Progress Towards an Absolute Calibration of Lunar Irradiance at Reflected Solar Wavelengths

Claire Cramer, Steve Brown, Keith Lykke, John Woodward
(NIST)

Tom Stone
(USGS)

Motivation for using the Moon

A well-calibrated moon is a uniquely valuable calibration light source for earth-observing instruments at visible to SWIR wavelengths

- Extremely stable reflecting surface
- Smooth reflectance spectrum, with only broad, shallow features
- Accessible to all spacecraft, regardless of orbit
- Can back-calibrate old data – the calibration will only get better with time
- Utilizes instrument's normal Earth-viewing optical path
- Appropriate brightness for terrestrial environment sensors (vs. Sun, stars)
- Complementary to vicarious calibration
- Already used for 0.1 % trending
- Unlikely to break or disappear if not funded

- A good *relative* calibration allows trending, a good *absolute* calibration can bridge gaps in the satellite data record

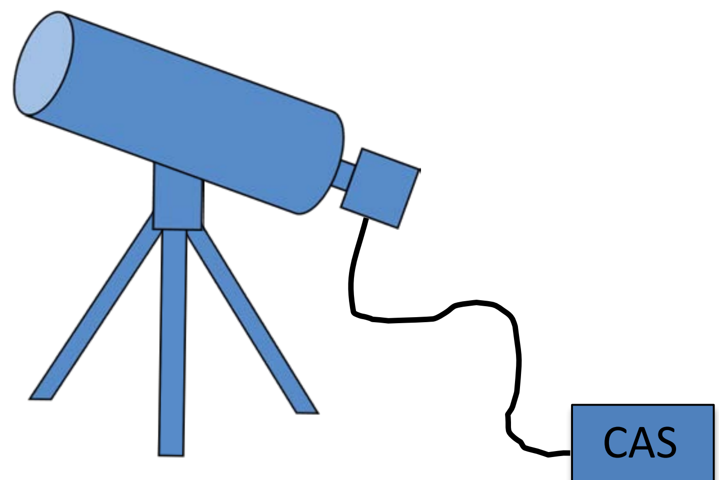
Short-Term Goal

SI-Traceable absolute calibration of lunar spectral irradiance at visible wavelengths from the ground with < 2 % accuracy.

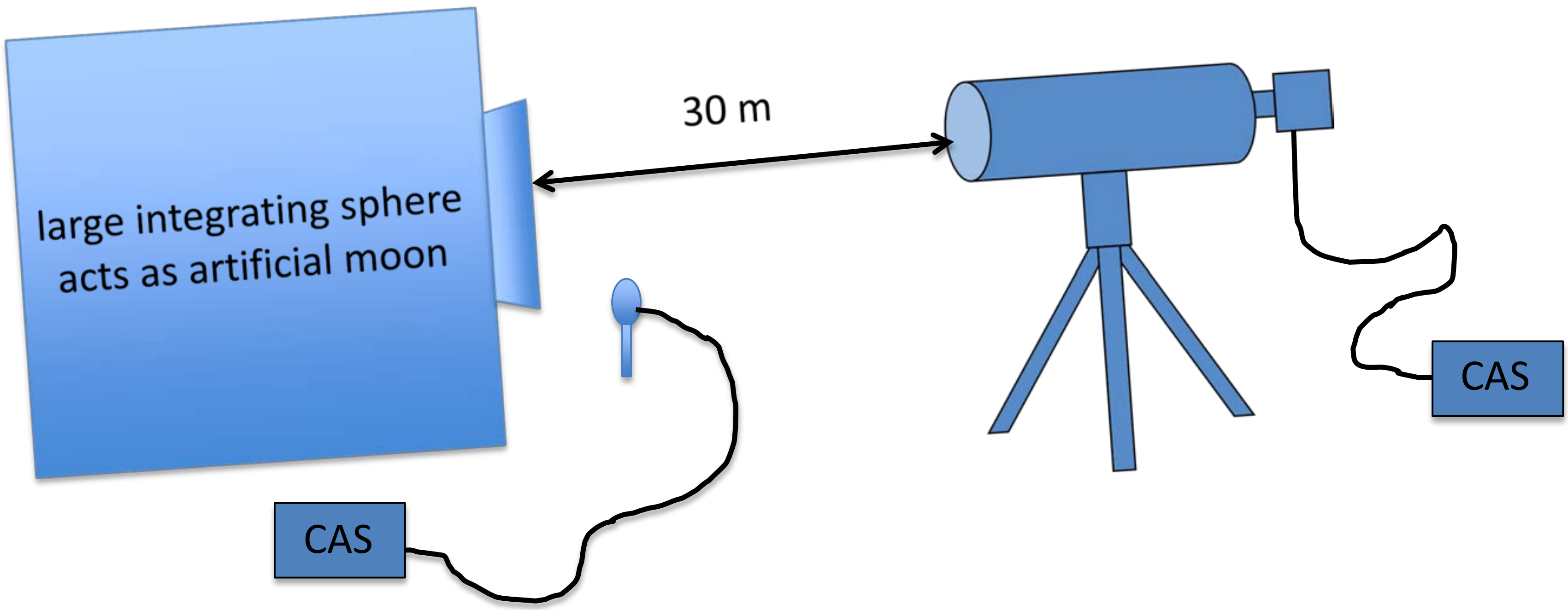
Lunar Telescope

- Takahashi FSQ-106 Astrograph Telescope (106 mm aperture)
- 50.8 mm integrating sphere, 12 mm entrance aperture
- CAS spectrometer (Instrument Systems)
- Located at 2379 m on ridge of Mt. Hopkins, AZ

- 4 mm lunar disk image easily fits inside sphere aperture
- integrating sphere scrambles incident light
- light guide ensures stable, uniform illumination of CAS



Calibrating the Telescope



- calibrated CAS spectrometer continuously monitors large sphere via irradiance head
- transfer calibration to lunar-observing CAS by pointing telescope at large sphere

- *calibrate several times each night, calibrations are consistent to 0.2 %*
- *combined uncertainty in telescope calibration is dominated by CAS calibration*

CAS Spectrometer

Instrument Systems Compact Array Spectrometer*

- CCD-based fiber-fed slit spectrograph
- 380 nm to 1040 nm
- 3 nm resolution
- extremely stable

Laboratory calibration:

1. FEL lamp
2. SIRCUS

Stray light correction:

SIRCUS + Zong, *et al.* (2007)

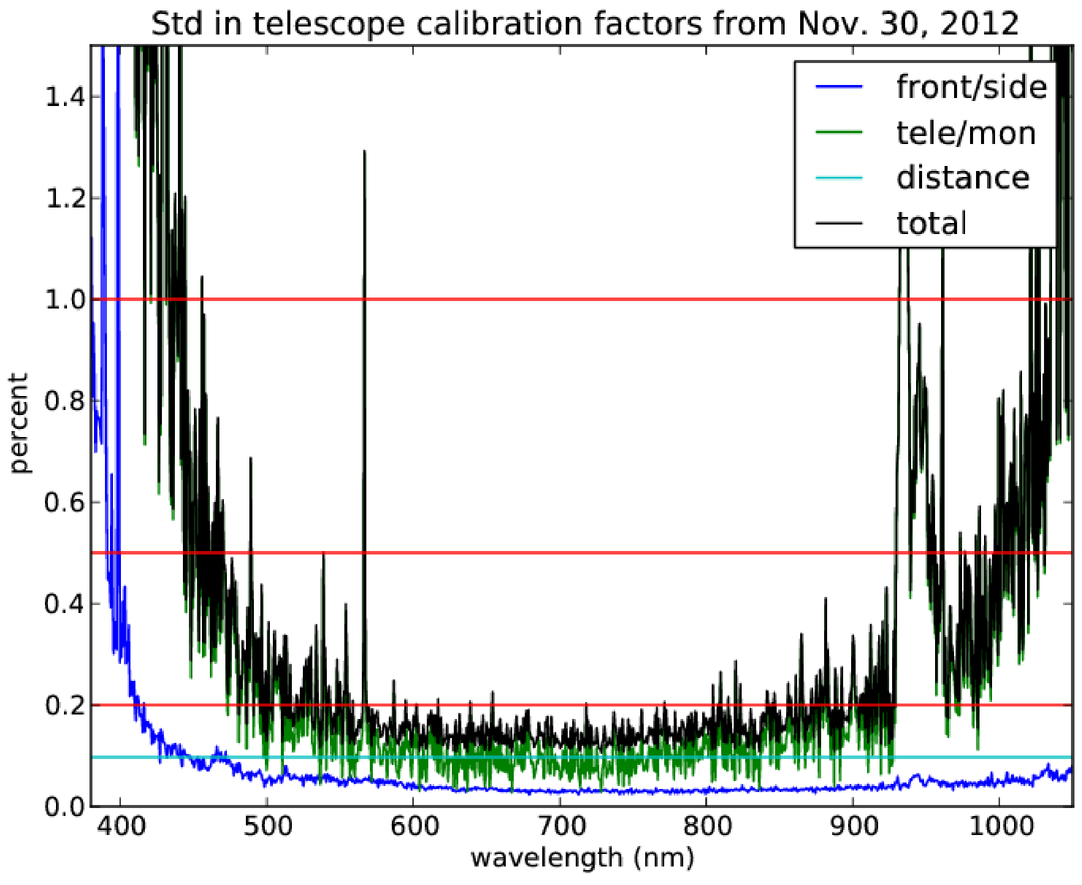
single largest source of uncertainty

how to make it better

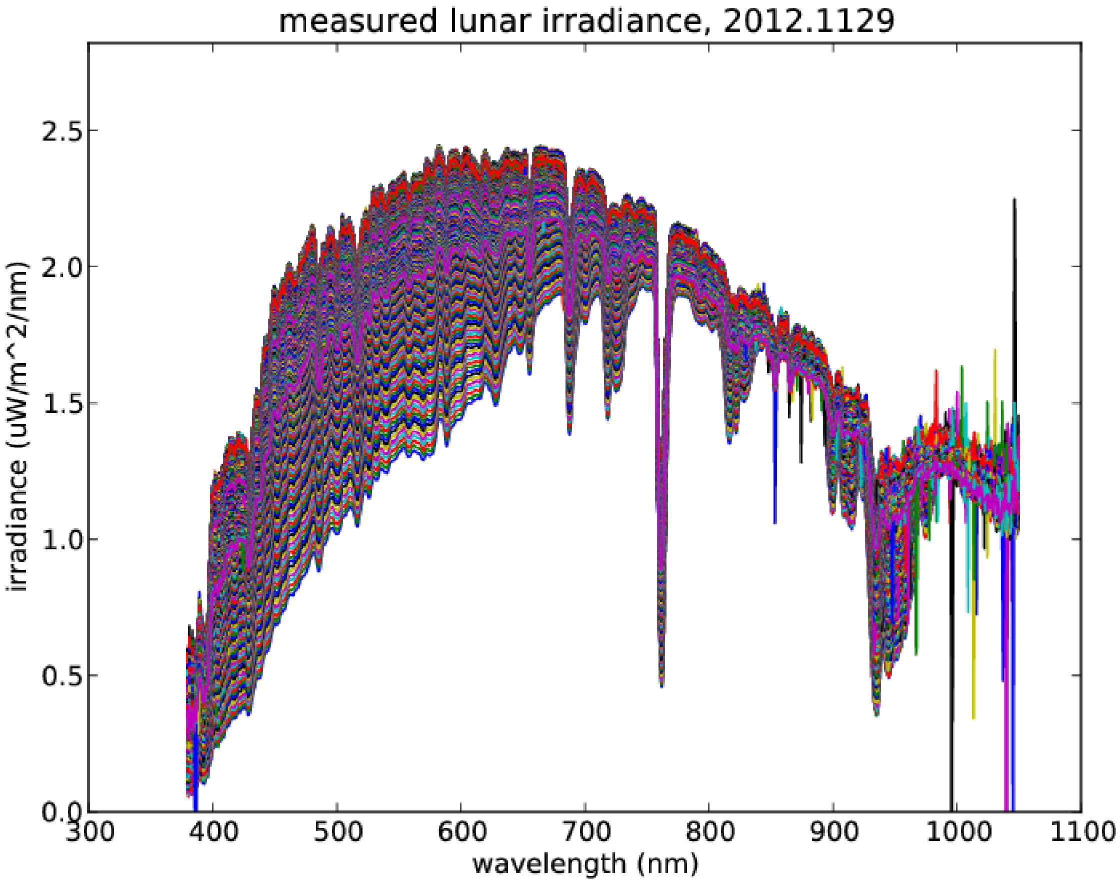
*Any mention of commercial products is for information only; it does not imply recommendation or endorsement by NIST.


THORLABS
Model LTS150

Calibration Uncertainty



Observed Lunar Spectra, Nov 29, 2012



airmass range: 1.02 to 6

593 spectra with
1-minute spacing

Langley Analysis

If the atmosphere is stable in time and composed of isotropic layers:

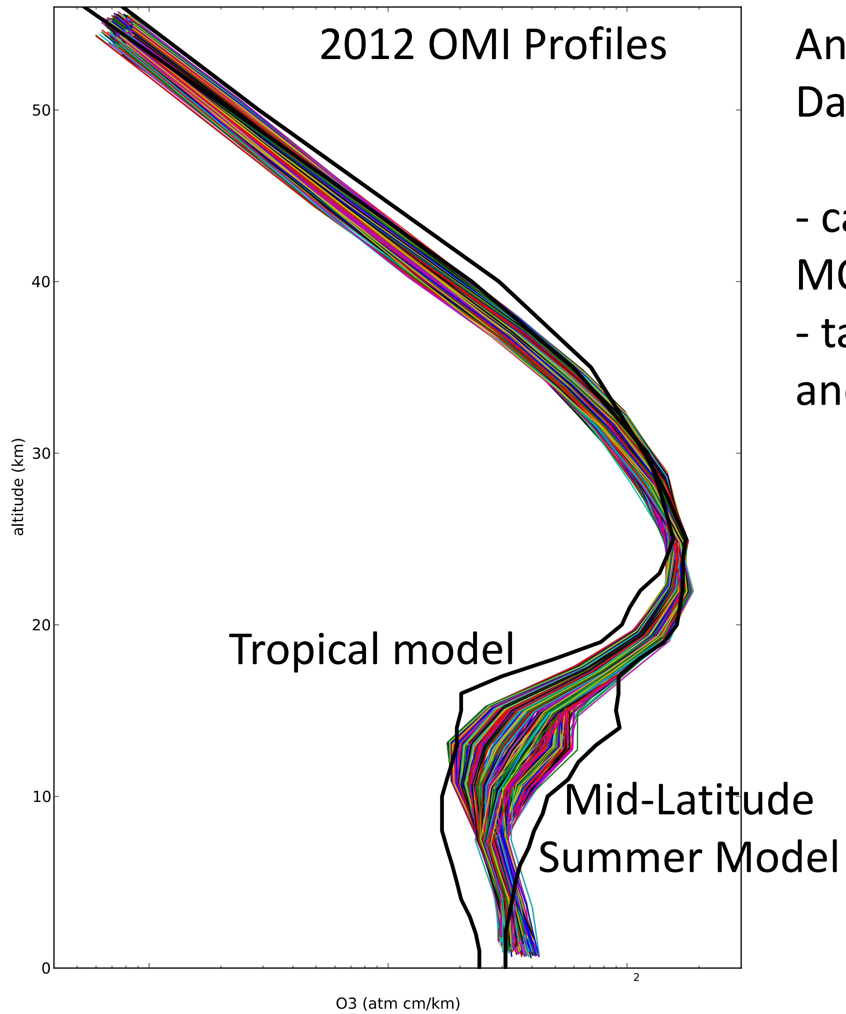
$$I_{meas}(\lambda, t) = I_0(\lambda, t)e^{-\sum m_i \tau_i}$$

- use USGS' ROLO model to account for time-dependence of I_0
- correct for: ozone, stratospheric aerosols
- ignore: molecular absorption lines (water, oxygen)
- fit for: Rayleigh scattering

At each wavelength, fit a line to the log of our measurement vs. airmass.
If assumptions are satisfied, then:

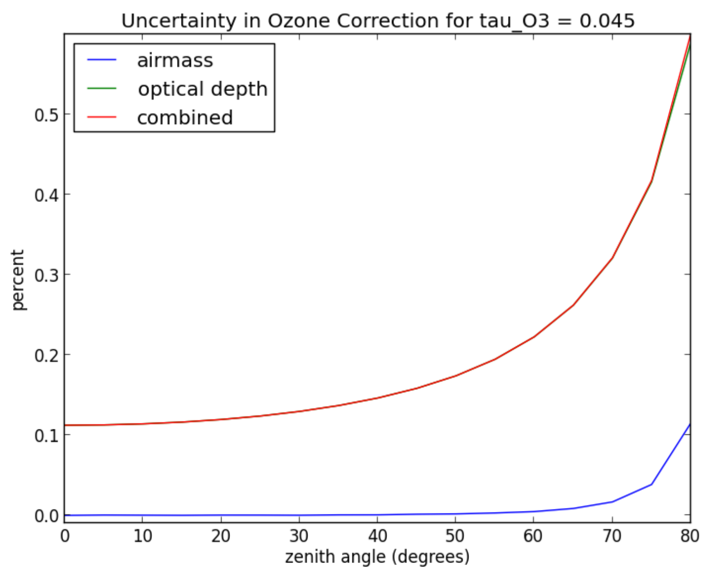
y-intercept gives TOA irradiance
slope gives atmospheric extinction

Ozone Correction

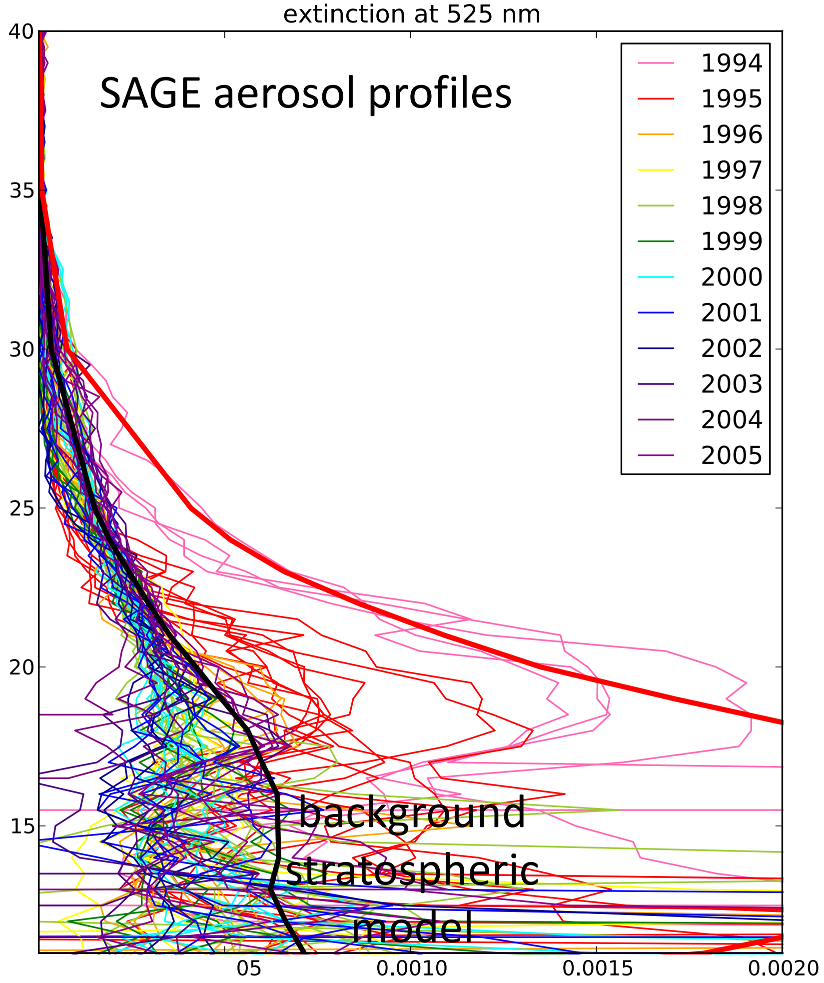


Annual variation in total column: 250-320 DU
Day-to-day variation: 10 DU

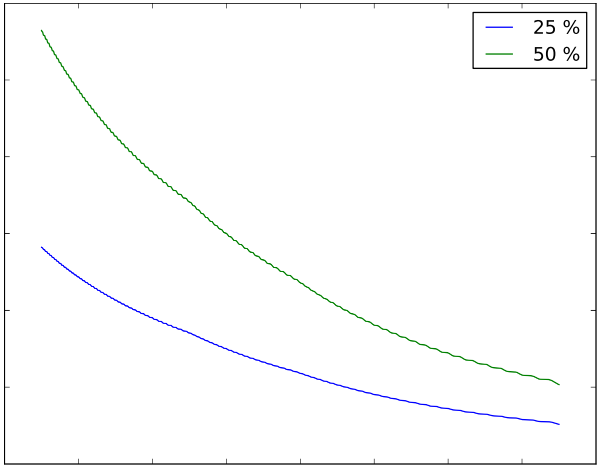
- calculate airmass function from mean of MODTRAN model profiles
- take total column to be mean of day before and day after



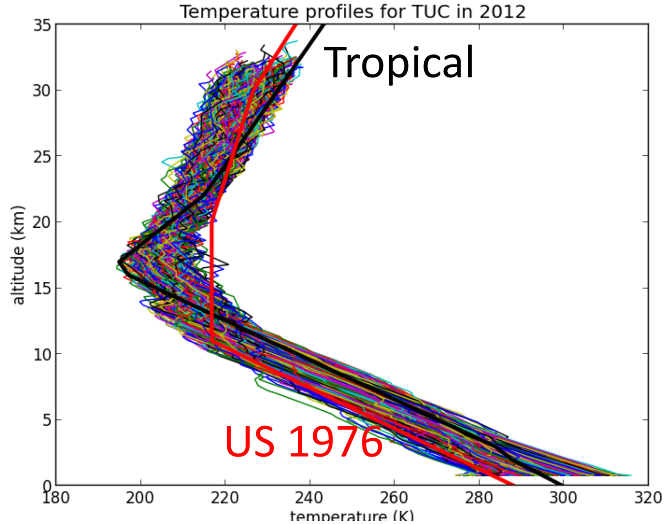
Stratospheric Aerosols



- constantly evolving background of volcanic origin
- no recent data over Southern AZ
- data through 2005 indicate that MODTRAN's model is roughly correct

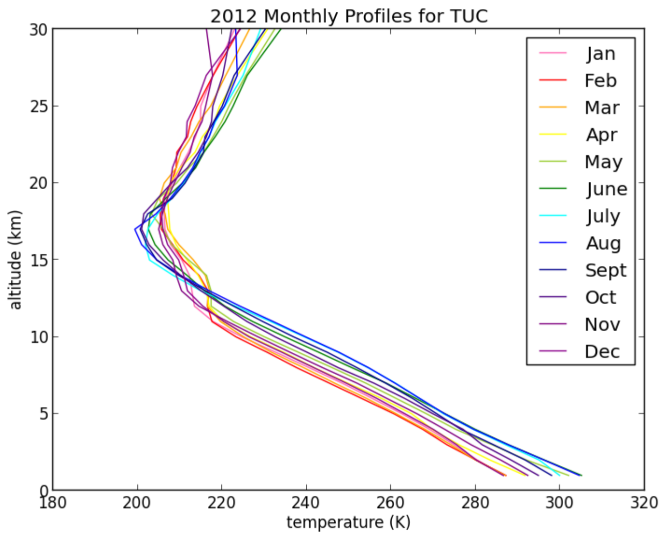


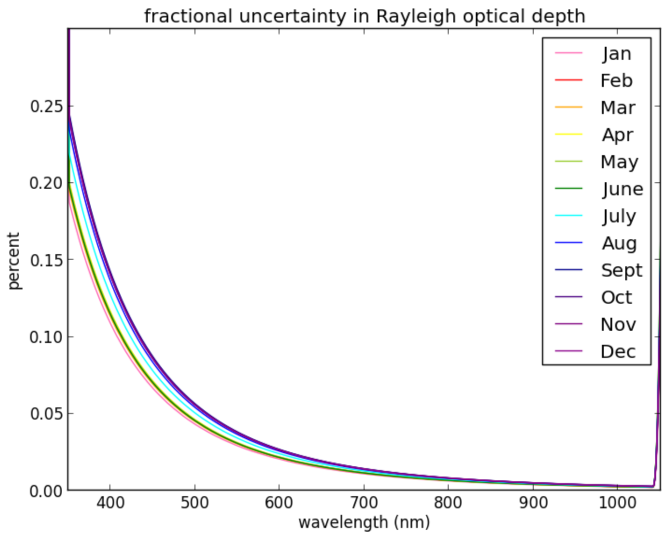
Calculated Rayleigh Scattering



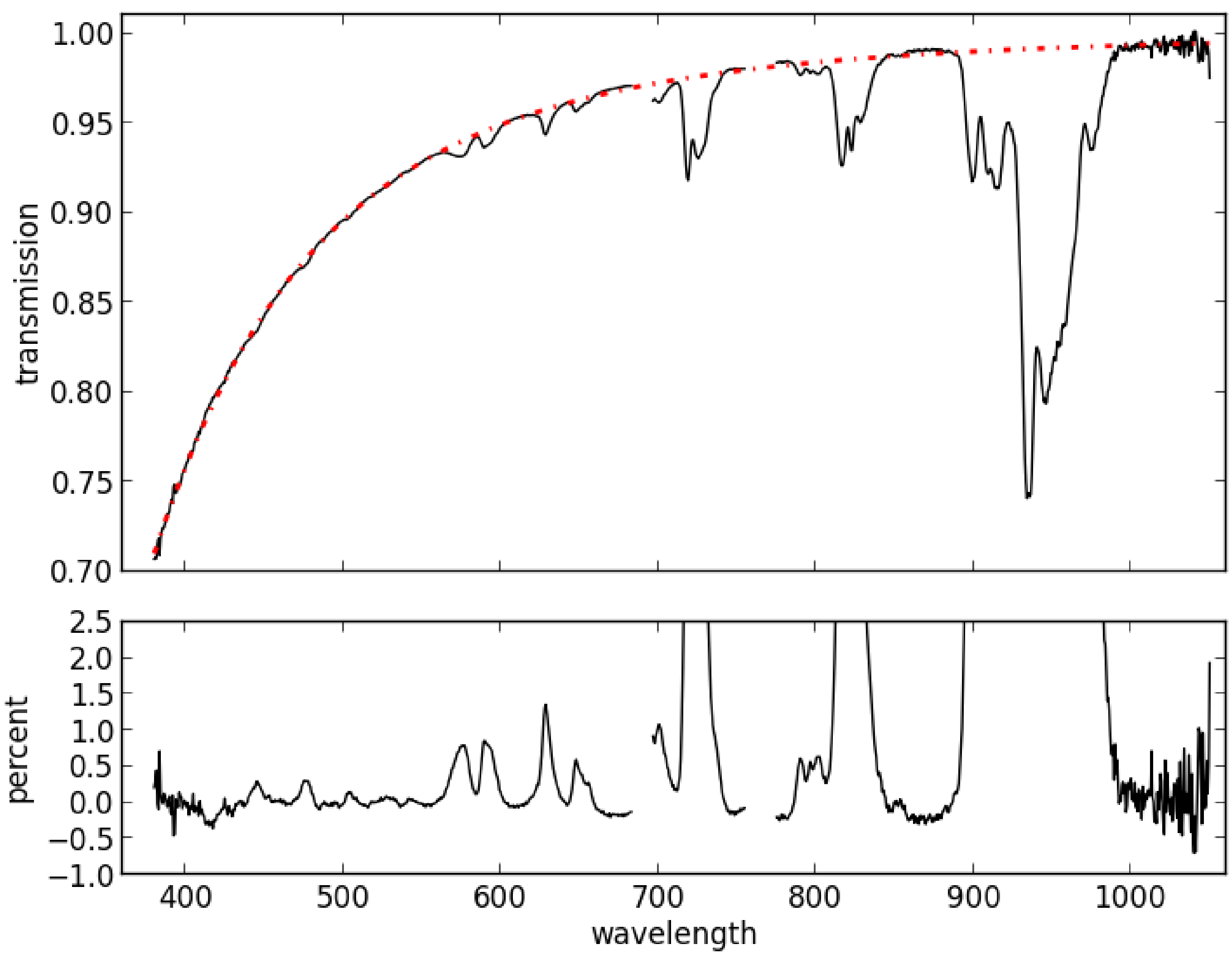
-difference between MODTRAN models and radiosonde profiles leads to unacceptable error

- use mean monthly profiles instead, assuming 1.5% uncertainty (estimate based on scatter in measurements)

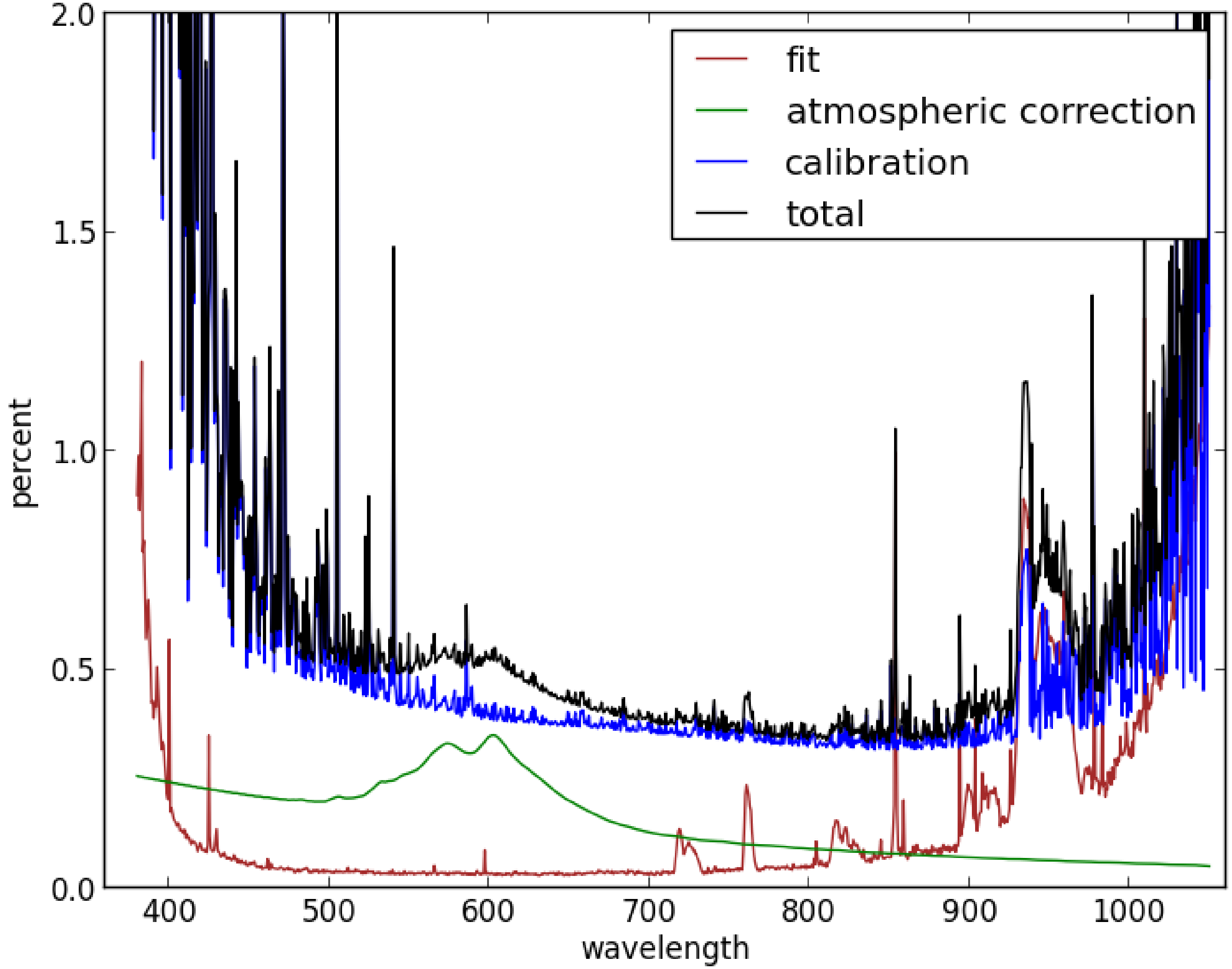




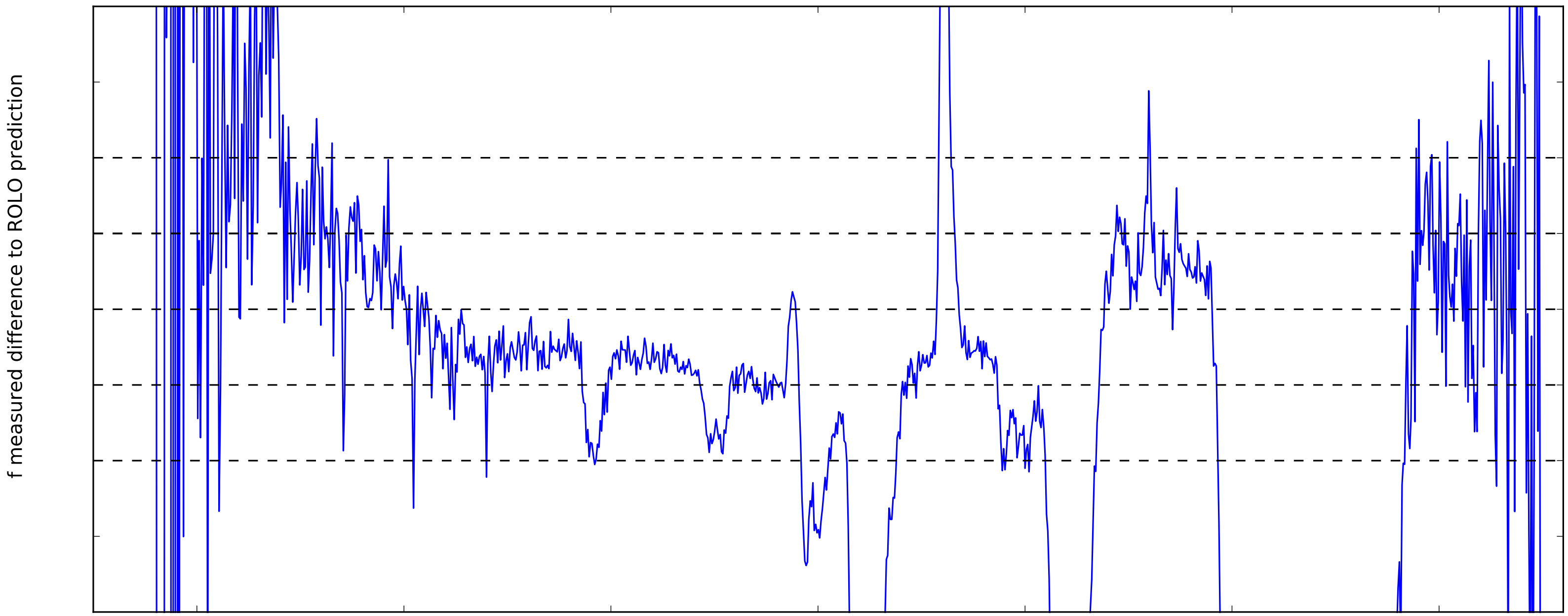
Compare Rayleigh fit to calculation:



Combined Uncertainty (k = 1)



Comparison to ROLO



Moving Forward

Next steps:

- SIRCUS calibration of CAS spectrometer
- Develop suite of atmospheric monitoring tools to validate and/or substitute for Langley method
- Account for oxygen (easy) and water vapor (hard) absorption
- Move to higher altitude site to reduce magnitude of atmospheric effects
- Obtain measurements spanning a range of phase and libration angles

Future goals:

- Expand wavelength range out to 2.5 μm
- Use high-altitude aircraft or balloons to reduce atmospheric extinction for 0.5 % accuracy at visible wavelengths and 2-3 % in SWIR