Remote Sensing of Planetary Boundary Layer Temperature and Water Vapor Using Near- and Thermal-Infrared Measurements

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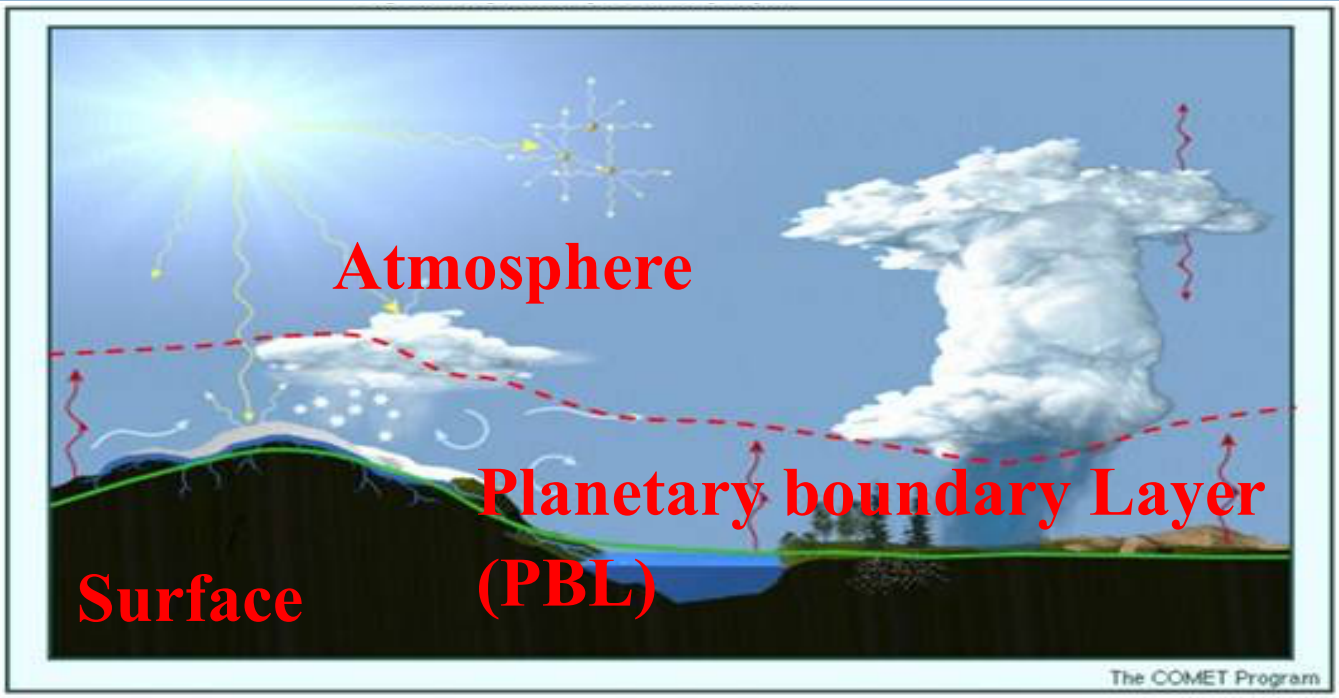
Motivation



- Physical quantities in the PBL (flow velocity, temperature, moisture) display rapid variations, and vertical mixing is strong.
- Remote sensing of PBL temperature and water vapor from the space is challenging.

Motivation

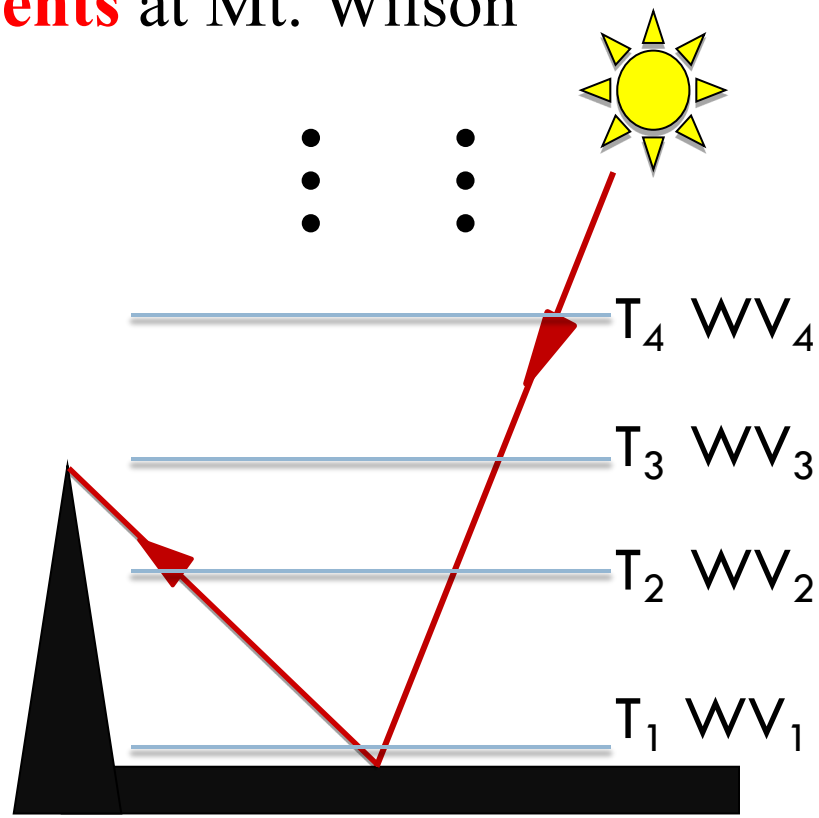
TARGETED OBSERVABLE	SCIENCE/APPLICATIONS SUMMARY	CANDIDATE MEASUREMENT APPROACH	Designated	Explorer	Incubation
Atmospheric Winds	**3D winds in troposphere/PBL** for transport of pollutants/carbon/aerosol and water vapor, wind energy, cloud dynamics and convection, and large-scale circulation	Active sensing (lidar, radar, scatterometer); passive imagery or radiometry-based atmos. motion vectors (AMVs) tracking; or lidar**		X	X
Planetary Boundary Layer	**Diurnal 3D PBL thermodynamic properties and 2D PBL structure** to understand the impact of PBL processes on weather and AQ through high vertical and temporal profiling of PBL temperature, moisture and heights.	Microwave, hyperspectral IR sounder(s) (e.g., in geo or small sat constellation), GPS radio occultation for diurnal PBL temperature and humidity and heights; water vapor profiling DIAL lidar; and lidar** for PBL height			X
Surface Topography & Vegetation	**High-resolution global topography** including bare surface land topography ice topography, vegetation structure, and shallow water bathymetry	Radar, or lidar**			X

Decadal Survey, 2018

CLARS

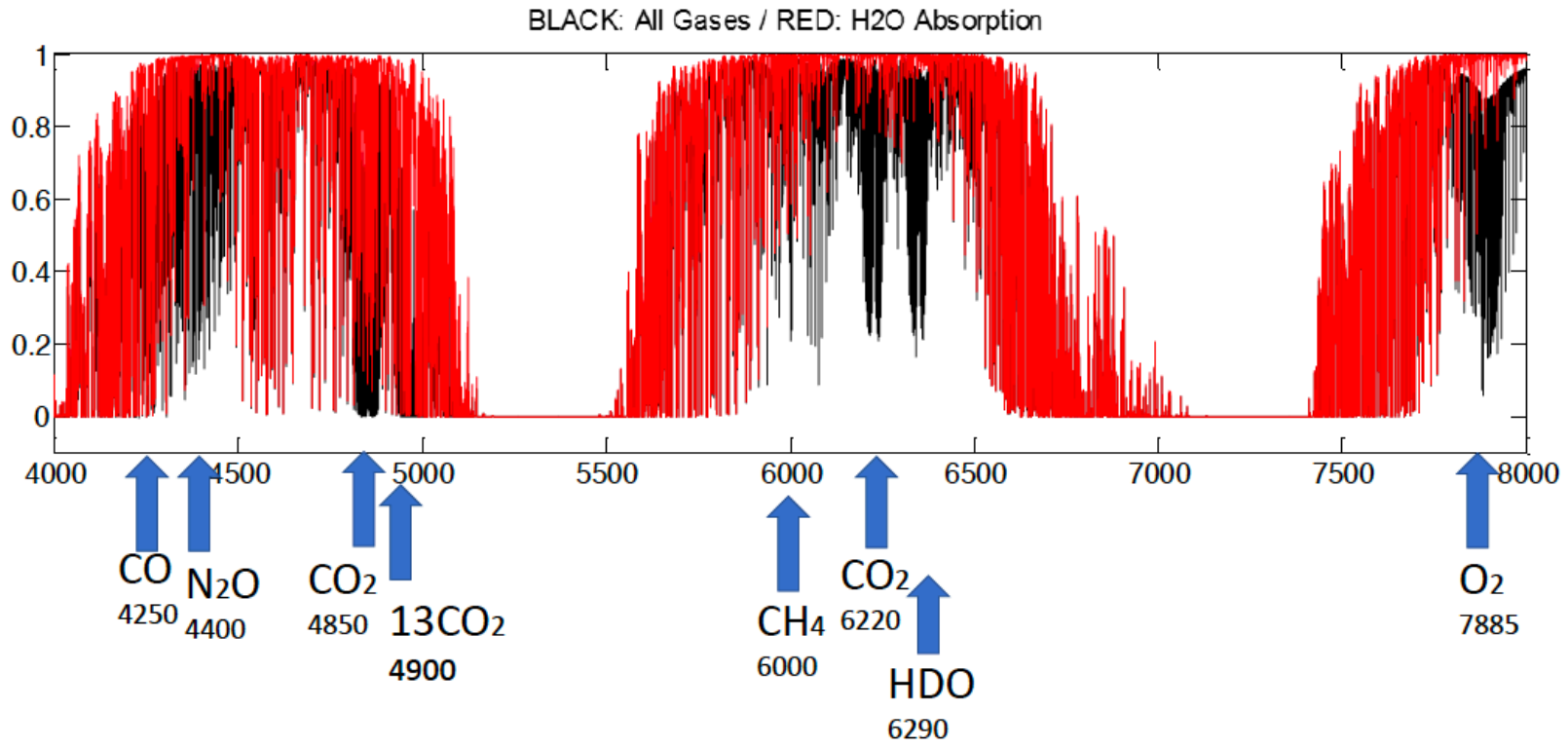
California Lab for Atmospheric Remote Sensing (CLARS):
High spectral resolution measurements at Mt. Wilson

Source: megacities.jpl.nasa.gov



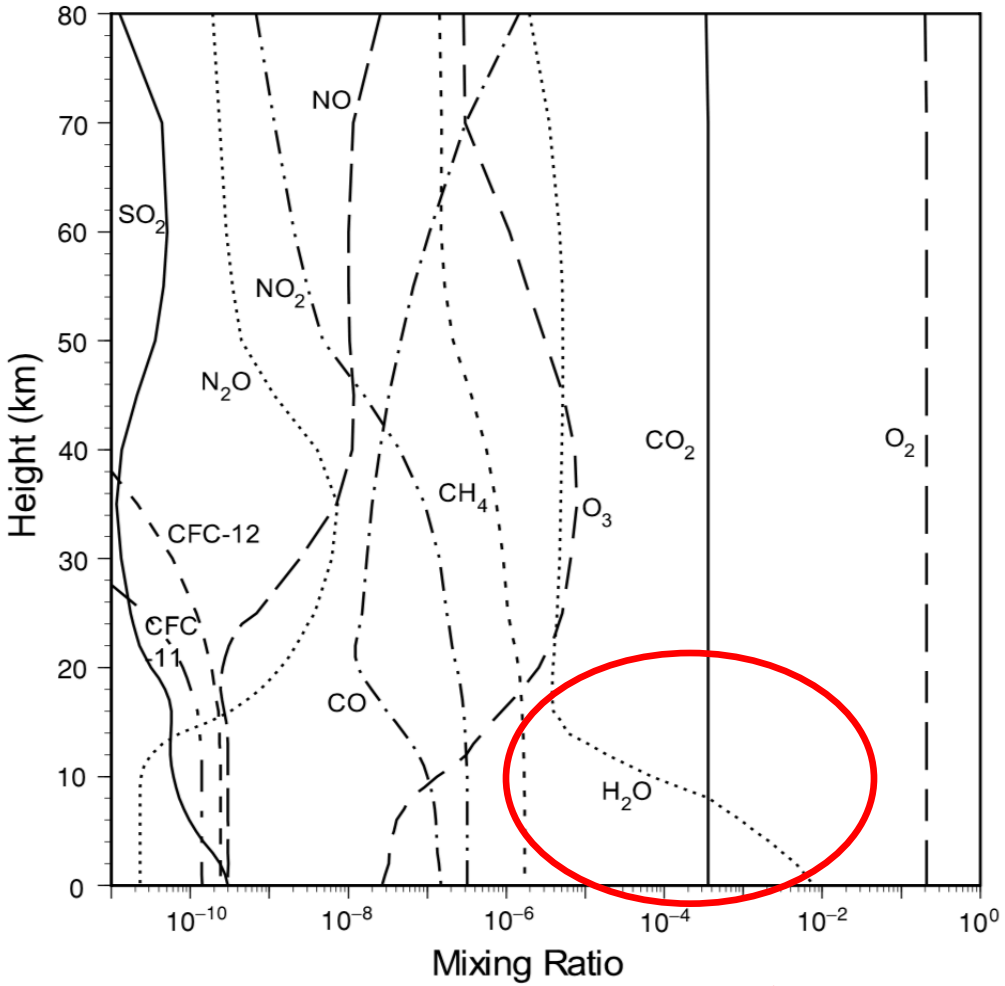
LA basin

CLARS Spectrum



Water Vapor

- Water vapor density decreases rapidly with altitude, with most of it concentrated in the lower part of the atmosphere.



Liou, 2002

Near-IR Bands

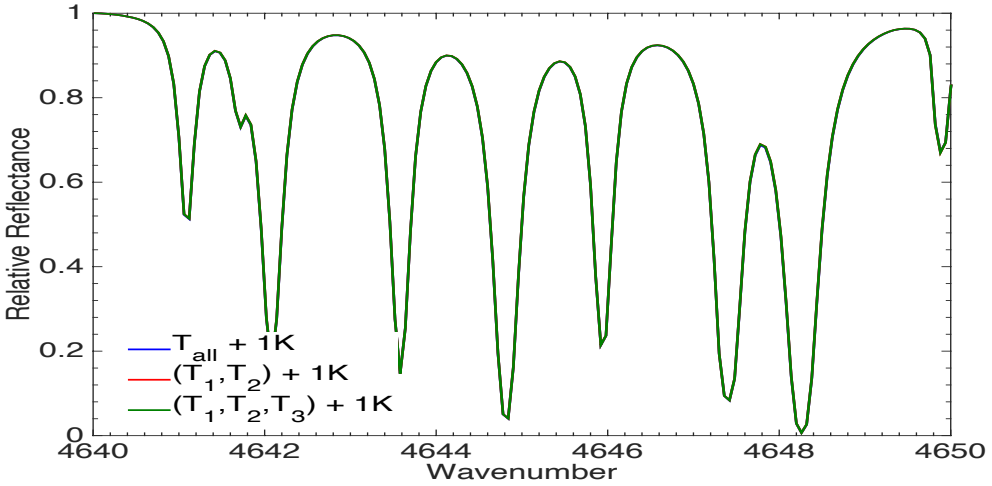
Central WV (cm^{-1})	Width (cm^{-1})	IC
4554.0	8.0	6.3
4568.0	12.0	6.4
4596.5	9.0	6.4
4632.0	8.0	5.9
4645.0	10.0	6.4
4703.0	14.0	6.4
5859.0	8.0	6.1
5910.0	6.0	5.6
6505.5	5.0	5.2
6534.0	12.0	6.2
6550.0	10.0	6.4
6618.0	10.0	6.5
7712.5	7.0	6.0
7738.0	12.0	6.2
7760.0	10.0	6.1

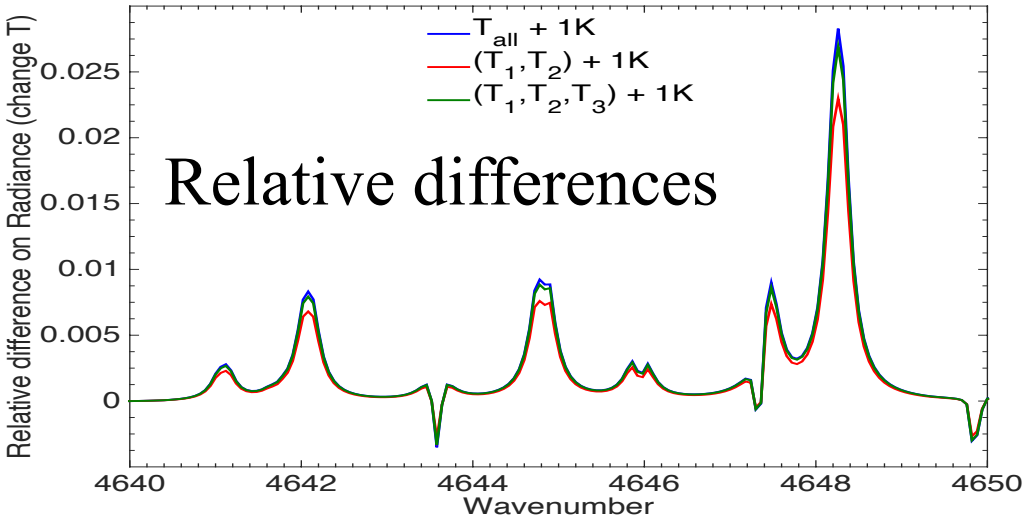
Results: Near-IR Bands

Temperature at high altitudes (>2 km) has small effects on the observed radiance

This implies that we can use climatological/model values for temperature profile above the PBL.

Simulated relative reflectance

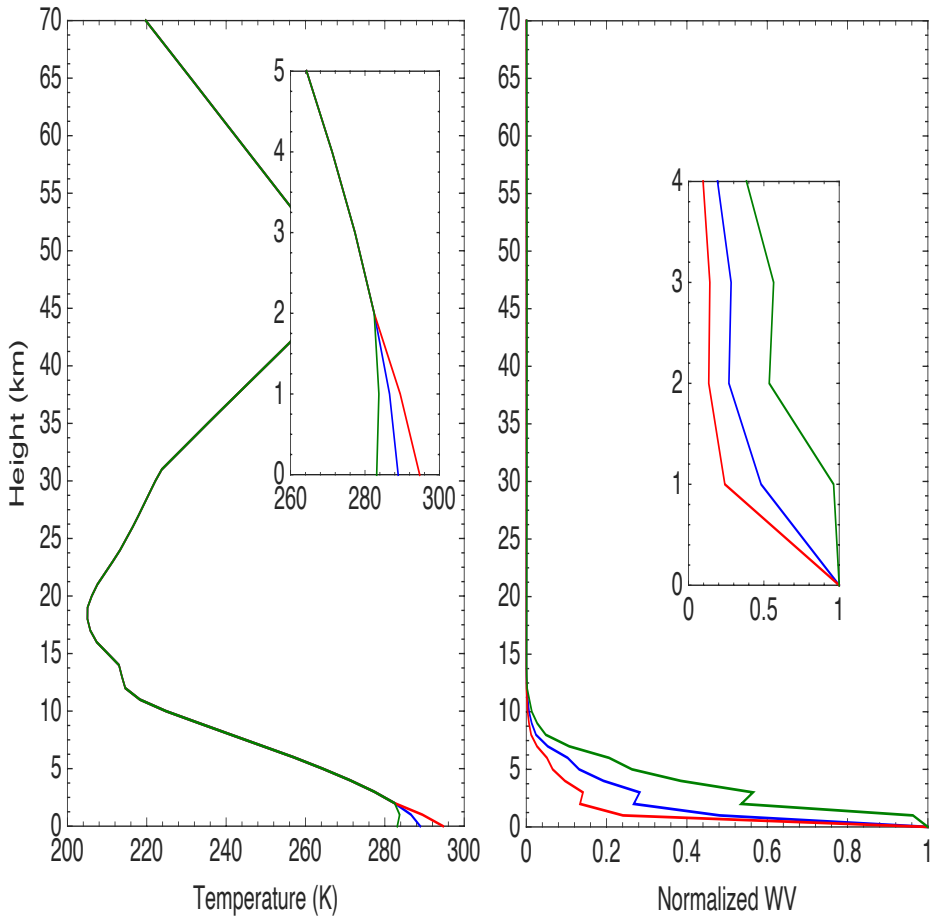




Results: Near-IR Bands

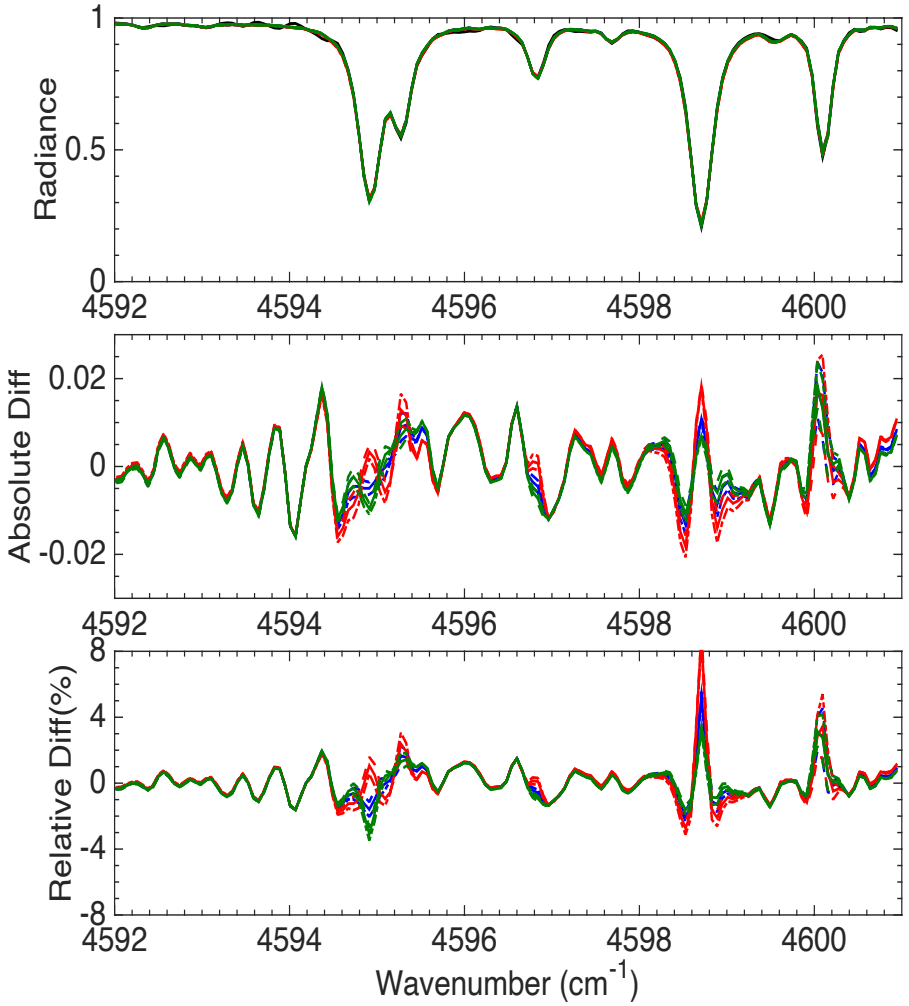
Sensitivities to temperature and water vapor profiles

CASE	T_1	T_2	WV_1	WV_2
1	1	1	1	1
2	1.02	1.01	1	1
3	0.98	0.99	1	1
4	1	1	2	1
5	1.02	1.01	2	1
6	0.98	0.99	2	1
7	1	1	0.5	1
8	1.02	1.01	0.5	1
9	0.98	0.99	0.5	1

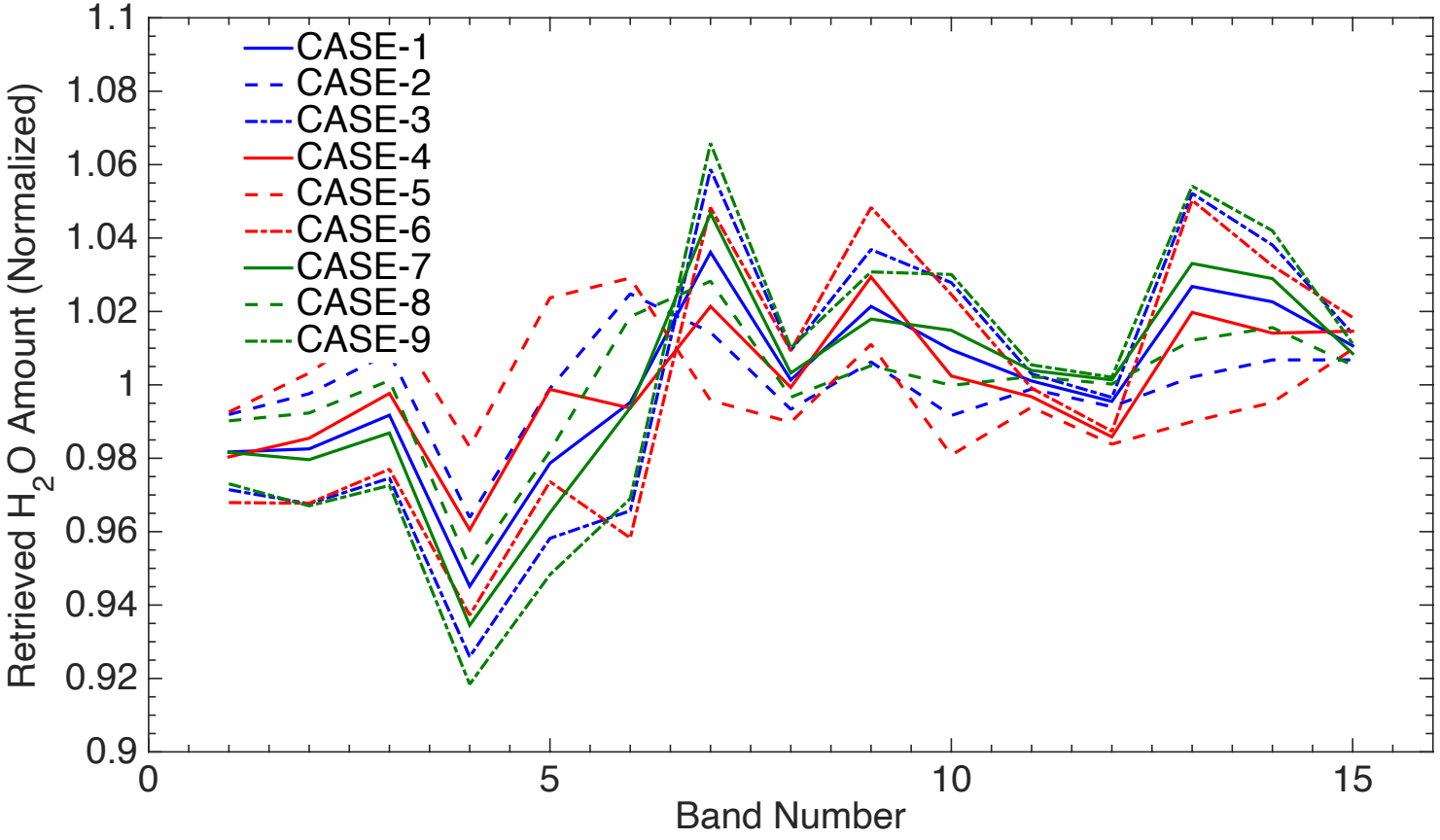


Results: Near-IR Bands

- By comparing with observed reflectance, a column vapor content is retrieved at each given water vapor or temperature profile condition
- Different PBL water vapor or temperature profiles can lead to similar reflectances but quite different total column water vapor



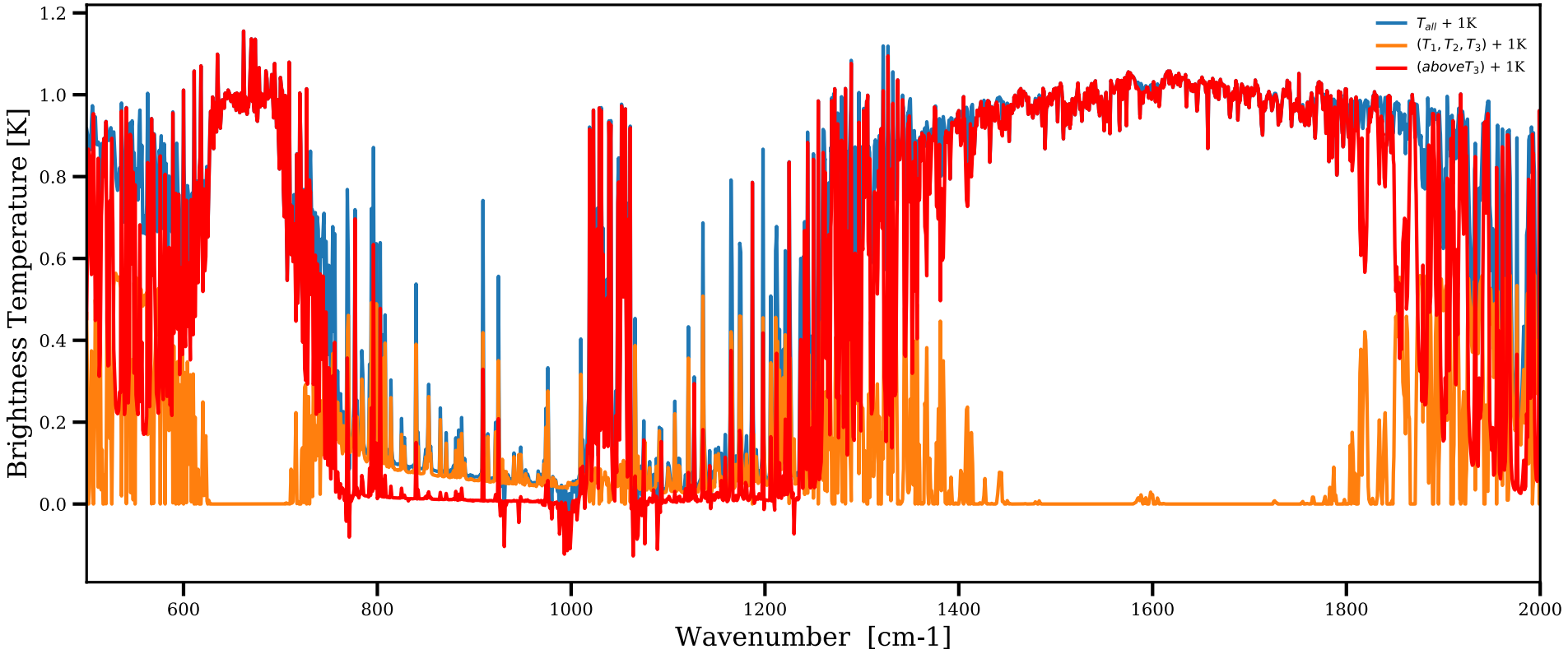
Results: Near-IR Bands



Different temperature or water vapor profiles lead to a relative difference of less than 20% for column water vapor

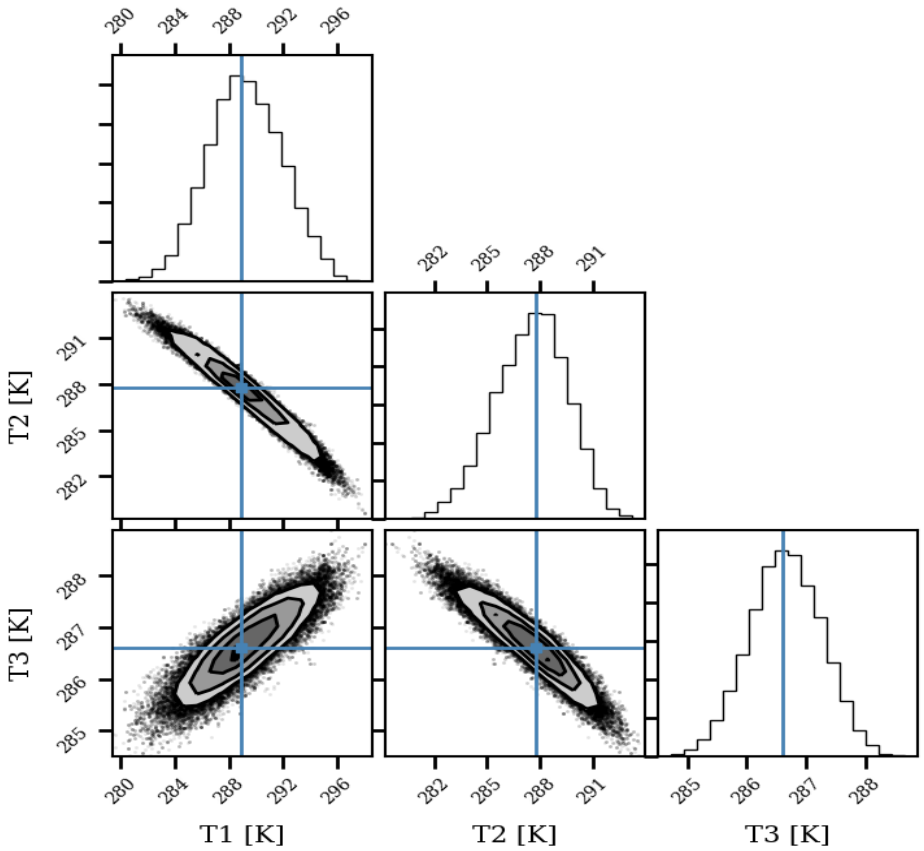
Results: IR Bands

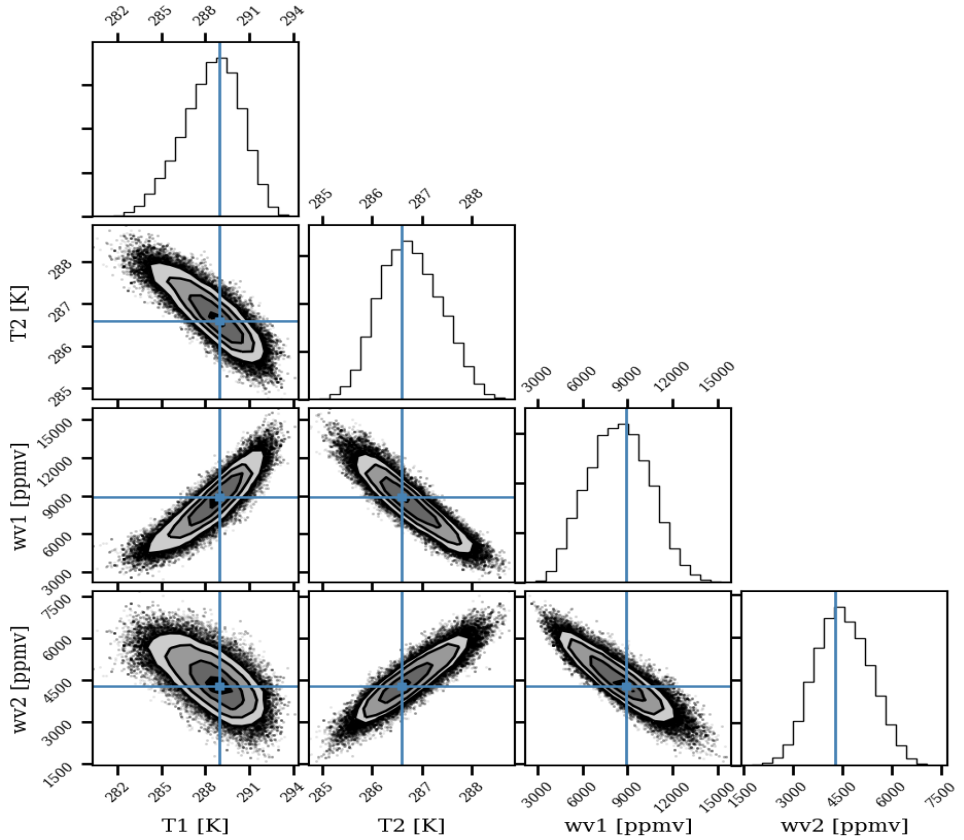
- **Problem for IR channels: upper layer temperature contributes more to the TOA brightness temperature variation**



Results: IR Bands

- **If we know the upper layer temperature and water vapor correctly:**





Retrievals based on Markov-Chain Monte Carlo Method

Conclusions

- Near-IR bands:
  - PBL water vapor can be retrieved provided there is a constraint on T.
- IR bands:
  - PBL temperature can be retrieved if upper layer temperature is known.
- Future work: combined Near-IR and IR retrievals

Backup Slides

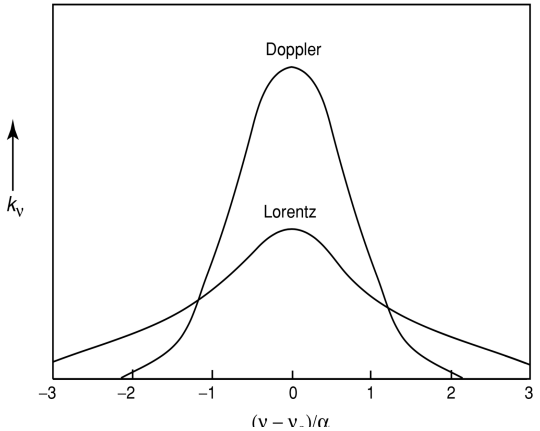
Known Facts (II)

- **Radiative transfer without scattering and emission:**

Gas density

$$I_\lambda(s_1) = I_\lambda(0)\exp\left(-\int_0^{s_1} k_\lambda \rho\, ds\right)$$

Absorption Coefficient



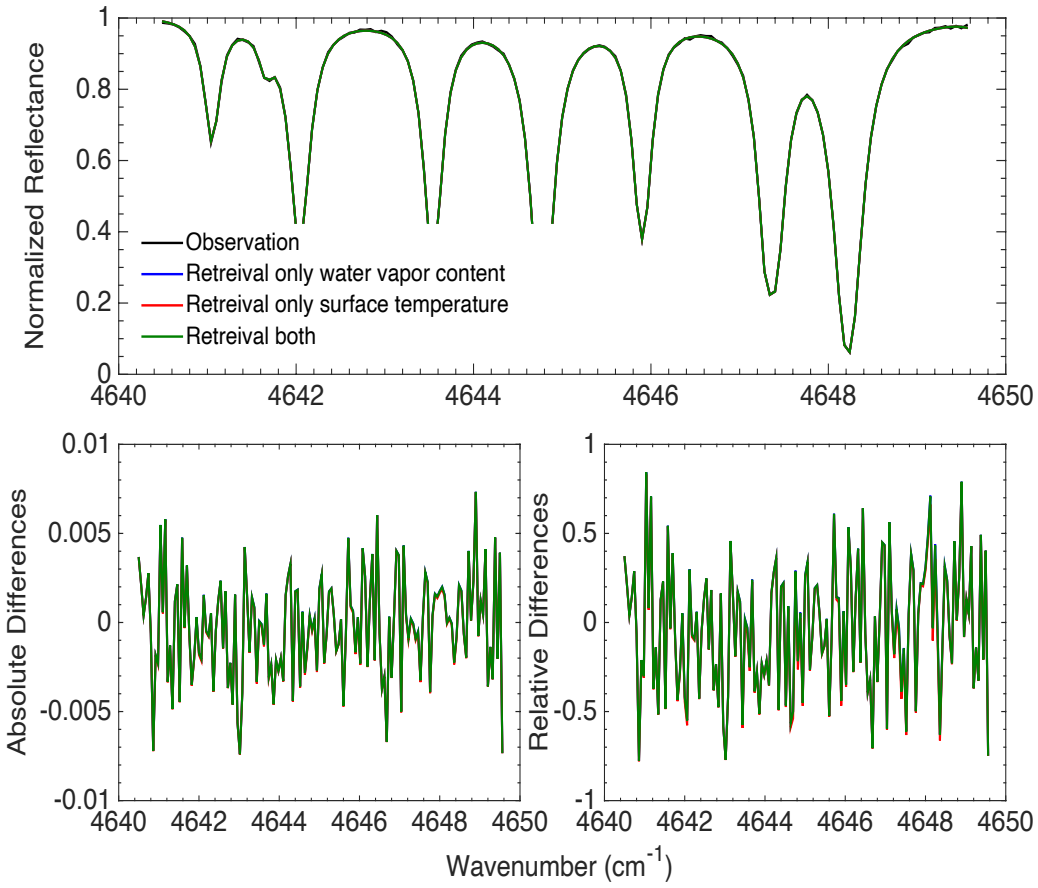
$$\alpha = \alpha_0(p/p_0)(T_0/T)^n$$

- **Questions:**
  - Is the information enough for PBL temperature and H_2O retrieval?
  - Can the influences of temperature and H_2O be separated?

Results: Near-IR Bands

Theoretical tests indicate that near-IR observations can be used to retrieve temperature and H_2O independently, if the other is known accurately.

Variable	Information Content (IC)
H_2O	5.9
T	6.3
H_2O & T	11.7



A measure of the sensitivity of the retrieved state to true state values.