HIGH ALTITUDE THERMAL SOUNDING USING DOPPLER MODULATED GAS CORRELATION

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1. INTRODUCTION

This paper describes an important new measurement technique for high altitude thermal sounding (HATS), based on the Doppler modulated gas correlation (DMGC) approach. HATS measurements can potentially provide global temperature fields from cloud-top to 95 km at unprecedented spatial resolution. When assimilated into numerical weather models, these measurements can dramatically enhance forecast accuracy. HATS will enable prediction of the structure and effects of gravity waves on the lower and upper atmosphere, including their transport of energy and momentum, generation of turbulence, and their influence on plasma instabilities in the ionosphere. Gravity waves play a major role in determining the circulation, thermal structure, and temporal and spatial variability of stratosphere and mesosphere, and their effects extend well into the thermosphere[1]. The studies presented here confirm the measurement proof-of-concept and identify the technique's potential in next-generation sensors for atmospheric dynamics forecasting.

2. CURRENT STATE OF TECHNOLOGY

Atmospheric thermal sounding is routinely accomplished by observing emission in multiple spectral intervals of varying absorption strengths. Radiation received by a down-looking spacecraft emanates from various depths in the atmosphere. To infer the temperature at a specific altitude, the instrument must measure and distinguish emission that predominantly emanates from that altitude. However, spectral absorption lines from gases at high altitude are very narrow due to their lack of pressure broadening. For example, the CO_2 emission lines near 15 μm require a resolution of 0.002 cm^{-1} or better. Thermal microwave and infrared sounding using current technology (AIRS[2], GOES[3], AMSU[4]) has proven successful, but only with moderate spatial resolution and not above the mid-stratosphere, as illustrated in Figure 1.

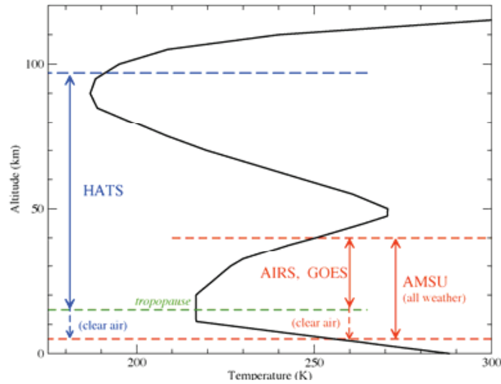

Figure 1. The HATS approach can sound atmospheric temperatures far higher than current operational sensors. This has important implications for weather forecasting, turbulence prediction, and monitoring upper atmospheric phenomena.

3. HATS DMGC TECHNIQUE

DMGC is a measurement technique that combines Doppler shifted observations with gas filter correlation radiometry, using a CO_2-filled gas cell to create a spectral filter. The effective spectral resolution of the system is equivalent to the gas cell line width, typically <0.002 cm^{-1}. This is an order of magnitude better than traditional optical sensors, and can be exploited by making Doppler modulated observations from low Earth orbit. By viewing the scene at various angles and hence Doppler shifts (Figure 2), a signal is created that is the equivalent of spectrally scanning the atmospheric emission lines, thus resolving the narrow lines that carry the high altitude information.

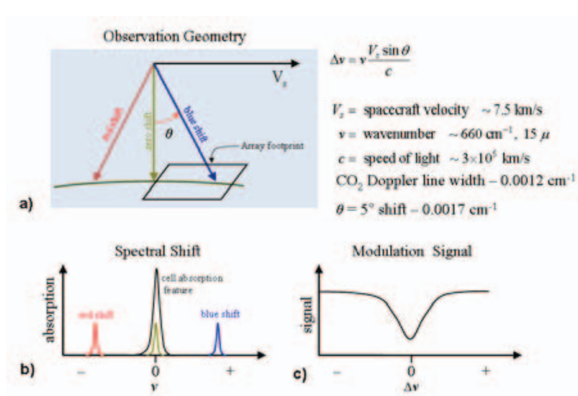

Figure 2. Illustration (not to scale) of the DMGC concept (patent pending, GATS, Inc.). By looking fore or aft, the atmospheric spectrum is shifted. This shifts the high altitude Doppler broadened emission features away from the un-shifted gas cell absorption features, unblocking the high altitude emission lines.

4. FEASIBILITY STUDY

A thorough feasibility study has demonstrated the ability to thermally sound the atmosphere from cloud top to 95 km using a nadir observing HATS DMGC radiometer in low Earth orbit. This study shows that HATS DMGC measurements of CO_2 emission at 15 μm can achieve the necessary effective spectral resolution of 0.002 cm^{-1} or better. Cryogenically cooled HgCdTe detector arrays have the sensitivity necessary to retrieve temperature with 2 K precision. 3-12 km vertical resolution and 4 km horizontal resolution is possible over this entire altitude range.

The HATS instrument concept is based on a composite imaging system. Multiple images are formed by gas cells positioned in front of separate but equivalent telescopes. Each image is passed through a distinct filter and collected on an isolated part of the focal plane array. Complete signal simulations using a 7-image system were performed, producing the averaging kernels and uncertainties displayed in Figure 3. These simulations include realistic detector performance characteristics and rigorous line-by-line radiance modeling ([5], www.spectralcalc.com). The excellent effective spectral resolution and radiometric precision of HATS creates a new measurement capability for space weather forecasting and climate research. The HATS sensor could provide daily gravity wave measurements for assimilation into upper atmospheric and space weather models.

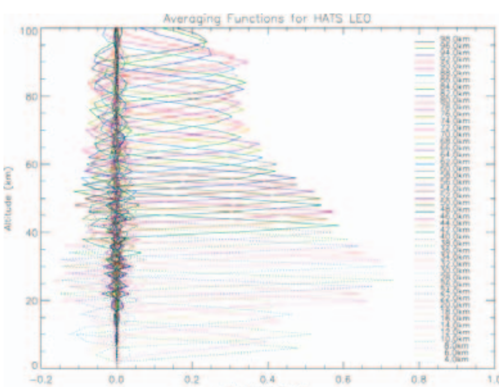

Figure 3a. Averaging kernels for a 7-image HATS system. These are the effective smoothing functions that convert the true temperature profile to the temperature profile retrieved from HATS measurements.

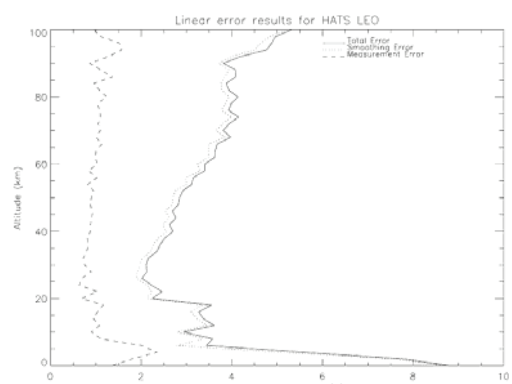

Figure 3b. Precision estimates for a 7-image HATS system. Error due to measurement noise (dashed) and averaging kernels (dotted) is shown, along with the total (solid). Smoothing error estimates assume a realistic temperature covariance matrix (see Rodgers 2000[6]).

5. BIBLIOGRAPHY

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