Integrating a Future Ground-based Profiling System with the Existing Satellite Observing System: The Benefits of a Synergy of Profilers

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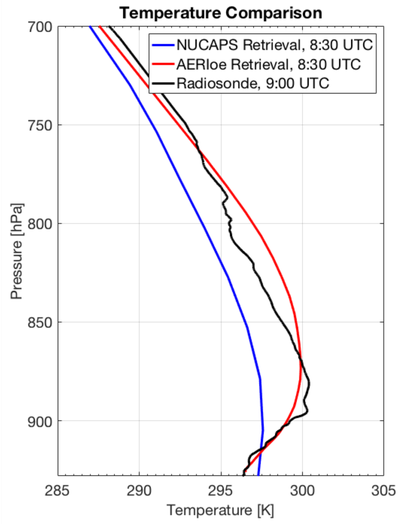
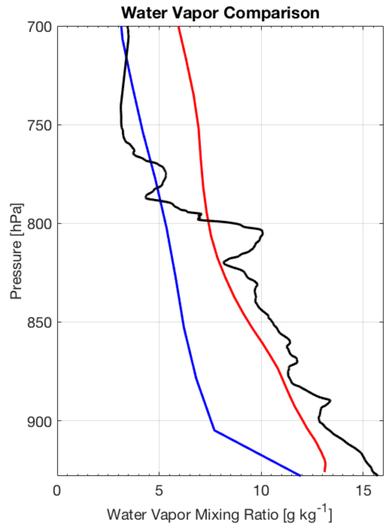
Introduction

Motivation:

The 2017 Decadal Survey highlighted the need to improve observations of the planetary boundary layer. However, space-based sounding lacks the necessary accuracy in the boundary layer. The National Research Council (2009) suggested the development of a nationwide network of ground-based profilers to supplement the space-based observing system in order to improve observations of the planetary boundary layer.





Objective: Develop synthetic information content studies in clear sky and cloudy sky environments to quantify the improvements offered by a synergy of space-based and ground-based IR sounders.

Quantifying Information Content – Degrees of Freedom:

Calculating degrees of freedom (DOF) is one way to quantify the information content of a retrieval. DOF is a measure of the independent pieces of information able to be determined by the measurements. DOF is the trace of the averaging kernel **A**:

$$\mathbf{A} = (\mathbf{K}^T \mathbf{S}_e^{-1} \mathbf{K} + \mathbf{S}_a^{-1})^{-1} \bullet (\mathbf{K}^T \mathbf{S}_e^{-1} \mathbf{K})$$

Where **K** is the jacobian and $\mathbf{S}_e$ is the error covariance matrix. Given the difficulties computing model error, we utilize instrument noise for the error covariance matrix $\mathbf{S}_e$. $\mathbf{S}_a$ is the a priori covariance matrix:

$$\mathbf{S}_a^{i,j} = \mathrm{CORR}(\mathbf{x}_i, \mathbf{x}_j)\, \boldsymbol{\sigma}_{\mathbf{x}i}\, \boldsymbol{\sigma}_{\mathbf{x}j}$$

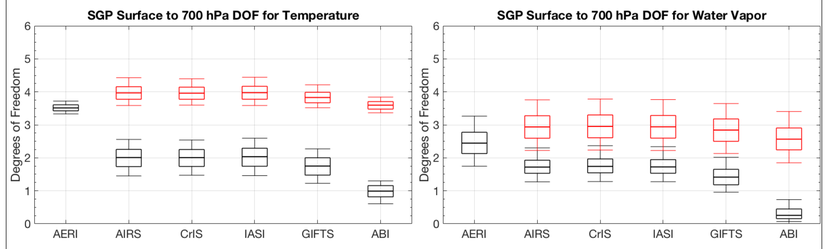
$\mathbf{S}_a$ is calculated from 2,905 summertime radiosondes in clear sky conditions from the ARM-SGP site.

Acknowledgements:
This research is supported by National Aeronautics and Space Administration (NASA) prime award number NNX15AQ03A "Educational Opportunities in NASA STEM (EONS)".

Key Point: A synergy of ground-based and space-based sensors provides more information content and better vertical resolution than any sensor operating individually.

Clear Sky Study

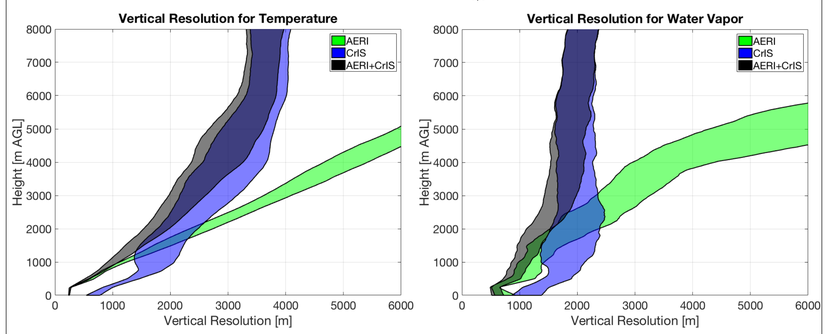
Clear sky radiosondes profiles from ARM-SGP between October 2013 and September 2019 are used to provide input thermodynamic profiles for radiative transfer simulation. 3765 profiles meet our clear sky criteria (relative humidity less than 90%).



- AERI has greater information near the surface than any of the space-based sensors.
- The synergy of AERI with any of the space-based sensors produces more information than either sensor individually

Vertical resolution of the retrieval may be calculated from **A**:

$$\mathbf{Vres}_i = \frac{z_{(i-1)} - z_{(i+1)}}{\mathbf{A}_{i,i}}$$



- A synergy of AERI+CrIS has better vertical resolution than AERI or CrIS individually from 500 m to 5000 m AGL
- A synergy of AERI+CrIS provides significant improvements to vertical resolution compared to CrIS alone from the surface to 5000 m AGL.

References:
Hewison, T. J., 2007: 1D-VAR retrieval of temperature and humidity profiles from a ground-based microwave radiometer. *IEEE Trans. Geosci. Remote Sens.*, **45**, 2163-2168.
Turner, D. D., S. A. Ackerman, B. A. Baum, H. E. Revercomb, and P. Yang, 2003: Cloud phase determination using ground-based AERI observations at SHEBA. *J. Appl. Meteor.*, **42**, 701-715.
Turner, D. D., 2005: Arctic mixed-phase cloud properties from AERI-lidar observations: Algorithm and results from SHEBA. *J. Appl. Meteor.*, **44**, 427-444.

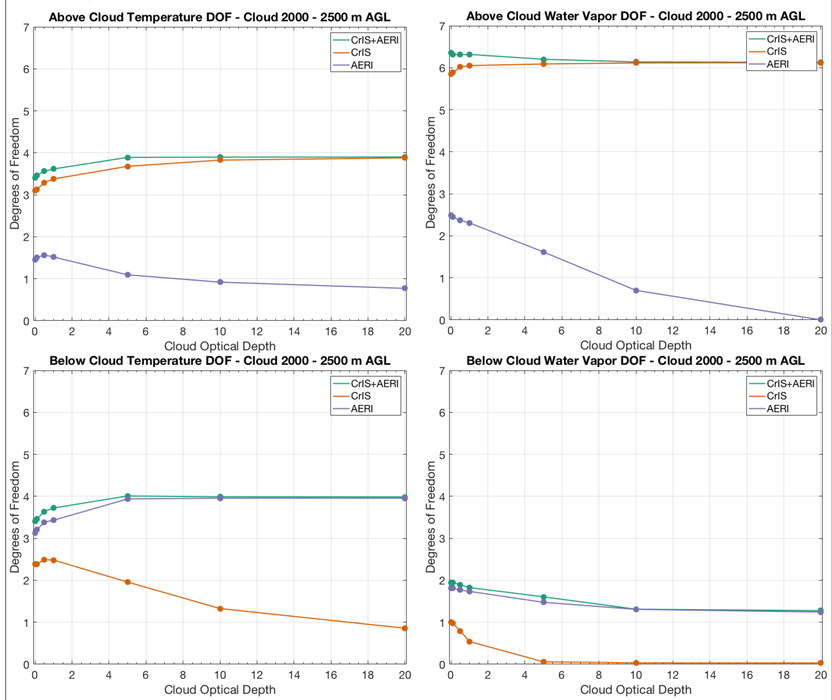
Cloudy Sky Study

Adding a ground-based sensor, such as AERI, would provide information below the cloud, providing a potential solution to IR sounding in cloudy environments.

Use LBLDIS (Turner et al. 2003, Turner 2005) to compute radiances for cloudy sky scene. Perturbations of 1 K and 10% water vapor mixing ratio are used to calculate temperature and water vapor jacobians.

Hypothesis: DOF for CrIS below the cloud and DOF for AERI above the cloud should both approach zero with higher cloud optical depths.

- This hypothesis is largely correct, however the below cloud DOF of CrIS and above cloud DOF of AERI do not go fully to zero all the time.



- At high optical depths, AERI provides all the information for the synergy below the cloud while CrIS provides all the information for the synergy above the cloud.
- While thicker clouds result in a decrease of water vapor DOF, it results in an increase of temperature DOF. The cloud presents an optically thick surface which makes it "easy" for each sensor to retrieve the temperature of that layer.

Future Work

- Develop a synergistic retrieval in order to quantify the improvements offered by a synergy of ground-based and space-based sensors outside of synthetic information content studies.