Determination of Near-IR Water Vapor Self Continuum from Field Observations

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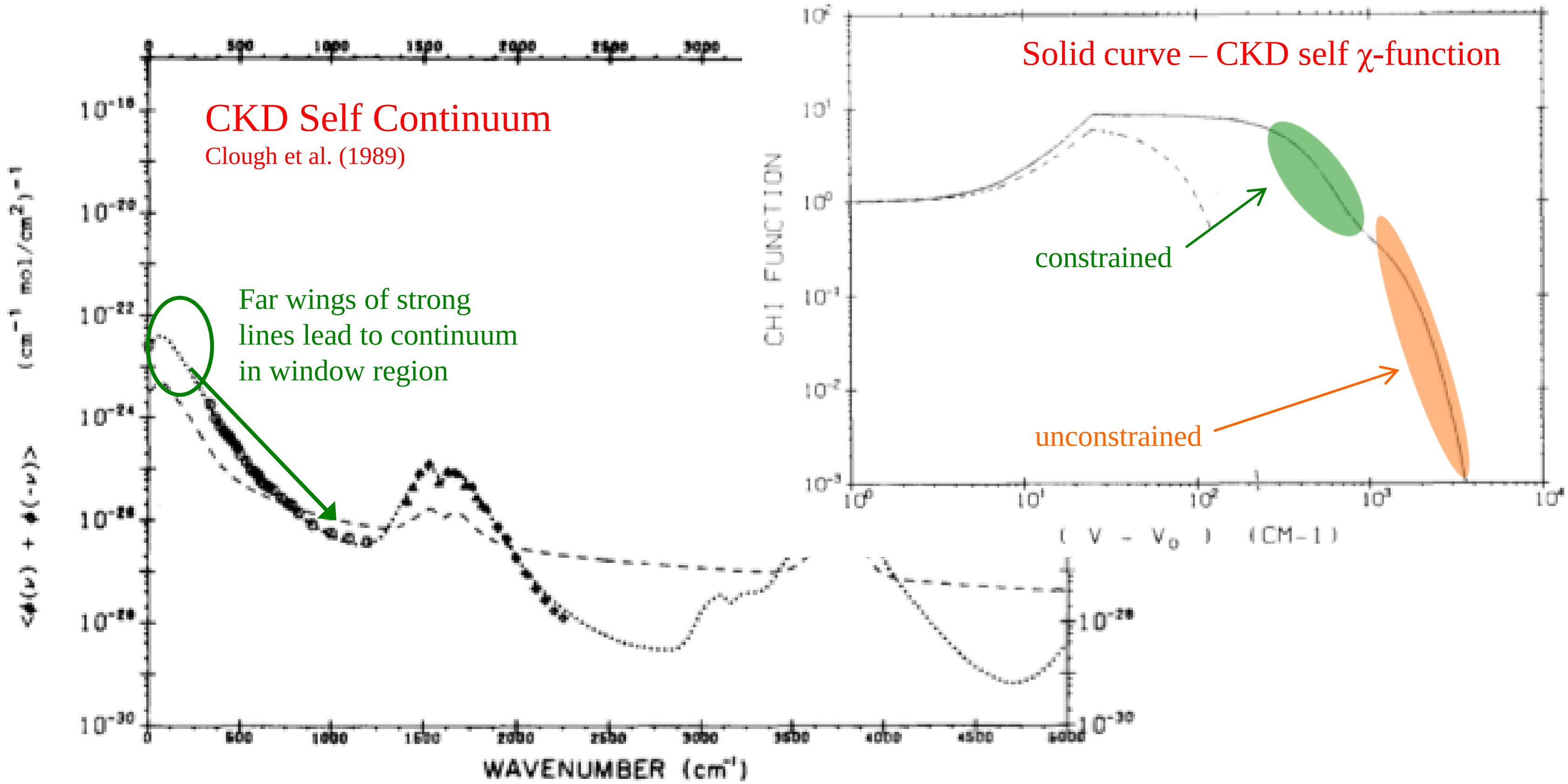
Overview

- Recent lab measurements of near-IR self continuum differ greatly
  - Results in significant uncertainty with respect to amount of solar irradiance absorbed
- MT_CKD (CKD) model: near-IR coefficients arise from extrapolation of modeled line shape from IR behavior (known from field obs)
  - Recent study pushed the (field-) observed spectral region from ~900 to 2500 cm^{-1}
  - Uncertainty of new ‘extrapolated’ continuum coefficients (MT_CKD_2.6) in near-IR remained high
- This study uses observations from a radiometer and solar FTS (TCCON network) located at ARM SGP site to derive self continuum coefficients in two near-IR window regions
  - Result: Derived coefficients fairly close to MT_CKD_2.6

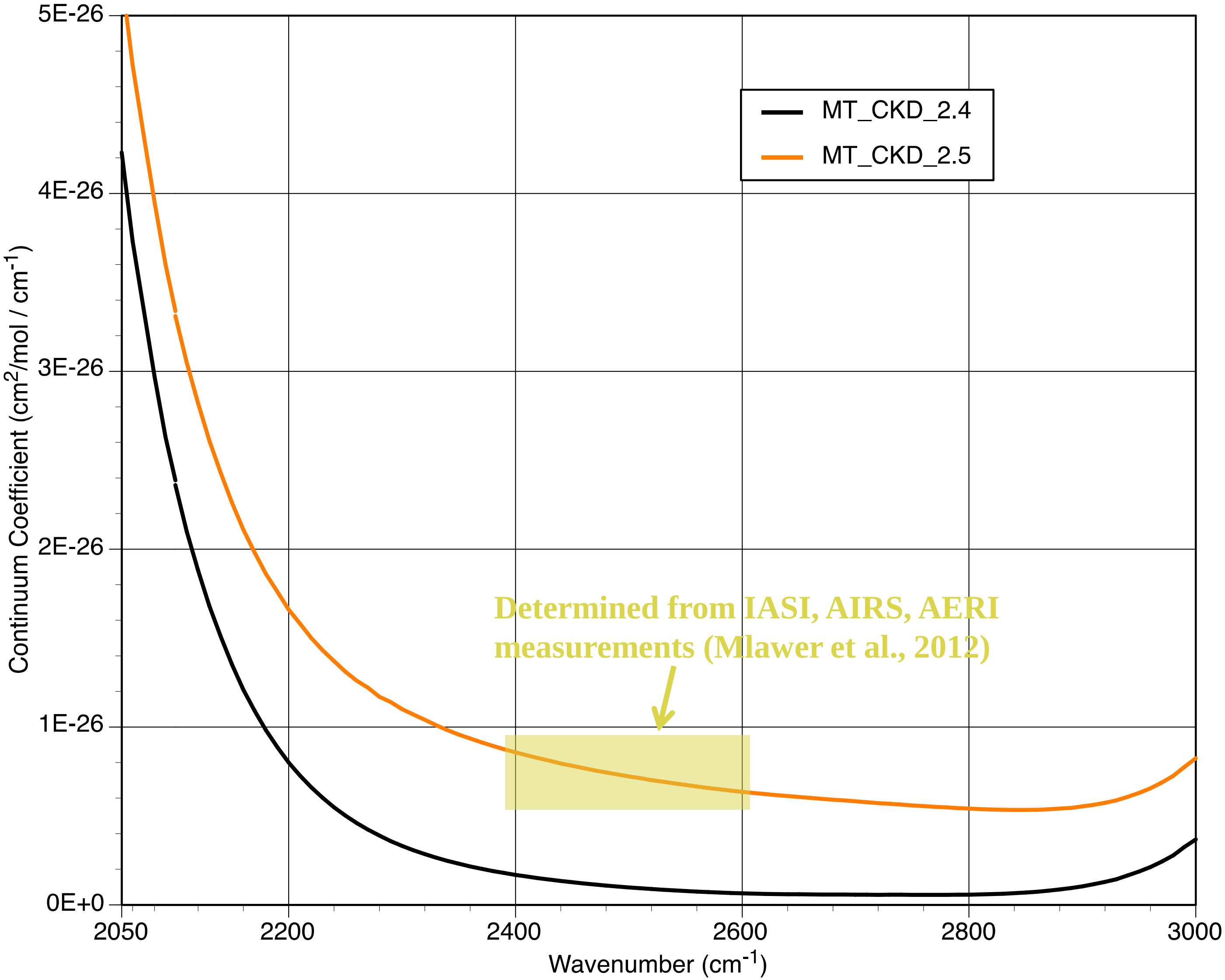
Modeling the Self Continuum in Window Regions

Until fairly recently, only measurements used to constrain the CKD and MT_CKD self continuum in window regions were at ~900 cm^{-1}.



$$\sum_{lines\ i} S_i \frac{1}{p} \frac{a_i}{(n - n_{0,i})^2 + a_i^2} c(n - n_{0,i})$$

Recent Adjustment to MT_CKD Self Continuum in 2500 cm^{-1} Window

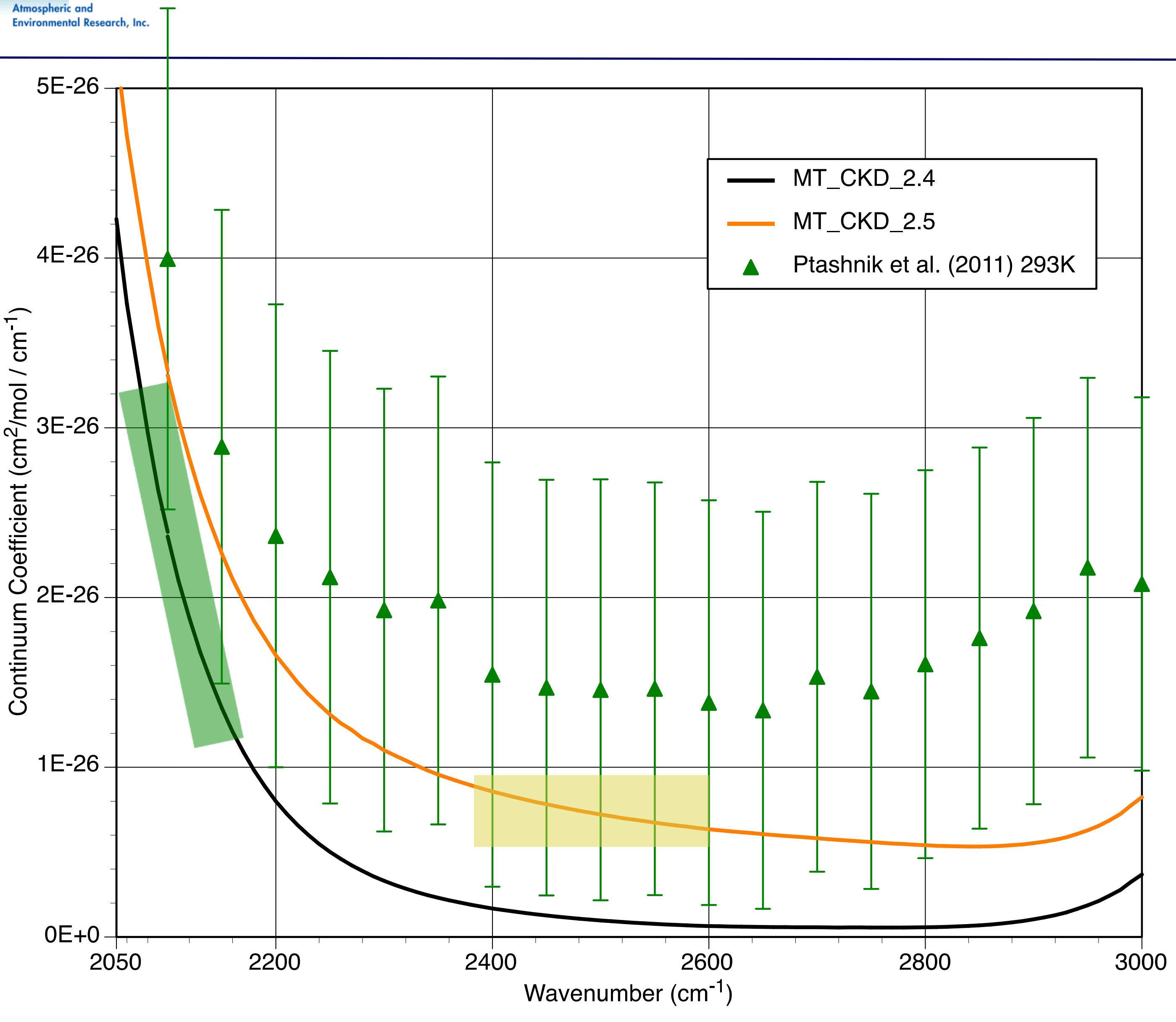


MT_CKD_2.4
Original MT_CKD line shape

MT_CKD_2.5
Adjustment applied only in 2000-3000 cm^{-1} window

MT_CKD_2.6
(unreleased)
Adjustment applied in all near-IR windows

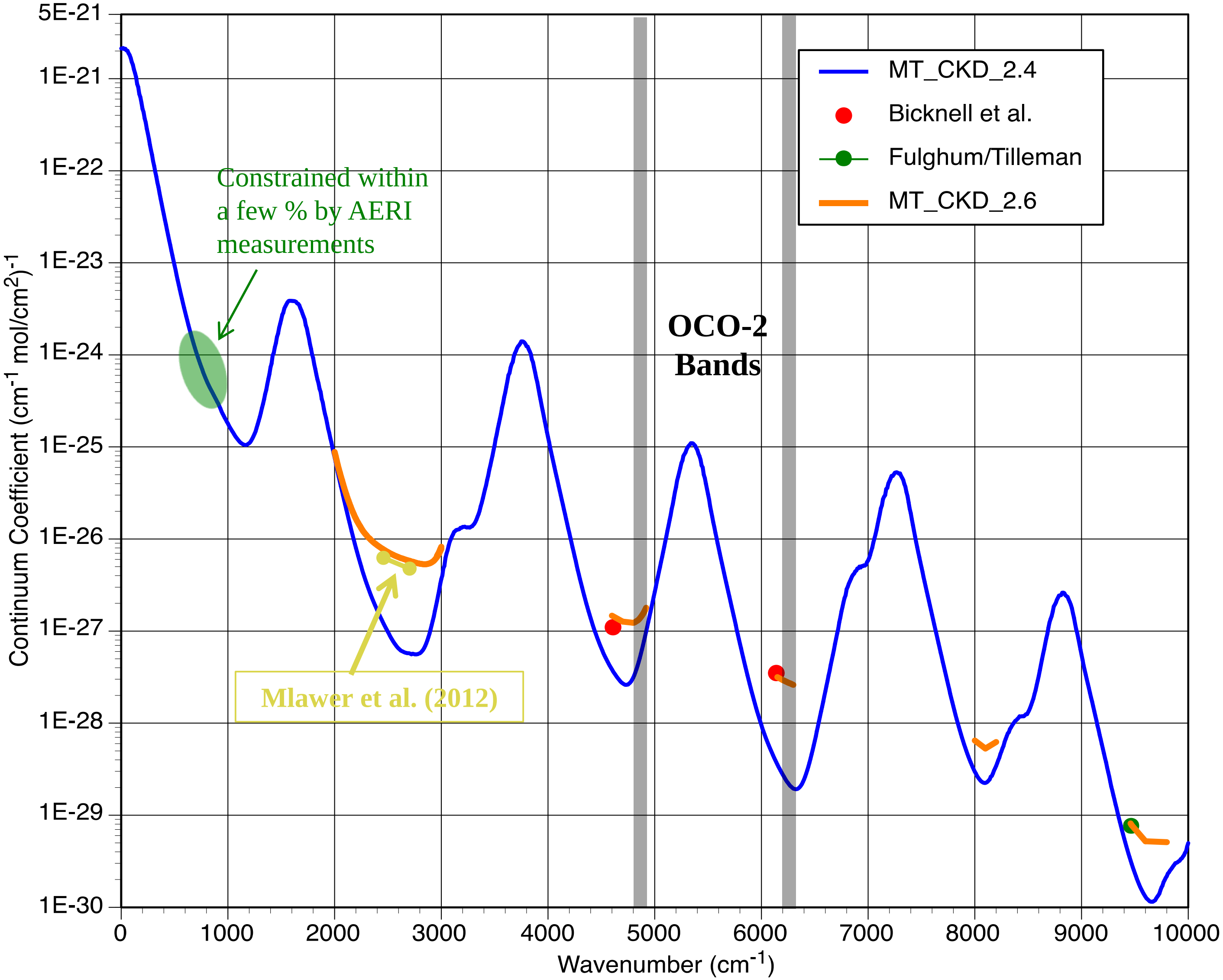
MT_CKD Self Continuum and Measurements in 2500 cm^{-1} Window



Known from Mlawer et al. (2012)

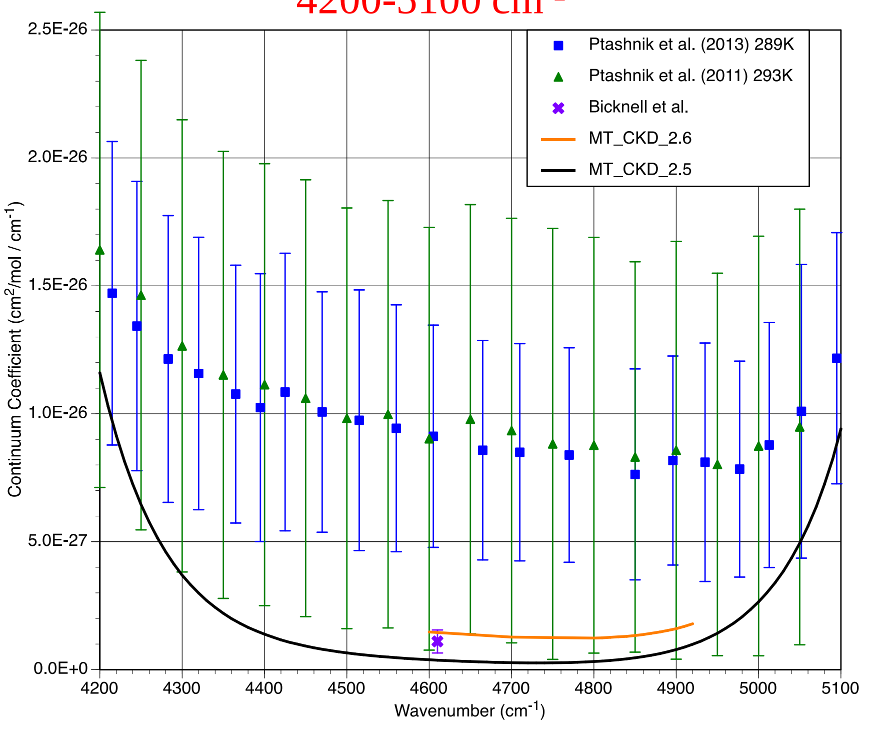
Known from Alvarado et al. (2013)

MT_CKD_2.6 in Near-IR Windows and Constraining Measurements

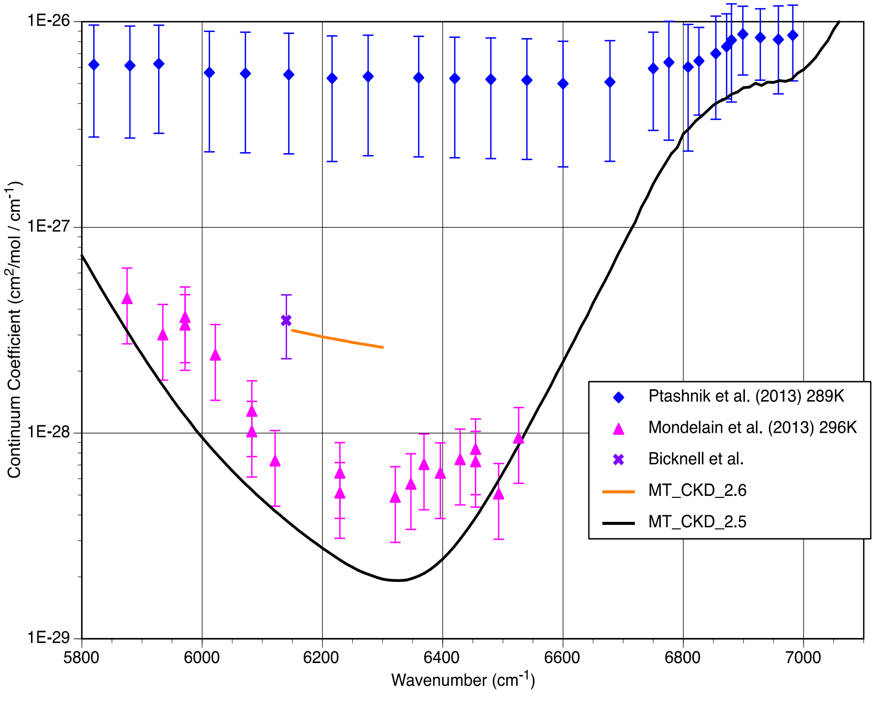


Recent Laboratory Measurements in Near-IR Windows

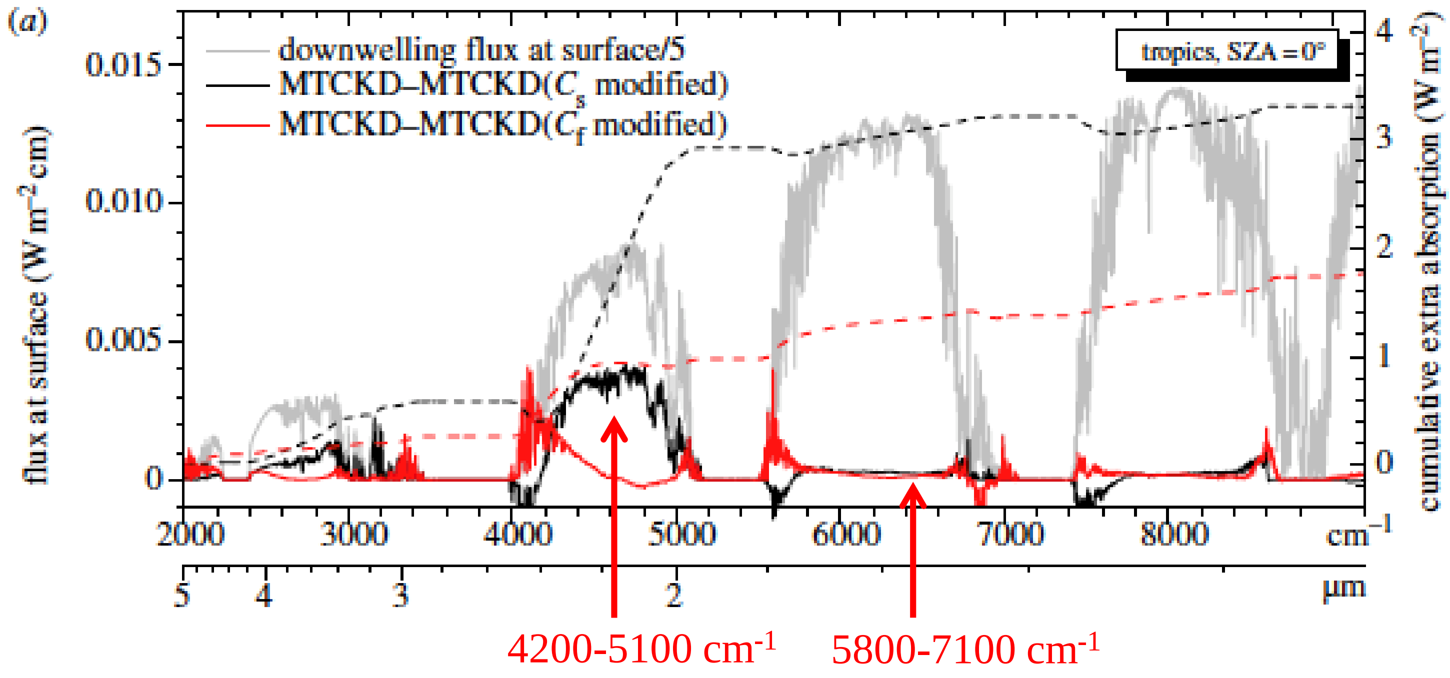
4200-5100 cm^{-1}



5800-7100 cm^{-1}



Impact of Higher Self Continuum on Absorbed Solar Flux

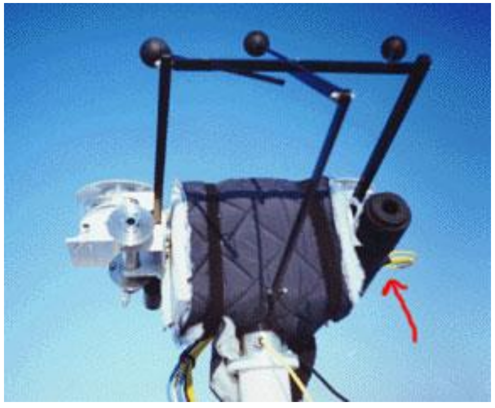


Black curve is additional solar flux absorbed of Ptashnik et al. (2011) compared to MT_CKD_2.5 for a tropical atmosphere (from Ptashnik et al. (2012)).

Datasets from SGP Site Used in this Study

1) Mergedsounding – profiles of T and moisture

2) Normal Incidence Multifilter Radiometer (NIMFR)

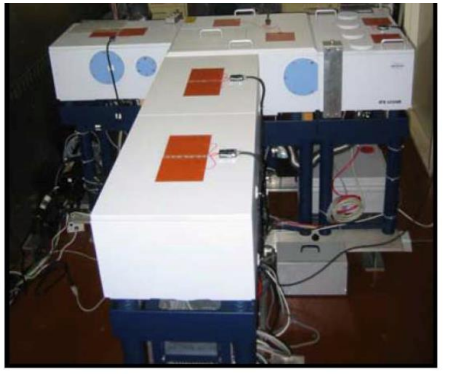


The NIMFR is considered the most accurate instrument at the ARM SGP site for providing aerosol optical depths. Benefits include long history, successful intercomparisons with other instruments, and QC applied by ARM.

Measures direct-normal irradiance at nominal channel wavelengths: 415, 500, 615, 673, 870, and 940 nm

3) Solar FTS from Total Column Carbon Observing Network (TCCON)

- Bruker IFS125HR
- Detectors
  - InGaAS (3900-9000 cm^{-1})
  - Si (9000-15500 cm^{-1})
- Resolution - 0.02 cm^{-1}



from Toon et al. (2009)

Procedure Used in NIR Self Continuum Study

1) Choose stable cases: Use SGP NIMFR to identify days that have a period of stability wrt AOD. Use ARM PWV time series to make sure also stable wrt water vapor loading.

12 days (some with multiple periods) → 13 'cases' → 5 summer cases (3-3.5 cm PWV)

2) Derive spectral total optical depths from FTS: (Langley method -- slope of log)

$$R/R_0 = \exp(-m\,\tau_0)$$

m is airmass factor, R is observed radiance, R_0 is the extraterrestrial radiance, and τ_0 is the total vertical optical depth.

3) Run LBLRTM (without continuum) corresponding to FTS cases, get ODs from Langley method.

- Subtract LBLRTM ODs from FTS ODs, get representative value for each sufficiently transparent 20 cm^{-1} bin.

4) Derive spectral behavior of AODs from NIMFR OD and representative FTS ODs.

- Derive AOD(ν) from AOD measurements in transparent regions between 8000-20000 cm^{-1}.

5) Subtract spectral AOD from representative FTS ODs to obtain spectral self continuum ODs.

6) Determine spectral self continuum coefficients for each case. Median over all cases for each spectral bin are final set of self continuum coefficients.

2) Derive Spectral Total Optical Depths

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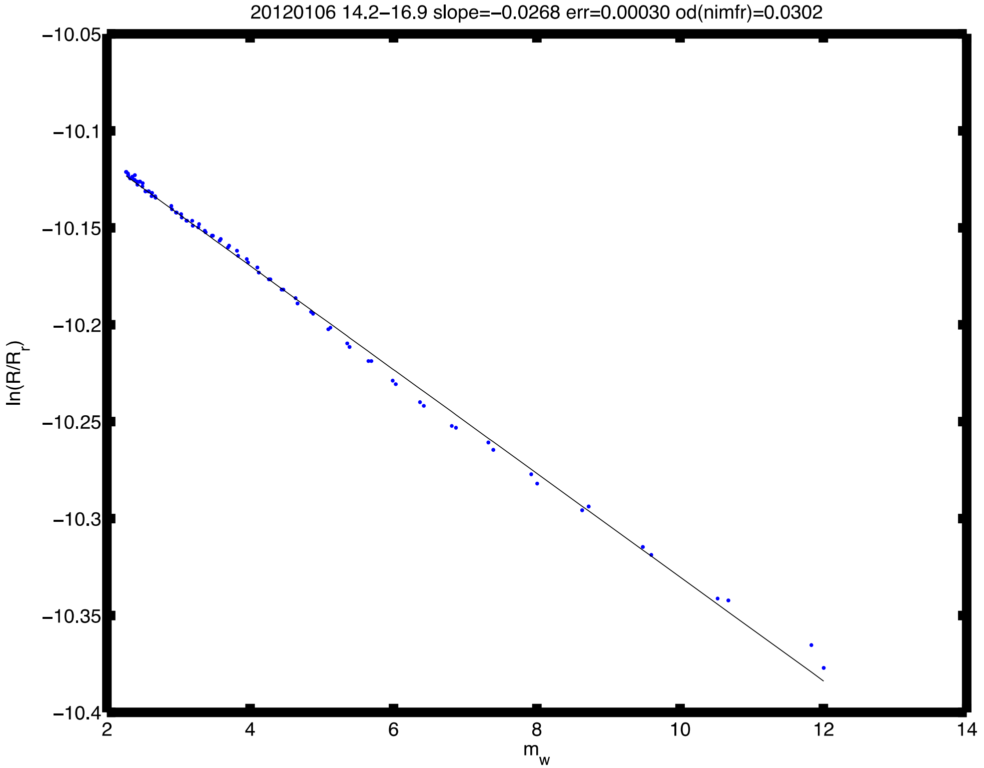

ν =~11,500 cm^{-1}

Overview of NIR Self Continuum Study

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3) Run LBLRTM

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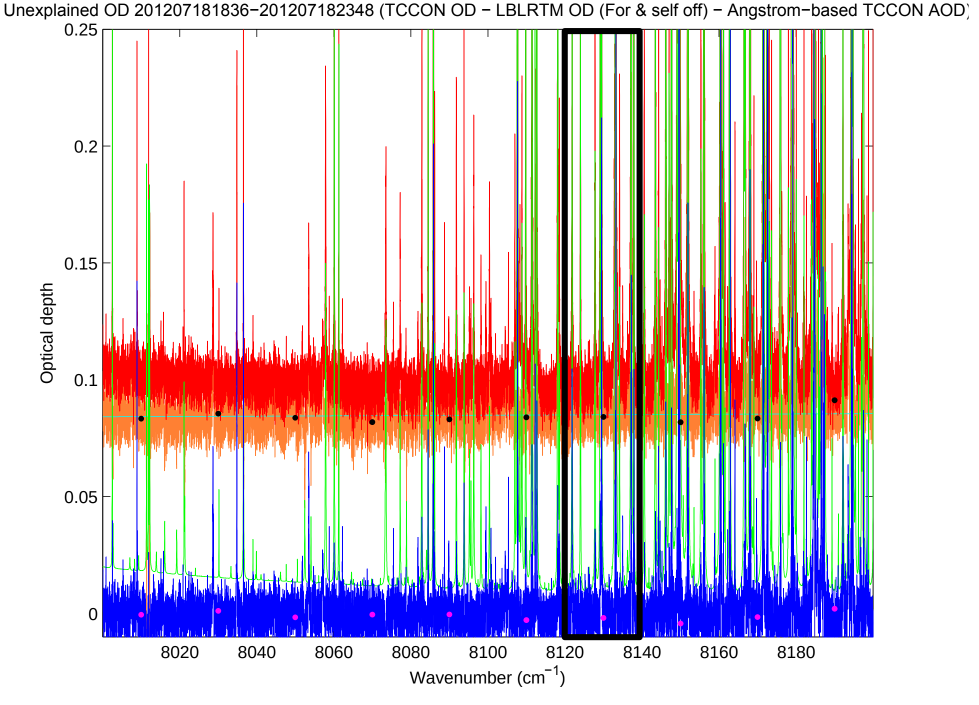

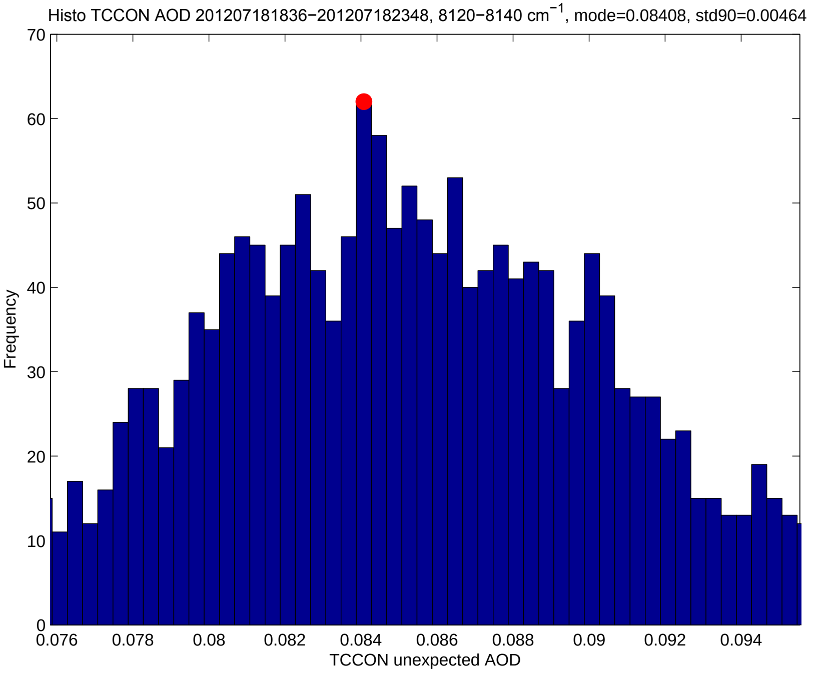

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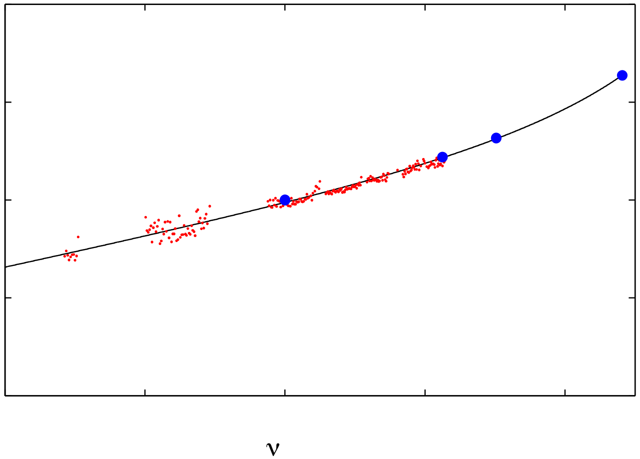
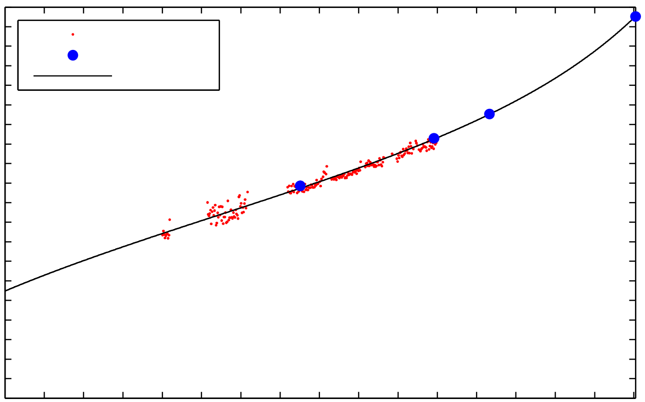


Generalized Angstrom relationship used (Molineaux et al., 1998):

$$AOD(\nu) = AOD_0 \, [u + y\,(\nu_0/\nu)] \, / \, [t + (\nu_0/\nu)^s]$$



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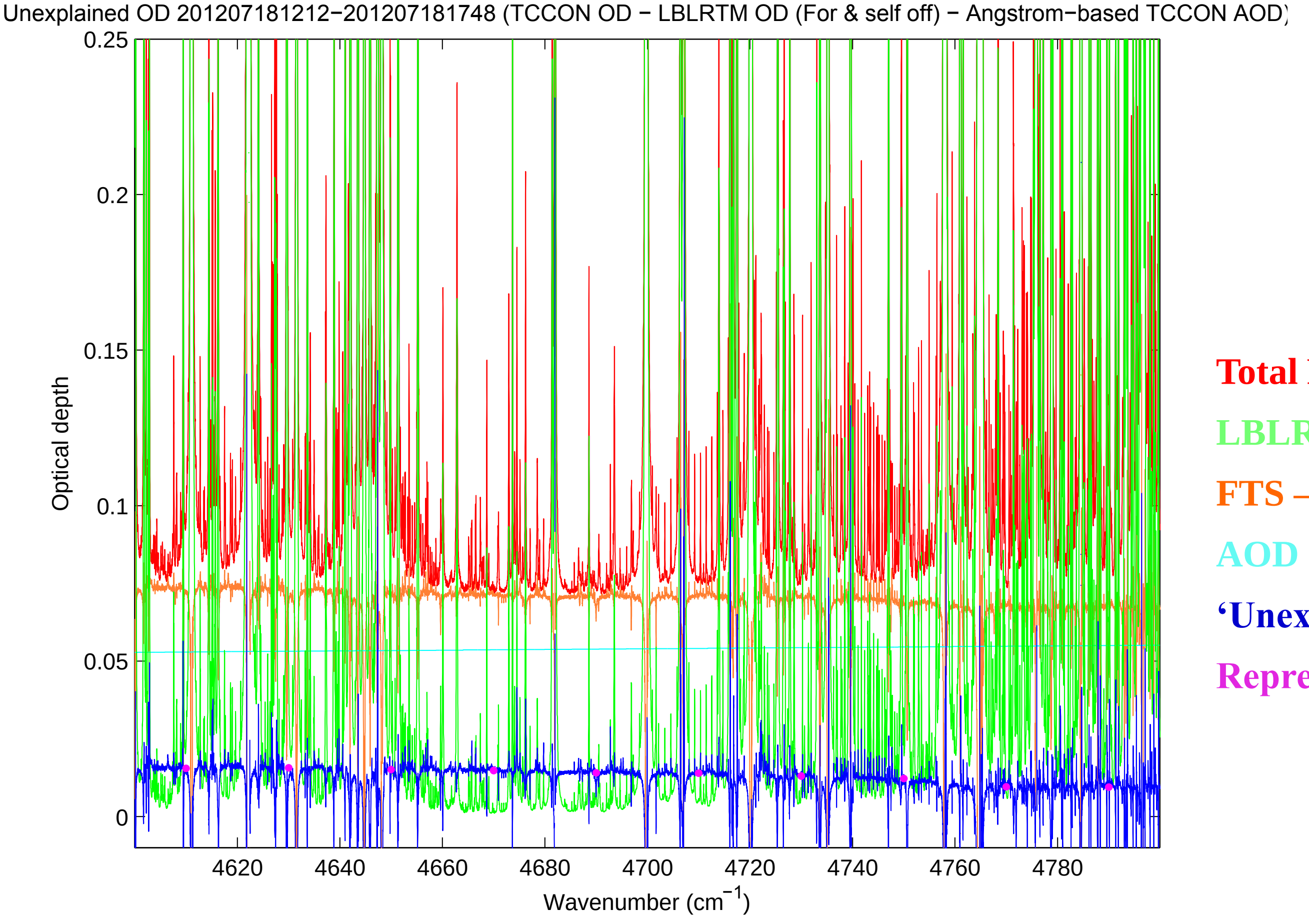
5) Obtain Self Continuum Optical Depths

Subtract spectral AODs from representative FTS ODs to obtain spectral self continuum ODs.



Total FTS OD

LBLRTM OD

FTS – LBLRTM (includes AOD)

AOD

'Unexplained' FTS OD

Representative 'unexplained' FTS OD

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6) Determine Self Continuum Coefficients

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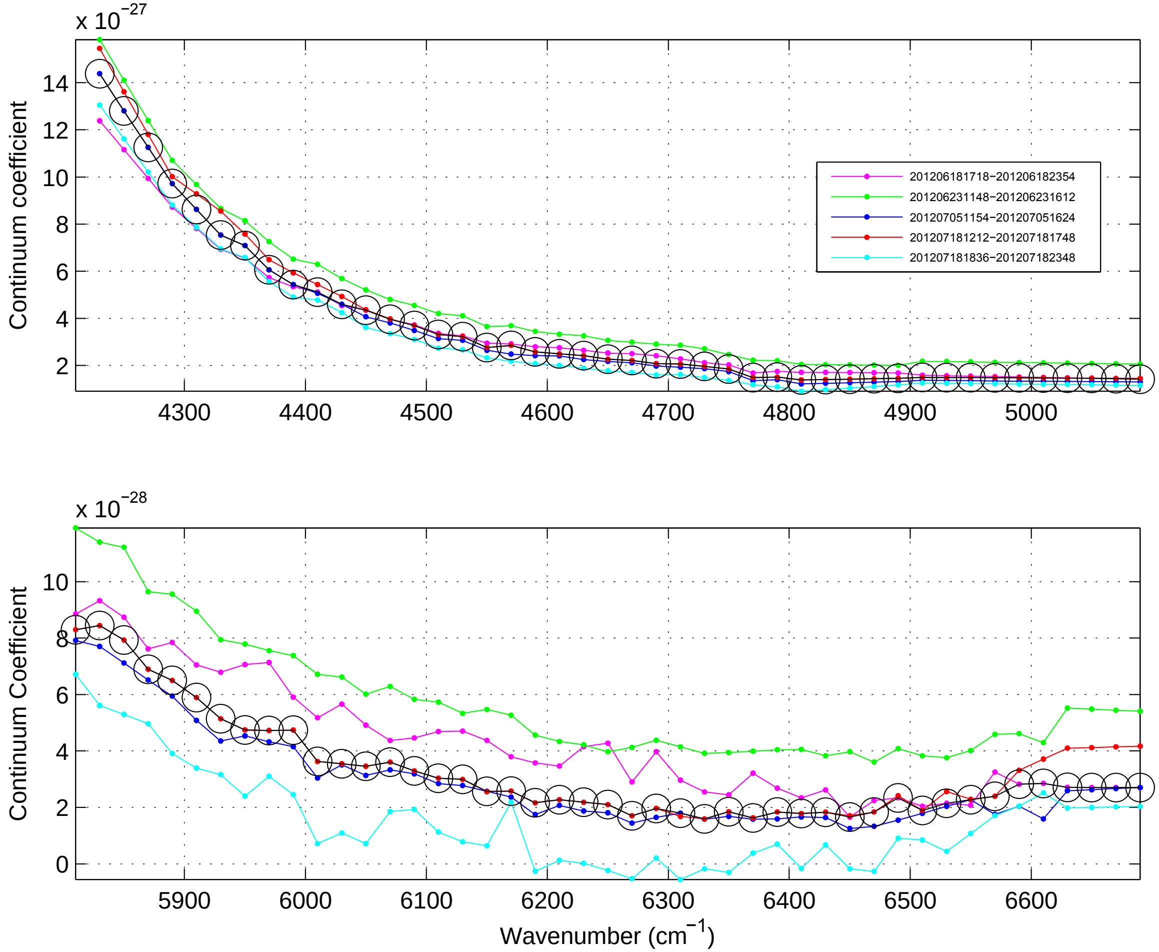
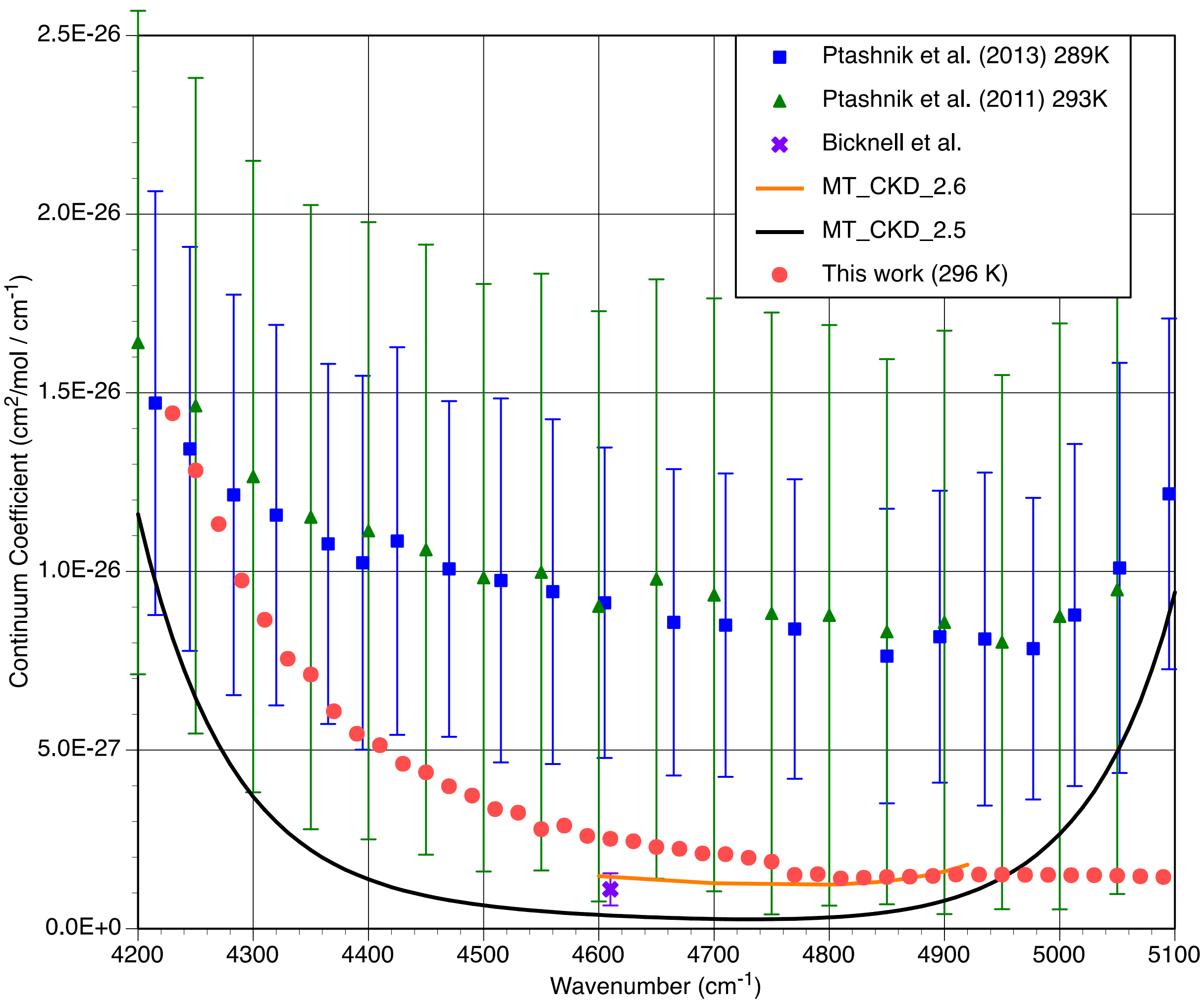


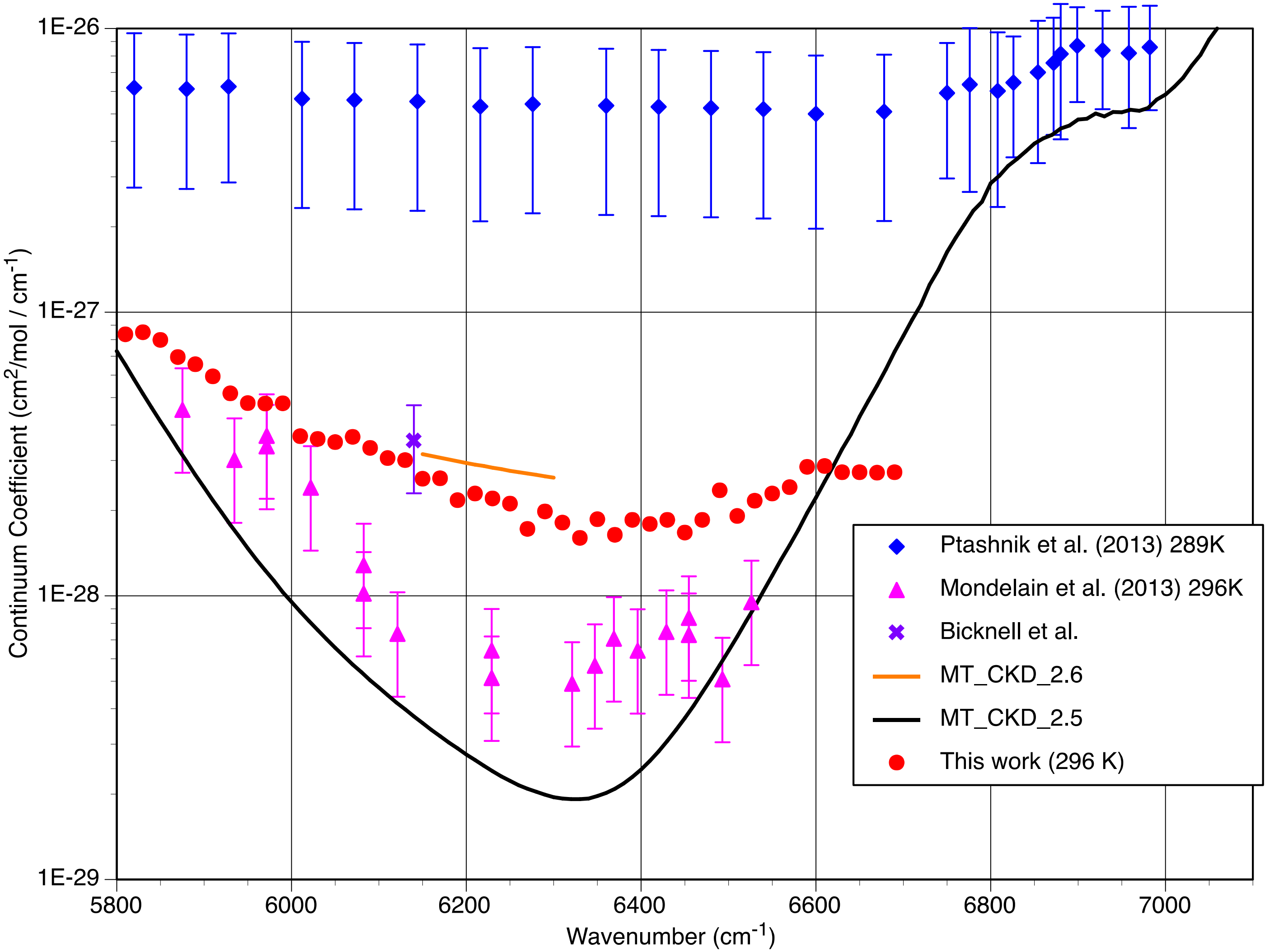
Self Continuum Optical Depths in 4200-5100 cm^{-1} Window



Results in this region are consistent with MT_CKD_2.6, somewhat higher than MT_CKD_2.5, a little higher than Bicknell et al., and a fair amount lower than both Ptashnik et al. results (but within the error bars of the 2011 study) in the majority of the window.

The ratio of foreign to self ODs is > 1 for ν > 5020 cm^{-1}, possibly explaining the flat behavior at the high wavenumber edge of the window.

Self Continuum Optical Depths in 5800-7100 cm^{-1} Window



Results in this region are somewhat higher than Mondelain et al., a little lower than MT_CKD_2.6 and Bicknell et al., a lot higher than MT_CKD_2.5, and a great deal lower than Ptashnik et al..

The ratio of foreign to self ODs is > 1 for ν > 6600 cm^{-1}, possibly explaining the flat behavior at the high wavenumber edge of the window.

Conclusions

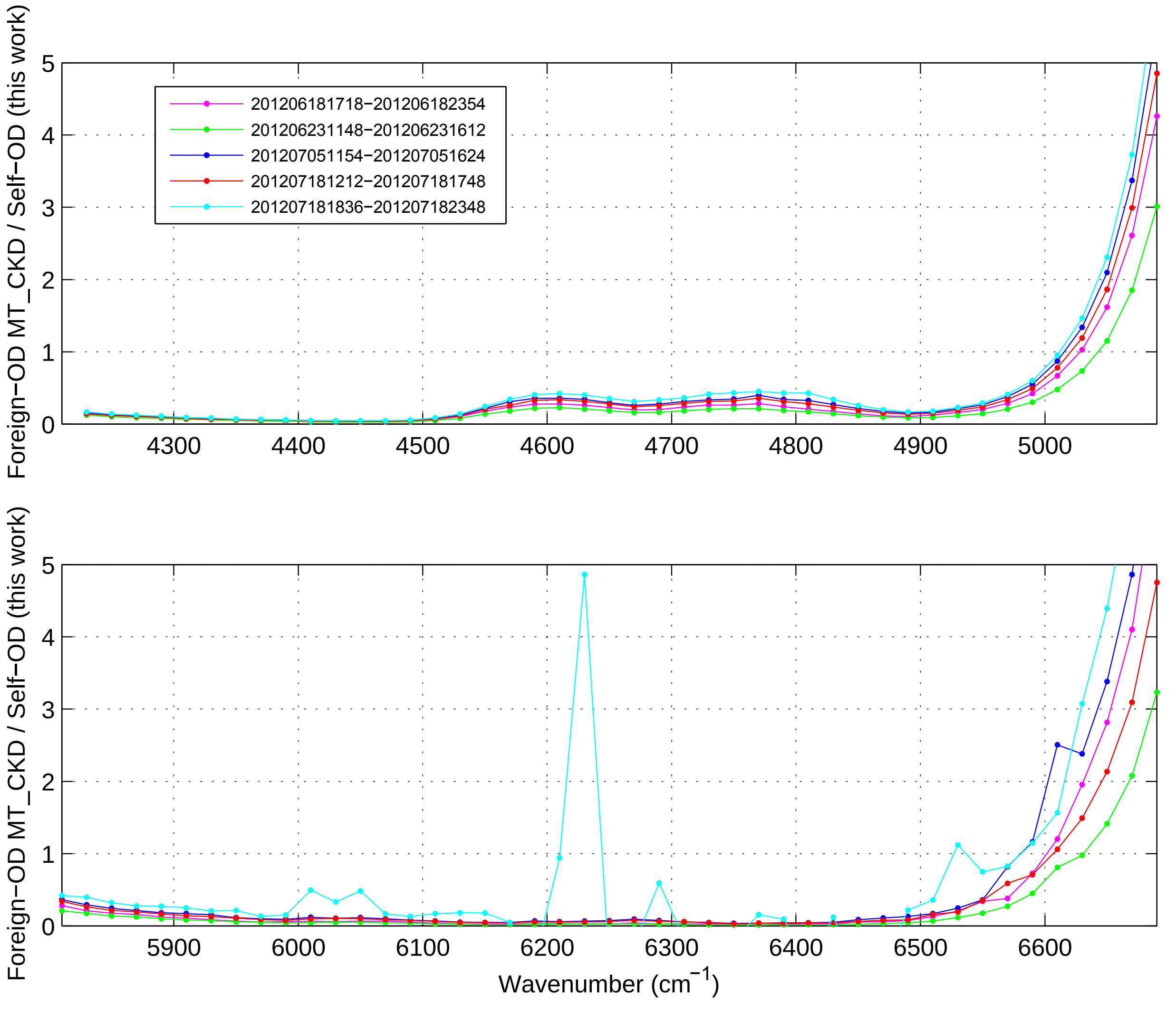
- The self continuum coefficients in MT_CKD_2.6 are reasonably consistent with those determined in this study
  - ➢ coefficients from this study consistent with Mlawer et al. (2012) coefficients

- Uncertainty analysis still needed, especially systematic uncertainties
  - NIMFR – 5-10% AOD
  - Molineaux fit to AOD(ν) – ~5-10% AOD
  - Foreign continuum

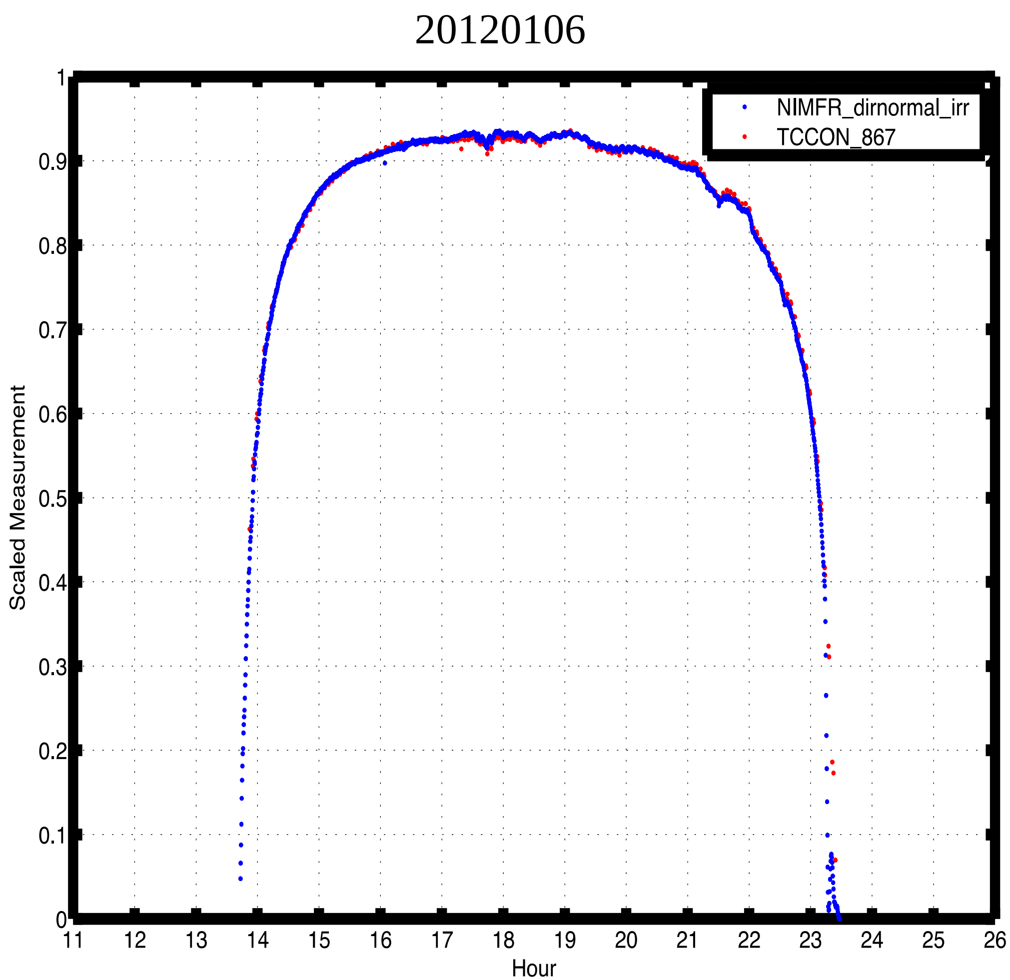
- In 6200 cm^{-1} window, Mondelain et al. (2014) gives slightly lower coefficients than Mondelain et al. (2013)
  - ➢ significantly less temperature dependence than MT_CKD

- Future: Rederive MT_CKD line shape to reflect new self coefficients in all three windows

Extra slides


Foreign−OD MT_CKD / Self−OD (this work)
5
4
3
2
1
0
4300
4400
4500
4600
4700
4800
4900
5000
201206181718−201206182354
201206231148−201206231612
201207051154−201207051624
201207181212−201207181748
201207181836−201207182348
Foreign−OD MT_CKD / Self−OD (this work)
5900
6000
6100
6200
6300
6400
6500
6600
Wavenumber (cm^{-1})

Combining NIMFR and Solar FTS Measurements to Obtain AOD(ν)



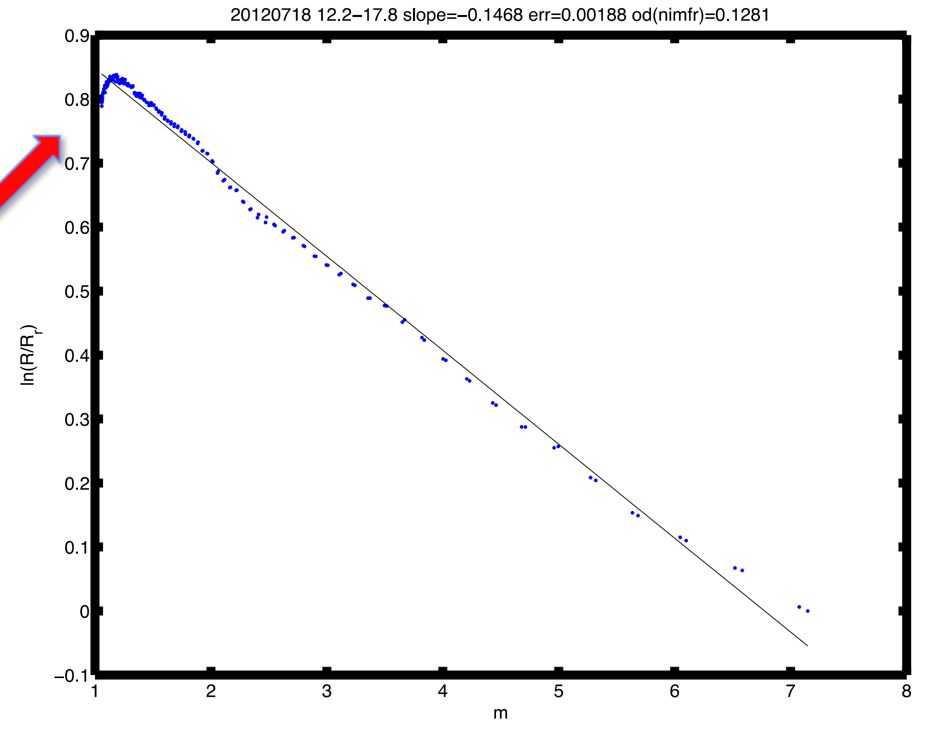
To examine consistency of two instruments, look at NIMFR and FTS measurements at common wavelength, 867 nm.

Determine a scale factor during a well-behaved period each day and multiply that day's time series of FTS data by this scale factor.

For winter cases, the two instruments track each other well, and therefore will provide consistent optical depths.

Combining NIMFR and Solar FTS Measurements to Obtain AOD(ν)

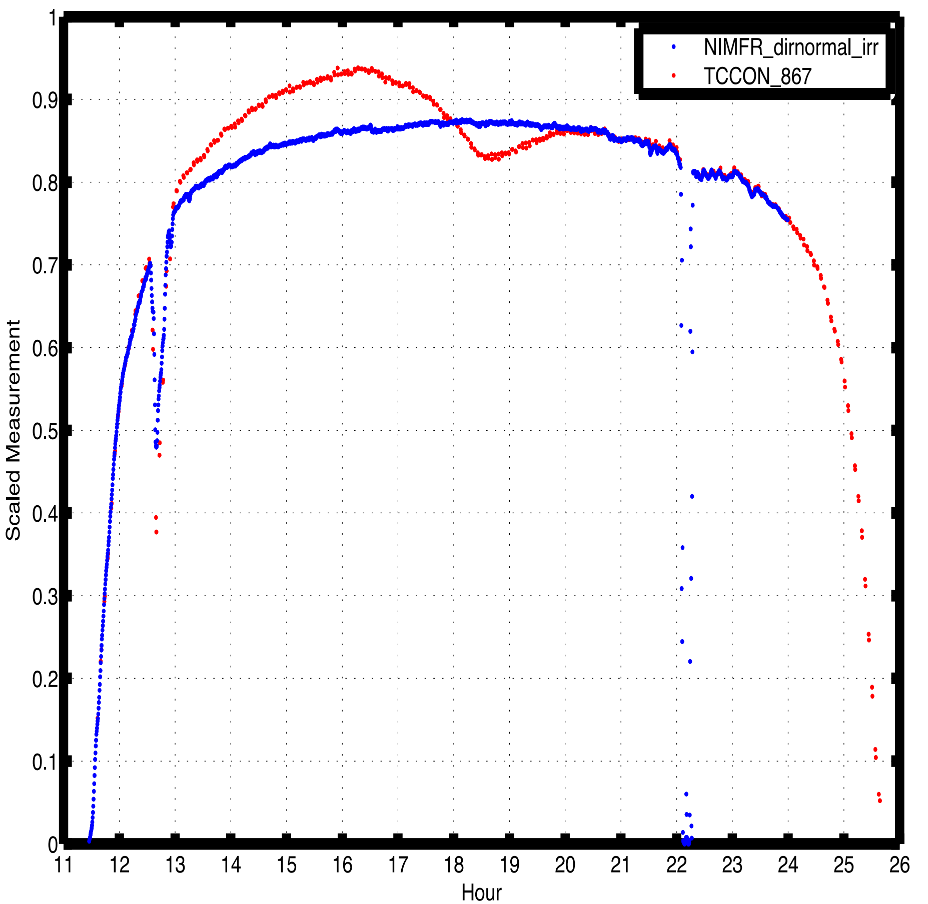
For a summer case, the FTS Langley plot had a strange hook.



Combining NIMFR and Solar FTS Measurements to Obtain AOD(ν)

Summer days looked something like this after applying the scale factor from a well-behaved period during the day.

20120720



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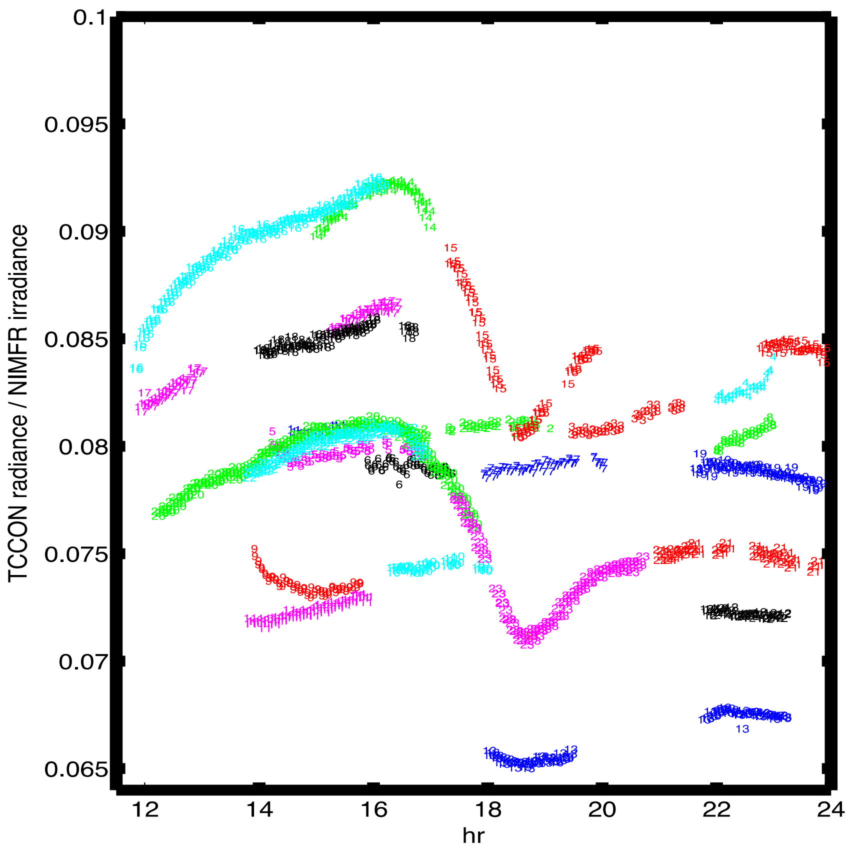


Guide to symbols on plot

(summer cases are numbers 14 and higher)

1 201201021430–201201021542
2 201201021624–201201021906
3 201201021912–201201022124
4 201201022200–201201022300
5 201201061412–201201061654
6 201201101554–201201101724
7 201201101754–201201102006
8 201201102200–201201102300
9 201202061354–201202061548
10 201202061618–201202061800
11 201202261348–201202261554
12 201202262148–201202262312
13 201203291800–201203292312
14 201206181136–201206181712
15 201206181718–201206182354
16 201206231148–201206231612
17 201207051154–201207051624
18 201207061400–201207061654
19 201207062130–201207062348
20 201207181212–201207181748
21 201207181836–201207182348
22 201207201348–201207201654
23 201207201724–201207202148

As a result of this issue, all FTS measurements for a day were scaled by the 867 nm NIMFR:FTS ratio for a well-behaved part of that day.

For any spectral point, get FTS optical depth from slope of log (R/R_0) vs. airmass relationship.

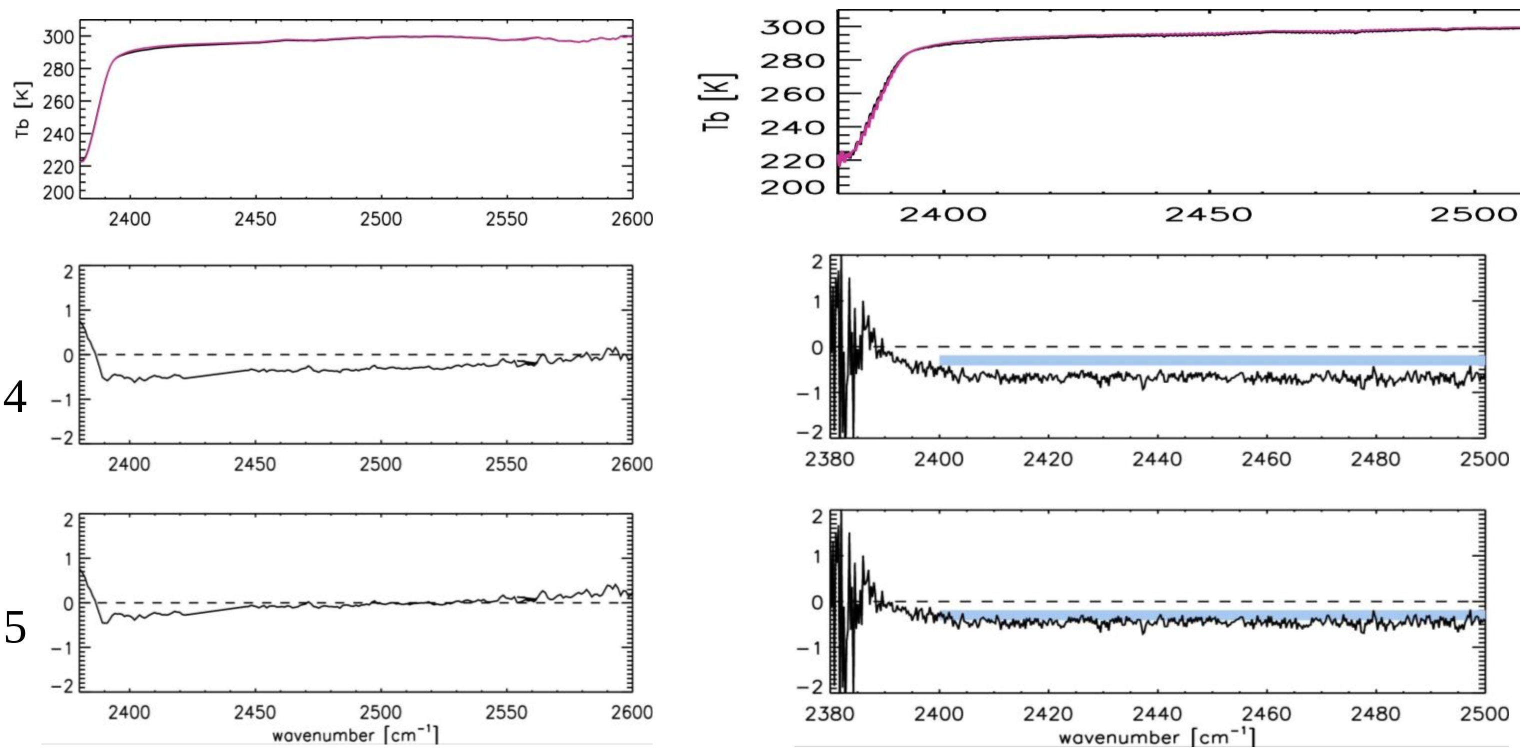
H_2O Continuum in 2500 cm^{-1} window for high PWV cases (over ocean)

AIRS IASI

Observations

Residuals w/ MT_CKD_2.4

Residuals w/ MT_CKD_2.5



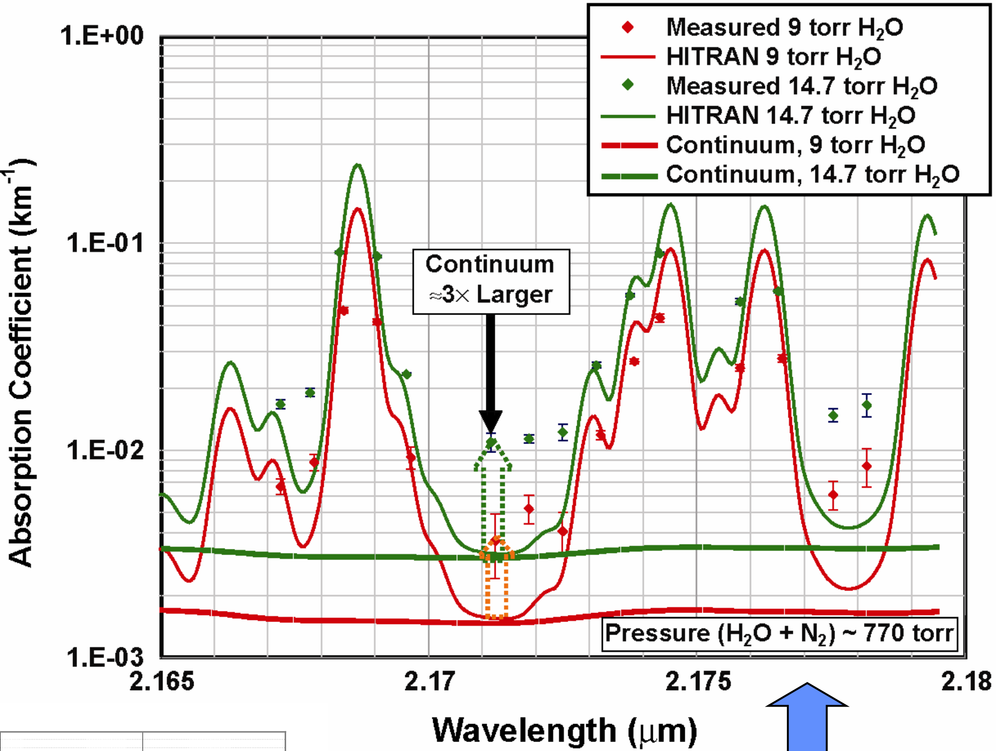
36 cases 34 cases

Ptashnik et al. (2011) self continuum (293K) in this region is MT_CKD_2.5 times a factor of 2 ± 1.6

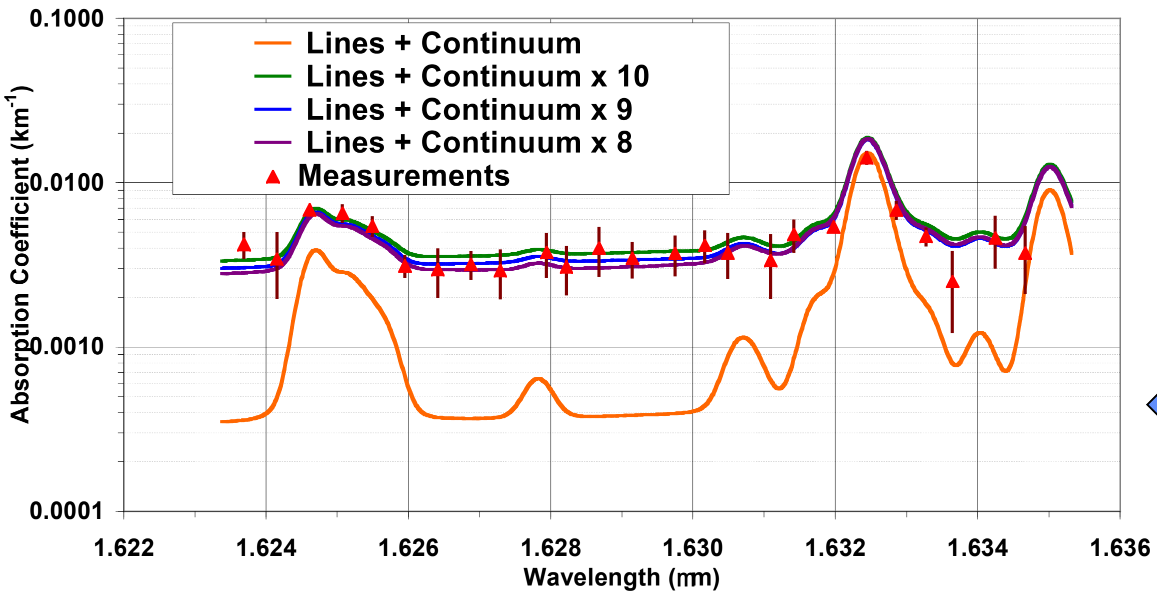
from Mlawer et al. (2012)

Near-IR Window Measurements

Bicknell et al. (2006)

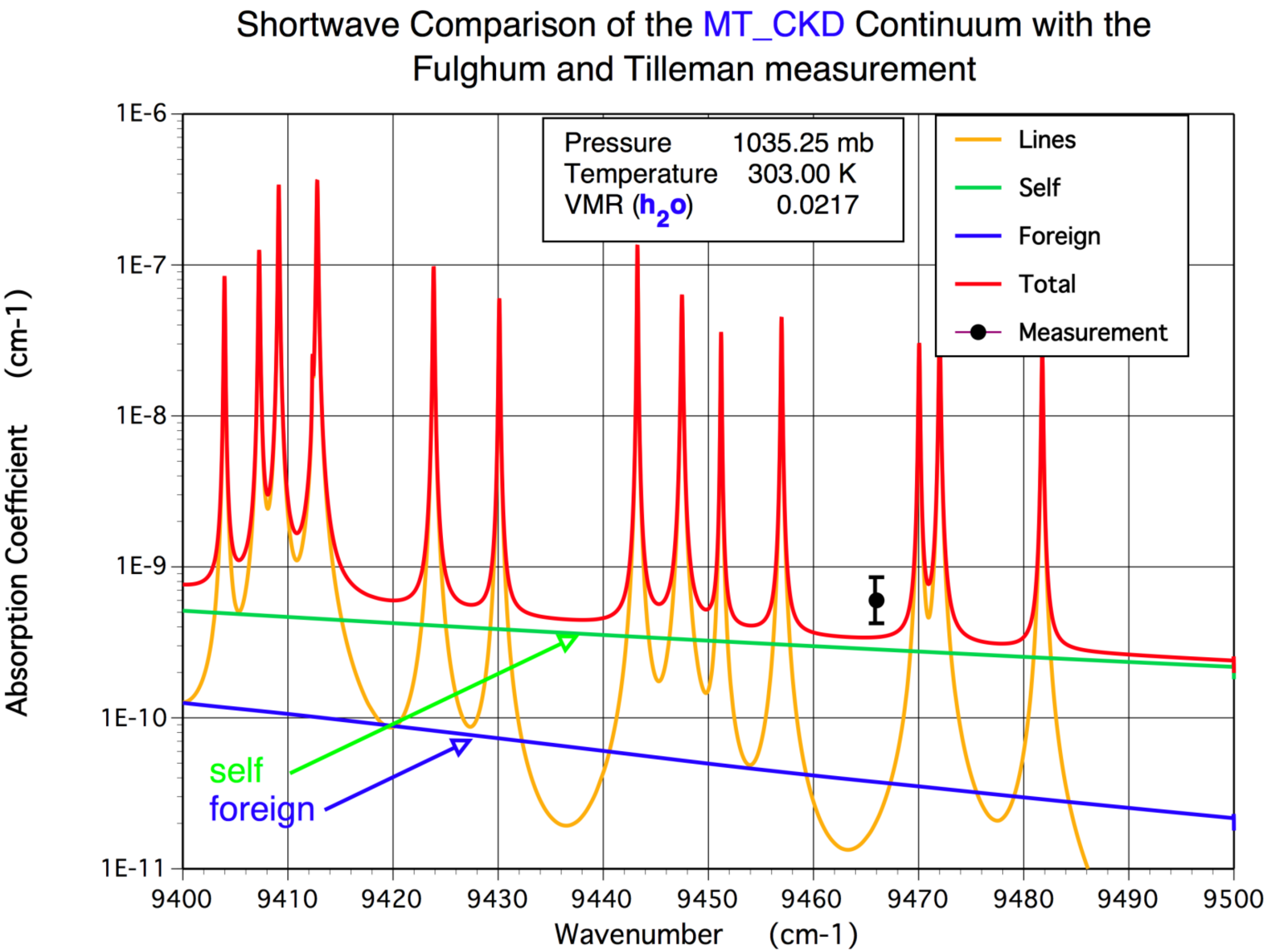


MT_CKD needs factor of 3 ~4600 cm^{-1}



Factor of 9 ~6140 cm^{-1}

Fulghum and Tilleman (1991)



Plot by S. Clough