INFLAME
In-situ Net Flux within the Atmosphere of the Earth Experiment

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INFLAME Objective

• Measure the spectral dependence of radiative heating rates in the troposphere.
  – Flight demonstration goal is to measure net flux with sufficient stability to estimate radiative heating rates from the net flux divergence in 1 km layers of the troposphere with an accuracy of 10% at 5 km.

• Milestones:
  – Funded: 11/2005
  – Calibration: 7/2009
  – Test flight: 1/5/2010
Measurement Overview

• Consider a unit cube in the terrestrial atmosphere:
  – Spectral flux is the energy per unit frequency interval flowing through one face ($F^+$ or $F^-$);
  – Net Flux is the difference in energy flowing through one face in opposite directions:
    \[ F_z = F^+ - F^- \]
  – Flux divergence is given by $dF_z/dz$;
    • Assume $dF_x/dx$ and $dF_y/dy$ are small.
• Radiative heating rate is estimated from the measured flux divergence:
  \[ \frac{dT}{dt} = -\frac{1}{\rho c_p} \frac{dF_z}{dz} \]
Measurement Challenge

• What if we use uplooking and downlooking instruments to measure fluxes as functions of altitude, subtract to get net flux, and take the derivative to get flux divergence?
  – Need to measure small changes in the difference of large numbers:

<table>
<thead>
<tr>
<th></th>
<th>F+, W/m²</th>
<th>F-, W/m²</th>
<th>Fz, W/m²</th>
<th>dFz/dz, W/m² km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal IR</td>
<td>344</td>
<td>263</td>
<td>81</td>
<td>16.1</td>
</tr>
<tr>
<td>Solar</td>
<td>80</td>
<td>768</td>
<td>-688</td>
<td>-13.6</td>
</tr>
</tbody>
</table>

• Small systematic errors in measured F+ and F- can easily be as large as dFz/dz.
• Most instruments measure radiance, not flux.
• Measuring flux requires collecting light over a full hemisphere.
• We use a non-imaging Winston cone to collect radiation and collimate it into an f/6.8 beam.
  – Input aperture is 1mm diameter.
  – Output aperture is 13.6 mm diameter.
INFLAME Approach: Fz

- Direct uplooking and downlooking apertures to the two inputs of a 4-port Fourier transform spectrometer (FTS);
- Scan FTS to produce complimentary interferograms at two outputs;
- Fourier transform interferograms to estimate the spectrum of the net flux

\[ F_z = F_+ - F_- \]
• Measure the net vertical flux $F(Z1)$ at the base of the cube (altitude $Z1$).
• Measure the net flux $F(Z2)$ at the top of the cube (altitude $Z2$).
• The vertical flux divergence is estimated by:
  
  $$\frac{[F(Z2) - F(Z1)]}{(Z2 - Z1)}$$
INFLAME Measurement Platform

Learjet

INFLAME mounted in wingtip fuel tanks

4/29/2010
• We use two instruments to cover the required spectral range:
  – LW instrument covers thermal IR, 100 µm to 3 µm.
  – SW instrument covers solar, 3 µm to 0.3 µm.
• Main differences between LW and SW are the calibration sources, optical coatings, and detectors.
INFLAME Block Diagram: SW

SW Instrument Block Diagram

4/29/2010
Fuel Tank Integration

- Tip Tank Instrument Access Door
- Instrument Assembly
- Tip Tank Wet Section
- Wet/Dry Bulkheads
- Instrument Mounting Bulkheads
- Existing Bulkhead
- Instrument Electronics Enclosures
- Tip Tank Nose Cone
- Tip Tank Electronics Access Doors
Flight Track and Accelerometer

[Graphs showing flight track and accelerometer data]
Measured (left) and calculated clear (right top) and cloudy (right bottom) upwelling flux for 1/5/2010 flight. Clouds were included at 1-1.5 km and 5.5-6 km.
LW Downwelling Flux

Measured (left) and calculated clear (right top) and cloudy (right bottom) downwelling flux for 1/5/2010 flight. Clouds were included at 1-1.5 km and 5.5-6 km.
Measured (left) and calculated clear (right top) and cloudy (right bottom) net flux for 1/5/2010 flight. Clouds were included at 1-1.5 km and 5.5-6 km.
Measured (left) and calculated clear (right top) and cloudy (right bottom) cooling rates for 1/5/2010 flight. Clouds were included at 1-1.5 km and 5.5-6 km.
Summary

• IR FTS (LW): 3-100 µm in lab; 10-100 useful during flight.
  – Analysis is ongoing.

• UV-NIR FTS (SW) 0.6-1.1 and 1.4-3 µm in lab; no useful flight spectra obtained.
  – Commercial controller failed due to excessive drift with temperature before takeoff.
  – Sensitivity lower than expected, possibly due to shear; further lab investigation is required.