Combining the High Altitude Lidar Observatory (HALO) and Scanning High-Resolution Interferometer Sounder (S-HIS) for Thermodynamic Retrievals

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Introduction

The 2017 Decadal Survey highlighted the need for improved observations of temperature and water vapor within the planetary boundary layer (PBL). Hyperspectral infrared (IR) sounders and microwave sounders provide most of thermodynamic sounding observations globally. However, these sensors fail to provide observations at the accuracy and vertical resolution required for many applications. Developing instrument synergies with IR sounders is a promising path to improving estimates of thermodynamic profiles, particularly in the PBL.

Instrumentation and Methods

S-HIS and HALO are aircraft based remote sensing instruments that make observations of the atmosphere below.

	S-HIS	HALO
Sensor Type	Hyperspectral IR	Water vapor DIAL
Variables Provided	T, q	q
Vertical Resolution	2000 - 3000 m	300 m

The high resolution and accuracy of water vapor measurements from the HALO allows for improved temperature retrievals from the S-HIS radiance observations. We simulate this synergy using a set of 703 radiosondes from the ARM SGP site in spring 2019.

Information Content:

The information content quantities we will base our analysis on are derived from the averaging kernel. Following the Rodgers (2000) formulation the averaging kernel **A** is calculated as:

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

where **K** is the Jacobian, $\mathbf{S}_e$ is the error covariance matrix (instrument noise), and $\mathbf{S}_a$ is the a priori covariance matrix (derived from a radiosonde climatology). We can derive degrees of freedom (DOF) and vertical resolution from **A**:

$$\mathrm{DOF} = \mathrm{trace}(\mathbf{A})$$

$$\mathrm{Vres}_i = (z_i - z_{i-1})(\mathbf{A}_{i,i})^{-1}$$

Retrieval uncertainties can also be derived from the posterior error covariance matrix:

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

$$\mathrm{uncert}_i = \mathrm{sqrt}(\mathbf{S}_{i,i})$$

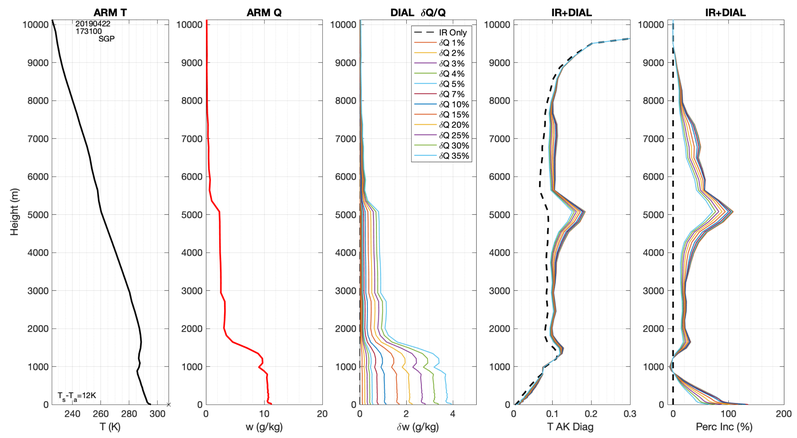
Radiosonde profiles are used for radiative transfer simulation to determine Jacobians for S-HIS. HALO uncertainties are simulated to be a percent of the ambient water vapor profile for each case.

Key Points:

1. Simulations of an instrument synergy between hyperspectral IR sounders and water vapor DIALs is shown to be a promising path for improving thermodynamic profiles in the PBL.
2. Simulations suggest that a combination of an IR sounder with a water vapor DIAL will improve temperature information content by about 20% compared to the IR sounder alone.
3. The vertical location and magnitude of the synergy gains are highly dependent upon the vertical moisture gradient.

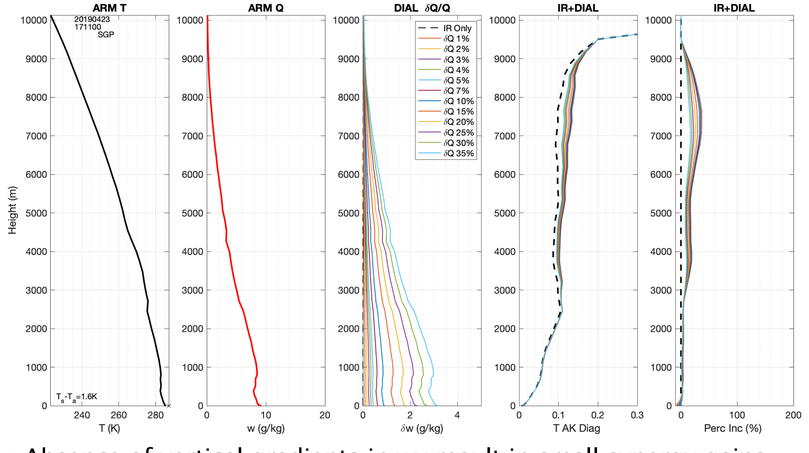
Case Study Profiles

1) Profile with sharp moisture gradient at top of PBL:



- Larger vertical gradients in water vapor (wv) result in large gains in temperature information for IR+DIAL compared to IR alone.

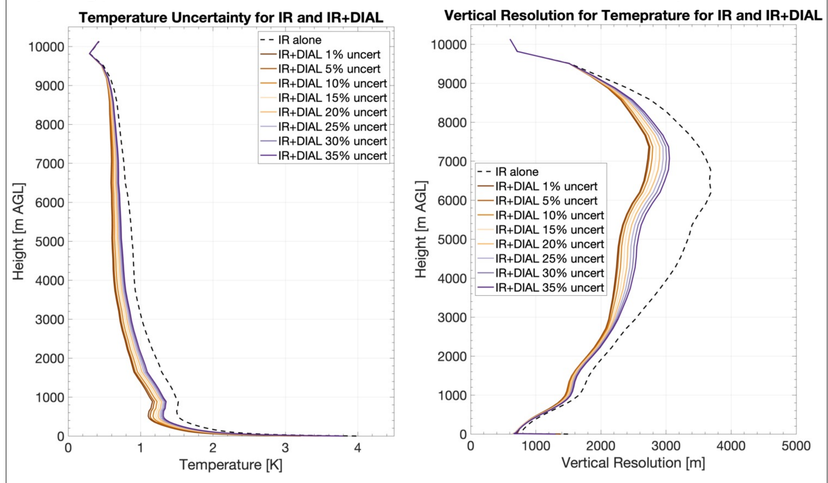
2) Profile with small moisture gradients:



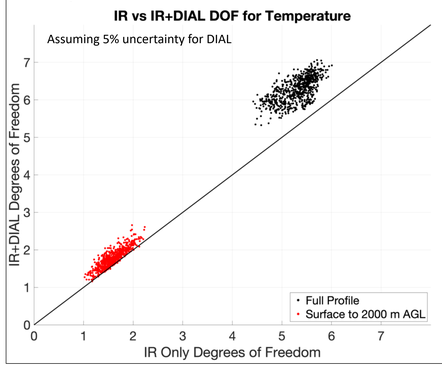
- Absence of vertical gradients in wv result in small synergy gains.

Composite View of the Synergy Gains for S-HIS+HALO

Here we will look look at a composite view of the benefits of the synergy over all 703 radiosondes simulated for this analysis.



- Adding the water vapor measurements of the dial can provide up to a 0.5 K decrease in temperature uncertainty and 1000 m improvement in vertical resolution of the temperature retrieval.



- The synergy improvement to degrees of freedom for the temperature retrieval of IR+DIAL compared to IR alone is typically 1-1.5 DOF, or 20%.
- The improvements in the surface to 2000 m AGL layer are smaller and seem to be more dependent upon profile shape.

Future Work

1. Develop synergistic retrievals to better understand how the benefits of this sort of synergy translate to the iterative retrieval process where a first guess is very different from the solution.
2. Seek opportunities for S-HIS and HALO to make co-located observations so that this instrument synergy can be applied to real observations.

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