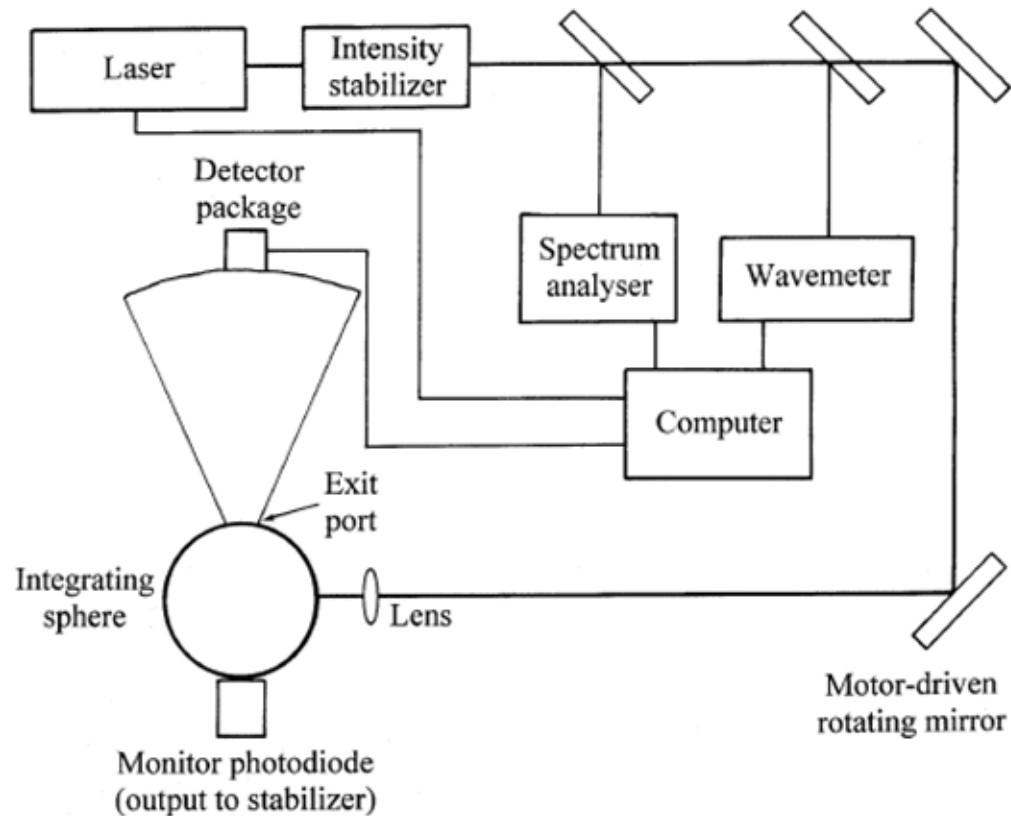


A STUDY OF OUT-OF-BAND UNCERTAINTIES FOR ON-ORBIT OCEAN COLOR MEASUREMENTS BASED ON LASER CALIBRATION OF FLIGHT RADIOMETERS

Steven W. Brown, Ping-Shine Shaw, and Keith R. Lykke/NIST
Joel McCorkel, Kurt Thome, and Xiaoxiong Xiong/NASA
Robert A. Barnes/ SAIC

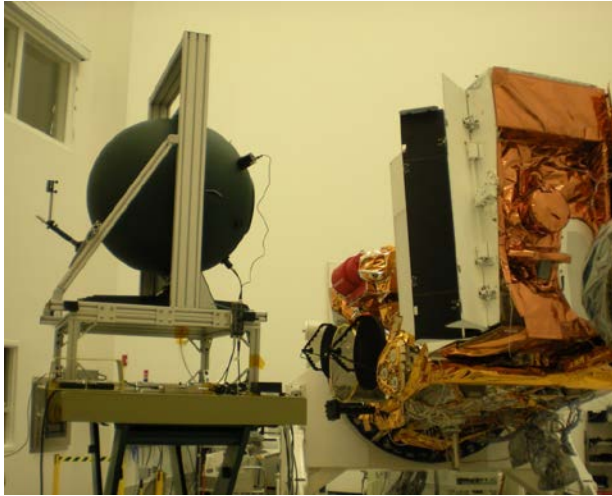
*Bryan Franz, NASA GSFC, provided ocean reflectance v chlorophyll concentration

Radiance and Irradiance Calibration Using High-Power High-Resolution Tunable Laser - SIRCUS



Less than 0.1% uncertainty in spectral response from 300 nm to 1100nm has been demonstrated

Applications of Laser-Based Radiometry



Calibration of remote sensing instruments



Water filtration measurements

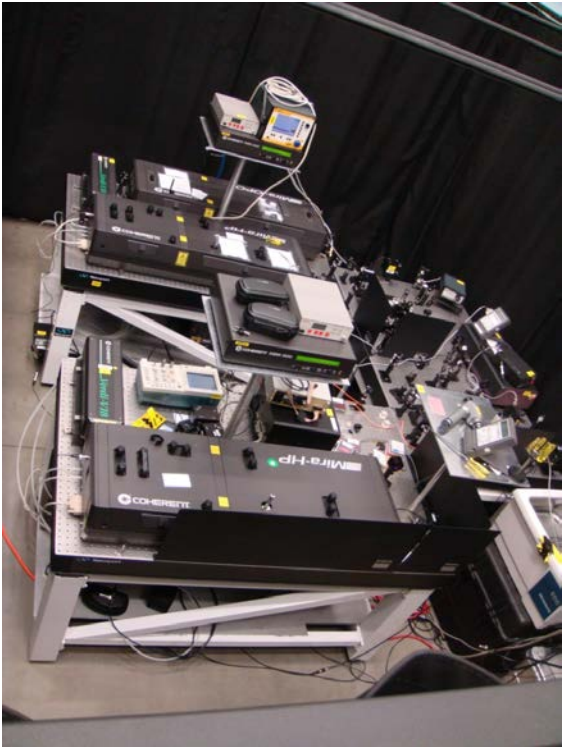
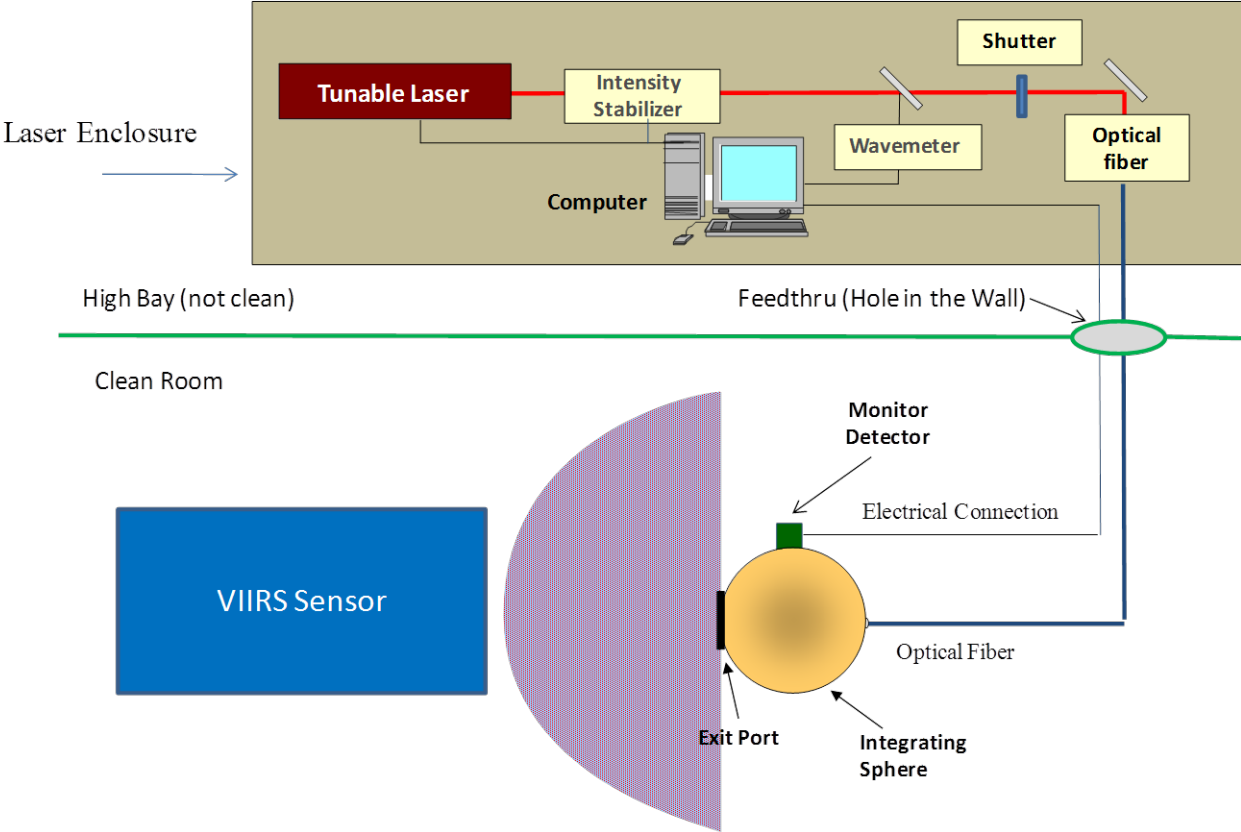


Lunar irradiance calibration

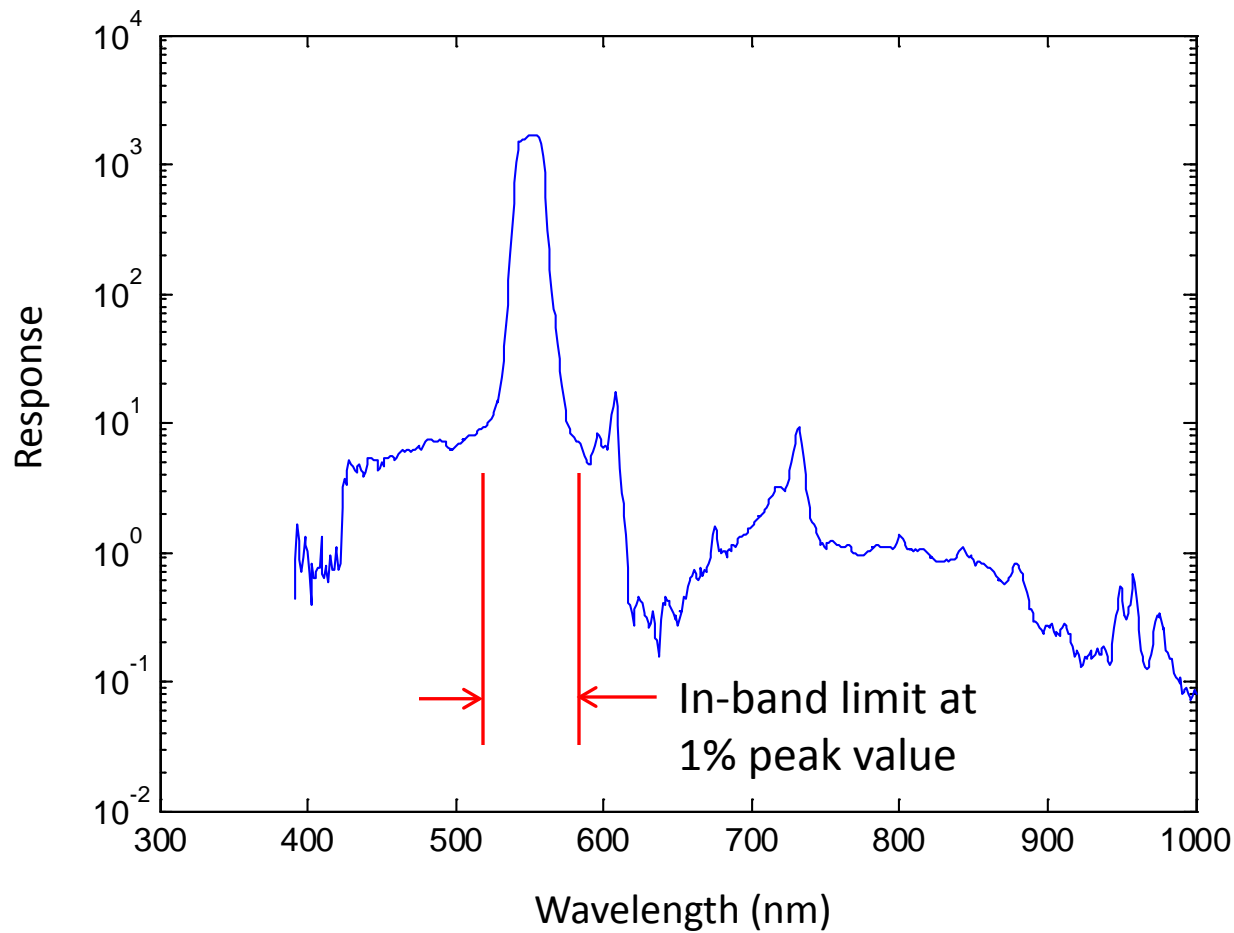


Telescope calibrations

Calibration of Suomi NPP VIIRS using Traveling-SIRCUS

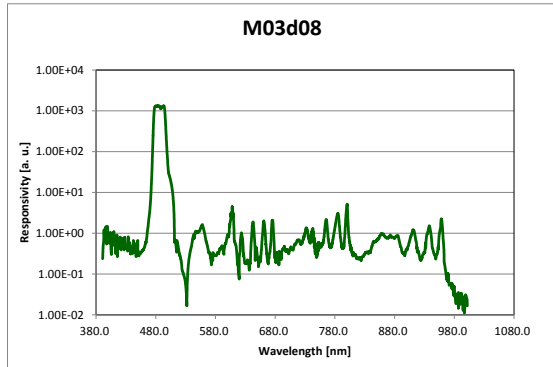
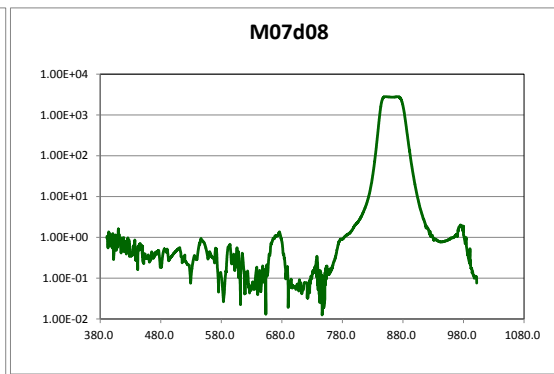
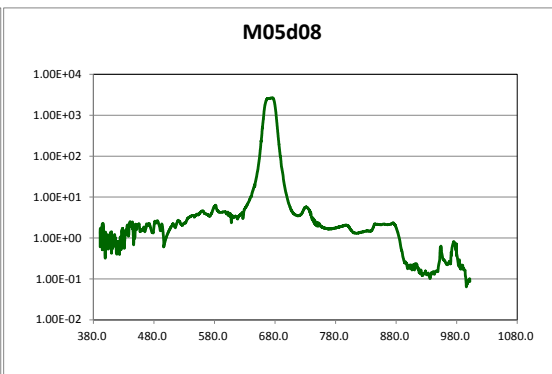
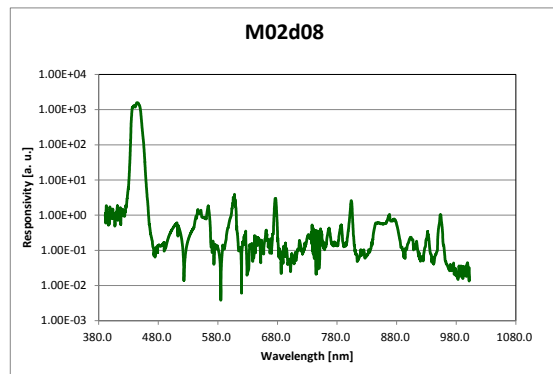
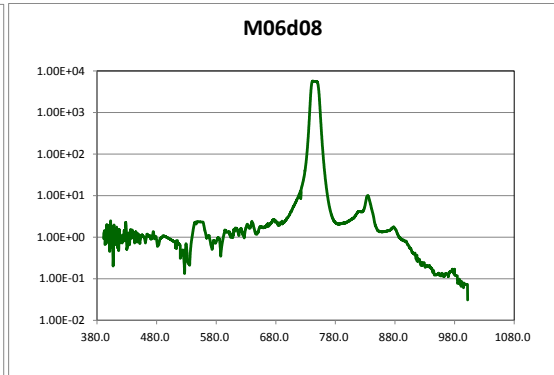
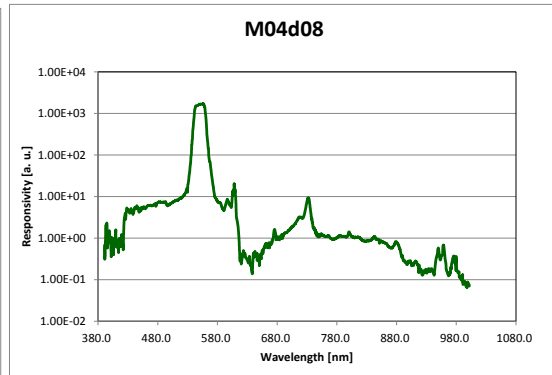
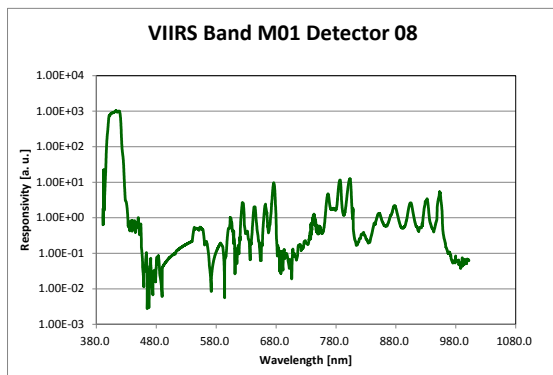


In-Band and Out-of-Band Spectral response of VIIRS Band 04 detector 08 measured using T-SIRCUS



Suomi NPP VIIRS Bands M01-M07 Detetor 08

Relative Spectral Response (RSR)



Evaluation of out-of-band (OOB) contribution using SIRCUS spectral response calibration

Consider total and in-band band-averaged spectral radiance from a scene

$$L_{total} = \frac{\sum_{\lambda=390}^{\lambda=1000} L_s(\lambda)R(\lambda)\Delta\lambda}{\sum_{\lambda=390}^{\lambda=1000} R(\lambda)\Delta\lambda}$$

$$L_{inband} = \frac{\sum_{\lambda=lower\ limit}^{\lambda=upper\ limit} L_s(\lambda)R(\lambda)\Delta\lambda}{\sum_{\lambda=lower\ limit}^{\lambda=upper\ limit} R(\lambda)\Delta\lambda}$$

The out-of-band contribution in % is the ratio of L_{total} and L_{inband}

$$OOB = \left(\frac{L_{total}}{L_{inband}} - 1 \right) * 100$$

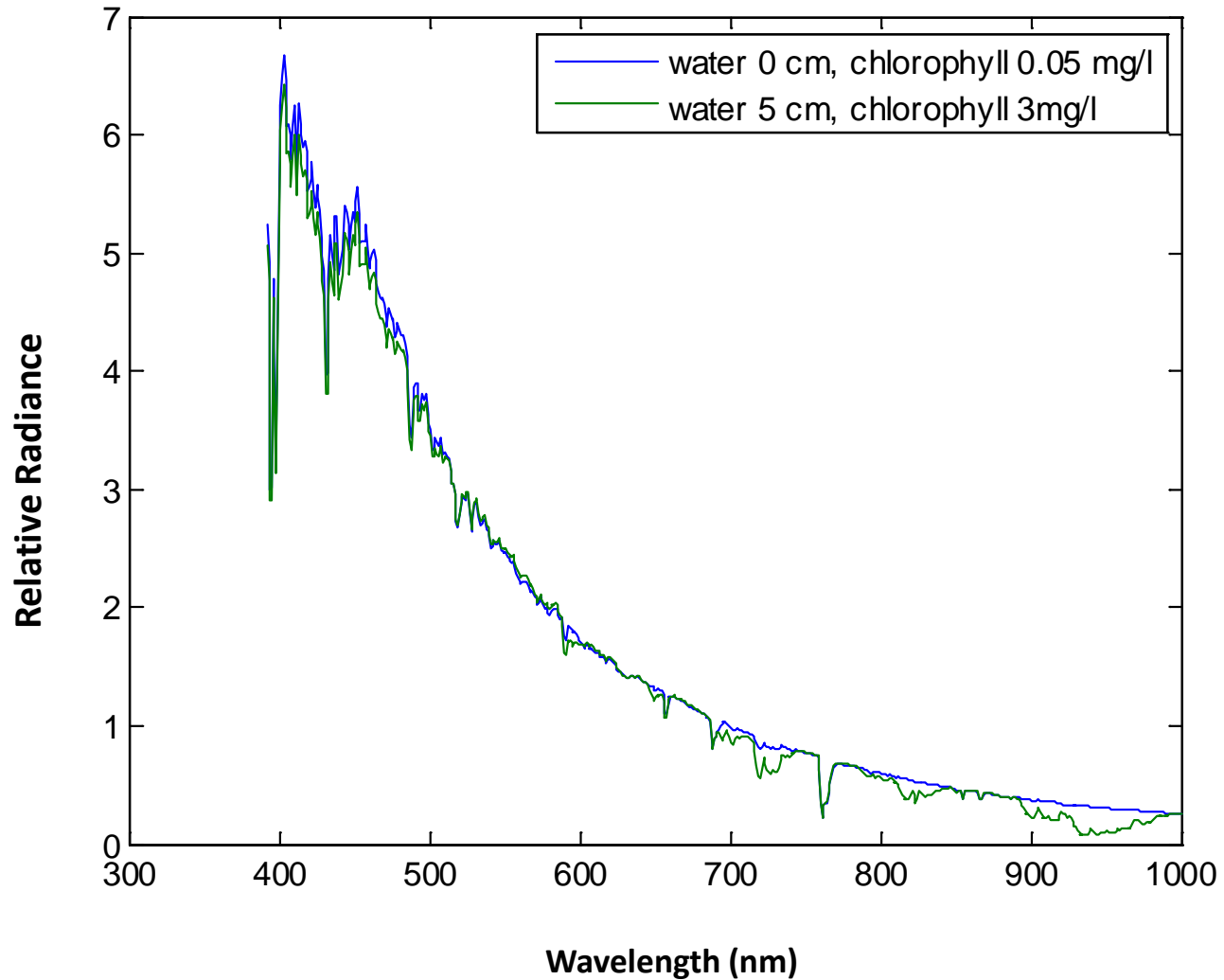
The OOB can be calculated given the spectrum of on-sensor radiance, L , and the spectral response of each band, R .

A Case Study of Out-Of-Band Contribution for On-Orbit Ocean Color Measurements

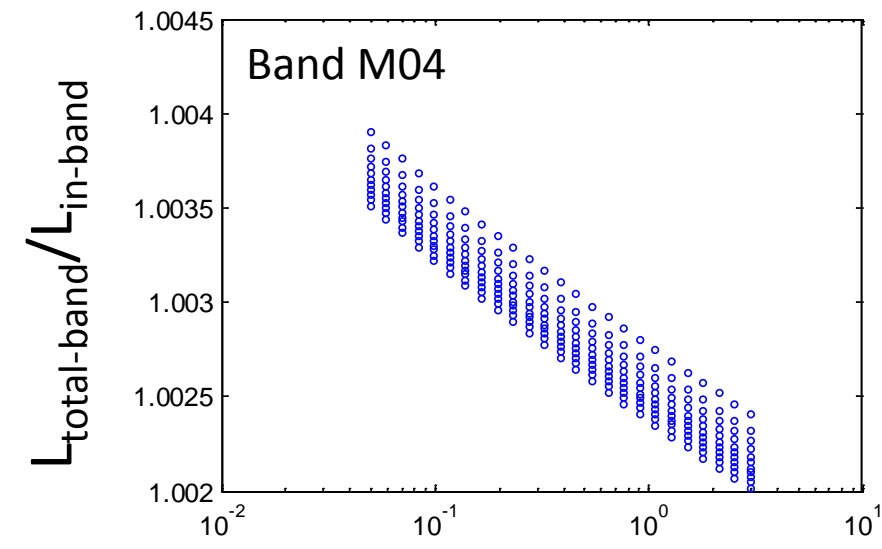
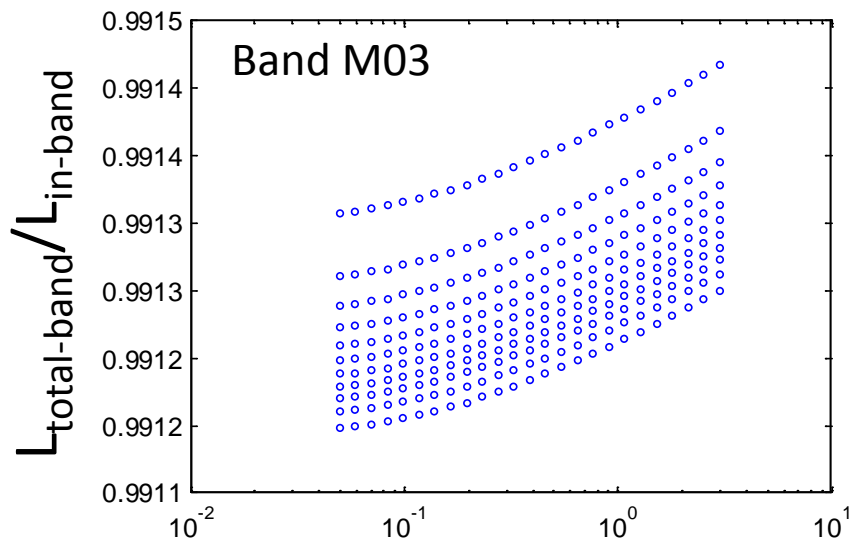
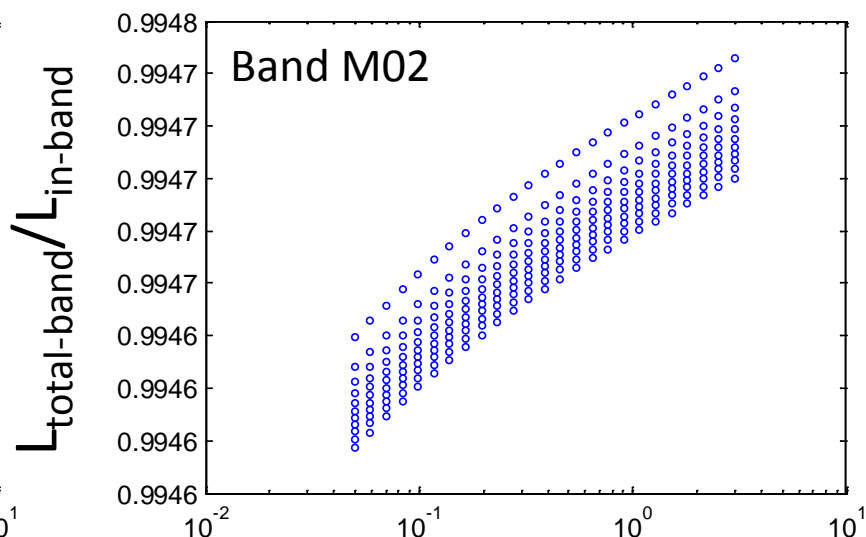
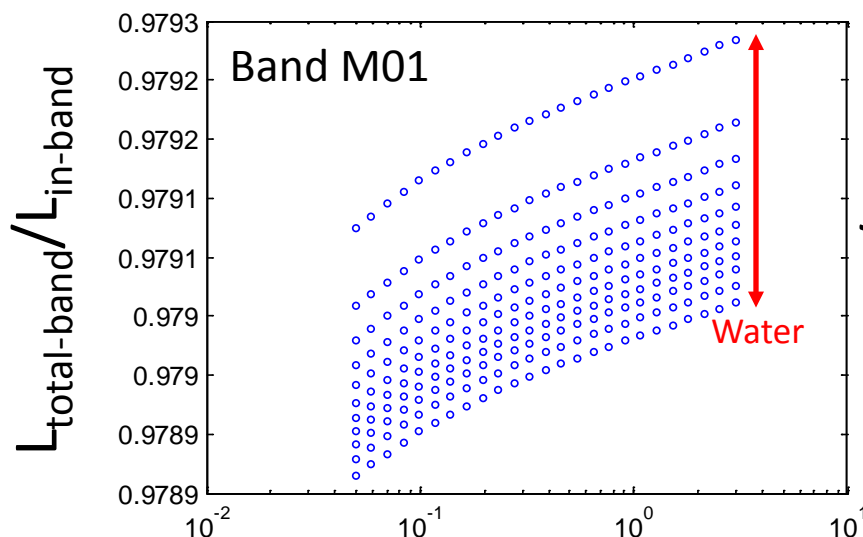
A total of 275 at-sensor spectral radiances, nadir view, were used for OOB evaluation:

- Near-surface phytoplankton chlorophyll-a concentration in the range of 0.05 mg/l to 3 mg/l
- Water vapor in the range of 0 cm to 5 cm
- A standard marine aerosol was selected
- Ozone at 300 DU
- Standard pressure

Examples of At- Sensor Ocean Color Data



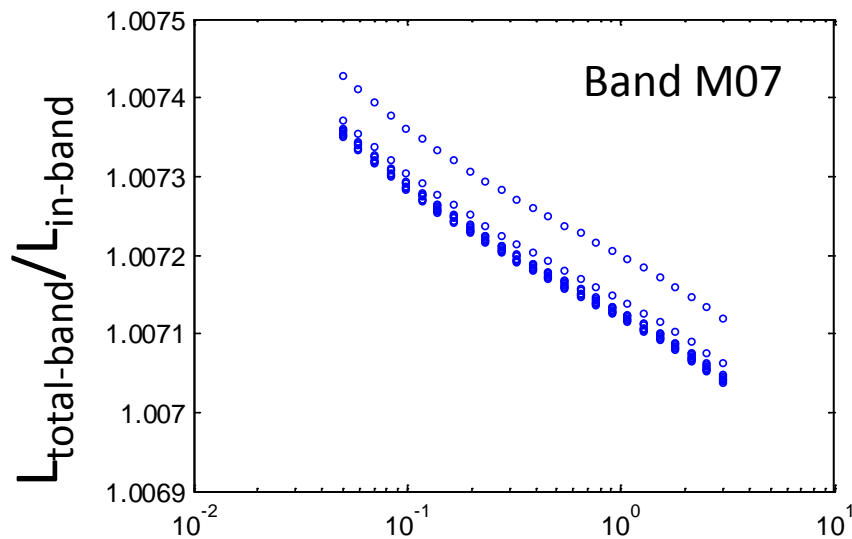
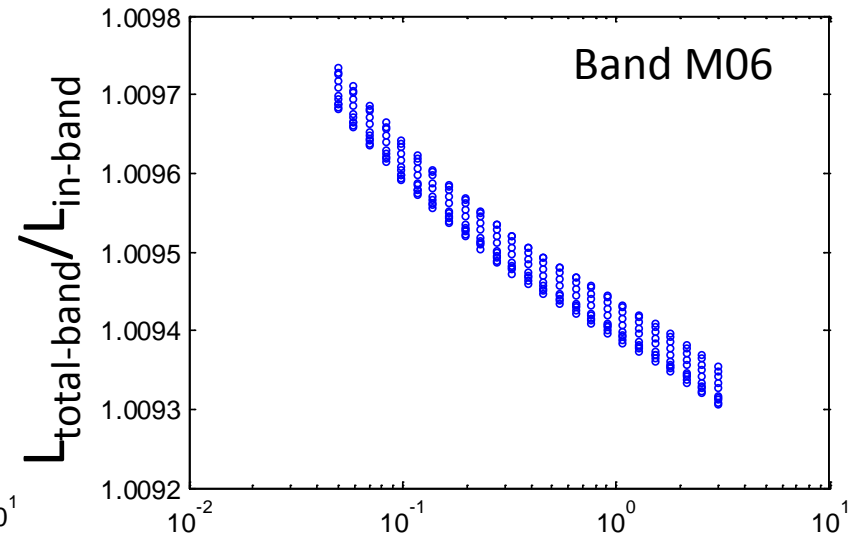
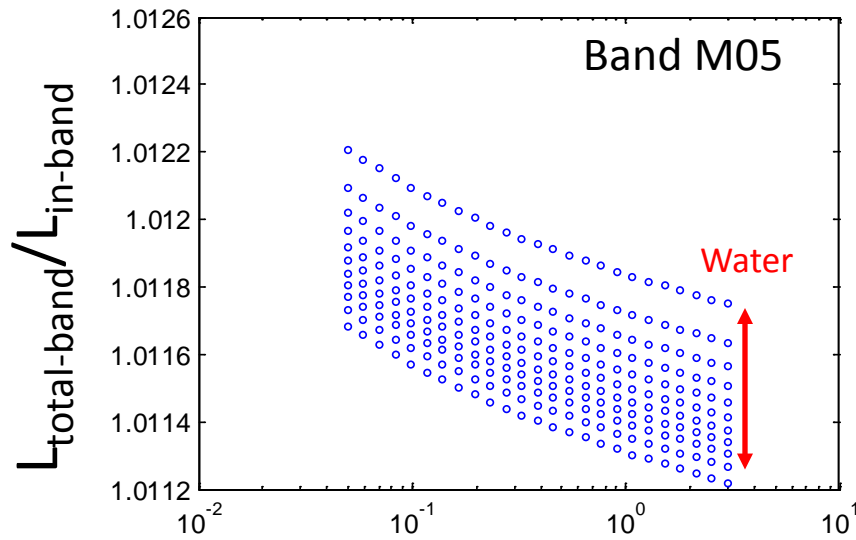
Out-of-band contribution as a function of chlorophyll concentration for water vapor of 0 – 5 cm



Chlorophyll concentration (mg/l)

Chlorophyll concentration (mg/l)

Out-of-band contribution as a function of chlorophyll concentration for water vapor of 0 – 5 cm

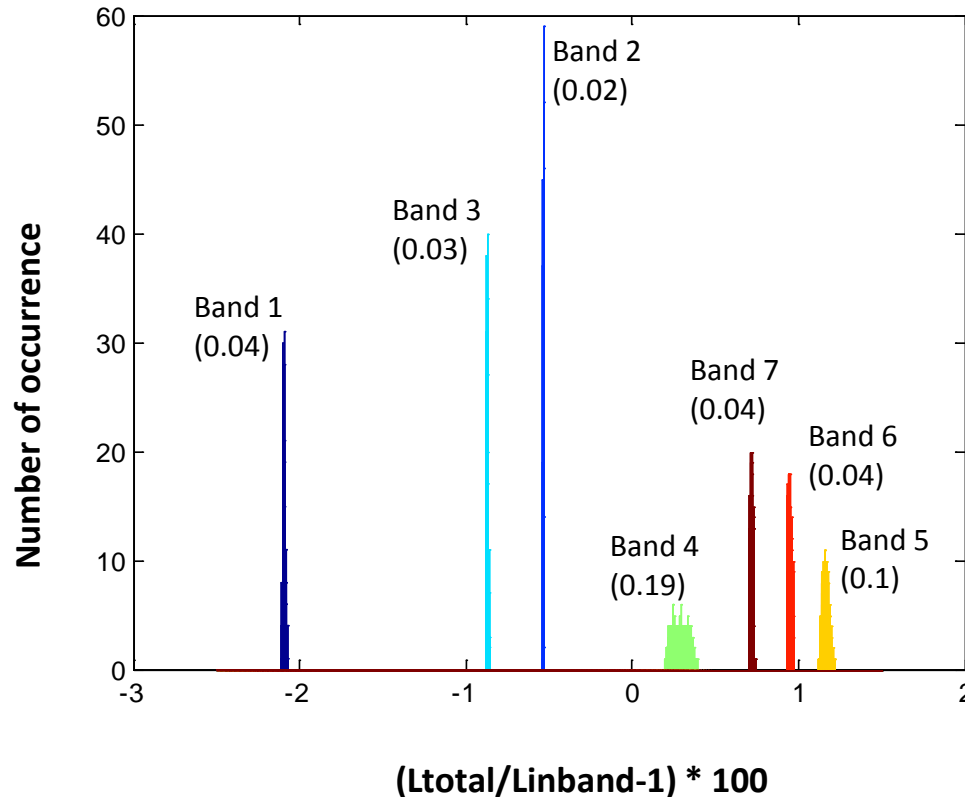


Chlorophyll concentration (mg/l)

Chlorophyll concentration (mg/l)

Ocean Color OOB Histogram for VIIRS Detector 8

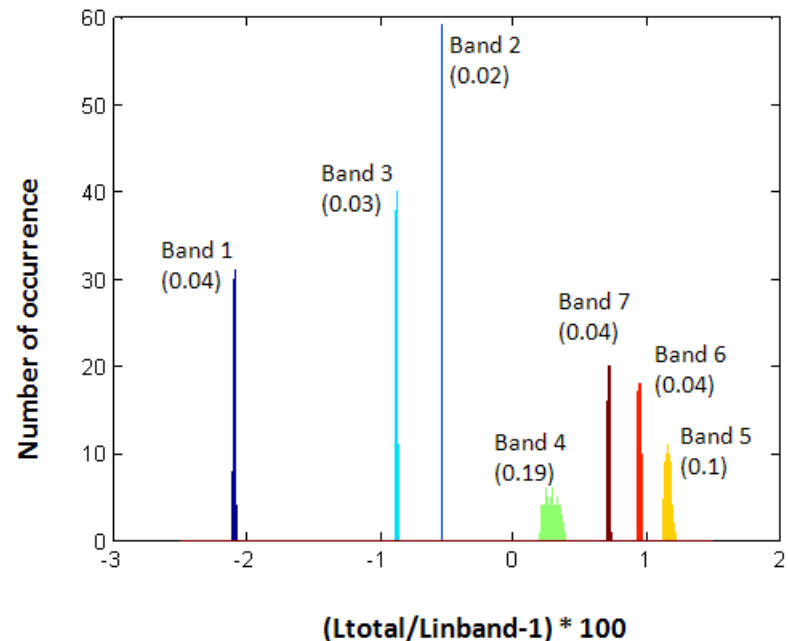
Water vapor from 0 cm to 5 cm and
chlorophyll concentration from 0.05 mg/l to 3 mg/l



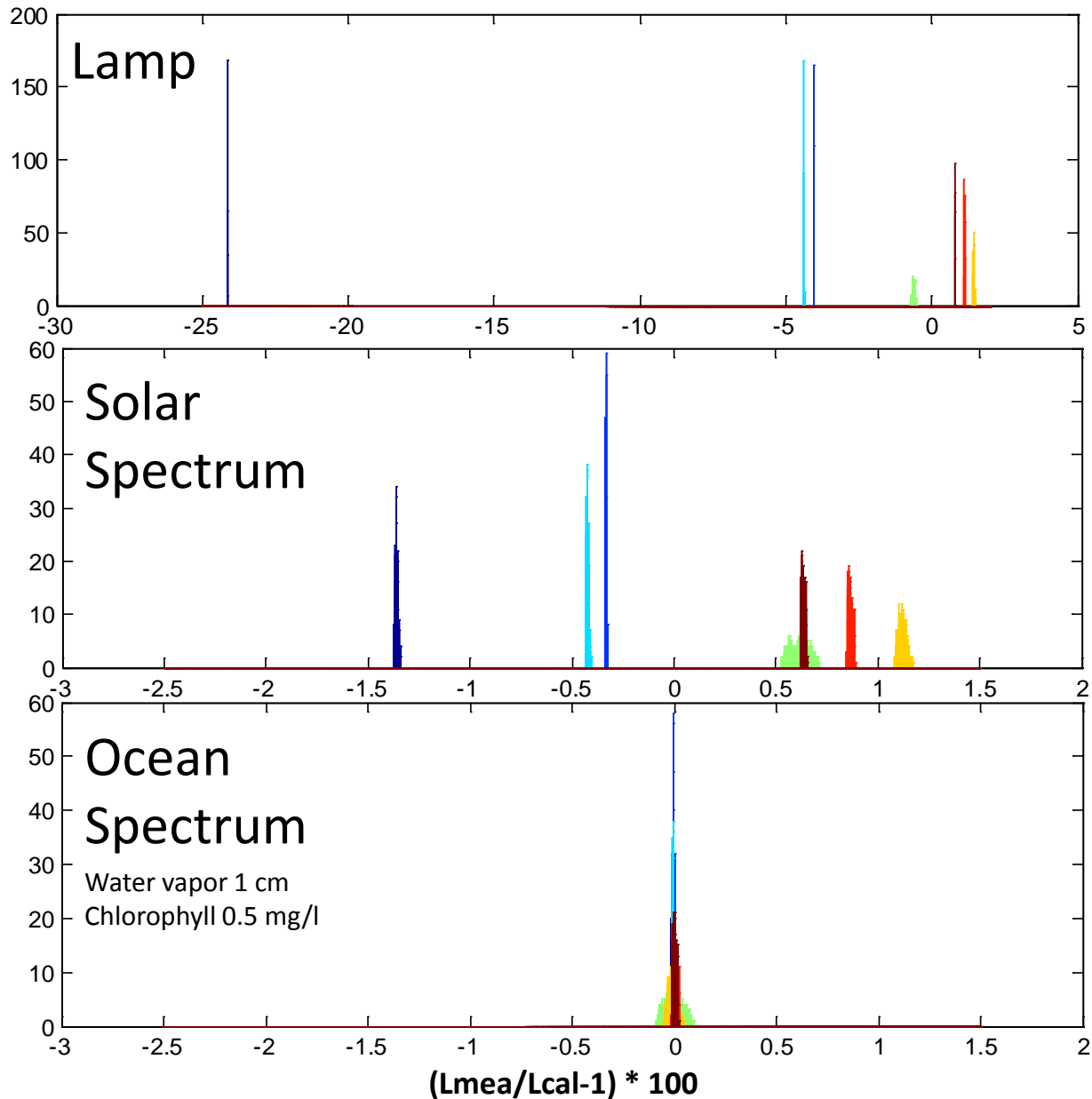
Large *out-of-band biases* – up to $> -2.1\%$ for Band 1
but small *variations (widths)* - 0.1 % or less for all bands
except for Band 4 (555 nm)

Simple Algorithm for OOB Correction

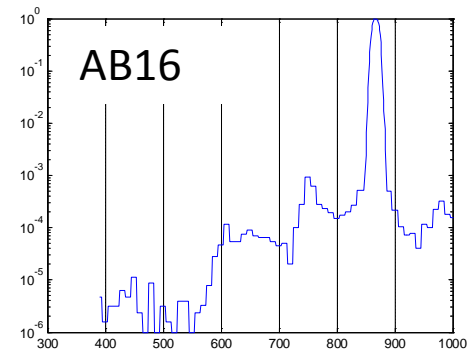
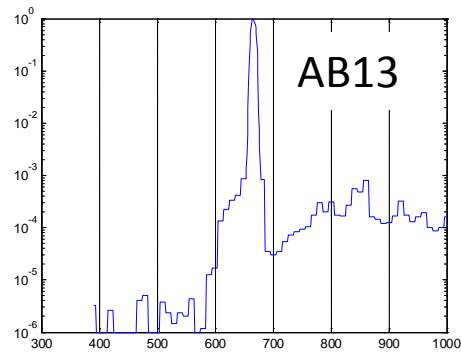
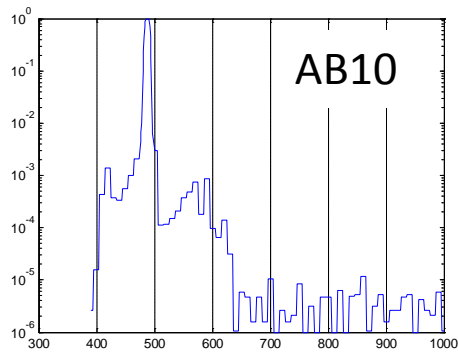
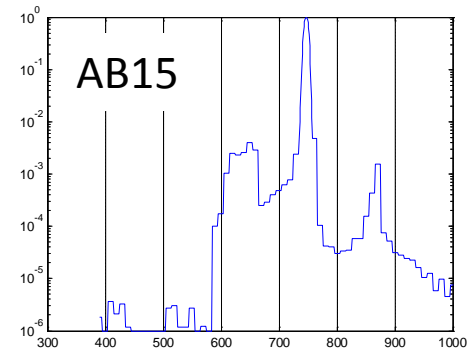
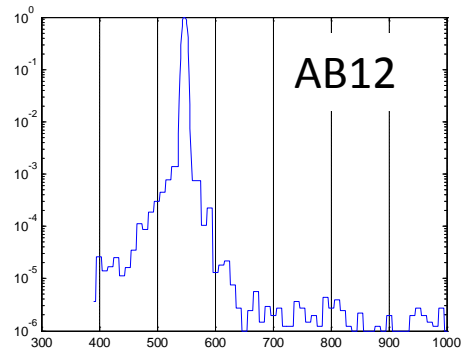
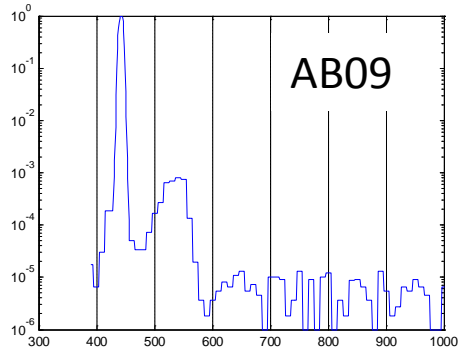
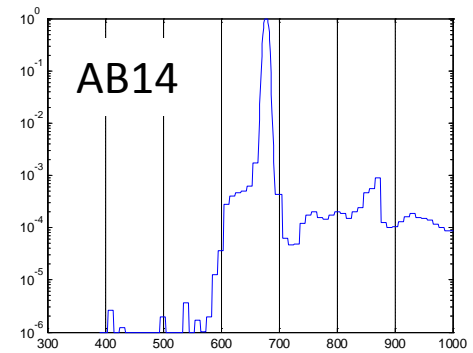
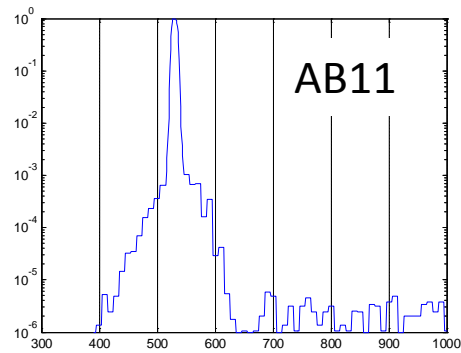
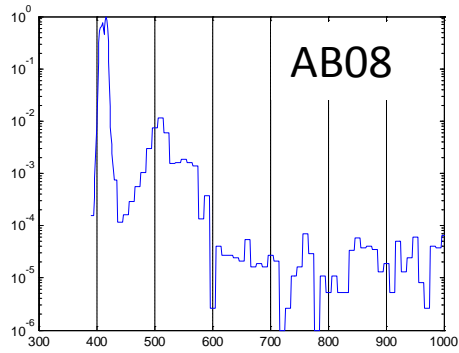
- A simple solution is to simply subtract the mean biases from each channel's measurement
- The residual uncertainty from OOB is then given by the width of the resultant distributions, in all cases but one less than or equal to 0.1 %.



OOB Histogram of VIIRS Detector 8 Based on Calibration Using Sources with Different Spectral Shapes

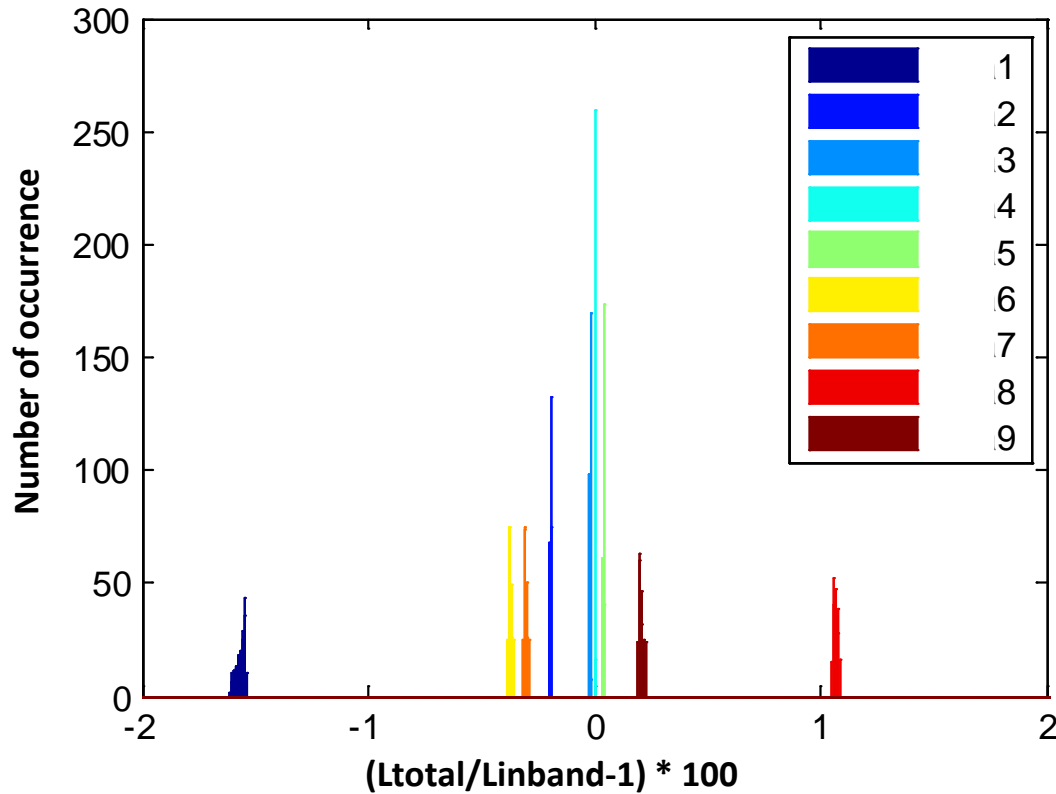


MODIS Band 1 – 9 Relative Spectral Responsivity



Ocean Color OOB Histogram for MODIS

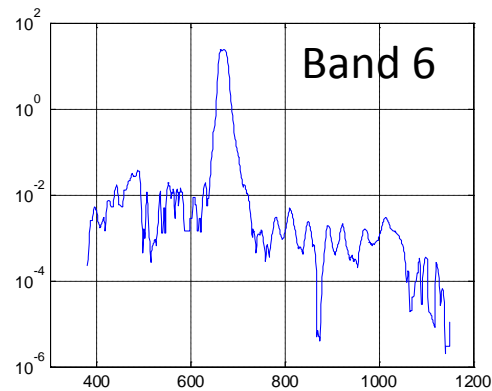
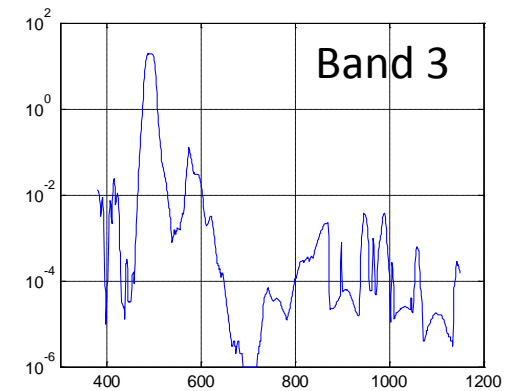
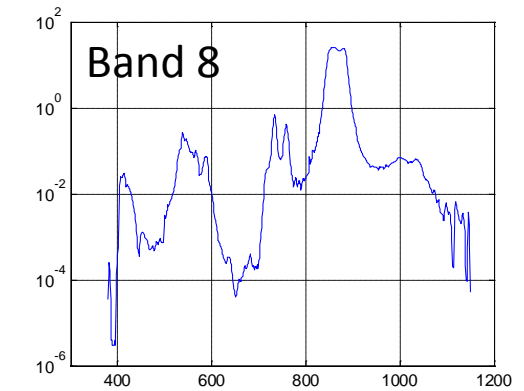
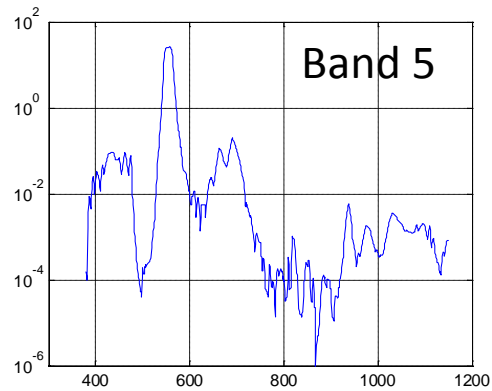
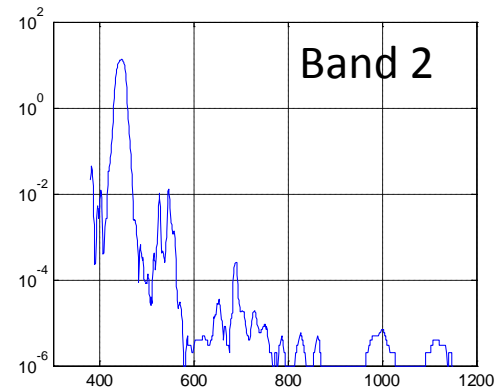
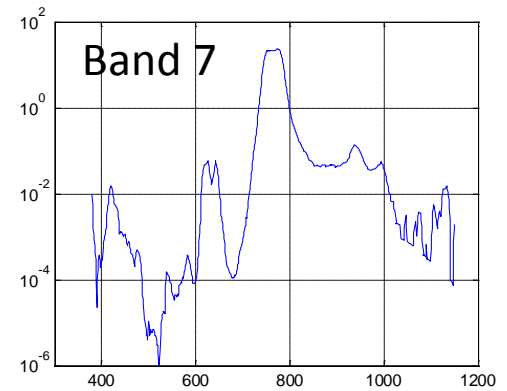
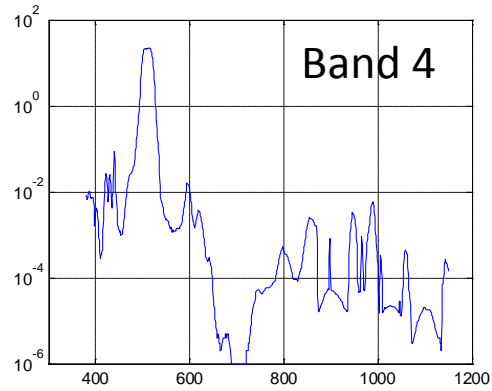
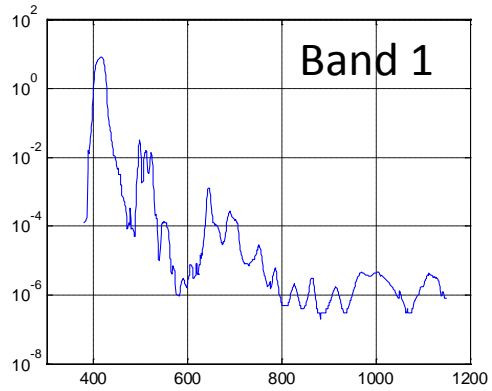
Water vapor from 0 cm to 5 cm and
chlorophyll concentration from 0.05 mg/l to 3 mg/l



OOB *biases* – up to 1.5 % for band 1

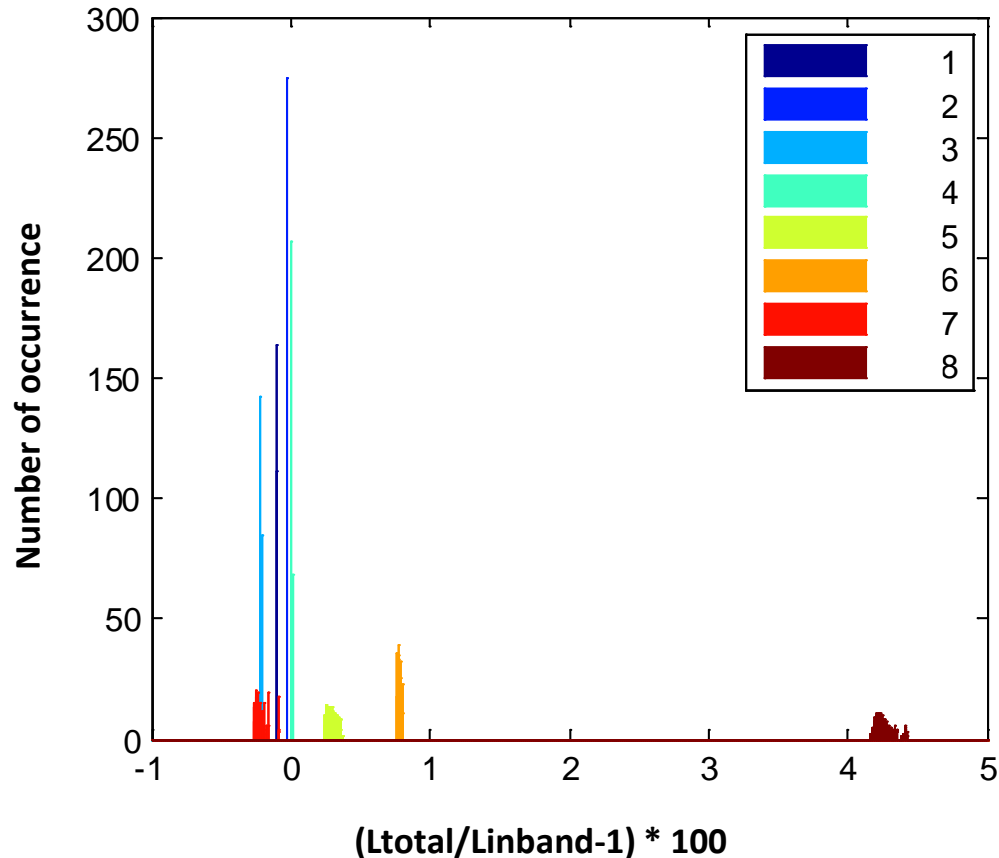
small *variations (widths)* - 0.2 % or less for all bands

SeaWiFS Band 1 – 8 Relative Spectral Responsivity



Ocean Color OOB Histogram for SeaWiFS

Water vapor from 0 cm to 5 cm and
chlorophyll concentration from 0.05 mg/l to 3 mg/l



Large *out-of-band biases* – up to > 4 % for Band 8
but small *variations (widths)* - 0.2 % or less for all bands
except for Band 8

Conclusion

- Tunable laser of SIRCUS can measure in-band and out-of-band response with up to 0.1% uncertainty
- Using the detector spectral response and the on-sensor ocean radiance, out-of-band contributions are assessed for chlorophyll concentration of 0.05 to 3mg/l and water vapor of 0 to 5 cm
- The out-of-band contribution shows large biases with small spread. The biases can be easily corrected
- Future work: include the effect of varying atmospheric aerosol and ozone, shifting in detector wavelength