
AN EXPLORATION OF THE VALLEY REGION IN THE LOW-LATITUDE IONOSPHERE: RESPONSE TO FORCING FROM BELOW AND ABOVE AND RELEVANCE TO SPACE WEATHER

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ABSTRACT

The ionosphere valley region extends from the peak altitude of the daytime E-region electron density profile to the bottomside F-region, typically covering the 110 to 200 km altitudes. This is a region of complex coupling processes between the neutral and ionized components of the atmosphere as plasma consists in this region of magnetized electrons and ions transitioning from collision to magnetically dominated domains. It is the effective boundary between terrestrial and space weather domains and is important for shaping the entire ionosphere. Yet it is one of the least understood regions of the atmospheric/ionospheric system. In the case of low magnetic latitudes, this region develops dynamical and chemical features modulated by a complex interplay of atmospheric and ionospheric processes. The low-latitude valley region (LLVR) has been mainly explored with ground-based radars. These have revealed the existence of strong irregularity structuring, the source of which as well as spatial, altitudinal, spectral, and temporal characteristics have been a long-standing mystery. Despite this lack of understanding, researchers often use the Doppler shifts of daytime LLVR echoes to monitor equatorial F-region zonal electric fields, a key parameter necessary for understanding the entire low latitude electrodynamics.

Observing this region remotely has always been a challenge due, among other factors, to the lower ionization than the surrounding E and F regions. It also lies above the range of balloons and below the orbit of satellites. It is now timely to put a special effort into investigating this region since an increasing number of global observations from ground and space, as well as sophisticated modeling of the whole atmosphere are making rapid progress to characterize the near space environment.

In order to further our understanding of lower atmospheric forcing of the LLVR and, in turn, low latitude space weather, we propose to bring together a multi-disciplinary group of experts to contribute to the 4D (altitude, longitude, latitude, time) exploration of the region. We will evaluate ground, satellite, and rocket observations as well as atmosphere-ionosphere coupled numerical models. In addition, since radar echoes can be used as responses of the different atmospheric/ionospheric drivers, expertise in plasma physics and plasma simulations is needed to connect the coupling processes with the plasma irregularities responsible of the echoes. In the process of understanding the echoes, we will improve the understanding of the region, since the required information, e.g., gravity wave forcing, is not well known.

Among other outputs, we expect to plan future observational campaigns that take into account the expertise gathered. By this effort we envision that the understanding of upper atmosphere electrodynamics will be enhanced by yet unexpected mechanisms hidden in the Valley region.

Note: This is the second time this proposal is submitted to ISSI. Based on the encouraging and positive reviews of the first proposal, we are submitting it again. This time we are making a clear emphasis in the synergy of the different components invoked by indicating the questions that they will be involved in, and by stressing that the proposal is not only devoted to understand the LLVR echoes, but more importantly to the understand the atmospheric and ionospheric processes of the region where the echoes occur.

SCIENTIFIC RATIONALE

The LLVR has a number of peculiarities: (a) it is the transition region between an atmosphere dominated by molecular ions to one dominated by atomic ions; (b) it connects to the northern and southern E region near the equatorial electrojet belt, (c) it contains intermediate layers of metallic ions, (d) its electron temperature exceeds the ion temperature by a larger fraction than at F region altitudes (e) it has the highest photoelectron production rate in the ionosphere, (g) its daytime electron density is usually less than the E and F region peak densities.

The LLVR has been difficult to explore with conventional ground-based ionospheric instruments because of its lower plasma density. Standard ionosondes generally cannot examine most of this region and incoherent scatter radar techniques cannot accurately determine the composition and temperatures simultaneously. Furthermore, the region is too low for *in situ* measurements with satellites. So far the LLVR has been mainly studied using powerful ground-based radars at different latitudes and longitudes and a handful of *in situ* measurements from rockets. It is therefore a challenge to characterize and understand the LLVR and the processes therein.

Figure 1 shows the altitude-time behavior of daytime radar echoes, usually called "150-km echoes", for nine days in January 2009, observed with Jicamarca VHF radar located in Peru. These echoes that occur in the LLVR have been studied for more than 50 years, but an explanation of the underlying drivers has been elusive. Note that the echoes are arranged in multiple layers presenting a necklace shape (i.e., higher around sunrise and sunset and lower around noon), the signals show periodicities ("pearls") that repeat every few minutes, and their day-to-day variability is significant. Characteristically similar echoes have been observed at other longitudes, but always at latitudes close to the magnetic equator. The annual characteristics of these echoes show different patterns at different longitudes. For example, in the central Pacific Ocean the echoes are mainly present during the June-August months, while in Peru and India, they are present all year long. A summary of the characteristics of daytime echoes can be found in *Chau and Kudeki* [2013] and references therein.

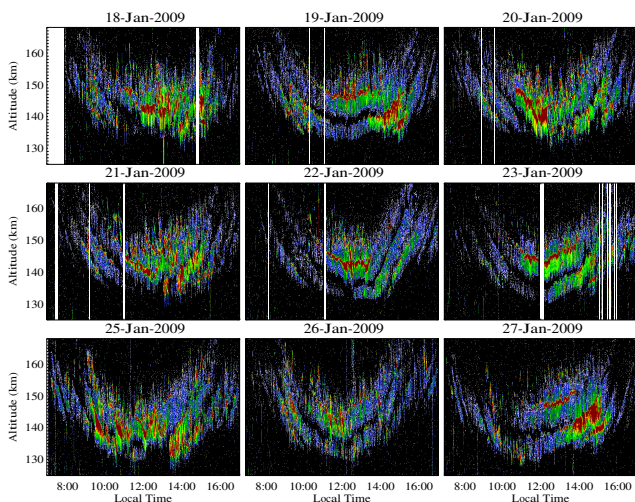


FIGURE 1. EXAMPLES OF DAYTIME VALLEY ECHOES OVER PERU. NOTE THE DAY-TO-DAY VARIABILITY IN TERMS OF STRENGTH, NUMBER OF LAYERS, SMALL PERIODICITIES, ETC (AFTER CHAU AND KUDEKI, 2013)

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Recently, *Oppenheim and Dimant* [2016] have suggested that photoelectron-induced plasma waves may play a role in the production of daytime echoes. This is an interesting and promising suggestion as the height distribution of photoelectrons in the daytime ionosphere may match the envelope of the necklace shape of the 150 km echoing regions. However, fine structure features like the pearls, layers, day-to-day variability, longitudinal and seasonal dependence of the necklace still need to be explained, presumably in terms of lower atmosphere forced waves coupling to the region, either directly or remotely via field line mapping.

During the nighttime, when the E region conductivity is low, the observed echoes present a different morphology to their daytime counterpart. In Figure 2 we show an example of nighttime echoes observed over Peru as function of time and altitude. The echoes above ~ 200 km are the so-called equatorial spread F (ESF) echoes associated with plasma depletions, plasma bubbles, scintillations, i.e., to low latitude space weather. For the proposed team, the echoes of interest are the echoes below 200 km, which can occur as early as twilight hours but show an important prerequisite for post-sunset irregularities.

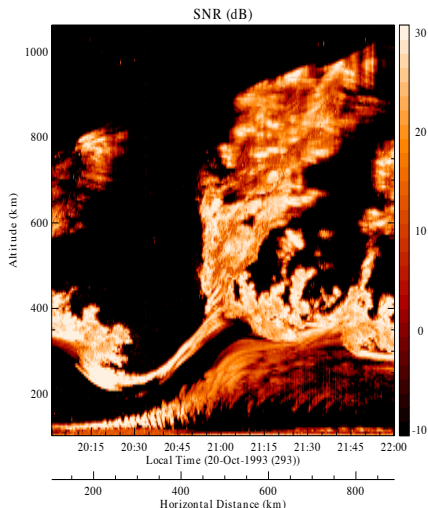


FIGURE 2. EXAMPLE OF NIGHTTIME ECHOES OBSERVED OVER PERU. THE ECHOES ABOVE ~ 200 KM ARE THE SO-CALLED EQUATORIAL SPREAD F (ESF) ECHOES. THE VALLEY ECHOES OCCURRED BELOW THE ESF ECHOES (ADAPTED FROM WOODMAN AND CHAU [2001]).

including metallic ions, (d) electric fields, (e) field-aligned currents, and (f) electron densities (profiles and perturbations). Determining these parameters requires tools beyond the historically used single-site radars and a multidisciplinary approach. In the process of understanding these echoes, we will improve the understanding of the processes governing the LLVR. For example, are the gravity wave features observed in the daytime LLVR echoes directly propagating from lower altitudes?, are the observed longitudinal and latitudinal differences of the echoes associated to lower atmospheric forcing via gravity waves and tides?

Some of the above parameters that are critical for understanding the LLVR will be available for the first time from the upcoming ICON satellite mission, and others can come from whole atmosphere models with and without data assimilation schemes. Among other parameters, ICON will measure remote sensing profiles of winds, composition and temperatures between 90 and 300 km, and *in situ* electric fields and electron densities. Almost simultaneously, the GOLD mission will provide composition and temperature measurements around 160 km, spanning the low-latitude region from South America to Western Africa. These observations, combined with high-resolution electrodynamics simulations that are constrained at the larger scales by whole atmosphere models and/or observations, present an opportunity to provide new insights into the processes governing the daytime and nighttime LLVR.

SCIENTIFIC GOALS

Based on the known features of daytime and nighttime radar echoes in the LLVR, the existing and upcoming observations from satellites and rockets, the availability of new ground-based capabilities to explore the region, and the recent developments in whole atmosphere modeling and high-resolution plasma simulations, we have identified several key scientific questions that will be addressed by the members of the proposed team.

1. How do daytime and nighttime LLVR parameters connect to nighttime low-latitude space weather?

2. What physical processes create the observed altitudinal (layering) and temporal (pearls) of daytime LLVR echoes?
3. How does the troposphere and stratosphere affect the observed spatial and seasonal variability of daytime LLVR echoes?
4. How do neutral winds and plasma instabilities interact to create and modify nighttime LLVR echoes?

Although the majority of the questions are related to the understanding of radar echoes and their features, answering them will help understanding the processes governing the LLVR. Therefore, we will require the different expertise of the proposed team members. For example, so far no one, as far as we know, has really looked in detail at these altitudes in the new coupled whole atmosphere-ionosphere models. Similarly, connecting existing in-situ rocket measurements of the LLVR with the radar echoes and the plasma and electrodynamics simulations will be needed.

The proposed team will also benefit from the on-going projects of the team members and from the goals of some of the scientific groups where they are currently participating. For example, team-members have recently completed a two-year long WACCMX (Whole Atmosphere Community Climate Model with thermosphere and ionosphere extension) reanalysis by using data assimilation to constrain the model meteorology. Similarly a low-latitude NASA rocket campaign is underway. In the case of the upcoming ICON satellite mission, one of their main questions is "What causes the high temporal and spatial quiet-time variability in the daytime low-latitude ionosphere?" that goes inline with our Question 3.

Finally, our efforts would also be beneficial for related communities. We expect that our efforts will contribute to a better understanding of the nighttime low latitude space weather, specifically the triggering of F region irregularities, which affect the accuracy of navigation signals like GPS or Galileo (Question 1).

EXPECTED OUTCOMES

The results of the proposed project will be presented at multiple national and international conferences. We expect to publish preliminary progress during the first year and identify special observing and modeling campaigns (e.g., around strong solar-flares, sudden stratospheric warming events, etc.). A special issue compiling results from concerted team efforts is expected to close the team activities. As by products, we expect that the proposed project activities will help promote seek funding at different national and international agencies to pursue some of the pending activities towards improving the exploration and understanding of the LLVR.

ADDED VALUE OF ISSI

The proposed project explores an important region of near Earth Space, the valley region that is so far not well understood, though being important for aeronomy. Advancing knowledge in this region will put ISSI into a key leader position in initiating novel efforts, where it is urgently needed. The project brings together a multidisciplinary team of experts on observational techniques and numerical modeling of the neutral atmosphere, the ionosphere, and plasma instabilities. Such a diverse and international team, needed due to the nature of the proposed topic, would be difficult to assemble through conventional funding. ISSI provides a unique opportunity to bring together this group of experts to comprehensively address the proposed research topic. ISSI further provides a forum for establishing and strengthening collaborations, propose international campaigns, and foments the publications of the progress promoted and obtained.

PARTICIPANTS

The proposed team is composed of an international group of scientists with expertise and interest on a broad range of disciplines, but more specifically with expertise on neutral atmosphere, ionosphere and plasma physics. It includes experts familiar with ground- and satellite-based observations of the

atmosphere/ionosphere with particular emphasis on the LLVR. The list is complemented with modeling expertise on global whole atmosphere, 3D electrodynamics, and 3D particle-in-cell simulations. The internationality and high scientific profile of the team reflects the large interest in this topic, and will anchor low latitude ionosphere and aeronomy research in Europe through exchange of expertise. Table 1 summarizes the list of confirmed team members, their country, their expertise (tool and area), and the questions that they will help answering. More specific information can be found in the accompanying curriculum vitae.

TABLE 1. LIST OF TEAM MEMBERS INDICATING NATIONALITY AND MAIN EXPERTISE.

Name	Country	Ground-Based	Satellites	Rockets	Models	Neutral Atmosphere	Ionosphere	Plasma Physics	Q1	Q2	Q3	Q4
Chau, J.	Germany	✓				✓	✓	✓	✓	✓	✓	✓
England, S.	USA		✓			✓			✓		✓	
Hysell, D.	USA	✓	✓	✓	✓		✓	✓	✓	✓		✓
Kudeki, E.	USA	✓		✓	✓	✓	✓	✓	✓	✓		✓
Liu, H.	Japan		✓		✓	✓	✓		✓		✓	
Oppenheim, M.	USA				✓			✓		✓		✓
Otsuka, Y.	Japan	✓				✓	✓		✓		✓	
Patra, A.	India	✓		✓		✓	✓	✓	✓	✓	✓	✓
Pedatella, N.	USA		✓		✓	✓	✓		✓		✓	
Stolle, C.	Germany	✓	✓				✓	✓	✓		✓	
Vierinen, J.	Norway	✓					✓	✓		✓		✓

PROJECT SCHEDULE

We plan to have two weeklong meetings held at ISSI (Bern). The first one between July 2018 and March 2019 and the second one will be 6-12 months later. Prior to the first meeting we will agree upon 3 campaigns with varying solar and lower atmospheric weather conditions, for example, under different Sudden Stratospheric Warming events (e.g., Pedatella *et al.*, 2016). During the first meeting we will present preliminary results from model simulations and observations, with the aim to help addressing any of the planned key question. Similarly new measurements (upcoming or not previously used) will be presented and discussed. One expected outcome of the first meeting is the identification and planning of a multi-instrument campaign around special lower atmospheric conditions. The second meeting will focus on a more detailed investigation around specific meteorological conditions identified during the first meeting. The aim is to have the publications of the progress accomplish under this team in a special issue.

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