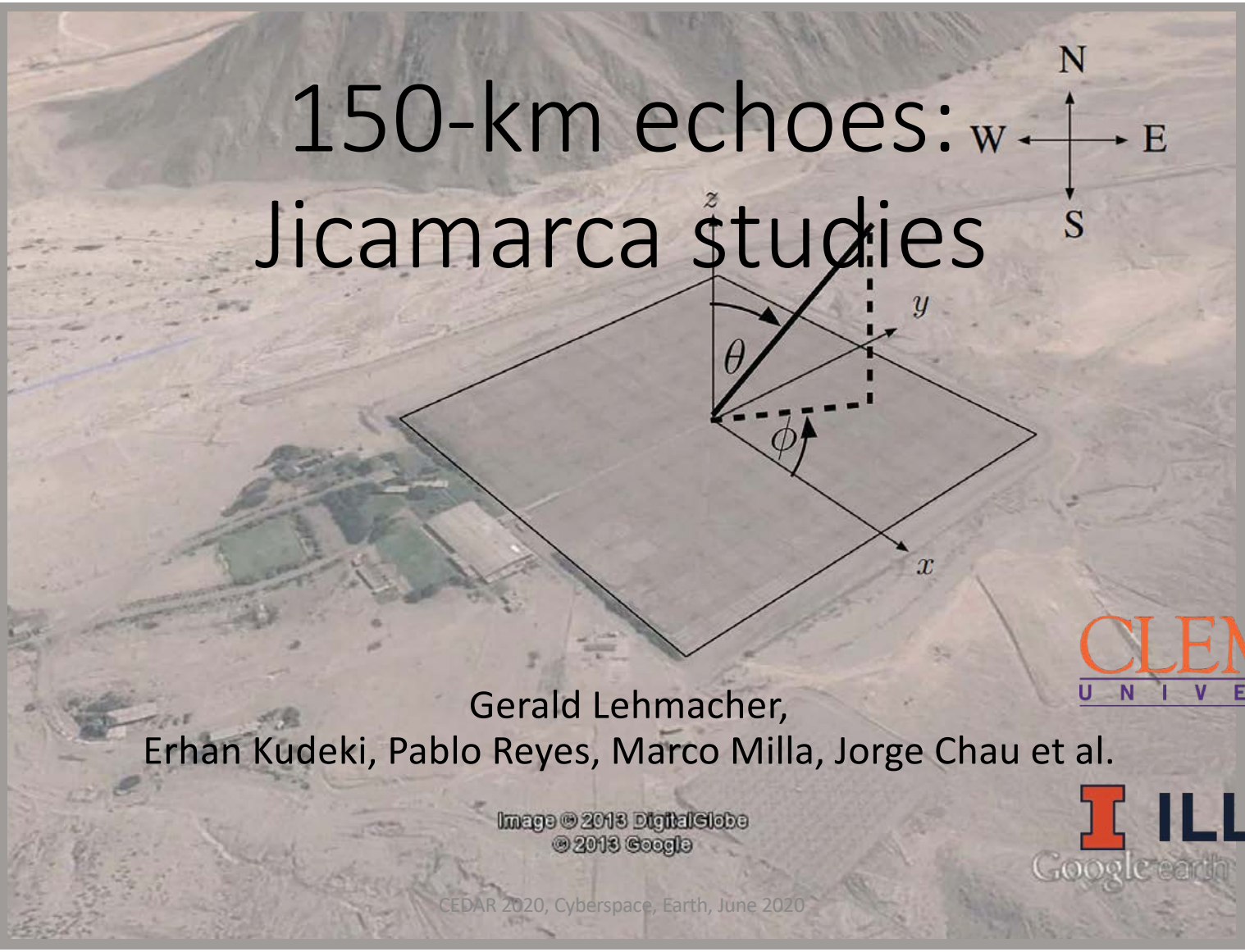
150-km echoes: Jicamarca studies



Gerald Lehmacher,
Erhan Kudeki, Pablo Reyes, Marco Milla, Jorge Chau et al.

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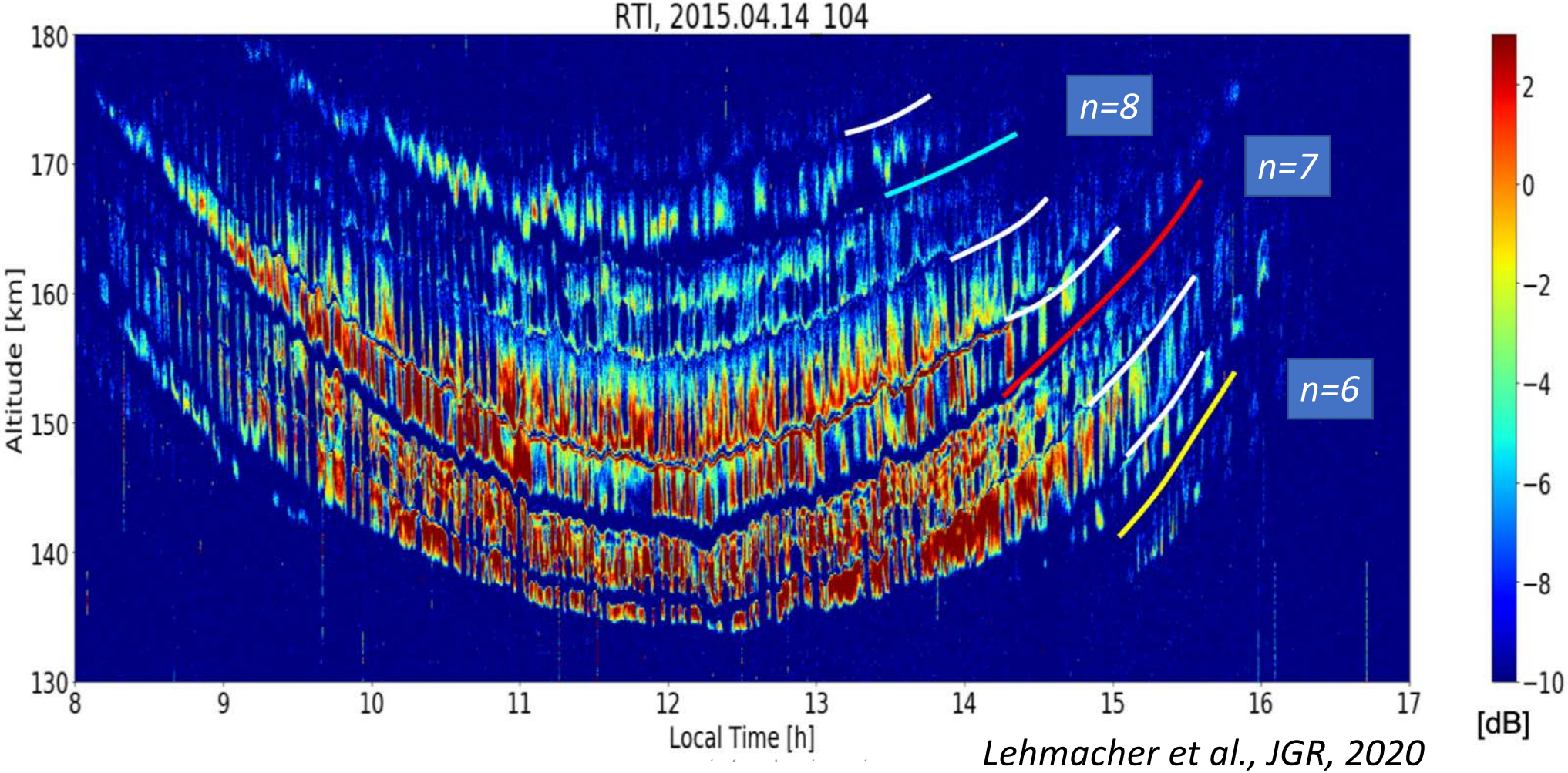
Previously…

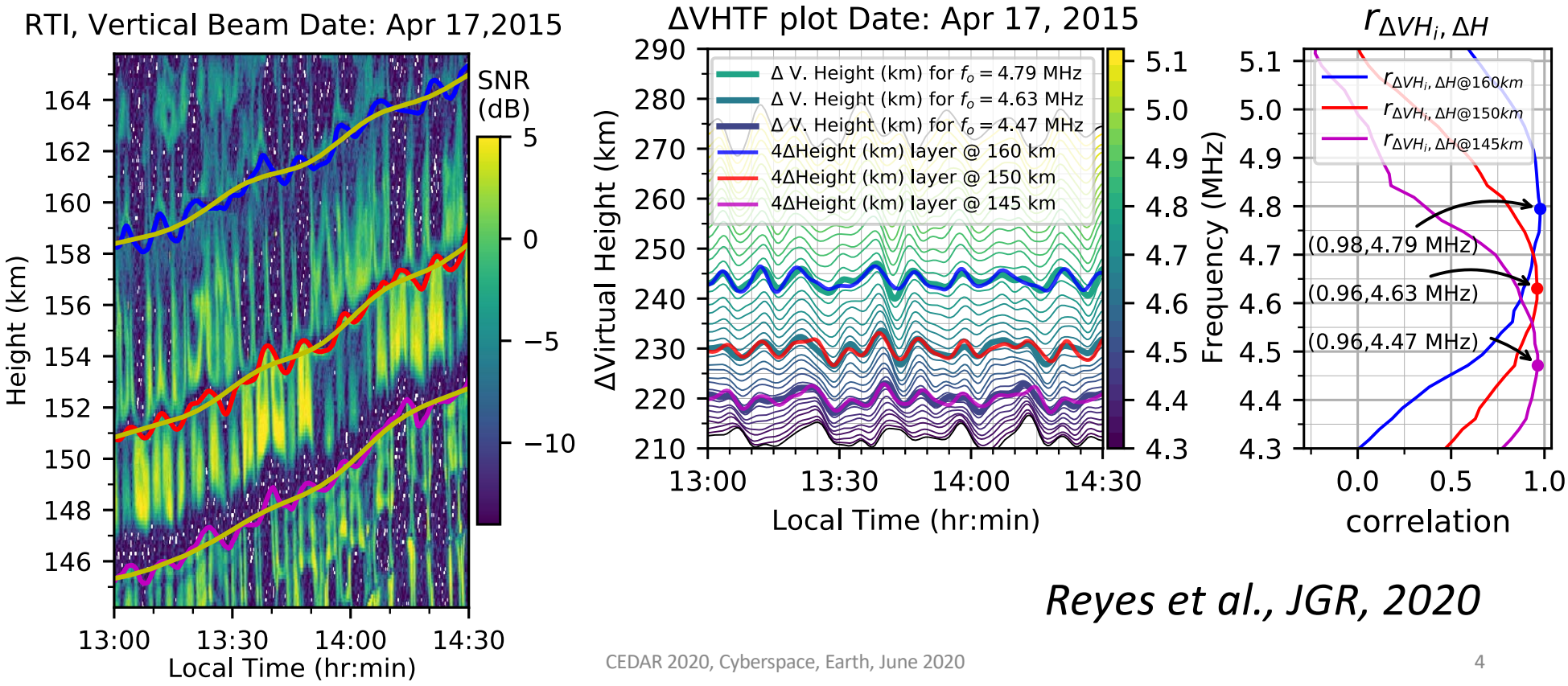
- 3-meter irregularities from 150 km (daytime) were first reported by *Balsley* (1964). Observed by many radars at low latitudes (and mostly perpendicular to **B**).
- *Kudeki and Fawcett* (1993) described the "necklace" pattern with multiple layers and gaps, and modulation of necklace by short period gravity waves (GW).
- *Reyes* (2012) studied how solar flares disrupted the necklace by sudden downshifts of layers; indirect evidence for connection with local electron density. *Pedatella et al.* (2019) successfully modeled such events with WACCM-X.
- *Reyes et al.* (2020) showed that GW modulations of certain gaps match modulations of VIPIR (dynasonde) plasma frequency contours, but no significant modulation of vertical ion drifts occurs, since small electric field modulations are shorted out.
- *Lehmacher et al.* (2020) compared gap heights with WACCM-X model over more than one solar cycle and concluded that certain gap heights correspond to a double resonance condition with $f_P^2 = (n^2 - 1) f_{B,e}^2$ with $n = 5,6,7,8$.
  … theoretical confirmation by *Longley et al.* (2020): **next talk!**

There is a regular pattern of wide and narrow gaps in the necklace



Lehmacher et al., JGR, 2020

Modulations in gaps (in radar back scatter) best match certain plasma frequency contours (in VIPIR)

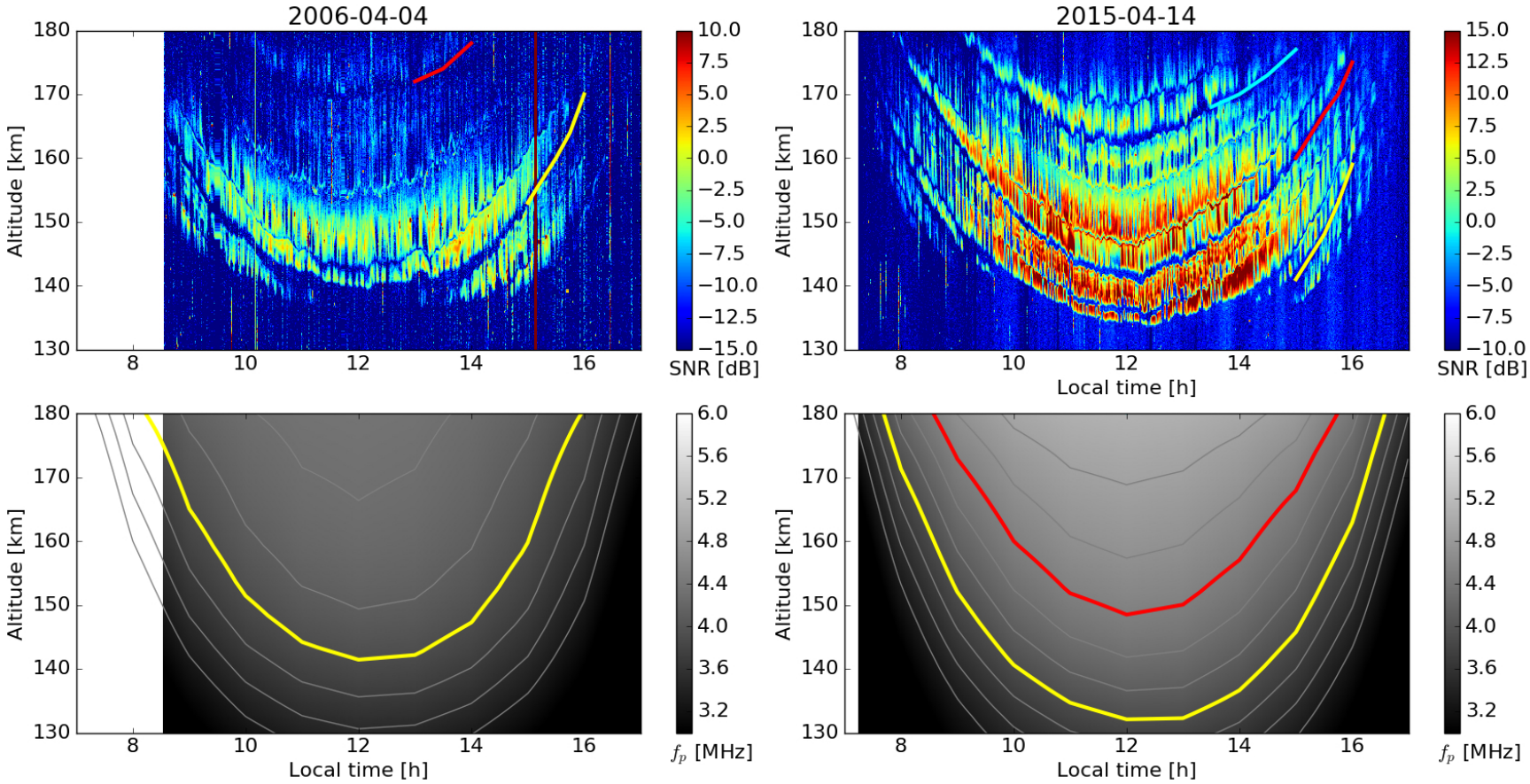


Reyes et al., JGR, 2020

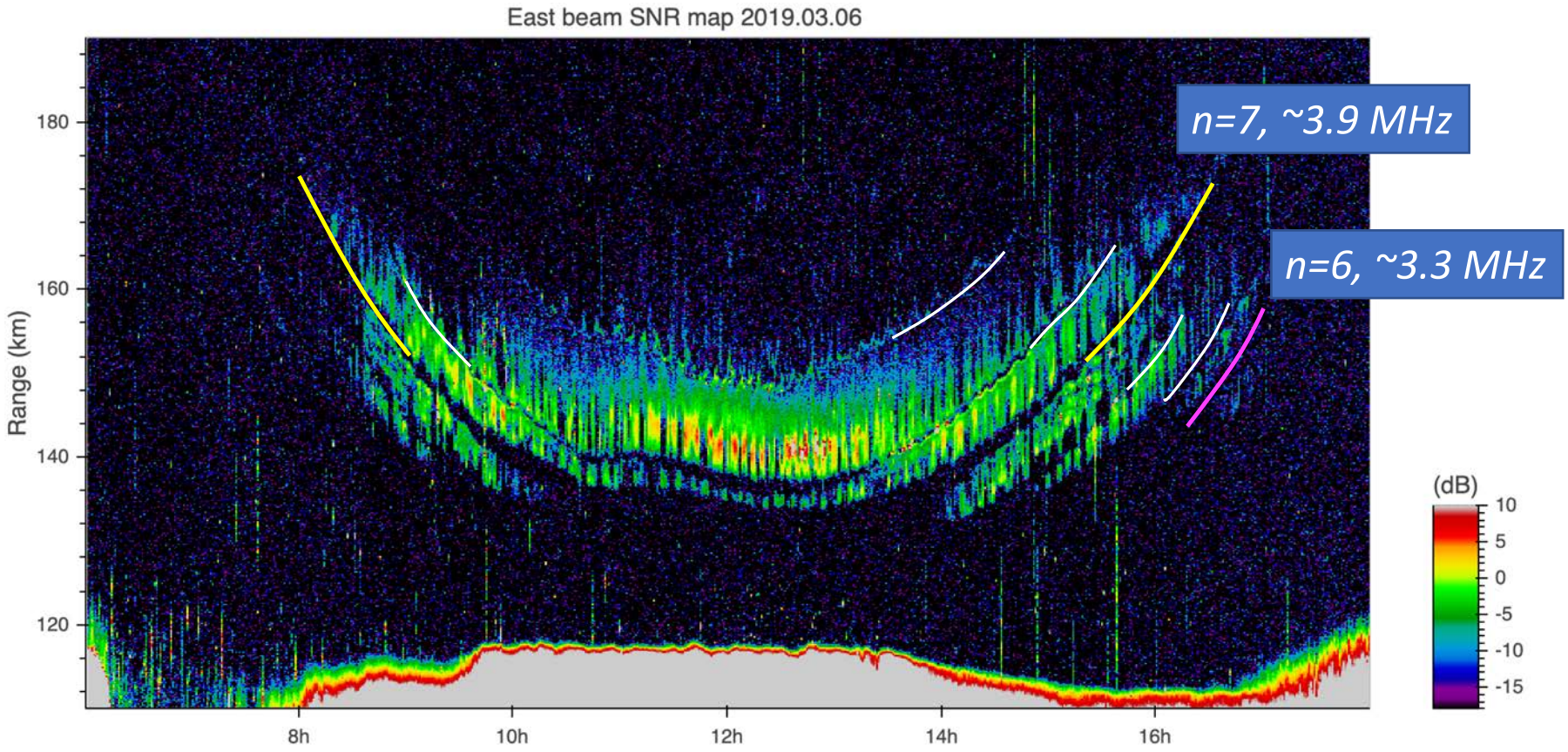
Strong variation of gap heights over solar cycle is consistent with electron densities

Lehmacher et al., JGR, 2020

WACCM-X (SD) electron dens., plasma freq.



2019: Solar minimum again…

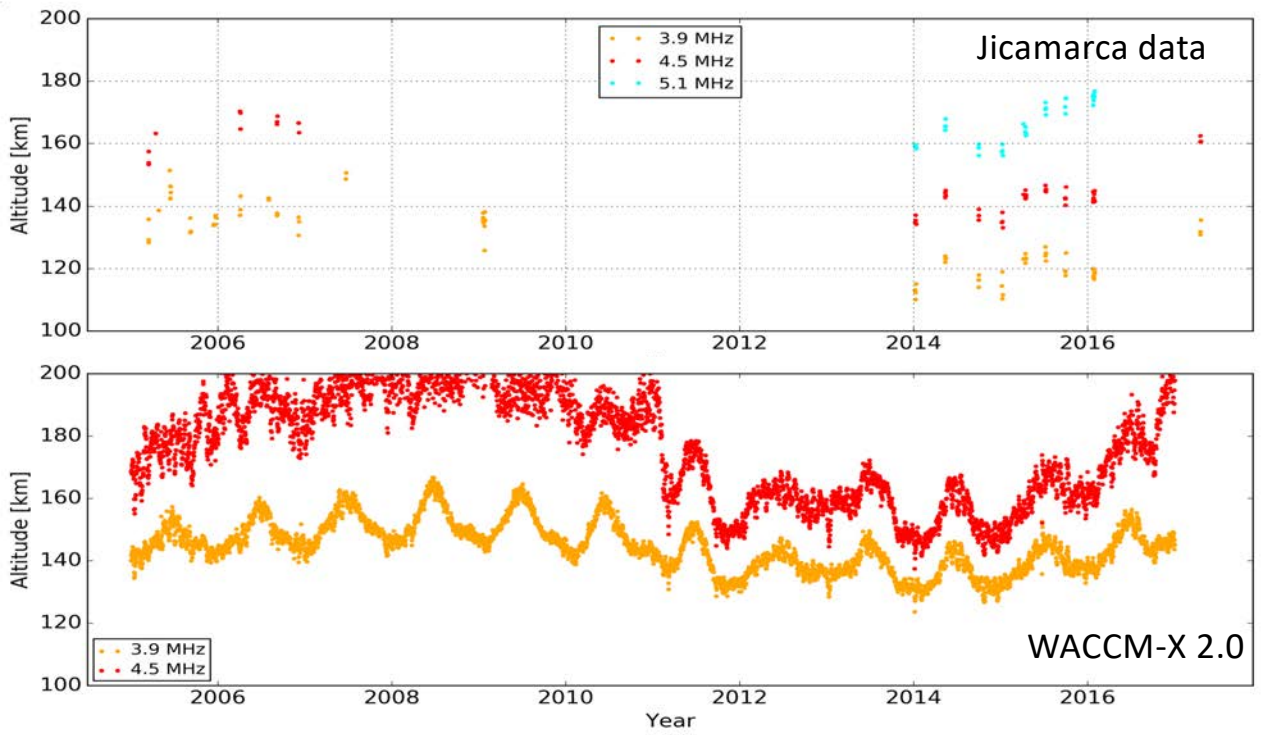


Solar cycle variations: gap height vs. WACCM-X 2.1

The **"4.5 MHz" gap** at local noon is near 170 km during solar minimum and near 130 km during solar minimum.

The gap is highest around June (winter) solstice and lowest in summer. There is large day-to-day variability as well.

WACCM-X 2.1 electron densities and the seasonal amplitude are more realistic than WACCM-X 2.0. Densities are higher and contours ~20 km lower.

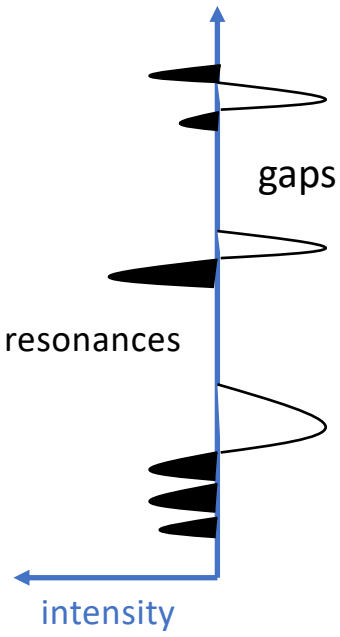


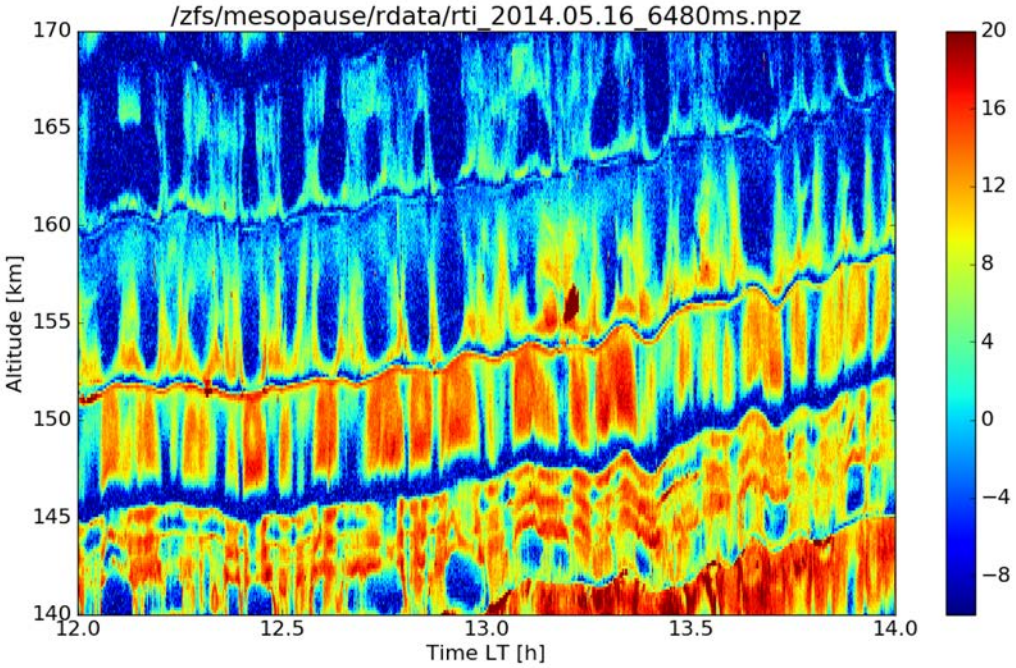
Further steps…

- As plasma drifts $\mathbf{V}_D = \mathbf{E} \times \mathbf{B}$ are a tool to estimate electric field variability, gap heights could be a new tool to study electron density variability in the valley region, the dependency of N_e on neutral wind, and to validate global models.
- GW modulations offer opportunity to study GW propagation in valley region. There are also strong transient wave events in the daytime valley. The source of the GWs is unknown, possibly secondary waves from M/LT below.
- Meridional wind fluctuations do move plasma across magnetic field lines and ripple electron density surfaces. The detailed mechanism of how GW turn on and off plasma irregularities is not yet understood.
- 150-km echoes also show sub-minute oscillations, possibly due to plasma waves moving along magnetic field lines
- **How can a rocket experiment help?** A high-resolution electron probe could directly observe the 3-meter (and smaller) irregularities as demonstrated by *Smith and Røyrvik* (1985). Could we probe different **k**-vectors and k-spectra?

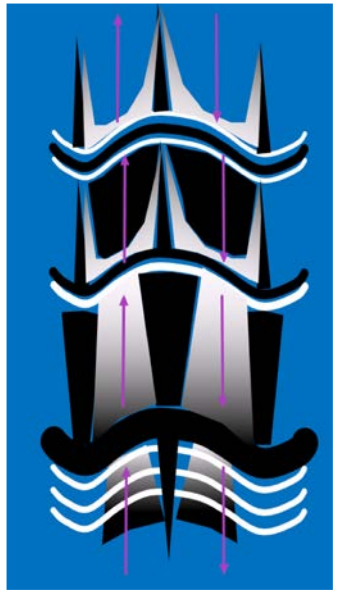
Fine structure of 150-km echoes: “checkerboard” and “fishbones”

plasma frequency

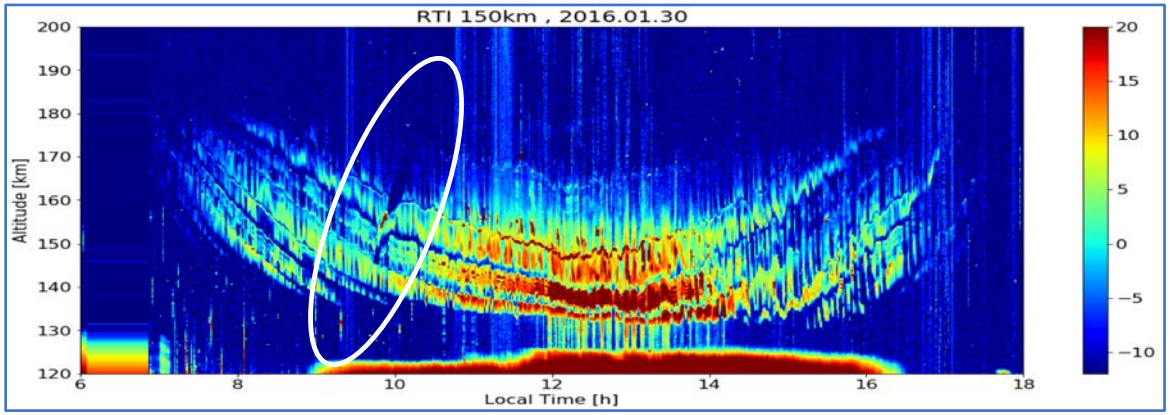


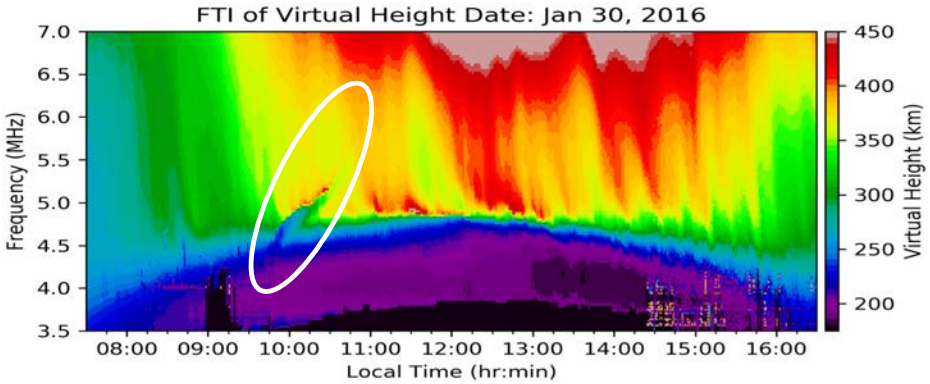


GW modulation (schematic)

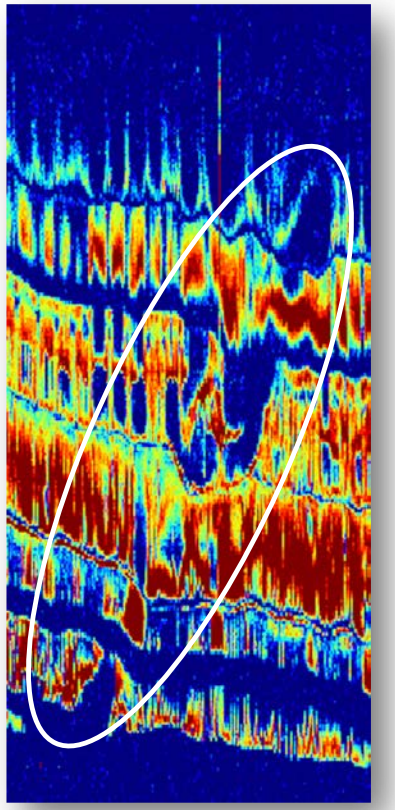


Large neutral disturbances in the daytime valley region



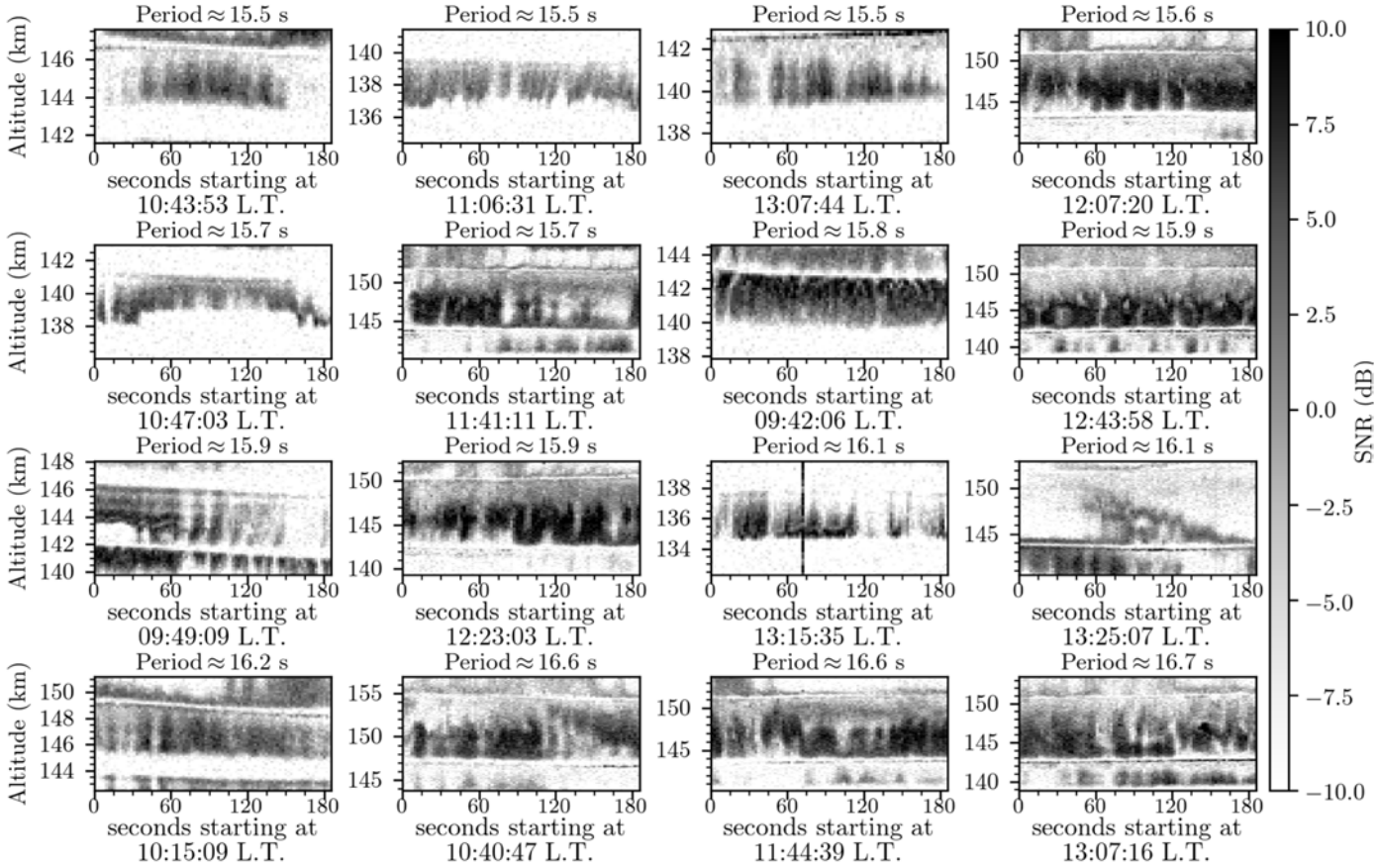


same event in 150-km echoes and VIPIR



different event

Sub-minute quasi-periodic echoes



Observed periods:
10-25 seconds increasing with altitude
Reyes (2017)

possibly waves propagating between conjugate points in E region?
Alfvén speed

$$v = \sqrt{B/\mu_0 \rho}$$

and bounce period

$$T = 2L/v$$

$$\sim 2 \cdot (20/360) \cdot 2\pi R$$

~ 15 seconds

Previous rocket results

show significant levels of meter-scale electron density fluctuations in daytime valley region, e.g.,

Prakash (1969)
Smith and Klaus (1978)
Smith and Røyrvik (1985)

What is their relationship to radar echoes?