Ocean Color Characterization Status for the *MOD*erate resolution *I*maging *S*pectroradiometer (MODIS).

R. H. Evans, E. J. Kearns, Kay Kilpatrick
Meteorology and Physical Oceanography
Rosenstiel School of Marine and Atmospheric Science
University of Miami

MODIS Color
Calibration Meeting
Feb 11-12, 2004

Calibration Related Activities of Greater MODIS community

Class 1 Potential Level-1 calibration coefficient sources of error

- **Excess radiance on the MODIS solar diffuser (SD) due to Earthshine**
- **Excess radiance on the MODIS SD due to uncertainties in the effects of SD attenuation screen**
- **Uncertainty in the SD bi-directional reflectance (BRF) correction**
- **Uncertainties in the focal plane temperature corrections**

Class 2 – Maintaining calibration intra-orbit and inter-season

- **Stray light in the optical path from Earth view**
- **Detector-based temperature correction estimates**
- **Changing polarization sensitivity, accuracy of polarization characterization**
- **Uncertainties in the focal plane temperature correction**

Topic outline - Present status

Inter-detector imbalance across the focal plane
Mirror-side differences
Response-versus-scan angle imbalance
Instrument state changes
Instabilities in maintaining calibration both along orbit and seasonally

Issue areas:

- Sun glint - Stray Light in Earth observations - RVS and Level-2 m1 corrections
- SD degradation - LUT m1 accuracy
- Polarization - High latitude 4xx nm behavior
- Tracking between cal sources - RVS characterization
- BRDF -RVS characterization

Conclusions

- MODIS Terra and Aqua are relatively stable, slowly varying instruments.
- MODIS (T&A) exhibit similar trends (e.g. RVS), Terra has additional mirror side 1 to 2 trends not yet seen in Aqua.
- MCST L1 correction captures most, but not all, MODIS trends.
- However, at the level of accuracy required to produce climate quality ocean color, L1 data are required to be stable and accurate at the level of 0.25 to 0.5%. This level of performance exceeds that achievable by the on board calibrators and requires some form of vicarious calibration.

Conclusions

- Relative degradation of and temporal trends in MODIS calibration sources, e.g lunar, SRCA, SD, are not completely characterized. This contributes 1-2% error in blue band Lt over Terra mission, (10-20% nLw). Impacts RVS and possibly m1 corrections.
- Uncertainties in m1 calculation contribute a significant percentage of nLw uncertainty, order 10%, This is a large contribution to the forward or near real-time processing. Suggest rapid update to L1 LUT to replace measured m1 with filtered m1.
- 412 and 443 bands show pronounced trend to low nLw relative to SeaWiFS, order 20-60% nLw at high solar zenith angle, >45 deg. Possible cause is error in polarization correction (polarization correction tables).

Conclusions

- Generation of stable L1 LUT and L2 corrections sufficient to produce climate quality ocean color fields is an extremely challenging but achievable task.
- For solar zenith angles < 25 degrees, MODIS retrieved nLw RMS (order 5-10%) is essentially equivalent to that measured by MOBY.
- Climate quality retrievals for all solar zenith angles is achievable once the 412 and 443 high solar zenith angle problem is solved.
- Low solar zenith angle problems with both MODIS, “excess light”, and MOBY, sun glint, measurements impart a seasonal 10-20% error in nLw by affecting the RADCOR RVS calculation. Problem solved by excluding summer time observation and interpolating RADCOR.
- Filter RADCOR to reduce noise in correction terms.

Magnitude of nLw error before and after correction

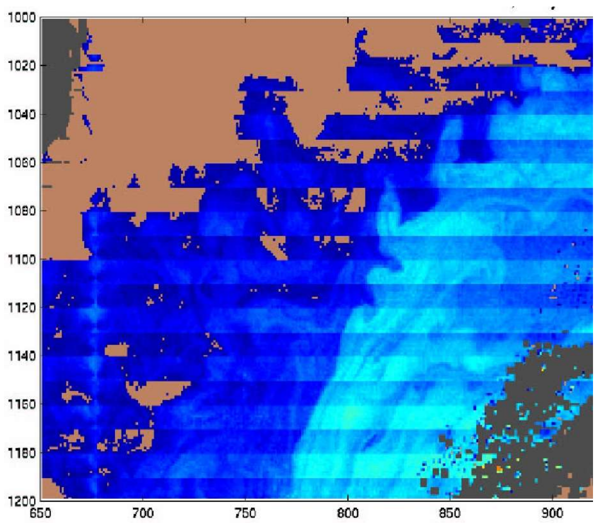
Types of correction:

Issue	**Effect on nLw images**	**Original variability after MCST corrections at L1B**	**Remaining variability after Miami corrections**	nLw
		Variability	Variability	Quasi-random
Inter-detector	Occasional striping, cross-scan variation	+/- 3% at center of scan +/- 6% at edges of scan	<1% at center of scan +/- 3% at edges of scan	3% 412 nm** 3% 551 nm**
Cross-scan	Mis-matches between adjacent orbits	30% @412 nm 30% @551 nm	<1%	3% 412 nm** 2% 551 nm**
Mirror-side	View Zenith Angle Dependent Banding	15% @412 nm 6% @551 nm	<1%	<1% 412 nm <1% 551 nm
Absolute calibration	Temporal variations	4%+/ - 15% @ 412 nm	<1% blue bands <4% green bands	10% 412 nm 10% 551 nm

North-south trends | temporal variation at sol zen >45 deg | blue band low by up to 60%

. Magnitudes of remaining nLw variability, both systematic biases and quasi-random variability in L2 products after MCST and the Miami corrections. Those quantities marked with asterisks (**) have a substantial portion of real geophysical variability included in the estimate.

Examples of Instrument effects before and after corrections – Figures 1a and b show the effects of mirror side and inter-detector banding. These instrument artifacts are a result of incomplete polarization correction (10 km wide mirror side banding) and detector gain characterization or an as yet unidentified source and introduces trends across the focal plane (1km stripes and mirror side trends). Mirror side difference, Figure 1a, is AOI and time dependent, order **±1.5% Lt;** Figure 1b shows the average detector-to-detector trends in gain that are necessary to minimize cross-focal plane trends and detector stripes, order **±0.2% Lt**.



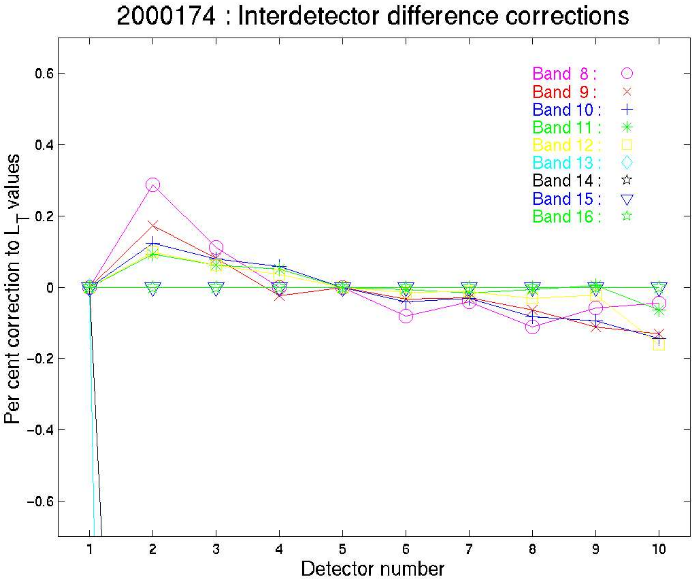
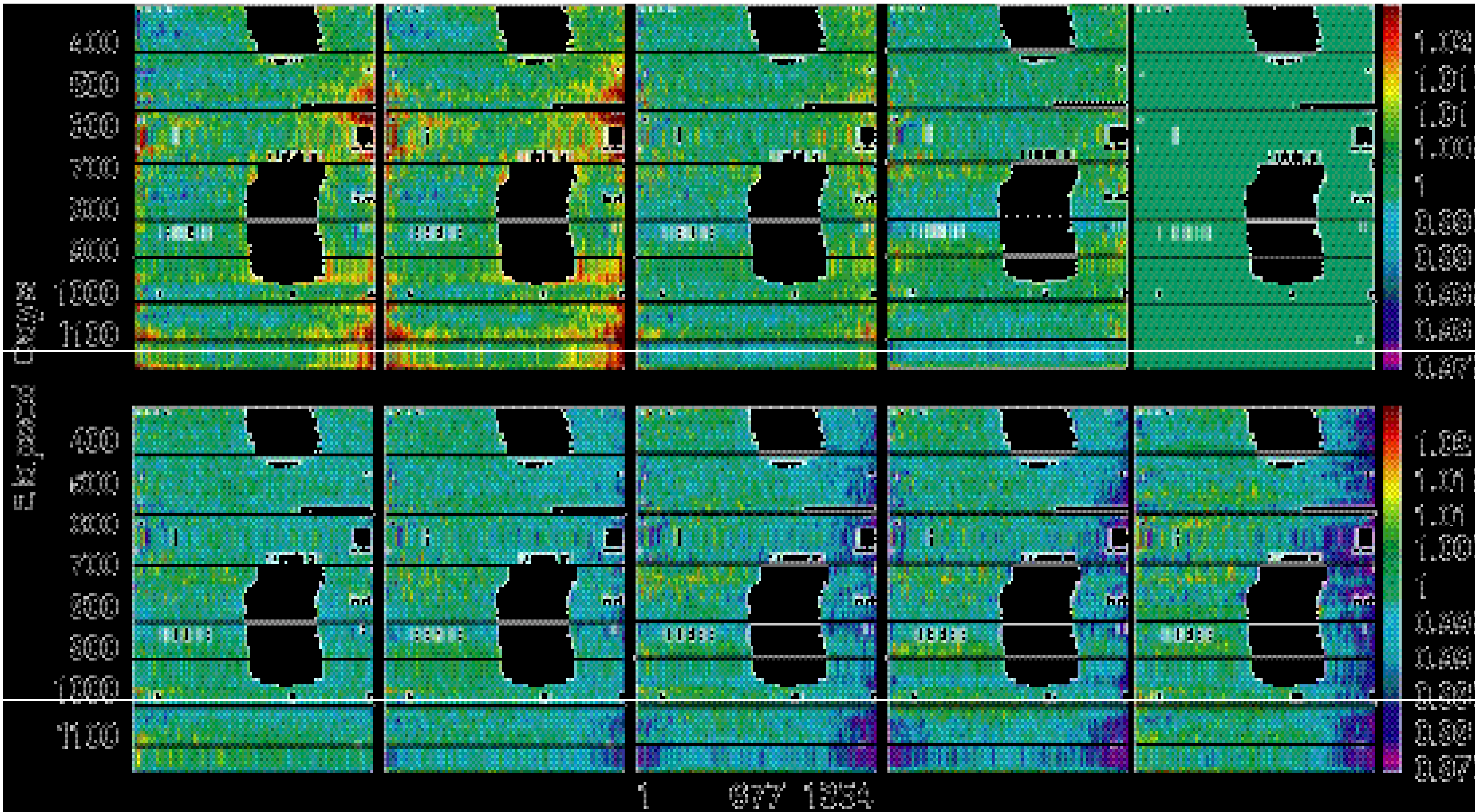


Figure 1a. Mirror Side Banding, nLw 412 November 1,2000 v3.0 .1 Level 1b no corrections applied beyond MCST

Magnitude of the inter-detector corrections required to achieve balance across the focal plane. Current corrections do not incorporate per detector RVS corrections, only average for all detectors, suggests polarization correction problem.

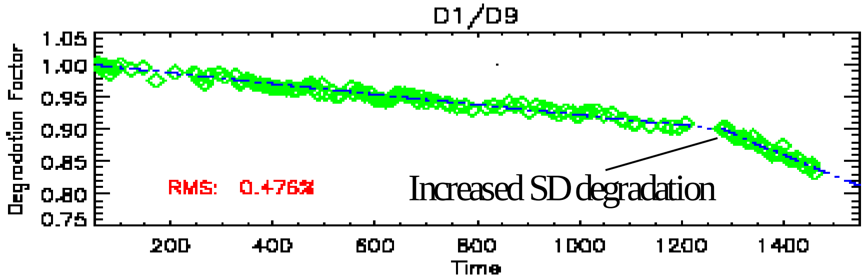


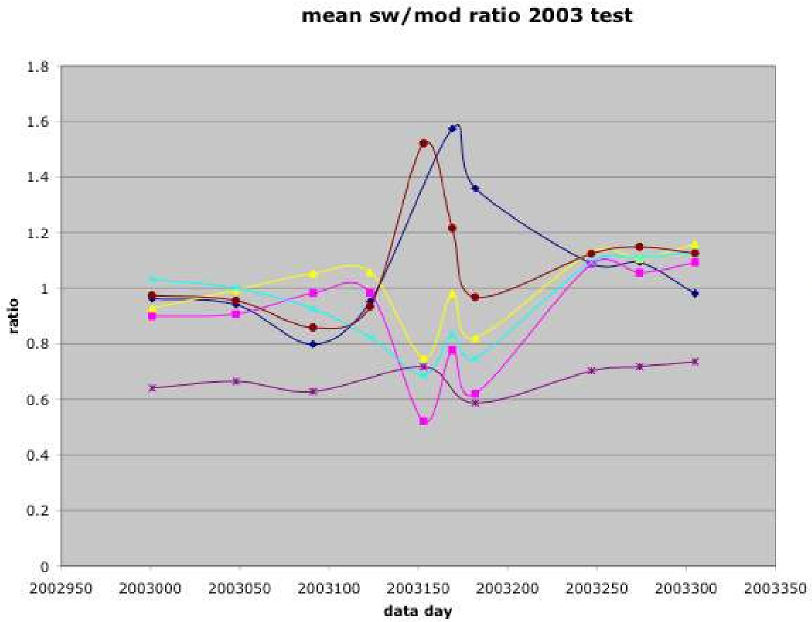
Pixel number cross-scan

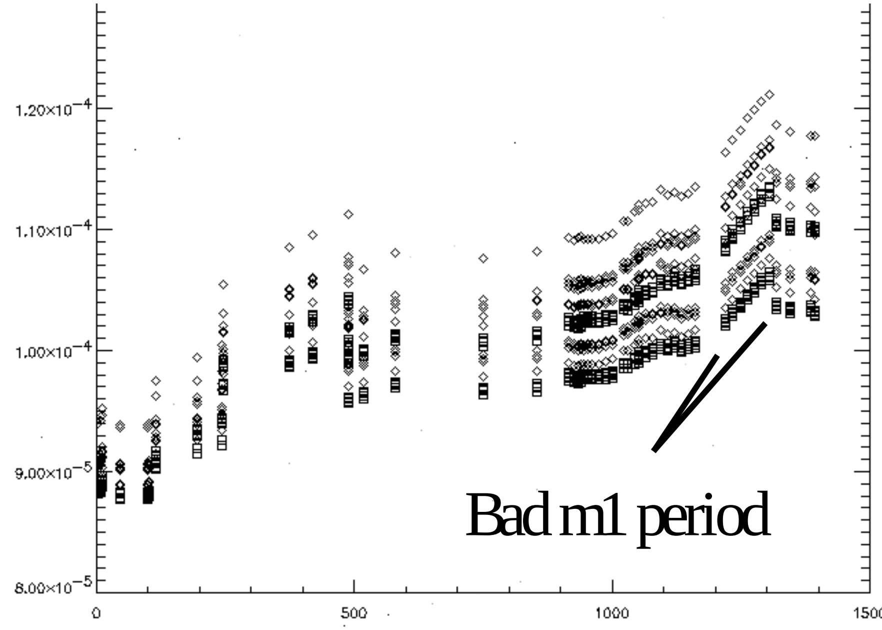
Fidelity of M1 calibration factors

- Temporal stability of the derived nLw is strongly dependent on accuracy of the Level-1 radiance calibration factors, 'm1'. Several problems have emerged over time and have been successfully treated by the MCST, e.g. vignetting in the Solar Diffuser Stability Monitor correction.
- Other corrections such as LUT forward stream m1 use the latest SD measurements without any time trending. This data set is subject to measurement noise. This noise can contribute to order 10% in nLw uncertainty. Retrospective processing using filtered m1 values can significantly reduce this problem.
- Trends in the MODIS calibrator suite, SD and SRCA, can be incorrectly diagnosed as trends in the MODIS scanner. This occurred following the event that resulted in the SD door remaining permanently open increasing the rate of SD degradation.

Change in Solar Diffuser degradation rate following diffuser door failure was initially incorrectly interpreted as increased instrument degradation rather than SD degradation. The Terra LUT was delivered with incorrect m1 values dates following May 26, 03. Incorrect m1 persist until late September, 2003. A corrected LUT has not been released for general use.







Atmospheric correction modifications

Sun glint correction - based on vector Cox-Munk slope distribution forced by model winds. Correction depends on fidelity of wind field and ignores any time history of wind-wave-current interaction. Use of a 'measured' rather than modeled sun glint distribution would minimize these limitations.

Polarization - HRG developed polarization correction with instrument polarization sensitivity provided by pre-launch measurements. Temporal change in relative scan mirror side to side performance and RVS (mirror response vs scan angle) suggest that further work is required in this area.

BRDF - uses Morel, Antoine, Gentillii, AO 2002

Flat field (detector, mirror side, cross-scan, time) Miami RADiance CORrection file)

Does the time history of Terra suggest future trends for Aqua?

Understanding the temporal evolution of Terra provides a window into potential changes that could occur with Aqua.

The next two figures present global MODIS-SeaWIFS difference fields. The MODIS fields were computed using only MCST L1b RVS correction. In both instruments, cross-scan differences appear in the 412nm nLw field as time progresses.

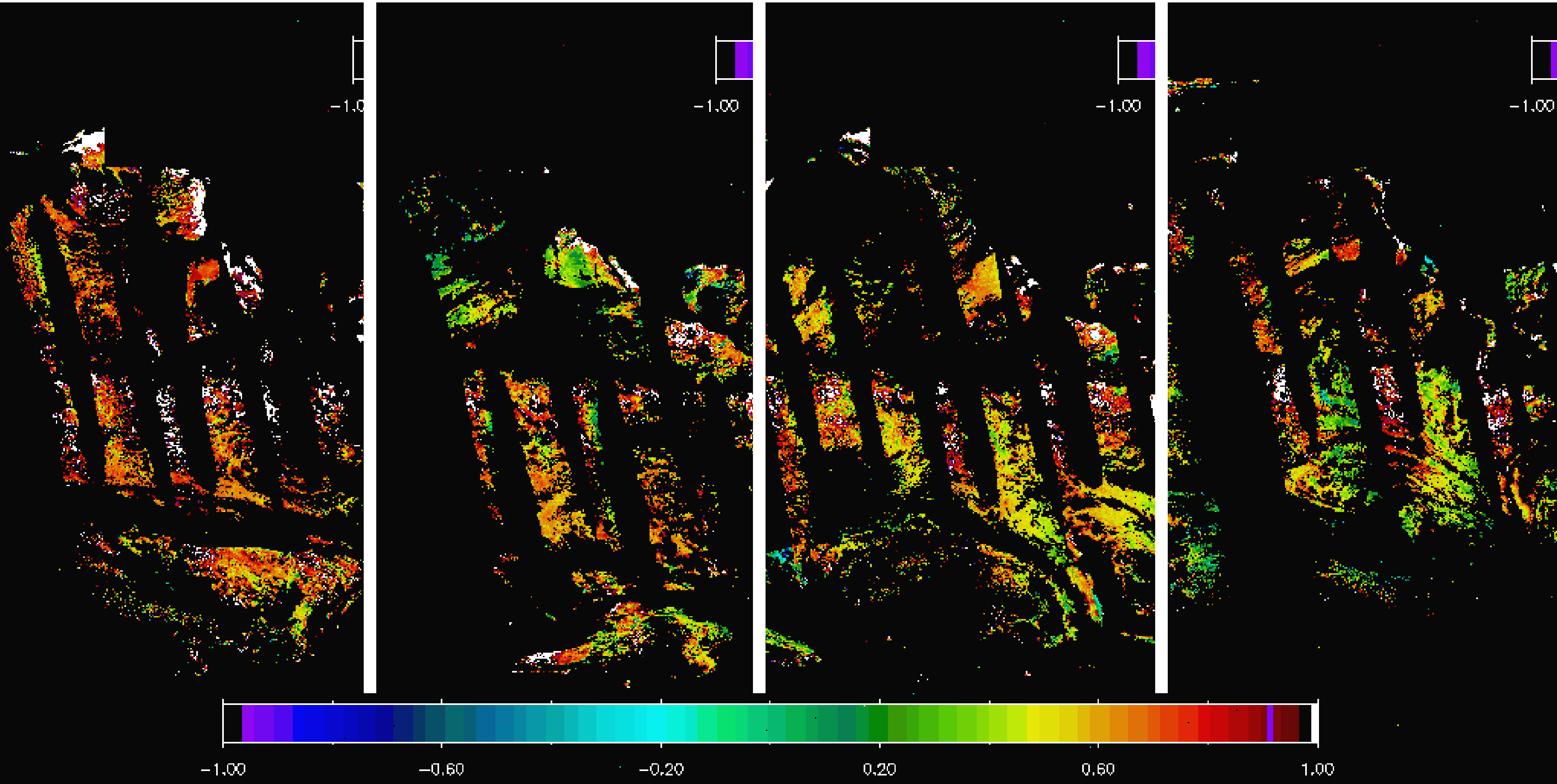
% Difference nLw 443 MODIS (Aqua-SeaWiFS)/SeaWiFS

West-East difference between Aqua and SeaWiFS increases with time

Comparison made without corrections applied to MODIS

For the first 9 months, Aqua cross-scan is relatively flat, between April and July, 2003 cross-scan differences appear

3 sep 02 1 jan 03 1 apr 03 10 jul 03



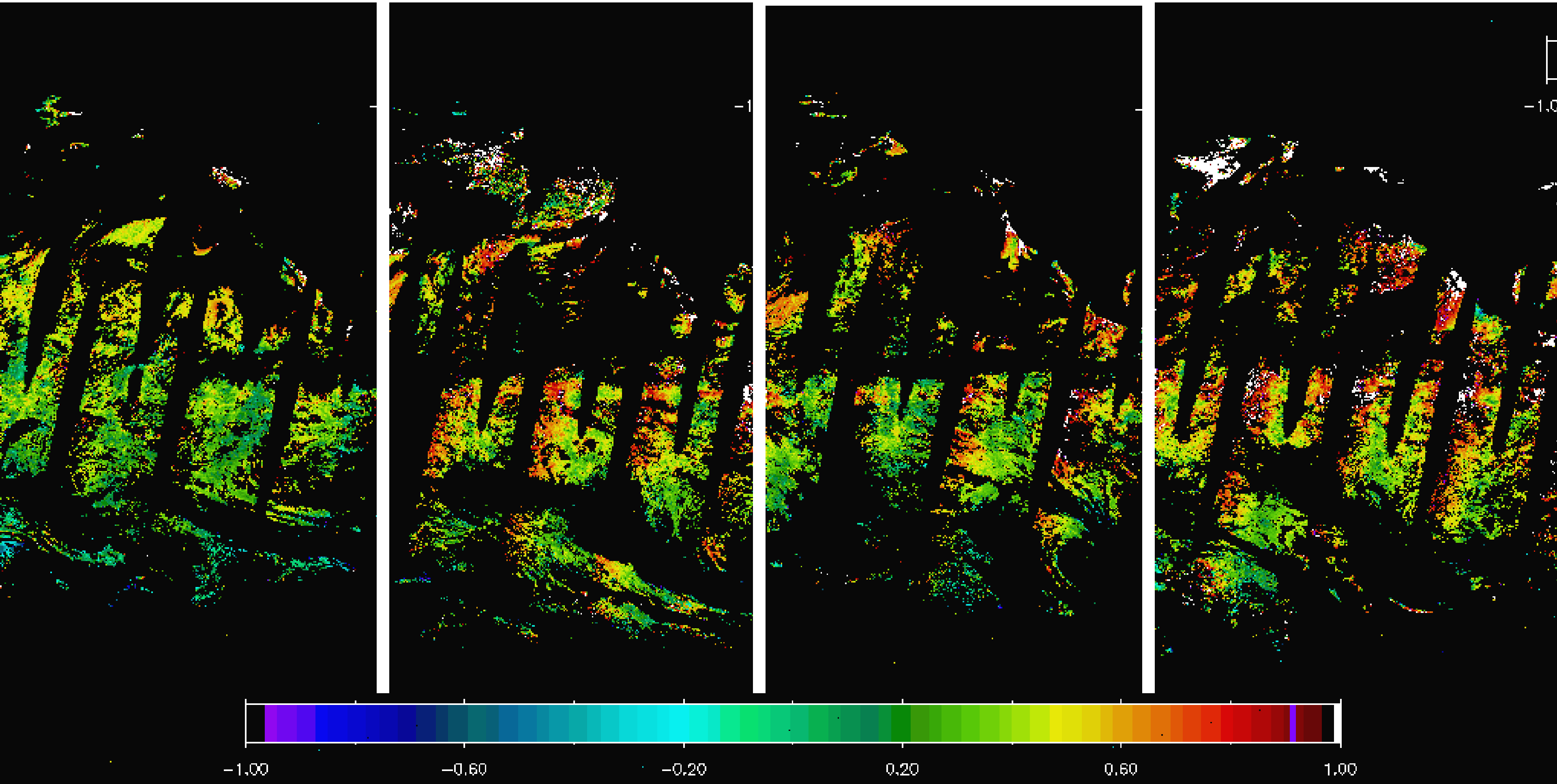
% Difference nLw 443 MODIS (Terra-SeaWiFS)/SeaWiFS

West-East difference between Terra and SeaWiFS increases with time

Comparison made without corrections applied to MODIS

Again cross scan differences appear 9 months of operation

18 Jun 00 | 30 Apr 01 | 24 Jun 01 | 1 Oct 02



Cross-Scan Correction

Is Aqua like Terra?

The following plots show cross-scan corrections of terra vs time. These are the factors needed to produce a flat field at Hawaii for nearly 4 years of data. MCST uses the lunar view (low AOI western part of the scan, pixel 80) , SRCA (scan center, 38 deg AOI, pixel 650) and Solar Diffuser (east, high AOI,~ pixel 1000) to compute cross-scan (RVS) corrections. The cross-scan behavior is relatively flat for winter observations (larger solar zenith angle) and shows a pronounced east/west trend during the low solar zenith angle, summer time observations. The magnitude of the summer oscillations increases with time.This pattern is present for bands 8-12 with 412 and 443 having similar trends, 488 its own, and 531 and 551nm being similar. The blue bands show an additional trend in that the part of the scan in the neighborhood of pixel 400 shows an increasing offset with time relative to the edges of the scan. Two conclusions could be drawn from these figures.

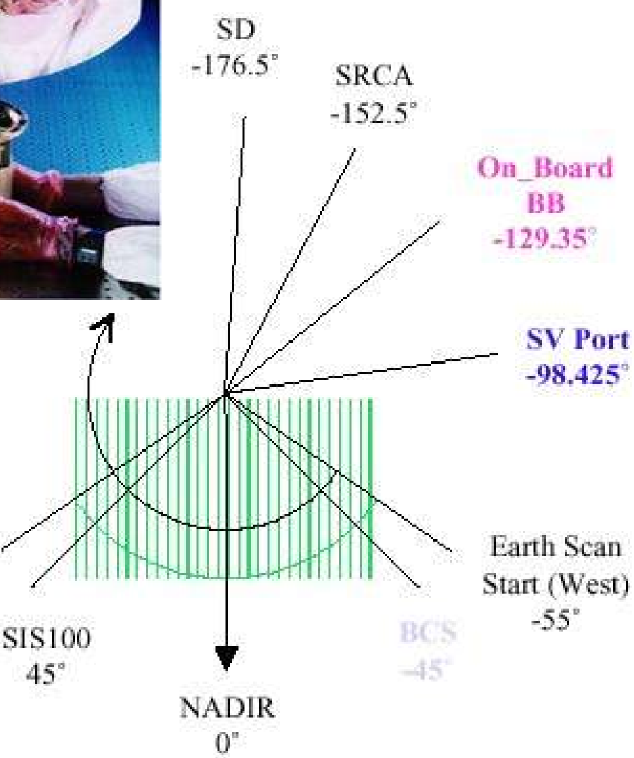
2) During summer there is a trend of increasing radiance going from west (small AOI) to east (high AOI, same AOI trend for Aqua) and that the slope of this trend increases with time. The trend does not show any evidence of sun glint, ie a change in slope east of the center of the field. Could this be a suggestion of stray light.

3) The western center trend seen in the blue bands could signify a relative calibration shift in the SRCA blue bands as compared to the lunar and solar diffuser calibration points.

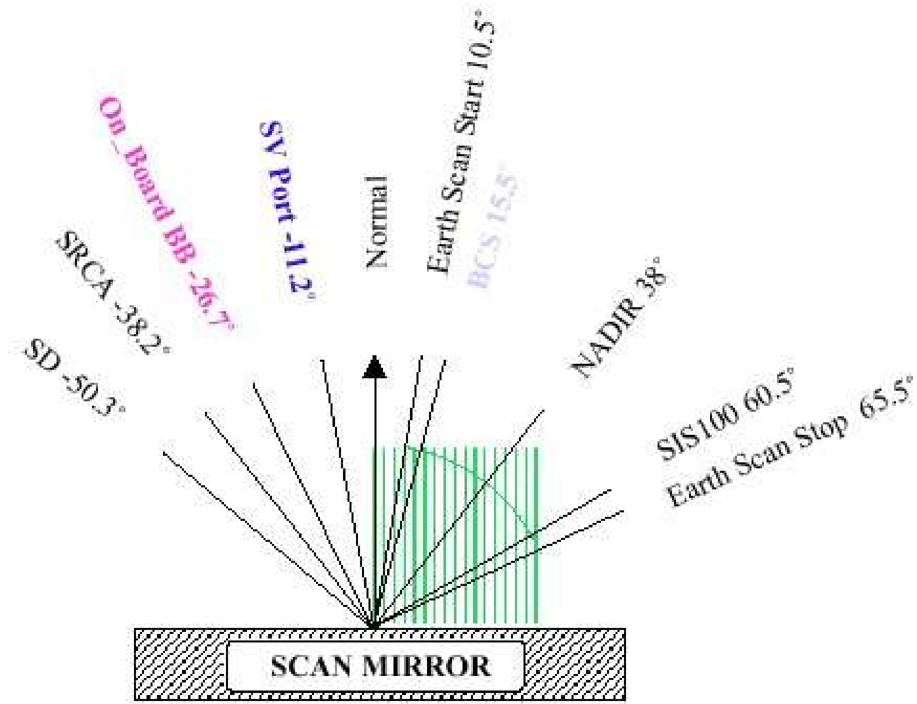
A quick examination of MODIS Aqua, SeaWiFS difference maps and Aqua RADCOR tables suggests that this pattern is present for both instruments.

Principal Scan Angles Mapped to Scan Mirror Angles of Incidence

From MCST



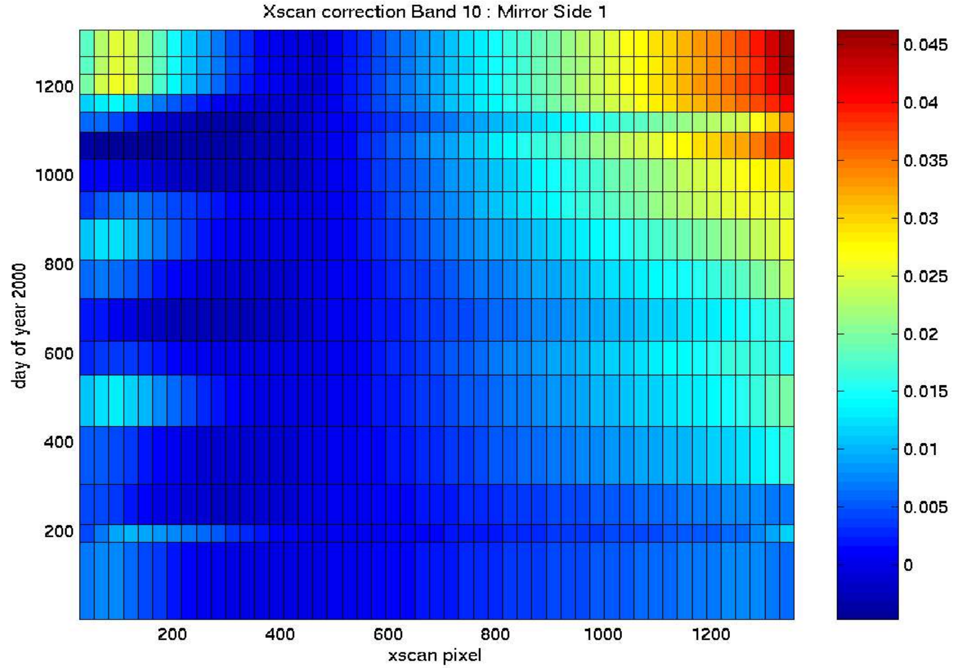
Principal Scan Angles
(Earth View: -55 to 55)

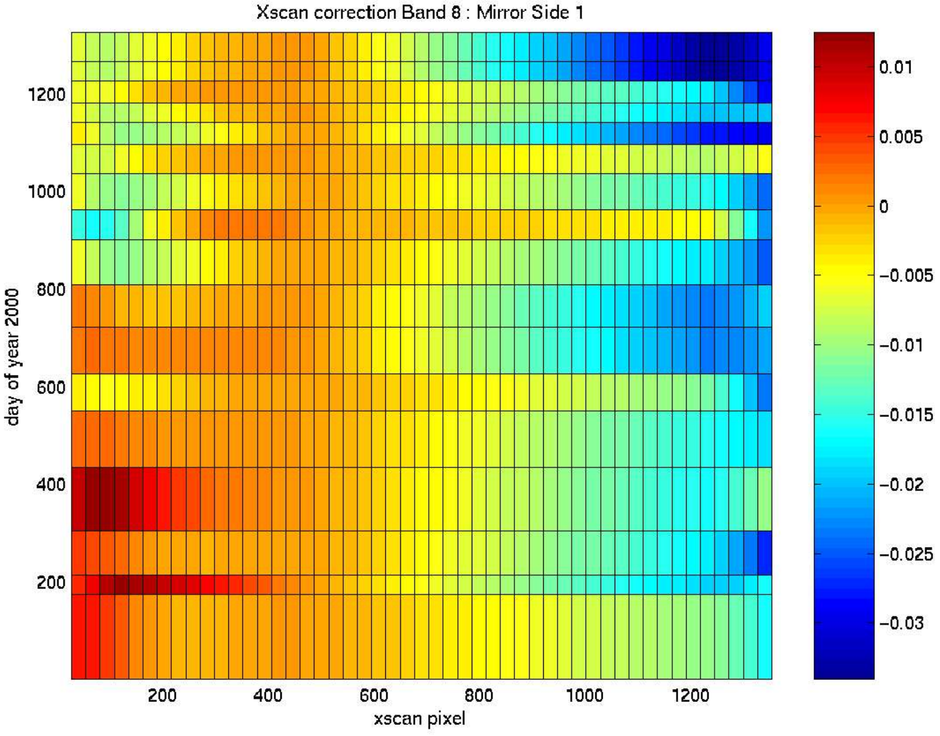


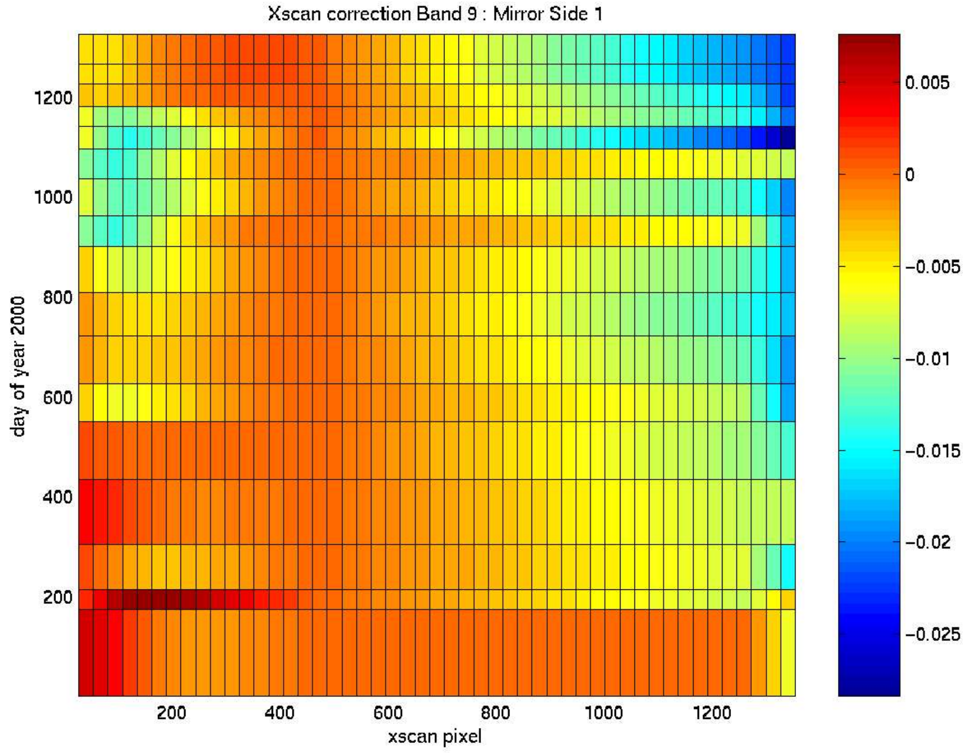
Angles of Incidence
(Earth View: 10.5 to 65.5)

SRCA (center) varies at different rate than lunar (west) and SD (east).

Terra cross-scan change, band 8, 9 & 10 added to MCST RVS to achieve a flat field at Hawaii. Trends normalized at pixel 475. Cross-scan relatively flat at launch and lunar, SD difference nearly constant over ~3.5 years. If the scan edge is used as a reference, the region around pixel 450 required increased correction with time while for band 10 the opposite is true. In the MCST RVS correction, the lunar view is used for start of scan, SRCA for middle and SD for end.

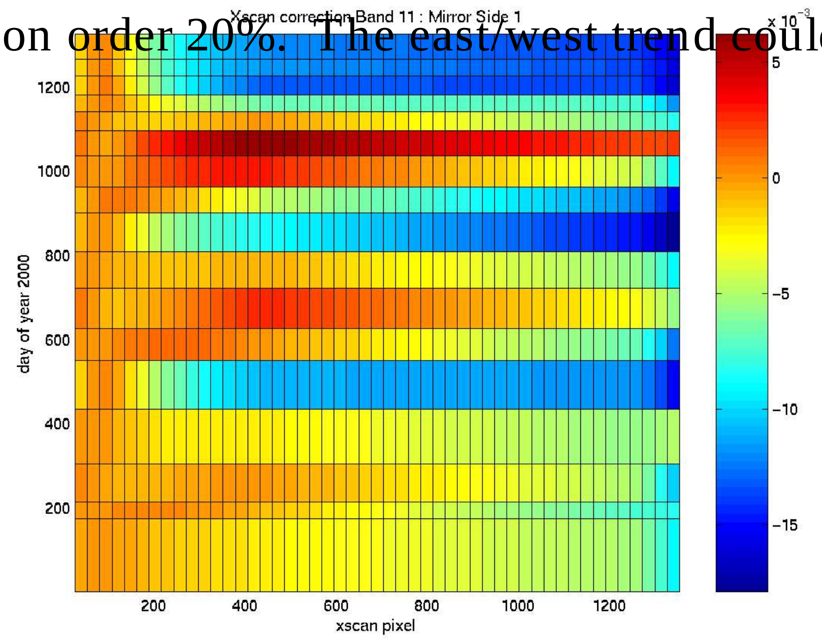


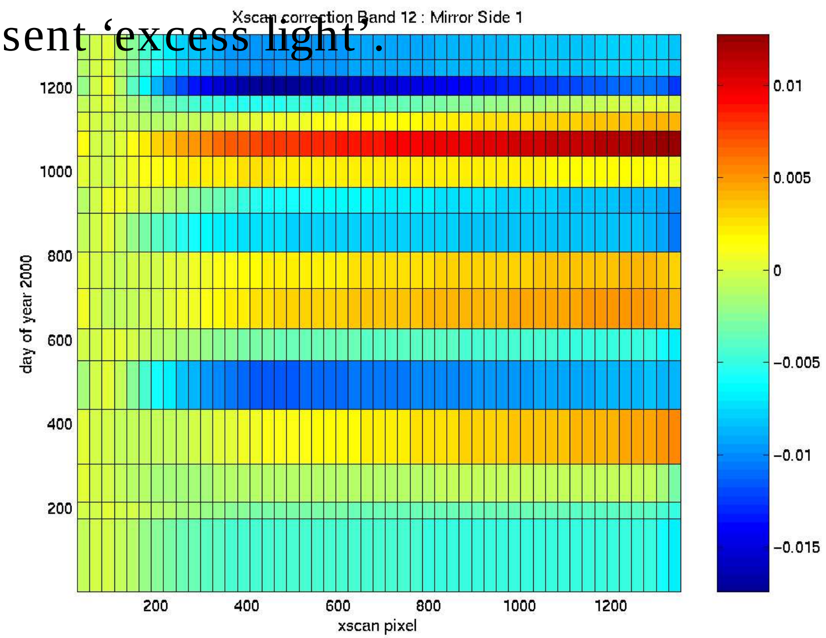




West side (Lunar normalized) cross-scan variation in bands 531 (left) and 551(right) nm bands

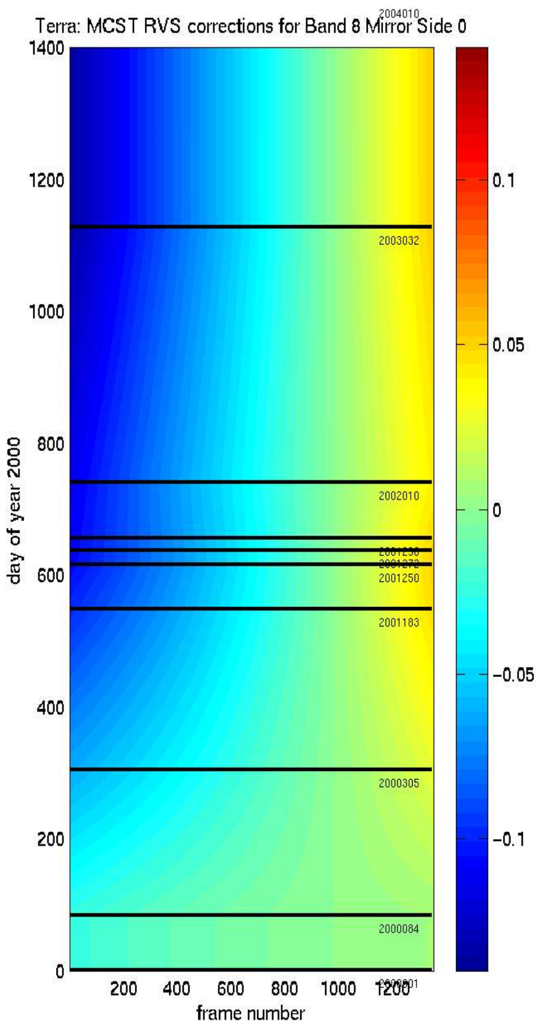
Cross-scan vs time for 500nm bands 11 & 12 normalized at pixel 80, lunar view. There appears to be little progressive trends as seen with the 400nm bands. However there is a yearly oscillation with low east correction (large sol zen angle) with the opposite cross-scan trend seen in the summer (small solar zenith angle). This trend could be interpreted as a spatial change, a function of solar zenith angle rather than a temporal change to be applied to an entire orbit. This interpretation would minimizes the east-west jump between adjacent orbits seen in the southern hemisphere July time frame images. nLw oscillations are on order 20%. The east/west trend could represent 'excess light'.

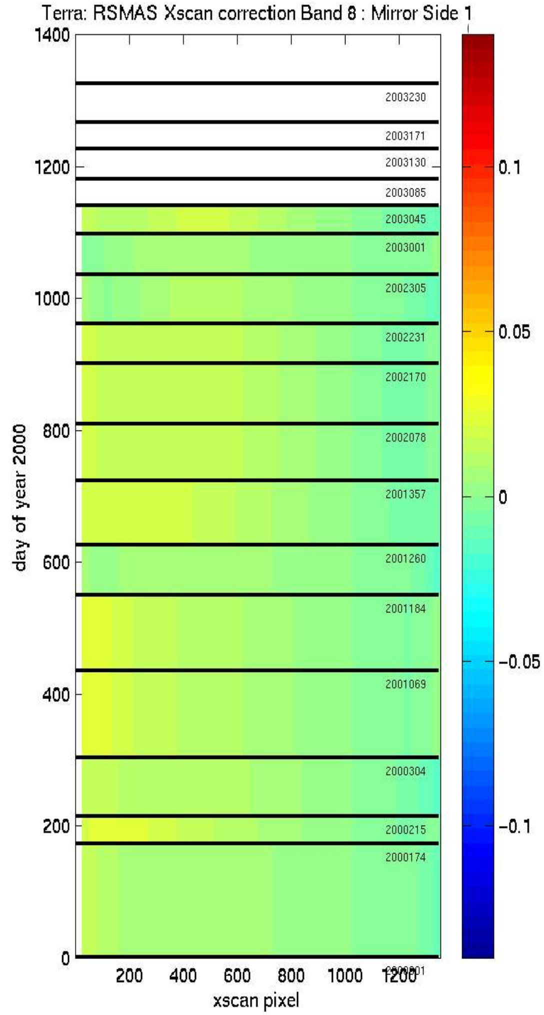




MCST RVS and Miami added corrections for Terra, 412nm, first mirror side, center under-corrected by ~1% over mission

Black lines show update times; each figure normalized to pixel 1000 (SD) and uses same scale

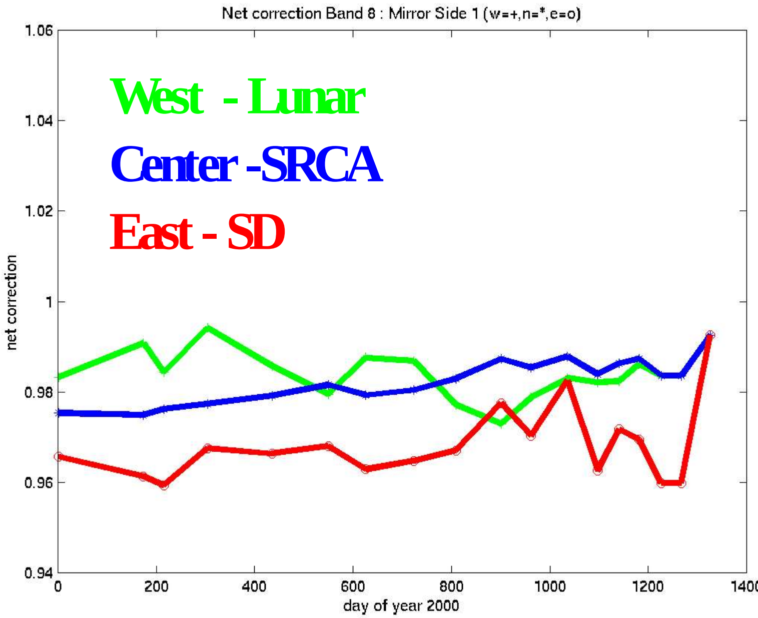




Total radcor correction vs time

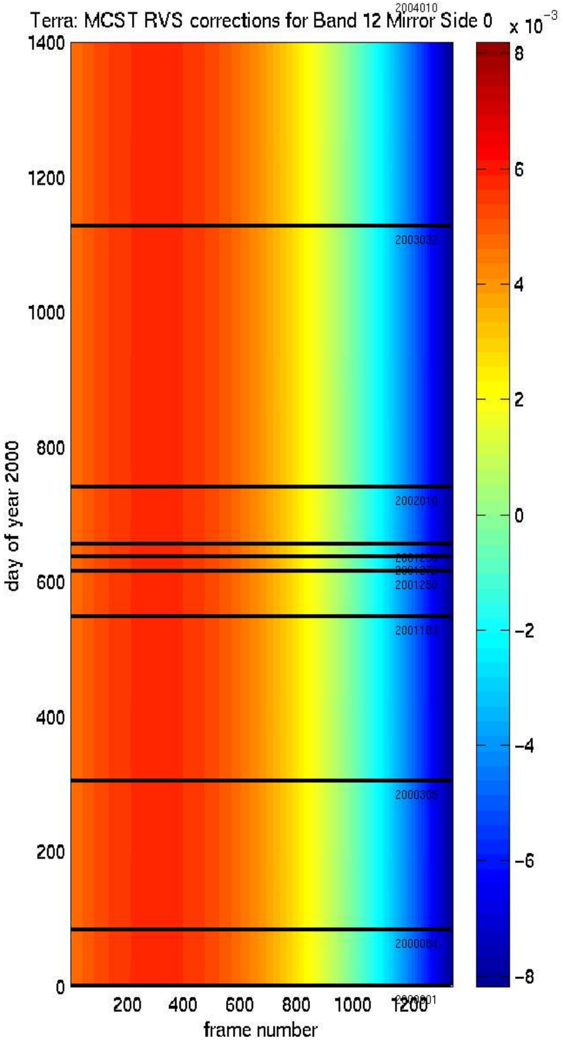
Trend in center (SRCA)

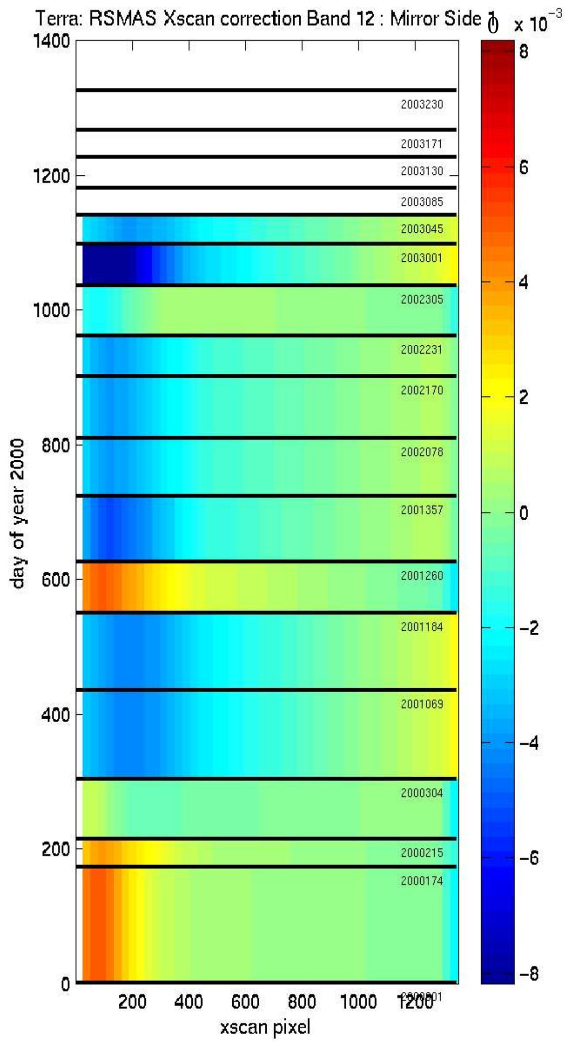
Correction suggestive of SRCA degradation



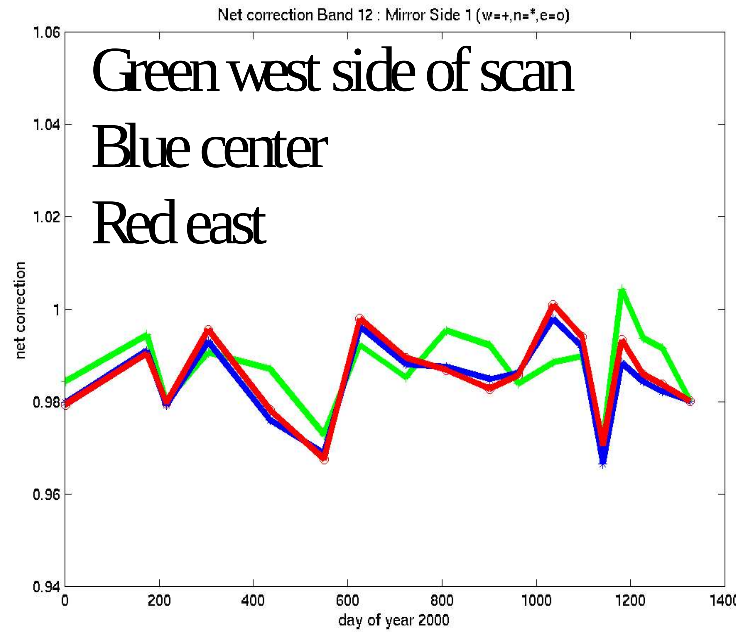
MCST RVS and Miami added corrections for Terra, 551nm, first mirror side, small correction needed, shifts in RVS correction trend in 'summer' suggestive of 'excess radiance'

Black lines show update times; normalized to pixel 1000 (SD)

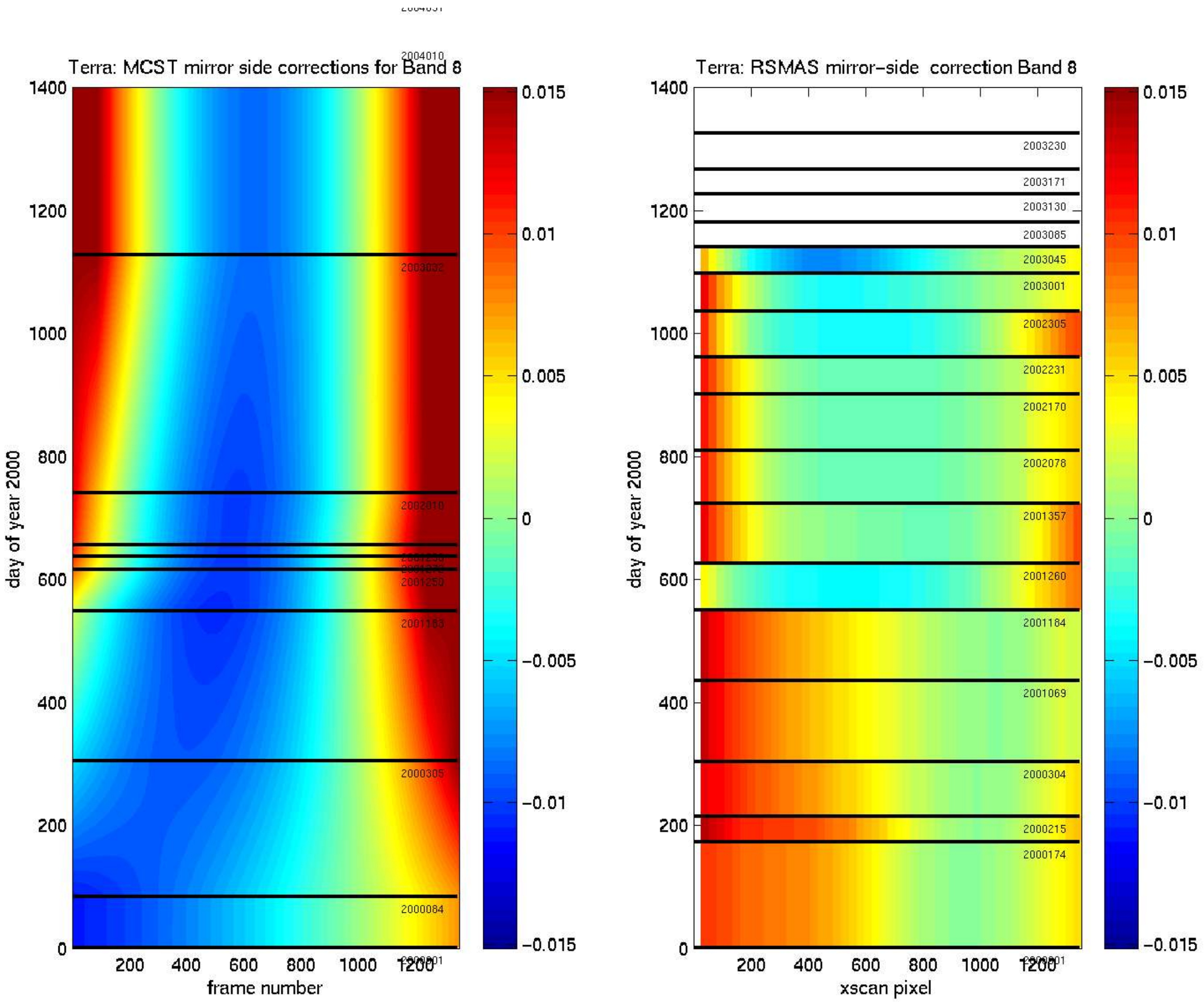




Total radcor correction vs time



MCST and Miami mirror side 1 to 2 corrections, 412 nm
MCST initially under-corrects on western side of scan



Seasonal progression

Several orbits are shown for summer solstice, fall equinox and winter solstice

Fidelity of corrections:

Good sun glint correction for most orbits - glint correction relies on modeled wind field and no ocean current

Mirror side banding only present at solar zenith angle > 45 degrees for blue bands

Minimal east/west discontinuities at some orbit boundaries

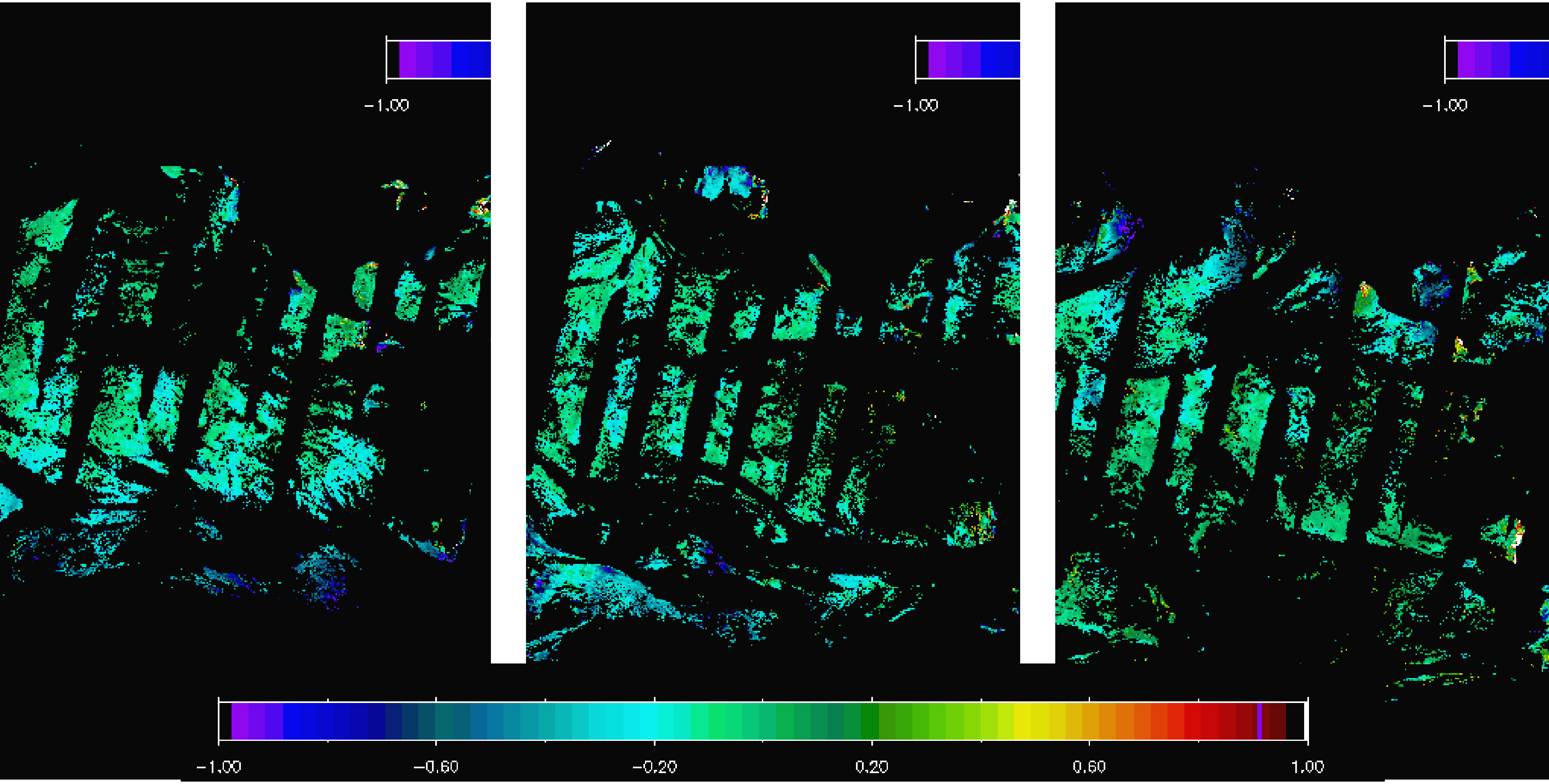
nLw trends:

551nm (531 and 488) flat relative to SeaWiFS

412nm (443) radiance decreases relative to SeaWiFS in the winter hemisphere

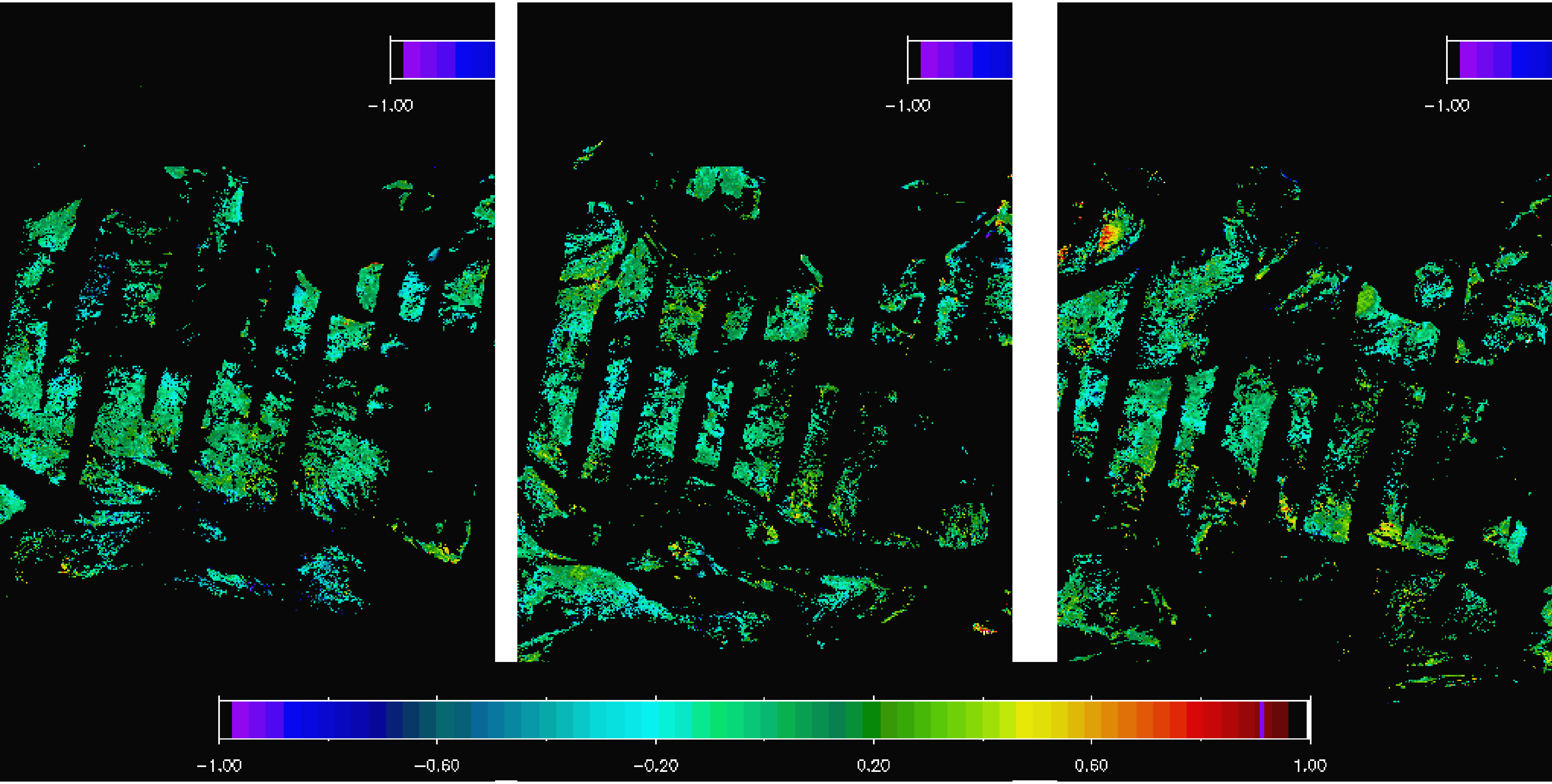
412nm (terra-seawifs)/seawifs

15Jul00 21Sep00 9Dec00



551nm (terra-seawifs)/seawifs

15Jul00 21Sep00 9Dec00



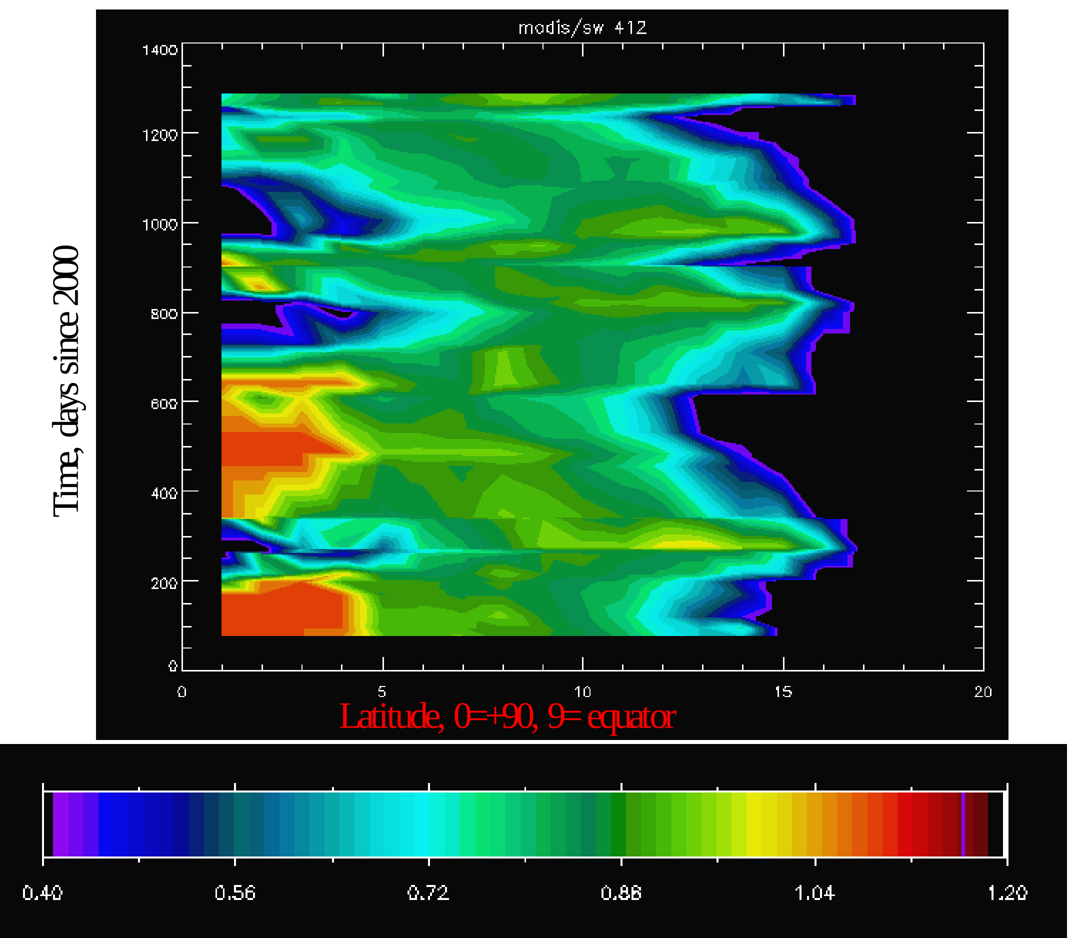
MODIS Terra nLw 412 space - time series

Problem areas:

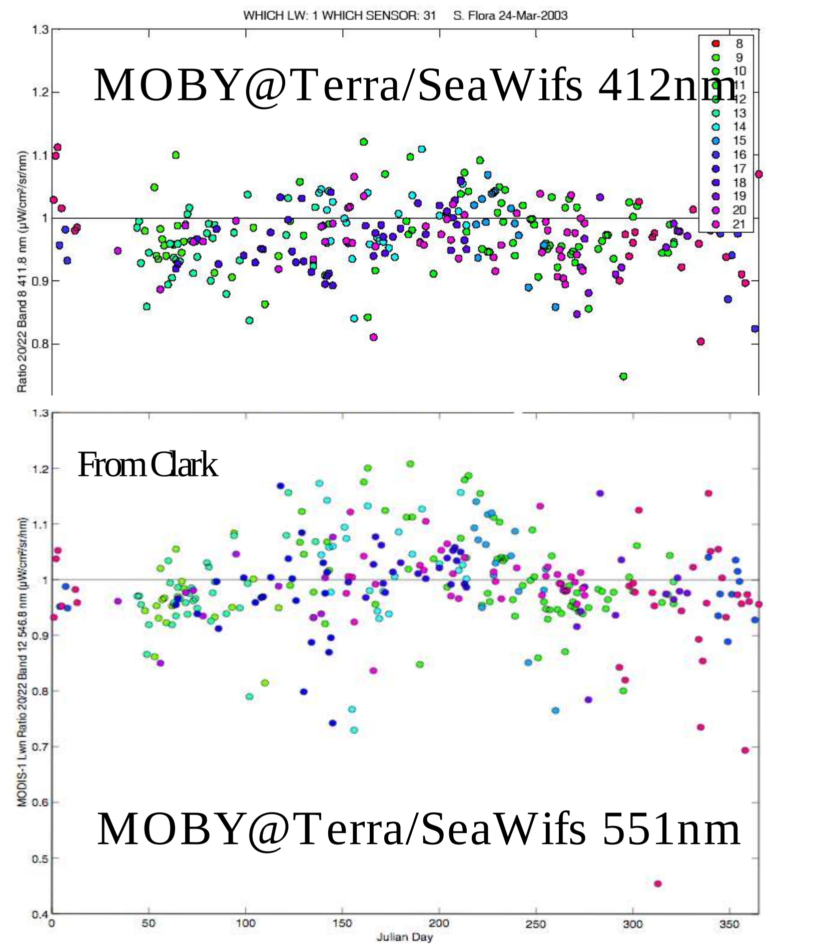
- Radcor or m1 induced nLw jumps and trends
- Blue band north-south trends

Spatial seasonality in MODIS blue band nLw
Modis/seawifs ratio, 412nm, MOBY @MODIS(T) ~ 5% lower than SeaWIFS overpass time, also sun glint present

(MODIS-SeaWiFS)/SeaWiFS



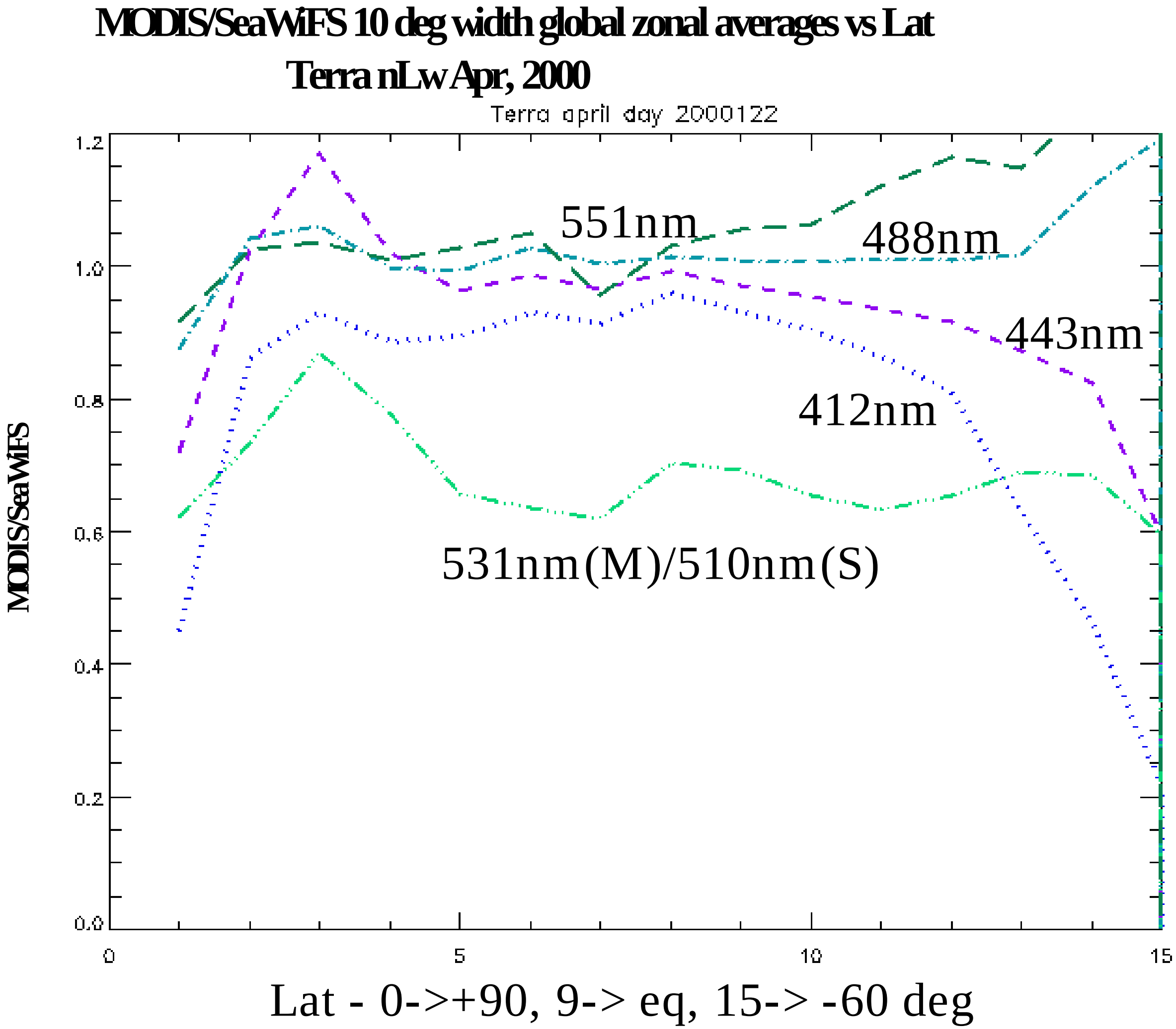
MOBY MODIS/SeaWiFS nLw ratio

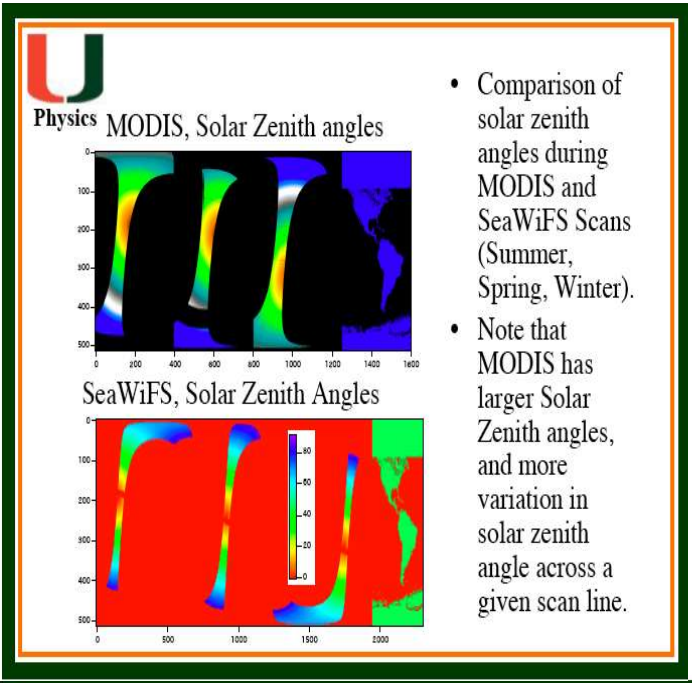


Meridional Trends in April MODIS Terra/SeaWiFS

Trends for 551, 531 and 488 show little variation with latitude

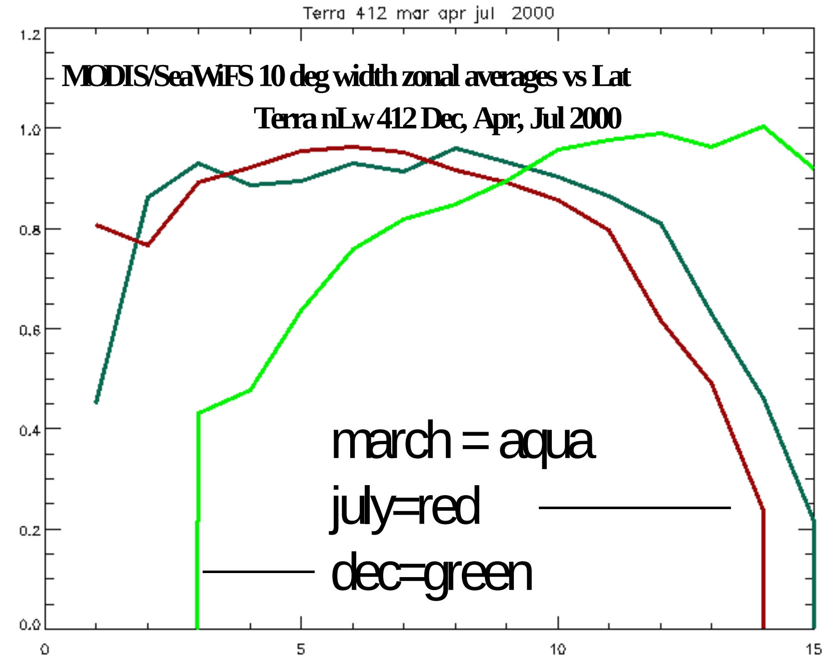
MODIS trend of decreasing radiance vs SeaWiFS is seen primarily in 443 and 412 nm bands



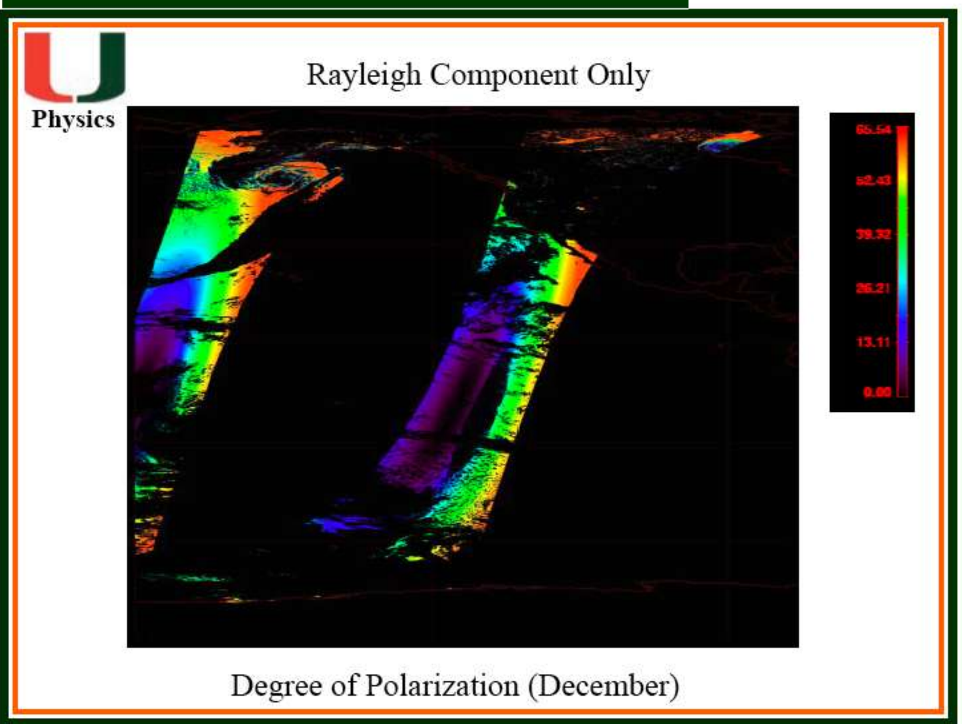


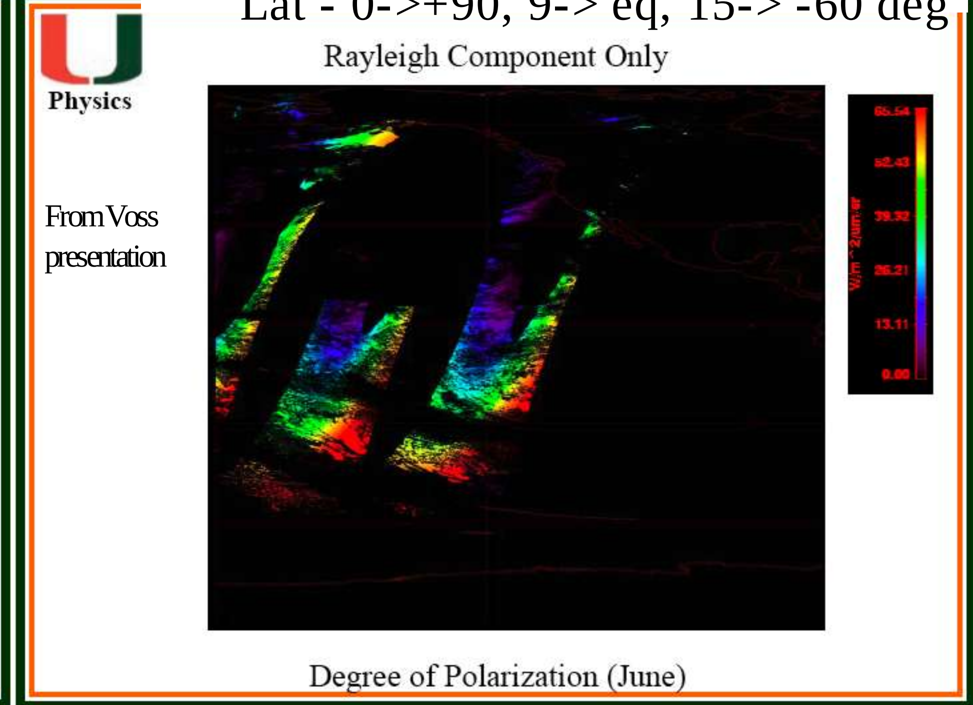
Seasonal 412 nLw variation vs latitude.

Change appears to be correlated with solar zenith angle or Raleigh polarization



Lat - 0->+90, 9-> eq, 15-> -60 deg





Temporal variations in nLw fields

M1 considerations:

Important to understand solar diffuser time trends

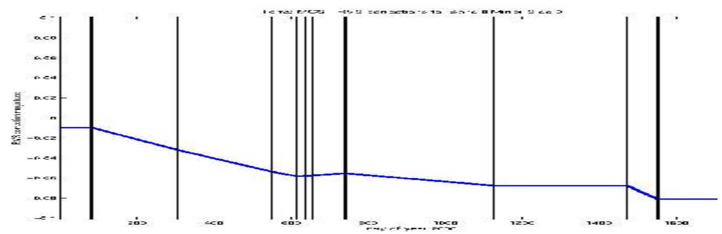
Forward (near real time) processing based on instantaneous solar diffuser measurements, no time interpolation

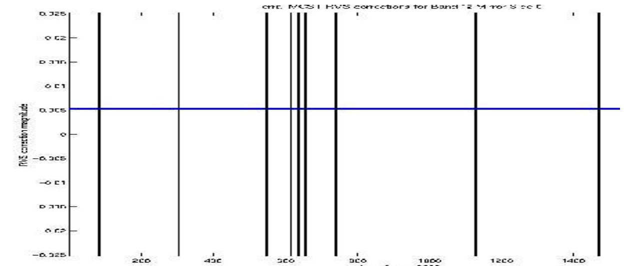
Retrospective processing based on 'smoothed' m1 that remove measurement artifacts (offsets, time trends)

RVS considerations:

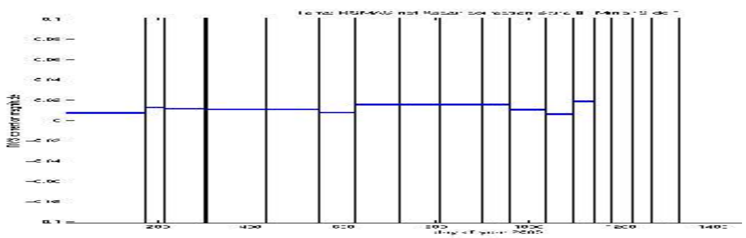
Need to track relative performance of calibration sources (lunar, SRCA, SD). This impacts both RVS and m1.

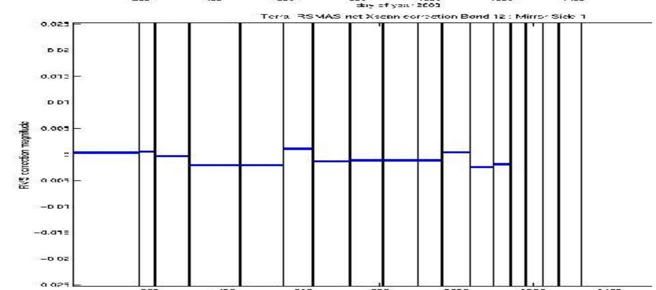
412 Trends in 412 and 551 nm bands 551



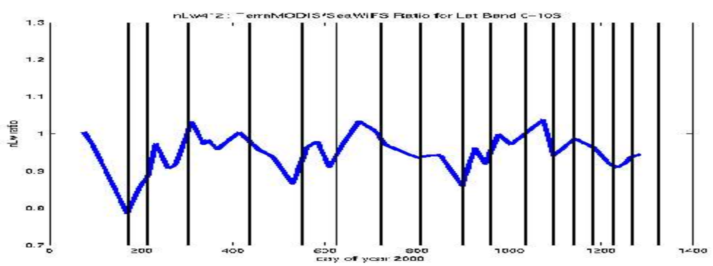


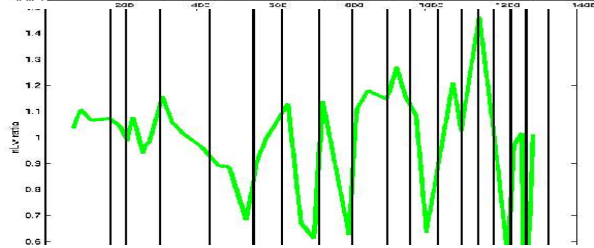
MCST RVS



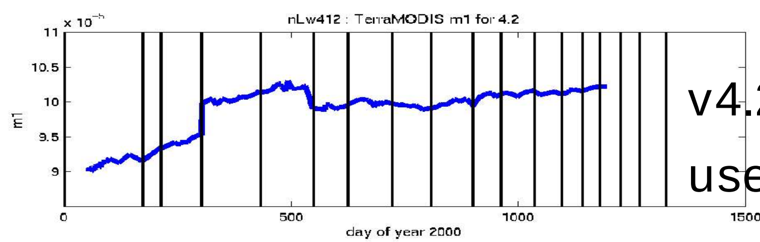


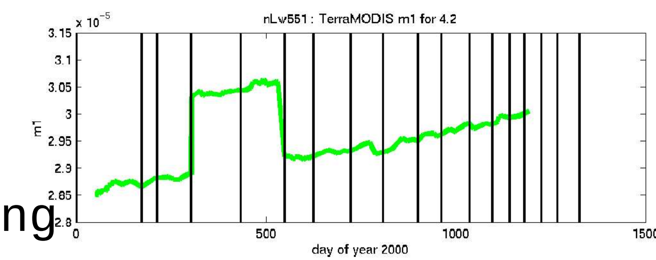
RADCOR net correction



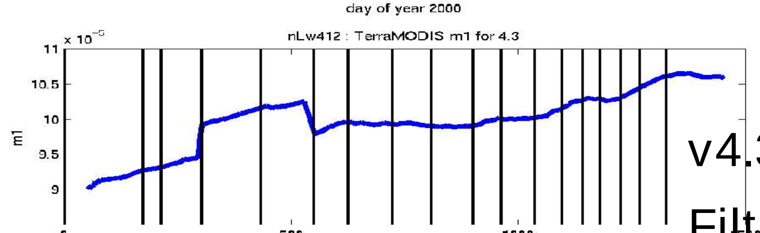


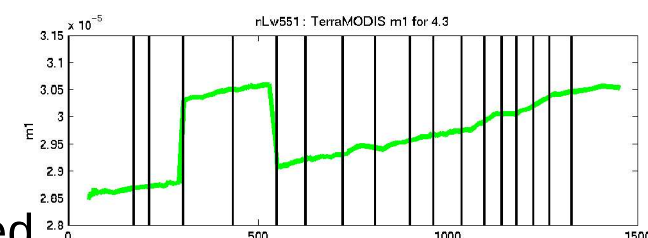
MODIS/SeaWiFS Global zonal Ratio 0-10S





v4.2.0.0M LUT used for reprocessing





v4.3.0.2M LUT Filtered, not released

Summary - Outstanding Issues

- Orderly update of LUT to include smoothed, detrended m1

  M1 calculation noise reduced when SDSM and SD measurements are smoothed with time. Increased SD degradation due to open SD door in 2003 not reflected in standard Level-1 LUT.

- Identify and correct for 'excess light' low solar zenith angle scans, impacts RVS and calibration adjustments

  Stray light - part in MOBY field, part in MODIS data, June-August period removed from MODIS characterization

- Identify and correct for blue band hemispheric trends - polarization, solar zenith angle

  Polarization, both mirror side difference and MODIS-SeaWiFS difference increase significantly when solar zenith angle > ~45 deg.

- Identify method to track changes in polarization sensivity, impacts mirror side balance, RVS and calibration

Summary - continued

- Track relative performance of calibration sources to better monitor MODIS scanner performance vs trends in calibration sources.

  Balance of calibration sources, SRCA appears to degrade in blue bands.

  This degradation is presently interpreted as MODIS scanner degradation.

- Sun glint - function of wind speed, does not track interaction with ocean current, also wind speed wind history and instantaneous local wind, preferred approach is to use ‘measured’ glint field