Turbulent seismoacoustic signals from a hurricane landfall

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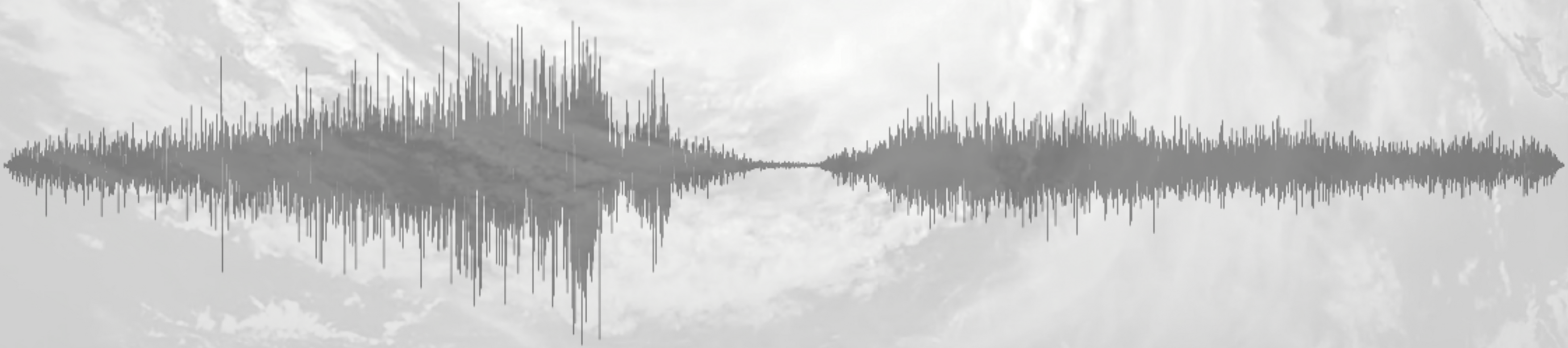
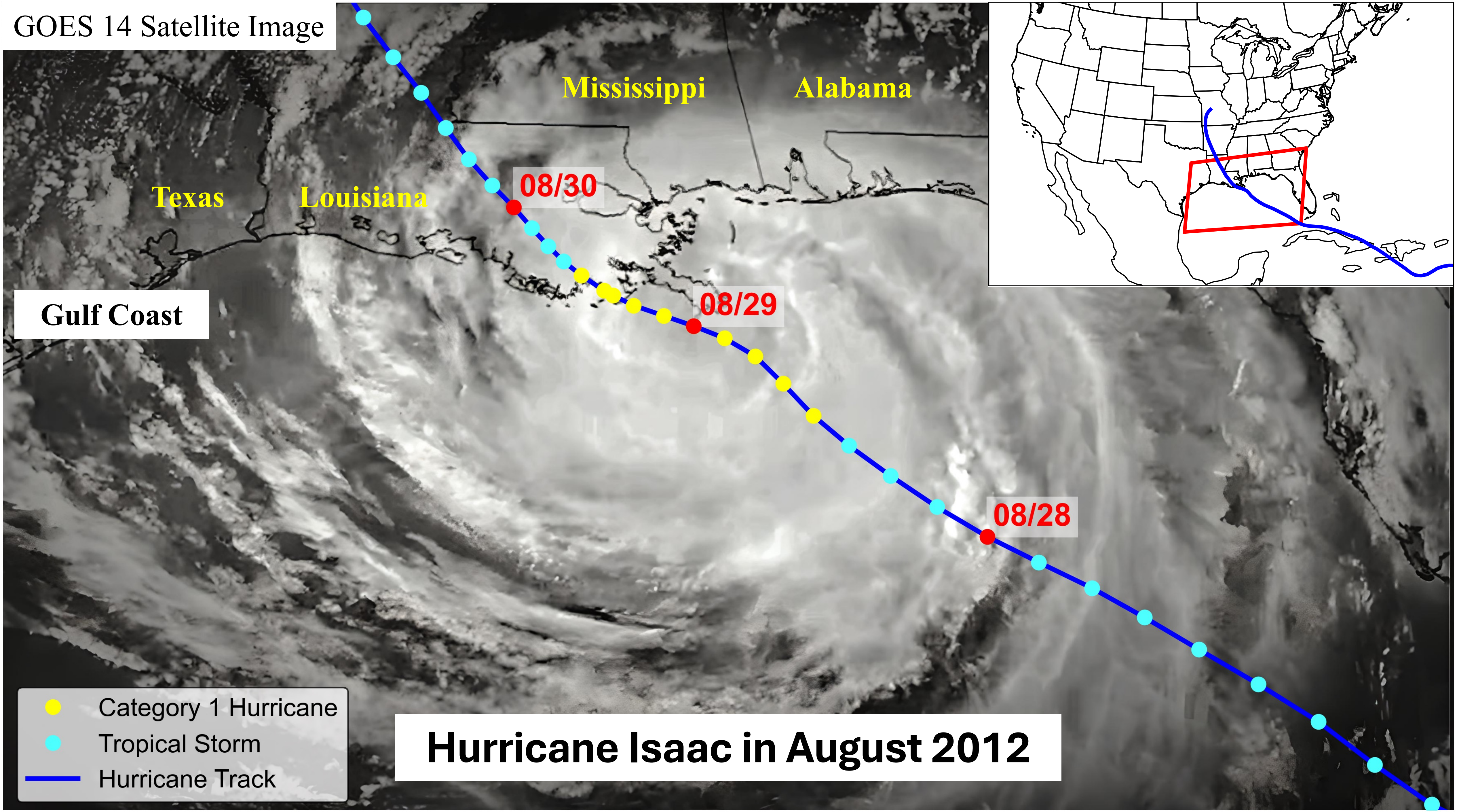
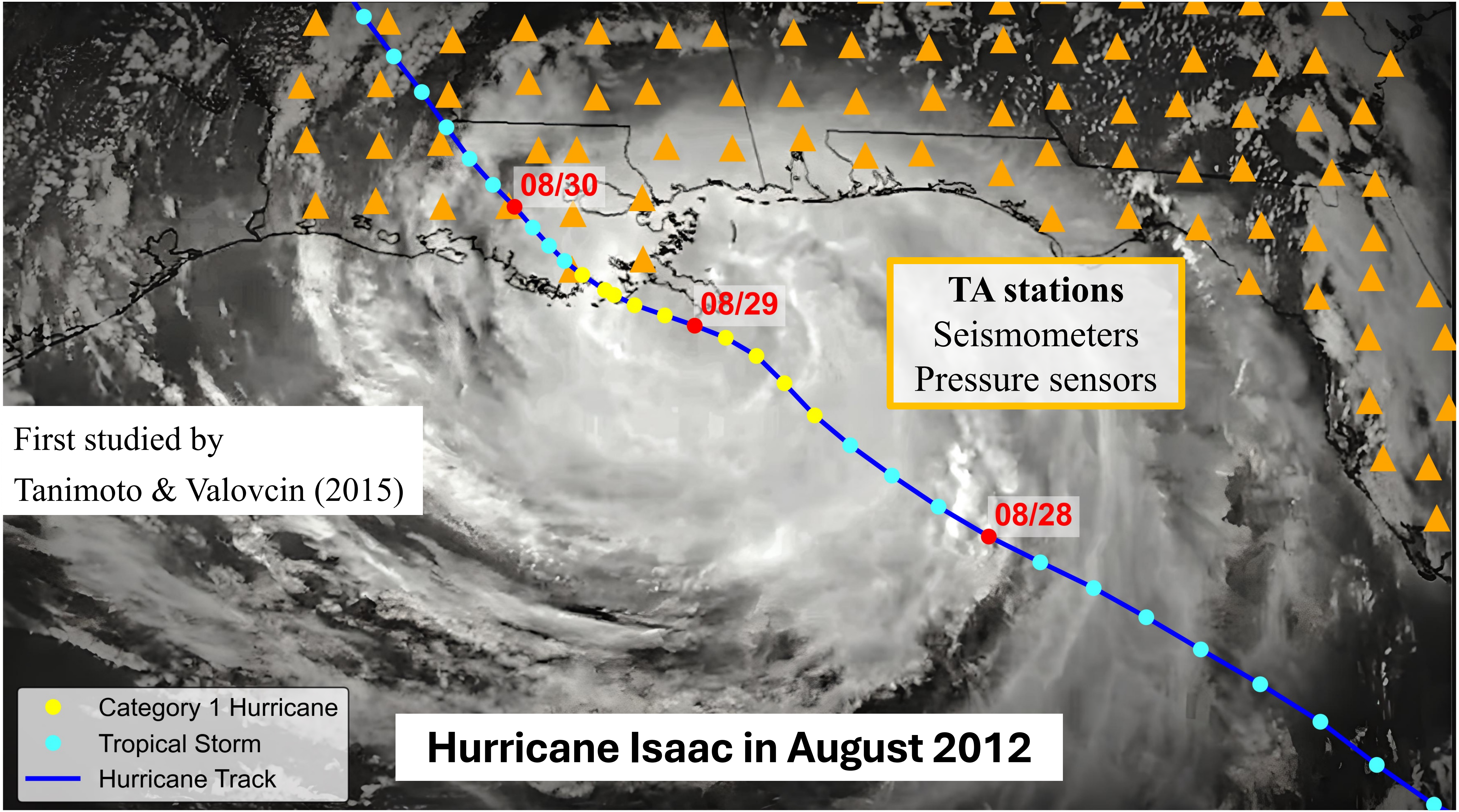
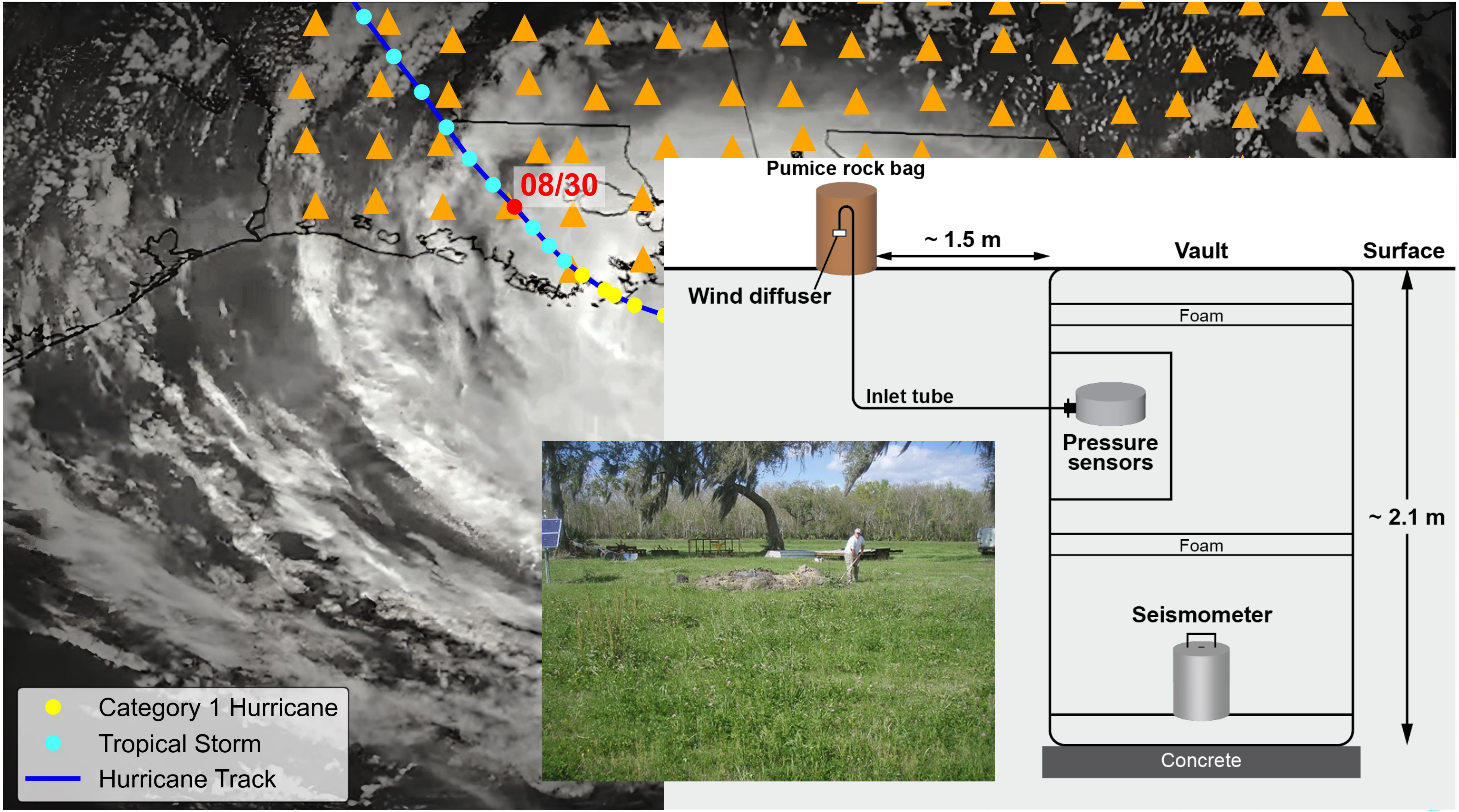
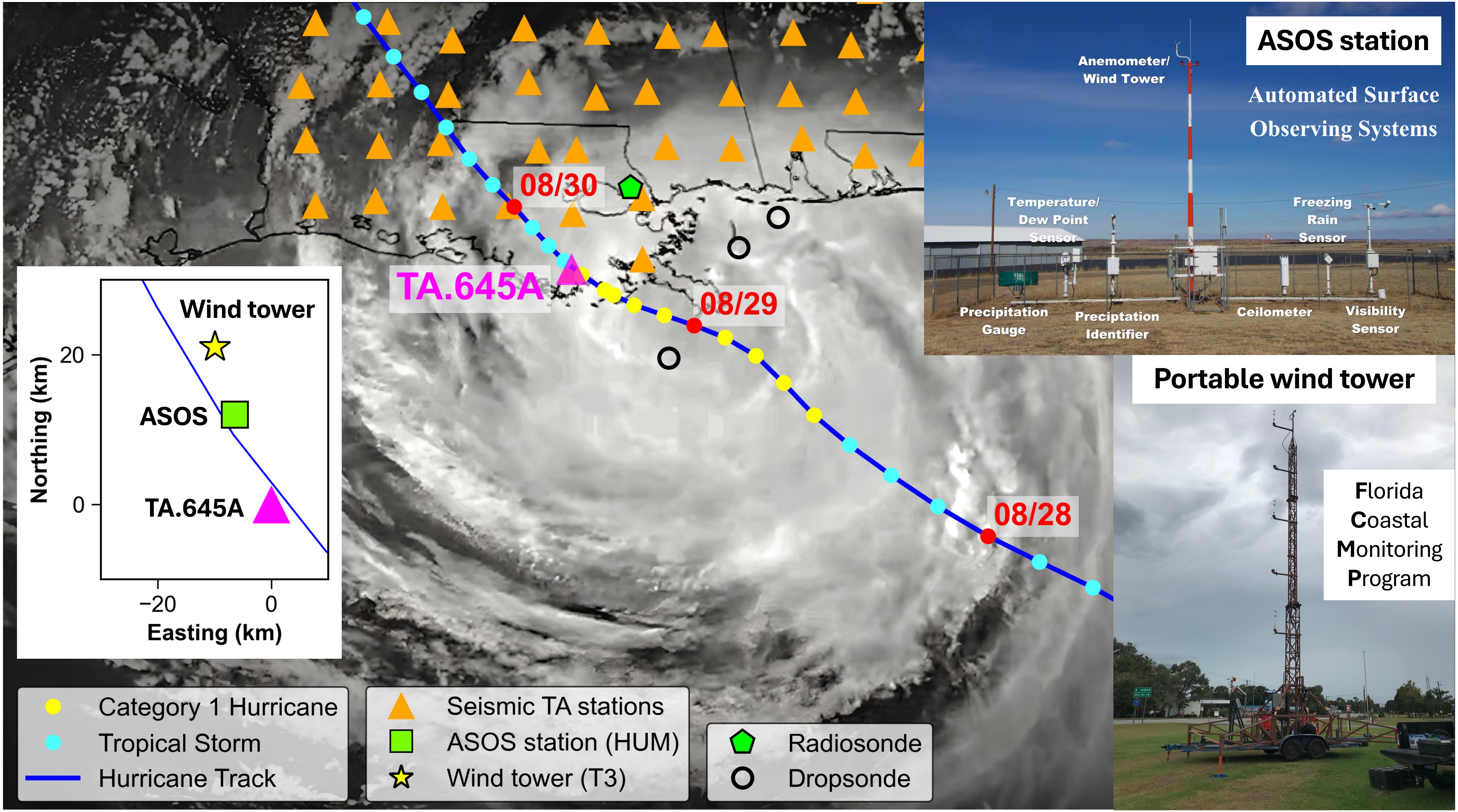



GOES 14 Satellite Image
Mississippi
Alabama
Texas
Louisiana
08/30
08/29
08/28
Gulf Coast
Category 1 Hurricane
Tropical Storm
Hurricane Track
Hurricane Isaac in August 2012


08/30
08/29
08/28
TA stations
Seismometers
Pressure sensors
First studied by
Tanimoto & Valovcin (2015)
Category 1 Hurricane
Tropical Storm
Hurricane Track
Hurricane Isaac in August 2012

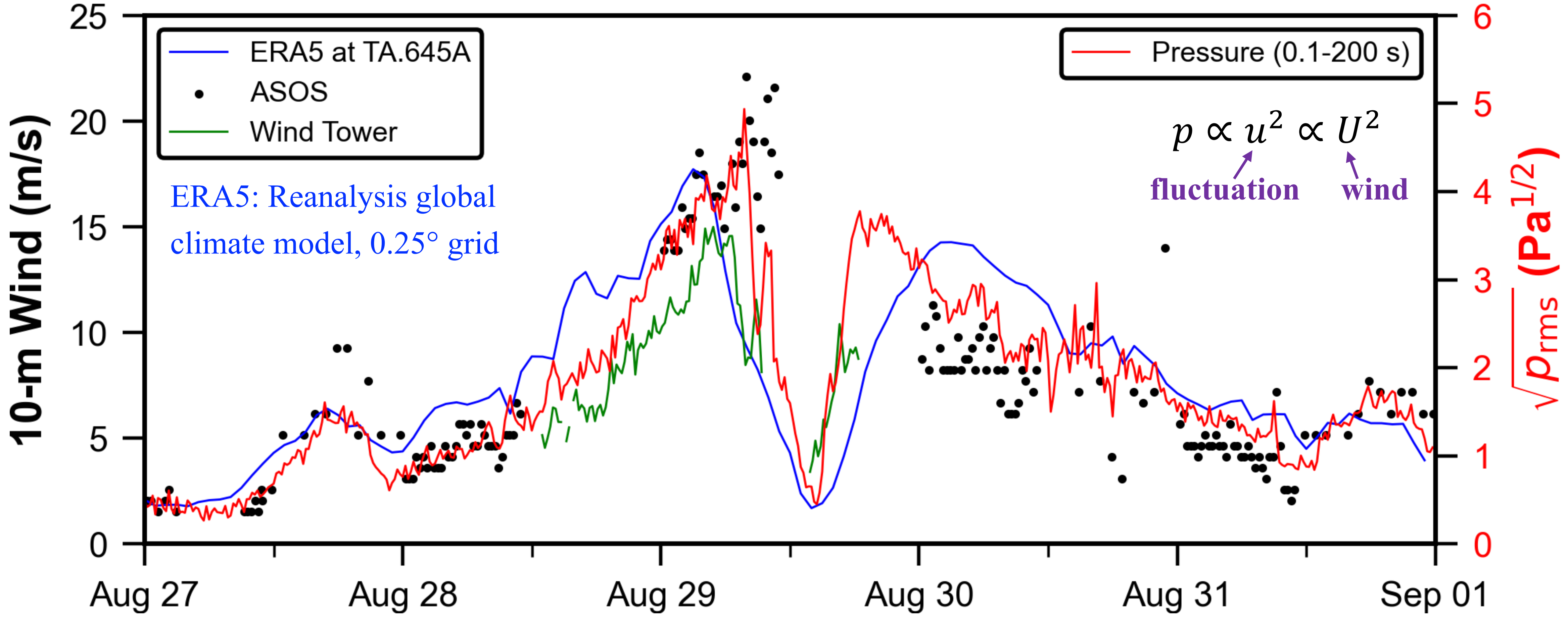


08/30
Category 1 Hurricane
Tropical Storm
Hurricane Track
Pumice rock bag
~ 1.5 m
Vault
Surface
Wind diffuser
Foam
Inlet tube
Pressure sensors
~ 2.1 m
Foam
Seismometer
Concrete



08/30
08/29
08/28
TA.645A
Wind tower
ASOS
TA.645A
Northing (km)
20
0
−20
0
Easting (km)
Category 1 Hurricane
Tropical Storm
Hurricane Track
Seismic TA stations
ASOS station (HUM)
Wind tower (T3)
Radiosonde
Dropsonde
ASOS station
Automated Surface Observing Systems
Anemometer/ Wind Tower
Temperature/ Dew Point Sensor
Freezing Rain Sensor
Precipitation Gauge
Preciptation Identifier
Ceilometer
Visibility Sensor
Portable wind tower
Florida Coastal Monitoring Program

Infrasound data for hurricane study

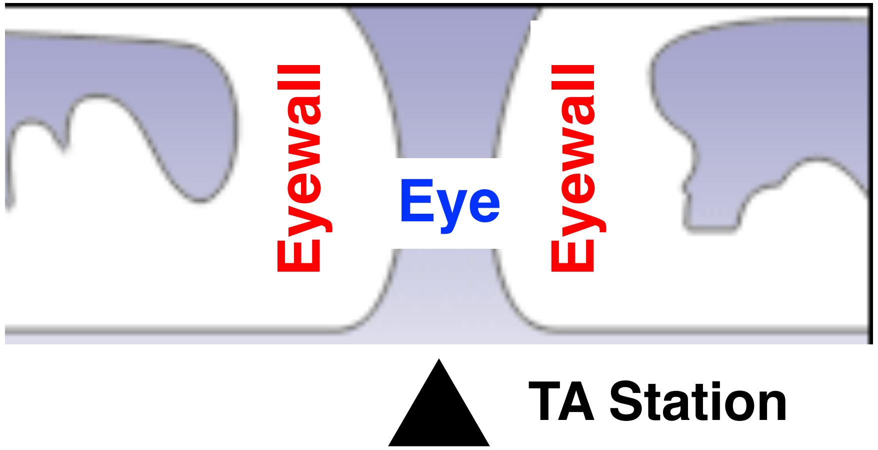


ASOS: Reports every 15 minutes

Wind tower: Sampling at 32 Hz

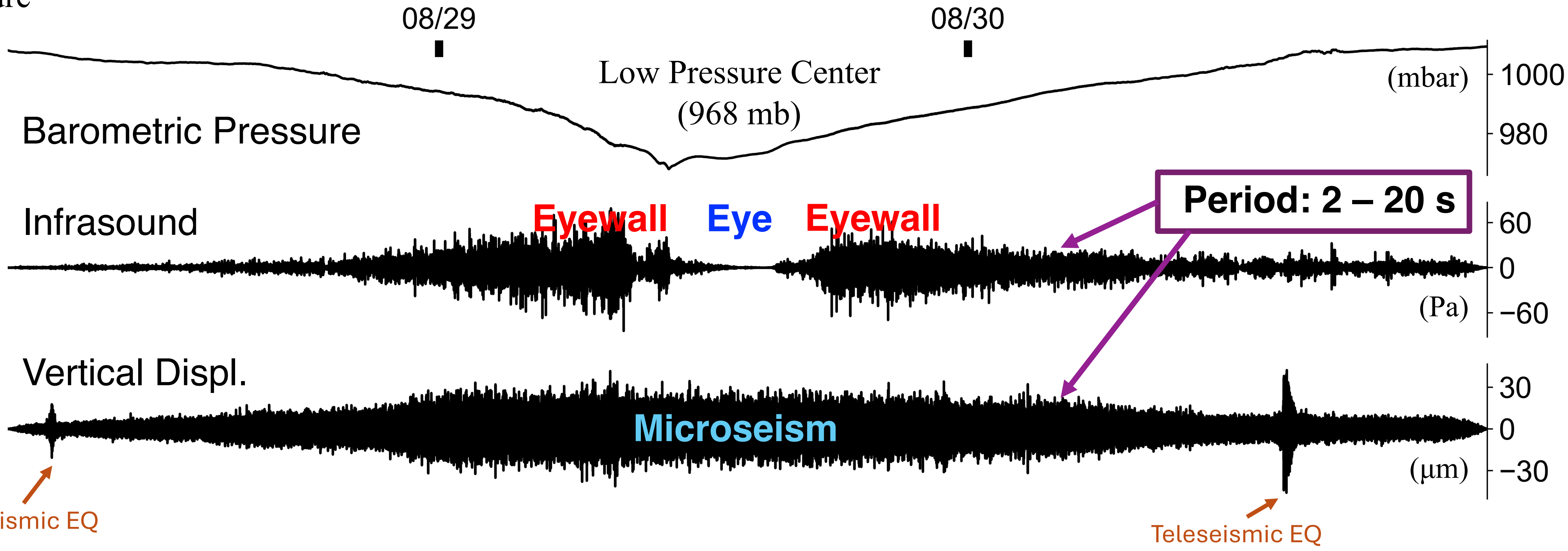
Potential: Continuous monitoring of the evolution of atmospheric quantities (e.g., wind speed, turbulence analysis, …)

As hurricane passes the station ......

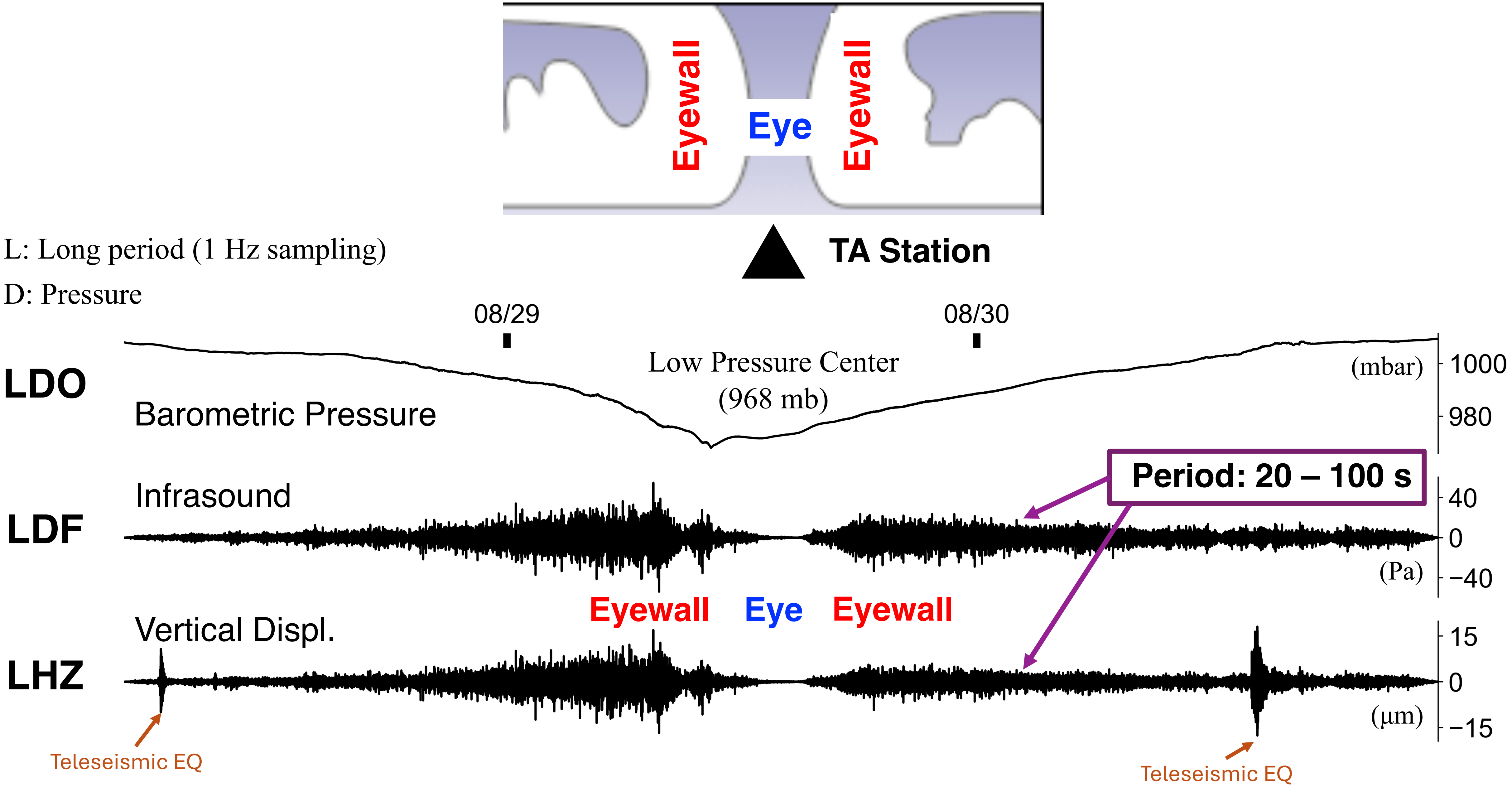


L: Long period channel

D: Pressure



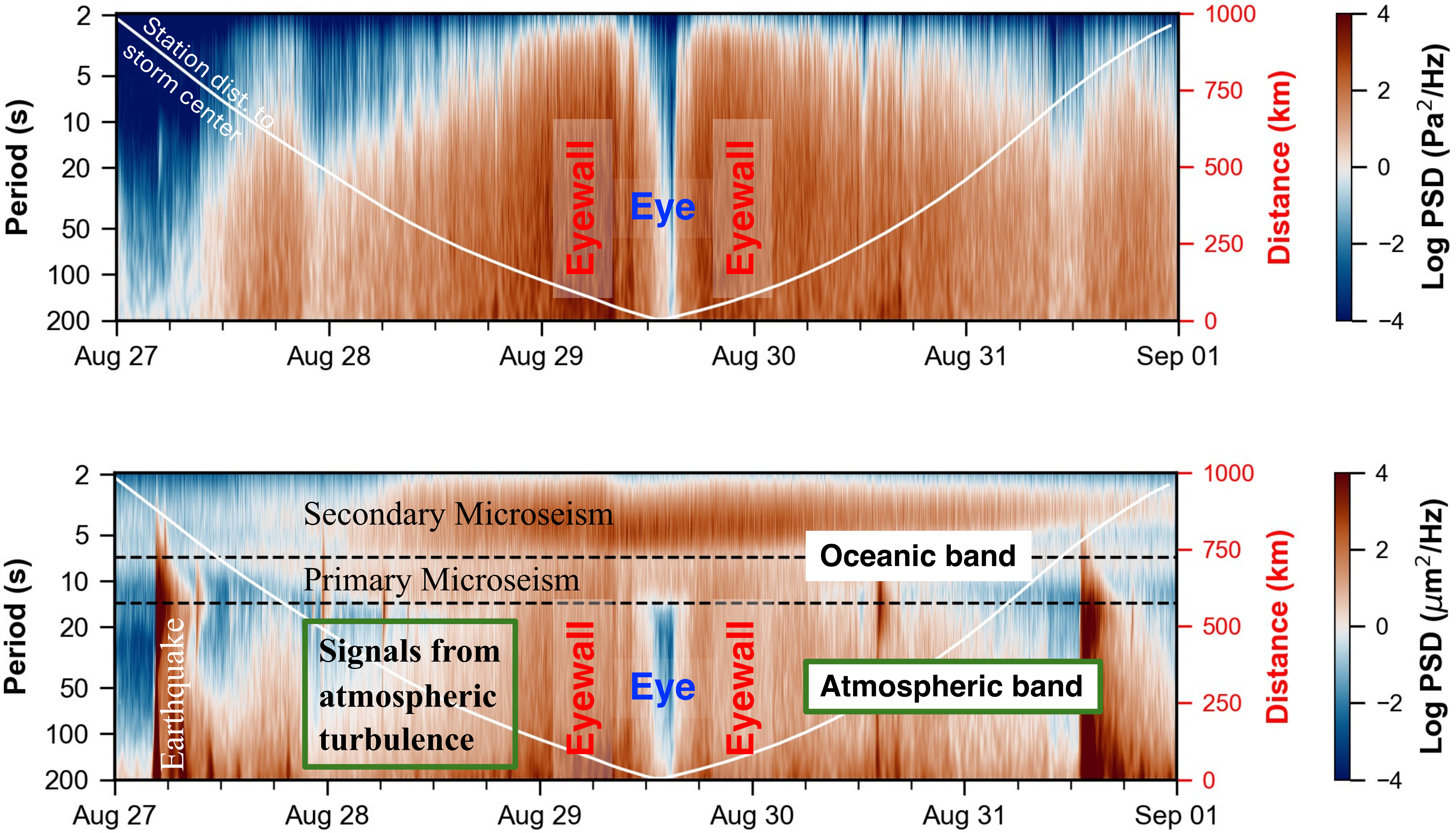
As hurricane passes the station ……



Wavelet spectrograms of infrasound & seismic data

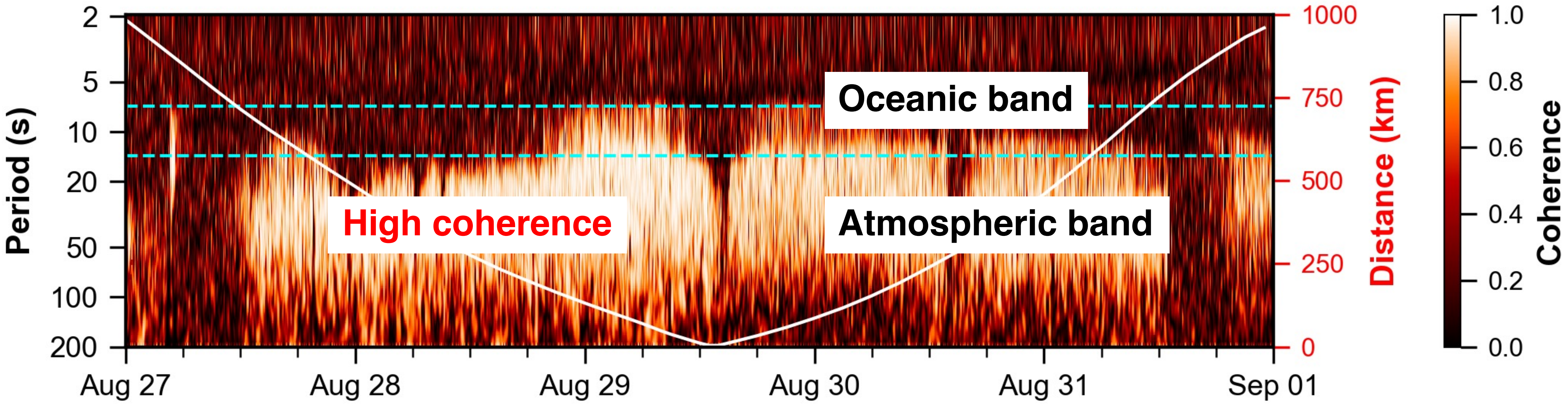
Surface Pressure

Seismic Vertical Displacement



Ji & Dunham (2024)

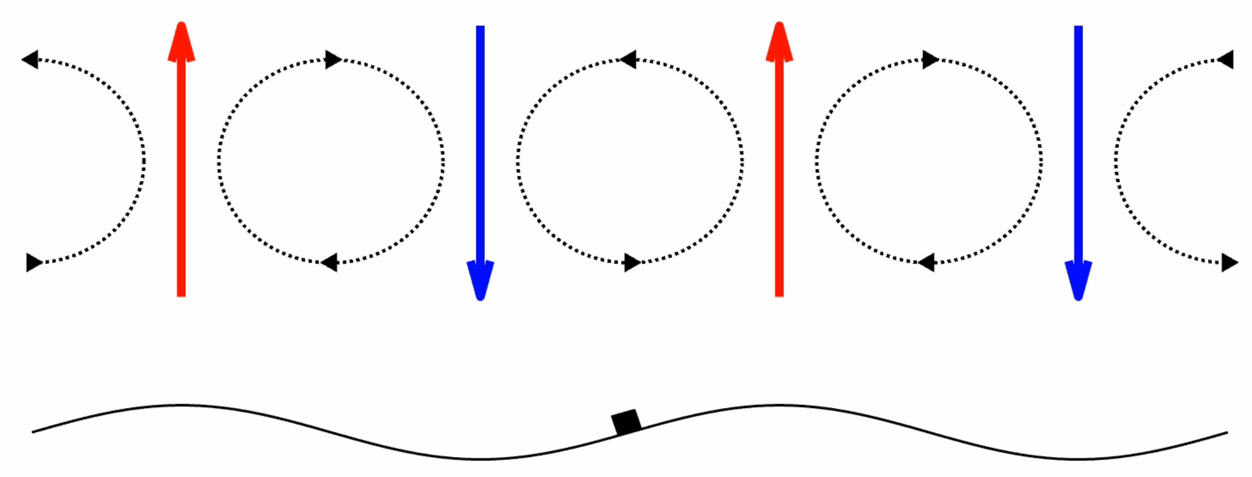
High coherence indicates local quasi-static response



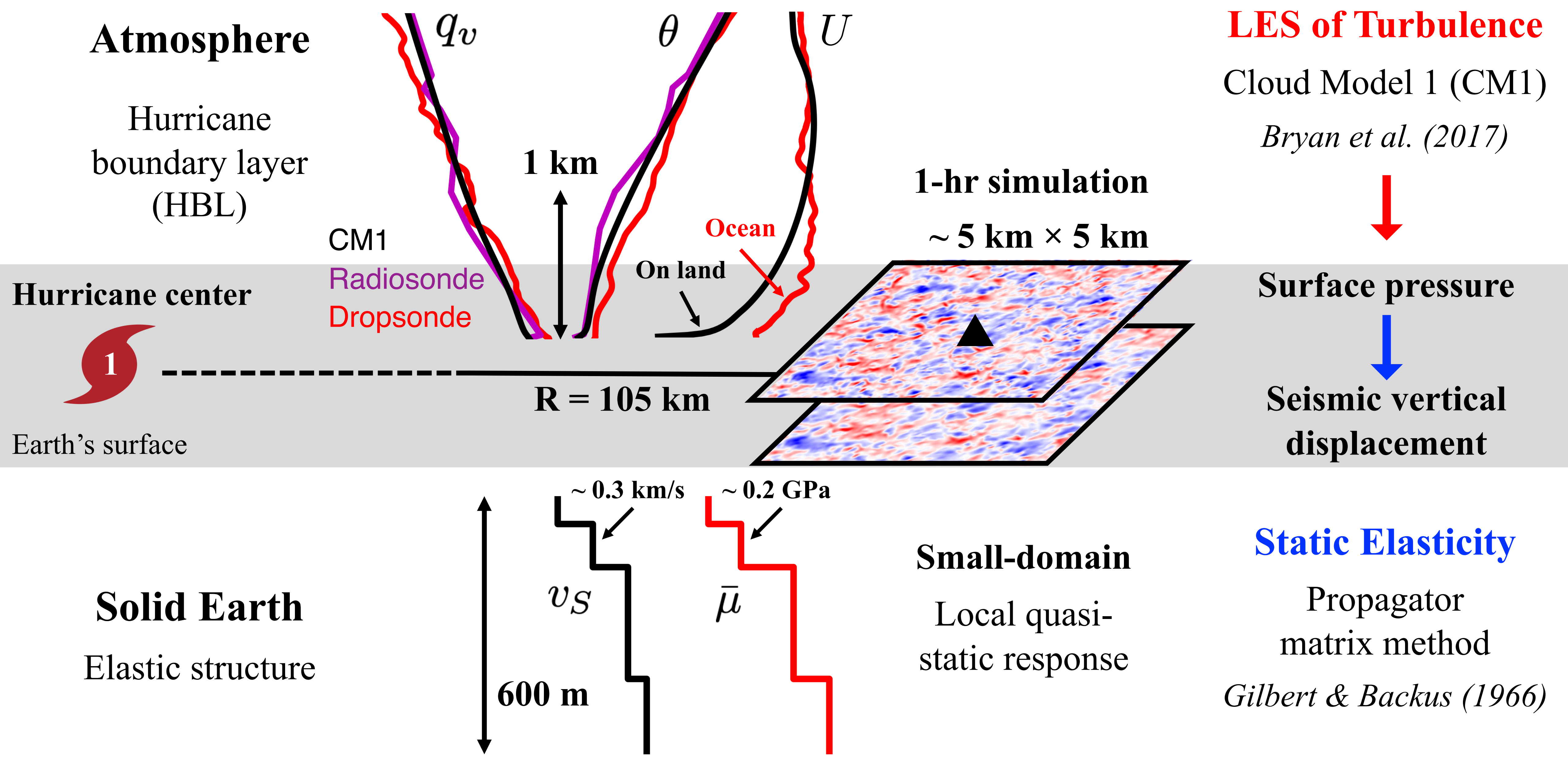
Simplified illustration

Sorrells (1971) theory

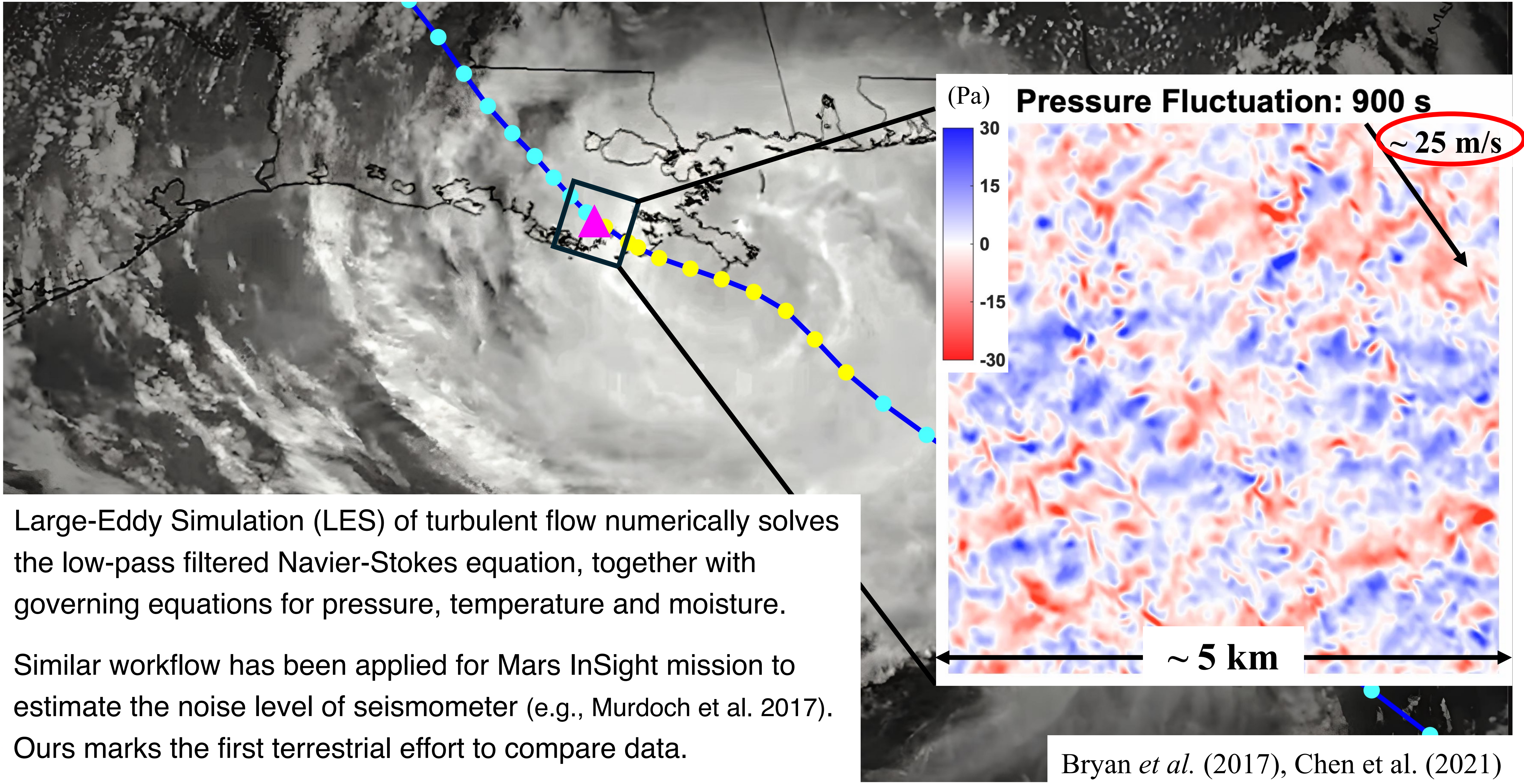
Pressure wave model



Interdisciplinary modeling



LES of Hurricane Boundary Layer (HBL) on land

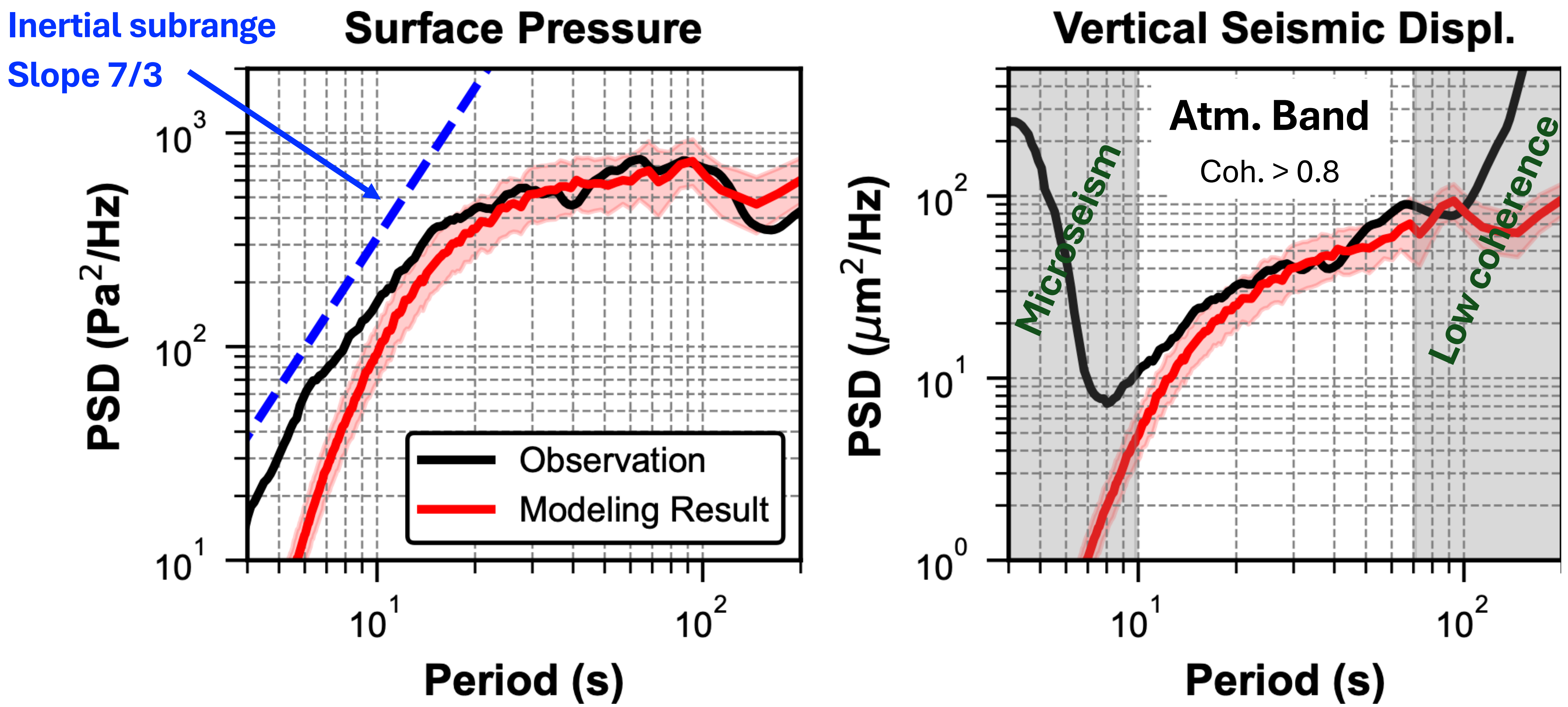


Large-Eddy Simulation (LES) of turbulent flow numerically solves the low-pass filtered Navier-Stokes equation, together with governing equations for pressure, temperature and moisture.

Similar workflow has been applied for Mars InSight mission to estimate the noise level of seismometer (e.g., Murdoch et al. 2017). Ours marks the first terrestrial effort to compare data.

Bryan *et al.* (2017), Chen et al. (2021)

Turbulent origin of signals

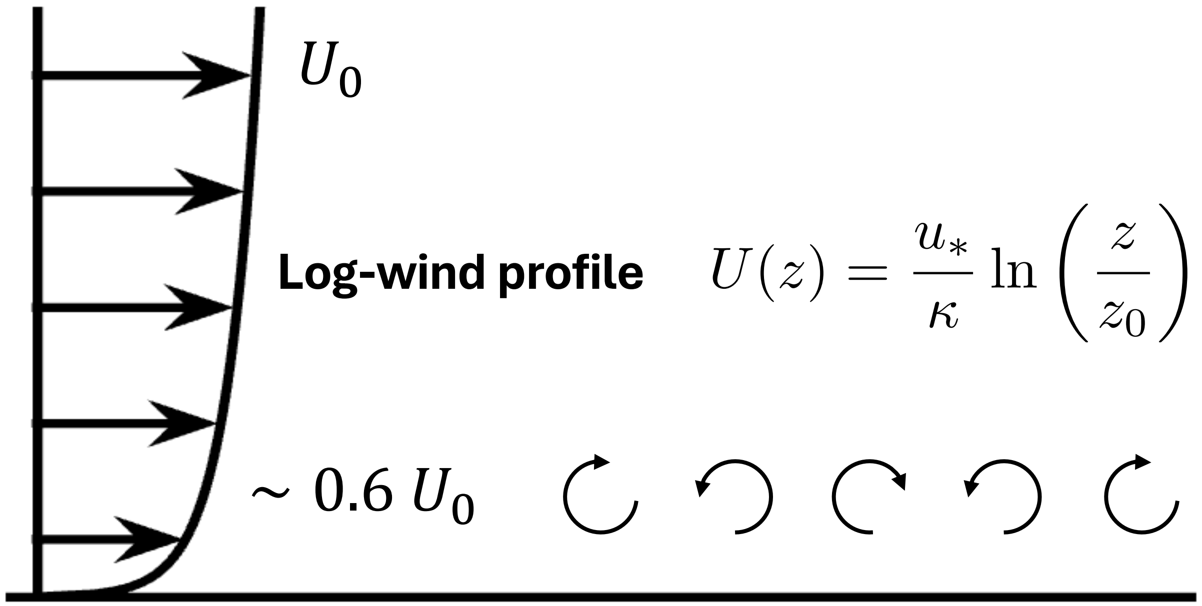


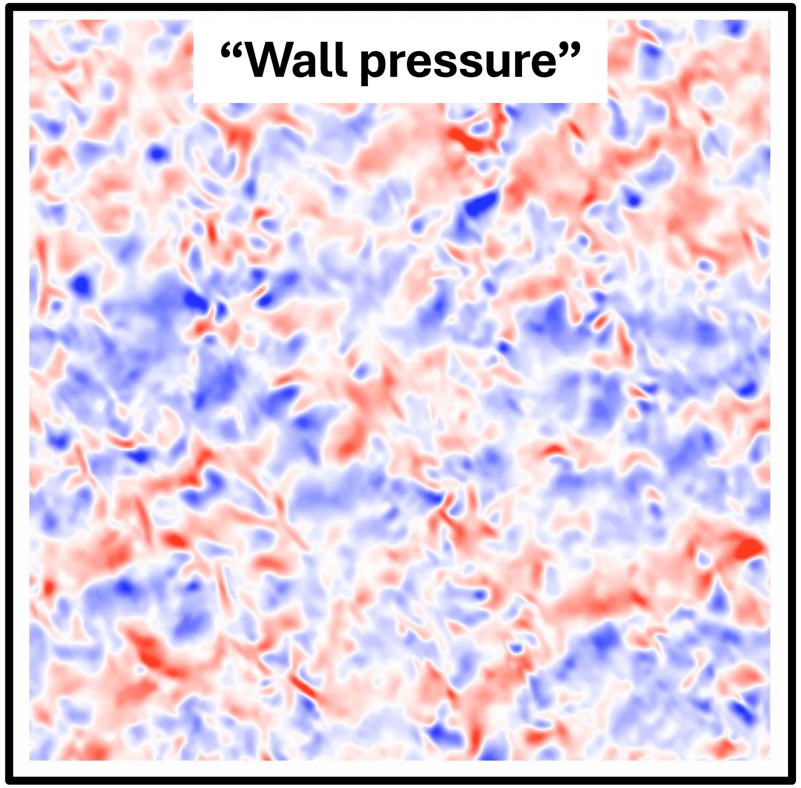
1. **Insights into Sorrells theory**
2. **Infrasound data for turbulence analysis**

Ji et al. (in revision)

Convection velocity of a turbulent field

Turbulent boundary layer





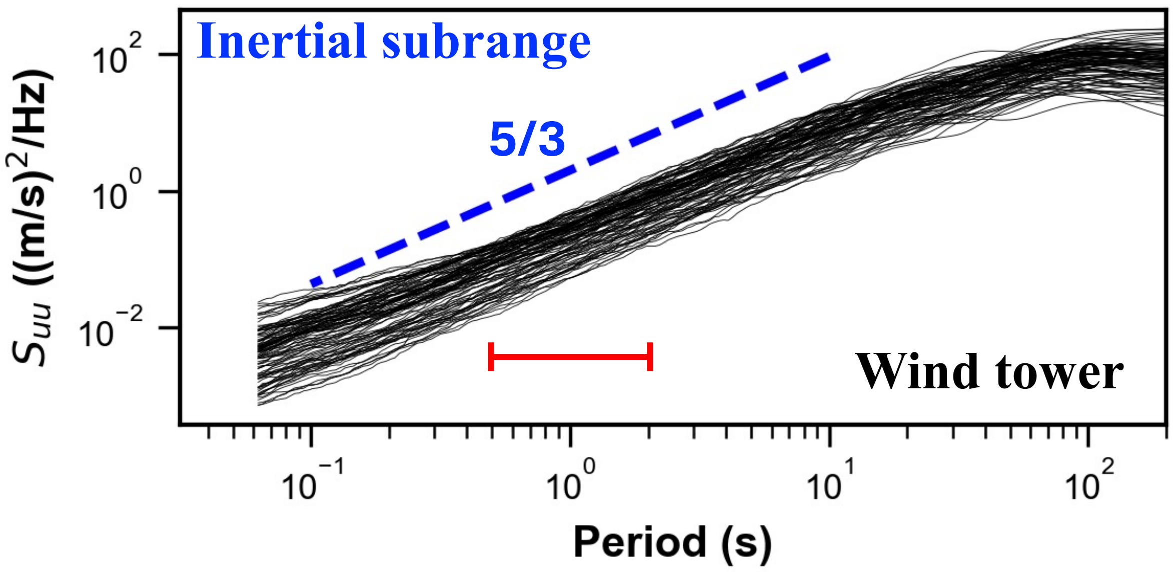
Velocity is zero at the wall, but wall stress / pressure advects with U_c (convection velocity)

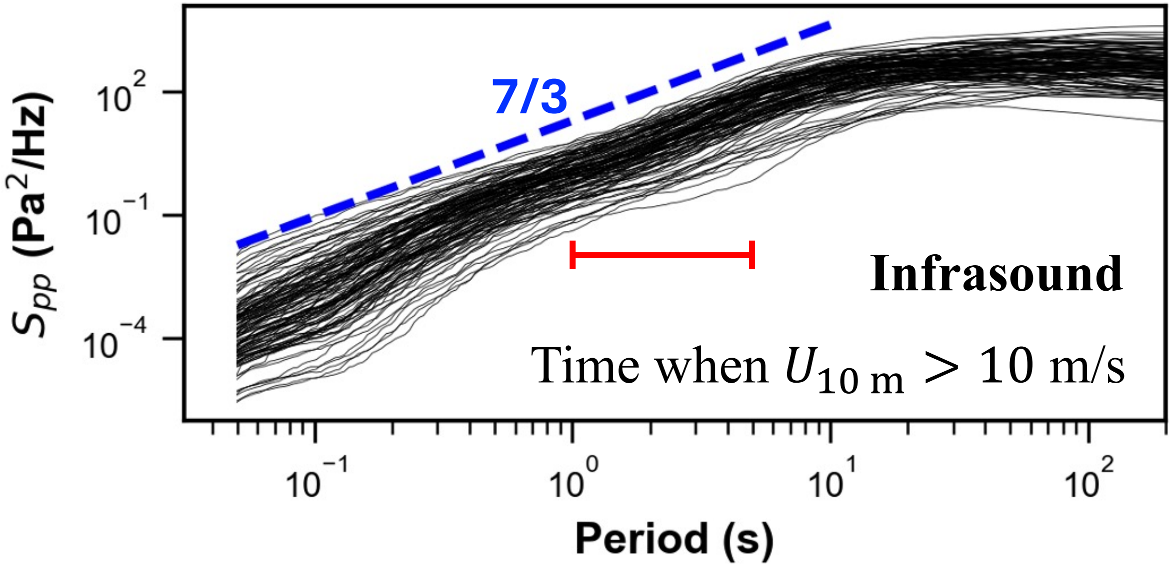
“Shadow” of eddies at height where wind speed $U = U_c \approx 0.6\ U_0$

Sorrells theory: “Pressure wave speed” $c \approx U_c$

Similar in Mars application, where $c \approx 0.5\ U_0$ work best for Sorrells results (Murdoch et al. 2017)

Turbulent spectra from wind tower and infrasound





Streamwise velocity PSD

$$S_{uu}(f) = \alpha_u \left(\frac{\varepsilon U}{2\pi}\right)^{2/3} f^{-5/3}$$

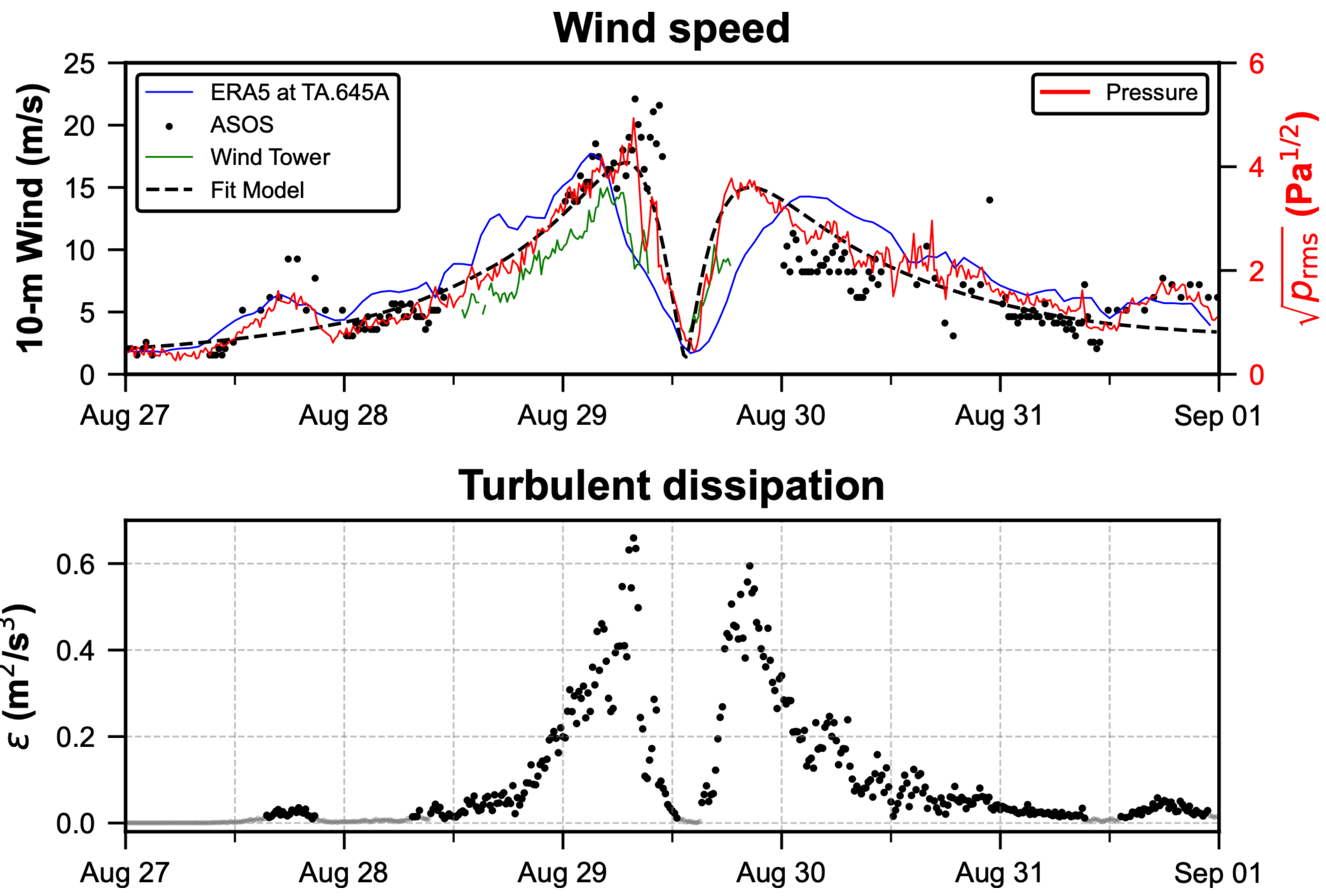
***Dissipation rate ε** is a key parameter describing the turbulence statistic, and contributes to an important energy source for hurricanes.* *(Bister & Emanuel, 1998)*

Pressure PSD

$$\frac{1}{\rho^2} S_{pp}(f) = \alpha_p \left(\frac{\varepsilon U_c}{2\pi}\right)^{4/3} f^{-7/3}$$

Kolmogorov (1941), Obukhov (1949), George et al. (1984) …

Continuous monitoring of hurricane landfall



Fluctuation: $p_{rms} \propto u_{rms}^2$

Turbulent intensity: $u_{rms} \propto U_{10\text{ m}}$

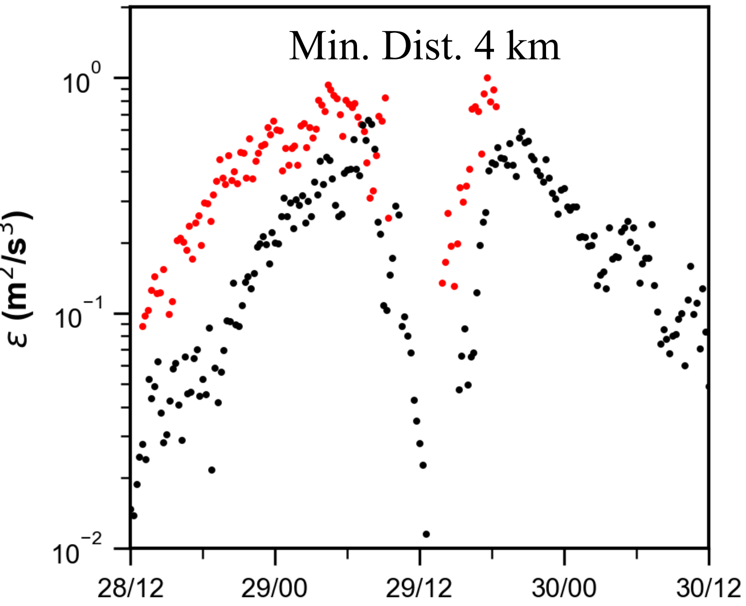
Fit wind model: $U_{10\text{ m}} = U(r)$

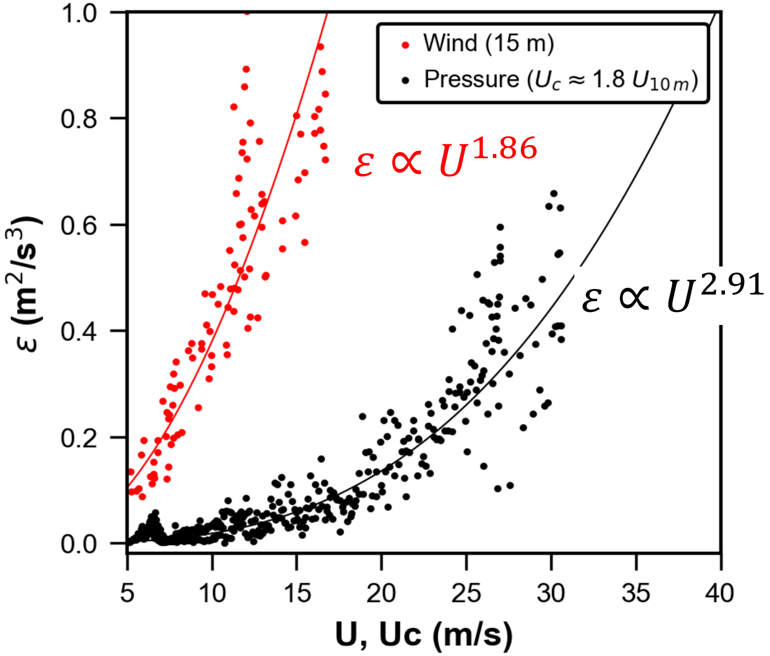
ERA5 reanalysis has a larger radius of maximum wind.

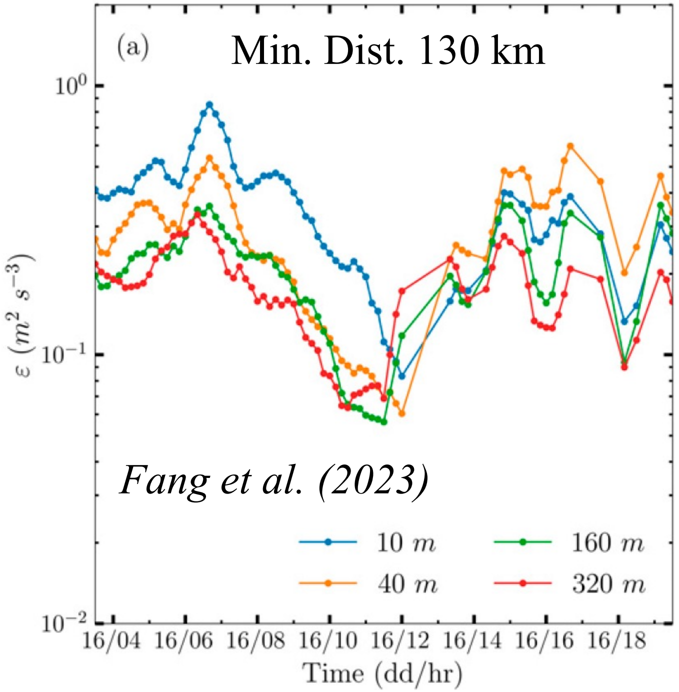
$O(0.1\text{ m}^2/\text{s}^3)$ or $O(0.1\text{ W/kg})$ dissipation rate

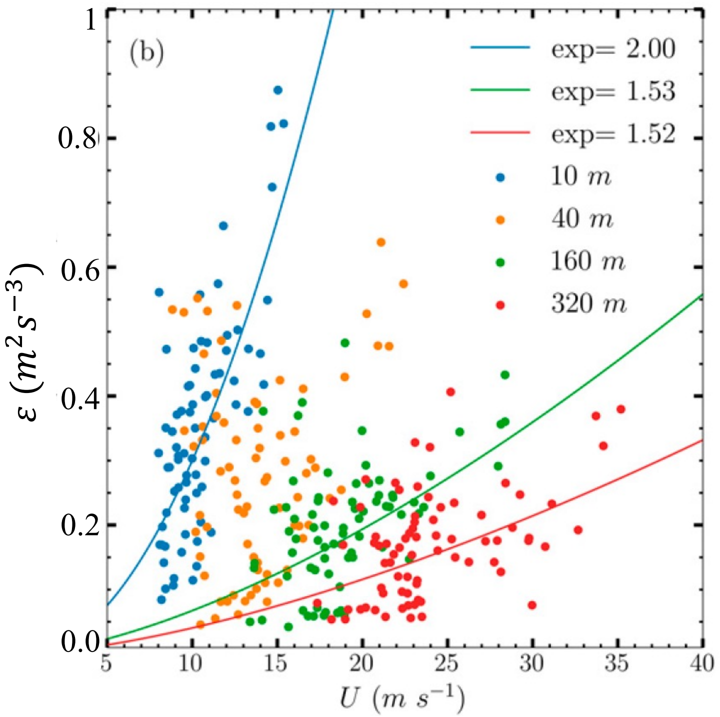
Interpreted as ε for height ~ 100 m where the wind speed equal to U_c

Ji et al. (in revision)









Turbulent dissipation rate during hurricane landfall

For **pressure** spectra:

Assume $U_c \approx 1.8\, U_{10\ \mathrm{m}}$ from our LES result

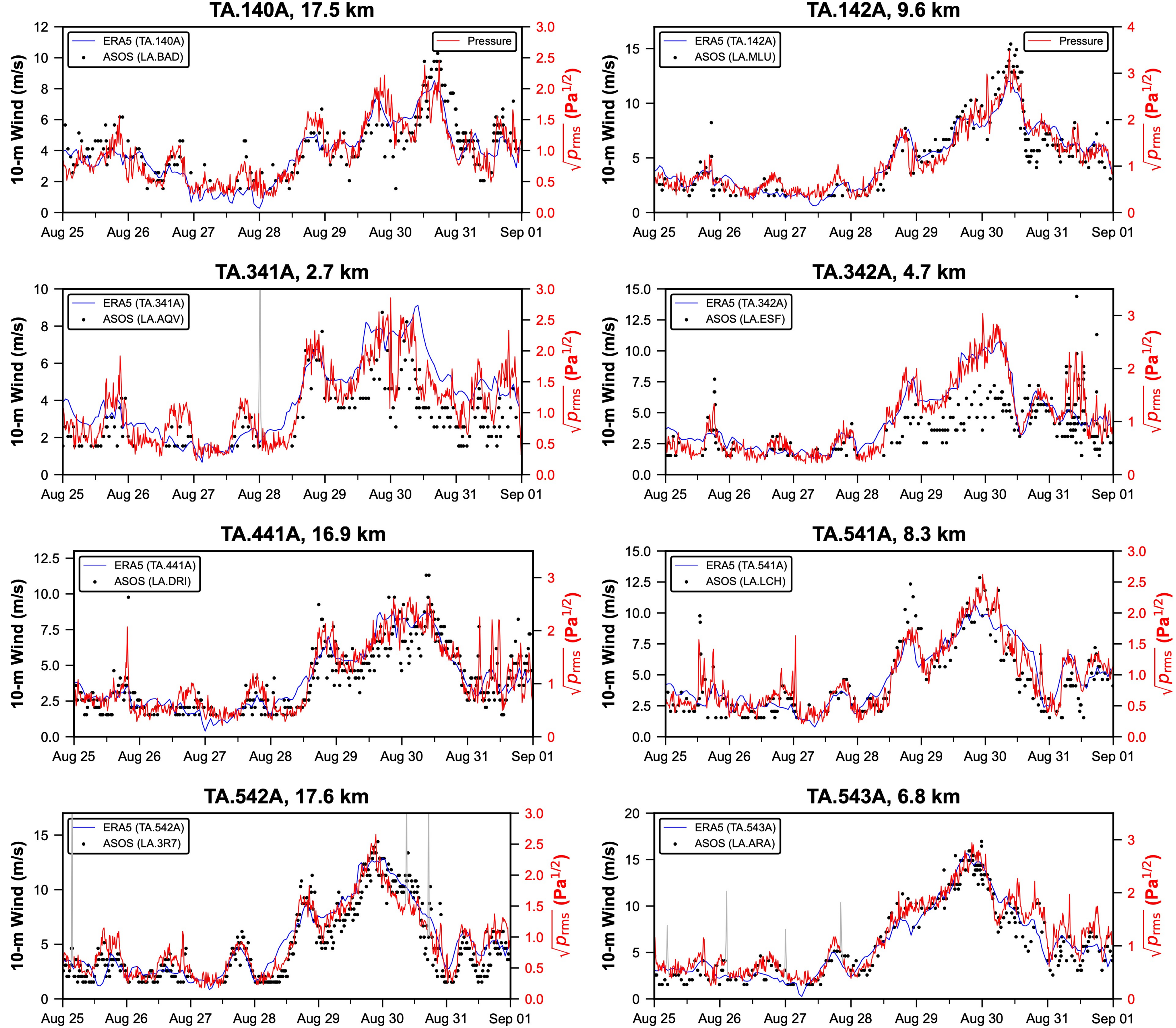
Directly use $U_{10\ \mathrm{m}} \approx 4.2\sqrt{p_{\mathrm{rms}}}$ in their units

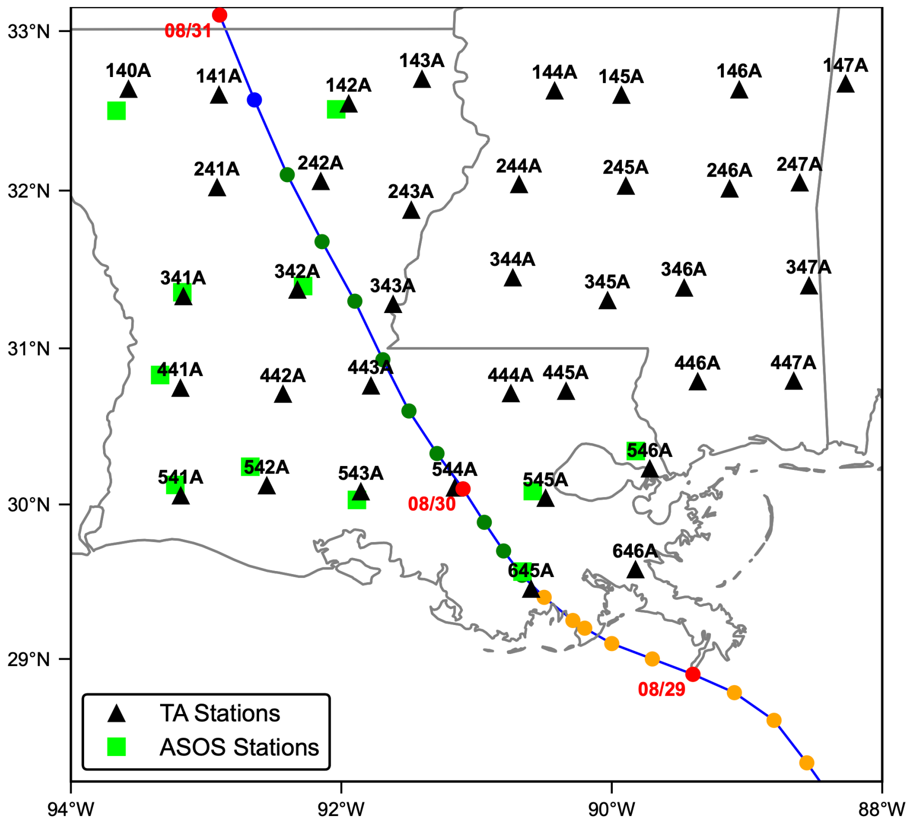
Wind tower for 15 m high, while **pressure** imprints from ~100 m high (where $U = U_c$)

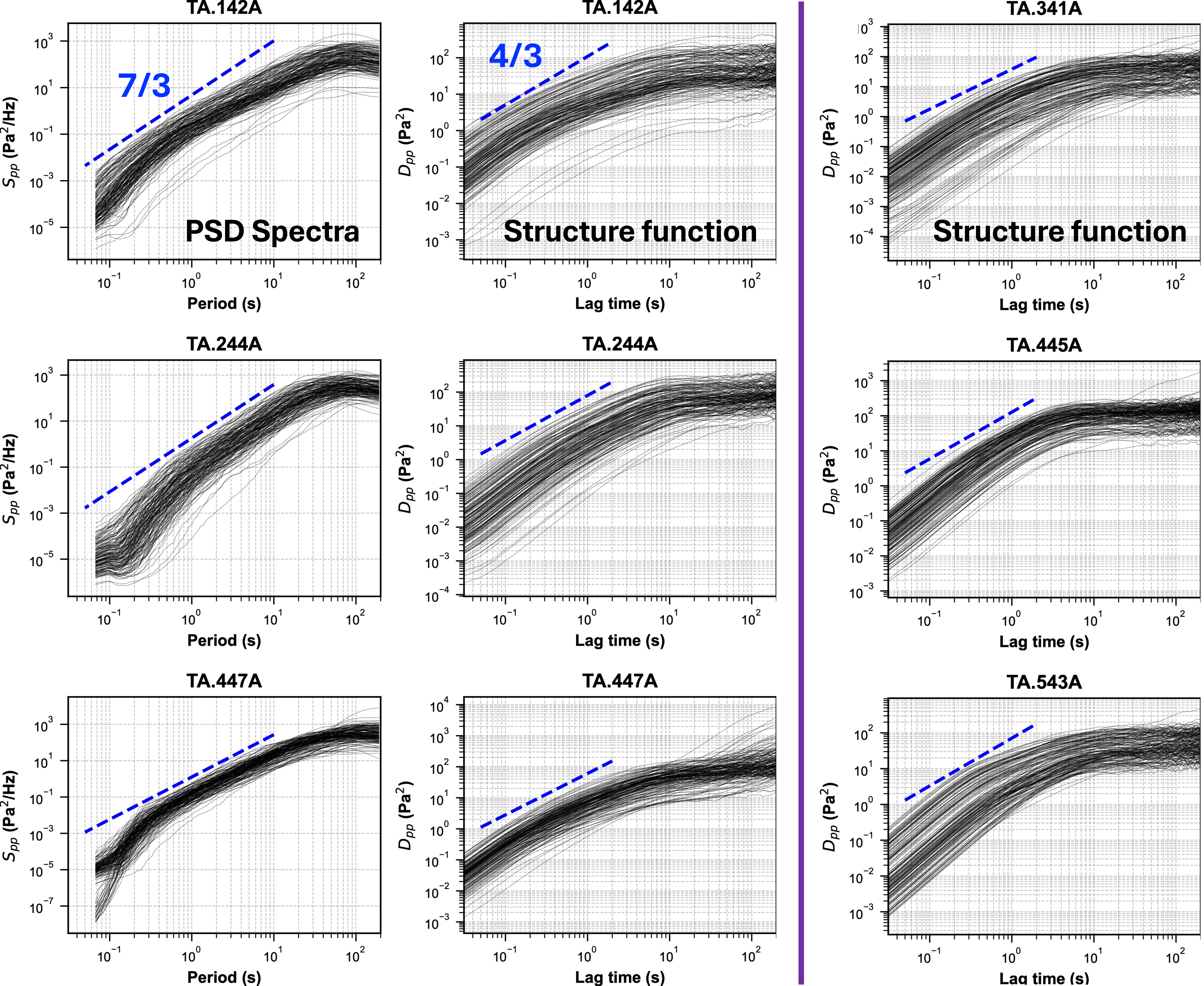
Magnitude of ε agrees with other studies on landfalling storms.

Scaling $\varepsilon \propto U^3$ considered for dominance of shear production, but less certain for storms.

Infrasound data as proxy of surface wind







Turbulent pressure

Structure function

$$D_{pp}(\tau) = \overline{[p(t+\tau) - p(t)]^2}$$

$$\frac{1}{\rho^2} D_{pp}(\tau) = C_p \left(\varepsilon U_c\right)^{4/3} \tau^{4/3}$$

Deviation from the slope:

- Violation of locally isotropic turbulence assumption
- Interaction of different scales

George et al. (1984), Katul et al. (2025)

Surprise #1: Seismic stations record in-situ data of Hurricane Issac after landfall

Distinct seismic ground motion contributed by ocean and atmosphere

Surprise #2: Turbulence explains the seismoacoustic signatures (in the atm. band)

Interdisciplinary modeling framework to explain observations

Surprise #3: Potential of seismoacoustic stations for environmental monitoring

Station networks with years of continuous data, especially infrasound

Thanks to Stanford Virgil Kauffman
Fellowship for interdisciplinary research