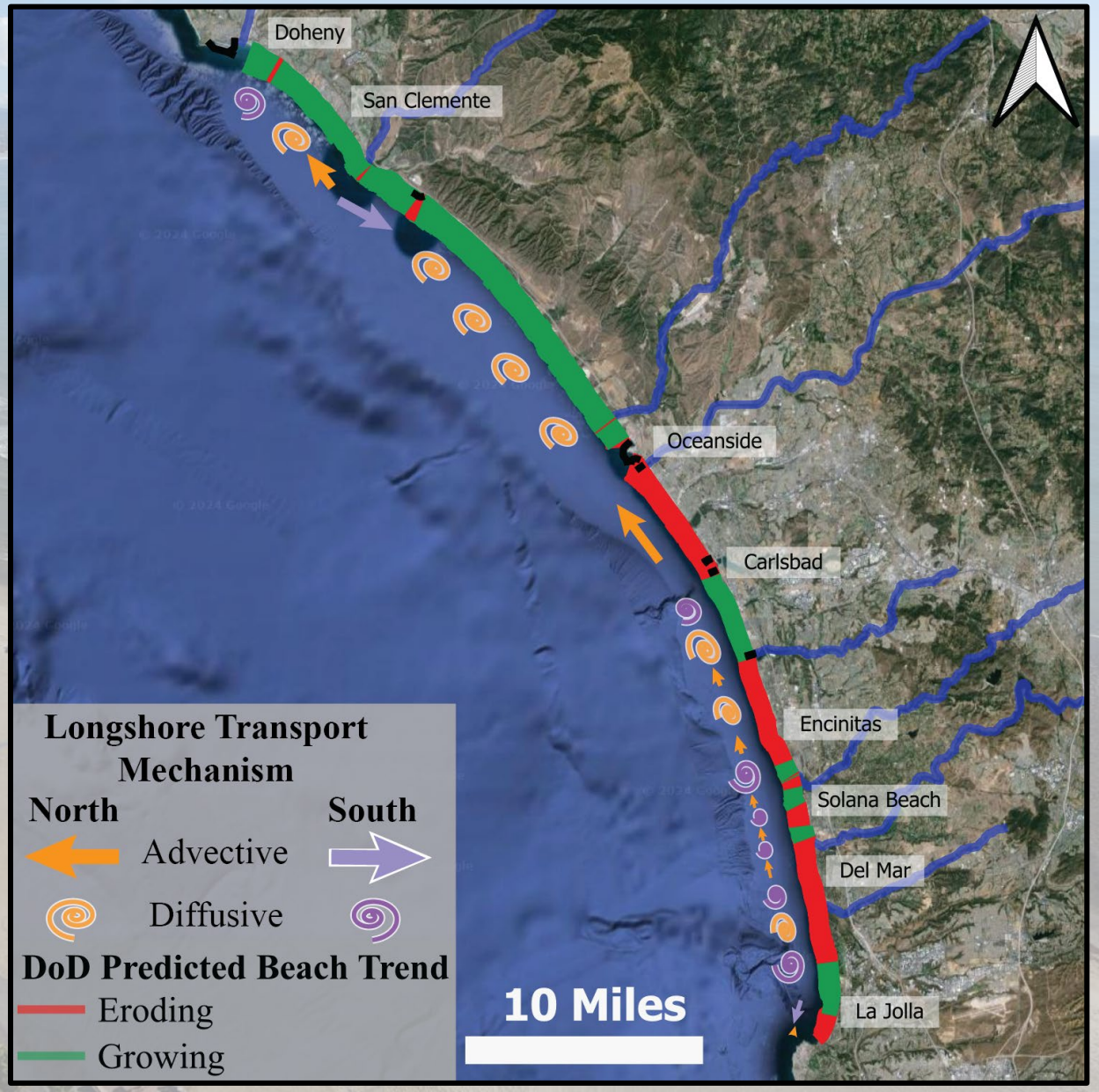
- Nourishments explain beach growth sometimes but not always
- Can longshore transport (DoD) explain long-term patterns of beach change in the Oceanside cell?



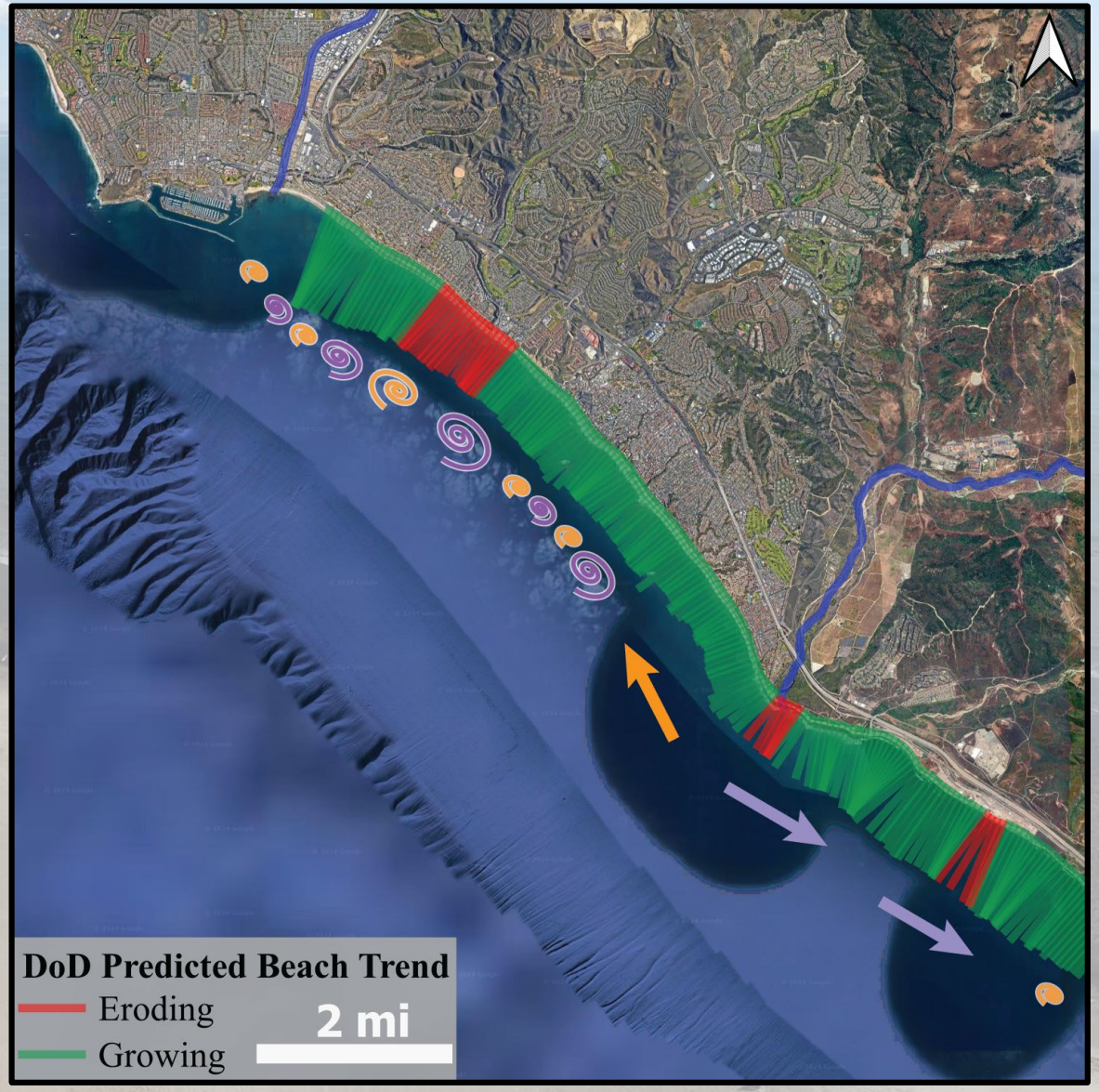
Nourishment data from 2000-2021
National Beach Nourishment Database, Elko 2020

- Simplified interpretation of longshore transport (advection or diffusion dominated)
- Green/red colors represents beaches *expected* to widen/narrow based on DoD
- Up to 73% of beaches either widen or narrow consistent with DoD south of Oceanside Harbor



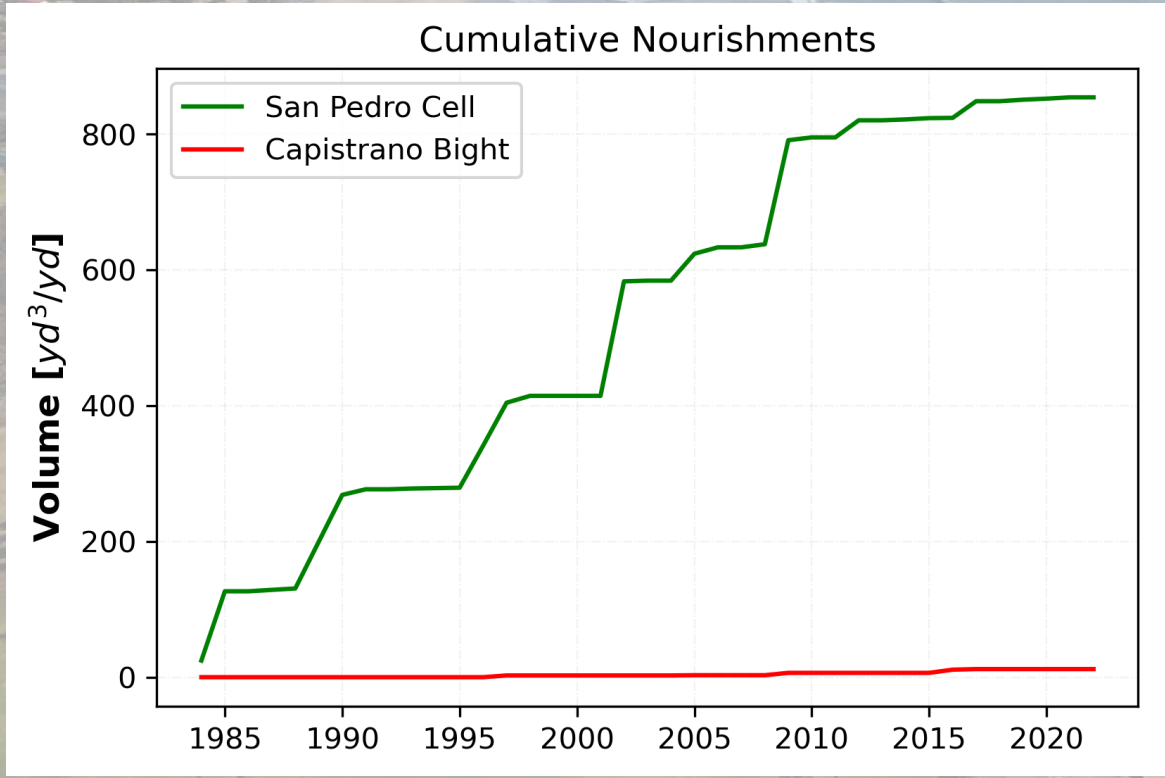
Capistrano Bight

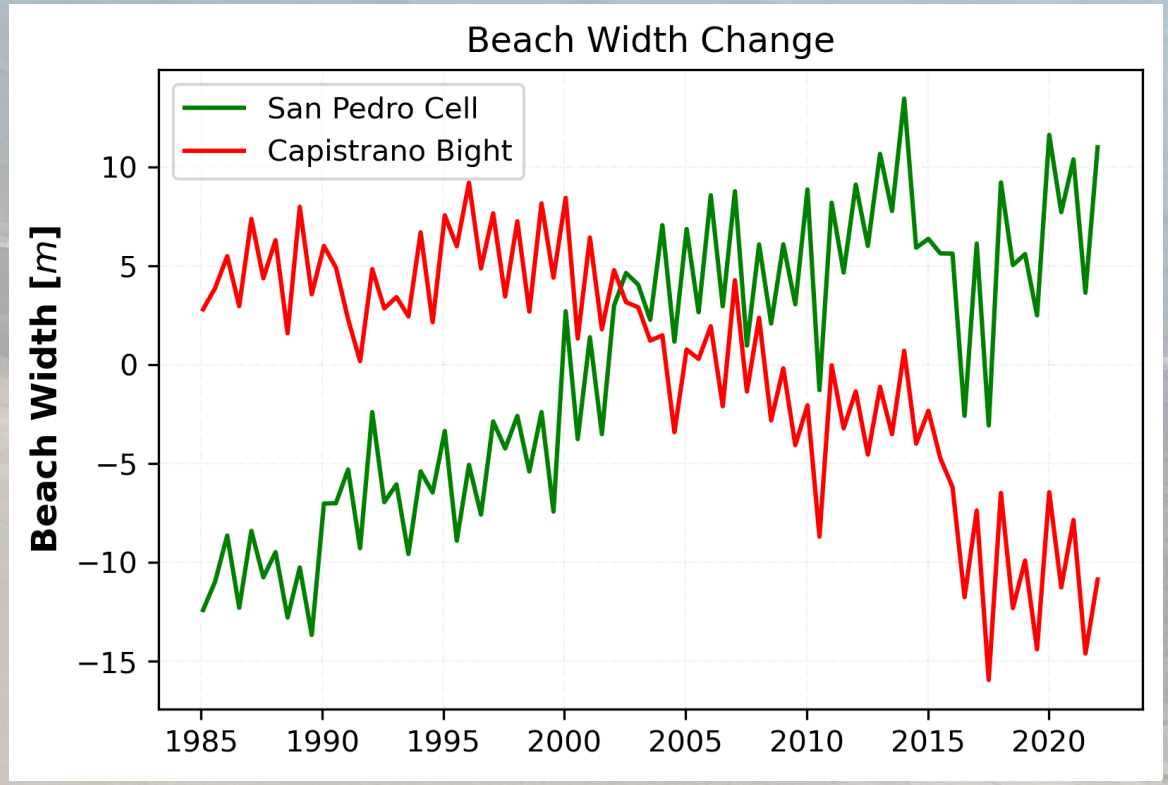
- Historical imagery suggests this region has been relatively stable until 1990s
- Satellite imagery shows erosion rates have accelerated in recent decades
- Divergent, advective currents at San Mateo Point, diffusive currents in Bight
- DoD suggests that much of Capistrano Bight beaches would widen given adequate sediment supply, and limited sediment would move south of the Bight



Why are Capistrano Bight beaches eroding while San Pedro cell beaches are growing?

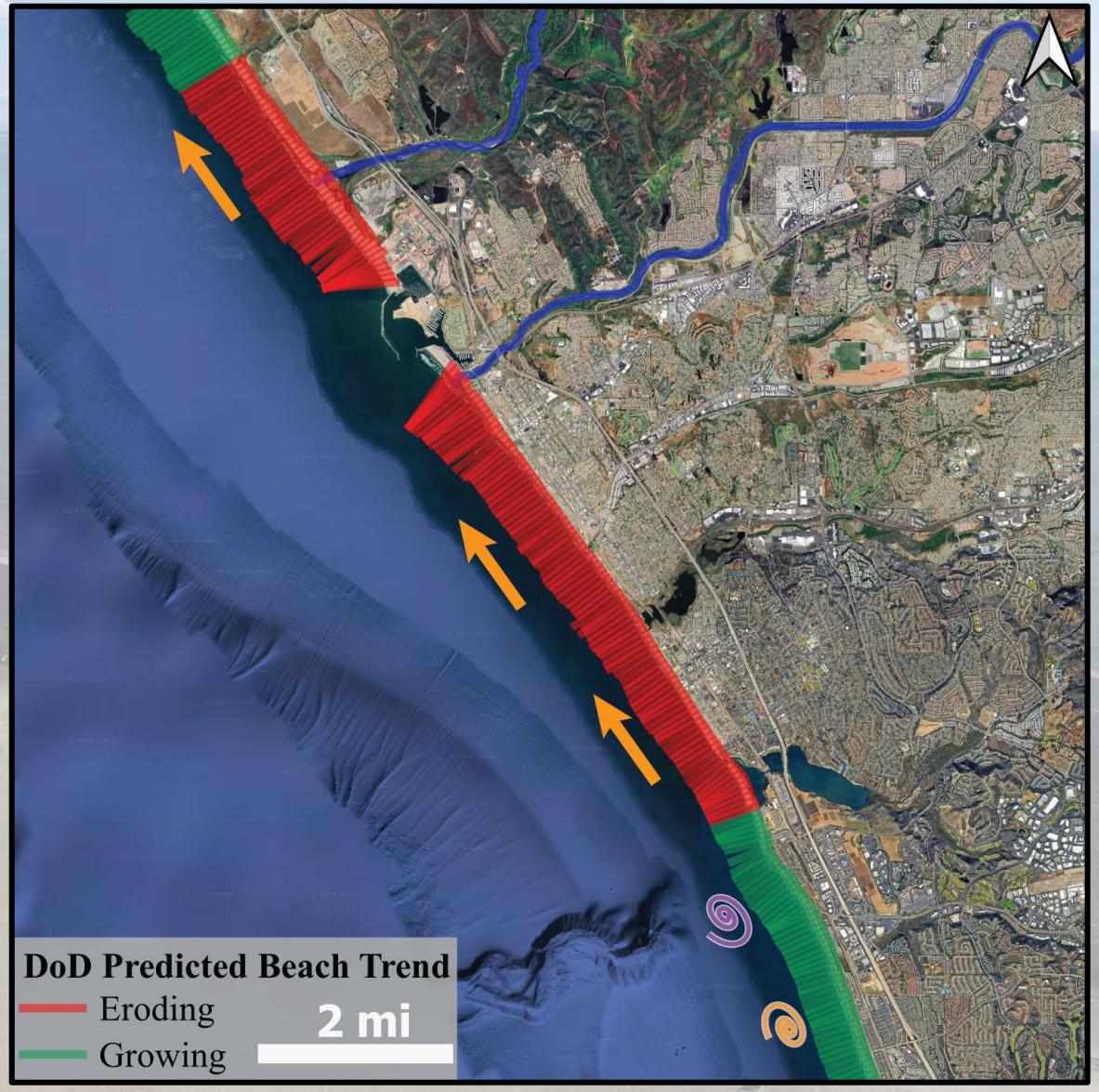
- San Pedro has benefitted from nourishments





Oceanside Harbor

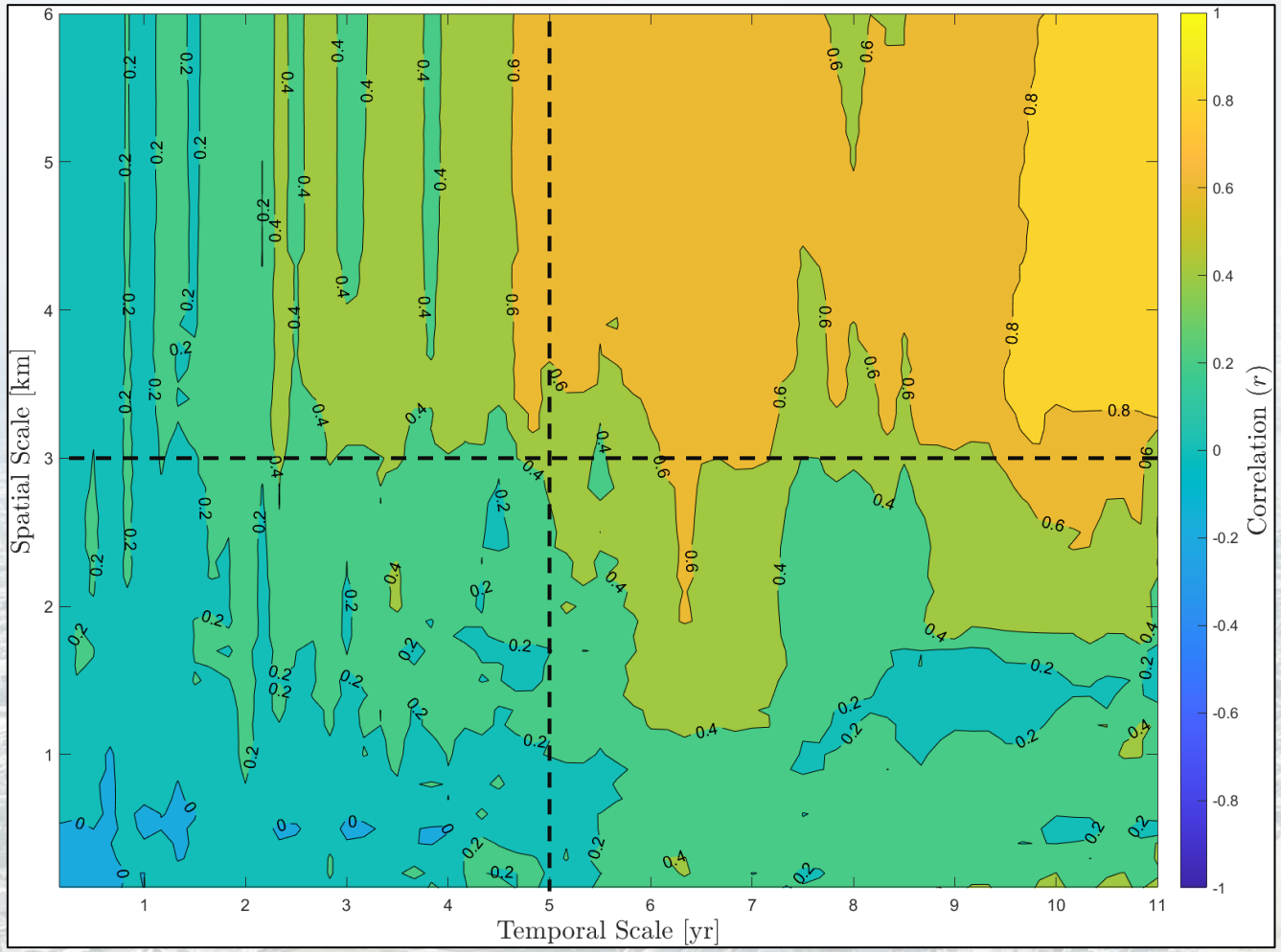
- Satellite imagery shows beaches have been eroding, despite routine nourishments
- Analysis of wave Data/longshore transport points to predominantly upcoast transport
- A recent analysis by Griggs and Patch (2023) suggests transport is downcoast during Fall and Winter, upcoast in Spring and Summer and net transport downcoast.
- “It is highly likely that a significant portion of the average annual dredged volume of sand is carried back into the harbor entrance.” (Griggs and Patch 2023)



Limitations

- Analysis is based on **longshore transport potential**, assumes unlimited availability of sand
- Analysis is based on a 20 year window that may differ from long-term average trends
- Wave height and direction evaluated at the 10 m isobath (CERC equation defined by wave height and direction at the breaker line)
- Differences in longshore transport models (e.g., Van Rijn) could yield differences in mean transport due to nonlinearities with respect to wave height and/or wave length.
- Representativeness of CDIP wave data at Oceanside Harbor versus other shoreline sites could be examined further.

Spatiotemporal Scales of DoD

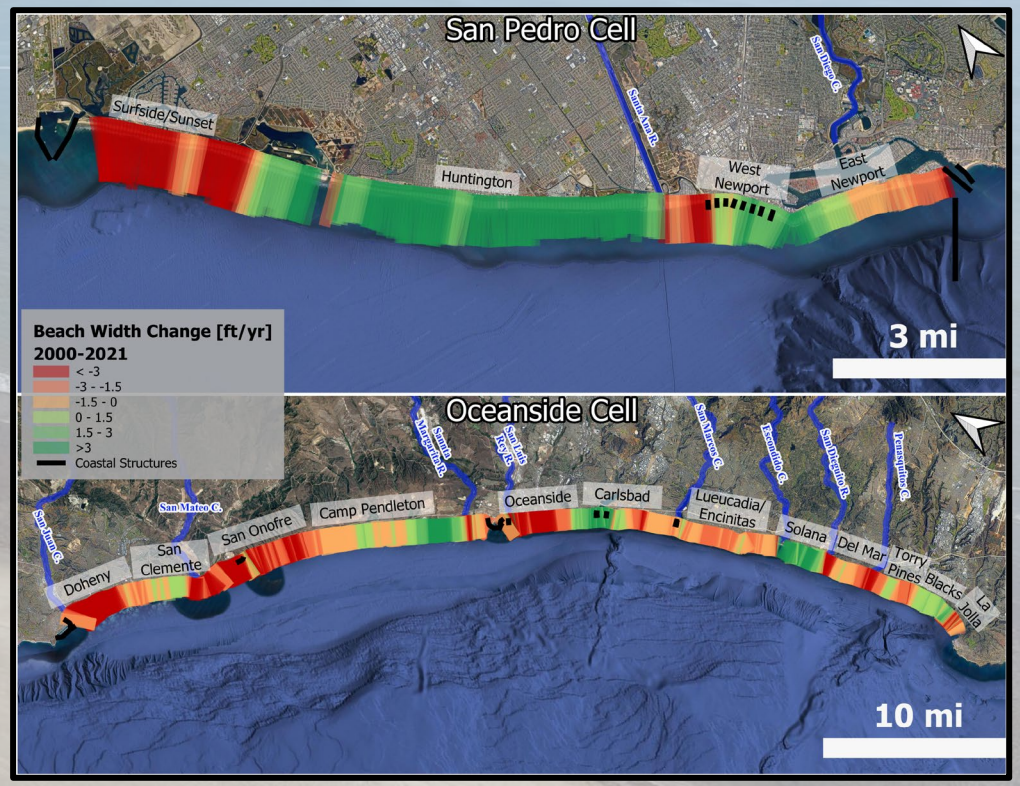


At what spatial and temporal scales does Divergence of Drift (DoD) explain beach width trends?

- Spatial averaging window of at least 3 km improves correlation between DoD and beach width trends
- Good correlations emerge at 2.5 years, and are consistently strong above 5 years

Summary

- Satellite data on beach change and modeled nearshore wave data (CDIP MOP) support a new type of sediment budget analysis
- Beach accretion/erosion trends are spatially fragmented - with hot spots of erosion.
- Spatial fragmentation explained by Divergence of Drift in many cases (e.g., San Pedro littoral cell)
- Suitability and prioritization of sites for sand nourishment (and shoreline stabilization more broadly) can be informed by DoD analysis.



Thank you!

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Metropolitan Beaches Project (beaches.eng.uci.edu)

UCI Flood Lab (floodlab.eng.uci.edu)

References:

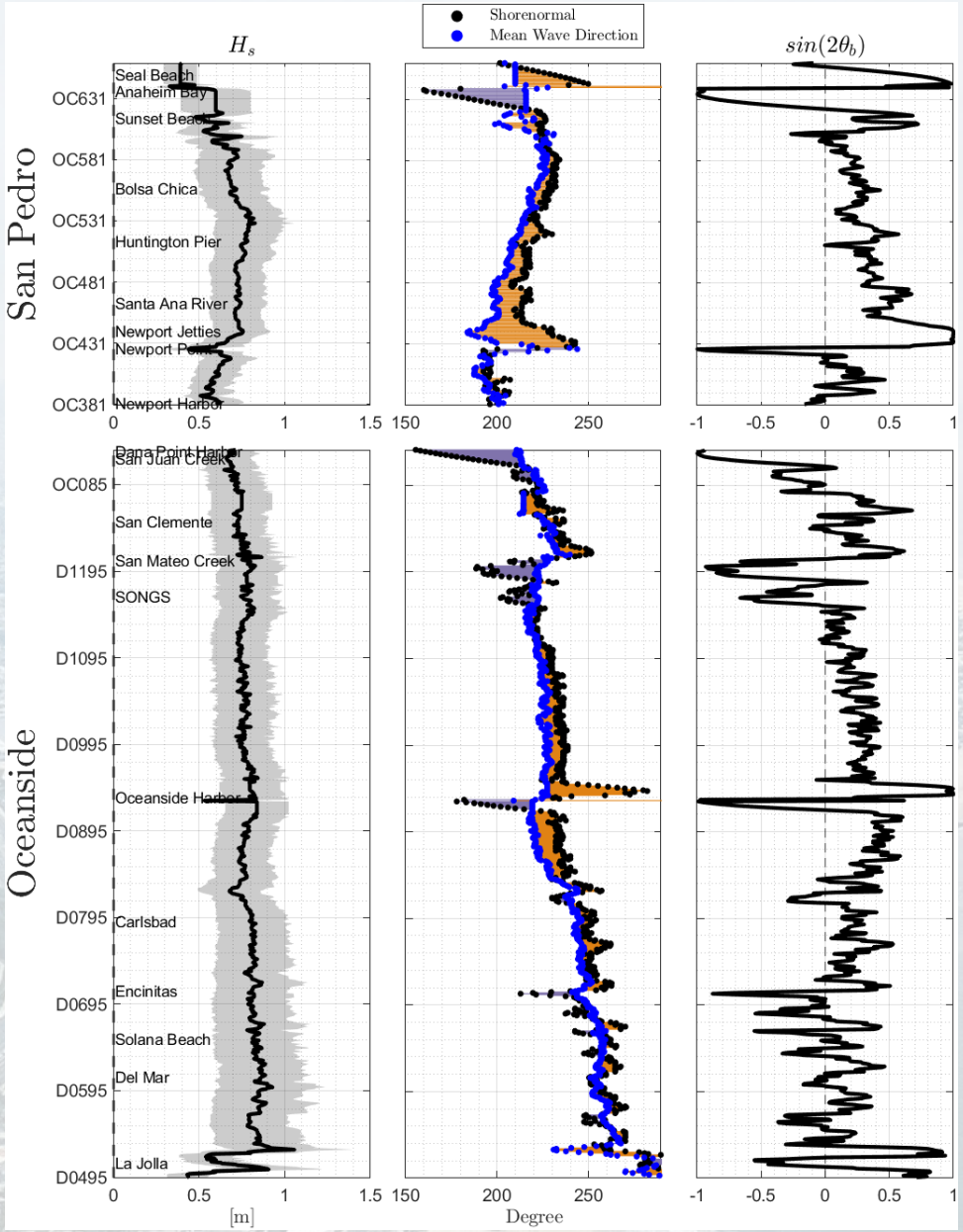
- CERC, 1984. Shore protection manual. volume 1. Department of the Army, Waterways Experiment Station, Corps of Engineers.
- Elko, N., Briggs, T. R., Benedet, L., Robertson, Q., Thomson, G., Webb, B. M., & Garvey, K. (2021). A century of US beach nourishment. Ocean & Coastal Management, 199, 105406.
- Flick, R. E. (1993). The myth and reality of southern California beaches. Shore & Beach, 61(3), 3-13.
- Kahl, D. T., Vulis, L. M., Schubert, J. E., & Sanders, B. F. (2024). Characterizing longshore transport potential and divergence of drift to inform beach loss trends. Coastal Engineering, 189, 104473.
- Komar, P. D., & Inman, D. L. (1970). Longshore sand transport on beaches. Journal of geophysical research, 75(30), 5914-5927.
- O'Reilly, W. C., Olfe, C. B., Thomas, J., Seymour, R. J., & Guza, R. T. (2016). The California coastal wave monitoring and prediction system. Coastal Engineering, 116, 118-132.
- Patsch, K., & Griggs, G. B. (2006). Littoral cells, sand budgets, and beaches: understanding California's shoreline (p. 40). Institute of Marine Sciences, University of California, Santa Cruz.
- Vos, K., Splinter, K. D., Harley, M. D., Simmons, J. A., & Turner, I. L. (2019). CoastSat: A Google Earth Engine-enabled Python toolkit to extract shorelines from publicly available satellite imagery. Environmental Modelling & Software, 122, 104528.
- Vos, K., Harley, M. D., Turner, I. L., & Splinter, K. D. (2023). Pacific shoreline erosion and accretion patterns controlled by El Niño/Southern Oscillation. Nature Geoscience, 16(2), 140-146.
- Yates, M. L., Guza, R. T., O'Reilly, W. C., & Seymour, R. J. (2009). Overview of seasonal sand level changes on southern California beaches. Shore & beach, 77(1), 39.

Funding sources:

Ridge 2 Reef
An NSF Research Traineeship in Ecosystem Management and Environmental Change

Appendix

CDIP MOP Wave Data



Seasonal and ENSO Distributions of Longshore Transport