Daedalus

a Candidate ESA Earth Explorer Mission for the Exploration of the Lower Thermosphere-Ionosphere

Theodoros Sarris and the Daedalus Science Study Team

EGU-2020, Thu, 07 May, 08:30–12:30

D2991 | EGU 2020-20711 ST3.1: Open Session on Ionosphere and Thermosphere
Background and Justification

**Lower Thermosphere-Ionosphere:**
A key transition region in the atmosphere
Background and Justification

Lower Thermosphere-Ionosphere:
A key transition region in the atmosphere

- Drastic Temperature Increases
- Sharpest gradients
- Largest variability

Lower Thermosphere-Ionosphere at altitudes 100-200 km:
Where the neutral atmosphere meets electromagnetic forcing
Background and Justification

The Lower Thermosphere-Ionosphere during the 2015 St. Patrick’s Day geomagnetic storm on March 17

WACCM-X simulation by Federico Gasperini (NCAR/HAO), AMIE assimilation of ionospheric electrodynamics by Gang Lu (NCAR/HAO), AE index data from WDC for Geomagnetism Kyoto, animation by Eelco Doornbos (KNMI)
Overview of main processes in the Lower Thermosphere-Ionosphere

Processes that Daedalus will directly observe in-situ are marked in red

Energetics
- Variations in magnetospheric and ionospheric electric currents
- Joule heating
- Energetic particle precipitation

Dynamics & Variability
- Upward propagating atmospheric gravity waves, planetary waves and tides
- Variations in satellite drag
- Thermosphere-ionosphere variability

Chemistry
- Variations in ionospheric electron density
- NOx production
- Geomagnetic field variations
- Geomagnetically Induced Currents (GIC)

Causes
- Solar active regions
- Eruptive phenomena on the Sun
- Solar wind variability
- Variations in solar radiation at Earth
- Solar wind structures at Earth
- EUV absorption, heating and ionisation
- Variations in magnetospheric and ionospheric electric currents

Consequences
- Uncertainty in orbit prediction
- Radio signal refraction and absorption
- Changes in Ozone
- Transformer heating, voltage and AC harmonics fluctuations

Impacts
- Large margins required in low Earth orbit space operations
- Navigation and communication signal degradation
- Impact on lower atmosphere
- Difficulties in management of and damage to power grid
Mission Objectives

Joule heating & particle precipitation in the Lower Thermosphere-Ionosphere and targeted altitudes of Daedalus
Mission Objectives

- **Daedalus in-situ sampling of Joule heating at the regions where it maximizes**
- **Discrepancies in existing Joule heating estimations**

- TIE-GCM TN
- 600-1200 K
- Height 5x

Scene Generation simulations for Daedalus Performance Demonstration

Palmroth et al., Ann. Geophys., 2004
Mission Objectives

A. Science Questions related to Energetics:

• What is the energy deposited per unit volume at Lower Thermosphere-Ionosphere altitudes via Joule heating & Energetic Particle Precipitation?

• How does this energy deposition affect the local transport, thermal structure, & composition within Lower Thermosphere-Ionosphere altitudes?
B. Science Questions related to Dynamics:

- What are the relative contributions of solar, magnetospheric, and atmospheric forcing influencing Lower Thermosphere-Ionosphere fluid dynamics and electrodynamics at high, mid and low latitudes?

- What are the amplitudes and spectra of small-scale Gravity Waves in the Lower Thermosphere-Ionosphere?

- How do large shears, sharp gradients, and small-scale plasma instabilities develop in the Lower Thermosphere-Ionosphere?
Mission Objectives

C. Science Questions related to **Chemistry:**

- **What are the effects of Energetic Particle Precipitation on the ionisation and composition of the Lower Thermosphere-Ionosphere?**

- **What are the dominant processes in HOx and NOx production in the Lower Thermosphere-Ionosphere?**

- **How much Energetic Particle Precipitation strikes onto the mesosphere/stratosphere?**

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## Mission Requirements

### Daedalus Derived Products:

<table>
<thead>
<tr>
<th>Derived Product</th>
<th>Derived Product Symbolism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joule Heating ( q_j )</td>
<td>( q_j = j \cdot (E + \tau_n \times B) )</td>
</tr>
<tr>
<td>Ohmic Heating ( q_o )</td>
<td>( q_o = \sigma_j</td>
</tr>
<tr>
<td>Frictional Heating ( q_f )</td>
<td>( q_f = m_i v_i N_e</td>
</tr>
<tr>
<td>Poynting Vector ( S ) in the neutral gas frame</td>
<td>( S = (E + \tau_n \times B) \times \Delta B / \mu_0 )</td>
</tr>
<tr>
<td>Energetic Particle Precipitation heating ( q_{EPP} ) (upper limit)</td>
<td>( q_{EPP} )</td>
</tr>
</tbody>
</table>

### Heating Sources:

| In-situ current density \( j \): Hall \( j_h \) and Pedersen \( j_p \) currents | \( j = q N_e (v_i - v_e) \) or: \( j = j_h + j_n \) |
| Magnetic Forcing (MF) | \( \tau \times B \) |
| Field Aligned Currents (FAC) | \( \Delta B / (\mu_0 \Delta x) \) |
| Magnetic Field Residuals \( \Delta B \) | \( \Delta B = B_{obs} - B_{mod} \) |

### Conductivities & Cross-Sections:

- Conductivities: \( \sigma_p, \sigma_{\parallel}, \sigma_{\perp} \)
- Ion-Neutral Cross Sections: \( \sigma_{in} \)
- Ion-Neutral Collision Frequencies: \( \nu_{in} \)

### Daedalus Geophysical Observables:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Geophysical Observable</th>
<th>Commonly used instruments</th>
<th>Instrument Abbreviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_i )</td>
<td>Ion Drift velocity</td>
<td>Thermal Ion Imager or Ion Drift Meter and Retarding Potential Analyzer</td>
<td>TI or IDM/RPA</td>
</tr>
<tr>
<td>( T_i )</td>
<td>Ion Temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( T_e )</td>
<td>Electron Temperature</td>
<td>Langmuir Probe and Mutual Impedance Probe</td>
<td>LPB and MPI</td>
</tr>
<tr>
<td>( N_i )</td>
<td>Ion Number Density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( N_e )</td>
<td>Electron Num. Density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEC</td>
<td>Total Electron Content</td>
<td>GNSS Receiver</td>
<td>GNSS</td>
</tr>
<tr>
<td>( n_{ix} )</td>
<td>Ion Composition</td>
<td>Ion Mass Spectrometer</td>
<td>IMS</td>
</tr>
<tr>
<td>( U_n )</td>
<td>Neutral Wind Velocity</td>
<td>Ram Wind Sensor and Cross-Track Wind Sensor</td>
<td>RWS/CWS</td>
</tr>
<tr>
<td>( N_n )</td>
<td>Neutral Density</td>
<td>Accelerometer</td>
<td>ACC</td>
</tr>
<tr>
<td>( T_n )</td>
<td>Neutral Temperature</td>
<td>Neutral Mass Spectrometer</td>
<td>NMS</td>
</tr>
<tr>
<td>( \Omega_{ex} )</td>
<td>Neutral Composition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( J_{\text{He}} )</td>
<td>Energetic Particles</td>
<td>Energetic Particle Detector</td>
<td>EPD</td>
</tr>
<tr>
<td>( B )</td>
<td>Magnetic Field</td>
<td>Magnetic Field Instrument</td>
<td>MFI</td>
</tr>
<tr>
<td>( E )</td>
<td>Electric Field</td>
<td>Electric Field Instrument</td>
<td>EFI</td>
</tr>
</tbody>
</table>
Mission Requirements

In-situ sampling by rockets:
Mission Requirements

Sarris et al., Geosci. Instr. Dev., 2020

Daedalus in-situ measurements

Joule heating Rate

Pedersen Conductivity

Electron Density

Sounding rocket measurements

Mission Requirements

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Electron Density $[\times 10^{11} \text{ m}^{-3}]$  
Pedersen Conductivity $[10^{-5} \text{ mho/m}]$  
Joule heating Rate $[\text{mW/m}^3]$
Mission Concept

Perigee and Local Time precession and Coverage (movie)  Preliminary concept with twin s/c configuration (movie)
Summary and Conclusions

- The QUEST for Daedalus is to explore the atmosphere-space transition region.
- The AIM is to better understand the atmosphere-space connection that plays out there.
- The PATH to science closure is to establish sufficient coverage of the relevant regions at the necessary scales with sufficient instrument performance.

Daedalus will improve our understanding of the **energetics**, **dynamics**, and **chemistry** of the atmosphere-space transition region in the lower thermosphere-ionosphere, and of the neutral-plasma interactions that affect them.
More information on Daedalus

For more detailed information on the mission definition and science visit:

- The **Daedalus website** at [https://daedalus.earth/](https://daedalus.earth/)

- Our **virtual conference** (originally planned as a splinter during EGU2020) with several presentations and discussions by scientists ([agenda here](#)). Registration is possible via: [https://tinyurl.com/vkvumuq](https://tinyurl.com/vkvumuq).