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Stratospheric Gravity Waves as the Seeds for E-F Coupling

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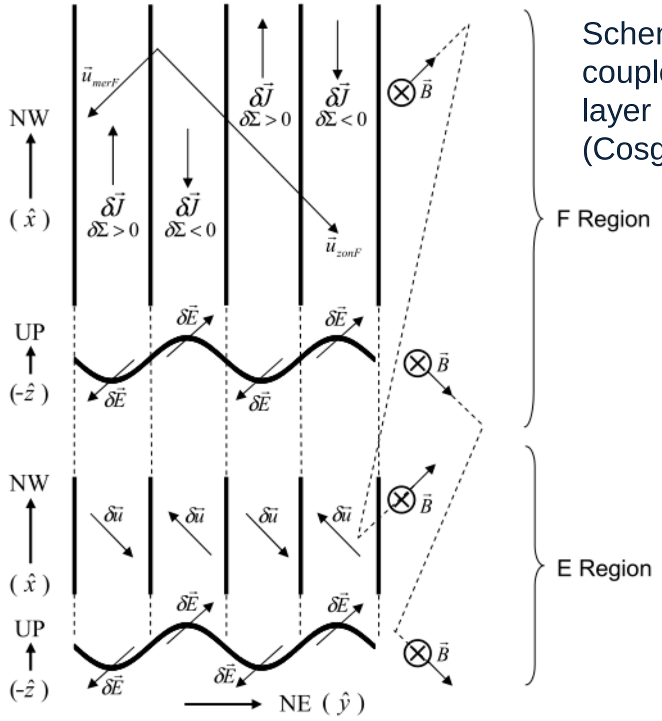
E-F Coupling

Summer nighttime TIDs

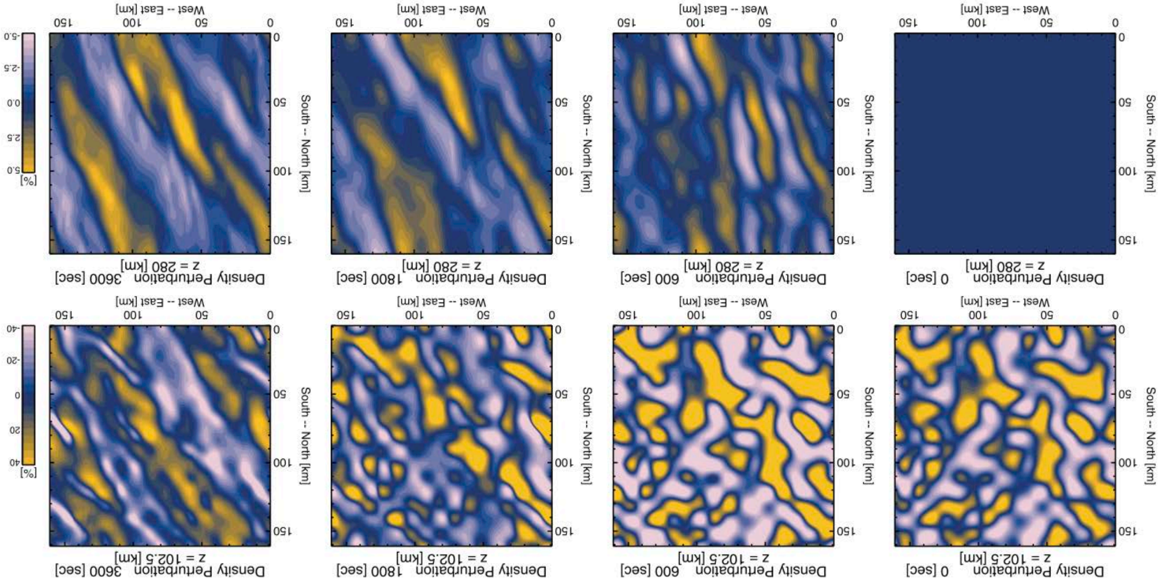
Cause of SW-directed TIDs prevalent in summer nighttime unknown

- Qualitatively consistent with formation via Perkins instability, but growth rate is too slow.
- Observed correlation between appearance of these TIDs and sporadic-E (E_S) may be big clue (e.g., Otsuka et al. 2008; Helmboldt 2012; Helmboldt 2016).
- Theory of coupled Perkins/E_S layer instability provides plausible mechanism (Cosgrove et al. 2004); favors NW-to-SE aligned structures.
- But, TID wavelengths (~100 km) typically larger than structures in E_S layers (~10s of km).
- How coupled instability is seeded also not clear; simulations (Yokoyama et al. 2009) show waves or random perturbations both plausible.
- Used combination of datasets (digisonde, GPS, VLA, NARR) to investigate further.



Schematic of the coupled Perkins/E_S layer instability (Cosgrove et al. 2004).

Simulations of the formation of TIDs via the coupled Perkins/E_S layer instability with random perturbations as the seeds (Yokoyama et al. 2009)



Ionospheric Impact on Interferometers

Observing through plasma

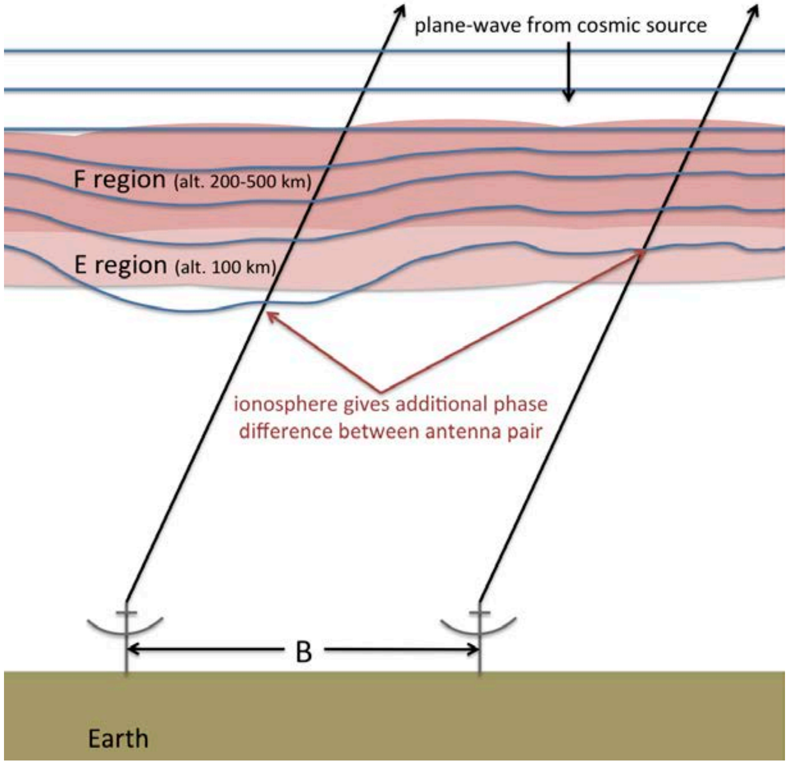
Simultaneously observe cosmic source and ionospheric structure

- Ionospheric delay proportional to total electron content (TEC) along line of sight times v^{-2}.
- Gradients in TEC lead to additional baseline phase ~$\delta\text{TEC}\times v^{-1}$, so impact much larger at low frequencies (dominates over troposphere blow roughly 1 GHz).

Turning trash into treasure

- Methods to solve for/remove ionospheric phase provide extremely precise measurement of TEC gradient.
- With VLA low-band system (74 and 330 MHz), δTEC precision as good as 10^{-4} TECU (1 TECU = 10^{16} e^{-} m^{-2}), or gradient precision ~2×10^{-4} TECU km^{-1}.
- Measuring gradient vs. actual TEC biases toward smaller-scale (larger wavenumber) disturbances.

Very Large Array (VLA): Array of 27 parabolic antennas, each 25-m in diameter. In central/western NM

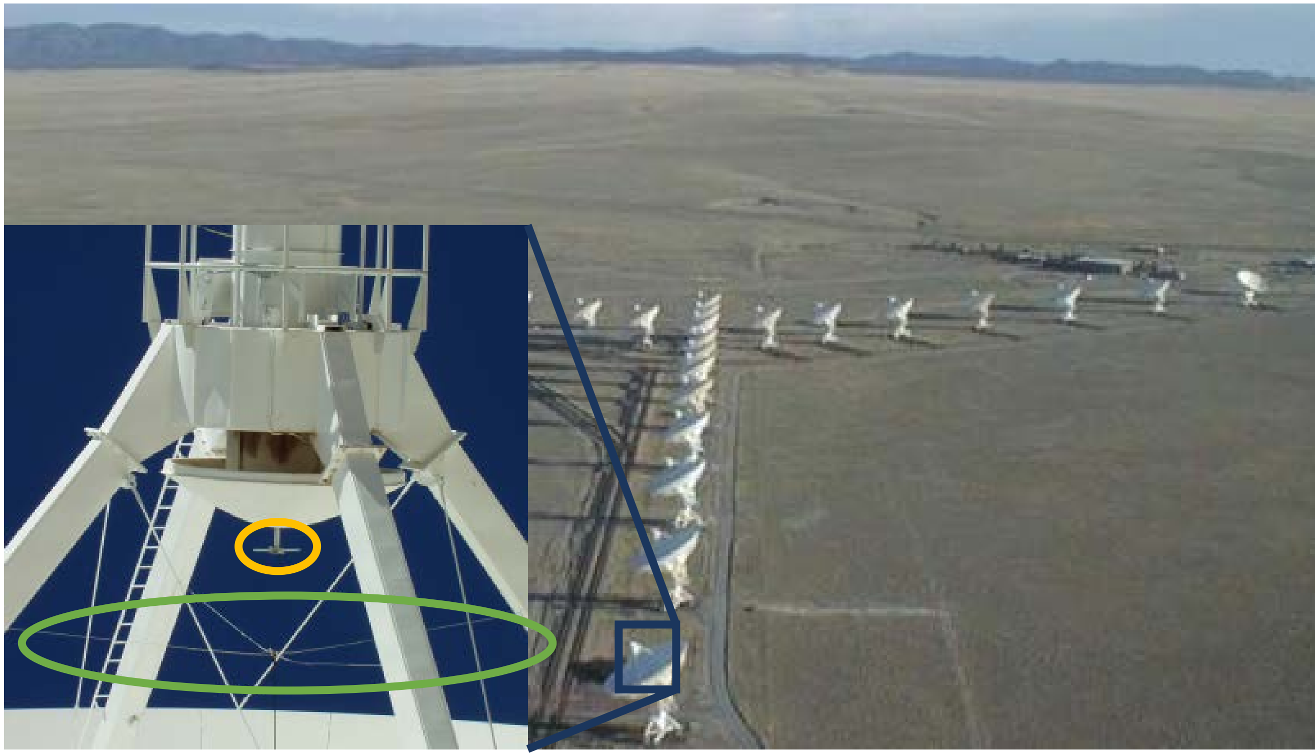


VLA Low-band Ionosphere and Transient Experiment (VLITE)

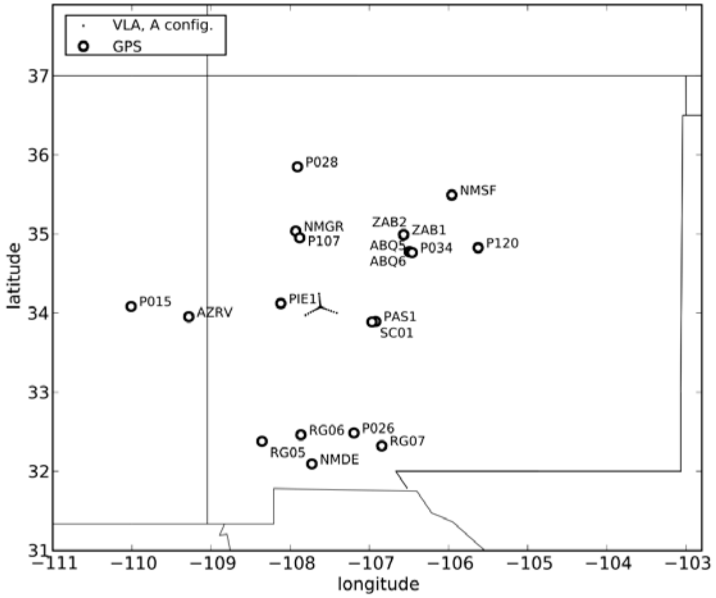
VLITE

Piggybacking on the VLA

- VLITE is dedicated backend on 10 VLA antennas.
- Takes advantage of P-band optics to continually stream 320—384 MHz band to dedicated software correlator (DiFX).
- Each scan output separately; real-time ionospheric pipeline automatically processes these as they arrive.
- Science operations started in Nov. 2014 and still going; recently expanded to 12 antennas with three more to be commissioned by Aug. 2017.
- Also use array of regional GPS receivers for complementary analysis of larger-scale TEC fluctuations.

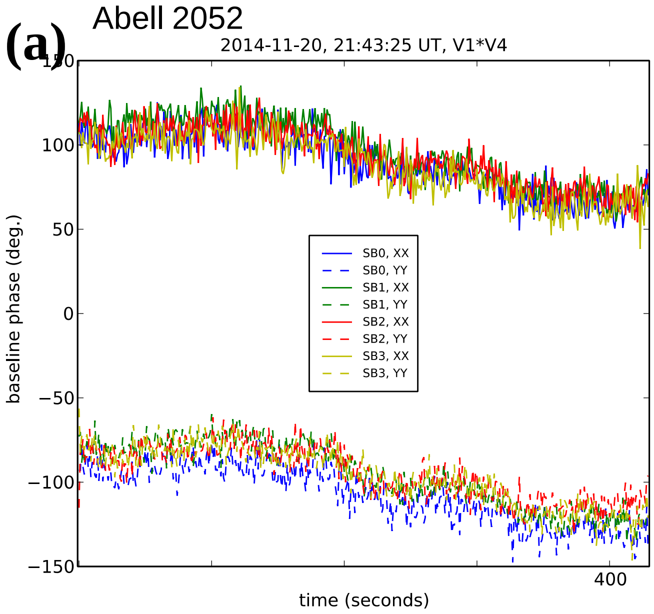


P-band feed
4-band feed (no longer used)

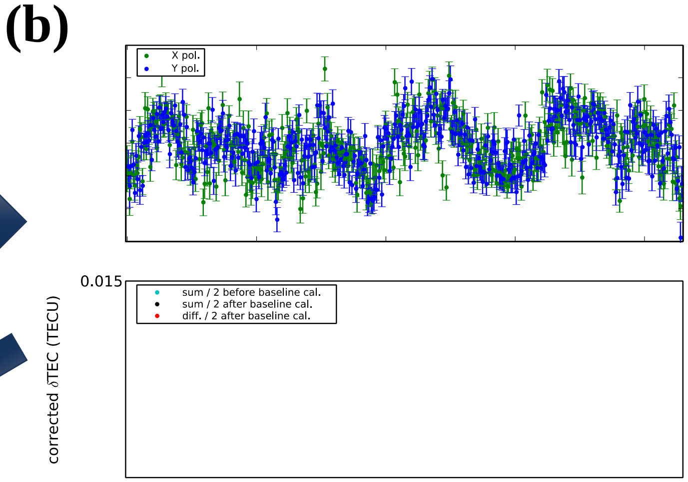


Array of 20 GPS receivers within 200 km of the VLA. Data downloaded and processed daily from publicly available databases (CORS & UNAVCO).

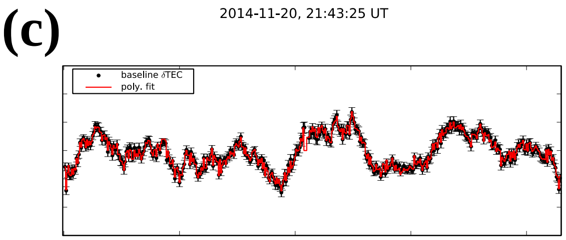
VLITE Ionosphere Pipeline

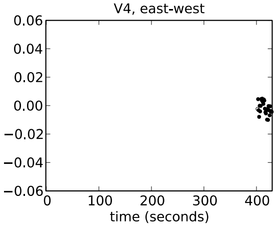


Raw phases; 4 sub-bands , 2 polarizations; bandwidth smearing isolates brightest source in FoV.

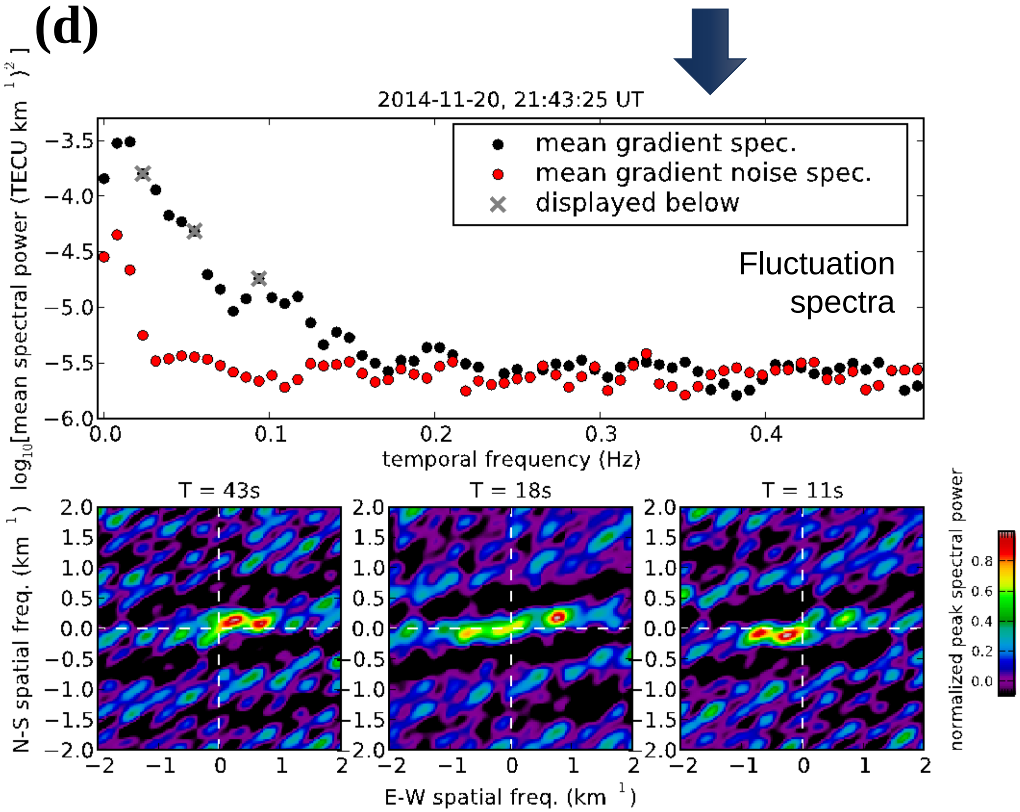


De-trend, convert to δTEC; use closure quantities/baseline calibrations to mitigate interference and reduce noise, then combine.





Polynomial fit converts δTECs to antenna-based TEC gradients.

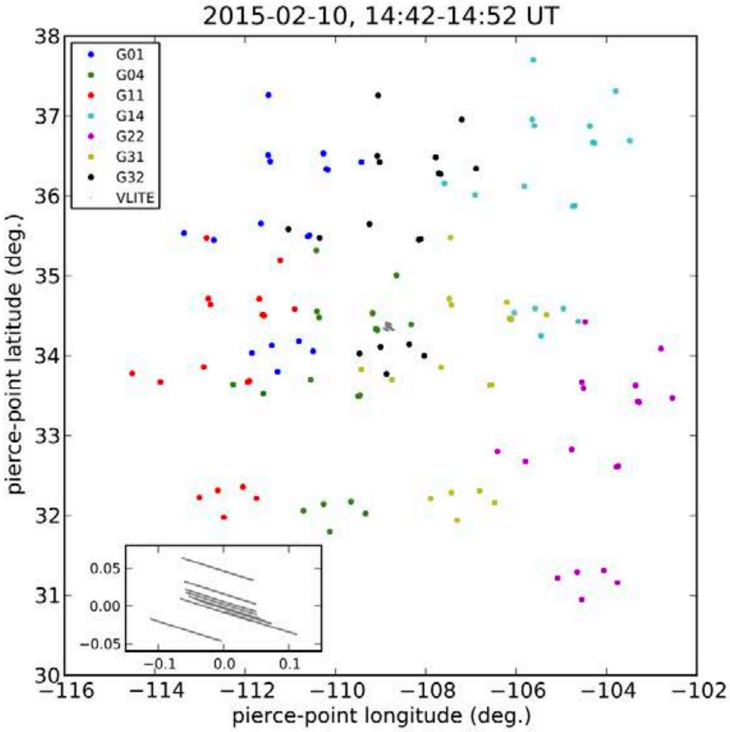


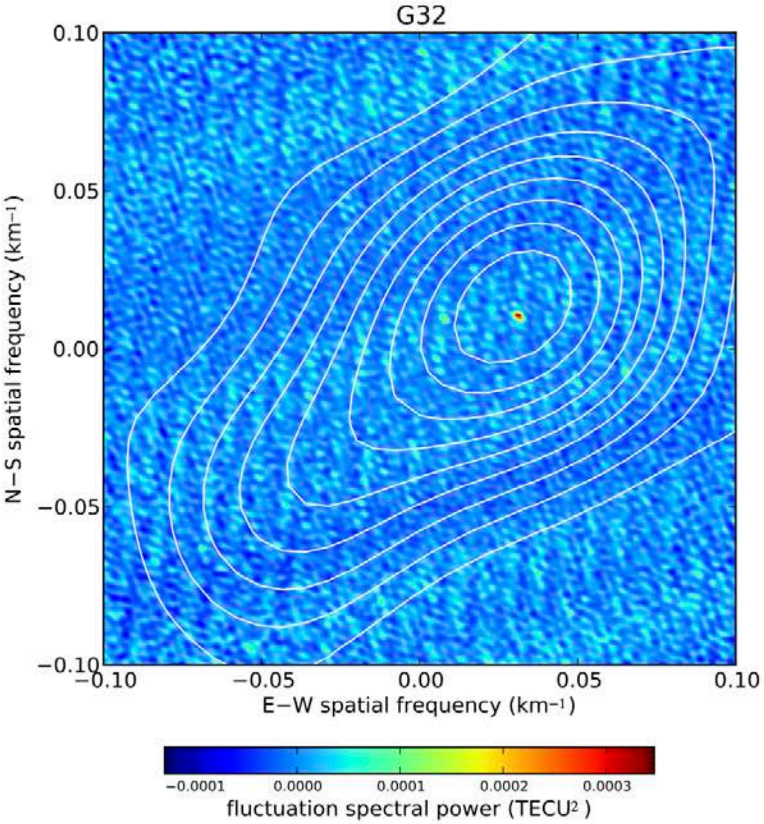
VLITE+GPS Pipeline

VLITE+GPS

Comparing VLITE and GPS

- Separate pipeline runs daily on GPS data, performing similar spectral analysis on TEC data.
- VLITE and GPS arrays typically probe different scales, but not always; allows for validation/self-consistency checks.
- Example: VLITE test data from 2015 with very bright source (Cygnus A) detected NE-directed TID.
- Same TID “seen” by GPS array toward one satellite (G32) with line of sight along phase fronts (wavelength ~30 km).





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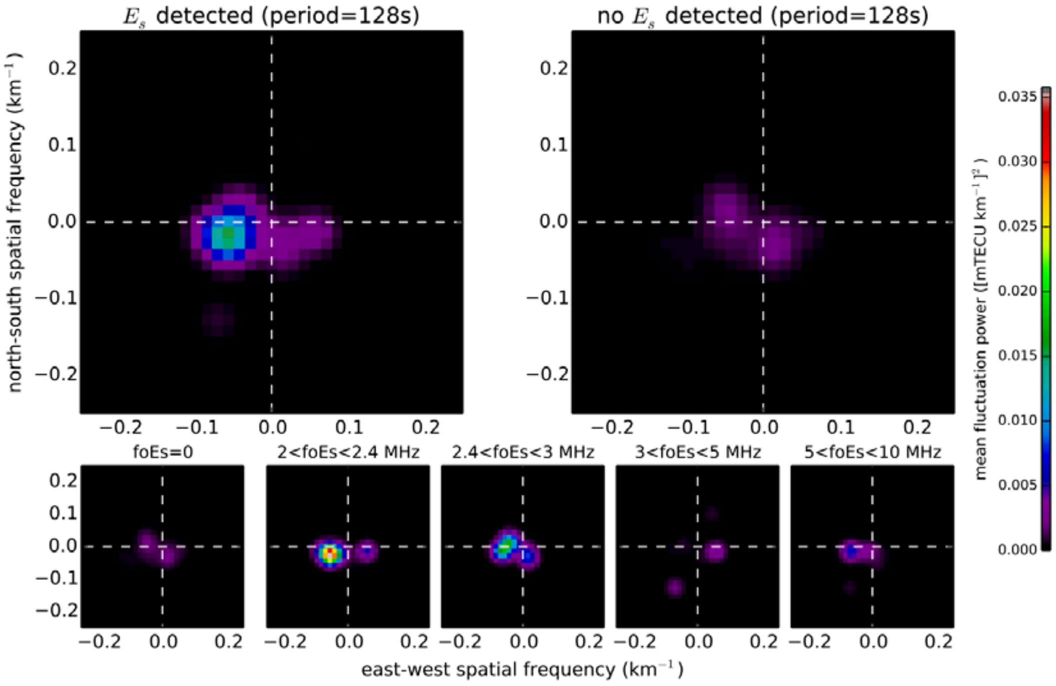
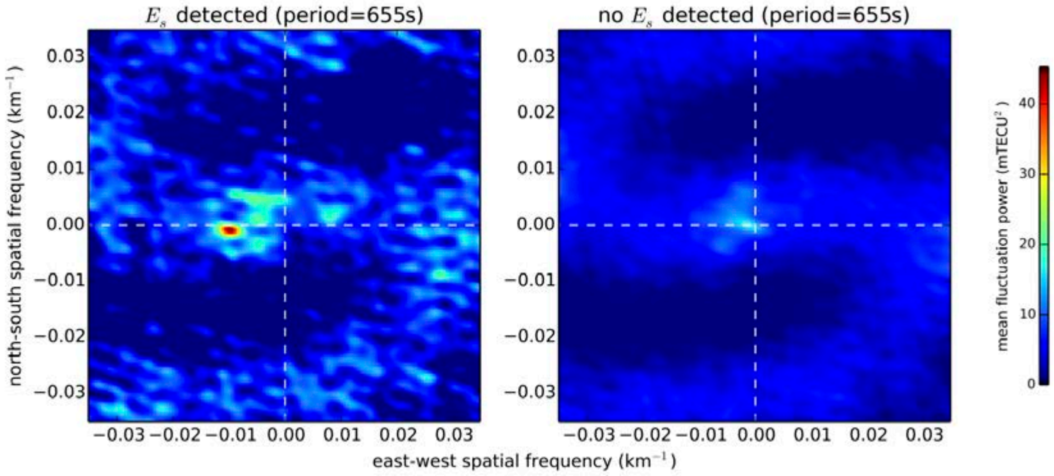
VLITE+GPS Observations of E-F Coupling



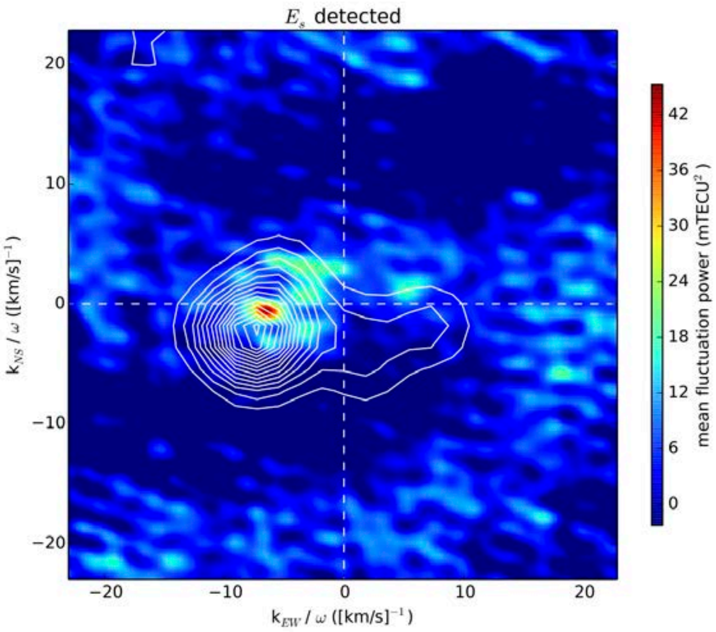
Above: Mean VLITE fluctuation spectra (summer nighttime, 2015) when E_S was and was not detected over Boulder, CO (upper) and as a function of peak E_S density (lower). *Below*: Fluctuation spectra from analysis of concurrent data from regional GPS stations.



Fluctuation spectra

Targeting summer nighttime TIDs

- Used data from the digisonde in Boulder, CO to measure E_S properties (or lack thereof) during summer nighttime, high-precision VLITE observations (δTEC precision 10^{-3} TECU or better).
- Also made mean spectra from GPS data for the same observing periods.
- SW-directed TIDs stronger when low/moderate density E_S layers present.
- VLITE and GPS TIDs different wavelengths (16 and 100 km, respectively), but have similar velocities.



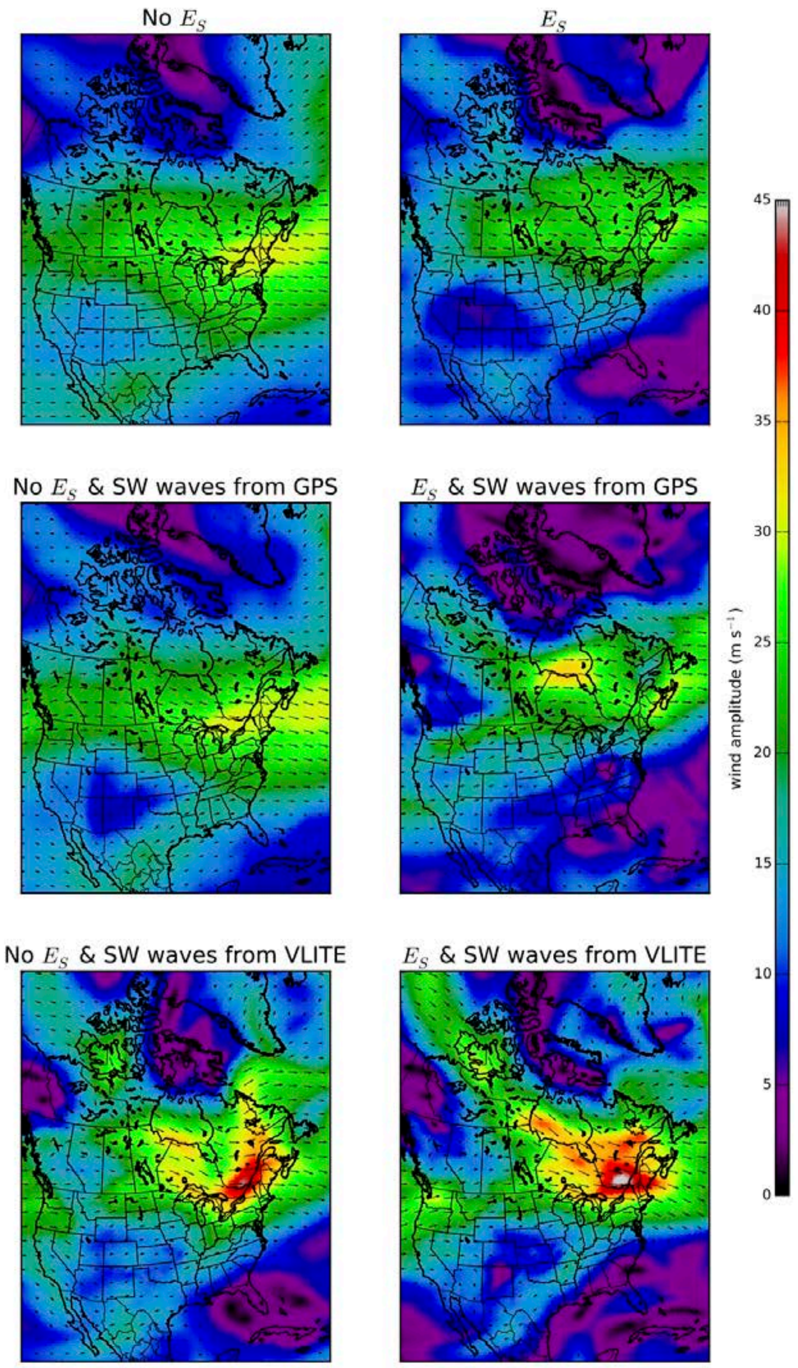
Fluctuation power as functions of velocity (reciprocal) from GPS (image) and VLITE (contours) data.

Seeds of E-F Coupling

Stratospheric gravity waves

Role of the jet stream

- To check possible origins of the SW-directed TIDs and test for causal connection between these and E_S, looked at possible sources of gravity waves.
- From NARR, found jet streaks to the northeast that can generate stratospheric gravity waves; more prominent when VLITE detected SW-directed waves.
- However, jet streaks equally prominent with and without E_S; implies the presence of E_S has effect of enhancing impact of gravity waves on the F region, likely through E-F coupling instability.
- Different scales probed by VLITE and GPS imply a spectrum of gravity waves whose impact is enhanced by the presence of E_S.
- VLITE data imply enhancement optimum when E_S layer peak density is low, implying “smooth” layers relatively undisturbed by shear instabilities (i.e., no dense “knots”).
- Basically consistent with Cosgrove et al. theory, but really need concurrent observations of E_S layers to confirm.



Vector winds at 300 mb from NARR for different groups of VLITE observing epochs.