Energy Budget of the Mesosphere and Lower Thermosphere from SABER Observations

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Outline

• Overview
• Methodology
• Infrared Cooling
• Solar Heating
• Chemical Heating
• Totals
• Thermosphere
• Summary
Overview

ENERGY BALANCE
Mesosphere and Lower Thermosphere

- Absorption of Solar Radiation
- Joule & Particle Heating
- Intense Currents
- Adiabatic Heating & Cooling
- Transport of Heat & Chemical Energy
- Winds & Tides Heat Flow
- Radiative Cooling
- Airglow Loss
- Redistribution of Energy by Chemical Reactions
- Gravity Wave Changes to Circulation & Intrachemical Heating
Overview

Launched Dec 2001
625 km circular orbit
74 degree inclination
17 + years of operation
Methodology

• SABER measures the vertical distribution of infrared radiation emitted by various atmospheric gases (ozone, water vapor, nitric oxide, and carbon dioxide), providing important information about the radiation budget in the upper atmosphere.

• From the SABER radiances, we determine the radiative cooling by CO$_2$, solar heating by O$_3$ and O$_2$, and chemical heating from a suite of exothermic reactions over the vertical range of 65-100 km. These measurements, combined with accurate determination of the temperatures allow the radiative and chemical contributions to the heat budget to be assessed and the net effect of dynamics to be inferred.

• SABER measurements also support the inference of atomic species, including atomic oxygen and atomic hydrogen.
The three major cooling sources in the mesosphere are:

- carbon dioxide at 15 μm
- ozone (9.6 μm)
- water vapor at 6.7 μm and in the far-IR (> 20 μm).

$\text{CO}_2$ radiative cooling in the fundamental, isotopic and hot bands at 15 μm is the dominant source of cooling in the 65-100 km altitude range.
Solar Heating

O₂ Heating

The predominant solar heating mechanisms in the upper mesosphere involving photolysis of molecular oxygen are in the Schumann-Runge bands (175-205 nm), the Schumann-Runge continuum (122-175 nm), the Lyman-alpha line (121.5 nm) and the O₂ A-band.
O₃ Heating

- The Hartley band region (~240-310 nm) is of primary importance for heating by photodissociation of ozone in the mesosphere.
Chemical Heating

A key component of heating in the 80-100 km region is energy released from exothermic chemical reactions:

- $O + O + M \rightarrow O_2 + M$
- $H + O_3 \rightarrow OH + O_2$
- $O + O_2 + M \rightarrow O_3 + M$
- $O + O_3 \rightarrow O_2 + O_2$
- $H + O_2 + M \rightarrow HO_2 + M$
- $O + OH \rightarrow H + O_2$
- $O + HO_2 \rightarrow OH + O_2$
Chemical Heating

SABER Daytime Chemical Heating Annual Average

SABER Nighttime Chemical Heating Annual Average

6/17/19
Component Totals

Global Annual Heating and Cooling, 2002

Global Annual Heating and Cooling, 2008

Global Annual Heating and Cooling, 2014

- O2 Solar Heating
- O3 Solar Heating
- Nighttime Chemical Heating
- Daytime Chemical Heating
- CO2 Radiative Cooling
Total Heating & Cooling

2002

Global Annual Heating and Cooling, 2002

2008

Global Annual Heating and Cooling, 2008

2014

Global Annual Heating and Cooling, 2014

- Total Heating (Solar + Chemical)
- CO2 Radiative Cooling
• Radiative cooling in the thermosphere is the action of infrared radiation to reduce the kinetic temperature of the neutral atmosphere. It is accomplished almost entirely by two species, CO2 at 15 μm and NO at 5.3 μm in response to solar input: flare, CME, energetic particles in the solar wind.

• Collisional processes are highly temperature dependent.

• Cooling depends on T, [O], and NO or CO2 amount

• NO is also chemically active, increasing substantially during geomagnetic storms
Poster LTVI-02 in the Mesosphere and Lower Thermosphere Session tomorrow
Summary

• The SABER instrument on the TIMED satellite is providing the first comprehensive measurements of key parameters for quantifying the heat budget and chemistry of this region. Key findings:
  
• Solar variability is observed in every parameter examined to date, including temperature, constituents and energetics (heating and cooling).

• Energetics changes appear consistent with changes in structure.

• Temperature, Atomic Oxygen decrease during the solar cycle minimum

• Atomic hydrogen is observed to increase during solar min consistent with Ly-α decrease

• Ozone variation depends on altitude, but increases during solar min above 60 km

• Within the mesosphere, the largest absolute changes are observed near the mesopause.

• In the thermosphere, NO and CO2 serve as a natural thermostat to convert incoming solar energy to infrared energy that is radiated to the lower atmosphere and to space.

• Solar cycles 23 and 24 are very different in many ways, and that is apparent in the Earth’s atmospheric response as well.
Backup Slides
## SABER Channels and Data

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<thead>
<tr>
<th>Species</th>
<th>Wavelength</th>
<th>Data Products</th>
<th>Altitude Range</th>
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<tbody>
<tr>
<td>CO₂</td>
<td>15.2 µm</td>
<td>Temperature, pressure, cooling rates</td>
<td>15-100 km</td>
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<td>15-100 km</td>
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<td>O₃</td>
<td>9.6 µm</td>
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<td>H₂O</td>
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<td>Water vapor, cooling rates</td>
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<td>NO</td>
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<td>Thermospheric cooling</td>
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<td>Day O₃, solar heating; Night O</td>
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<td>OH(u)</td>
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<tr>
<td>OH(u)</td>
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