A modeling framework for total column humidity and water vapor isotopic composition applied to moistening of the subtropical free troposphere

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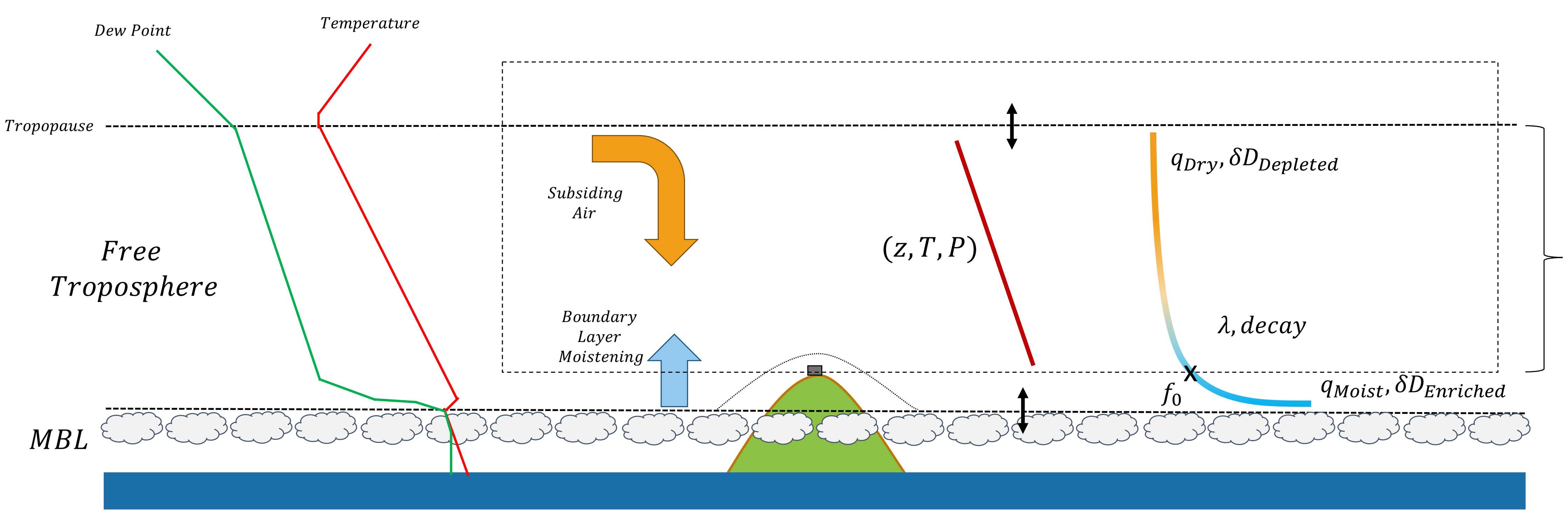
Introduction

- In the marine subtropics, vertical mixing of moisture between the marine boundary layer (MBL) and the free troposphere (FT) is fundamental for setting of the vertical humidity profile. This in turn is important for controlling both low-clouds in the MBL and water vapor concentrations in the upper troposphere. However, this moistening is difficult to constrain.
- Total column water vapor and δD measurements available from ground-based remote sensing, such as Fourier Transform Infrared (FTIR) Spectrometers, represent quasi-direct measurements with minimal a priori assumptions.
- **Questions**: *Can the total column water vapor molecule v. δD space be characterized by mixing a dry, depleted, subsiding source and a moist, enriched boundary layer source via an exponential decay of moisture? Can this help constrain moistening of the subtropical troposphere from the MBL?*
- Here a forward model is tested against NDACC FTIR observations from the Mauna Loa Observatory (MLO), Hawaii using a Kolmogorov-Smirnov Goodness of Fit Test (K-S test). compared to humidity profiles from ESRL radiosonde frost-point data from Hilo.

Model Framework



$q_{Sub}, \delta D_{Depleted}$

$q_{MBL}, \delta D_{Enriched}$

$$\longrightarrow \quad f = f_0.*(exp(-z/\lambda)) \quad \longrightarrow$$

where f_0 is the starting fraction of MBL moisture at MLO

$$Water\ Vapor = \int_{MLO}^{Tropopause} f[q_{MBL} * \rho]_1 + (1-f)[q_{Sub} * \rho]_2$$

$$R_{mix} = \int_{MLO}^{Tropopause} \frac{f[HDO]_1 + (1-f)[HDO]_2}{f[H_2O]_1 + (1-f)[H_2O]_2}$$

Results

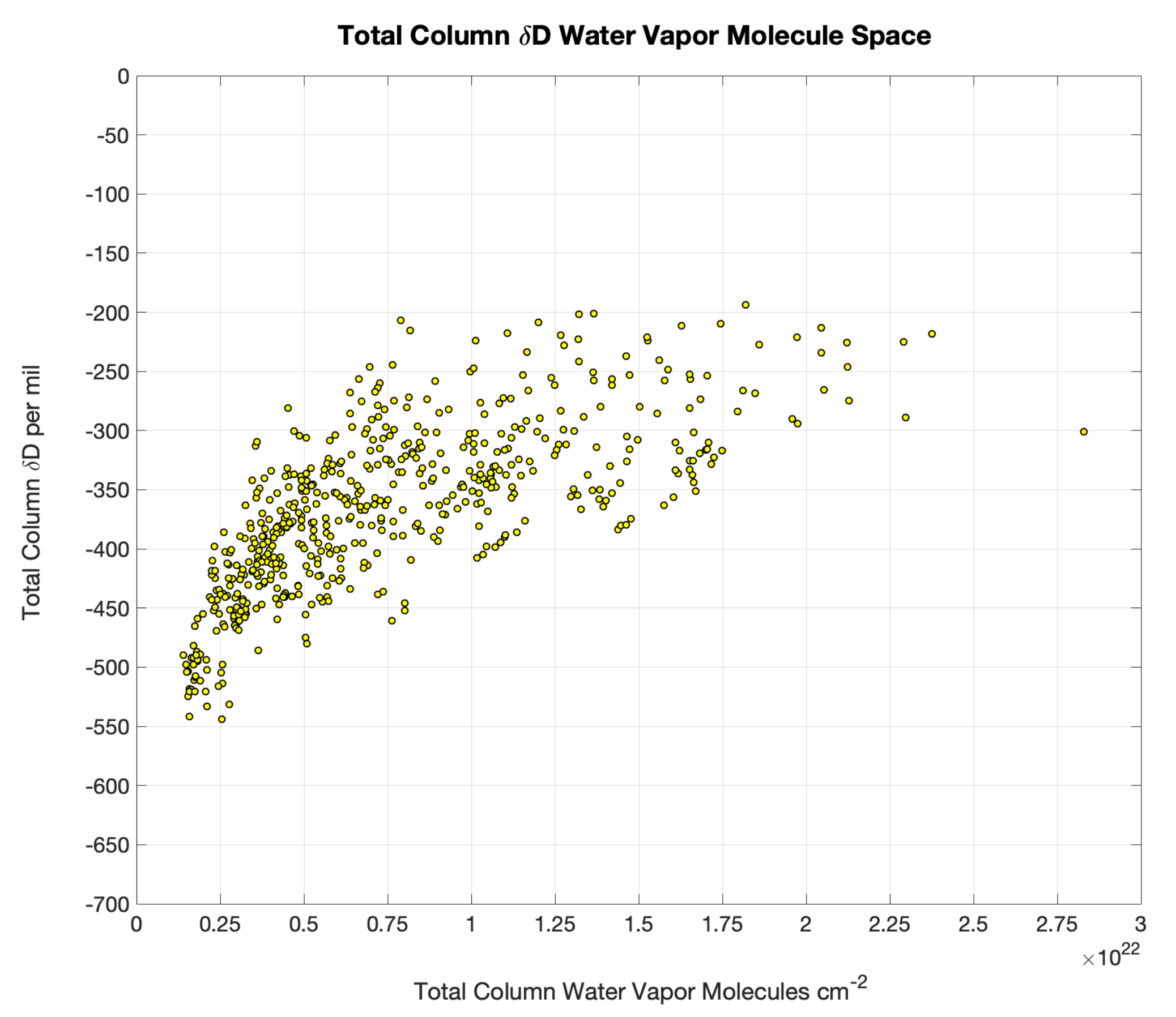


Figure 1. FTIR Total column observations from Mauna Loa, Hawaii (19.5362° North, 155.5763° West, 3397 m) from 4/2016 – 3/2017, n = 558

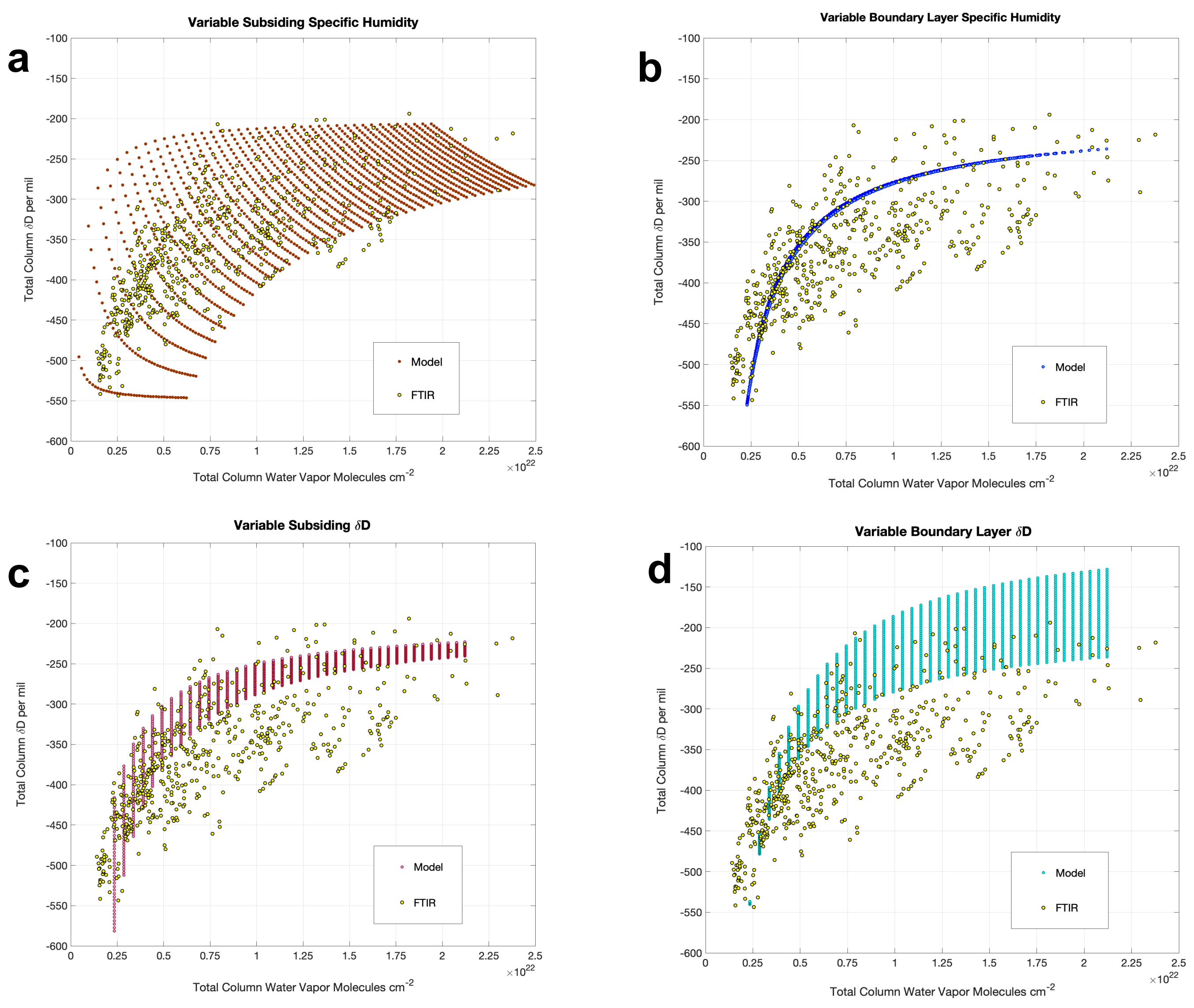
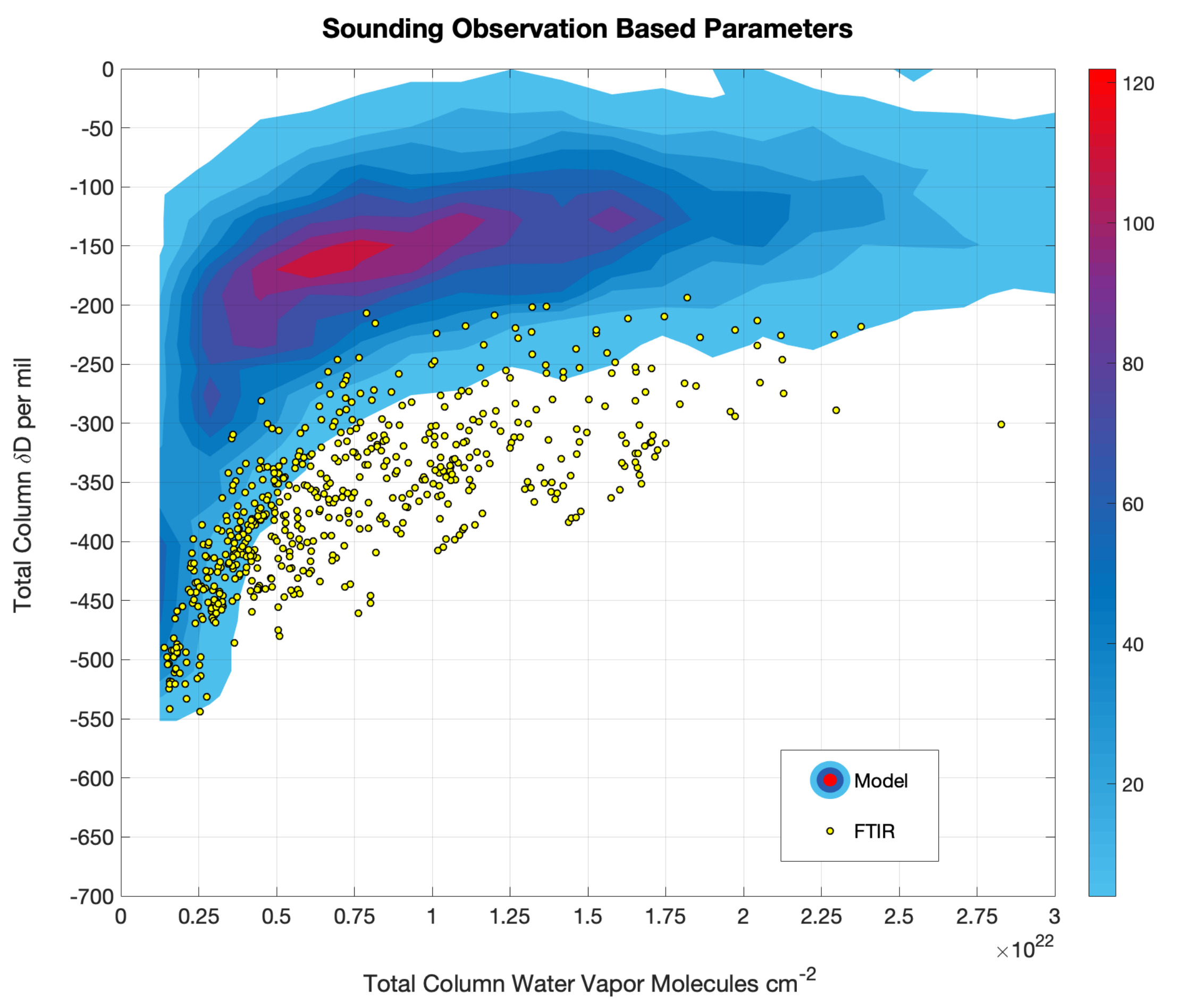
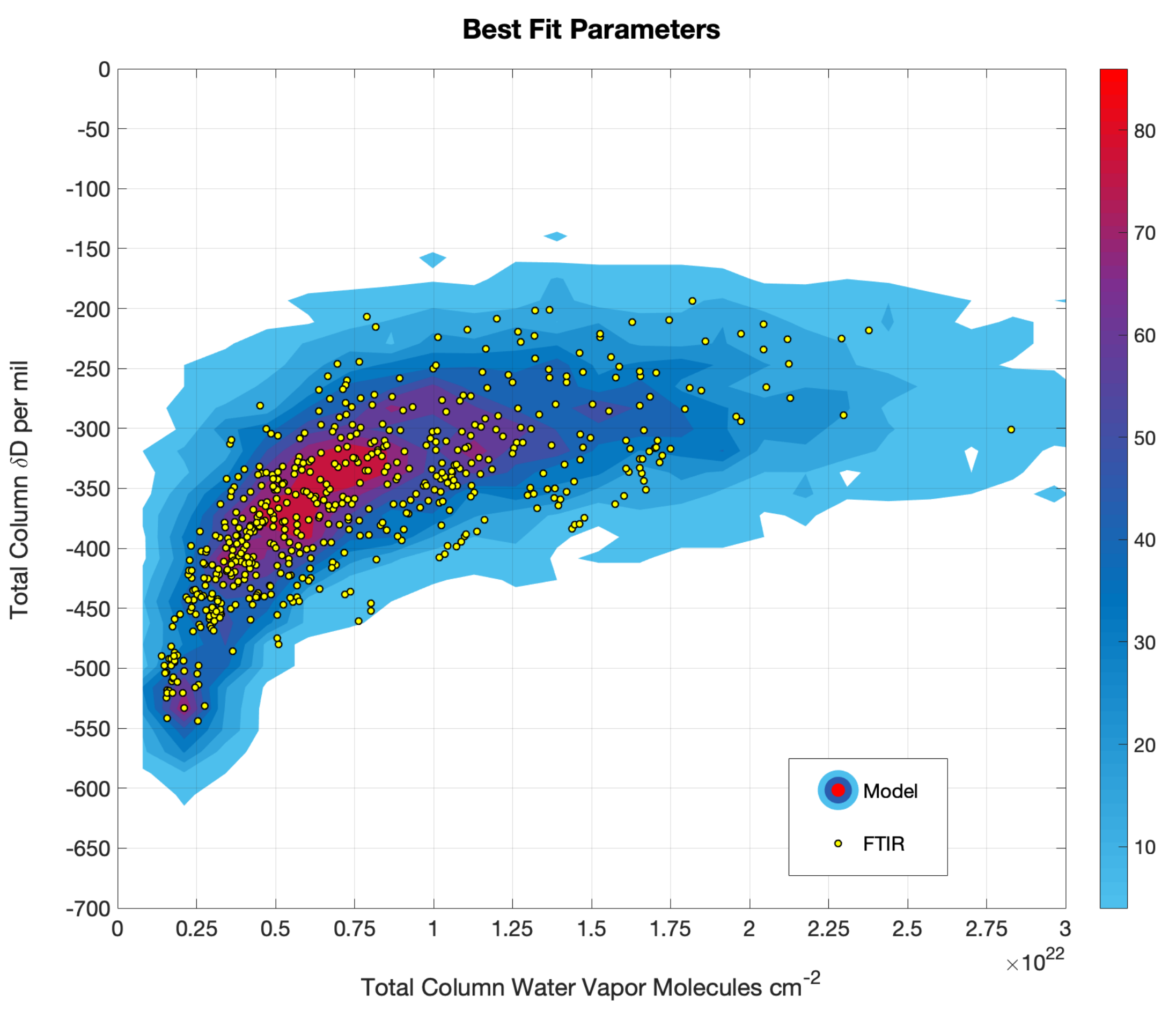


Figure 2. Sensitivity tests fixing all parameters, while allowing variations in λ and **a)** subsiding humidity q_{Sub}, **b)** boundary layer humidity q_{MBL}, **c)** subsiding δD, or **d)** boundary layer δD set by realistic distributions.



Parameter	Mean	Std Dev.	Unit
q_{Sub}	0.006	0.001	g kg^{-1}
δD_{Sub}	-500	10	per mil
q_{MBL}	16	4.3	g kg^{-1}
δD_{MBL}	-80	10	per mil
f_0	0.5	0.2	fraction
λ	0.015	0.003	L^{-1}

Figure 3. FTIR observations and point density cloud of 2000 forward model solutions using humidity and decay parameter values based on ESRL sounding observations. K-S Test value = 0.73



Parameterd	Mean	Std Dev.	Unit
q_{Sub}	0.1	0.035	g kg^{-1}
δD_{Sub}	-530	21	per mil
q_{MBL}	14	3.1	g kg^{-1}
δD_{MBL}	-160	40	per mil
f_0	0.5	0.2	fraction
λ	0.02	0.004	L^{-1}

Figure 4. FTIR observations and point density cloud of 2000 forward model solutions using best fit parameter values. K-S Test value = 0.23

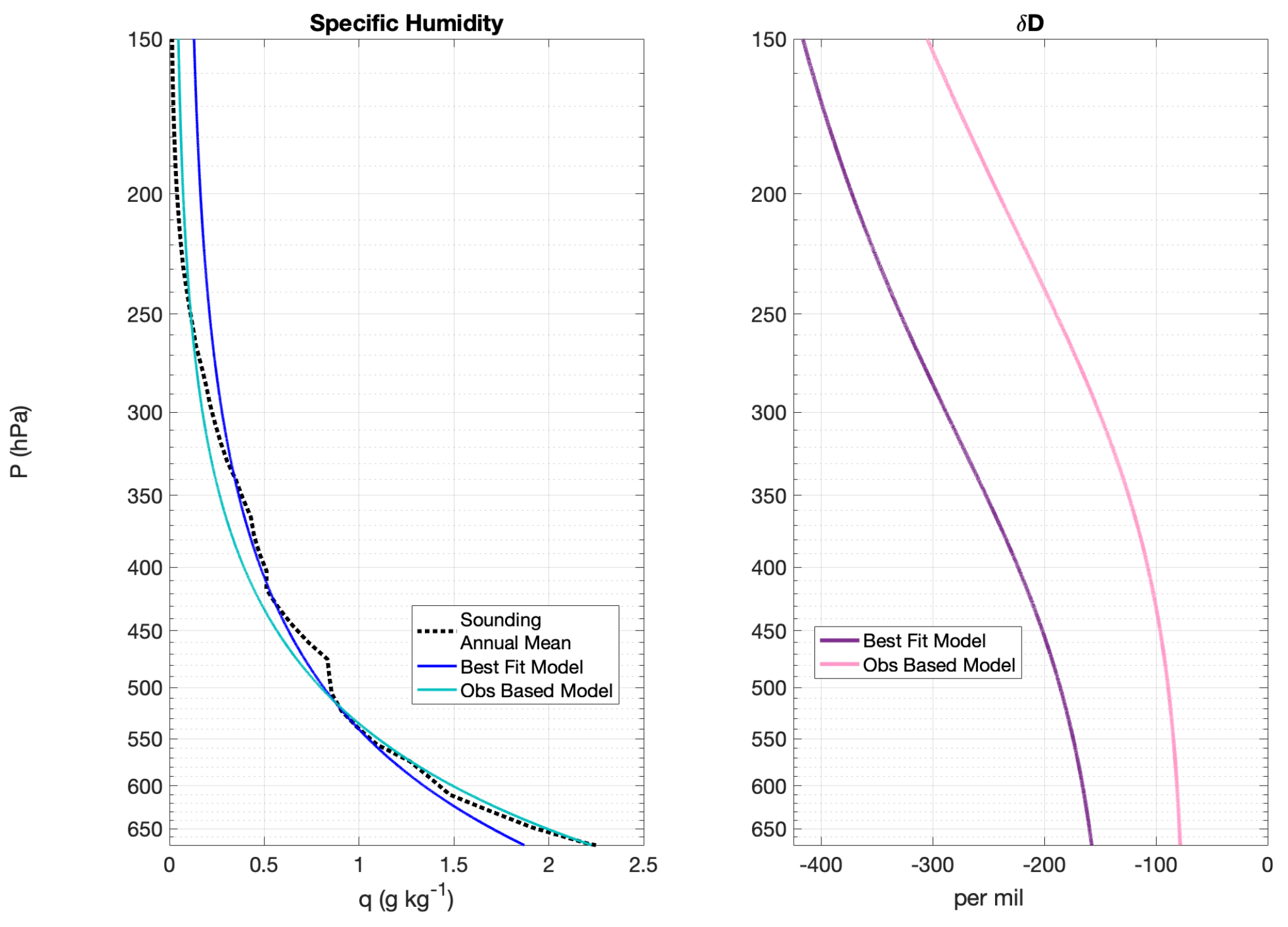


Figure 5. Left: profiles of specific humidity q from observed sounding annual mean and forward model means from the cases above in Fig. 3 and Fig. 4., Right: corresponding model mean δD profiles

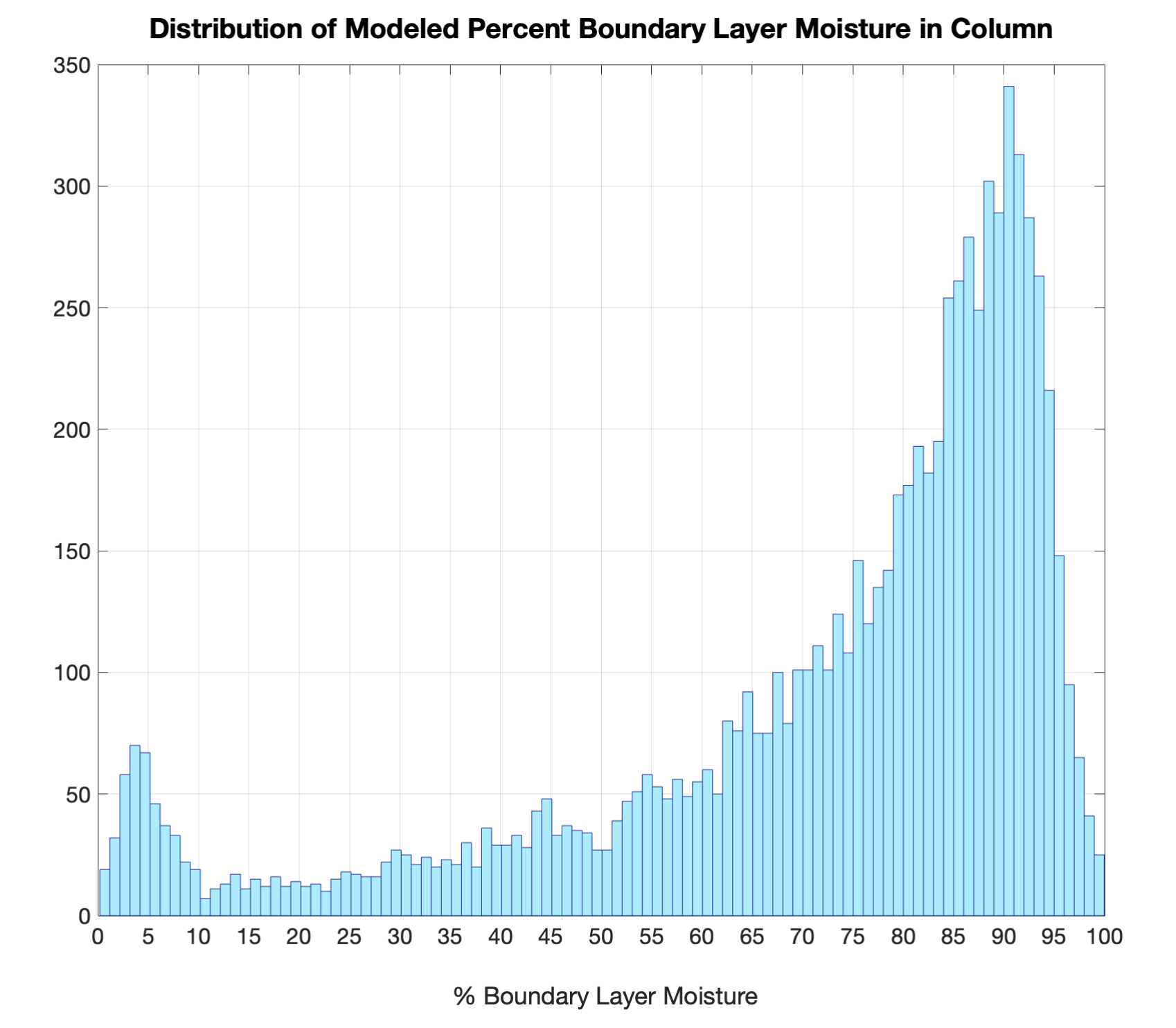


Figure 6. Distribution of percent boundary layer moisture making up forward modeled columns, corresponding to best fit solutions in Fig. 4.

Conclusions

- A simple forward mixing model is able to characterize variability in total column water vapor molecule - δD space.
- Fitting subtropical observations with realistic parameters requires both a relatively moist subsiding air mass (~0.1 g kg^{-1}), and a relatively depleted boundary layer moistening source (~140 – 200 δD per mil).
- This, in conjunction with the most moist, depleted observed total columns, suggests that an additional mid-tropospheric partially depleted moisture source term may be necessary representing lateral advection.
- The isotopically-based framework is able to estimate the percent boundary layer moisture in the tropospheric columns.

Acknowledgements

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