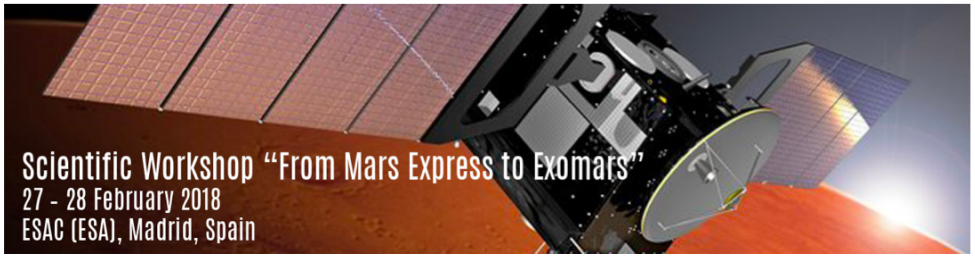
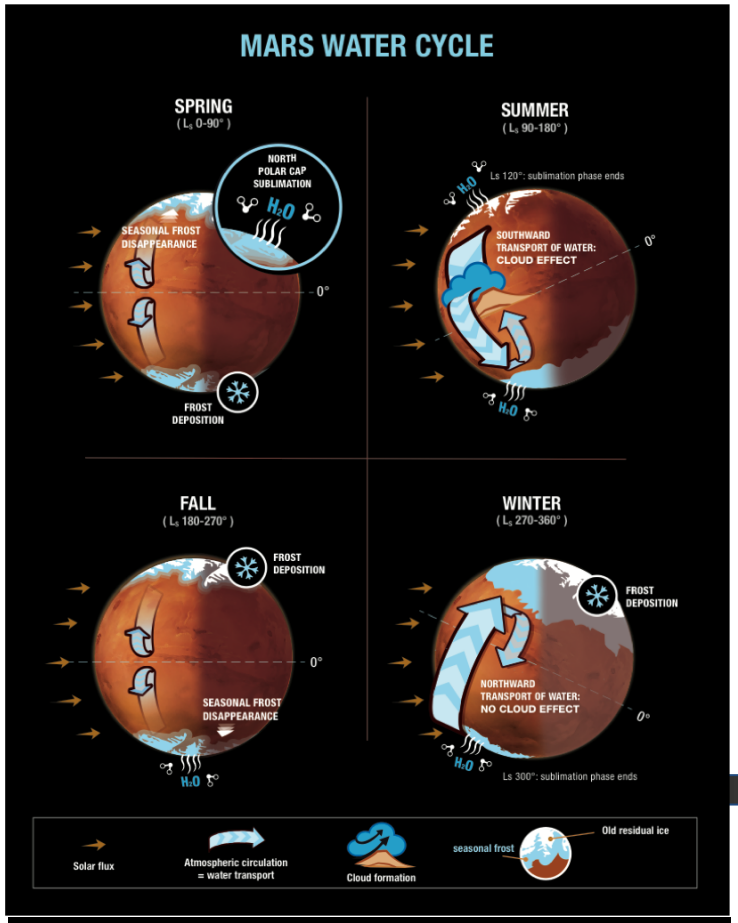
UPWARDS
UNDERSTANDING PLANET MARS



Synergistic retrieval of H_2O vapor in Mars' atmosphere: the path to a systematic 3D exploration of H_2O vapor

Franck Montmessin (LATMOS)

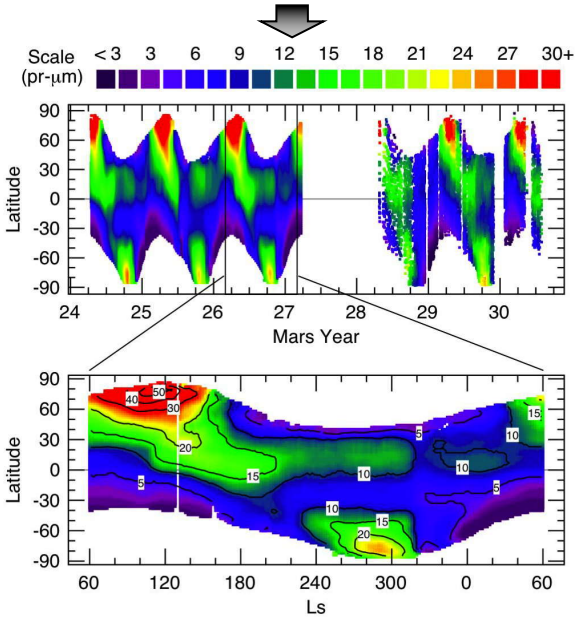
Stéphane Ferron (ACRI-ST)



Montmessin et al. (2017)

Exploring H_2O vapor in every dimension

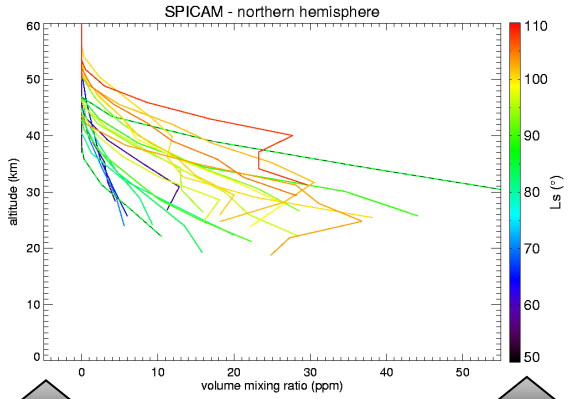
Very dense & wide coverage of nadir observations



NADIR

retrieves the column abundances of water and essentially explores ***(x , y)* - variability.**

Figure: Multi-annual compilation of nadir TES (TIR) and CRISM (NIR) results covering > 5 Martian Years.



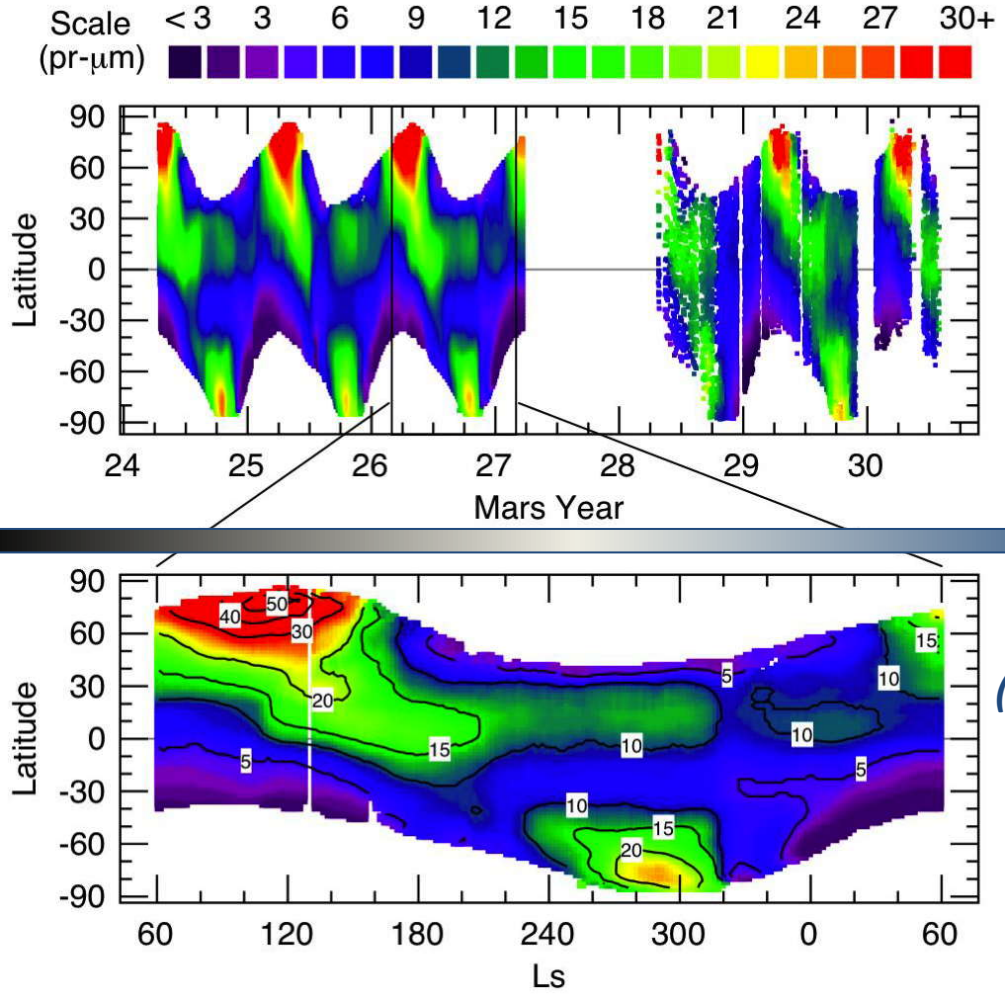
Vertical profiles only at sunrise/sunset and only in selected places

SOLAR OCCULTATION

retrieves the local concentrations of water and essentially explores **(*z*) - variability.**

Figure: Altitude profiles collected by SPICAM-IR. (Maltagliati et al., 2011).

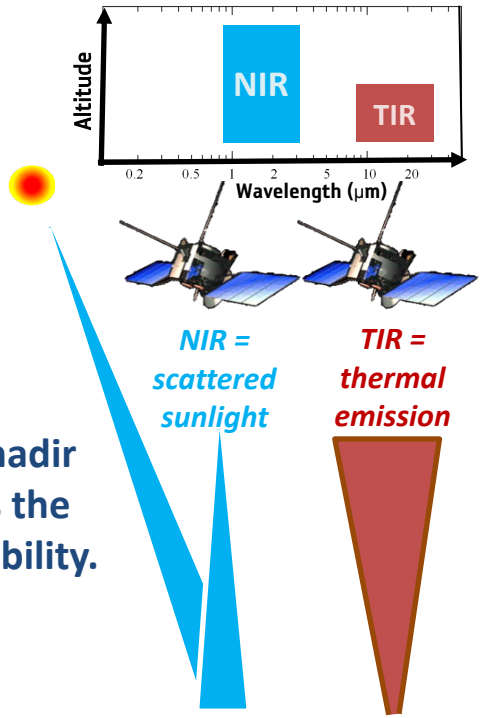
Extracting information on (z) from nadir



Synergistic retrieval

=

Simultaneous inversion of H_2O in 2 spectral domains: NIR & TIR



NIR + TIR in nadir might access the *(x, y, z)* - variability.

Only Mars Express enables synergy with SPICAM and PFS.

Study Goals and « Experimental » Set-Up

Study funded by the UPWARDS project led by M.L. Valverde
(Horizon 2020 – EU program)

Study Goals:

1. **Assess theoretical performances of synergy**
2. **Apply it on actual MEX datasets**

UPWARDS
UNDERSTANDING PLANET MARS

Methodology:

M1. Build **a forward model** to solve the radiative transfer problems in the TIR and NIR bands
M2. Create **synthetic datasets** representative of existing ones (SPICAM and PFS on Mars Express)
M3. Insert the forward model into a **bayesian optimization scheme** to retrieve **optimal parameters** for H_2O:
(1) column-abundance
(2) parameter related to vertical distribution (partial column in the first 5 km)

Forward model:

- LIDORT solver
- Dust model from Wolff & al. (2009), no ice cloud included
- Gaseous absorption (Correlated-K D approach, HITRAN 2012 + Brown 2007)
- Lambertian surface assumed
- MCD v5.2 used to constrain *prior* state vector for T_s, T_{atm}, etc.

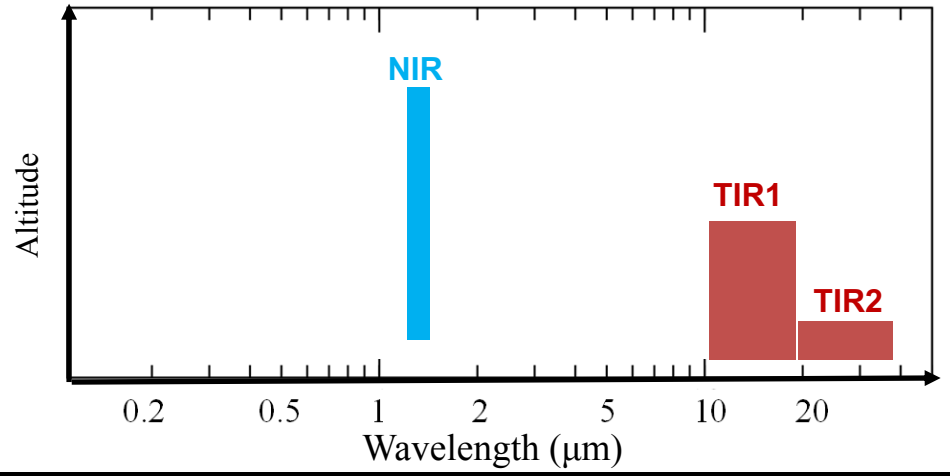
Synthetic Data set (Goal 1):

- Reproduce SPICAM-type data @ 1.38 μm **(NIR)**
- Reproduce PFS-type data @ **20 μm for H_2O (TIR2) and 15 μm for Temperature (TIR1)**

Real Data set (Goal 2):

- Made of **233 different joint SPICAM and PFS observations** performed during Martian Year 27.
- Each observation corresponds to the compilation of 9 spectra.

Goal I: Assess theoretical performances of synergy



Domain	Wavelength Range	Spectral features	Retrieved Parameters	Instrument
NIR	1.35-1.43 µm	H_2O	H_2O (z) Albedo Dust	SPICAM-IR
TIR1	12.2-19.2 µm	CO_2	T(z) Surface Temperature Dust Opacity	PFS-LW
TIR2	20-34 µm	H_2O	H_2O (z)	PFS-LW

Goal I: Assess theoretical performances of synergy

The number of independent parameters (Degree Of Freedom-DOF) is given by **the trace of the covariance matrix** (computed through optimization procedure).

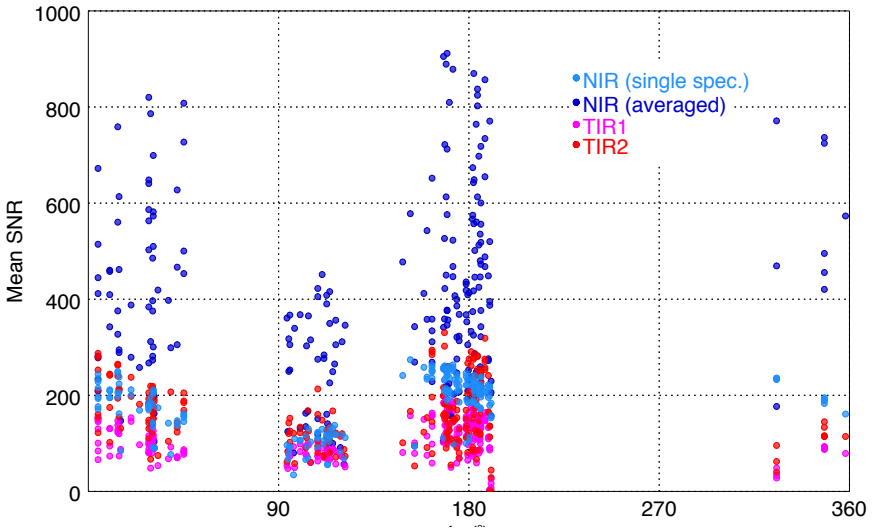
	NIR -SPICAM-	TIR -PFS-	NIR+TIR -SPICAM+PFS-
Wet area (moderate dust) – north pole in summer			
DOF (Degree Of Freedom)	1.13	0.87	**1.68**
Wet area (no dust) – north pole in summer			
DOF	1.14	1.16	**1.87**
Dry area (low dust) – southern mid latitude in summer			
DOF	1.22	0.36	**1.56**

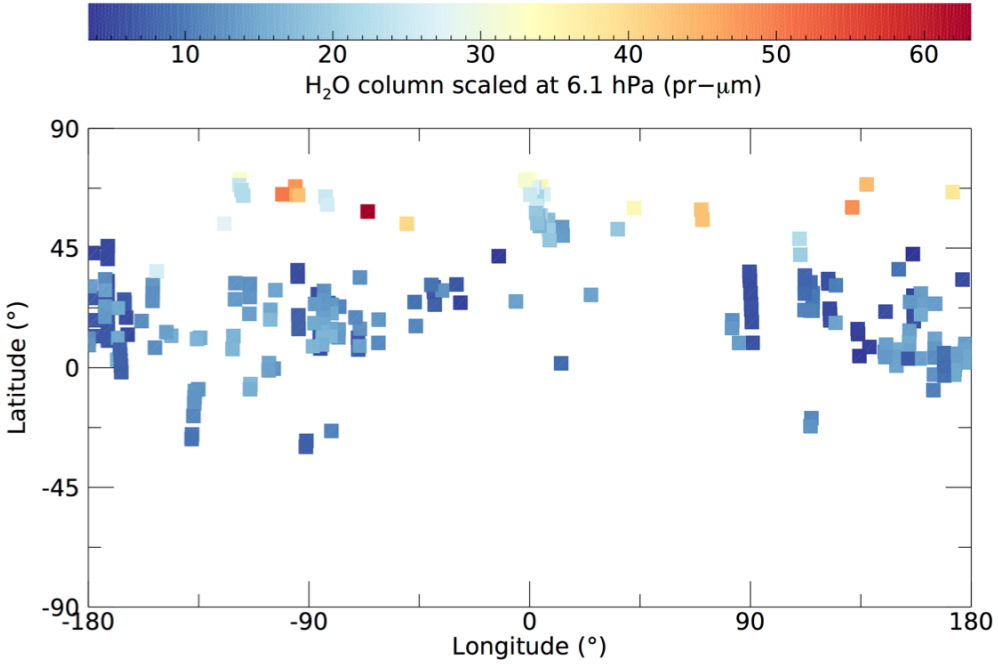
- With synergy, nearly **2 independent parameters** for H_2O can be retrieved compared to 1 (whole column) with NIR or TIR nadir observations alone.

- **Theoretically, H_2O vertical distribution can be constrained by NIR+TIR synergy**

Goal II: Apply synergy on actual MEX datasets

Testing made on 233 samples of MY27.
Each sample consists of 9 spectra.

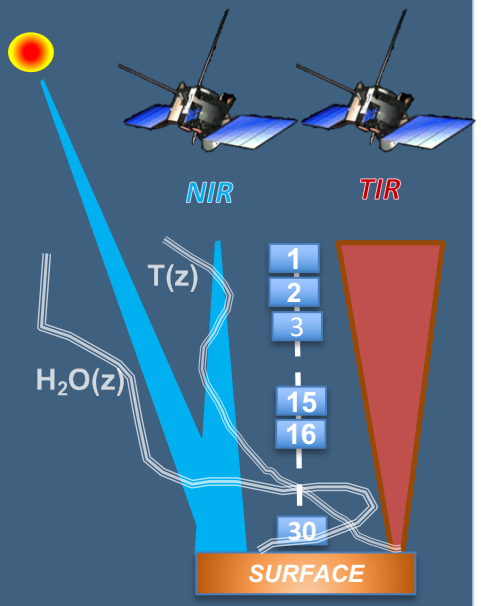




Goal II: Apply synergy on actual MEX datasets

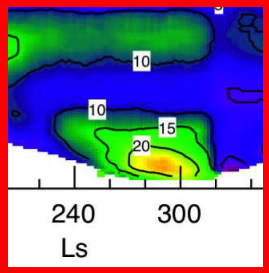
Retrieval is based on a bayesian estimation with simultaneous adjustment of 64 parameters with a prior assumption on averaging kernels and on parameters (constrained by MCD).

		NIR	TIR
Atmosphere	• Temperature: 30 levels	----------	X
	• H_2O mixing ratio: 30 levels	------ X ---	X
	• Dust column-opacity	------ X ---	X
Surface	• Temperature	----------	X
	• Albedo	------ X ----	
	• Emissivity	----------	X

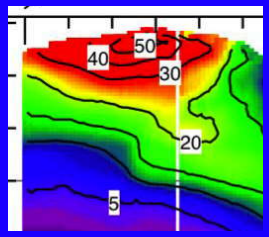


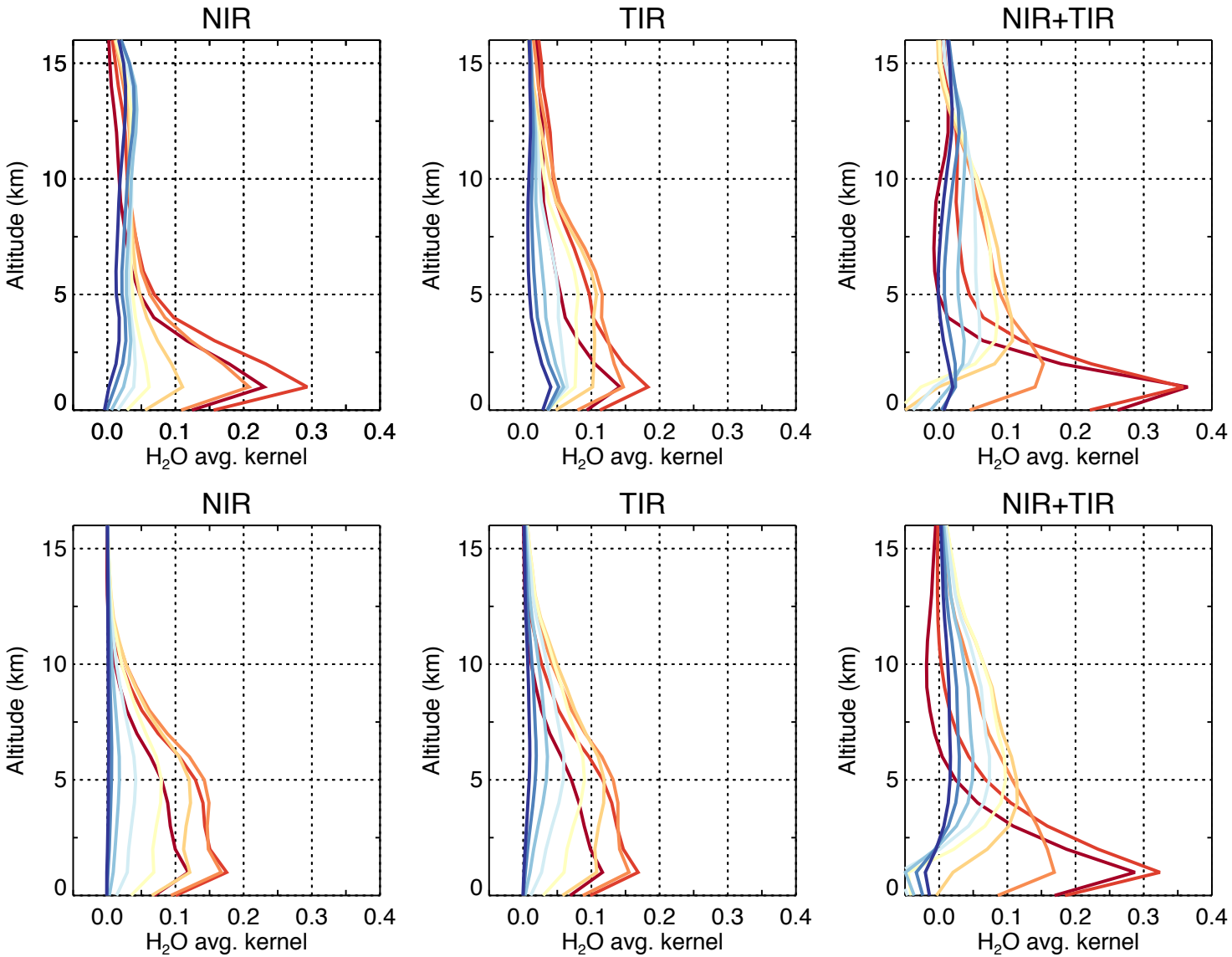
Averaging kernels for H_2O

Dry Case
(southern summer mid-latitude)



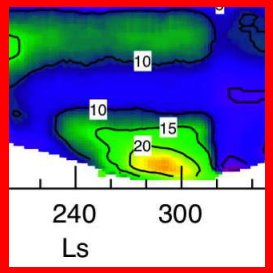
Wet Case
(northern summer pole)

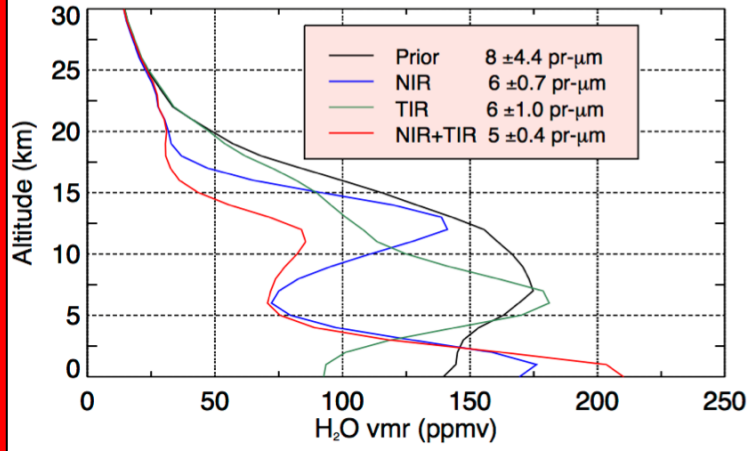


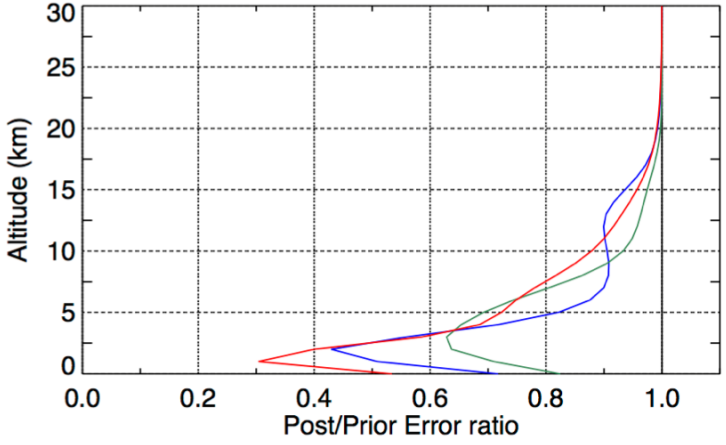


Two examples of retrieved H_2O parameters

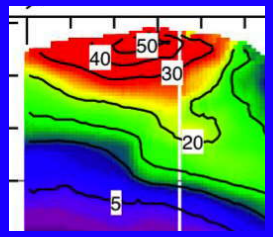
Dry Case
(southern summer mid-latitude)

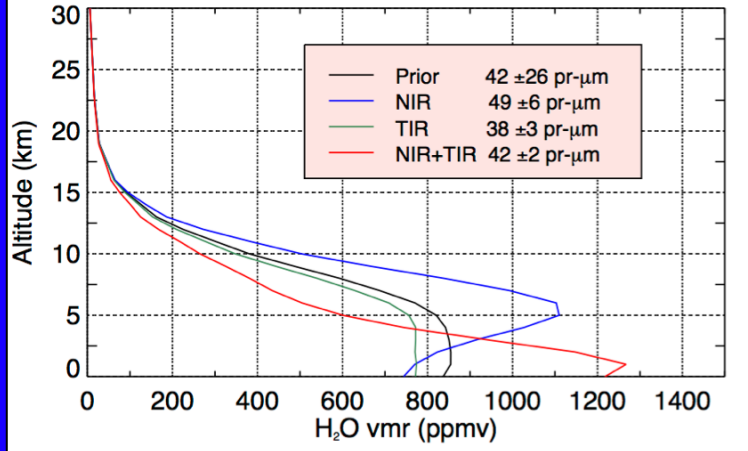


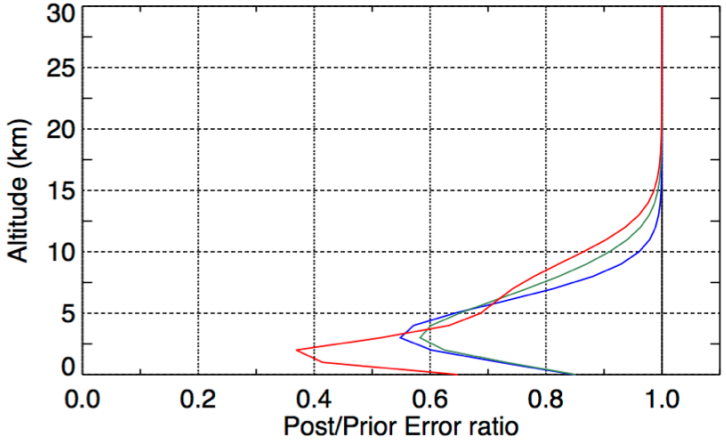




Wet Case
(northern summer pole)



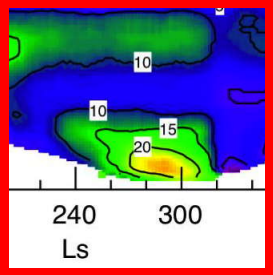


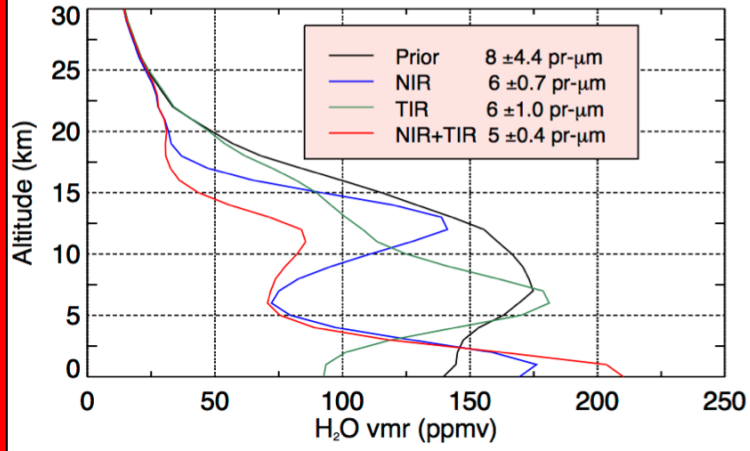


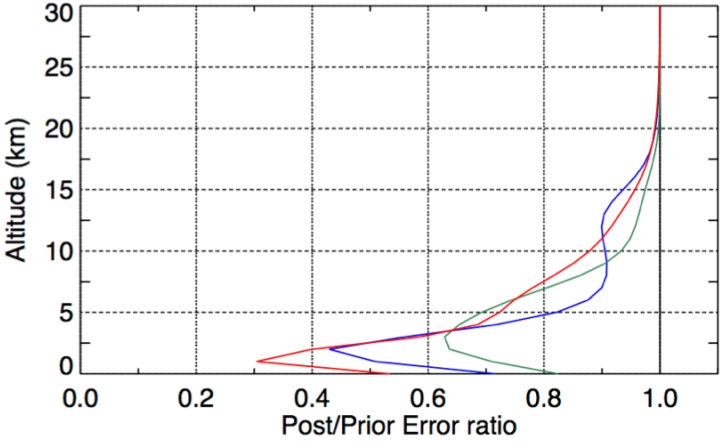
The NIR+TIR synergistic inversion gives stronger constraints on the shape of the profile and it also refines the estimate of the full column.

Two examples of retrieved H_2O parameters

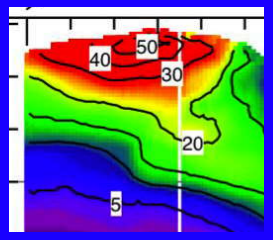
Dry Case
(southern summer mid-latitude)

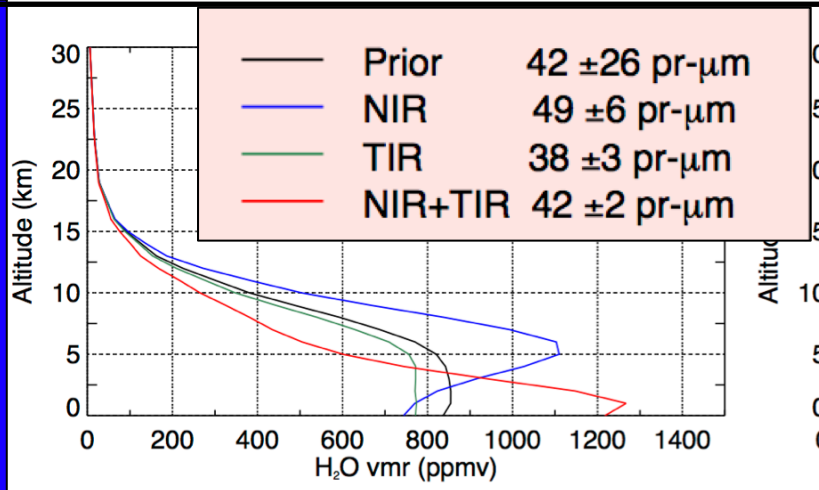


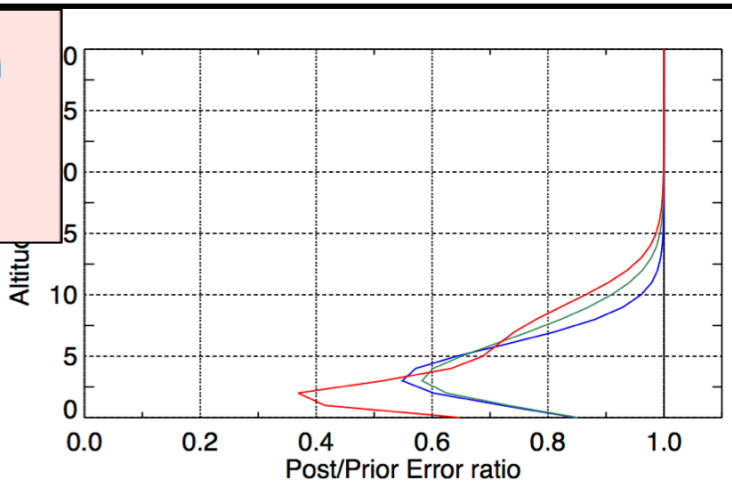




Wet Case
(northern summer pole)

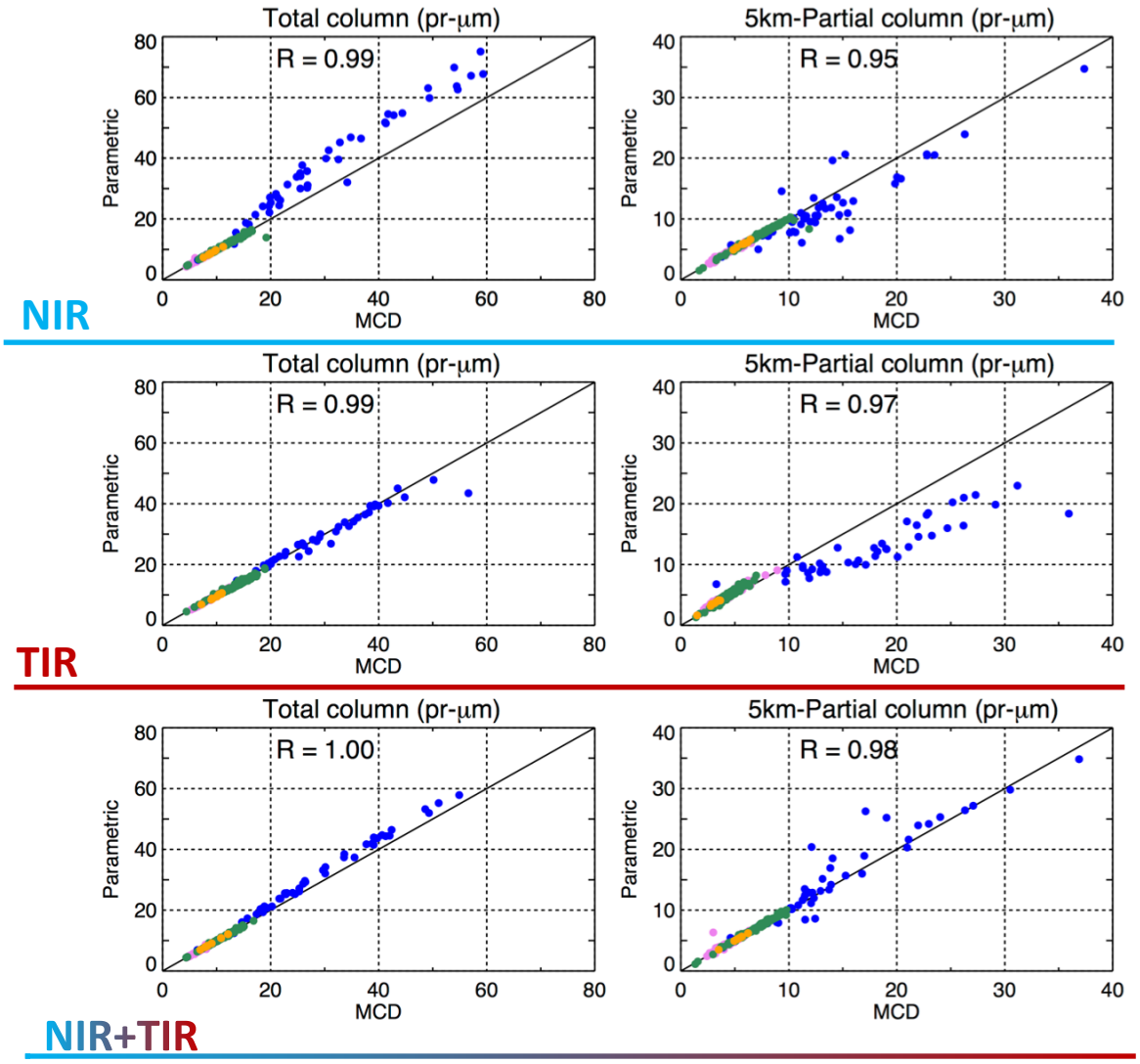






The NIR+TIR synergistic inversion gives stronger constraints on the shape of the profile and it also refines the estimate of the full column.

Exploring the lower part of the H_2O profile



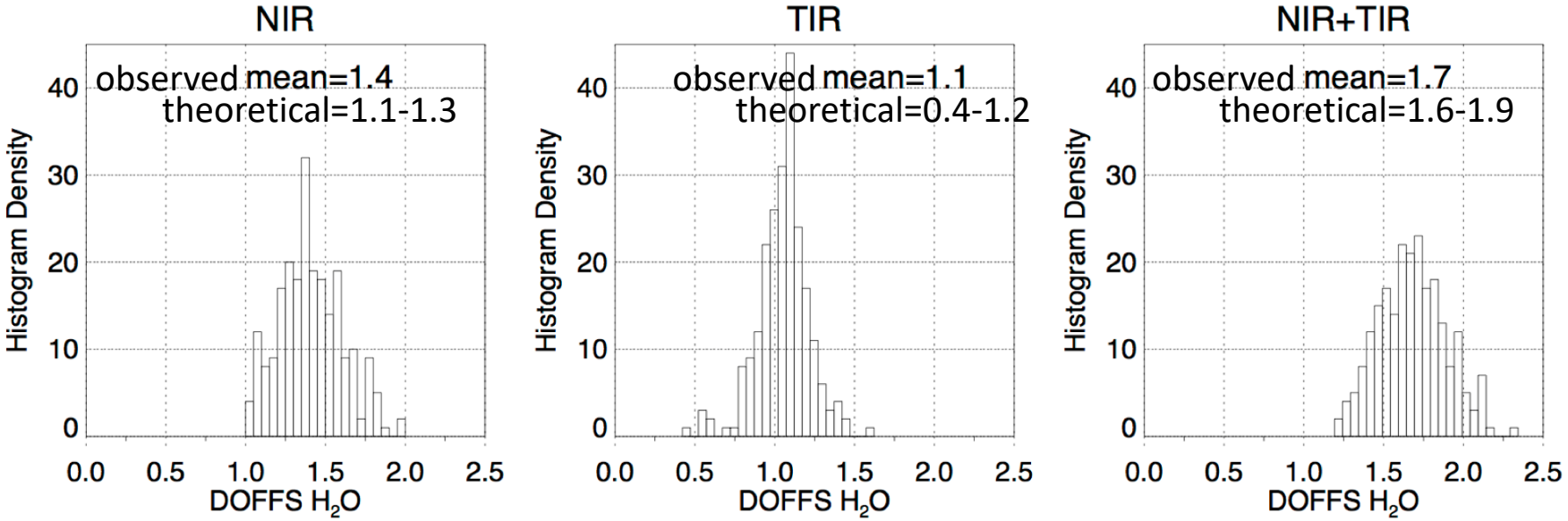
Full columns (*left*) and Partial columns (*right*) of H_2O derived from observations (NIR, TIR, NIR+TIR) compared (correlation level) to predictions (MCD)

Correlation (R) are given between model & observations.

Color code refers to the various L_s shown previously.

Conclusions

- A model for the synergistic retrieval of H_2O from SPICAM and PFS datasets has been developed and validated based on a terrestrial methodology (Wörden et al., 2010)
- Our study shows that **synergy increases the content of retrieved information on H_2O by 20 to 80%** compared to NIR or TIR alone.



Conclusions

- A model for the synergistic retrieval of H_2O from SPICAM and PFS datasets has been developed and validated based on a terrestrial methodology (Wörden et al., 2010).
- Our study shows that **synergy increases the content of retrieved information on H_2O by 20 to 80%** compared to NIR or TIR alone.
- So far NIR or TIR have only provided estimates of the full H_2O column.
- Now with synergy:
  1. **a new parameter for H_2O can be extracted** from nadir observations and it is now possible to estimate with no bias the partial column in the **first 5 km** above the surface
  2. **a more (>40%) reliable estimate of the full H_2O column** can be obtained when combining instrument data together

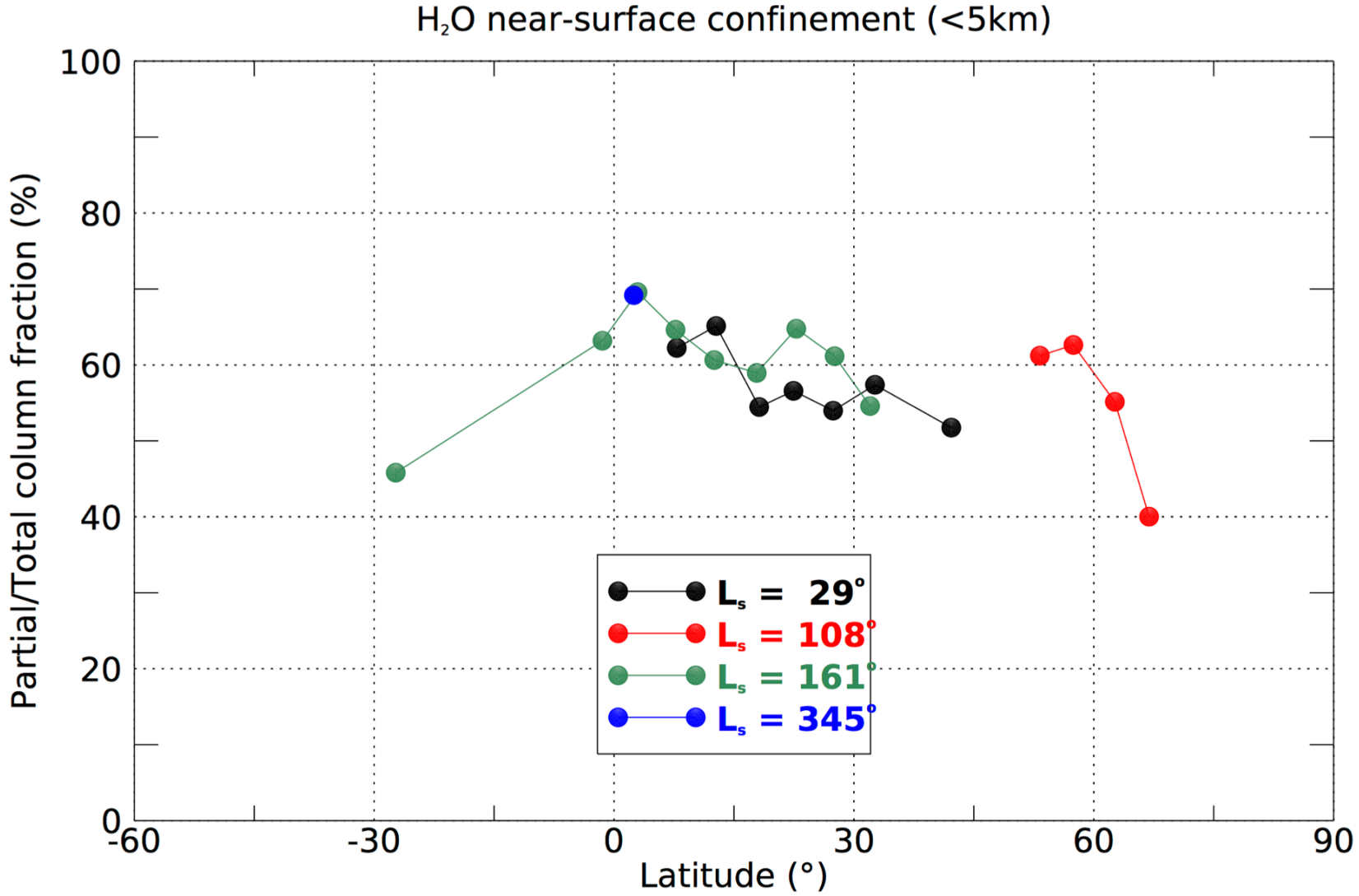
Perspectives

These results open the door to a range of extensions:

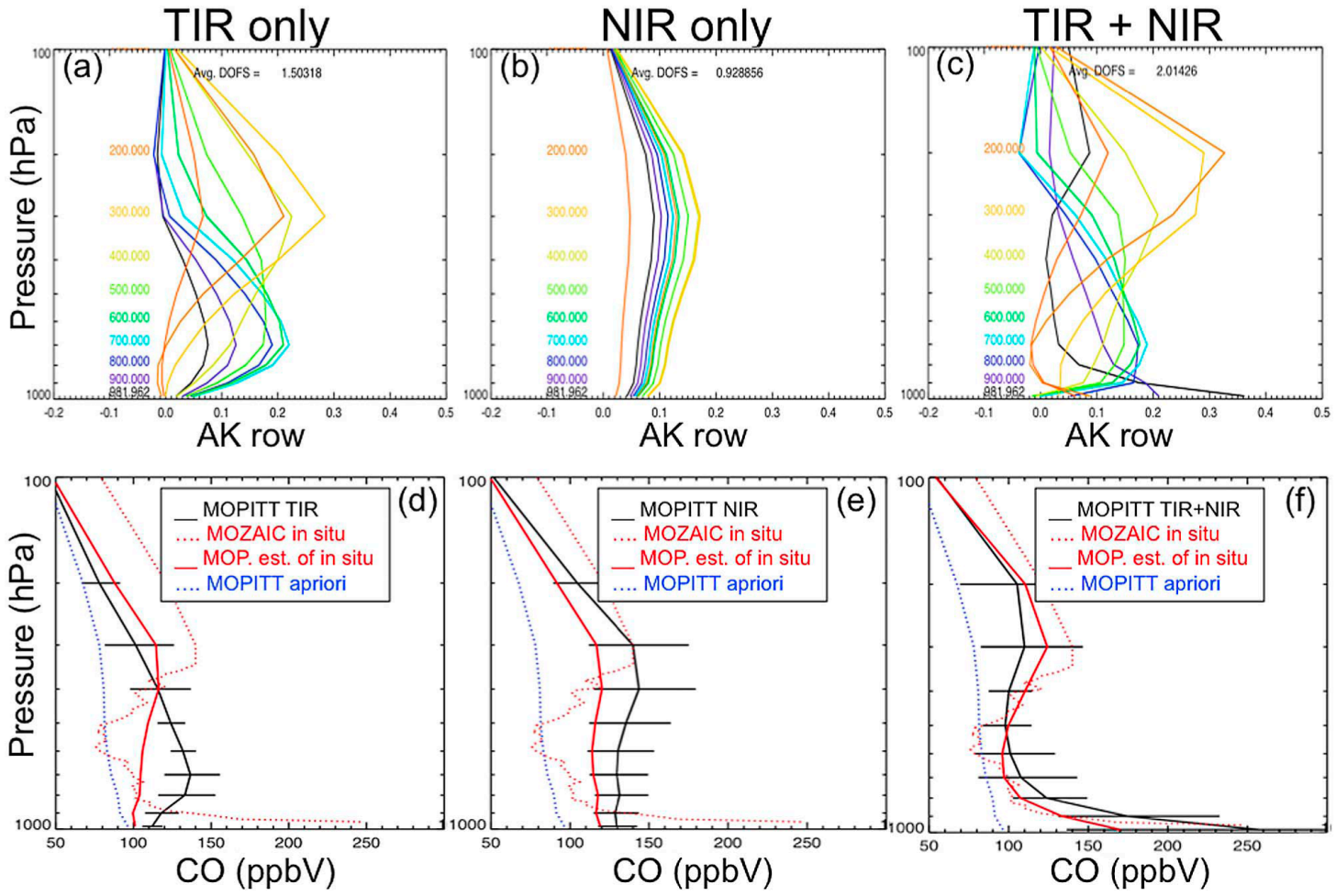
1. **Only a small (<10%) subset of MEX data has been used here, 90% remain to be done……while both PFS and SPICAM still operate**
2. **Dust opacity could be similarly tentatively analyzed using SWIR scattering and TIR emission (synergistic retrieval of CO attempted by S. Robert et al., 2017)**
3. **Future concepts of mission and/or instrumentation should explore this type of NIR+TIR combination**

- Submitted article: Montmessin & Ferron, "*A spectral synergy method to retrieve Martian water vapor column-abundance and vertical distribution applied to Mars Express SPICAM and PFS nadir measurements*"

Back-Ups

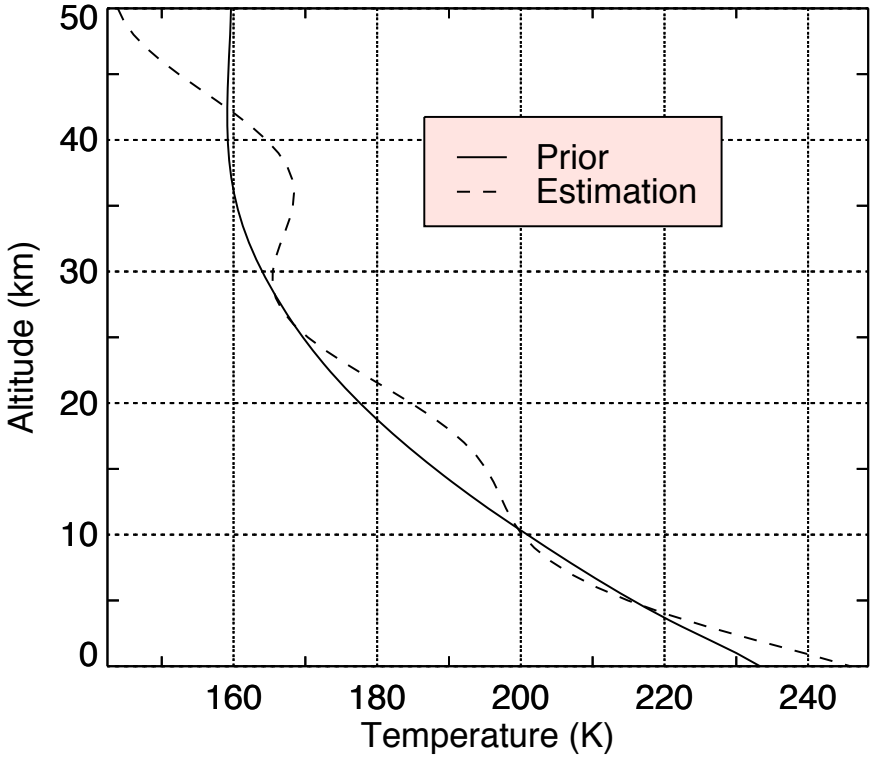

H2O near-surface confinement (<5km)
Partial/Total column fraction (%)
Latitude (°)
100
80
60
40
20
0
-60
-30
0
30
60
90
Ls = 29°
Ls = 108°
Ls = 161°
Ls = 345°

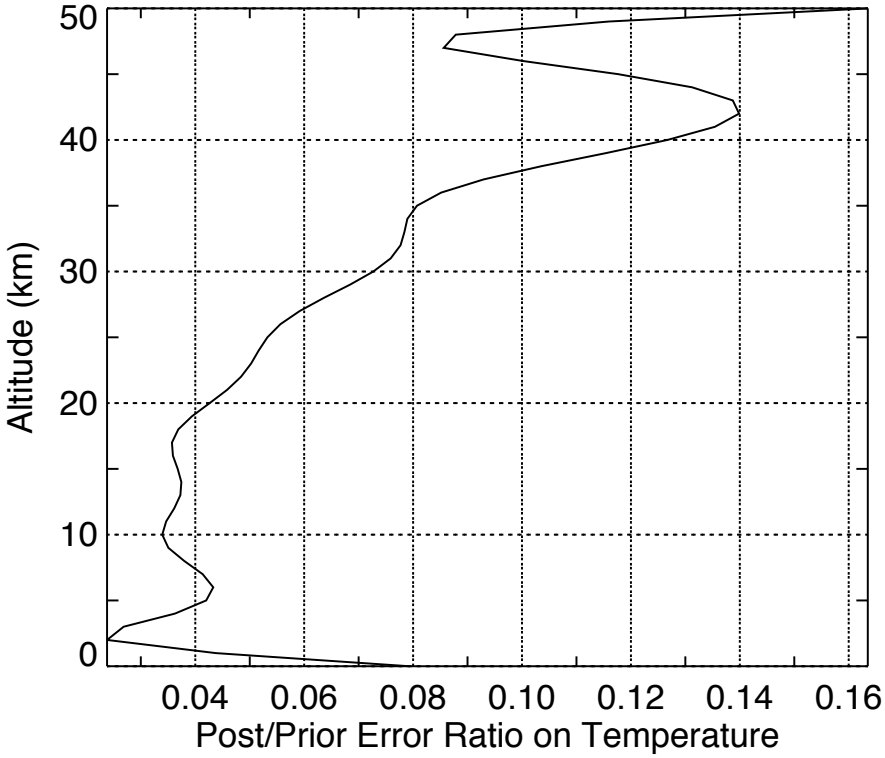
Synergistic retrieval of terrestrial CO from MOPITT nadir measurements

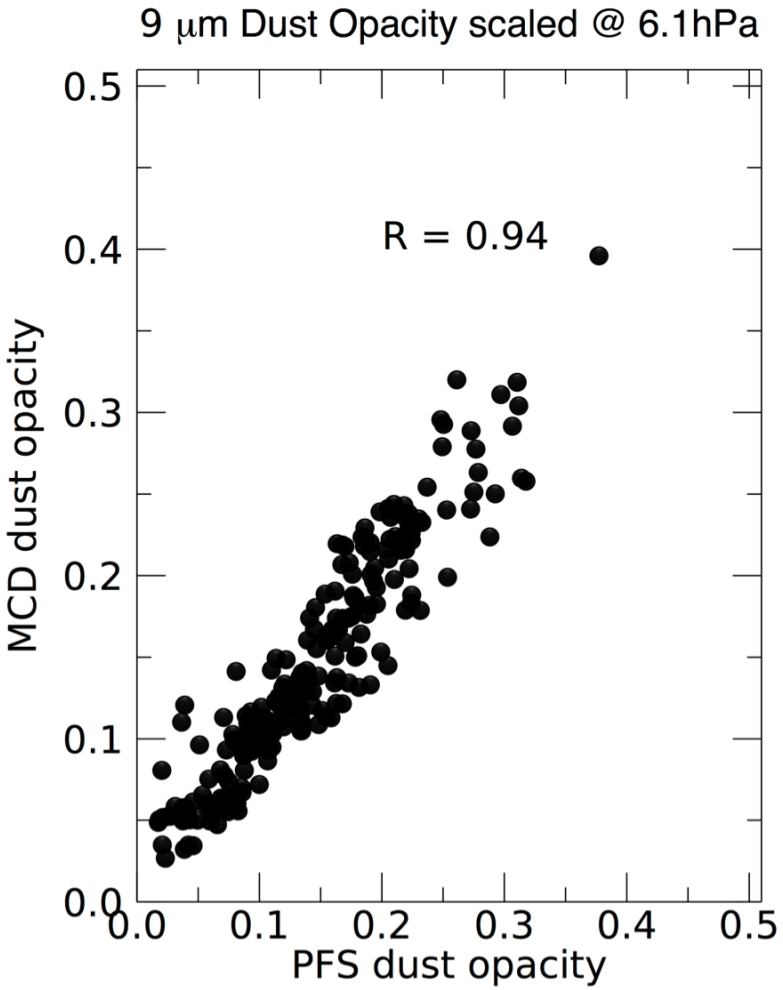


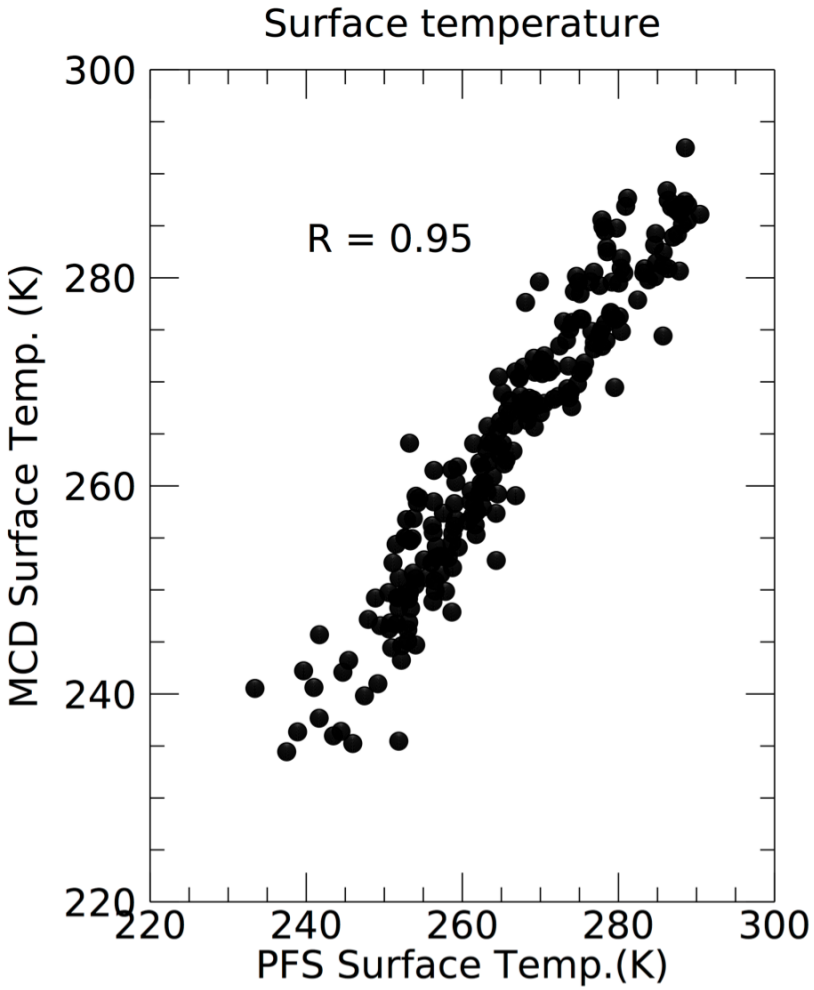
Wörden et al. (2010)

Retrieval by-products: atmospheric temperature









As a test of consistency, the dust opacity and the surface temperature derived from the PFS data (as by-products of the synergy) are compared to MCD predictions.

The high degree of correlation between the two is a good indicator that the retrieval method works well.