F-region vertical drifts and equatorial spread F: An investigation combining ground-based radar observations and *in-situ* satellite measurements

F. S. Rodrigues and J. M. Smith
The University of Texas at Dallas, Richardson, TX, US

E. R. de Paula
Instituto Nacional de Pesquisas Espaciais – INPE, Sao Jose Campos, Brazil

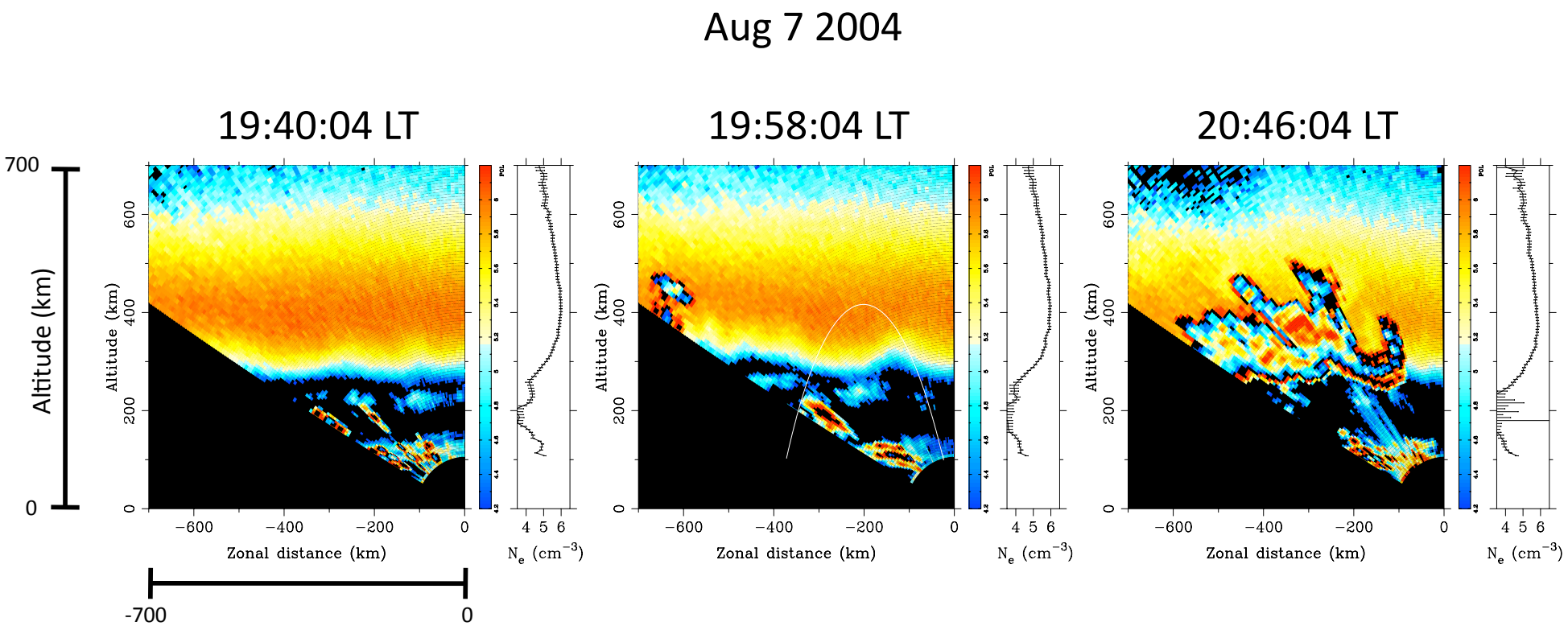
Acknowledgments

- The UT Dallas Coupled Ion-Neutral Dynamics Investigation (CINDI) Team for making ion drift measurements available.

- The Sao Luis Observatory (INPE) technical staff for radar operation and data management.

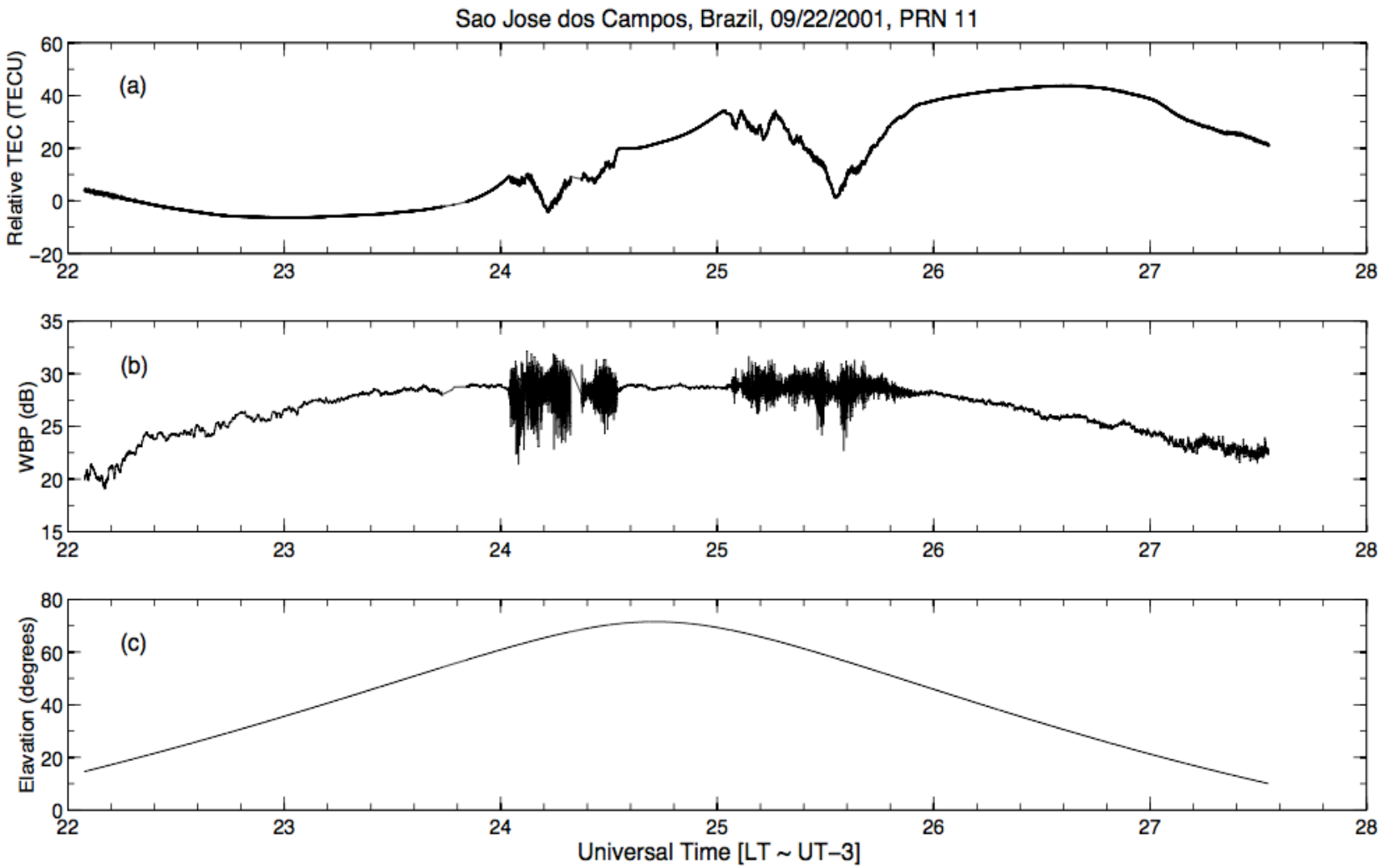
Equatorial Spread F (ESF)

- Equatorial spread F refers to signatures of ionospheric F-region electron density irregularities.



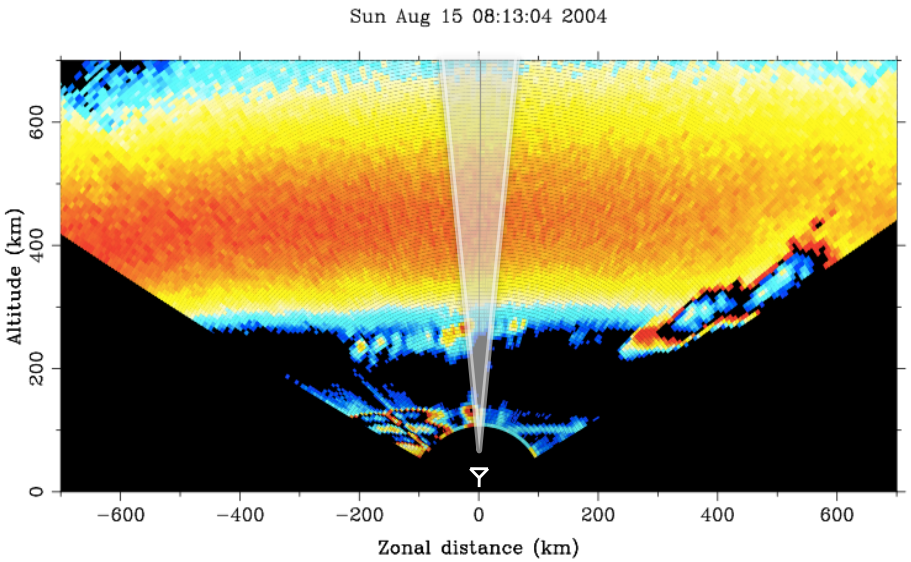
Hysell *et al.* (2005)

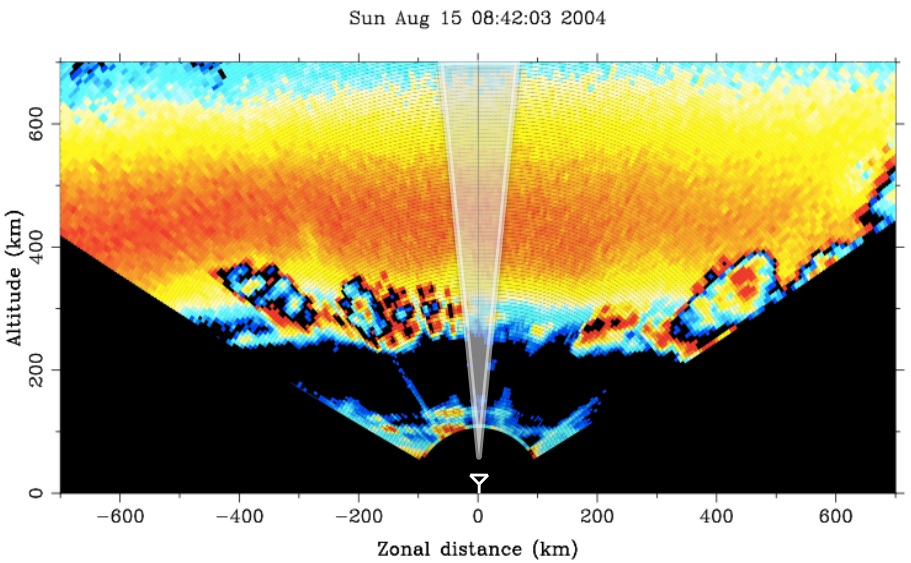
Equatorial Spread F (ESF)



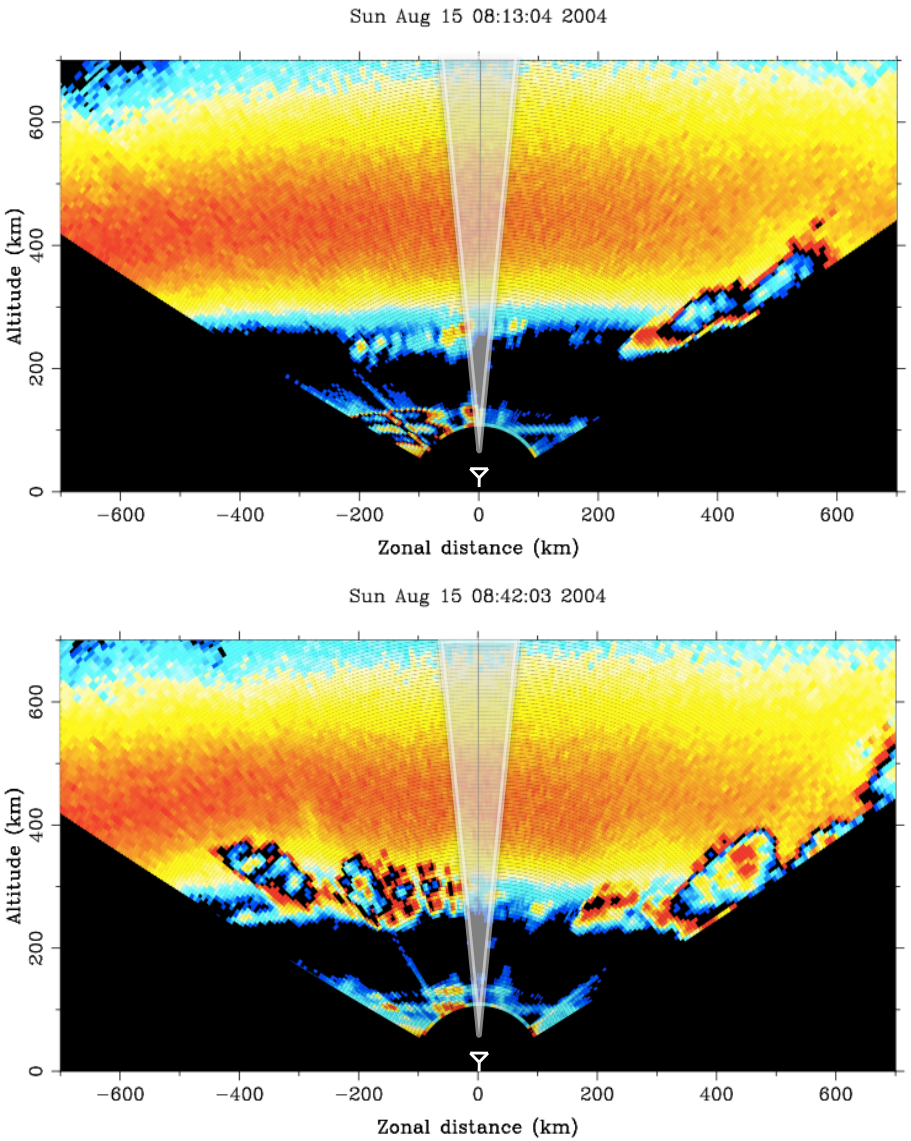
Rodrigues (2008)

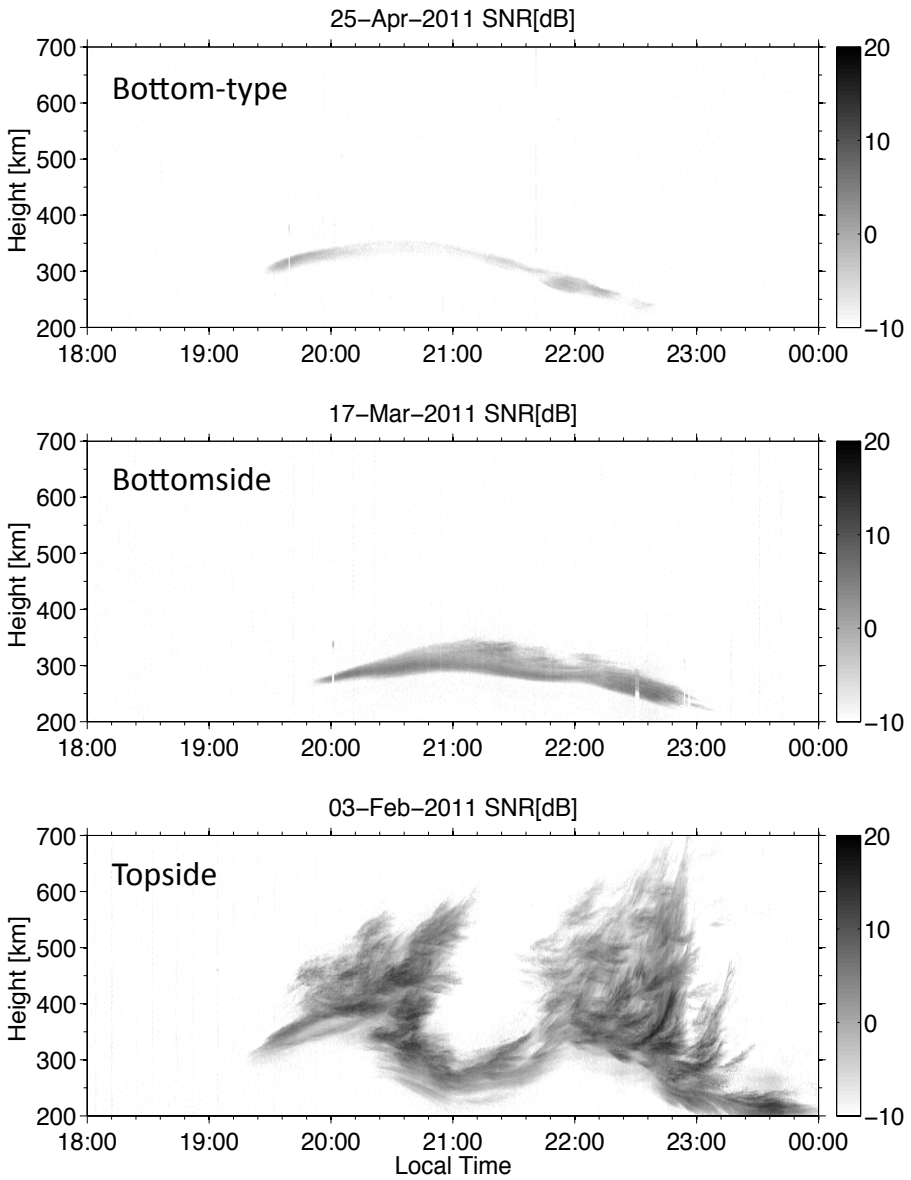
ESF: RTI signatures





ESF: RTI signatures





ESF and vertical plasma drifts

- The magnitude of the PRE is often suggested to be a good indicator of ESF development (e.g. Fejer et al., 1999 and many others)

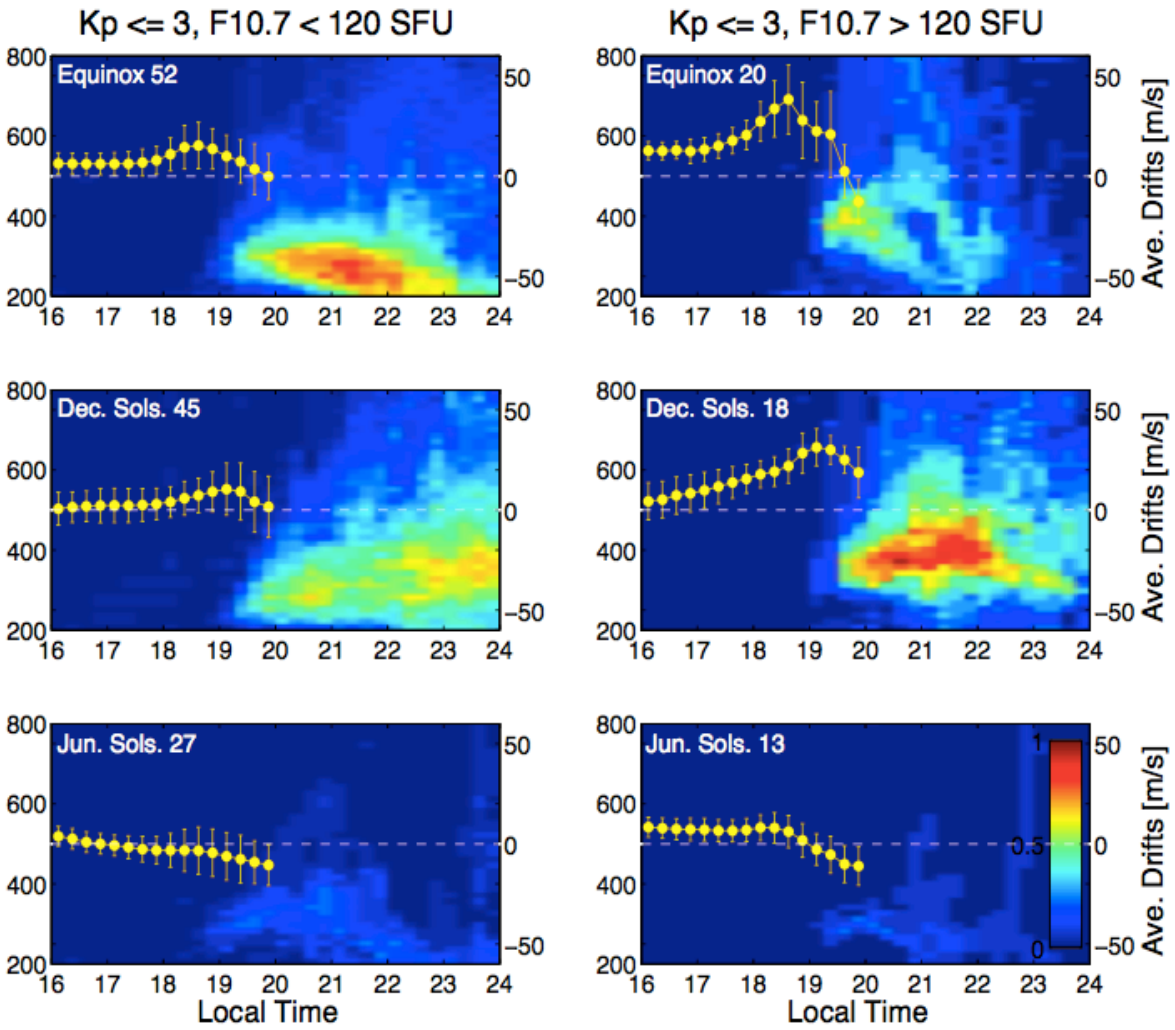
- Local growth rate ionospheric Rayleigh-Taylor instability:

$$\gamma = \frac{1}{n_0}\frac{dn}{dz}\left[\frac{g}{\nu_{in}} + \frac{E}{B} - U_v + \frac{\nu_{in}}{\Omega_i}U_z\right]$$

Basu (2002)

ESF and vertical plasma drifts

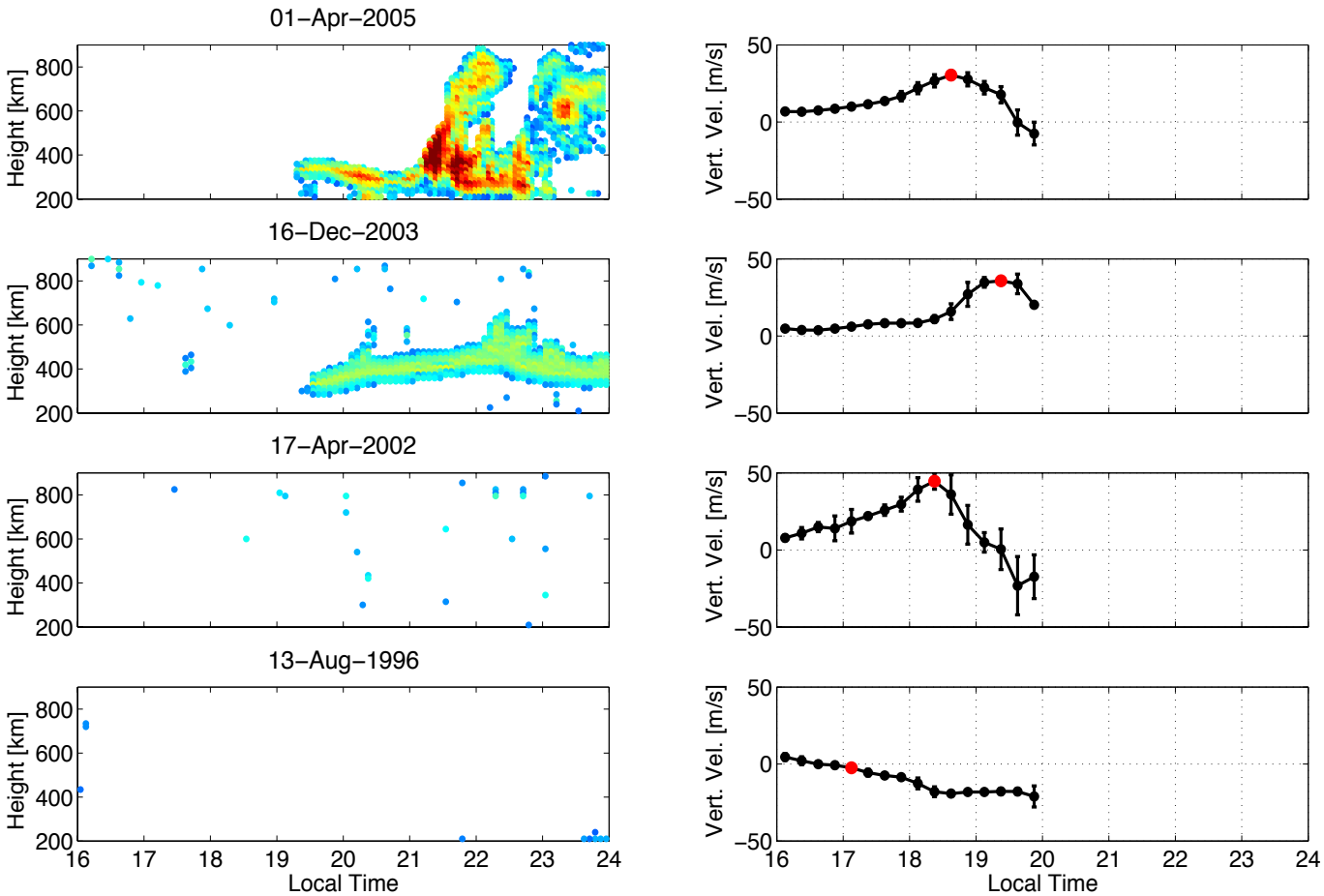
- The magnitude of the PRE is often suggested to be a good indicator of ESF development (e.g. Fejer et al., 1999 and many others)



Smith *et al.* (2014)

ESF and vertical plasma drifts

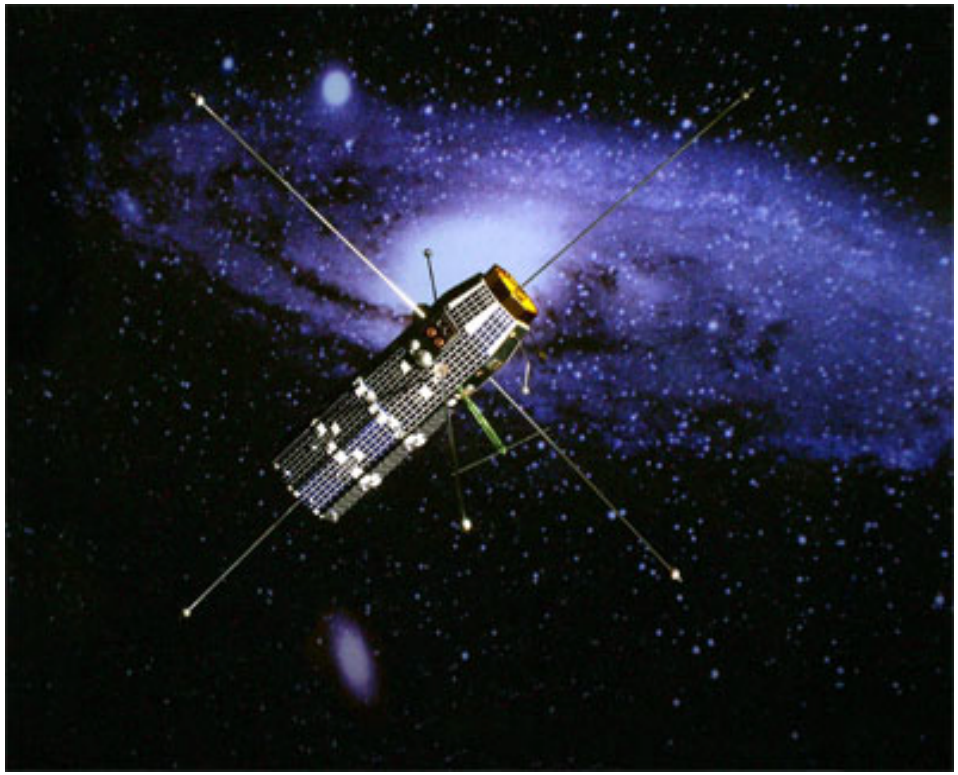
- The magnitude of the PRE is often suggested to be a good indicator of ESF development (e.g. Fejer et al., 1999 and many others)



Smith *et al.* (2014)

Global drift measurements

- USAF C/NOFS Mission

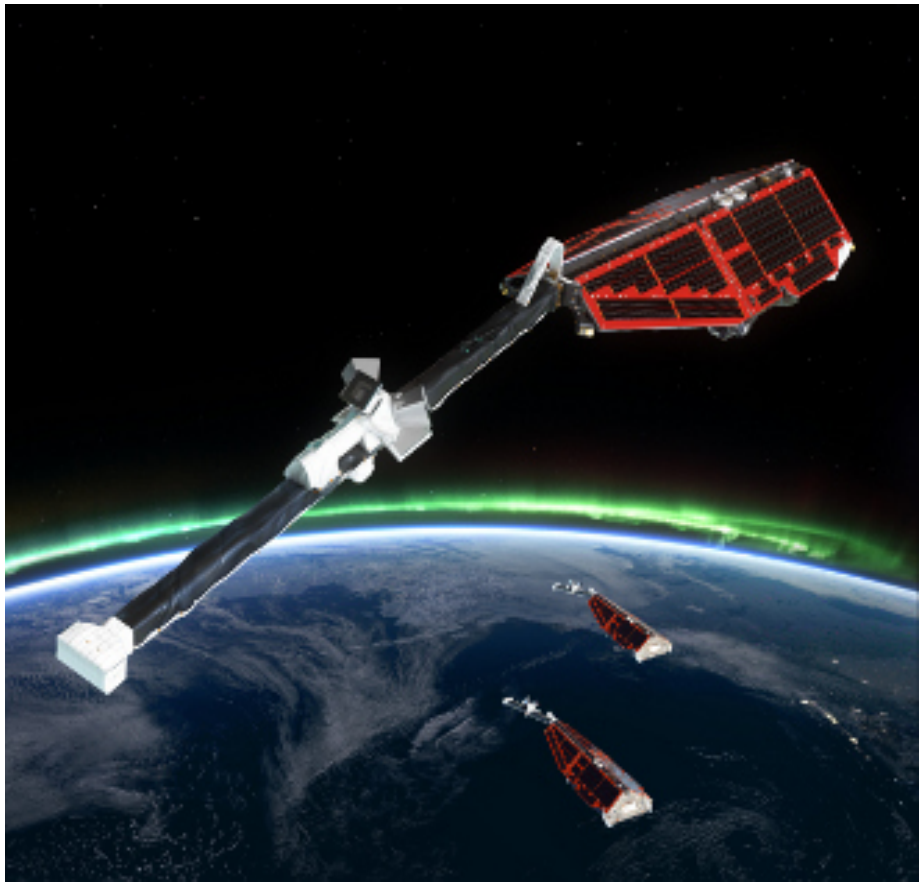


- Single satellite
- Launched in April 2008
- 13^{o} inclination
- Elliptical orbit @ 400/850km
- Instruments:

  - Ion velocity meter
  - Neutral wind meter
  - Vector electric field instrument
  - Planar Langmuir probe
  - CORISS
  - CERTO

Global drift measurements

- ESA Swarm Mission

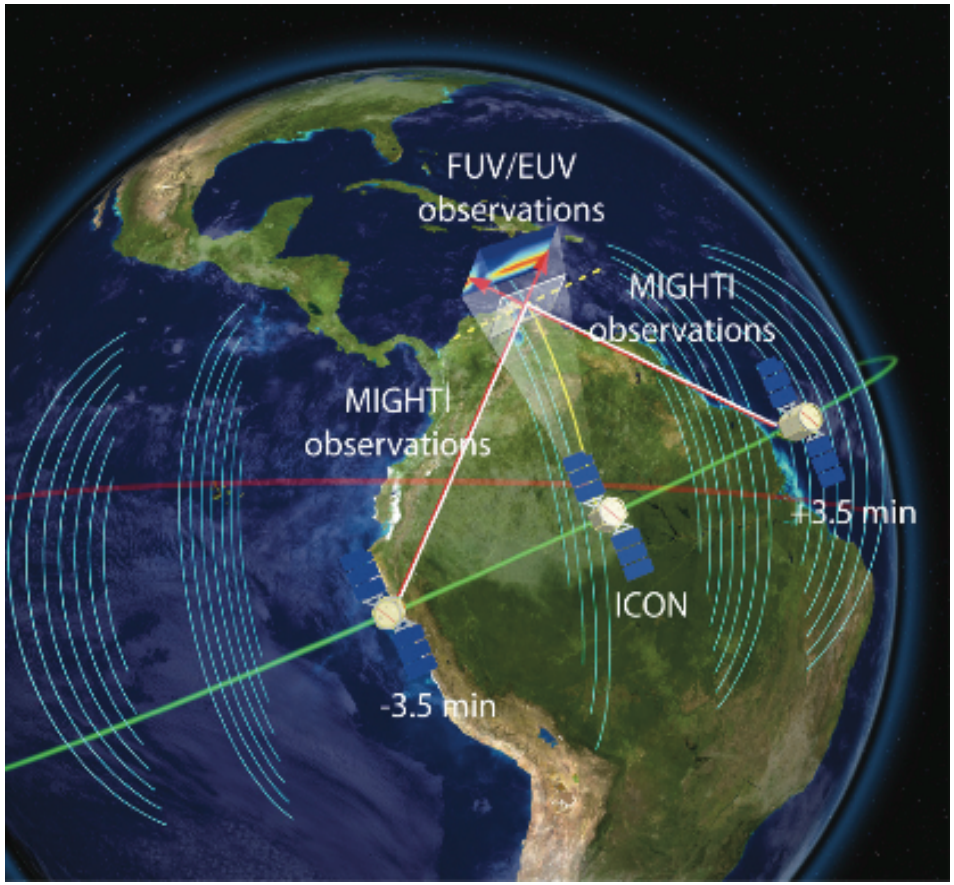


- 3 Satellites
- Launched in Nov. 2013
- 2@450 km and 1@550 km
- 550 km polar orbit
- Instruments:

  - Electric Field Instrument
  - Vector Field Magnetometer
  - Absolute Scalar Magnetometer
  - Accelerometer
  - Laser Range Reflector

Global drift measurements

- NASA Ionospheric COnnection Explorer (ICON)



- Single satellite
- 550 km circular orbit
- 27^{o} inclination
- Launch: Nov. 2016
- Instruments:

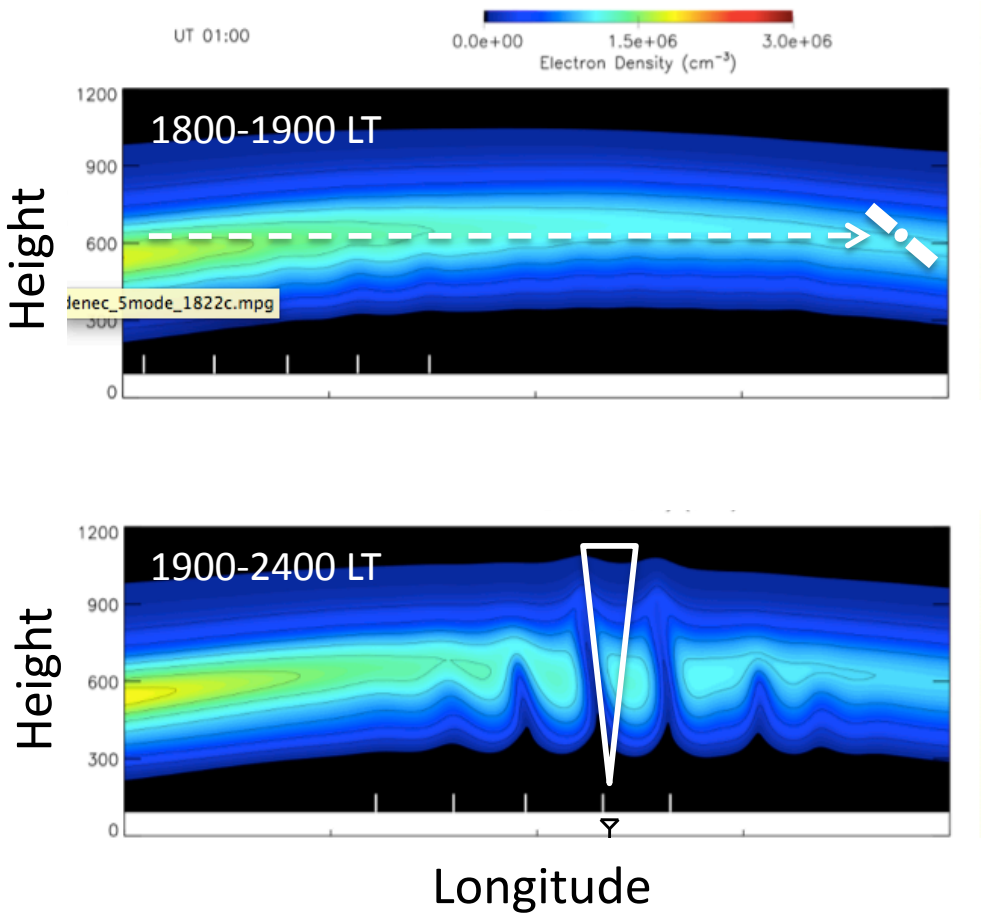
  - Ion Velocity Meter
  - Michelson interferometer (winds)
  - FUV (ion density)
  - FUV (O/N_2 ratio)

This work

- Results of an investigation about evening vertical drifts provided by a space-based platform and ESF (topside) occurrence detected by a ground-based station.

- Can *in-situ* measurements provide an useful proxy for ESF development?

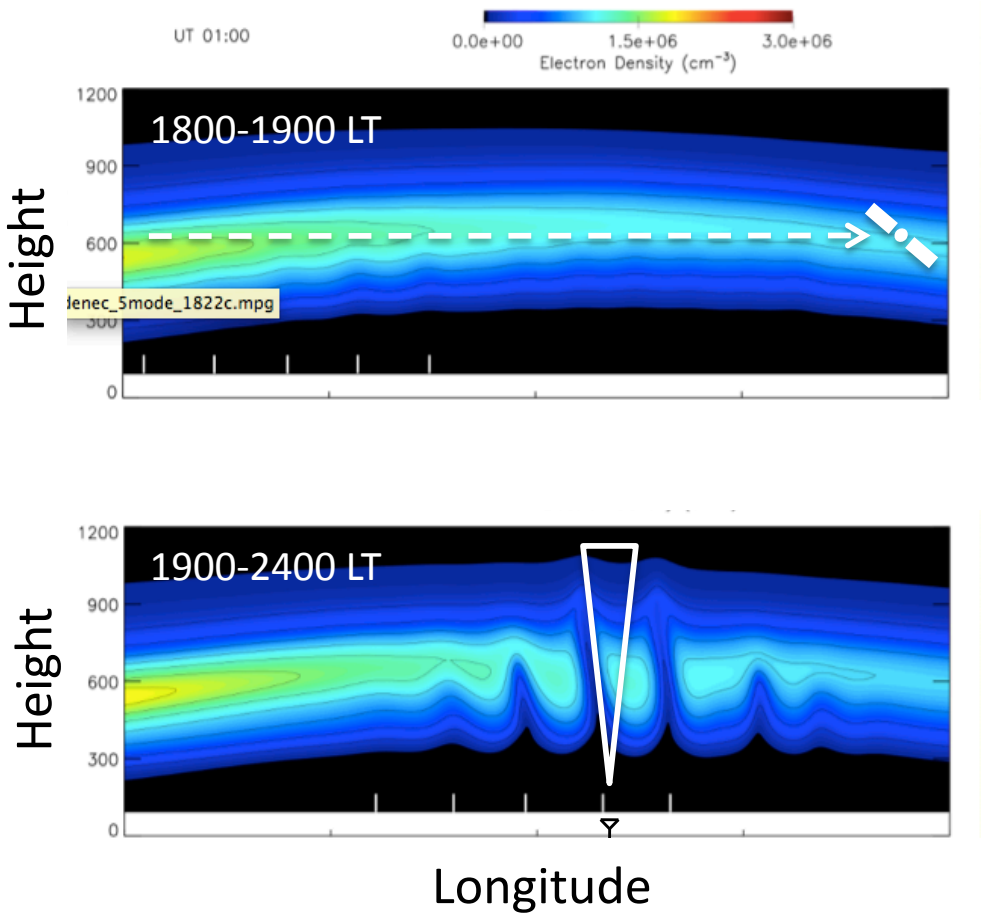
Approach



- Space segment would provide vertical drifts
- Ground segment would provide metrics of ESF occurrence and morphology

SAMI3, Huba *et al.*

Challenges



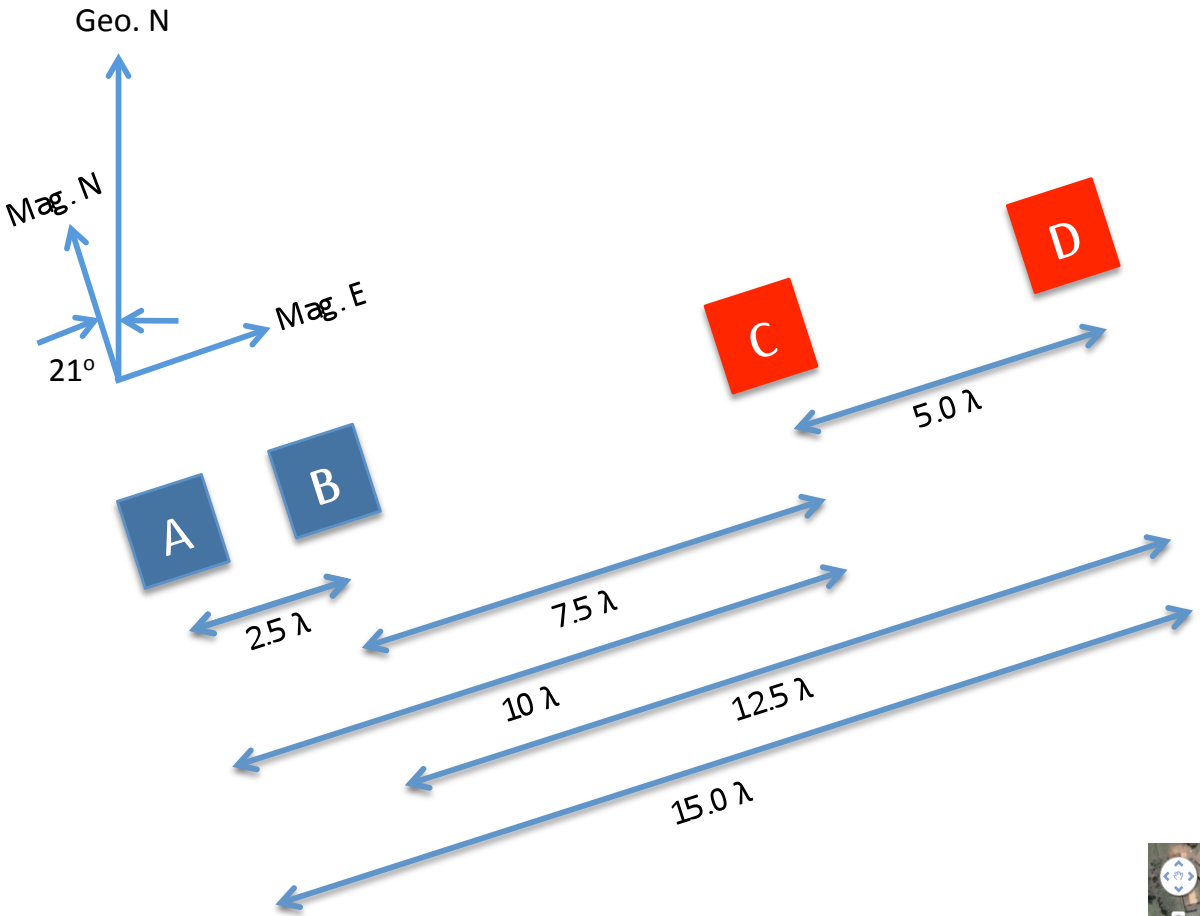
- Accuracy of drift measurements
- Altitude of the *in-situ* measurements
- Temporal resolution of space measurements
- Limited number of collocated observations

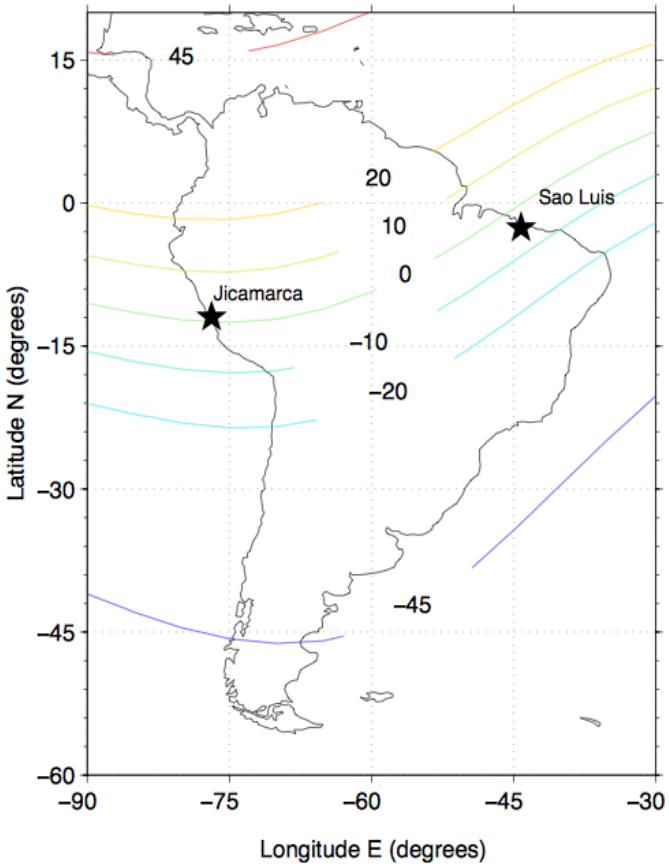
SAMI3, Huba *et al.*

Instrumentation and data

- Ground-based segment: The Sao Luis radar
- Space-based segment: Communication/Navigation Outage Forecasting System (C/NOFS)
- Complementary: Scherliess & Fejer (1999) empirical drift model

[1] Sao Luis 30 MHz radar interferometer





[1] Sao Luis 30 MHz radar interferometer

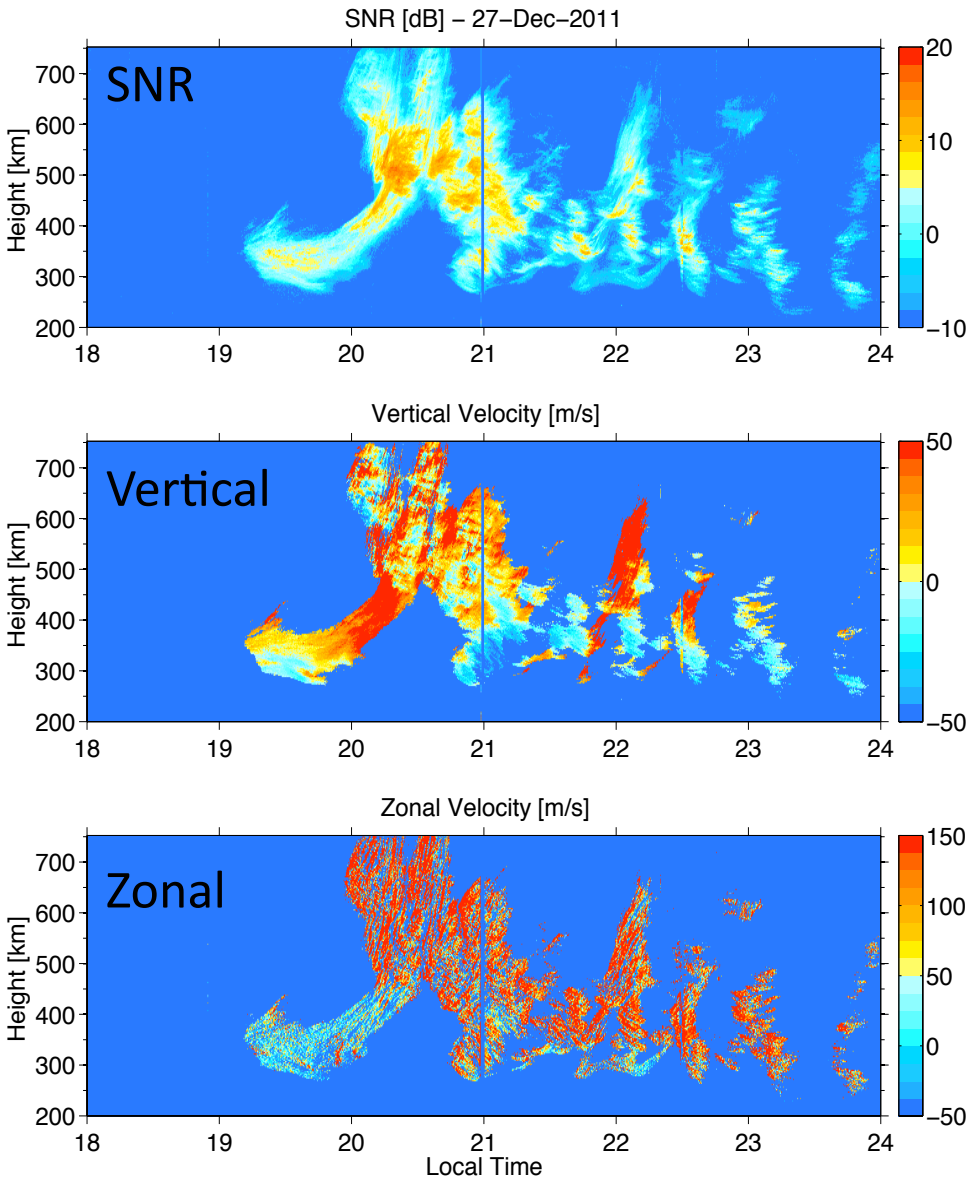
	F-region*	
Peak power	8 kW	- Uses both 4kW RX
Code length	28 bauds	- Coded pulse
Baud length	2.5 km	- 2.5 km height resolution
IPP	1400 km	- ±270 m/s un-aliased Doppler
Initial sampling height	200 km	
Number of samples	250	- Sounding up to 750 km

*Typical configuration

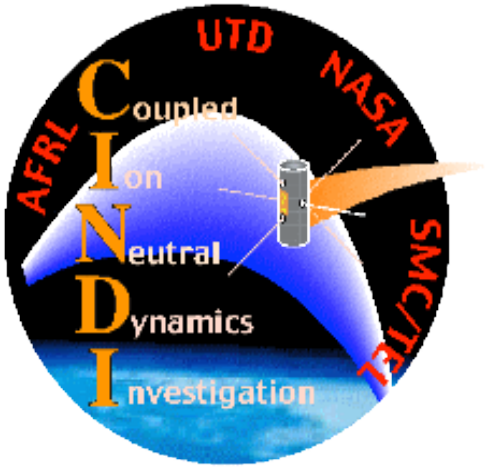
- Processing follows Jicamarca's JULIA procedure:

  - SNR and Doppler (vert.) velocity from ACF
  - Phase (and zonal vel.) from complex XCF (antennas 1 and 2)

[1] Sao Luis 30 MHz radar interferometer

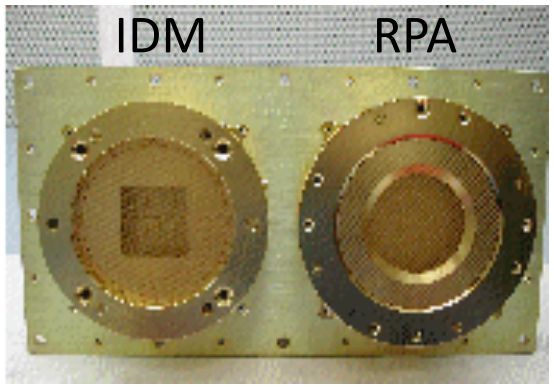


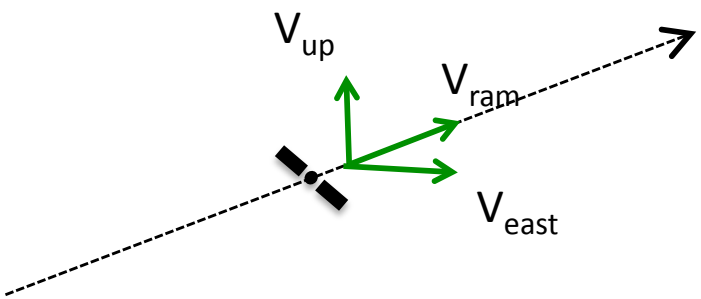
[2] C/NOFS ion drift measurements

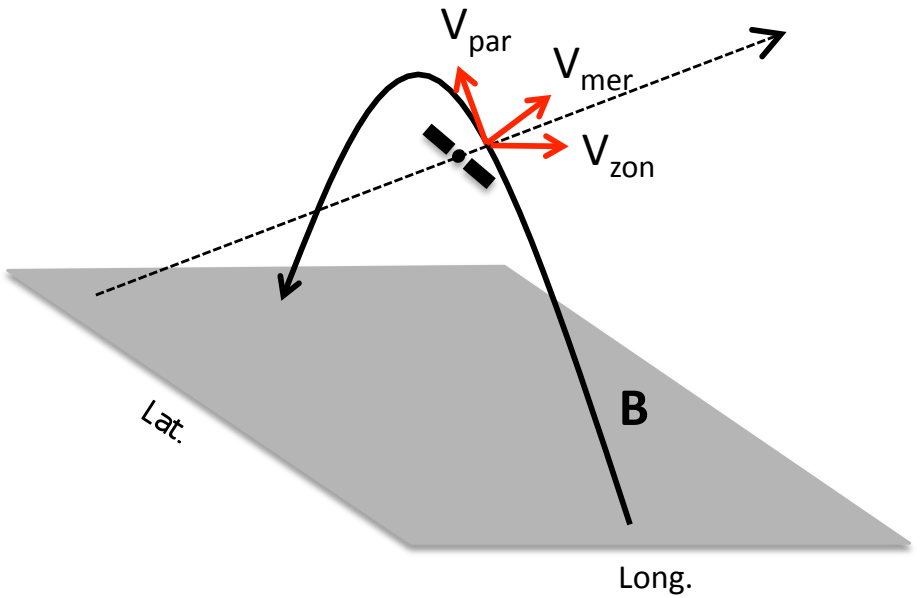


Ion Velocity Meter (IVM):

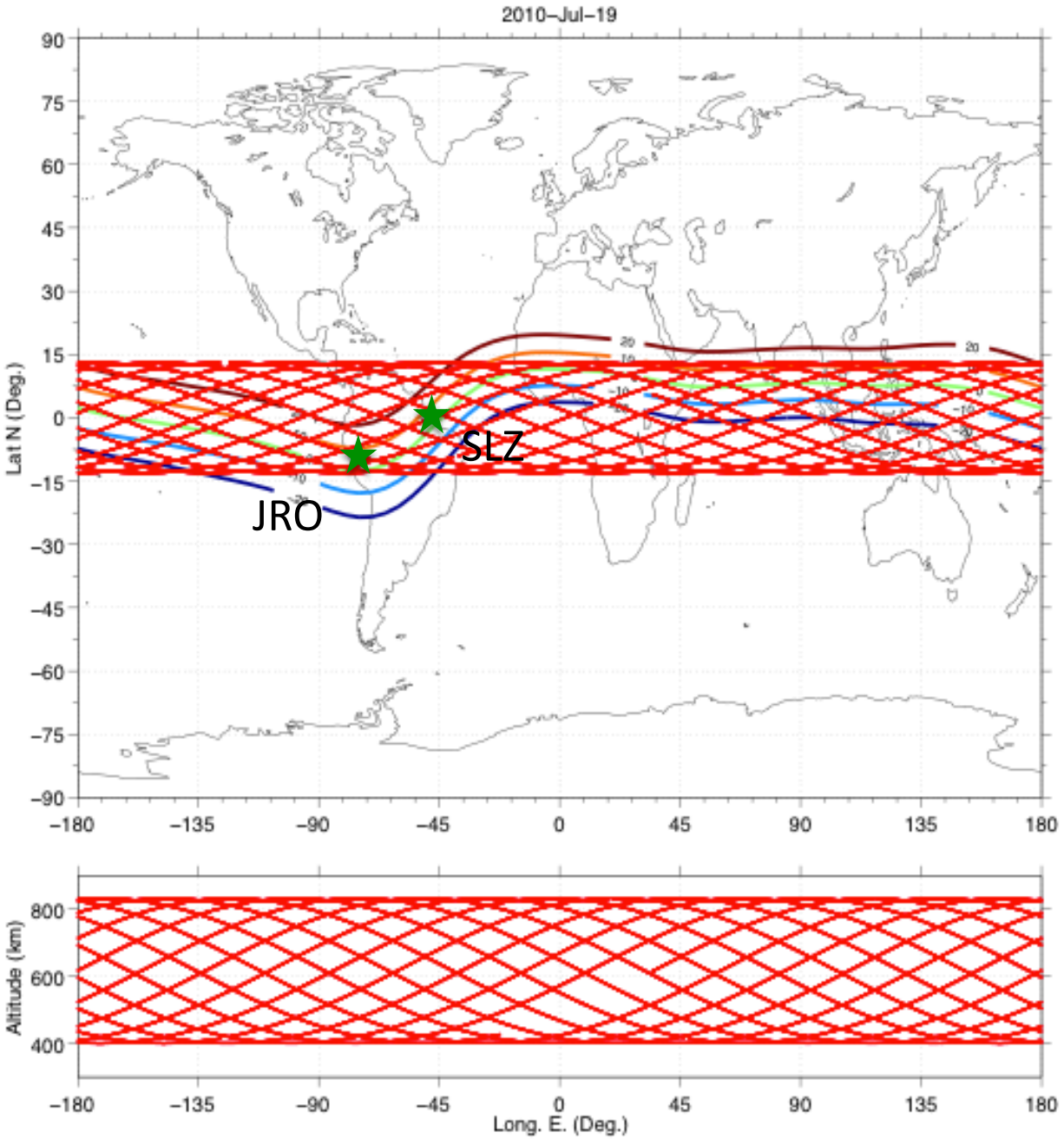
RPA: Ram direction velocity component
IDM: Transverse velocity components







[2] C/NOFS ion drift measurements



[3] Scherliess and Fejer (1999) Drift Model

- Global, empirical model of equatorial vertical drifts
- 1968-1992 Jicamarca ISR measurements
- Augmented with 1977-1979 AE-E measurements
- Drifts are described by 4^{th} order cubic splines
- Function of LT, DOY and F10.7

Analysis

- Radar and IVM measurements between July 2010 and June 2012

- Monthly analysis:
  - Only quiet-time measurements (Kp ≤ 3)
  - Drift measurements within ±15^{o} apex longitude from Sao Luis and ±10^{o} magnetic inclination
  - Drifts measurements below 600 km

- Day-to-day analysis:
  - Only quiet-time measurements (Kp ≤ 3)
  - Only pre-midnight topside (>400 km) echoes (>0 dB)

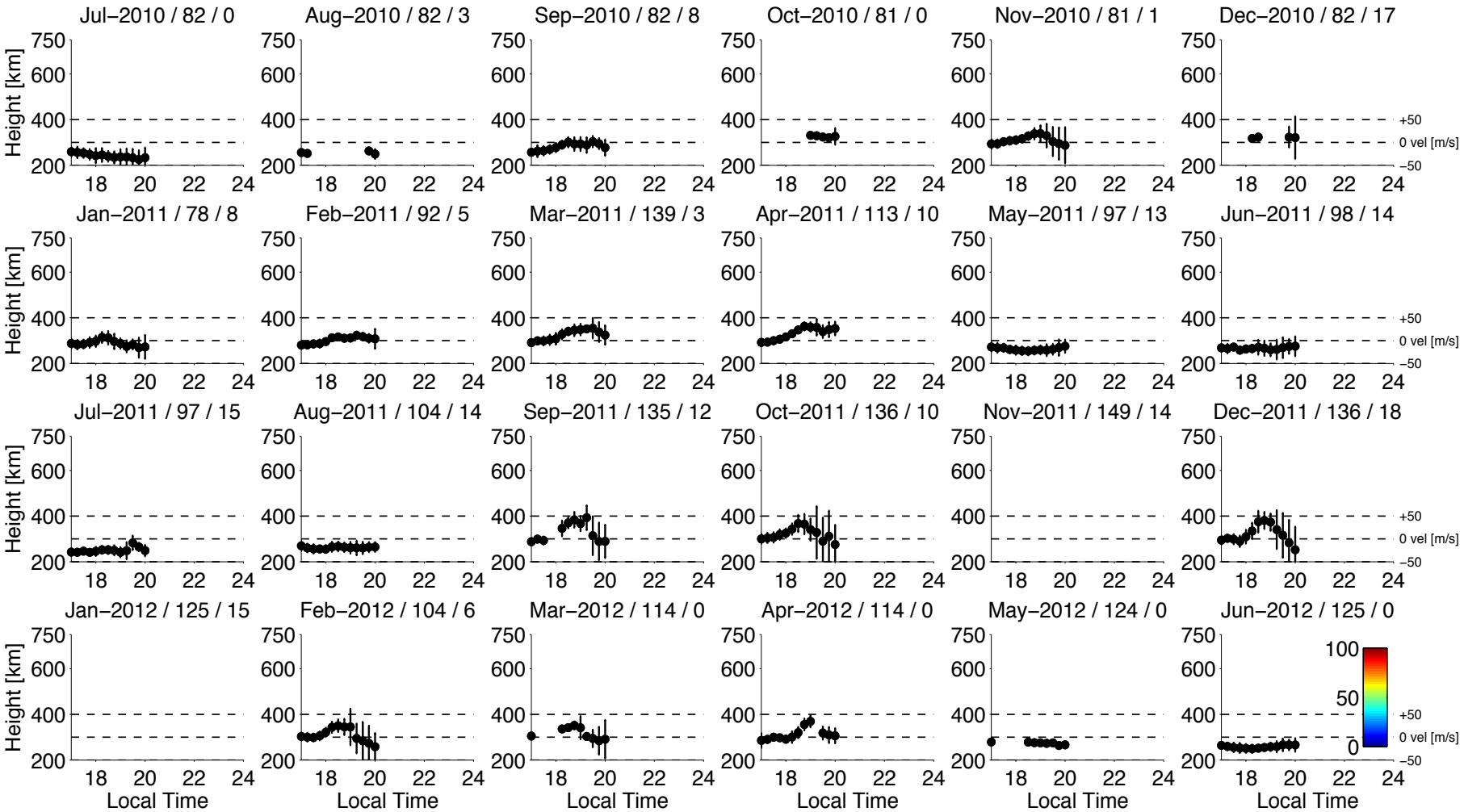
Results and Discussion

- Monthly variability

- Day-to-day variability

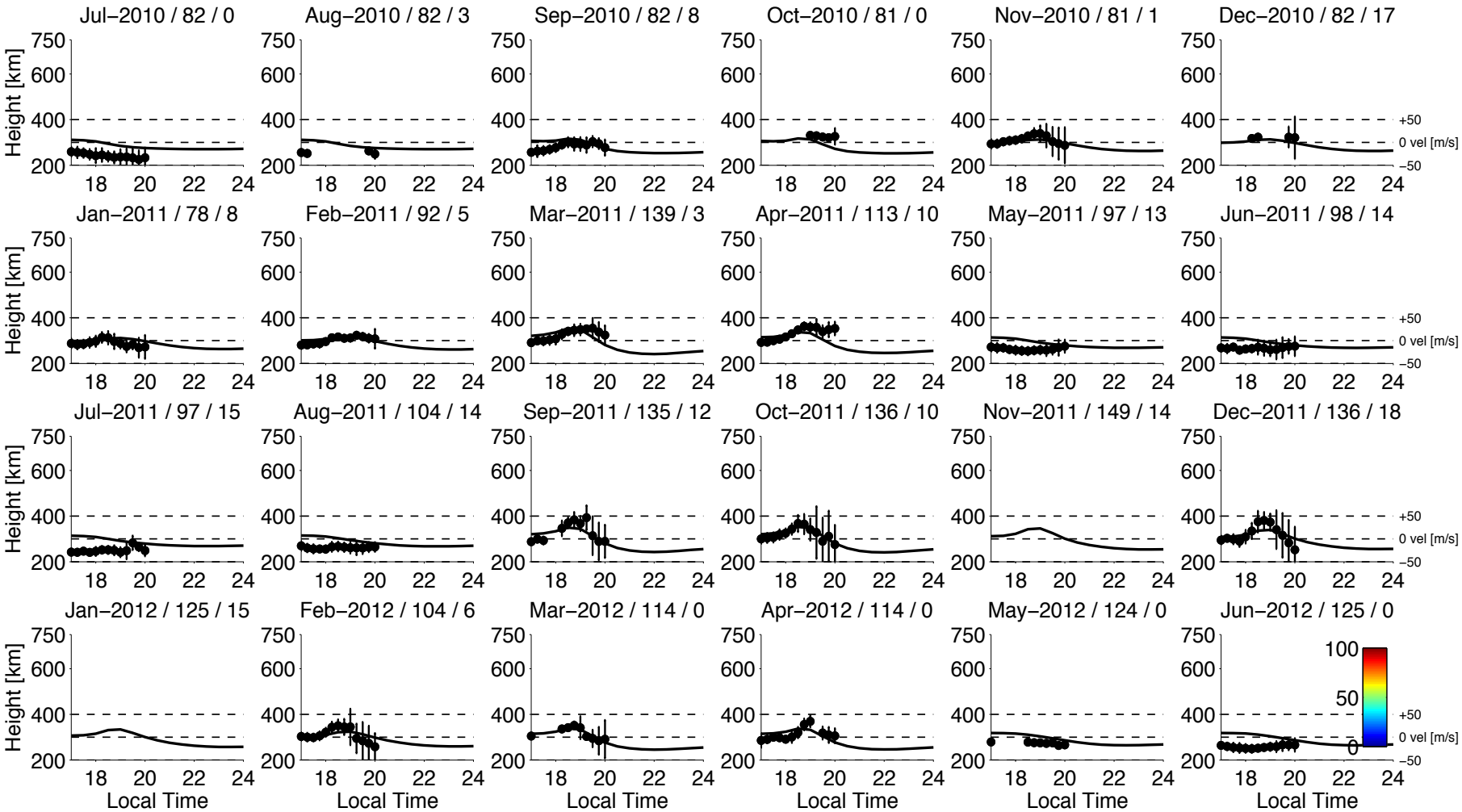
Results: Monthly variability

- Capable of reproducing PRE despite only 1 month of data
- PRE observed during ESF months



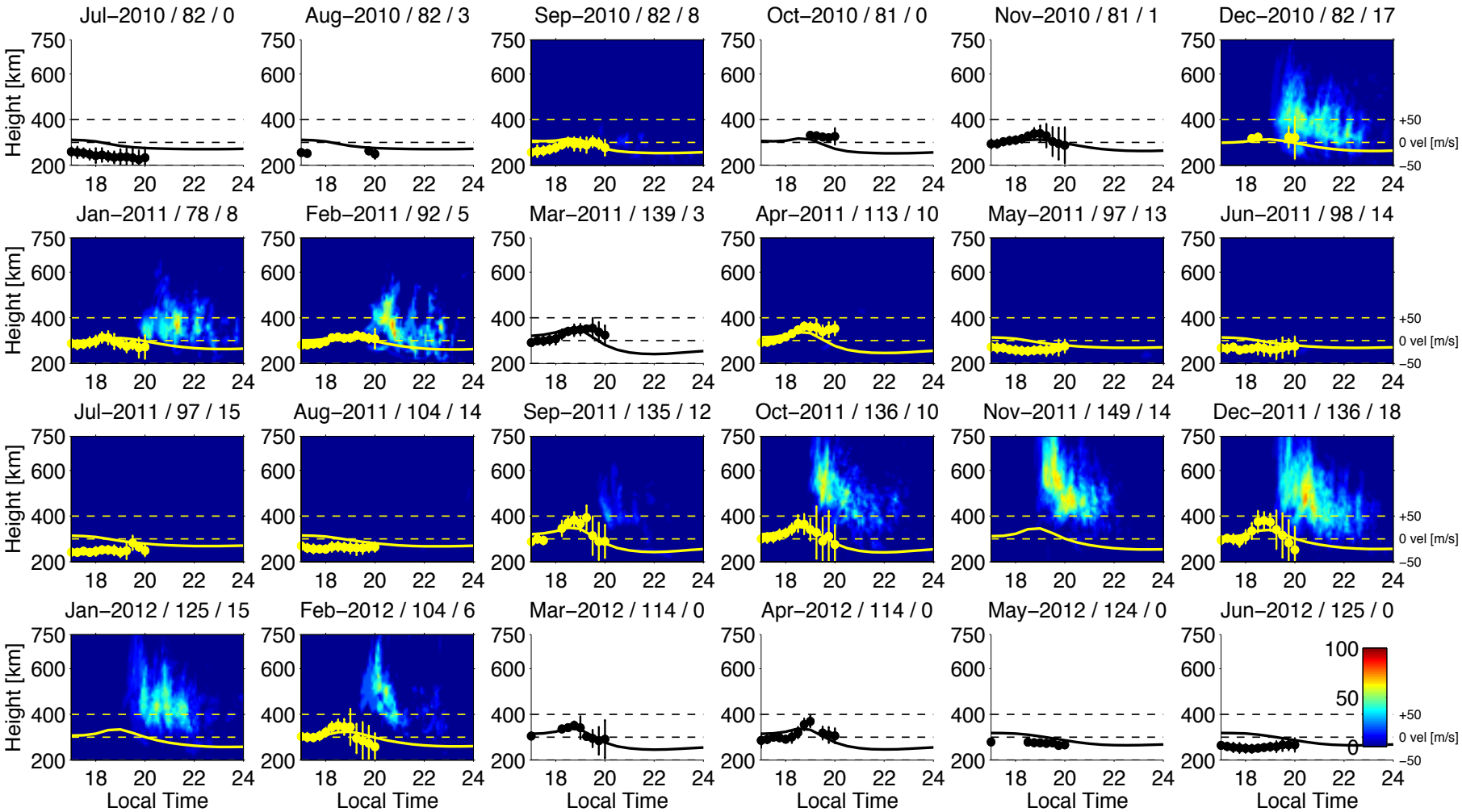
Results: Monthly variability

- Excellent agreement between measurements and model (ESF months)
- Unusual negative drifts during non-ESF months



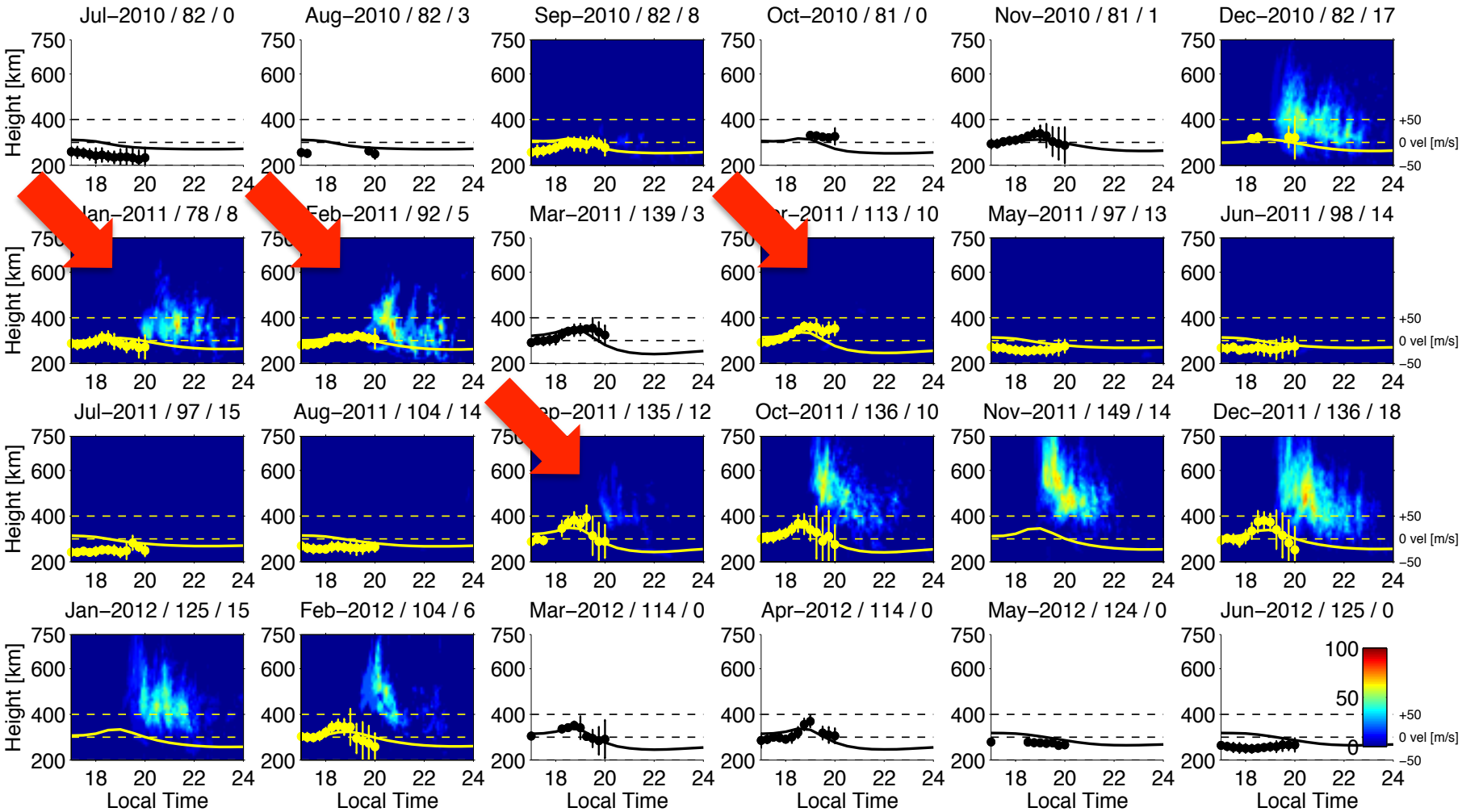
Results: Monthly variability

- Shows solar flux control over ESF morphology
- High (low) ESF occurrence during weak (strong) PRE



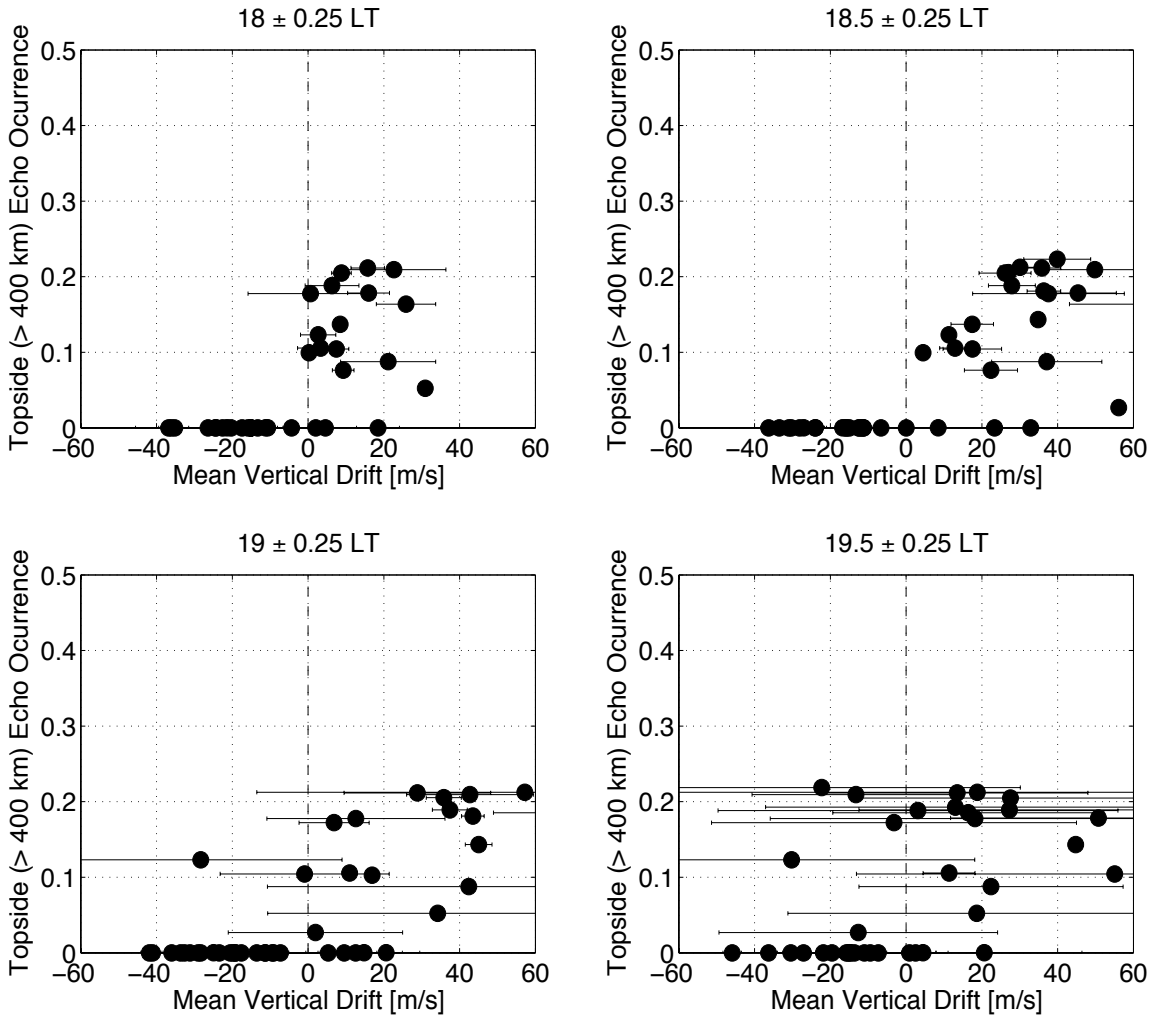
Results: Monthly variability

- Shows solar flux control over ESF morphology
- High (low) ESF occurrence during weak (strong) PRE



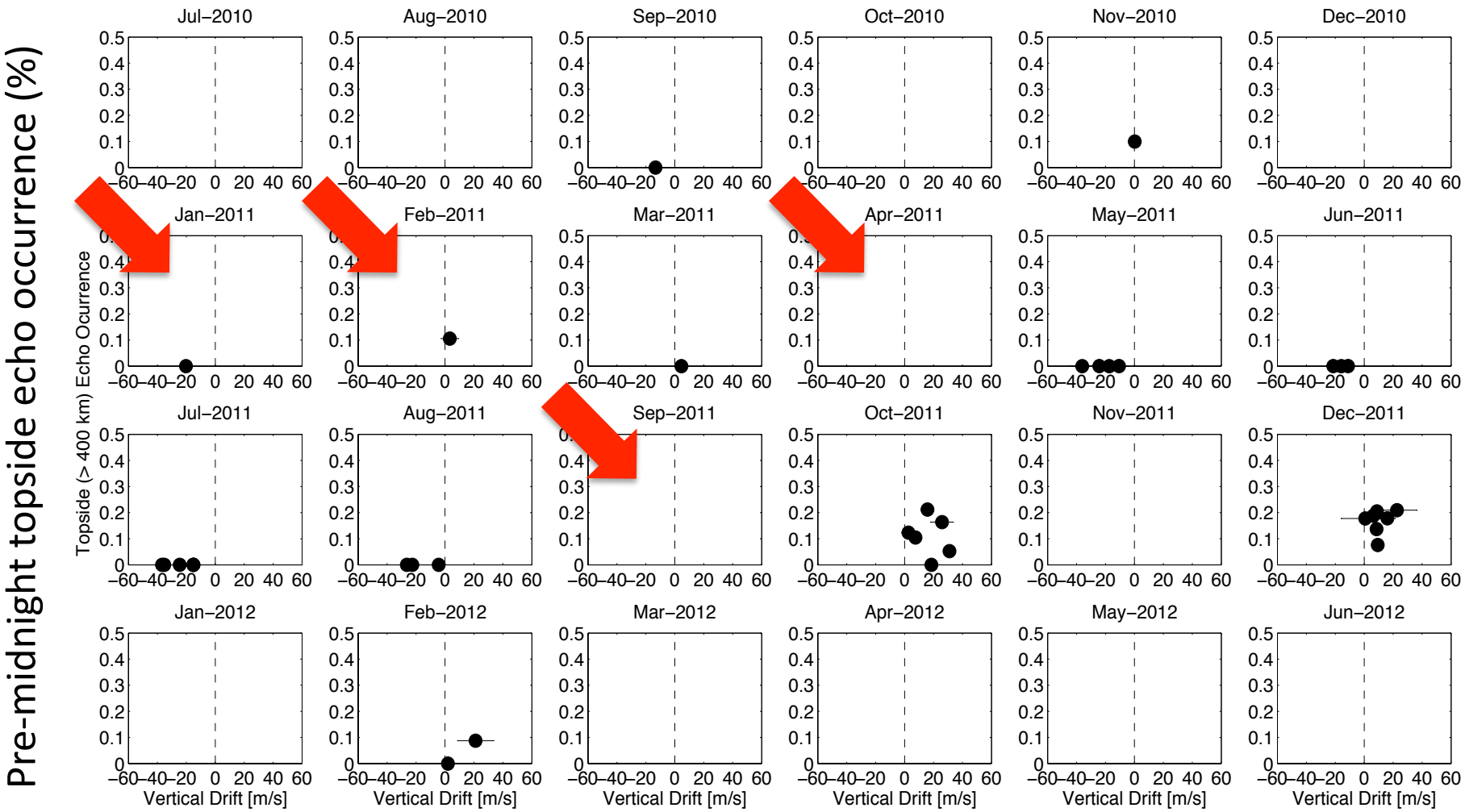
Results: Day-to-day variability

- About 30-35 measurements in the same longitude/LT sector
- PRE > 0 m/s is **necessary but not sufficient condition** for topside echoes



Results: Day-to-day variability

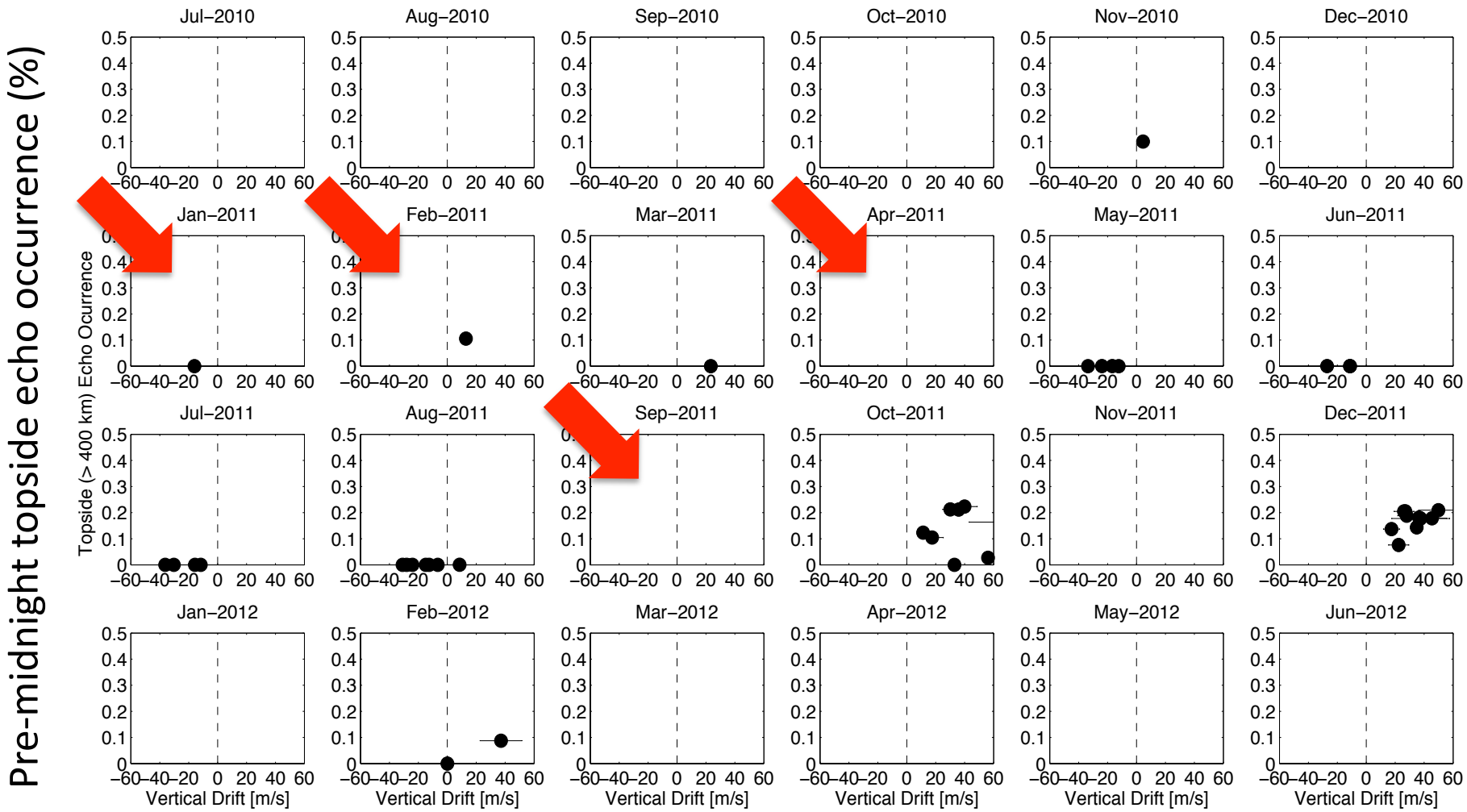
- Discrepancies between monthly drifts and ESF occurred when only one (or none) measurements occurred on the same day.



Mean Drifts around 18:00 ±15 LT

Results: Day-to-day variability

- Discrepancies between monthly drifts and ESF occurred when only one (or none) measurements occurred on the same day.



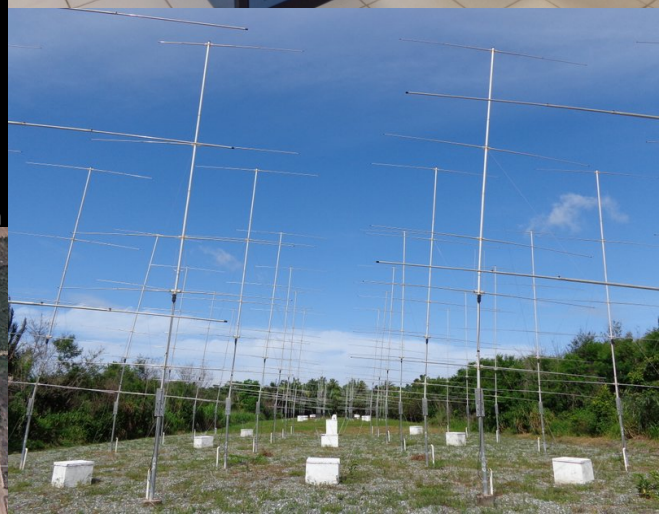
Mean Drifts around 18:30 ±15 LT

Concluding remarks

- Remarkable agreement between model and measured drifts mean drifts for the Brazilian sector during ESF season.
- Unexpected downward drifts in the afternoon sector between May-August. Agrees with previous analyses (Stoneback et al., 2011) for 2008-2011.
- High (low) monthly ESF occurrence rate during months when average PRE is weak (strong). Lack of same-day measurements. More joint measurements needed.
- Results from same-day observations, however, indicate positive mean vertical drifts are necessary but not sufficient conditions for ESF.

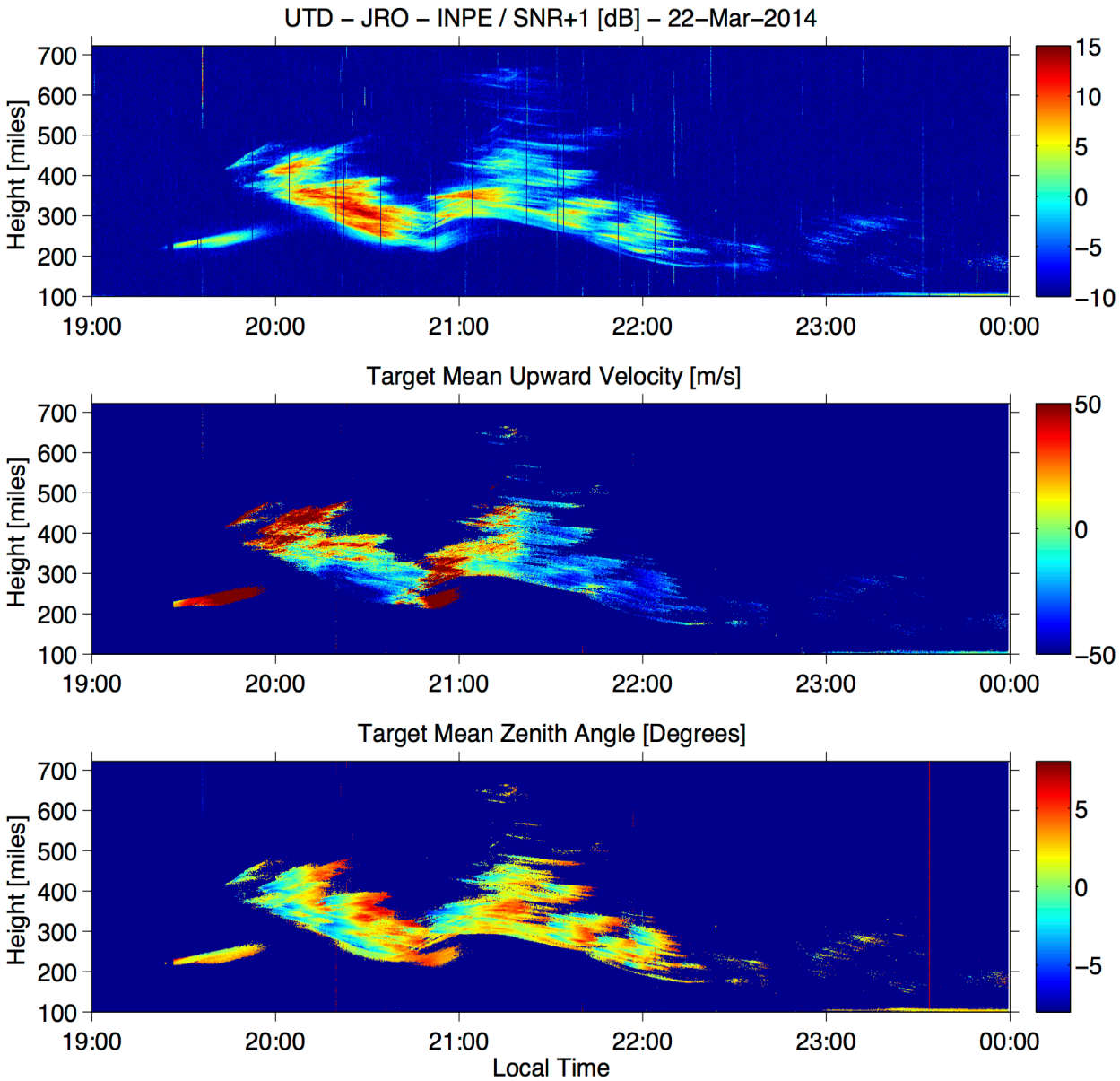
MELISSA

- MELISSA: Monitoring Equatorial and Low-latitude Irregularities over Sao Luis, South America
- Collaborative effort between UT Dallas, JRO and INPE.



- 16 kW peak power
- 10% duty cycle
- 4 antenna sets
- Remote operable

MELISSA


UTD – JRO – INPE / SNR+1 [dB] – 22–Mar–2014
Height [miles]
700
600
500
400
300
200
100
19:00
20:00
21:00
22:00
23:00
00:00
15
10
5
0
−5
−10
Target Mean Upward Velocity [m/s]
50
0
−50
Target Mean Zenith Angle [Degrees]
5
0
−5
Local Time