Broadband vs Spectral Radiative Closure: Synergy Between RSS Measurements and Modeling

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Overview

- AIOP ‘03 broadband radiative closure experiment findings
- Is diffuse irradiance correctly measured and modeled?
- RSS measurements: Irradiance vs Transmittance
- Broadband vs spectral closure: some typical cases
- Sources of measurement error
- Sources of indirect modeling errors
- Extraterrestrial spectrum
- Need for more ancillary data
- Summary

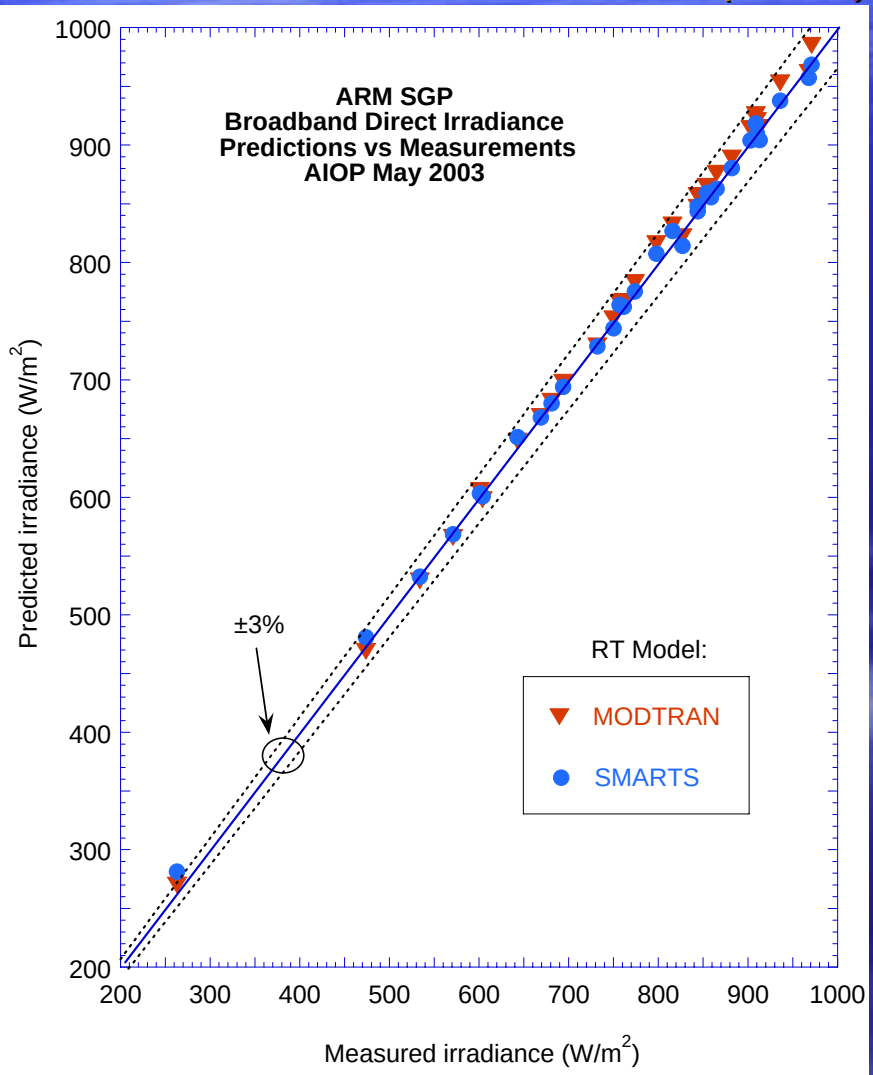
AIOP '03 Radiative Closure Experiment

- Michalsky et al. paper, JGR 2006
- 6 RT Models:
  - MODTRAN, RAPRAD, RRTM, SBDART, SBMOD, SMARTS
- 30 Data points, large range of conditions:
  - $12.2° < SZA < 75.0°$
  - $0.054 < AOD_{500} < 0.487$
  - $0.32 < \alpha < 1.62$
  - $0.85 < SSA_{550} < 0.97$
  - $0.98 < PW < 3.48$ cm
- Common ETS, 1366.1 W/m^2 (except RRTM)

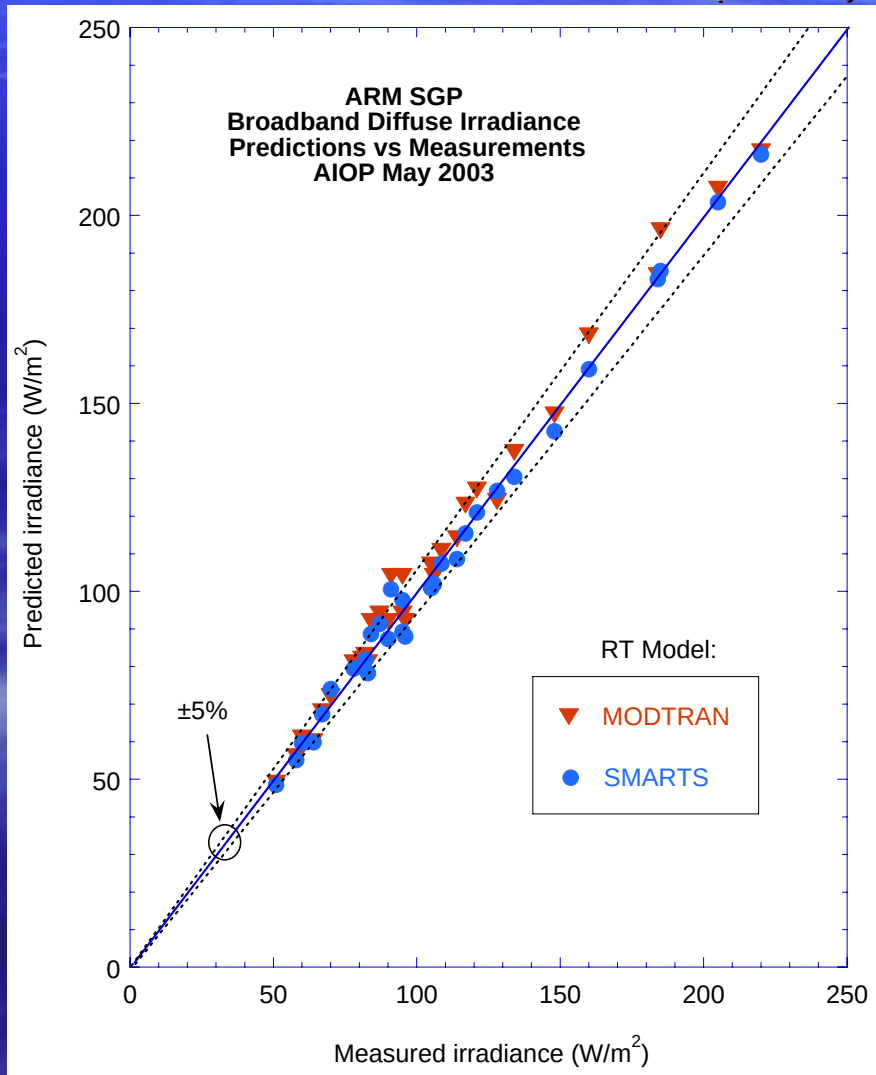
AIOP '03 Radiative Closure Experiment

Main Finding: *Closure achieved most of the time*

≈97% of cases for direct irradiance (< ±3%)



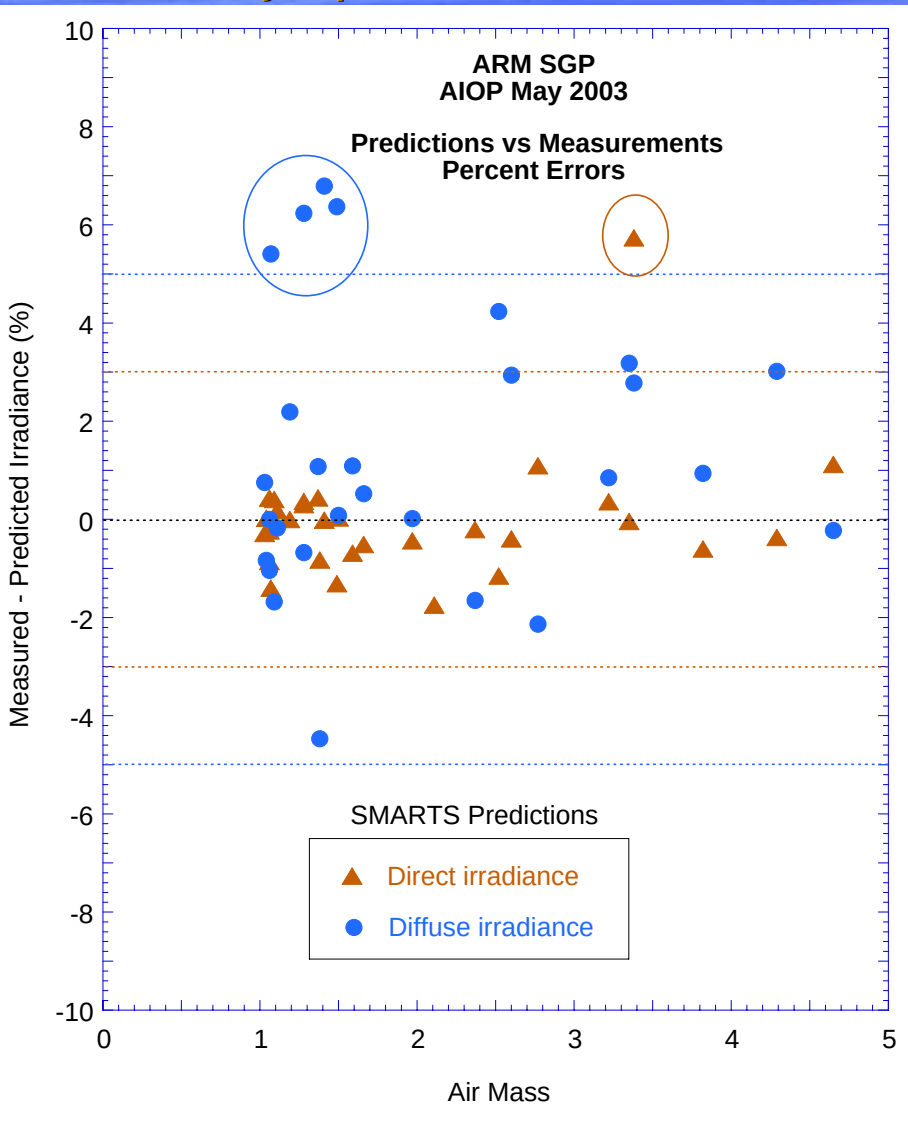
≈87% of cases for diffuse irradiance (< ±5%)



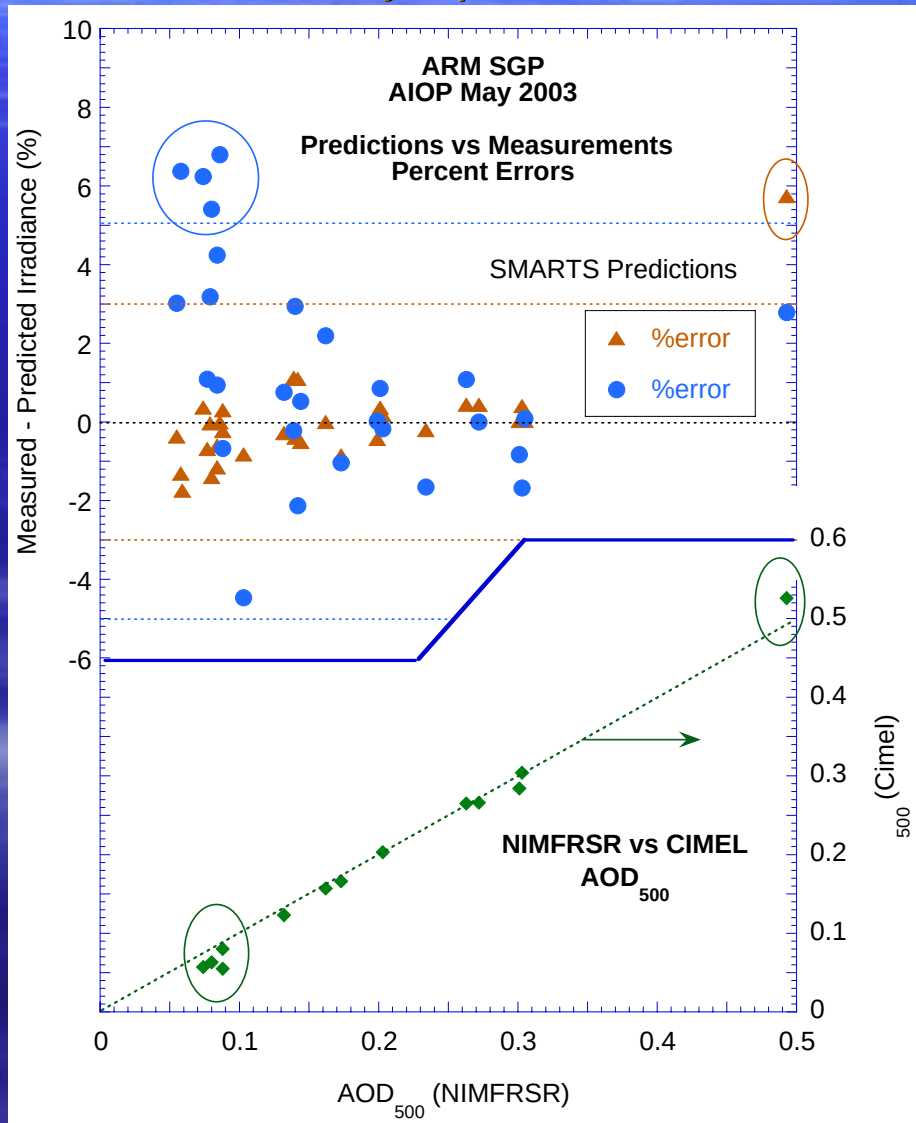
AIOP '03 Radiative Closure Experiment

Distribution of "Errors"

Do they depend on Air Mass?



Do they depend on AOD?



AIOP '03 Radiative Closure Experiment

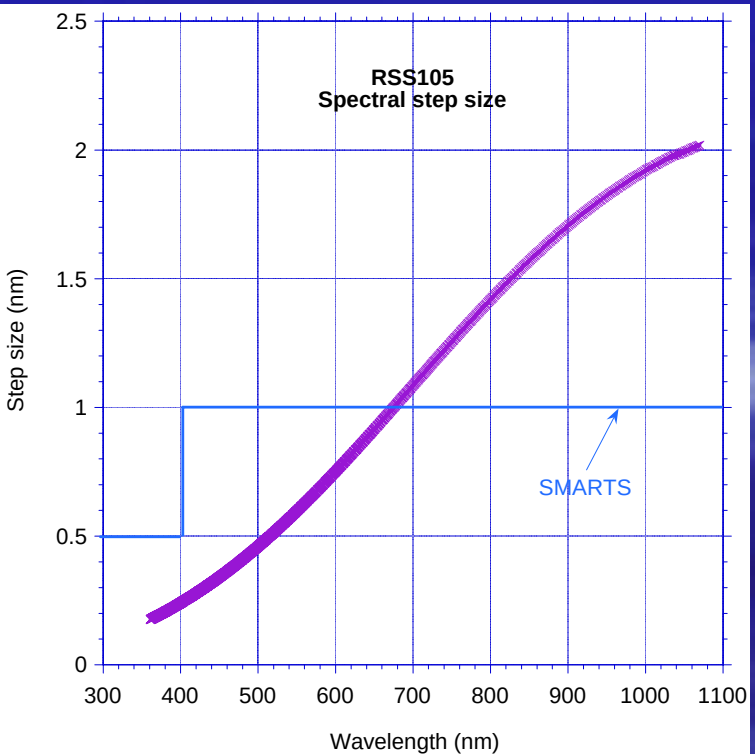
Summary of Findings

- Apparent prediction error does not increase with air mass
  (largest errors on diffuse occur at low air mass)
- Apparent prediction error *decreases* with AOD
- Largest errors (direct and diffuse) occur when AOD is most probably off
  (correcting AOD in these exceptional cases would bring closure)
- Significant "unknown absorber" or "anomalous extinction" is unlikely
- Closure is confirmed for direct radiation
- Closure is now achievable on diffuse radiation thanks to improved pyranometry; no need for extravagant SSA or ground albedo!
- Inadvertent "model errors" due to inaccurate ancillary measurements may account for a large part in the modeled/measured differences

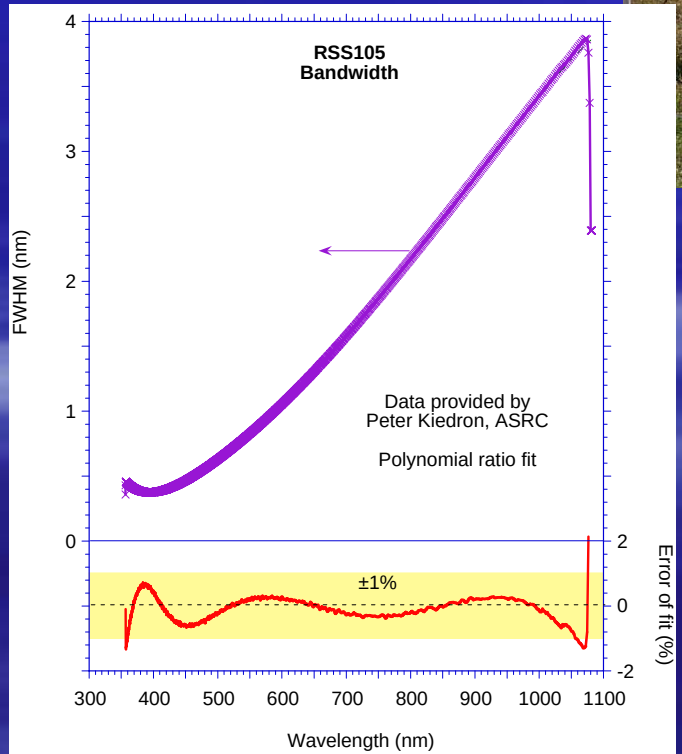
RSS

- Possibly ideal instrument for spectral radiative closure study because direct and diffuse radiation are obtained simultaneously, with a single detector
- Spectral step size and bandwidth are variable (tenfold), hence complicate comparisons with RT models
- Usable range: 360–1070 nm, where most diffuse is concentrated

Variable step size

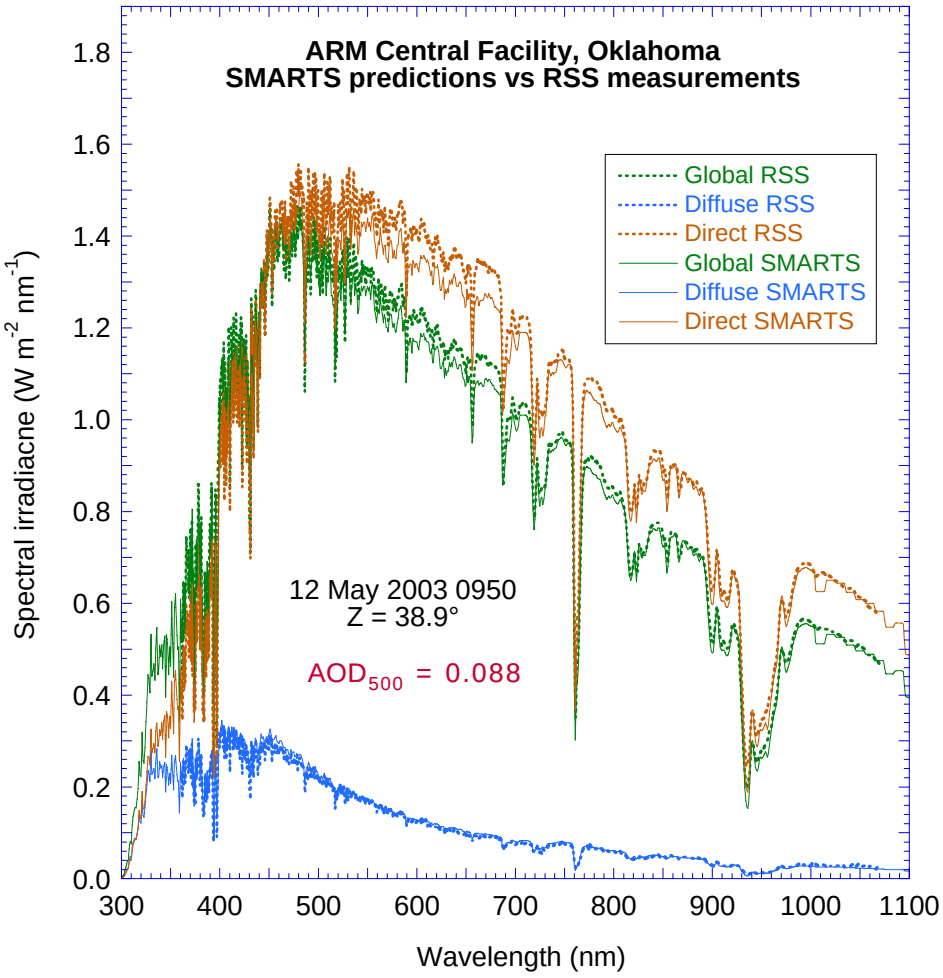


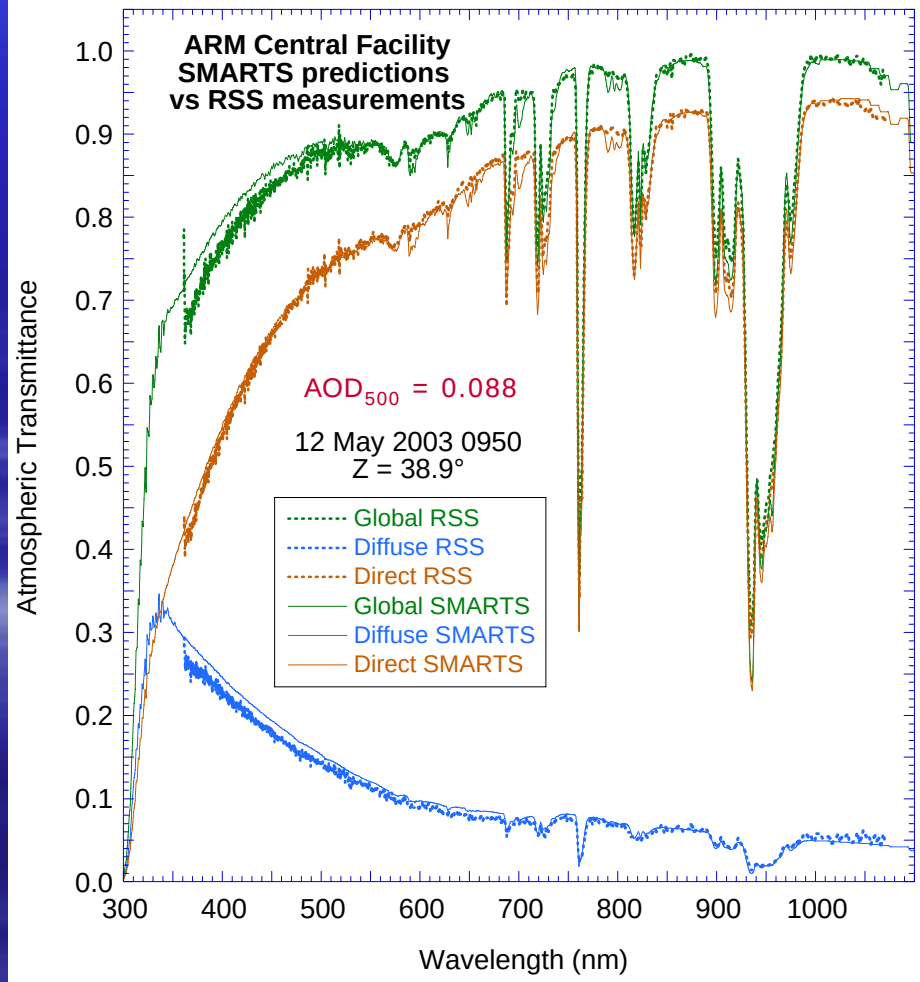
Variable bandwidth



Spectral Comparisons with RSS105

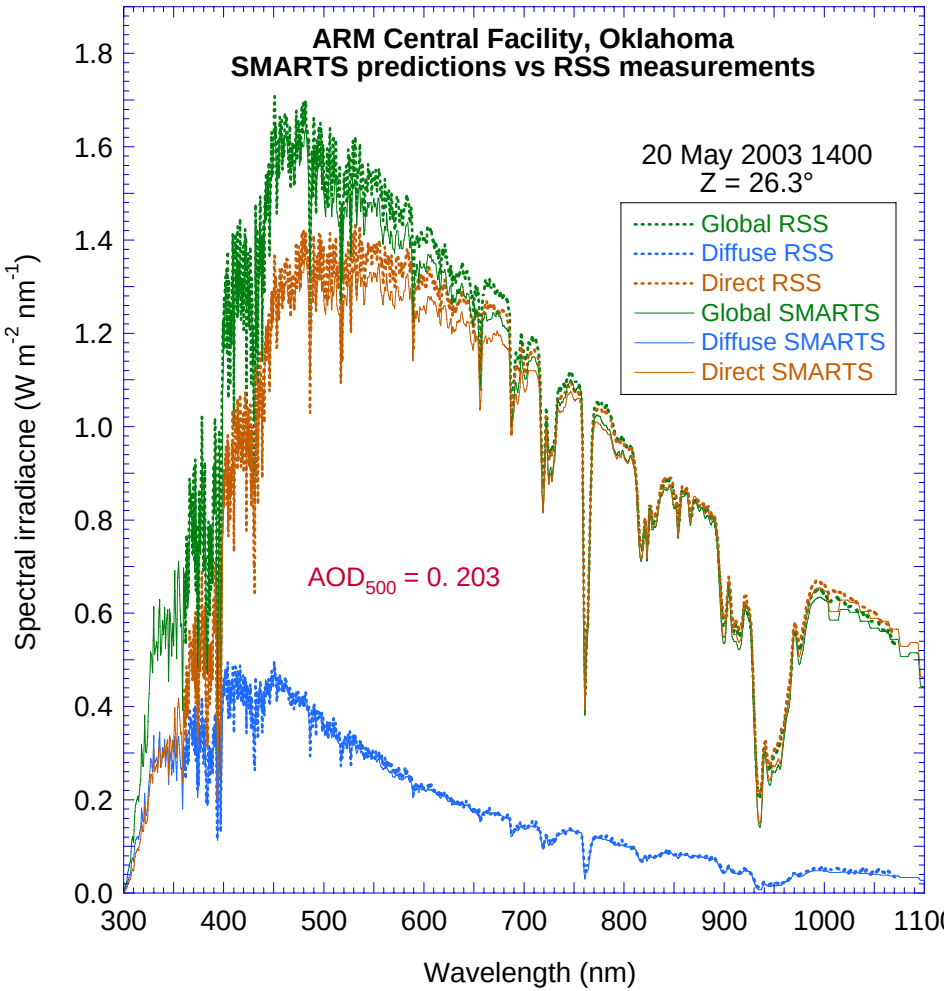
- Simulation of **RSS105** with SMARTS in *irradiance* or *transmittance* mode showed generally excellent agreement
- Measured data included latest calibration & corrections from *Peter Kiedron*
- Spectra coincident with AIOP closure experiment data points were used

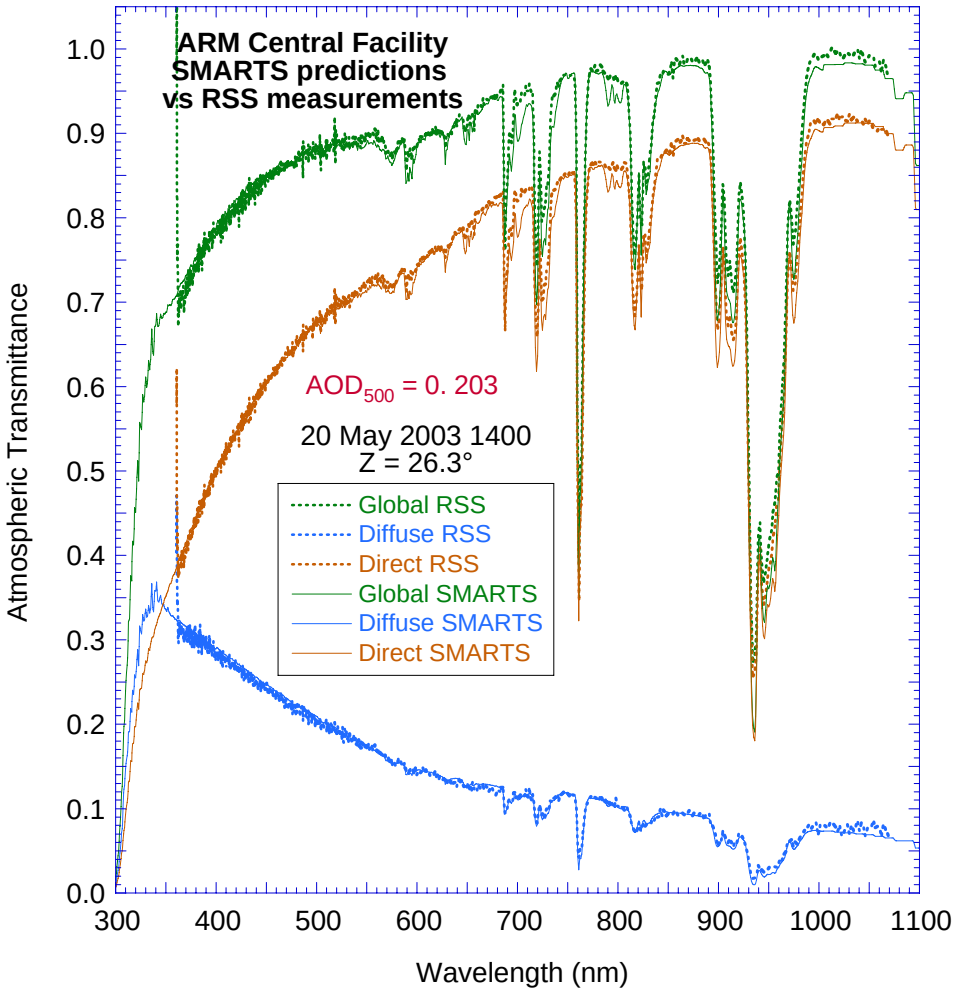




Spectral Comparisons with RSS105

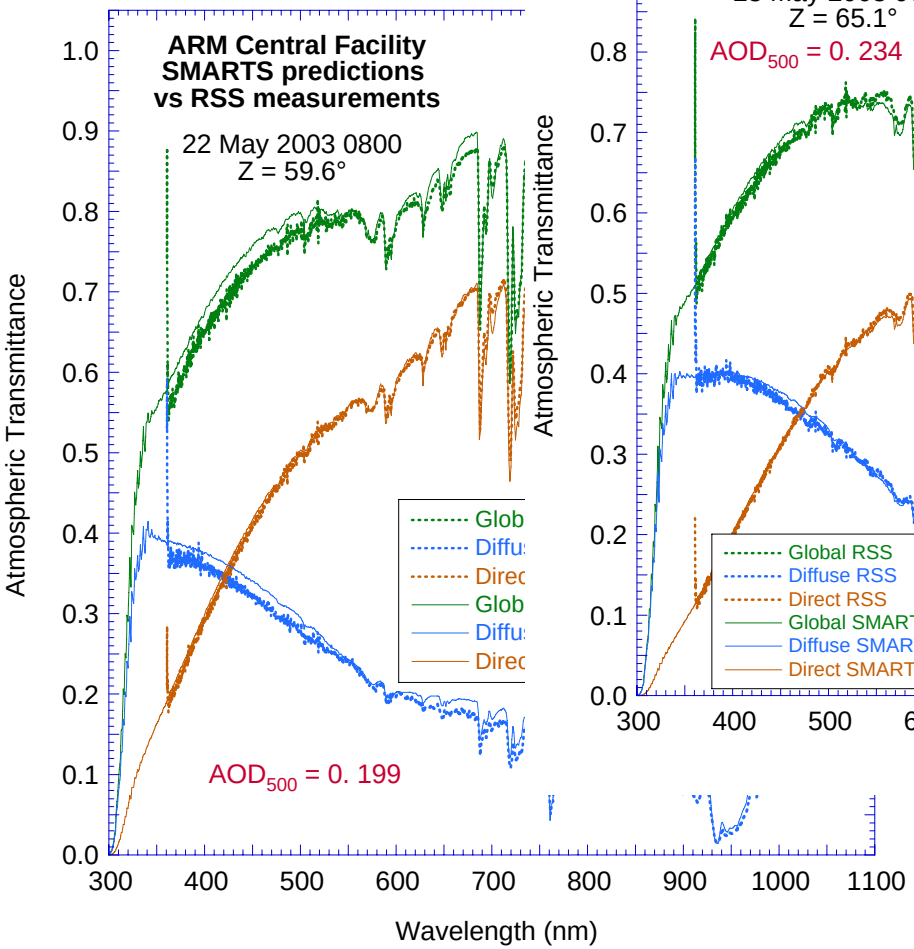
→ Irradiance or transmittance mode?

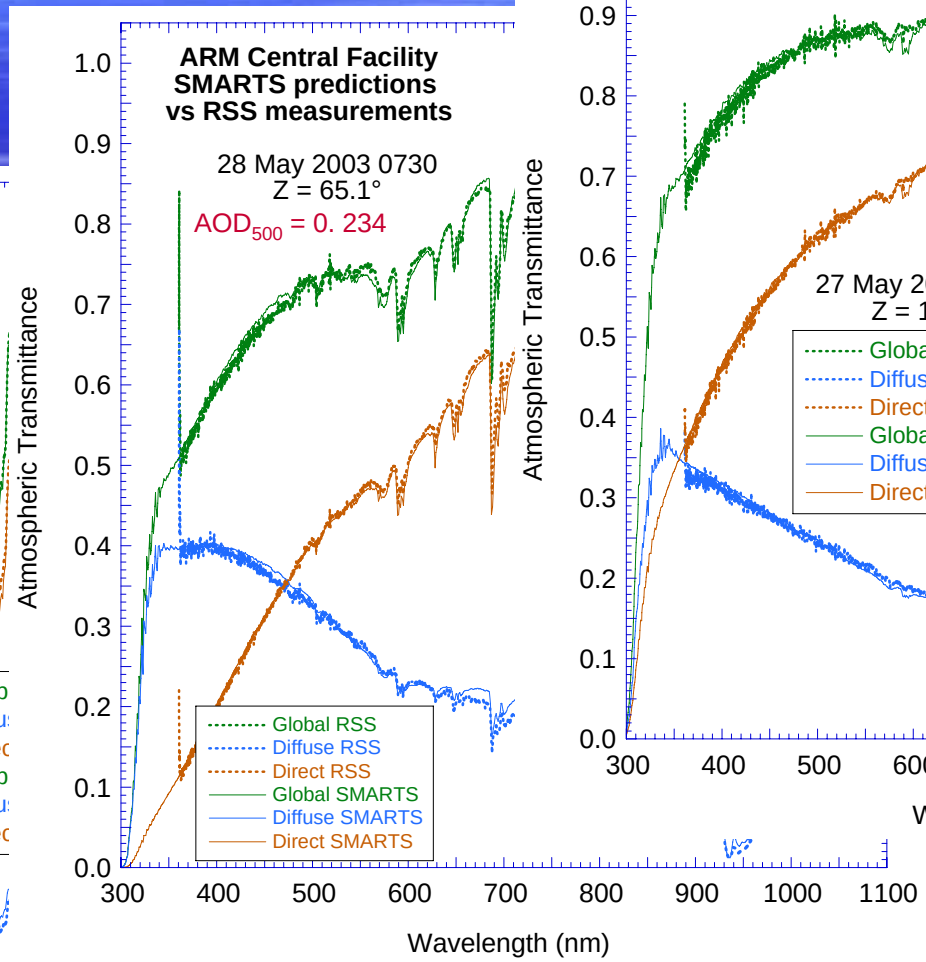


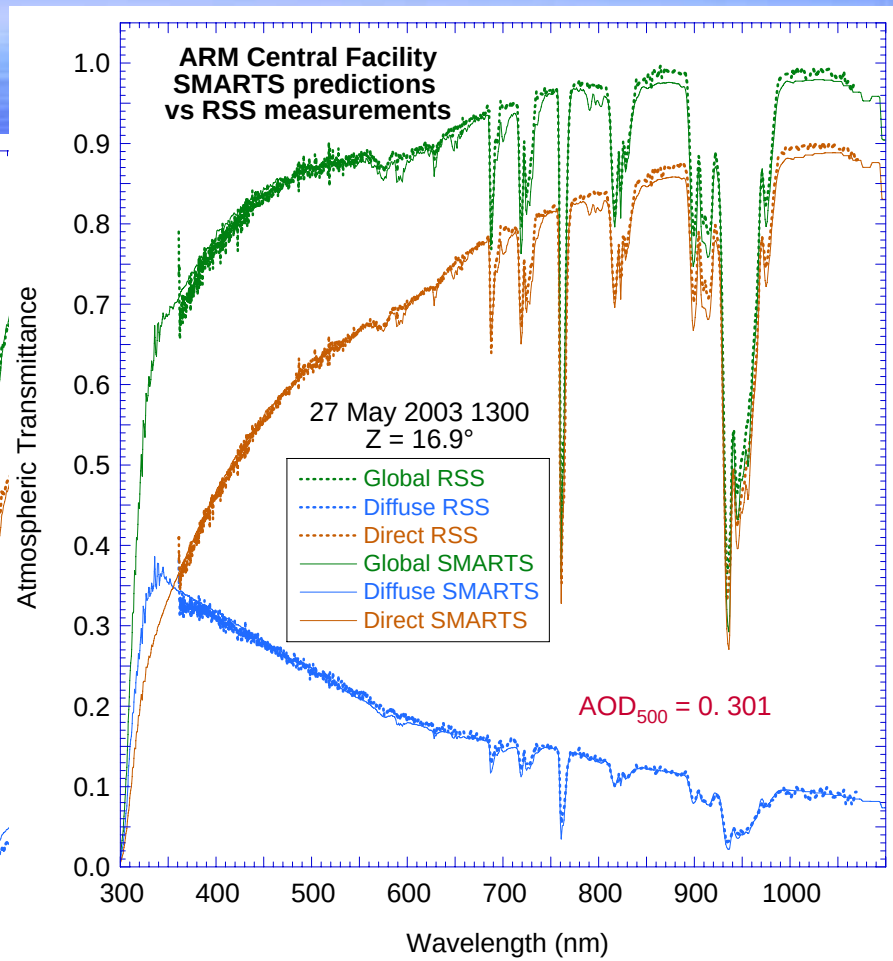


Spectral Comparisons with RSS105

Transmittance spectra







Spectral Comparisons with RSS105

Summary of Findings

- Most generally, better agreement in transmittance mode than in irradiance mode
- Explained by better calibration/corrections of RSS in transmittance mode (according to *Peter Kiedron*)
- The uncertainty in ETS used by RT model plays a role in irradiance mode, but cannot account for all differences (they are not systematically in the same wavebands or for all irradiance components)
- Spectral closure is confirmed for direct radiation
- Spectral closure is not always achieved on diffuse and global radiation, probably due to uncertainties in AOD, SSA, ground albedo, or RSS measurement
- Frequent unexplained differences in some wavebands (740–800, 850–900, and 1000–1050 nm) where measured transmittance is often *larger* than predicted
- Significant “unknown absorber” is highly unlikely within 360–1070 nm, where most diffuse is concentrated

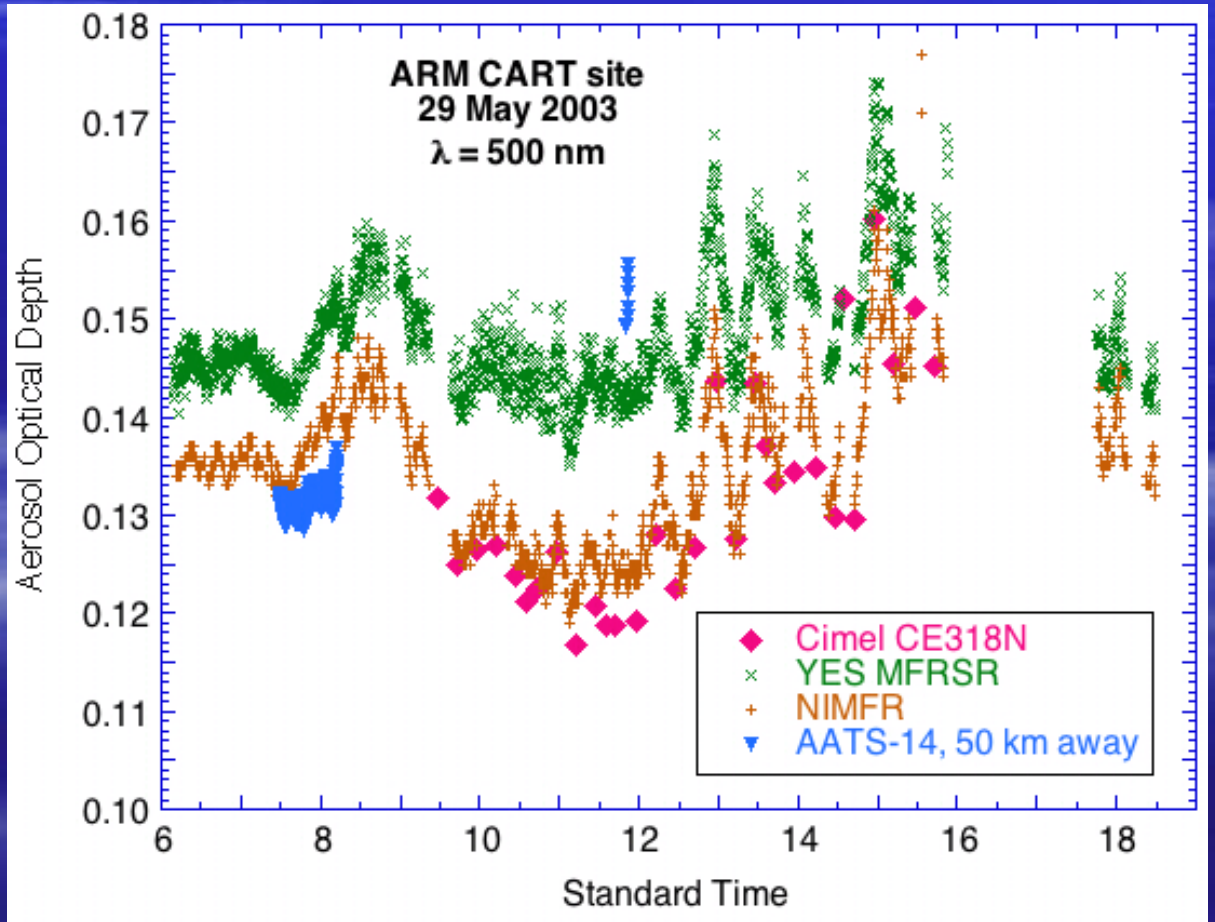
Spectral Comparisons with RSS105

Suggestions for Future Work

- Compare the same transmittance spectra with other RT models
- Identify small bands where extinction is under- or over-estimated by RT models
- Investigate broader effects of uncertainties in AOD, SSA and ground albedo
- Investigate uncertainties in O_3 and NO_2 absorption due to lack of on-site data
- Investigate uncertainties in Langley-plot calibration for critical wavebands

AOD Measurements

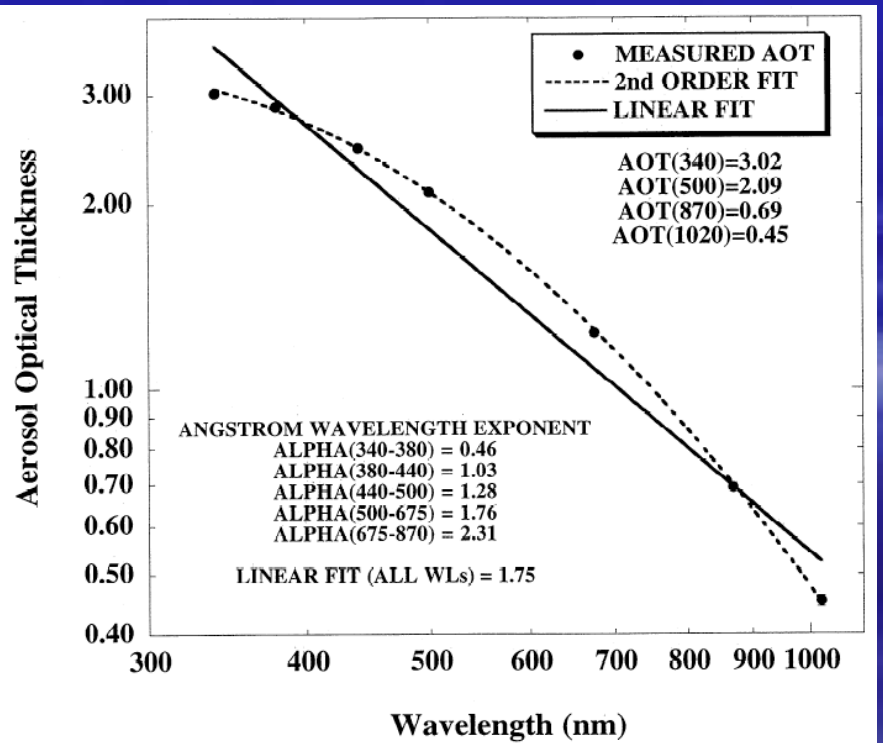
- Having multiple determinations of AOD is a great thing…
- But *which one* is the most accurate?
- Regular intercomparisons of sunphotometers would be necessary, with simultaneous predicted-measured spectral irradiance comparisons

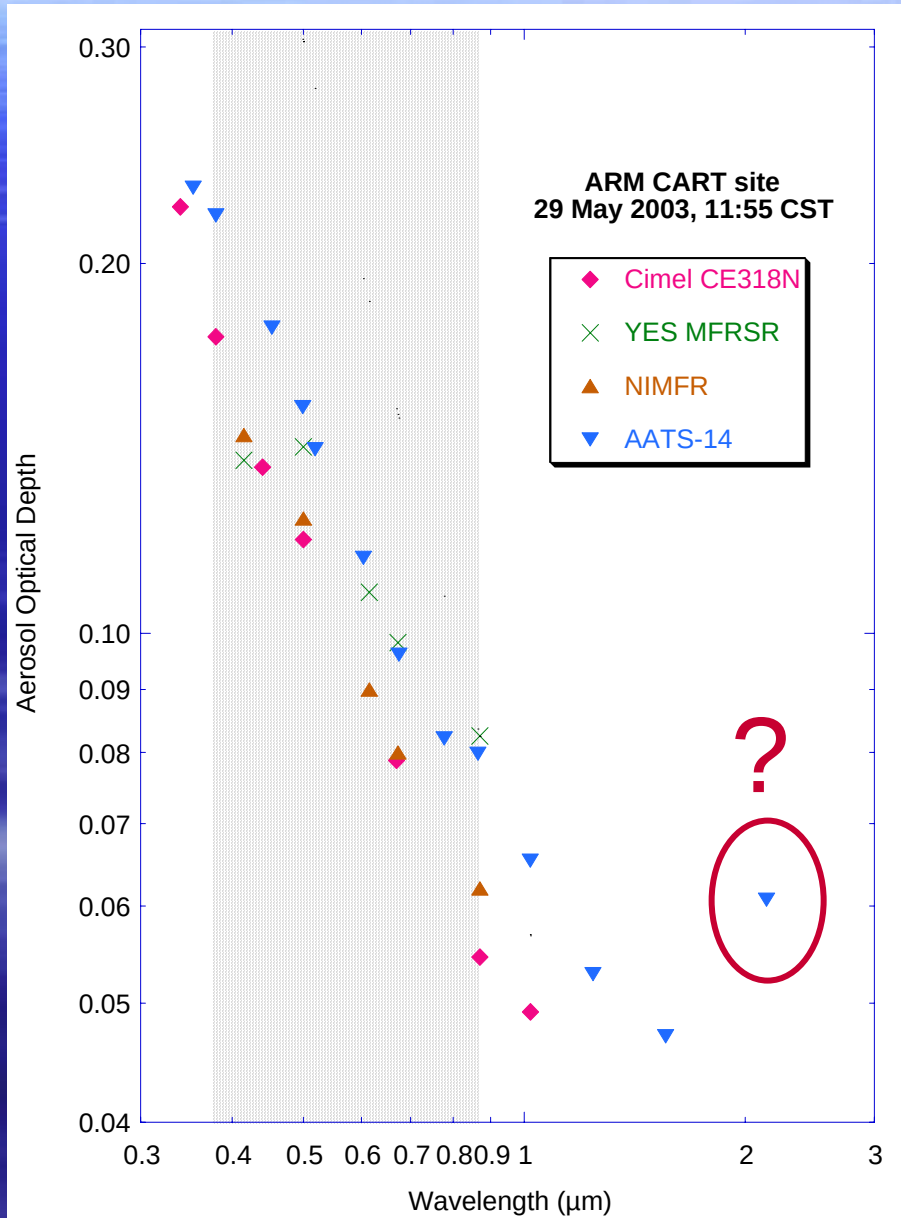


AOD Measurements

Very few instruments can measure good AOD below 380 nm, even fewer are capable above 1050 nm. How should we extrapolate to UV or NIR?

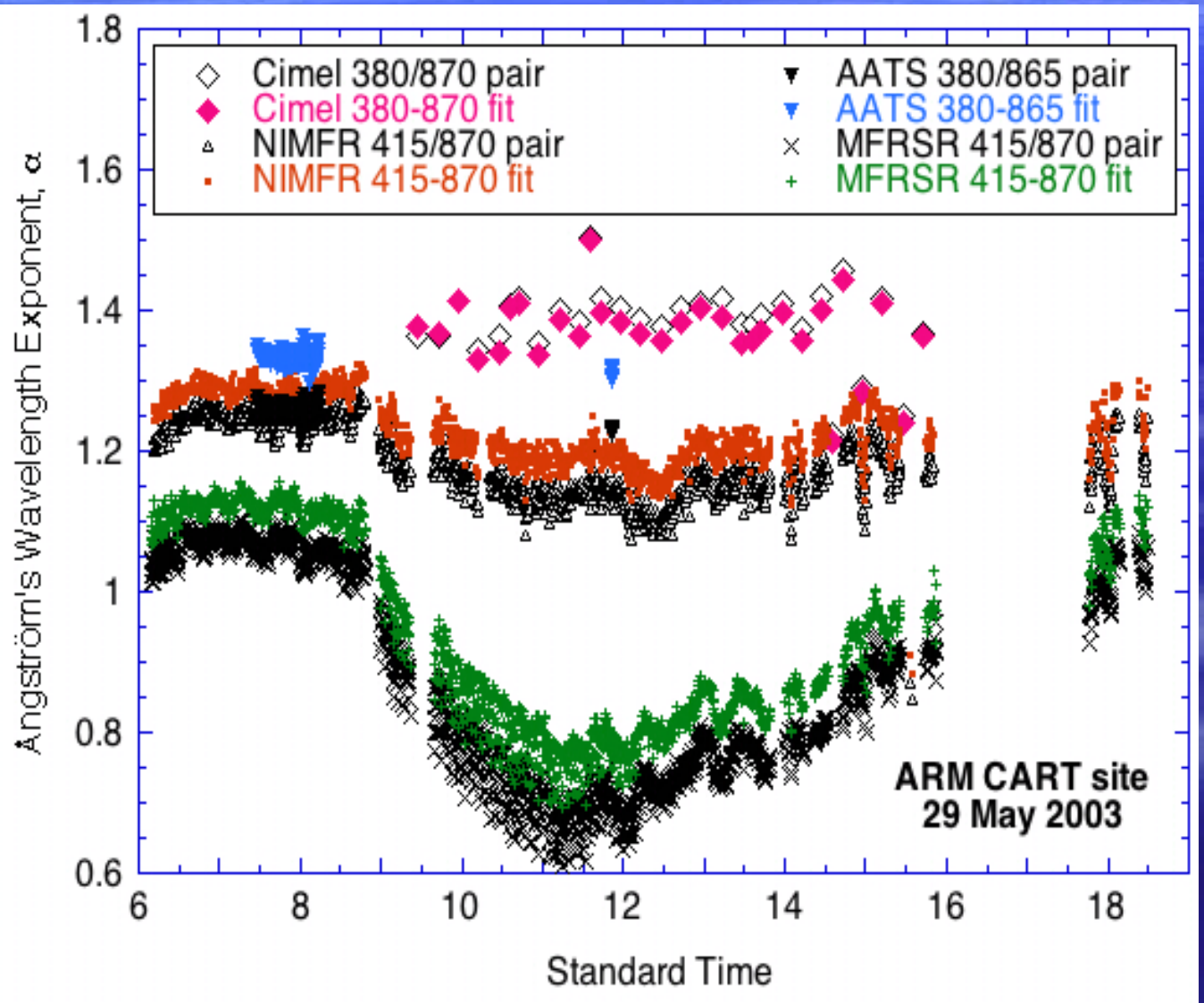
→ Frequent curvature in AOD = f(λ)
[e.g., Eck et al., JGR 1999]





Spectral Variation of AOD

Accurate determination of Ångström's exponent α is difficult!

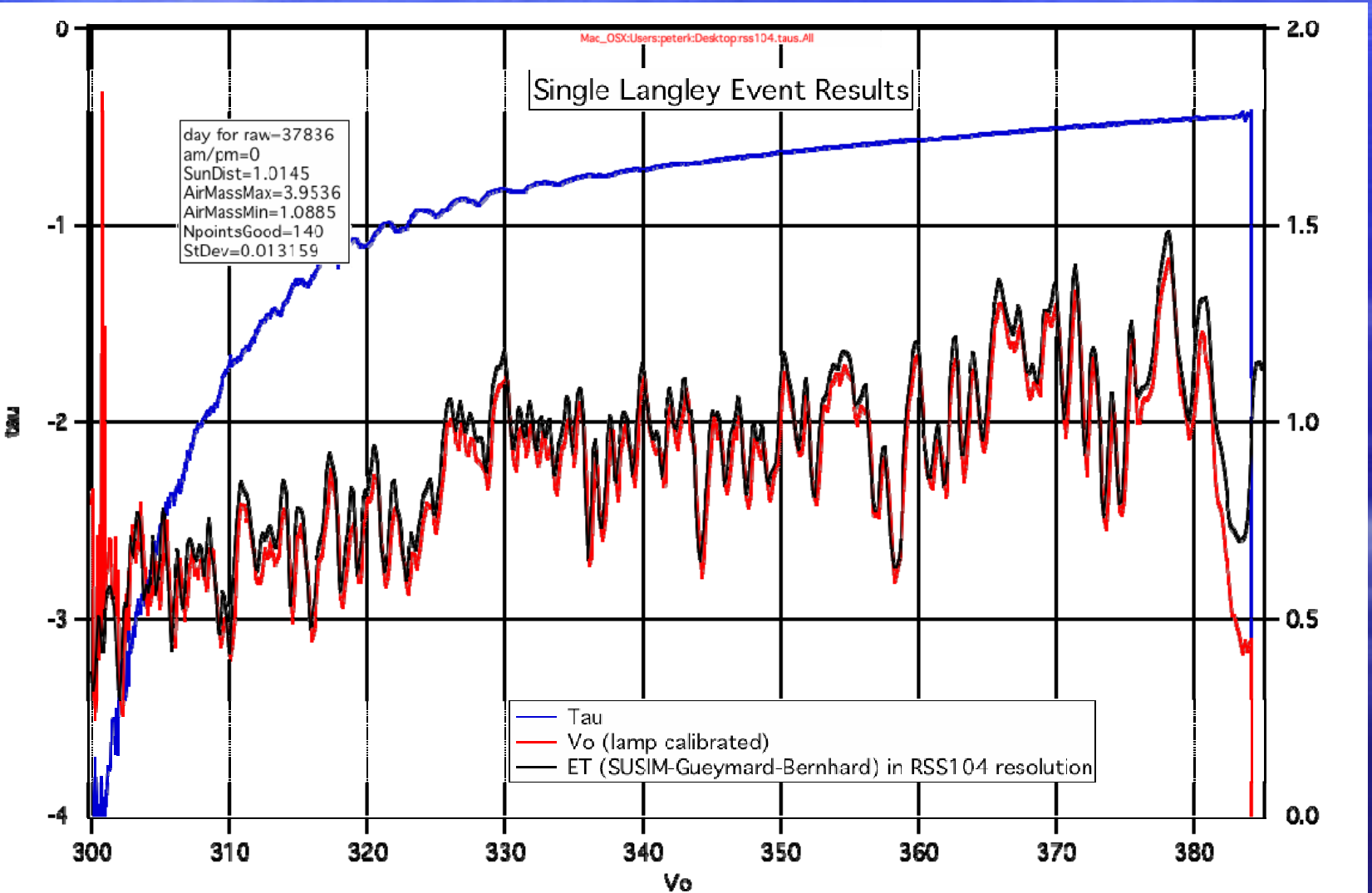


Possible options:

- Use a pair of stable channels, e.g. 440 and 870 nm; but method prone to large errors (Cachorro, 1987) and misses any curvature feature
- Use linear fit in log-log coordinates to fit Ångström's Law over 2 bands, e.g., 380–500 and 500–1020 nm
- Use polynomial fit as in Eck et al.
- ***Which one is best?***

Uncertainties in ET Spectrum

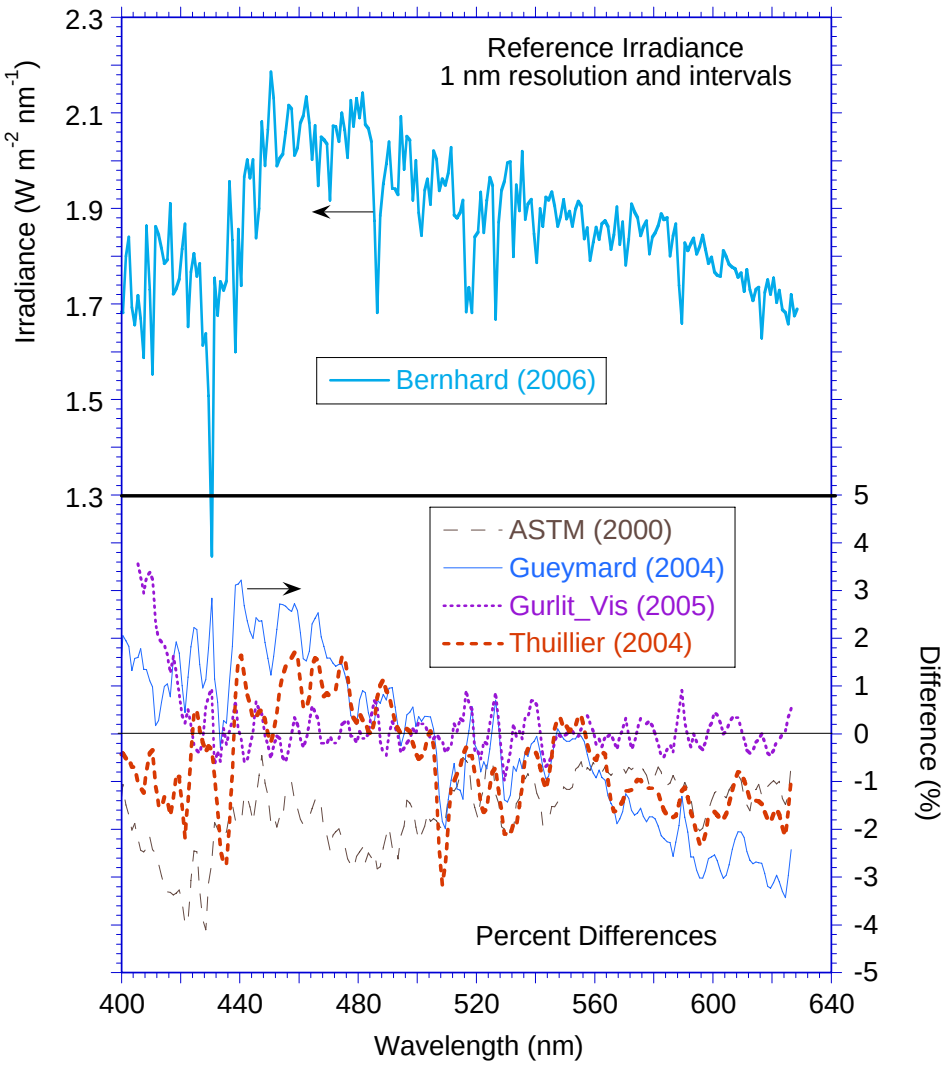
- Work underway with *Peter Kiedron* and *Germar Bernhard*
  1. Langley plots using lamp-calibrated RSS

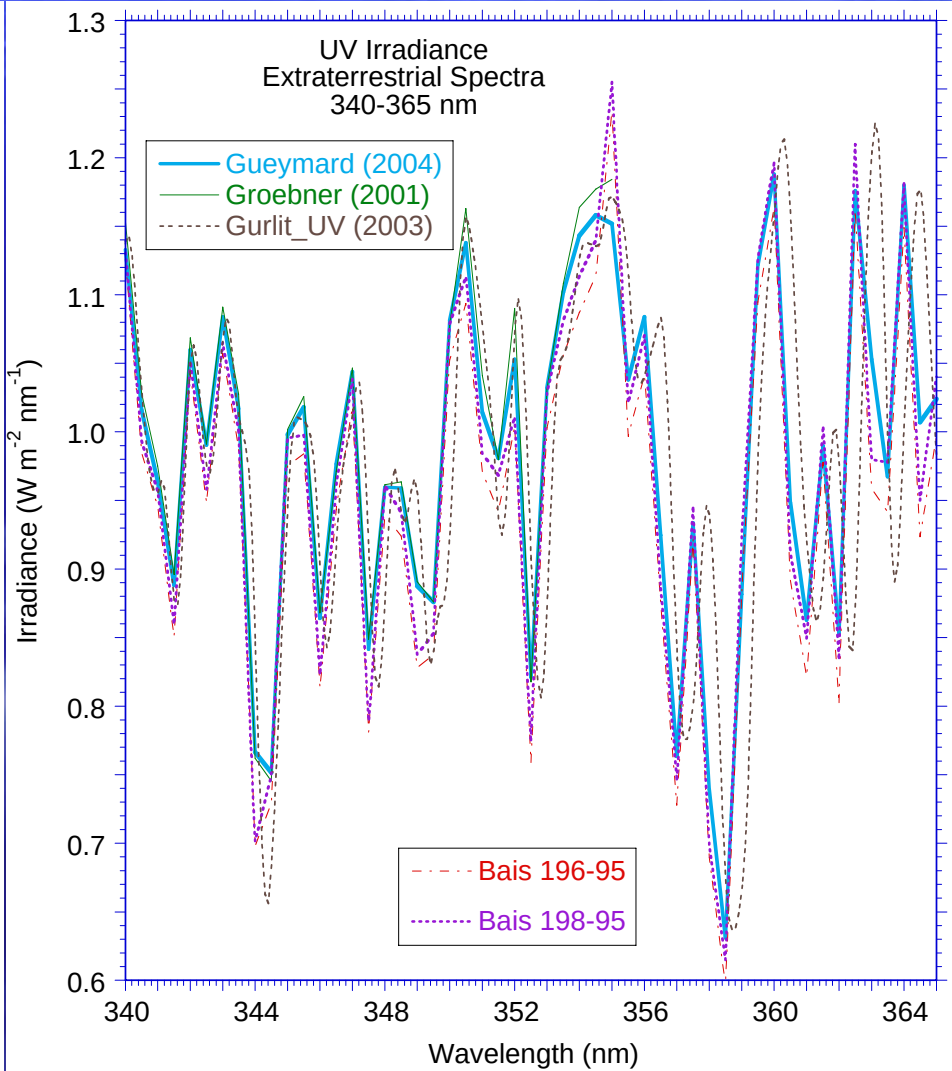


Uncertainties in ET Spectrum

2. Intercomparison of various reference spectra

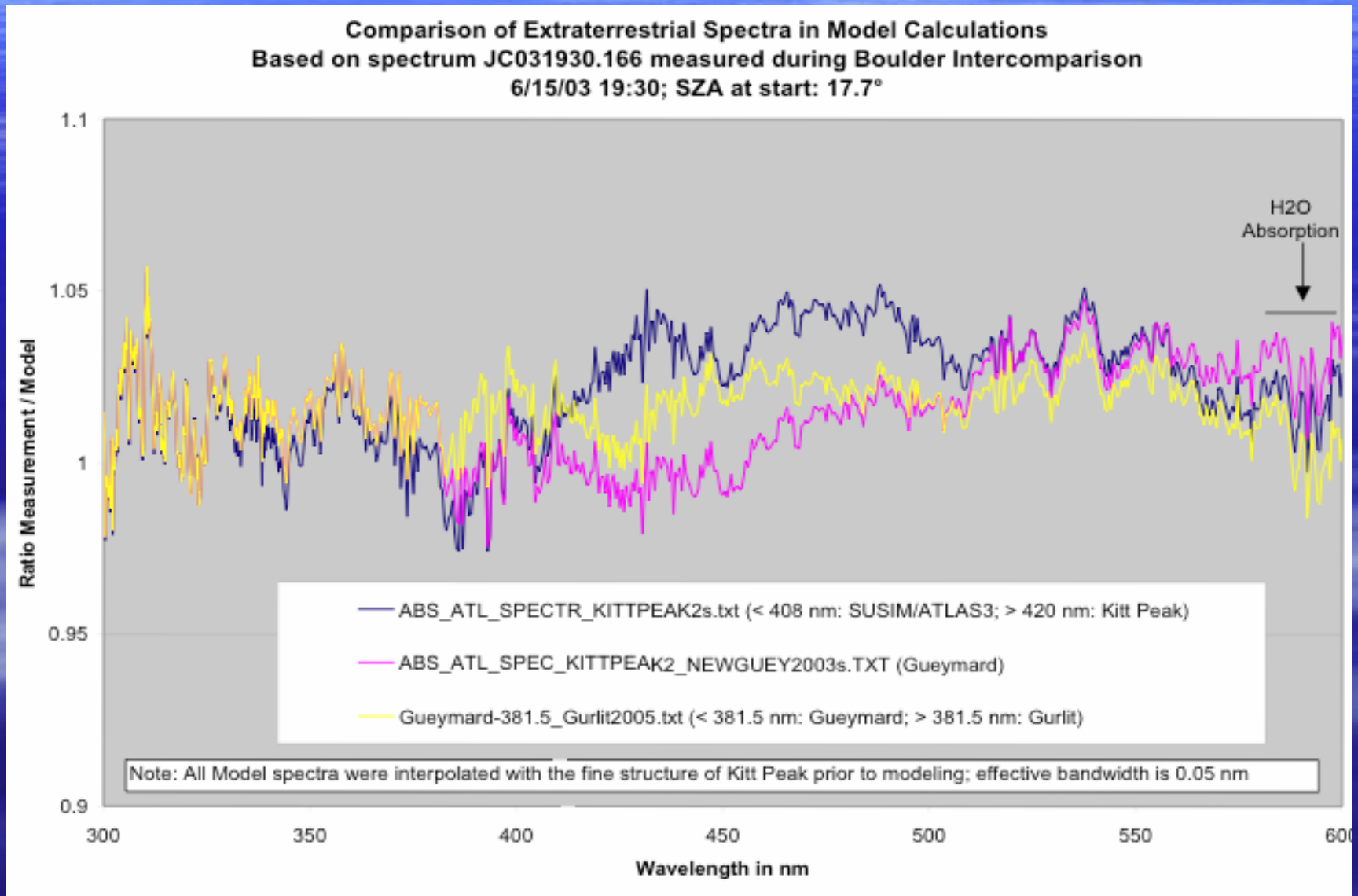
3. Comparison of modeled *vs* measured UV and VIS irradiance spectra





Uncertainties in ET Spectrum

High-res Kitt Peak spectrum can be improved by scaling it with low-res Gueymard spectrum



Summary

More radiative closure experiments are needed, using various RT models, with more attention to:

- AOD accuracy
- Spectral SSA
- Spectral variation of AOD, specially in UV and NIR
- Vertical aerosol profile
- Lambertian *vs* non-Lambertian ground reflectance
- Simultaneous closure in *both* broadband and spectral sense
- Extraterrestrial spectrum
- Additional co-located measurements of O_3, NO_2, and far-field spectral ground albedo (Trishchenko's method) up to 10–50 km
  Albedo measurements from tower are not enough!
- Judicious RSS and UV-RSS deployment

Special Thanks!

Peter Kiedron, NOAA