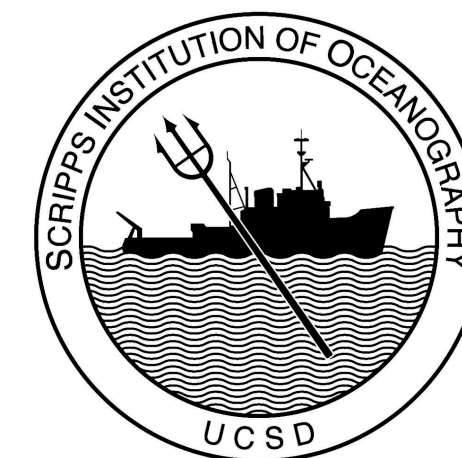


Abundant spontaneous and dynamically triggered submarine landslides in the Gulf of Mexico

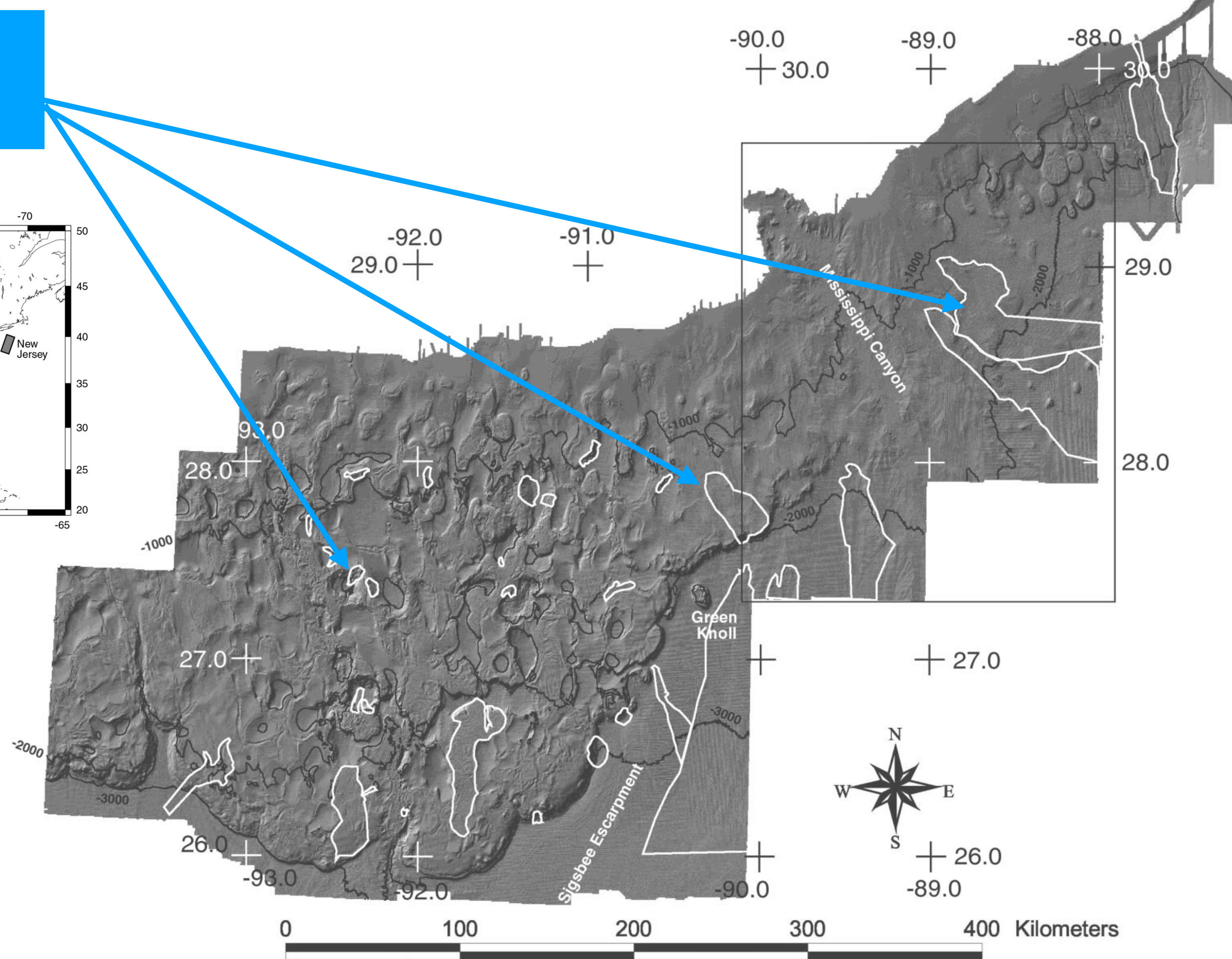
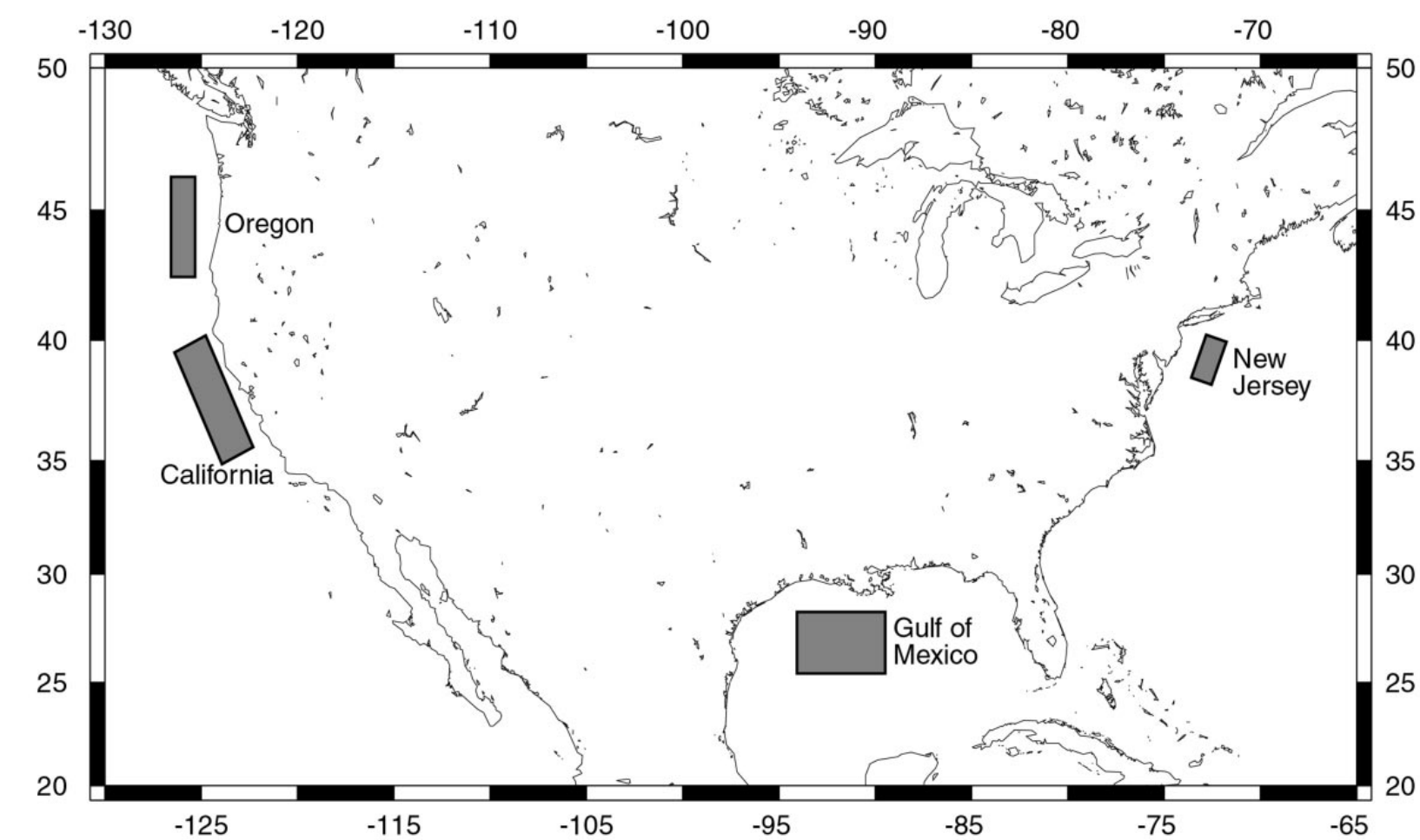
Wenyuan Fan

Assistant Professor
Institute of Geophysics and Planetary Physics
Scripps Institution of Oceanography
University of California, San Diego

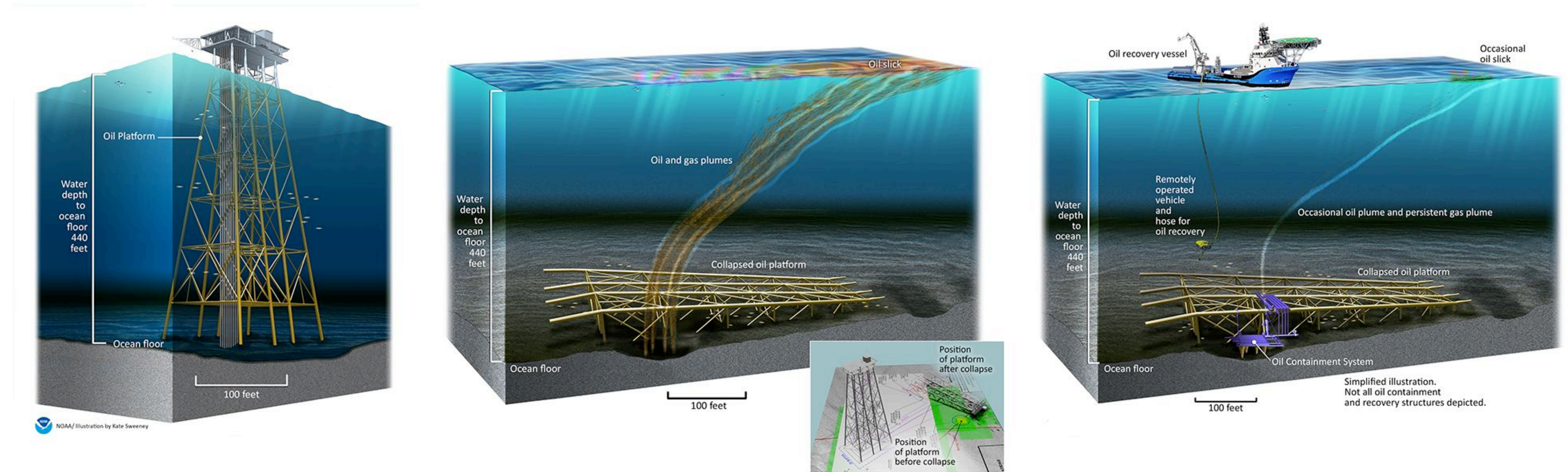
In collaboration with Jeff McGuire, Peter Shearer, Catherine de Groot-hedlin, Michael Hedlin



Submarine landslides !!



Submarine landslides can damage offshore infrastructure

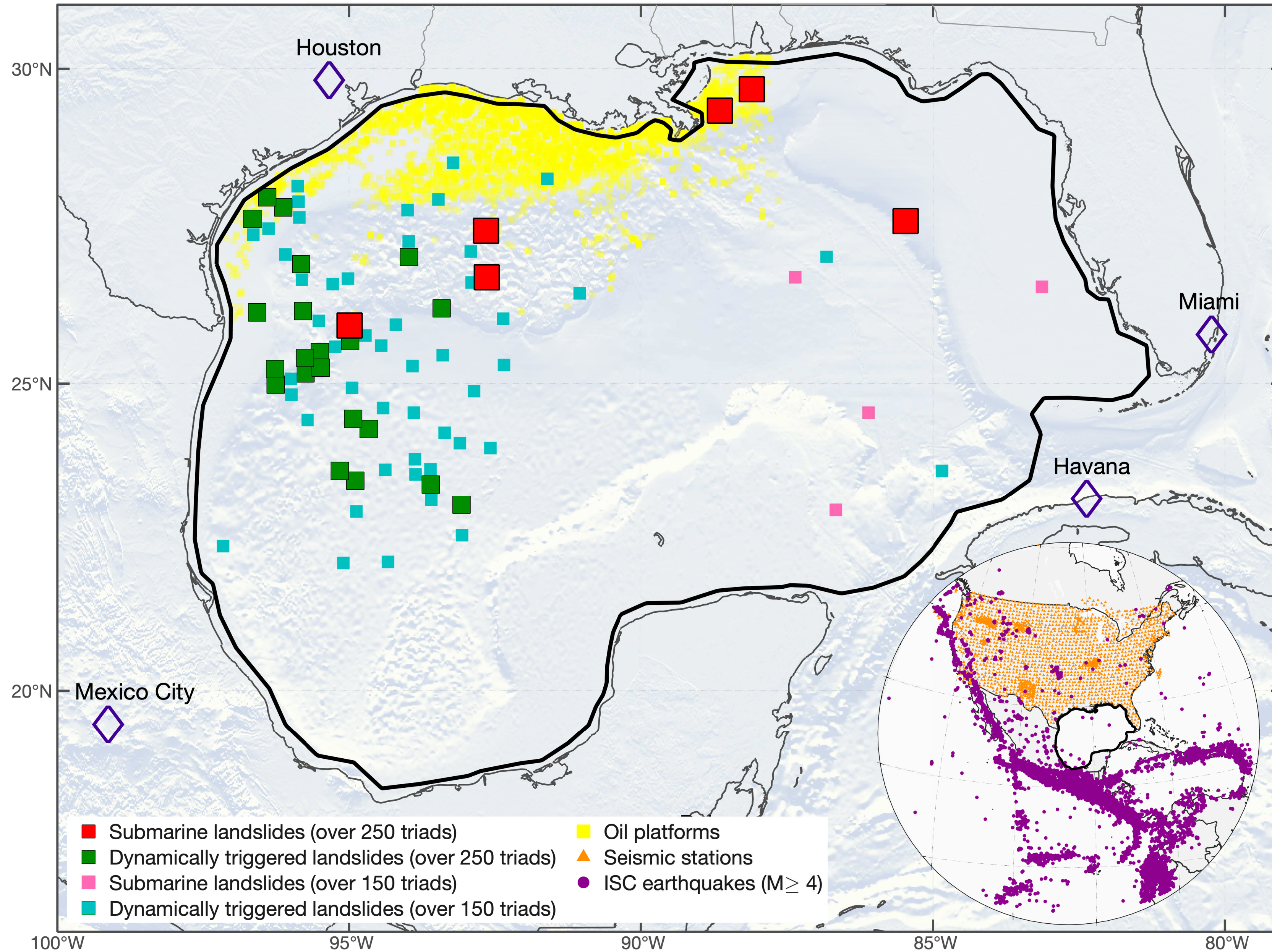


Taylor Energy site has been leaking since **2004** after the drilling platform was destroyed by a **submarine landslide**, the leaking would last for about **100 years** if there is no intervention

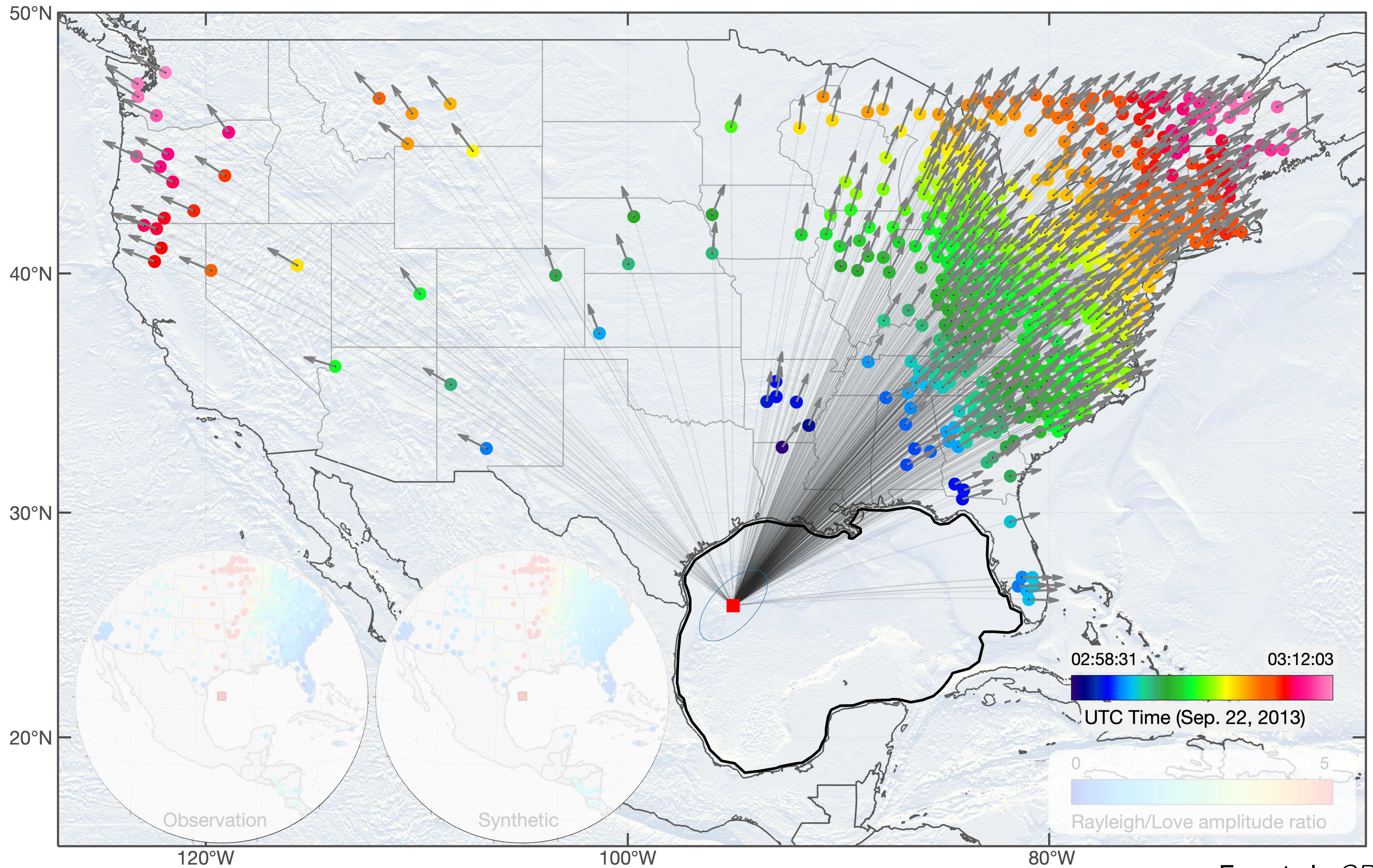


When, Where, thus Why?!

Abundant submarine landslides in the Gulf of Mexico

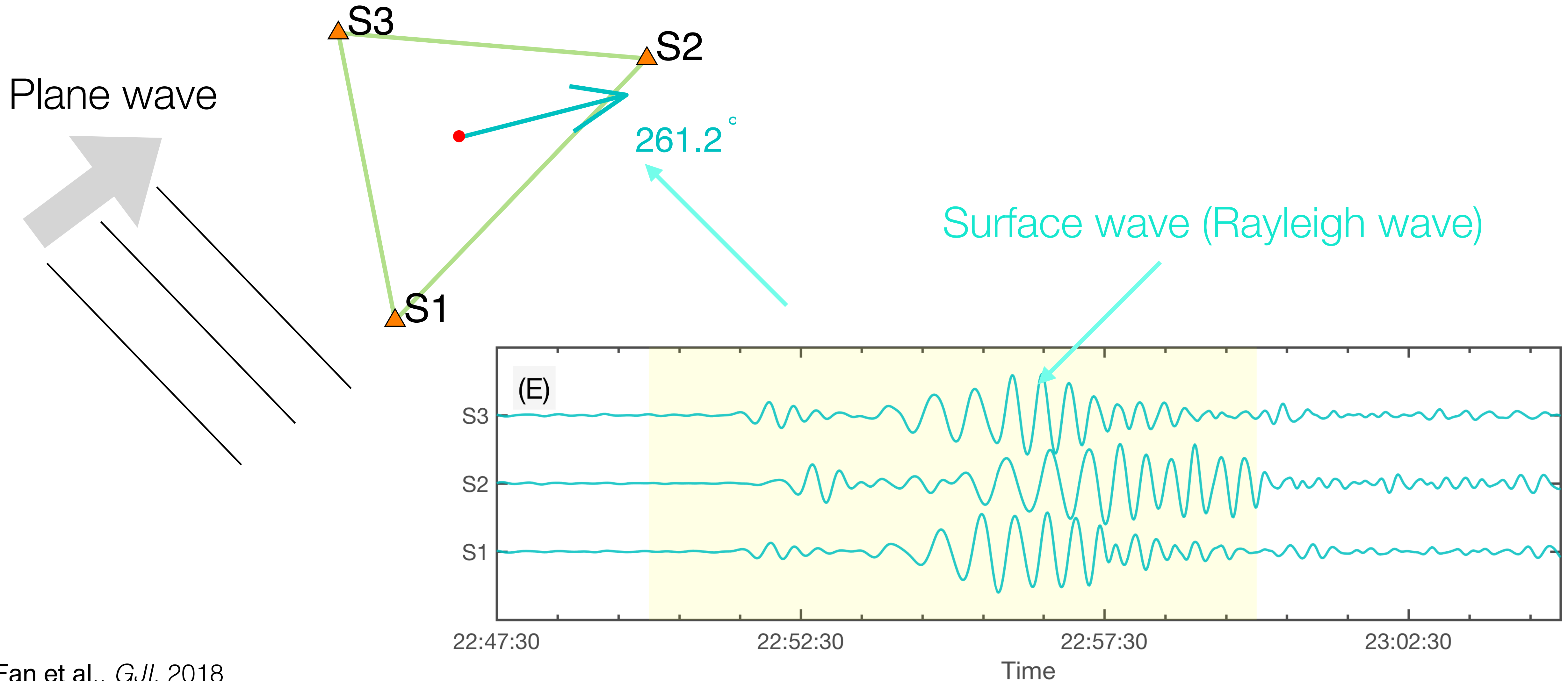


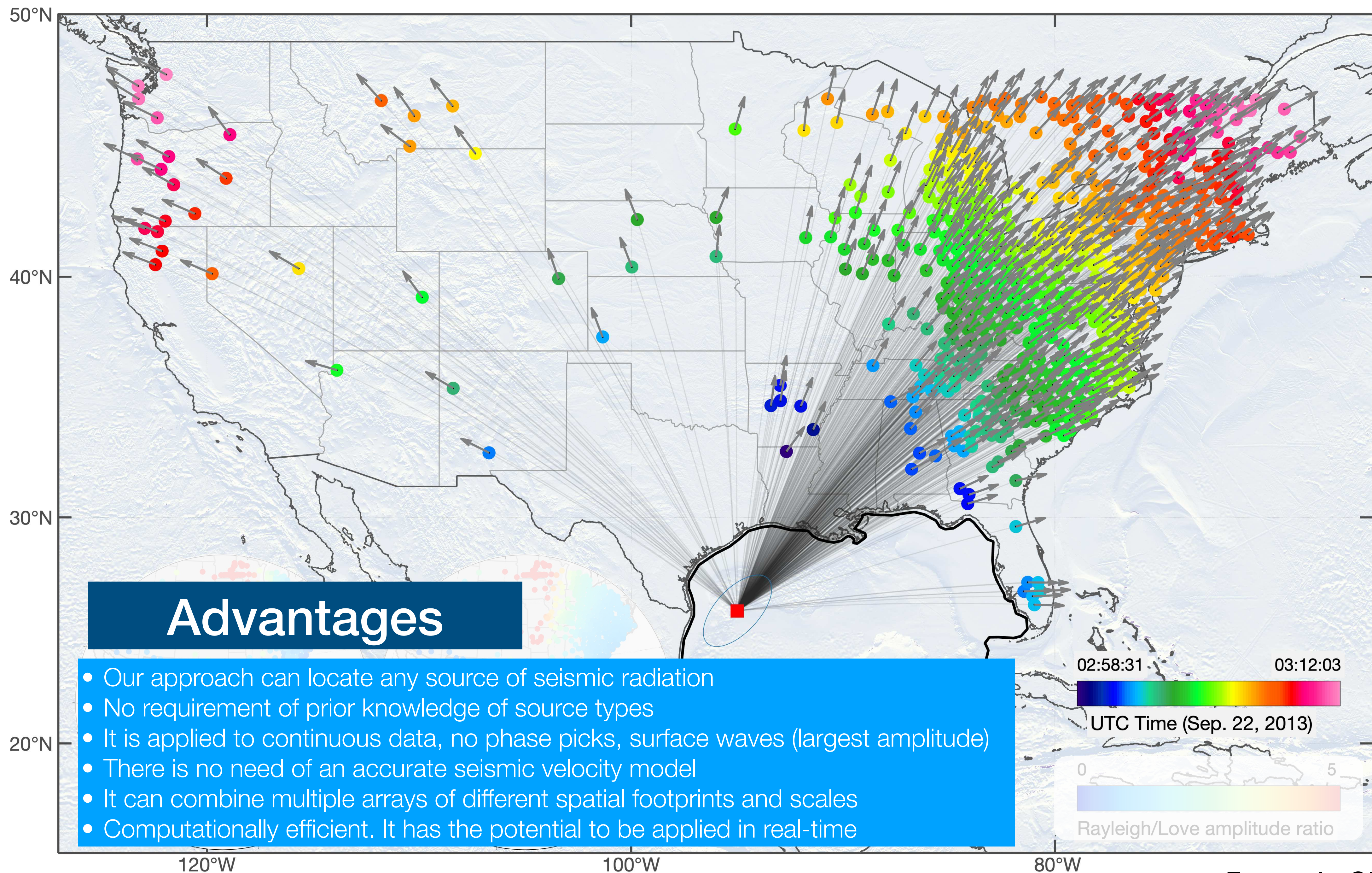
2008—2015, **85** in total
Spontaneous: **10**
Dynamically triggered: **75**



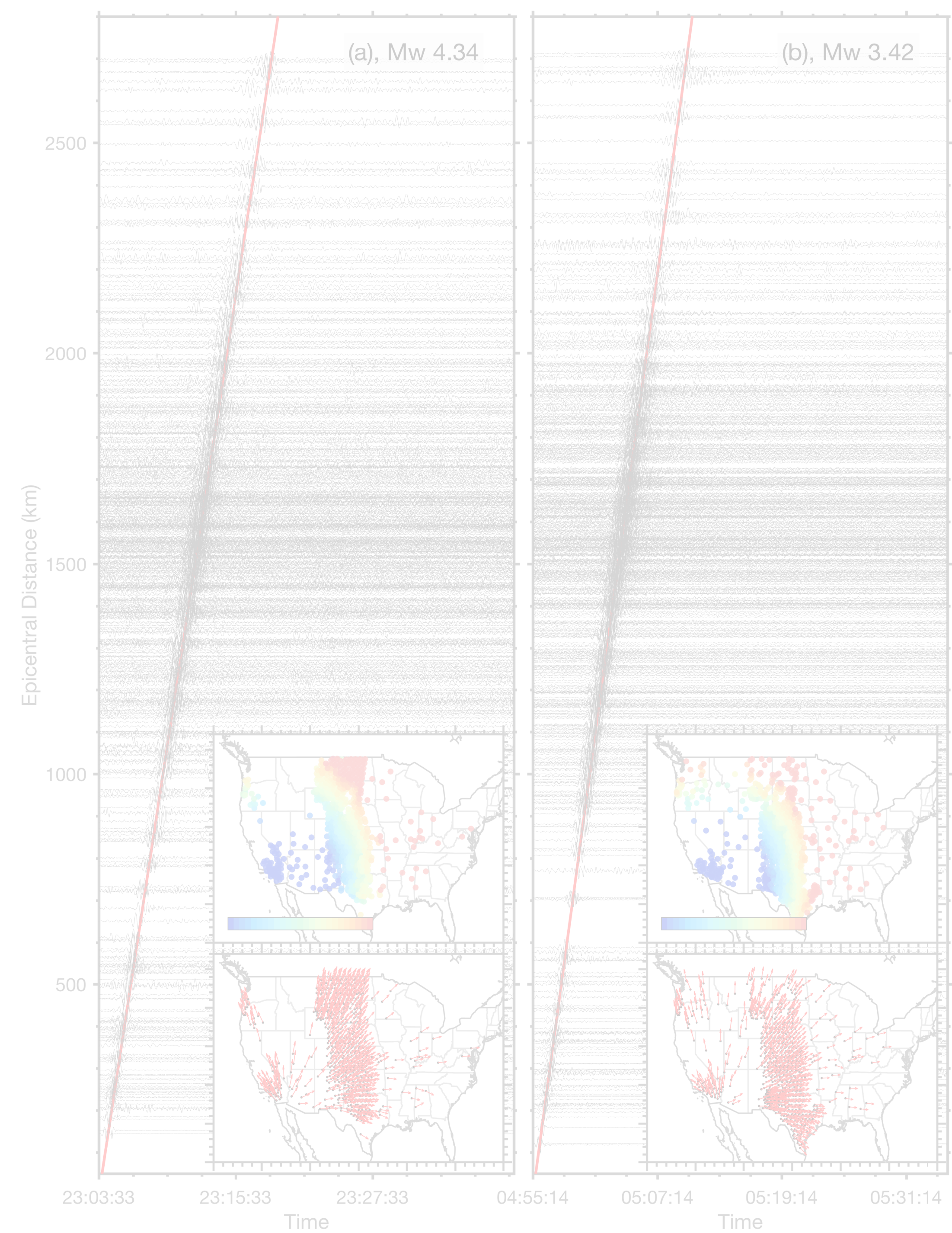
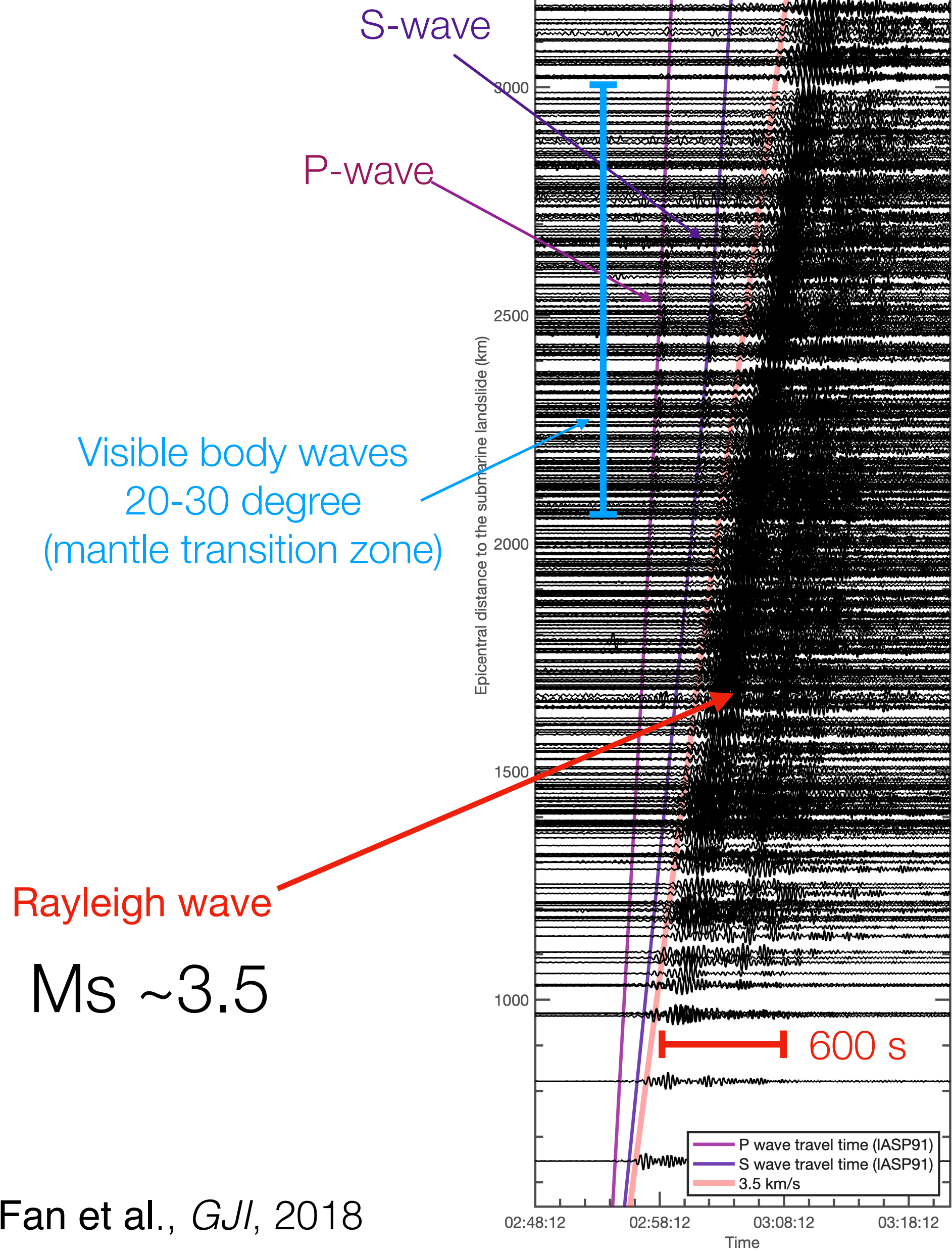
Direction of highly coherent local surface waves

Vertical component (filtered at 20–50 s)





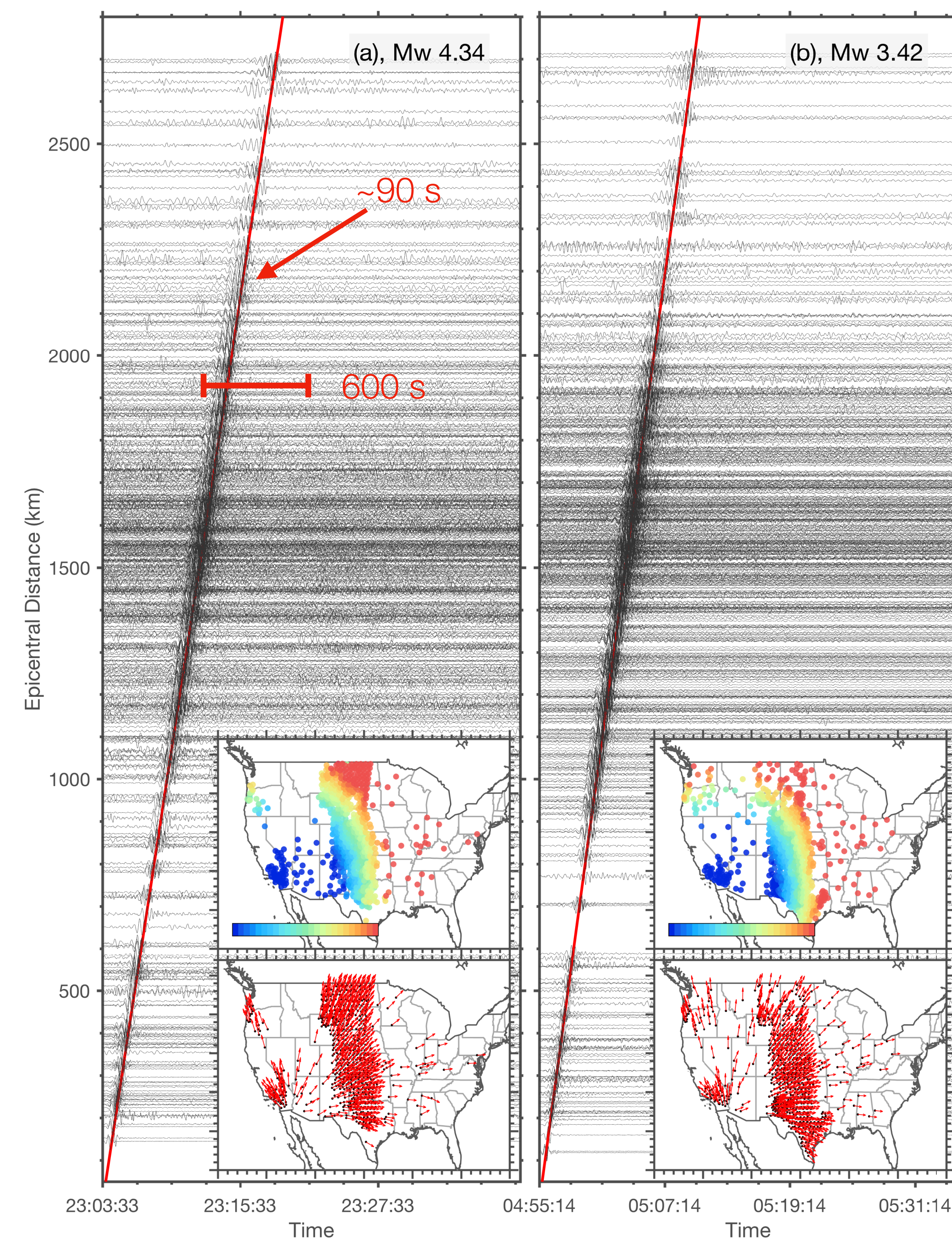
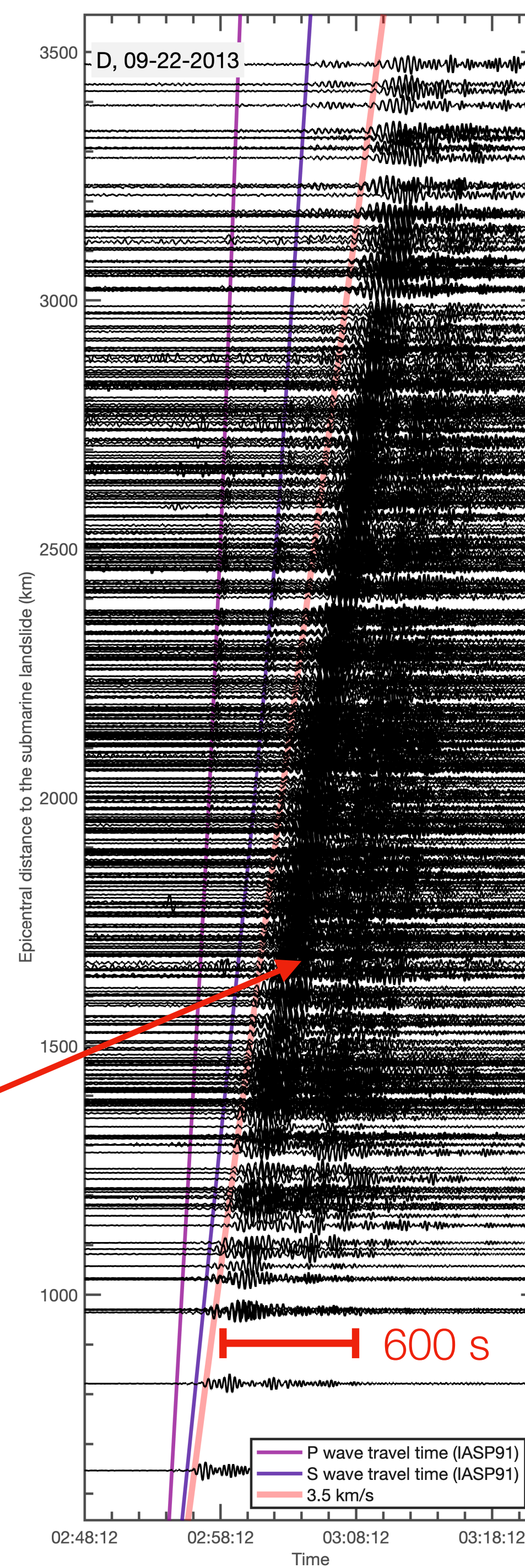
Strong transcontinental long-duration surface waves



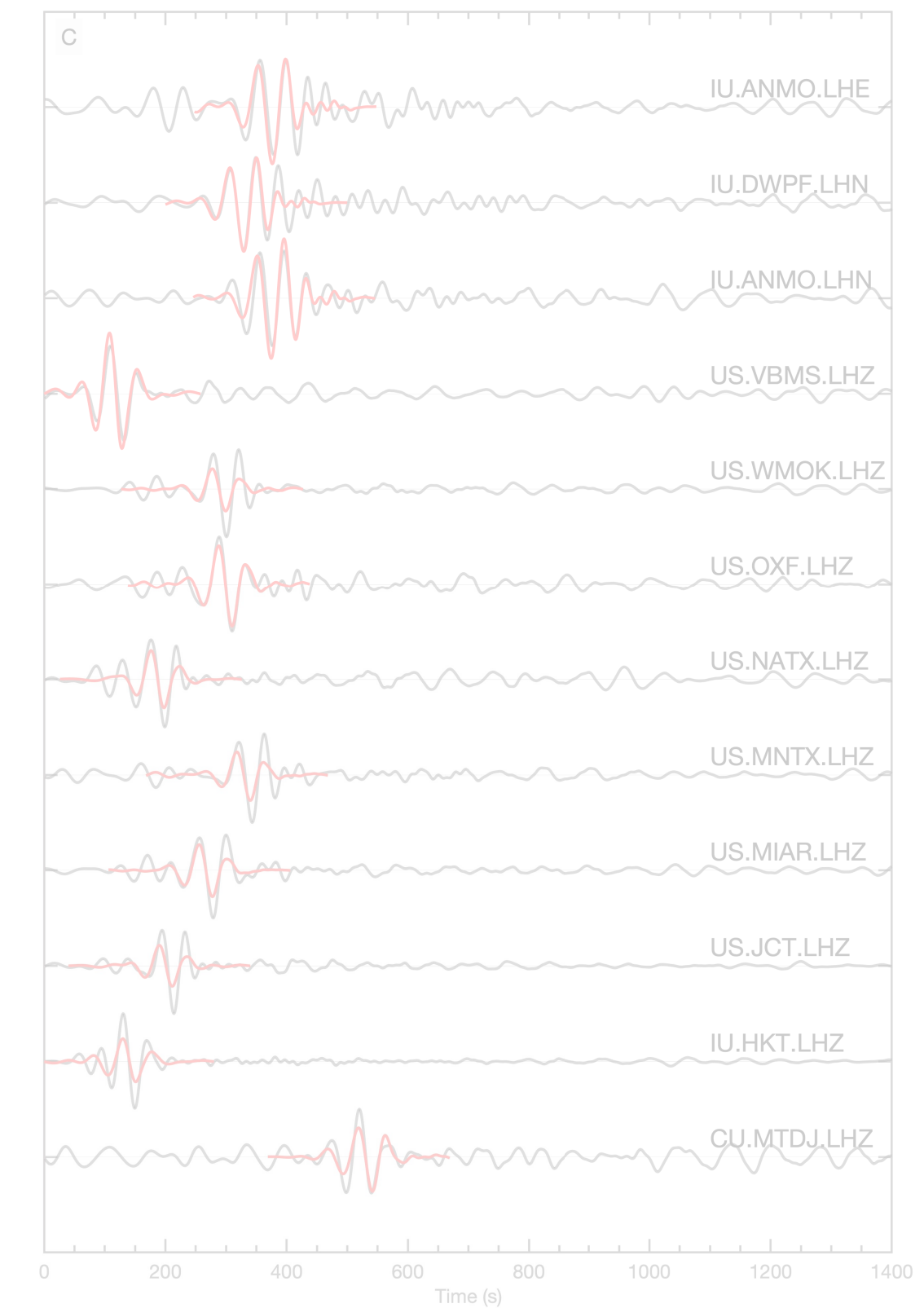
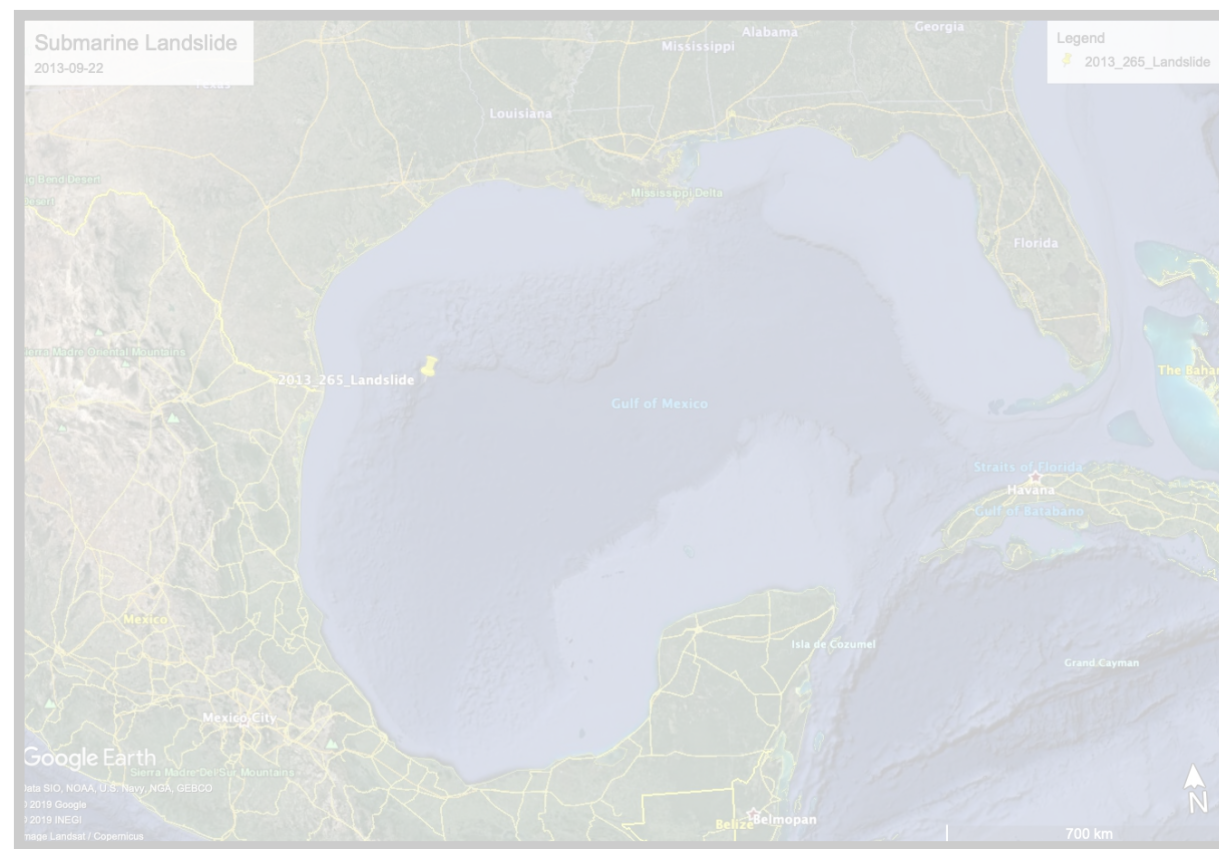
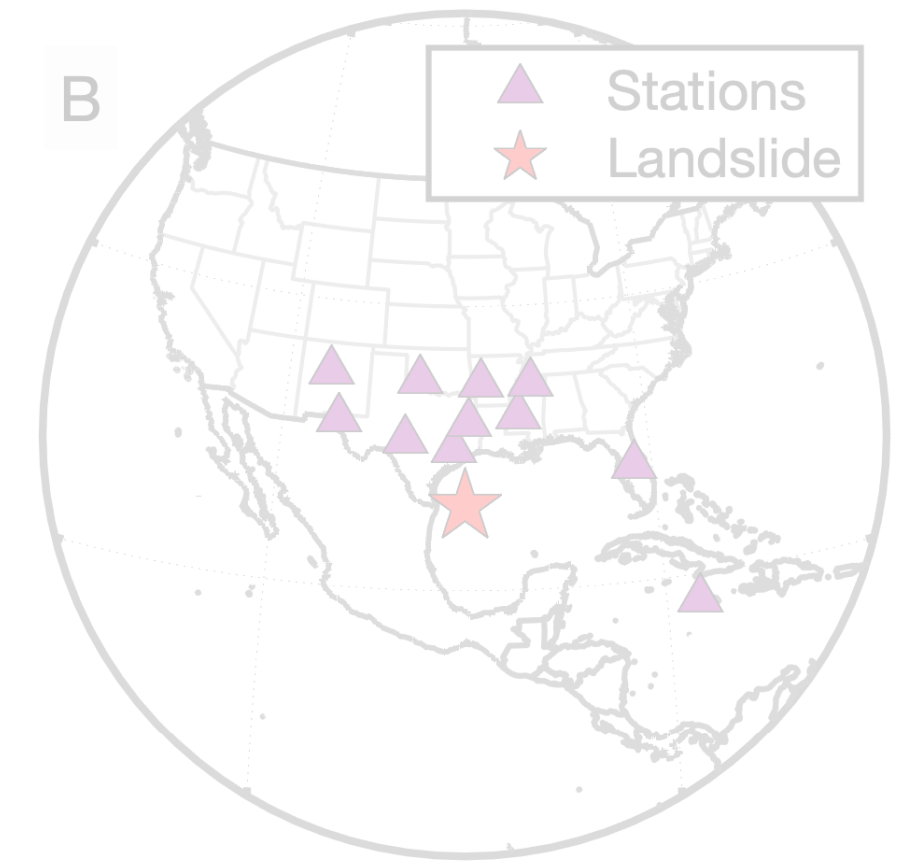
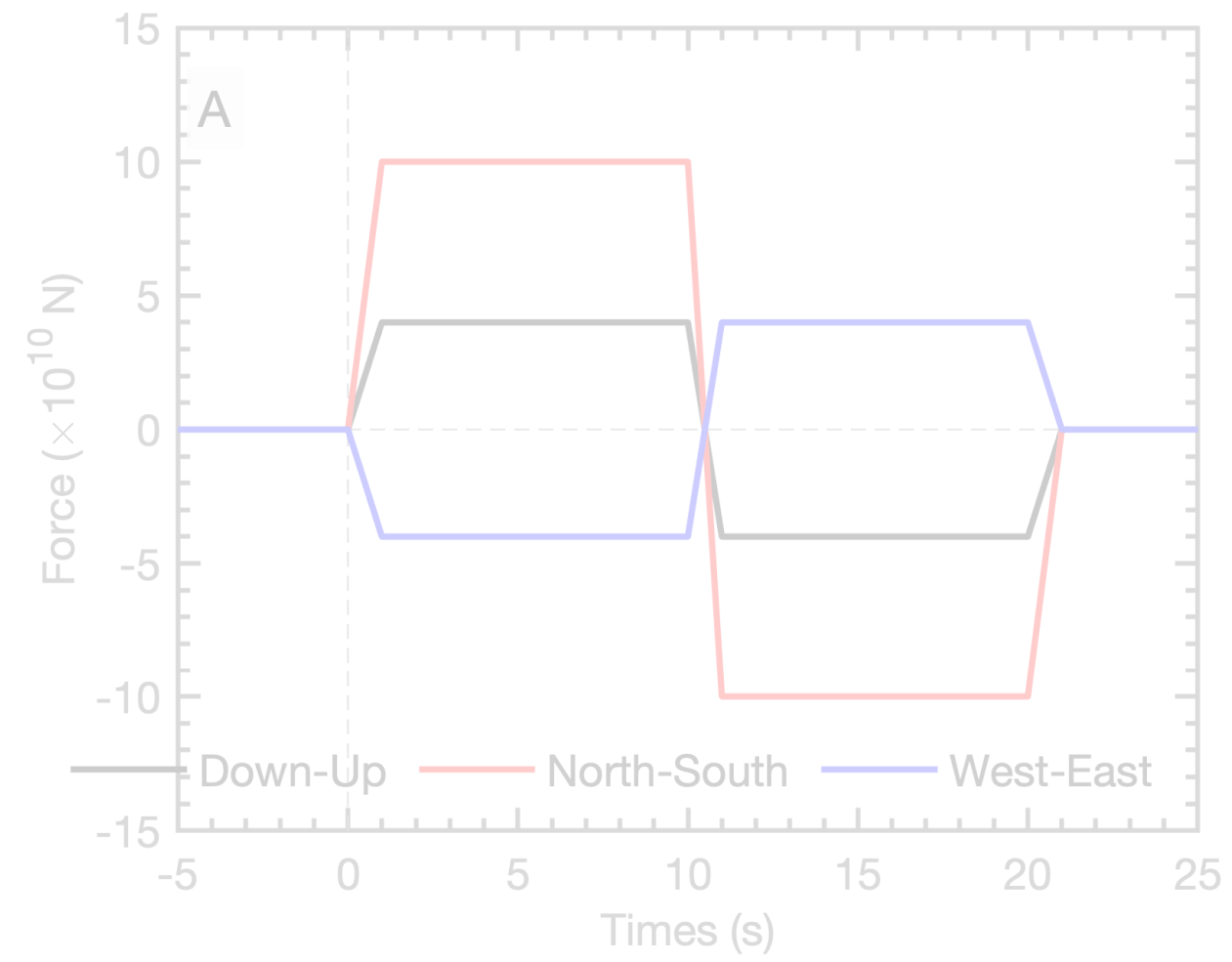
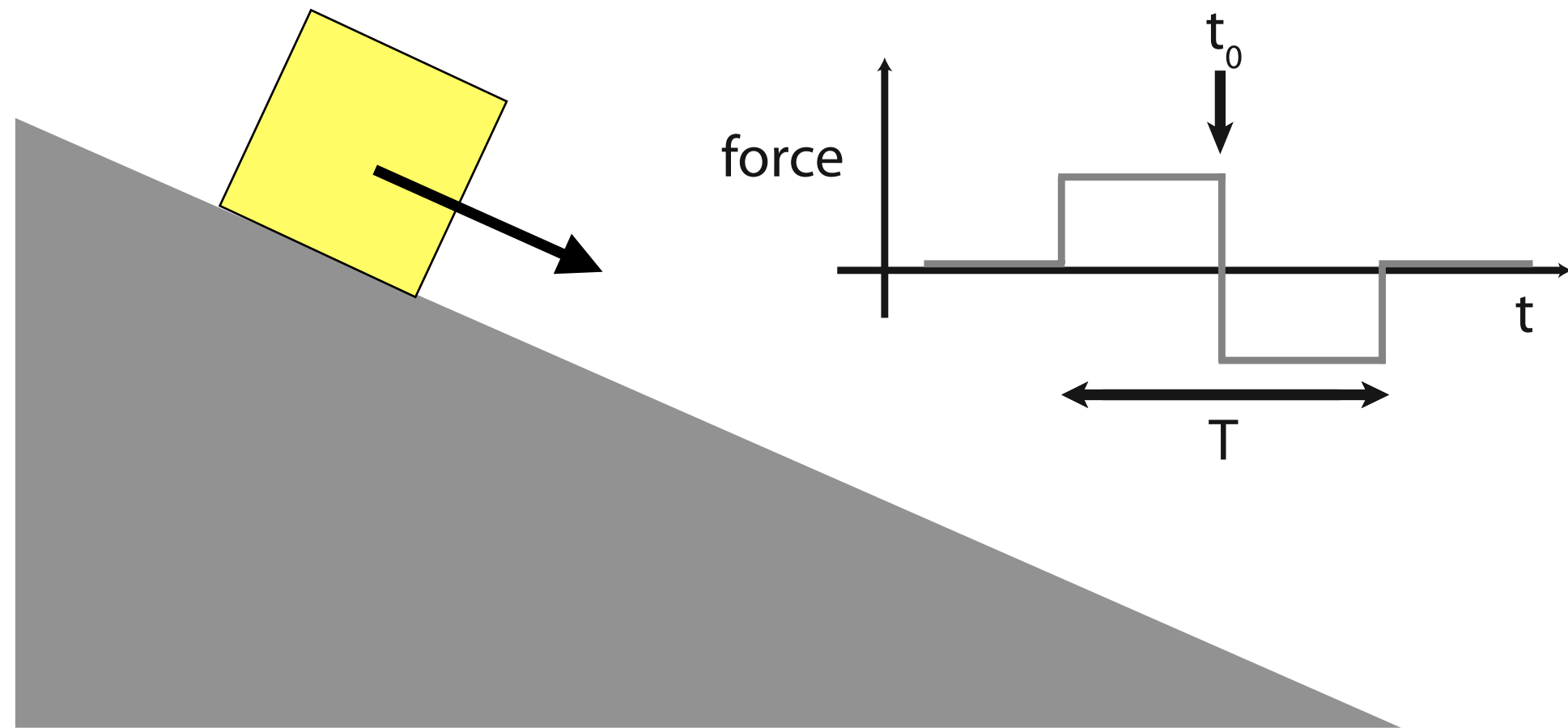
Strong transcontinental long-duration surface waves

Rayleigh wave

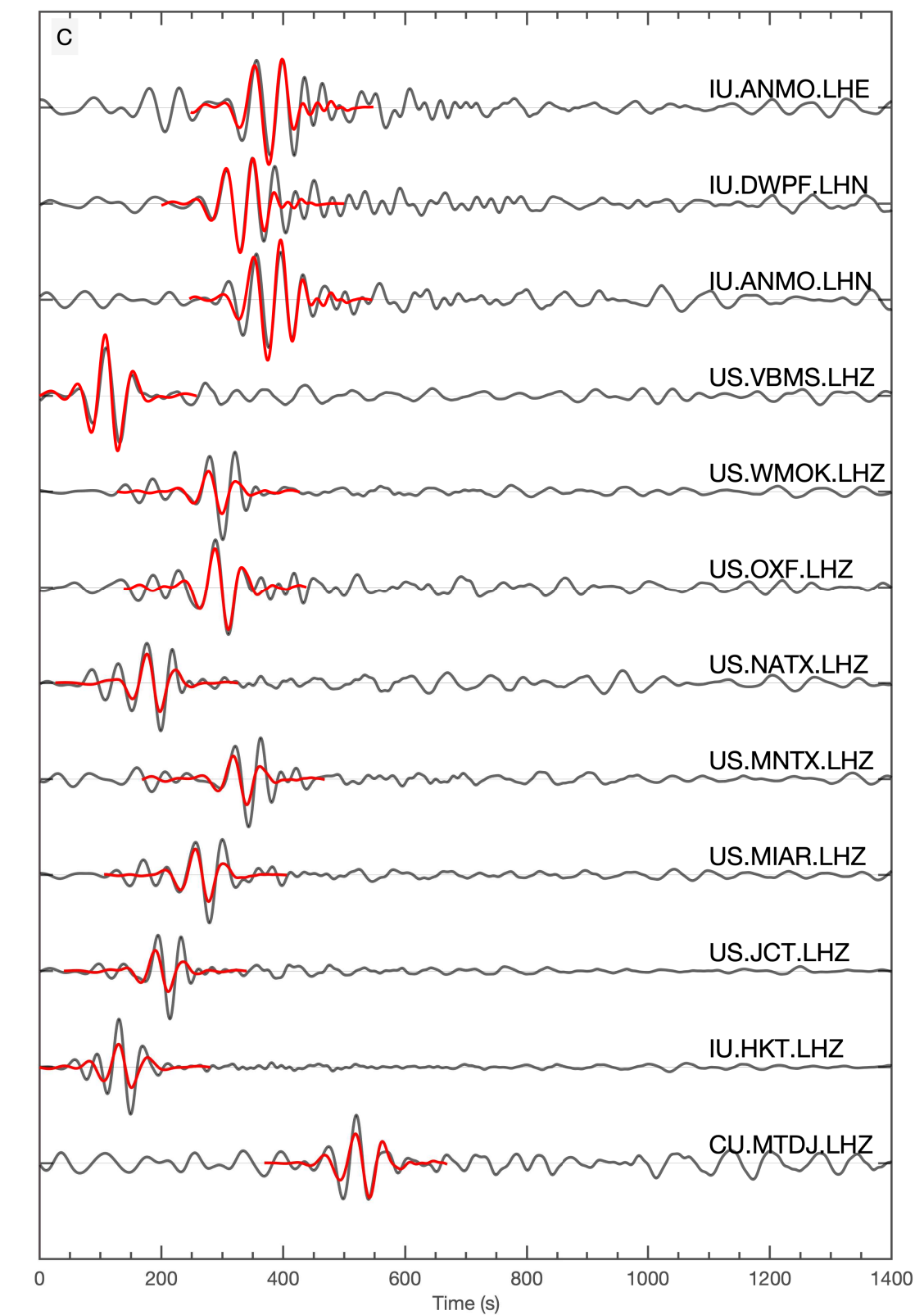
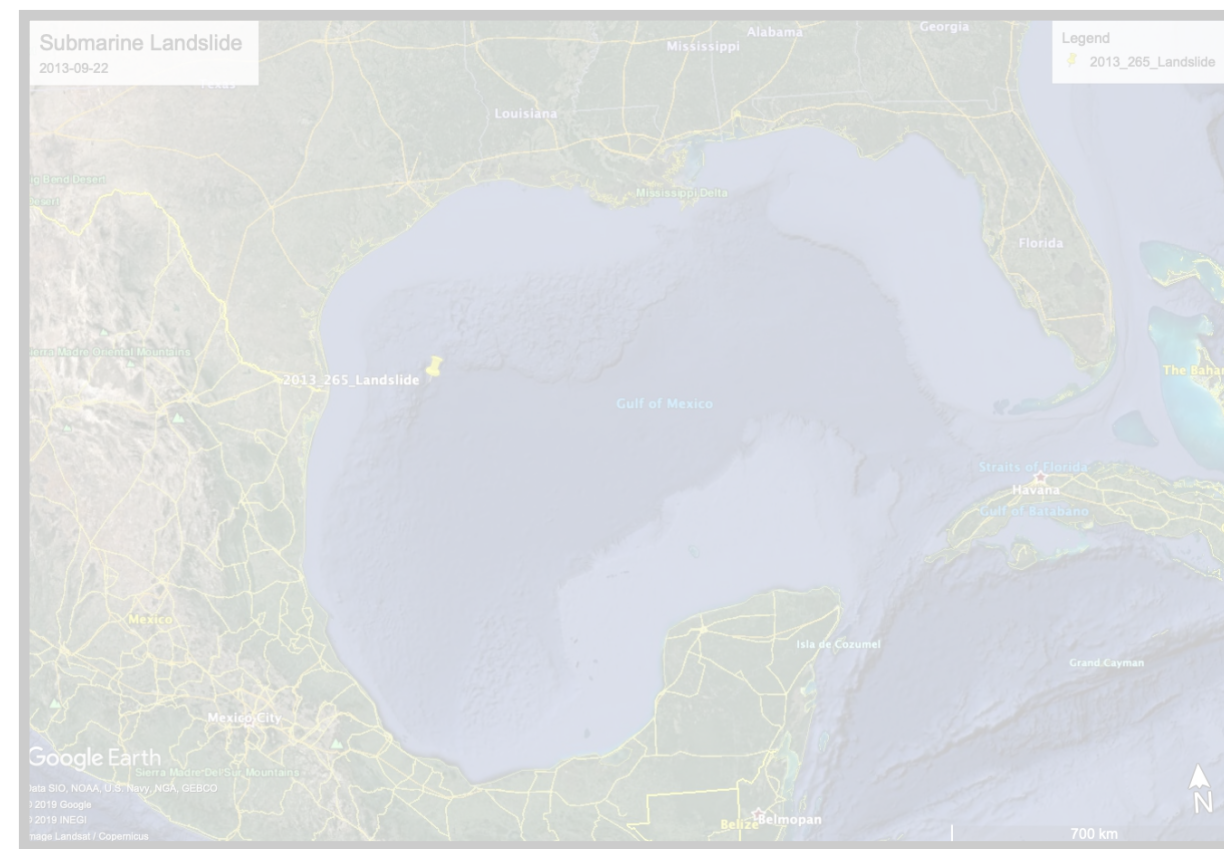
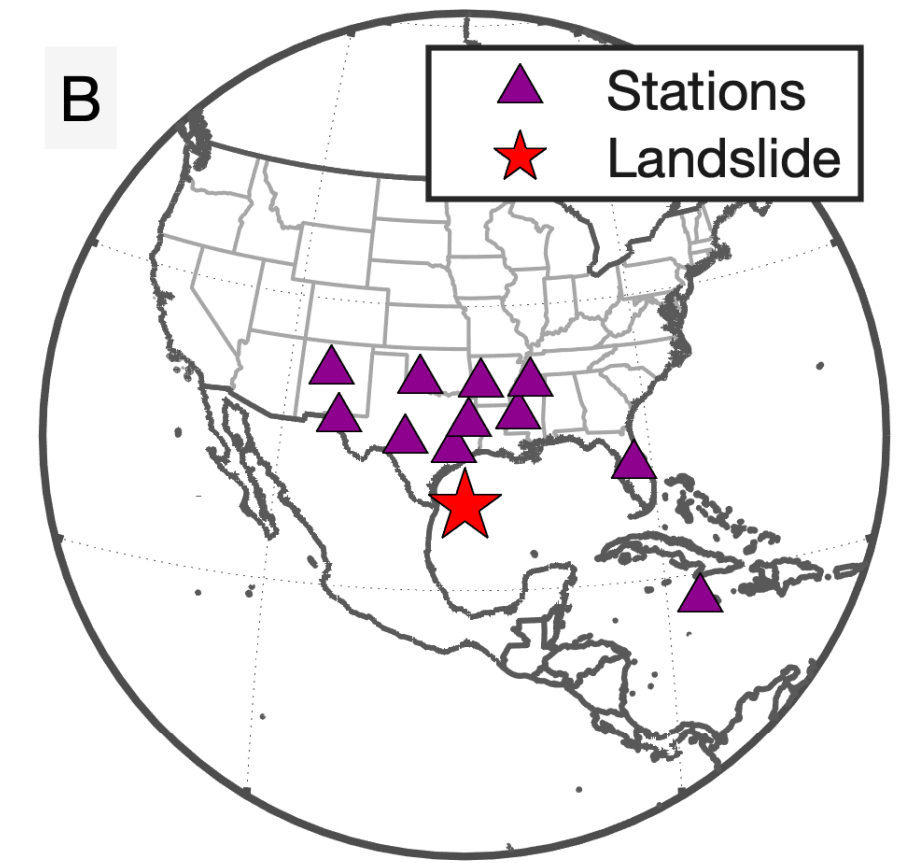
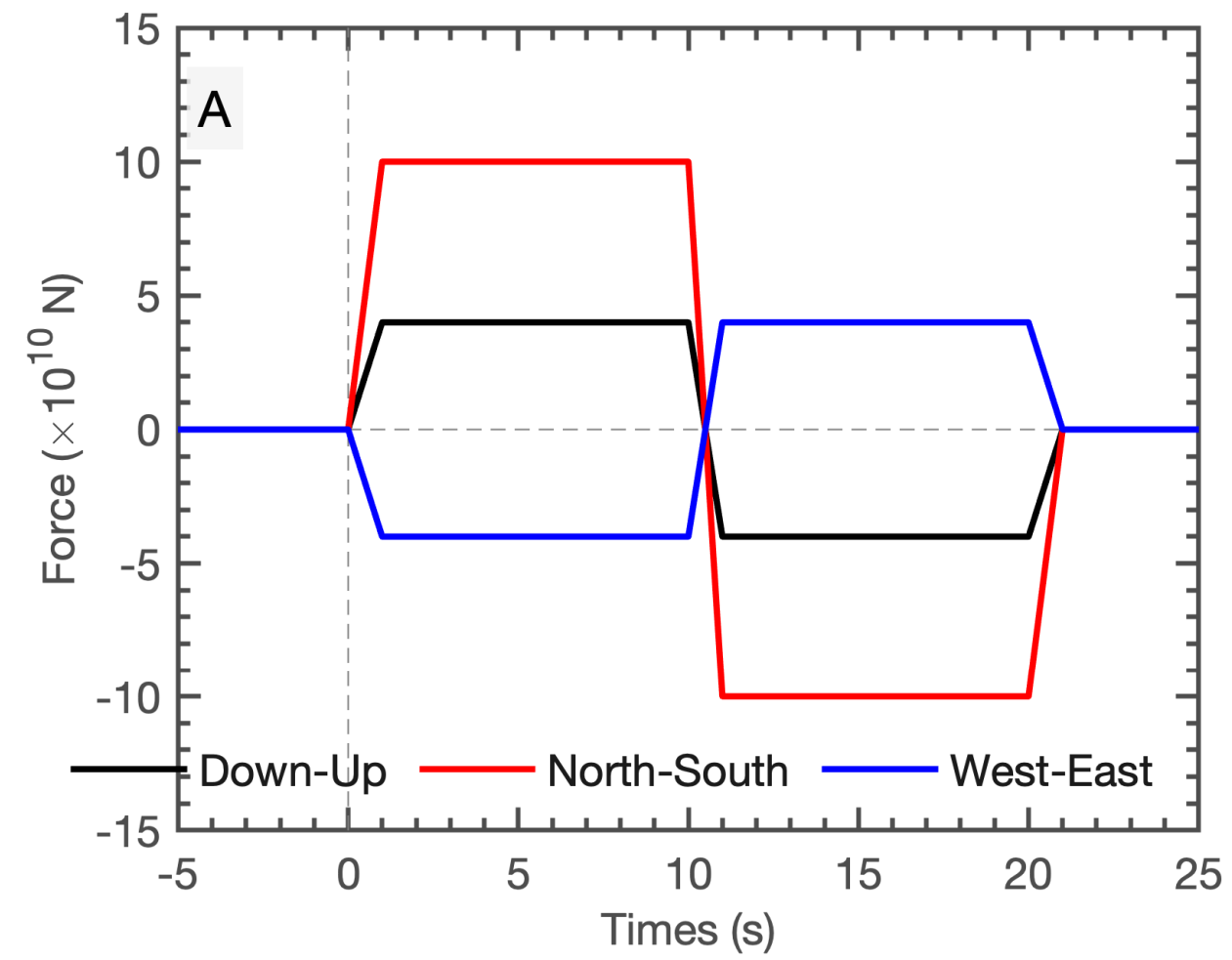
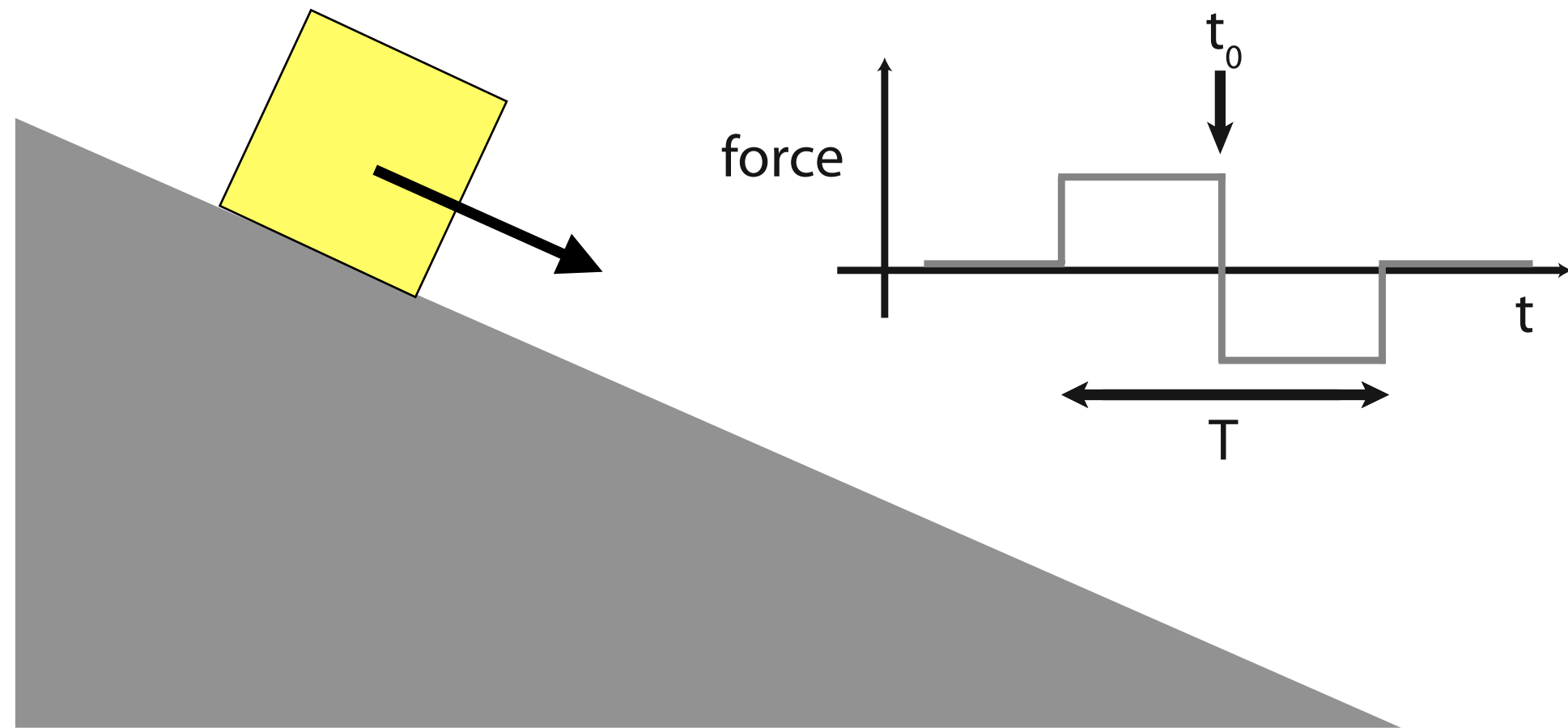
$M_s \sim 3.5$



Centroid single force (CSF) inversion

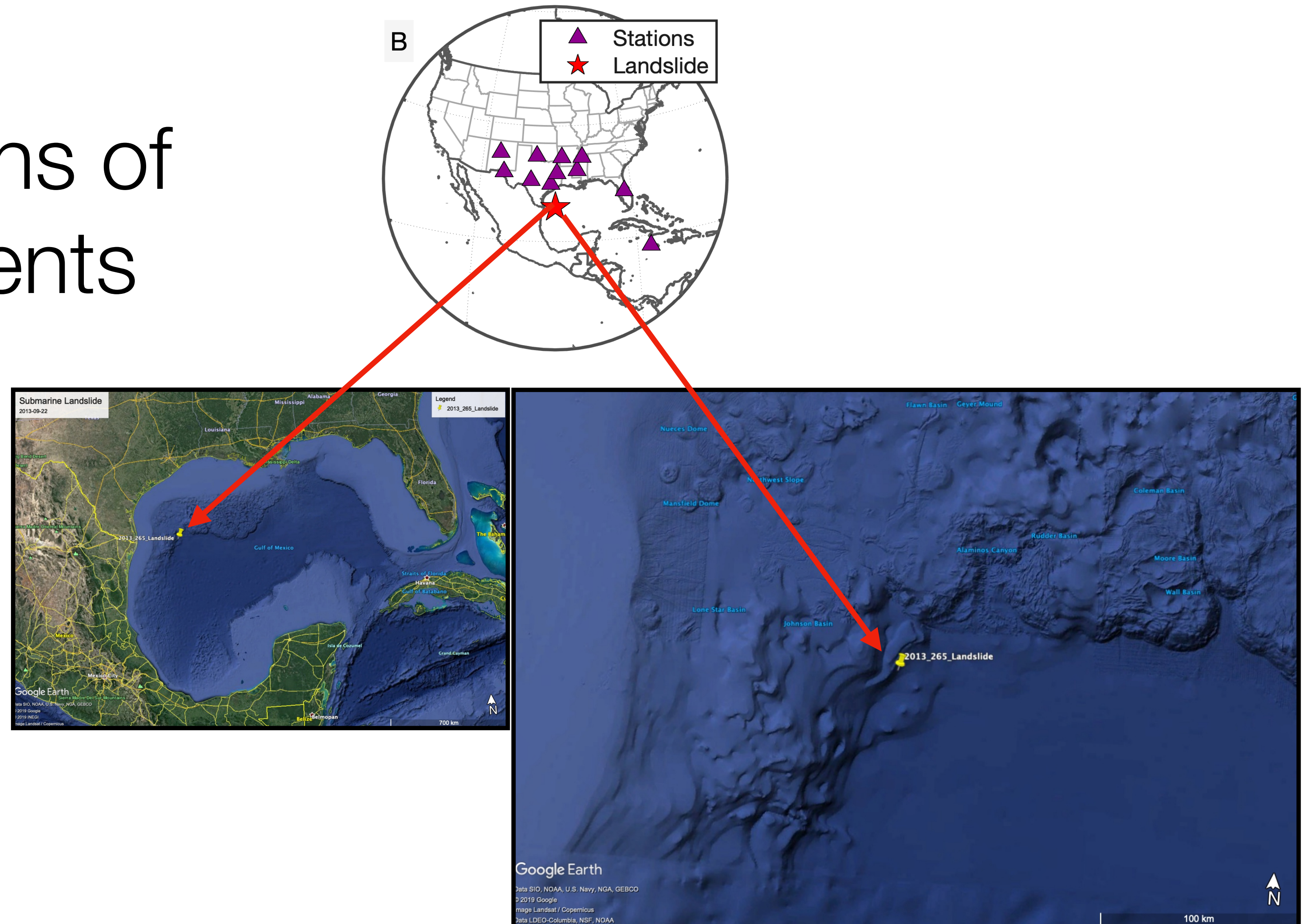


Centroid single force (CSF) inversion



Centroid single force (CSF) inversion

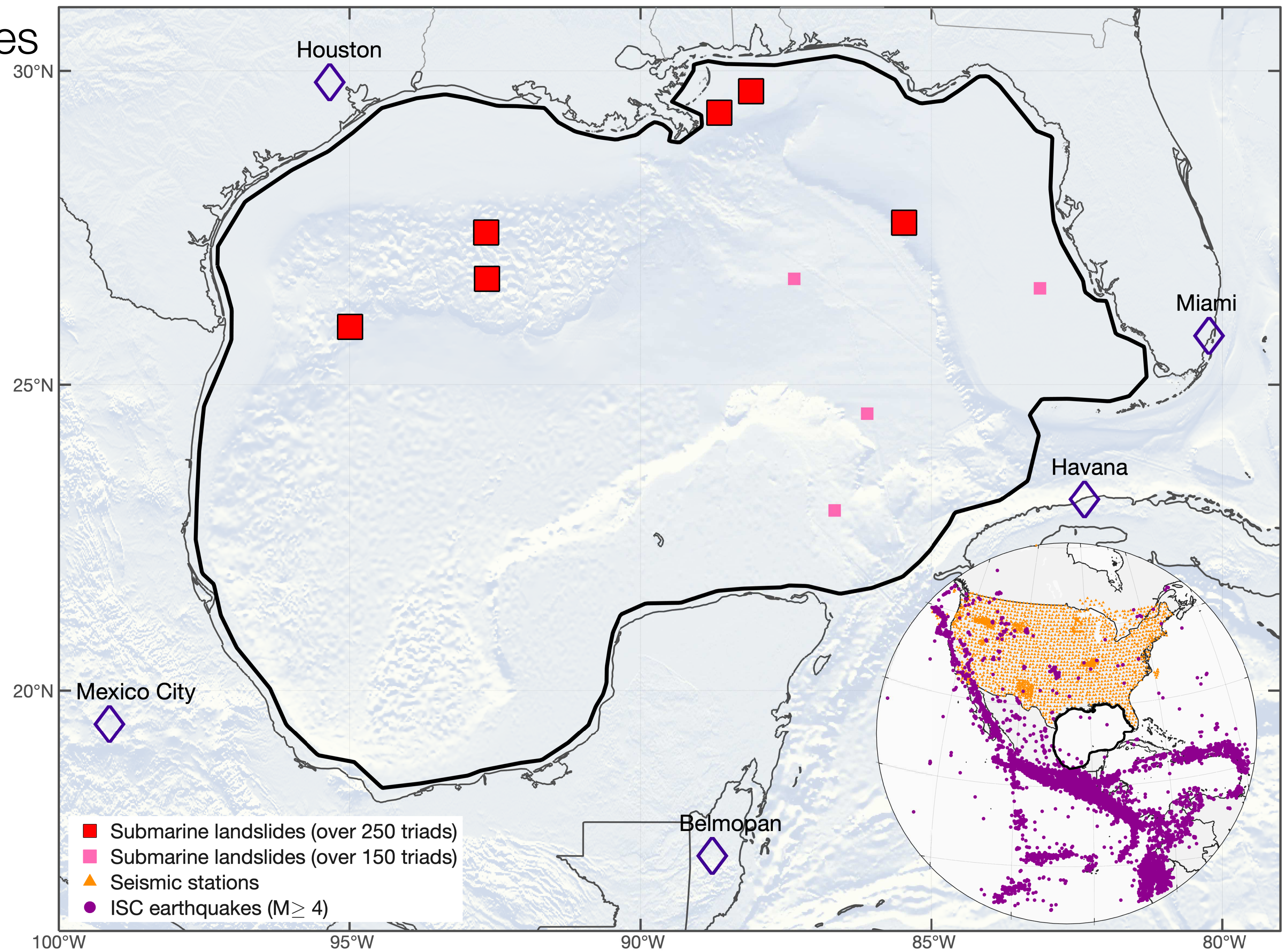
~62 million tons of
rocks/sediments



Ten submarine landslides (2008–2015)

 Detected over 250 triads

 Detected over 150 triads

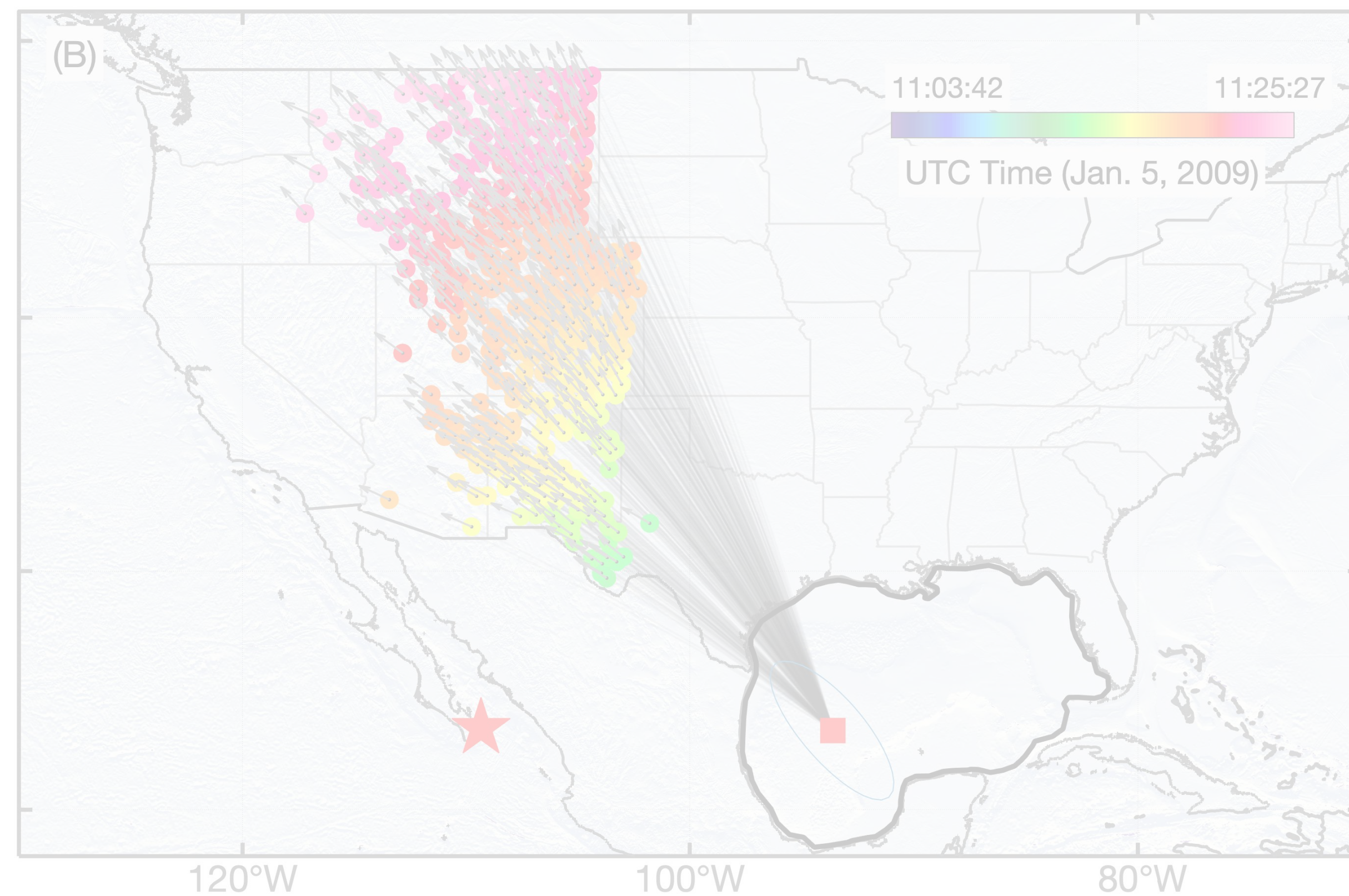
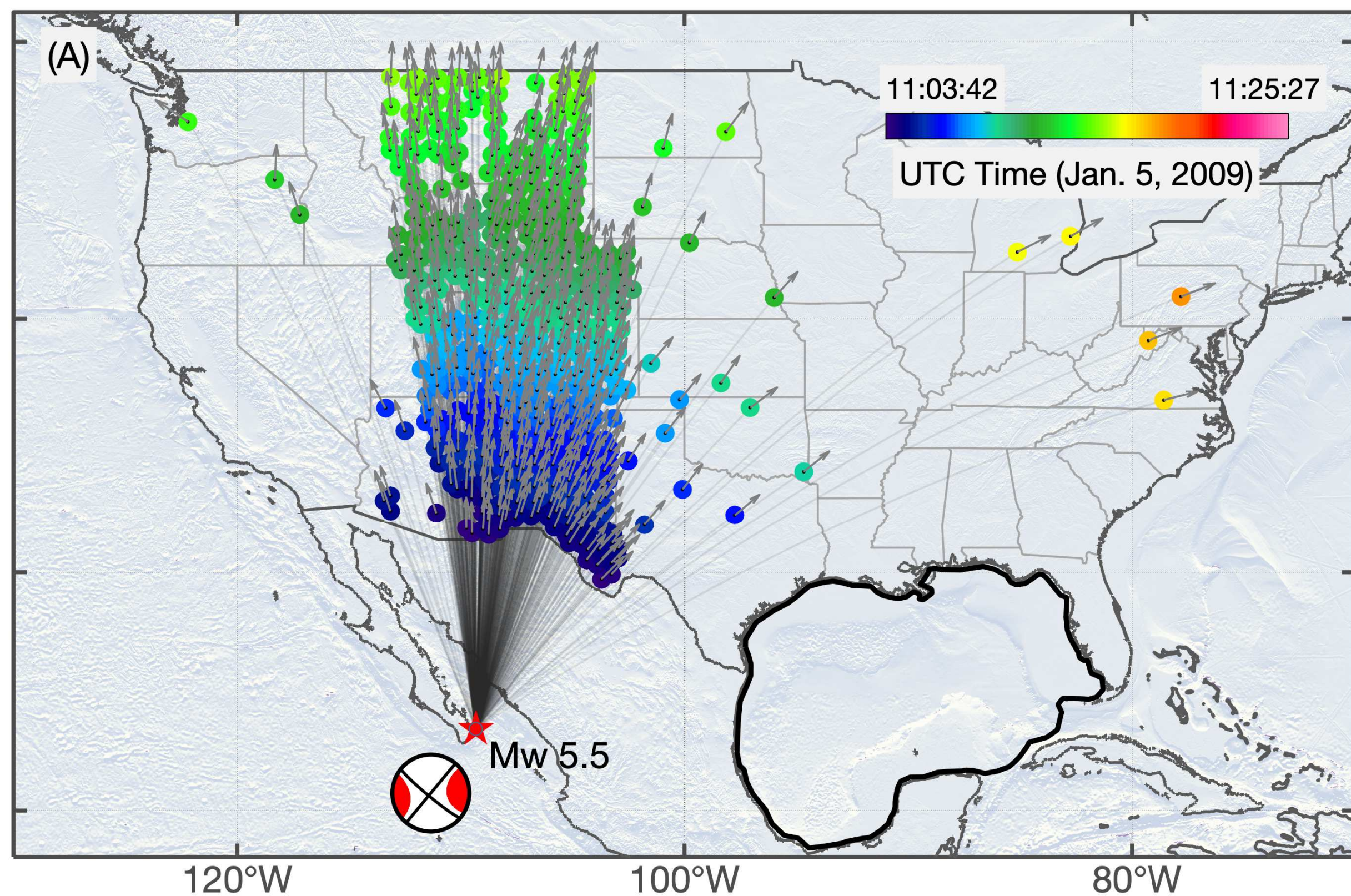


Submarine landslide **dynamically triggered** by a distant earthquake

Distance = 1547 km

Time = 435 s

Triggering velocity = 3.6 km/s

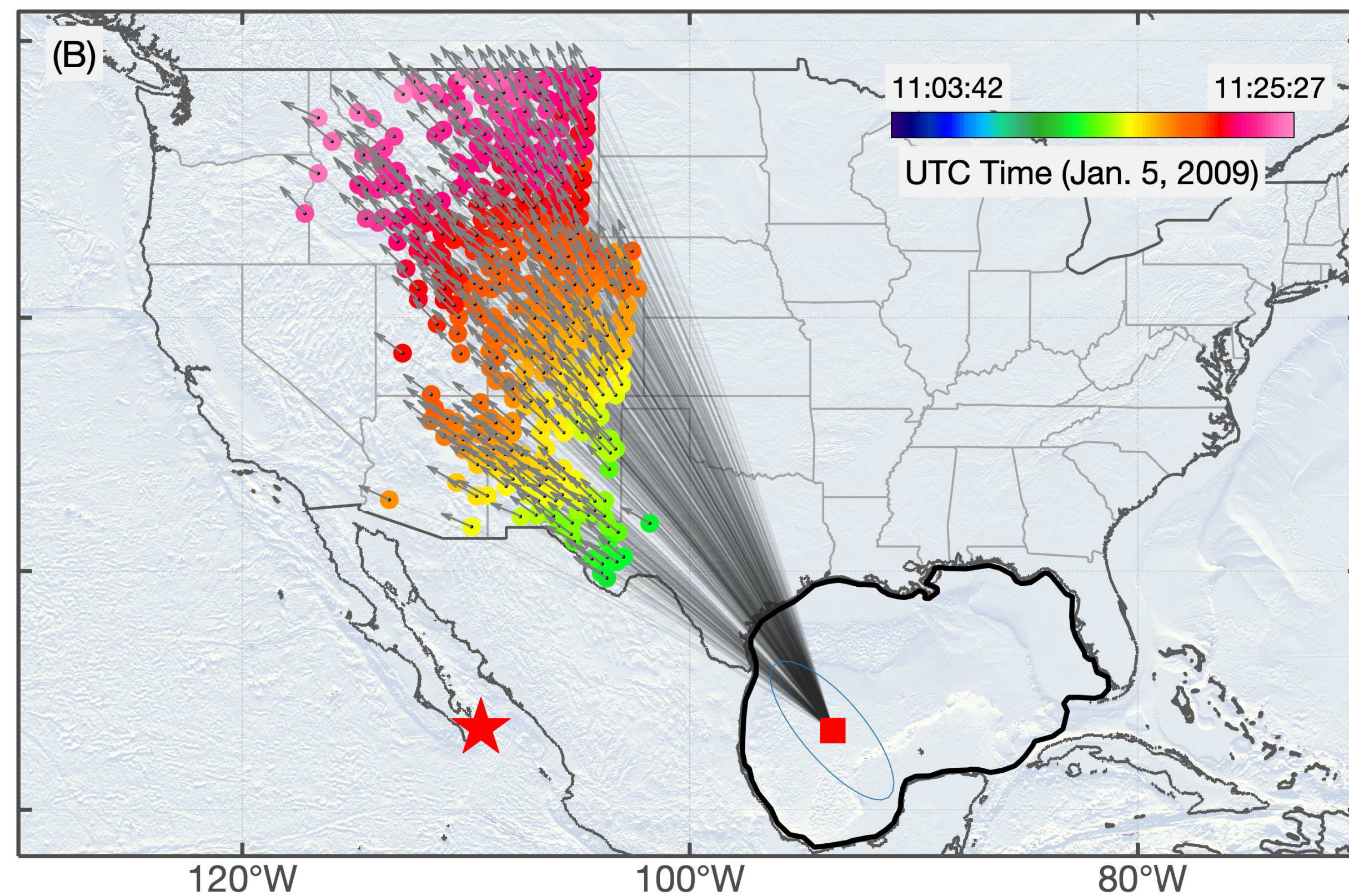
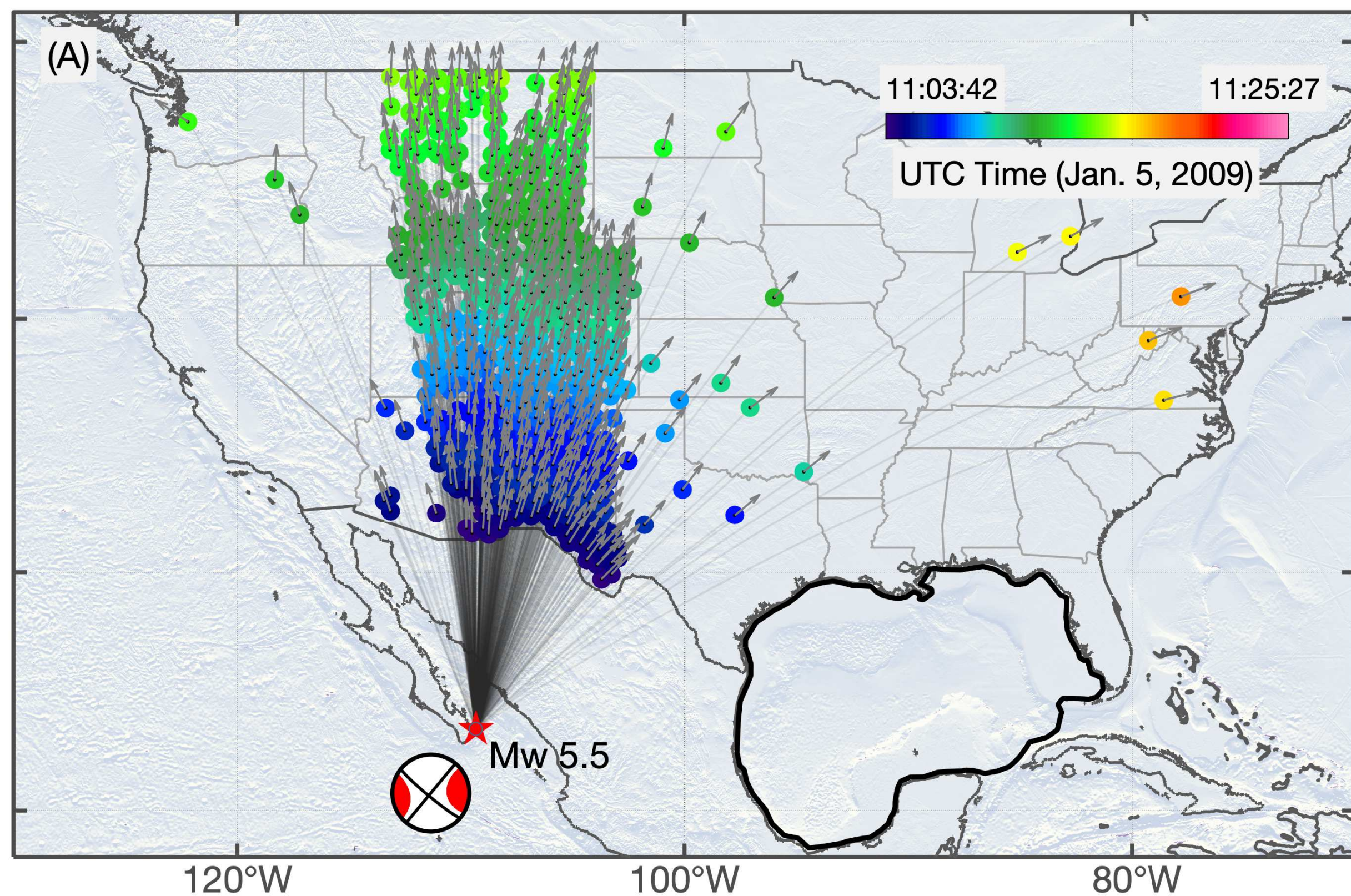


Submarine landslide **dynamically triggered** by a distant earthquake

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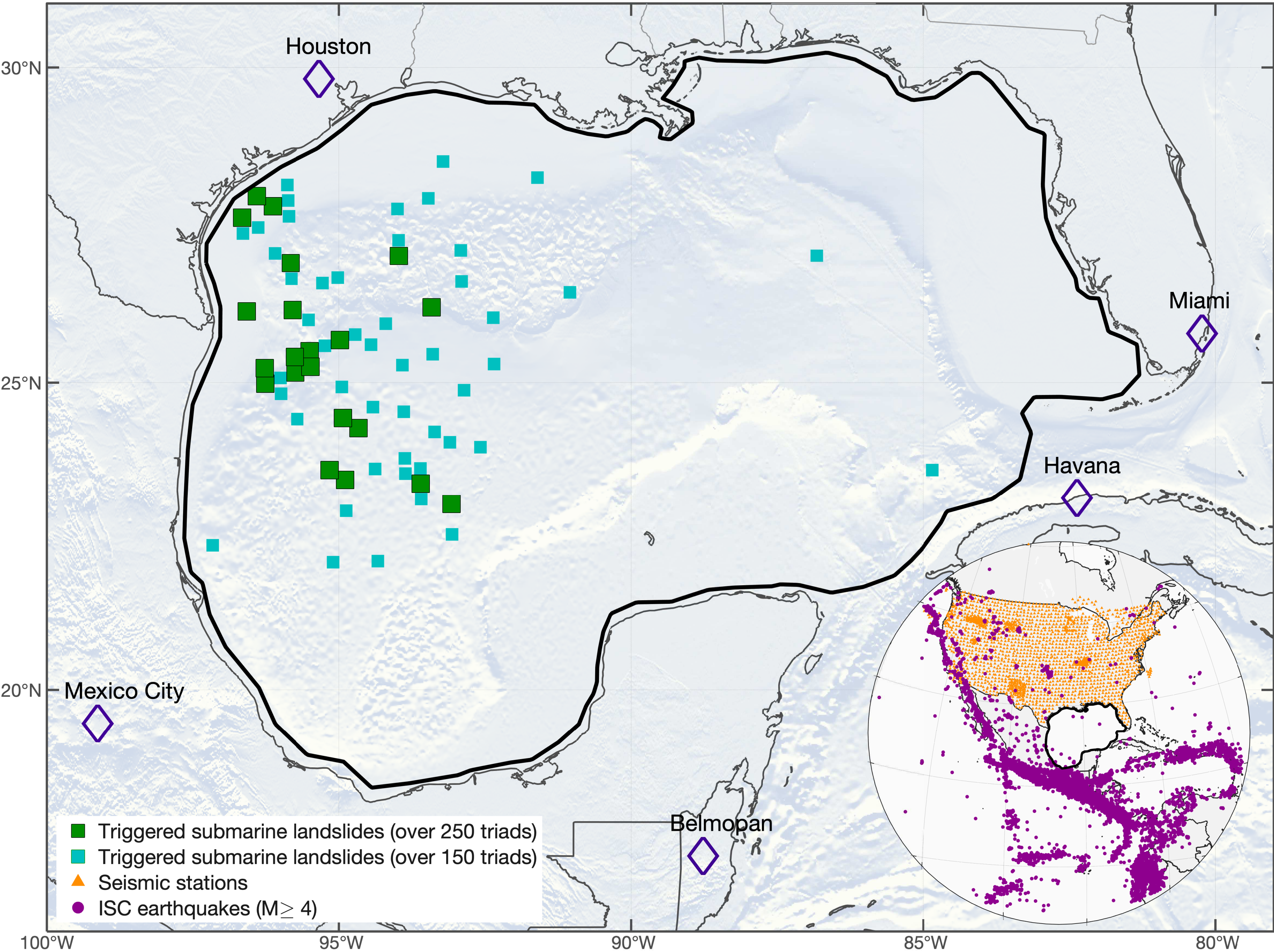
Triggering velocity = 3.6 km/s



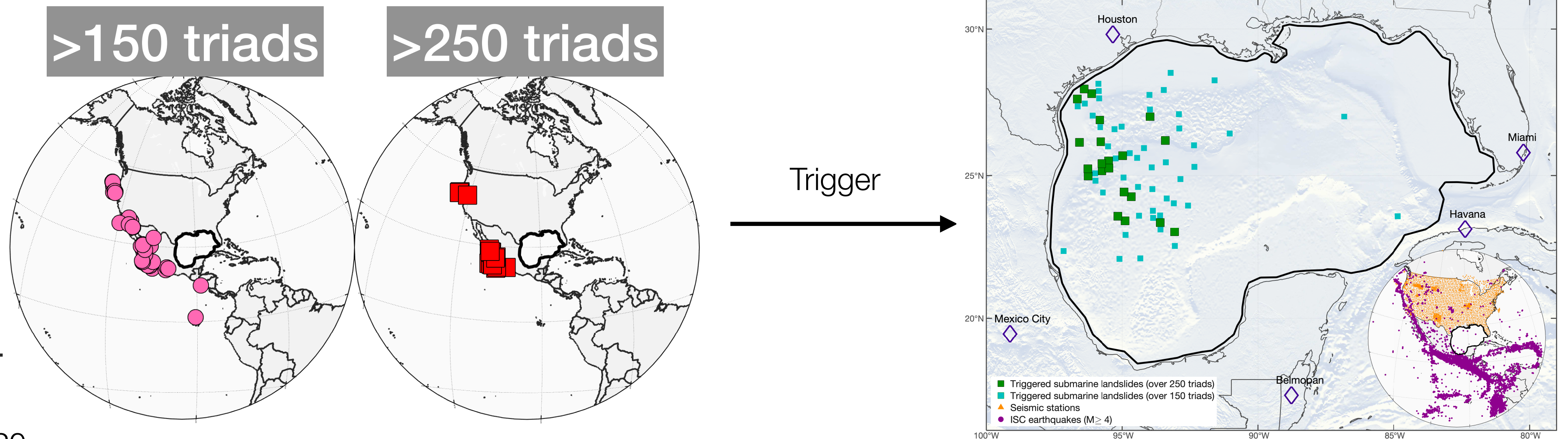
This is **NOT** the near-field (< 100 km) type earthquake-landslide triggering process (PGA: $\sim 1g$?)

The earthquake and the submarine landslide are $\sim$ **1500 km** away.... ($\sim$ KPa?)

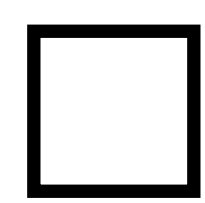
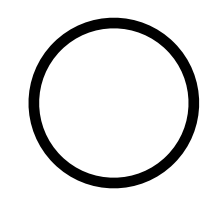
75 dynamically triggered submarine landslides
(2008–2015)

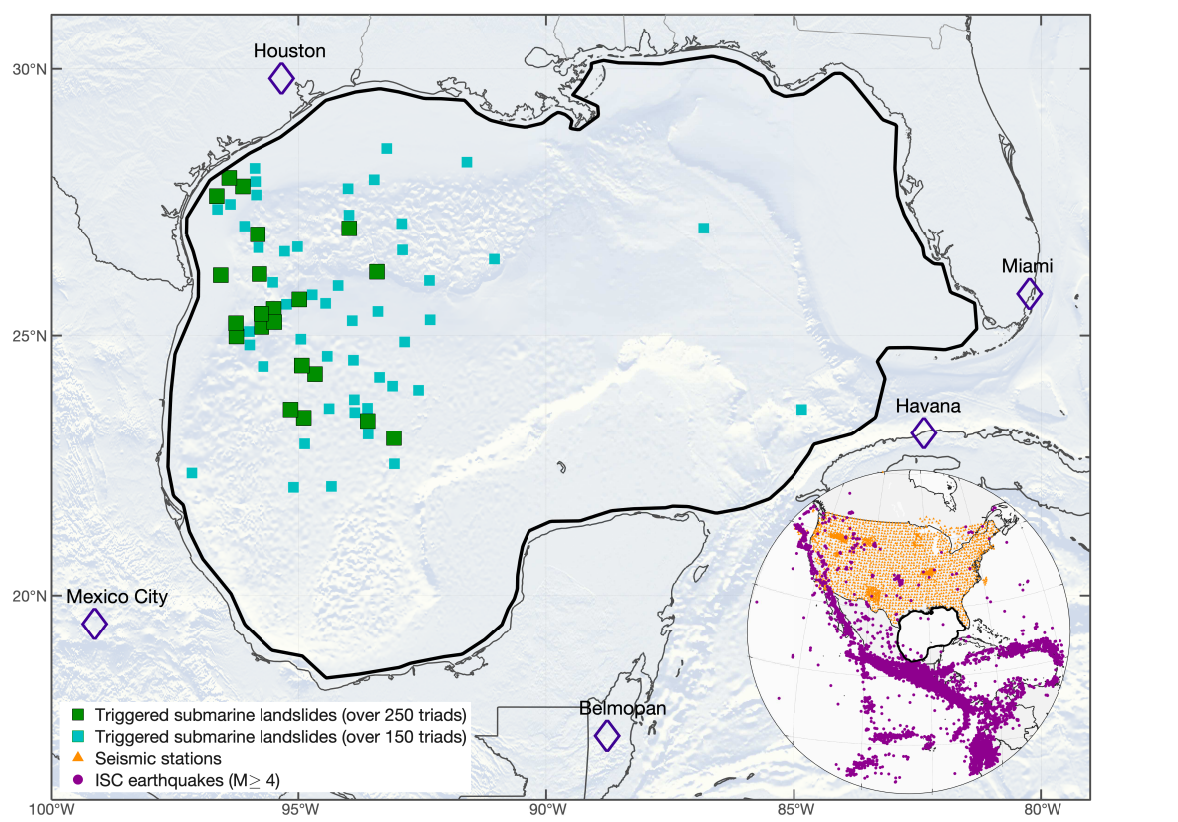
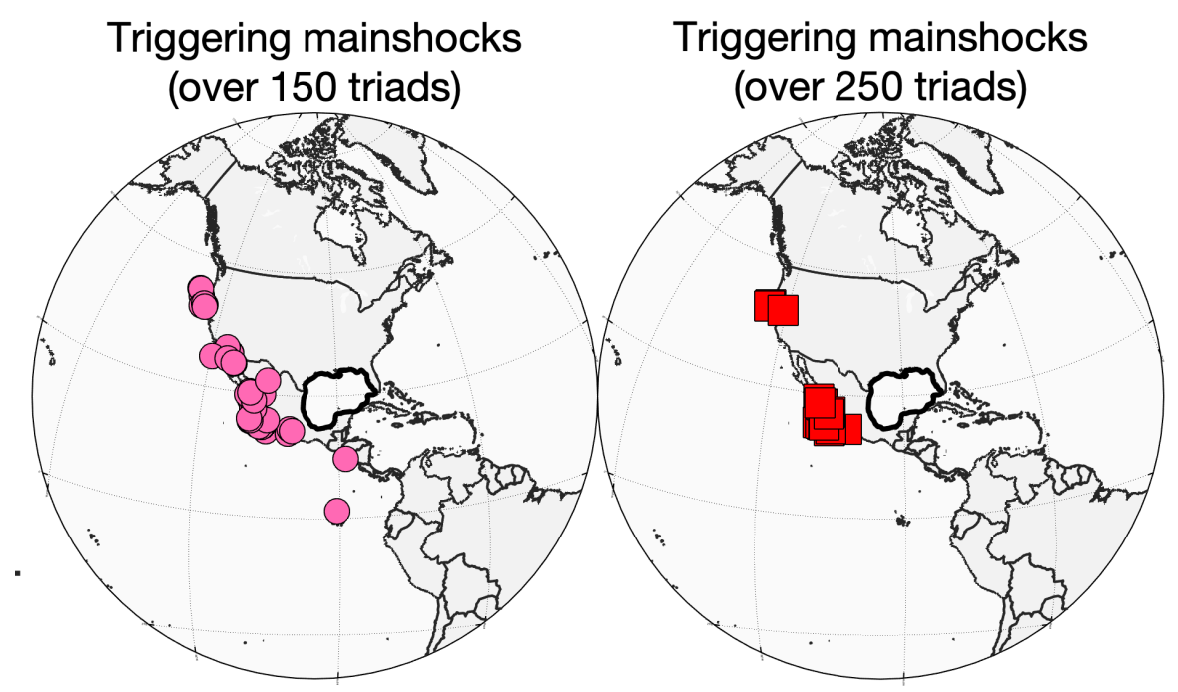
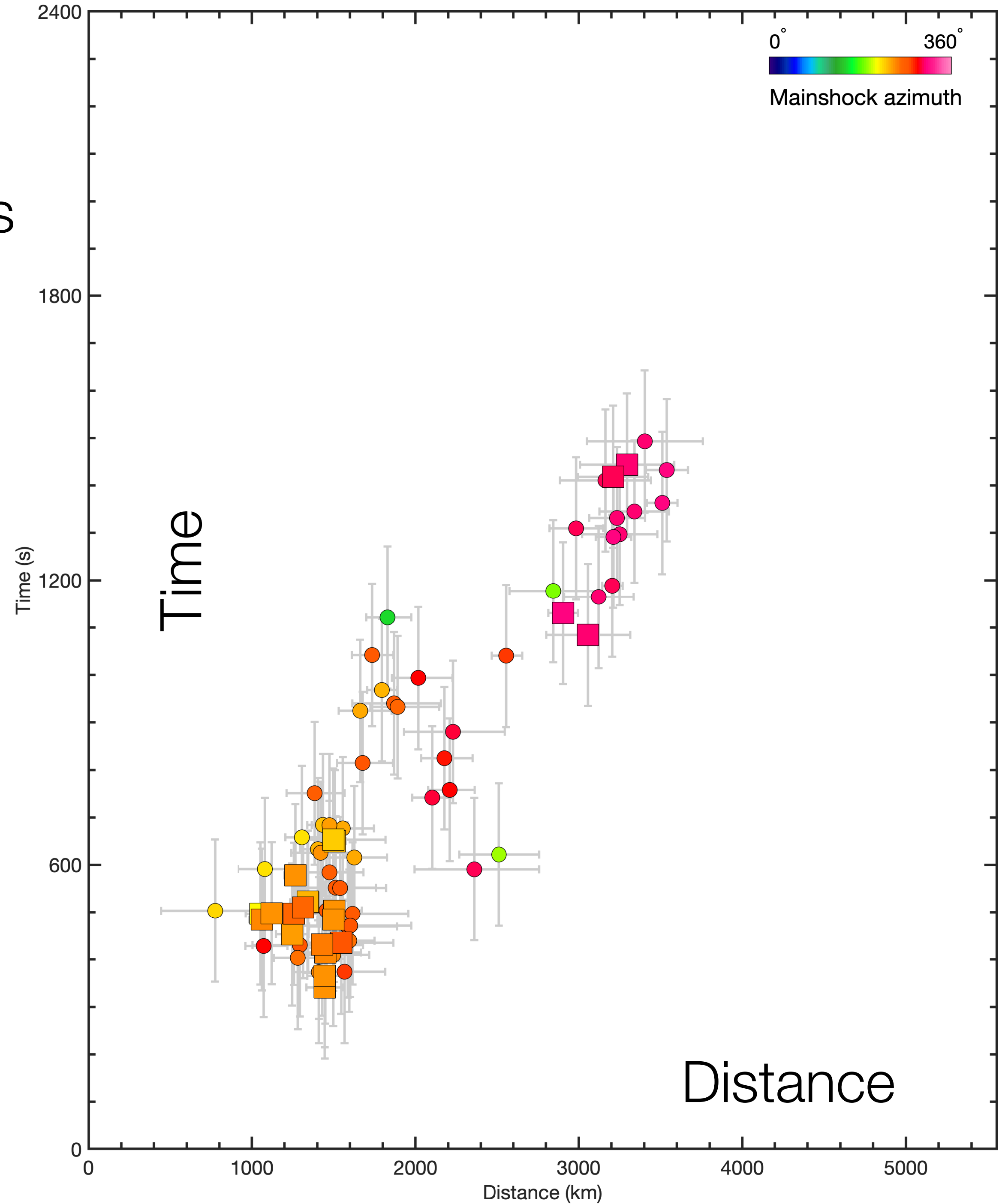


75 dynamically triggered submarine landslides (2008–2015)

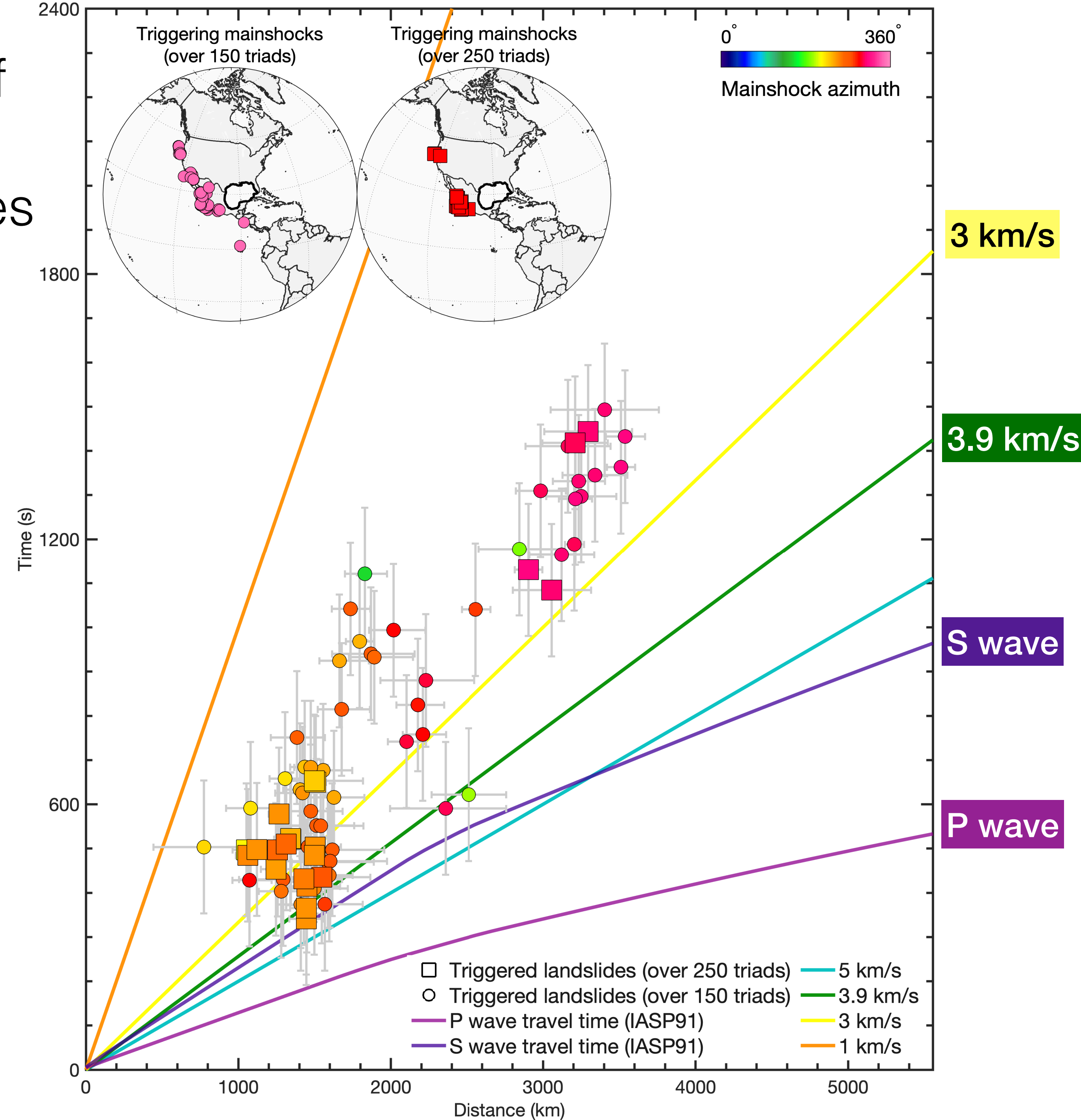


Distance vs time of the triggered submarine landslides

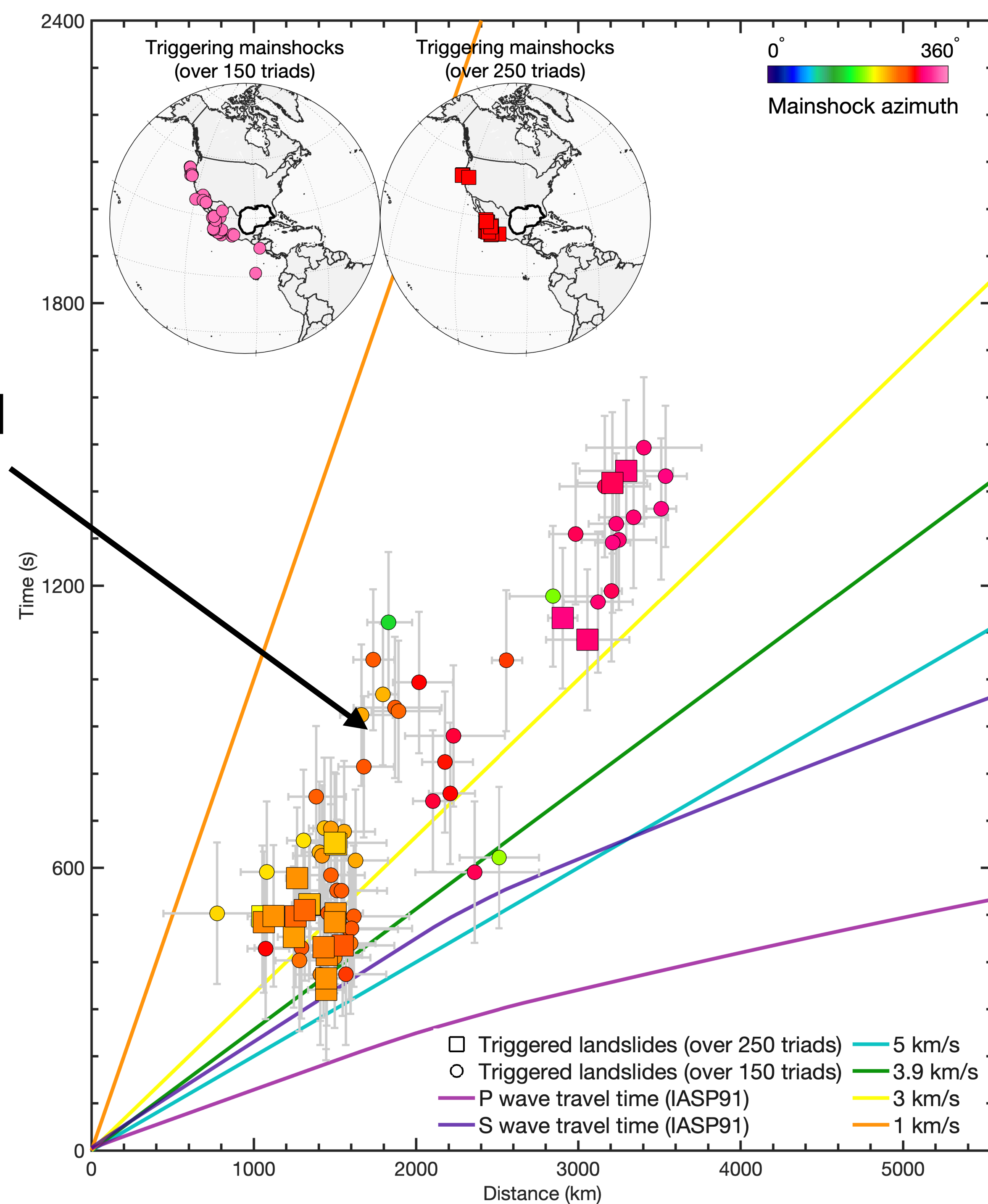
-  Detected over 250 triads
-  Detected over 150 triads



Distance vs time of the triggered submarine landslides



Immediately
dynamically triggered
or very short delay

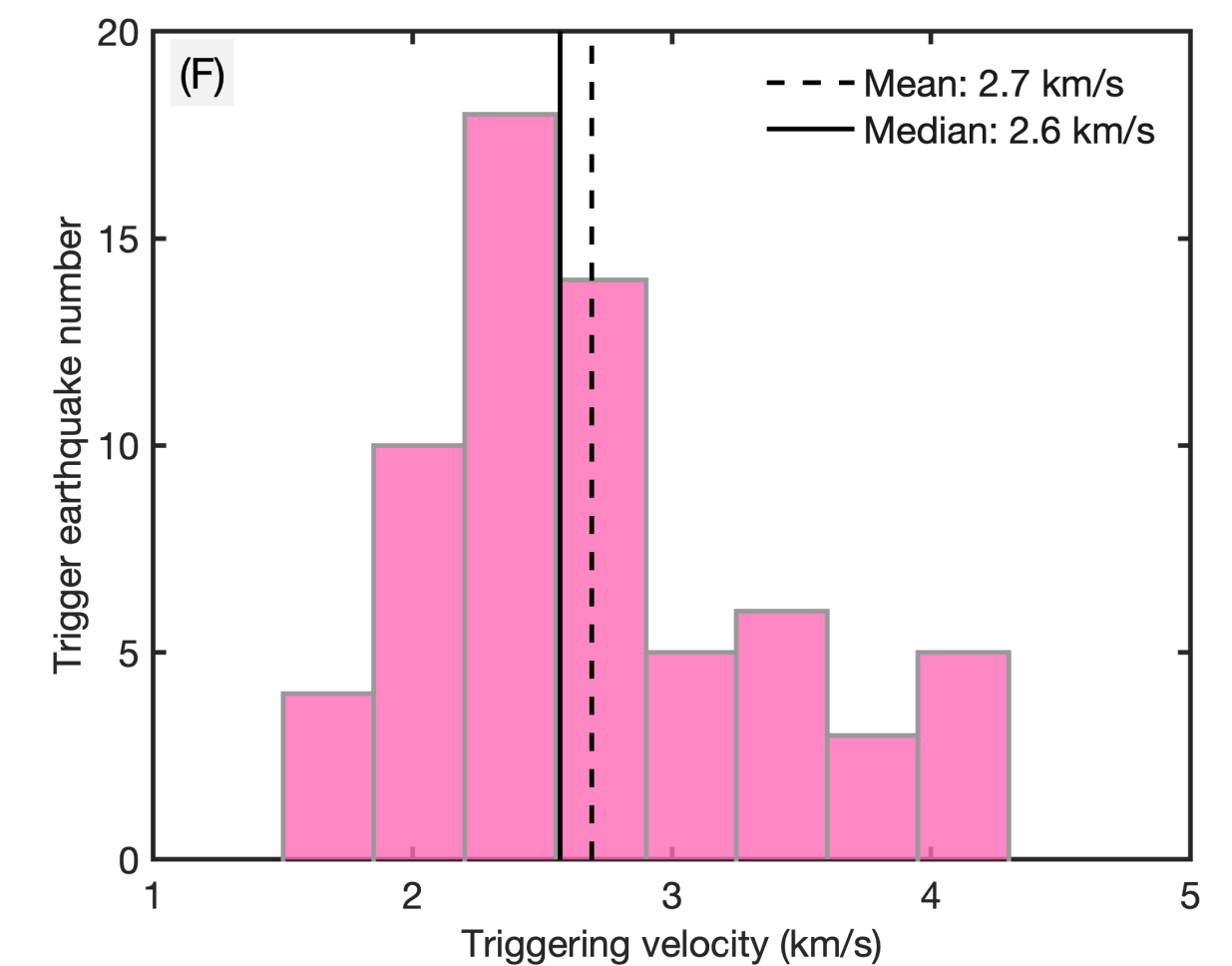


Surface waves

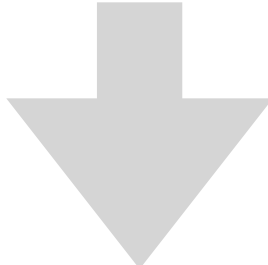
3 km/s

3.9 km/s

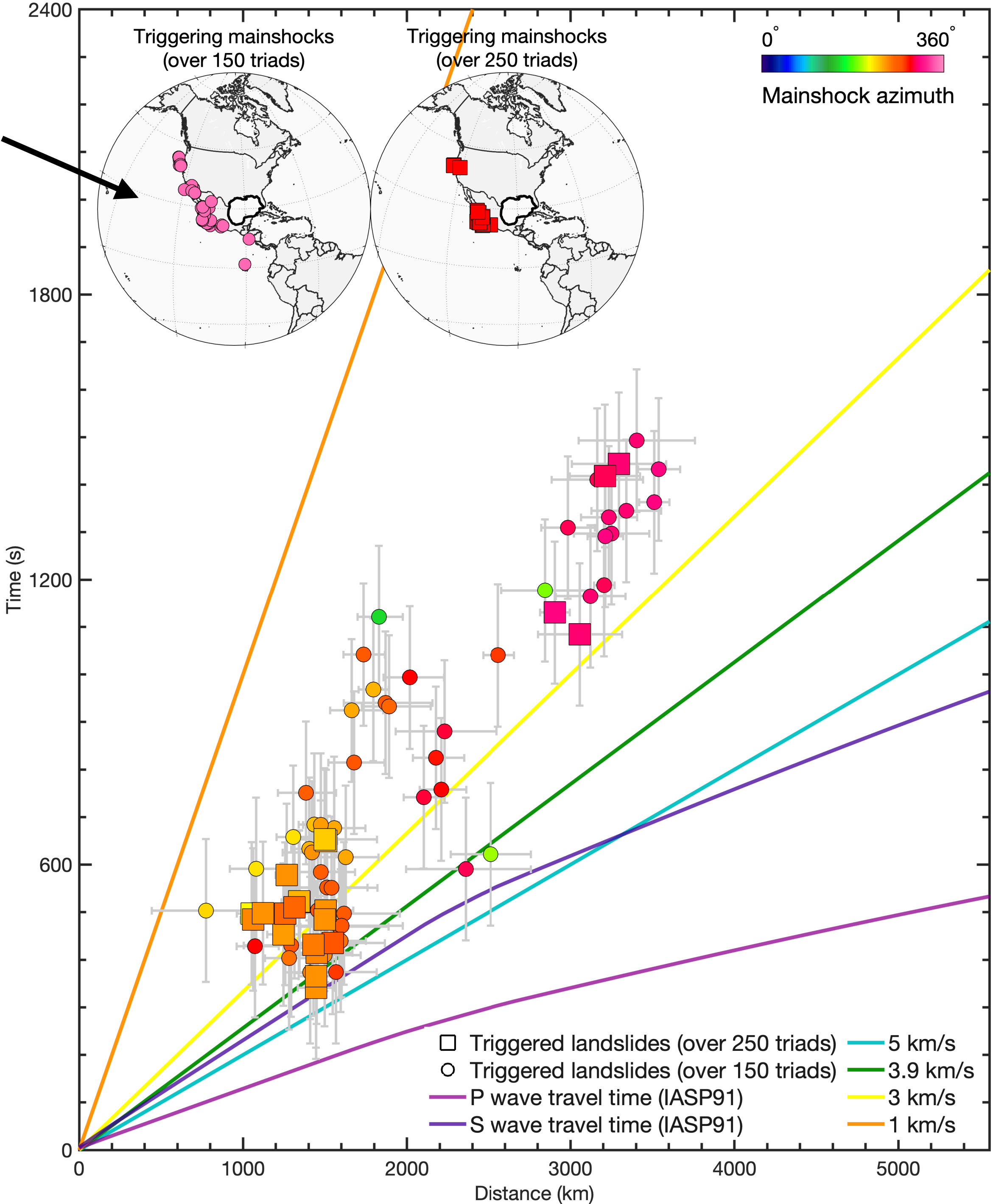
Triggering velocity
histogram



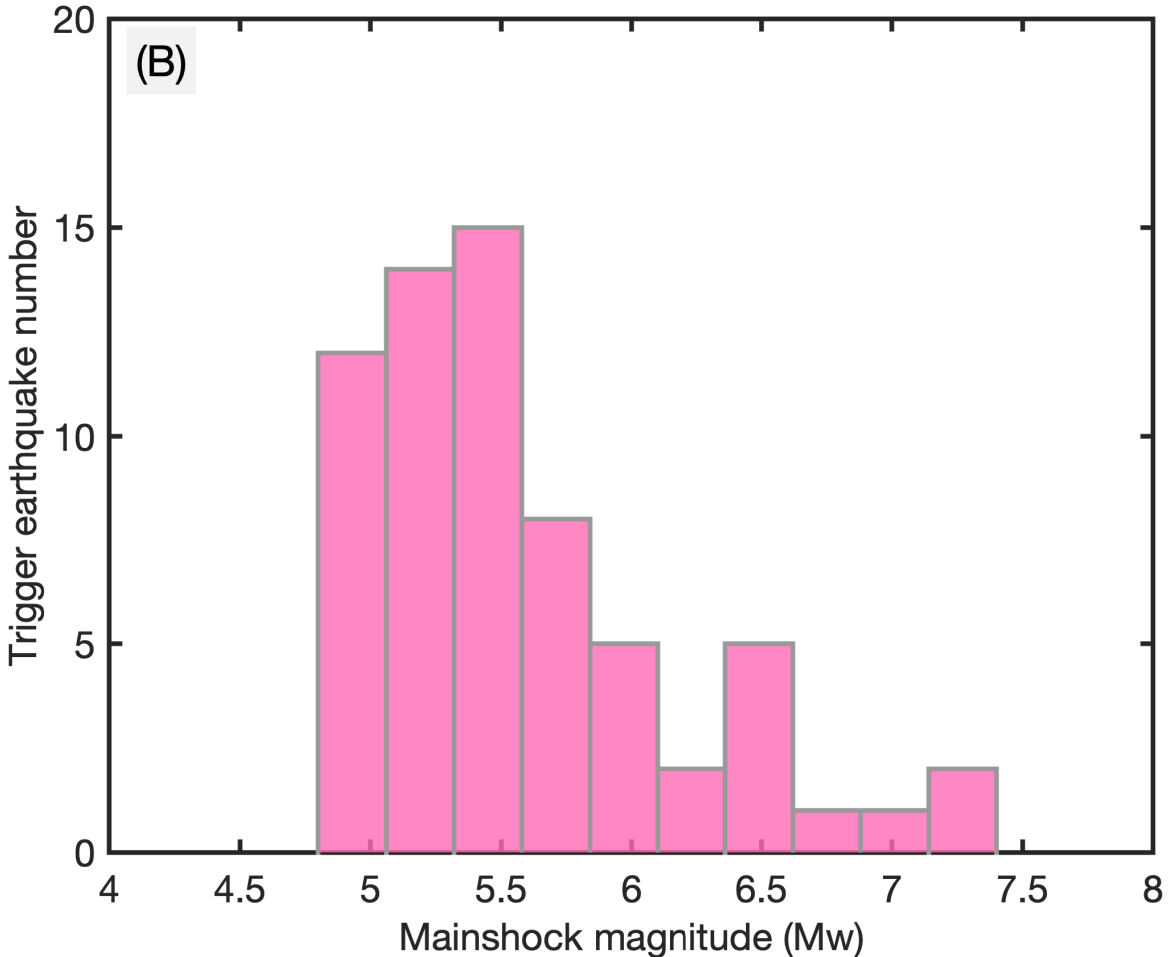
No magnitude dependence



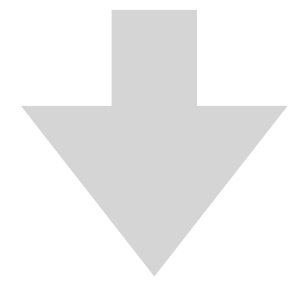
Peak dynamic strain (stress) is not the only triggering threshold



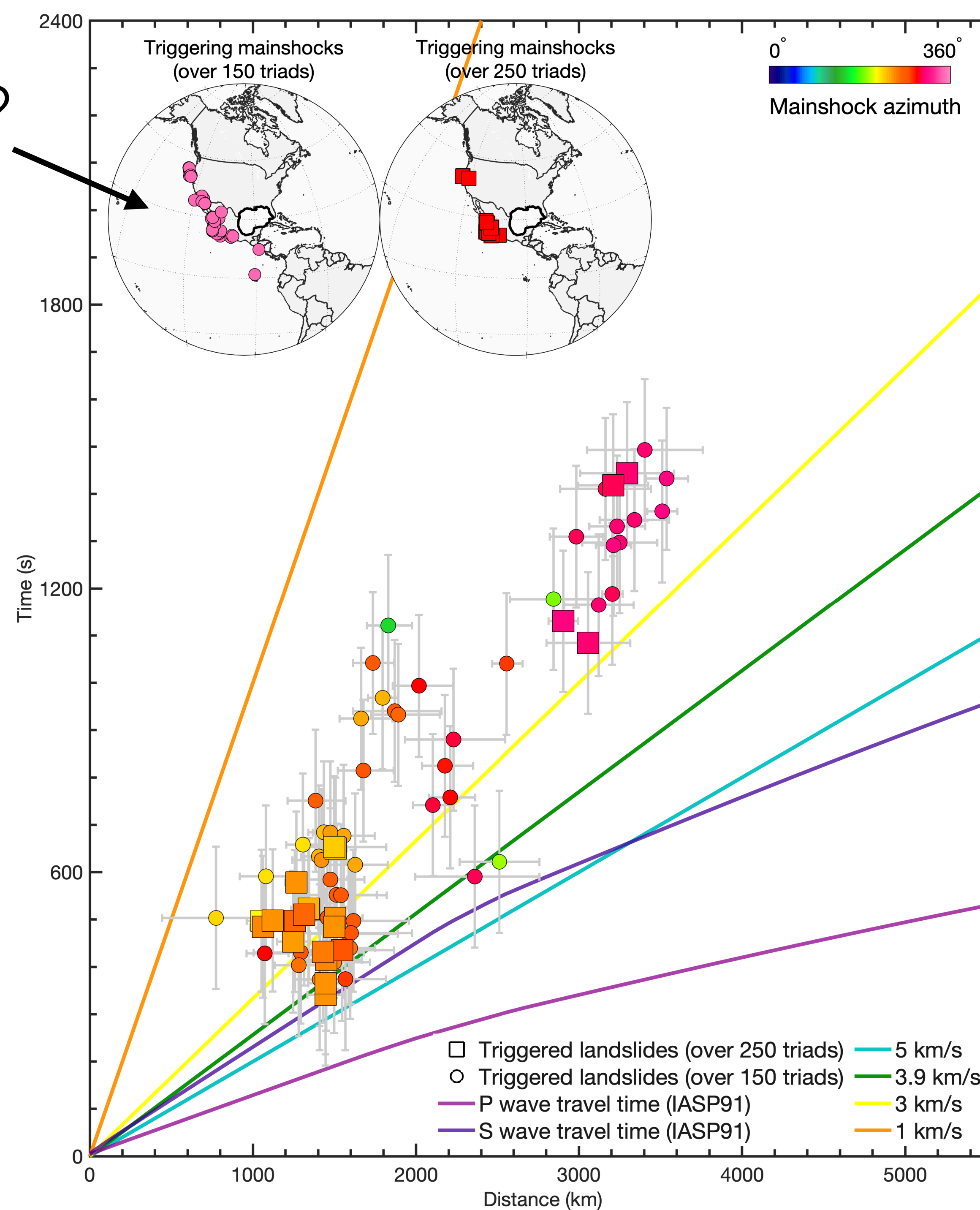
Triggering magnitude histogram



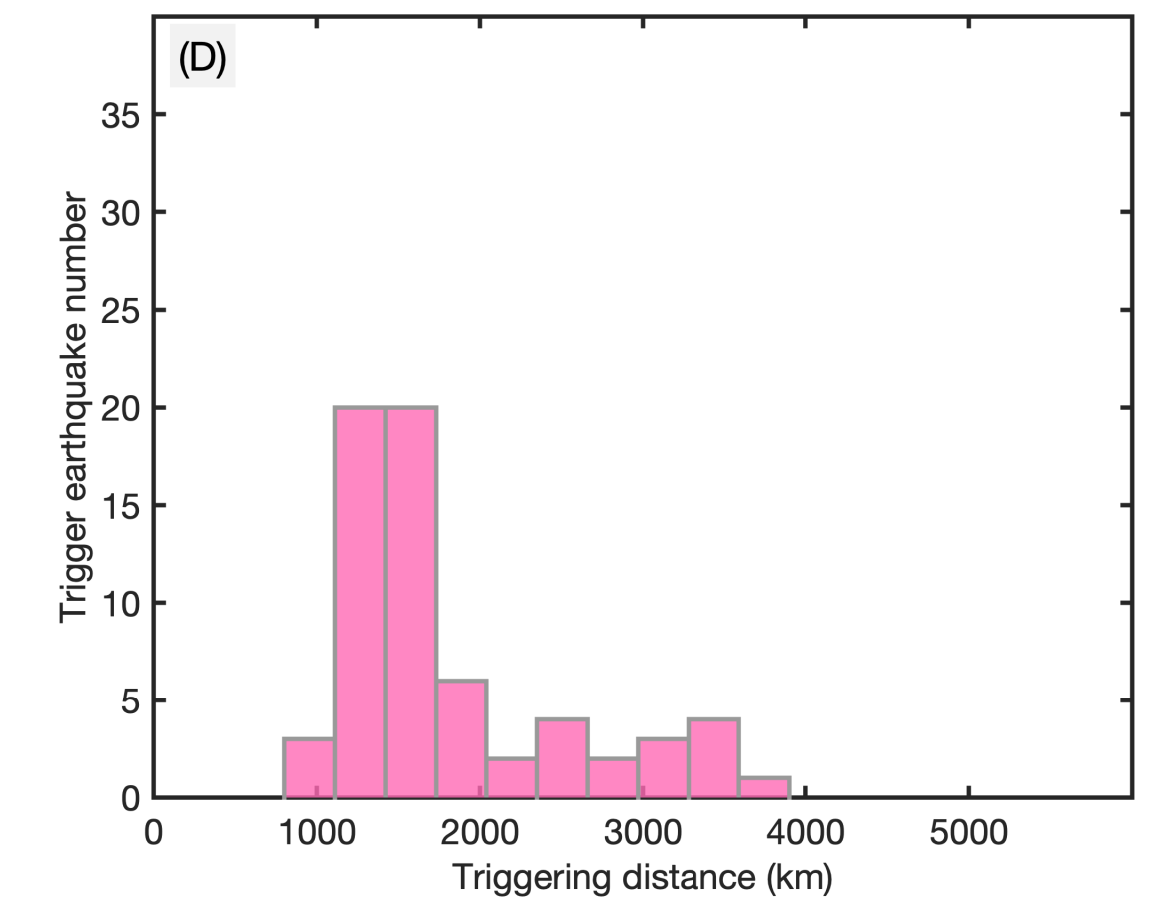
A distance limit ?



A frequency dependence ?

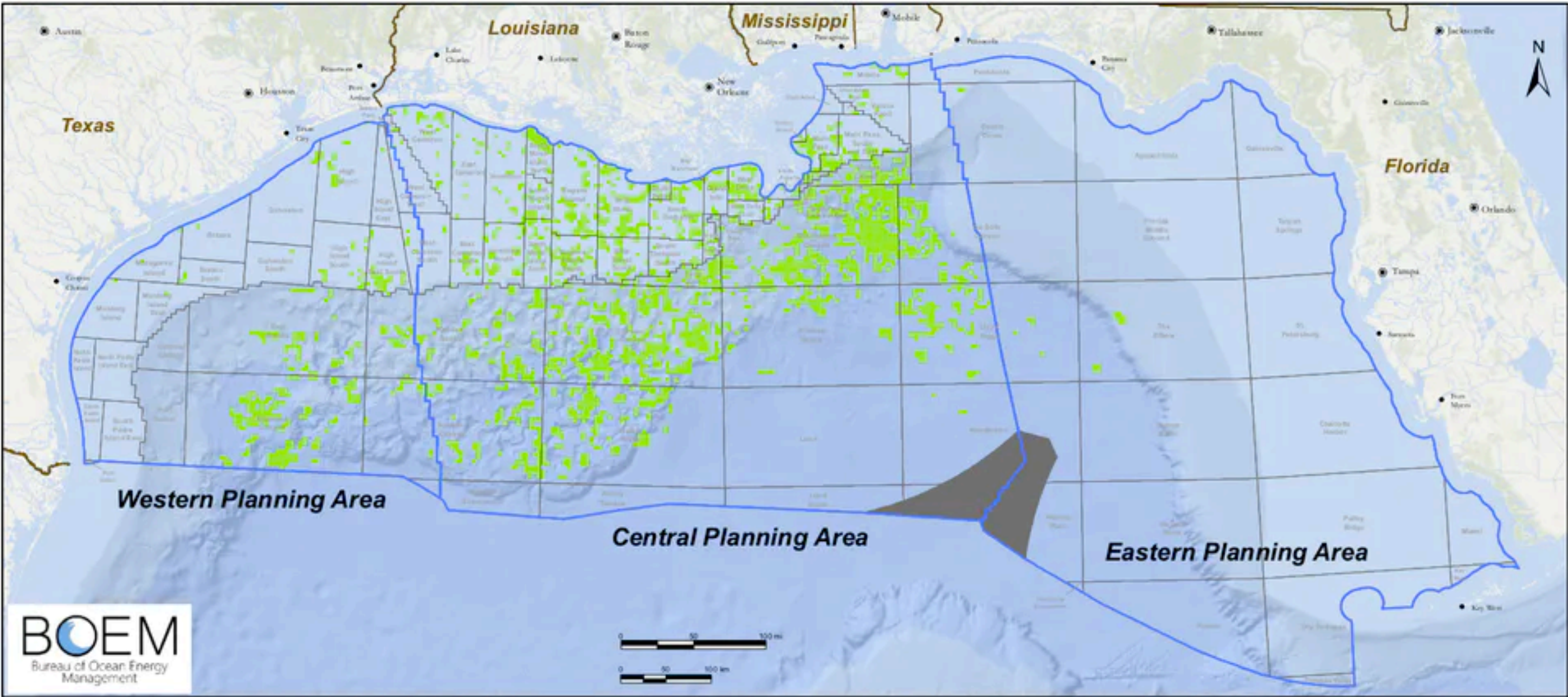


Triggering distance histogram



Abundant submarine landslides in the Gulf of Mexico

BOEM Gulf of Mexico OCS Region
Blocks and Active Leases by Planning Area
March 1, 2019



Planning Areas	Total Blocks	Total Acres	Number of Leases	Acres Leased
Western	5,240	28,576,813	318	1,816,148
Central	12,409	66,446,351	2,188	11,434,683
Eastern	11,537	64,357,859	18	103,680
Sub-Totals	29,186	159,381,023	2,524	13,354,511
CPA / EPA Shared Blocks*	(86)		0	
Totals	29,100	159,381,023	2,524	13,354,511

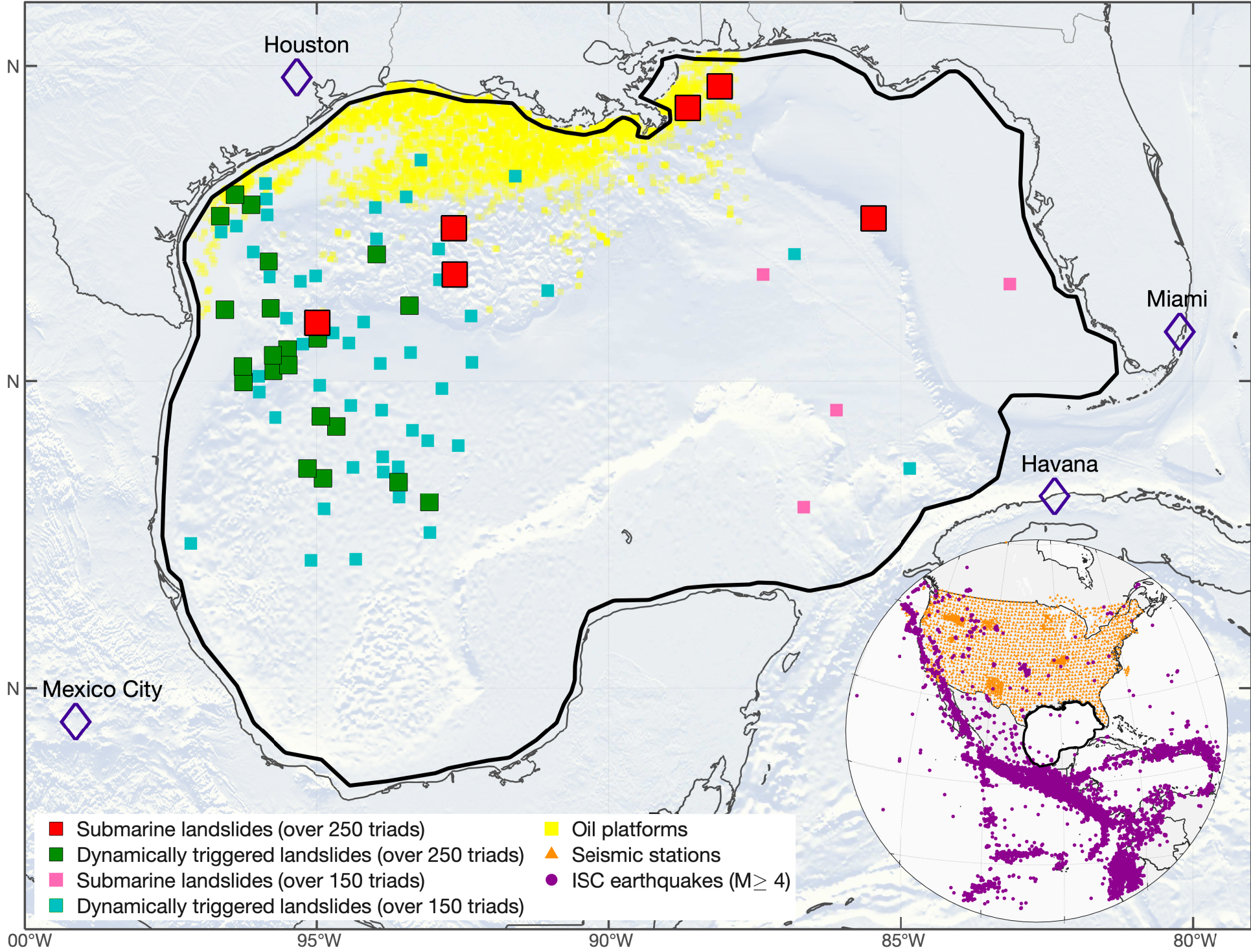
Active Lease

Exclusive Economic Zone
Northern Portion of the Eastern Gap

Planning Area Boundary

* CPA and EPA contain 86 shared blocks. These blocks are given both a CPA and EPA designation in the data which may account for a higher block total.

Office of Leasing and Plans, Mapping and Automation Section | MAS201900175 | 01 March 2019

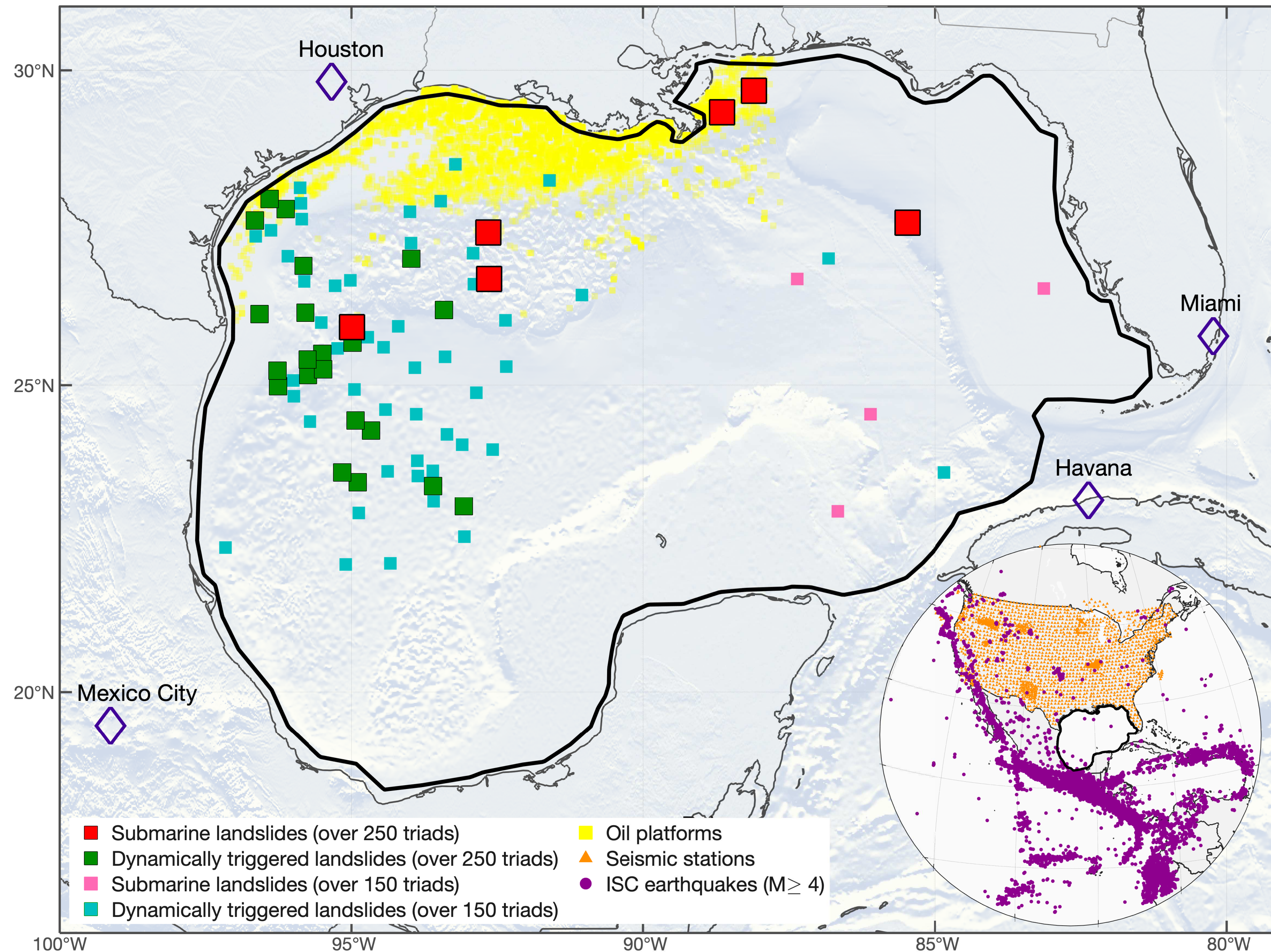


2008—2015, **85** in total

Spontaneous: **10**

Dynamically triggered: **75**

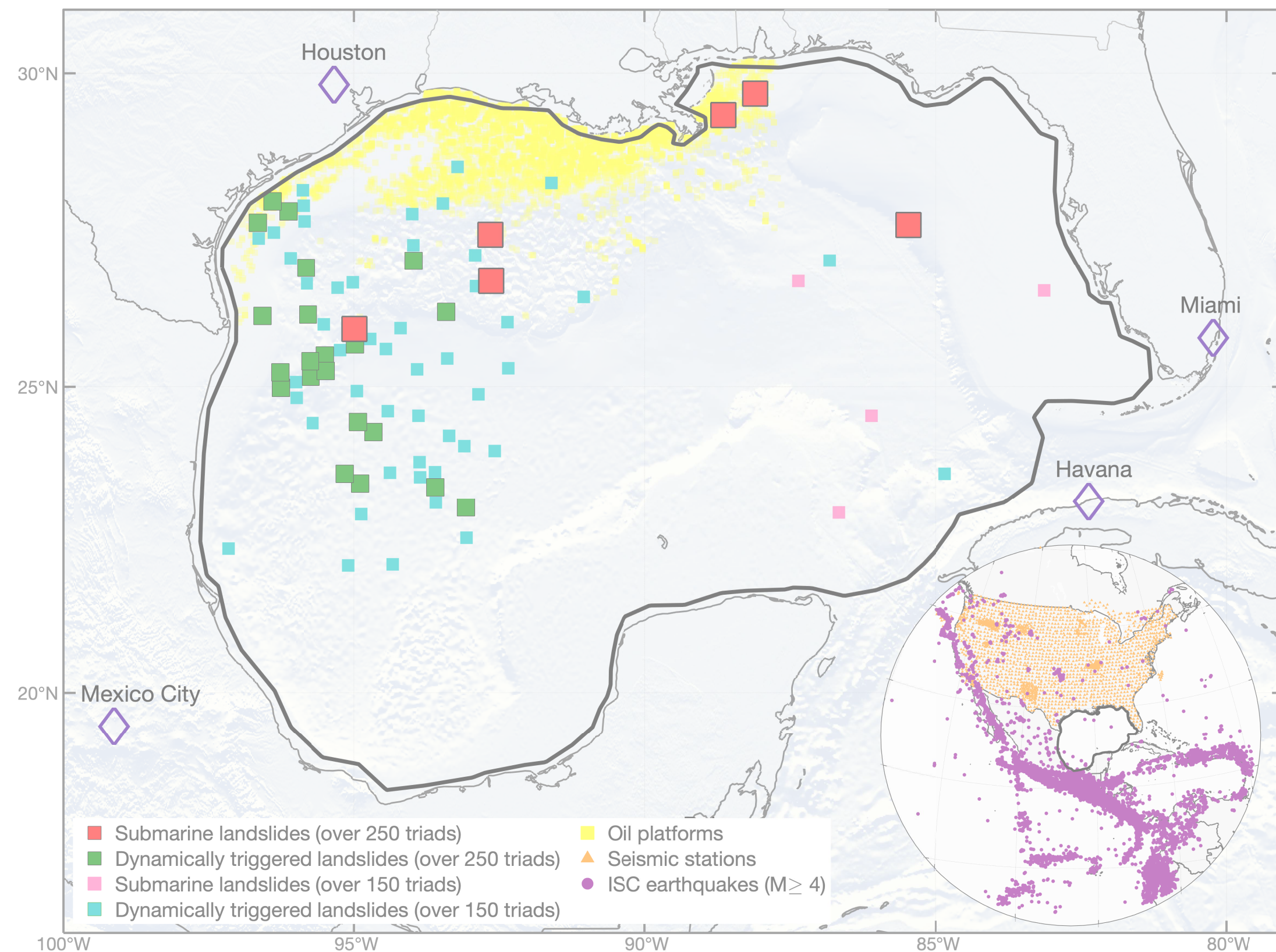
Abundant submarine landslides in the Gulf of Mexico



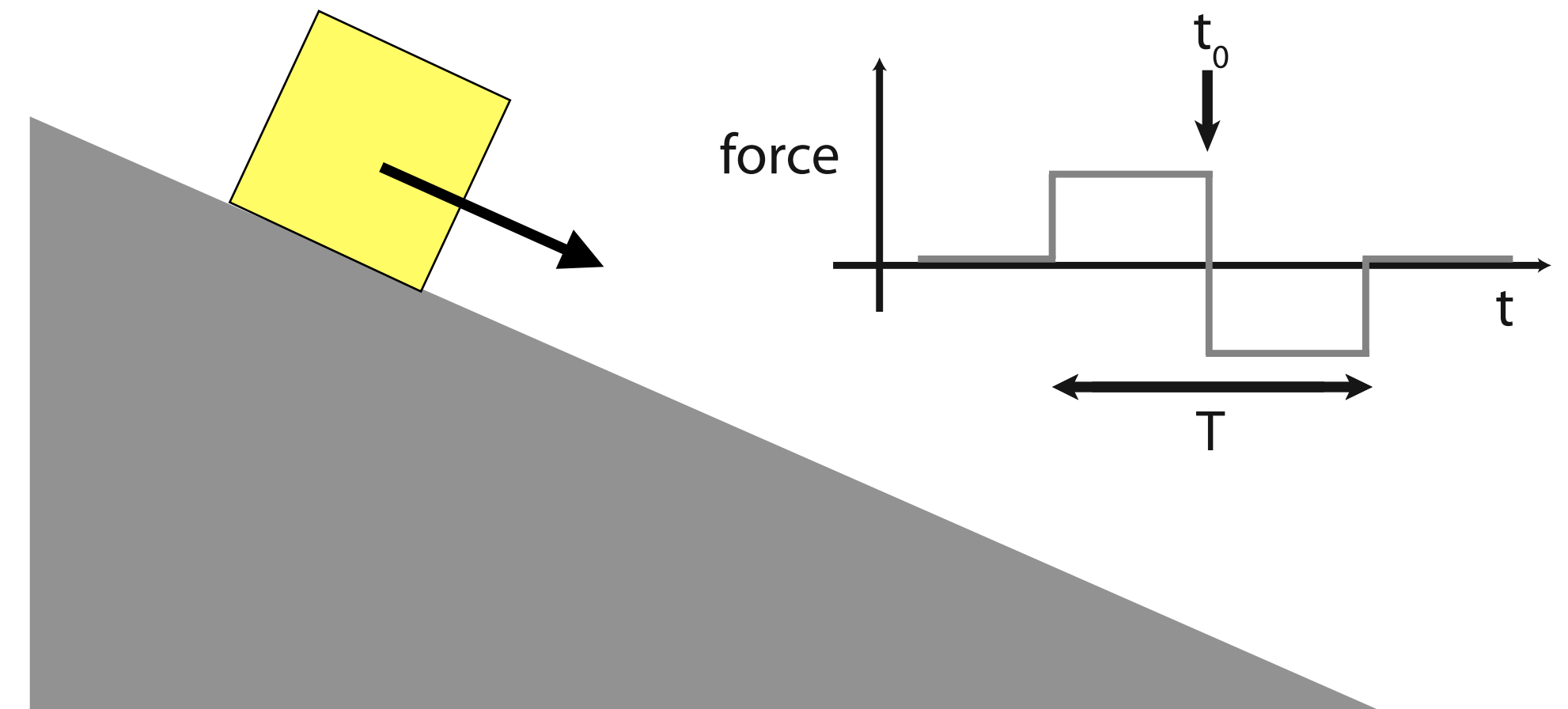
WHY?
HOW?

2008—2015, **85** in total
Spontaneous: **10**
Dynamically triggered: **75**

Mechanisms of submarine landslides in the Gulf of Mexico



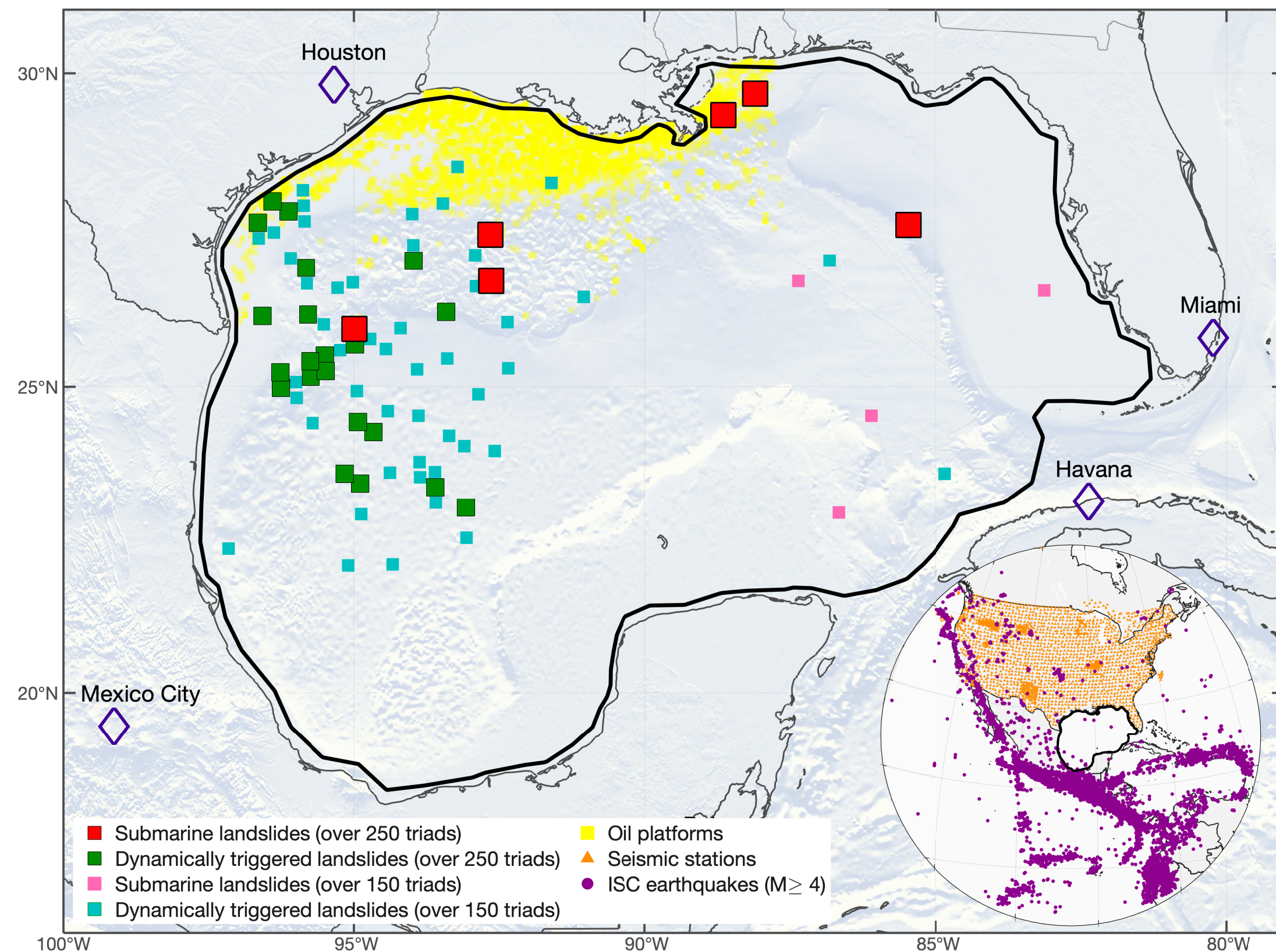
Complex ocean basin + thick sediment



fast, block, weak zone

2008—2015, **85** in total
Spontaneous: **10**
Dynamically triggered: **75**

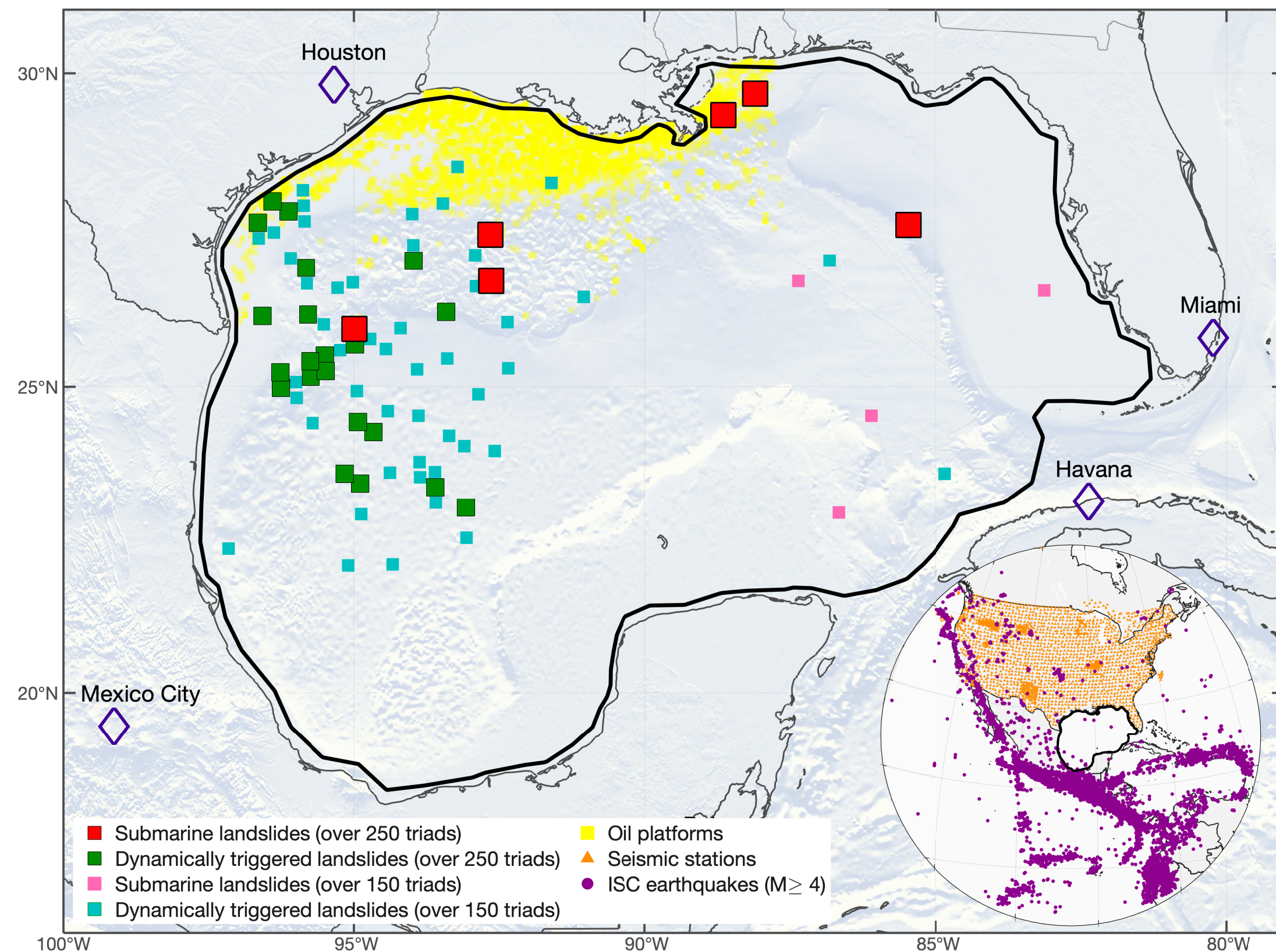
Mechanisms of submarine landslides in the Gulf of Mexico



- Rapid sediment accumulation
- Overly steep topography
- Over pressurization
- Gas hydrate
- Weak oil layer
- Ground water / oil seepage
- Prolonged strong ground motion
- Cyclic shearing -> plastic strain -> strength reduction
- Cyclic shearing -> permeability enhancement

2008—2015, **85** in total
Spontaneous: **10**
Dynamically triggered: **75**

Mechanisms of submarine landslides in the Gulf of Mexico



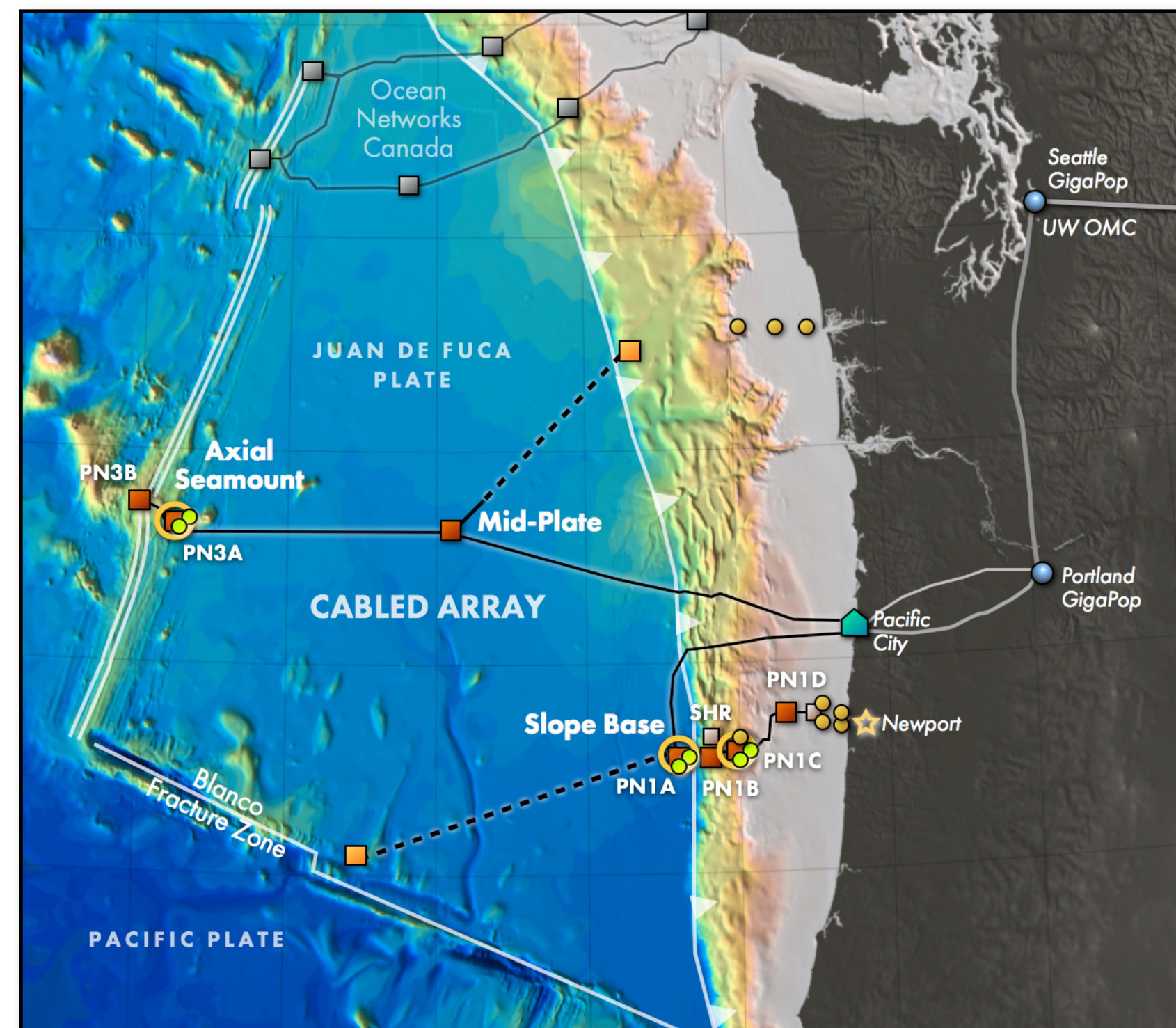
- Complex ocean basin + thick sediment
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- Overly steep topography
- Over pressurization
- Gas hydrate
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2008—2015, **85** in total
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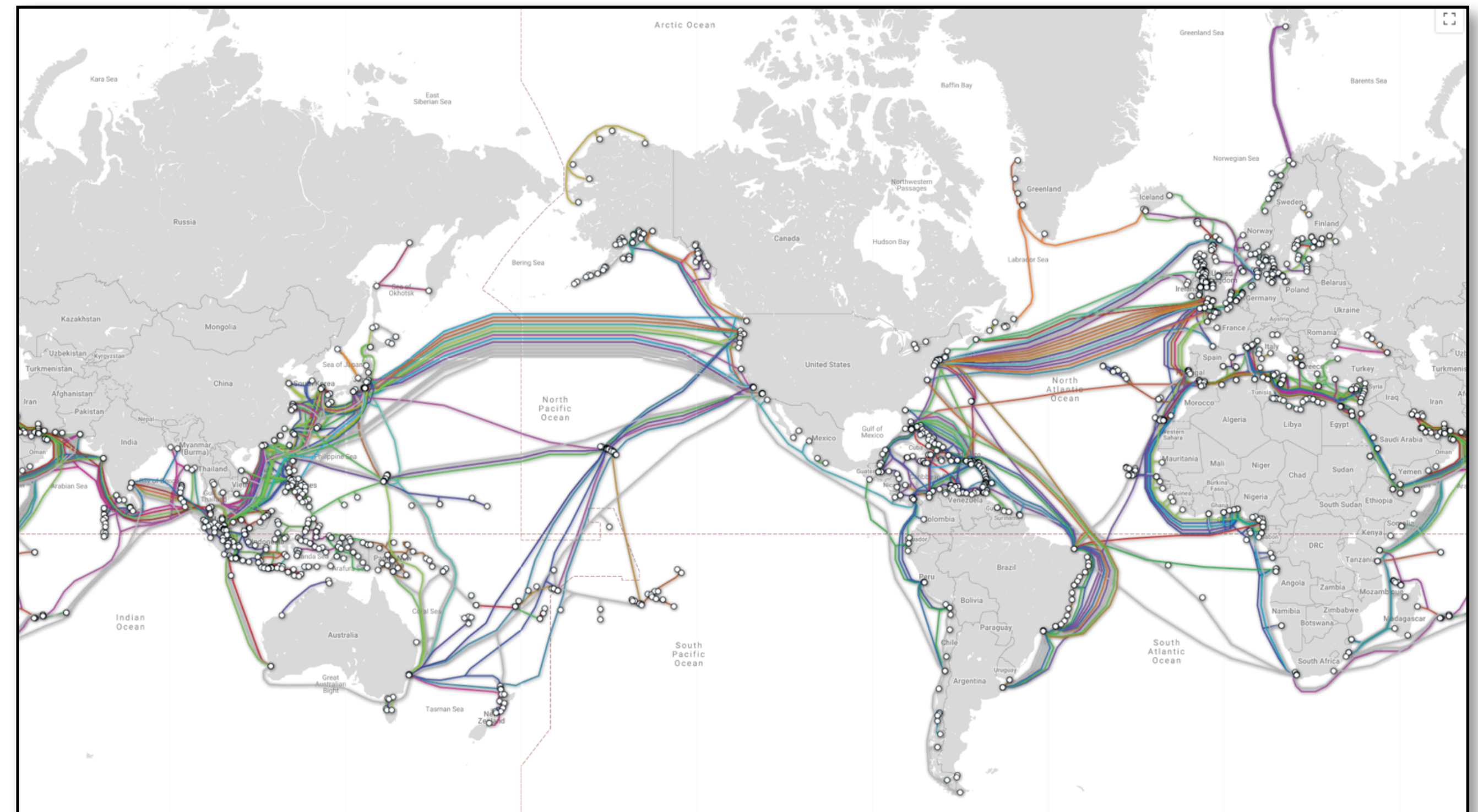
Conclusions

- The ambient seismic wavefield records the coupled Earth systems
- Large seismic array can help revealing complex surficial processes
- Abundant submarine landslides are detected in the Gulf of Mexico
- Majority of the landslides are dynamically triggered by distant earthquakes

Submarine Environmental Sensing Over Telecommunication Fiber Optic Cables



Cabled Observatories



Transoceanic Cables

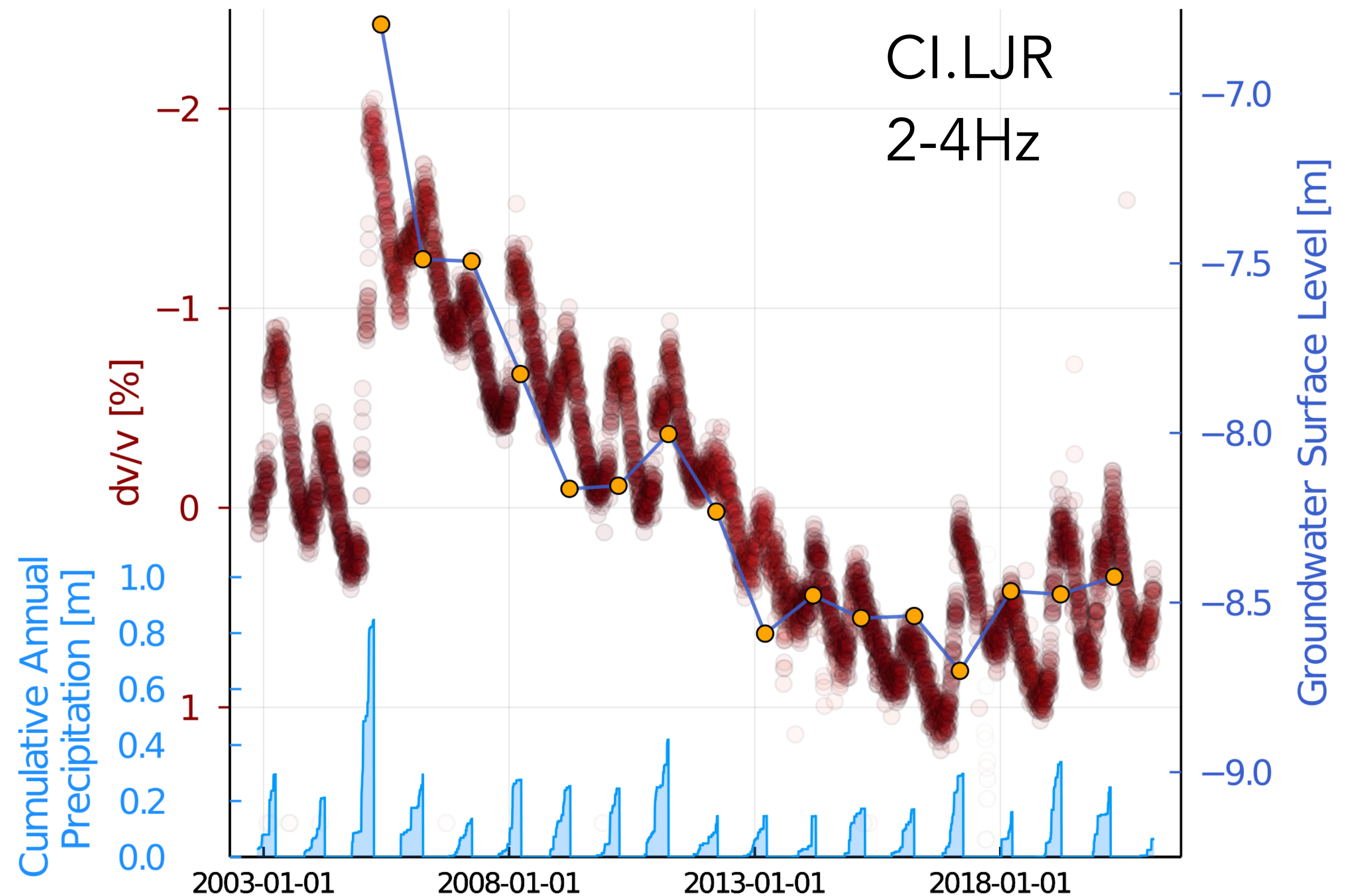
Groundwater monitoring using ambient noise seismology

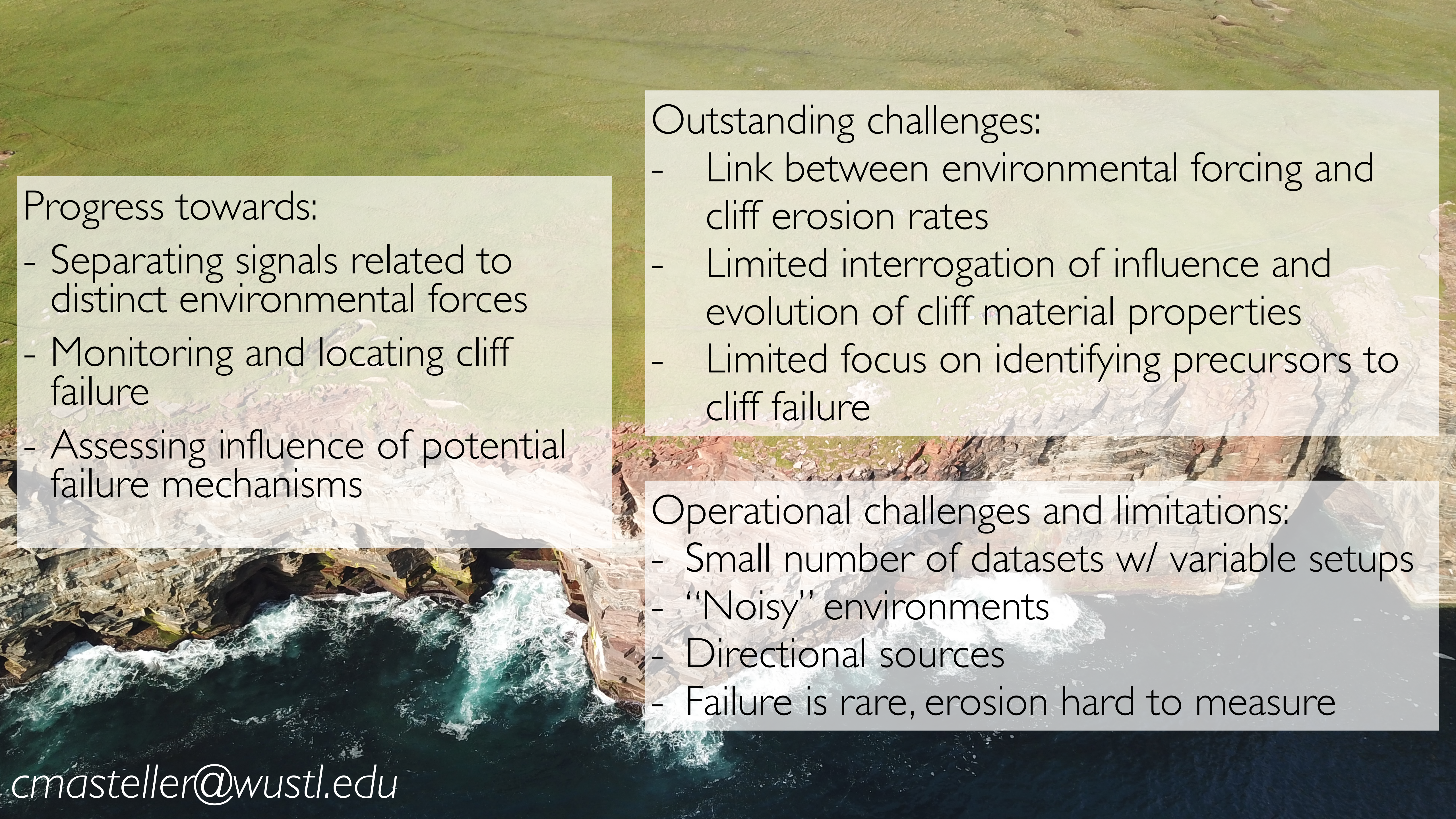
Marine Denolle, Tim Clements, Laura Ermert, Julian Schmitt



- Large-scale computing on the cloud
- 100-150 TB data archives
- 100s stations
- Julia scripting for fast processing

We could use ambient vibration to extrapolate or interpolate groundwater levels





Progress towards:

- Separating signals related to distinct environmental forces
- Monitoring and locating cliff failure
- Assessing influence of potential failure mechanisms

Outstanding challenges:

- Link between environmental forcing and cliff erosion rates
- Limited interrogation of influence and evolution of cliff material properties
- Limited focus on identifying precursors to cliff failure

Operational challenges and limitations:

- Small number of datasets w/ variable setups
- “Noisy” environments
- Directional sources
- Failure is rare, erosion hard to measure



Opportunities

- Identification of rare events, forcing/precursors and process cascades
- High spatial/temporal resolution for process monitoring
 - With independent calibration/data: direct estimates of sediment transport rates
 - Without independent calibration/data: tracking of qualitative patterns, relative rates
- Characterizing bed organization/evolution or energy transfer

Challenges/Needs

- Complex coupling between sediment transport, hydraulic parameters and environmental variables
- Site-specific attenuation (i.e., empirical Green's functions) – riverbeds are heterogeneous!
- Parallel development and validation of theoretical models will require controlled seismic deployments co-located with traditional instrumentation to independently measure environmental variables
 - Weather/meteorological data
 - Water level/discharge
 - Sediment transport rates
 - High resolution topography/change detection
 - Substrate characteristics (attenuation)
 - Video/time-lapse imagery

Innovative seismic techniques can be used
to study the *environment*
to **benefit** the society

