Equatorial Spread *F*

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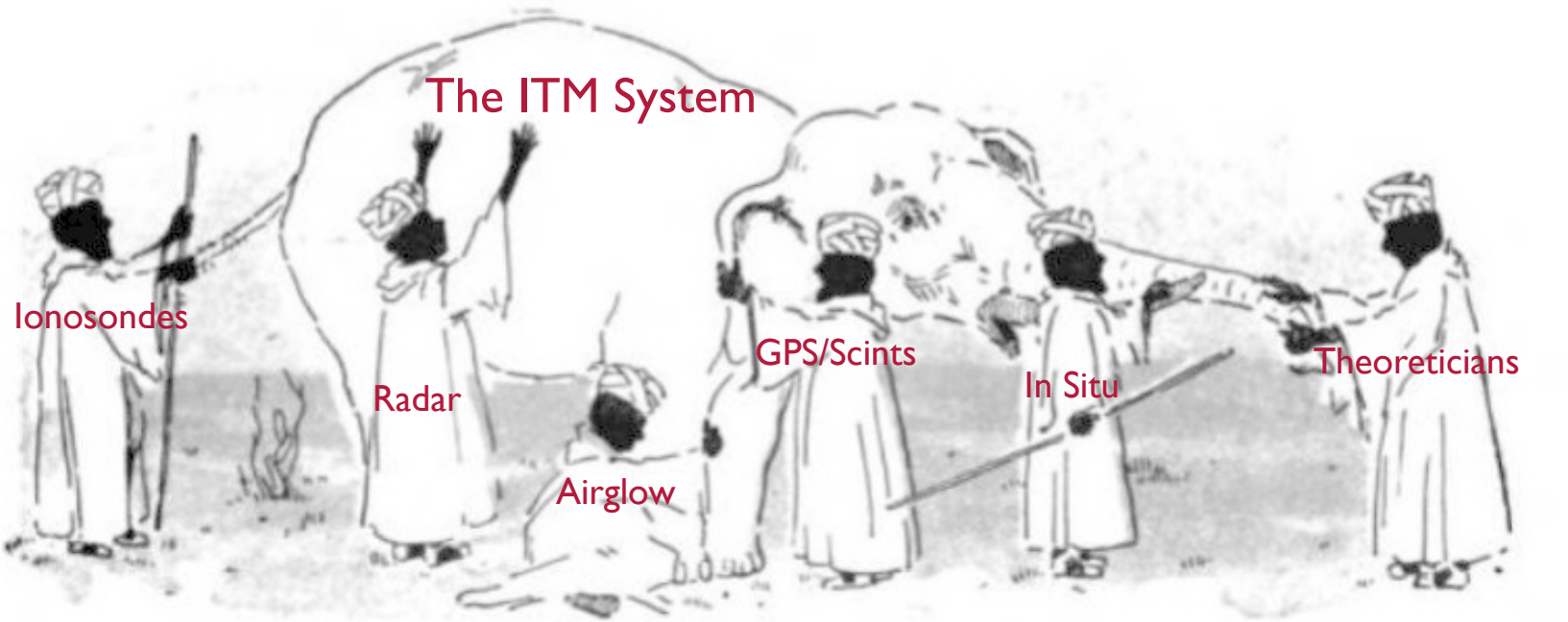
Outline

- The Aeronomy Problem
- Techniques and Taxonomy
- Physical Explanations
- Practical Consequences
- Outstanding Questions

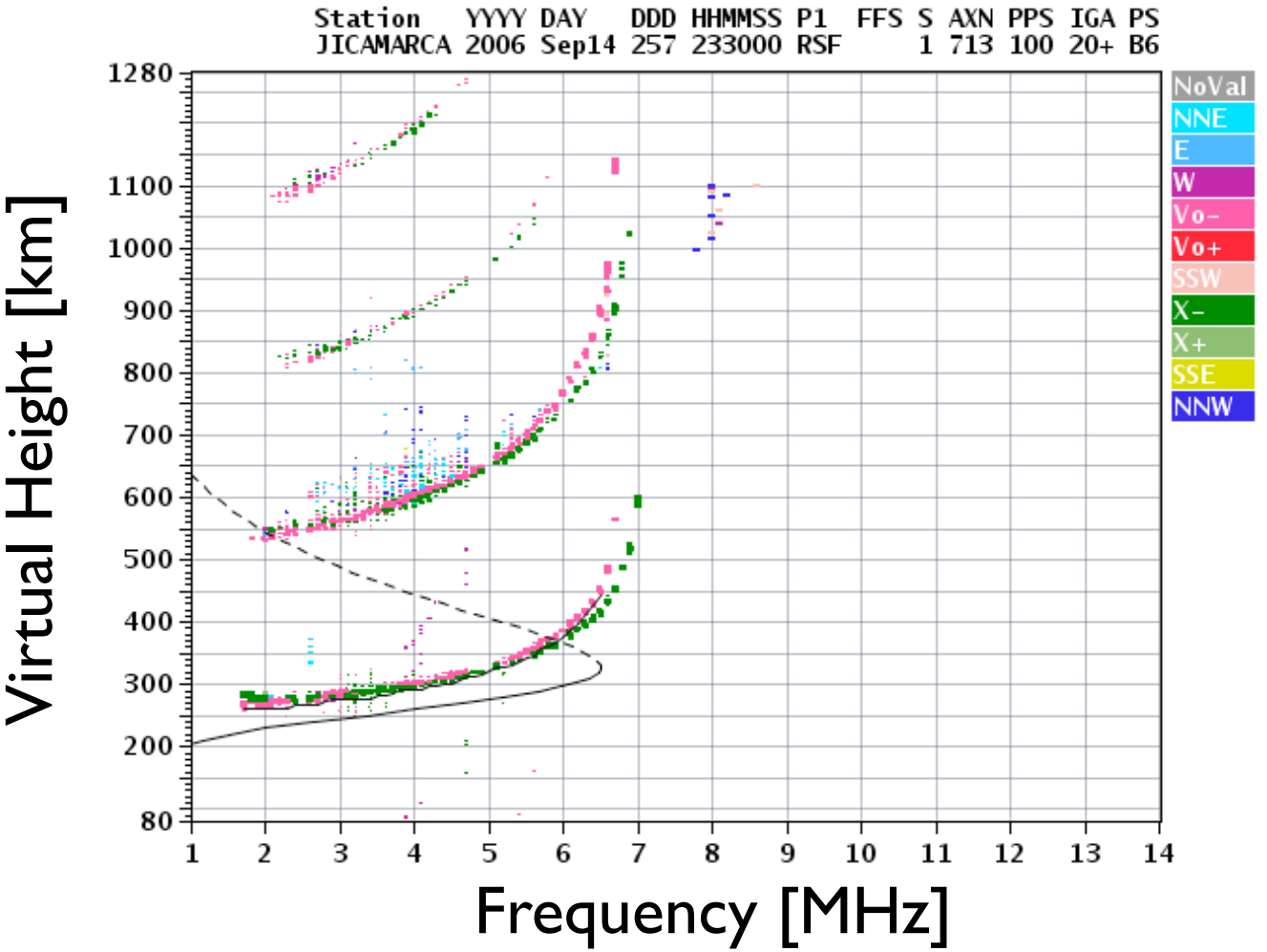
The Aeronomy Problem

The Aeronomy Problem



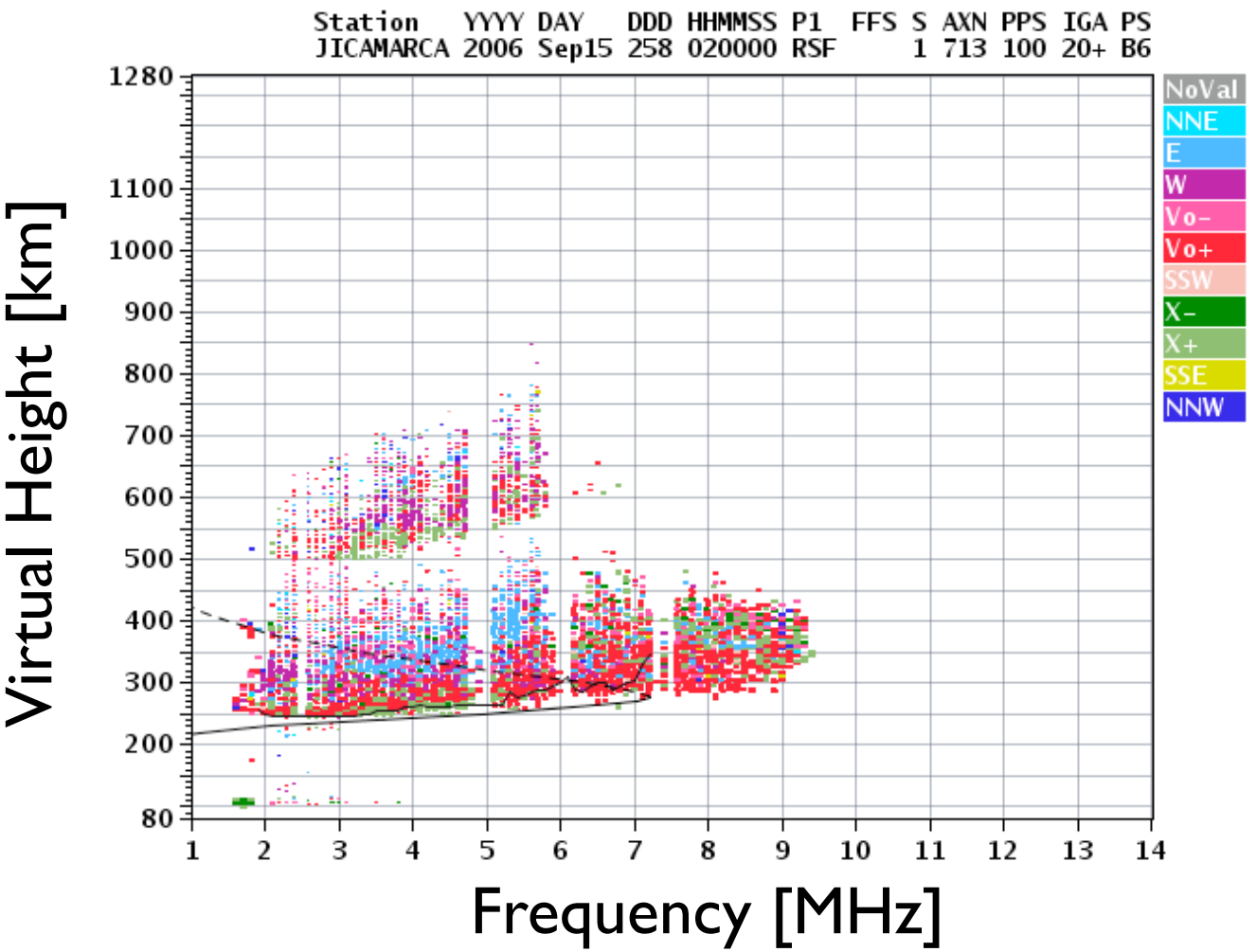
Ionosondes: Equatorial Spread *F*

Jicamarca, Perú 1930 LT 14 Sep (257) 2006



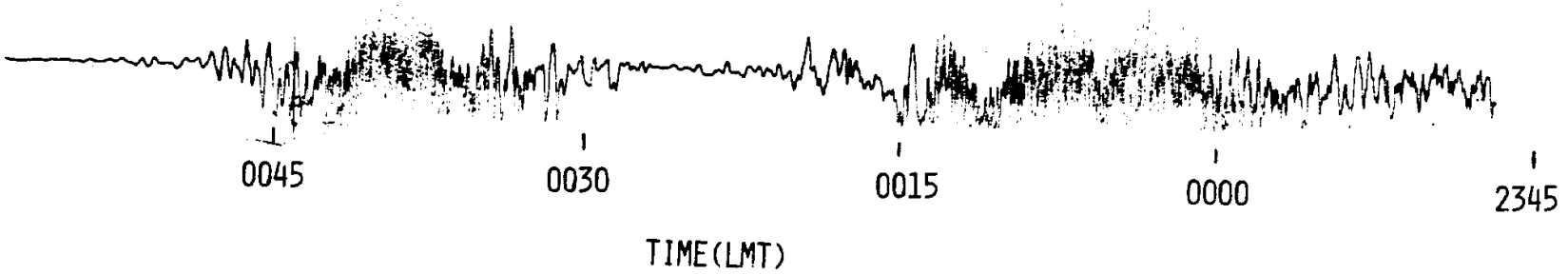
Ionosondes: Equatorial Spread *F*

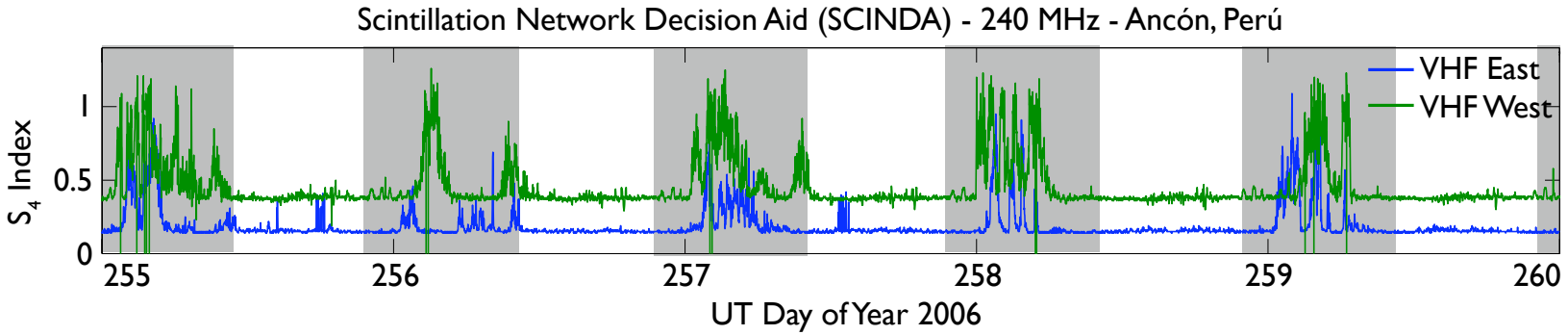
Jicamarca, Perú 2200 LT 14 Sep (257) 2006



Transionospheric Radio: Scintillation

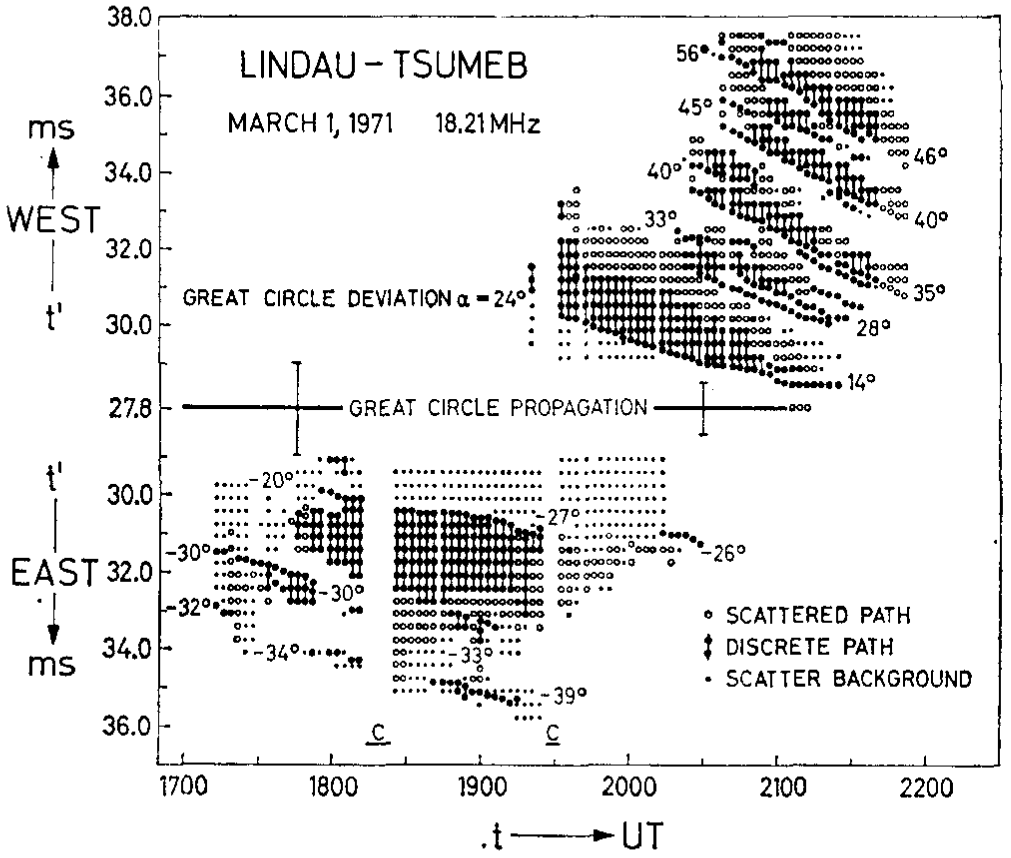
136-MHz scintillation at Natal, Brazil ($\sim$ 18 dB full scale, from *Yeh and Liu*, 1982)

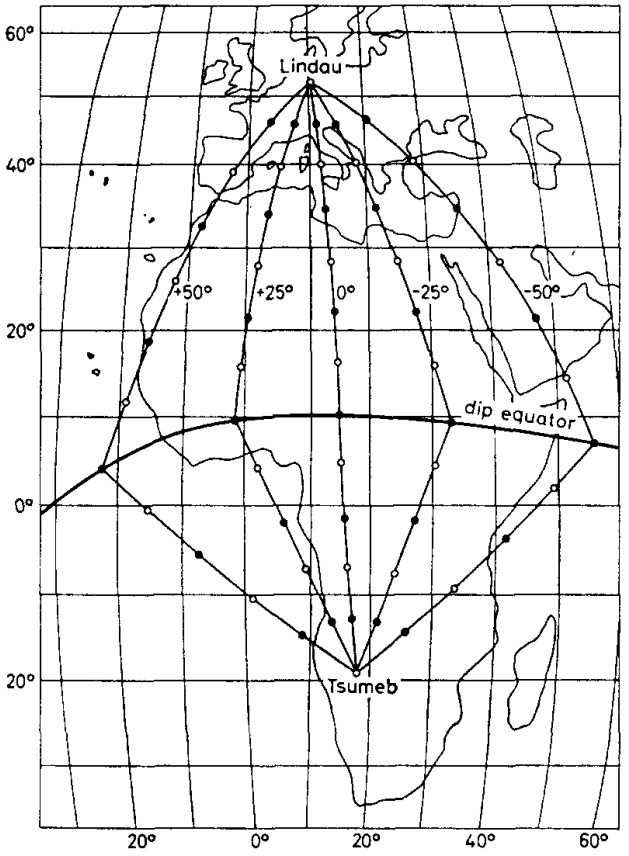




- Fresnel-scale ($\sqrt{\lambda z}$) irregularities.
- $S_4^2 = \frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}$

HF/VHF Radio: Transequatorial Propagation

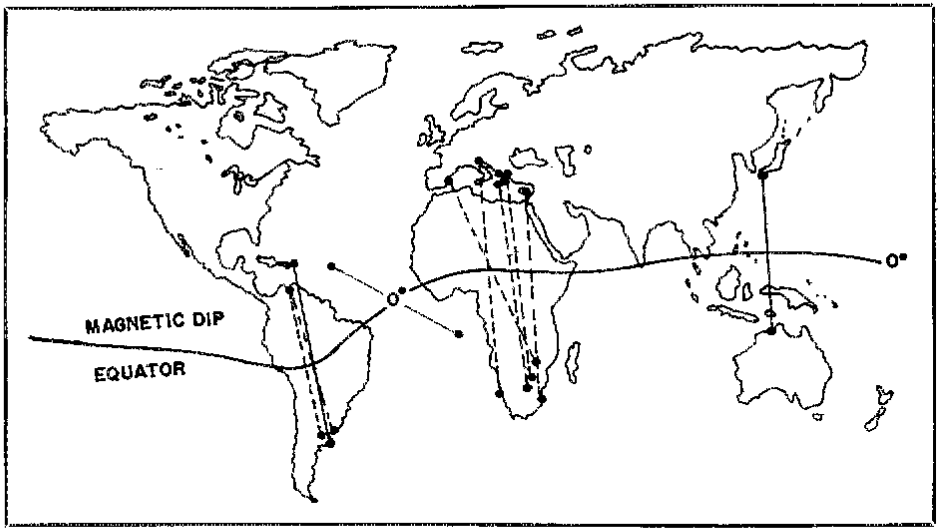




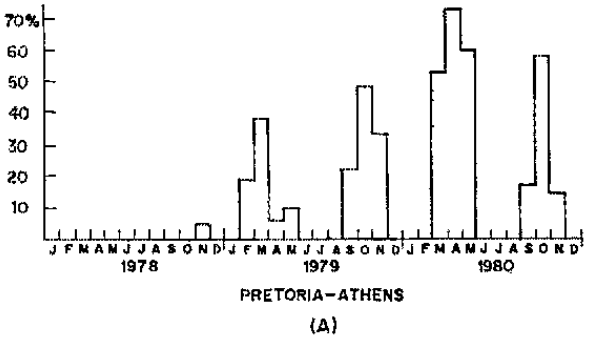
from *Röttger*, 1973.

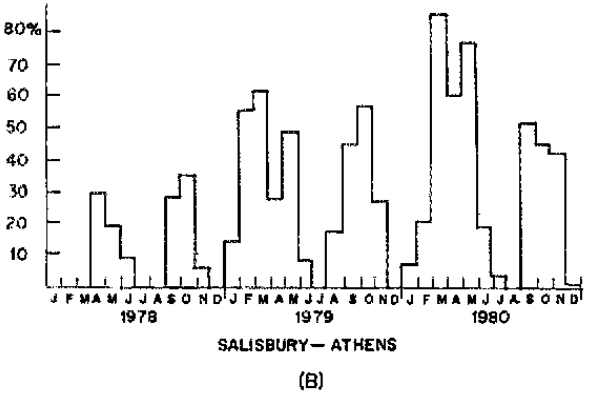
HF/VHF Radio: Transequatorial Propagation

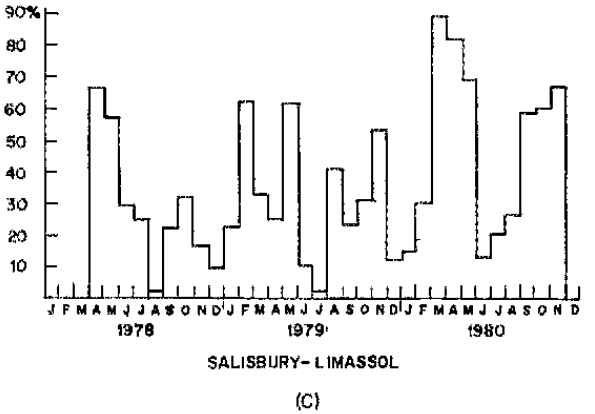
Transequatorial paths on 144 MHz.



from *Cracknell, et al*, 1981 (Nov 1981 *QST*, reproduced with permission of ARRL).

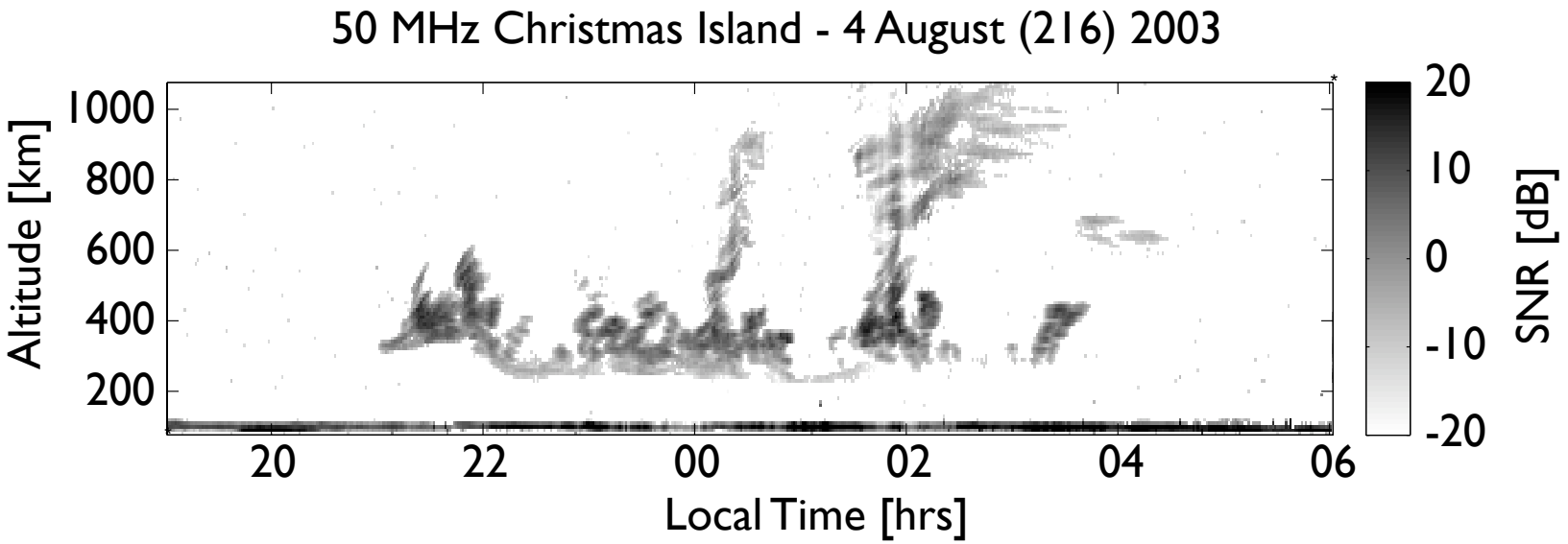






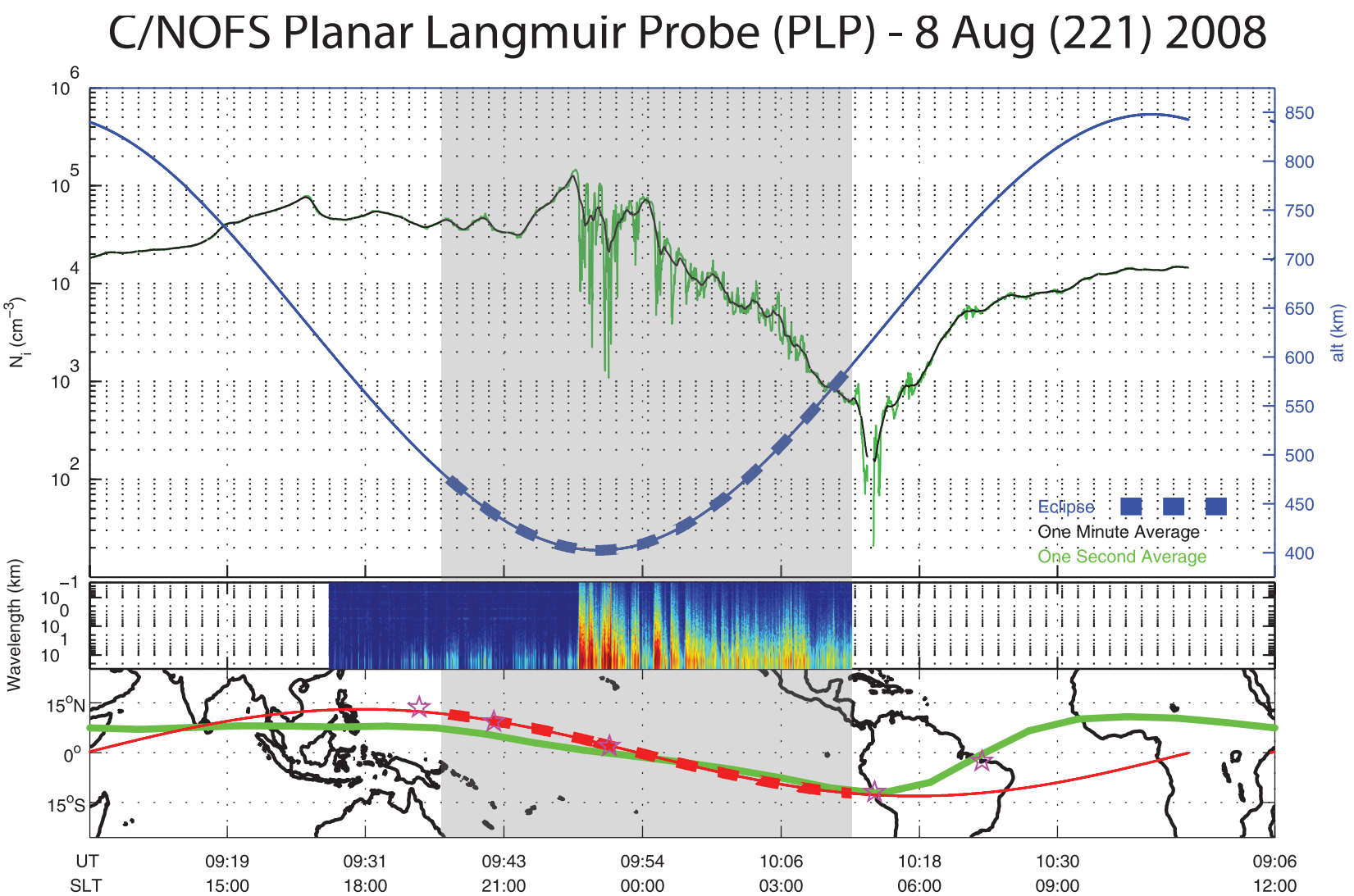
VHF Radar: Field-Aligned Irregularities

- Bragg-scale ($\lambda_{rad}/2$) irregularities.
- Strong returns where $\mathbf{k} \perp \mathbf{B}$.



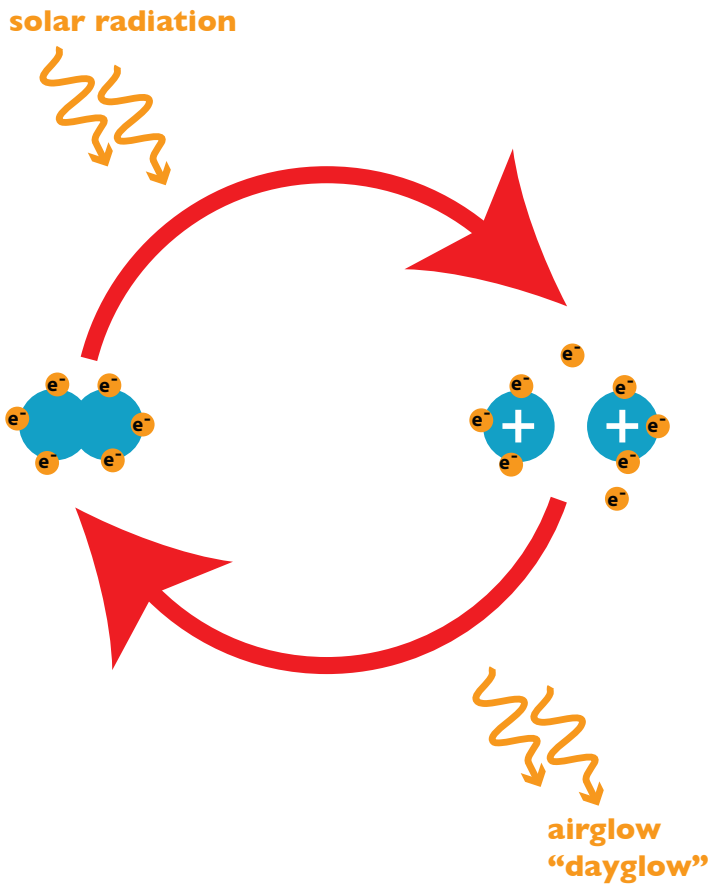
(Show movie from Koki if Dave didn't.)

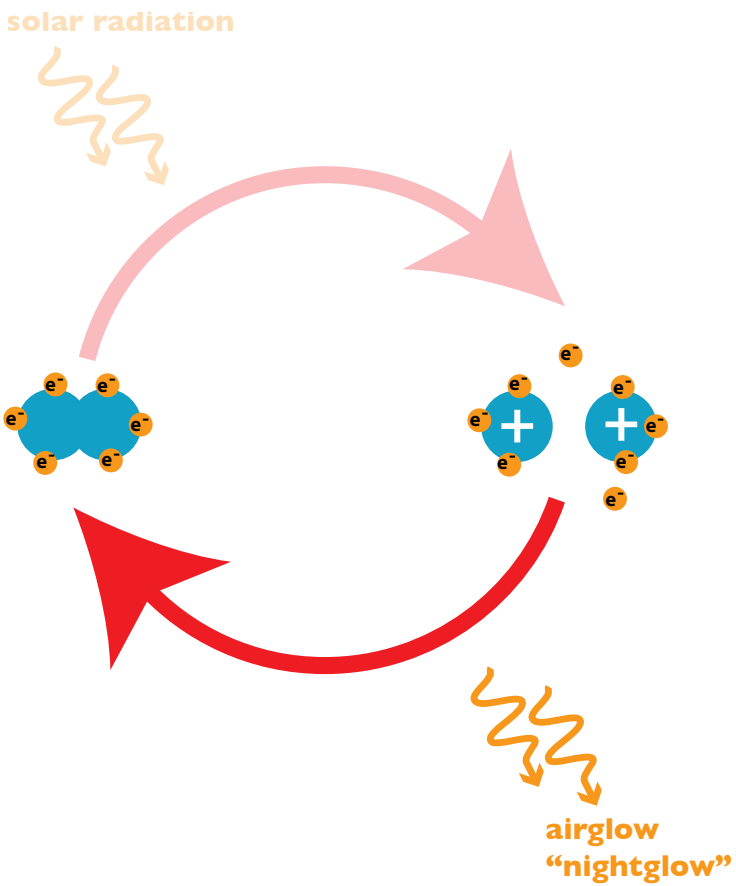
In Situ: Equatorial Plasma Depletions



from *Roddy, et al*, 2010 (Reproduced with permission of AGU).

Optical: Equatorial Plasma Bubbles

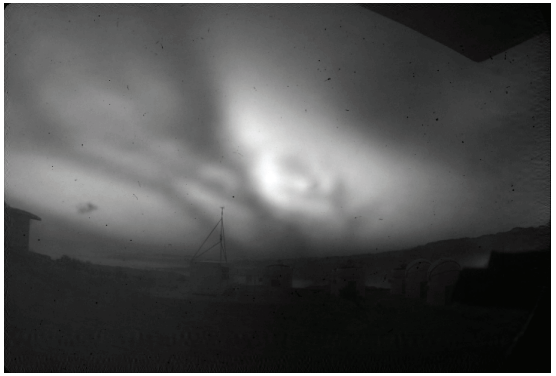


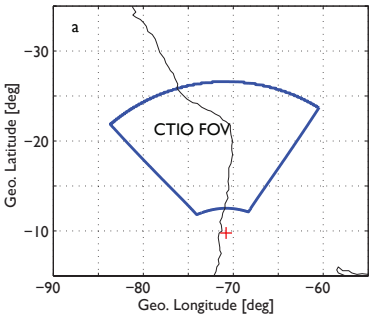


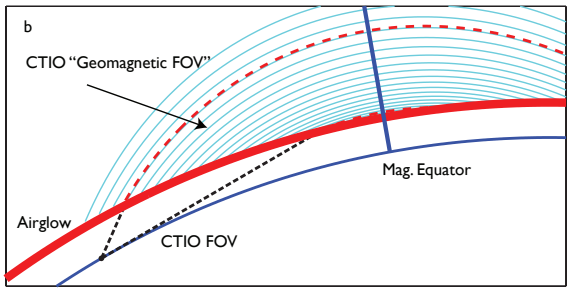
$$O_2 + h\nu \rightarrow 2O^+ + 2e^-$$

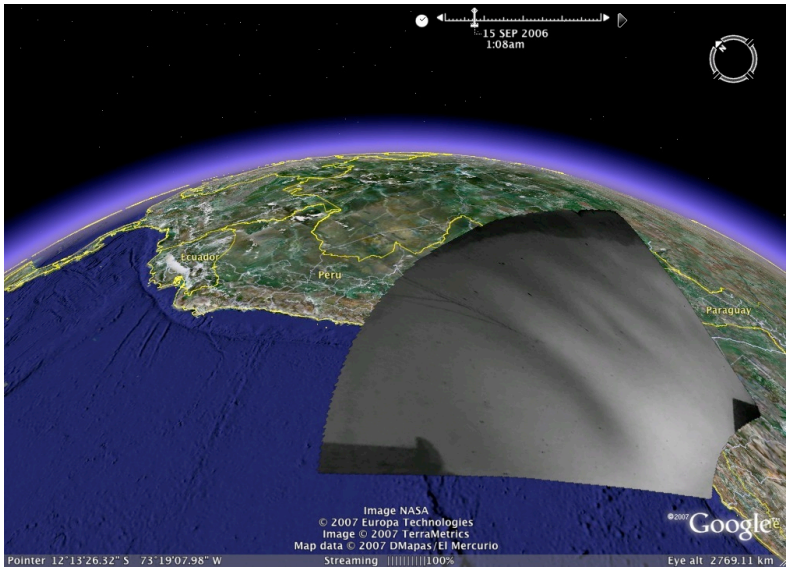
$$O^+ + O_2 \rightarrow O_2^+ + O$$
$$O_2^+ + e^- \rightarrow O + O + 4.99\text{eV}$$
$$O(^1D) \rightarrow O(^3P) + h\nu$$

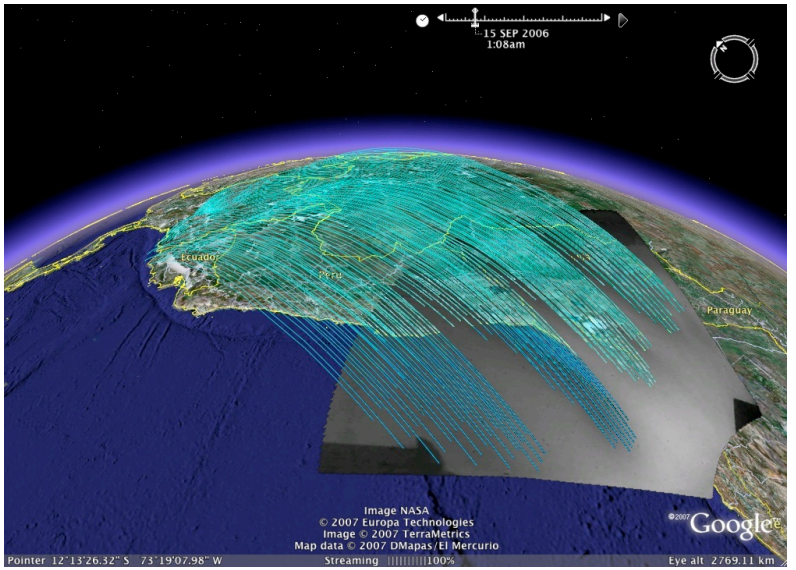
Optical: Equatorial Plasma Bubbles





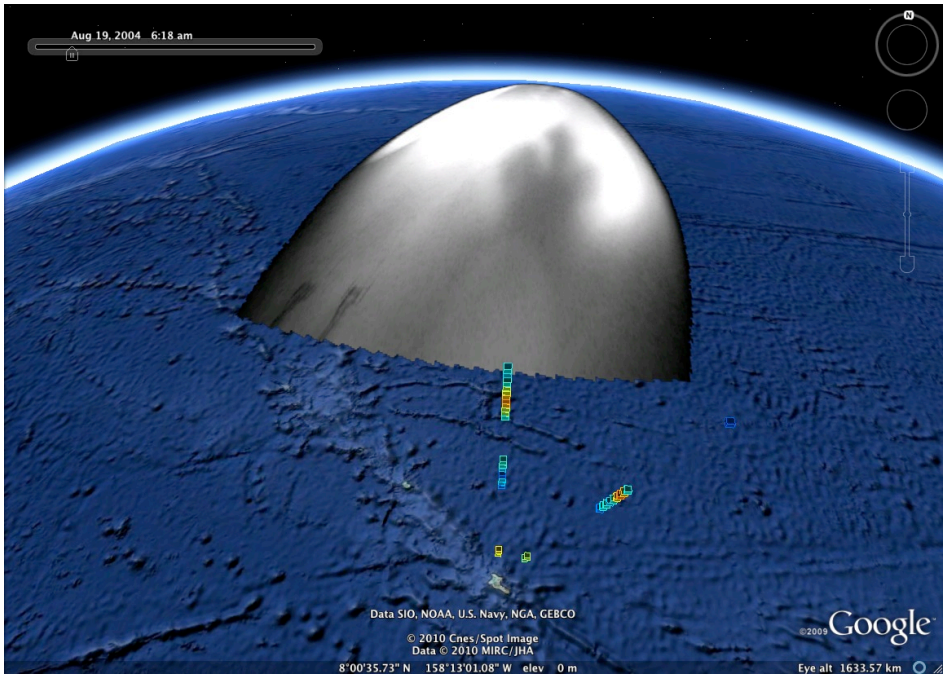


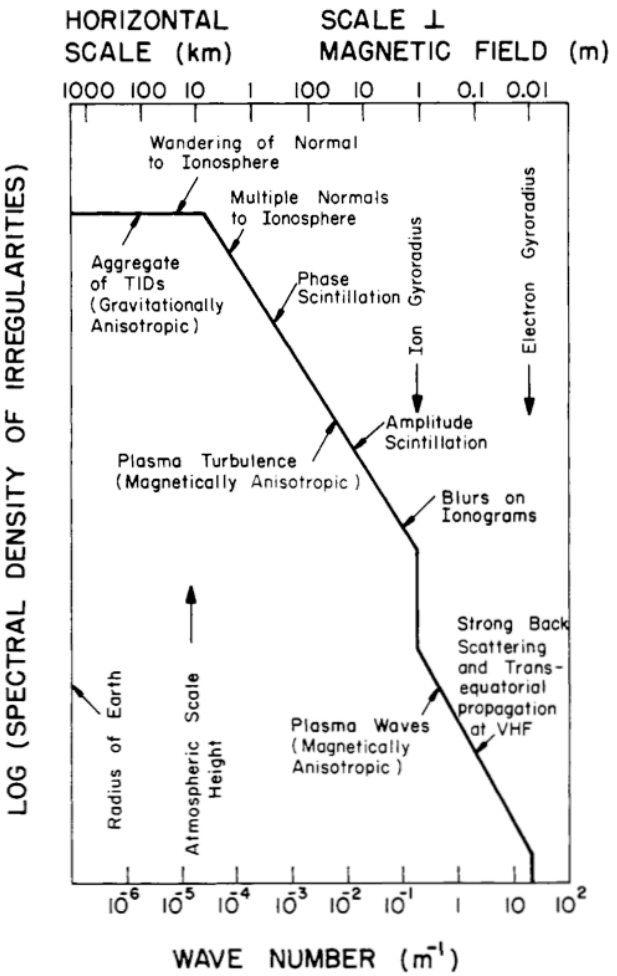




A Composite Picture

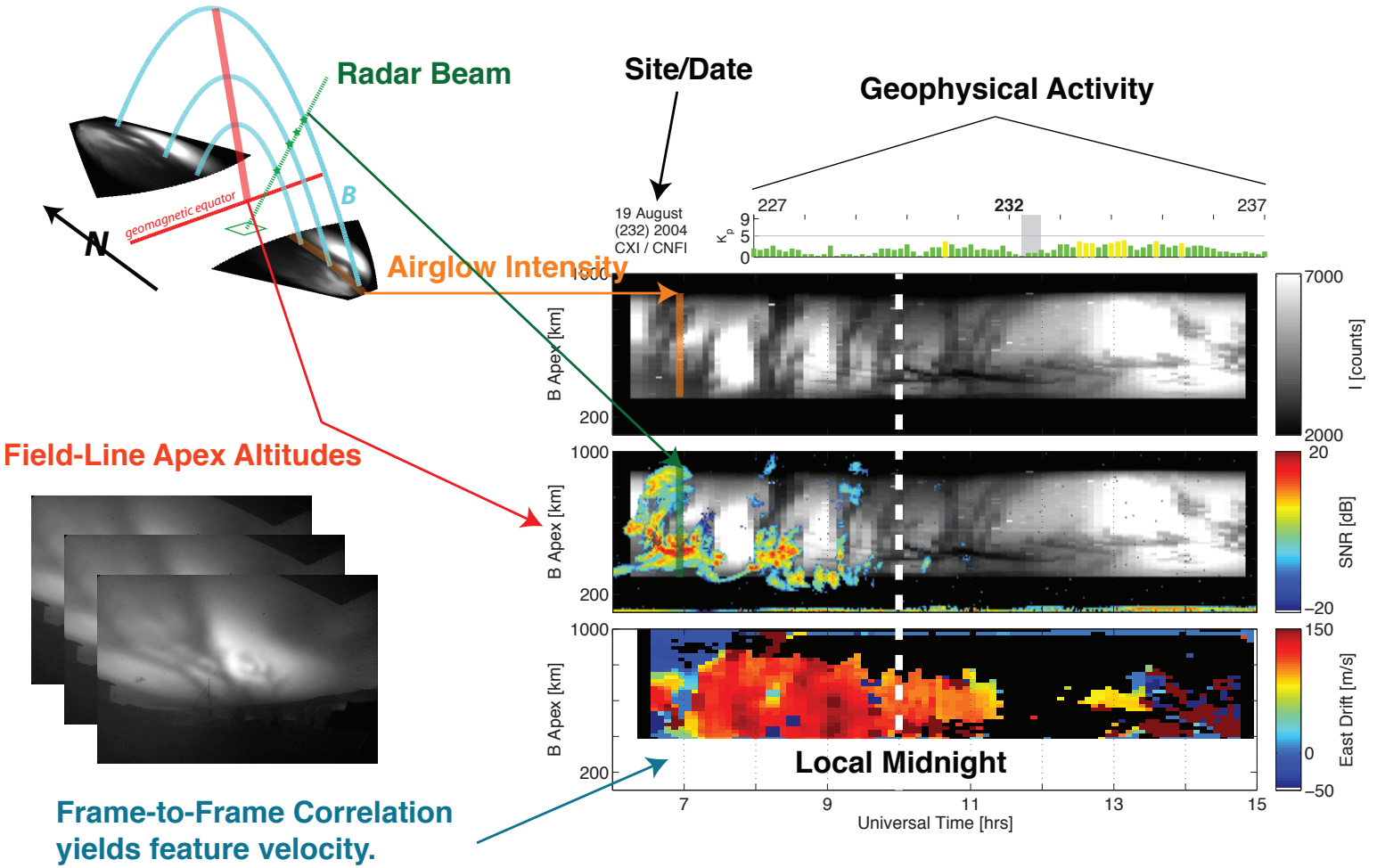
19 August (232) 2004 CXI/CNFI



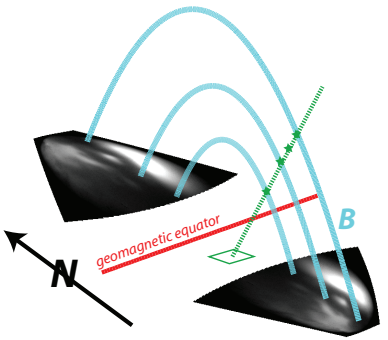


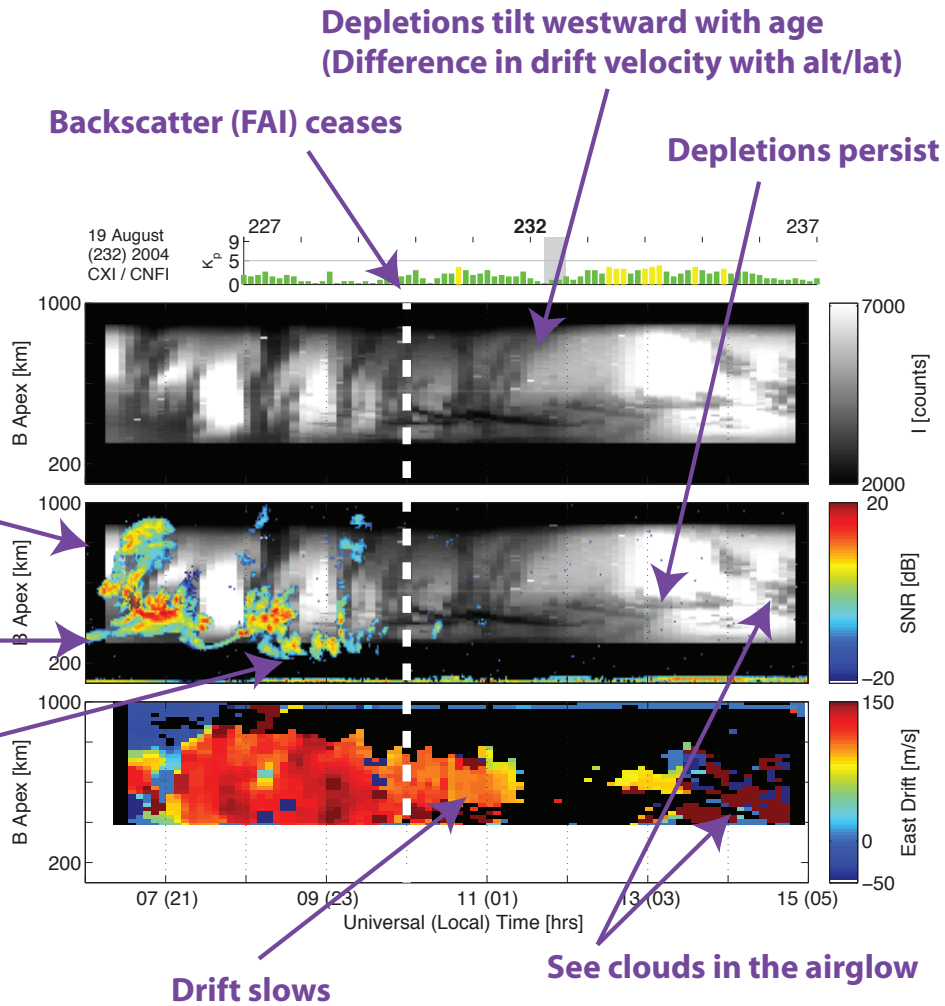
From *Yeh and Liu*, 1982.

Occurrence (Day-to-Day)

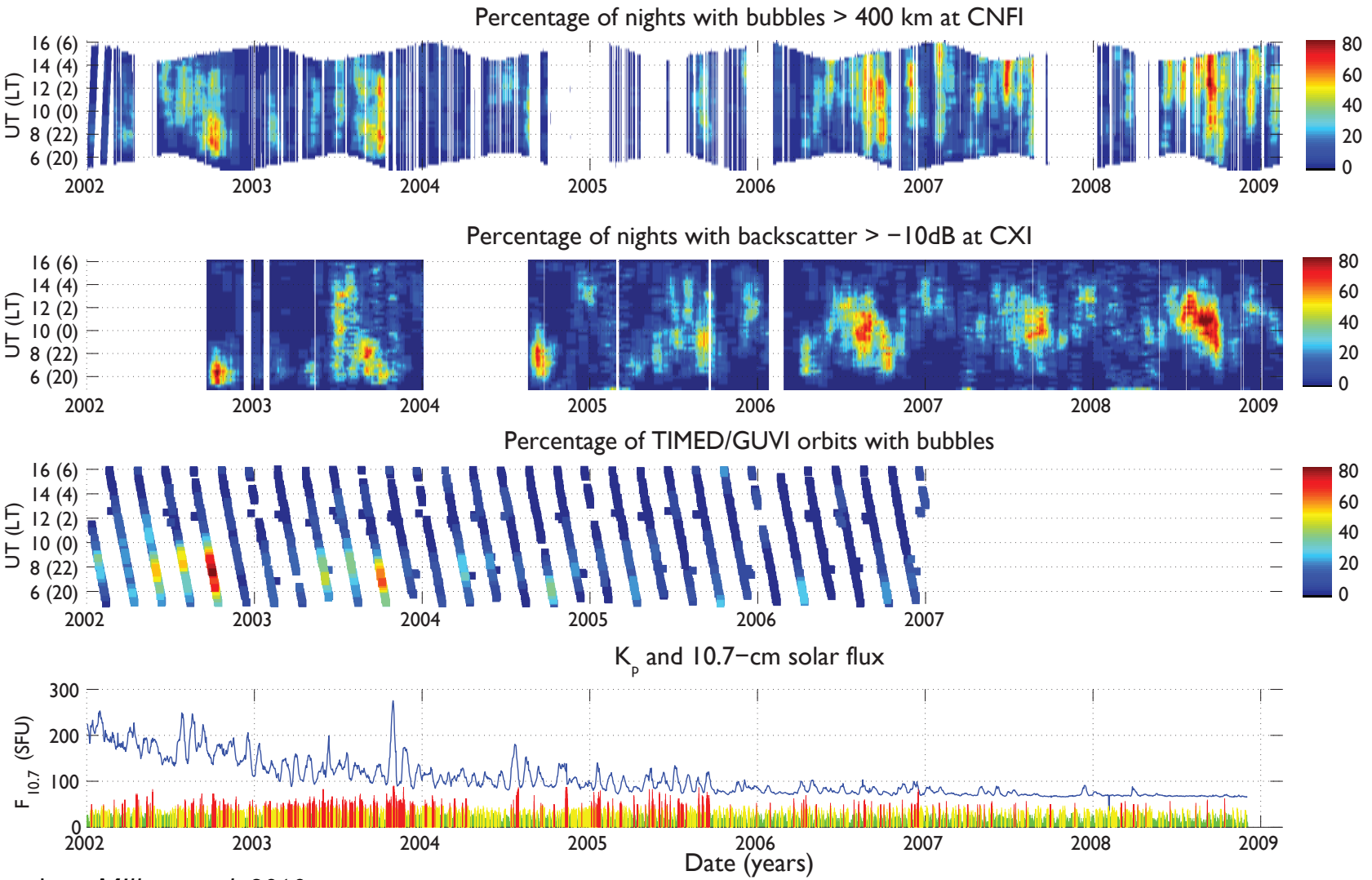


Occurrence (Day-to-Day)



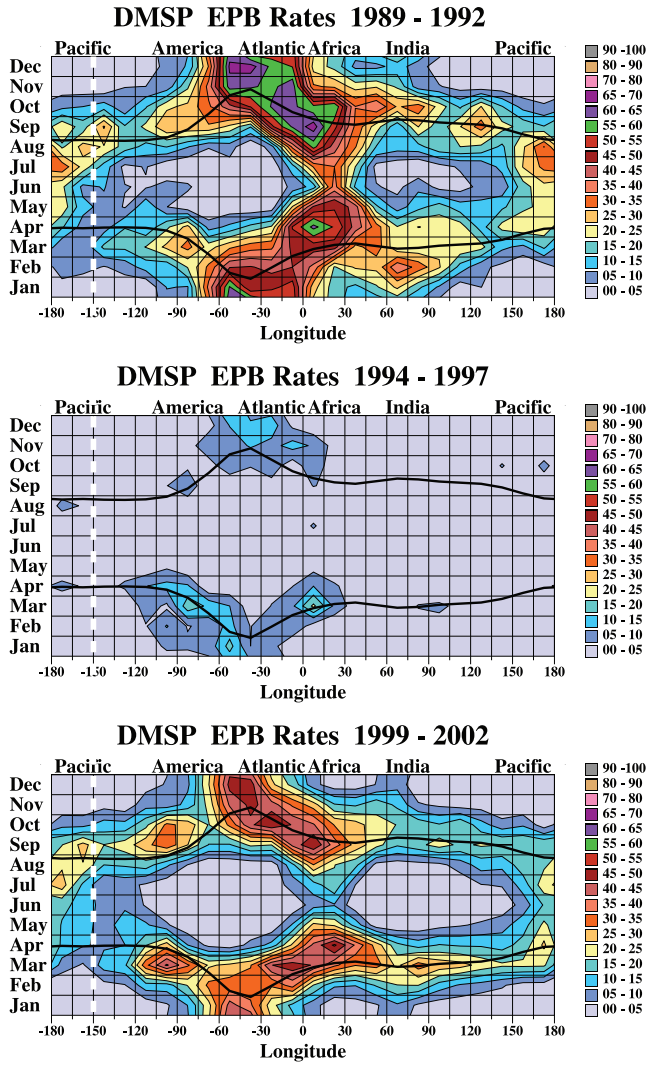


Occurrence (Local)



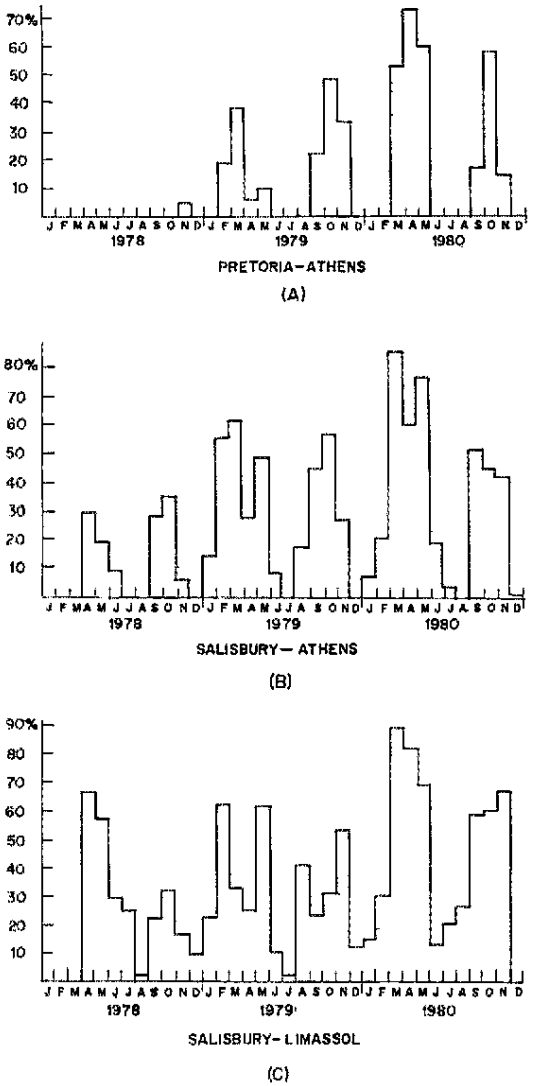
based on *Miller, et al*, 2010.

Occurrence (Global/Local)



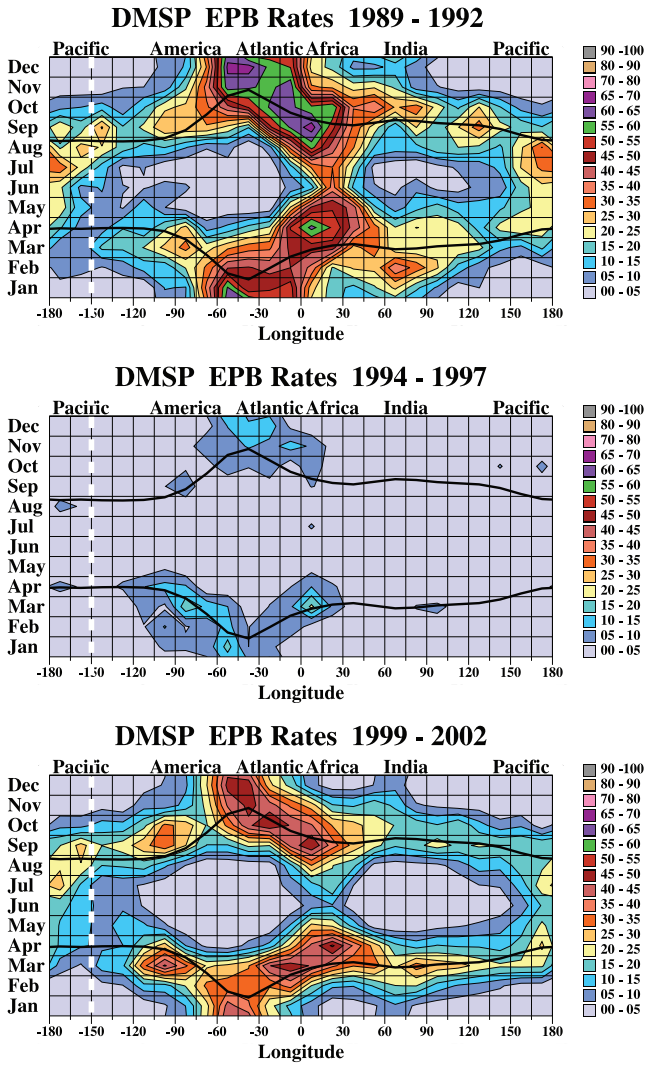
From *Gentile, et al*, 2006.

African TE Propagation Rates 1978–1980



from *Cracknell, et al*, 1981 (Nov 1981 *QST*, reproduced with permission of ARRL).

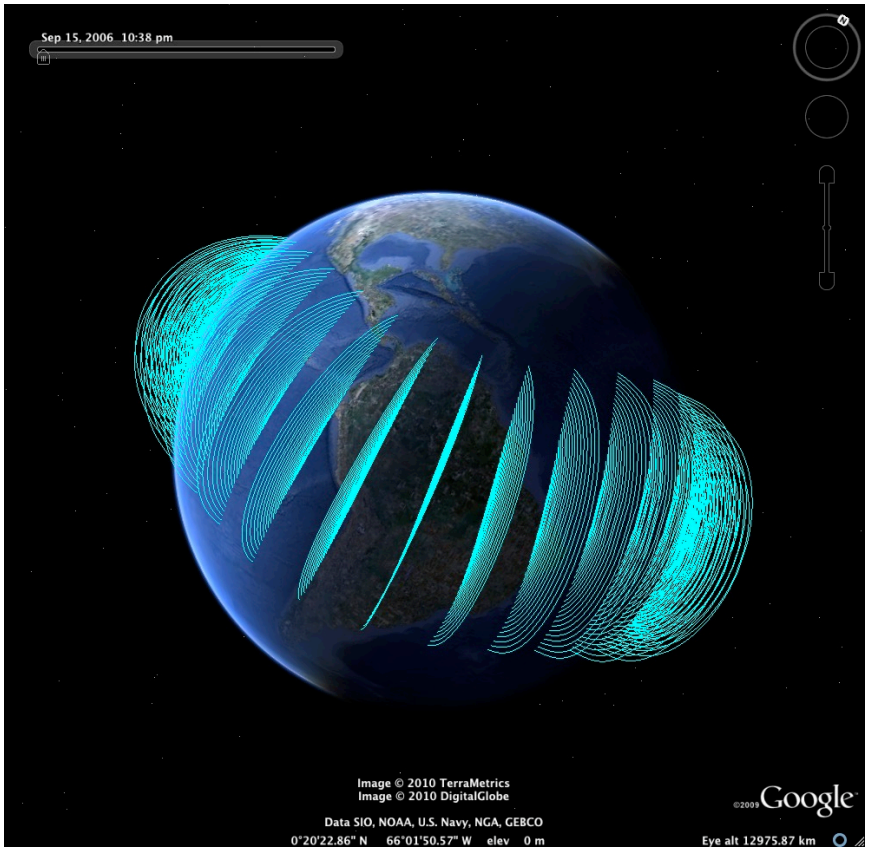
Occurrence (Global)

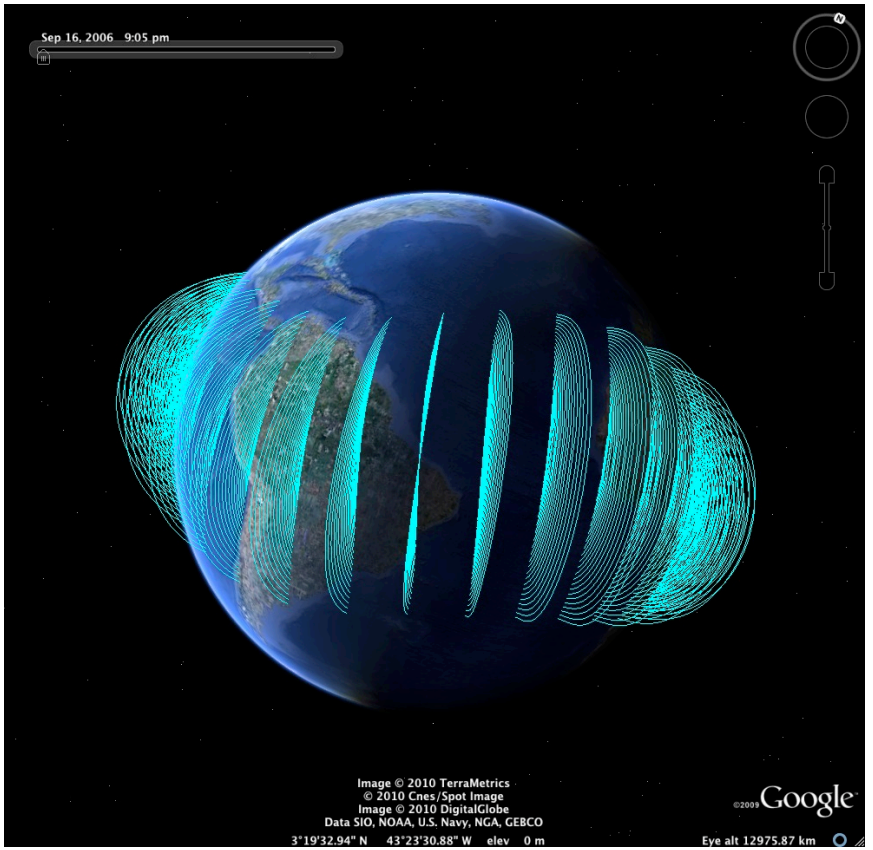


From *Gentile, et al*, 2006.

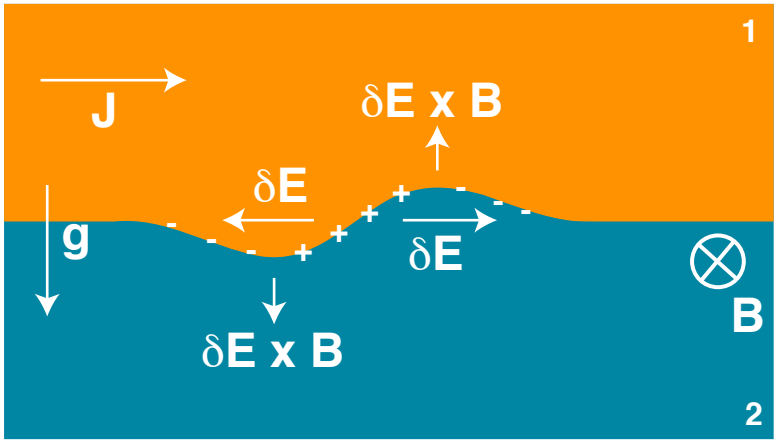
- Differences? Similarities? DMSP surveys...
  - a narrow window of times (18–22 LT, most at 20 LT).
  - bubbles that reach the 840-km orbit altitude.
- Considerable coincidence to terminator "locus of meridionallity." (*Tsunoda*, 1985)

Physical Explanations: Dynamo Transition



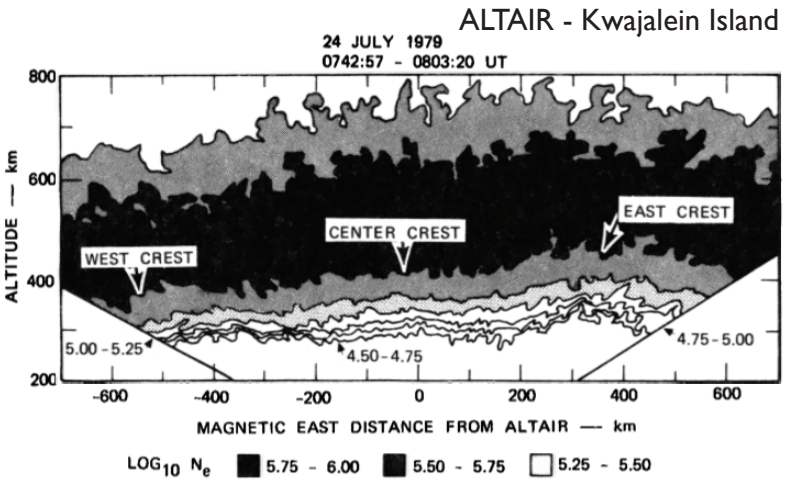


Physical Explanations: Instabilities

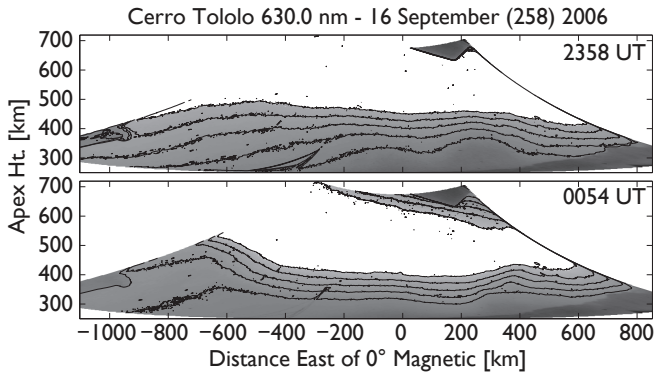


- Interchange ("Rayleigh-Taylor") instability $\longrightarrow$ widely understood to be responsible for the largest-scale (larger than $\sim$ 10s–100s m) irregularities.
- Irregularities responsible for VHF backscatter are likely due to a different instability process that is pumped/driven by the interchange instability, neutral wind, or both.

Physical Explanations: Precursors



From *Tsunoda and White*, 1981 (Used with permission of AGU).

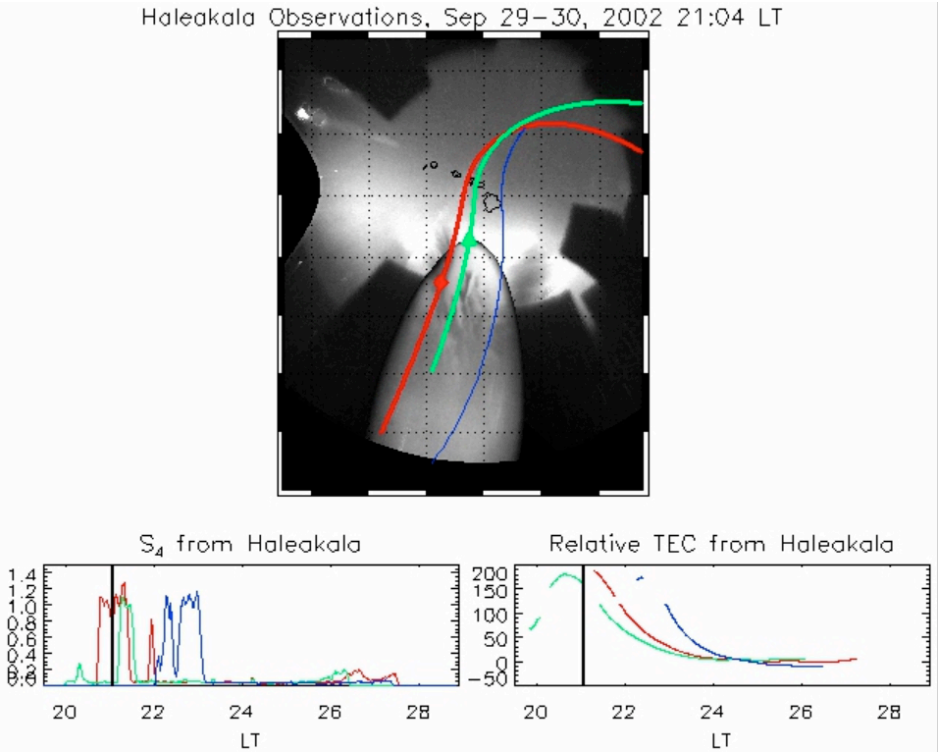


After *Makela and Miller*, 2008.

- Large-Scale Wave Structure (visible in ISR and imaging); relation to PRE?
- Bottom-type layers $\longrightarrow$ patchy irregularities that grow within LSWS/PRE structure
- Depletions always grow out of crests; crests do not always produce depletions

Practical Consquences

- Time transfer and timing on trans-ionospheric radio circuits (e.g., Global Navigational Satellite Systems (GNSS)).
- Loss of lock on coded/spread communication links.

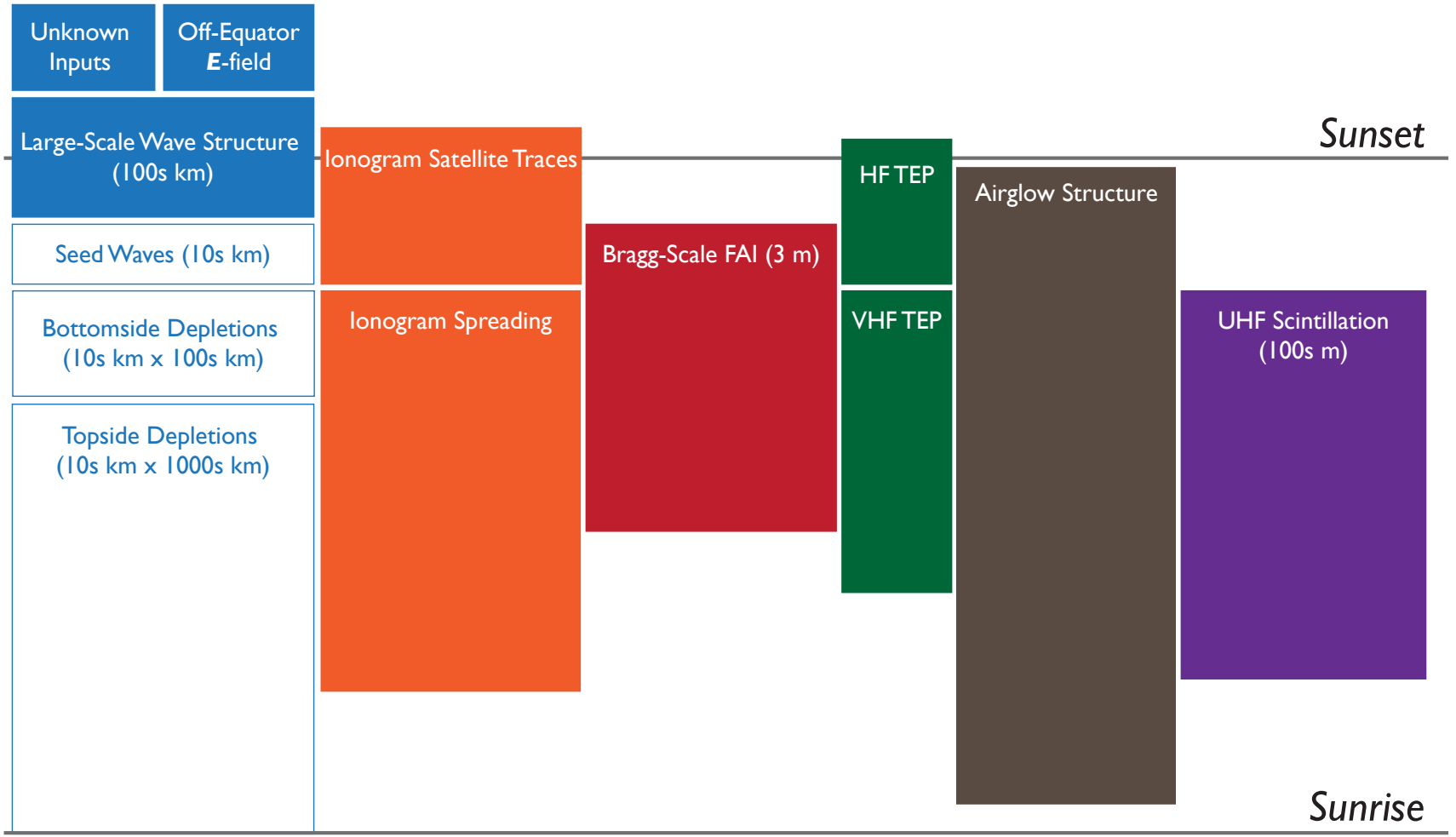


(Show movie from Jonathan.)

Open Questions

- Role of neutral dynamics in seeding.
  - Neutral wind.
  - Gravity wave sources.
- Role of E-region density in seeding $\longrightarrow$ hard to observe.
- Distribution of irregularities by scale and location.
- Conjugacy (**E**-field mapping).
- Forecasting.

Conclusions



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- César Valladares at BC/ISR: SCINDA Data.
- Warner Ecklund, Roland Tsunoda at SRI, and Keith Groves at AFRL: Christmas Island Data.
- Ionograms from Lowell DIDbase.

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