Using Small Satellites to Investigate Energy Input into the Ionosphere-Thermosphere by ULF Waves and Improve Space Weather Forecasting

O. P. Verkhoglyadova, A.J. Mannucci, X. Meng (1), R.M. McGranaghan (2,1)

[1]*Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA*

[2] *University Corporation for Atmospheric Research (UCAR), Boulder, CO*

Outline

- Closing gap in space weather observing system
  - The need for a dedicated mission focused on evaluating energy input into the IT system at mesoscales
- Observation and modeling evidence supporting a concept of dynamic mesoscale energy input
- Science objectives
- SITE mission concept suggestion
  - Integration of small satellite-based information in the space weather modeling framework

Relevance

The National Space Weather Action Plan (NSTC, 2015), the Goal 5:

"Improve Space-Weather Services through Advancing Understanding and Forecasting" and specifically

sub-Goal 5.4: "Improve Forecasting Lead-Time and Accuracy" and

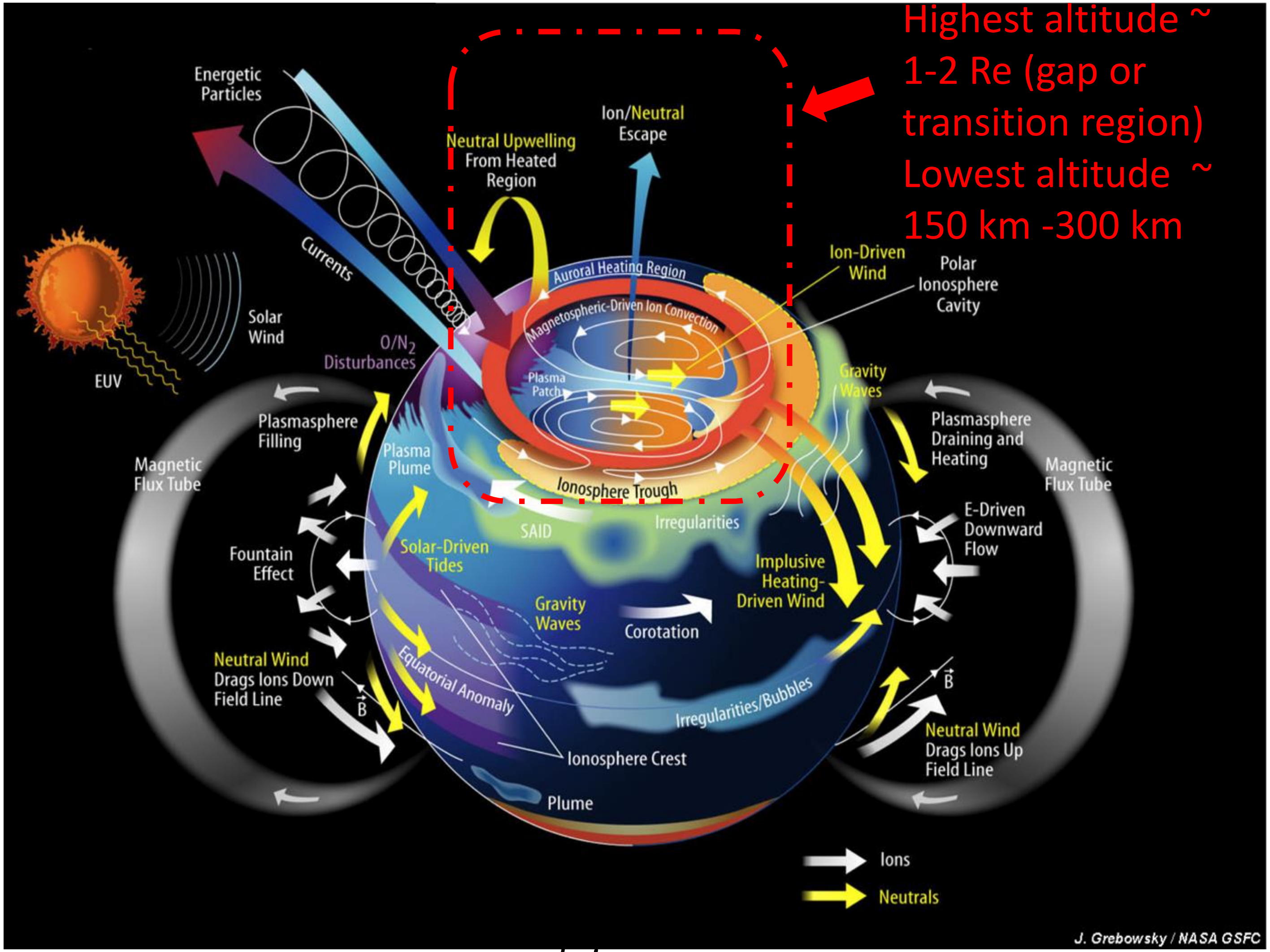
sub-Goal 5.5: "Enhance Fundamental Understanding of Space Weather and Its Drivers to Develop and Continually Improve Predictive Models".

The core space weather problems include the important questions:

- What is the amount of *energy* transferred from the heliosphere to the Earth’s magnetosphere-ionosphere-thermosphere (M-I-T)?

- How is it transferred (e/m disturbances, particles, mechanical motions) and at what scales?

Region of interest



Highest altitude ~ 1-2 Re (gap or transition region)
Lowest altitude ~ 150 km -300 km

not to scale!

Motivation

- **Energy** is one of the most universal characteristics describing a physical system

- High-latitude IT drivers (e.g., the convection electric field) are often under-sampled when input to global circulation models (GCMs). Typical temporal scales in modeling are larger than ~1000s (16 min) and spatial scales are larger than ~1000 km (Richmond, 2010).

- It has been shown that an increase in temporal and/or spatial resolution of global IT modeling can substantially modify the estimates of energy input and dissipation in the IT system (*Codrescu et al., 1995; Deng and Ridley, 2007; Matsuo and Richmond, 2008; Deng et al., 2009; Cosgrove et al., 2009; 2011*)

- IT heating can be strongly influenced by ULF wave processes (*Brekke, 1997; Lotko, 2004; Lysak & Song, 2006; Deng et al., 2009*). The target frequency range is from 0.1 Hz to 10 Hz.

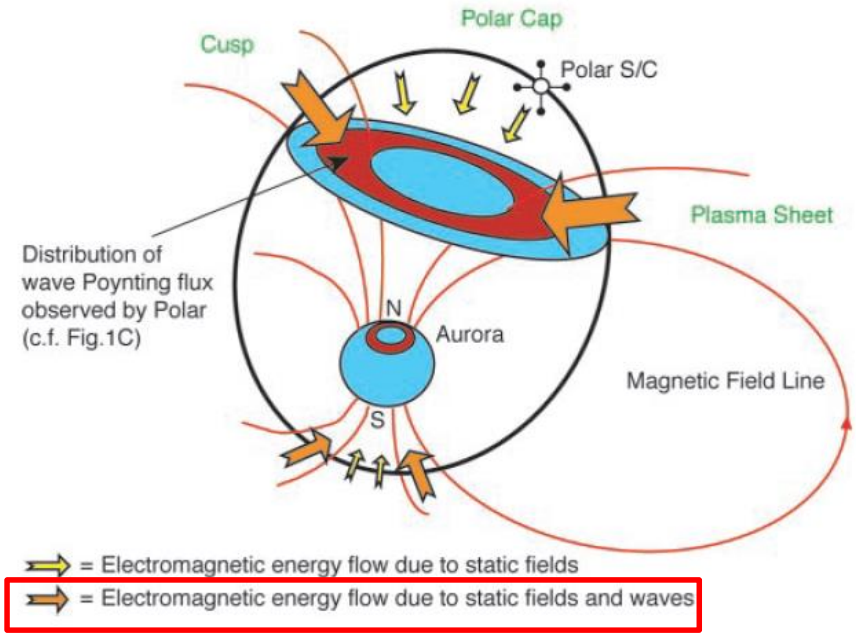
- **Currently, energy transport at mesoscales is not well quantified to be used for GCMs.**

Importance of ULF waves

Polar SC observations (1997):

Keiling+, 2002

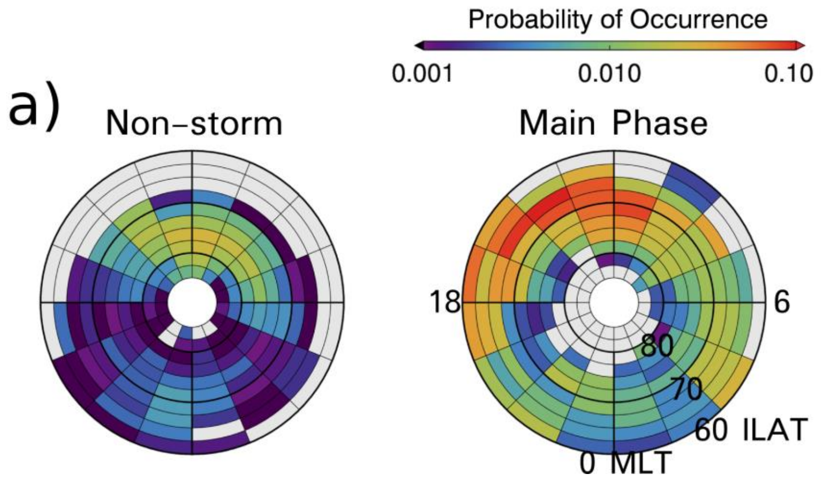
Altitudes of the measurements ~ 25,000 km to 38,000 km. The Poynting Flux (PF) values are mapped to 100 km.



E/m energy flow into ionosphere due to ULF waves is larger than due to quasi-static fields

Importance of ULF waves

FAST SC observations of Alfven waves (1996 -1999):



PF increase ~ 5 to 10 times in localized enhancements

Alfvén wave occurrence on FAST during geomagnetic storm phases mapped to 100 km altitude (Hatch et al., 2016)

Observational evidence for dynamic mesoscale nature of energy transport

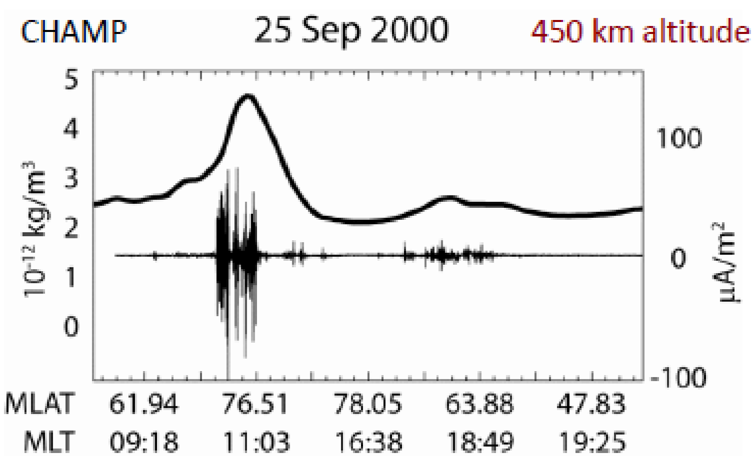
- AMIE results showed almost simultaneous (~2 min) global response in plasma convection and magnetic perturbations to IMF Bz <0 (Ridley at al., 1998; Lu et al., 2001; 2002)
- Dynamical variability in F-region composition driven by electric field within auroral arcs can be ~ 30 sec to 1 min (Zettergen et al., 2010) and is resolved by electronically steered ISRs.
- Transient FACs were observed by DMSP (Huang and Burke, 2004)
- Small-scale and dynamic features in electric field are frequently observed by PFISR at ~ 2 min time scale (Semeter et al., 2010)
- Energy input into the polar cap ionosphere occurs through dynamic and localized Poynting flux (Huang et al., 2016)
- Synergetic connection between dynamic mesoscale magnetospheric and IT processes was demonstrated by Lyons et al. (2016)

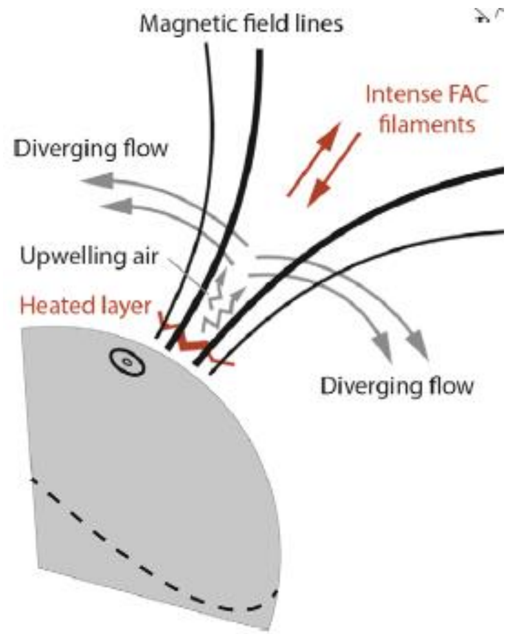
There is a growing observational evidence that without considering energy transport at mesoscales (at horizontal scales ≤500 km and at time scales <15 minutes), a significant energy input into the IT might not be accounted for

Why high-latitude ionosphere?

- “… The heating above 150 km is responsible for a large increase of the average vertical velocity (40 m/s) and neutral density (50%) at 300 km and higher altitudes.” (Deng et al., 2011).

- “… air density enhancements of almost a factor of two are observed whenever the satellite passes the cusp region. Small-scale FAC filaments (1-km size) seem to play an important role in the heating. Whenever these very intense FACs with amplitudes of several hundreds of mA/m2 show up, density enhancements occur.” (Lühr et al, 2004).





Concurrent neutral density and FAC enhancement measured in the cusp by CHAMP

Science Objectives

- Quantify contributions from localized and transient (or ULF frequency range) phenomena to the IT energy budget
- Provide necessary dataset of e/m field measurements for global IT models at the scales <15 min and < 1000km
- Enhance our understanding of the ionosphere-thermosphere as a multi-scale dynamical system, by utilizing satellite-based observations of mesoscale and transient phenomena

- **What could be a critical definitive measurement to understand the mesoscale e/m coupling of the M-I-T system?**

SITE Mission Concept

Sampling Ionosphere Thermosphere Energy (SITE)

Target region:

the high- and middle-latitude ionosphere at altitudes between 150 km and 600 km

- Magnetospheric option: map fields down to the ionosphere

What to measure:

- 3 components of nearly DC magnetic field (in the frequency range from ~1mHz to ~5Hz)
- 3 components of electric field (in the same frequency range)

- Particle detector (limited channels) to constrain in situ conductivity estimates

Multi-spacecraft platform to separate spatial and temporal effects (to distinguish Doppler-shifted static structures from temporal variations)

Pearls-on-a string constellation of several CubeSats

Heritage missions

(DE-2, Polar, FAST, DMSP, SWARM, etc.) have been providing important contributions, but each has ***one or several*** of the following limitations:

- Not focused on high-latitude (coupling) region
- E field is estimated from drift meter technique rather than double-probe technique (2 components only)
- Single-point measurements: can not separate temporal and spatial effects
- Focus on understanding magnetospheric rather than IT processes
- Not focused on e/m energy transfer.

For the first time we propose to investigate a small satellite (or CubeSat) mission for understanding fundamentals of dynamic M-I-T wave coupling and how it affects storm-time IT

Reliability of space weather forecasting frameworks based on IT global circulation models strongly depends on adequate representation of high-latitude driving and energy flow in the system.

Assimilation of multiple data sources (*e.g.*, *Matsuo and Richmond*, *2008; Cousins et al.*, *2013*) can help to resolve IT processes better and will lead to a better agreement between GCMs and IT observations.

SITE Mission Concept

Sampling Ionosphere Thermosphere Energy (SITE)

Target region:
the high- and middle-latitude ionosphere at altitudes between 150 km and 600 km

- Magnetospheric option: map fields down to the ionosphere

What to measure:

- 3 components of nearly DC magnetic field (in the frequency range from ~1mHz to ~5Hz)
- 3 components of electric field (in the same frequency range)
- Particle detector (limited channels) to constrain in situ conductivity estimates

Multi-spacecraft platform to separate spatial and temporal effects (to distinguish Doppler-shifted static structures from temporal variations)

Pearls-on-a string constellation of several CubeSats

