Vicarious calibration for off-nadir sensors, using the MODIS-brf surface product

CEOS WGCV IVOS 30
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Randy Pollock, Florian Schwandner, Rob Rosenberg

Photo: JPL field team driving off-nadir at Railroad Valley, 08Mar2018.

OCO-2 calibration approach

- In calibrating Earth-viewing sensors from space, the error in Vicarious Calibration (VC) is dominated by the uncertainty in surface reflectance.
- Traditionally surface-reflectance is measured by a nadir-viewing spectrometer, ideal for calibrating nadir-viewing sensors.
- Sensors, such as GOSAT (Greenhouse Gases Observing Satellite), OCO-2 (Orbiting Carbon Observatory-2), and MISR (Multi-angle SpectroRadiometer) view and 20º, 30º, or even larger view zenith angles. For these, the reflectance at the off-nadir viewing angle is required: BRF(θsza,ϕsza; θsza,ϕsza)
- OCO-2 VC uses the MODIS land-surface BRF to adjust the nadir-view surface reflectace

BRF(θsza,ϕsza; θsza,ϕsza) =

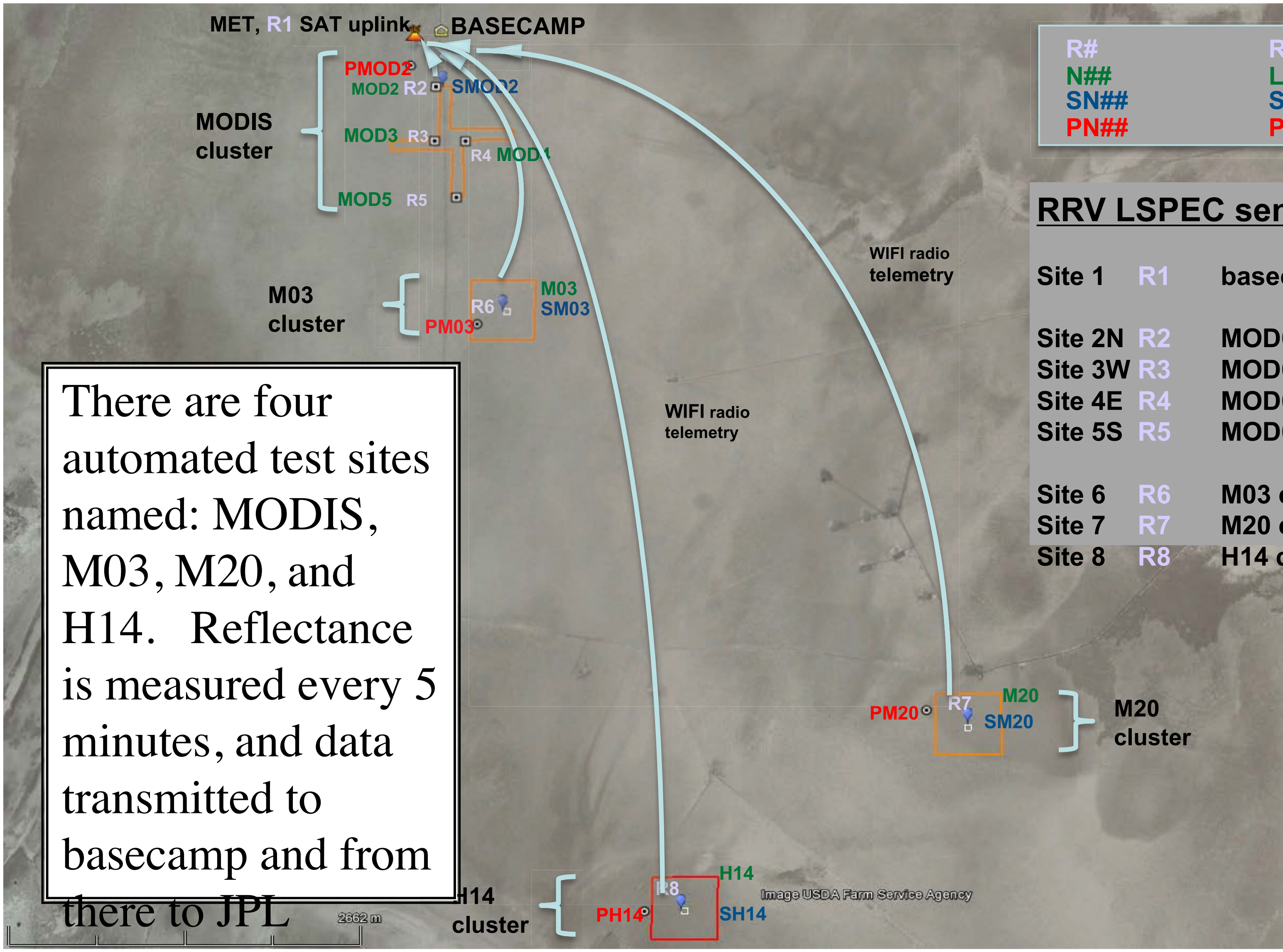
BRF(θsza,ϕsza; 0º,0º) * [BRF_modis(θsza,ϕsza)/BRF_modis(0º,0º)

Photo: off-nadir ASD measurements for MODIS BRF validation.

JPL automated sensors at Railroad Valley

Upper left: Center of communications is at *Basecamp*, located just north of the MODIS-N site. Here weather information from the meteorological sensors are uploaded along with the playa reflectance data.
Lower left: AERONET Cimel measures aerosol optical depth.
Right: Low-cost radiometer measures surface reflectance. 8 such detectors are located at 3 test sites, 1 co-located with the 4 RadCalNet sensors.

JPL RRV VicCal facility



R#	Radio number
N##	LSPEC site number
SN##	Soil Moisture site number
PN##	PARABOLA mast number

RRV LSPEC sensor network

Site 1	R1	basecamp, met station, sat uplink	
Site 2N	R2	MOD02	MODIS cluster, pod 2
Site 3W	R3	MOD03	MODIS cluster, pod 3
Site 4E	R4	MOD04	MODIS cluster, pod 4
Site 5S	R5	MOD05	MODIS cluster, pod 5
Site 6	R6	M03 cluster site	
Site 7	R7	M20 cluster site	
Site 8	R8	H14 cluster site	

There are four automated test sites named: MODIS, M03, M20, and H14. Reflectance is measured every 5 minutes, and data transmitted to basecamp and from there to JPL

VicCal input sources

- Surface reflectance
  - In-situ measurements
    - Site visits 3X/ year (spring, summer, fall)
    - Major campaign in support of GOSAT each June (June 24-July 3, 2018)
  - JPL automated sensors (LSpec). Data collected at 5 min. samples during daylight hours.
  - And now, RadCalNet!!!
- Meteorology from JPL station
- Aerosol from aeronet
  - validated with microtops during field campaigns
- MODIS BRF for off-nadir correction
- MODIS L1B for VicCal validation

OCO-2 radiative transfer code

(D. Crisp)

- OCO-2 radiative transfer code
  - The OCO-2 forward RT model combines the scalar LInearized Discrete Ordinate Radiative Transfer (LIDORT, Spurr et al., 2001; Spurr 2002; 2006), with a linearized 2-Order of Scattering (2-OS) model that accounts for polarization (Natraj et al., 2007a,b; 2008), and the novel low-streams approximation (O'Dell et al., 2010) designed to reduce RT computation time.
- References

  - Spurr, R. J. D., Simultaneous derivation of intensities and weighting functions in a general pseudo-spherical discrete ordinate radiative transfer treatment, J. Quant. Spectrosc. Rad. Tran., 75(2), 129–175, 2002.
  - Natraj, V., and R. J. D. Spurr, A fast linearized pseudo-spherical two orders of scattering model to account for polarization in vertically inhomogeneous scattering–absorbing media, J. Quant. Spectrosc. Rad. Tran., 107, 263–293, 2007.
  - O'Dell, C. W. Acceleration of multiple-scattering, hyperspectral radiative transfer calculations via low-streams interpolation Journal of Geophysical Research-Atmospheres, 115, D10206, doi:http://dx.doi.org/10.1029/2009JD012803, 2010.

  - The OCO-2 L2 ATBD provides a more complete description.

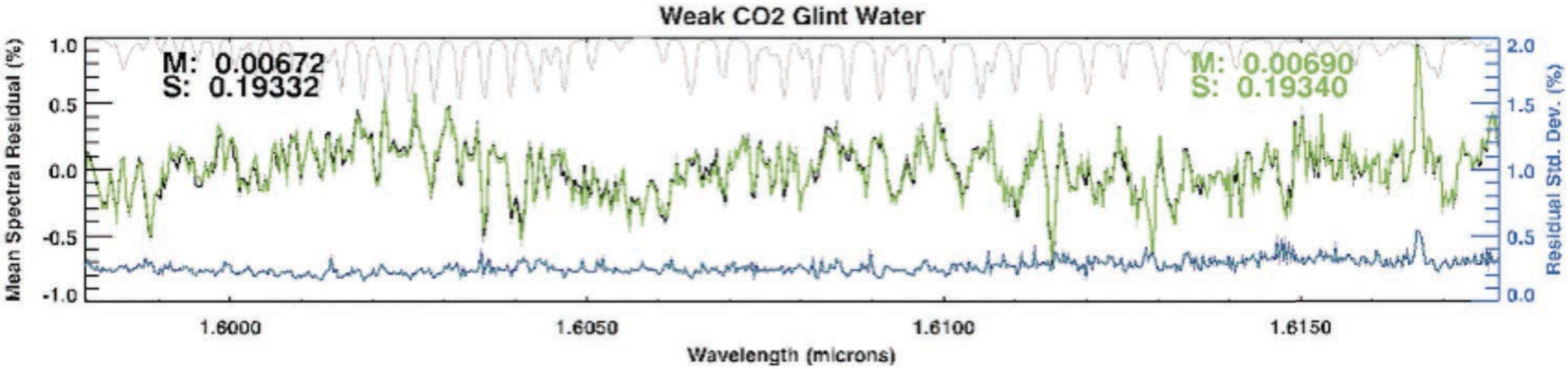
LIDORT validation

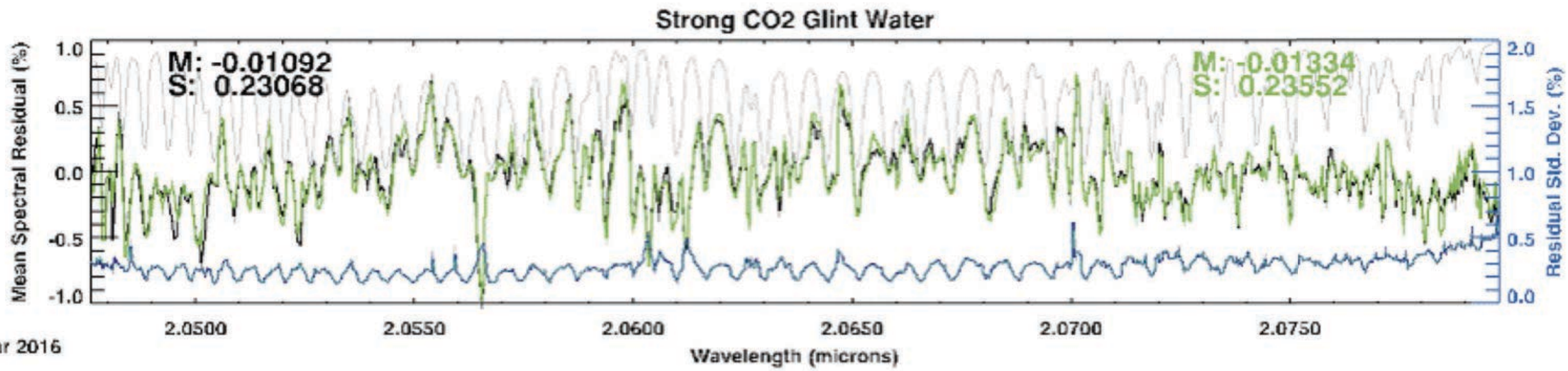
(D. Crisp)

- LIDORT and VLIDORT have been validated to ~0.1% against analytic cases. For real atmospheres, we can never achieve this because of uncertainties in input parameters.

- The HITRAN 96 database is a disaster, with line strengths and line widths with errors > 6% relative to more recent databases. I am not at all surprised that they are seeing large errors. HITRAN 2012 is better, but still has line strength and width errors >> 1% in many bands throughout the NIR and SWIR, and still assumes that absorption lines have Voigt profiles with no line mixing. We abandoned that approach a decade ago because it wasn't accurate enough. Since then, we have invested over 10 M$ in new laboratory measurements and analysis techniques. Our databases now have RMS errors around 0.1 to 0.2% within the bands that we measure. There are still some regions with ~1% errors, but those regions are known and most are not used in our retrievals. Typical OCO-2 residuals in the WCO2 and SCO2 bands are shown in the attached plots, which show glint retrievals over water. The RMS residuals in these tests are 0.19% (WCO2) and 0.24%.The largest residuals are due to H2O lines (from HITRAN 2012).

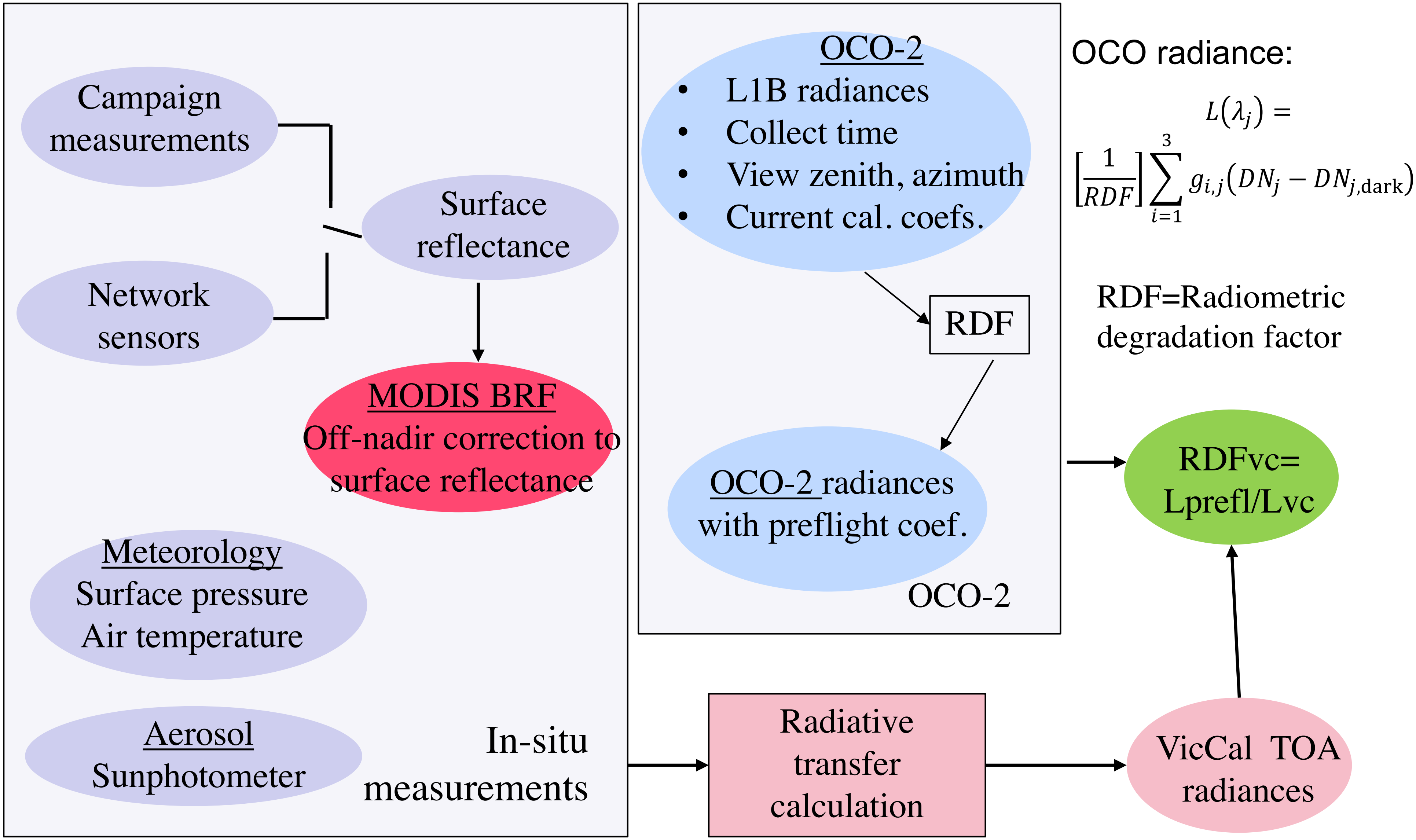
Residuals





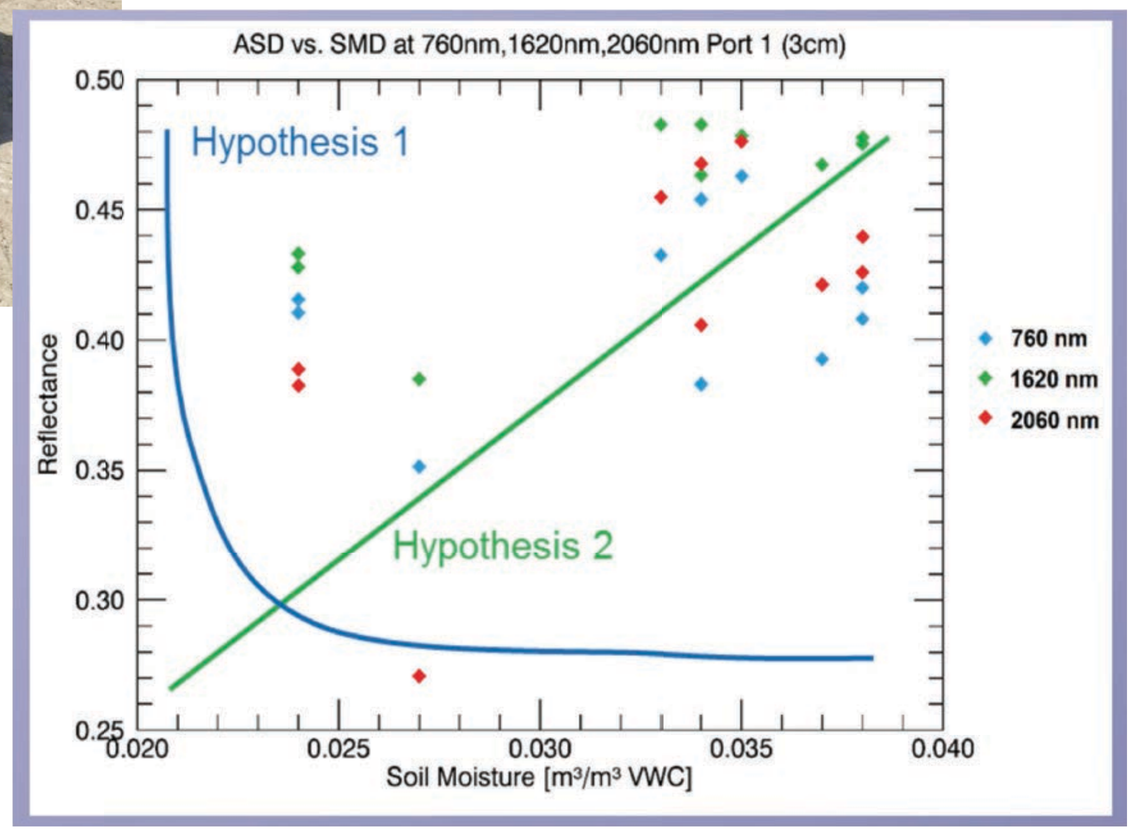
16 Mar 2016

OCO-2 VicCal

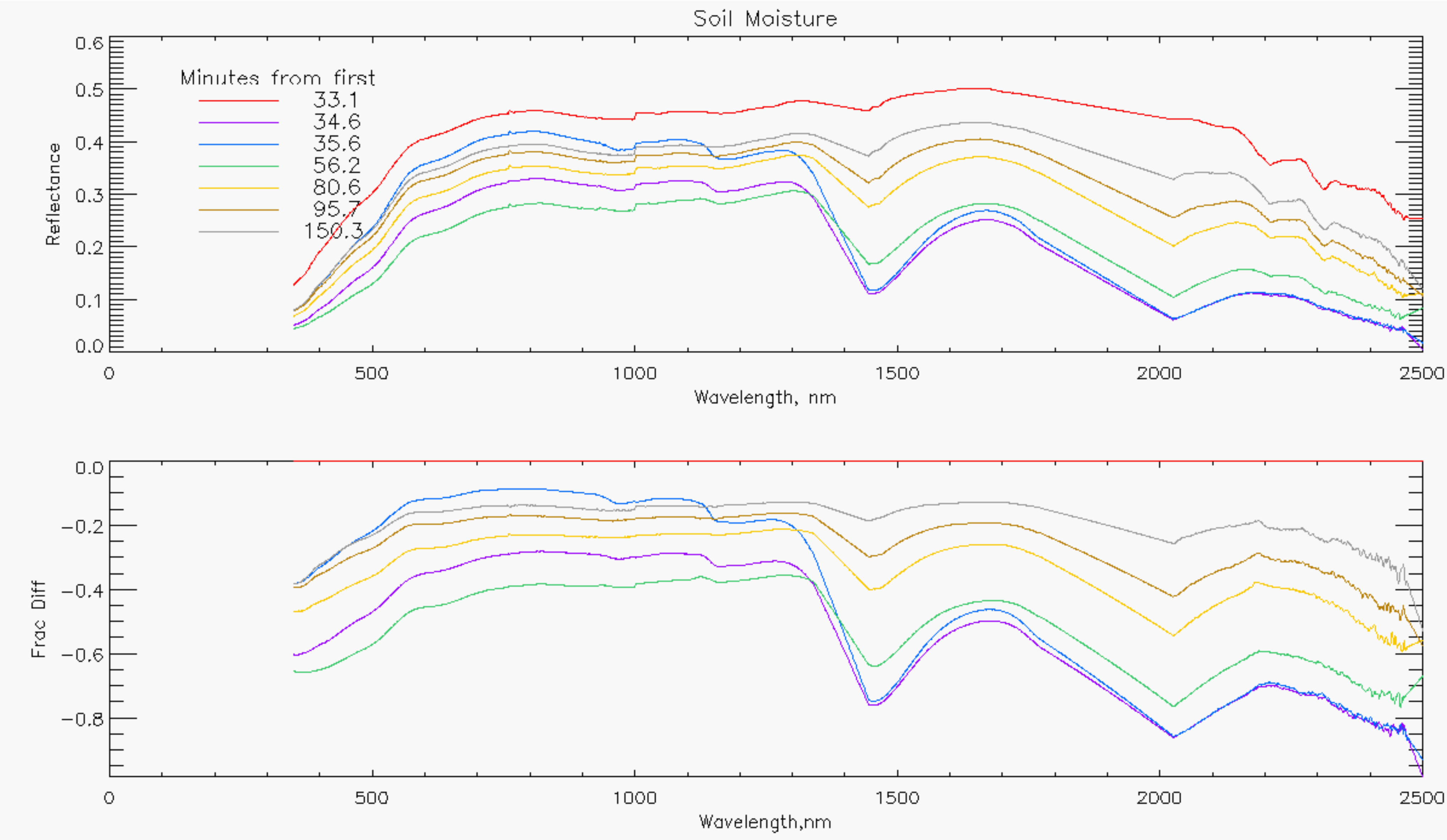

Campaign measurements
Network sensors
Surface reflectance
MODIS BRF
Off-nadir correction to surface reflectance
Meteorology
Surface pressure
Air temperature
Aerosol
Sunphotometer
In-situ measurements
OCO-2
L1B radiances
Collect time
View zenith, azimuth
Current cal. coefs.
RDF
OCO-2 radiances with preflight coef.
OCO-2
OCO radiance:
$L(\lambda_j) = \left[\frac{1}{RDF}\right] \sum_{i=1}^{3} g_{i,j} \left(DN_j - DN_{j,\mathrm{dark}}\right)^i$
RDF=Radiometric degradation factor
RDFvc= Lprefl/Lvc
Radiative transfer calculation
VicCal TOA radiances

Soil moisture experiment

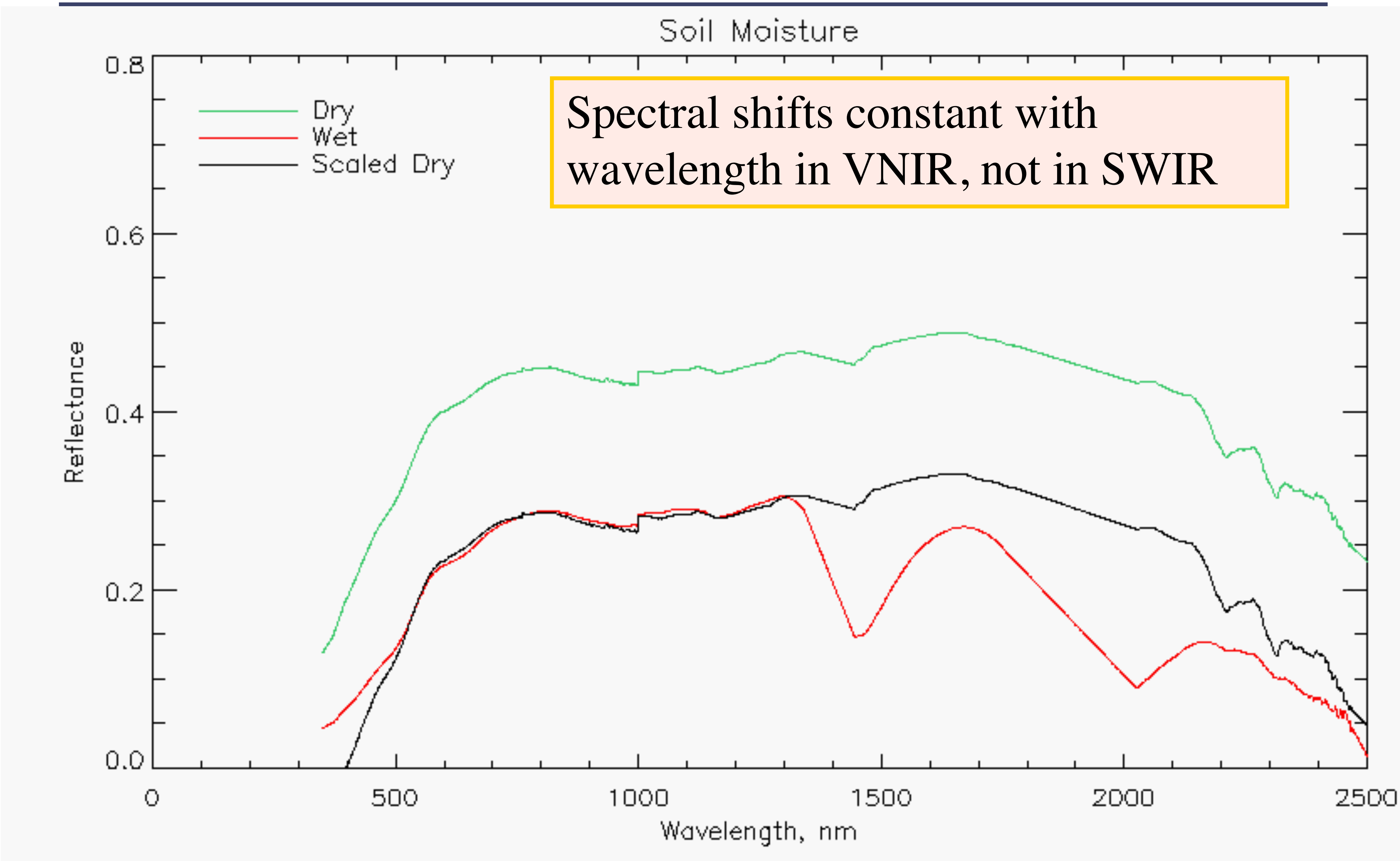
(A. Korde)



Spectral shape changes with SM

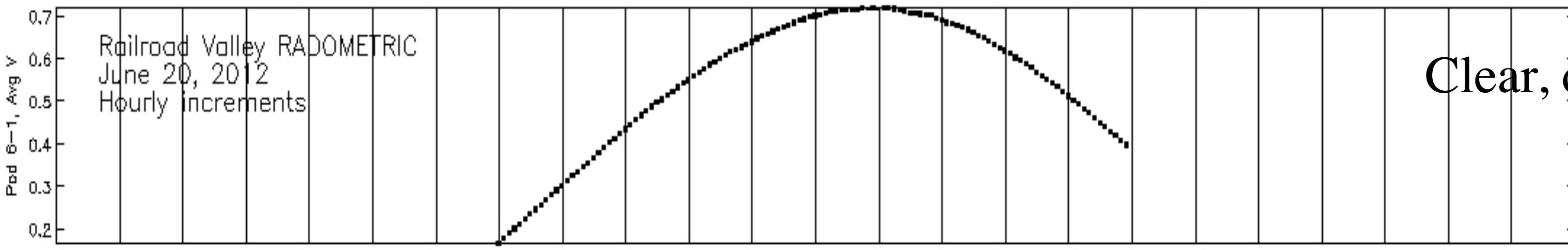


Relative spectral shape vs. SM

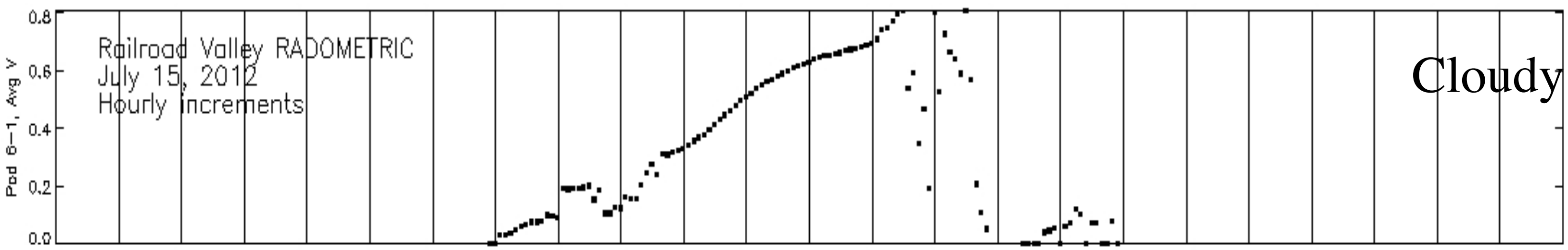


BRF vs time of day (sun angle)

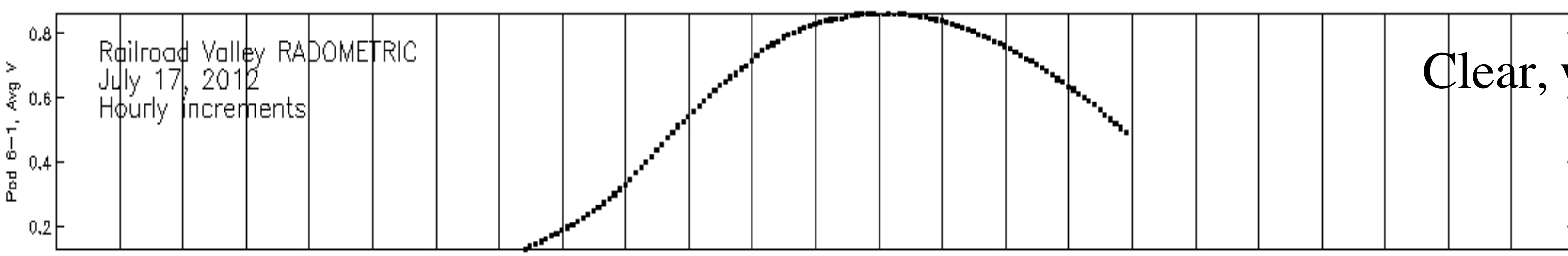
Plot: Reflectance measured at 5 minute samples (JPL network sensors). Temporal shape indicates clear/ cloudy conditions as well as soil moisture.



Clear, dry

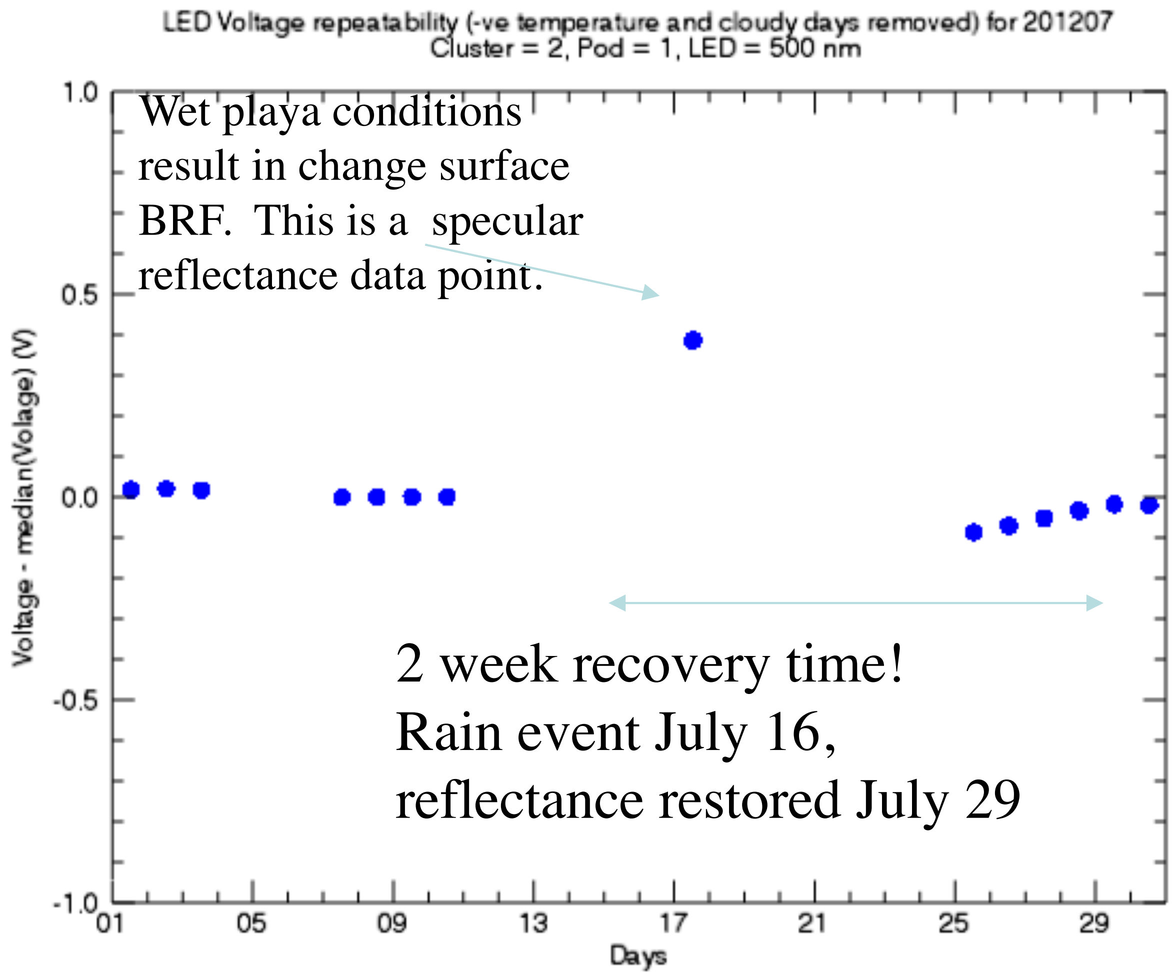


Cloudy



Clear, wet

How long does it take the surface to day out after a rain?



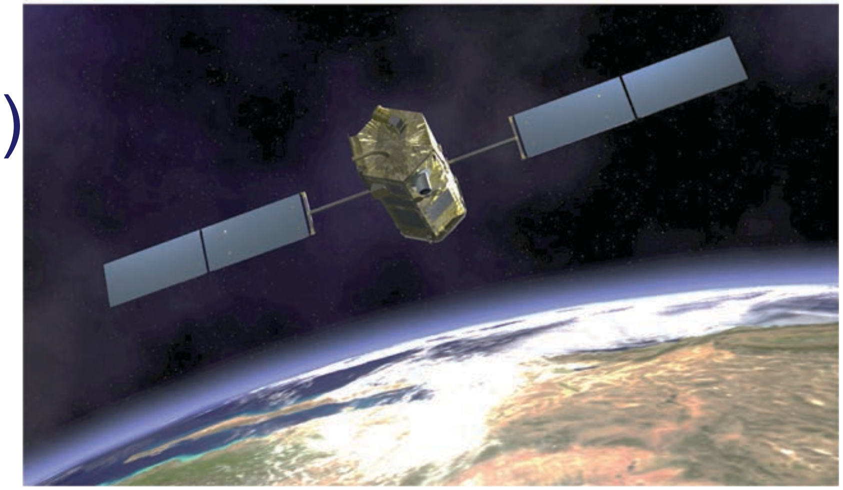
VicCal uncertainty

- Given nadir surface-reflectance, "dry" surface conditions be detected
- If surface is dry, MODIS BRF file can be validated against "Golden Day" MODIS nBRF (BRF normalized to BRF(nadir view))
- Uncertainty in using the MODIS BRF product is computed using
  - max(|stdev(nBRF)/mean(nBRF)|, 1-|nBRF|)

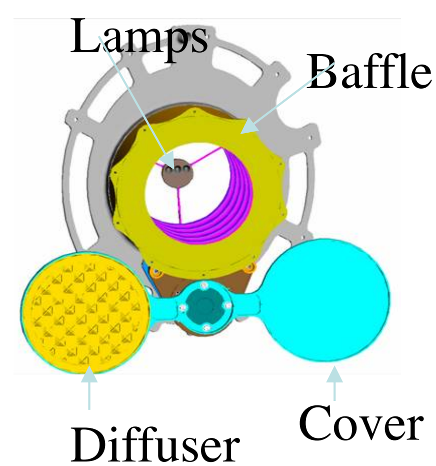
Parameter	Uncertainty %, min	Uncertainty %, max
Nadir reflectance	3	
Off-nadir correction*	0	3
RTC	1	
Atmosphere	1	
RSS	3.3	4.5

* Cases > 5% are eliminated from report

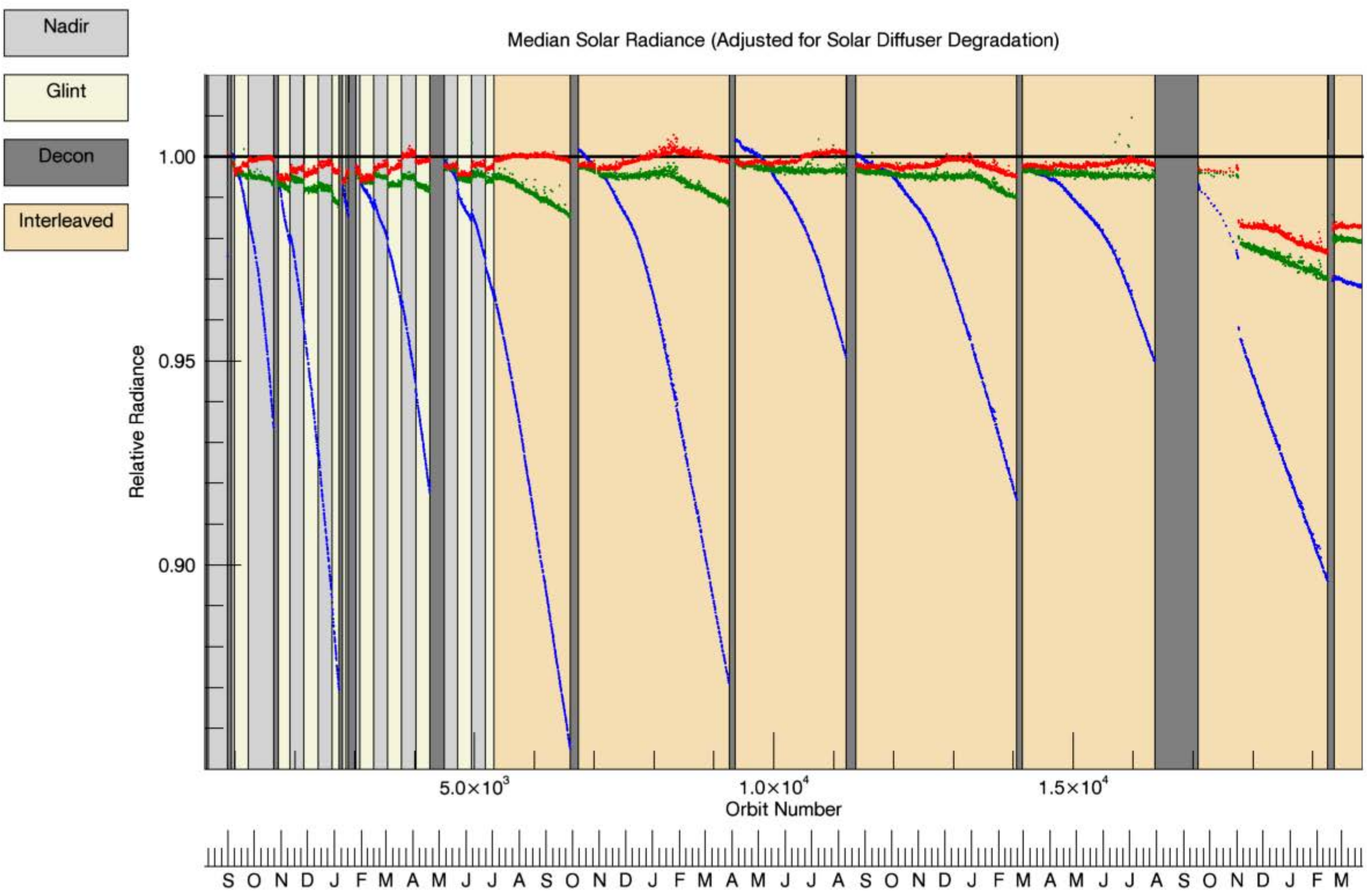
Orbiting Carbon Observatory-2 (OCO-2)



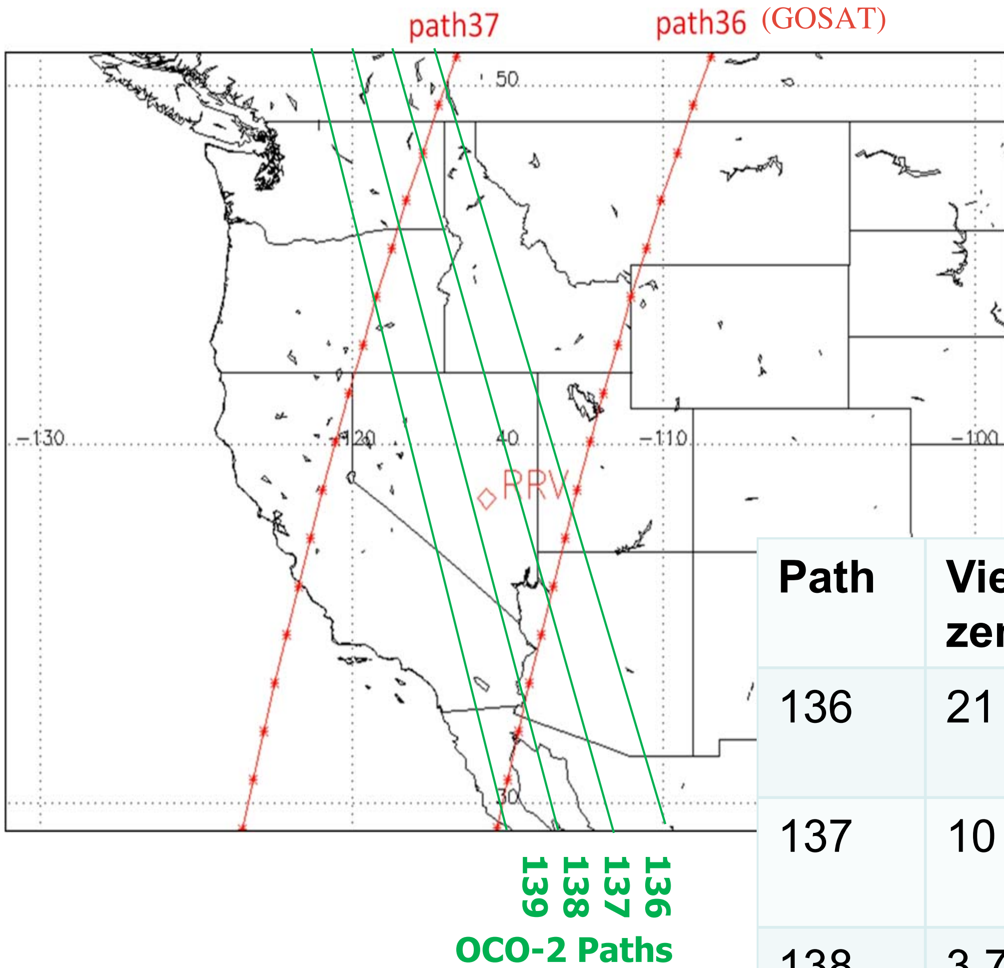
Launch date	July 2, 2014
Instrument	
3 Spectrometers "Channels"	0.76 µm - O_2 1.61 µm - Weak CO_2 2.06 µm - Strong CO_2
# Spectral channels	900
$\lambda/\Delta\lambda$	17,500 for O_2bands ; 21,000 for CO_2bands
Optics	Cassegrain telescope, F/1.8
CCD architecture	1024x1024 pixel Si/ $Hg_{1-x}Cd_xTe$ (MCT)
Swath width	10 km
Sample angular FOV	8 samples (sum of 20 pixels) within 14 mrad FOV
Sample spatial FOV	1.25 km crosstrack x 2.2 km downtrack
On-board calibrator	3 lamps/ reflector assembly Solar attenuator, Dark cover.
Requirements	
X_{CO2}	1 ppm (0.3%)
Absolute radiometric	±5%
Channel relative	±1%
Sample relative	±0.1%



RDF summary: solar
(L. Chapsky)



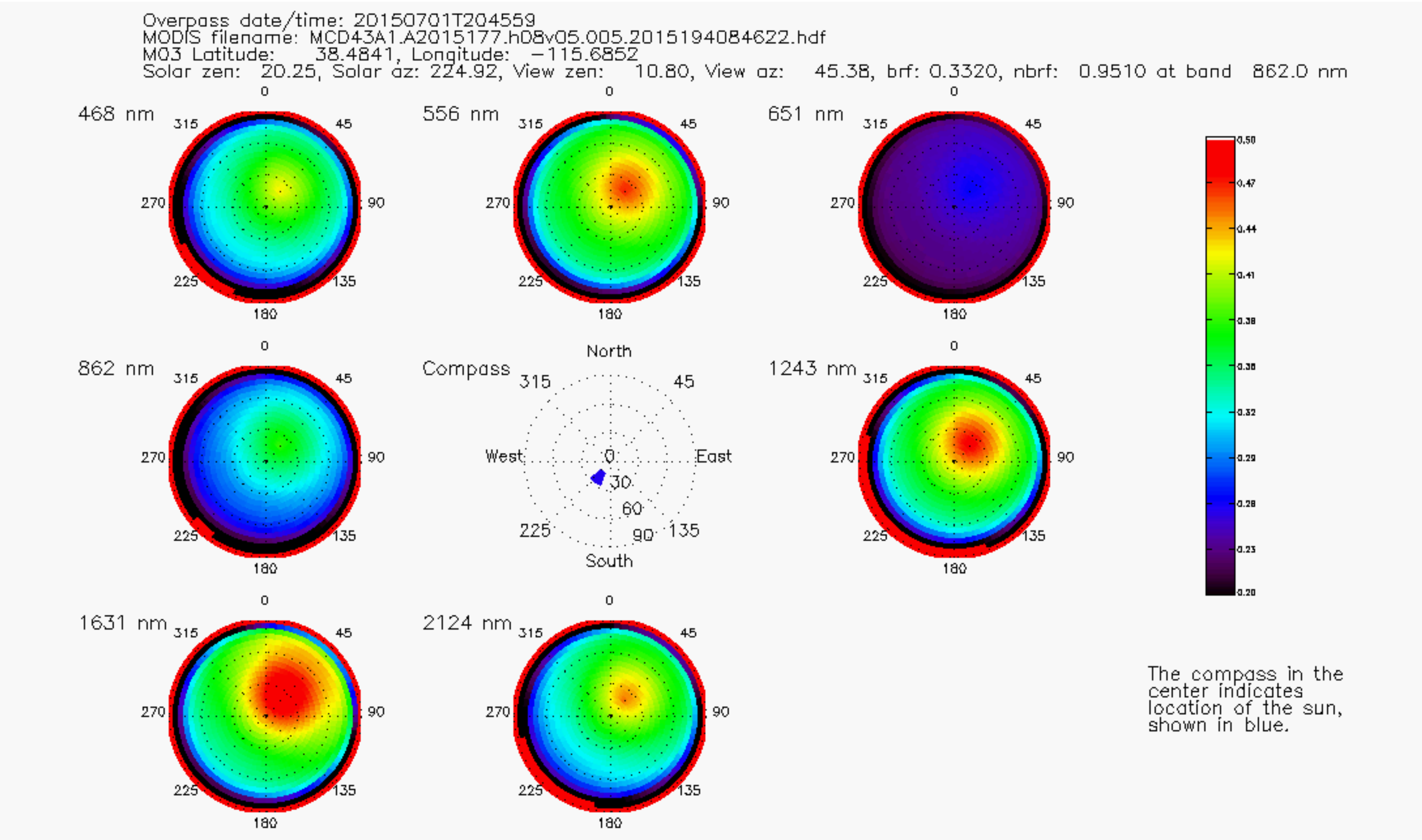
OCO-2 views of Railroad Valley (RRV)



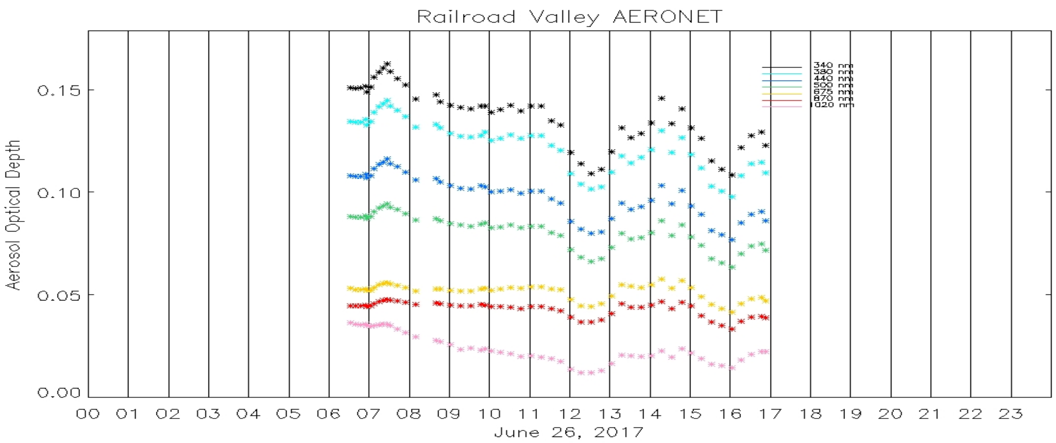
- OCO-2 views RRV in a targeting mode from Paths 136 – 139. Preferred path 138 (near nadir).
  - Overpass time, 20:40 – 21:00 UTC
  - June VicCal campaigns support both OCO-2 (paths shown in green) and GOSAT (paths shown in red)

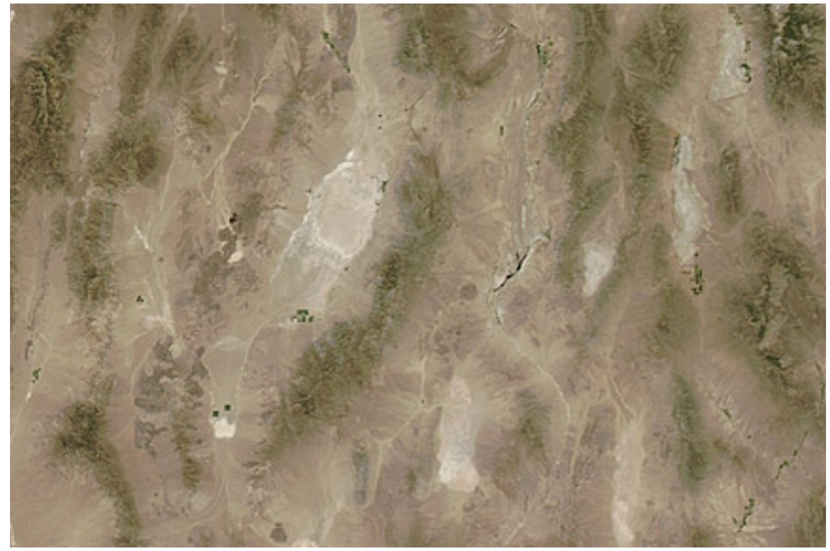
Path	View zen, °	Azimuth view	Example
136	21	to west, away from hotspot	2017-06-29
137	10	to west, away from hotspot	2016-07-03
138	3.7	Closest to nadir	2017-06-27
139	13	to east, into hotspot	2016-07-01

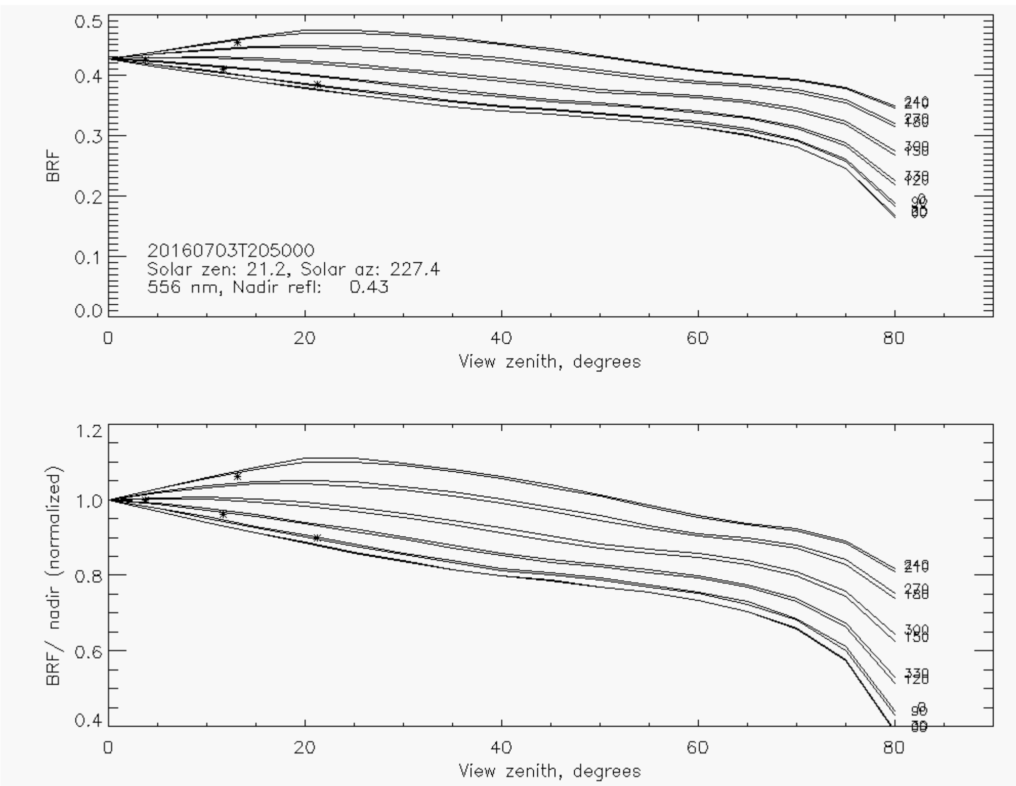
MODIS BRF product

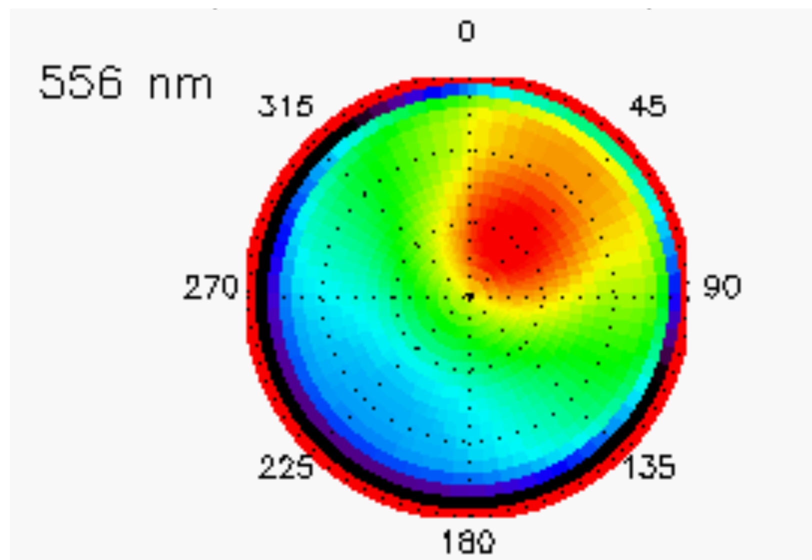


"Golden Day"
27Jun2017 Path 138

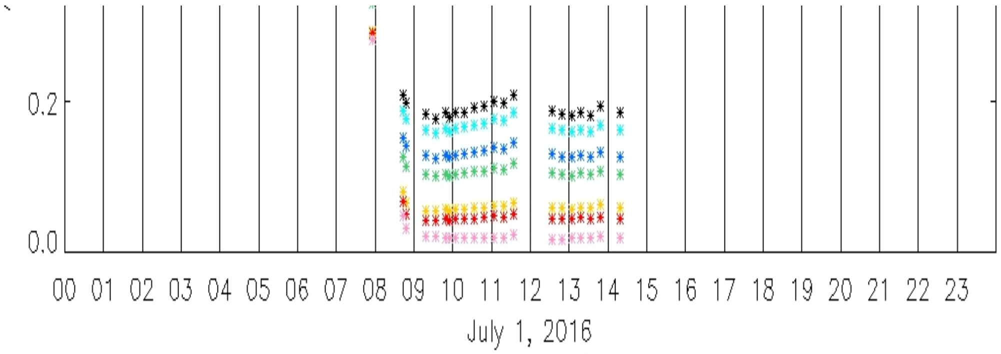


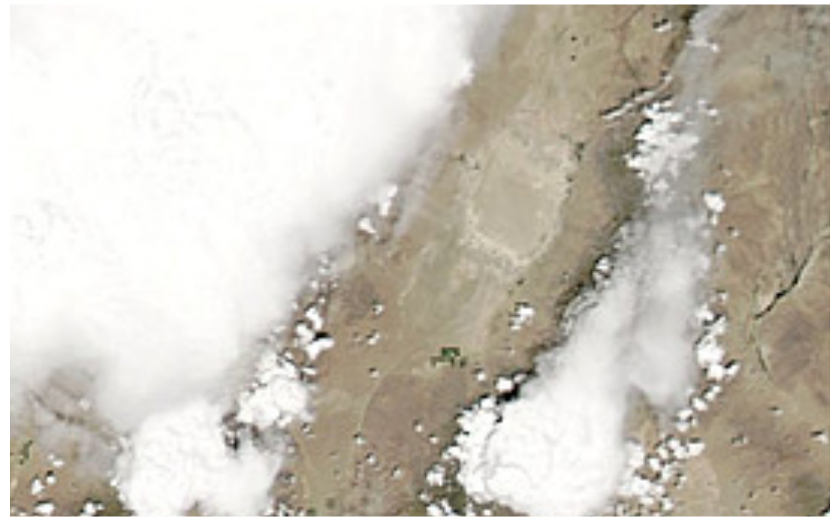


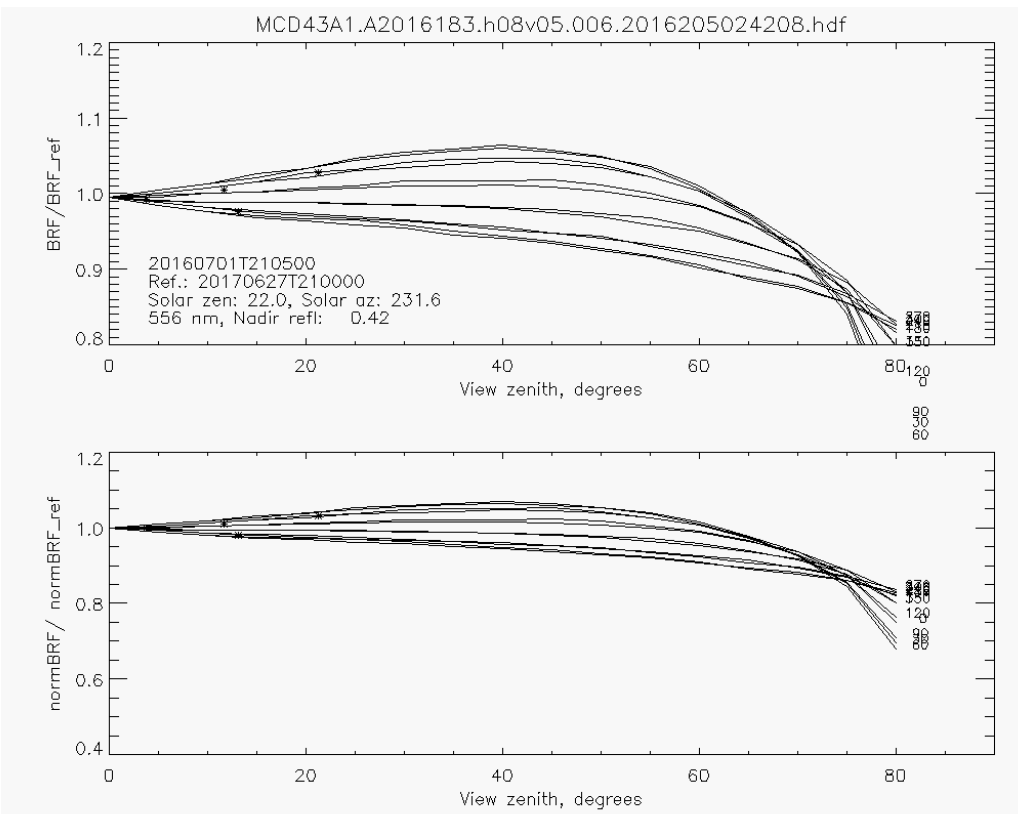


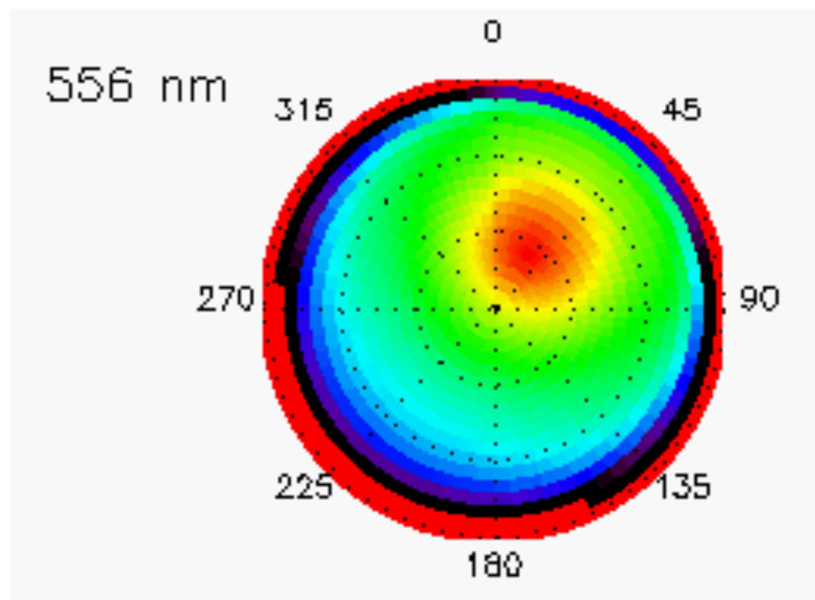


01Jul2016 Path 139

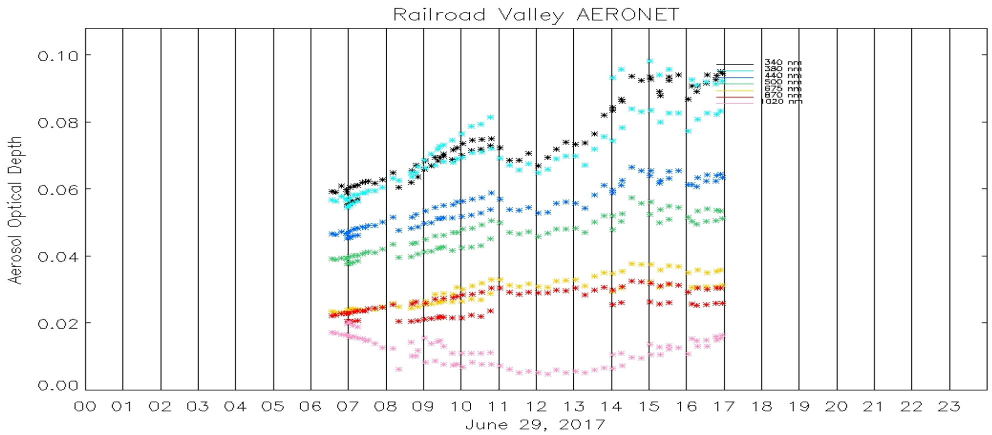


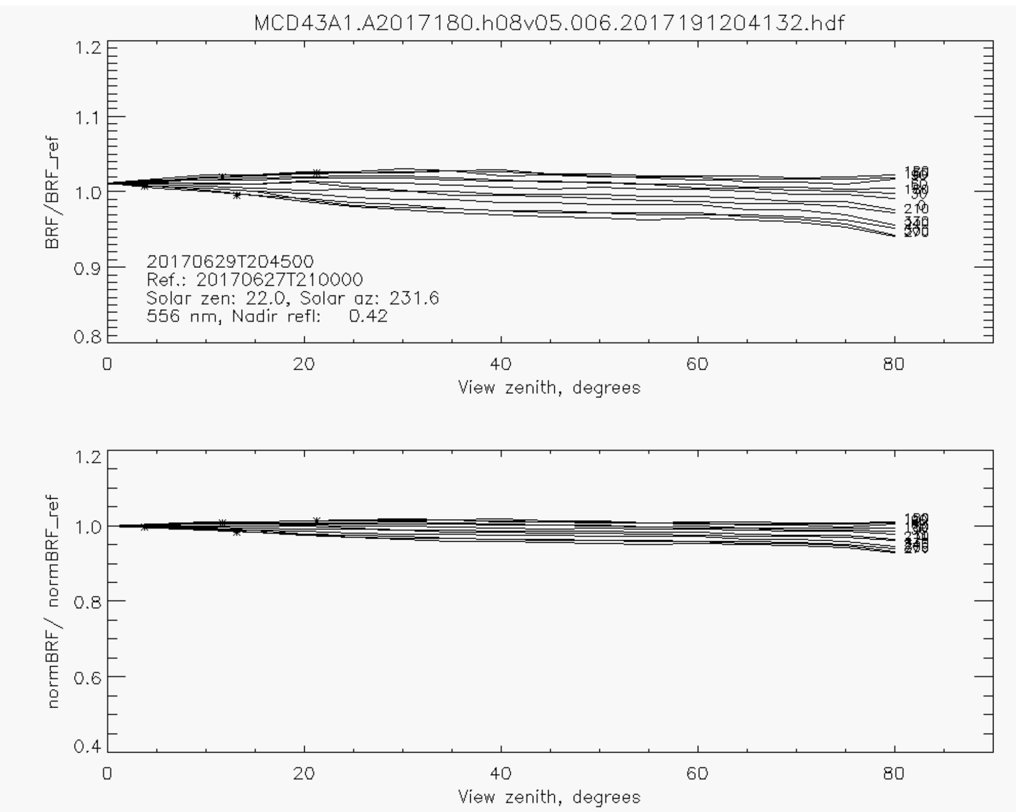


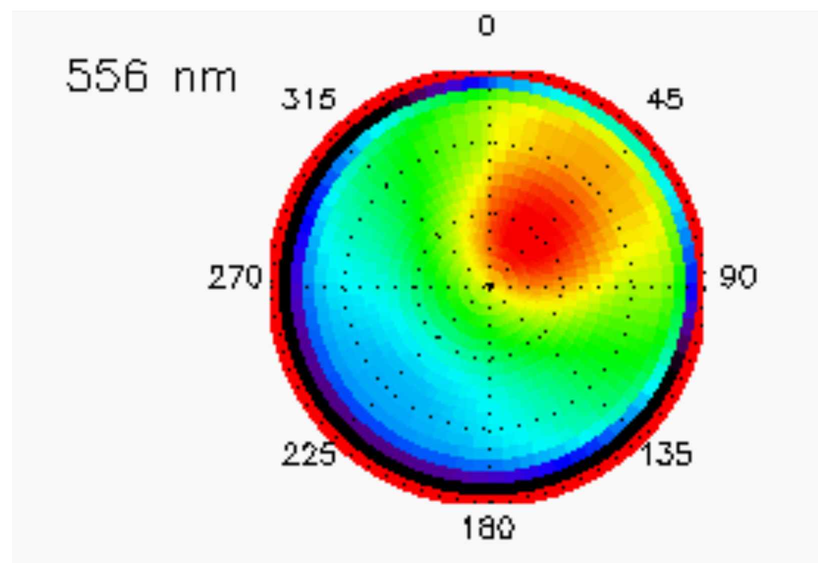




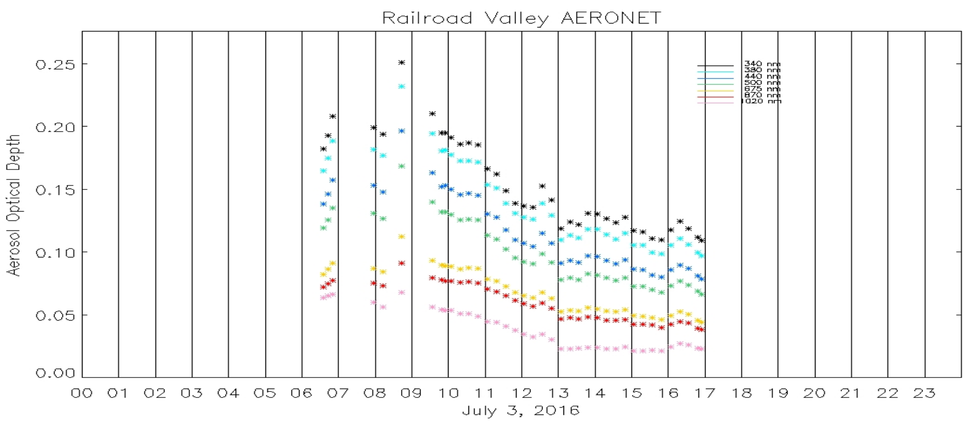
Largest uncertainty case
29Jun2017 Path 136

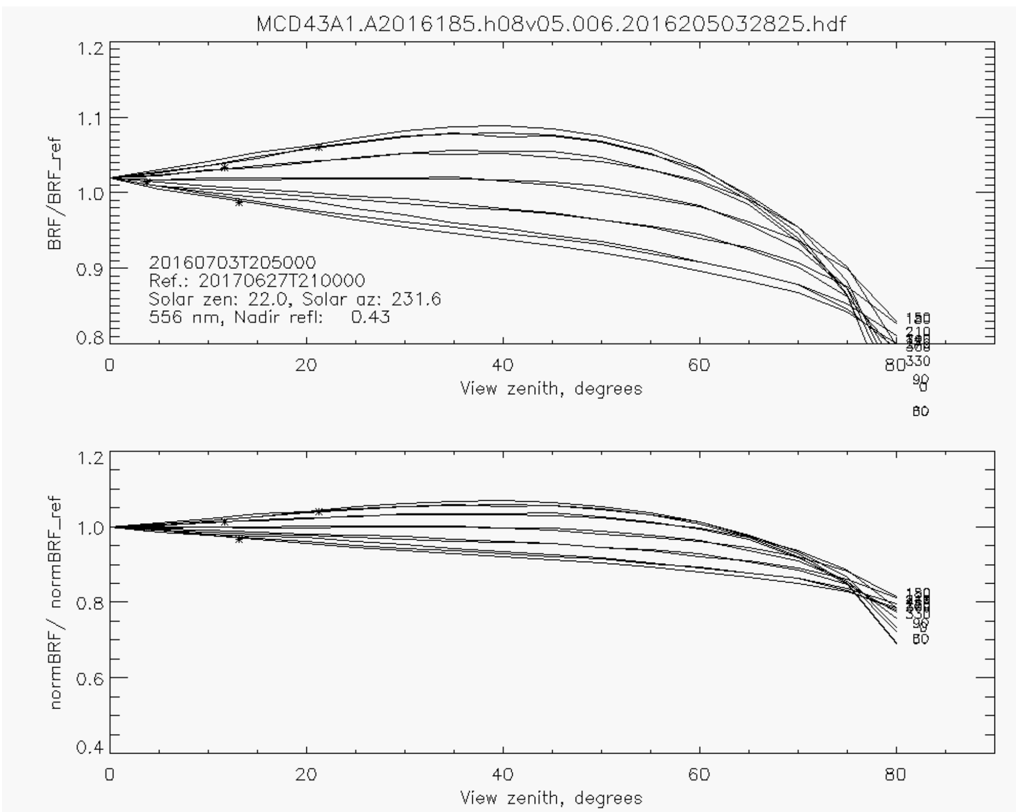


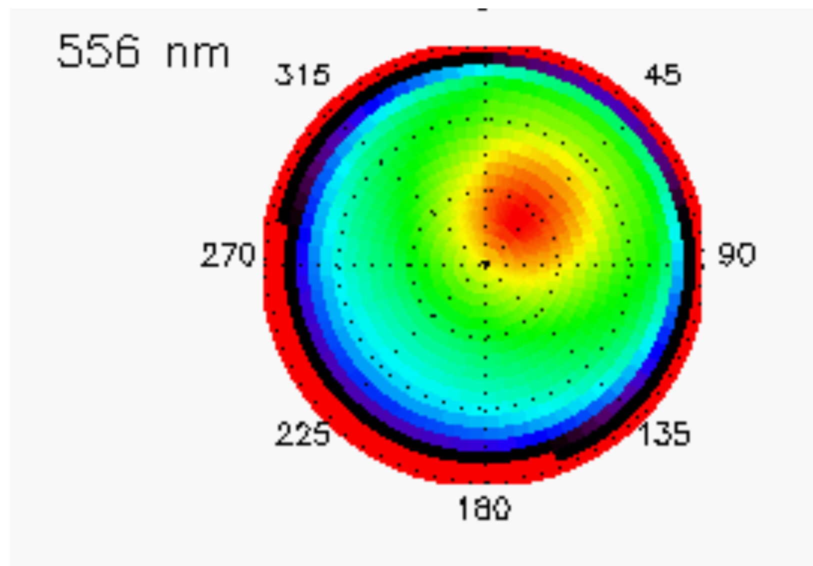




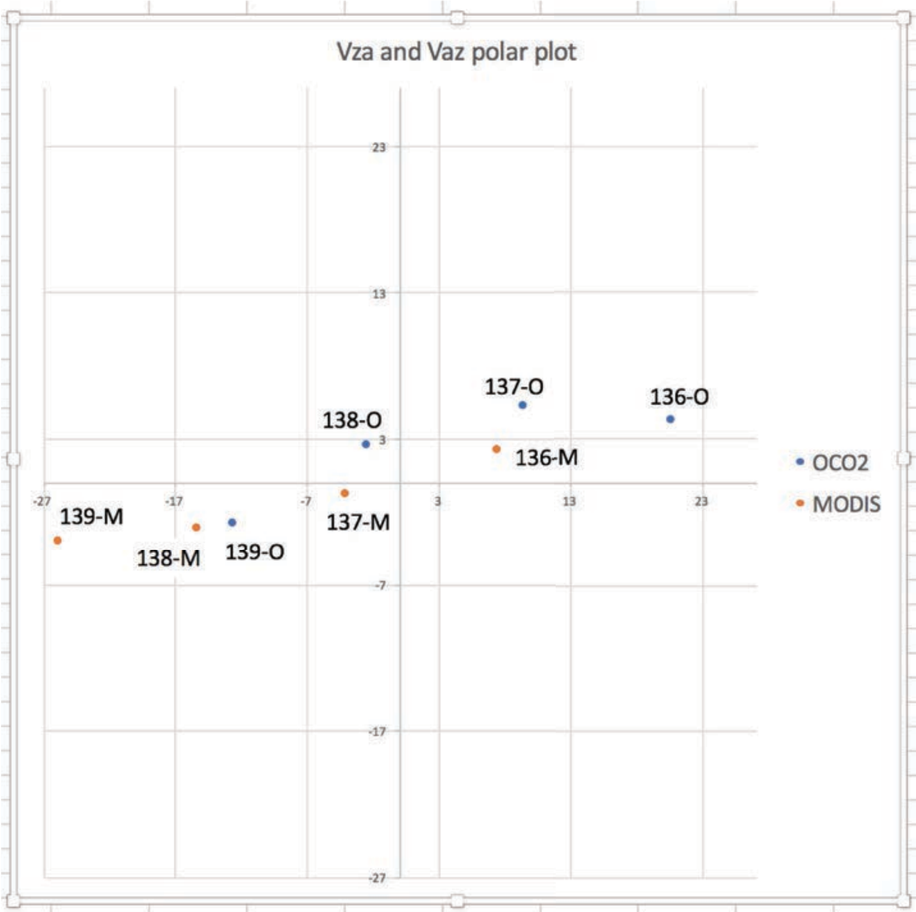
03Jul2016 Path 137



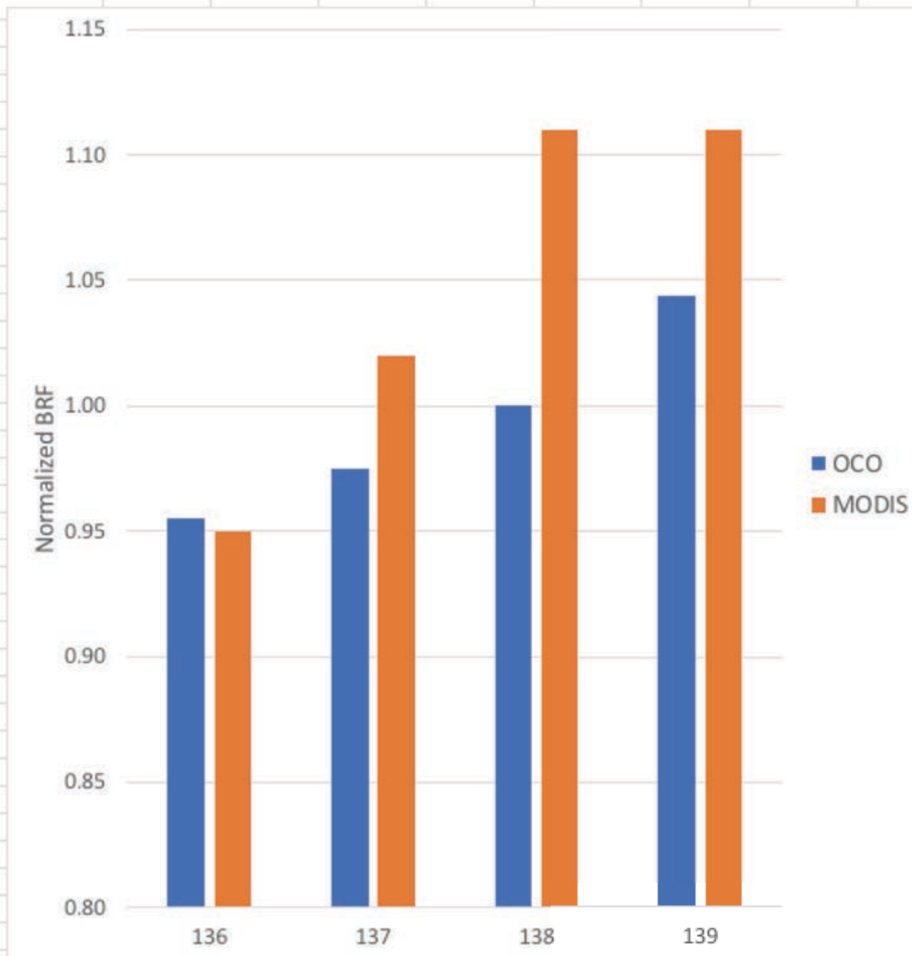




View angle, BRF vs. Path

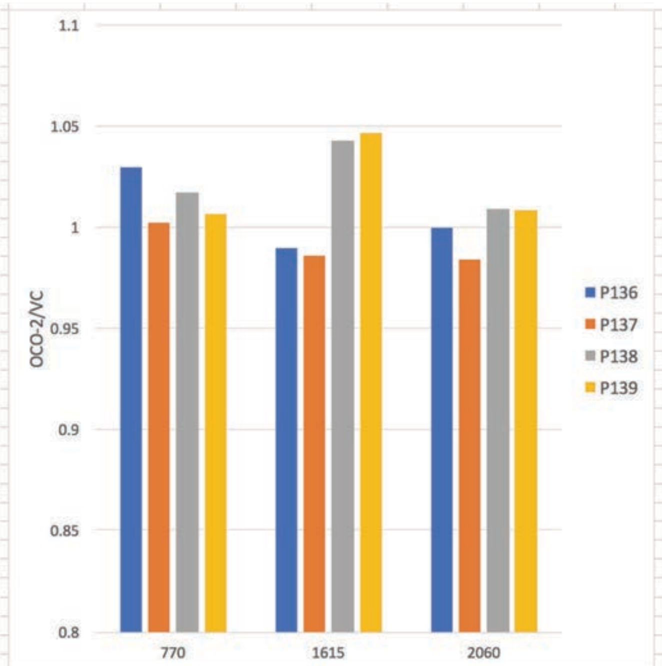


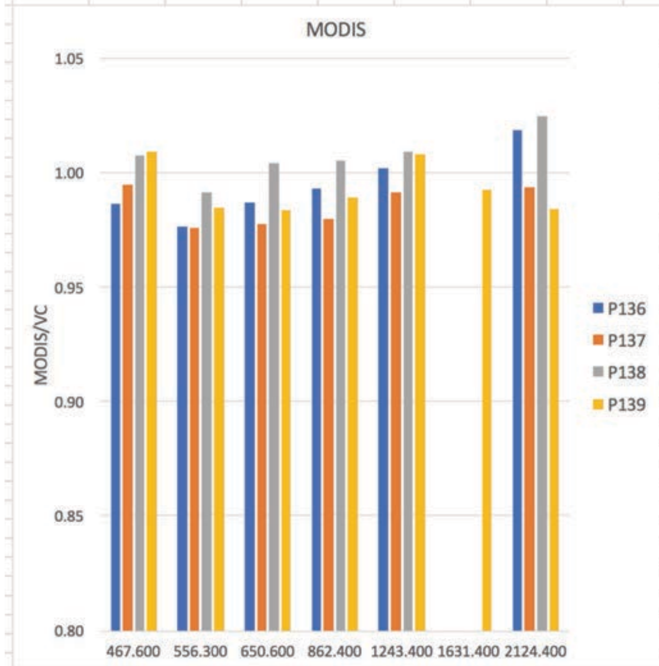
View angle polar plot

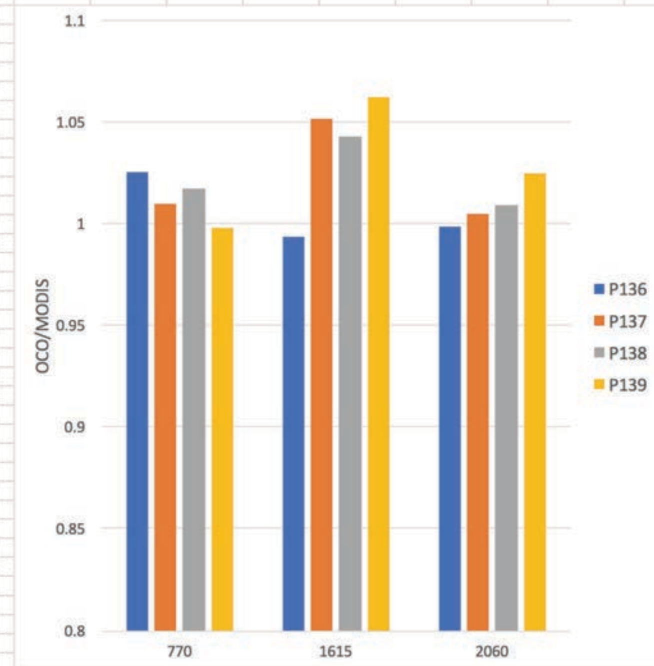


Normalized BRF vs. OCO-2 path

Vicarious calibration results







OCO-2/VC

MODIS/VC

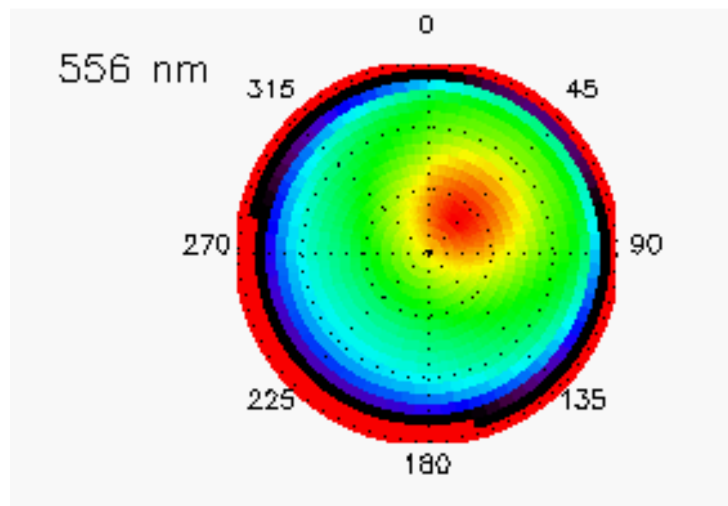
OCO/MODIS

	770	1615	2060
mean	1.01	1.02	1.00
stdev	0.01	0.03	0.01
rel stdev	0.01	0.03	0.01

	467.600	556.300	650.600	862.400	1243.400	1631.400	2124.400
mean	1.00	0.98	0.99	0.99	1.00	0.99	1.01
stdev	0.01	0.01	0.01	0.01	0.01	NaN	0.02
rel stdev	0.01	0.01	0.01	0.01	0.01	NaN	0.02

03Jul2016 Path 137

- The Portable Apparatus for Rapid Acquisition of Bidirectional Observation of Land and Atmosphere (PARABOLA) instrument measures surface off-nadir reflectance throughout the day
- Data critical for the calibration of sensors that view greater than 10° from nadir
- Installation of masts at various RRV locations permits easy setup during field campaigns

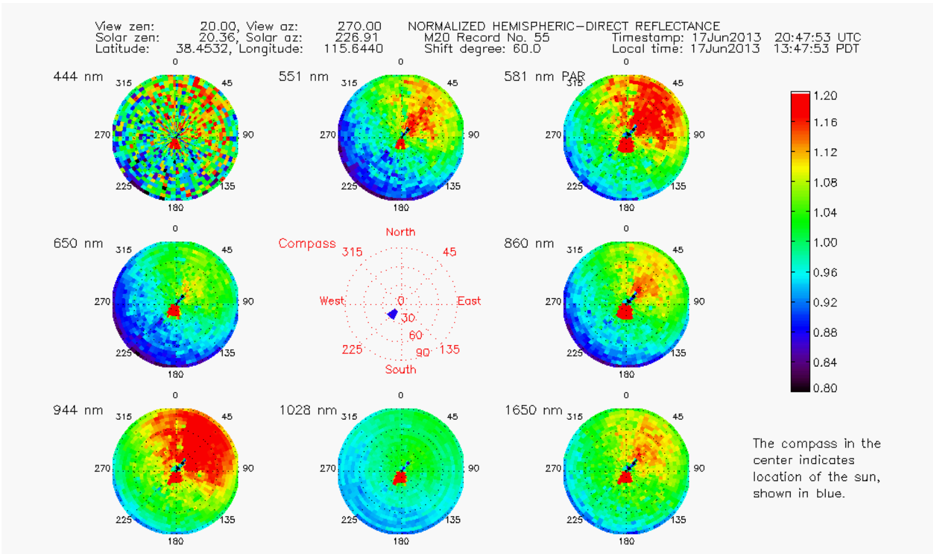


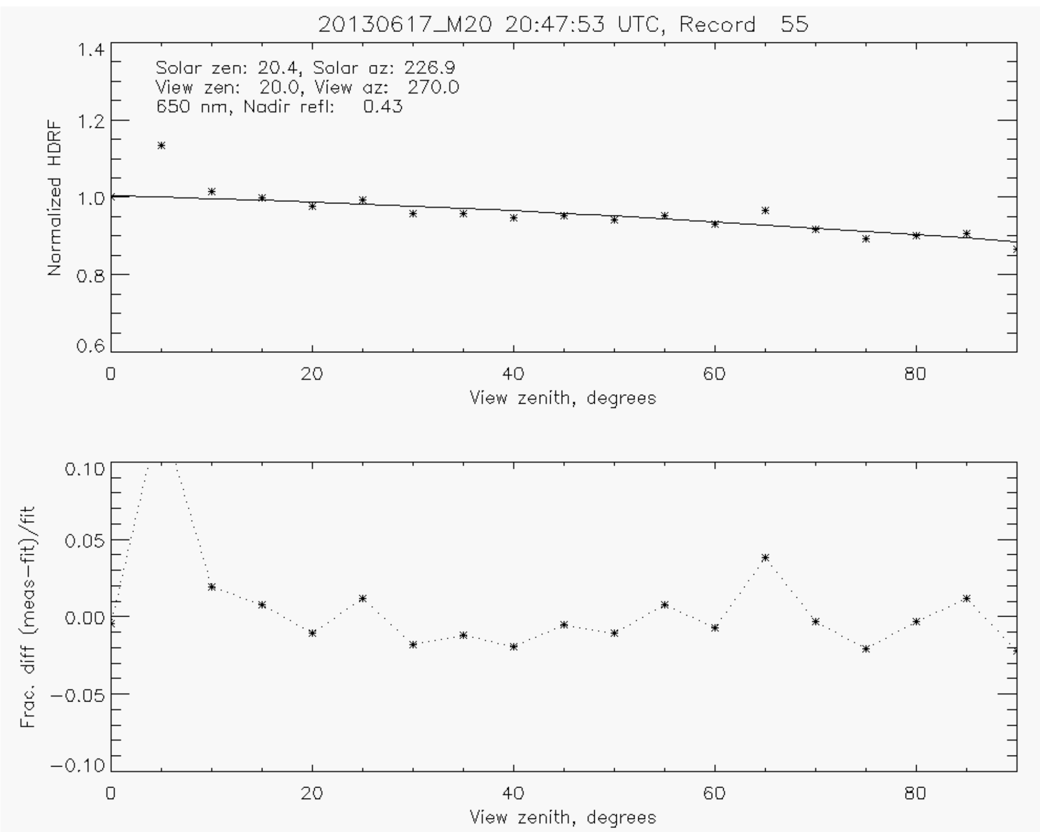
Jun 2013 M20

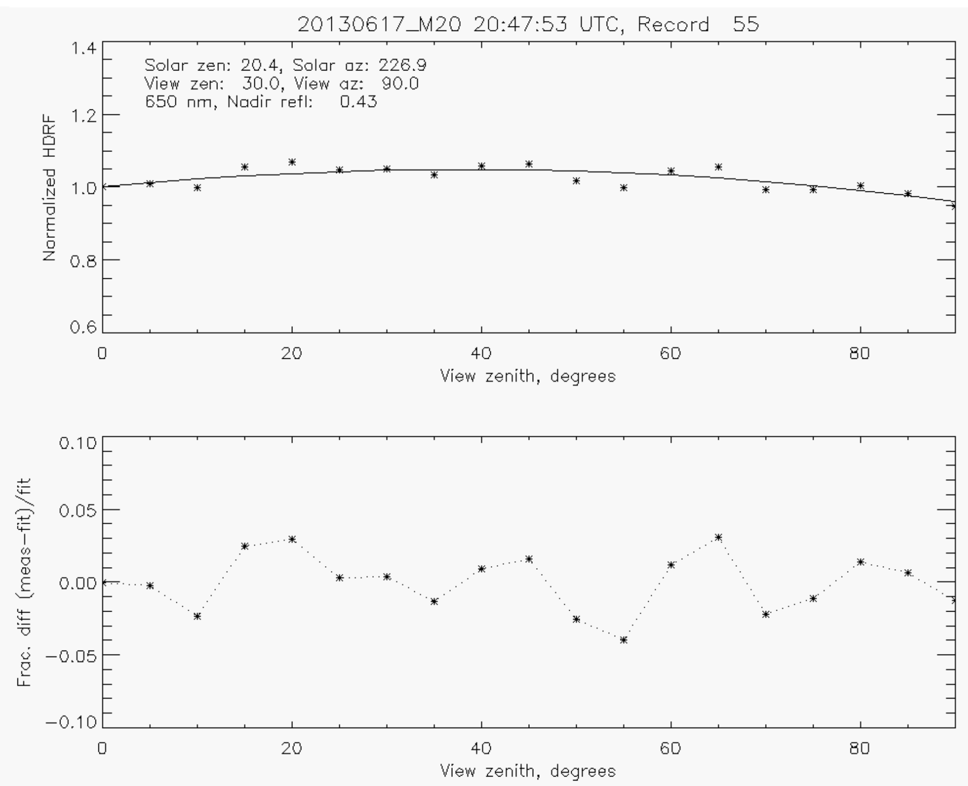
[M20 Movie]

[M03 Movie]

Solar zenith ~ 20deg







Questions?