Accuracy and Information Content on Thermodynamic Profiling from Active and Passive (Ground-based) Sensors

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Thermodynamic Profiling in the Boundary Layer

- Lot's of scientific and operational reasons for these profiles
- Generally there are only three remote sensing methods that could be used from orbit to sample the BL
  - Spectral microwave sounder
  - Spectral infrared sounder
  - Water vapor lidar (most likely DIAL, but Raman also possible)
- Each method has strengths and weaknesses
  - Strength for IR/MW sounders: spatial coverage
  - Strength for lidar: vertical resolution
  - Weakness for IR/lidar: clouds
  - Weakness for MR sounder: land surface emissivity
  - All three methods have poor temporal coverage

Why Information Content?

Passive Remote Sensing

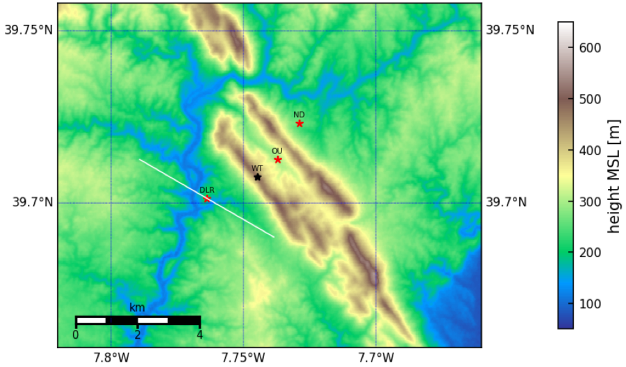
- Sounders measure radiation emitted from the atmosphere in channels sensitive to emission from different gases and over a range of optical depths
  - Radiance contains info on T(z) and q(z) (and clouds, other TGs, etc)
- Ill-defined problem; retrievals need to be constrained by either a priori data or model background
- Information content is key: what part of retrieved profile is from obs vs. from a priori information
- Calibration is absolutely key
- No real information on how temperature covaries temporally / spatially / vertically, which hinders retrievals

Synergistic Remote Sensing

- Combining active and passive observations into a retrieval can improve accuracy and information content of retrieved profiles
- Consistent forward models and no systematic errors critical
- Strength of one observing technology can be used to overcome the weakness of the other
- Uncertainty analysis and information content is important
- Demonstrate with a ground-based application
- Retrievals performed using AERIoe algorithm (Turner and Löhnert 2014; Turner and Blumberg 2018)
  - Physical-iterative method using optimal estimation framework
  - Able to combine different types of observations to retrieve T(z) and q(z)
  - Full error characterization and vertical resolution are standard output products

Examples Using Real Ground-Based Obs

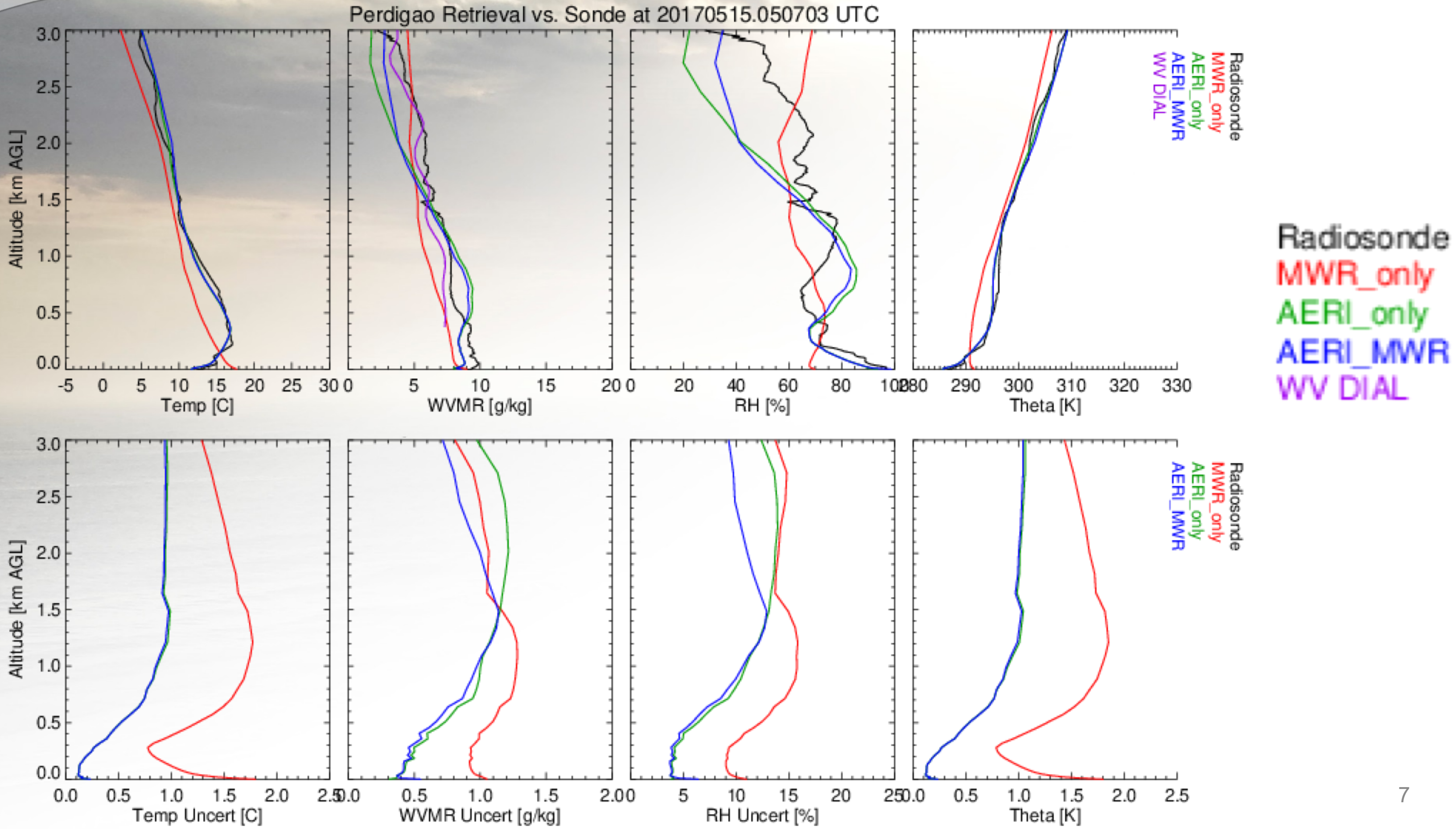
- Perdigao field campaign conducted in Portugal to study wind flow in the boundary layer in complex terrain (Fernando et al. BAMS 2018)
- IR, MW and WV lidar all collocated over 45 day experiment
  - IR: Atmospheric Emitted Radiance Interferometer (AERI)
    - Downwelling radiance from 520-3000 cm-1 at 0.5 cm-1 every 30 s
  - MW: Humidity and Temperature Profiler (HATPRO)
    - Downwelling radiance in 14 chs from 22.2 to 58.0 GHz every 1 s
    - Zenith and elevation scanning (latter improves resolution near instrument)
  - NCAR water vapor micropulse differential absorption lidar (DIAL)
    - WV profile from 700 m to ~3 km every minute
    - Data below 700 m had systematic error (overlap?) that needed to be avoided
- PWV had a mean of 1.96 cm and StDev of 0.60 cm



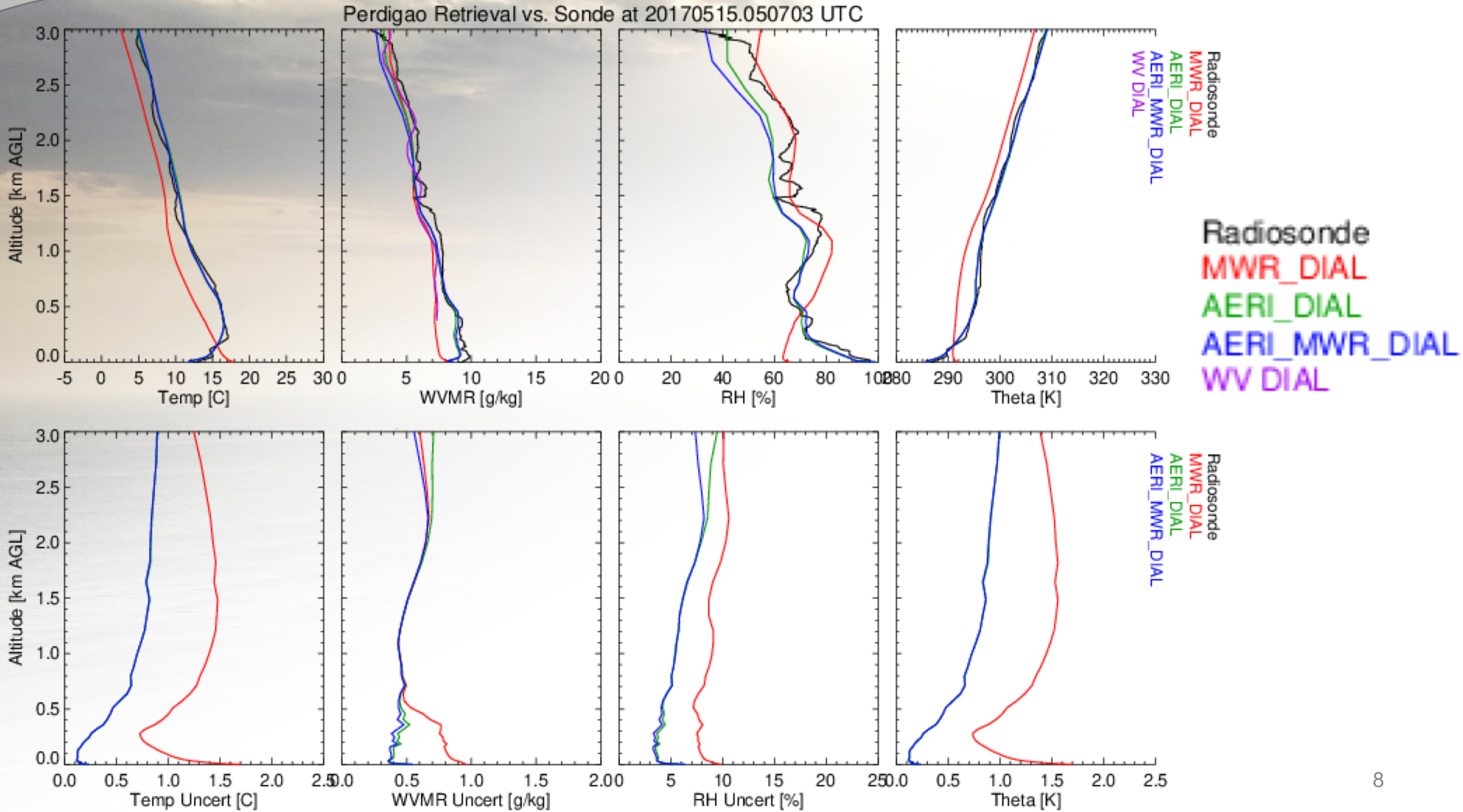
PERDIGÃO

Field experiment

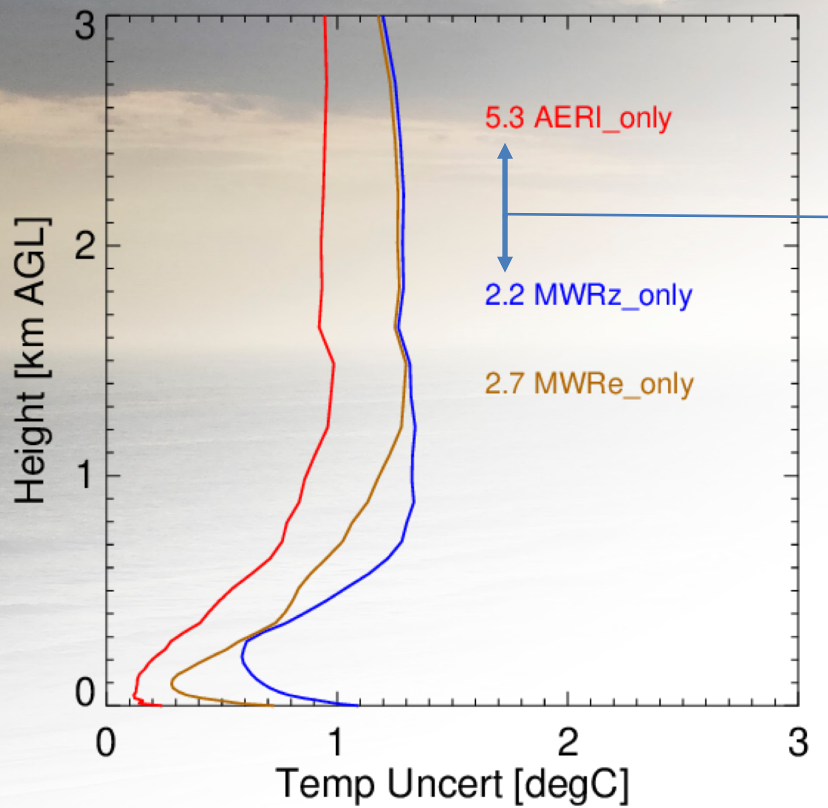
Example: Passive-Only Retrieval



Example: Active+Passive Retrieval

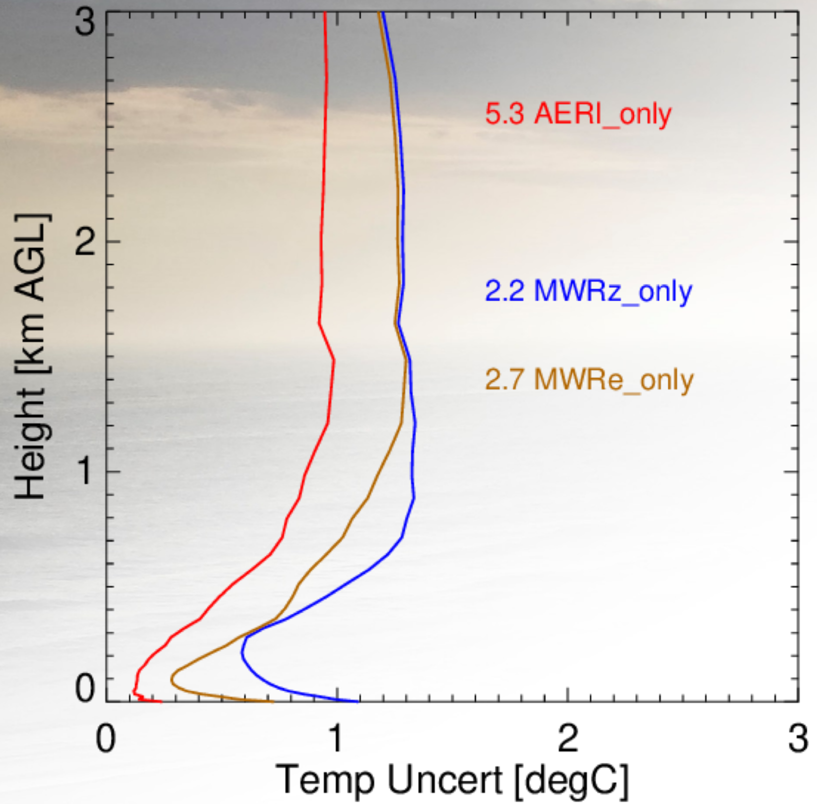


Single-instrument Passive-only Retrieval

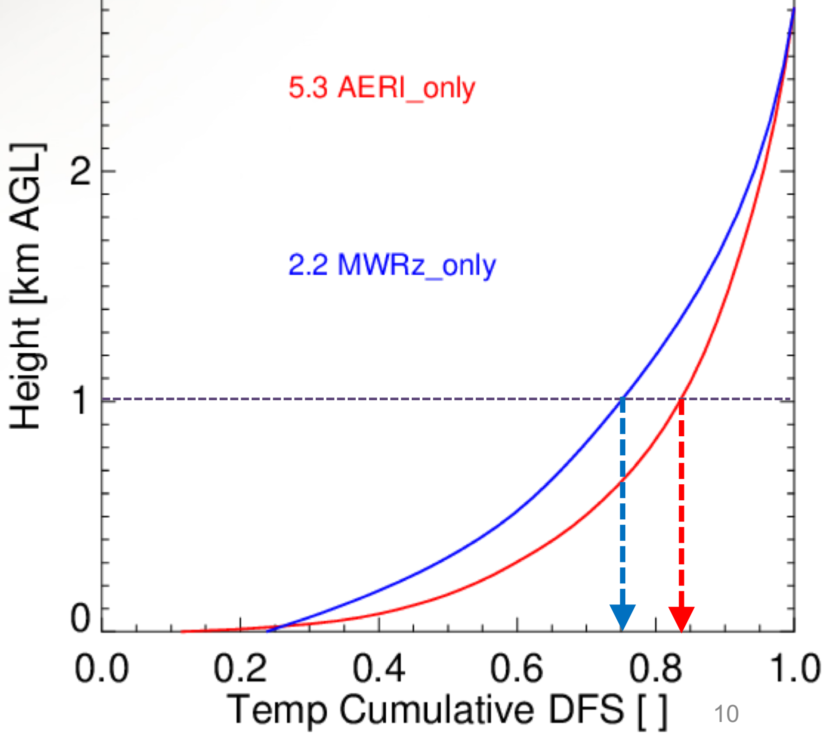


Degrees of Freedom of Signal
(number of independent pieces of information)

Single-instrument Passive-only Retrieval



84% of 5.3 pieces of info below 1 km = 4.4 indep levels
75% of 2.2 pieces of info below 1 km = 1.7 indep levels



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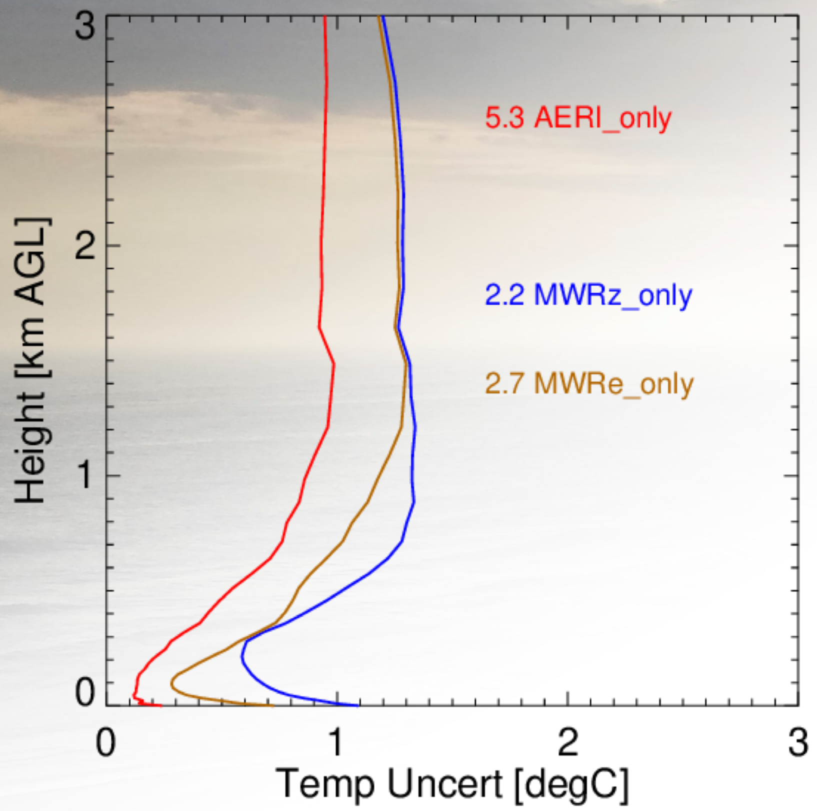
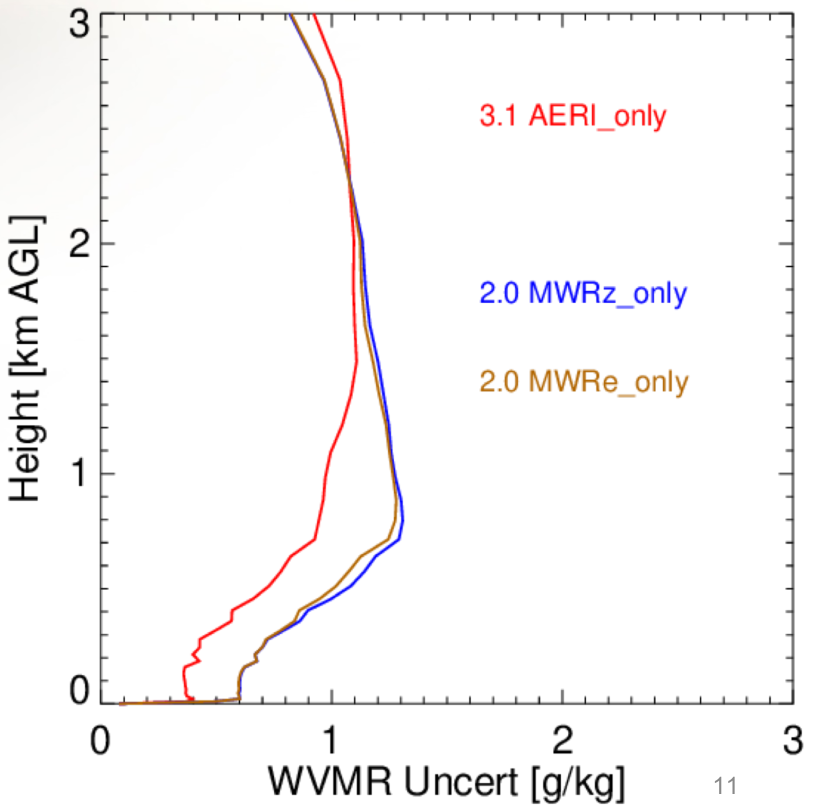
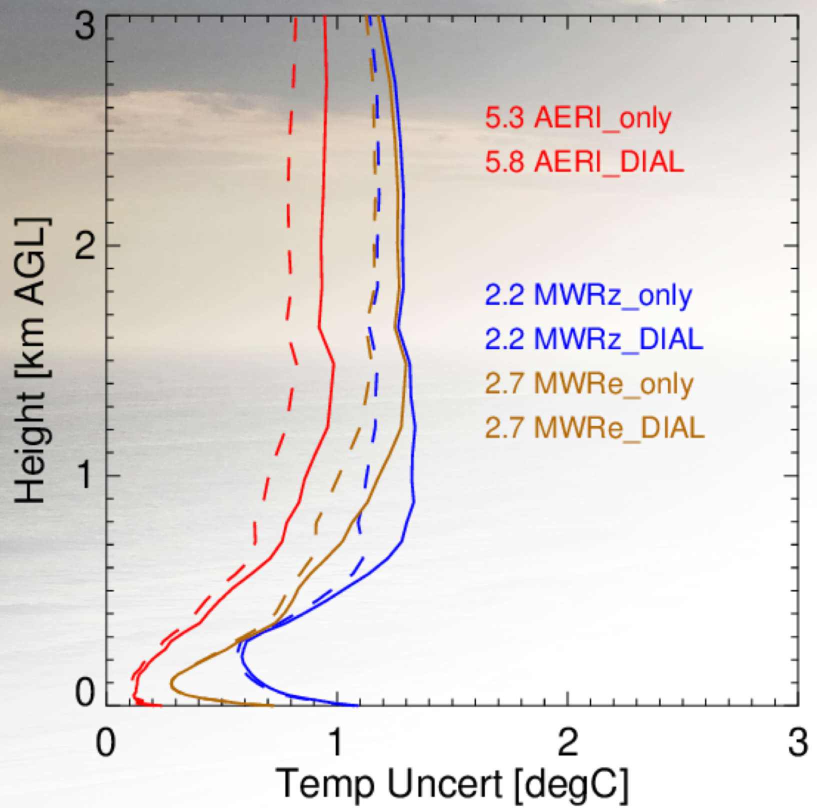
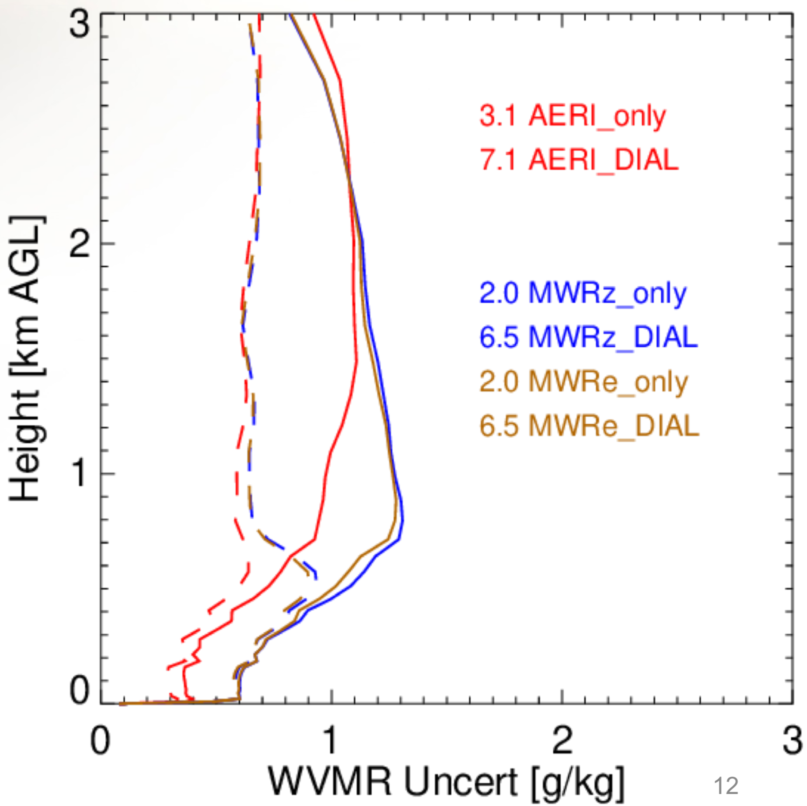


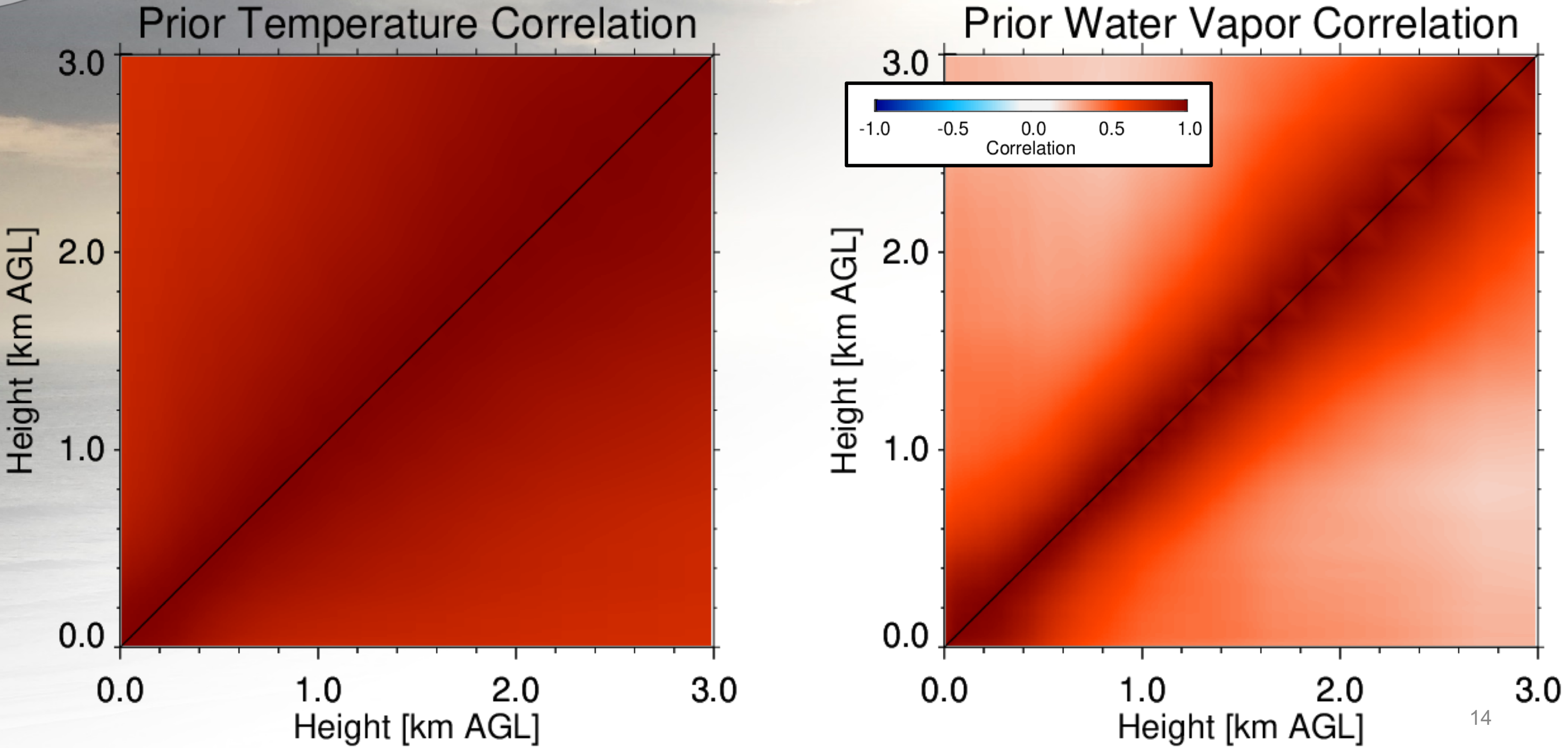


Passive+Active Combined Retrieval

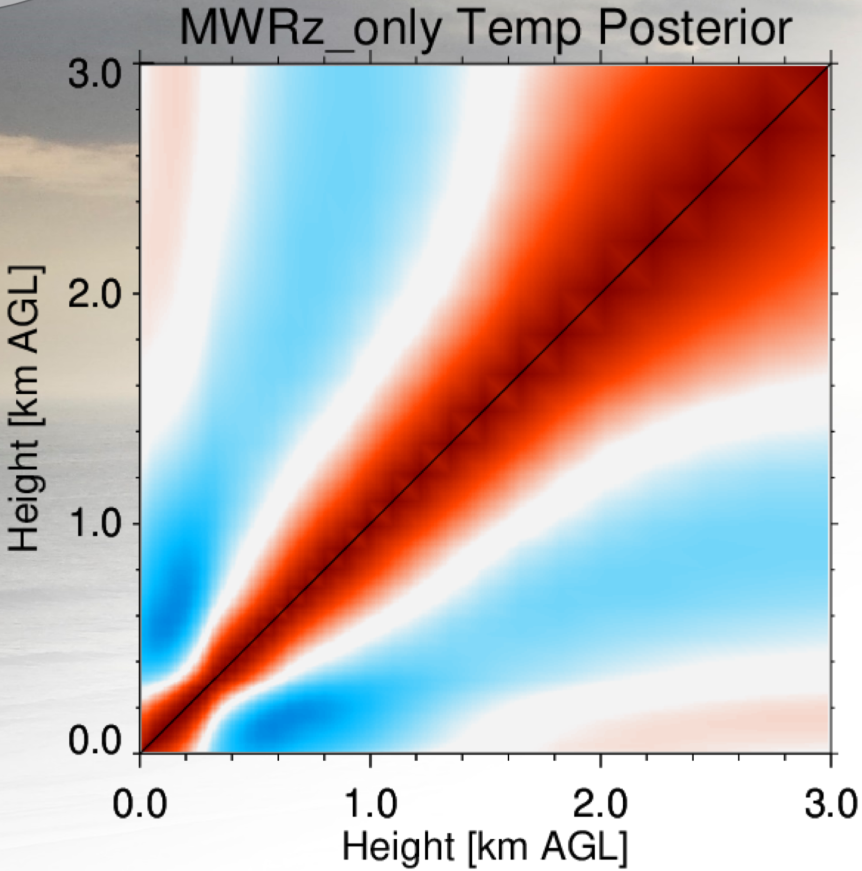


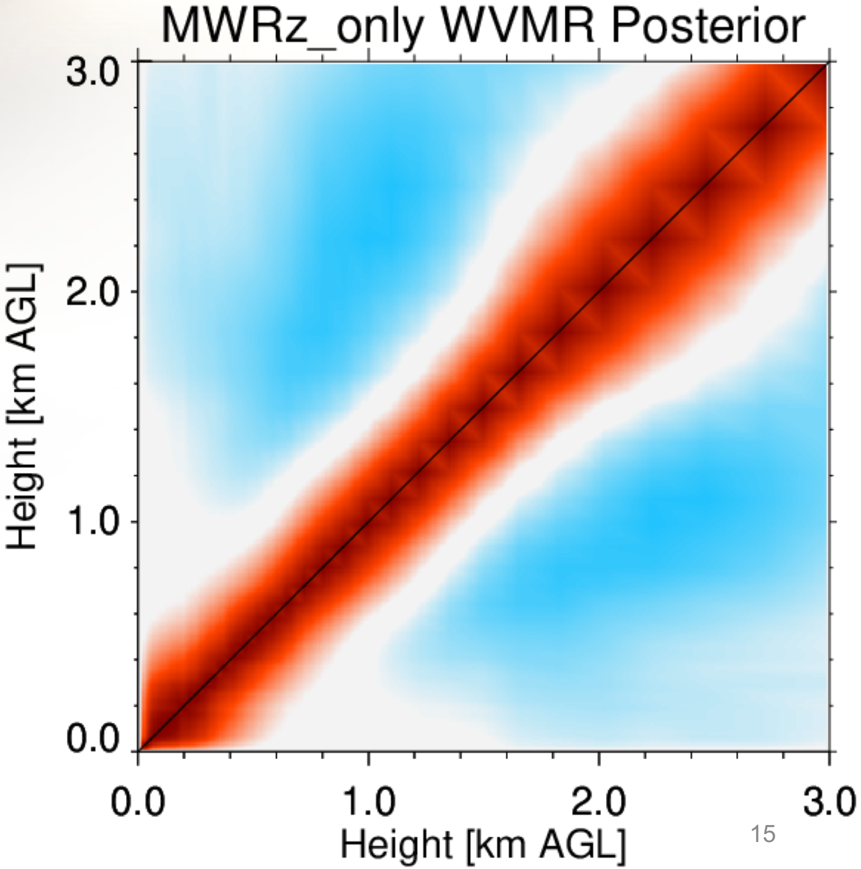


Level-to-level Correlations are Important

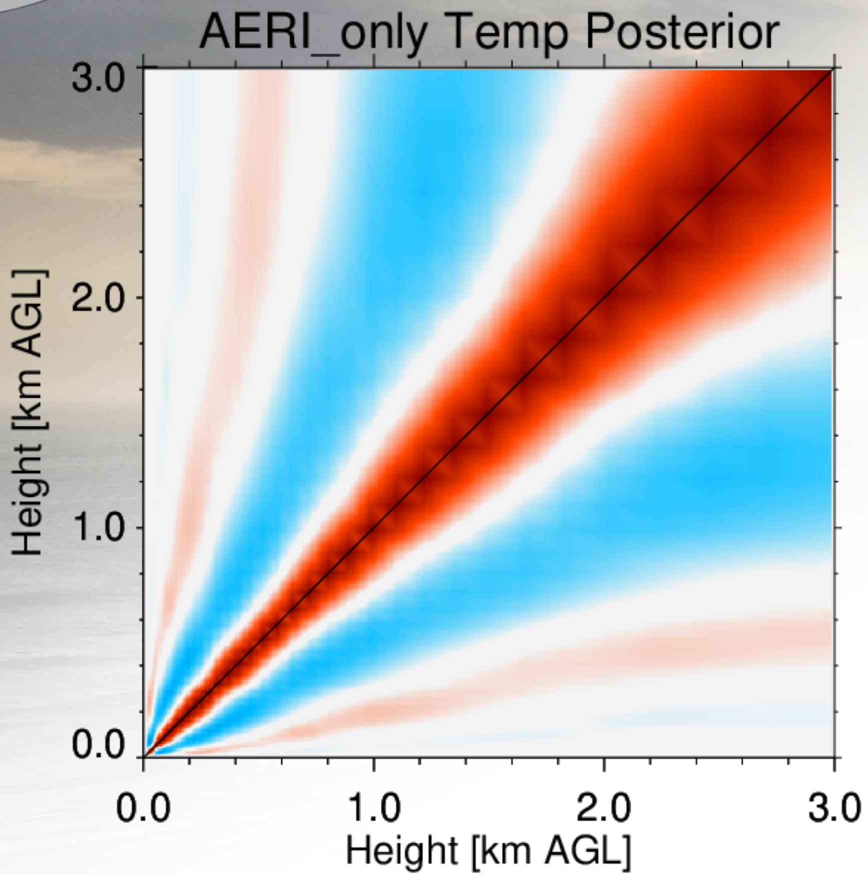


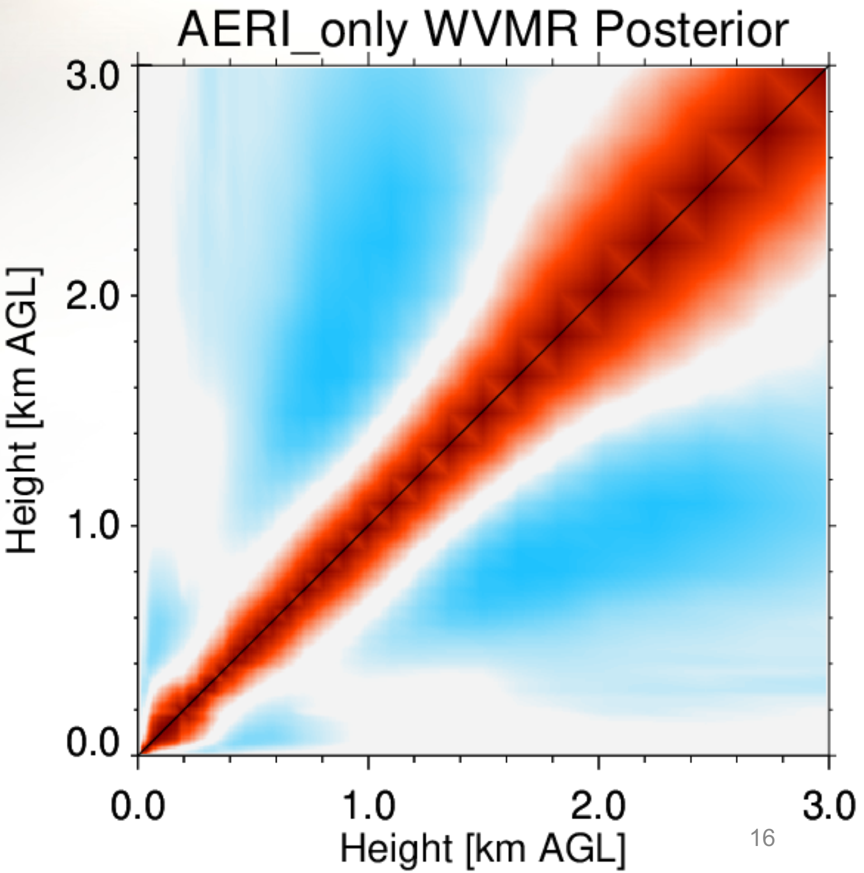
Posterior Correlation for MWRz-only Retrieval



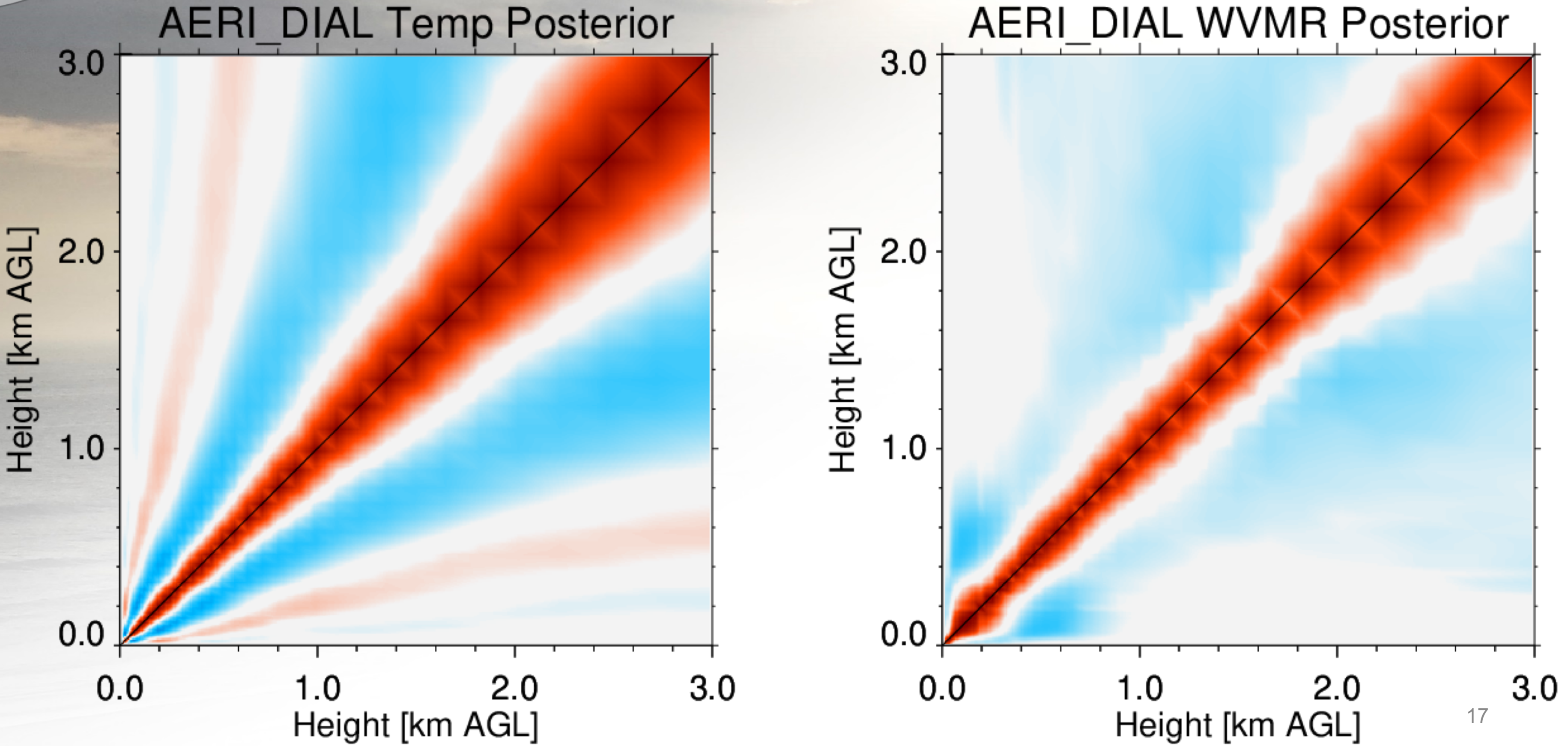


Posterior Correlation for AERI-only Retrieval

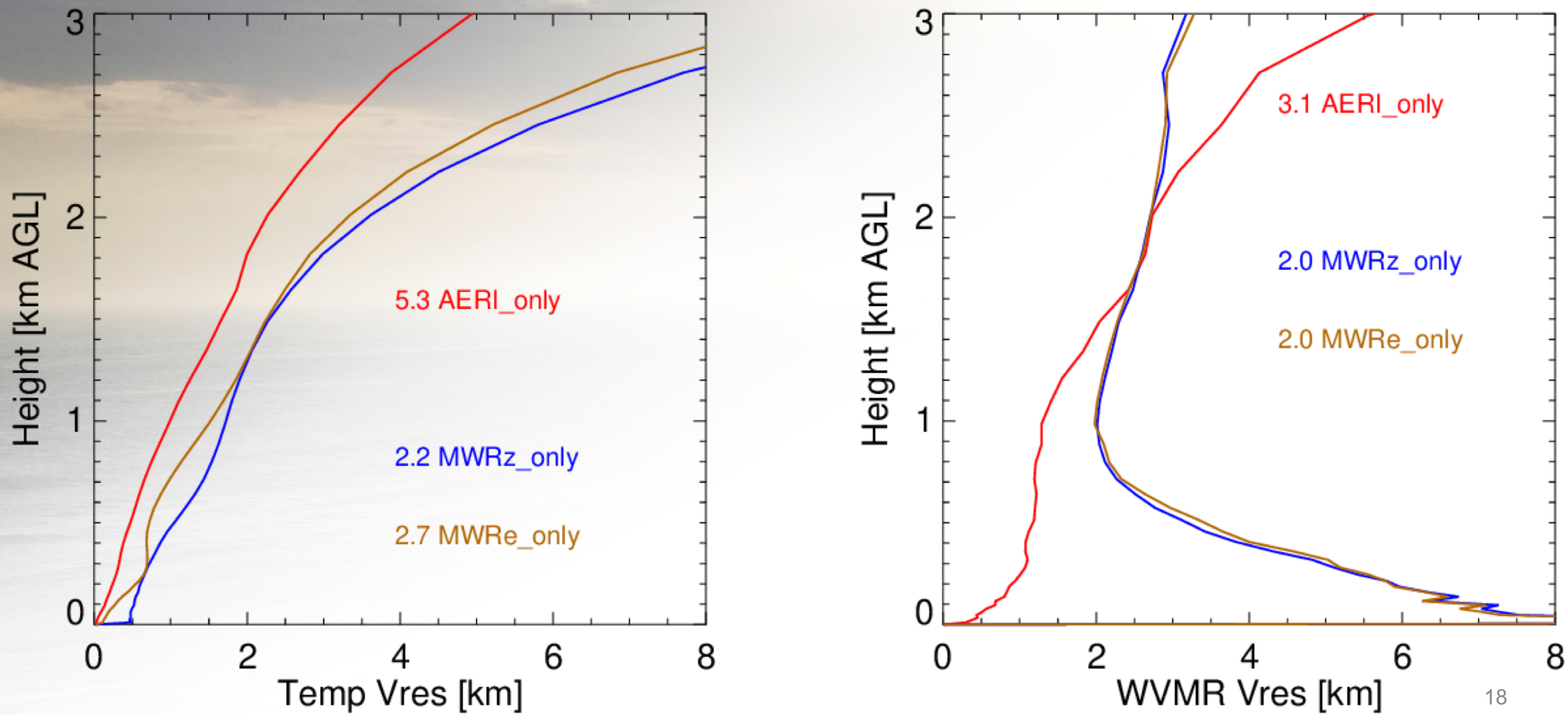




Posterior Correlation for AERI+DIAL Retrieval

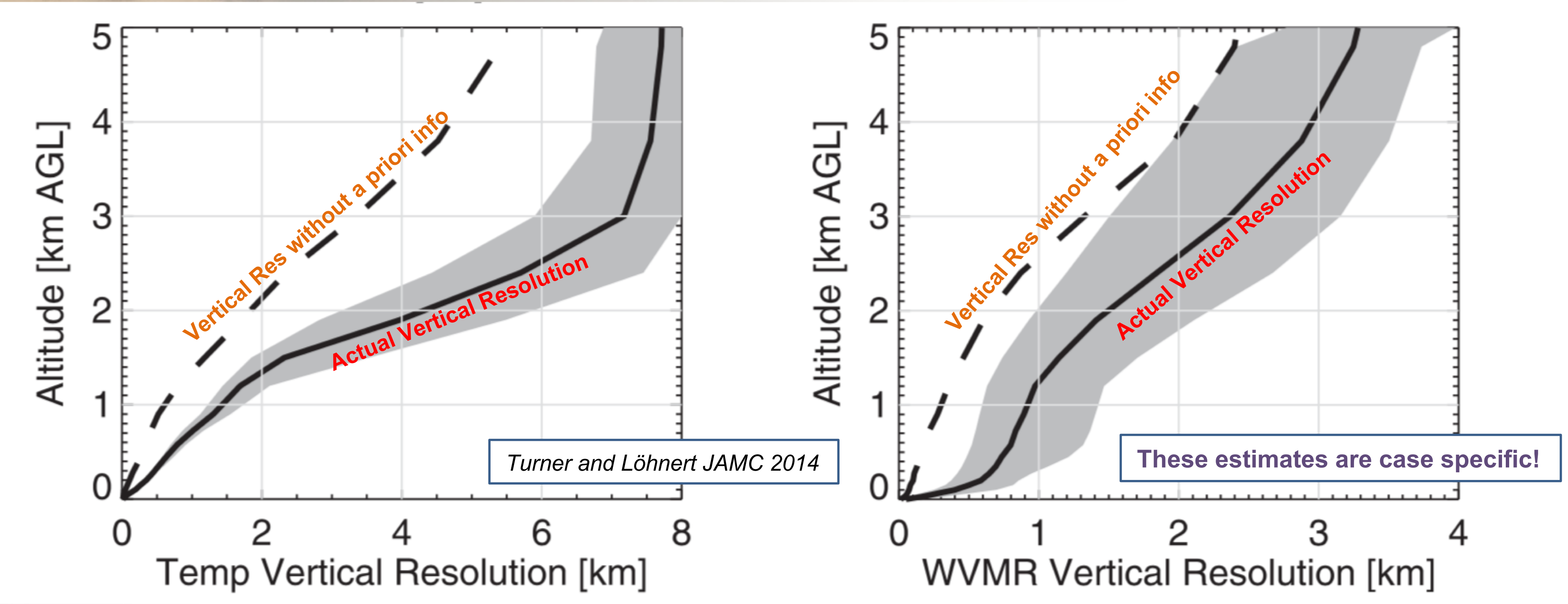


Single-instrument Passive-only Retrieval

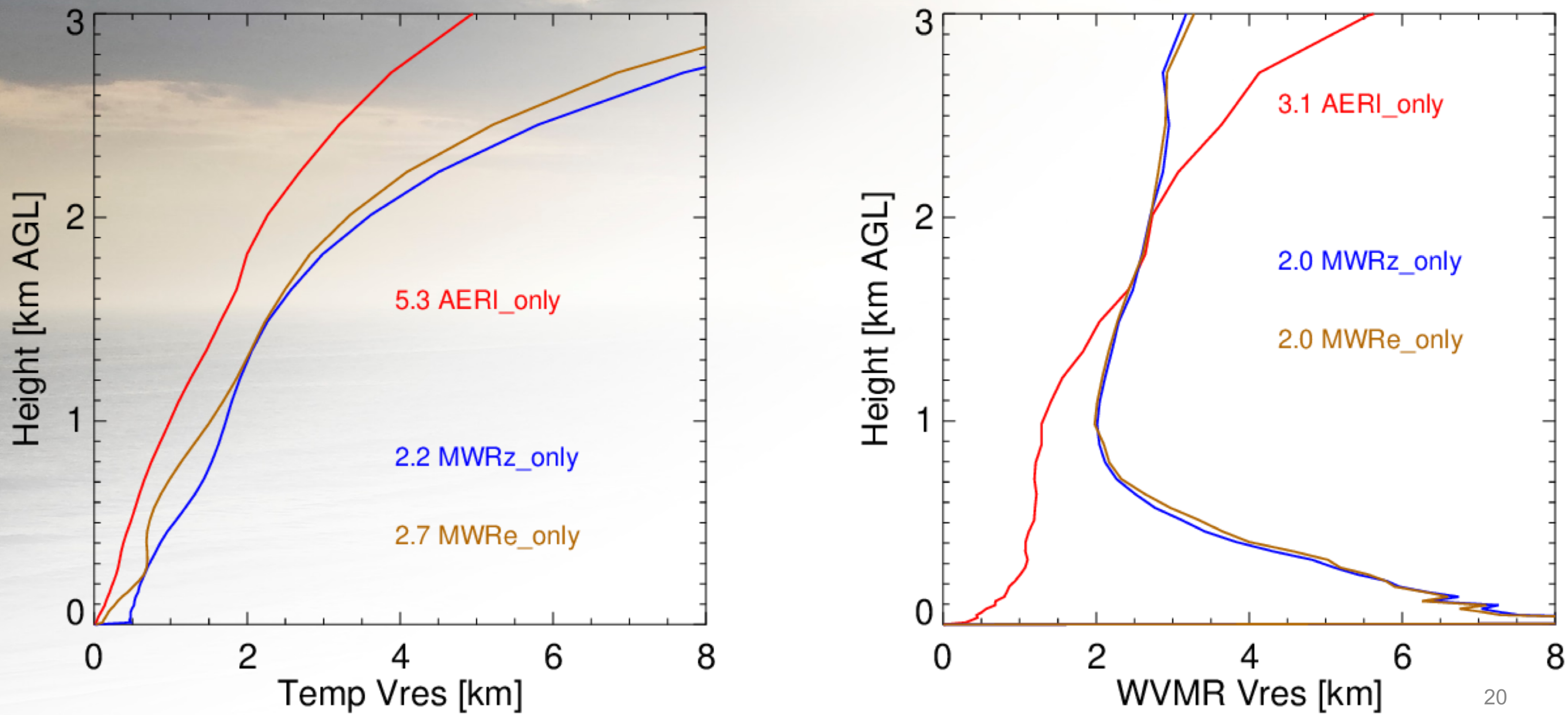


Vertical Resolution Depends on:

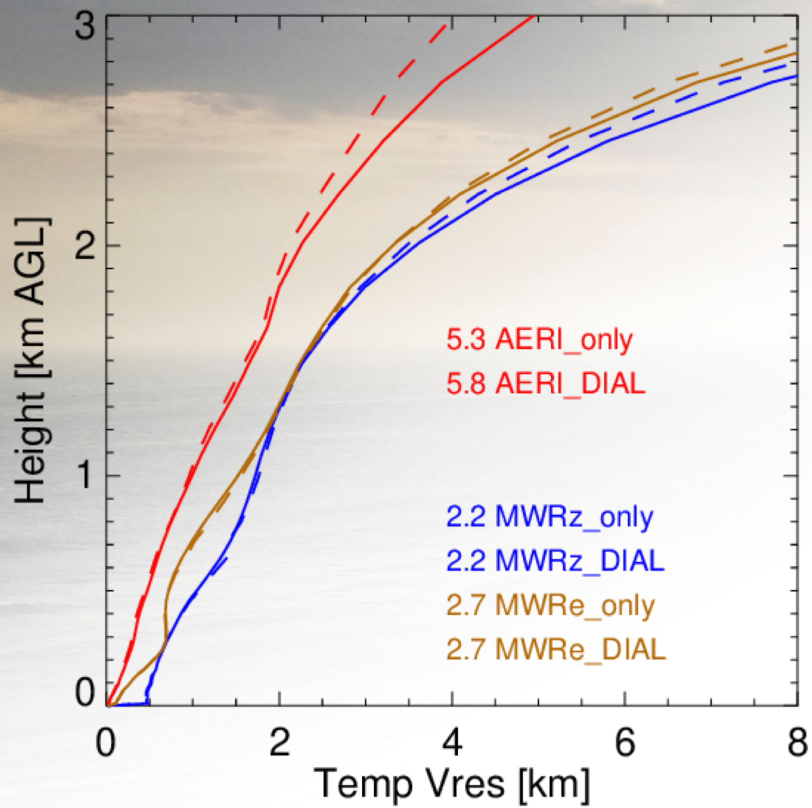
1. Weighting functions of instrument
2. *A priori* data used to the constrain the retrieval

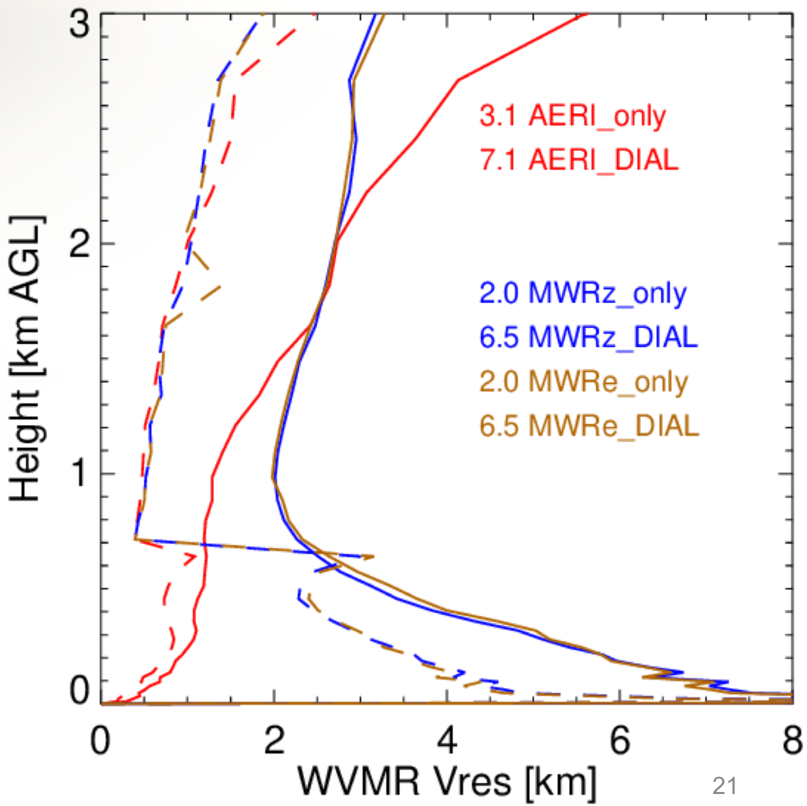


Single-instrument Passive-only Retrieval



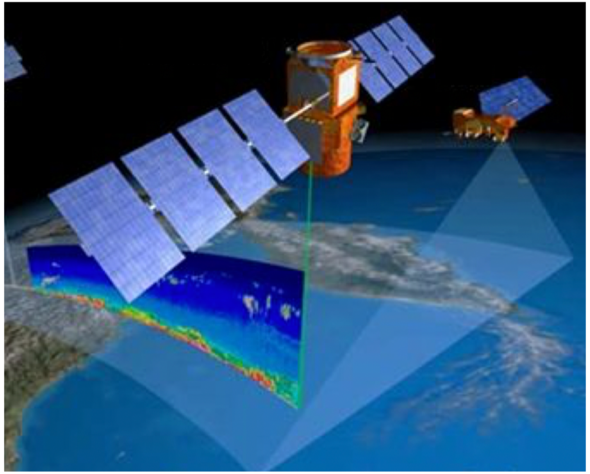
Passive+Active Combined Retrieval





So What Does this Mean in Our Context?

- One possible synergistic solution is to co-deploy a water vapor lidar with an imaging/scanning spectral IR or MW instrument
- Approach
  - – Nadir pixels that have both lidar and spectral passive obs retrieved just like that done here
  - – Use lidar-only data (over time) to develop spatial and vertical covariance matrices
  - – Use covariance matrices and nadir data to improve (add information to) off-nadir spectral passive only retrievals



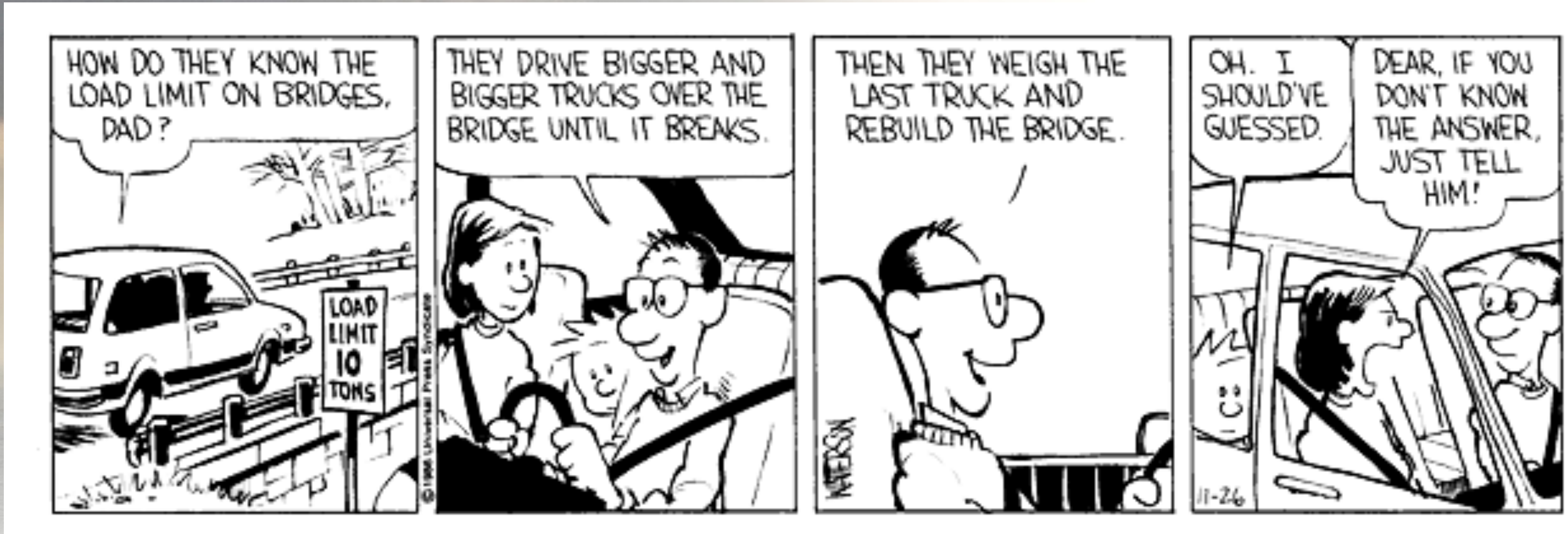
Caveats (of course)

- These GB examples, drawn from zenith pointing instruments, are simpler than airborne/spaceborne instruments
  - Nadir passive sensors have uncertainties with surface temp & emissivity
  - Lidars may not be able to sample lowest few hundred meters close to sfc
- Also, different spectral resolutions and/or bands can change the information content of the passive obs
  - E.g., addition of 183 GHz MW sensor would change info content
- Instrument simulation activities can be useful to characterize the synergistic approach
  - Probably would have to use a (mesoscale) model to determine covariances

The Enemy of the Good is the Better

- NASA already has (has access to) these types of airborne instruments now, such as
  - LASE (and the new HALO) water vapor DIAL
  - NAST-I and S-HIS (scanning spectral IR radiometers)
  - HAMSR (scanning spectral MW radiometer)
- Recommend using physical retrievals to get full error characterization like done here
- Several future flight opportunities to help with evaluation:
  - 2019 and 2020: Vortex-SE: NOAA program in southeast part of US
  - 2019-2020: MOSAiC: Arctic ocean
  - 2020: EUREC^{4}A: just east of Barbados in marine environment
- All offer a large number of additional datasets that are able to provide BL truth and context information

Last Thoughts



- Passive-only systems will always have coarse vertical res in BL
- Lidar Vres is better; however, likely will be sampling along a curtain
- Clouds will remain as a large challenge, as will temporal resolution
- I don't know the answer, but this approach has (potentially a lot of) value