Toward Understanding the Day-to-Day Variability in Structuring of the Nighttime Equatorial *F* layer

Roland Tsunoda
Center for Geospace Studies
SRI International
Menlo Park, California, USA

SRI International

- Private, non-profit research institute (staff > 2000)

-- contract research; project oriented

- Center for Geospace Studies (staff ~ 20)
- Current Projects

-- Build, deploy and operate incoherent-scatter radars (Resolute Bay, Sondrestrom, Poker Flat, Arecibo)

-- Ionospheric, magnetospheric research

- Personal interest: Physical processes that lead to the structuring of ionospheric plasma

Some Background

- Quality of radio signals is degraded while propagating through ionospheric plasma structure
- Plasma structure in nighttime equatorial *F* layer is referred to as equatorial spread *F* (ESF)
- Propagation effects most severe within plasma-depleted regions, called equatorial plasma bubbles (EPBs)
- Mitigation difficult; avoidance is most viable strategy
- Occurrence of ESF/EPBs can vary dramatically from day-to-day
- Reliable methods for short-term forecasting have yet to be developed – A SPACE-WEATHER CONCERN

How to Best Address the Day-to-Day Variability Problem

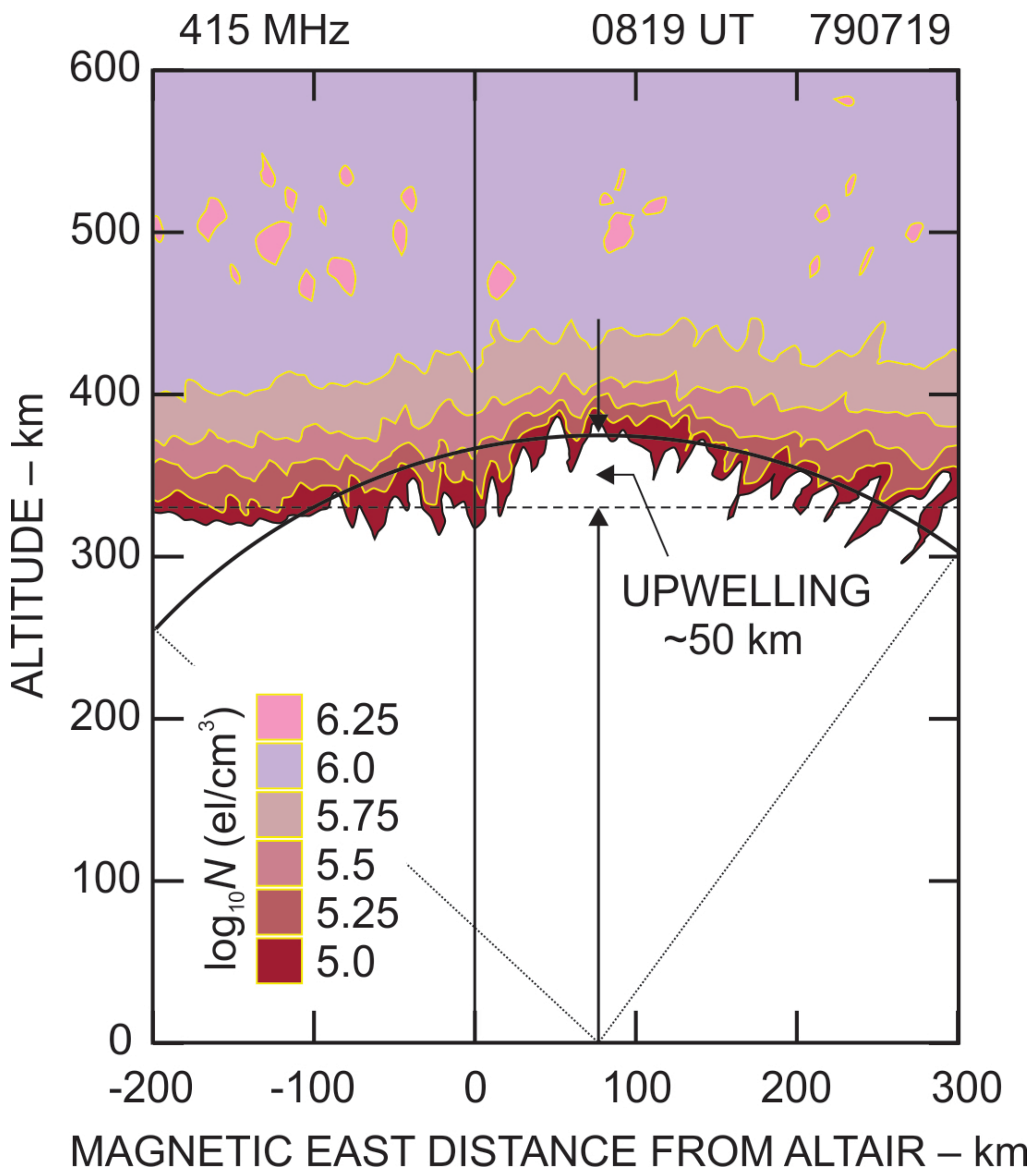
- Construct working hypothesis
- Test hypothesis with well-designed experiments, with comparisons to theories or computer simulation results
- Working hypothesis:

Large-scale wave structure (LSWS) controls when and where ESF/EPBs develop

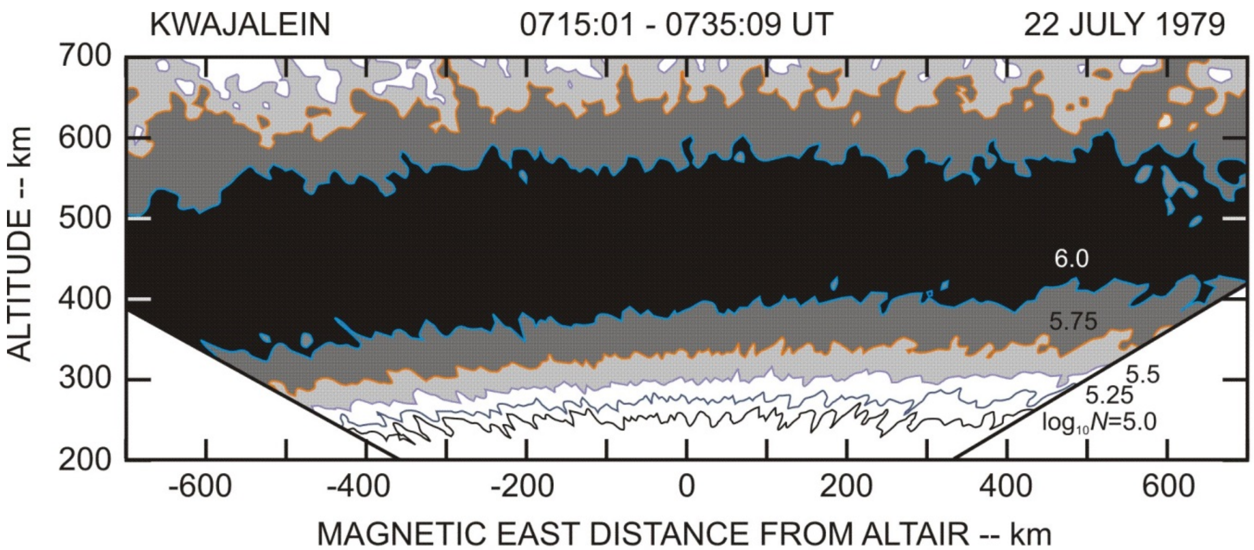
Main drivers: (1) post-sunset rise (PSSR) of *F* layer and (2) eastward neutral wind

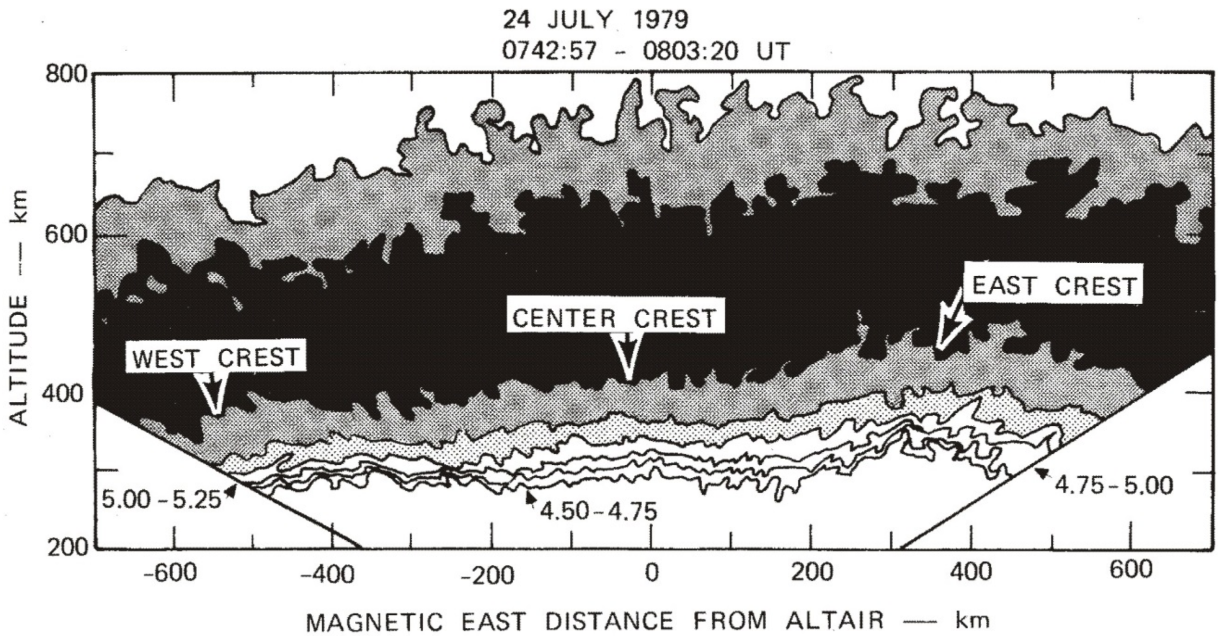
What is LSWS?

- LSWS: train of upwellings in bottomside of equatorial *F* layer
- Example of a single upwelling from ALTAIR measurements (right figure)



No LSWS (top), LSWS (bottom)





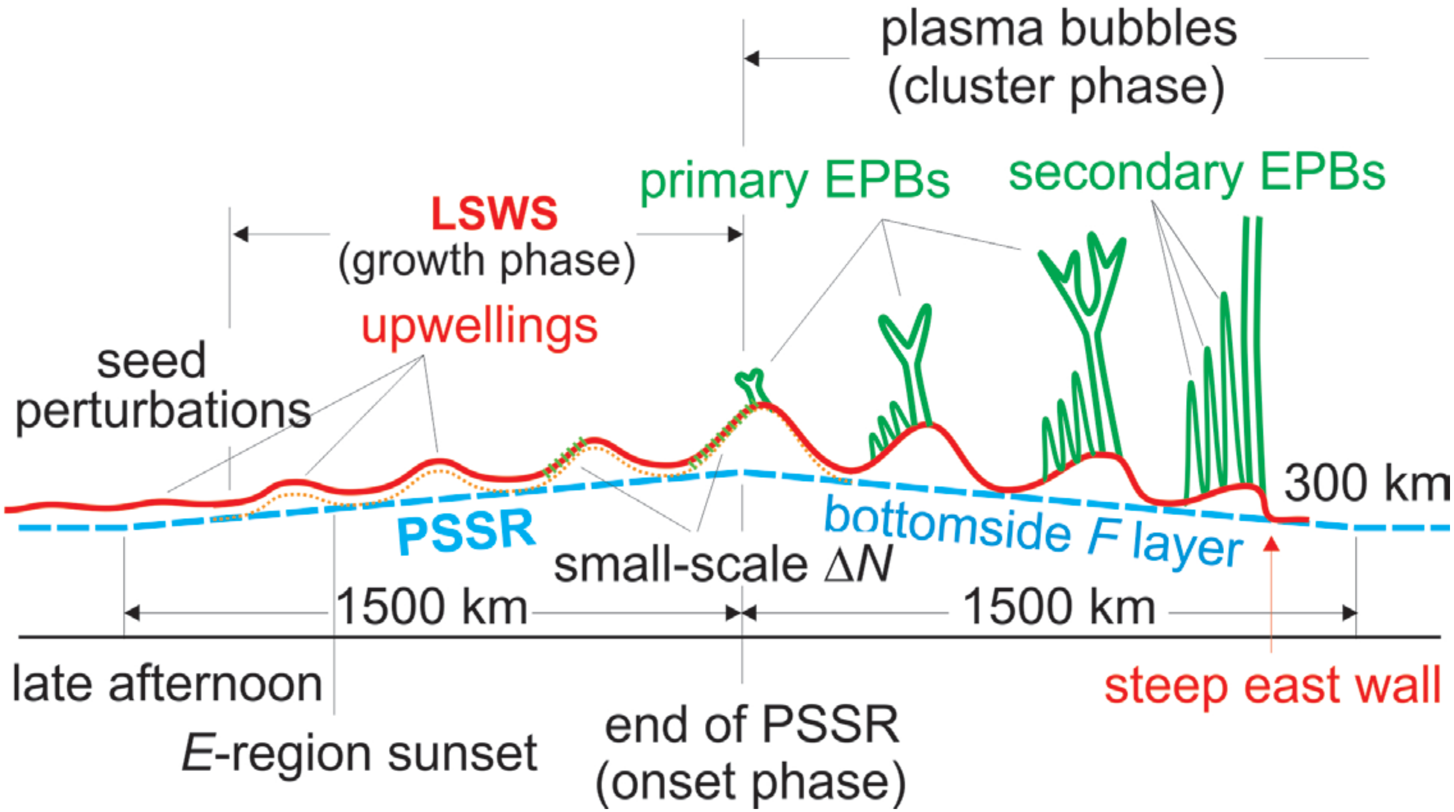
Properties of LSWS

- Very little is known about LSWS
  -- Zonal wavelength ~ 400 km
  -- Upwelling amplitude can exceed 100 km
- Most of information about upwelling properties have been obtained with ALTAIR, a fully-steerable incoherent-scatter radar
- But, ALTAIR rarely available for basic research
- Lack of knowledge about LSWS is a major reason why we have not yet been able to solve the day-to-day variability problem

Serious Obstacle to LSWS Measurement

- Upwellings are spatial structures, virtually stationary during their growth phase (PSSR)
- Hence, sensors that use temporal variation to infer spatial structure, by assuming zonal drift cannot be used
- In lieu of ALTAIR, limited information have been extracted from ionogram signatures, total electron content (TEC) derived from beacon signals transmitted by equatorial-orbiting satellite (C/NOFS), HF transequatorial propagation (TEP)

Sketch of Working Hypothesis

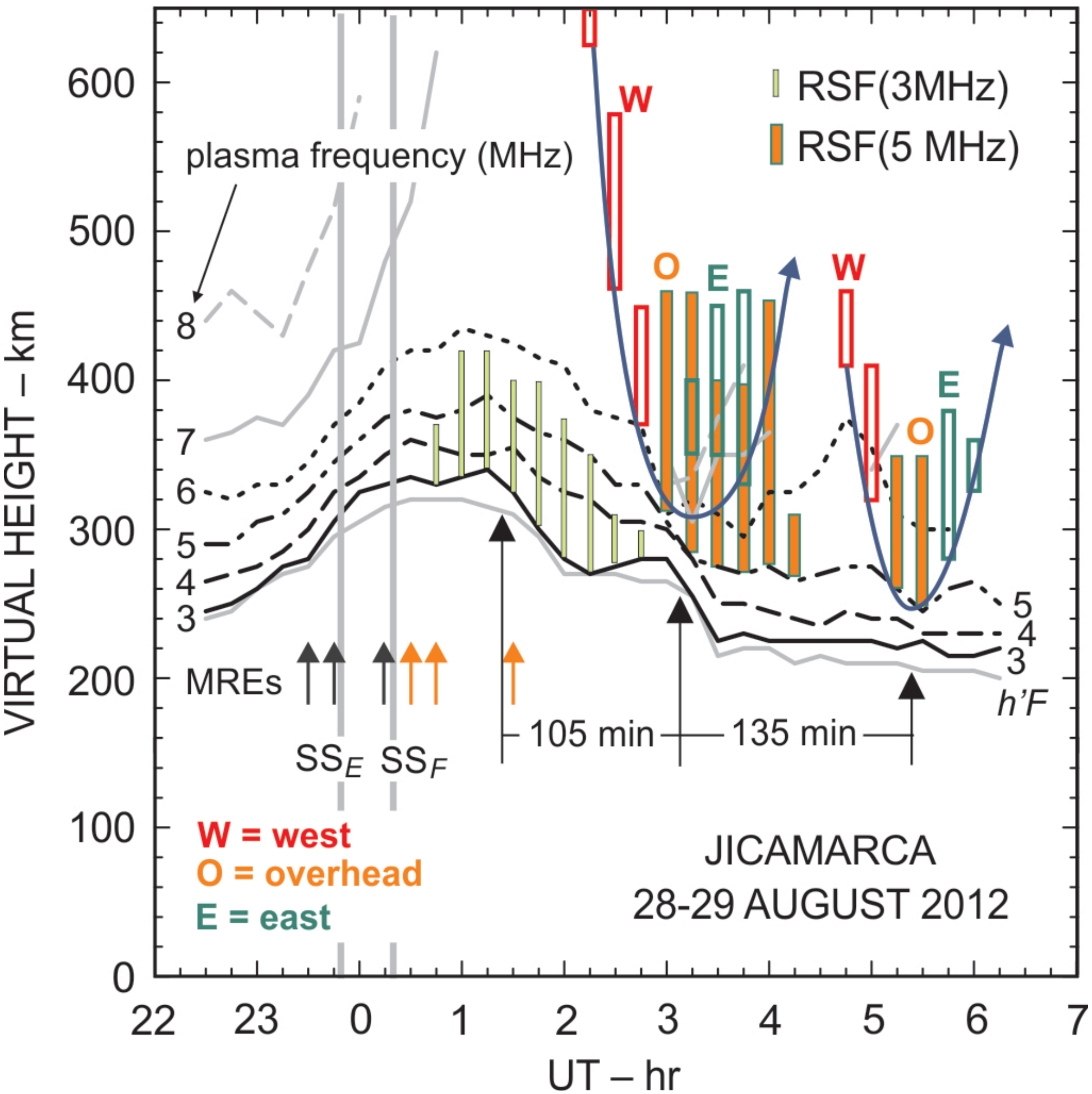


- LSWS grows in amplitude such that each 'upwelling' becomes a regional center within which ESF develops

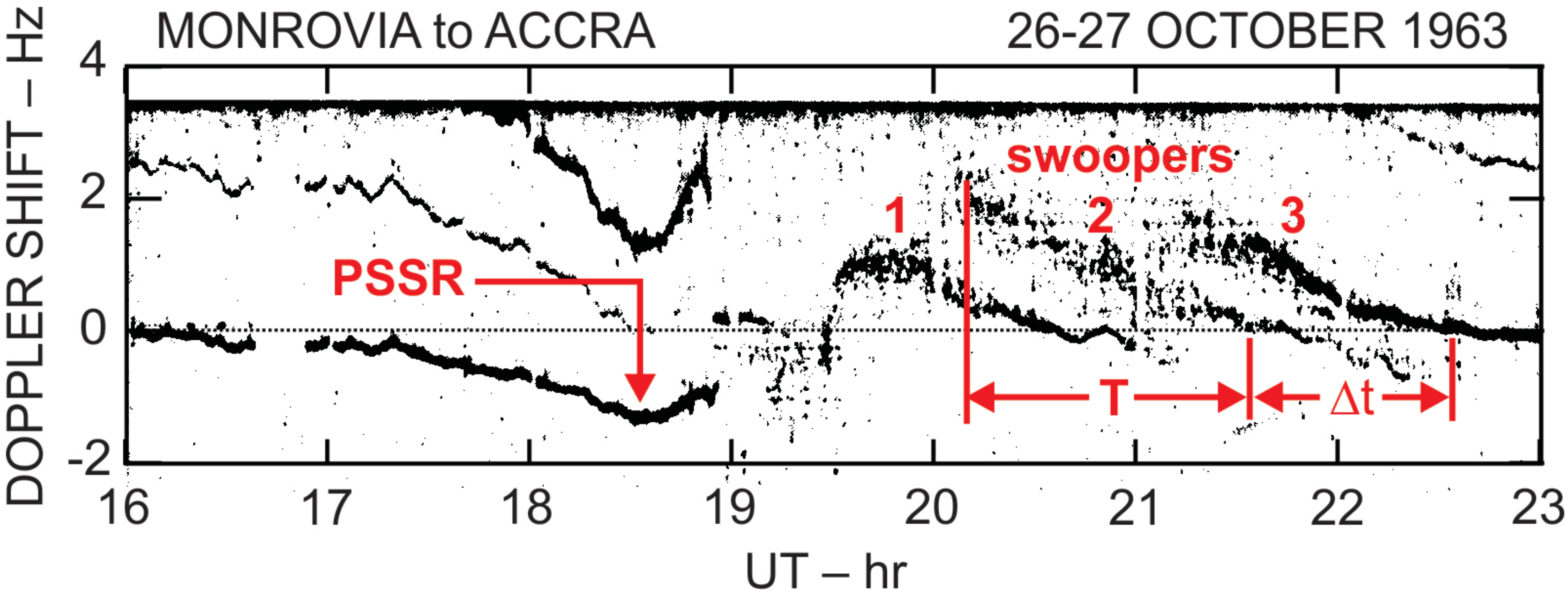
R.T. Tsunoda, 'Upwelling, A unit of disturbance in equatorial spread *F*,' *Prog. Earth, Planet. Sci*., in review, 2015.

Ionogram Signatures of Bottomside Patches

- Ionosonde observations with angle-of-arrival
- ESF patches arrive from west, recede to east
- East-west asymmetry is evident

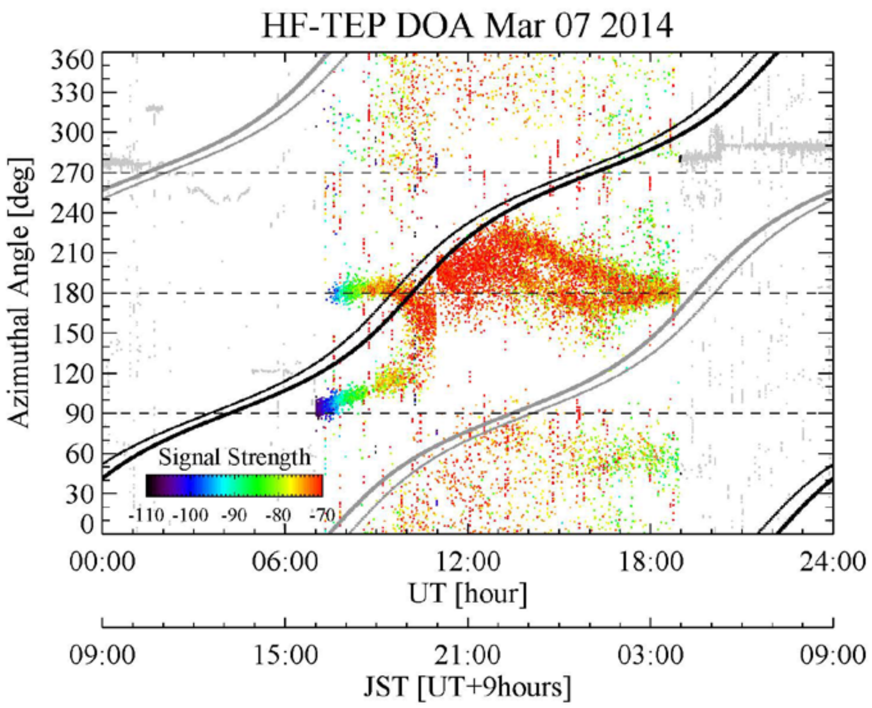


Swooper: Another Bottomside Patch Signature

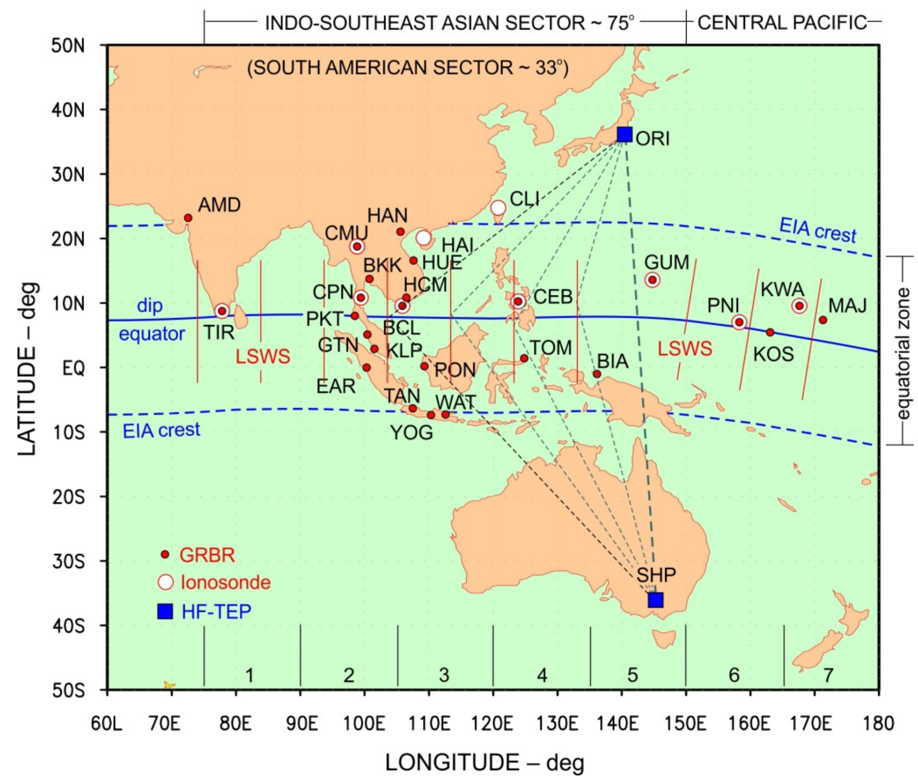


- Doppler shift of continuous-wave radio signals versus UT
- Sequence of events: PSSR, arrival of swoopers” from west
- Asymmetry prevents detection of signatures to east of station

HF-TEP Evidence of Bottomside Patches

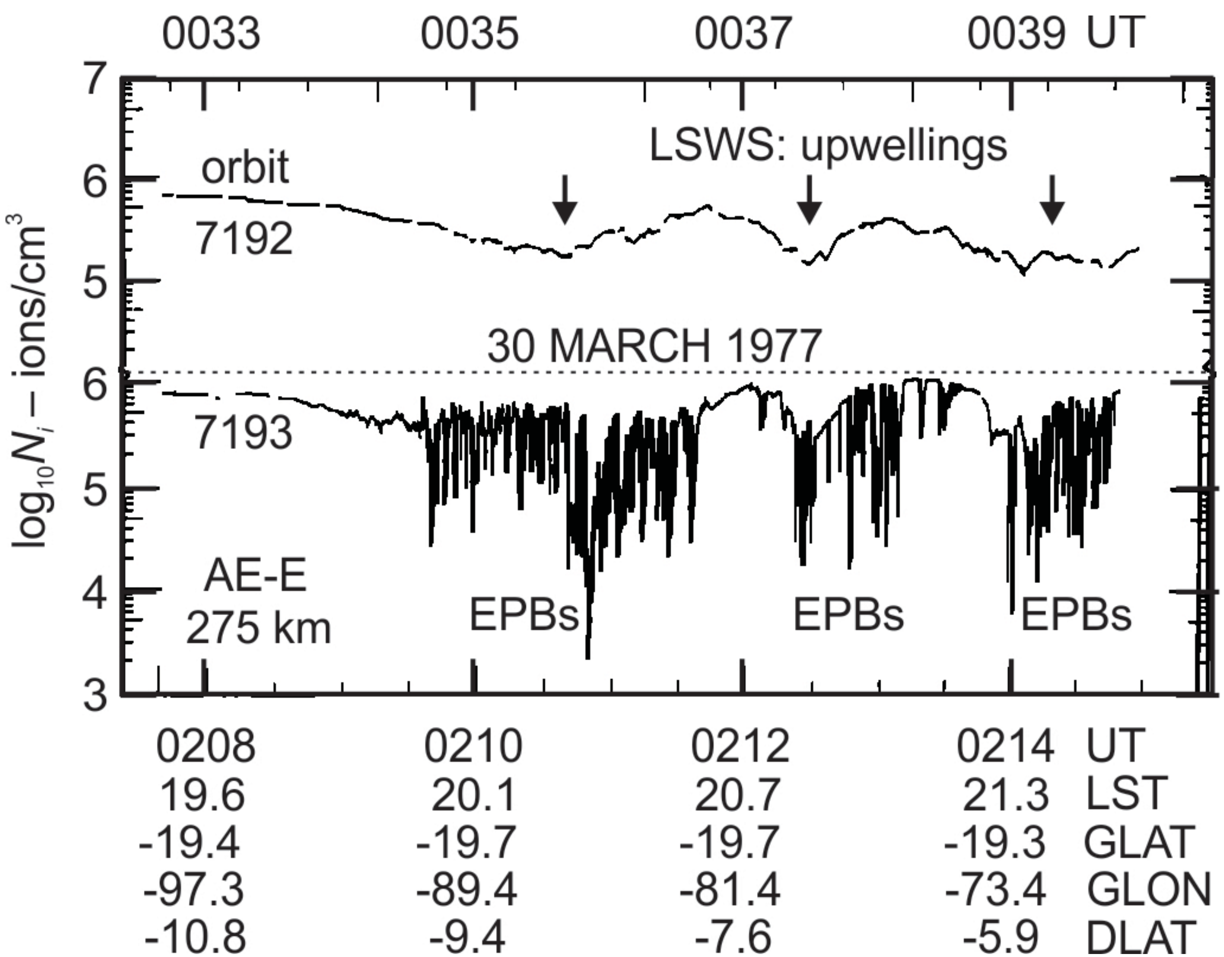


Multiple striations associated with off-great-circle (OGC) propagation paths



Sketch of OGC paths that could occur in a HF-TEP experiment from Australia to Japan

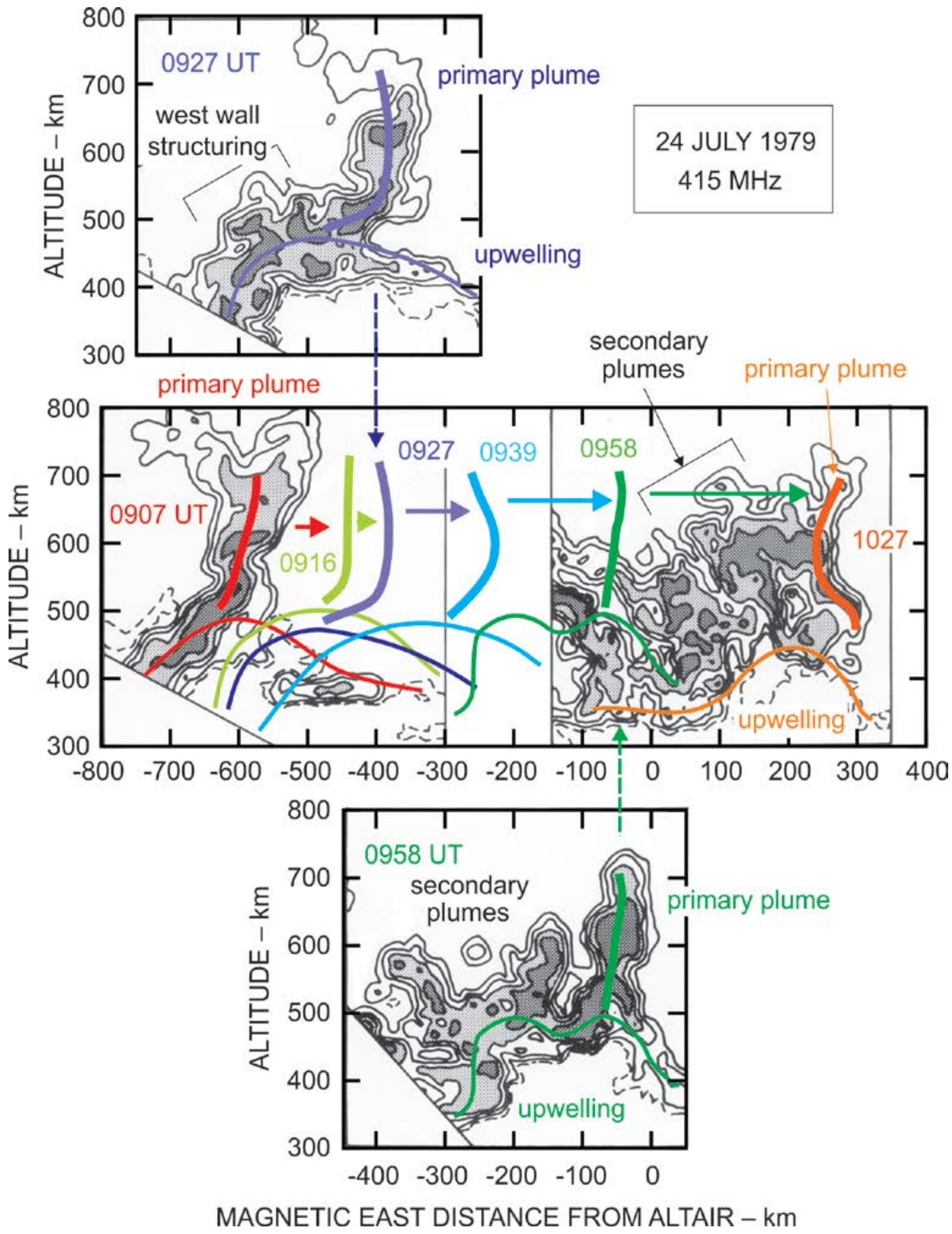
EPB Clusters: In Situ Measurements



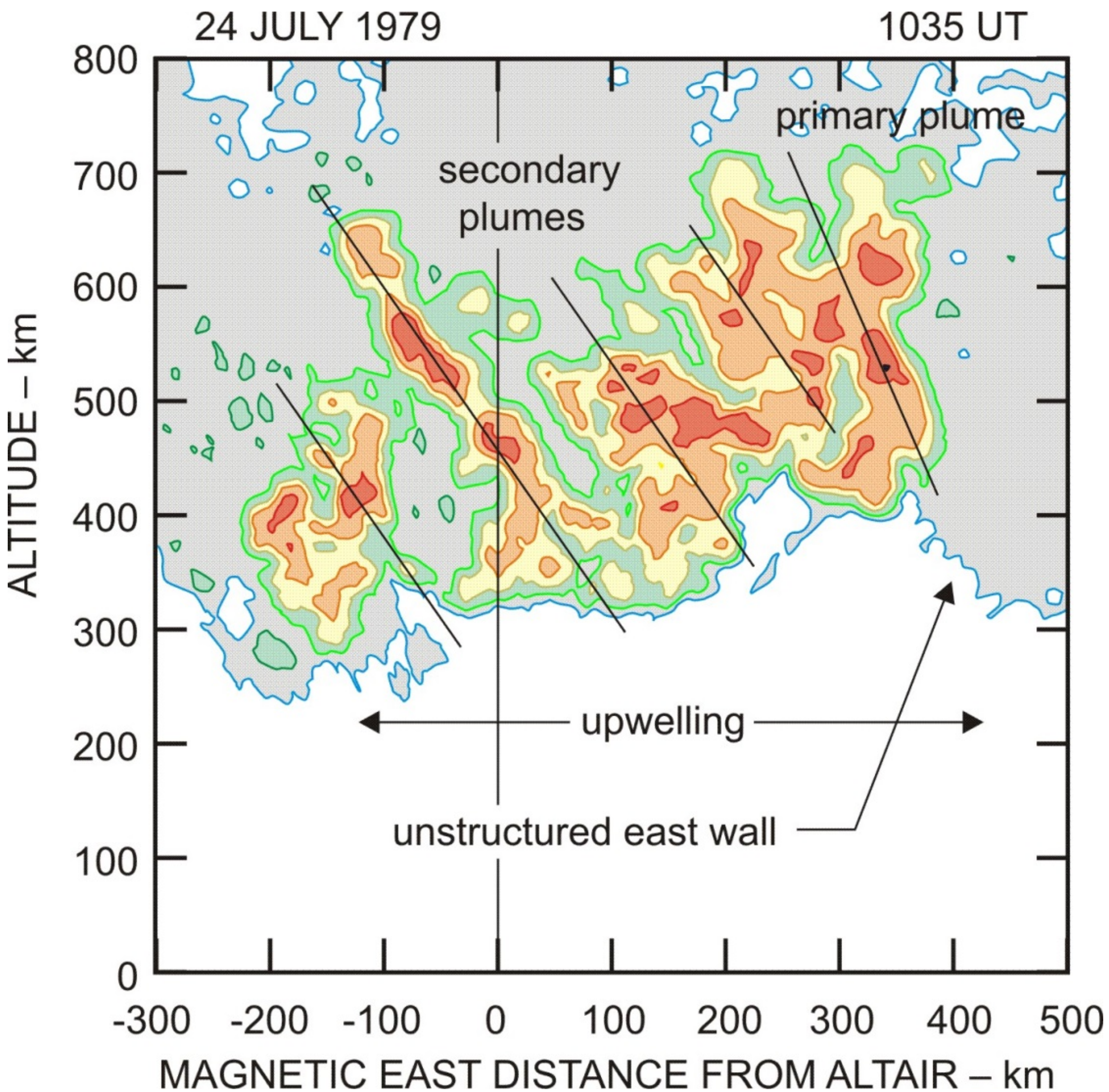
- AE-E ion-density measurements
- First pass: LSWS without EPBs
- Second pass: Filling of upwellings with EPBs

Development of EPB Cluster

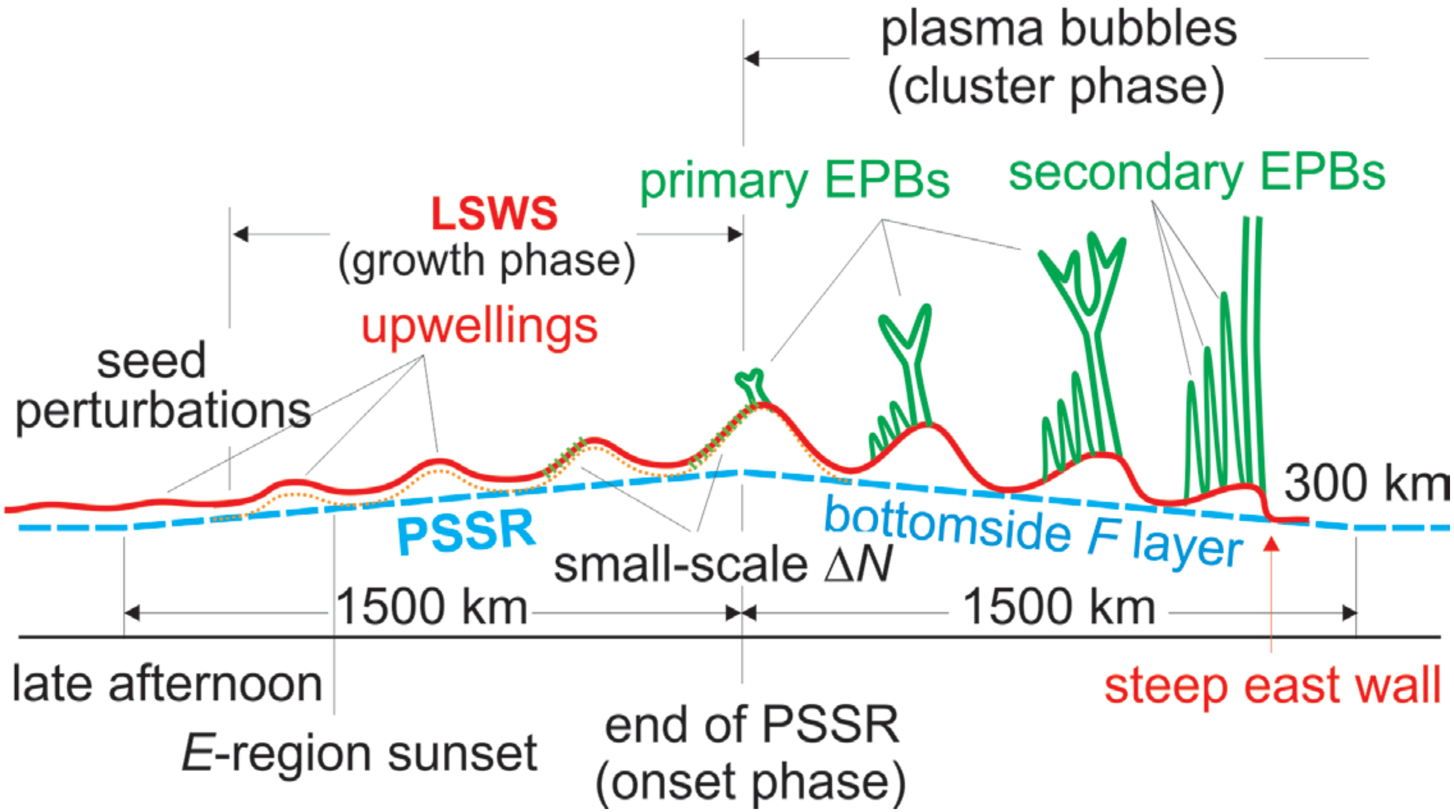
- Primary EPB from crest of upwelling (0907 UT)
- Secondary EPBs along west wall of upwelling
- Eastward transport of EPBs relative to upwelling
- Filling of upwelling with EPBs



Clear Example of Upwelling Filled with EPBs



Sketch of Working Hypothesis

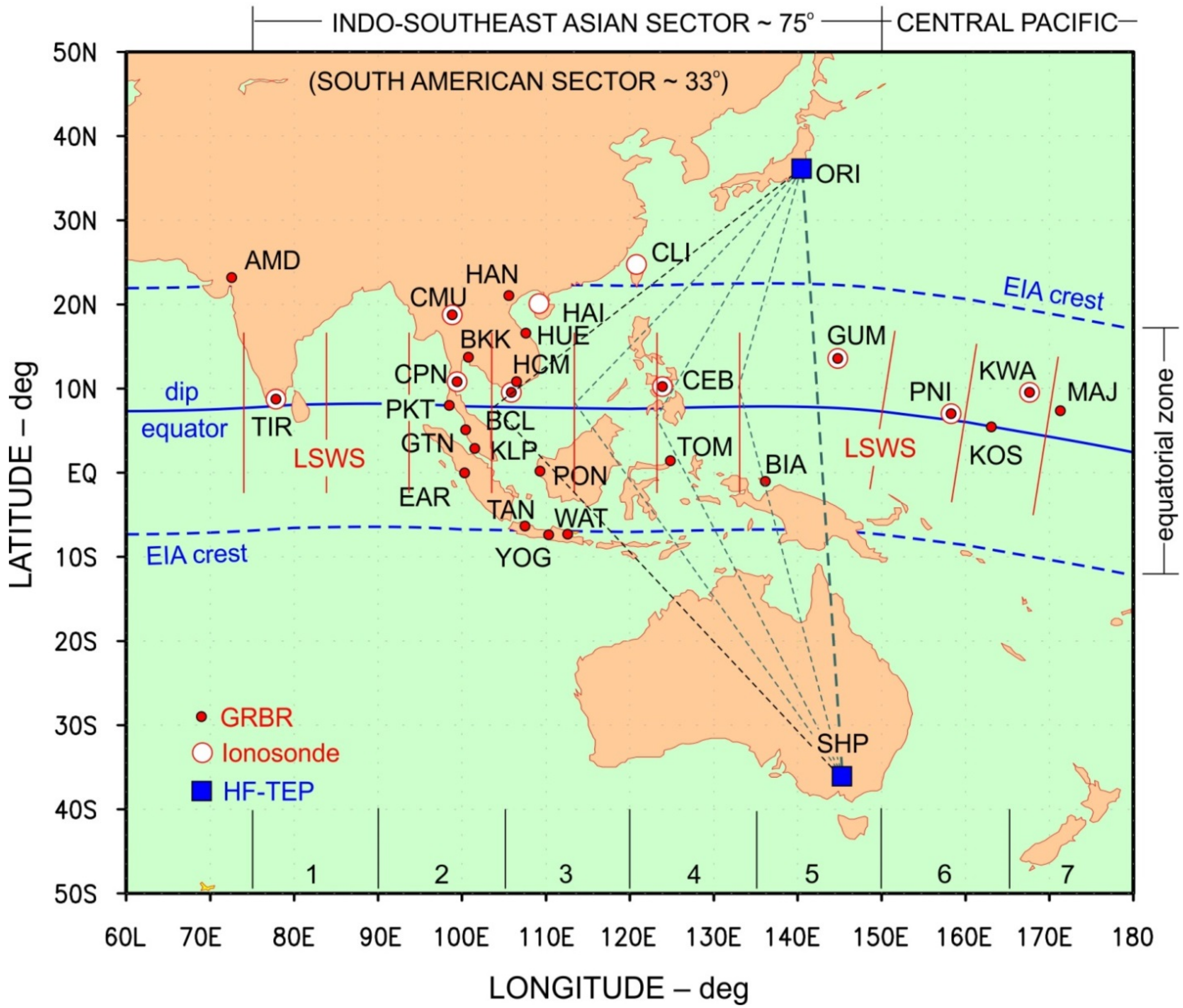


- LSWS grows in amplitude and each upwelling becomes a regional center within which ESF develops

R.T. Tsunoda, 'Upwelling, A unit of disturbance in equatorial spread *F*,' *Prog. Earth, Planet. Sci*., in review, 2015.

Indo-Asian-Pacific Region: Ideal Testbed

- Uniform geometry over extended (75°) longitude sector
- Sensor network includes zonal chain of 6-8 ionosondes
- Other sensors provide description of LSWS (GRBR network, all-sky imagers, GPS network, radars, HF-TEP experiment)



One Useful Experiment

- Determine the longitudinal correlation in behavior of LSWS, PSSR, and ESF/EPB development
- On a given night, compare the above development process at longitudes spaced 1-2 hrs in LT with "expected" behavior
- Do LSWS properties explain observations?
- Can we separate contributions from PSSR and LSWS?

New Opportunity

Formosat-7/COSMIC-2

- Constellation Observing System for Meteorology, Ionosphere, and Climate (COSMIC) – total of 12 micro-satellites
- First six will be launched in 24° inclination orbit; will carry radio beacons and VIDI (velocity, ion density, and irregularities)
- Launch: ~ May 2016; SpaceX Falcon-Heavy rocket; from Cape Canaveral, Florida (28.49°N, 80.58°W), or Brownsville, Texas (25.93°N, 97.48°W)

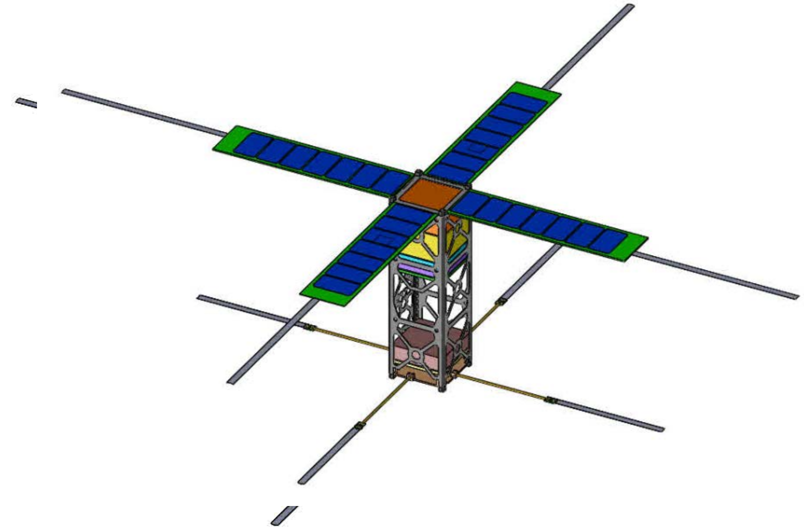
Tandem Beacon Explorer (TBEx)

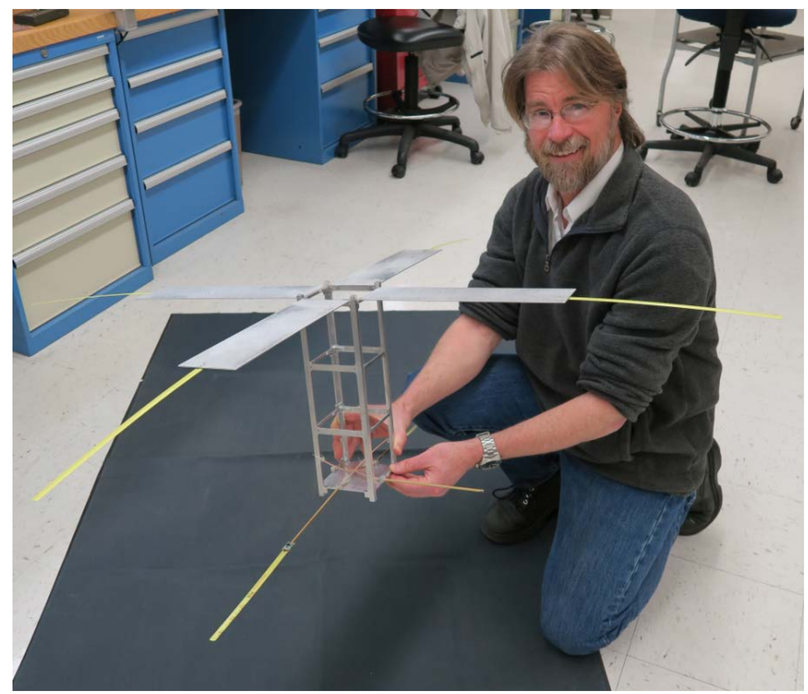
- Two CubeSats will be flown in near-identical orbits; each will carry a tri-frequency beacon
- 150, 400, 1067 MHz
- Measurements: Total electron content (TEC), amplitude scintillations
- Objective: Description of LSWS and ESF with higher temporal resoluton
- To be launched with six COSMIC-2 satellites in low-inclination orbits (~ May 2016)

  -- COSMIC-2: Ion-drift meter, radio beacons

TBEx

- Tandem Beacon Explorer
- Two "3U" CubeSats in near-identical orbits
- Orbital inclination ~ 28°
- 600 (400) km, apogee (perigee)
- Each: Radio beacons at 150, 400, 1067 MHz (identical to C/NOFS)





Coordinated Field Campaigns Using Instrument Clusters

- Indo-Asian-Pacific Network
- Conduct campaigns during ESF season, moon-down conditions (optics), nights of favorable number of satellite passes
- Obtain comprehensive description of LSWS and ESF/EPBs
- Data analysis, model simulations, etc., for field campaign periods
- Present results at an AOSWA workshop

Possible Collaborations

- NICT

-- HF-TEP, ionosondes

- RISH, Kyoto University

-- GRBR (GNU Radio Beacon Receiver) network

-- Equatorial Atmosphere Radar (EAR)

- STEL, Nagoya University

-- 630 nm all-sky imagers

-- 30 MHz radar (at EAR)

- UKM

-- GRBRs in Malaysia

-- GPS receiver network in Malaysia

- LAPAN

-- GRBRs, ionosondes in Indonesia