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Analysis of GPS TEC TIDs Launched by the 2011 Tohoku Earthquake

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INTRODUCTION

- **At ionospheric heights, the motion of the neutral gas in the AGW sets the ionosphere into motion.**
- **The waves displace the isoionic contours, resulting in a travelling ionospheric disturbance (TID).**
- **Traditionally, TIDs observed in the *F* region have been classified into two categories**
  - **Medium Scale TIDs (MSTIDs)**
  - **Large Scale TIDs (LSTIDs)**
- **Confusion: In past 10 yrs, another class of TIDs has been identified – *electrobuoyancy waves*. Unfortunately, they have been labelled "MSTIDs", which has confused the community.**

TID Classification

- **Large-Scale Traveling Ionospheric Disturbances (LSTID)**
  - Amplitude: ~20%
  - Wavelength: 300 - 5,000 km
  - Propagation velocity: 300 - 1000 m/s, equatorward
  - Occurrence: Geomagnetic activity (Kp) dependence
- **Medium-Scale Traveling Ionospheric Disturbances (MSTID)**
  - Amplitude: ~10% (0.5 - >1.5 TECU)
  - Wavelength: 100-300 km, Propagation velocity: 50-300 m/s

Classification of Gravity Waves/TIDs

	Medium Scale	Large Scale
Period	10-60 min	1-5 hr
V_H (m/s)	50-300	300-1000
λ_H (km)	100-300	300-5000

Electrobuoyancy Waves? (Erroneously called "MSTIDs")

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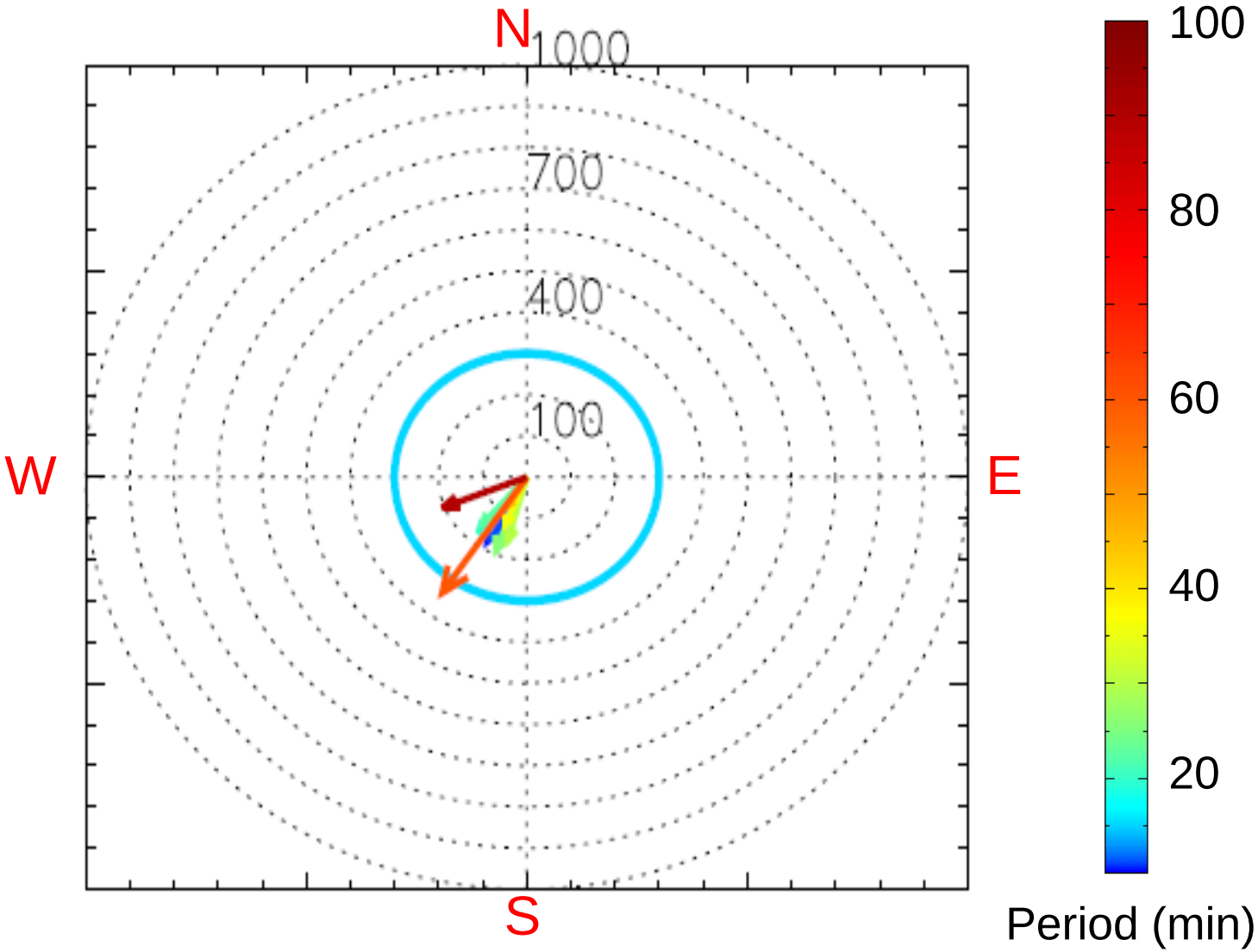

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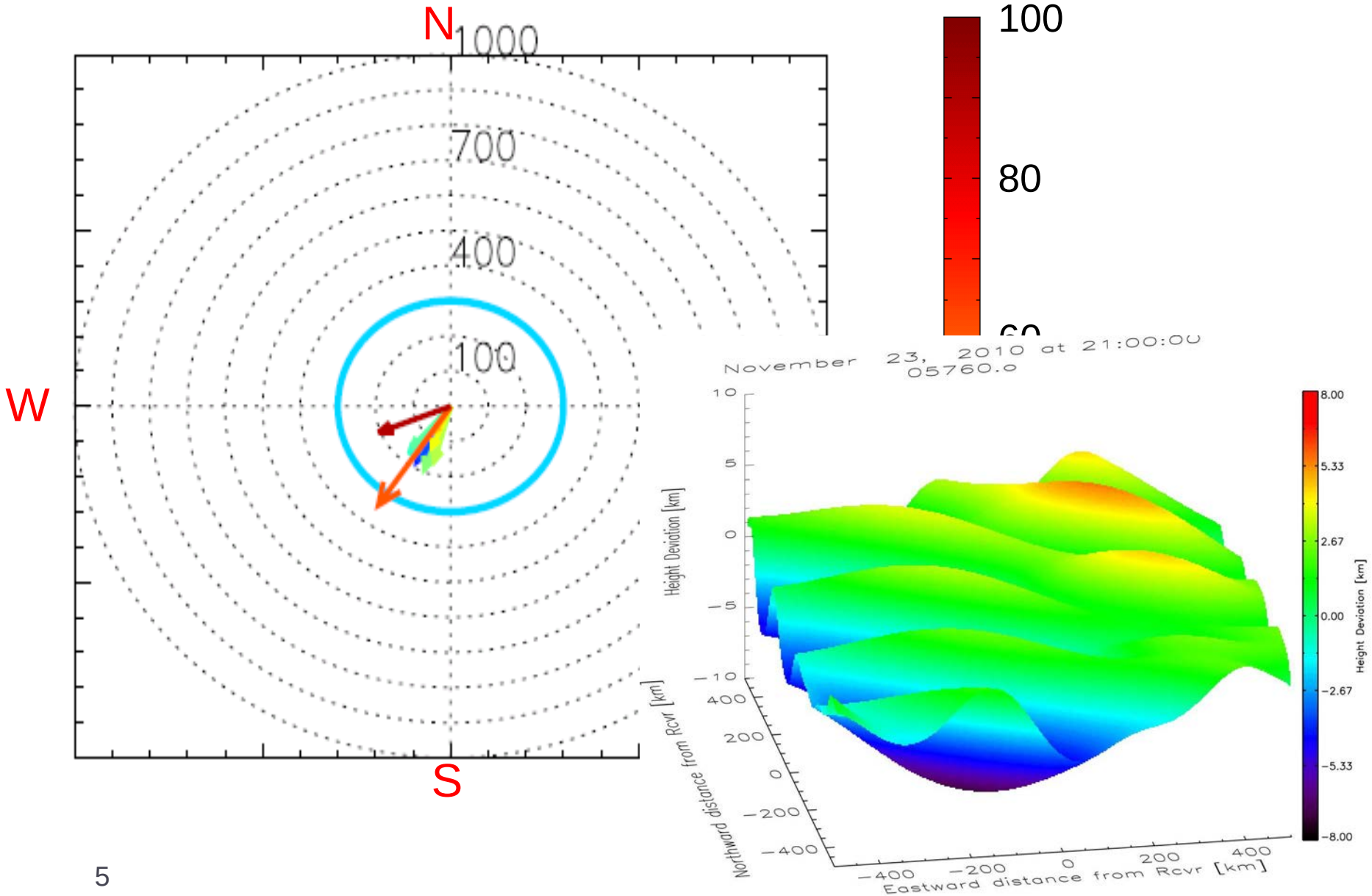
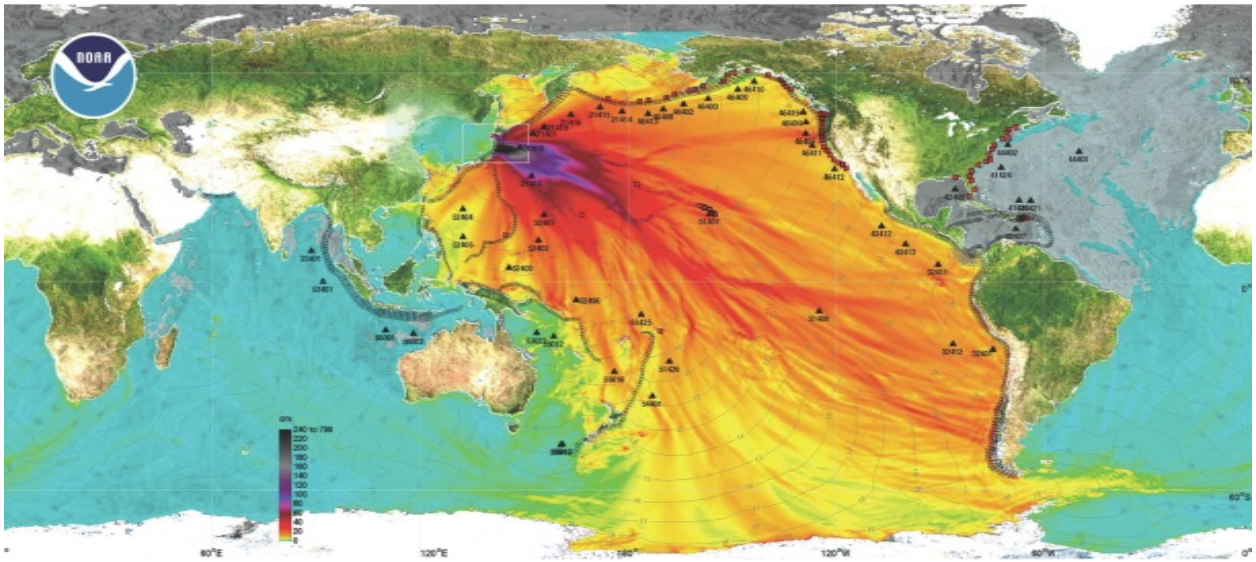


2011 TOHOKU EARTHQUAKE AND TSUNAMI

- A magnitude 9.0 earthquake occurred on March 11, 2011 at 05:46:23 UT near the northeast coast of Honshu, Japan.
- Figure shows the NOAA simulations of the 2011Tohoku tsunami source and water heights over a tsunami travel time (TTT) map.
- According to these simulations, the tsunami reached the west coast of the United States about 10 to 11 hours after the earthquake.



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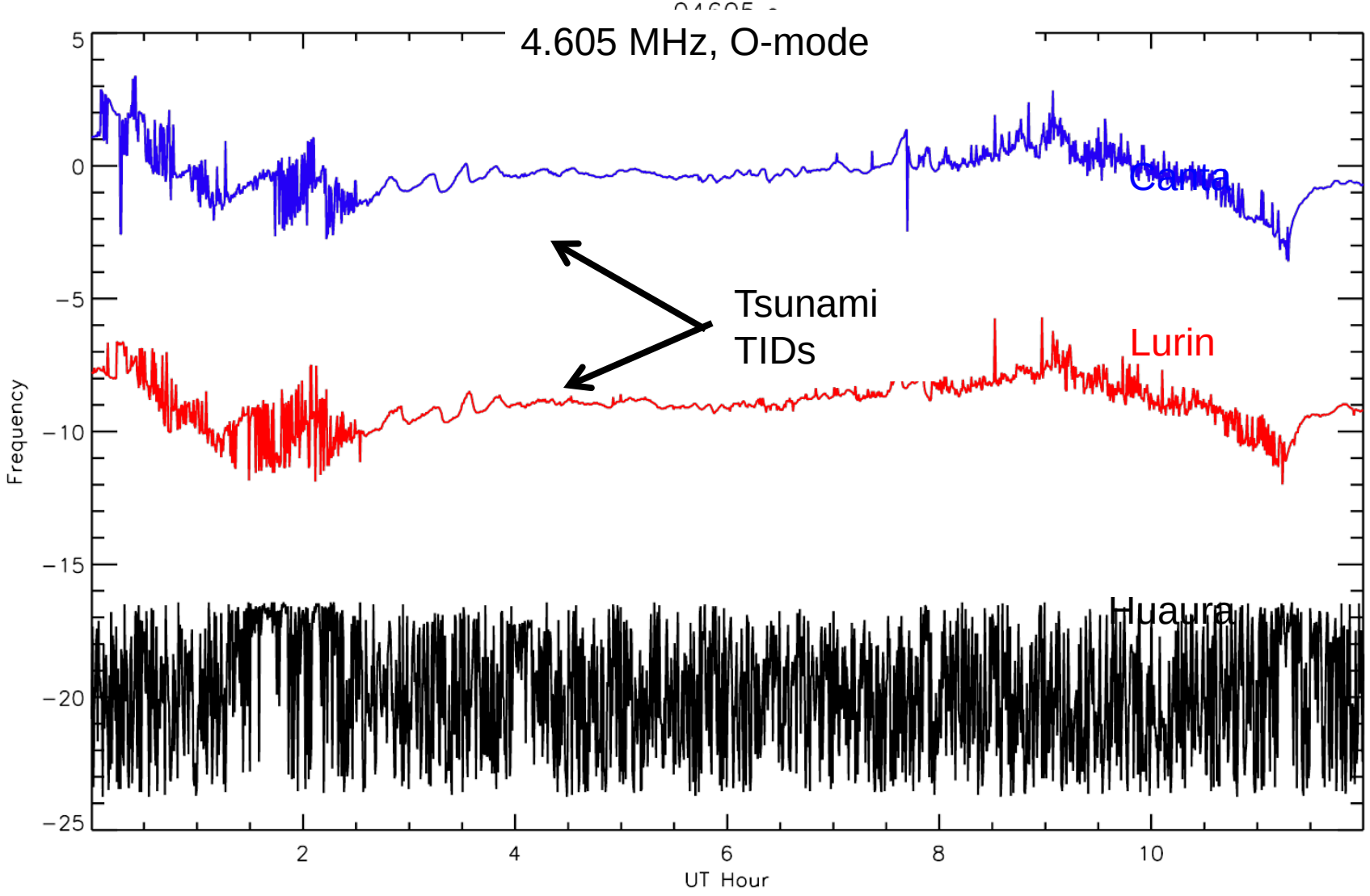
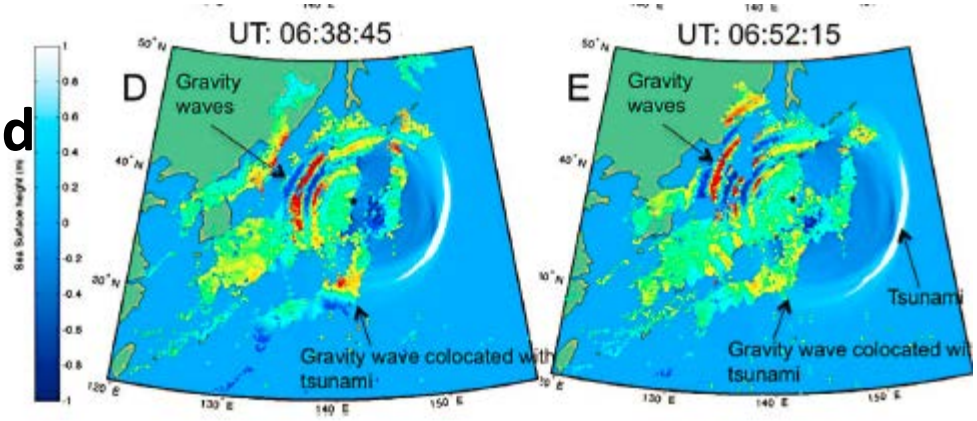
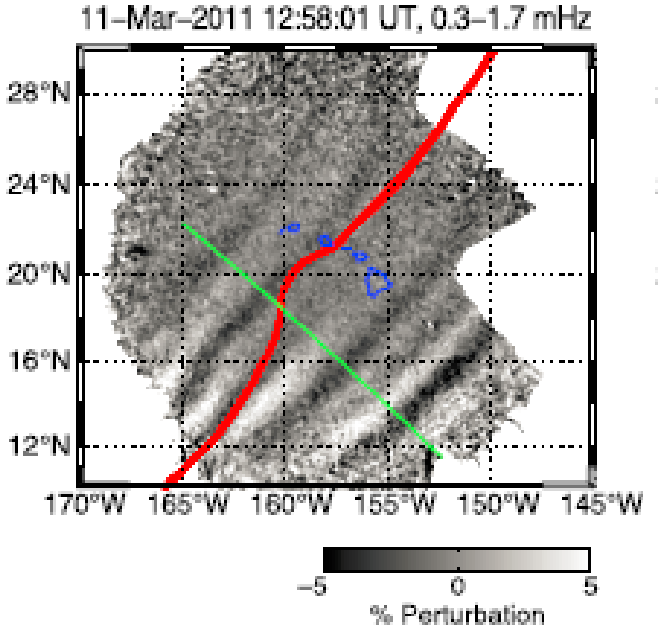


PREVIOUS TSUNAMI STUDIES

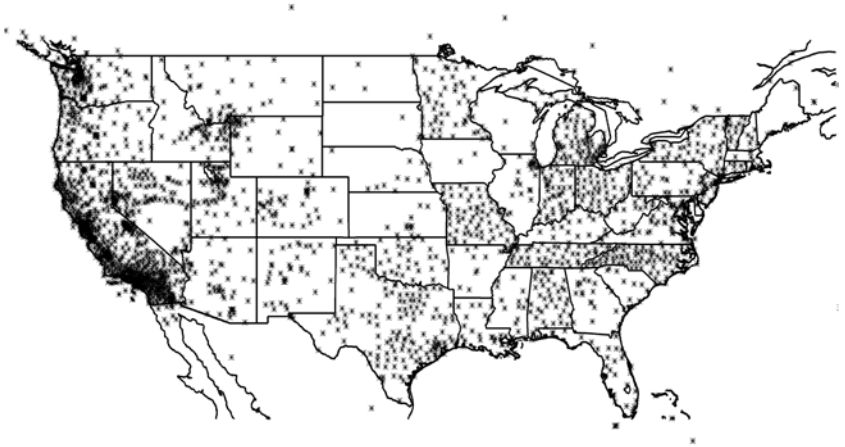
- ***Galvan et al.*** **[2011] studied ionospheric perturbations caused by the Tohoku earthquake and tsunami. Perturbations were found in TEC near the epicenter of the 2011 earthquake.**



- ***Makela et al***. **[2011] presented observations of the airglow signature of GW, resulting from the 11 March 2011 Tohoku earthquake off the eastern coast of Japan.**

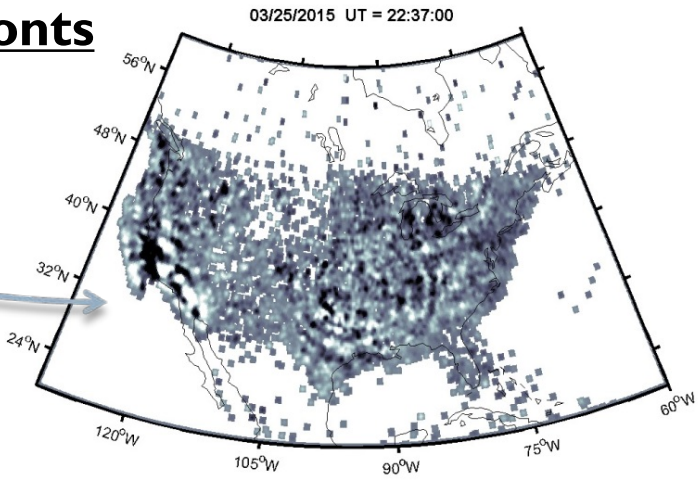


GPS Data Analysis

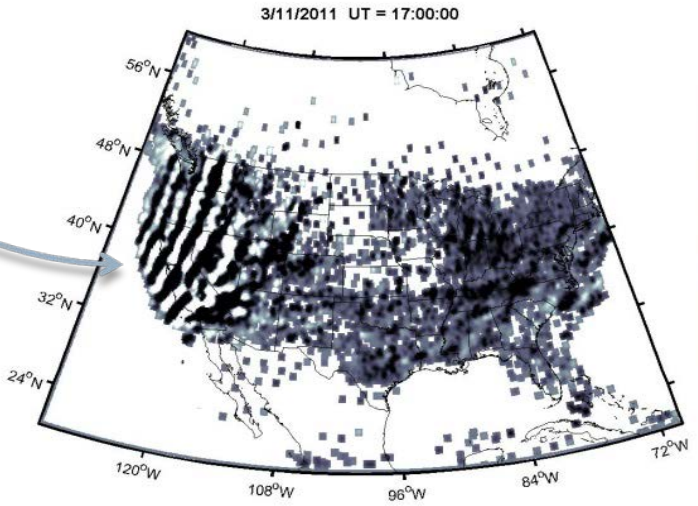


- **~4000 GPS receivers throughout the continental United States**
- **Provides a 2D spatial map of TEC perturbations, which can be used to calculate TID parameters, including horizontal wavelength, phase speed, and period.**
- **The work presented in this paper demonstrates a technique for the study of ionospheric perturbations that can affect navigation, communications and surveillance systems.**

- **Near-field waves appear as <u>spherical wave fronts</u>**
  - ***Example: Thunderstorm***

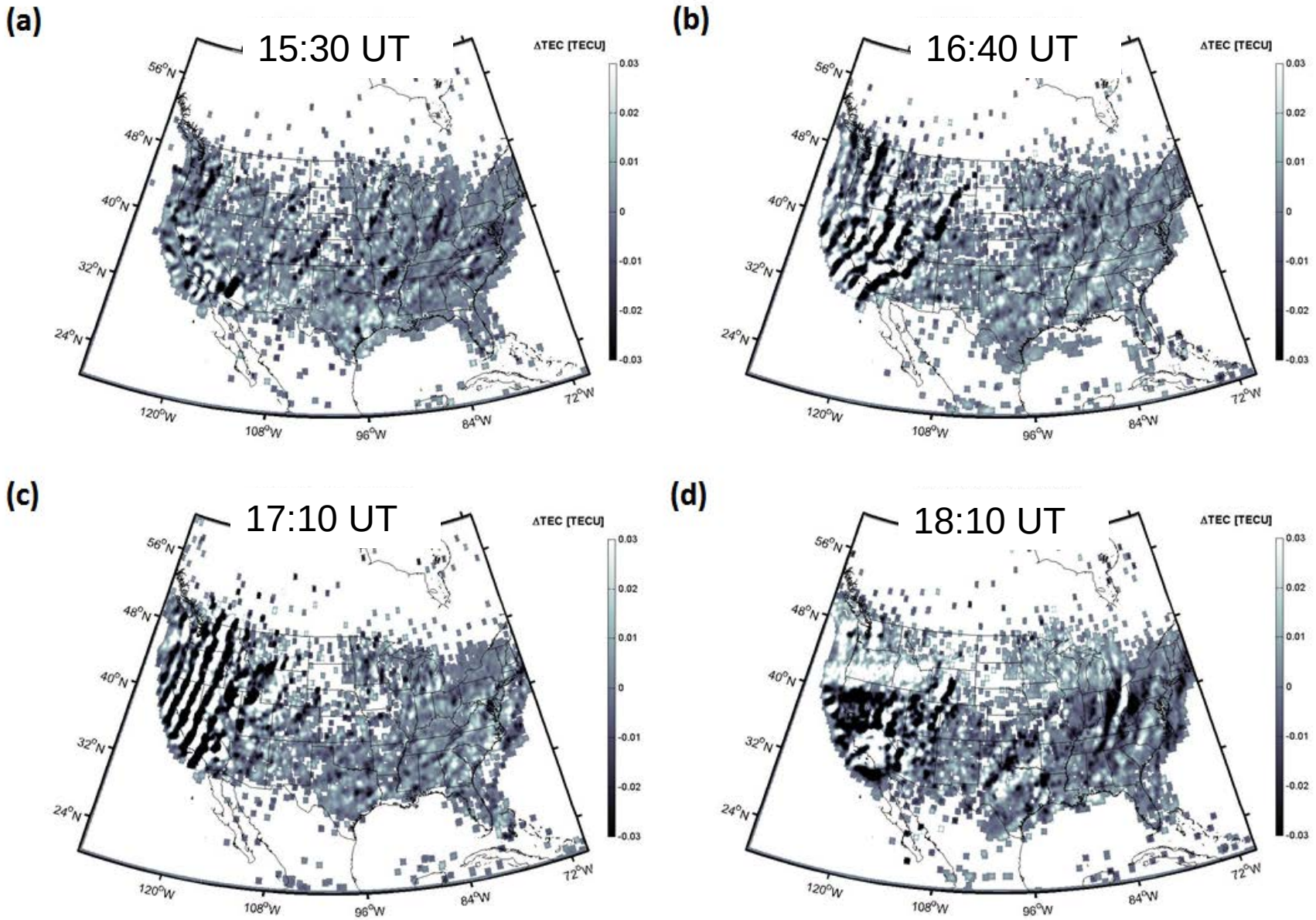


- **Far-field waves appear as <u>plane waves</u>**
  - ***Example: Tsunami above the West Coast of US from the 2011 Tohoku Tsunami***



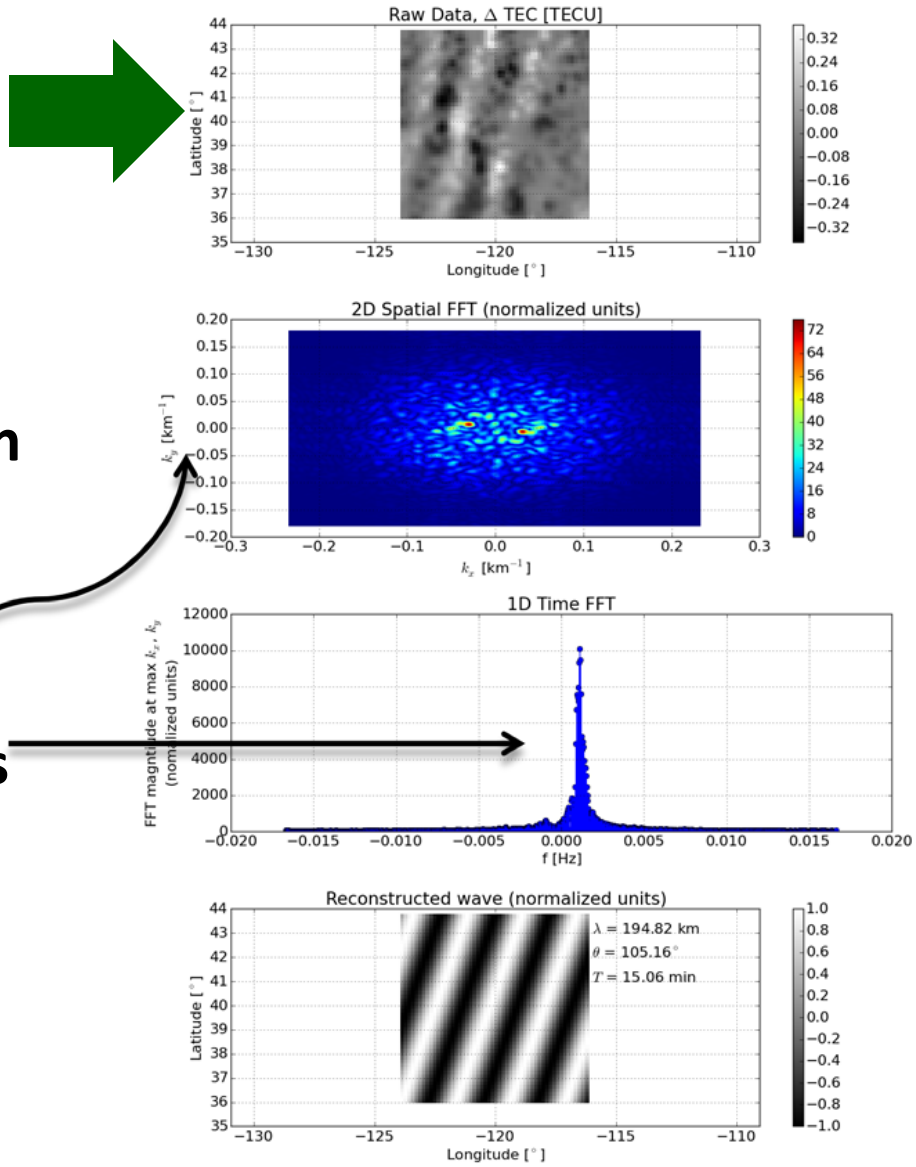
- **Develop algorithms to extract coherent w features in 2D maps of GPS TEC perturba**
- **Augmented 3D FFT algorithms to extrac parameters of all extracted waves**

TIDs IN GPS TEC OVER THE WESTERN US



CALCULATING TID WAVE PARAMETERS

- A subset of GPS data was selected covering the Western United States of ~4°x4° in latitude and longitude.
- Within this region, a 2 hour time window was selected from 17:03:30 to 19:03:30 UTC, representative of the TID passing through this region.
- A 3D FFT was calculated for this 3D "block," and the data are zero padded to provide interpolation in the frequency domain.



DERIVED TID PARAMETERS

- From the k_x vs. k_y "slice" of the maximum value of the FFT, we computed the horizontal wavelength and azimuth of the wave.
- From the FFT of the third dimension (i.e., time) we estimate the wave period.

Wave Parameters	
Period	15.1 min
Horizontal Wavelength (λ_H)	194.8 km
Phase Speed (υ_P)	215.0 m/s
Azimuth (θ)	105.2°

CONCLUSIONS

- Used GPS receivers to image TIDs over the US
- Quantitative characterization of the occurrences of TIDs over CONUS
- 11 March 2011 Tohoku tsunami.
- The tsunami propagated across the Pacific to the *West Coast* of the *US* over a ten-hour period
- Corresponding TIDs were observed in ionospheric TEC measurements.
- The period of the wave was 15.1 minutes with a horizontal wavelength of 194.8 km, phase velocity of 233.0 m/s, and an azimuth of 105.2° (propagating in the direction of the tsunami wave).
- Consistent with TID observations in airglow measurements from Hawaii earlier in the day, and other GPS TEC observations.
- Observations of long range propagation of TIDs have significant implications for advancing our understanding of TID sources including earthquakes, tsunamis, large explosions, etc