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Understanding Large-Scale Wave Structure and Equatorial Plasma Bubbles: Mission of the Tandem-Beacon Explorer (TBEx)

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ABSTRACT

There is mounting evidence that the process that leads to the development of equatorial plasma bubbles (EPBs) involves, more often than not, the appearance of large-scale wave structure (LSWS) in the bottomside of the equatorial *F* layer. In fact, each upwelling in an LSWS (i.e., localized upward displacement in isodensity contours) displays essentially the same pattern for EPB development [4]. How an upwelling is initiated, amplified, and becomes the 'arena' within which EPBs grow and evolve, remains as a cutting-edge research topic that needs to be understood by those interested in the physics of EPB development. Those interested in forecasting EPB-related plasma structure and their effects on satellite communications and navigation, may also wish to incorporate physics as a basis for adding flexibility to their models.

The fundamental obstacle to progress on this research topic is the lack of information about zonal plasma structure in the bottomside of the equatorial *F* layer. Although the vertical profile of the bottomside *F* layer can be monitored routinely with ground-based ionosondes, there are virtually no instruments that can measure plasma structure as a function of zonal distance in the plane transverse to the geomagnetic field (***B***). Zonal structure is usually inferred from temporal measurements with spaced instruments, presuming presence of a mean zonal drift. Clearly, zonal structure remains undetected, when drift is zero. It turns out, that growth of LSWS takes place at altitudes, where zonal drift is small [4,5]. This explains why LSWS continues to elude detection by conventional instruments such as vertical-incidence ionosondes and even the Jicamarca incoherent-scatter radar, and not to draw the attention of researchers.

Breakthrough observations were made with the launch of the Air Force Communication/Navigation Outage Forecasting System (C/NOFS) satellite [2] into a low-inclination orbit. Using the radio beacons [1] on board C/NOFS, both total electron content (TEC) and amplitude scintillation could be measured as a function of zonal distance in the vicinity of the magnetic equator. These TEC measurements were shown to be capable of detecting localized upwellings (in isodensity contours) in the bottomside of the equatorial *F*

layer that appears to be associated with LSWS [3,6]. Numerous other papers have since been published on the association of LSWS to TEC variations.

In coming months, a pair of CubeSats is expected to be launched together from Cape Canaveral, Florida, into essentially identical, low-inclination, low-Earth orbits. Each of the CubeSats will carry tri-frequency radio beacons (150, 400, 1067 MHz). This mission, referred to as the Tandem-Beacon Explorer (TBEx), is sponsored by the National Aeronautics and Space Administration (NASA), as part of its small-satellite and Low-Cost Access to Space (LCAS) program. The TBEx mission is not simply a continuation of radio beacon measurements similar to those that have been made with the C/NOFS satellite. In this regard, however, the TBEx measurements would be more comprehensive than those from C/NOFS. Much of the C/NOFS measurements were made (1) only at 150 and 400 MHz, (2) only with local-time (LT) coverage, that extended past sunset, but not deep into the night sector, and (3) during a period of extremely-low (but rising) solar activity. Much of the restrictions placed on beacon transmissions were driven by other mission priorities. On the other hand, the overall TBEx objective is to optimize radio beacon operations to maximize scientific yield associated with the physics of the bottomside equatorial *F* layer and the development of EPBs. In this regard, TBEx measurements will be made (1) at all three radio frequencies, (2) with LT coverage that will be selected to probe into different aspects of EPB development, and (3) during a period of high (though declining) solar activity.

The fundamental objective of the TBEx design concept, however, is to overcome the basic restriction in measurements made by a single satellite in a low-inclination orbit; that is, to use two identically-instrumented satellites in near identical orbits to obtain measurements that are more frequent than once a single-satellite orbit, and to obtain more than one cross-sectional cut through upwellings, EPBs, and smaller-scale structures that are three-dimensional by nature and evolving with time. The separation of the tandem pair of CubeSats is expected to provide measurements with varying temporal and spatial separation.

While searching for launch opportunities to place the TBEx satellites into low-inclination orbits, we learned that the STP-2 mission will carry six radio-beacon payloads from Cosmic-2, as well as the NPSAT1 satellite from the Naval Post-Graduate School, which also contains a radio beacon. We further learned that the STP-2 mission, which is scheduled for launch in 2016, on a Falcon-9 booster, had slots available for several CubeSats. The TBEx satellites have since been approved for launch with this mission. From our perspective, this opportunity is not only unprecedented, it is expected to open a new era for satellite beacon science. For the first time, there will be as many as nine eight tri-frequency beacon satellites operating simultaneously, eight will provide coverage of the low-latitude ionosphere. We refer to this combined set as the enhanced TBEx (eTBEx) opportunity or mission. In this presentation, we describe the TBEx and eTBEx concepts in more detail, and discuss some of the expected scientific results.

It is abundantly clear that a ground-based network of radio receivers that can receive the satellite transmissions are crucial to the success of this eTBEx mission. In this regard, there is complementary effort underway to design new antennas and digital receivers that will be capable of receiving the transmissions from both TBEx and Cosmic-2 satellites. A companion presentation that will describe the progress will be presented by Professor Mamoru Yamamoto.

Key words: Tandem Beacon Explorer (TBEx), Low-inclination beacon satellites, Total electron content, Scintillation, Large-scale wave structure, Equatorial plasma bubbles

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