Sensitivity of Infrared Radiances to Changes in Planetary Boundary Layer Water Vapor

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AMS Annual Meeting
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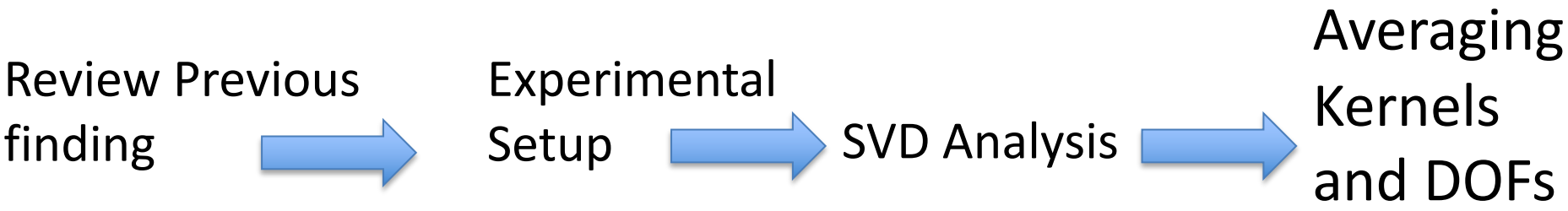
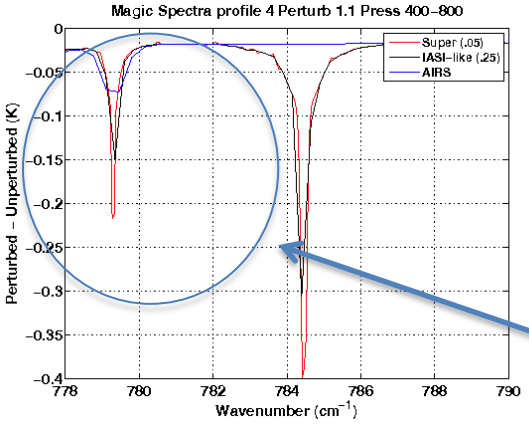
Goal: To understand the limits of space borne passive IR remote sensing of PBL water vapor

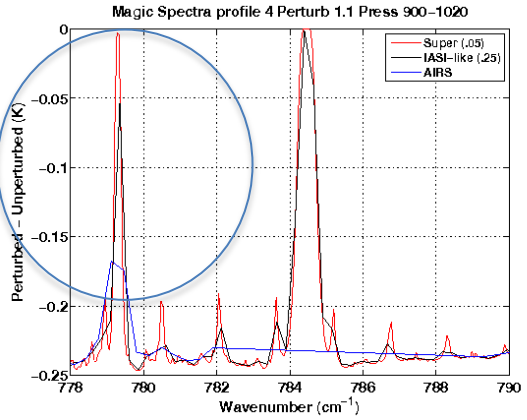


400-800 10 Percent Increase

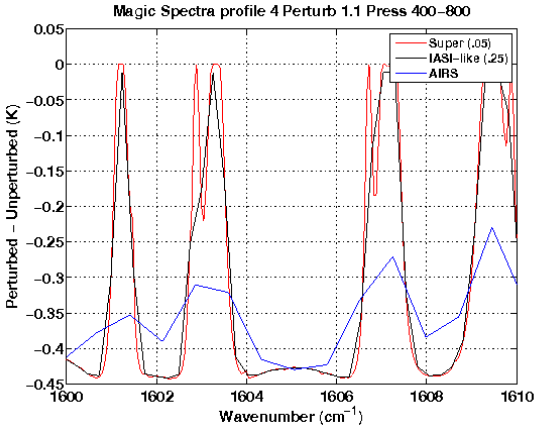
Surface-900 10 Percent Increase



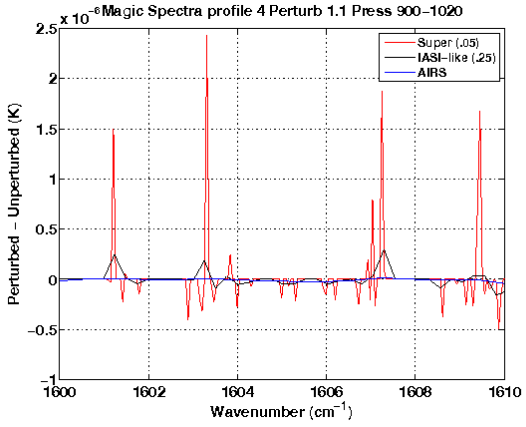
- AIRS insensitivity to mid-tropospheric perturbation is due to spectral resolution

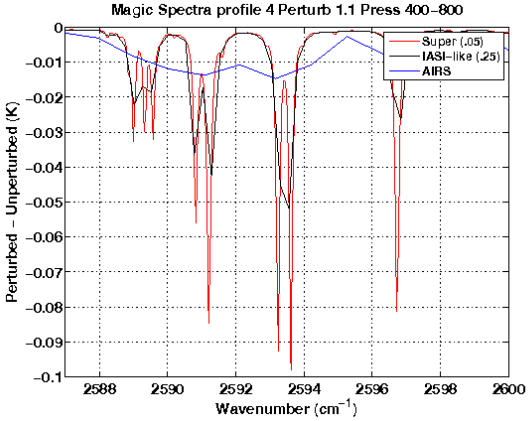


- LW has unique signal when spectral resolution is higher than AIRS

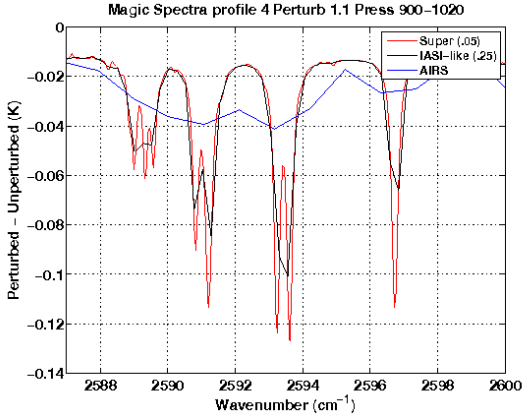


- To measure something you need signal and the signal needs to be unique





- Perturbation signal is larger in SW for PBL change, but is not unique
- IASI is almost .1K while AIRS is .05K.
- At IASI Resolution you can resolve online vs off line differences



400-800 10 Percent Increase

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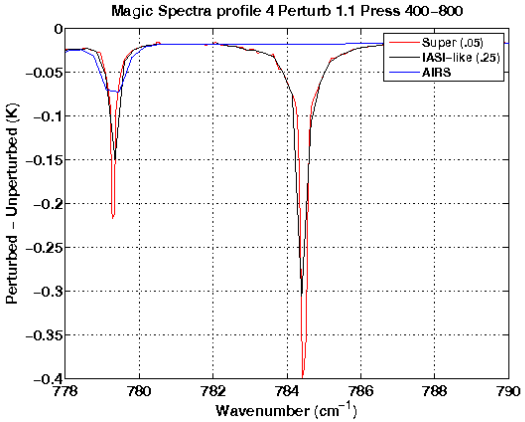
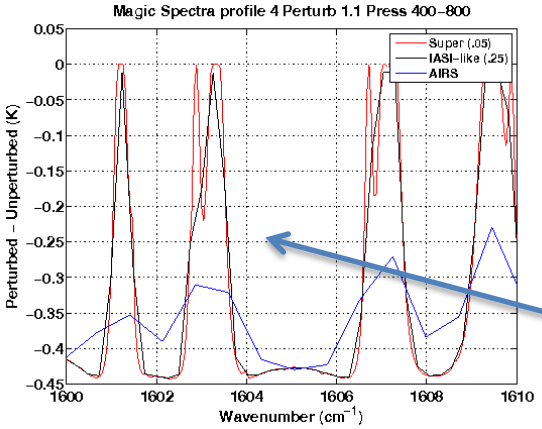
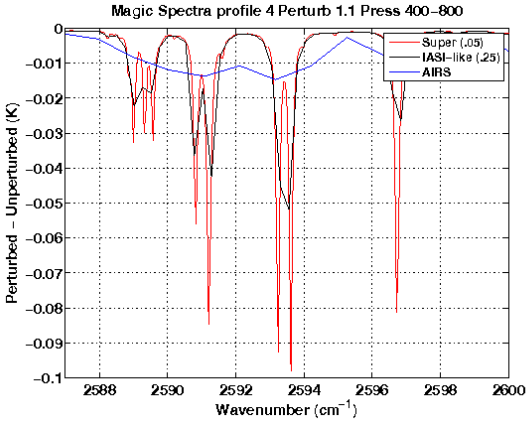
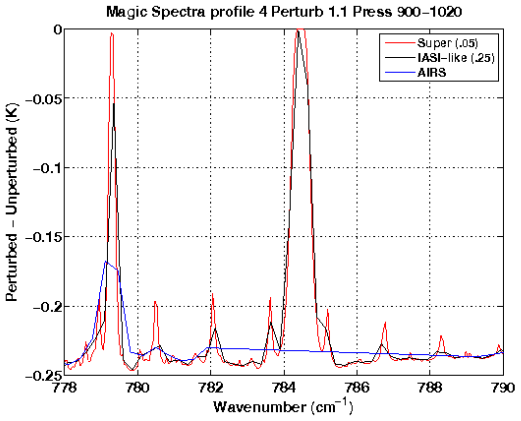
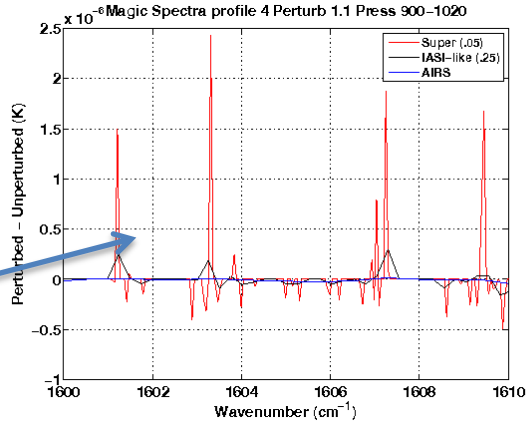


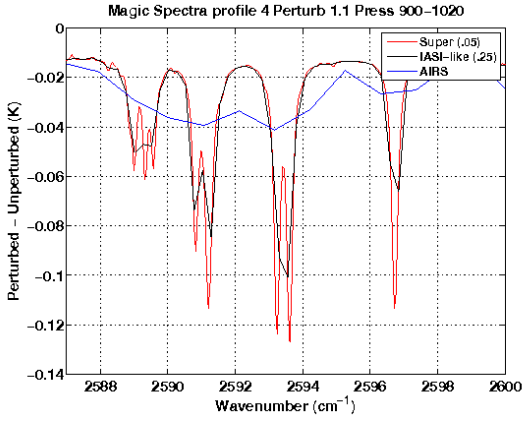




- AIRS insensitivity to mid-tropospheric perturbation is due to spectral resolution
  - LW has unique signal when spectral resolution is higher than AIRS
- To measure something you need signal and the signal needs to be unique
- These midwave channels are primarily senstive to mid tropospheric changes
  - Perturbation signal is larger in SW for PBL change, but is not unique
  - IASI is almost .1K while AIRS is .05K.
  - At IASI Resolution you can resolve online vs off line differences







Experimental Setup

- 554 MAGIC campaign radiosonde profiles used to analyze *apriori* and covariance
- Ship based campaign in subtropical region of pacific traveling between Long Beach, CA and Hawaii

4 Simulated Sensors

1. AIRS
2. IASI
3. Super .1 cm^{-1}
4. Super2 .05 cm^{-1}

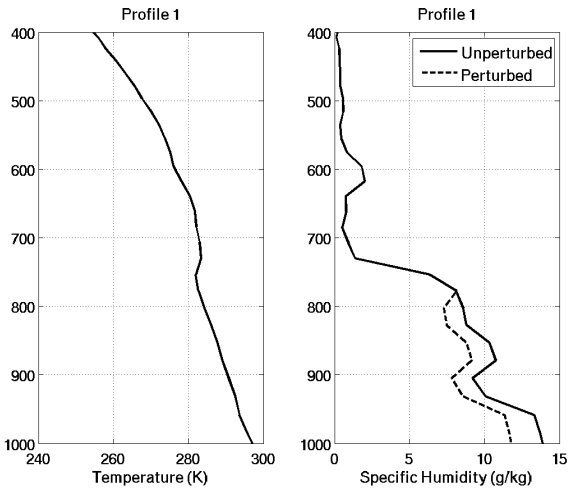
4 Error models

- 4 diagonal error covariances with .1, .25, .5, and $1K^2$

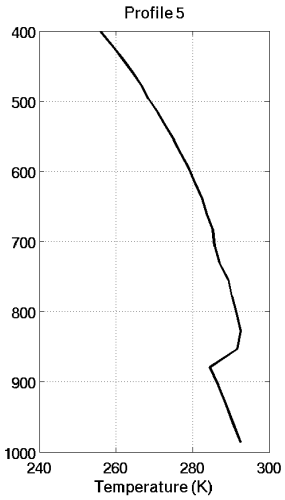
RTA: kCARTA

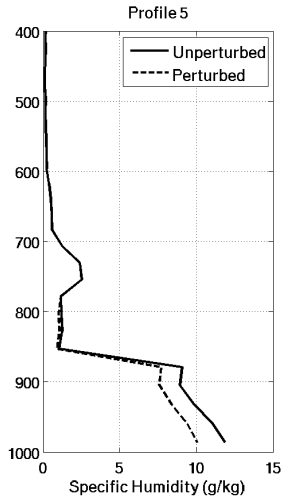
- kCompressed Radiative Transfer Algorithm
- Pseudo line by line
- Used to calculate Jacobians by finite difference

Information Content



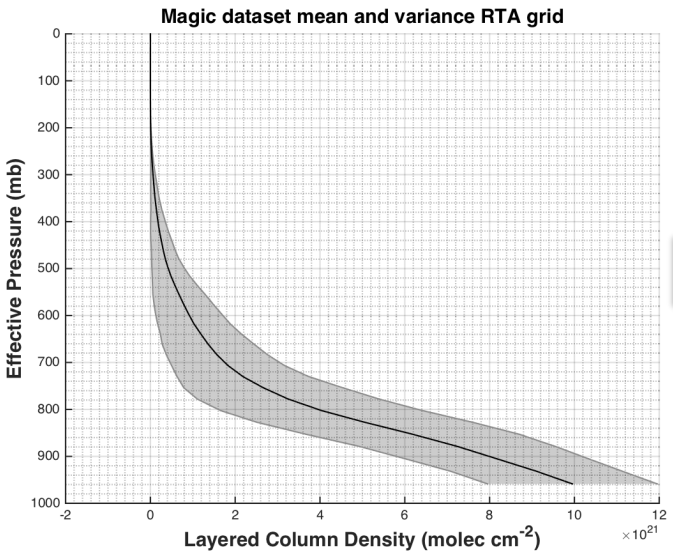
- Information content analysis was performed for two profiles out of the magic dataset
- Profile 5 has a strong capping inversion while Profile 1 is more adiabatic



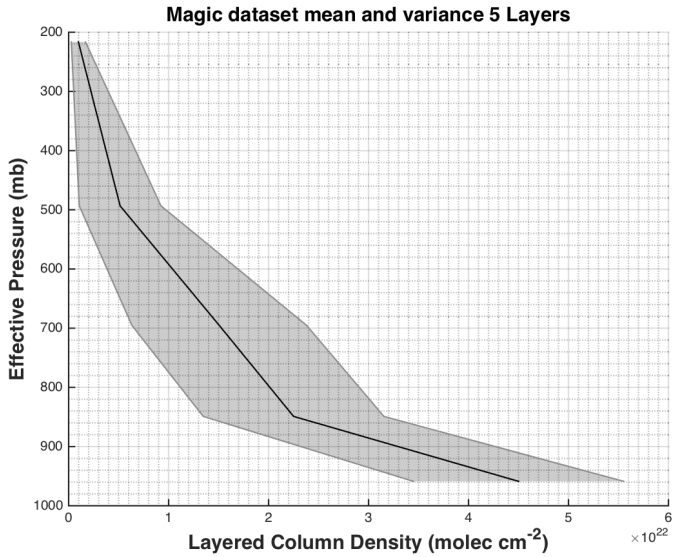


Magic to RTA Grid to Retrieval Grid

- Magic Radiosondes are a leveled profile with units of g/kg
- These are converted to 101 column density measurements on effective pressure layers (molecules cm^{-2})
- Retrieval grids of 2,4,5, and 7 effective layers were tested to overcome large null space of RTA grid

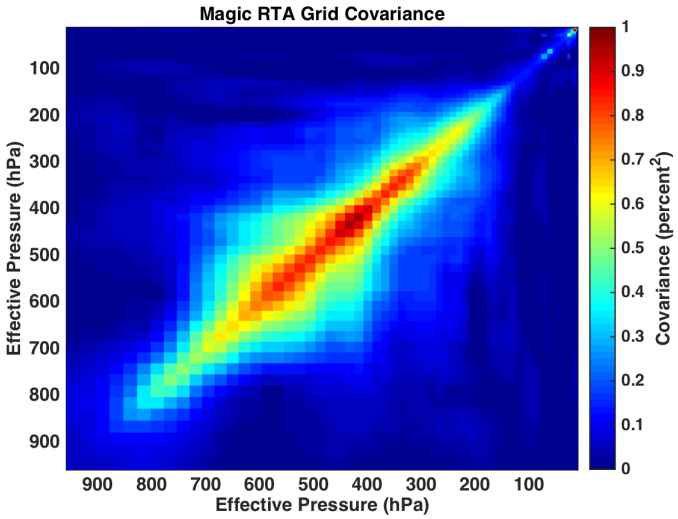


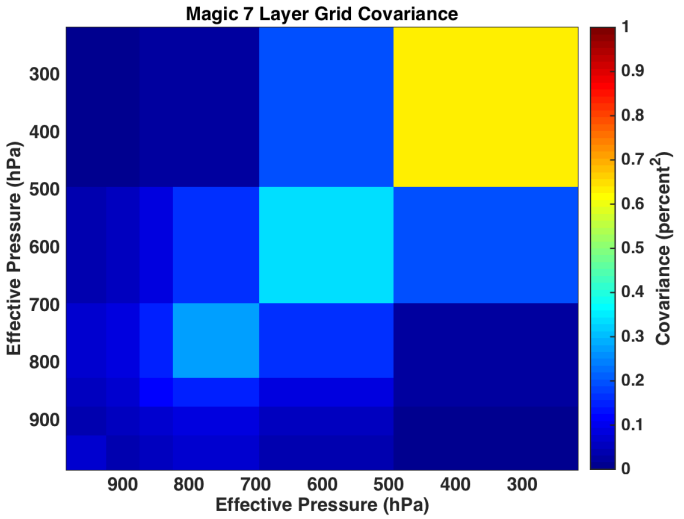
101 to 5



Apriori Covariance

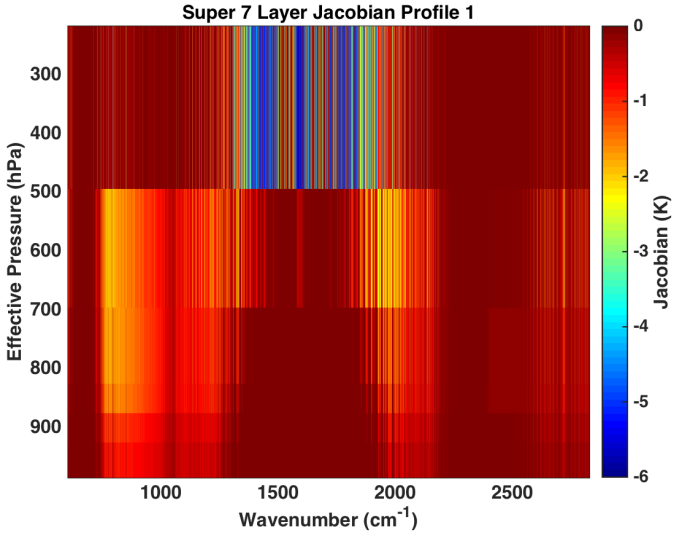
- I used an ad hoc *apriori* covariance matrix because of the low numbers of radiosondes in the data set
- Used the diagonals of from converted retrieval grid
- Then used an exponentially decreasing function of pressure to calculate off diagonals. 100 mb was used as the as a 1/e reduction in off diagonal covariance

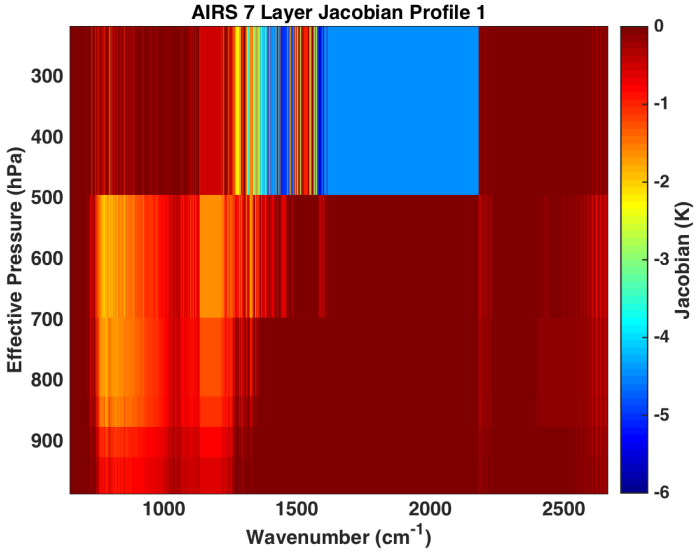


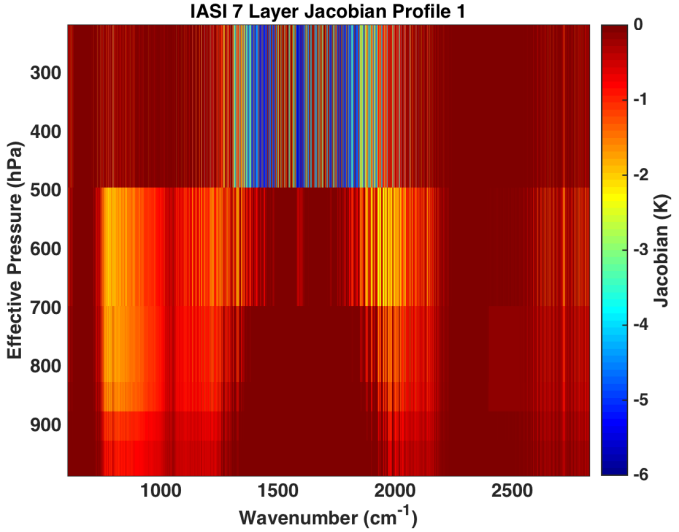


Weighted Jacobians

- 5 percent perturbation was done to each layer to calculate finite difference jacobians
- Each layer is weighted by its layered average column density to convert the retrieval equation to a percent change
- Used as a broad picture of where to look for sensitivity to changes in state vector
- AIRS smooth's across spectral lines shown in IASI and Super. Especially in upper troposphere. Results in less DOFs for AIRS compared to IASI





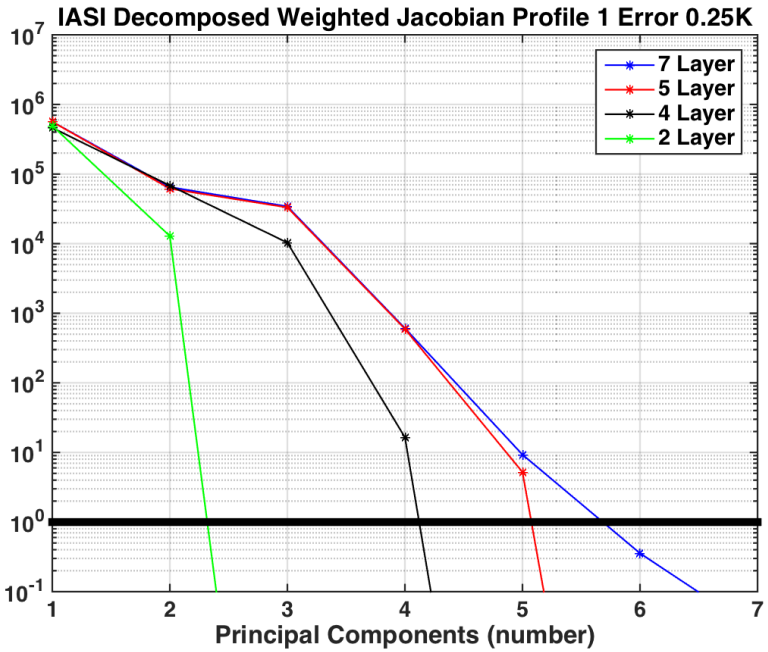


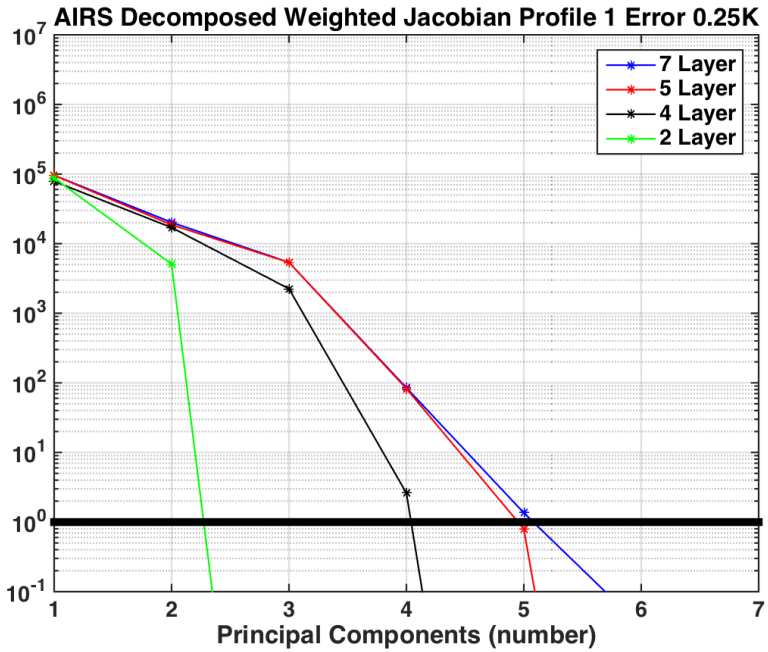
SVD Analysis

$$S_e^{-1/2} K S_a^{1/2} > 1$$

Number of independent measurements made to better then the measurement error

- The calculation shown here is for the entire IASI and AIRS spectrums respectively
- IASI Singular values are higher in magnitude then AIRS
- **IASI and AIRS have more information, but limited by retrieval grid**





SVD Analysis

AIRS Full Spectrum Information

	2 Layer	4 Layer	5 Layer	7 Layer
.1K Error	2	4	5	5
.25K Error	2	4	4	5
.5K Error	2	4	4	4
1K Error	2	4	4	4

- These results are for full spectrum SVD decompositions

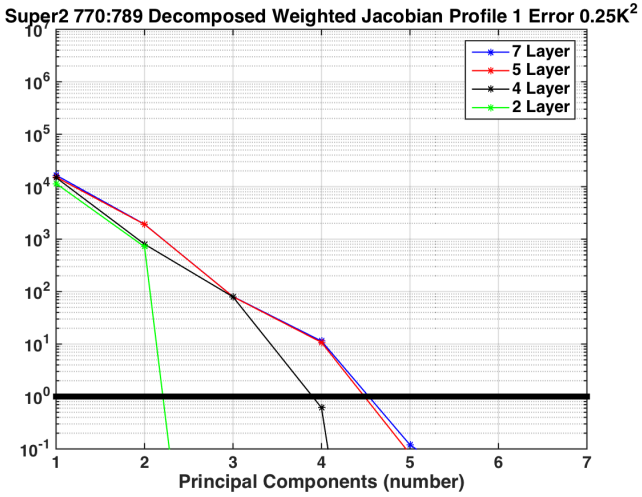
IASI Full Spectrum

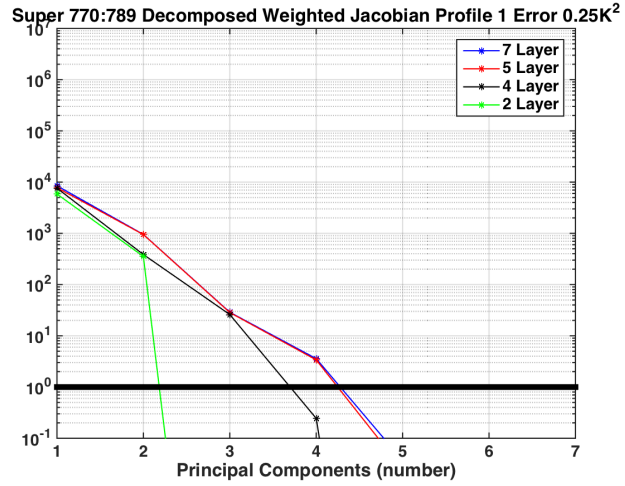
	2 Layer	4 Layer	5 Layer	7 Layer
.1K Error	2	4	5	5
.25K Error	2	4	5	5
.5K Error	2	4	5	5
1K Error	2	4	5	5

- IASI and AIRS both only see 5 independent pieces of information at max in with these retrieval grids

SVD Analysis

- The SVD shown here is for wavenumbers (cm^{-1}) 770-790





- The 7 Layer and 5 Layer retrieval grid had the same number of independent pieces of information
- Noise only reduced Full AIRS Information content
- The 20 wavenumber region for Super and Super 2 have almost same information content as AIRS/IASI full spectrums

Number of $S_e^{-1/2} K S_a^{1/2} > 1$ for Profile 1

	5 Lay .1K²	.7 Lay .1K²	5 Lay 1K²	7 Lay 1K²
Super 2	4	4	4	4
Super	4	4	4	4
IASI	3	3	3	3
AIRS	2	2	2	2
IASI Full	5	5	5	5
AIRS Full	5	5	4	4

Averaging Kernel

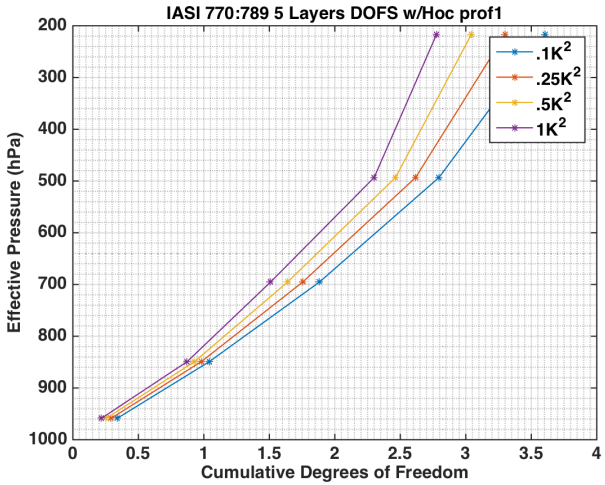
$$A = \frac{d\hat{x}}{dx}$$

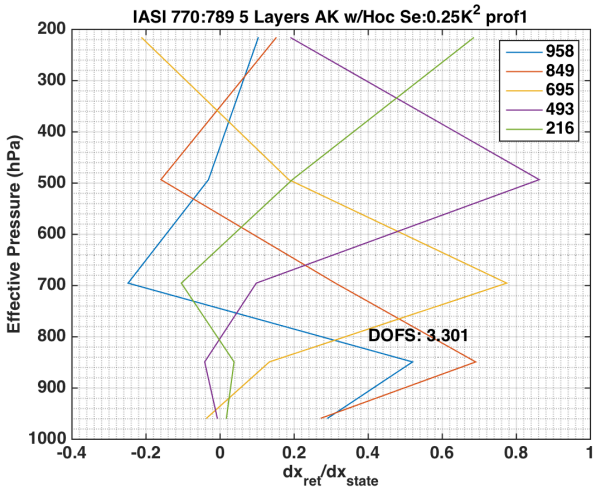
- Describes how the retrieval changes when you change the state variable (e.g. water vapor)
- Helps understand vertical resolution of retrieval

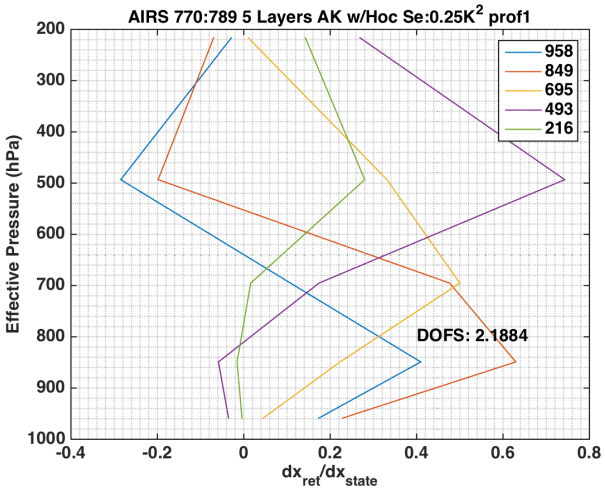
Degrees of Freedom

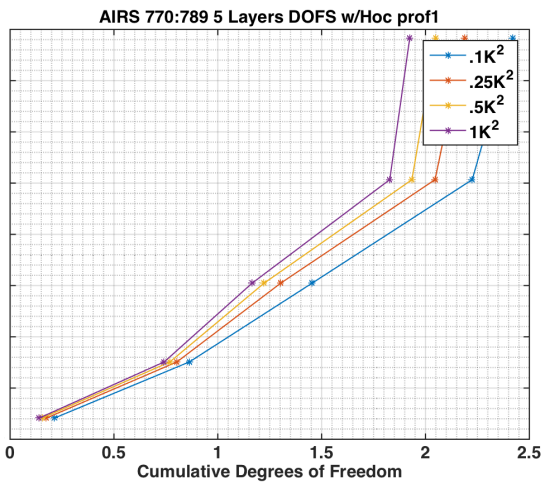
$$dof = trace(A)$$

- Another measure of independent pieces of information
- Lets you understand how much information comes from different parts of the atmosphere

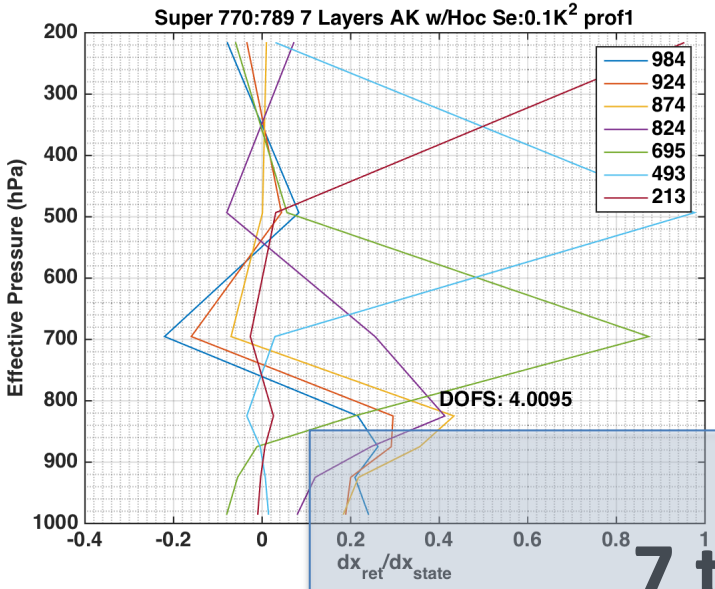




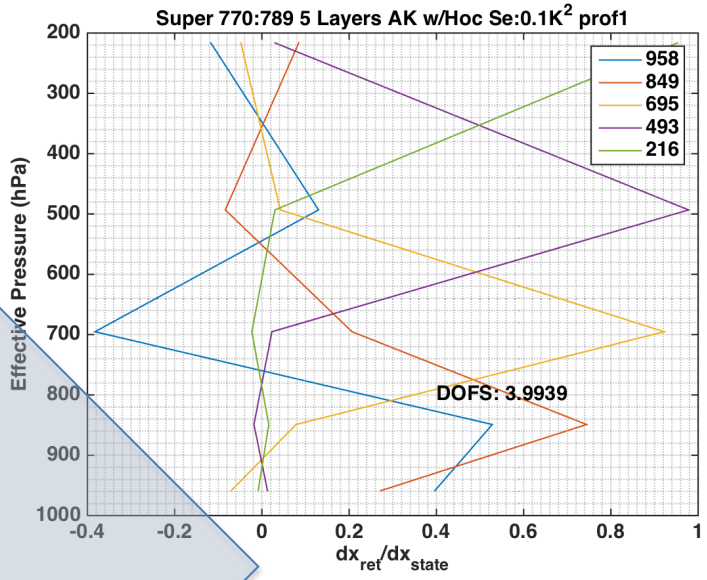




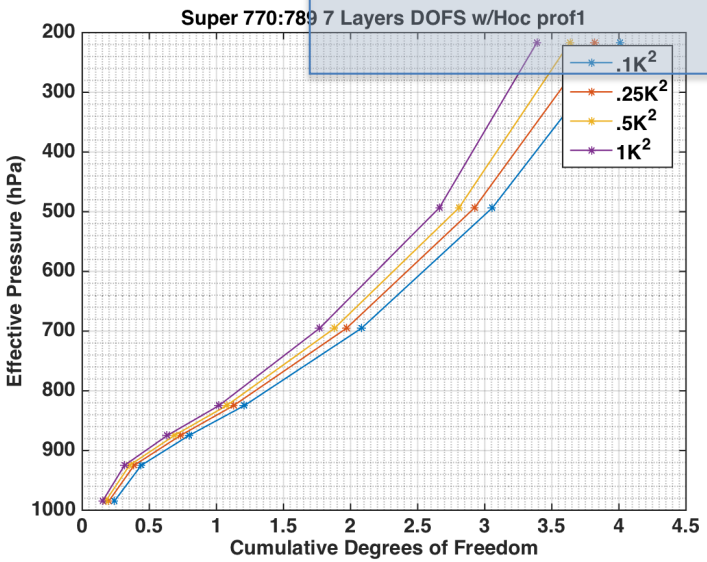
Higher Resolution



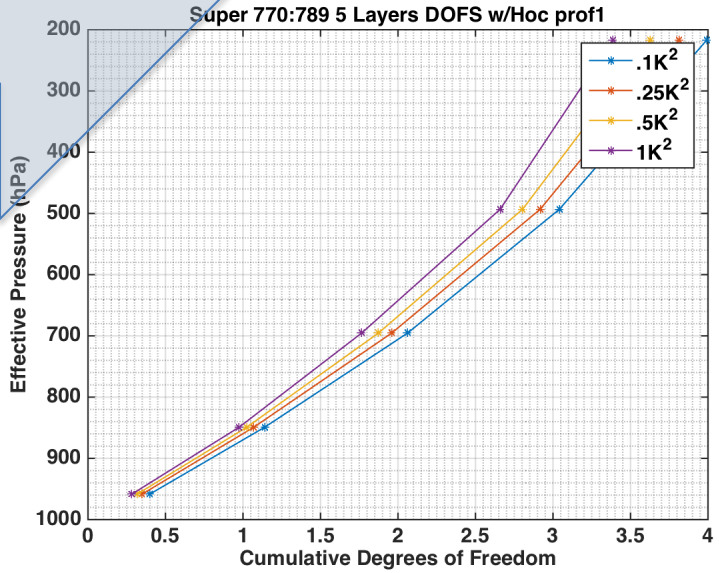
- Finer resolution in 7 Layer grid adds little extra information



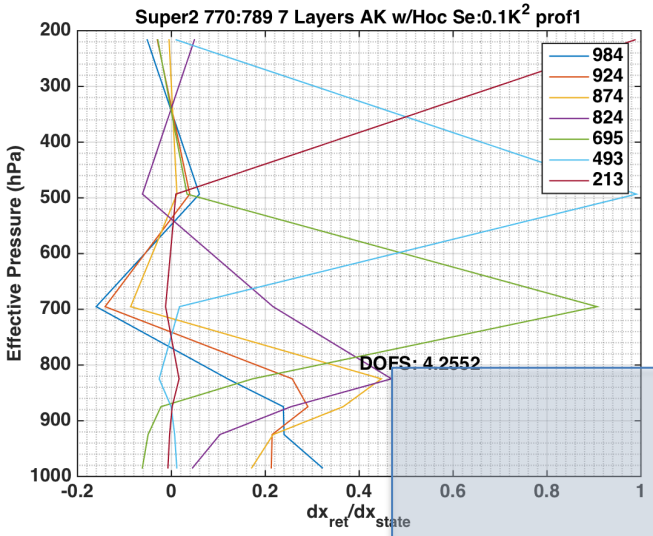
7 to 5 layers



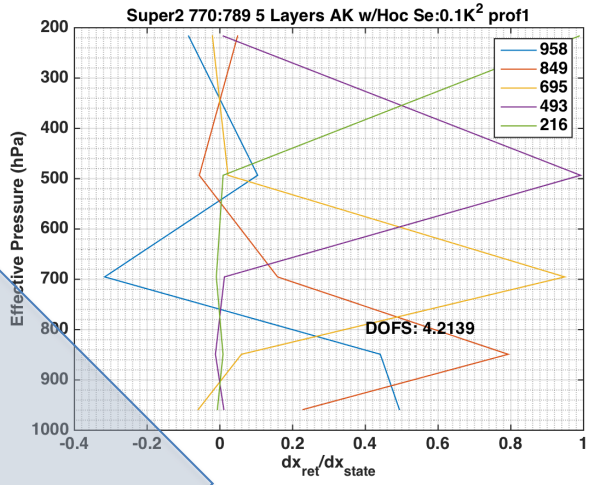
- Getting nearly 1 piece of information



Even Higher Resolution



- PBL AK starting to peak in correct places
- Still broadly sensitive to whole PBL



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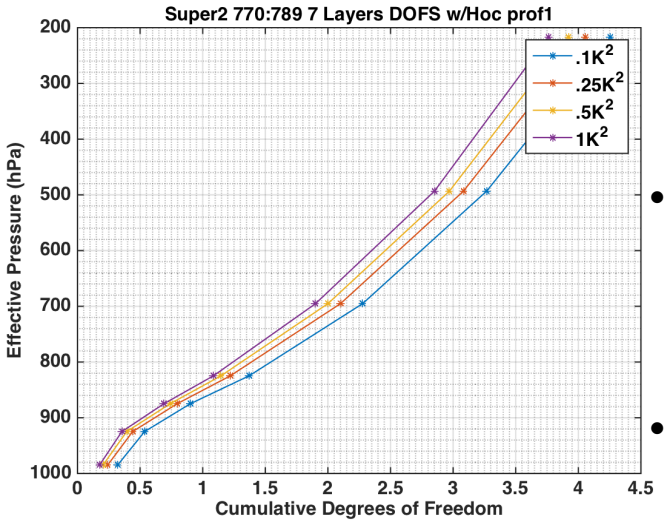
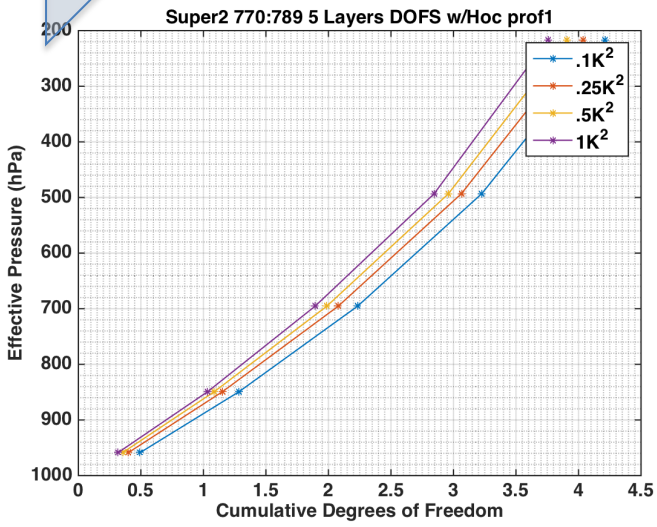


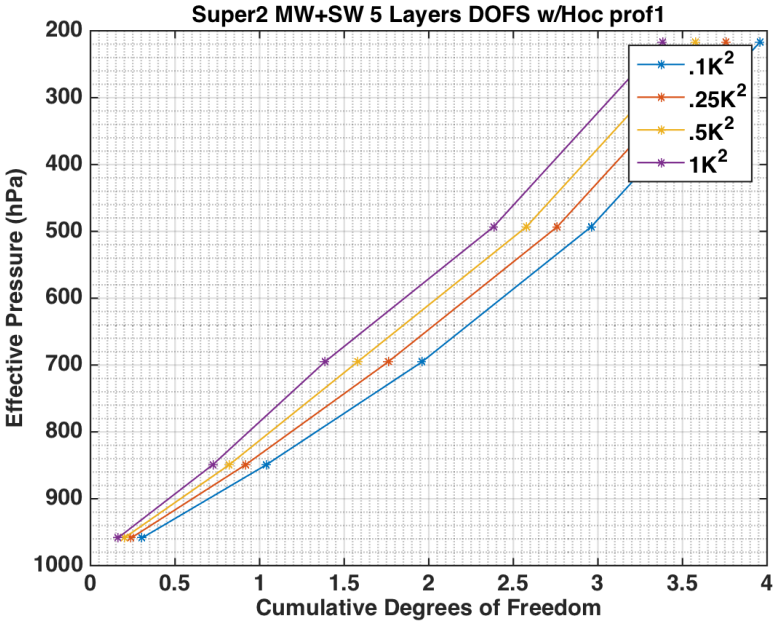
- Good sounding information from just above PBL to upper troposphere
- Suggests finding more spectral lines may increase information content
- Noise did not affect PBL content much

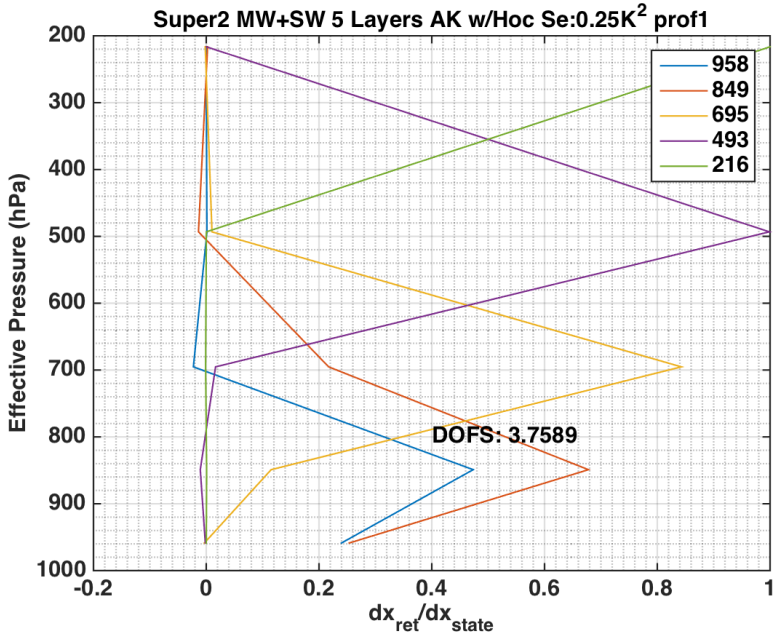


Other Spectral Regions

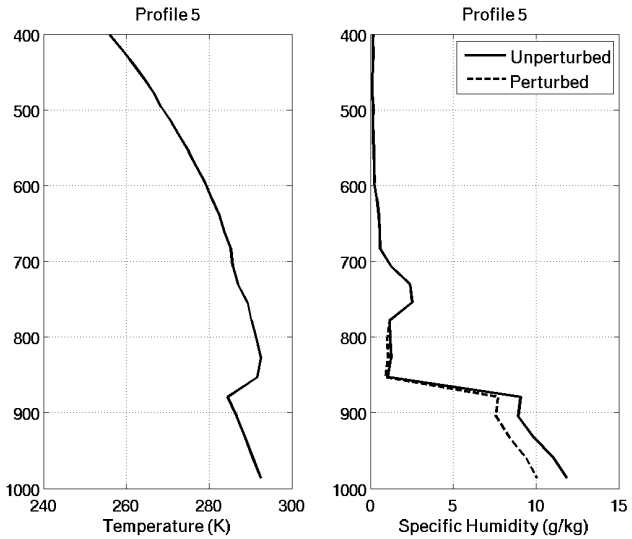
- Looked in Mid-Wave (1600-1609) and Shortwave (2588-2599)
- Little information when used independently of one another
- Here are the combined results of both regions

- Averaging Kernel suggests this is more well behaved then the LW channels.
- DOFs more affected by the noise estimate
- Maybe some DOFs are causing ringing in LW?
- Almost 1 piece of information in PBL

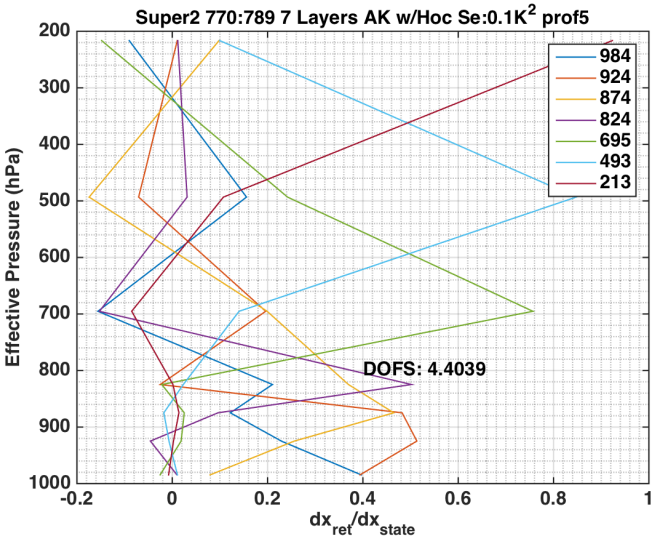


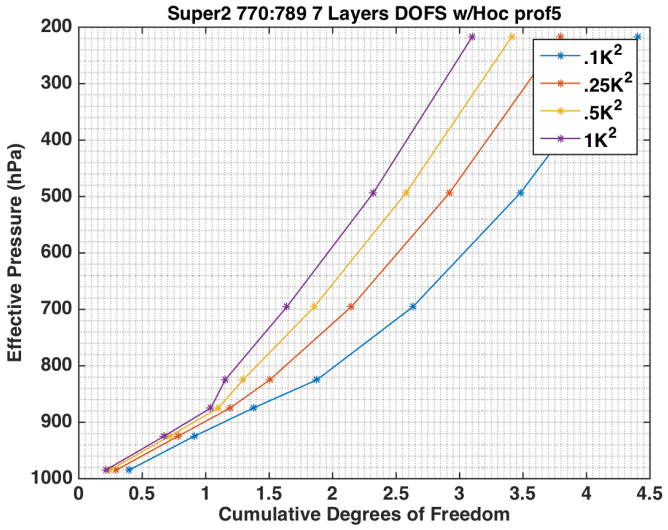


Temperature Inversion

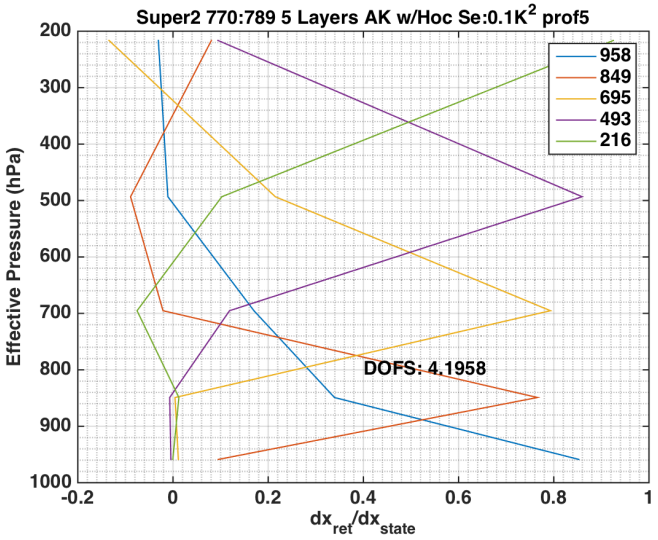


- 5 Layer is close to 2 pieces of information in PBL
- Peaks are in correct places





- IASI and AIRS both had approximately 1 piece of information in PBL for this profile



Summary

- Full AIRS (and IASI) spectrums contained 2-4 (2-5) pieces of information, largely invariant to modeled noise
- The longwave provided the most information for all sensors, though the MW+SW was better behaved
- For adiabatic case the 5 layer and 7 layer PBL measurements were nearly the same
- Super2 (.05 cm^{-2}) had near 2 pieces of PBL information for thermal inversion case
- Need to do a more rigorous checking of spectral channels for added information in all bands

Extra Slide: Conversion to Percent Change

$$\tilde{\mathrm{K}} = x_i K$$

$$x_{i+1} = x_i + (\frac{x_i}{x_i} K^T S_e^{-1} K \frac{x_i}{x_i} + \frac{x_i^2}{x_i^2} H)^{-1} K^T \frac{x_i}{x_i} S_e^{-1} [y - F(x_i)]$$

$$x_{i+1} = x_i + (\frac{1}{x_i^2} \tilde{K}^T S_e^{-1} \tilde{K} + \frac{x_i^2}{x_i^2} H)^{-1} \tilde{K}^T \frac{1}{x_i} S_e^{-1} [y - F(x_i)]$$

$$x_{i+1} = x_i + x_i (\tilde{K}^T S_e^{-1} \tilde{K} + x_i^2 H)^{-1} \tilde{K}^T S_e^{-1} [y - F(x_i)]$$

$$x_{i+1} = (1 + \alpha) x_i$$