Sporadic-E and its Ties to E-F Coupling and Meteor Activity

2014 LWA Users Meeting

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Sporadic-E Primer

- Sporadic-E (E_S) is ionospheric phenomenon caused by zonal wind shears in the E region (~100 km altitude).

- In E-region, ion/neutral collision rate relatively high ➔ currents strongly driven by the wind.

- If zonal wind is westward slightly above ~100 km and eastward slightly below, **E×B** force is downward above and upward below (for northern hemisphere) ➔ ions (especially long-lived, metallic ones) squished into a dense "pancake"

- So, E_S needs the right wind shears and metallic ions to form; both more prevalent in summer, the latter thanks to increased meteor activity.

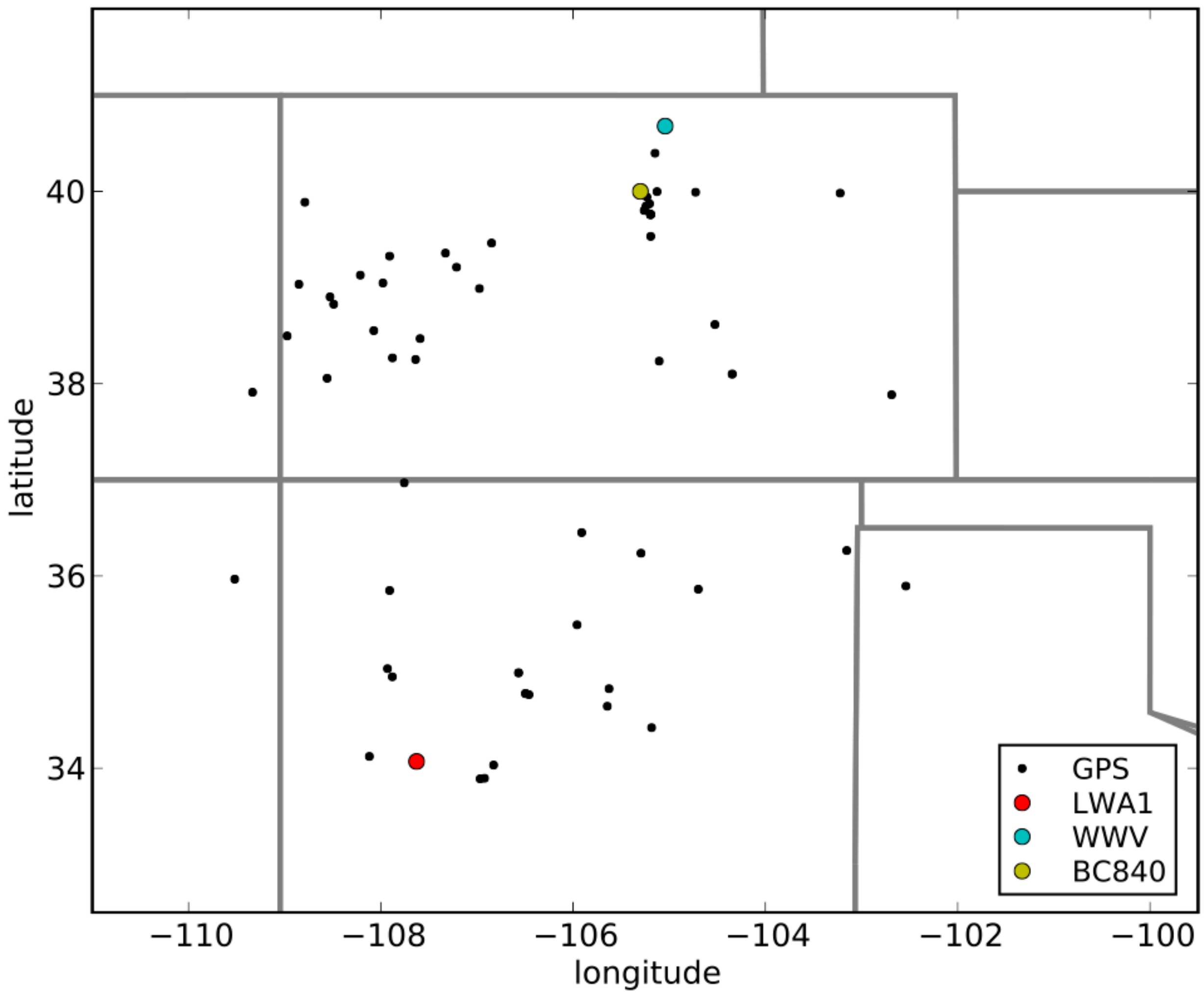
- Wind shears cause formation of Kelvin-Helmholtz (KH) instabilities in neutral component; ion/neutral coupling can lead to E_S structures/clumps to form on scales comparable to KH wavelength (~10 km); thought to be origin of quasi-periodic (QP) echoes.

- E_S also has inherent instability that can form northwest-to-southeast aligned wave fronts; coupling between this and Perkins instability within F-region (E-F coupling) thought to be source of summer nighttime traveling ionospheric disturbances (TIDs) that propagate toward the southwest.

Multi-platform Campaign

- ❖ Conducted a joint observing campaign using (1) the LWA1+WWV radar system, (2) LWA1 observations of meteor activity, (3) the Boulder digisonde (BC840), and (4) an array of continuously operating GPS receivers to study E-F coupling in detail.

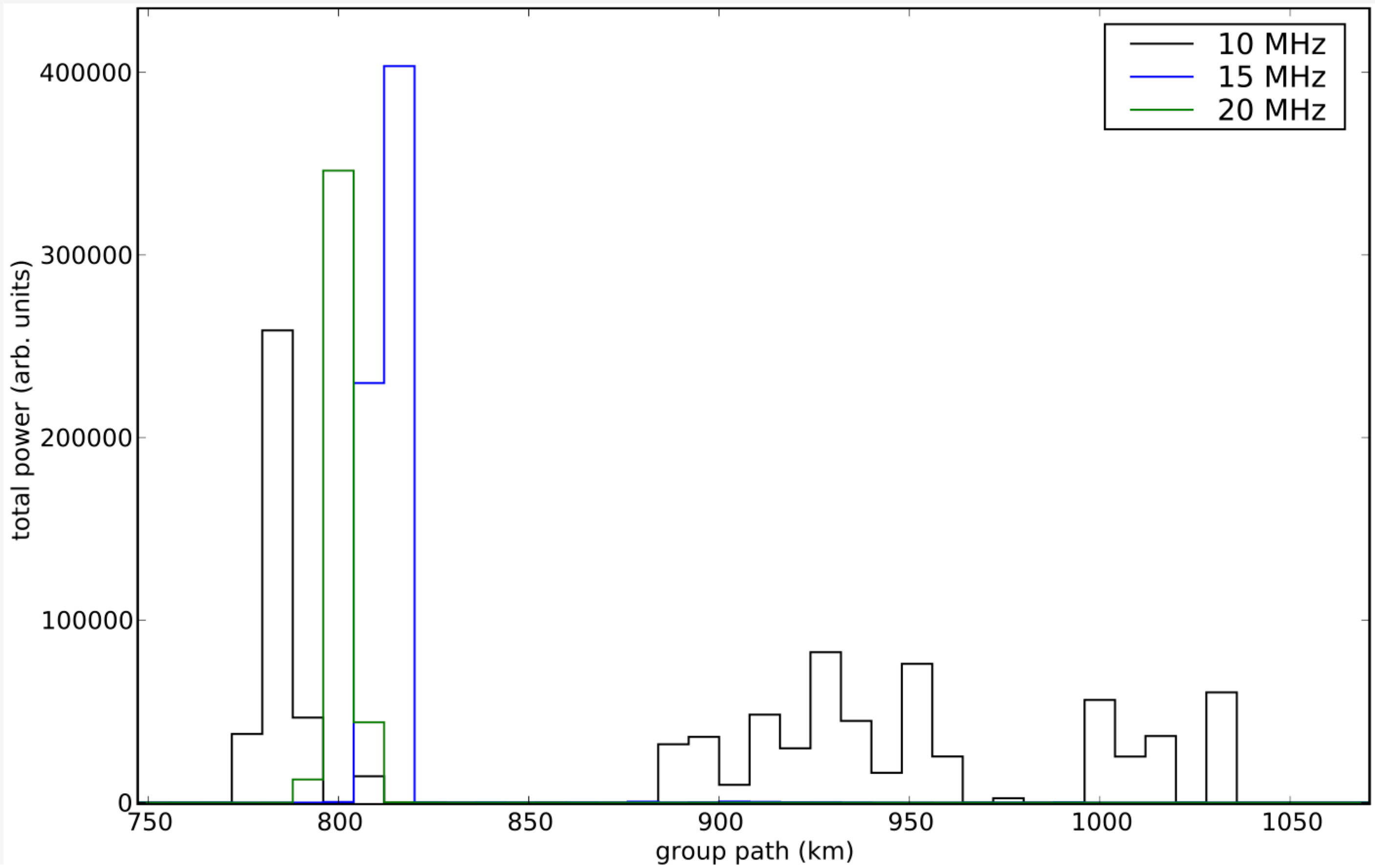
- ❖ Applied new, advanced spectral analysis techniques to GPS data to detect evidence of F-region TIDs during instances of sporadic-E detected with LWA1 and/or BC840; meteor activity monitored at 55.25 MHz (reflections of TV signals; see S. Cockrell's talk).



LWA1 Observations

- Eight LWA1 observing runs conducted during summer 2013; each consisted of 80 transient buffer, wideband (TBW) captures over 8 hours (i.e., one every 6 minutes).
- These simultaneously detected and located sky-waves from WWV at 10, 15, and 20 MHz; 15 and 20 MHz reflections exclusively from E_S.
- Also simultaneously observed meteor-trail reflections at 55.25 MHz

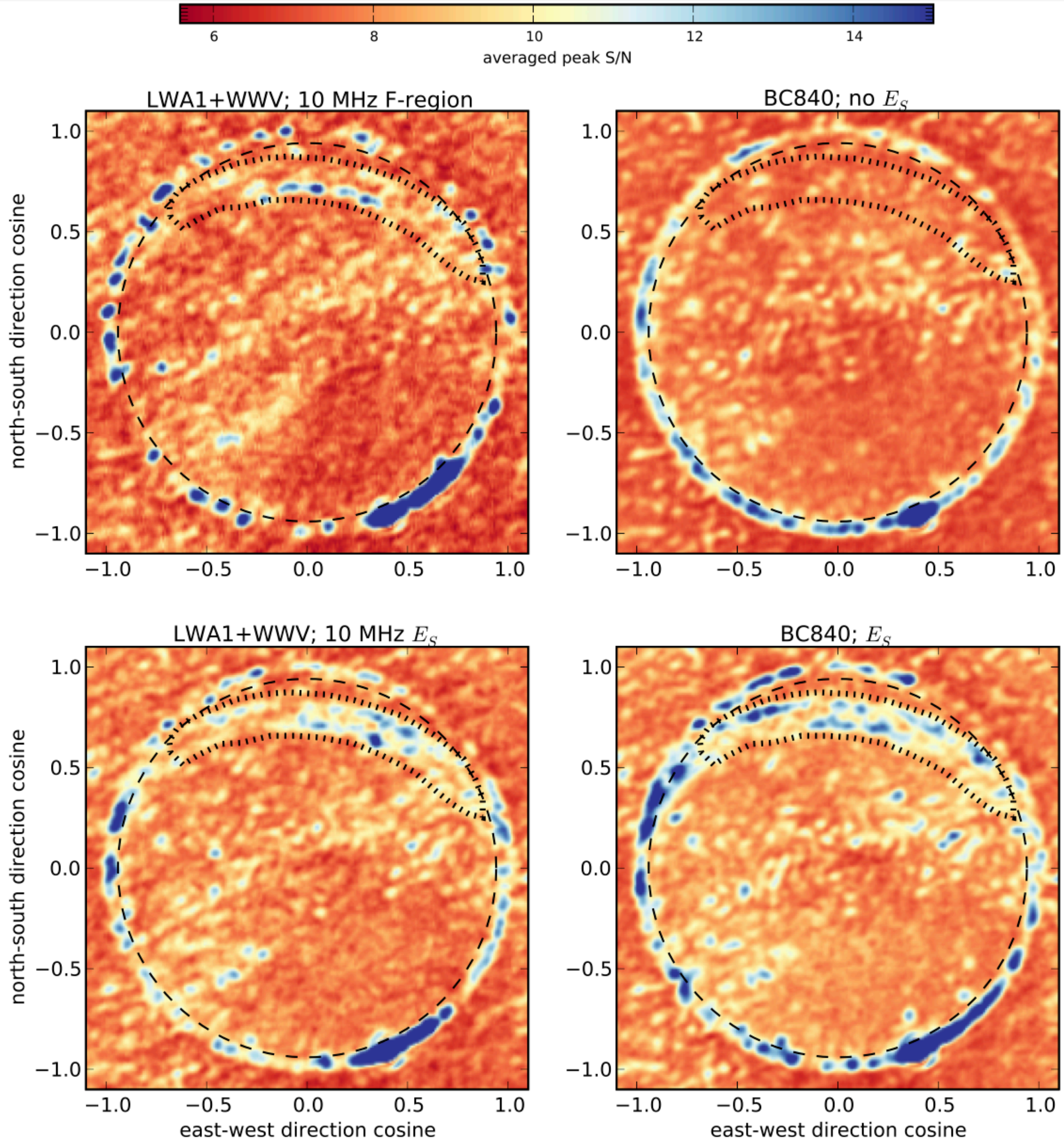
Distribution of power and group path over the entire summer 2013 campaign; ray-tracing calculations imply minimum group path of about 820 km without sporadic-E



LWA1 Observations (cont.)

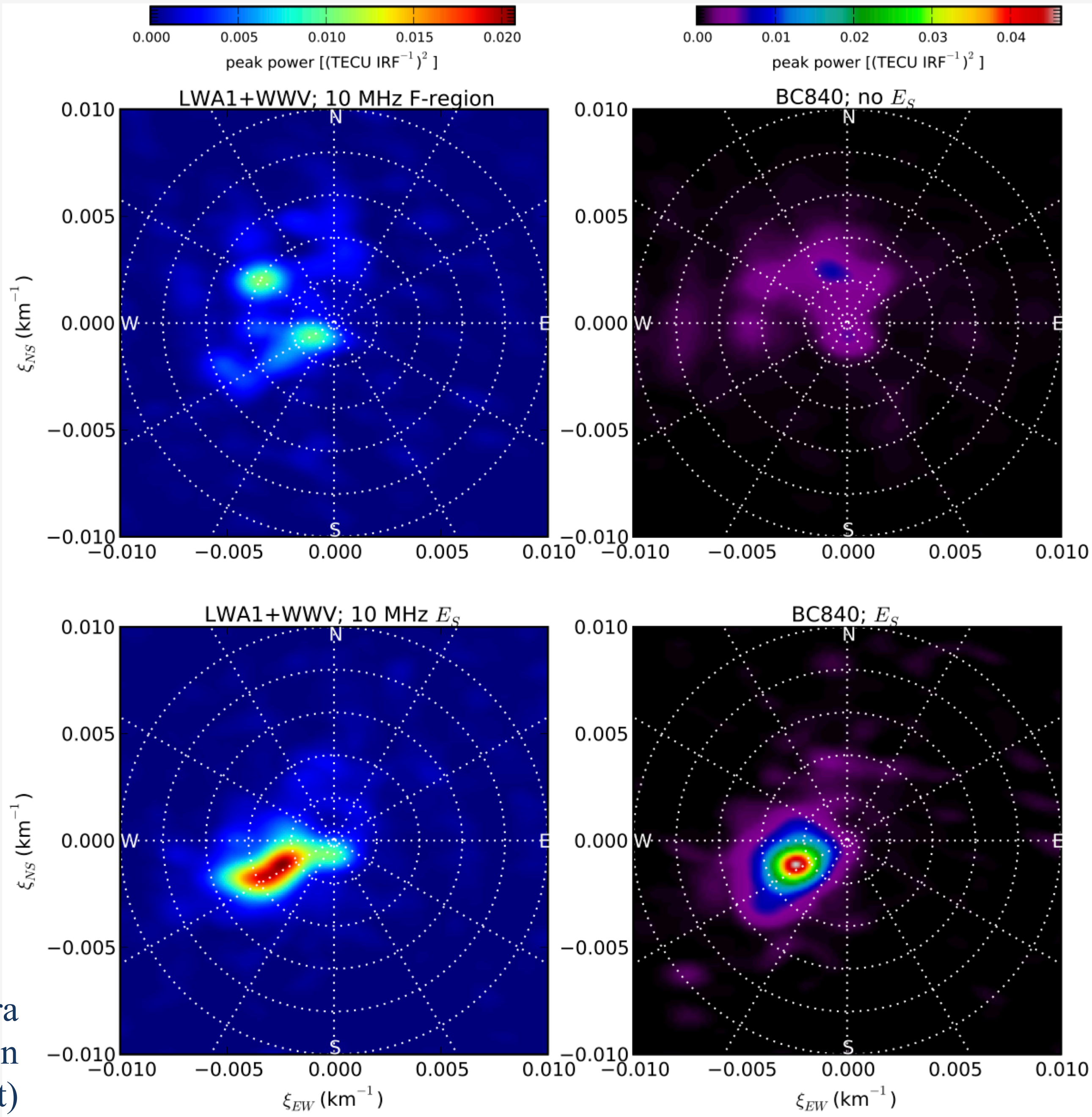
- All-sky maps of meteor trails at 55.25 MHz from TBW captures show increased meteor activity when E_S present.
- Especially true within northern arc caused by specular reflections off trails associated with zodiacal dust (again, see S. Cockrell's talk).

Mean maps of meteor trail signal-to-noise at 55.25 MHz with and without sporadic-E, based on LWA1 (left) or BC840 (right)



GPS Observations and E-F Coupling

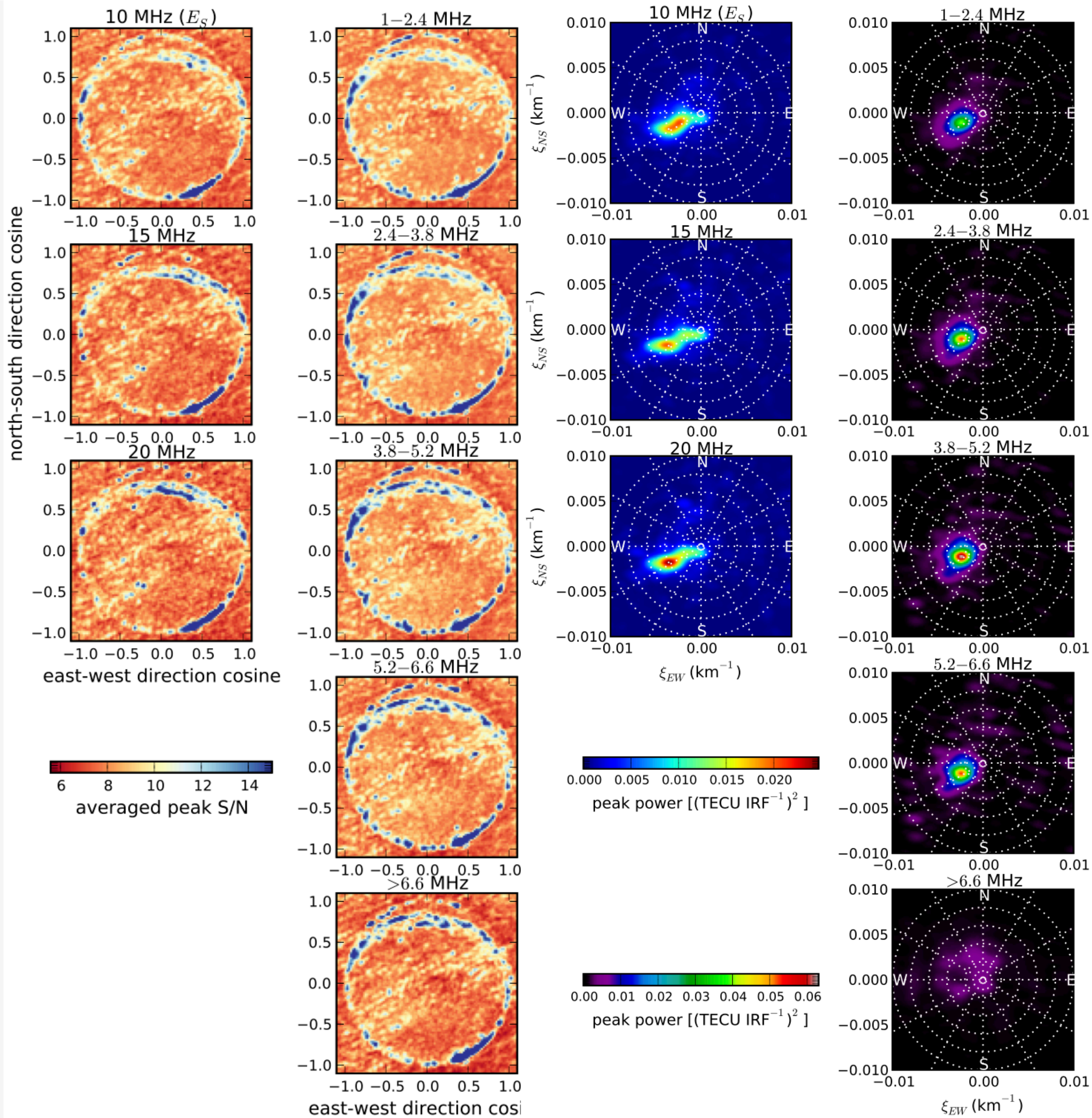
- ❖ Used concurrent GPS observations to generate fluctuation spectral cubes (one temporal dimension, two spatial) to look for TIDs/waves (manifest as point-sources).
- ❖ New observing campaign confirms earlier result based on analysis of VLSS data and previous Boulder and Dyess AFB (in TX) ionosondes; SW-directed waves seen predominantly during E_S



Mean GPS-based fluctuation spectra with and without E_S, based on LWA1 (left) or BC840 (right)

Trends with E_S Density/frequency

- Found a dependence on E_S density/plasma frequency for both TID strength and meteor activity
- But, TID strength peaks at a lower inferred plasma frequency, f_p.

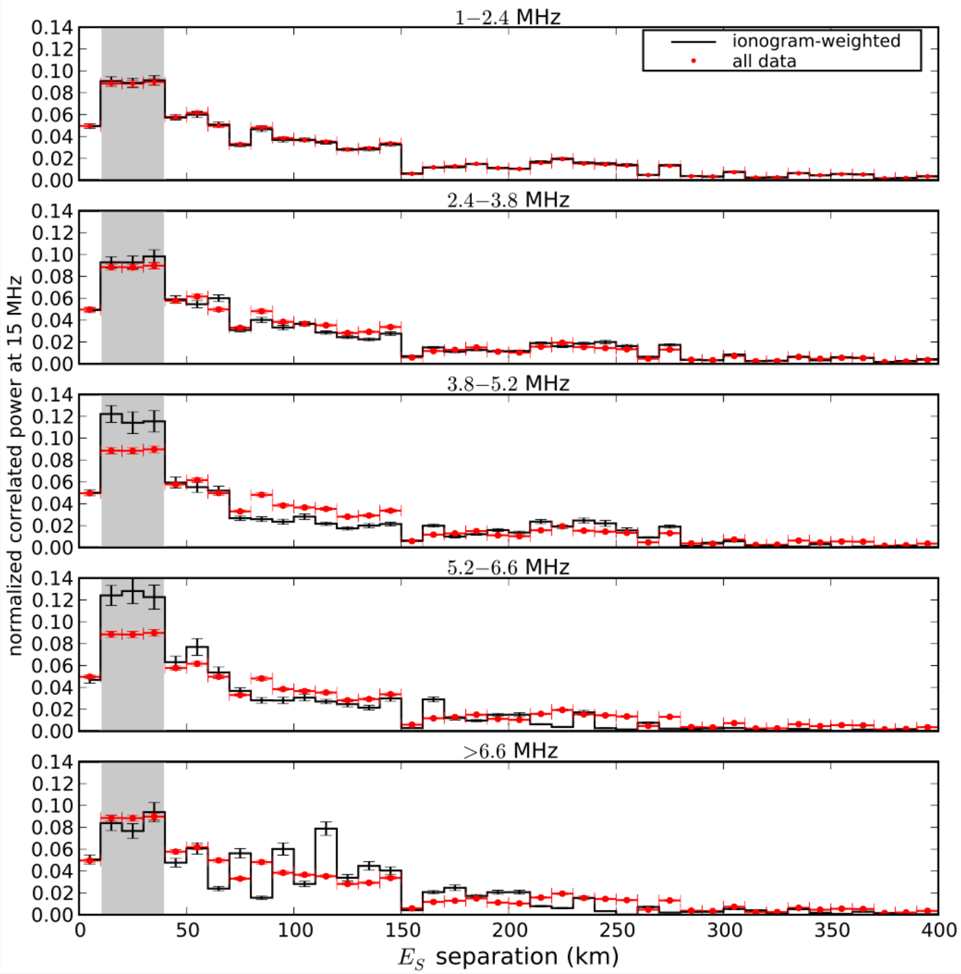


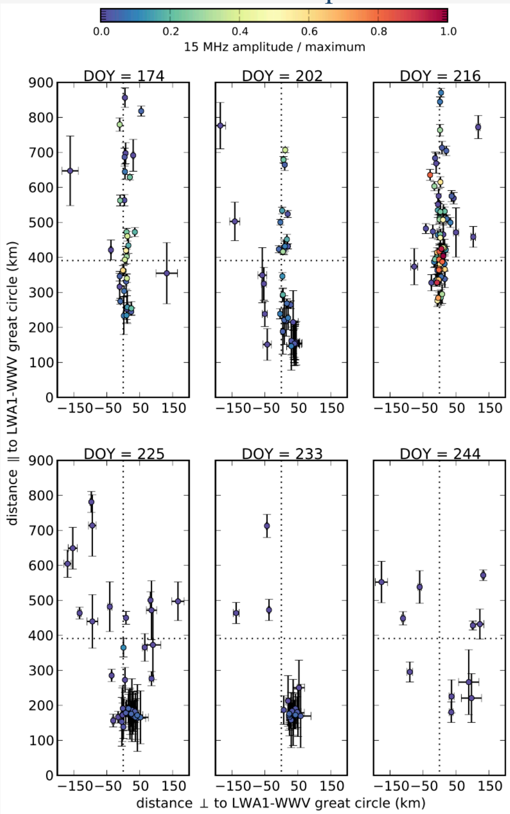
Meteor S/N maps and fluctuation spectra combined according to signal strength at LWA1 (left columns) and BC840 (right columns)

Horizontal Structure

- Mapped locations of E_S reflections at 15 MHz using LWA1+WWV observations.
- Computed correlated power among reflections as a function of horizontal separation within each 8-hour observing run.
- Significantly more correlated on scales ~10-40 km, increasing with f_p up to ~6 MHz.

Mean correlation function over all observing runs with (red) and without (black) weighting by ionogram amplitude at different frequencies





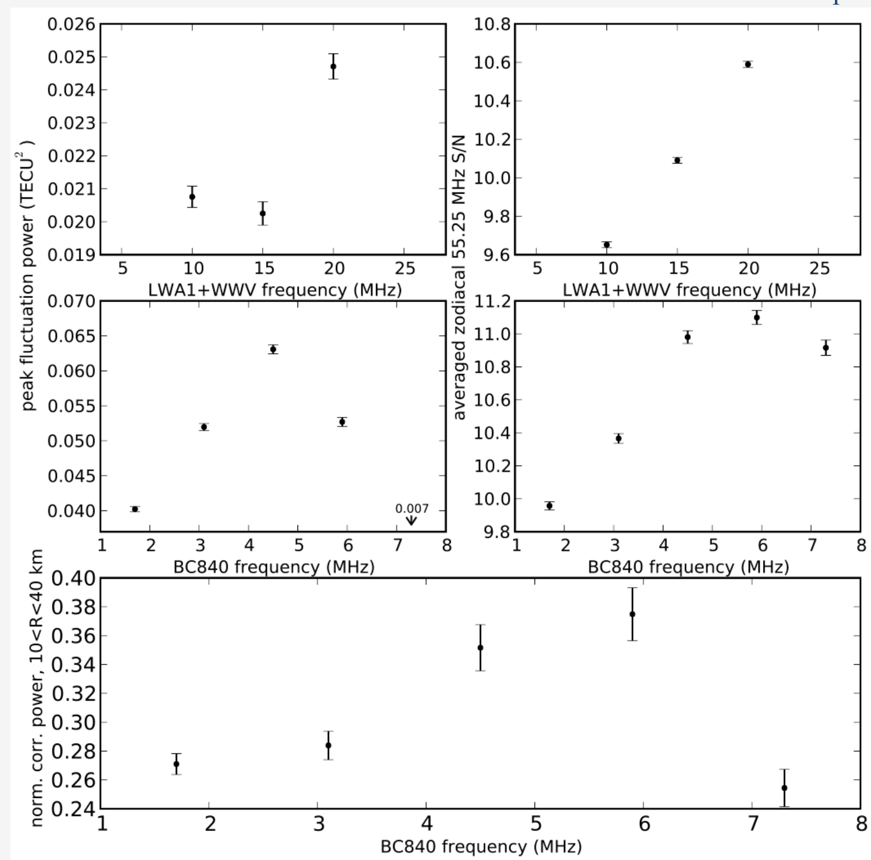
Horizontal positions of 15 MHz WWV reflection points relative to great circle between LWA1 and WWV

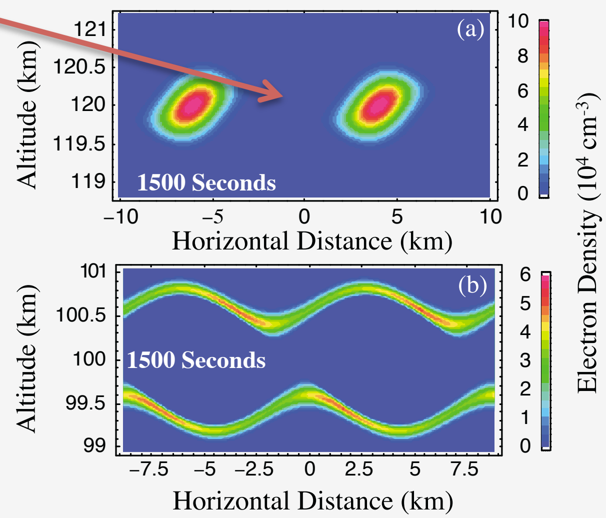
Conclusions

❖ Observations consistent with:

1. Summer nighttime TIDs moving to SW generated via E-F coupling instability.
2. Not only is density of E_S layers enhanced by increased meteor activity, but so are relatively dense structures on scales ~10-40 km.
3. When these dense structures get too dense (f_p ~4.5 MHz), the E-F coupling instability is weakened, possibly due to accompanying “holes” in the E_S layer.
4. Extremely dense structures (f_p > ~6.5 MHz) apparently unaffected by increased meteor activity and (nearly) spatially uncorrelated.

Trends of previously shown observables with f_p.

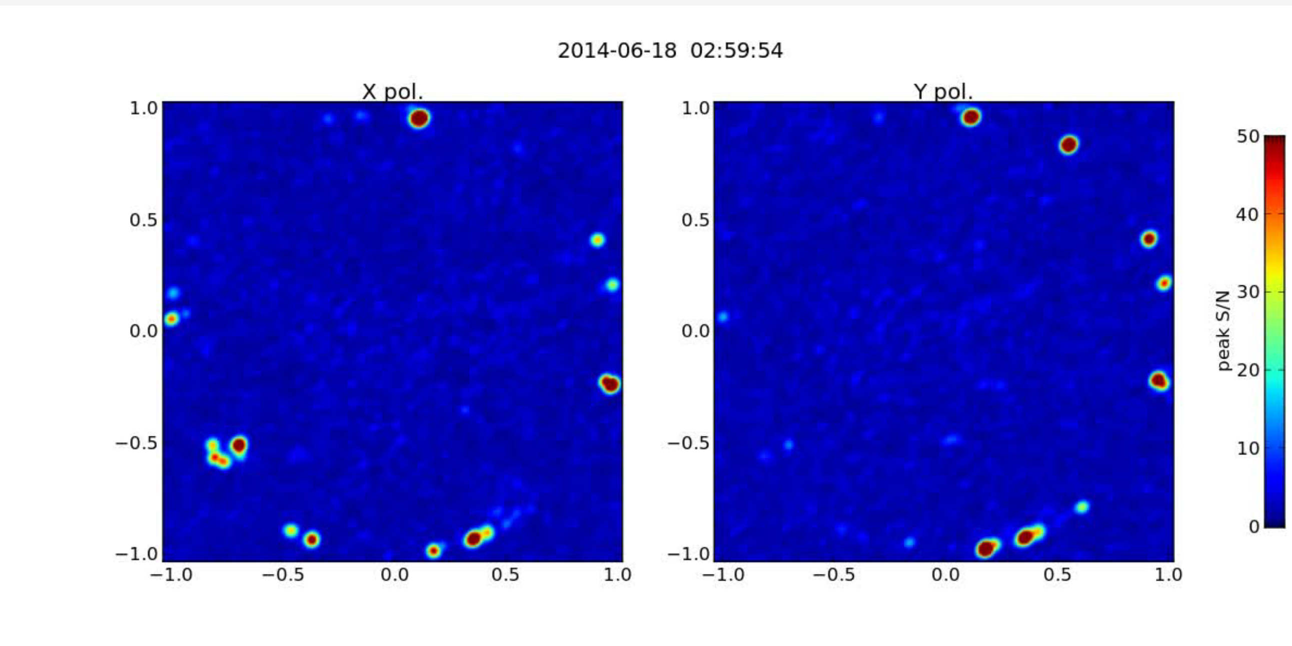




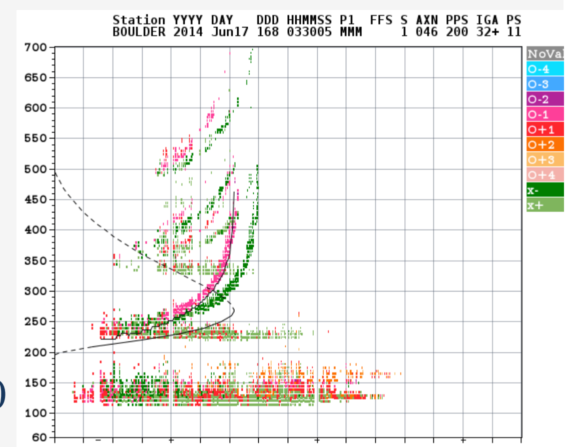
Simulations of impact of K-H instabilities on sporadic-E (Bernhardt 2002)

Connections to Other LWA1 Programs

- Also learning about connection to meteor activity from ongoing TBN meteor survey at 55.25 MHz to be detailed later by S. Cockrell.
- During summer observing runs, we are seeing long-duration trails that may be caught in the same wind shears as E_S.
- May be the origin of extremely dense structures that do not get more dense with increased meteor activity.



Movie of meteor (and airplane) activity from last month.



Ionogram from BC840 during this observing run.