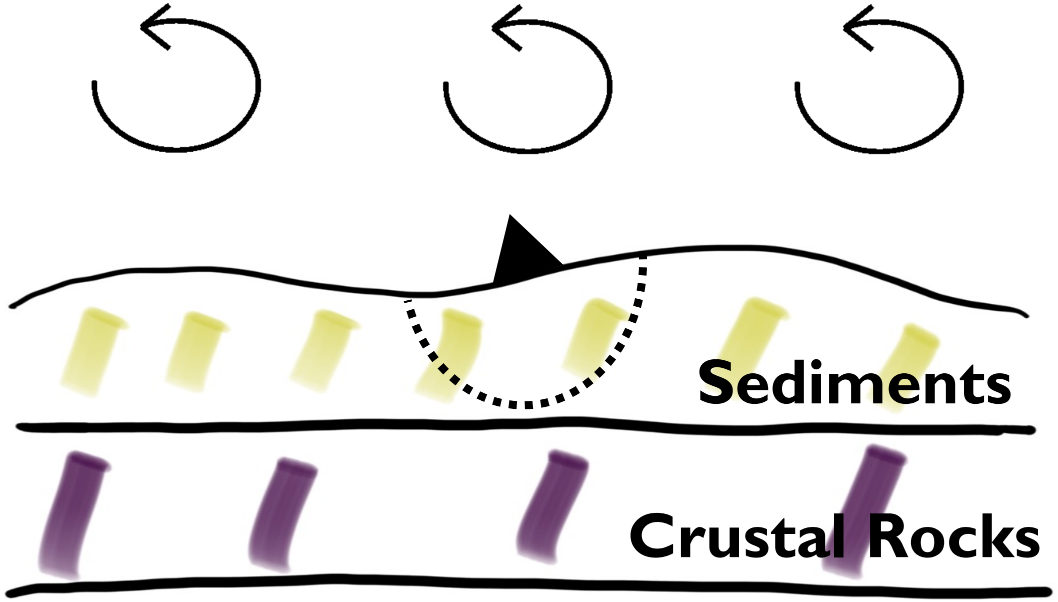
Long-period seismic signals from hurricane landfalls:

Are these local or hurricane-wide effects?



Qing Ji & Eric M. Dunham

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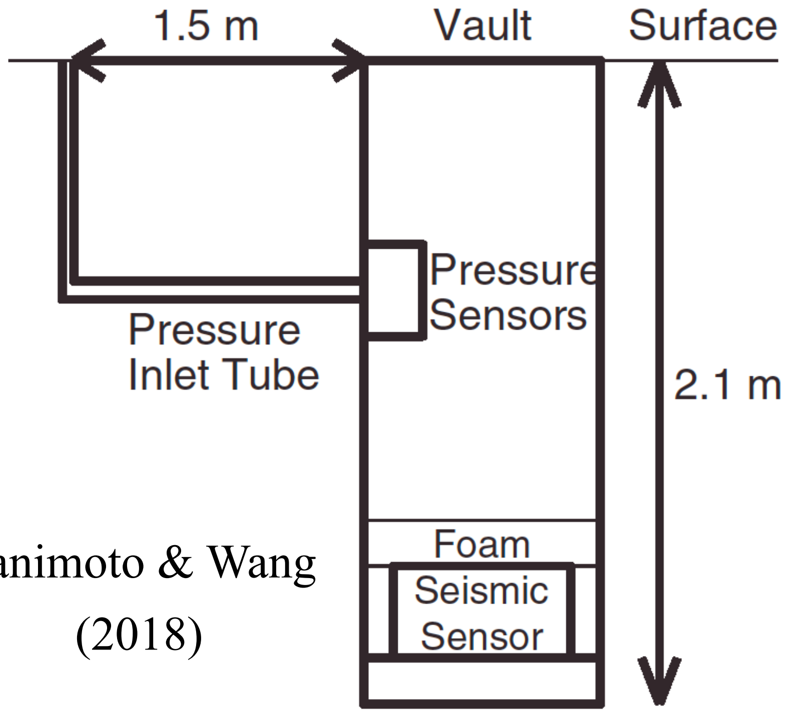
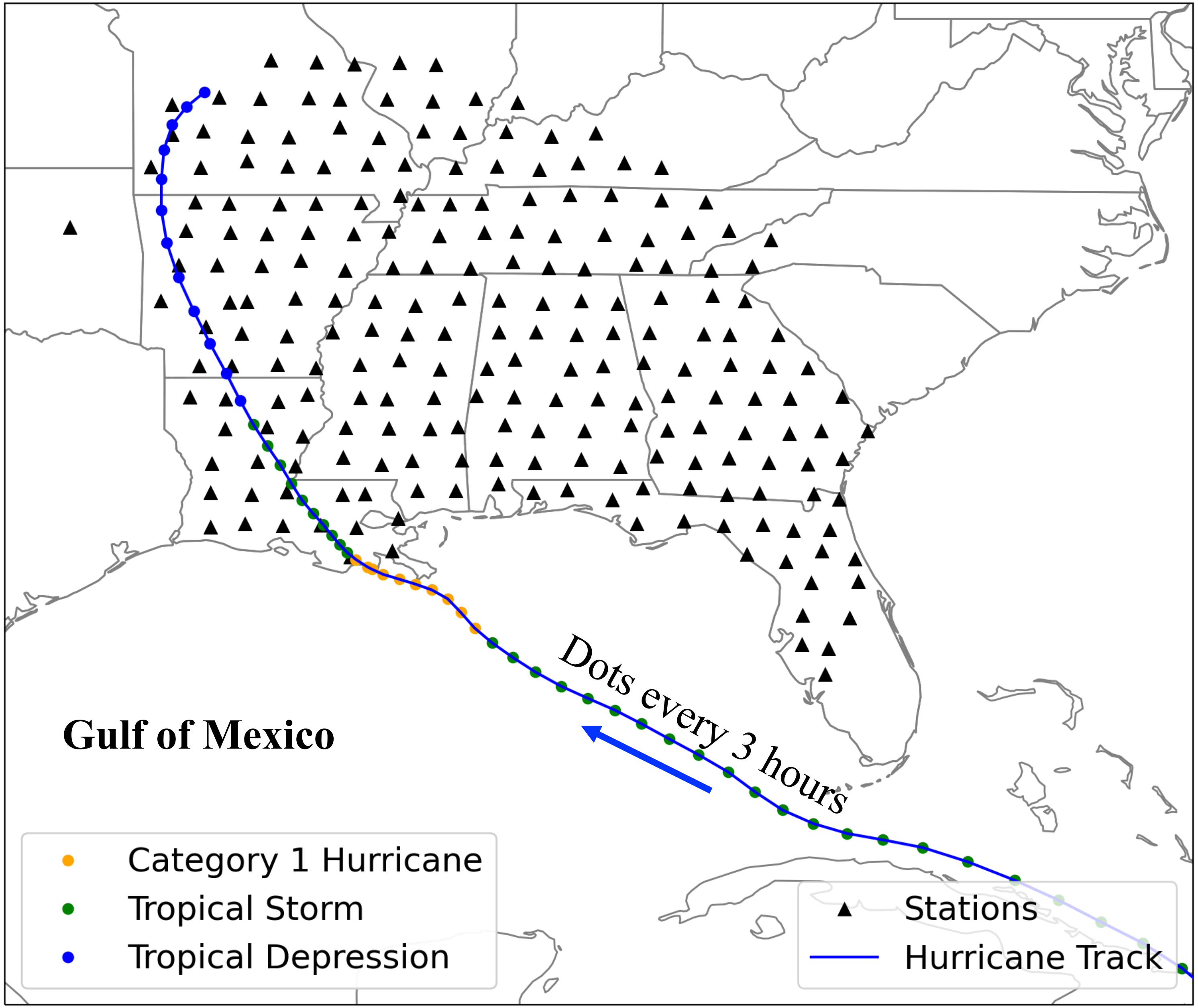
Stanford | Doerr
School of Sustainability

Hurricane Isaac in Aug. 2012

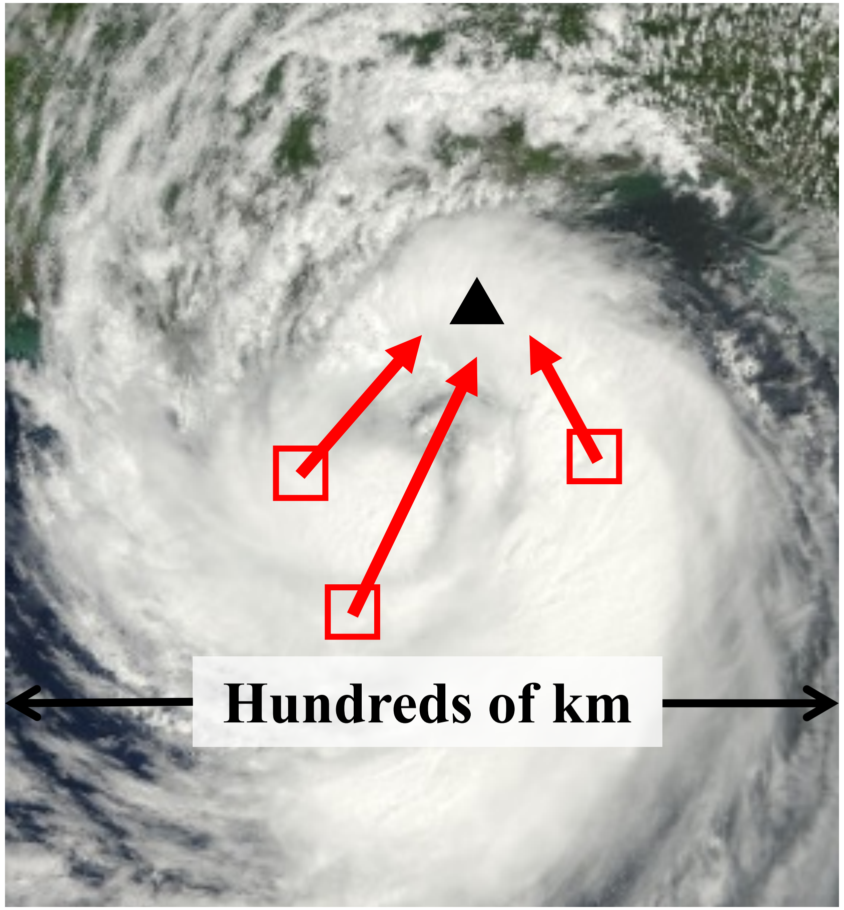
Passed through Transportable Array (TA) stations with co-located pressure sensors and seismometers



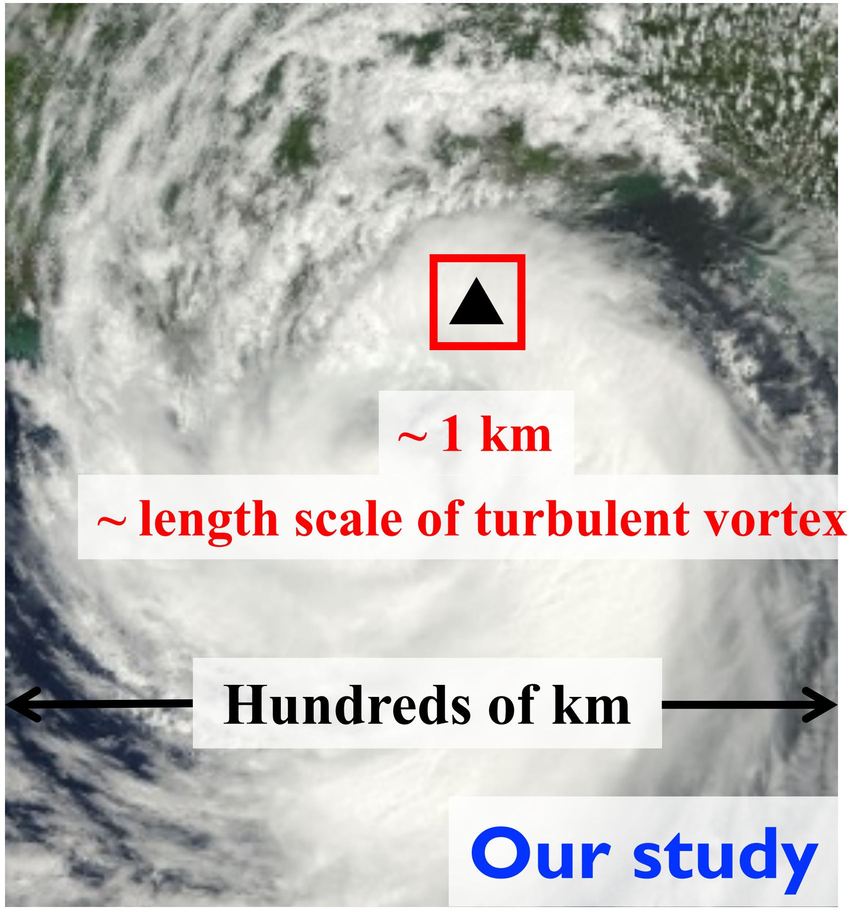
Tanimoto & Wang (2018)



To explain observed vertical displacement:



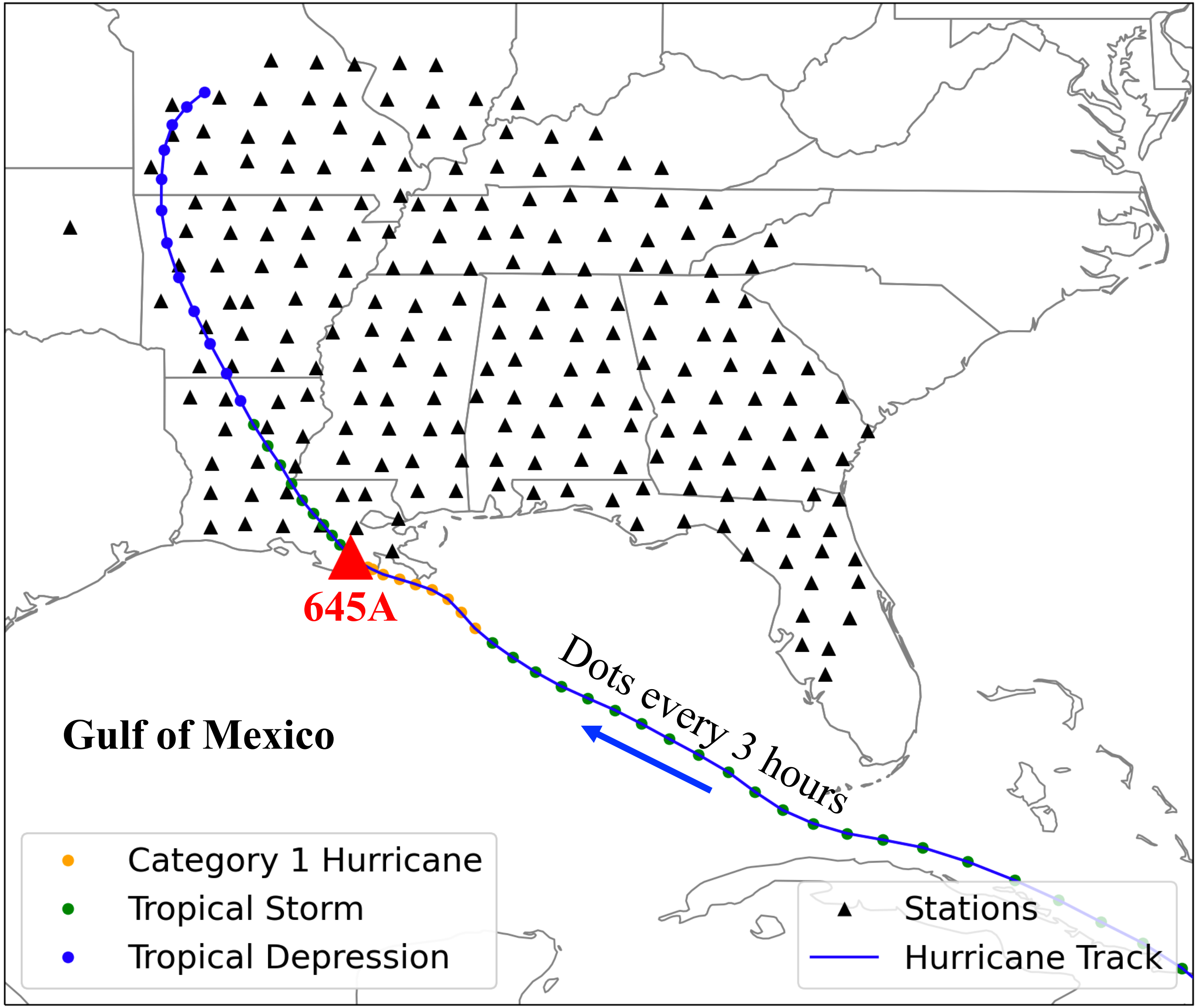
Contributions from whole hurricane

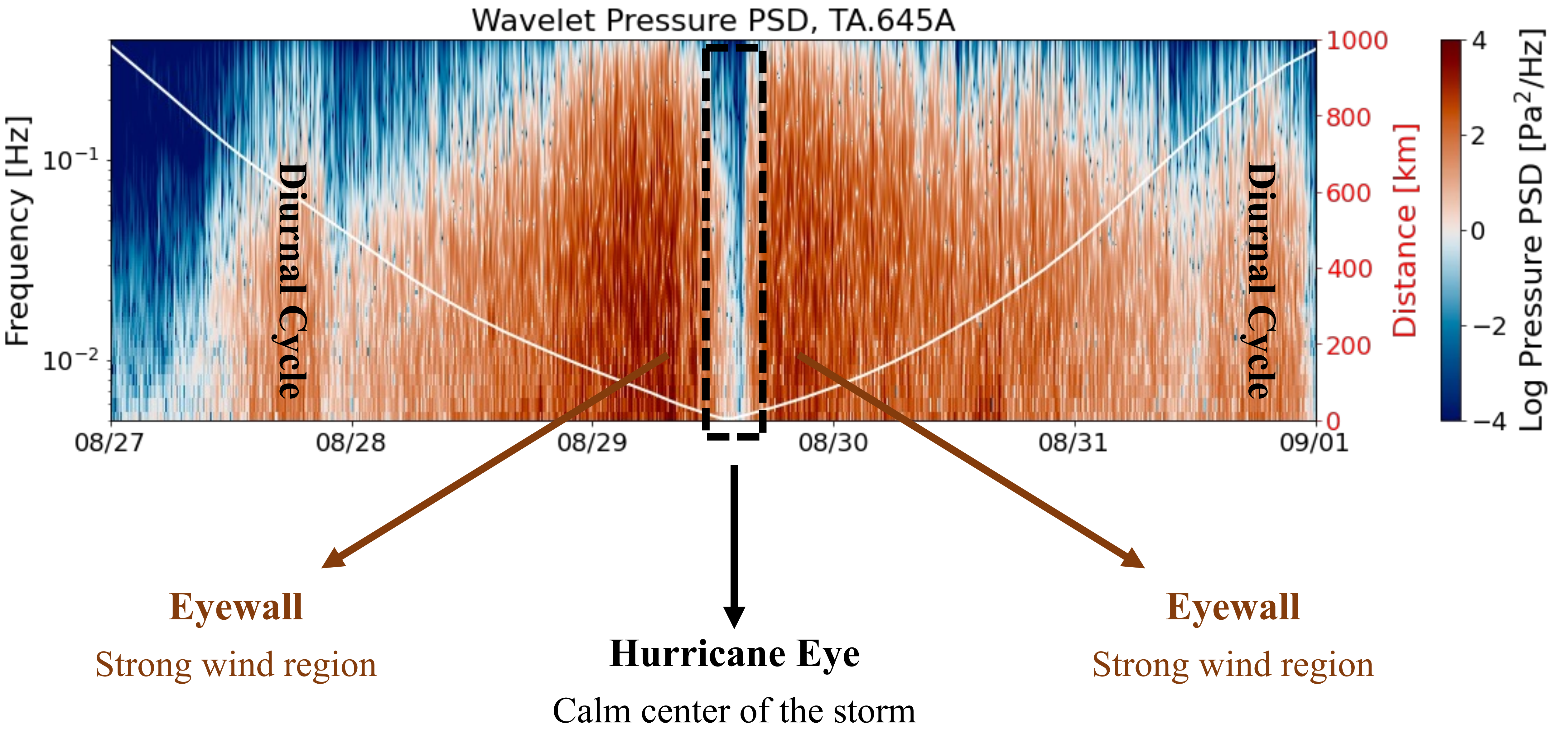


Local contribution is sufficient

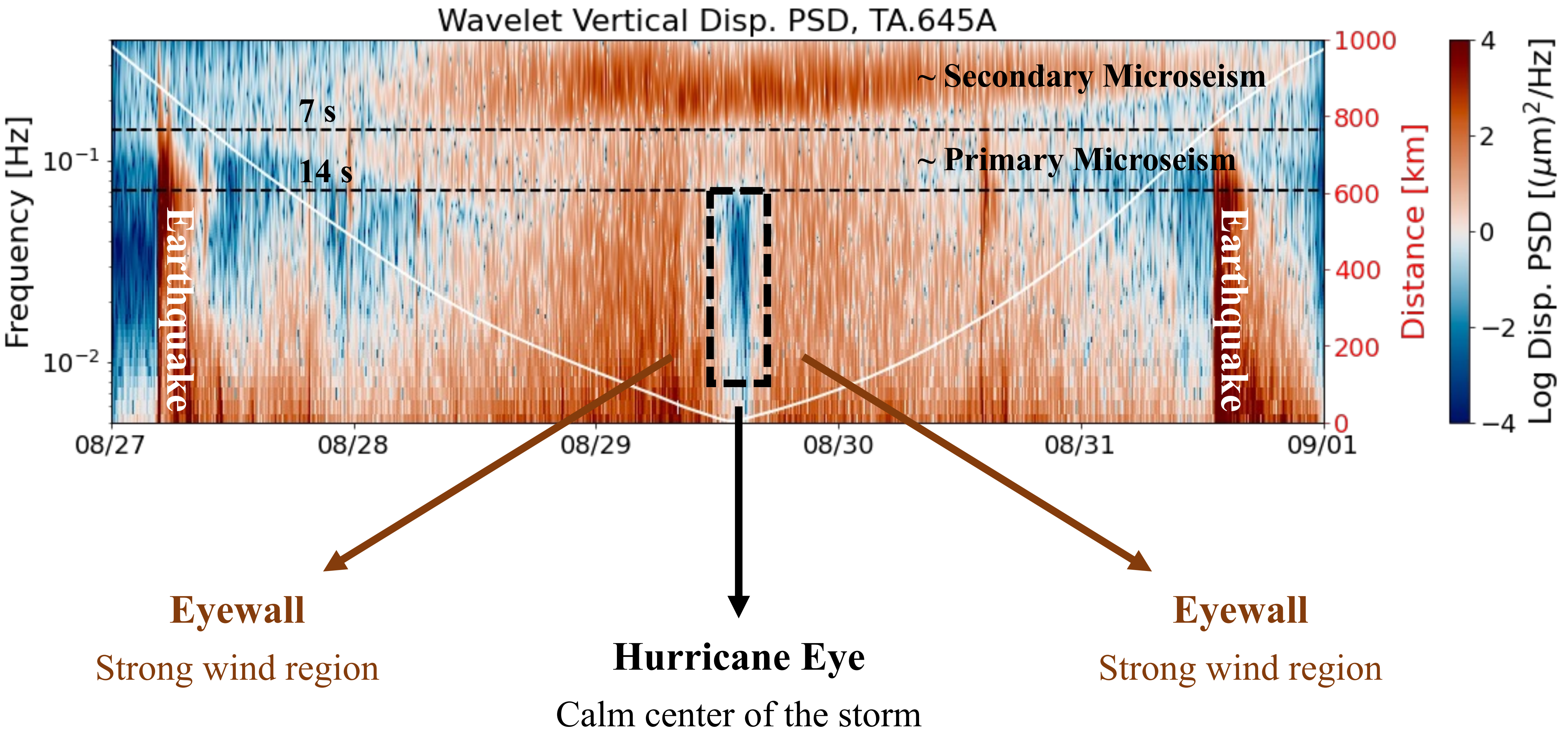
Time-frequency analysis using wavelet transform

Analyze wavelet power spectral density (PSD) for pressure and vertical displacement at one station





Wavelet Pressure PSD, TA.645A
Frequency [Hz]
10^{-1}
10^{-2}
Distance [km]
1000
800
600
400
200
0
Log Pressure PSD [Pa^2/Hz]
4
2
0
−2
−4
08/27
08/28
08/29
08/30
08/31
09/01
Diurnal Cycle
Diurnal Cycle
Eyewall
Strong wind region
Hurricane Eye
Calm center of the storm
Eyewall
Strong wind region


Wavelet Vertical Disp. PSD, TA.645A
Frequency [Hz]
10^{-1}
10^{-2}
08/27
08/28
08/29
08/30
08/31
09/01
1000
800
600
400
200
0
Distance [km]
Log Disp. PSD [(μm)^2/Hz]
4
2
0
−2
−4
7 s
14 s
~ Secondary Microseism
~ Primary Microseism
Earthquake
Earthquake
Eyewall
Strong wind region
Hurricane Eye
Calm center of the storm
Eyewall
Strong wind region

Hurricane Isaac in Aug. 2012

Analyze time snapshot at Aug. 30, UTC 00:00

Variation of PSDs with distance from the hurricane center

Numerical Modeling

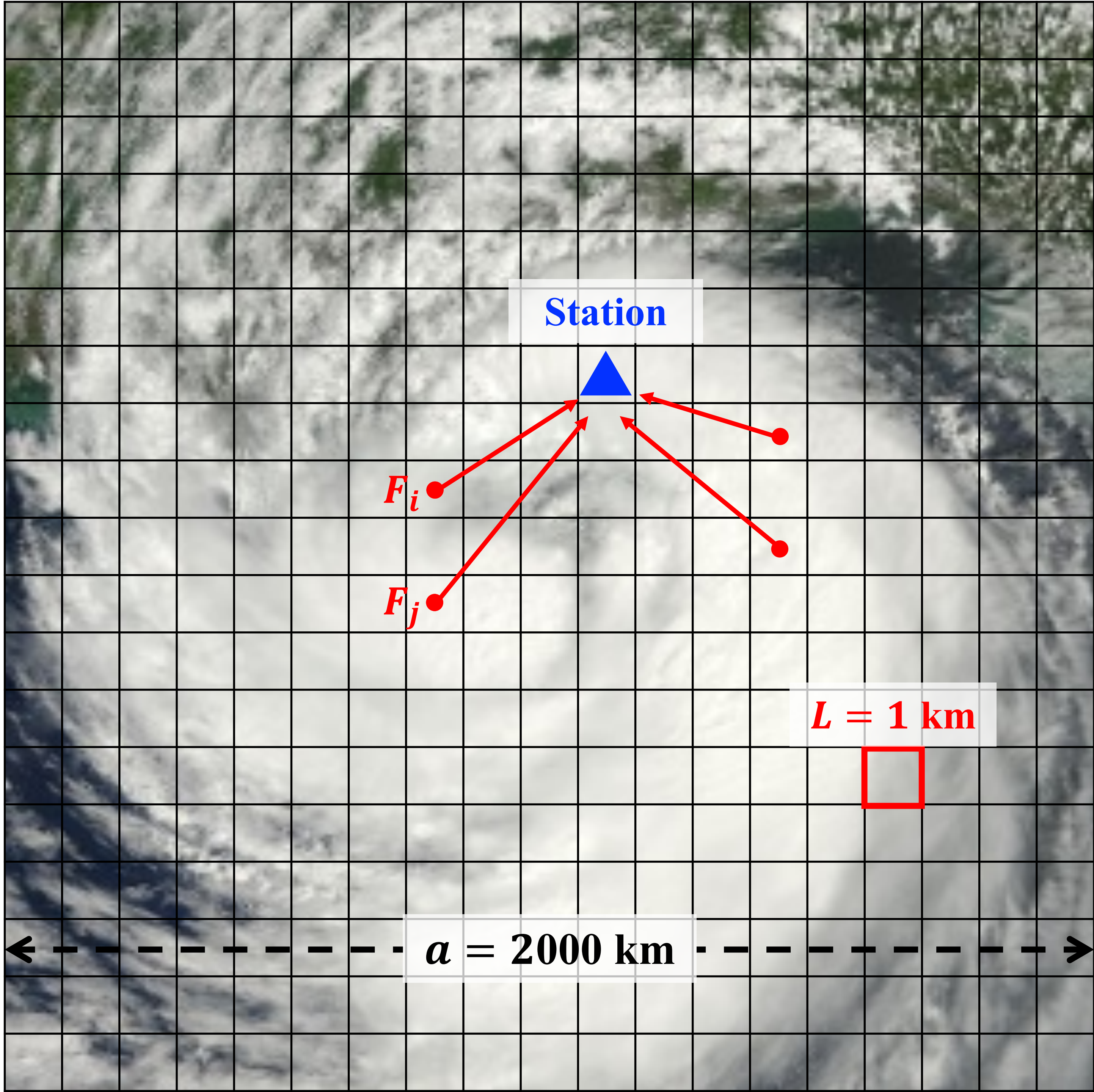
Pressure ⟶ Vertical Displacement

Discretized into 1 km × 1 km grids

Within each grid, pressure fluctuations are coherent (correlation length $L = 1$ km).

We represent it with a vertical point force

Forces from different grids are uncorrelated



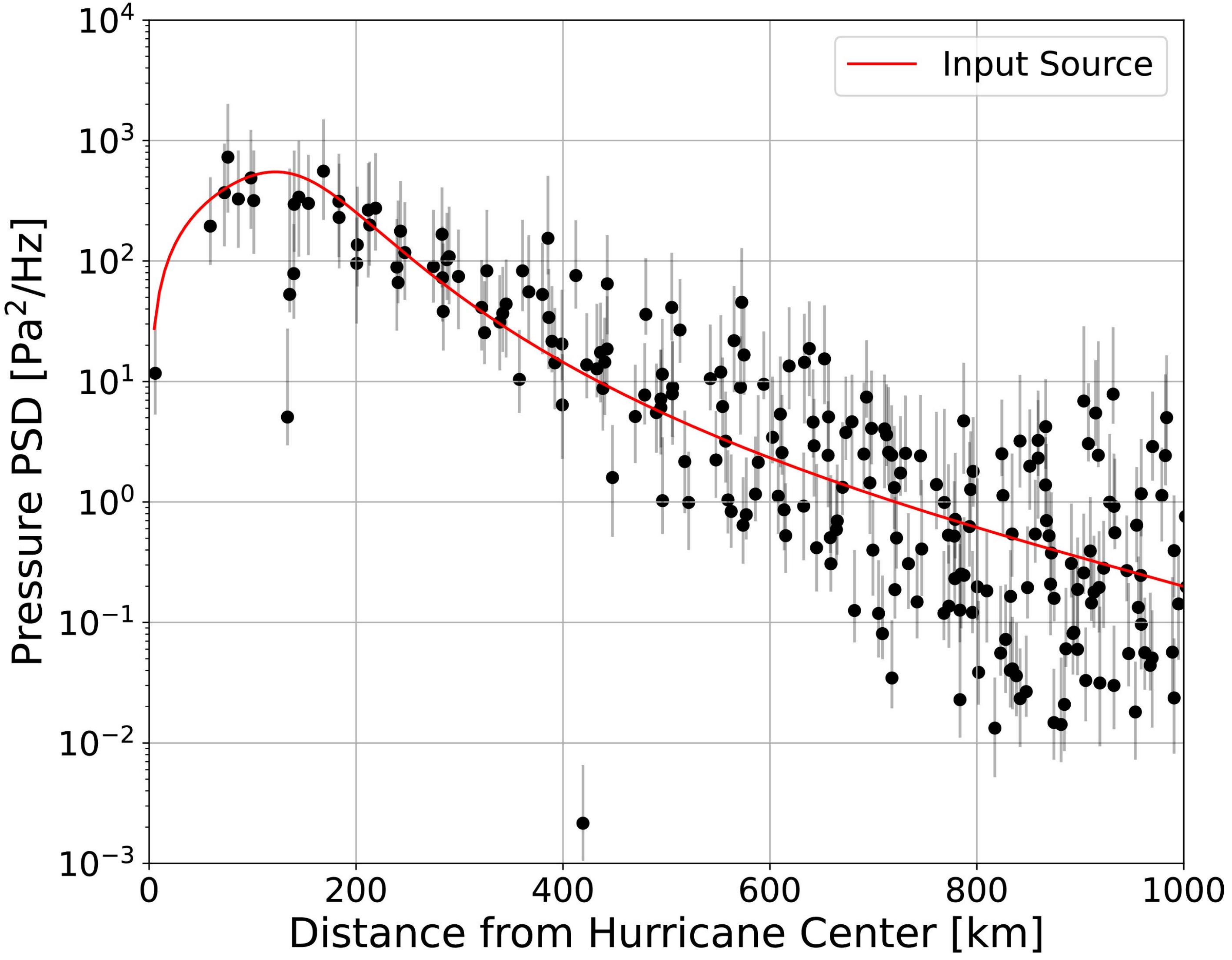
Numerical Modeling

$$S_z(\boldsymbol{x}_R, \omega) = \sum_{i=1}^{N(L)} \left|\tilde{G}(\boldsymbol{x}_R, \omega; \boldsymbol{x}_i)\right|^2 S_p(\boldsymbol{x}_i, \omega)\, L^4$$

Input Pressure PSD: $S_p(\boldsymbol{x}_i, \omega)$

- Median and inter-quartile range obtained from 1-hr wavelet PSD
- Fit with a parametric profile from hurricane study (Morris & Ruf 2017)
- Assume **axi-symmetric** source

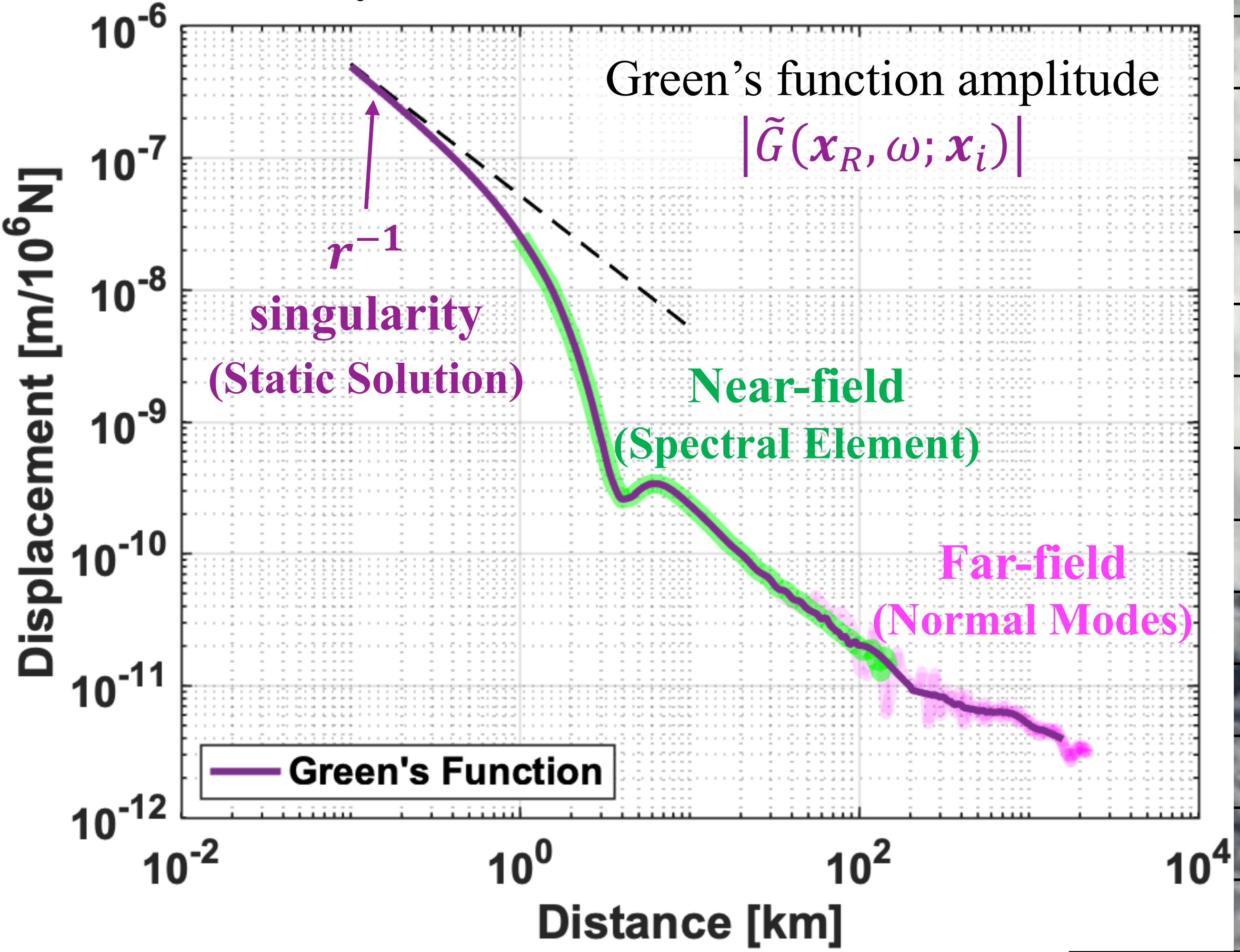
Time snapshot at Aug. 30, UTC 00

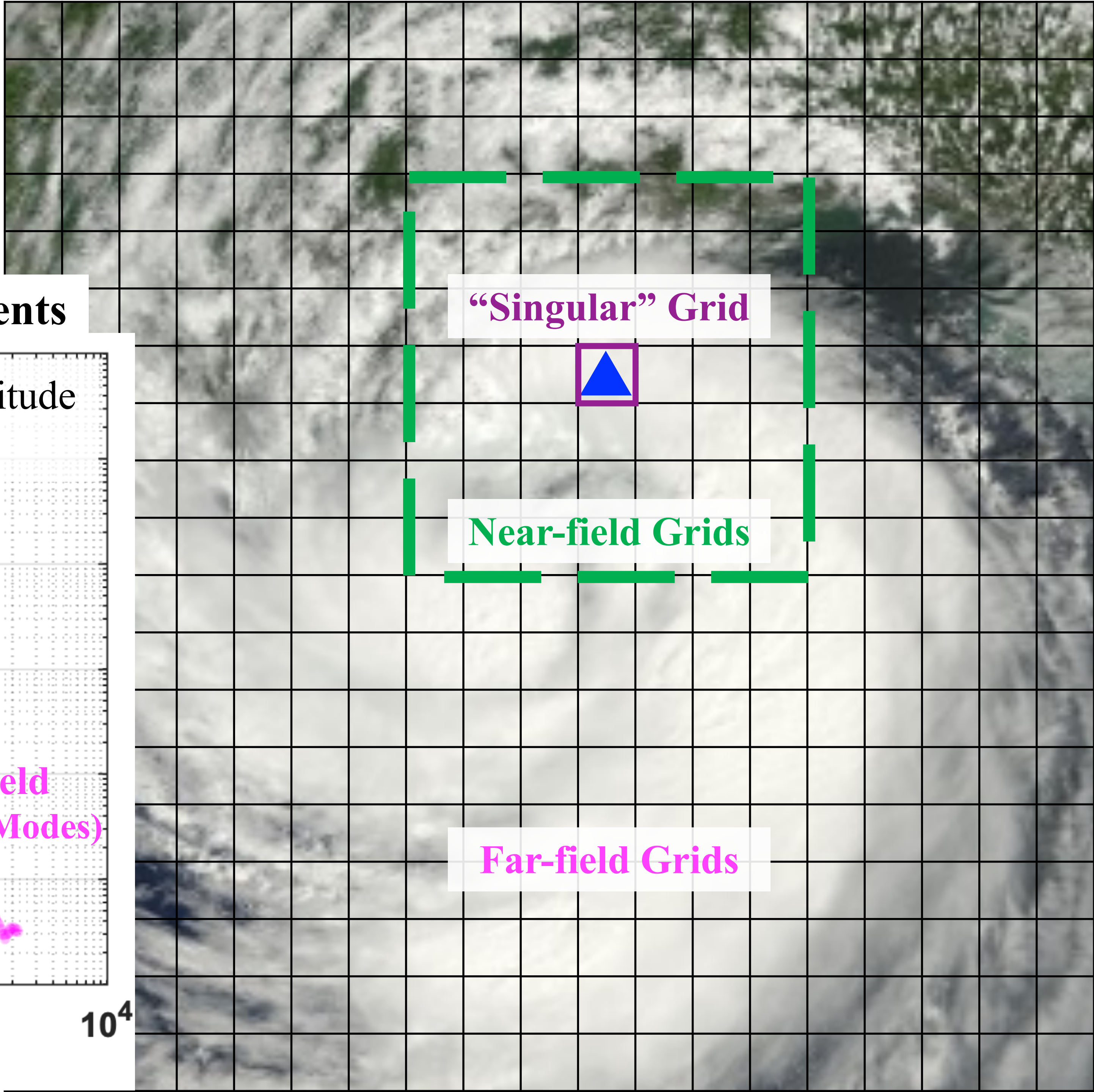


Numerical Modeling

$$S_z(\boldsymbol{x}_R,\omega) = \sum_{i=1}^{N(L)} \left|\tilde{G}(\boldsymbol{x}_R,\omega;\boldsymbol{x}_i)\right|^2 S_p(\boldsymbol{x}_i,\omega)\, L^4$$

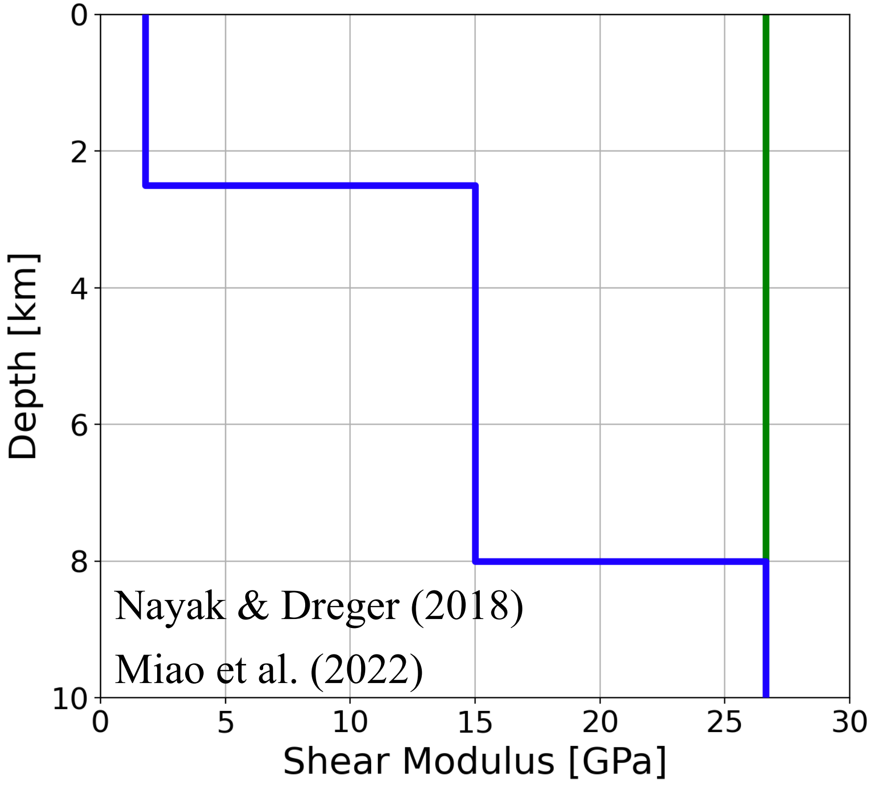
1D layered model: PREM + Sediments

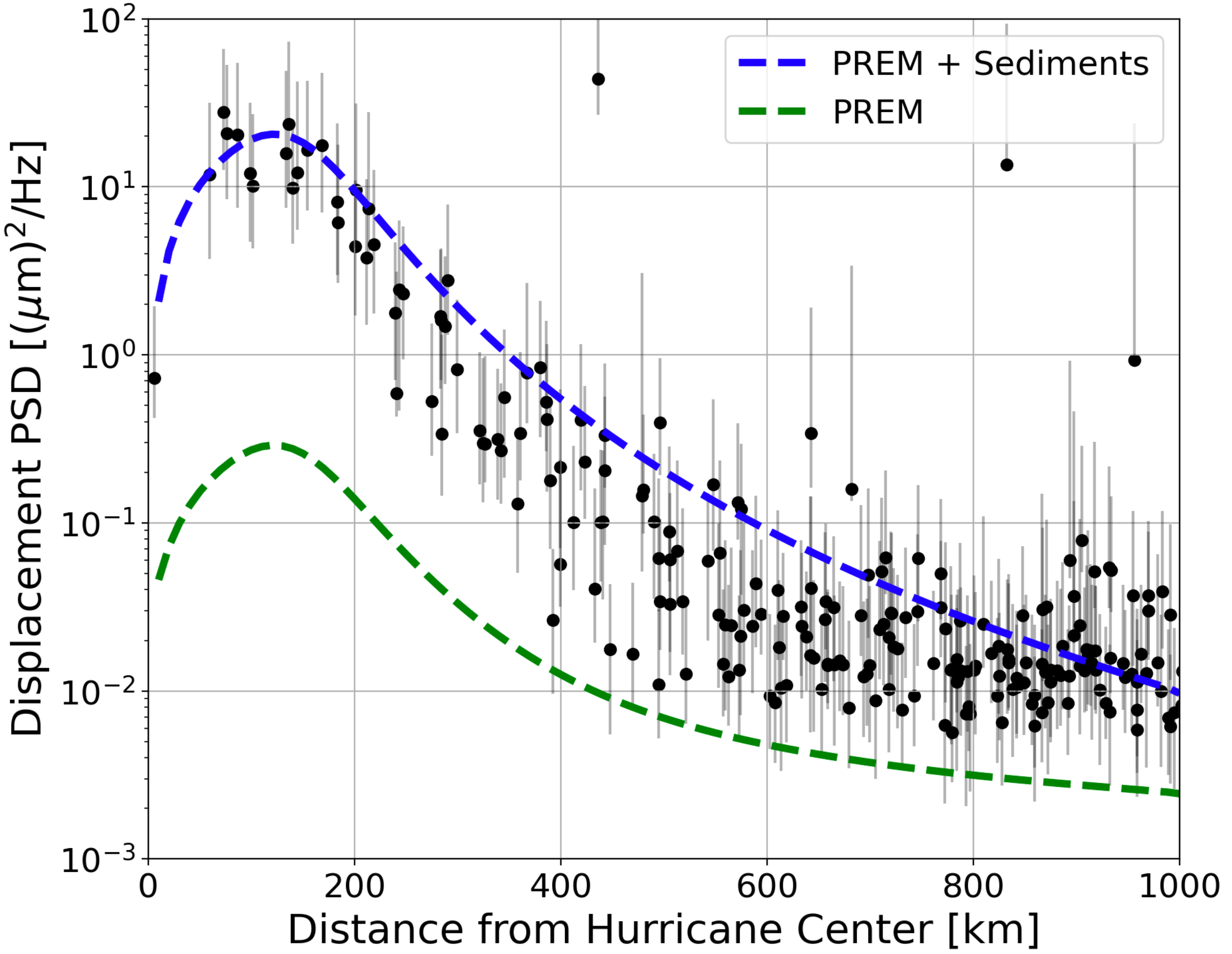




Results of Numerical Modeling

Shallow compliant sediment layers are needed to explain the amplitude of seismic signal

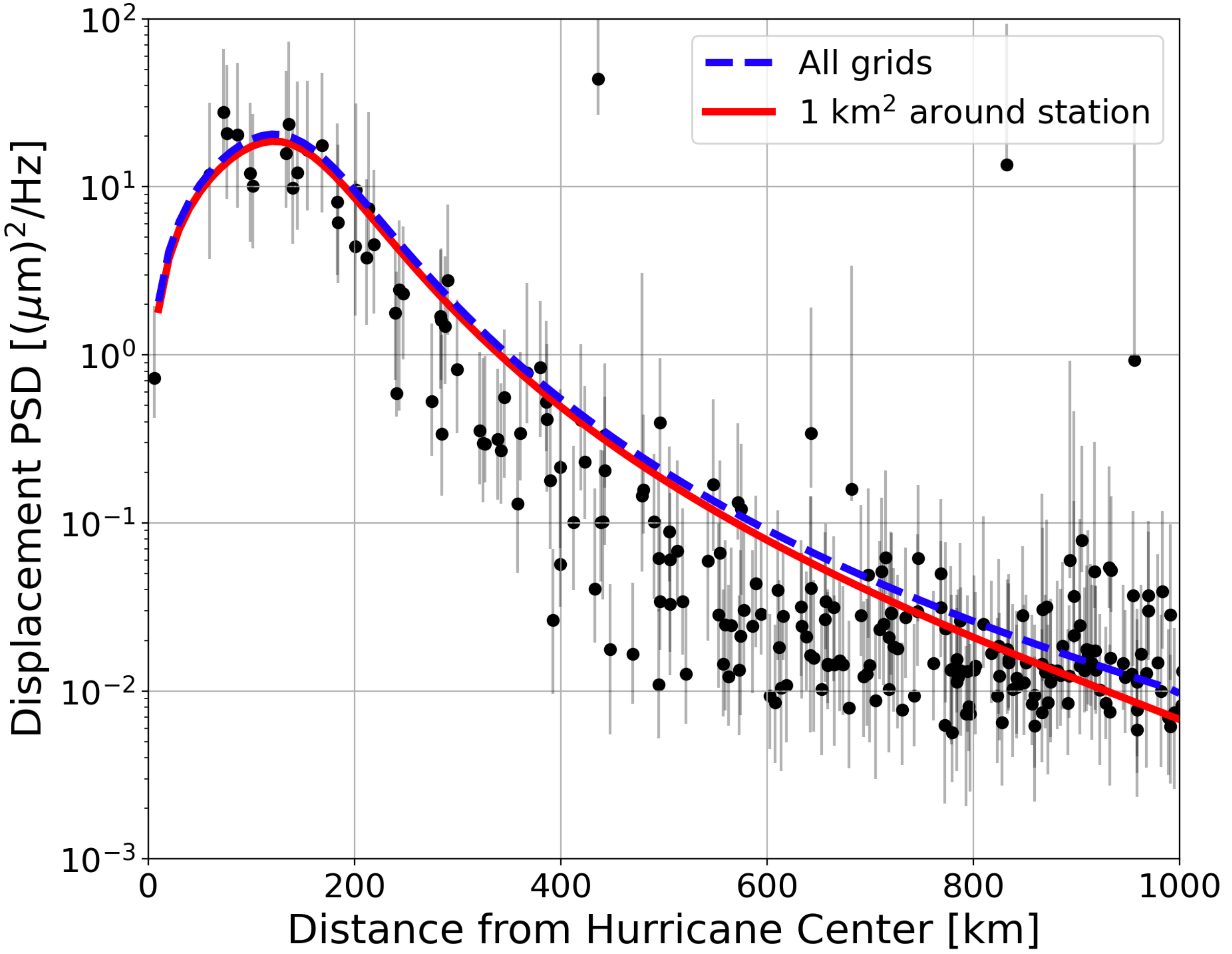




Results of Numerical Modeling

Nearest 1 km^2 grid around station contributes ~ 90 % vertical displacement PSD

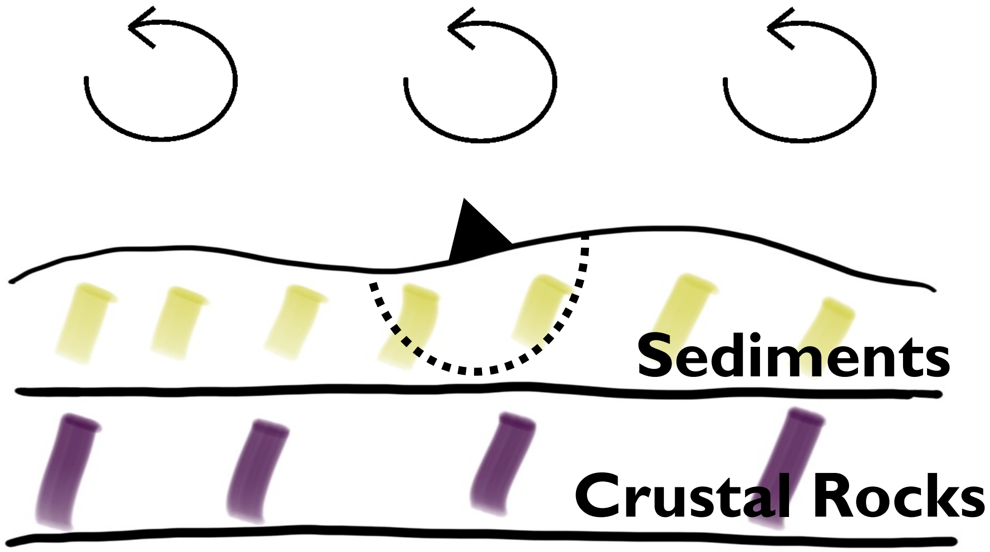
Better data fit can be obtained by assuming smaller correlation length at large distance (Tanimoto & Valovcin, 2015)



Two Key Points

Seismic observations are dominated by local coupling (~ 1 km potentially related to turbulent structures) between the atmosphere and the solid Earth.

Important to include the shallow compliant sediment layers



Caveat & Prospect

Trade-off between correlation length scale and topmost layer properties

Hurricane modeling and observation could better constrain the correlation structure of pressure field and its relationship with turbulence, e.g. roll vortices (Foster, 2005)