Simulation study for Ku-band microwave radiometry of the polar atmosphere

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BAS – Space Weather & Atmosphere

Electrons

Protons

Solar wind

Outer belt

Inner belt

Chorus source region

Electron slot

Plasmasphere

Protons

British Antarctic Survey

Polar Science for Planet Earth
BAS – Space Weather & Atmosphere
Science & Innovation

• Science priorities
  – Space radiation environment.
  – Atmospheric heating.
  – Space-atmosphere coupling.
  – Solar effects on climate.

• Technologies / expertise
  – Instruments: Ground-based radars, radiometers, VLF receivers, & magnetometers.
  – Computer models: BAS radiation-belt model, atmosphere models.
  – Data: Exploiting ground and space-based observations.
Ku-band atmospheric microwave radiometry
Space weather and the polar atmosphere

Hydroxyl (OH) at 70–78 km

Mesospheric ozone (O₃)

High 100-300 keV electron flux

Low 100-300 keV electron flux
Ku-band atmospheric microwave radiometry
Space weather and the polar atmosphere

• The polar middle atmosphere responds strongly to solar variability and space weather.

• ~1250 magnetospheric substorms / year ⇒ high energetic electron flux.

• New O₃ and OH measurements are needed to verify model predictions.
Ku-band atmospheric microwave radiometry

Atmospheric model – Sub-storms in December 2007

O₃

OH
Ku-band atmospheric microwave radiometry
Ku-band microwave region

O₃ 11.072 GHz
OH 13.44 GHz
Ku-band atmospheric microwave radiometry
From satellite TV to remote sensing

- Continuous atmospheric $O_3$ and OH profiling from the ground using satellite TV receiver technology.
- Ground-based, passive technique.
- Radiometers can be assembled from low-cost, COTS components.
Ku-band atmospheric microwave radiometry
Optimal estimation retrieval

- Measured calibrated spectrum,
  \[ y = F(x, b) + \epsilon \]
  - \( F \) – Forward model
  - \( x \) – State vectors
  - \( b \) – additional parameters;
  - \( \epsilon \) – Measurement noise

- Linearised forward model,
  \[ y = F(\hat{x}_i, b) + K(x - \hat{x}_i) + \epsilon \]
  \( \hat{x}_i \) - Retrieval solution after \( i \)th iteration

- Jacobian matrix,
  \[ K = \frac{\partial F}{\partial x}\bigg|_{\hat{x}_i, b} \]

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Target species</th>
<th>Retrieved interfering* and background species</th>
<th>Bandwidth (MHz)</th>
<th>( \Delta T ) (mK)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.072</td>
<td>O_3</td>
<td>H_2O continuum*, OH, N_2, O_2, CO_2, HNO_3, H_2O_2, HO_2</td>
<td>12, 320</td>
<td>1–5</td>
</tr>
<tr>
<td>13.434, 13.441</td>
<td>OH</td>
<td>H_2O continuum*, O_3, N_2, O_2, CO_2, HNO_3, H_2O_2, HO_2</td>
<td>1, 12</td>
<td>1–10</td>
</tr>
</tbody>
</table>
Ku-band atmospheric microwave radiometry
Simulation results - Ozone
Ku-band atmospheric microwave radiometry
Simulation results – Hydroxyl (OH)
Ku-band atmospheric microwave radiometry

Conclusions

• Simulation techniques have been developed for modelling the retrieval of ozone and OH vertical profiles from 11–14 GHz microwave observations.

• Ku-band observations are highly applicable to future microwave instruments designed to study space weather events, atmospheric dynamics, planetary scale circulation, and chemical transport for polar and global climate modelling.

• Ground-based passive microwave remote sensing complements space-based EO.
  
  – \( \text{O}_3 \), \( \text{NO}_x \) \((\text{NO} + \text{NO}_2)\), \( \text{HO}_x \) \((\text{OH} + \text{HO}_2)\), \( \text{NO}_y \) species, tracers, temperature, humidity, zonal and meridional winds, vertical transport.