Supplementing Space-based Sounding with Ground-based Sensors to Improve Monitoring of the Planetary Boundary Layer

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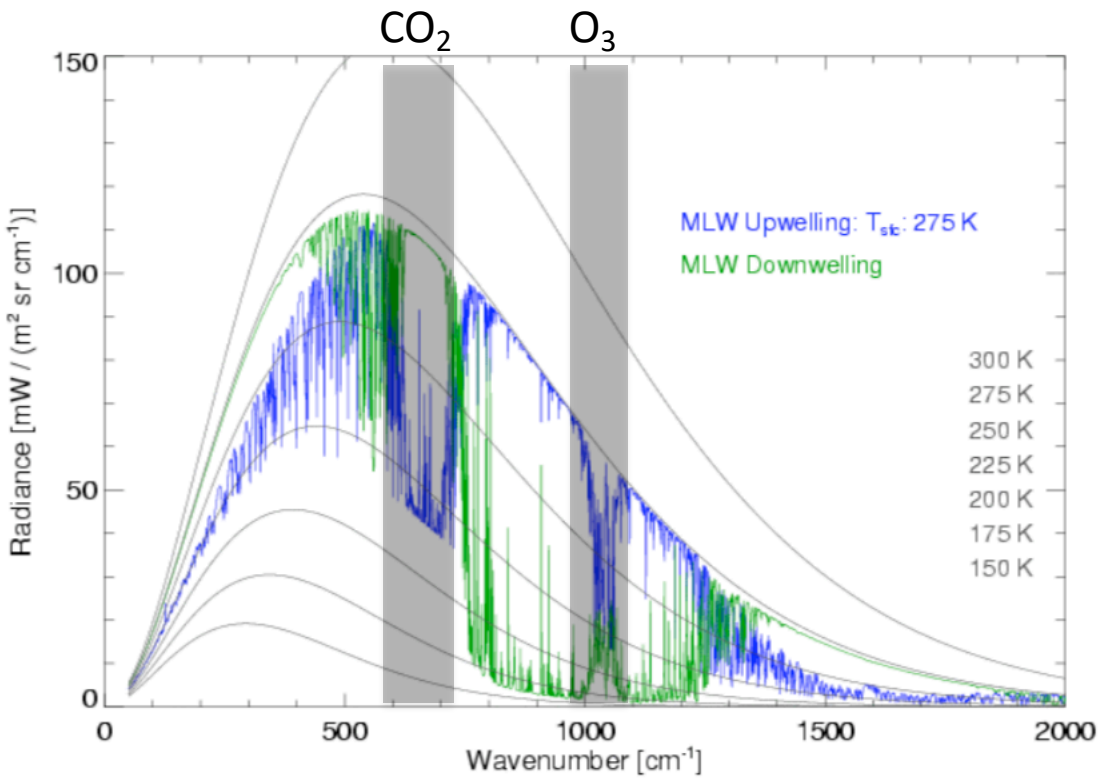
Motivation

- 2017 Decadal Survey identified improving observations of the PBL as an area of future investment
  - How can we improve our estimates of thermodynamic profiles in the PBL?

- NRC report in 2009 “Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks” suggested the development of a network of ground-based sensors to supplement space-based sounding

Example: Upwelling vs. Downwelling



SSEC

Ground-based/Space-based Synergies

- Ebell et al. (2013) explored a synergy between a ground-based microwave radiometer and IASI.
  - Synergy increases the information of the retrieval by a factor of 1.8 (temperature) and 1.5 (water vapor) compared to ground-based MWR alone
  - Similarly the synergy resulted in decreases in uncertainties
- Reverse the question: *how much information does a ground-based instrument provide when combined with existing space-based sounder?*

Objectives:

1. What is the improvement in information content of the retrieval when we add a ground-based sensor to a retrieval with a space-based sensor?
   - Calculate degrees of freedom to quantify information

2. How does the information content change with varying water vapor concentrations?
   - Consider three stations in different climate regimes

Sensors of Consideration

- Sensors of consideration:
  - AERI (ground-based)
  - AIRS, CrIS, IASI
    - Nadir only
  - ABI, GIIRS
    - 49 degrees for SGP – simulates GOES-16 look angle
    - 54 degrees for ENA – simulates Meteosat-11 look angle
    - Not run for NSA

Calculating Degrees of Freedom

A priori covariance matrix: $\mathbf{S}_{a\ j,k} = \mathrm{CORR}(\mathbf{x}_j,\mathbf{x}_k)\ \sigma_{\mathbf{x}j}\ \sigma_{\mathbf{x}k}$

- computed from clear sky profiles for each season for each station

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

- Use instrument noise for $\mathbf{S}_e$

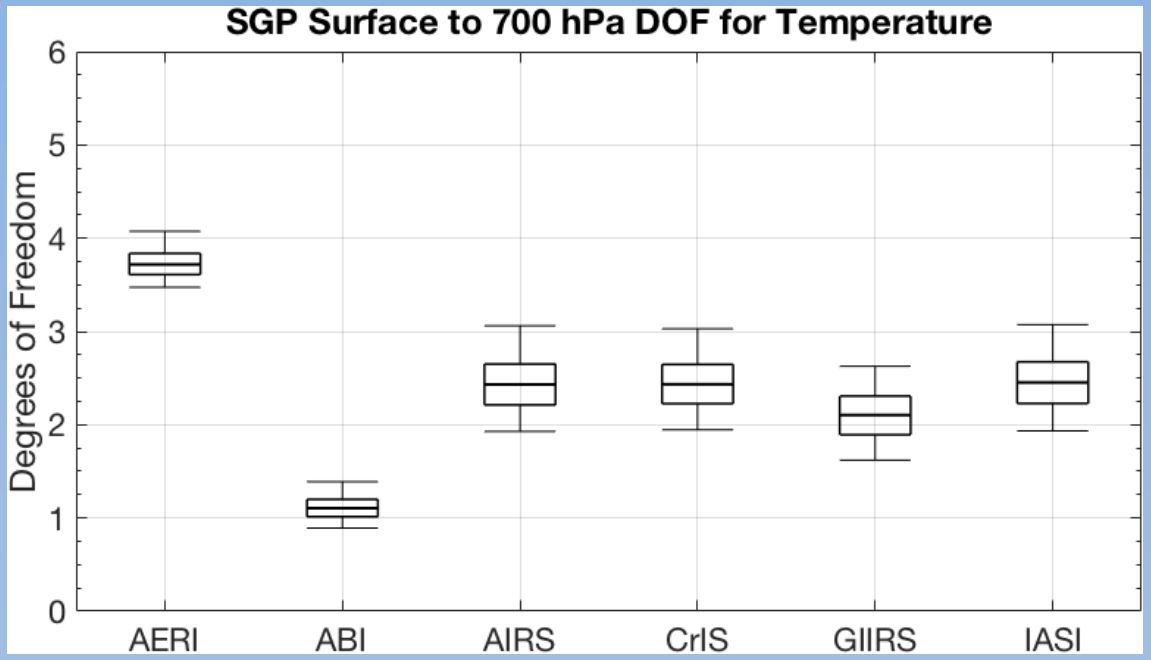
DOF = trace($\mathbf{A}$)

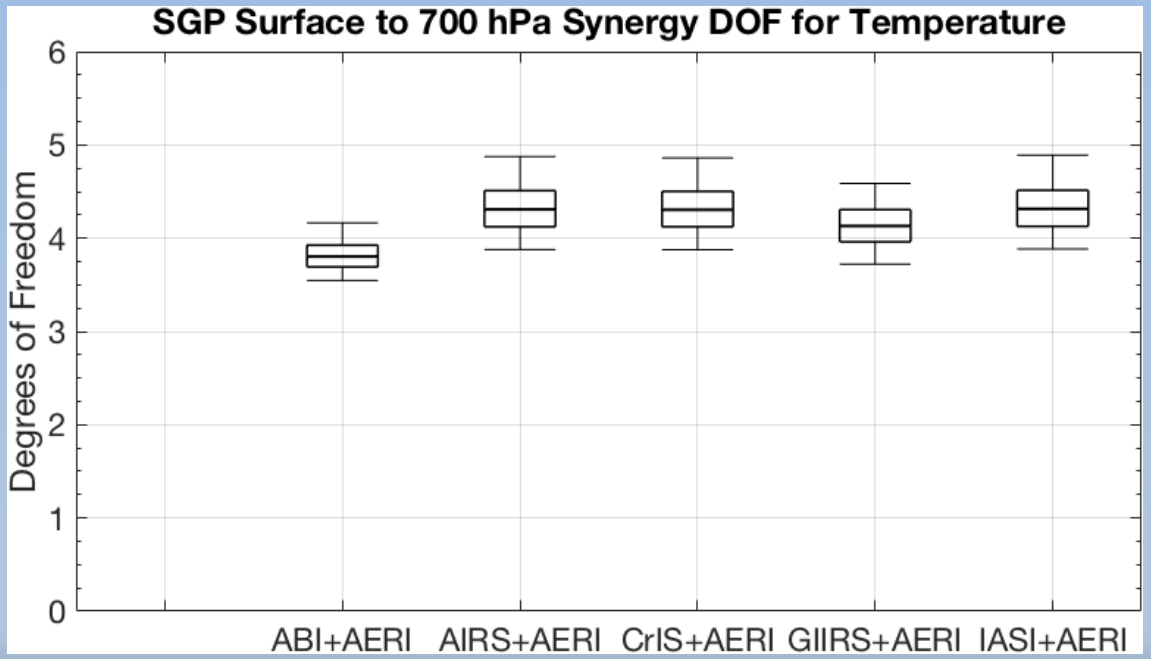
Atmospheric Profiles

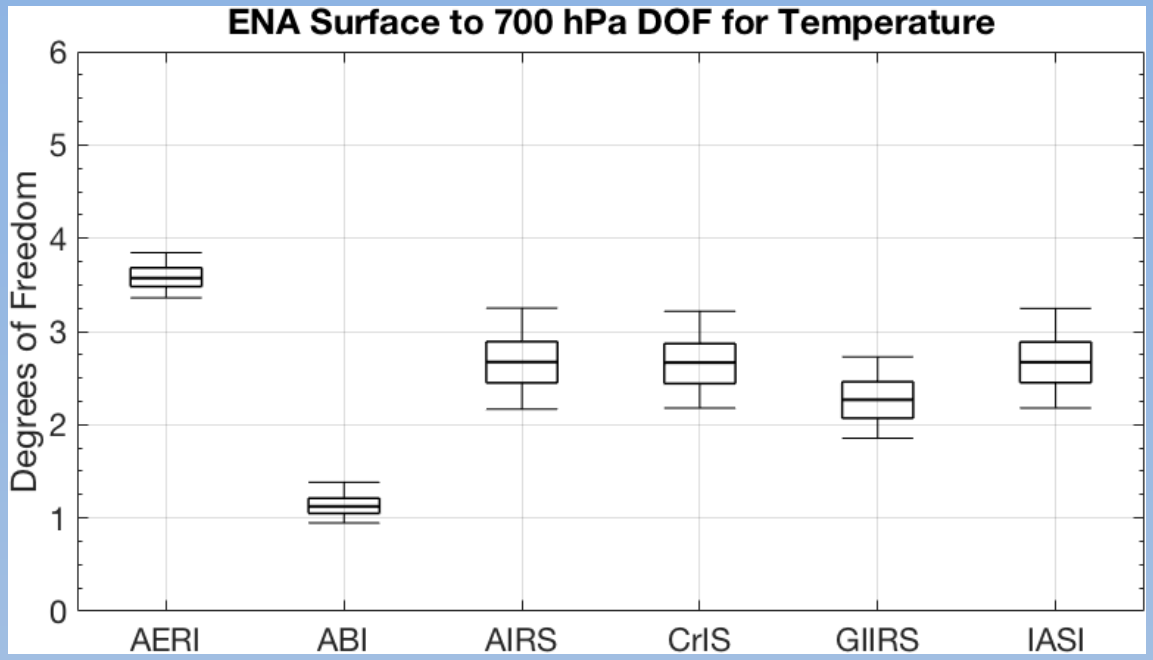
- Three ARM stations to get a variety of conditions:
  - Lamont, OK (SGP)
  - Azores (ENA)
  - Utqiagvik, AK (NSA)
  - Radiosonde profiles from Oct 2013 – Sept 2019
- Cloud clearing: RH > 90% is considered a cloud
  - 3765 clear sky profiles at SGP (Lamont, OK)
  - 464 clear sky profiles at ENA (Azores)
  - 491 clear sky profiles at NSA (Utqiagvik, AK)

Radiative Transfer

- OSS (fast model, derived from LBLRTM)
  - Allows for the analysis to be run over a large number of profiles
- Trace gases: CO_2 N_2O O_3 CH_4 H_2O
- CAMEL emissivity monthly climatology for each site
- Use AIRS 101 pressure levels
  - Have found this degrades the information the AERI provides


SGP Surface to 700 hPa DOF for Temperature
Degrees of Freedom
0
1
2
3
4
5
6
AERI
ABI
AIRS
CrIS
GIIRS
IASI


SGP Surface to 700 hPa Synergy DOF for Temperature
Degrees of Freedom
0
1
2
3
4
5
6
ABI+AERI
AIRS+AERI
CrIS+AERI
GIIRS+AERI
IASI+AERI


ENA Surface to 700 hPa DOF for Temperature
Degrees of Freedom
0
1
2
3
4
5
6
AERI
ABI
AIRS
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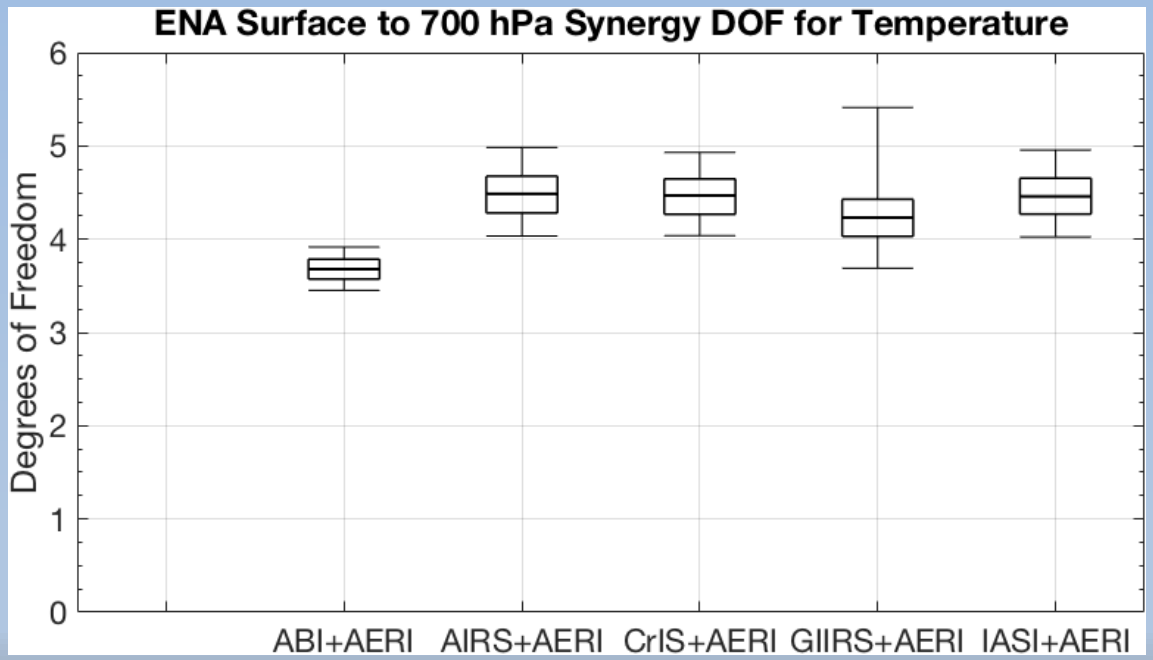
GIIRS
IASI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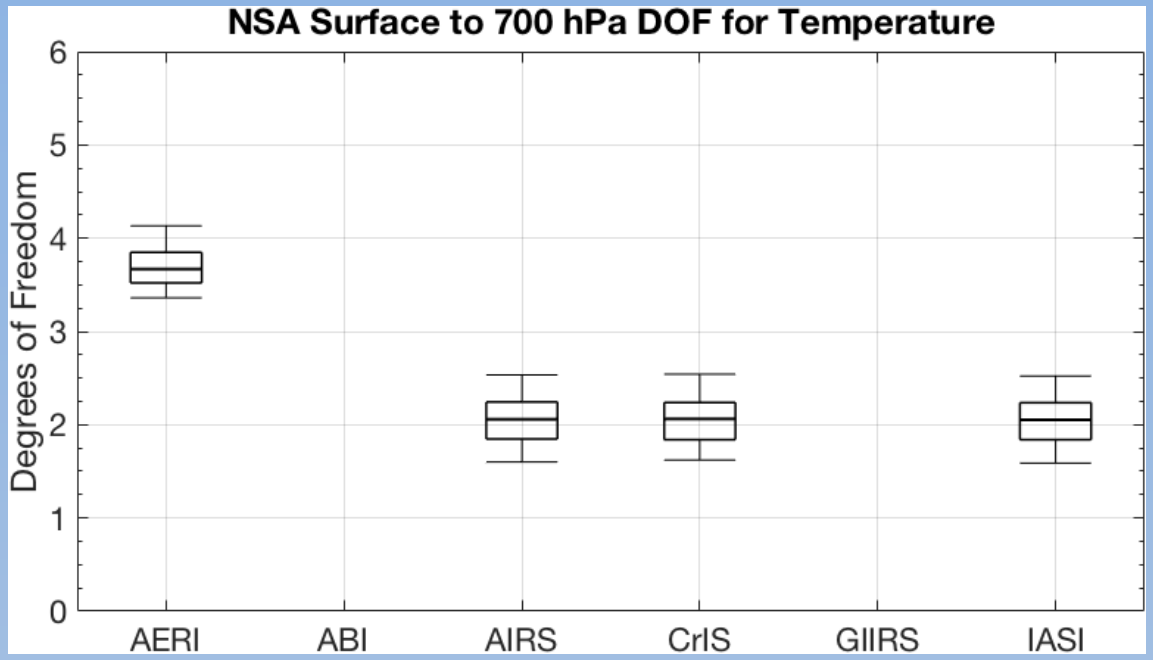
NSA Surface to 700 hPa DOF for Temperature
Degrees of Freedom
0
1
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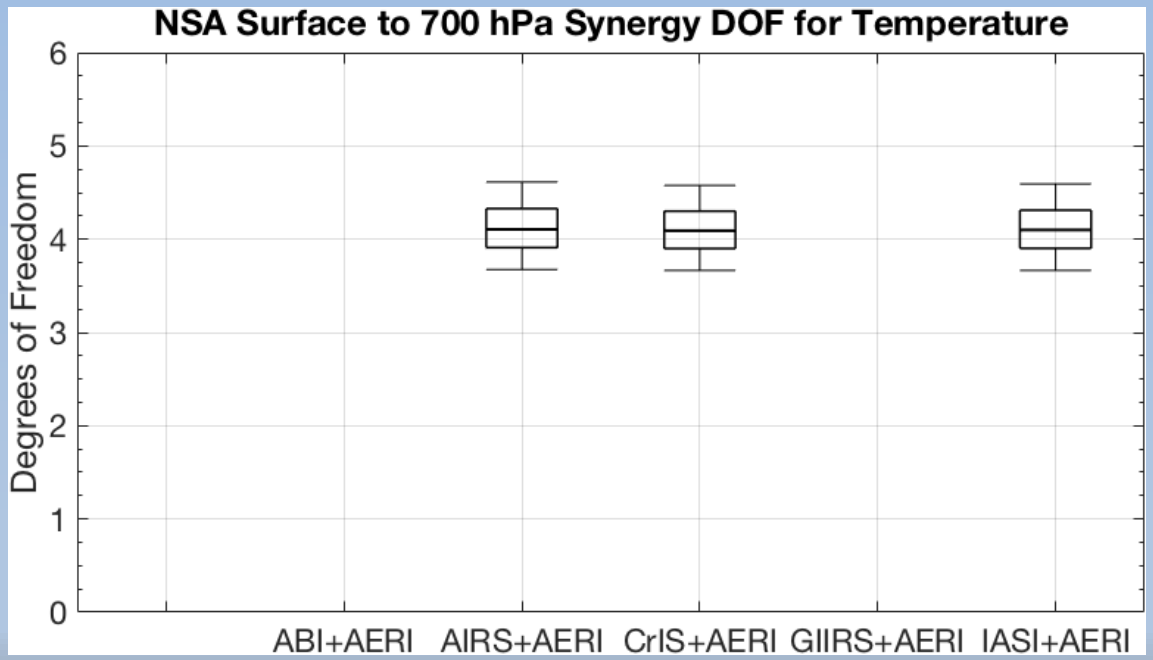
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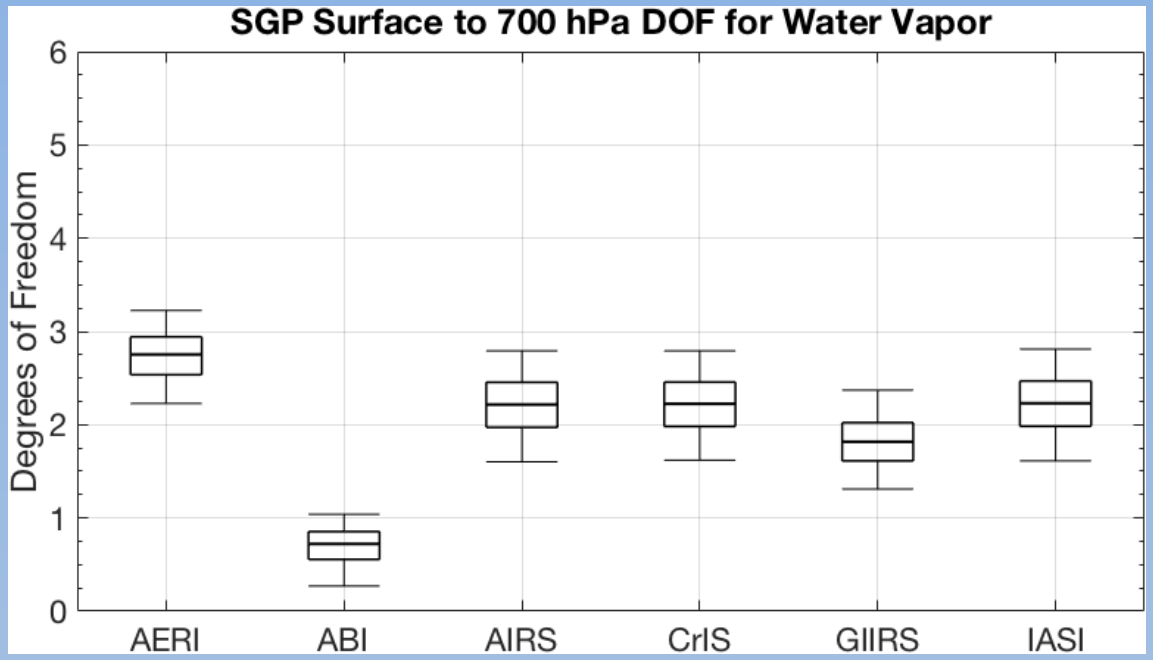
SGP Surface to 700 hPa DOF for Water Vapor
Degrees of Freedom
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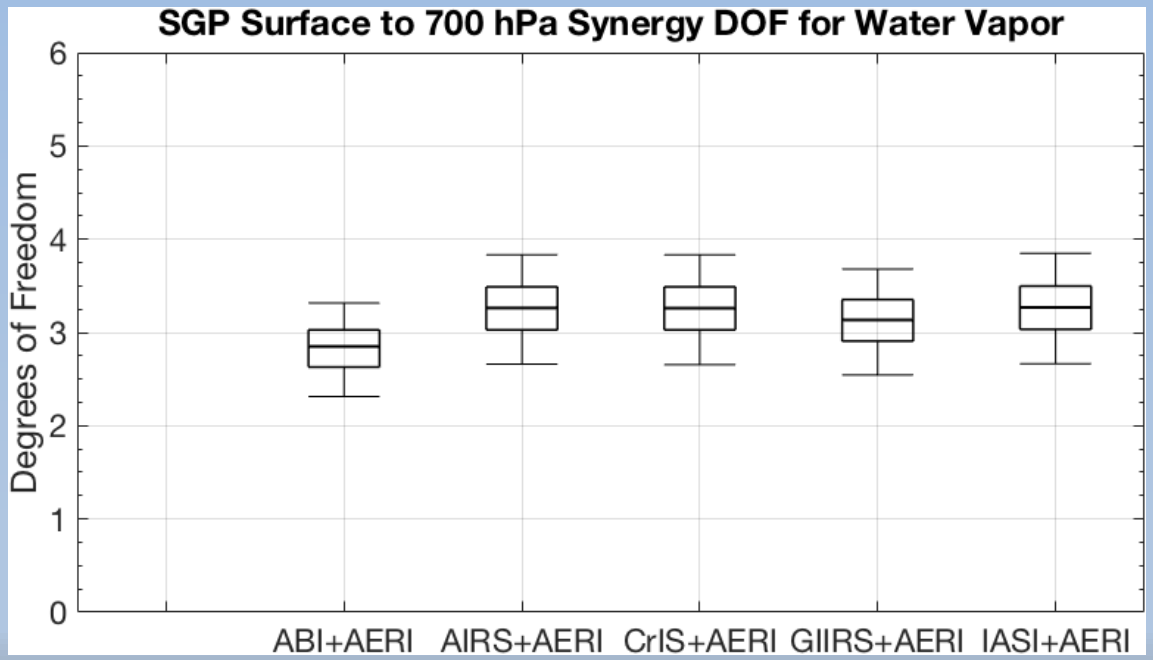
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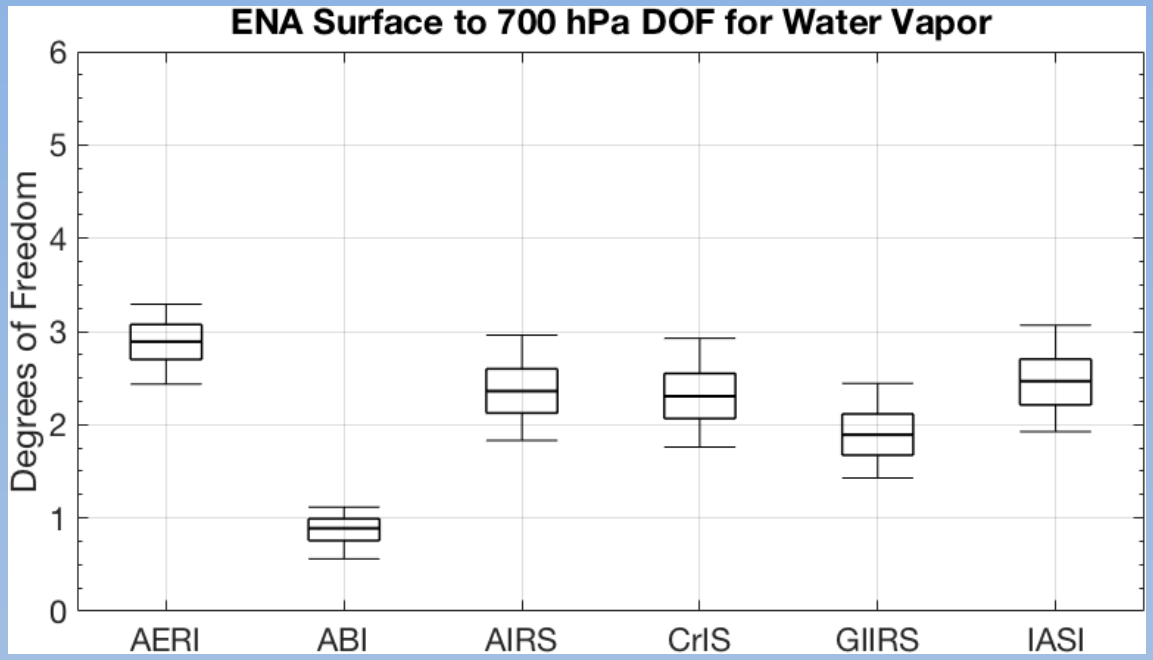
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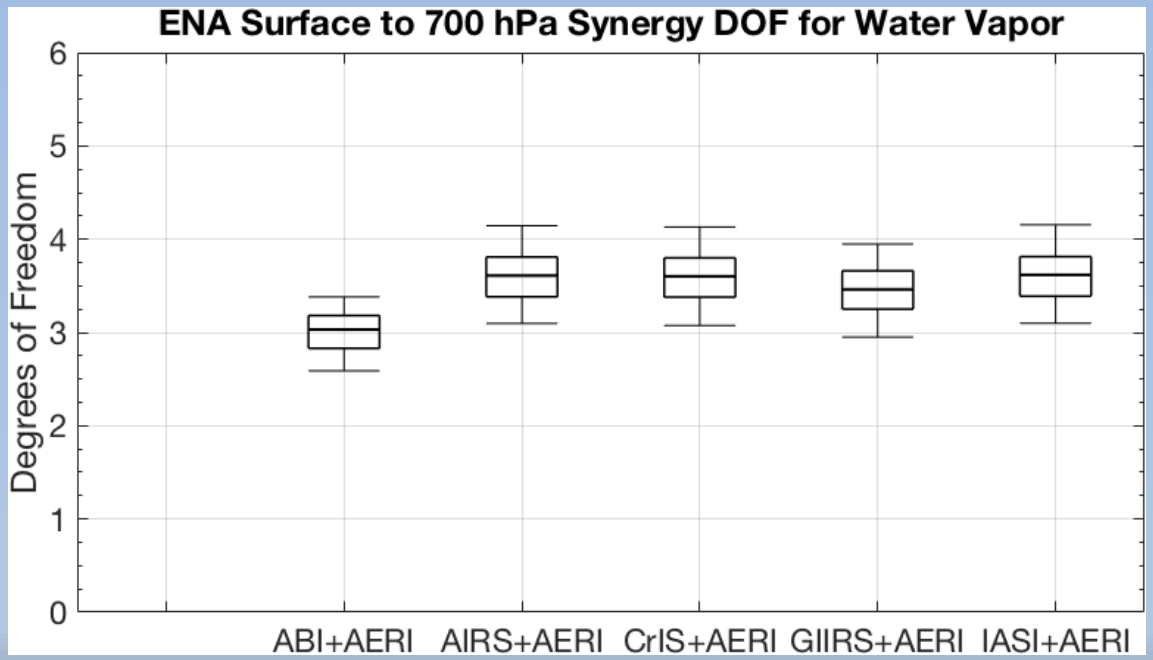
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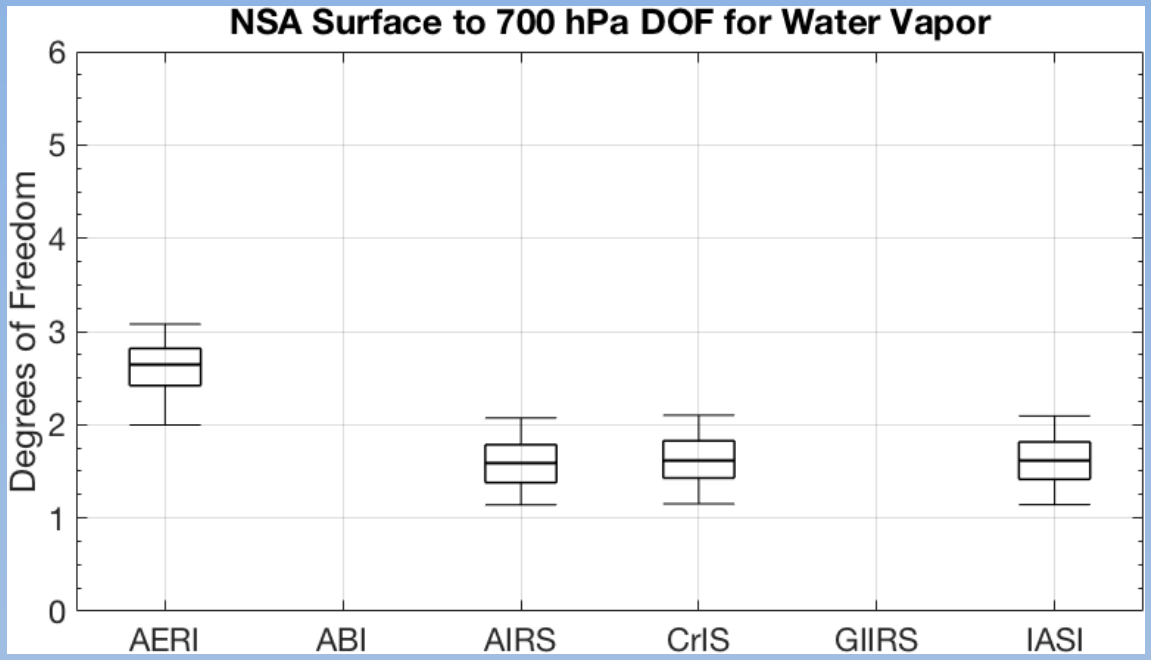
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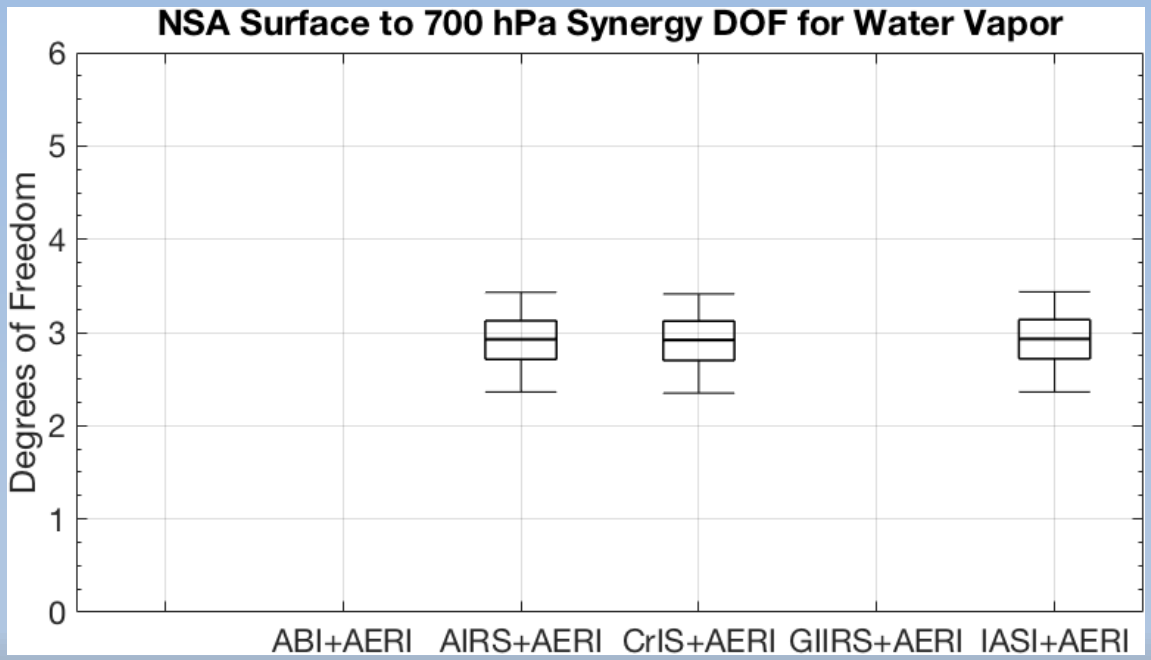
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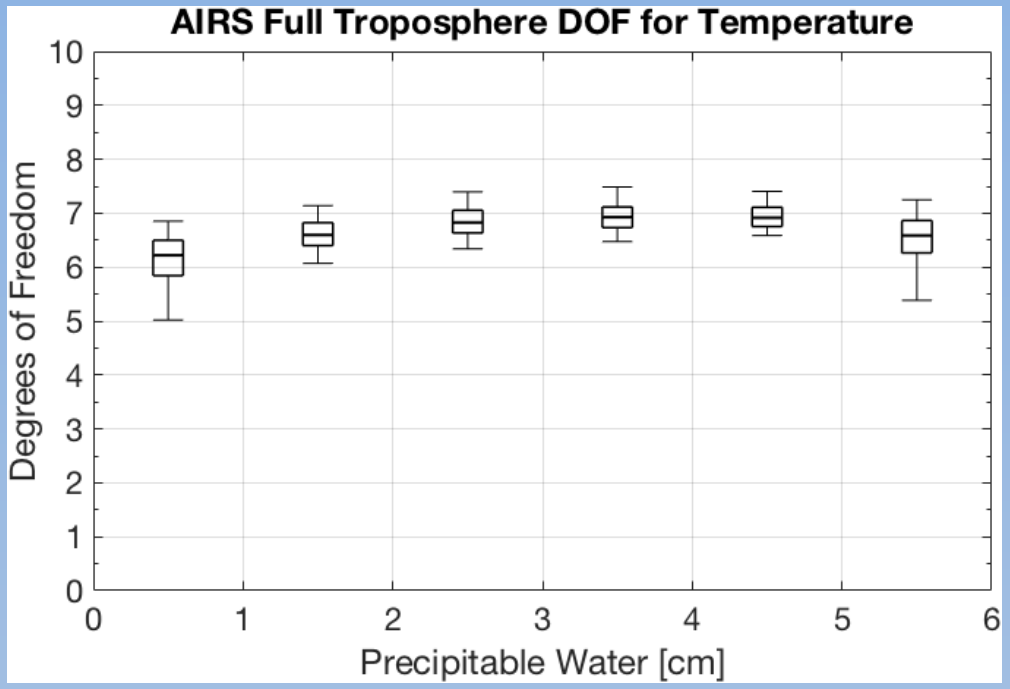
AIRS Full Troposphere DOF for Temperature
Degrees of Freedom
Precipitable Water [cm]
0
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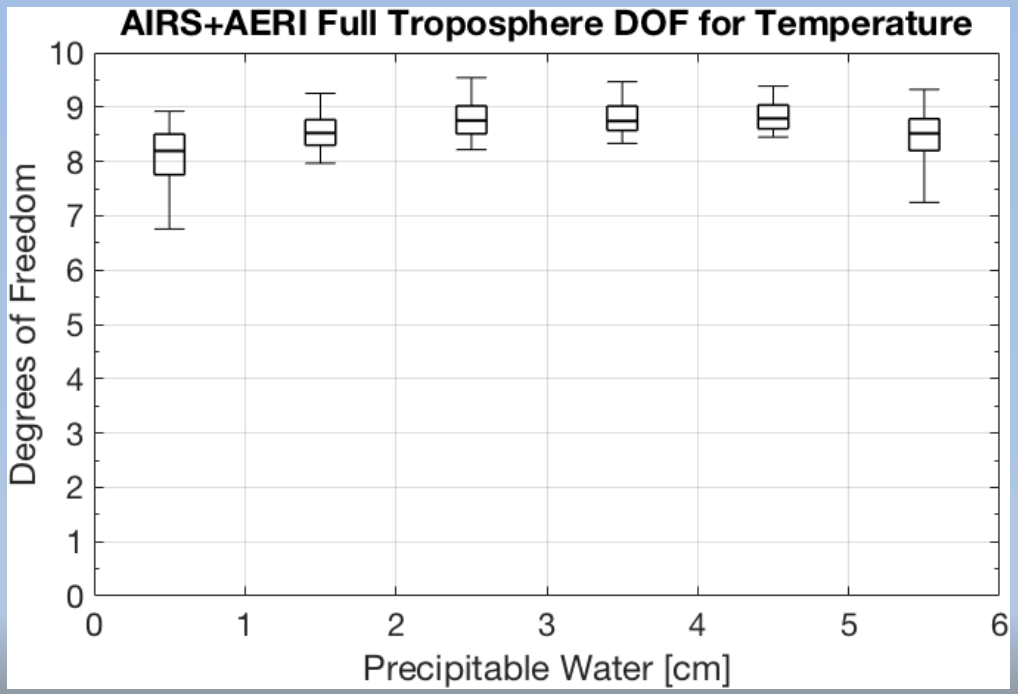
10


AIRS+AERI Full Troposphere DOF for Temperature
Degrees of Freedom
Precipitable Water [cm]
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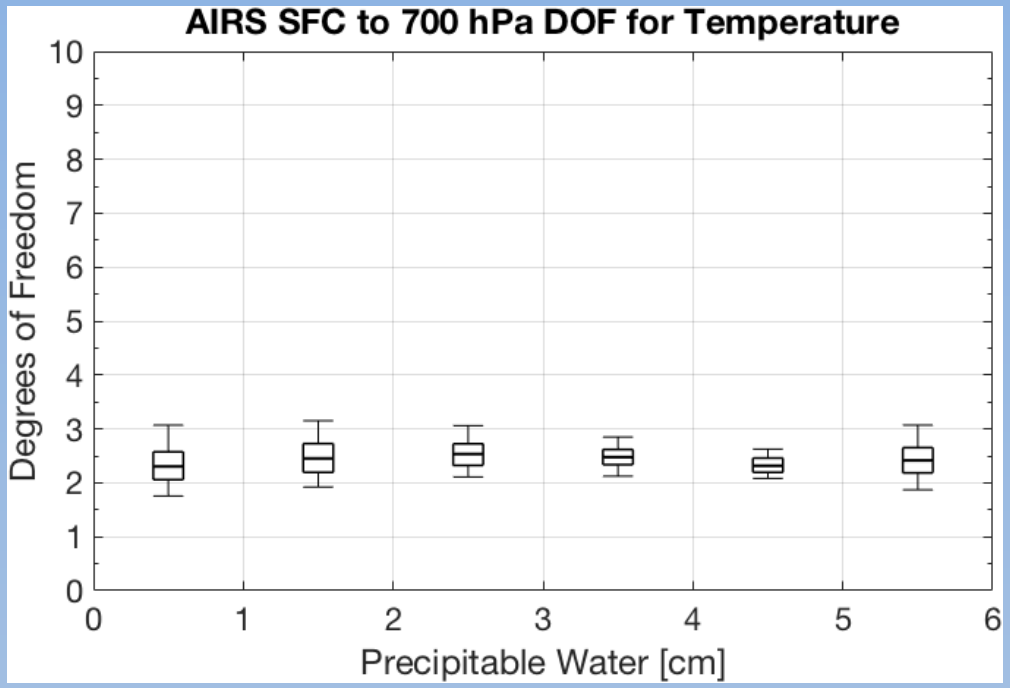
AIRS SFC to 700 hPa DOF for Temperature
Degrees of Freedom
Precipitable Water [cm]
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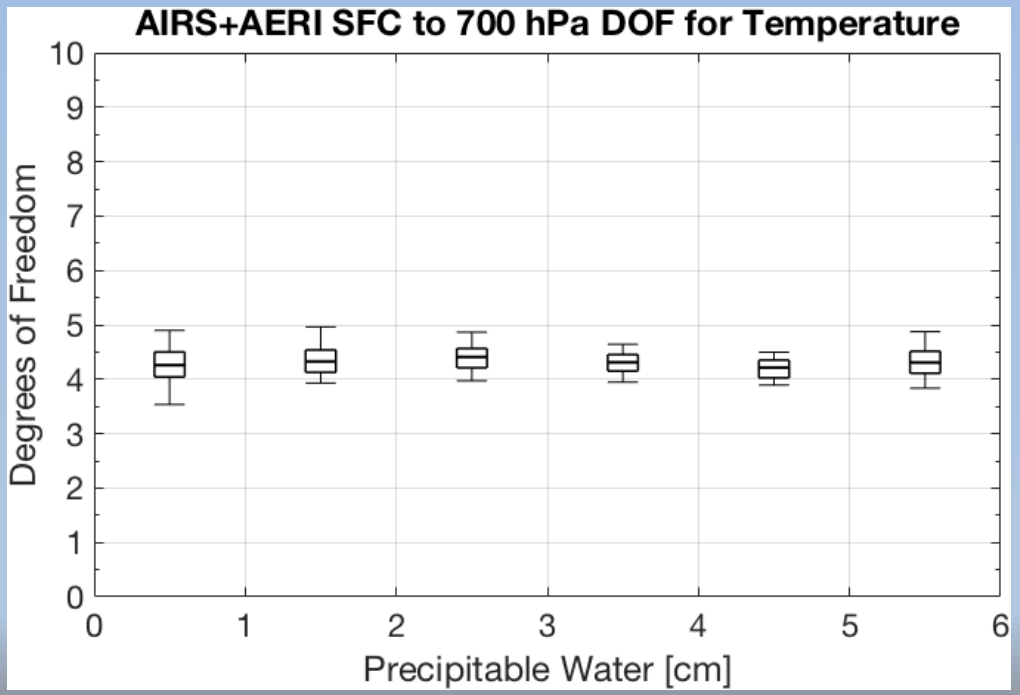
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9
10

Open Questions on Precipitable Water

- Does changing S_a cause that pattern or is there really less signal in a dry environment?

- Why does that pattern exist?
  - Why for the full troposphere but not for the near surface layer?

Open Questions about Ground-based Network:

- Would not solve PBL sounding issues over ocean, thus limited improvements in 3+ day forecasts
- Being over land, a ground-based network would provide strong improvements in 1-3 days forecasts
- Works best with a geostationary sounder
- How many locations for this network?

Conclusions

- Adding the AERI to the retrieval increases the information content by a factor of 1.5 across all three stations
- Synergy (both instruments into one retrieval) produces more information content than an a posteriori combination of separate retrievals
- Working to expand this analysis to vertical resolution and uncertainties
  - What about cloudy sky conditions?

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