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# LAICE CubeSat mission for gravity wave studies

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**Abstract**

The Lower Atmosphere/Ionosphere Coupling Experiment (LAICE) CubeSat mission will focus on understanding the interaction of atmospheric gravity waves generated by weather systems in the lower atmosphere with the mesosphere, lower thermosphere, and ionosphere (MLTI). Specifically, LAICE will focus on the energy and momentum delivered by these waves and attempt to connect the wave sources and the wave effects in three widely different altitude ranges, substantially adding to our knowledge of critical coupling processes between disparate atmospheric regions. The LAICE mission consists of a 6U CubeSat with a four-instrument payload. The retarding potential analyzer (RPA) will provide in-situ ion density and temperature measurements. A four-channel photometer will measure density and temperature variations in the mesosphere through observations of $O_2$ (0, 0) Atmospheric band and $O_2$ Herzberg I band airglows. There are two pressure sensors that comprise the Space Pressure Suite (SPS): the Space Neutral Pressure Instrument (SNeuPI) and the LAICE Ionization gauge Neutral Atmosphere Sensor (LINAS). Both will provide neutral density measurements, but SNeuPI is a prototype sensor that will be validated by LINAS. This CubeSat mission, scheduled for launch in early 2016 from the International Space Station, provides a cost-effective approach to measuring low altitude in-situ parameters along with simultaneous imaging that is capable of addressing the fundamental questions of atmospheric gravity wave coupling in the MLTI region.


*Keywords:* CubeSat; Atmospheric coupling; Gravity waves; Airglow; Ionosphere

## 1. Introduction

The Lower Atmosphere/Ionosphere Coupling Experiment (LAICE) is a groundbreaking mission in low Earth orbit (LEO) focused on understanding how atmospheric gravity waves generated by weather systems in the lower atmosphere propagate and deliver energy and momentum into the mesosphere, lower thermosphere, and ionosphere (MLTI). These waves are an important facet of atmospheric physics, but their effects in the thermosphere and ionosphere are under-explored. They strongly influence the dynamics of the media through which they travel via momentum and energy deposition at altitudes well above their source regions, and they can seed the development of plasma instabilities that scintillate

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and disrupt radio propagation. LAICE will focus on these waves and attempt to connect their causes and effects in three widely different altitude ranges, substantially adding to our knowledge of a critical coupling process between disparate atmospheric regions.

LAICE will utilize in-situ instrumentation to measure the perturbations the waves produce in both neutral and ion densities at F-region heights, while on-board photometers simultaneously remotely measure the wavelengths and amplitudes of the wave fields in the upper mesosphere. Subsequent modeling coupled with meteorological data will be used to study the connections between tropospheric storms and the MLTI system using ray tracing techniques that include the effects of viscosity and wave dissipation. This mission data will also be applied to additional coupling studies, e.g., analyzing connections between other wave-generating mechanisms and the MLTI system.

### 1.1. Background and motivation

In Earth's high latitude regions the ionosphere is primarily influenced by energy flowing downward along magnetic field lines from high altitudes, but at middle and low latitudes the ionosphere is also affected by energy and momentum transferred via upward-propagating gravity waves. Bauer (1958) was one of the first to notice such an effect, using ionogram data to reveal variations in the height of the F-region associated with a tropical hurricane. Subsequent studies with greater sensitivity confirmed these early observations (e.g., Bishop et al. (2006)), while other studies have reported ionospheric manifestations of less severe terrestrial weather systems, including tropical storms, tornadoes, and even thunderstorms (Pierce and Coroniti, 1966; Hung et al., 1978; Larsen et al., 1982; McClure, 1998; Earle et al., 2008, 2010). Importantly, every one of these studies cites gravity waves (e.g., Hines (1960)) as the most likely mechanism by which energy is transferred from low to high altitudes.

The wealth of observational evidence for tropospheric weather-induced gravity wave influences on the ionosphere is not disputed, but despite the half century over which these phenomena have been observed the relative magnitude of the energy transferred, the spatial scales of the affected regions, the locations of the strongest coupling regions, and the climatology of the coupling events are not well known. The references above provide anecdotal observations of ionospheric effects that appear to be driven by weather systems, but we do not have detailed measurements relevant to the coupling processes, largely because the region where it occurs is too low to be readily accessible to satellites, and not easily monitored by ground-based systems.

Theory predicts that gravity waves (GWs) with large vertical and horizontal group velocities can propagate to high altitudes and survive the pervasive molecular viscosity that is characteristic of the thermosphere (i.e., $z > 110$ km) (Vadas and Fritts, 2005, 2006; Vadas and Liu, 2009, 2013; Liu and Vadas, 2013; Vadas et al., 2014). Questions about the influences of these waves are among the most important unknowns in atmospheric coupling studies. For example, are the electric fields generated in highly conductive regions by GW-driven perturbations important drivers of higher altitude plasma drifts, as some studies suggest (Hanson and Johnson, 1992; Farrell et al., 1994)? Do wave disturbances from below occur preferentially in particular geographic regions, at particular local times, or in specific seasons? How are active wave regions in the thermosphere related to the wave spectrum in the underlying mesosphere and to terrestrial weather systems in the troposphere? Is there a storm severity threshold or governing temporal characteristic controlling the efficacy of upward wave coupling? These are just a few of the fundamental questions whose answers have eluded atmospheric scientists largely because of restricted access to the altitudes of interest. In-situ wave observations are needed to address issues of such a global nature, but these must occur at relatively low altitudes where the short lifetimes of traditional satellite missions are unacceptable relative to their high cost.

### 1.2. LAICE mission

The CubeSat approach to space science in LEO helps to mitigate restrictions to such research, and enables missions that can address these and other fundamental science questions at a reasonable cost. The LAICE CubeSat mission has been designed address these questions with two fundamental mission goals:

1. Systematically observe and correlate gravity waves that have large vertical wavelengths (>30 km) by combining remote sensing of wave-induced airglow perturbations in the upper mesosphere with in-situ measurements of ion and neutral density fluctuations at ionospheric F-region altitudes;
2. Produce global maps of active gravity wave coupling regions in the mid- and low-latitude ionosphere over multiple seasons at all local times, so that global patterns and climatological variations can be quantitatively compared to and correlated with terrestrial weather systems.

Though the focus of LAICE is on waves generated in the troposphere which propagate upward to ionospheric heights, GWs have other sources, e.g., Joule heating of neutrals during magnetic activity and GWs excited by the solar terminator. These other sources have been studied for decades, however (Hocke and Schlegel, 1996). Gravity waves propagating to the thermosphere from lower atmospheric sources have only been known to occur for the last decade, and have gained increasing importance in the community for causing large fluctuations in the thermosphere and ionosphere when the Kp is low. Deep convection is likely an important everyday source of gravity waves in the thermosphere based on recent modeling studies