Physics

MODIS ocean color atmospheric correction, BRDF, Polarization, and in-band or total-band calculations

Kenneth Voss and Howard Gordon

Outline:

- Atmospheric correction basics
- cross scan epsilon
- Polarization in atmospheric correction
- Polarization in sun glitter
- BRDF issues in ocean color data
- In-band vs total band signal

Physics

MODIS Atmospheric Correction*

Gordon and Wang (1994)

*The SeaWiFS instrument was used as a test bed for the MODIS atmospheric correction algorithm, therefore the two algorithms are nearly identical (except for some changes made by the SeaWiFS project). The principal differences are the need to correct for the polarization sensitivity of MODIS and the absence of a correction for the Oxygen absorption at 759 nm in MODIS (required for SeaWiFS).

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Atmospheric Correction (simplified)

$$\rho = \frac{\pi L}{F_0 \cos\theta_0}$$

$$\rho_t(\lambda) = \rho_r(\lambda) + \underbrace{\rho_a(\lambda) + \rho_{ra}(\lambda)}_{\rho_A(\lambda)} + t_s(\lambda)t_v(\lambda)n\rho_w(\lambda)$$

$$\varepsilon(\lambda,\lambda_0) \approx \frac{\rho_A(\lambda)}{\rho_A(\lambda_0)}$$

In NIR $n\rho_w$=0, so

$$\varepsilon(15{,}16) \approx \frac{\rho_A(15)}{\rho_A(16)}$$

Get $\varepsilon(\lambda,16)$ from $\varepsilon(15,16)$ using aerosol models. Then

$$n\rho_w(\lambda) = t_s^{-1}(\lambda)t_v^{-1}(\lambda)\{\rho_t(\lambda) - \rho_r(\lambda) \\ - \varepsilon(\lambda{,}16)[\rho_t(16) - \rho_r(16)]\}$$

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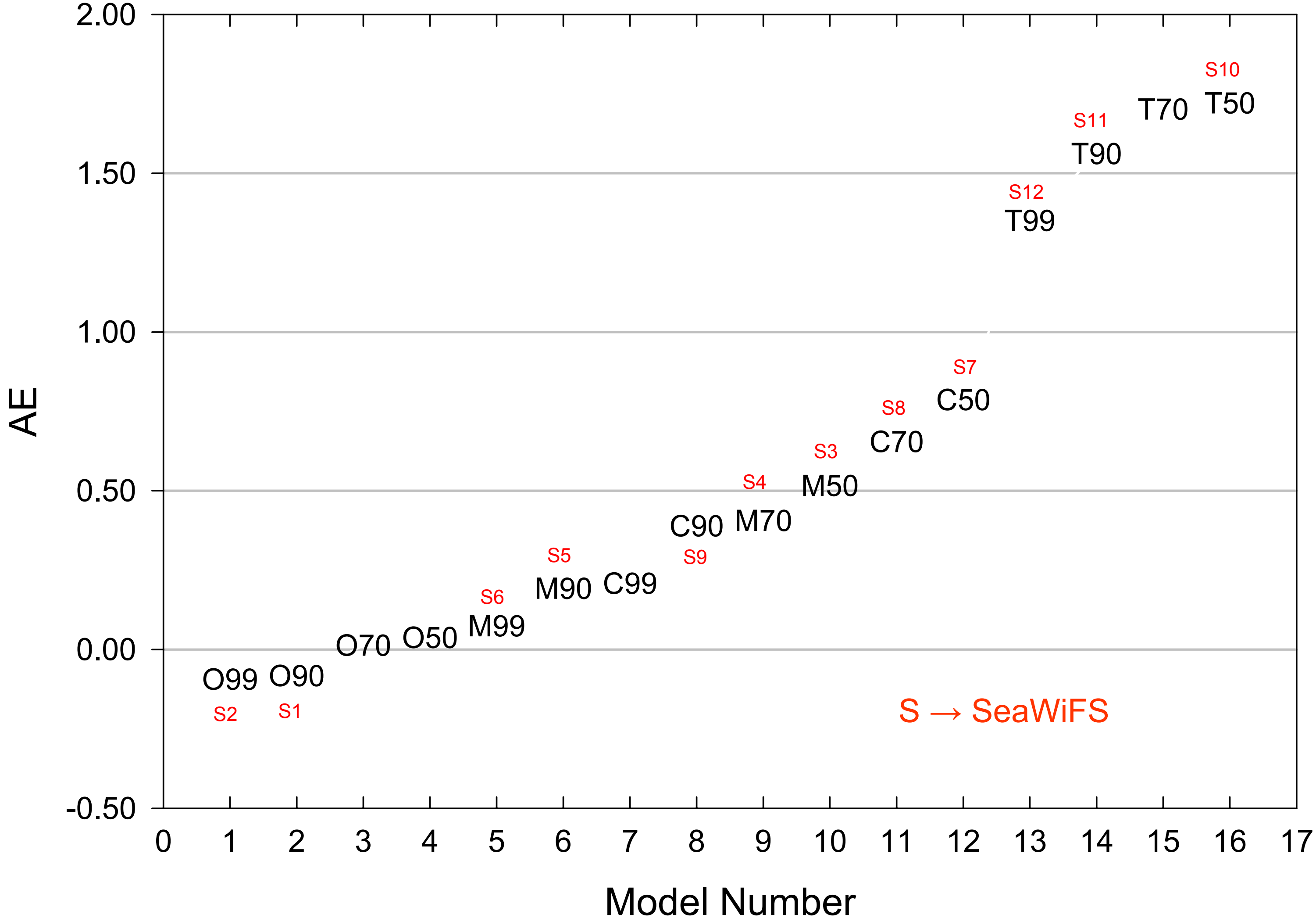
$$\tau_a(765)/\tau_a(865) = (865/765)^{AE}$$



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Summary

$$t\rho_w(\lambda) = \rho_t(\lambda) - \rho_r(\lambda) - \left[\rho_a(\lambda) + \rho_{ra}(\lambda)\right]$$

$$\underbrace{\rho_t - \rho_r}_{765,865} \overset{N \text{ Models}}{\longrightarrow} \epsilon(765,865) \rightarrow 2 \text{ Models}$$

$$\epsilon(765,865) \overset{2 \text{ Models}}{\longrightarrow} \epsilon(\lambda,865)$$

$$\rho_{as}(865) \overset{\epsilon(\lambda,865)}{\longrightarrow} \rho_{as}(\lambda)$$

$$\rho_{as}(\lambda) \overset{2 \text{ Models}}{\longrightarrow} \rho_a(\lambda) + \rho_{ra}(\lambda)$$

The same two models are also used to estimate the diffuse transmittance.

Physics

Notes:

1. BRDF influence on diffuse transmittance is *not* included. It is assumed that the upwelling spectral radiance *beneath the surface* is totally diffuse. This can cause errors in water-leaving radiance of the order of +/- 4% (*Yang and Gordon,* 1997).
2. Direct BRDF influence on water-leaving radiance is assessed using the *Morel and Gentili* analysis.
3. *Siegel et al.* (2000) "Black Pixel" correction is used.
4. Rayleigh contribution is computed exactly, i.e., polarization is included (*Gordon Evans and Brown* (1988), *Gordon and Wang* (1992)).
5. Aerosol LUTs are computed using scalar radiative transfer theory (*Gordon and Wang* (1994)).
6. Sun glitter is assessed and masked using the *Cox and Munk* (1950) approach; however, the *C-M* parameters are not well established.

Physics

Cross Scan Epsilon Behavior

Since the MODIS Band 16 (869 nm) calibration is assumed to be correct, the behavior of epsilon (15, 16) is determined by the calibration (assumed) for Band 15 (749 nm). These slides show a good agreement between the measured cross scan behavior of epsilon and that predicted by the atmospheric correction aerosol models (in particular M70).

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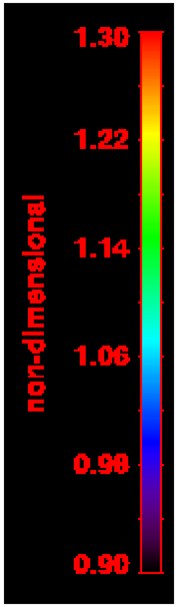
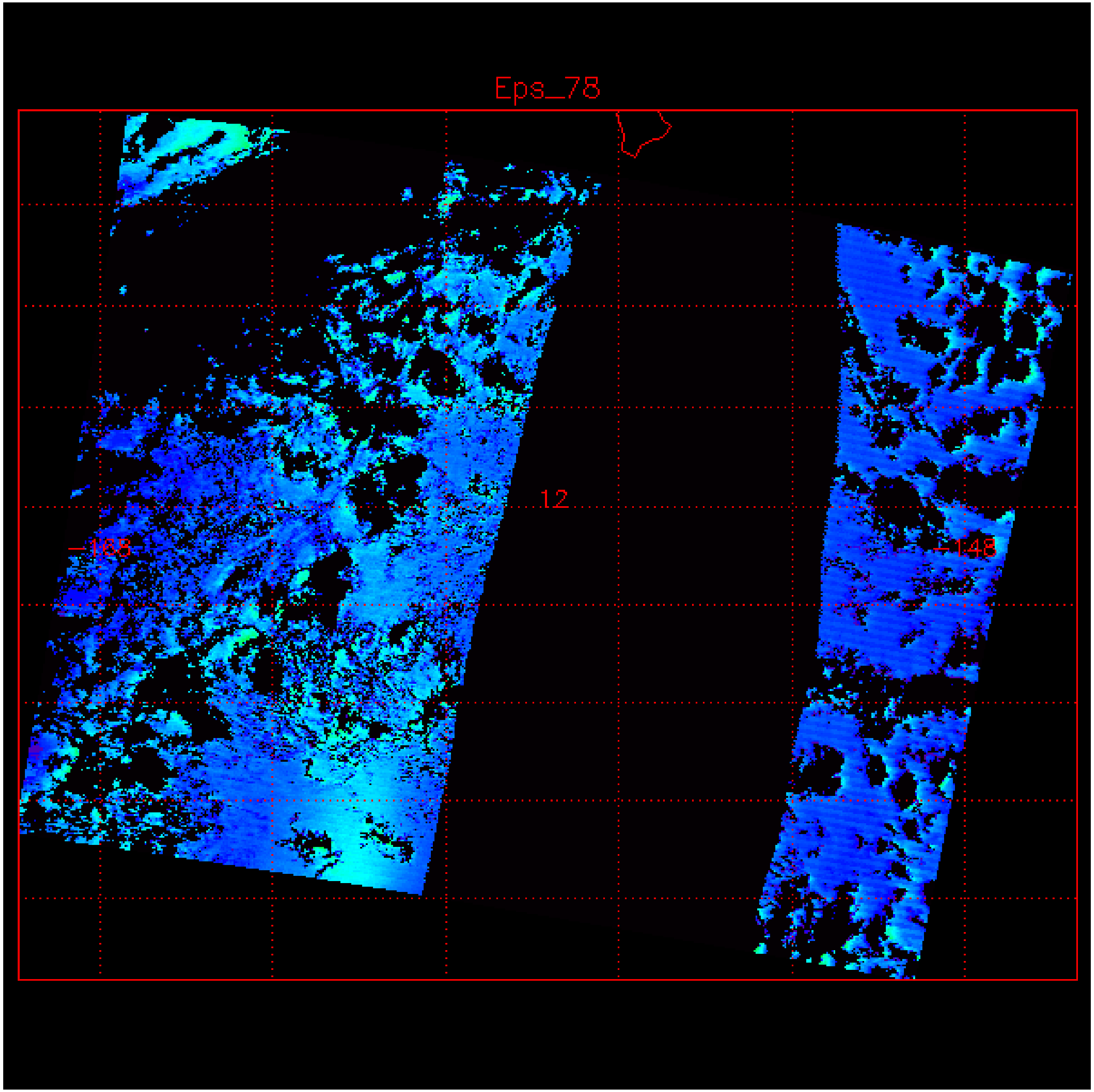
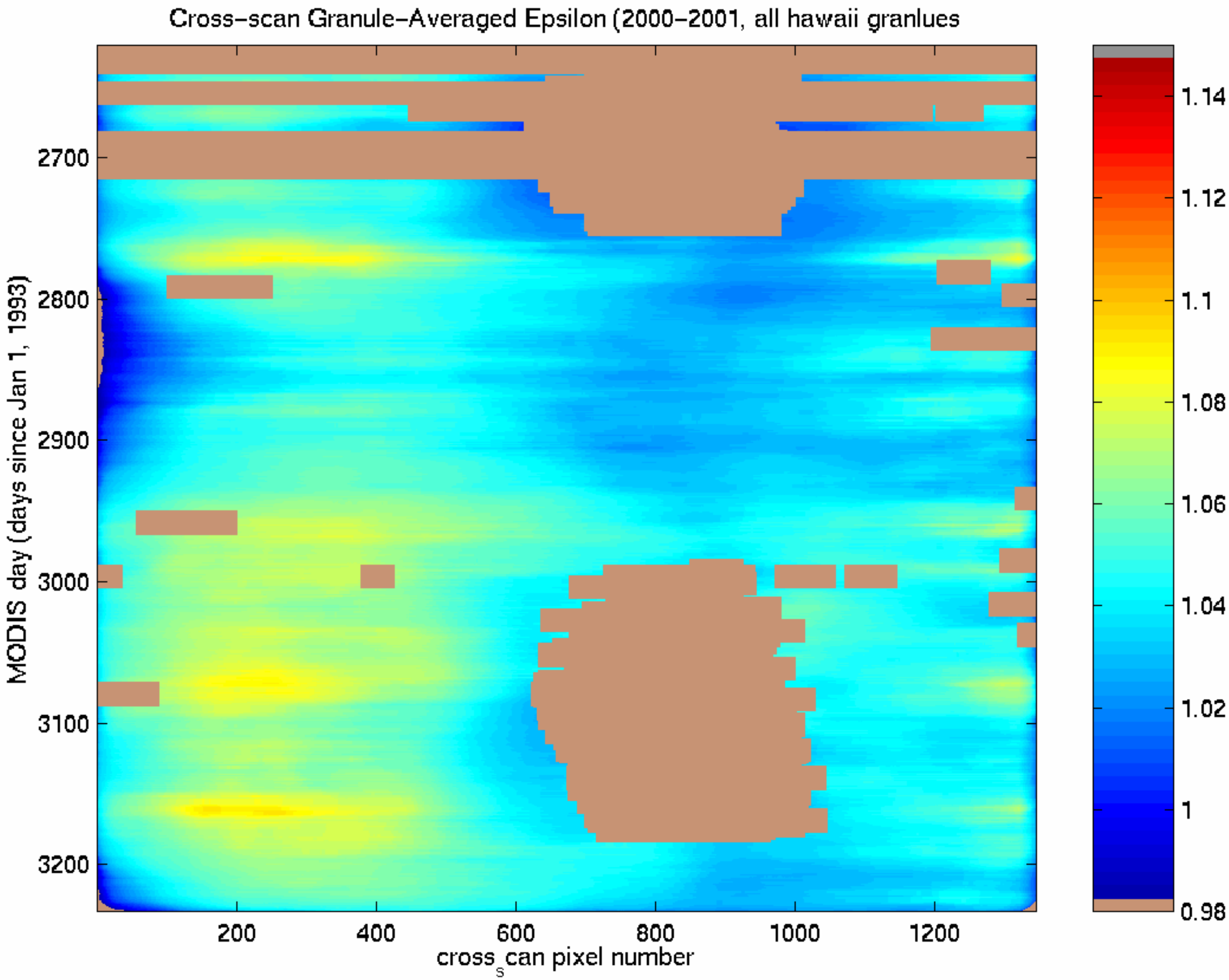
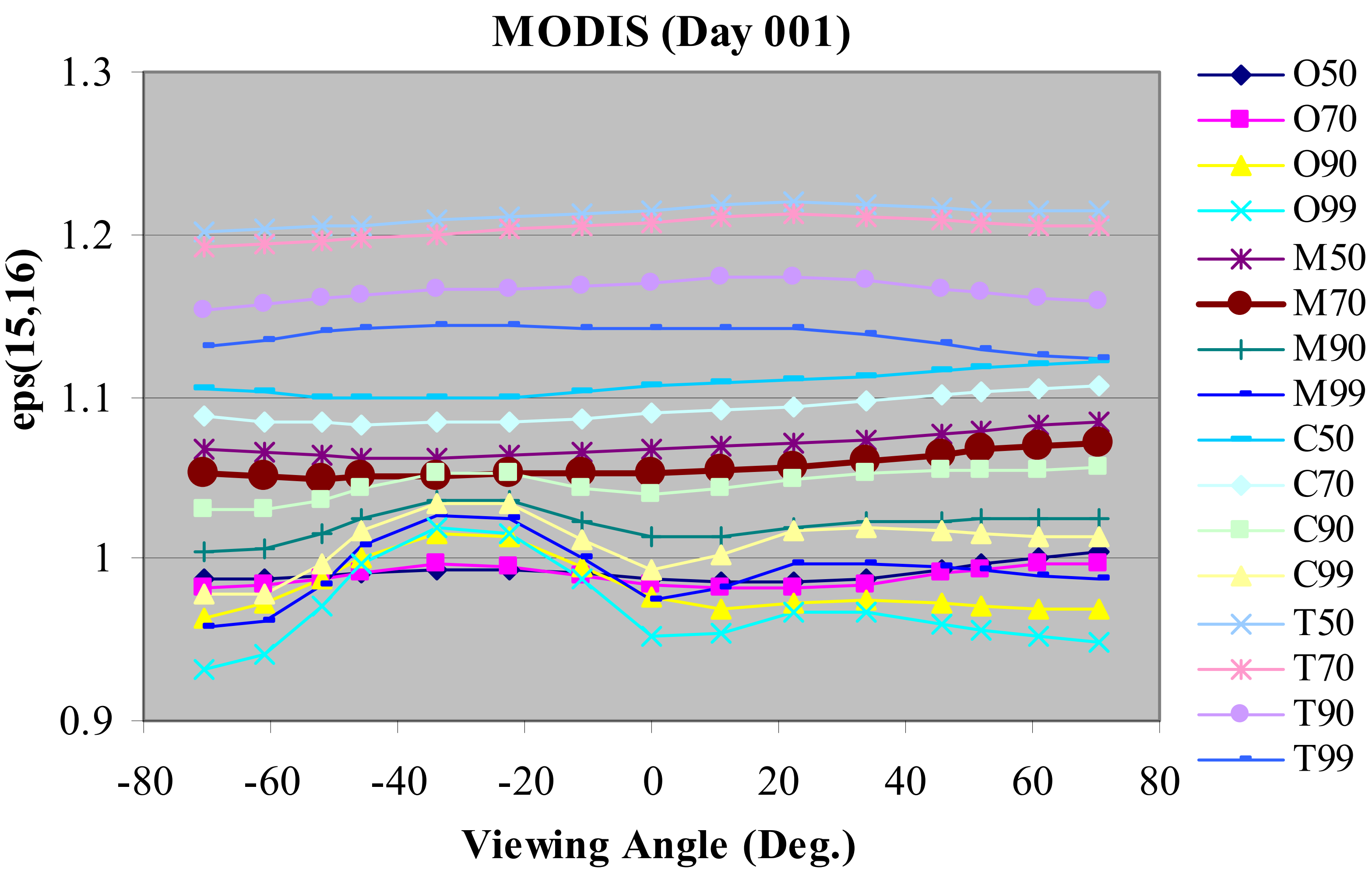




Physics

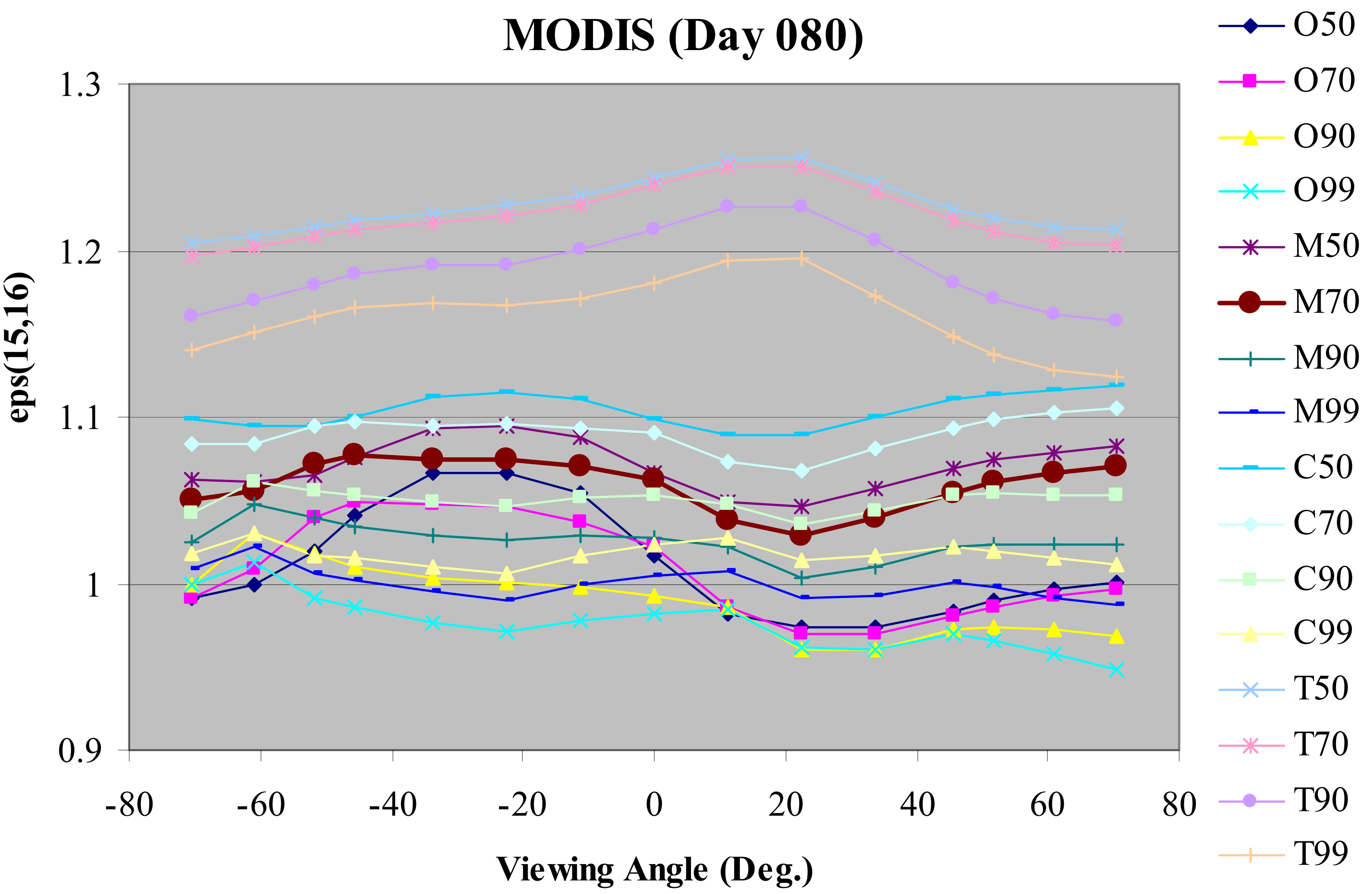

Cross-scan Granule-Averaged Epsilon (2000-2001, all hawaii granlues
MODIS day (days since Jan 1, 1993)
2700
2800
2900
3000
3100
3200
200
400
600
800
1000
1200
cross$_s$can pixel number
1.14
1.12
1.1
1.08
1.06
1.04
1.02
1
0.98

Physics

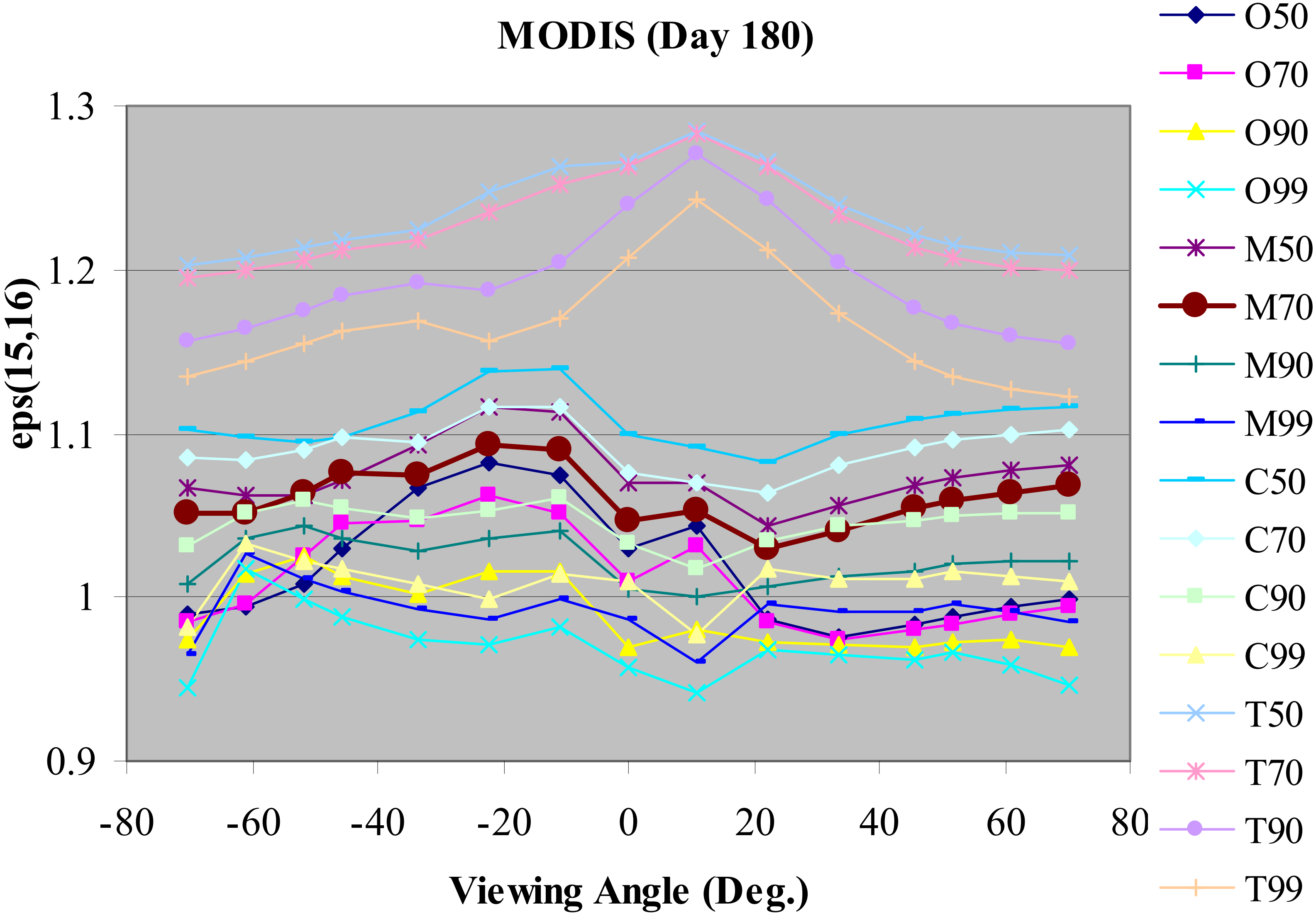


MODIS (Day 001)
1.3
1.2
1.1
1
0.9
eps(15,16)
-80
-60
-40
-20
0
20
40
60
80
Viewing Angle (Deg.)
O50
O70
O90
O99
M50
M70
M90
M99
C50
C70
C90
C99
T50
T70
T90
T99

Physics


MODIS (Day 080)
1.3
1.2
1.1
1
0.9
eps(15,16)
-80
-60
-40
-20
0
20
40
60
80
Viewing Angle (Deg.)
O50
O70
O90
O99
M50
M70
M90
M99
C50
C70
C90
C99
T50
T70
T90
T99

Physics


MODIS (Day 180)
eps(15,16)
1.3
1.2
1.1
1
0.9
-80
-60
-40
-20
0
20
40
60
80
Viewing Angle (Deg.)
O50
O70
O90
O99
M50
M70
M90
M99
C50
C70
C90
C99
T50
T70
T90
T99

Physics

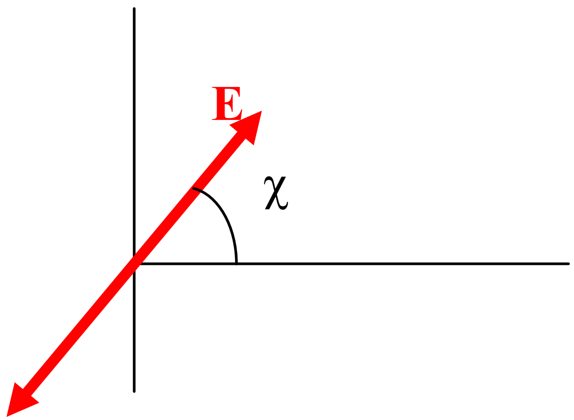
Polarization Sensitivity

Physics

Instrument Polarization Sensitivity

Shine linearly polarized radiance from a source into the instrument.

Let polarization (direction of **E** field**)** be specified by the angle χ with respect to some direction.



Then

$$L_m(\chi) = M_{11} L_{\text{Source}} \left[1 + a \cos 2(\chi - \delta) \right]$$

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Phase Convention

We will provide examples of *a* and δ later.

The relation between the Miami and the MCST convention for the polarization sensitivity phase δ is given below.

Miami: $L_m(\chi) = M_{11} L_{\text{Source}} \left[1 + a\cos 2(\chi - \delta_{\text{Miami}})\right]$

MCST: $L_m(\chi) = M_{11} L_{\text{Source}} \left[1 + a\cos(2\chi + \delta_{\text{MCST}})\right]$

Note position of the "2".

Therefore: $\delta_{\text{Miami}} = -\dfrac{\delta_{\text{MCST}}}{2}$

Physics

If the incident light is partially polarized, i.e., has a degree of polarization ($0 \le P \le 1$), then

$$L_m(\chi) = M_{11} L_{\text{Source}} \left[1 + aP\cos 2(\chi - \delta)\right]$$

To calibrate the instrument, use an unpolarized source of known radiance, then

$$L_m^{UP}(\chi) = M_{11} L_{\text{Source}}^{UP} \qquad \Rightarrow \qquad M_{11}$$

Note that this would be the measured radiance for $a = 0$, i.e., an instrument with no polarization sensitivity. Call this L_{true}. Then

$$L_m(\chi) = L_{\text{True}}\left[1 + aP\cos 2\alpha\right],$$

and if the polarization sensitivity is not addressed, the error in the associated radiance could be as much as $\pm aP$.

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Given a, δ and P, χ, we can find L_{True} from L_m.

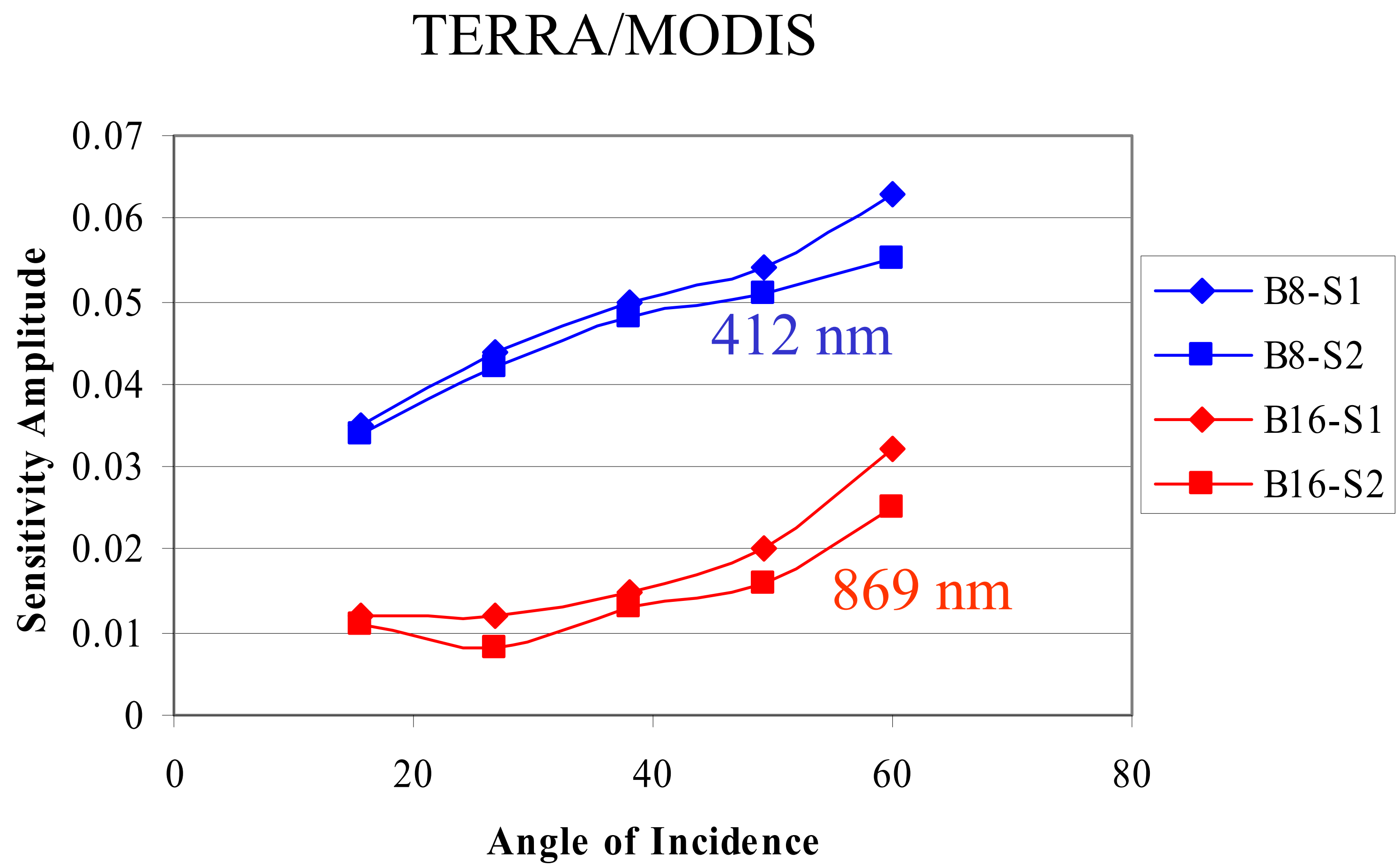
MODIS
Characterization

Radiance
into MODIS

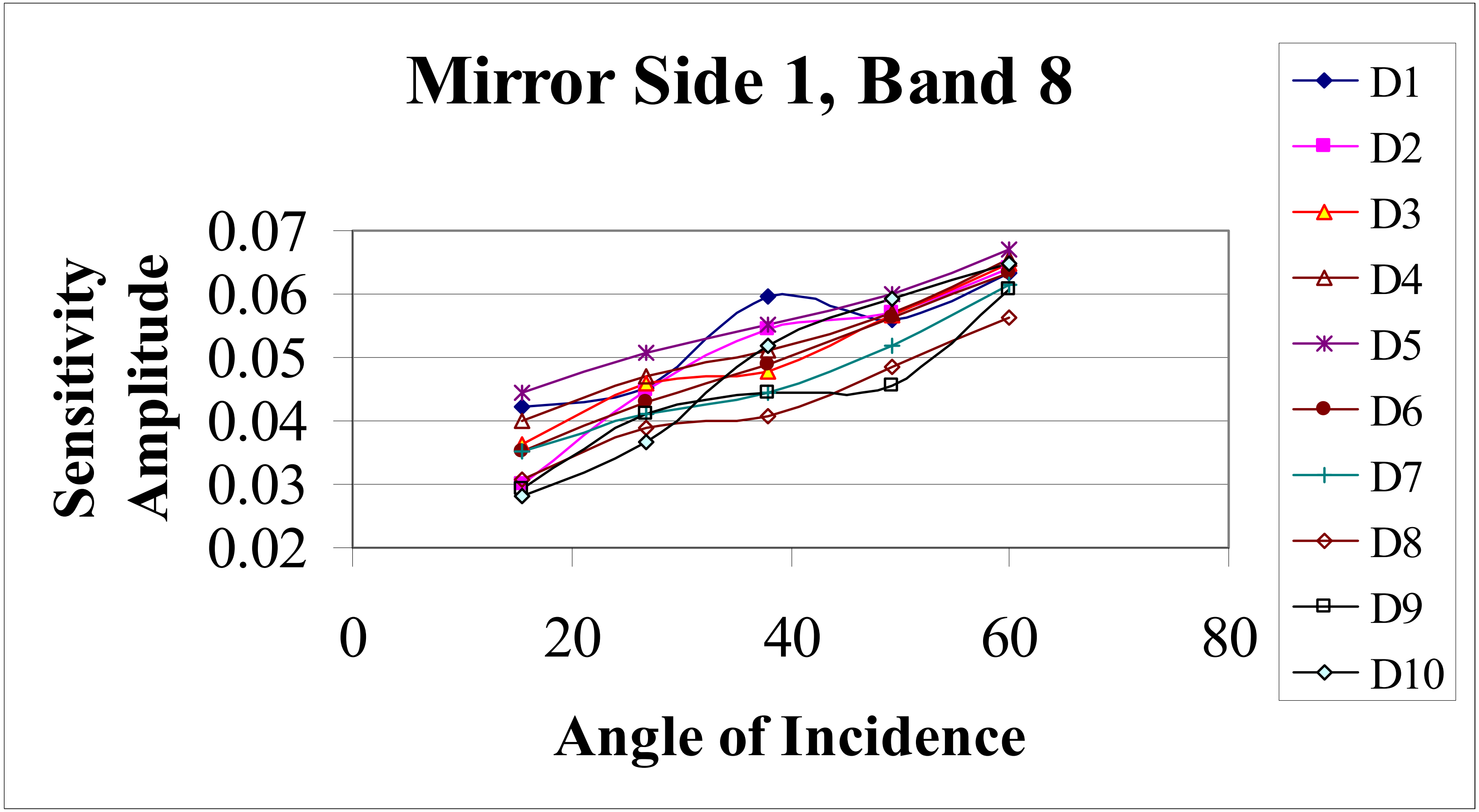
Physics

Note: a radiance error of 1% at 412 nm results in a water-leaving radiance error of ~ 10%.

How large are a and δ? How large is P?

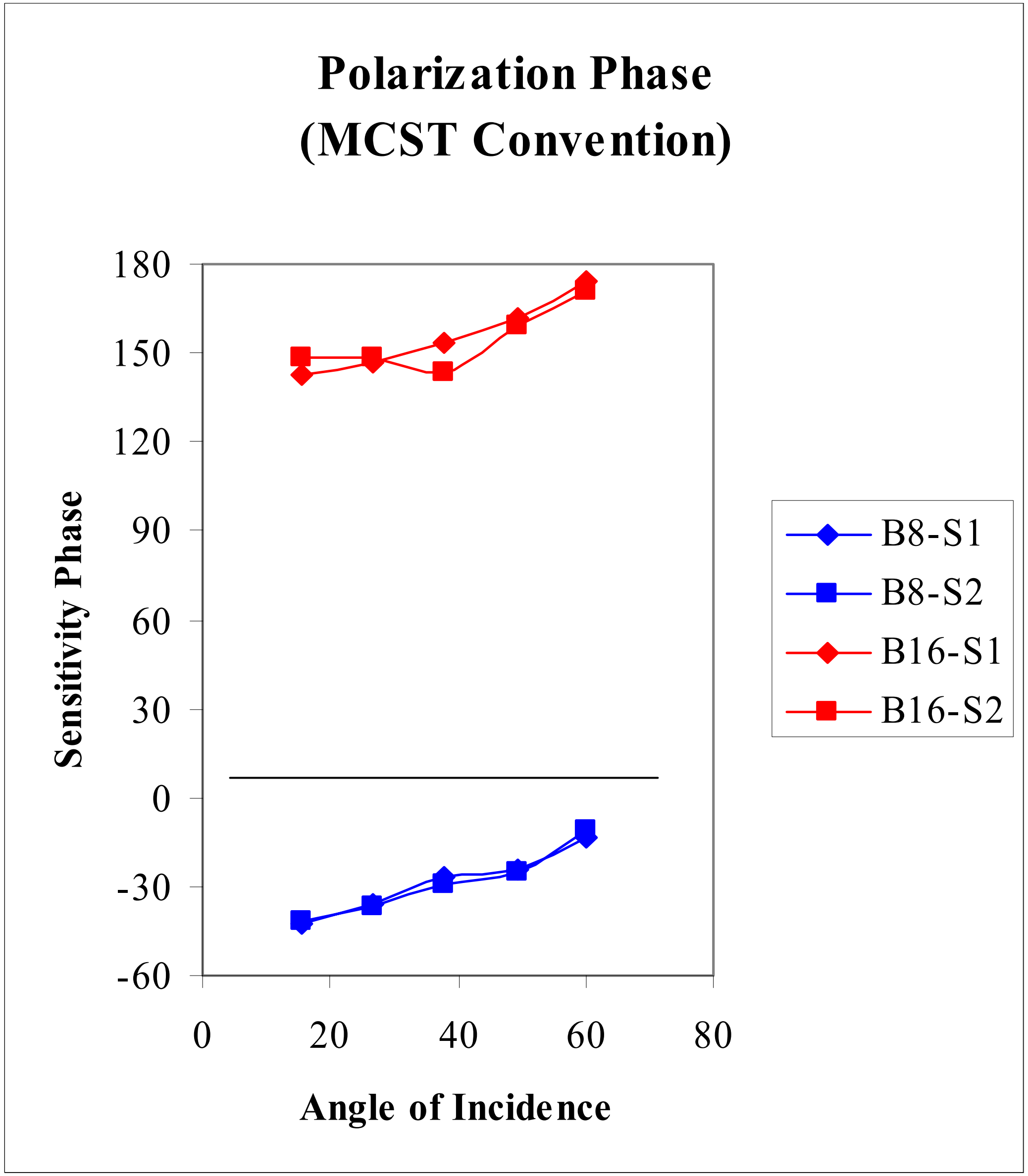


Physics

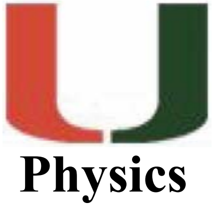


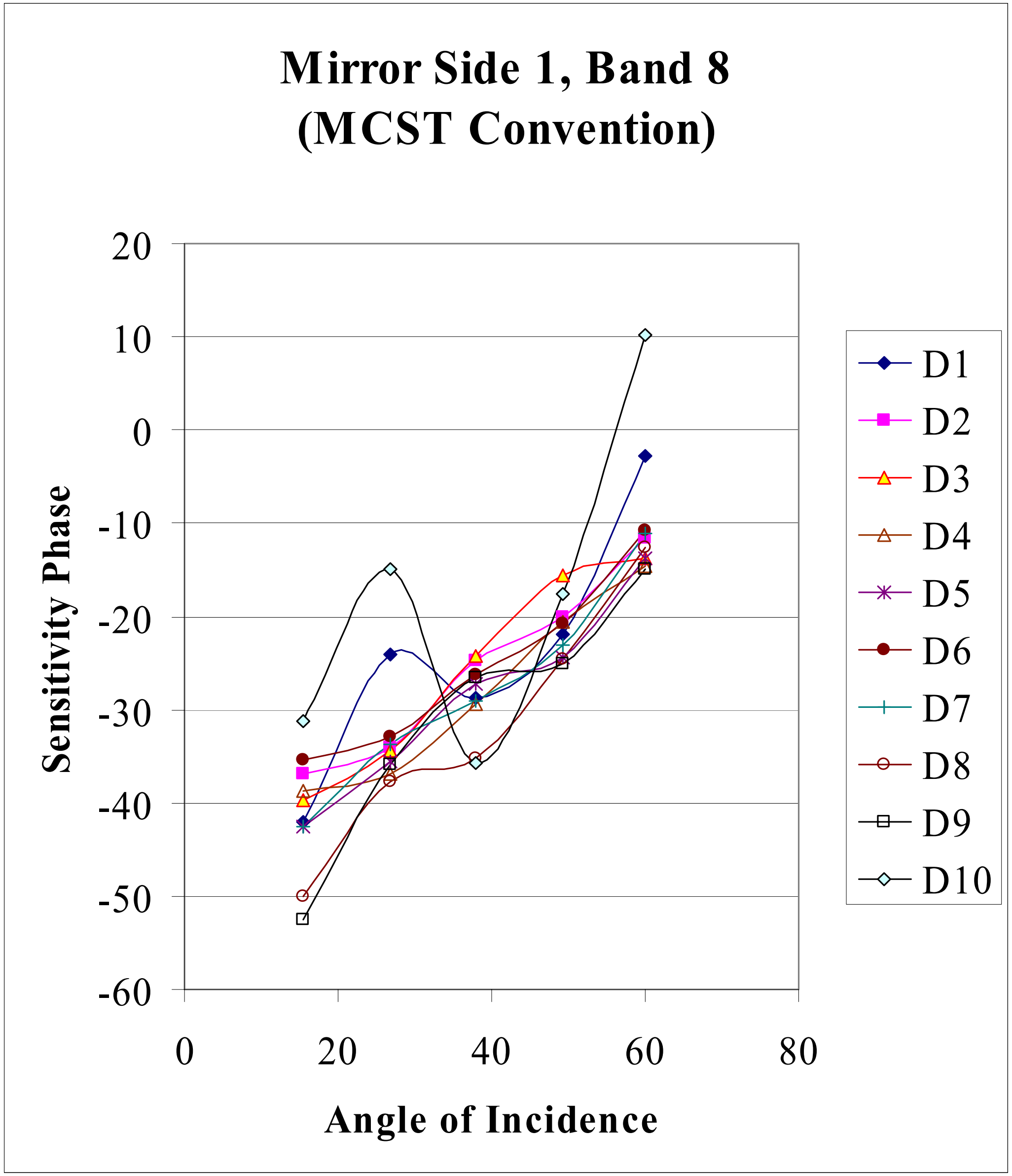
Mirror Side 1, Band 8
Sensitivity Amplitude
0.07
0.06
0.05
0.04
0.03
0.02
0
20
40
60
80
Angle of Incidence
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10

Physics

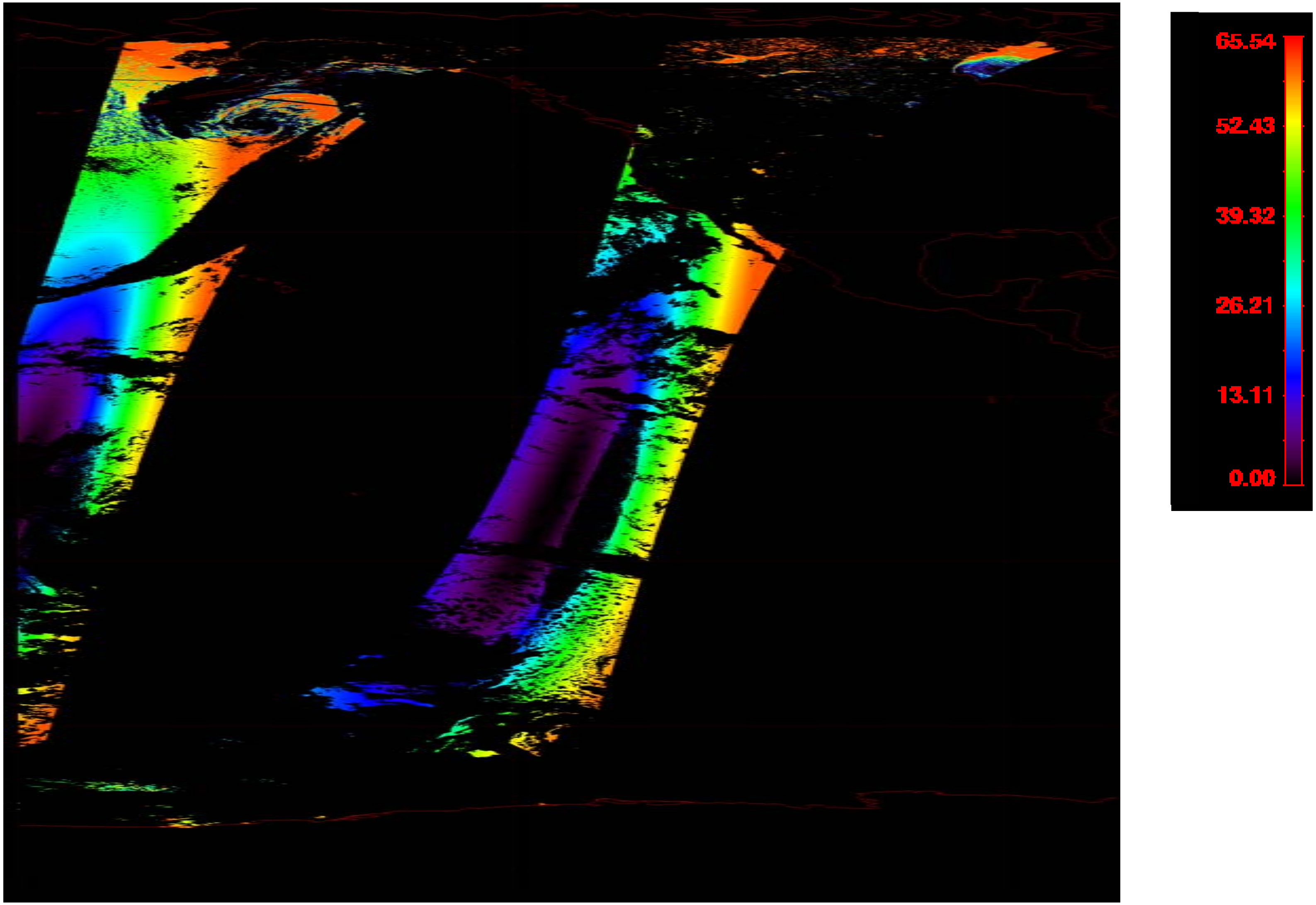


Polarization Phase
(MCST Convention)
180
150
120
90
60
30
0
-30
-60
0
20
40
60
80
Sensitivity Phase
Angle of Incidence
B8-S1
B8-S2
B16-S1
B16-S2


Physics


Mirror Side 1, Band 8
(MCST Convention)
Sensitivity Phase
Angle of Incidence
20
10
0
-10
-20
-30
-40
-50
-60
0
20
40
60
80
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10

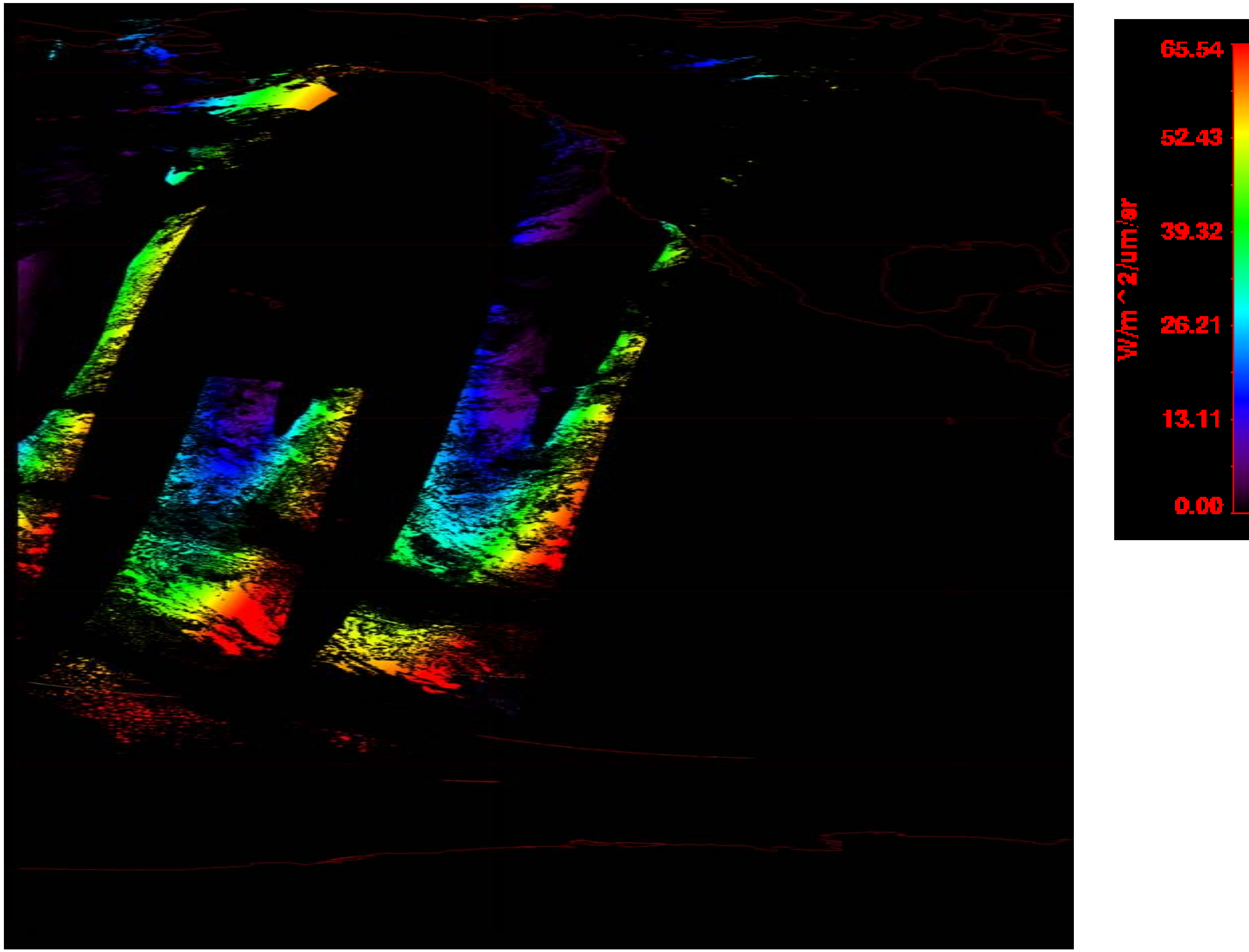
Rayleigh Component Only



Degree of Polarization (December)

Physics

Rayleigh Component Only



Degree of Polarization (June)

Physics

Correction for Polarization Sensitivity

Note: Polarization properties of the aerosols are unknown, and can be estimated *only after* atmospheric correction

Original Polarization Sensitivity Correction: *Assume that the total radiance is polarized in a manner identical to the Rayleigh component*. [Gordon, H.R., T. Du, and T. Zhang, 1997, Atmospheric Correction of Ocean Color Sensors: Analysis of the Effects of Residual Instrument Polarization Sensitivity, *Applied Optics*, **36**, 6938-6948.]

Revised Polarization Sensitivity Correction: *Assume that the only the Rayleigh component is polarized.*

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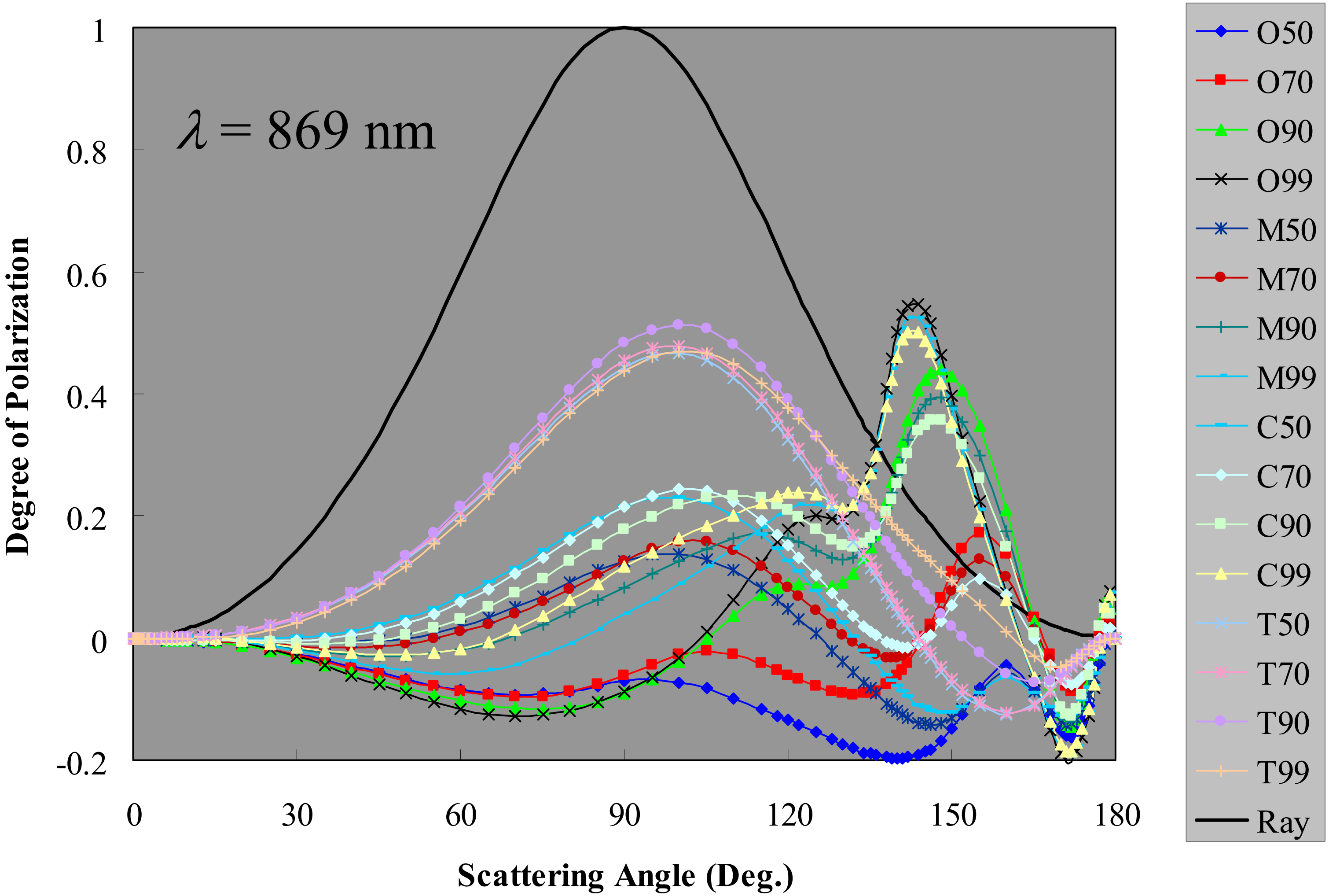
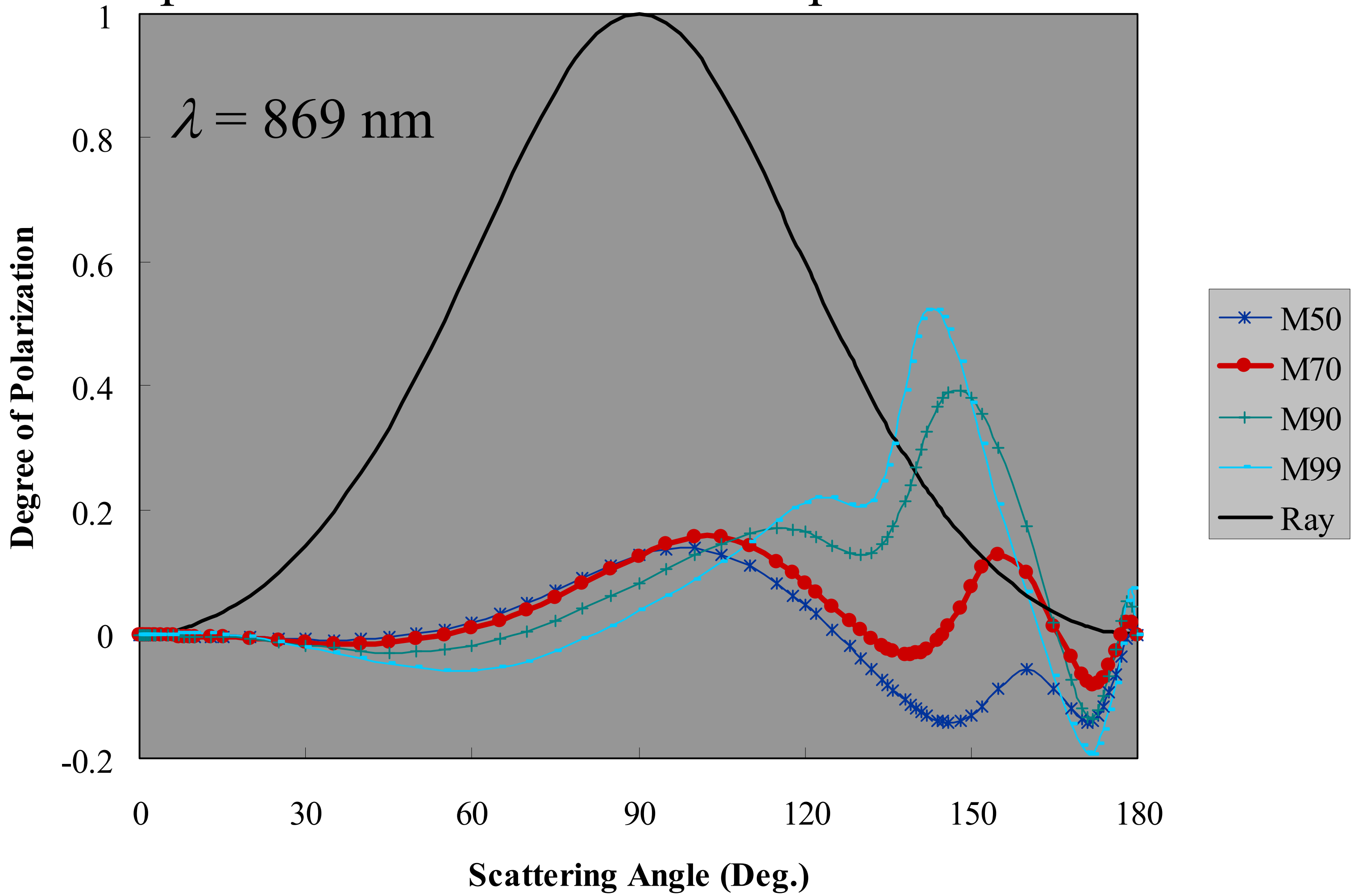
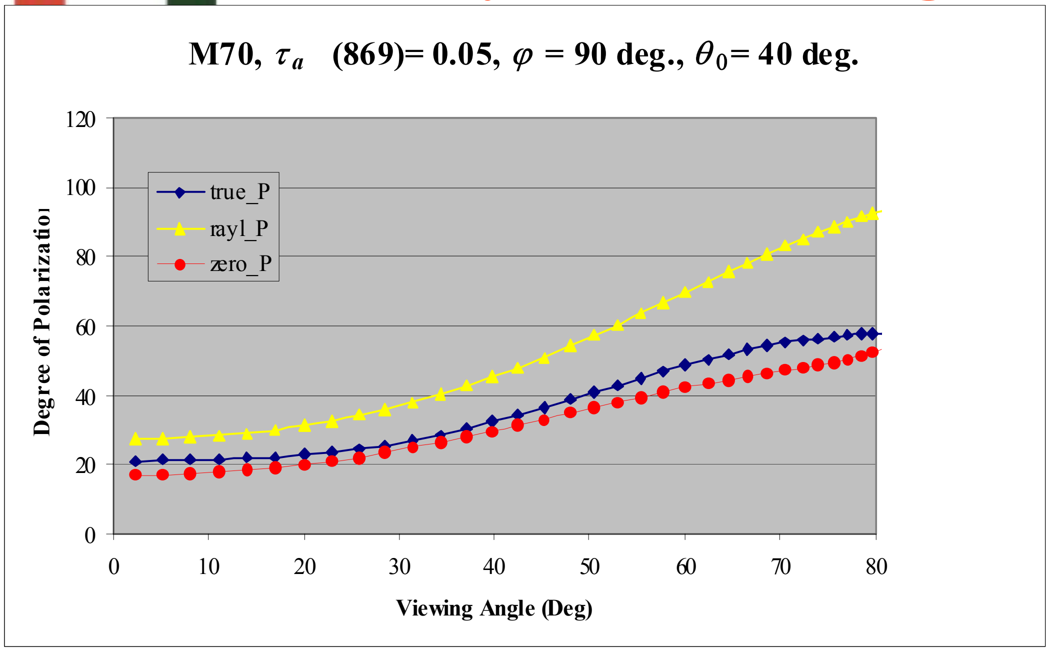

λ = 869 nm
Degree of Polarization
Scattering Angle (Deg.)
1
0.8
0.6
0.4
0.2
0
-0.2
0
30
60
90
120
150
180
O50
O70
O90
O99
M50
M70
M90
M99
C50
C70
C90
C99
T50
T70
T90
T99
Ray

Physics

At MOBY the M70 aerosol model is representative when the atmosphere is clear.



Efficacy in Predicting Top-of-Atmosphere *P*

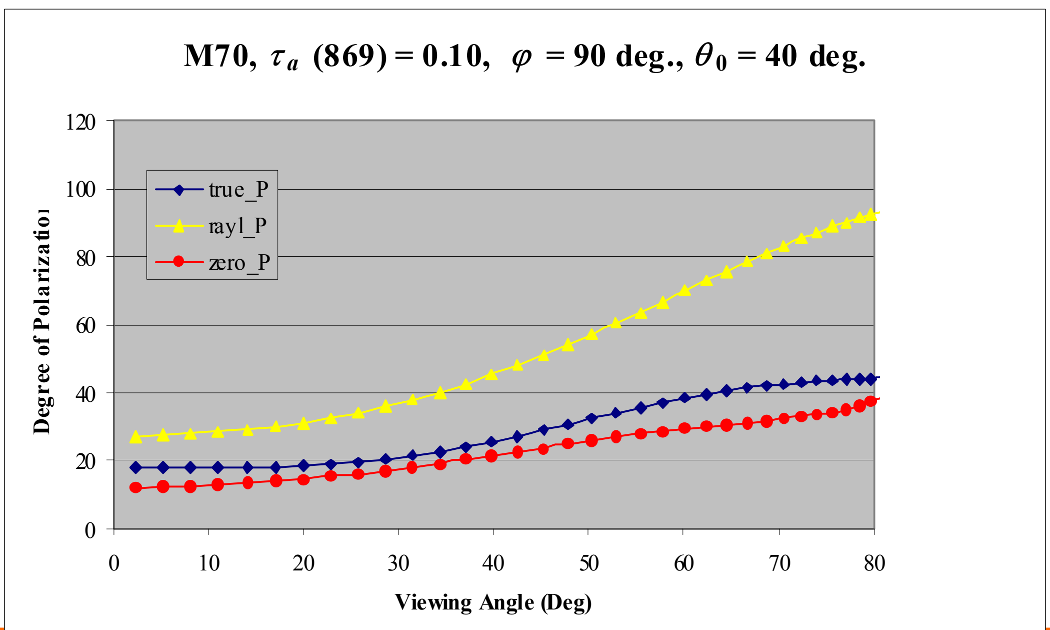


Typical (Clear) Aerosol Concentration

Original

True

Revised



Aerosol Doubled

Original

True

Revised

REVISED IS FAR BETTER

Physics

These simulations suggest that the revised polarization correction should be adequate at MOBY (~M70 aerosol). Note that this conclusion is contingent on the validity of the pre-launch polarization characterization of MODIS, e.g., no change in orbit.

Physics

For general processing we proposed to include aerosol polarization in the *Gordon and Wang* (1994) algorithm in order to correct for the polarization sensitivity. This will require at least two passes through the atmospheric correction algorithm.

Physics

Polarization in Sun Glitter

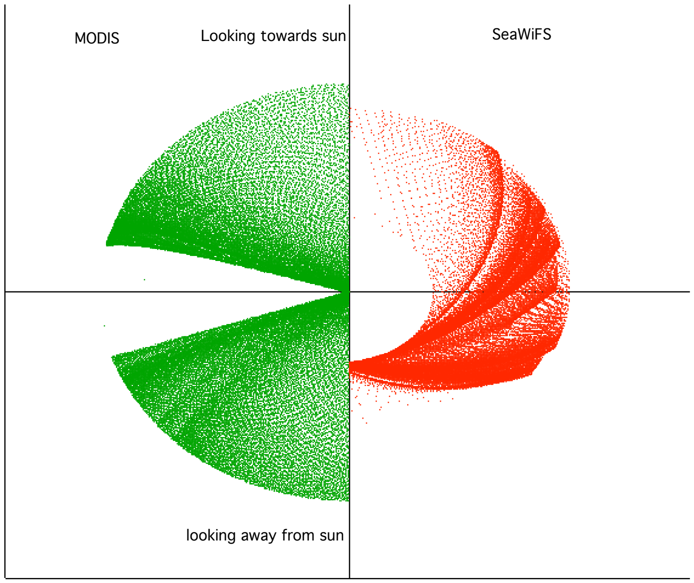
Basically, we investigated the influence of the polarization of Sunglitter. Where Sunglitter is strong, polarization is relatively weak. Where polarization is strong, sunglitter is weak. Seemed to be a non-issue at this point.

Physics

BRDF in ocean color

One way to look at Satellite view geometry

Physics



- This is a polar chart showing the range of different view geometries which each satellite uses. Each dot represents a different view azimuth/zenith in an orbit. This is restricted to between 70N and 70S. Zenith angle ranges from 0 (center) to the edge of the swath on outside of circle. These were abstracted from the 3 swaths (NH Summer, Spring(Fall), NH Winter)

This shows that the SeaWiFS view geometry is mostly restricted to a smaller range of possible geometries (dense points), while MODIS views almost all possible combinations. Thus understanding the BRDF is much more important for MODIS.

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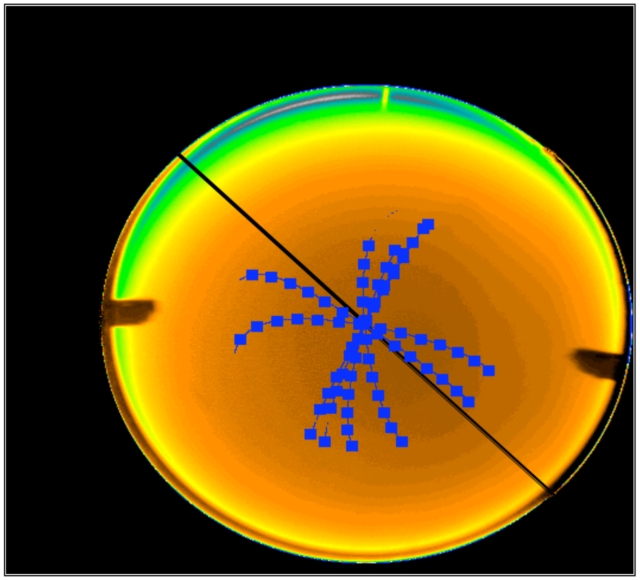
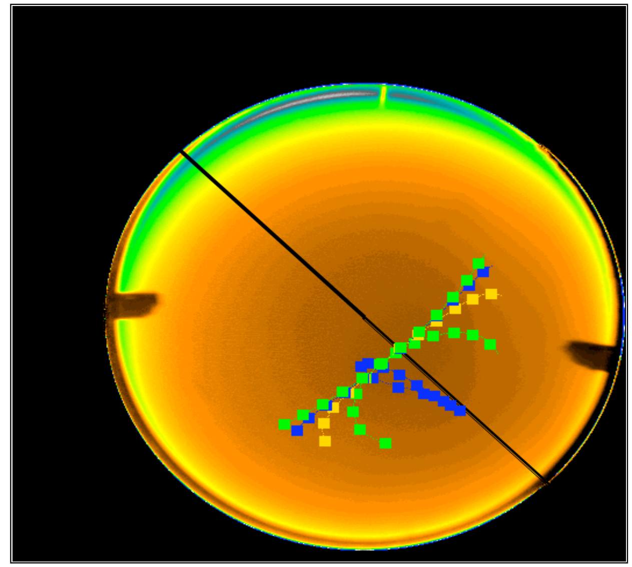
Another view along representative swaths in Northern Hem.

MODIS (Terra), 0-80N



SeaWiFS, 0-80N



- MODIS vs. SeaWiFS scan geometries displayed with an upwelling radiance distribution image.
- SeaWiFS tends toward scan lines oriented perpendicular to the principal plane, while MODIS actually has some oriented along the principal plane (very large variation in BRDF).

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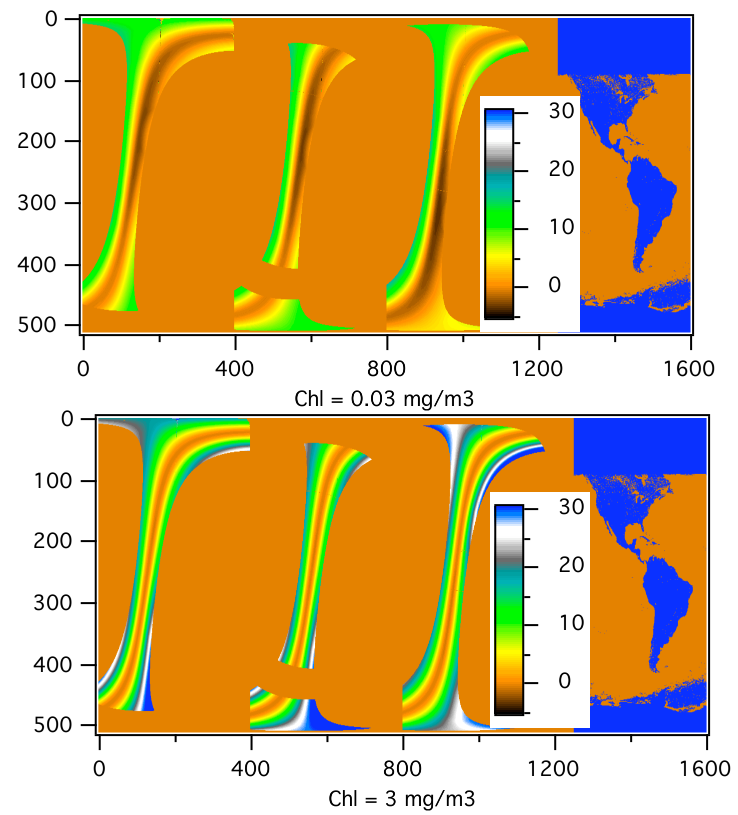
MODIS, 412 nm



BRDF correction factor

Because MODIS views at small rel. azimuth directions (towards the sun) there are areas where the viewed radiance is actually less than the nadir radiance in clear waters. The BRDF factor grows in higher Chl waters.

[f/q(sat view zenith,rel Azimuth,Sol zenith)/f/q(0,0,solZenith)-1]*100

Or (Lview/Lnadir -1)*100

30 would mean that the Lview is 30% greater than Lnadir.

MODIS, ratio of BRDF corrections (440/560)

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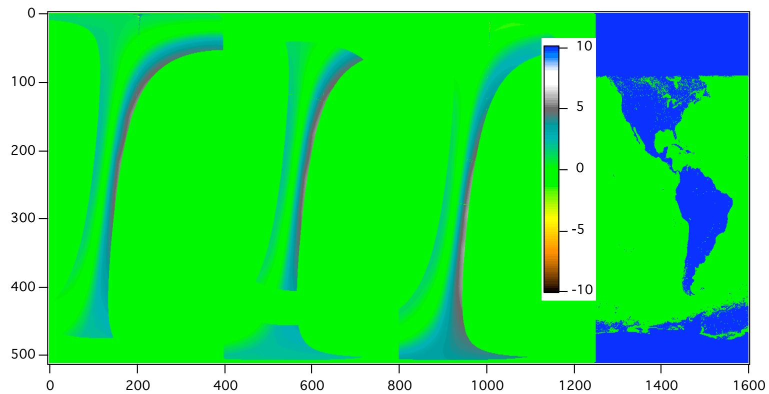
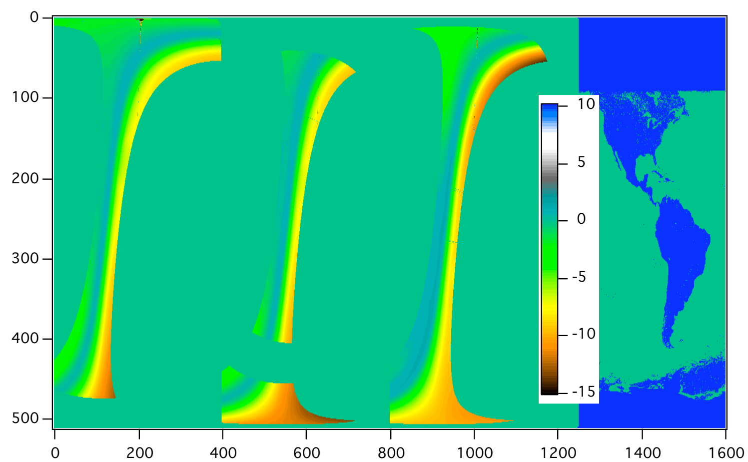




- Top figure is 0.03 mg, bottom figure is 3 mg.
- Values are 1-ratio of BRDF correction at the two wavelengths.

- At low chl, BRDF correction larger at 440 nm.
- At high Chl, BRDF correction larger at 560nm.

Physics

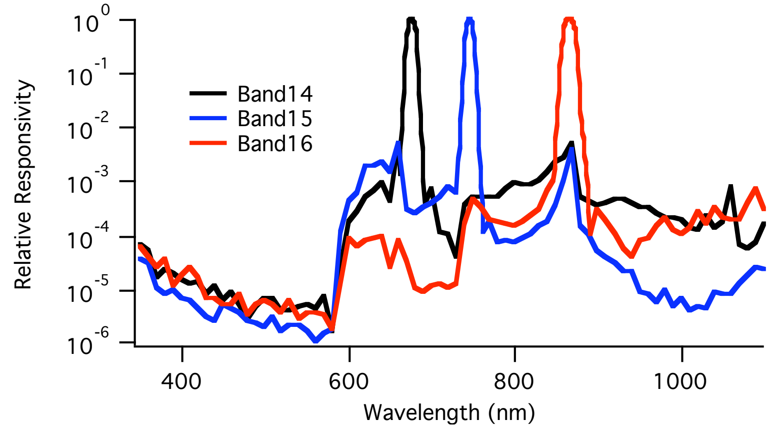
In-band vs Total band in MODIS

Physics

Out of band issues.

First issue, calibration coefficient (m1): in- band or total- band?

Looking at the solar diffuser one forms the calibration coefficient by calculating the ratio of :
Cal = L/DC
Where L is the radiance calculated as coming from the diffuser, and DC is the corrected digital counts from the instrument.



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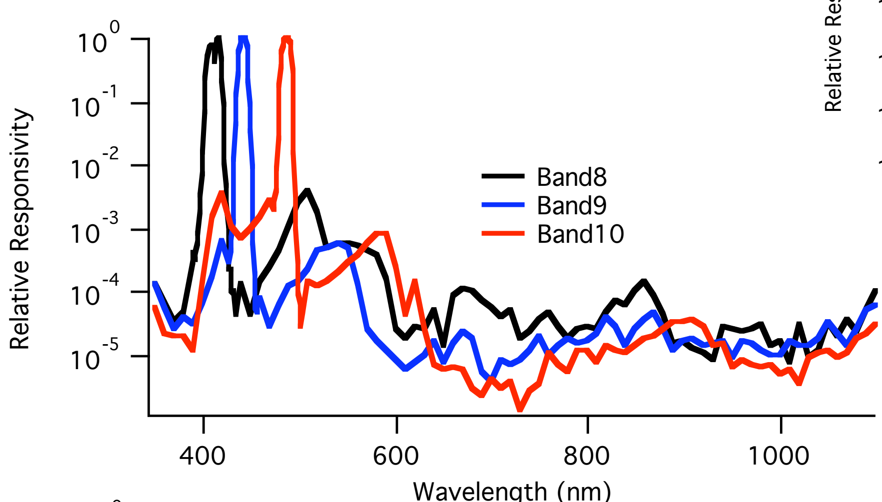
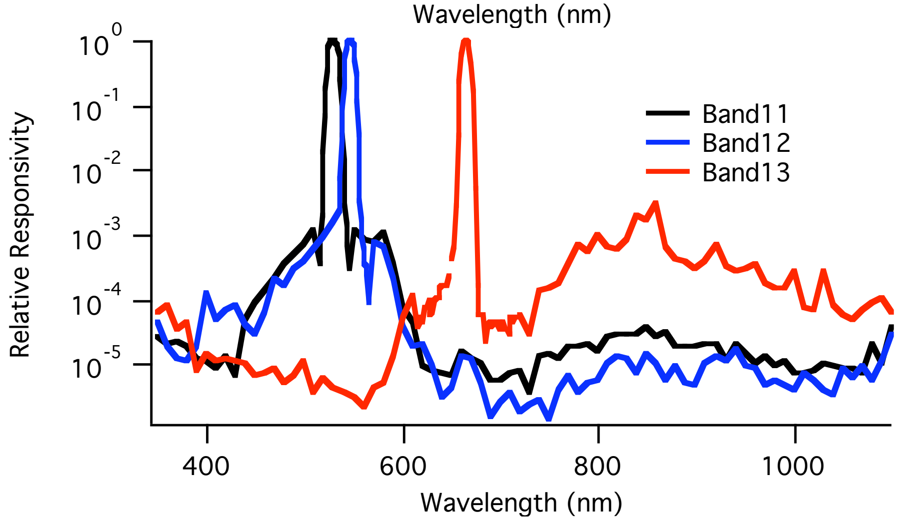


Just a little reminder of what the MODIS ocean color bands look like….



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For L one can form two different ratios, Ltotal or Linband:

$$Ltotal = \frac{\int_{350nm}^{1000nm} L(\lambda)R(\lambda)\,\partial\lambda}{\int_{350nm}^{1000nm} R(\lambda)\,\partial\lambda}$$

$$Linband = \frac{\int_{lowLimit}^{highLimit} Lt(\lambda)R(\lambda)\,\partial\lambda}{\int_{lowLimit}^{highLimit} R(\lambda)\,\partial\lambda}$$

Where R is the spectral response of the instrument, and the high and low limits are determined in some manner (1% peak response for our case).

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For MODIS the ratio of the Ltotal/Linband for the ocean color bands are:

Band	Ltotal/Linband	lower(nm)	upper(nm)
8	1.0003	399	424
9	0.9995	432	452
10	0.9989	477	496
11	0.9998	519	541
12	0.9998	537	557
13	0.9944	655	657
14	0.9939	665	688
15	1.0021	735	757
16	1.0007	850	882

Basically is within 0.2% for almost all the bands, so m1 coefficient will be the same for both inband or total band.

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This is not to say that there is not significant response from out of band:

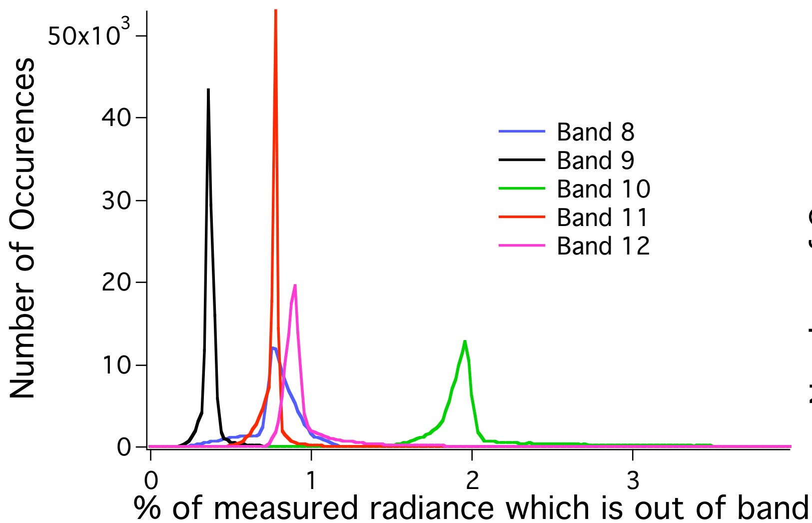
Band	total/inband Response
8	1.0150
9	1.0053
10	1.0170
11	1.0079
12	1.0075
13	1.0190
14	1.0289
15	1.0261
16	1.0057

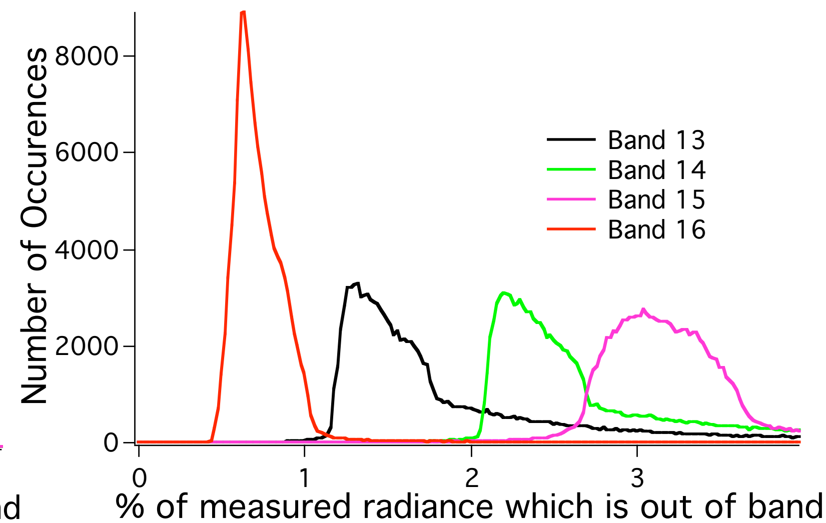
This is the ratio of the sum of the spectral response over either total band or in-band. What can be seen is that there is significant response (almost 3% in some channels) from the out-of-band region.

Earth View Scenes

Physics

One can also calculate the out-of-band component for an earth view scene using Lt's from MODIS. For each pixel calculate the % of the total radiance which is out-of-band. Below are histograms of the Earthview scenes for each ocean color band.





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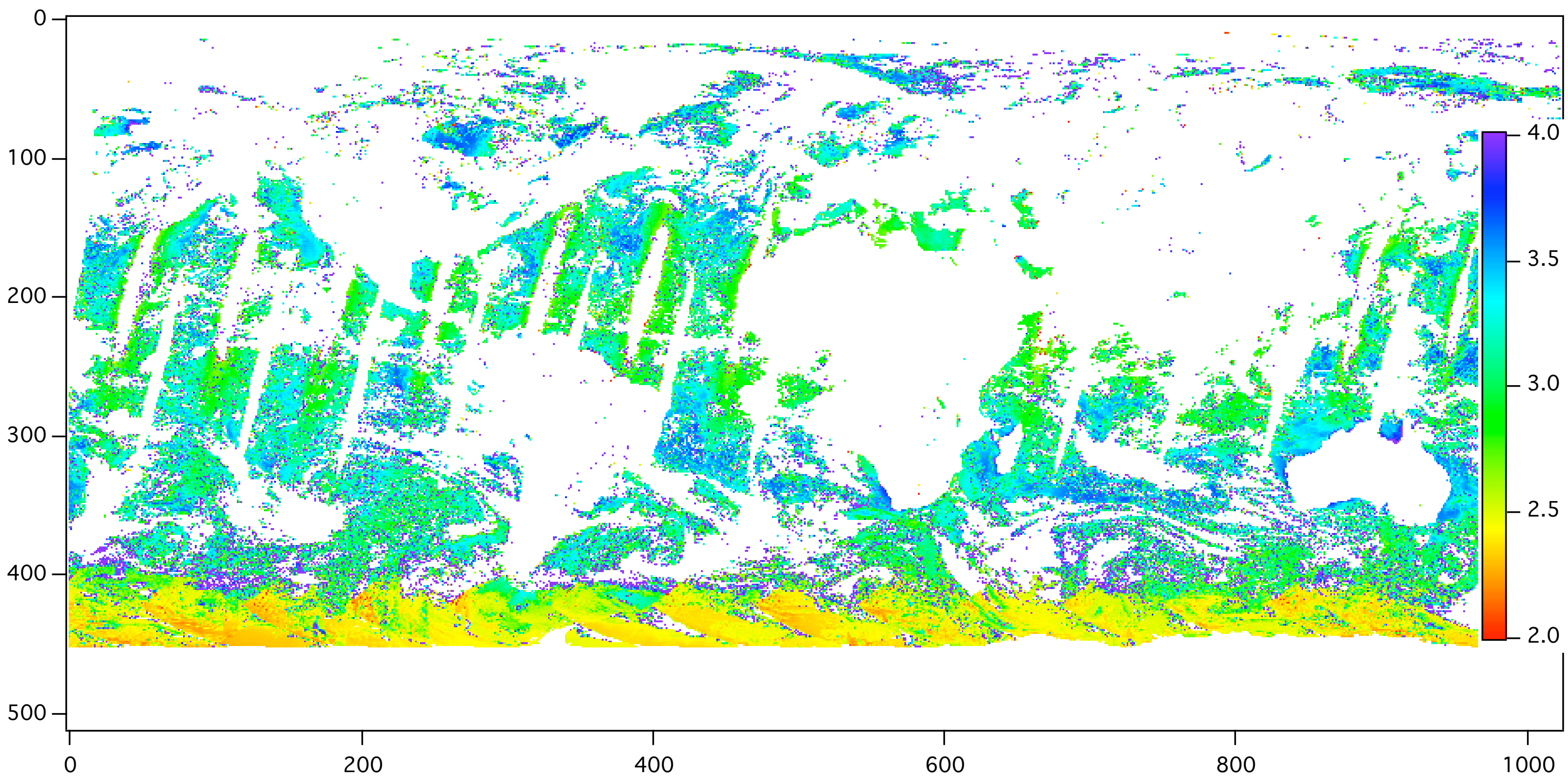
It is instructive to look at where the variation occurs, for example in Band 15 (765nm), note changes around glitter pattern and extensions, also in Southern Hemisphere.



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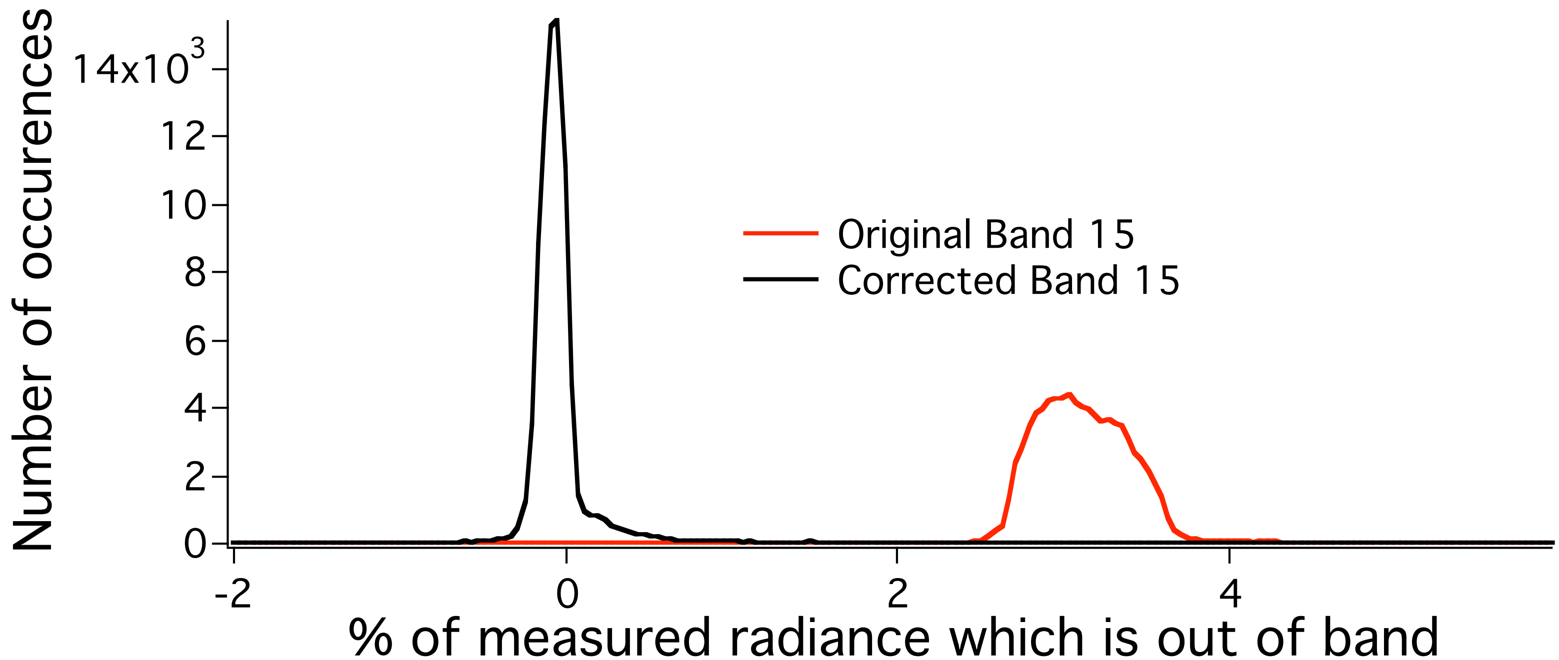
It is something that could be corrected however. Below is a simple correction which uses the ratio Lt(Band 14) and Lt(Band 16) to estimate the out-of-band contribution to Band 15 (simple linear regression).



Physics

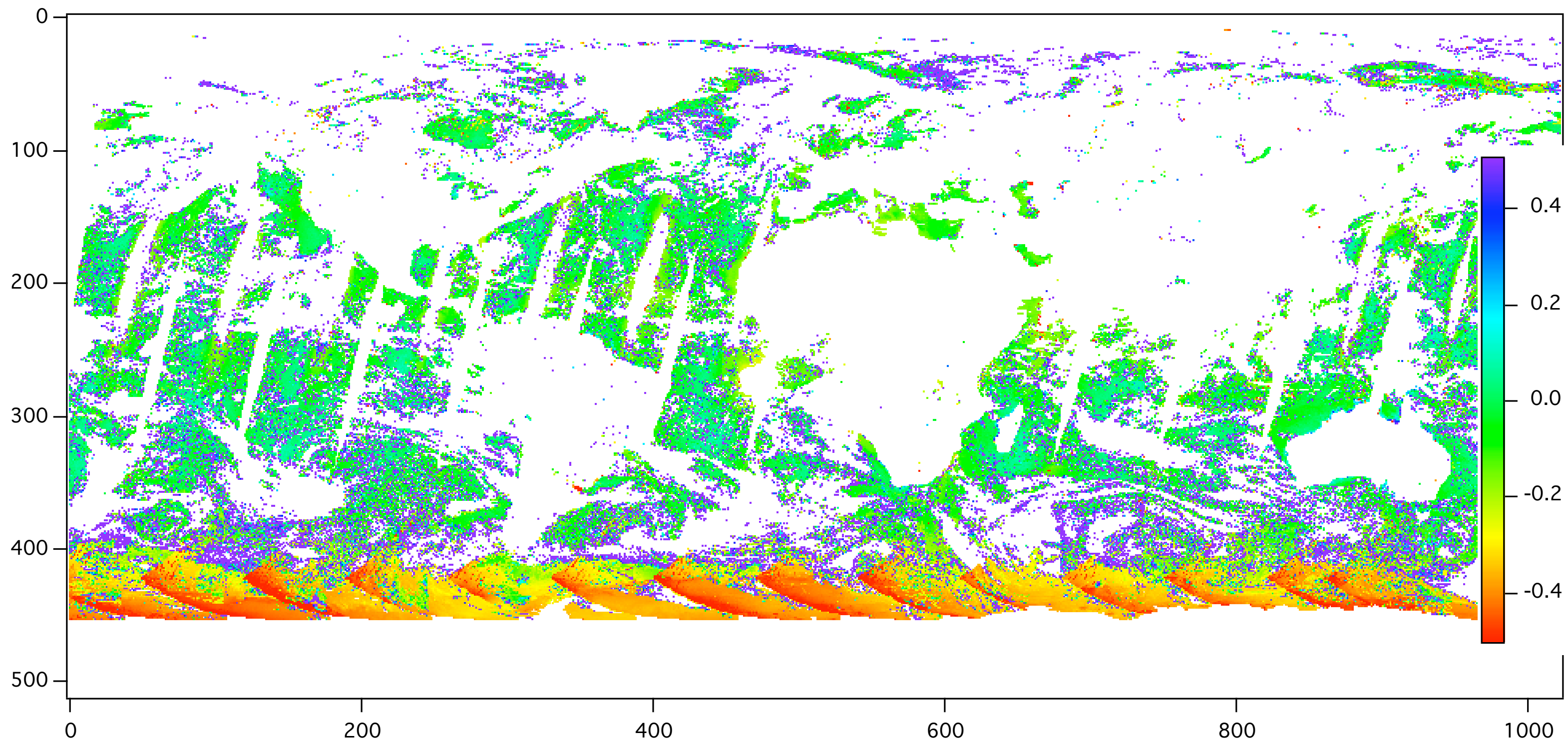


Image still shows some effects in high latitudes, but this simple correction has cleaned up the area around the sunglint, and note the scale even for the high latitude area.