USGS
science for a changing world

Land Uses Mission Area
National Land Imaging Program

Requirements Capabilities & Analysis for Earth Observations

L8 OLI vs PlanetScope SR comparison
L8 OLI AC mitigation

Minsu Kim, PhD, KBRwyle / USGS EROS

JACIE, 2018

Atm. Corr. Scene selection

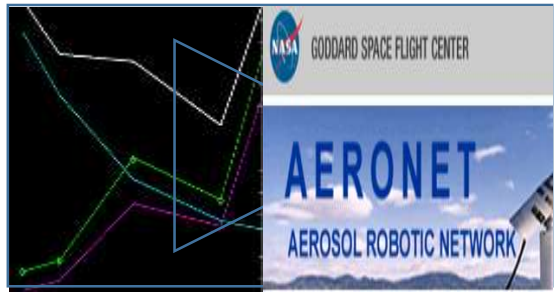
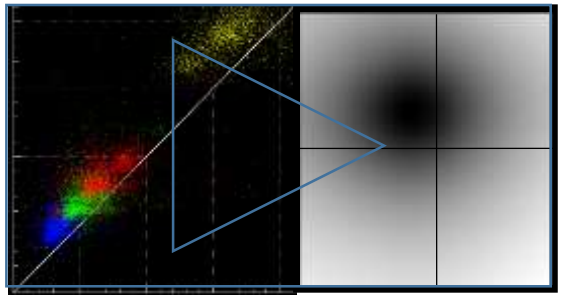
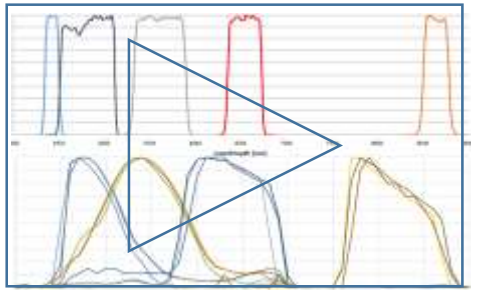


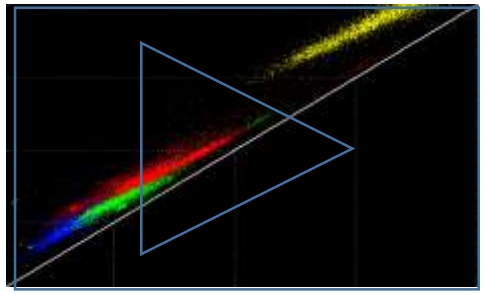
Image Resampling Geo-correction



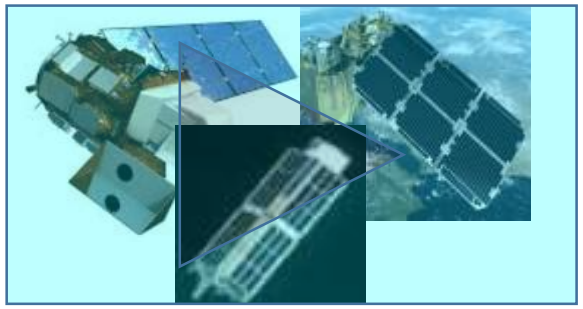
Spectral Response



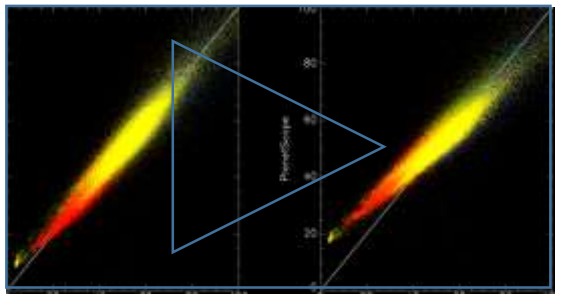
AC analysis Surf. Refl.



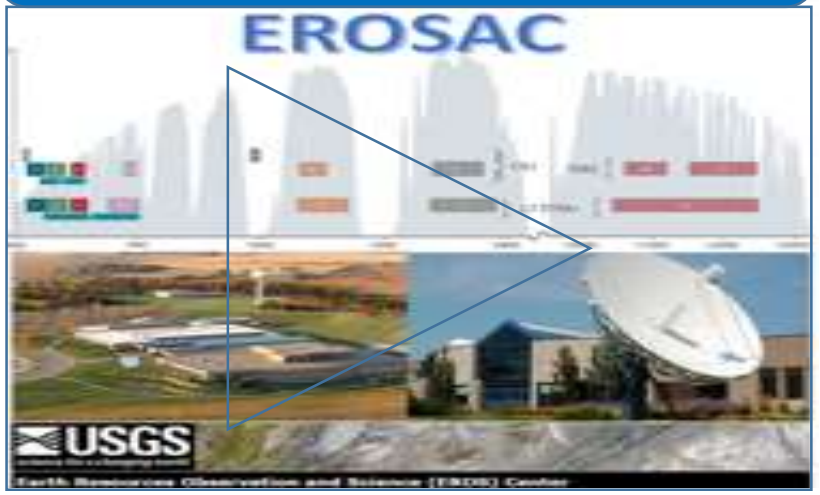
TOA Rad. Refl. L8_OLI vs S2_MSI



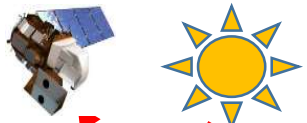
OLI – Planet Rad. Correction



OLI AC Mitigation



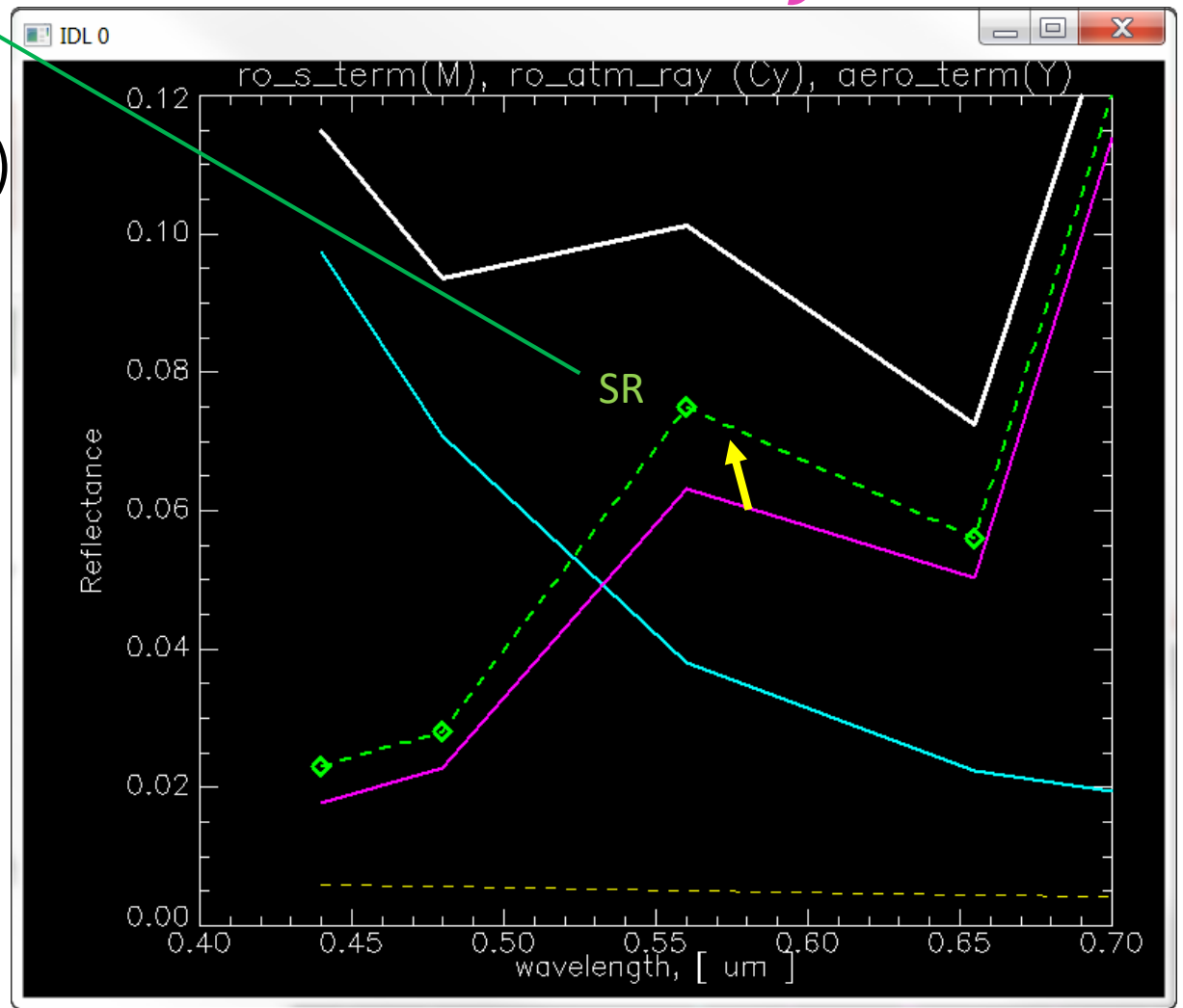
$$\rho_{TOA} = f(\ \ ,\ \ Atm,\ \ \rho) \approx Atm + Surf$$



SZA Gases (. . . , O3 , H2O)

VZA Pressure

ΔAA Aerosol (Type, AOT)



PlanetScope GEOTIFF SR file information

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"aot_coverage": 0.5
"aot_mean_quality": 1.0
"aot_method": "fixed"
"aot_source": "mod09cma"
"aot_status": "Data Found"
"aot_std": 0.002165954105599790 5
"aot_used": 0.01755555470784505
"atmospheric_correction_algorithm":"6Sv2.1"
"atmospheric_model": "water_vapor_and_ozone"
"luts_version": 3
"ozone_coverage": 0.5
"ozone_mean_quality": 255.0
"ozone_method": "fixed"
"ozone_source": "mod09cmg"
"ozone_status": "Data Found"
"ozone_std": 0.0
"ozone_used": 0.2924999925825331

"satellite_azimuth_angle": 0.0
"satellite_zenith_angle": 0.0
"solar_azimuth_angle": 150.32522363
"solar_zenith_angle": 55.4013318347
"sr_version": "1.0"
"water_vapor_coverage": 0.5
"water_vapor_mean_quality": 1.0
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"water_vapor_source": "mod09cma"
"water_vapor_status": "Data Found"
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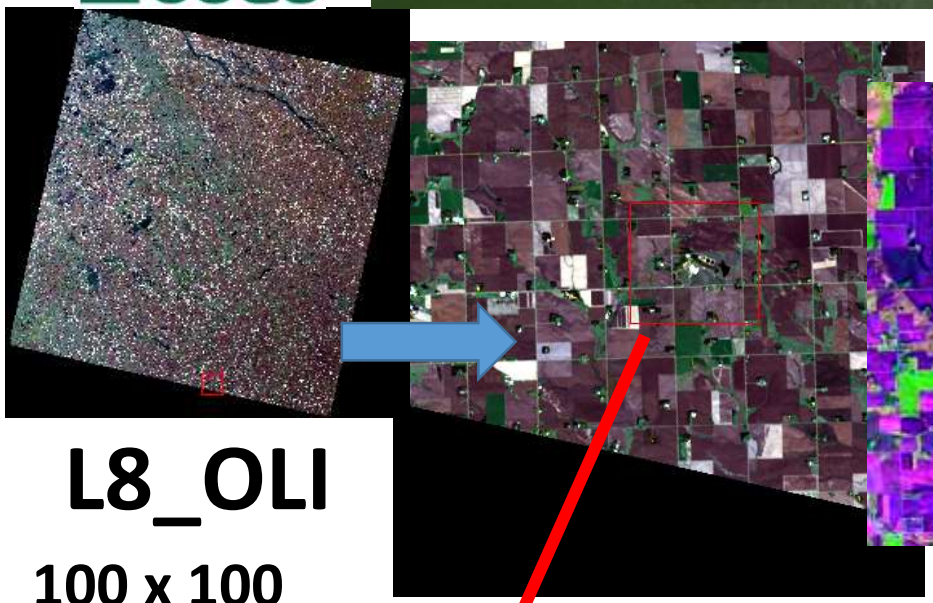
"water_vapor_used": 0.51888889736}}

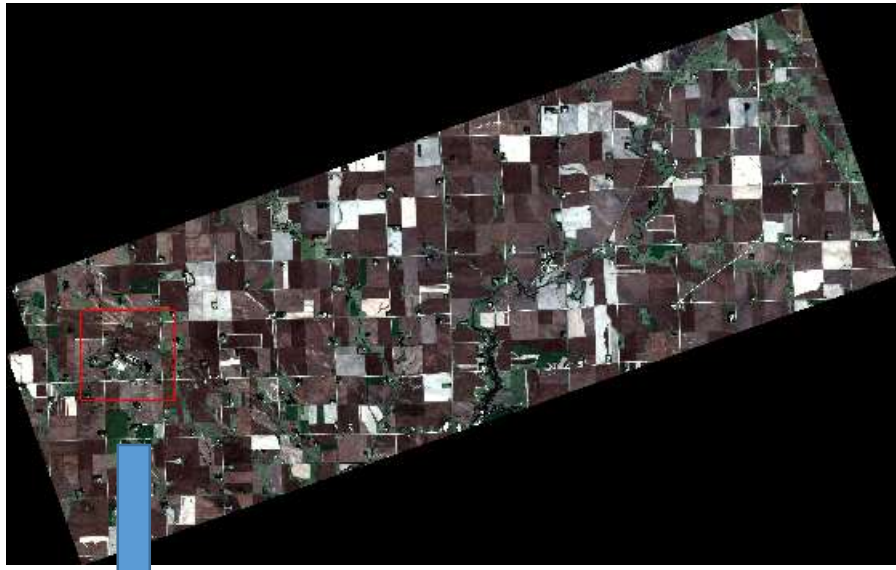


L8_OLI

100 x 100
(30 m pixel)

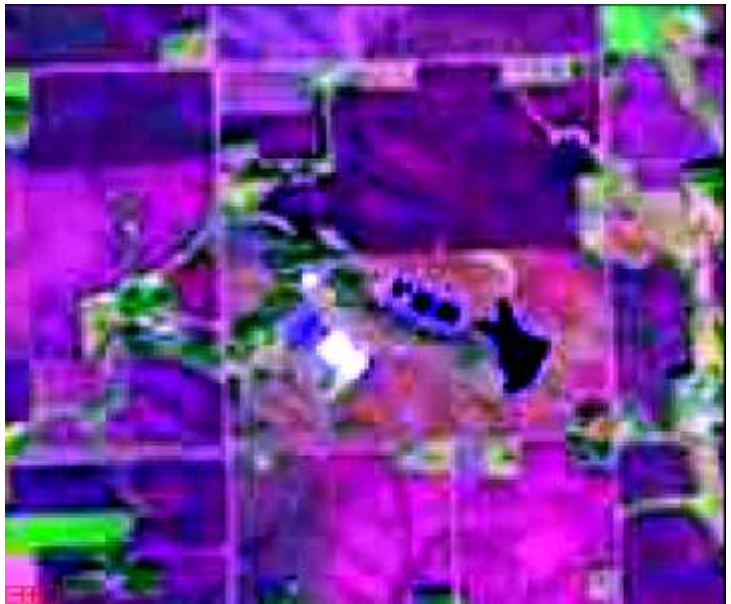
S2 MSI

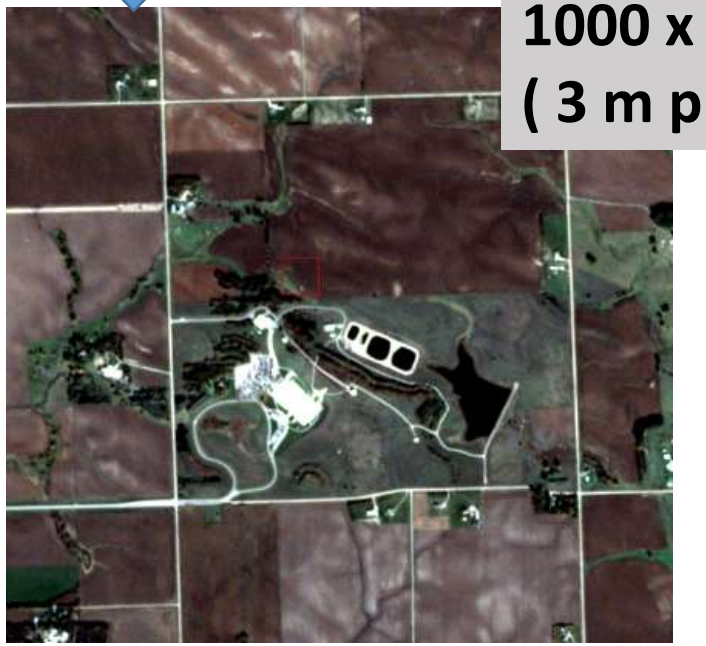
300 x 300 (10 m pixel)

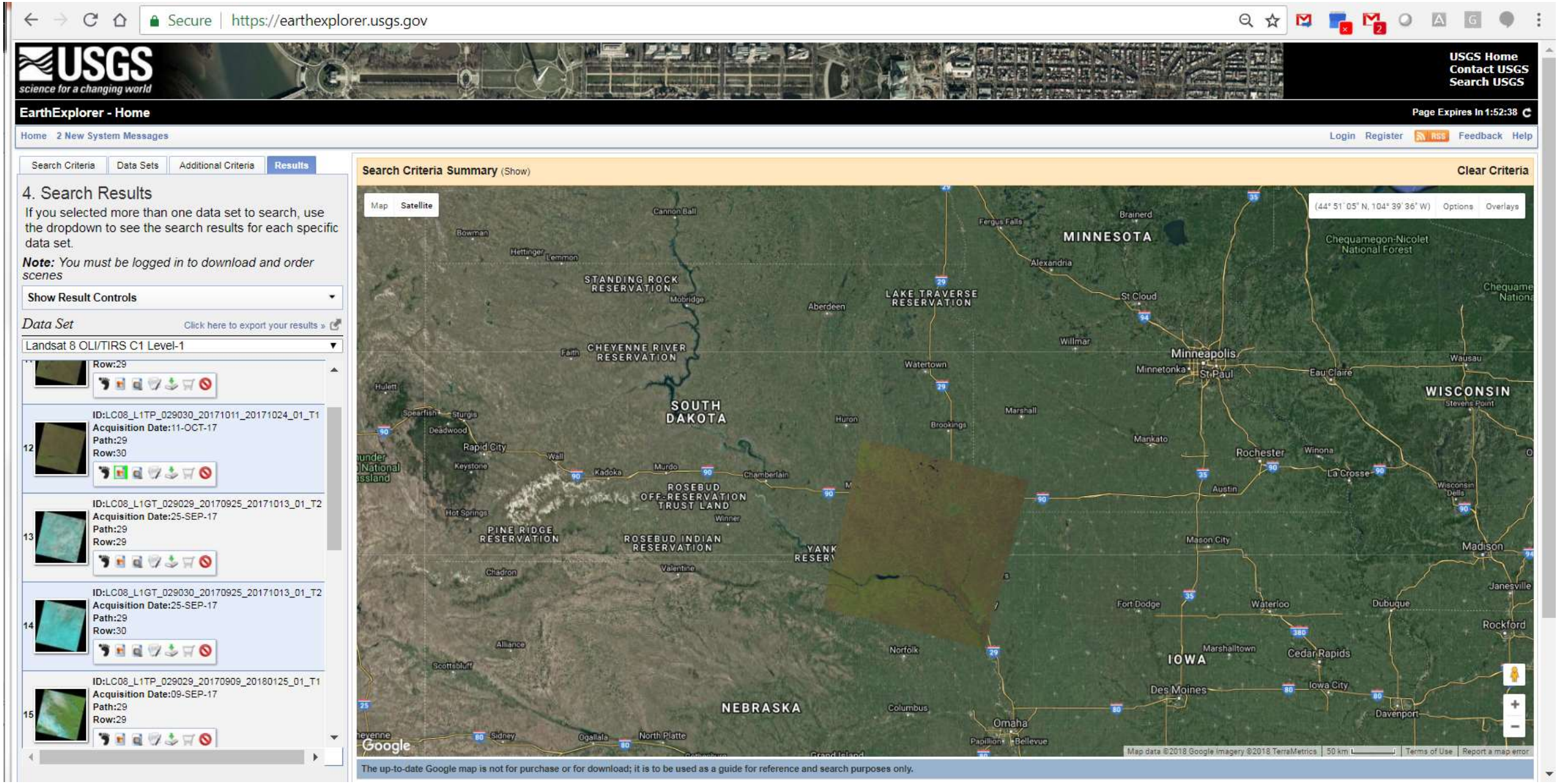


PlanetScope

1000 x 1000
(3 m pixel)






Secure
https://earthexplorer.usgs.gov
USGS
science for a changing world
USGS Home
Contact USGS
Search USGS
EarthExplorer - Home
Page Expires In 1:52:38
Home
2 New System Messages
Login
Register
Feedback
Help
Search Criteria
Data Sets
Additional Criteria
Results
4. Search Results
If you selected more than one data set to search, use the dropdown to see the search results for each specific data set.
Note: You must be logged in to download and order scenes
Show Result Controls
Data Set
Click here to export your results »
Landsat 8 OLI/TIRS C1 Level-1
Row:29
12
ID:LC08_L1TP_029030_20171011_20171024_01_T1
Acquisition Date:11-OCT-17
Path:29
Row:30
13
ID:LC08_L1GT_029029_20170925_20171013_01_T2
Acquisition Date:25-SEP-17
Path:29
Row:29
14
ID:LC08_L1GT_029030_20170925_20171013_01_T2
Acquisition Date:25-SEP-17
Path:29
Row:30
15
ID:LC08_L1TP_029029_20170909_20180125_01_T1
Acquisition Date:09-SEP-17
Path:29
Row:29
Search Criteria Summary (Show)
Clear Criteria
Map
Satellite
(44° 51' 05" N, 104° 39' 36" W)
Options
Overlays
MINNESOTA
WISCONSIN
SOUTH DAKOTA
NEBRASKA
IOWA
STANDING ROCK RESERVATION
CHEYENNE RIVER RESERVATION
LAKE TRAVERSE RESERVATION
ROSEBUD OFF-RESERVATION TRUST LAND
ROSEBUD INDIAN RESERVATION
PINE RIDGE RESERVATION
Minneapolis
St Paul
Rochester
Des Moines
Omaha
Cedar Rapids
Waterloo
Madison
Rockford
Chequamegon-Nicolet National Forest
Map data ©2018 Google Imagery ©2018 TerraMetrics
50 km
Terms of Use
Report a map error
The up-to-date Google map is not for purchase or for download; it is to be used as a guide for reference and search purposes only.

USGS

Requirements Capabilities & Analysis for Earth Observations

GODDARD SPACE FLIGHT CENTER

AERONET
AEROSOL ROBOTIC NETWORK

Data Display Controls

AERONET Data Type:
- AOD
- Water Vapor
- 440-870 Angstrom
- SDA Fine/Coarse AOD
- SDA Fine Mode Fraction

AOD Level (2017): Level 1.0 | Level 1.5 | Level 2.0

Data Format: All points | Daily averages

Triplet Error Bars (All Points Only): Off | On

SELECT CHARTS FOR LARGER IMAGES

Choose year :	1997	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Choose month of 2017 :	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT										

Year

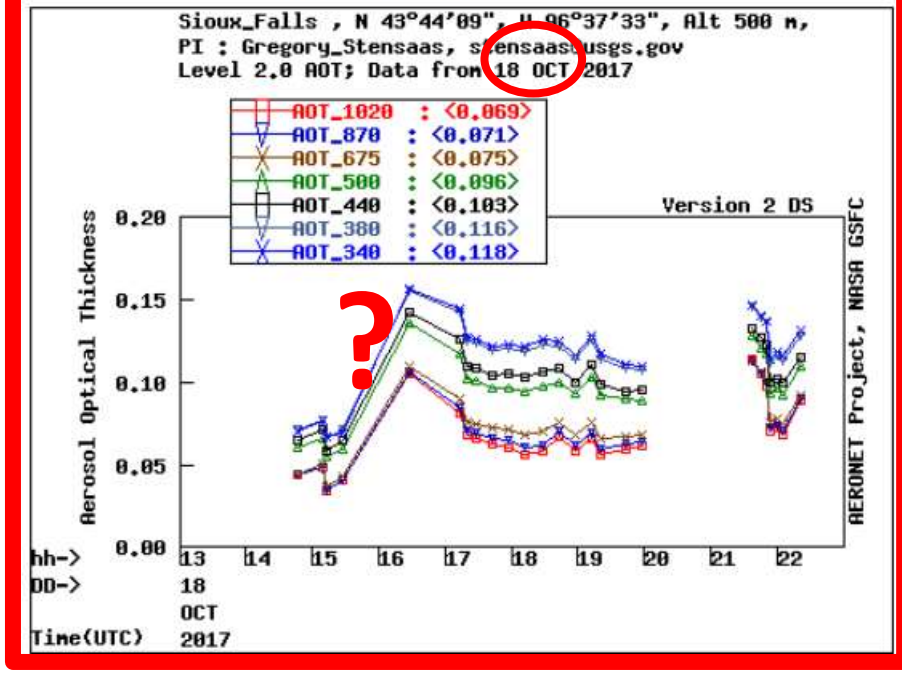
Month

Date

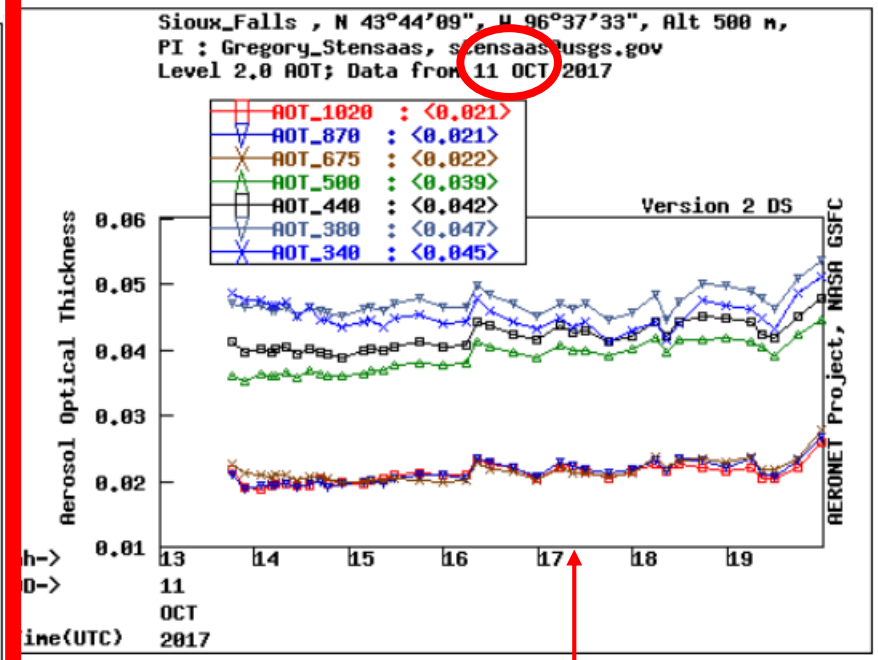
Choose day of OCT 2017

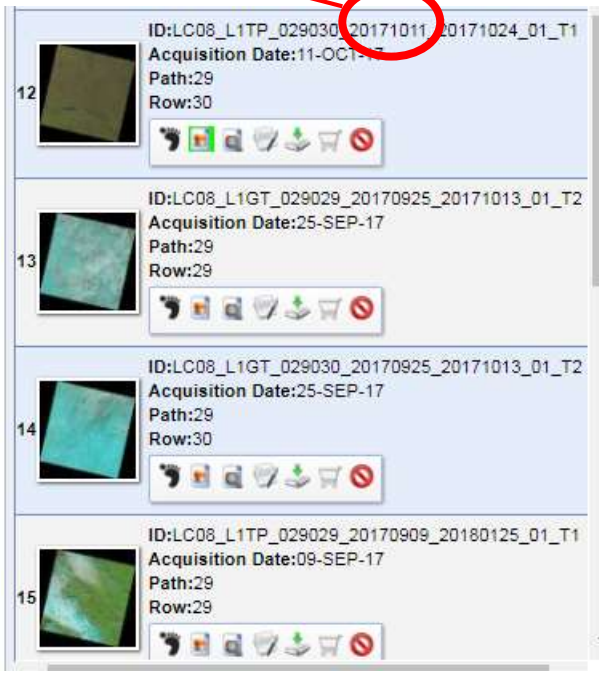
1	2	3	4	5	6	7	8	9	10	11	12
13	14	15	16	17	18	19	20	21	22	23	24
25	26	27	28	29	30	31					

AOD Level 2.0 data from OCT 18 of 2017



AOD Level 2.0 data from OCT 11 of 2017





Start Time	2017:284:17:11:47
Stop Time	2017:284:17:12:19

Name

AERONET

Planet

Sentinel

L8 OLI

LC08_L1TP_116034_20180202_20180220_01_T1_MTL.txt

LC08_L1TP_116034_20180202_20180220_01_T1_sr.hdr

LC08_L1TP_116034_20180202_20180220_01_T1_sr.img

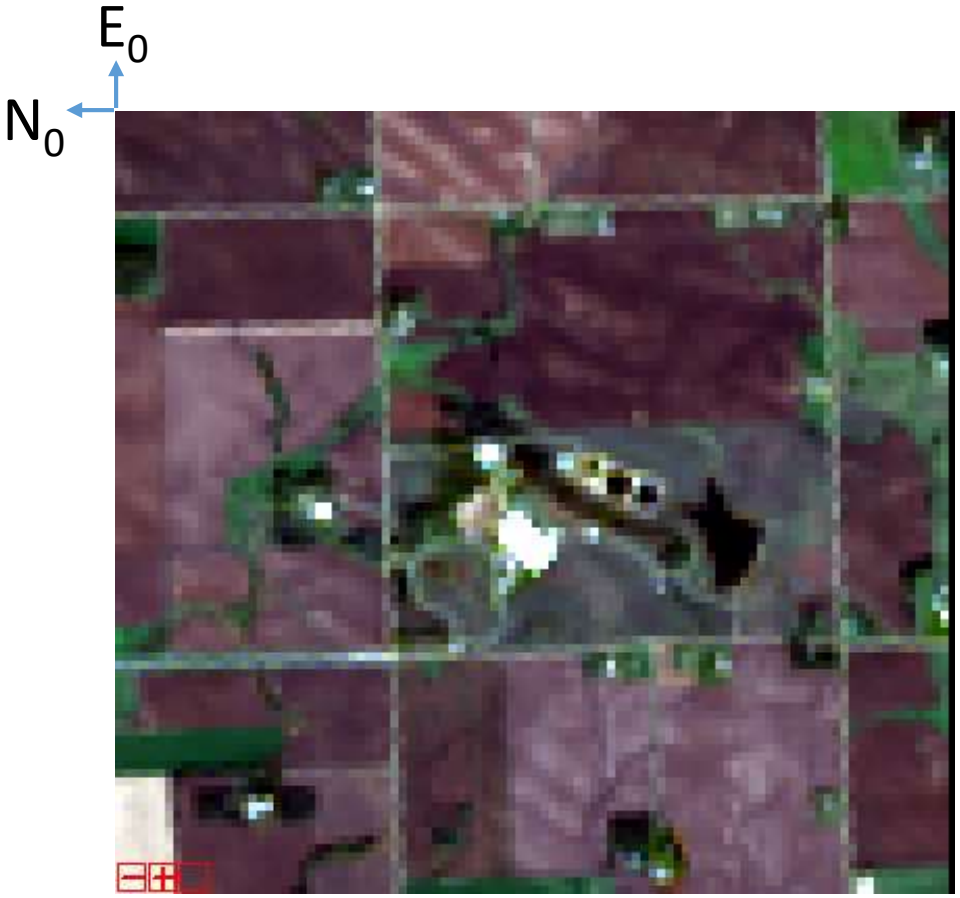
LC08_L1TP_116034_20180202_20180220_01_T1_toa_band1.hdr

LC08_L1TP_116034_20180202_20180220_01_T1_toar.hdr

LC08_L1TP_116034_20180202_20180220_01_T1_toar.img

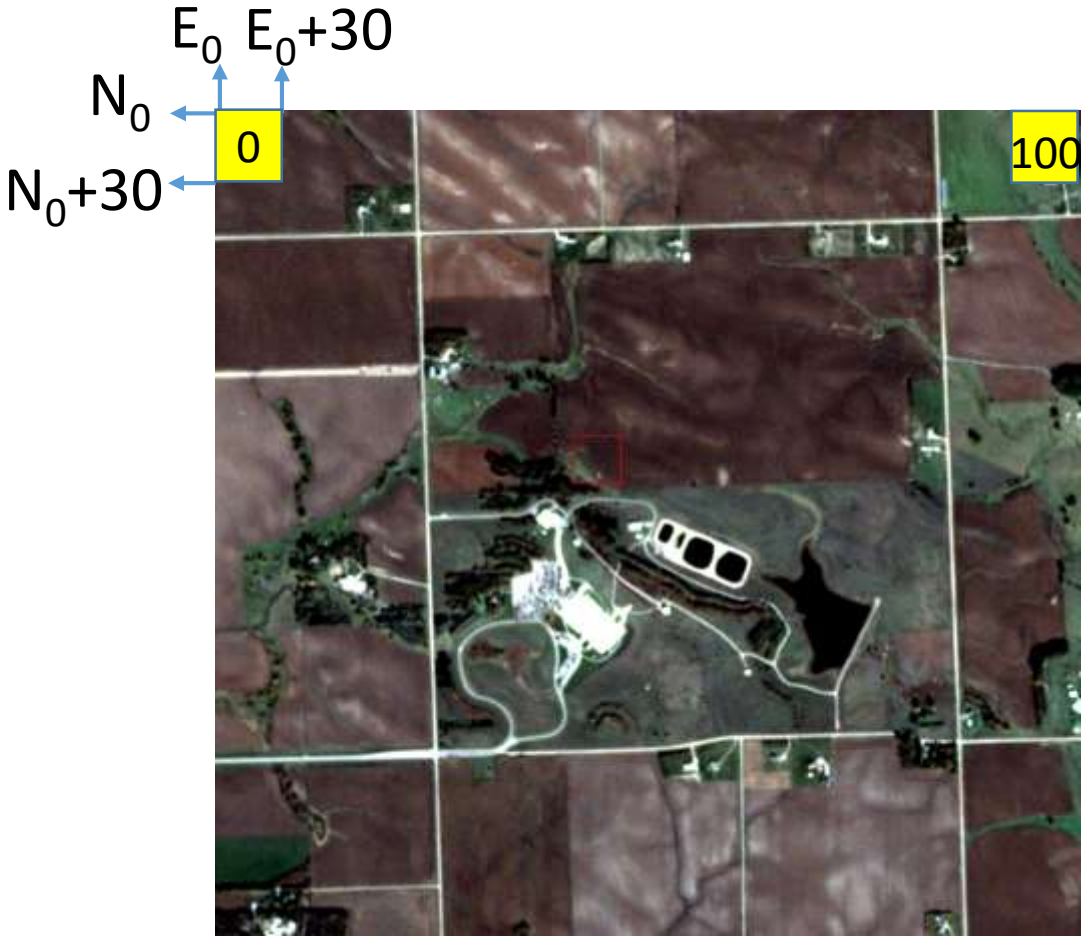
Image resampling

L8_OLI



100 x 100
(30 m pixel)
Center : AERONET

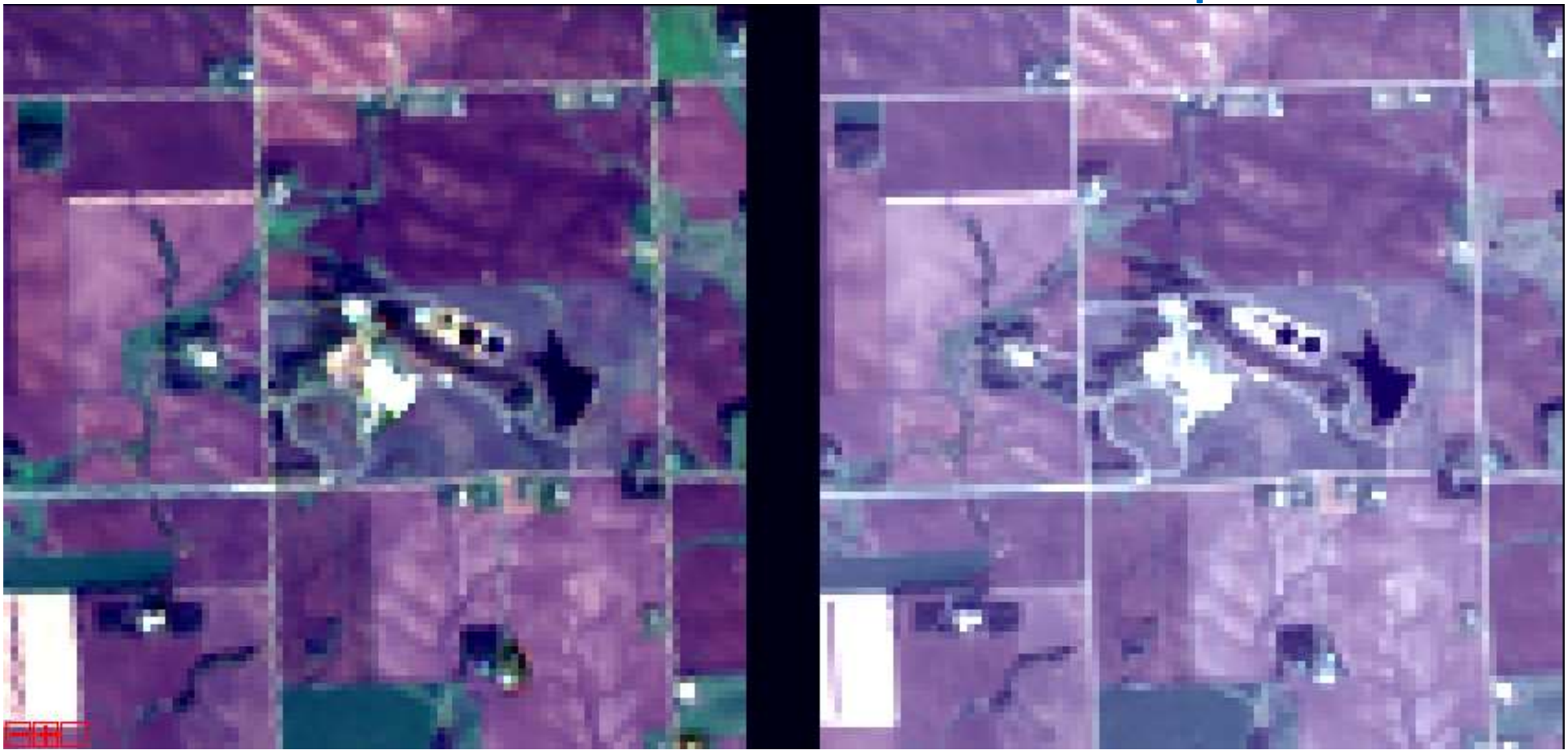
PlanetScope

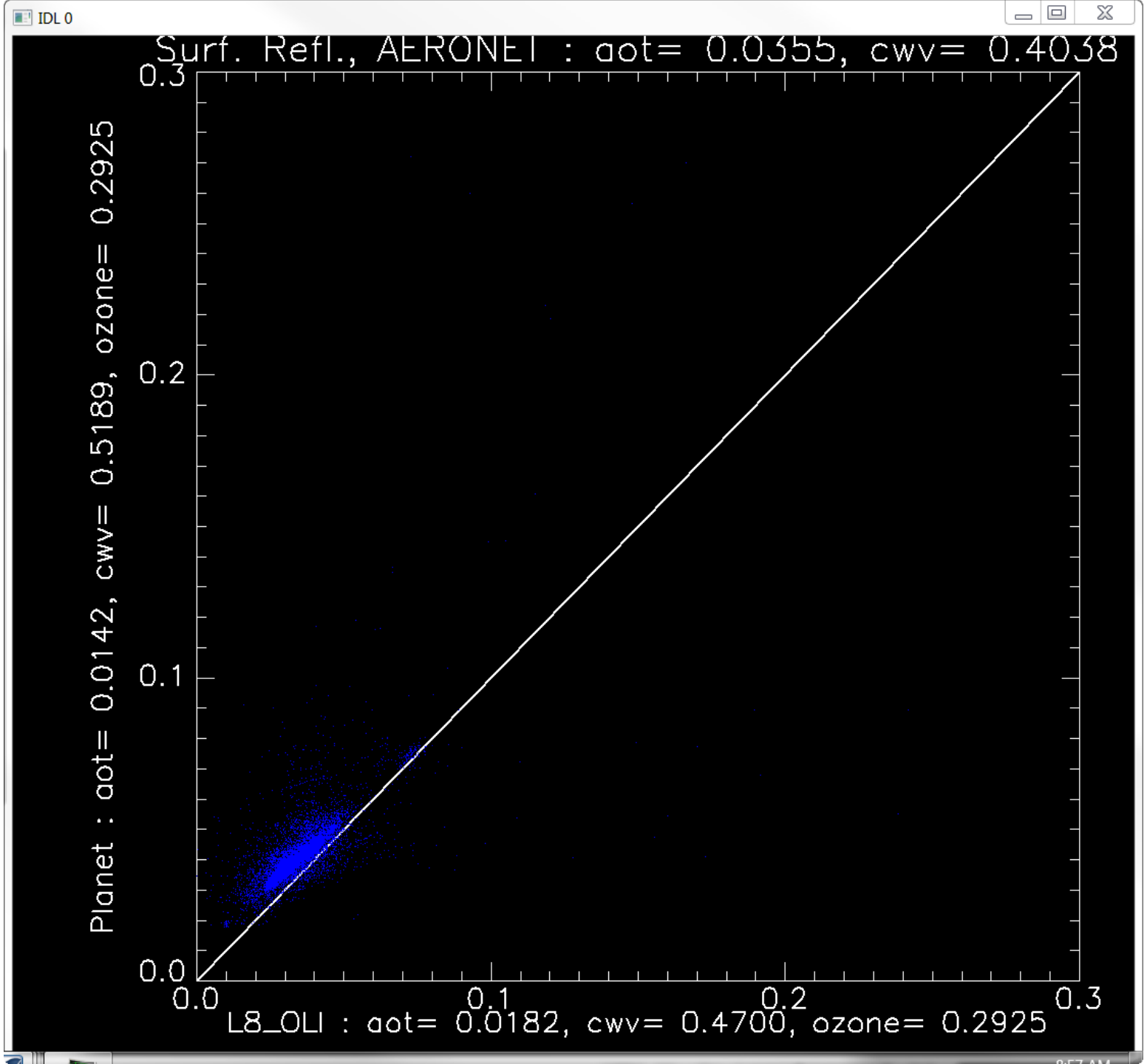


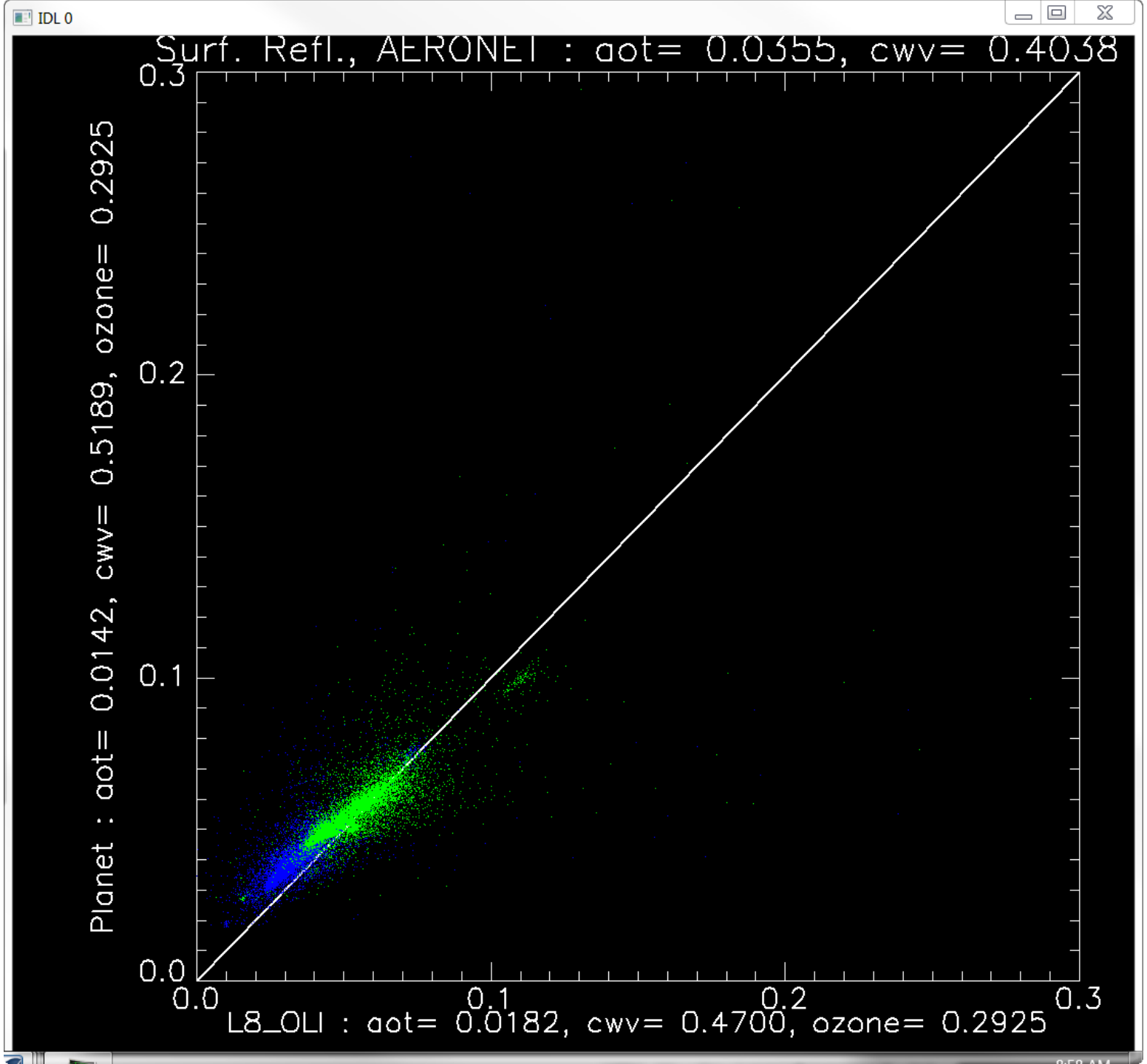
1000 x 1000
(3 m pixel)

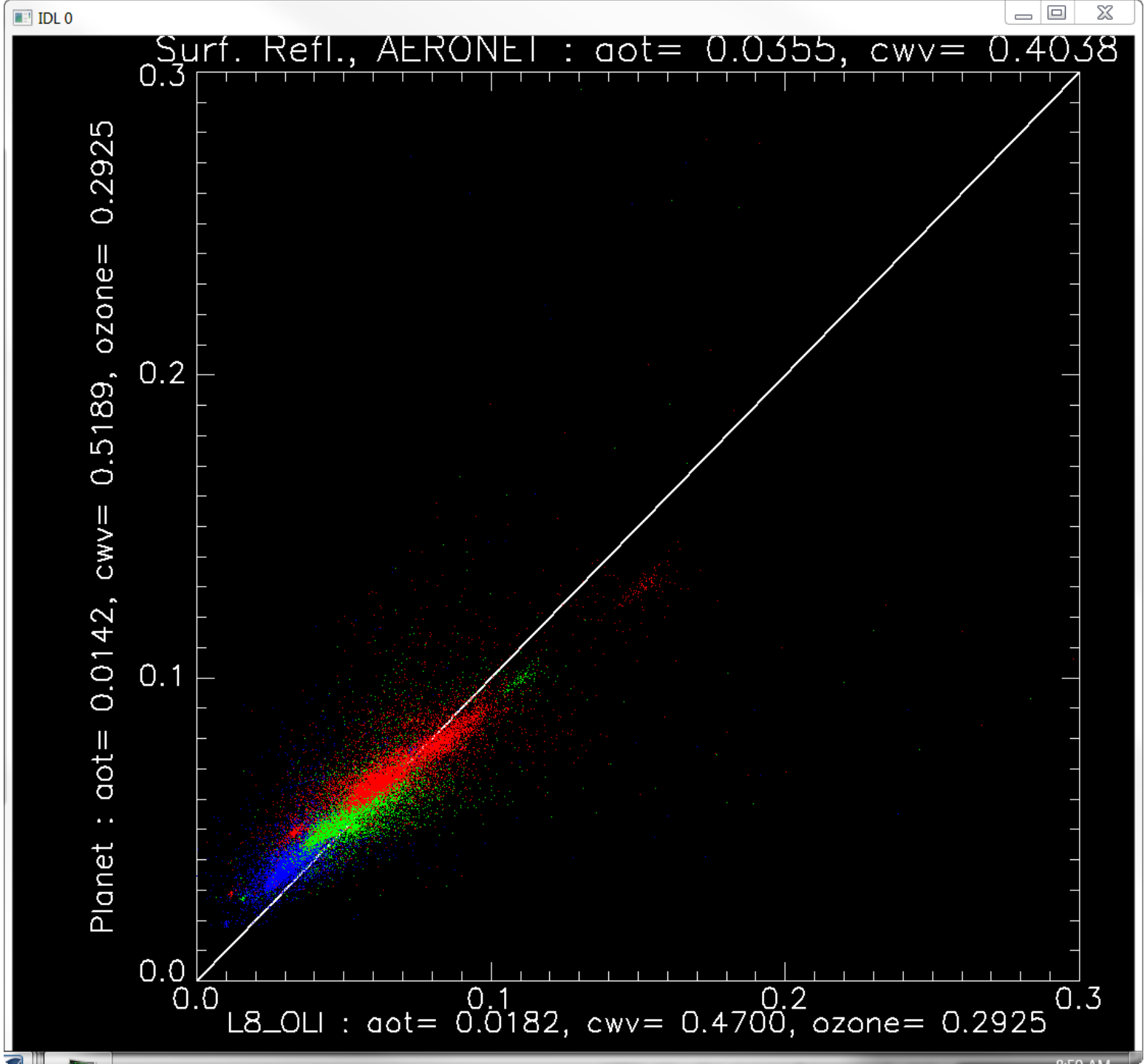
L8_OLI **No Image Shift** **PlanetScope**

30m native **Resampled to 30m**




IDL 0
Surf. Refl., AERONET : aot= 0.0355, cwv= 0.4038
Planet : aot= 0.0142, cwv= 0.5189, ozone= 0.2925
L8_OLI : aot= 0.0182, cwv= 0.4700, ozone= 0.2925
0.0
0.1
0.2
0.3


IDL 0
Surf. Refl., AERONET : aot= 0.0355, cwv= 0.4038
Planet : aot= 0.0142, cwv= 0.5189, ozone= 0.2925
L8_OLI : aot= 0.0182, cwv= 0.4700, ozone= 0.2925
0.0
0.1
0.2
0.3


IDL 0
Surf. Refl., AERONET : aot= 0.0355, cwv= 0.4038
Planet : aot= 0.0142, cwv= 0.5189, ozone= 0.2925
L8_OLI : aot= 0.0182, cwv= 0.4700, ozone= 0.2925
0.0
0.1
0.2
0.3

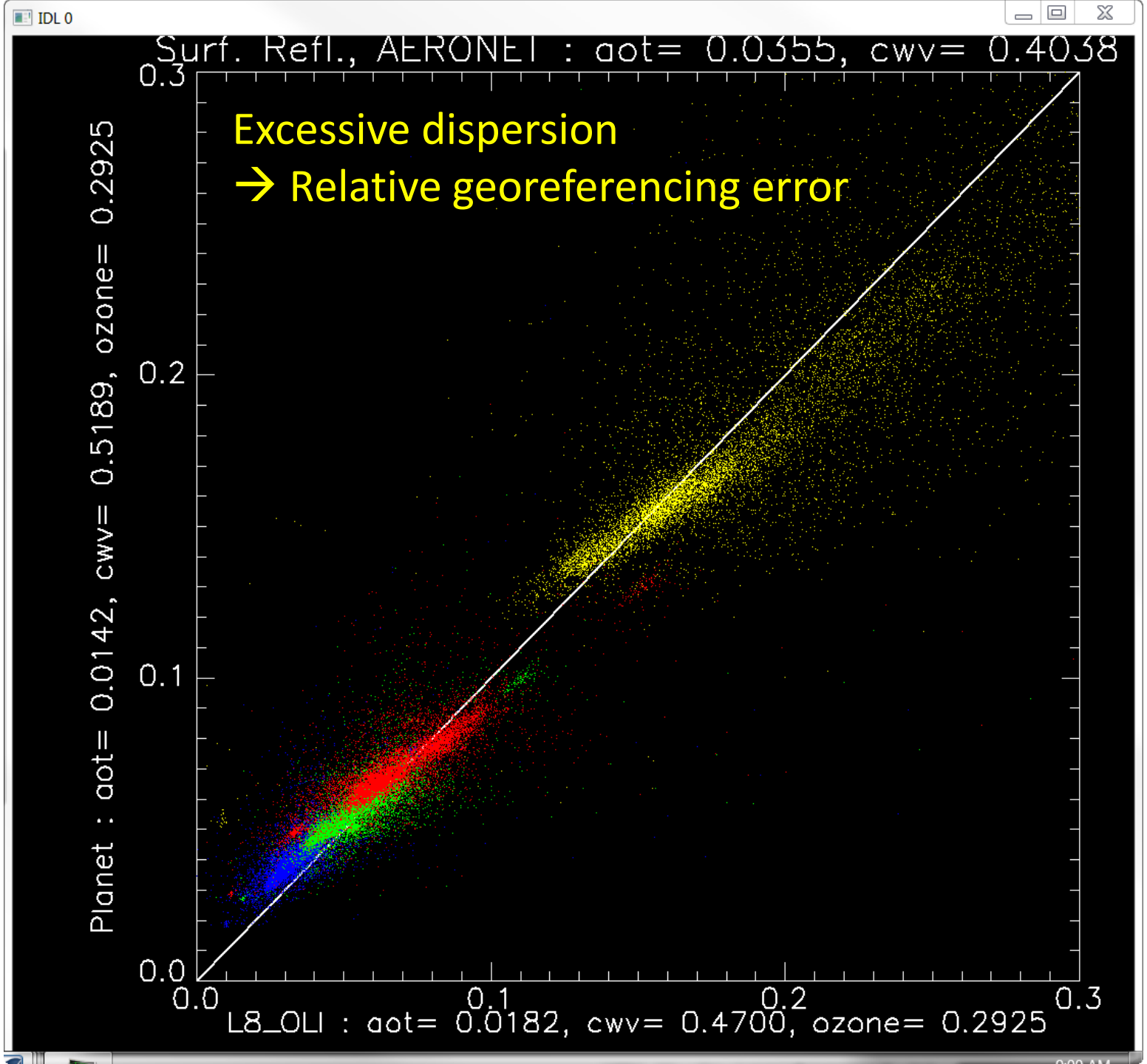

IDL 0
Surf. Refl., AERONET : aot= 0.0355, cwv= 0.4038
Excessive dispersion
→ Relative georeferencing error
Planet : aot= 0.0142, cwv= 0.5189, ozone= 0.2925
L8_OLI : aot= 0.0182, cwv= 0.4700, ozone= 0.2925
0.0
0.1
0.2
0.3

Image Shift

(ΔE, ΔN)

L8_OLI

E_0

N_0

100 x 100

(30 m pixel)

Center : AERONET

PlanetScope

E_0+ΔE+30

E_0+ΔE

N_0+ΔN

N_0+ΔN+30

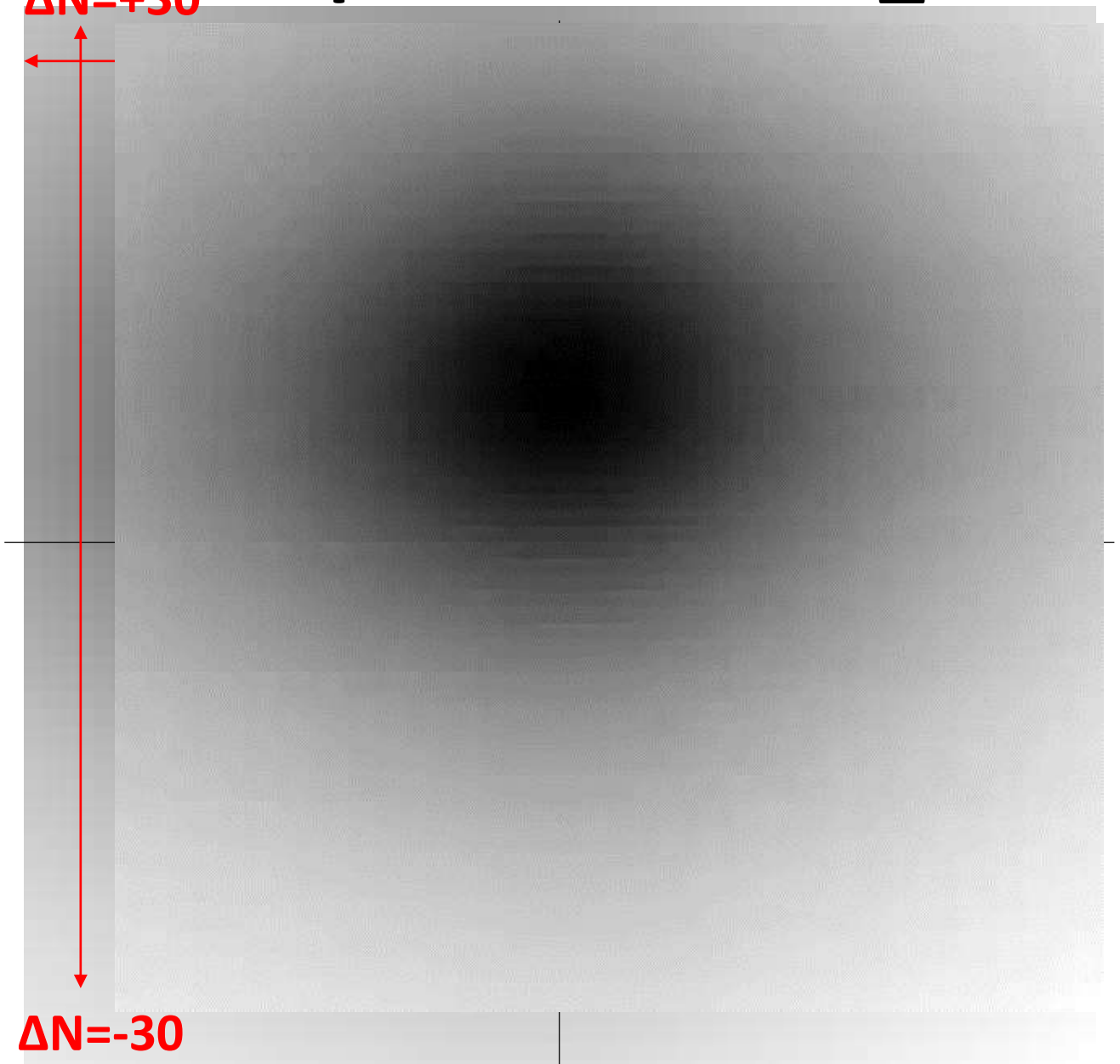
0

100

1000 x 1000

(3 m pixel)

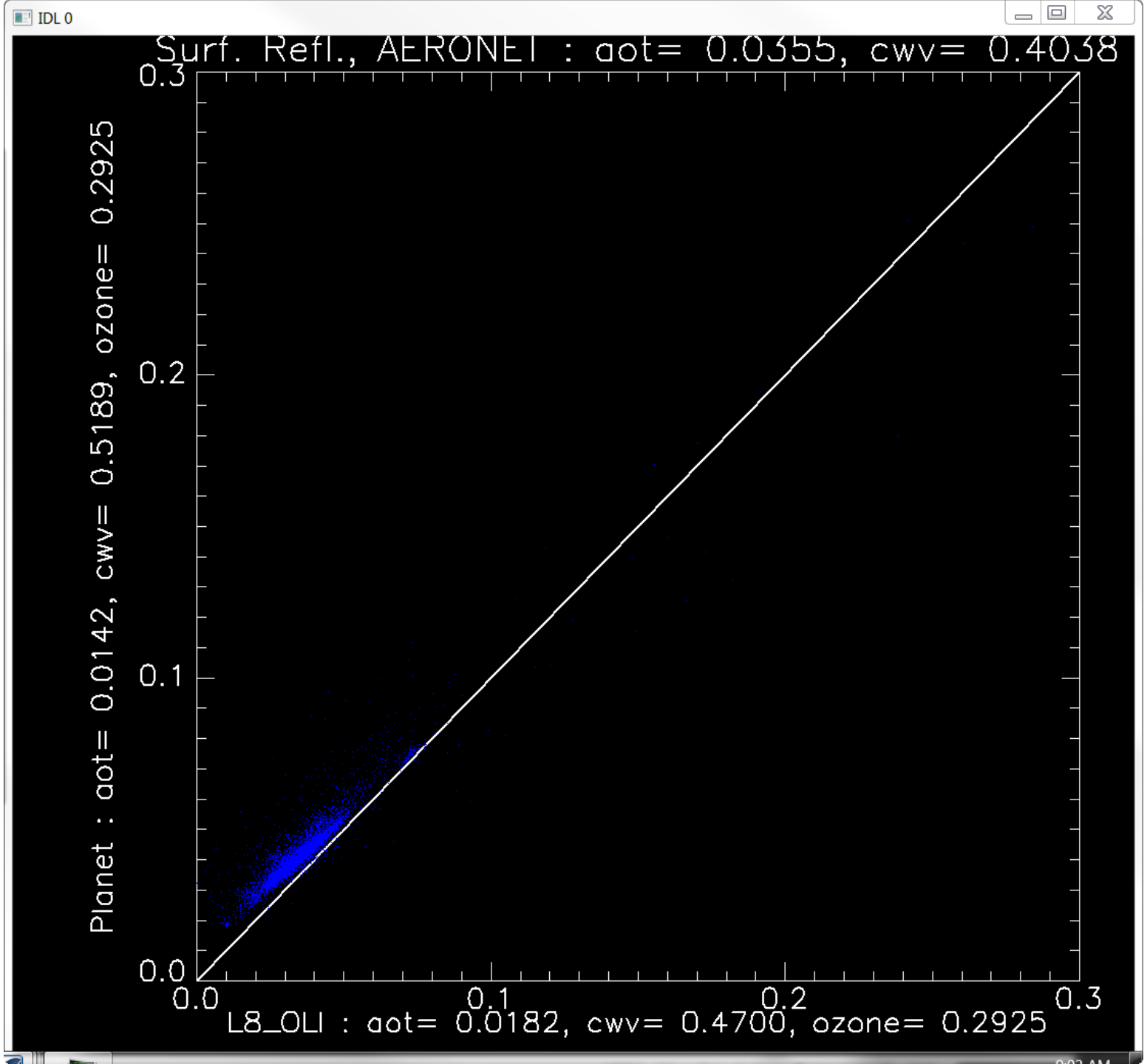
Spatial shift : L8_OLI vs Planet



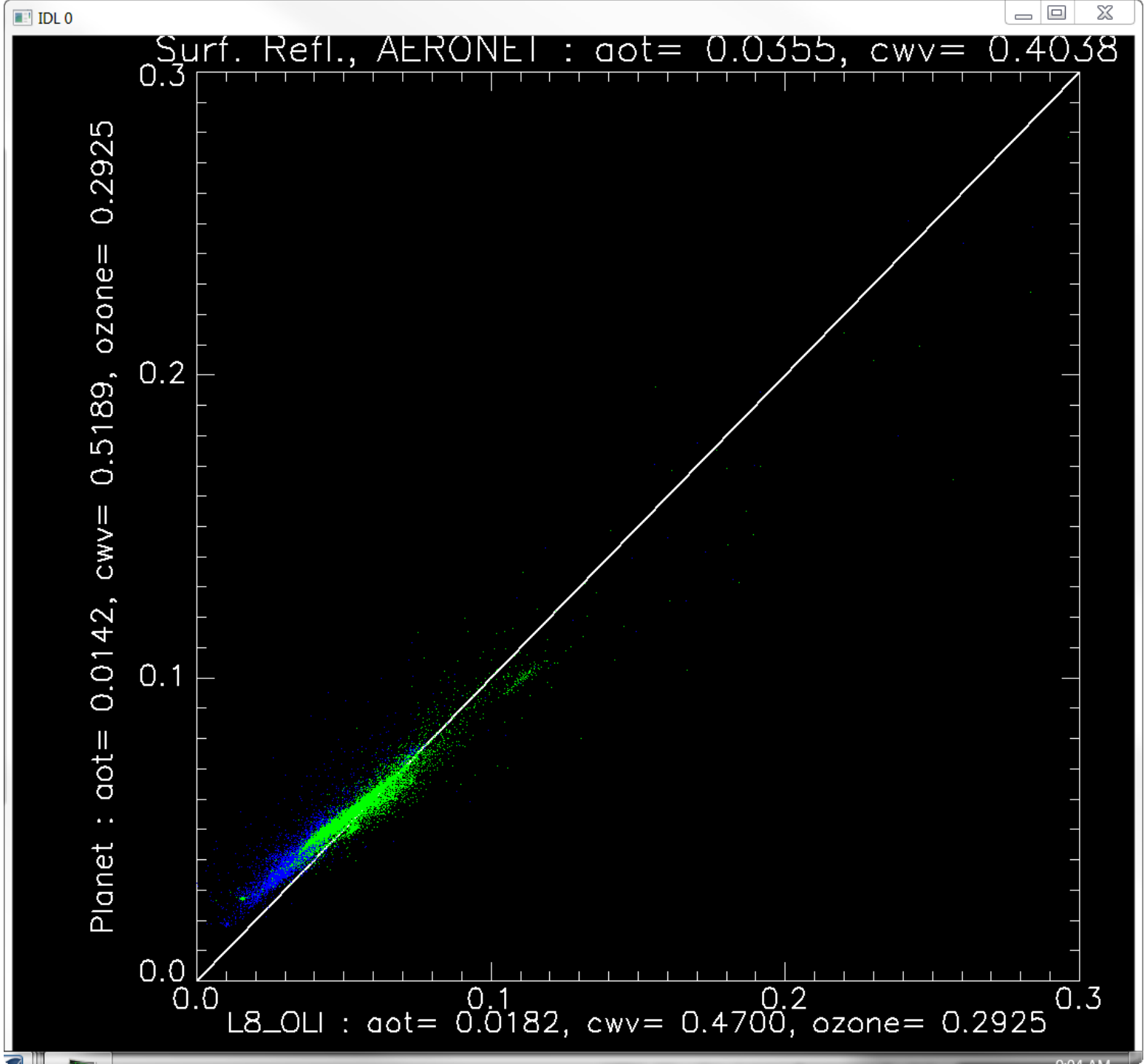
Easting : -3 pixel (- 9 m)

Northing : 8 pixel (24 m)

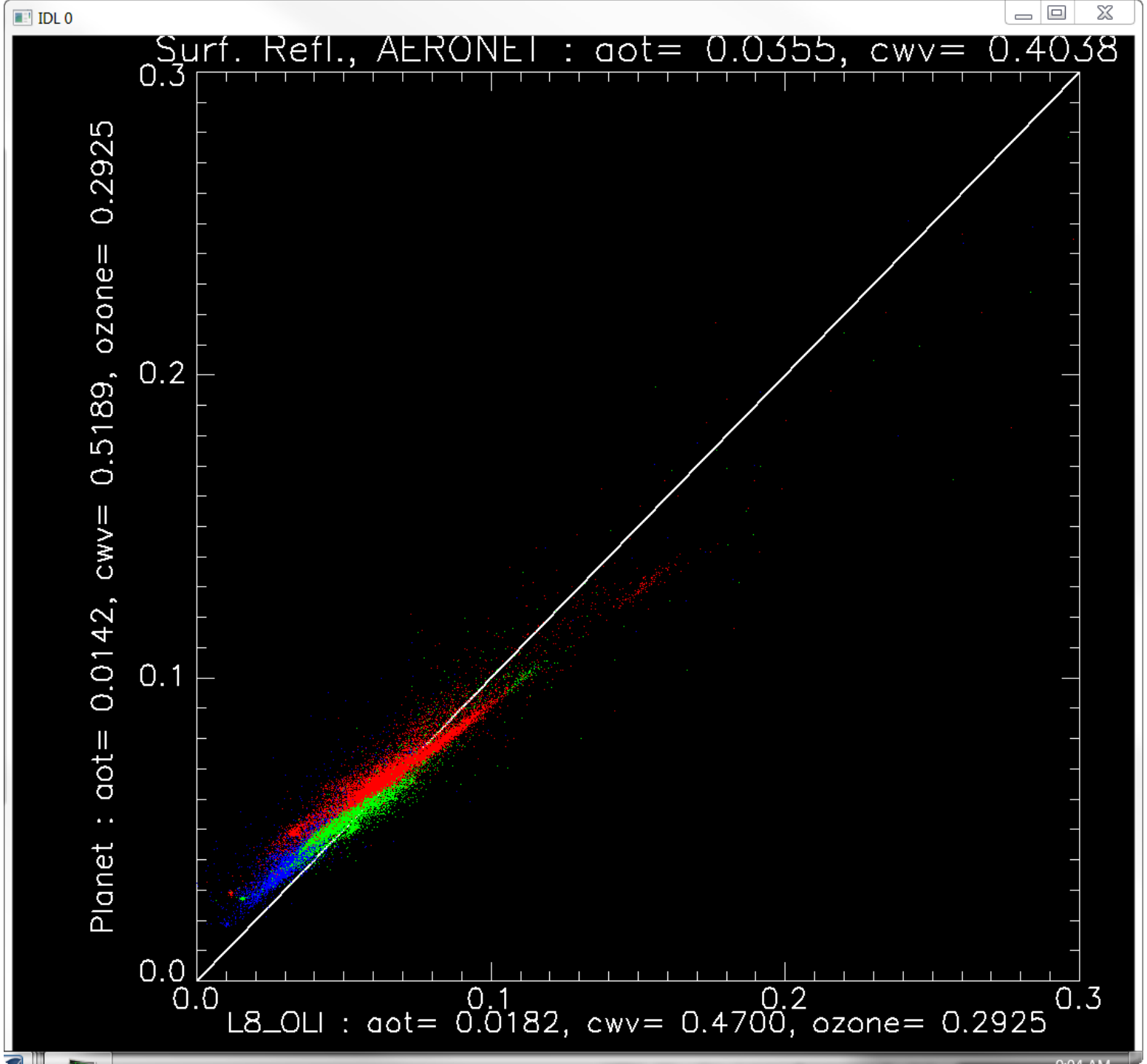
-3, 8


IDL 0
Surf. Refl., AERONET : aot= 0.0355, cwv= 0.4038
Planet : aot= 0.0142, cwv= 0.5189, ozone= 0.2925
L8_OLI : aot= 0.0182, cwv= 0.4700, ozone= 0.2925
0.0
0.1
0.2
0.3

-3, 8


IDL 0
Surf. Refl., AERONET : aot= 0.0355, cwv= 0.4038
Planet : aot= 0.0142, cwv= 0.5189, ozone= 0.2925
L8_OLI : aot= 0.0182, cwv= 0.4700, ozone= 0.2925
0.0
0.1
0.2
0.3

-3, 8


IDL 0
Surf. Refl., AERONET : aot= 0.0355, cwv= 0.4038
Planet : aot= 0.0142, cwv= 0.5189, ozone= 0.2925
L8_OLI : aot= 0.0182, cwv= 0.4700, ozone= 0.2925
0.0
0.1
0.2
0.3

-3, 8

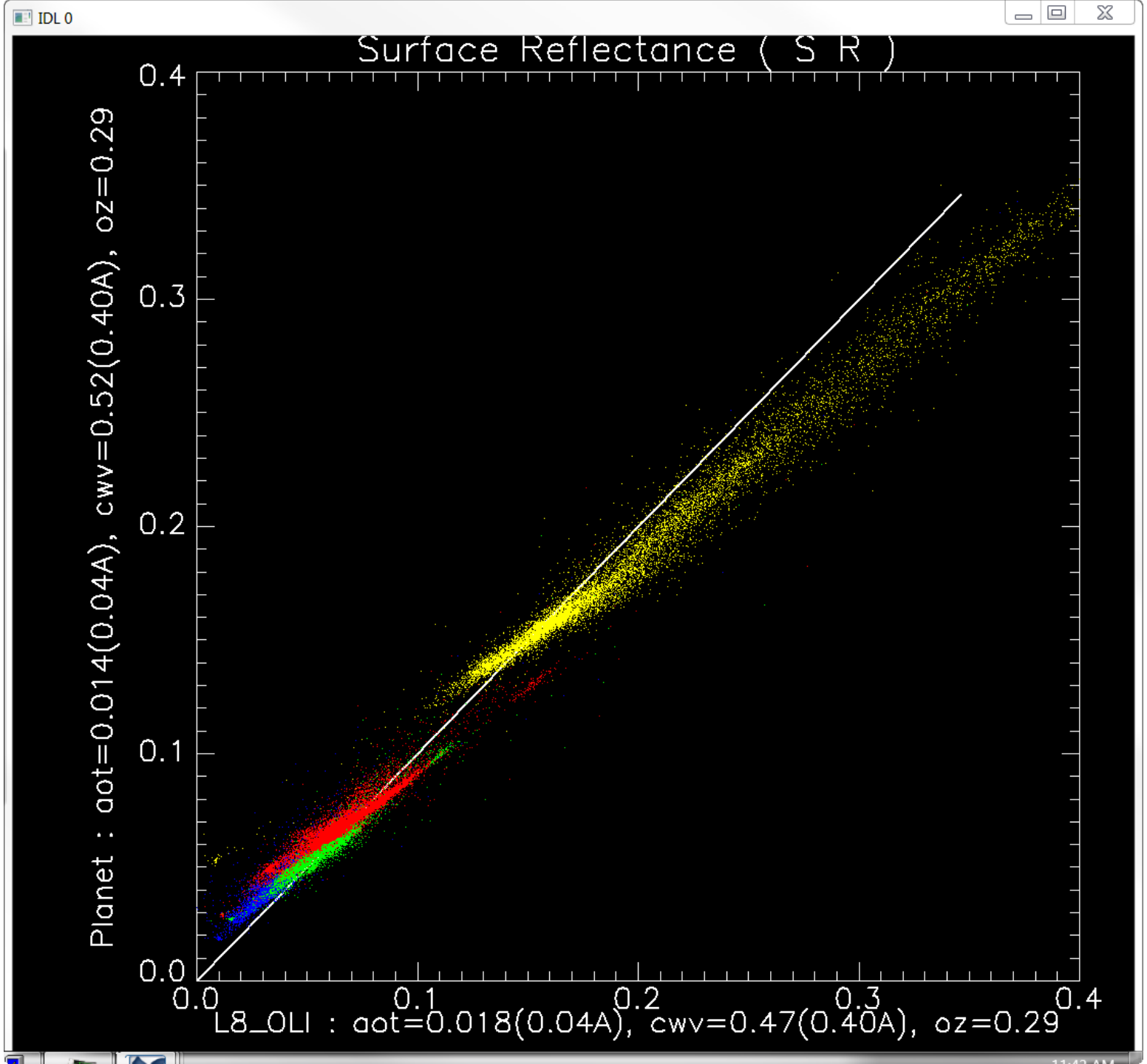
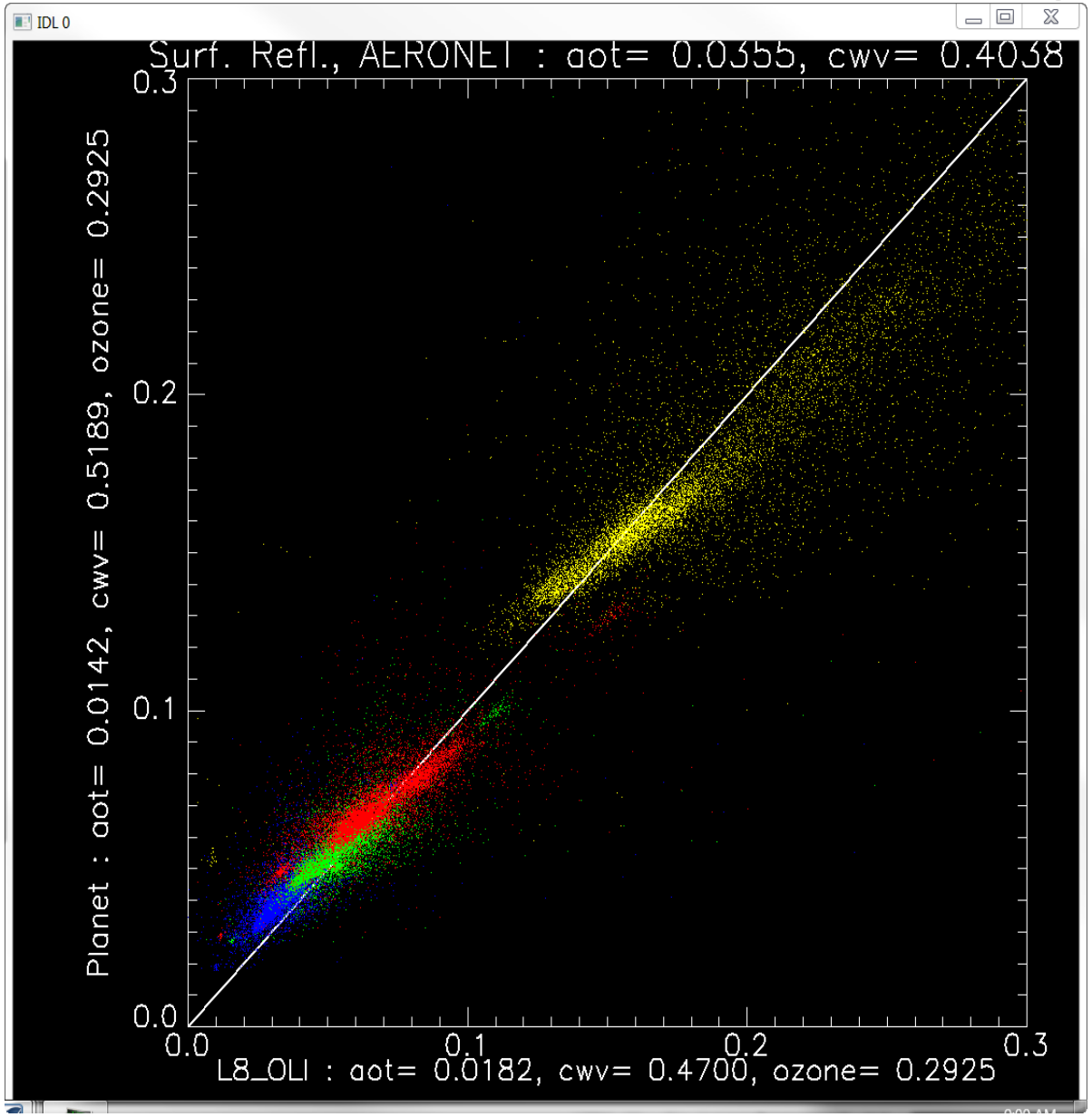
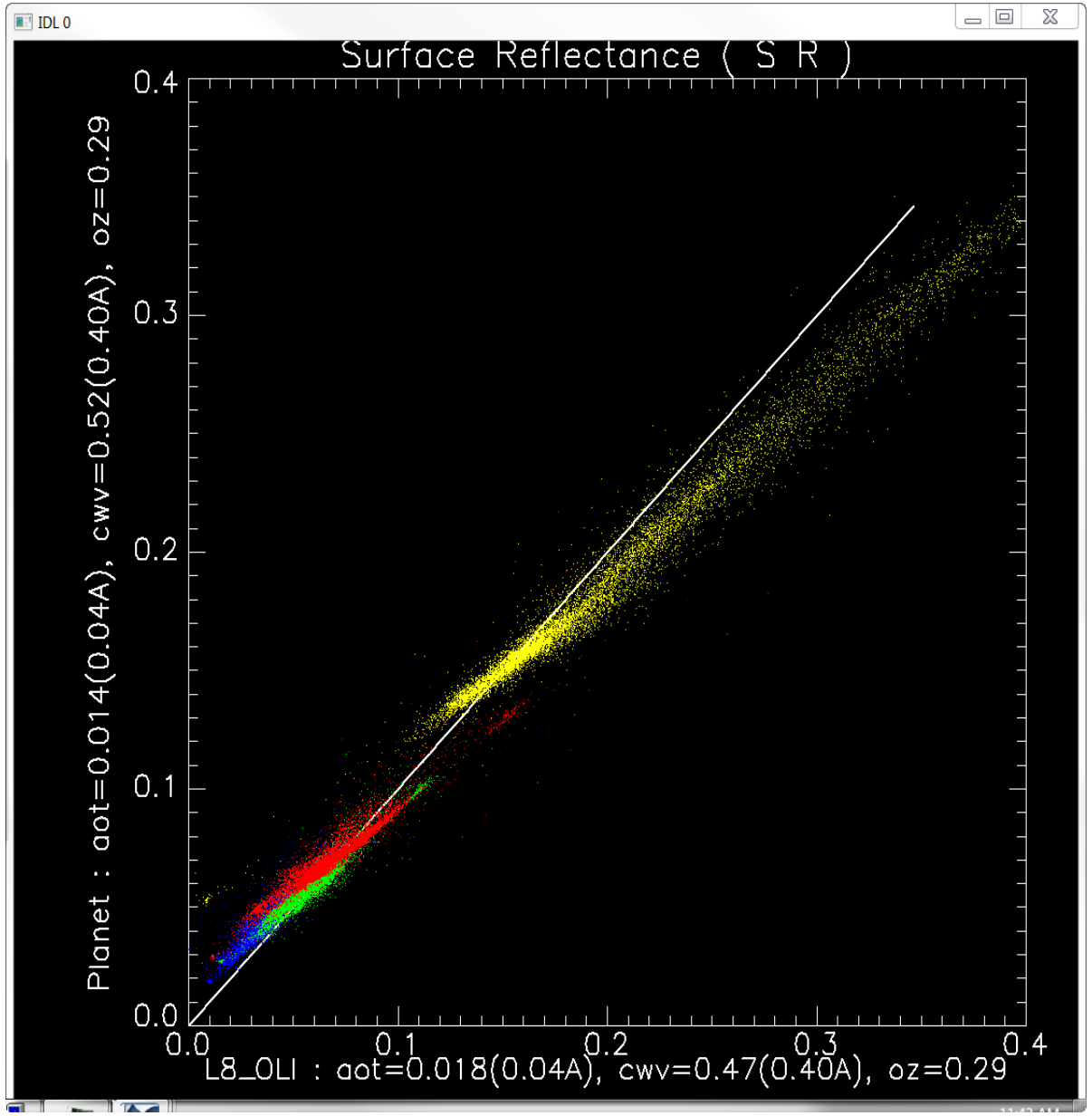

IDL 0
Surface Reflectance (S R)
Planet : aot=0.014(0.04A), cwv=0.52(0.40A), oz=0.29
L8_OLI : aot=0.018(0.04A), cwv=0.47(0.40A), oz=0.29
0.0
0.1
0.2
0.3
0.4

Image Shift

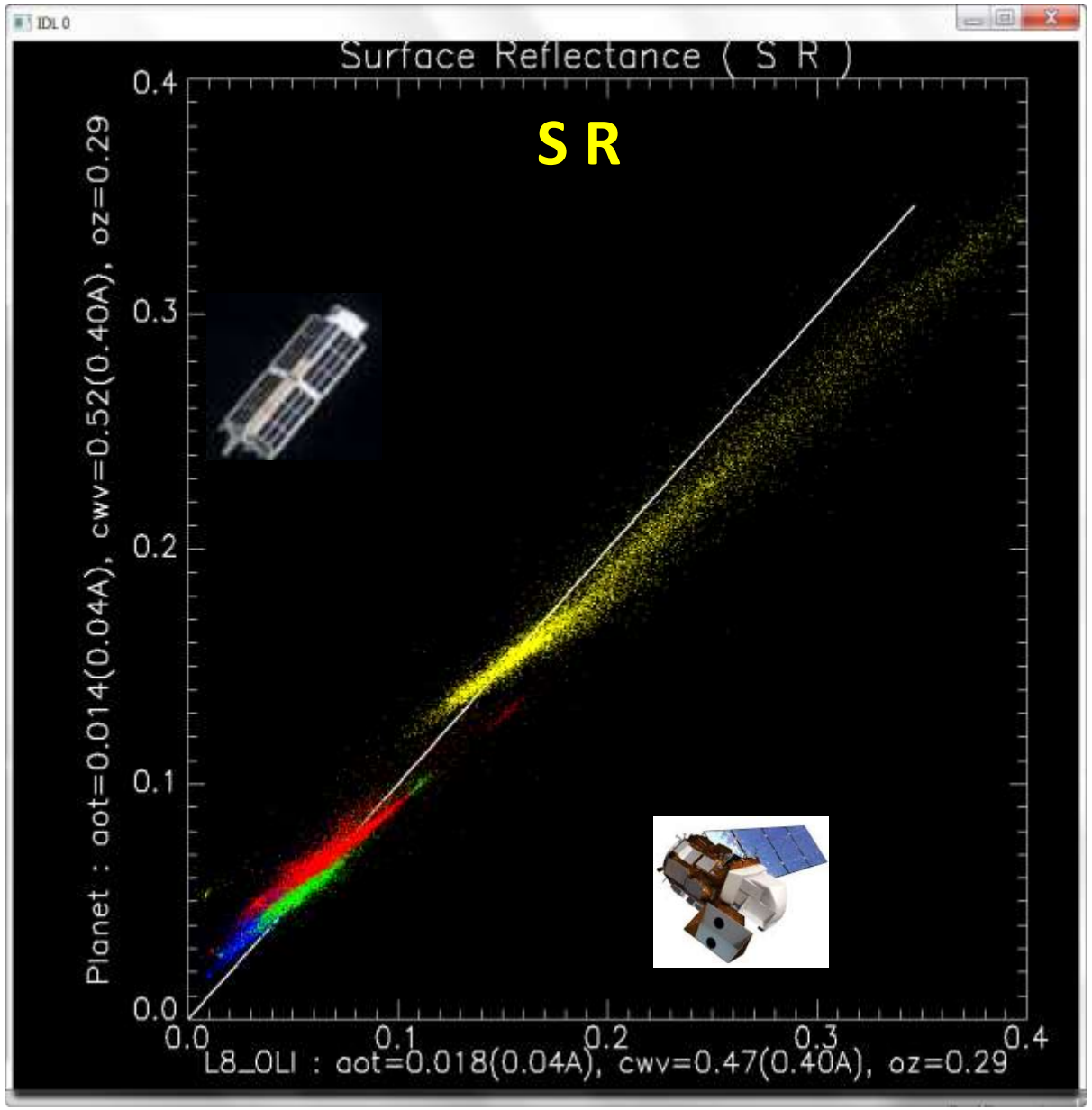
(0, 0)



(-3, 8)



SR apparent mismatch



Strictly speaking, mismatch in SR will cause

➔ error in the downstream application

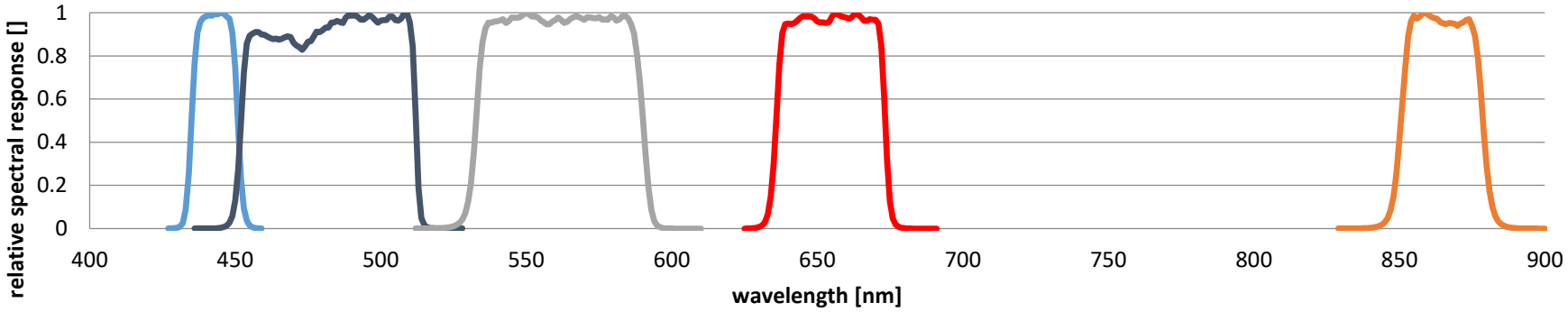
$$(\sigma_{NDVI})^2 = \left(\frac{\partial NDVI}{\partial \rho_R}\Big|_{\rho_R,\rho_{NIR}} \cdot \sigma_{\rho_R}\right)^2 + \left(\frac{\partial NDVI}{\partial \rho_{NIR}}\Big|_{\rho_R,\rho_{NIR}} \cdot \sigma_{\rho_{NIR}}\right)^2$$

* Georeferencing error ? ➔ Checked

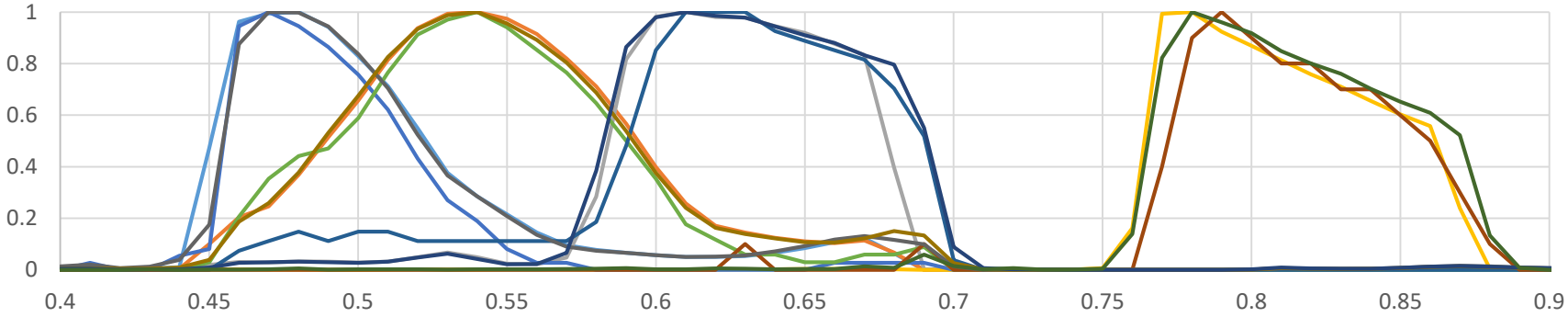
Other reasons for the mismatch?

* Spectral Response
* Atmospheric Correction
* Improper Radiometric Correction
  (Stray light, post-launch drift)

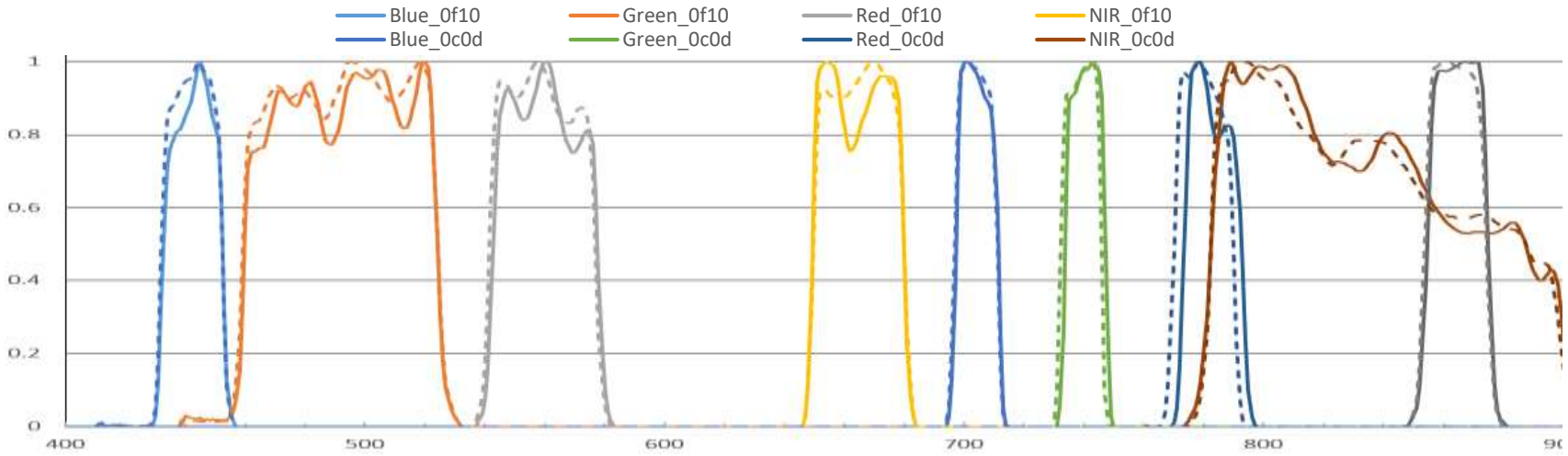
In-Band Band-Average Relative Spectral Response



Landsat 8 OLI

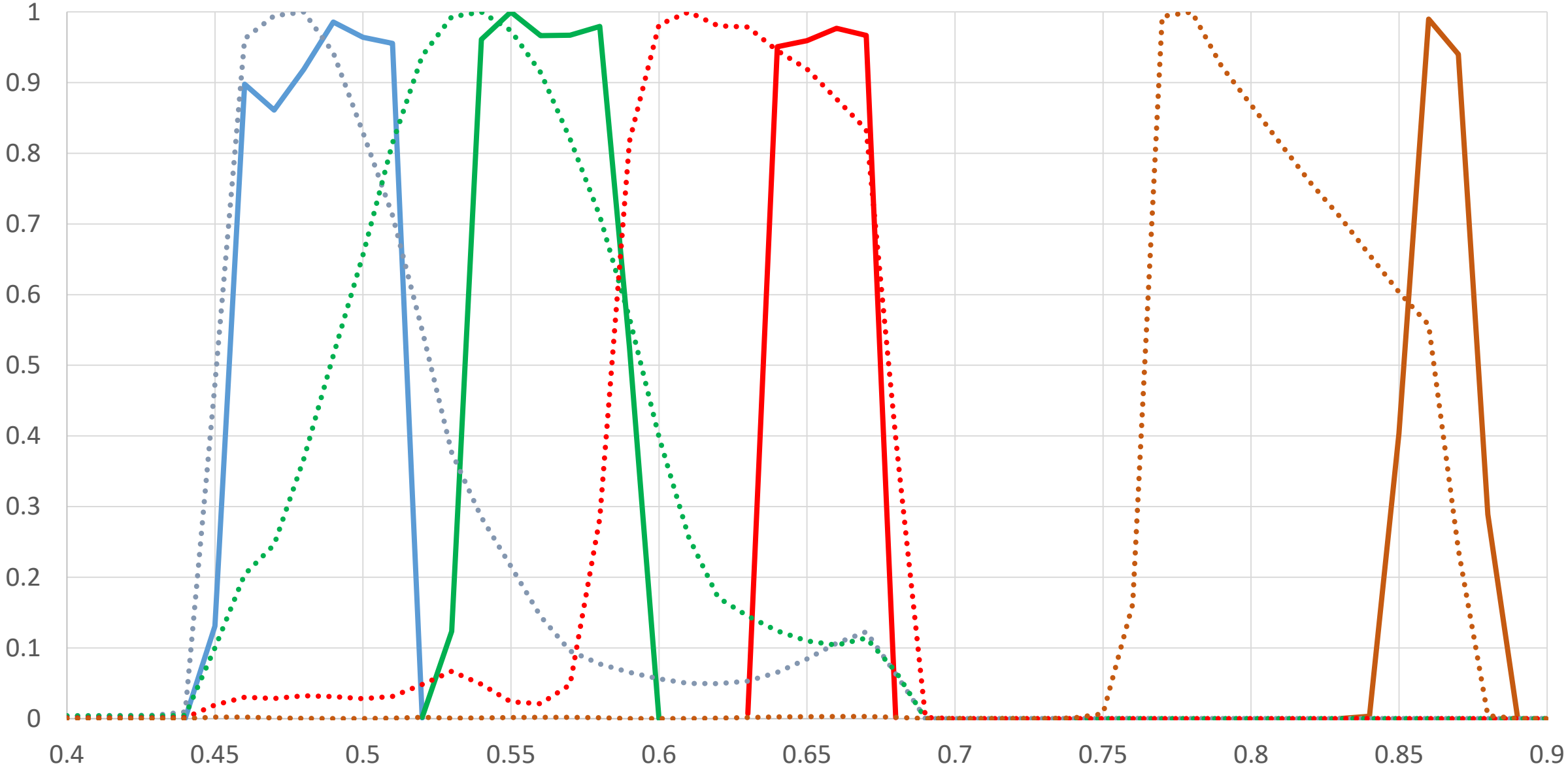


Planet

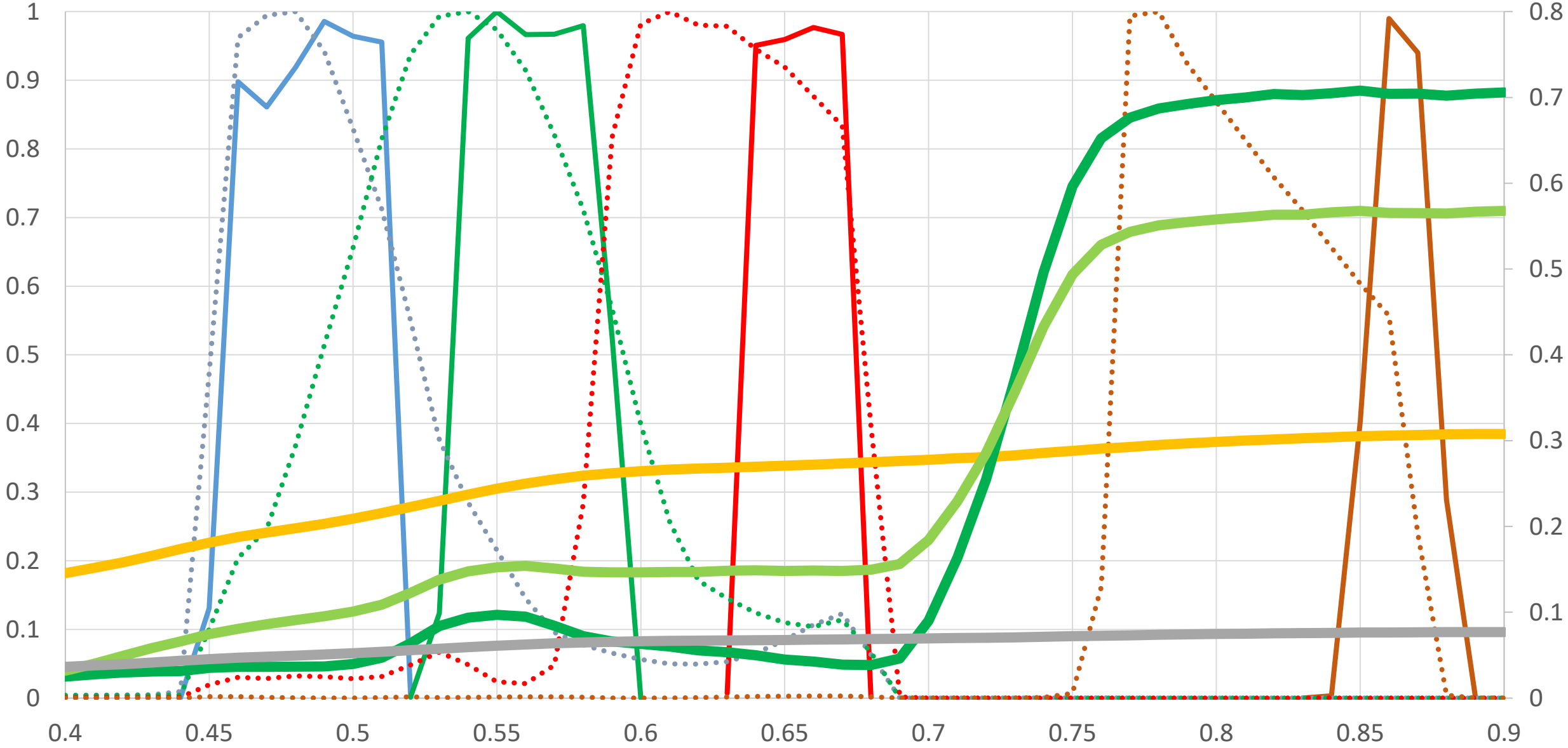


Sentinel2 MSI

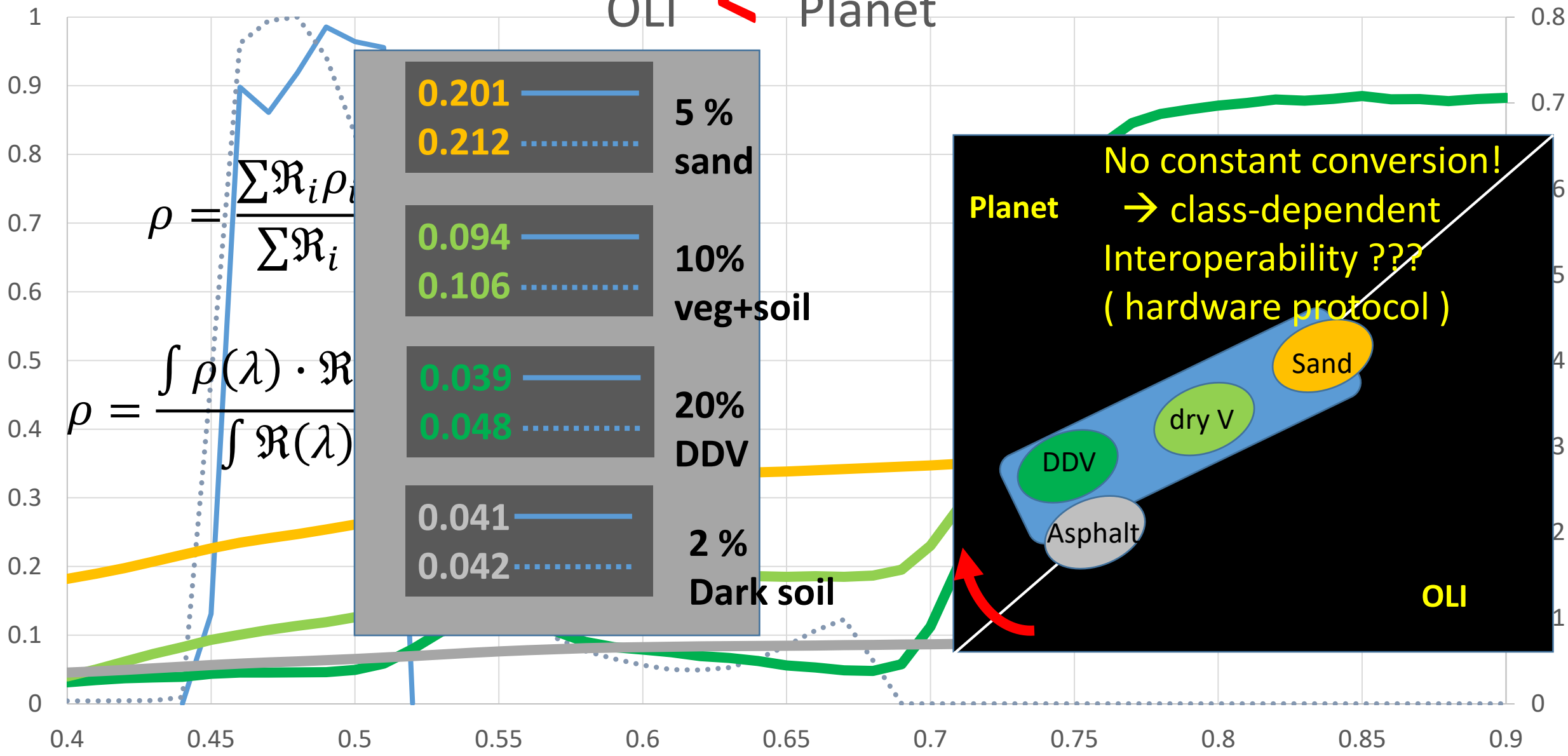
OLI vs Planet



OLI vs Planet



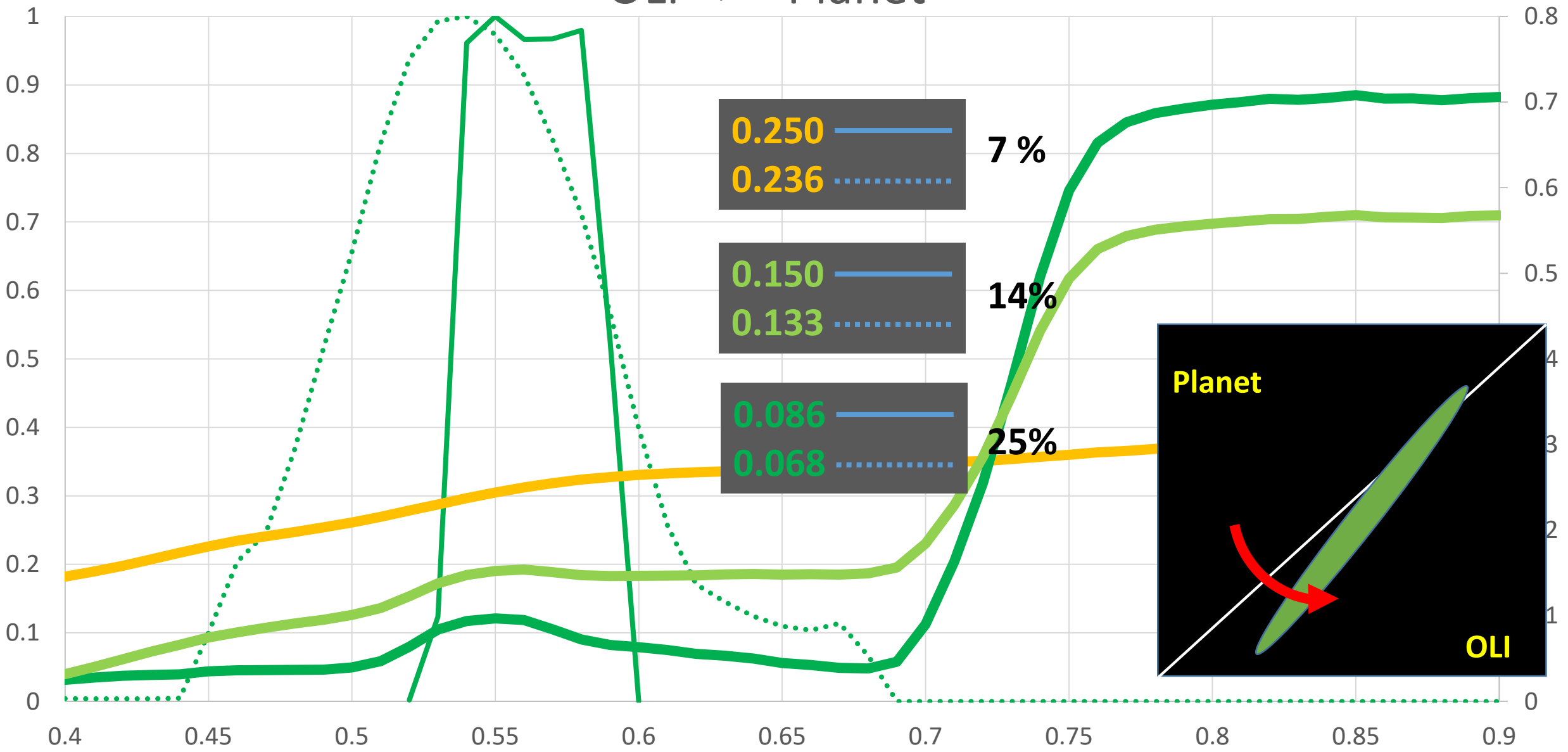
OLI < Planet



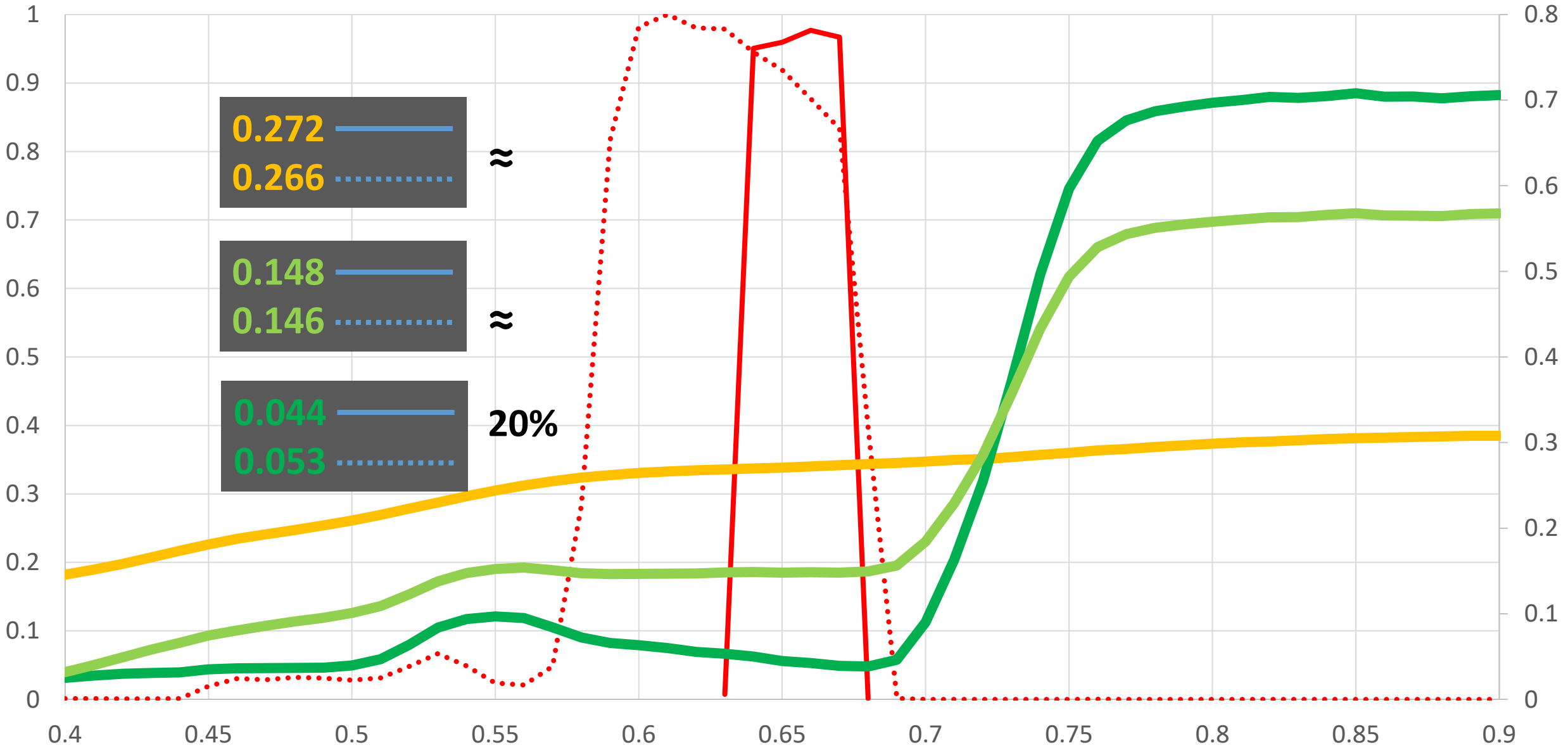
$$\rho = \frac{\sum \Re_i \rho_i}{\sum \Re_i}$$

$$\rho = \frac{\int \rho(\lambda) \cdot \Re}{\int \Re(\lambda)}$$

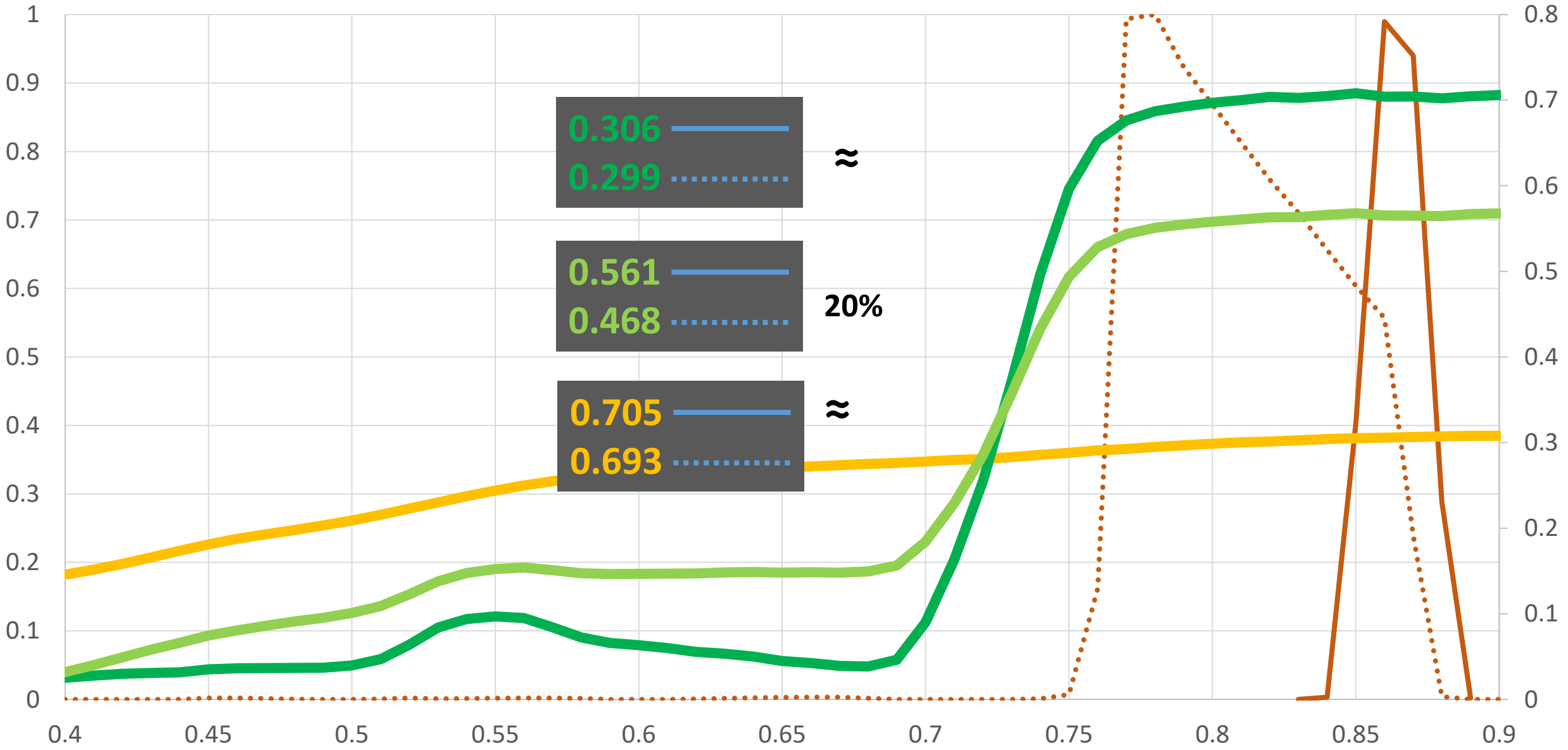
OLI > Planet


1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.8
0.7
0.6
0.5
4
3
2
1
0
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.250
0.236
7 %
0.150
0.133
14%
0.086
0.068
25%
Planet
OLI

OLI vs Planet



OLI vs Planet



Spectral Response Function Issue

The Correction factor should be different for

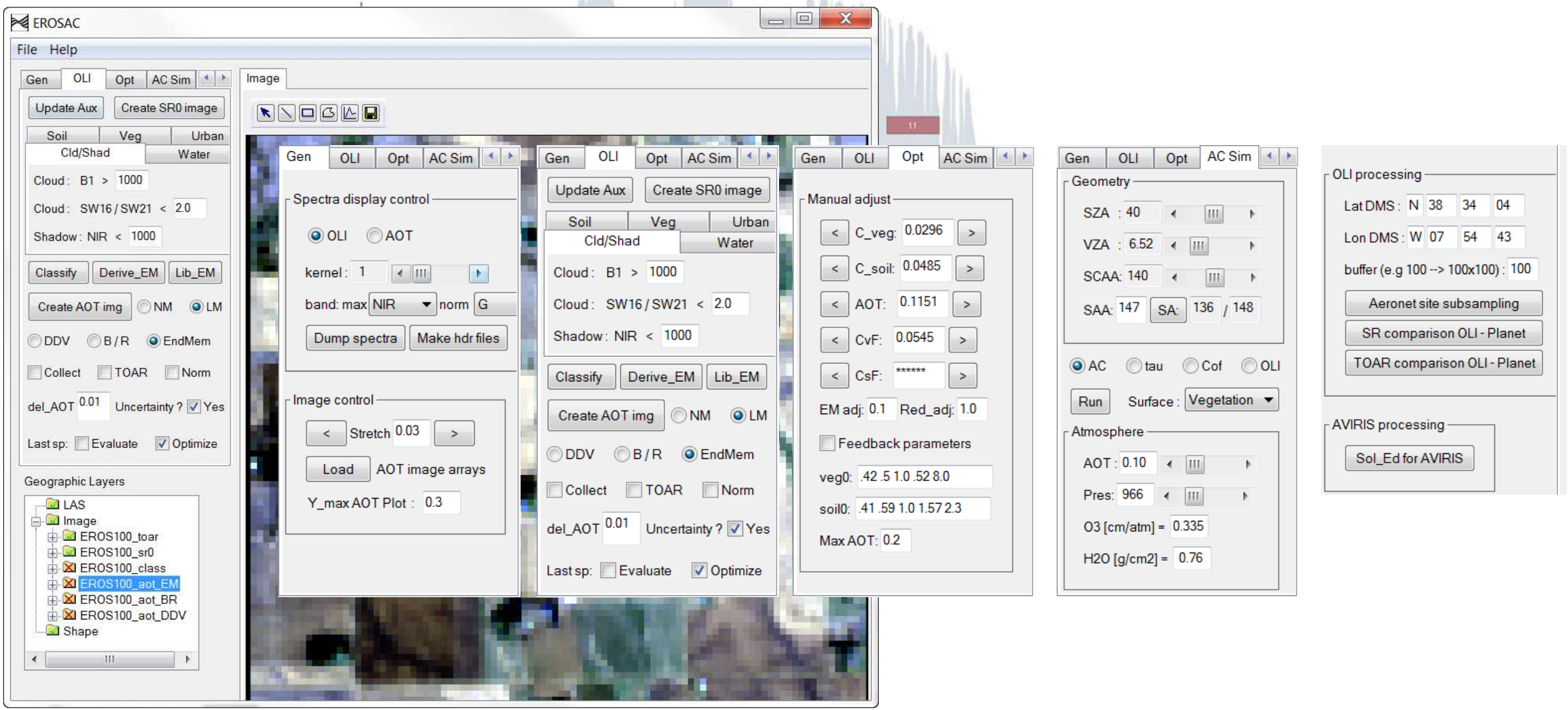
* varying reflectance (dark to bright)
* different classes (spectral shape)
* different bands (channels)

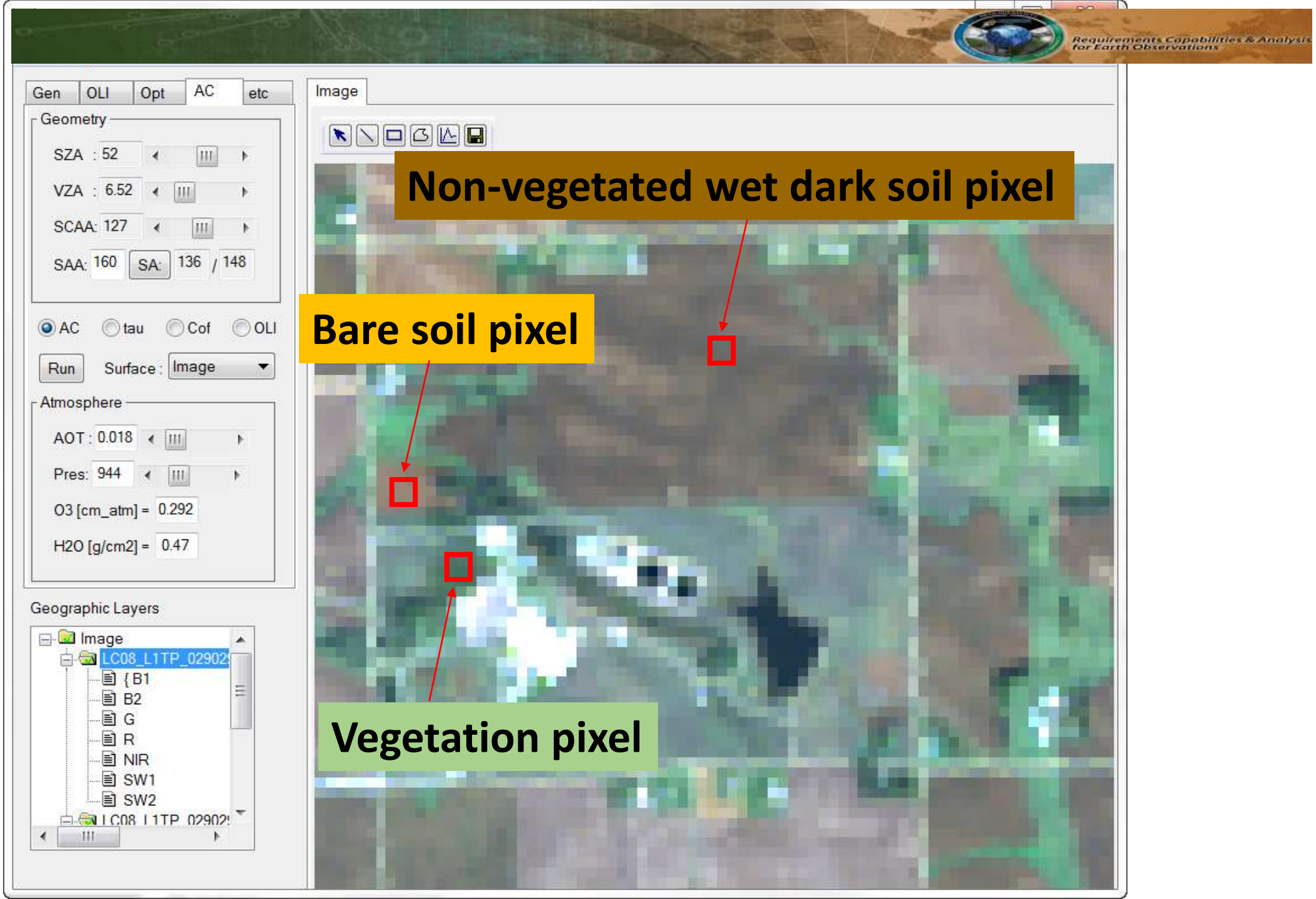
→ Ideally, (1) extensive modeling study (2)classification (3) apply varying degree of correction based on (1) & (2)

(it is very difficult, if not impossible)

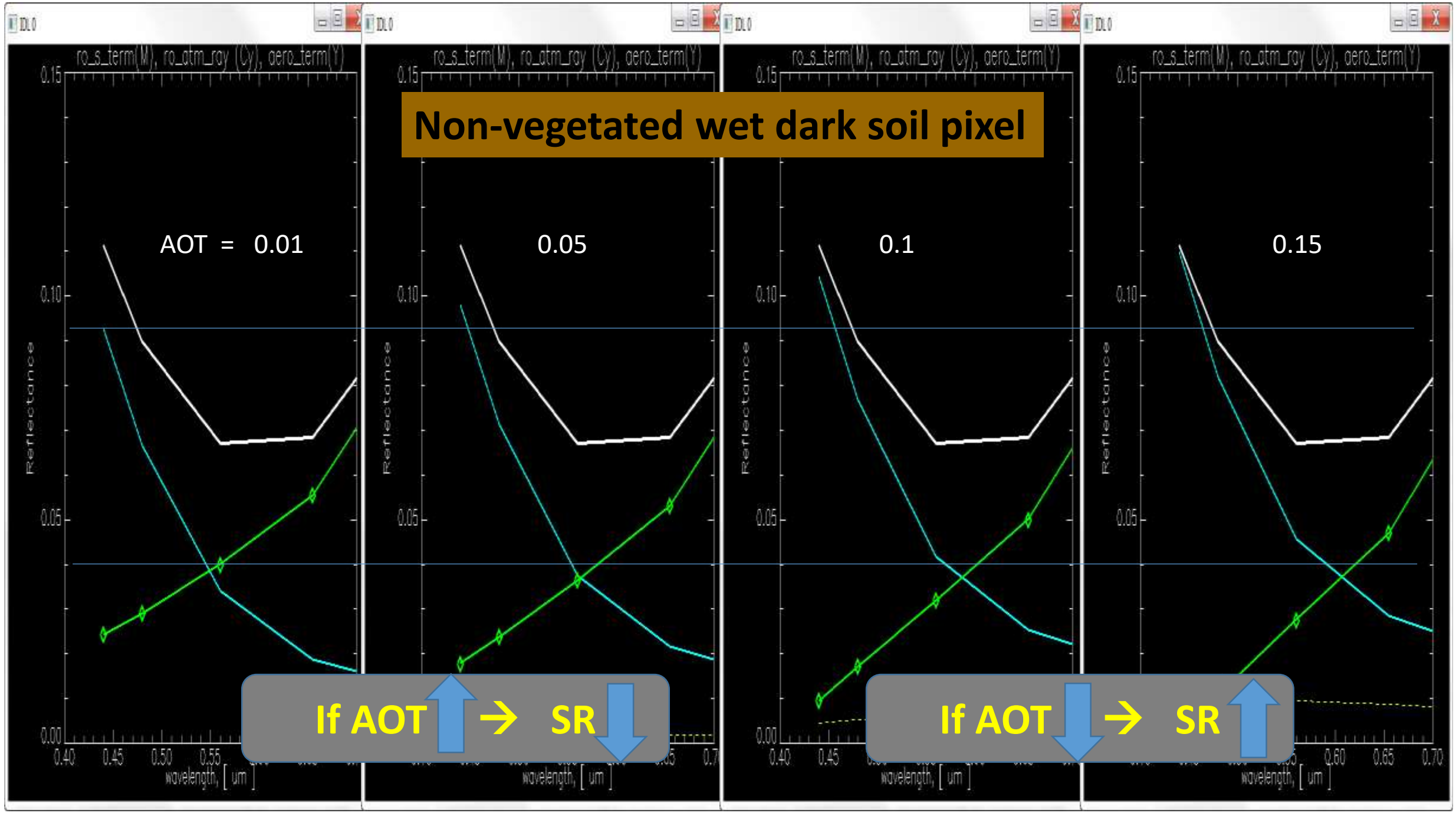
➔ Let's leave it uncorrected. This effect definitely adds substantial uncertainty in SR comparison

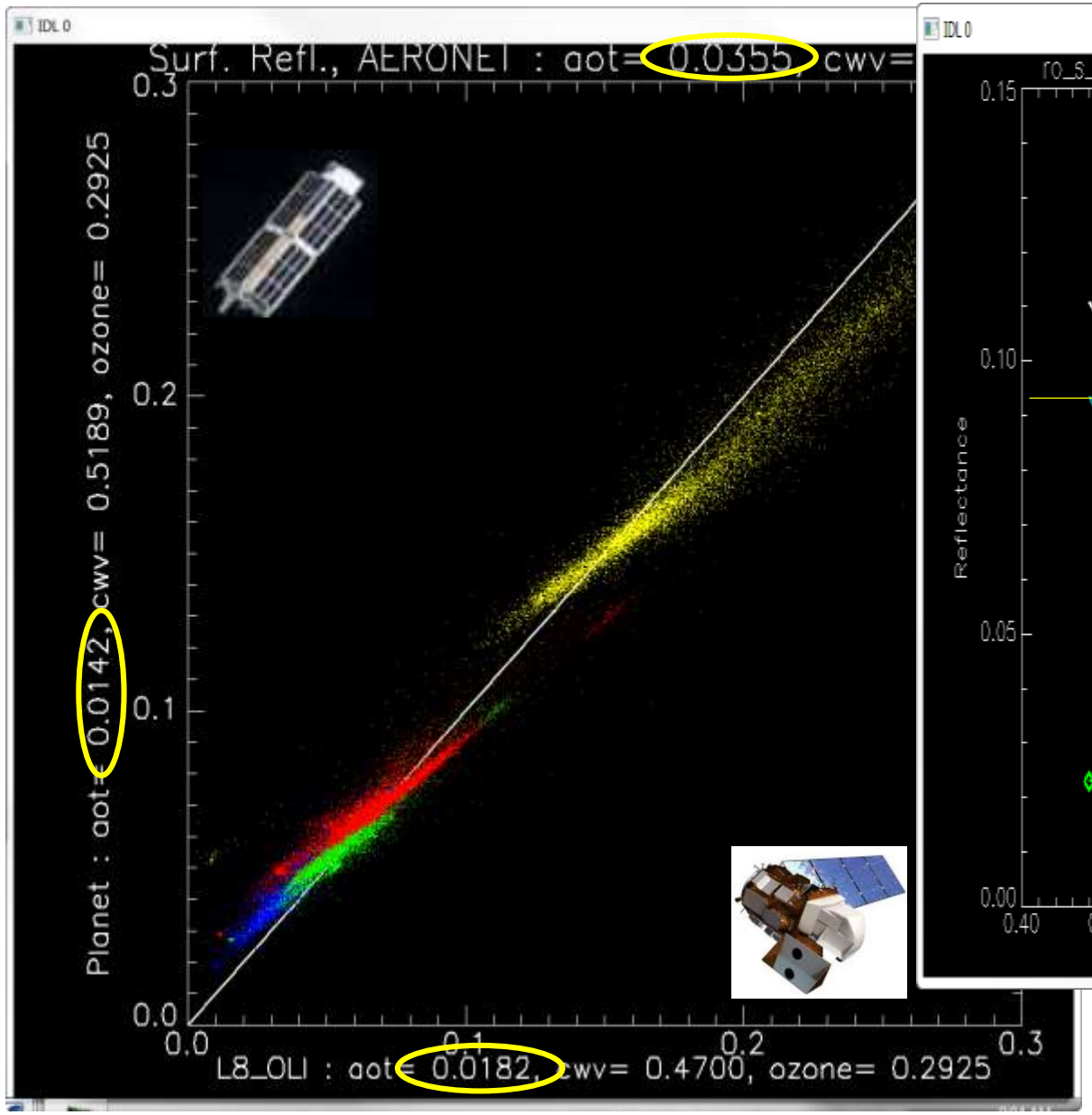
EROSAC Atmospheric Correction

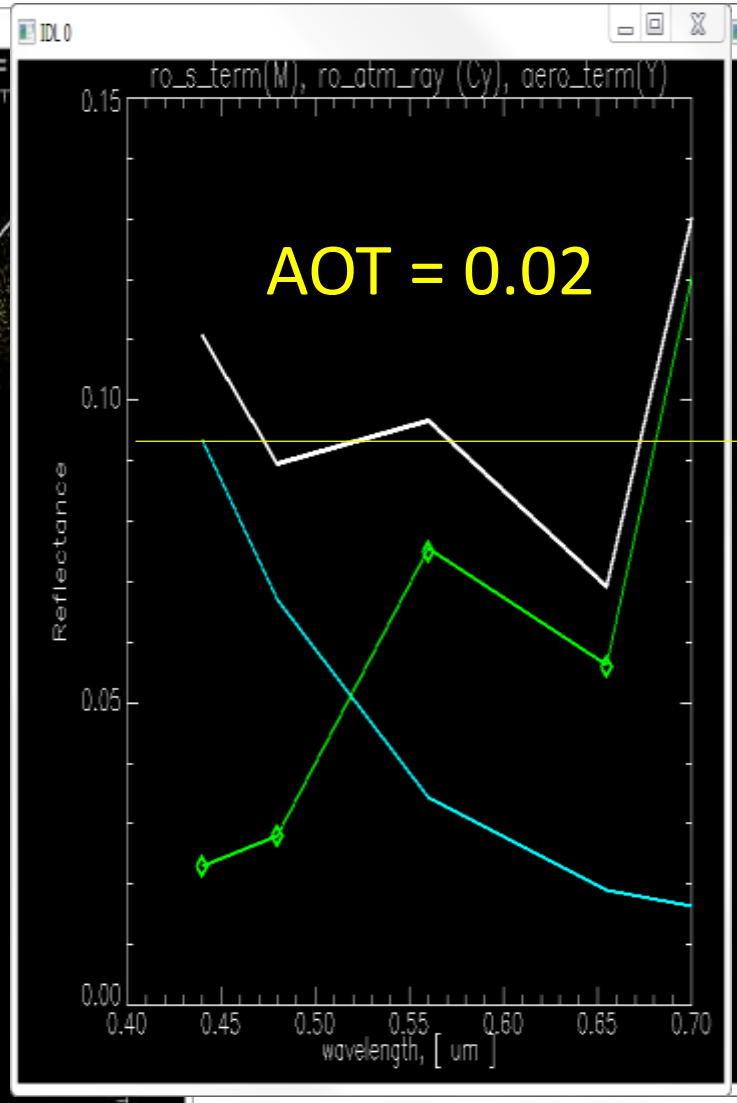


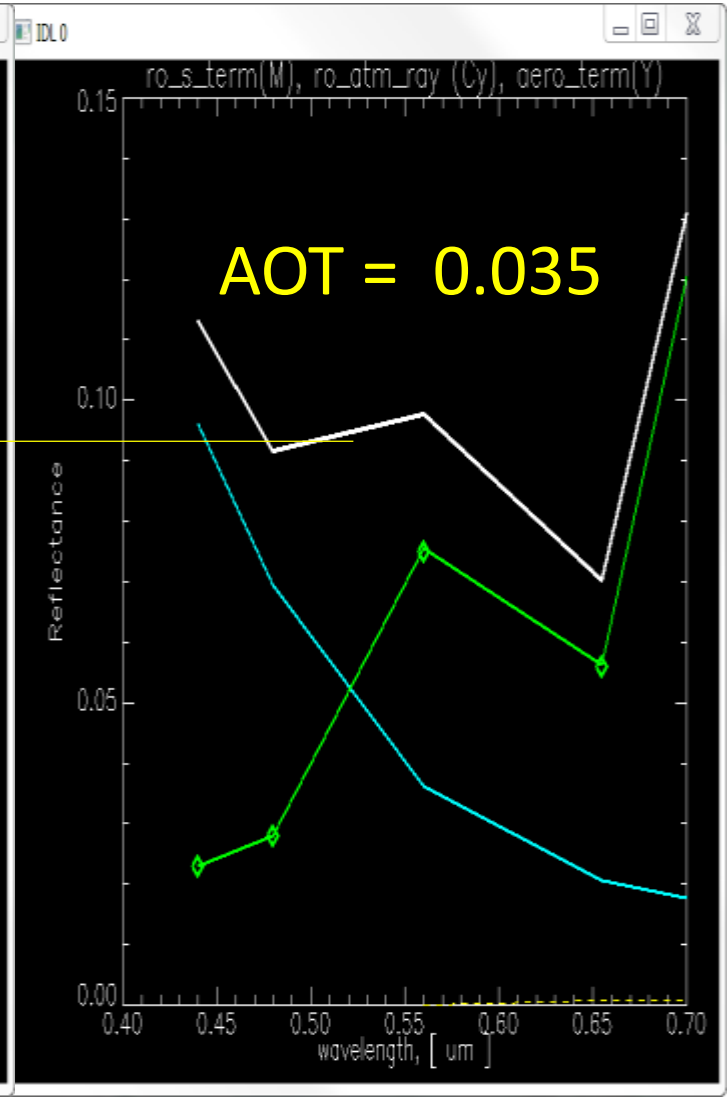

Gen
OLI
Opt
AC
etc
Geometry
SZA : 52
VZA : 6.52
SCAA: 127
SAA: 160
SA: 136 / 148
AC
tau
Cof
OLI
Run
Surface : Image
Atmosphere
AOT : 0.018
Pres: 944
O3 [cm_atm] = 0.292
H2O [g/cm2] = 0.47
Geographic Layers
Image
LC08_L1TP_02902
B1
B2
G
R
NIR
SW1
SW2
Image
Non-vegetated wet dark soil pixel
Bare soil pixel
Vegetation pixel

Non-vegetated wet dark soil pixel



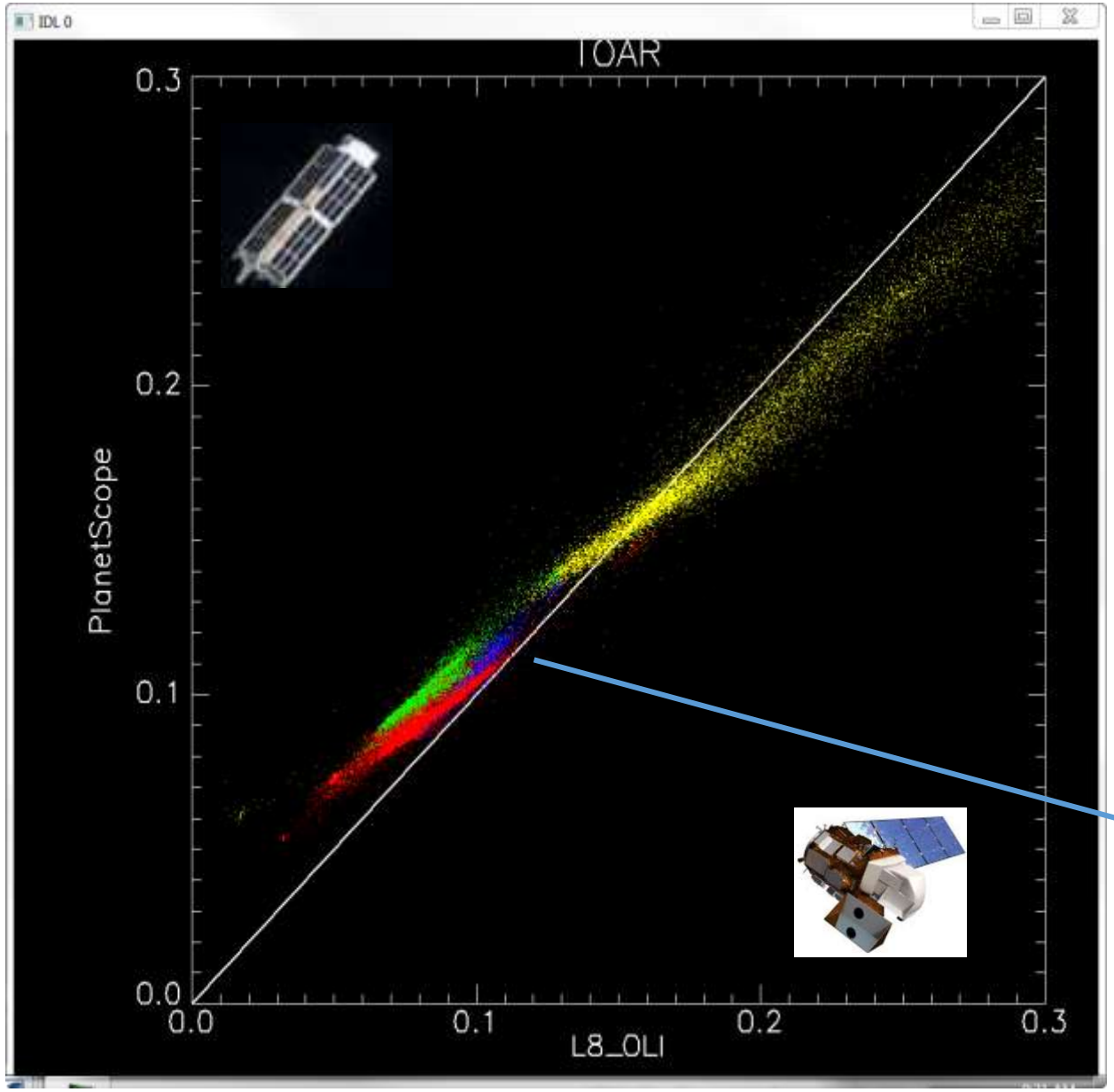




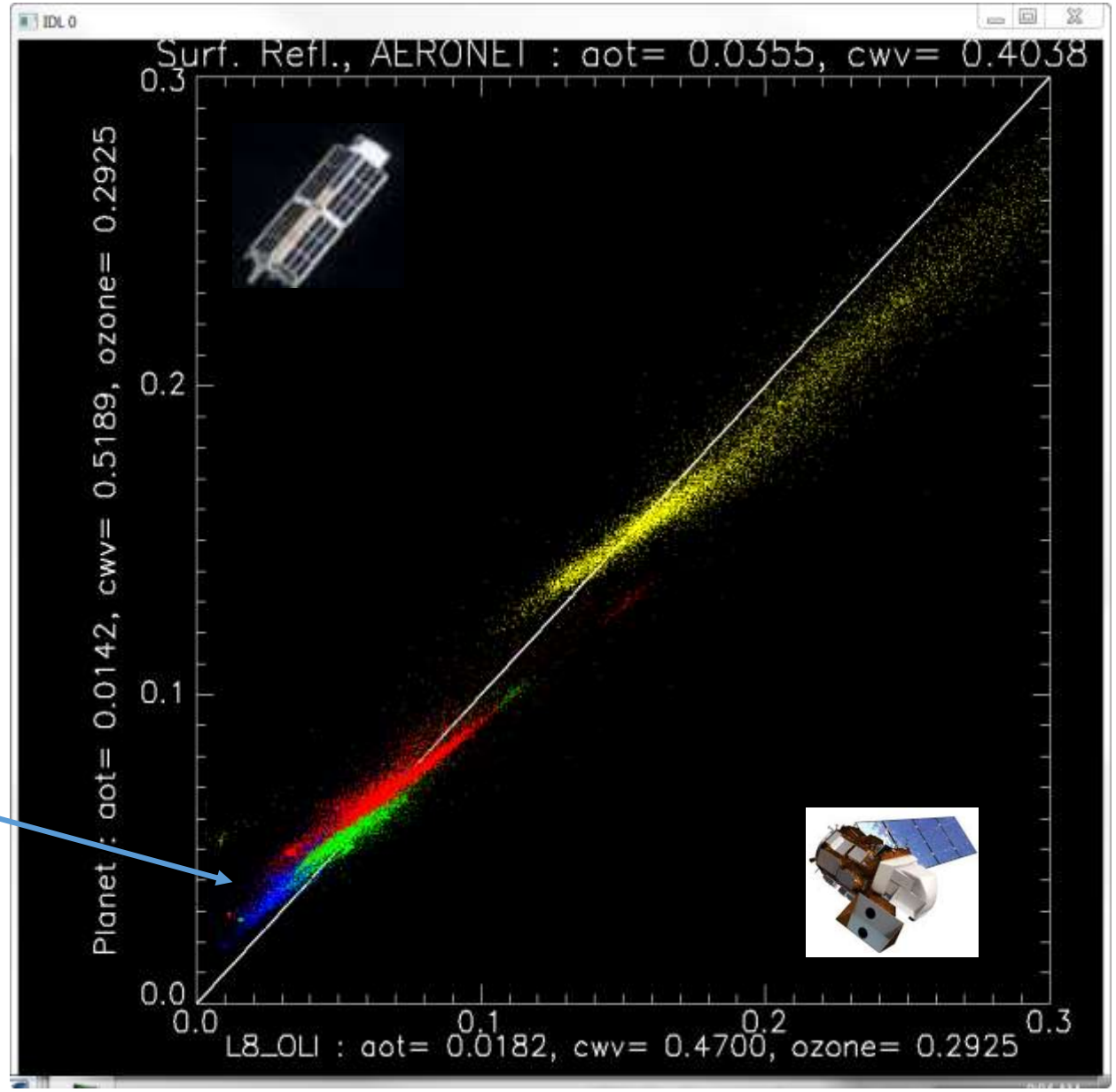


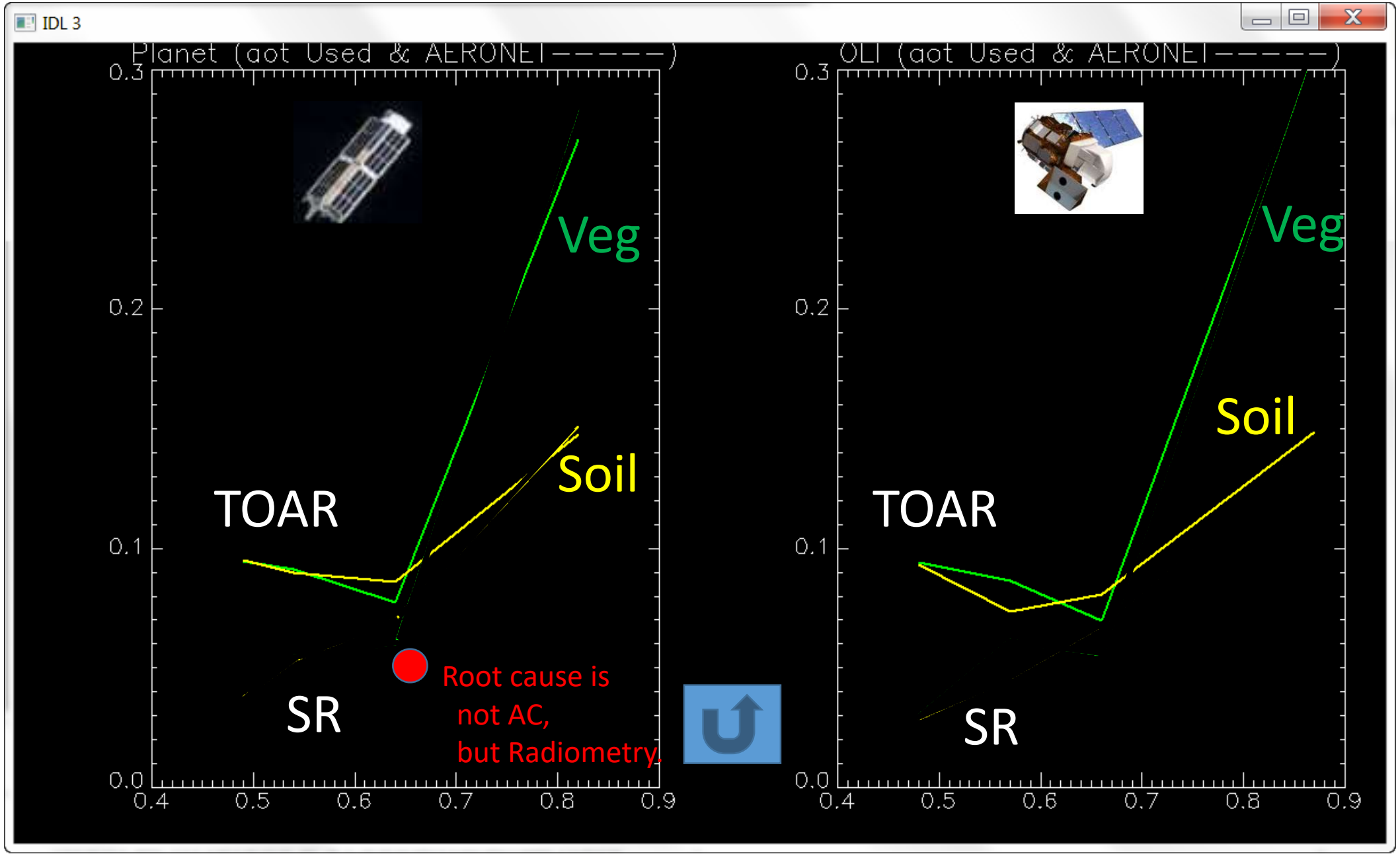
➔ AOT (CWV, O_3) in AC should be no issue !

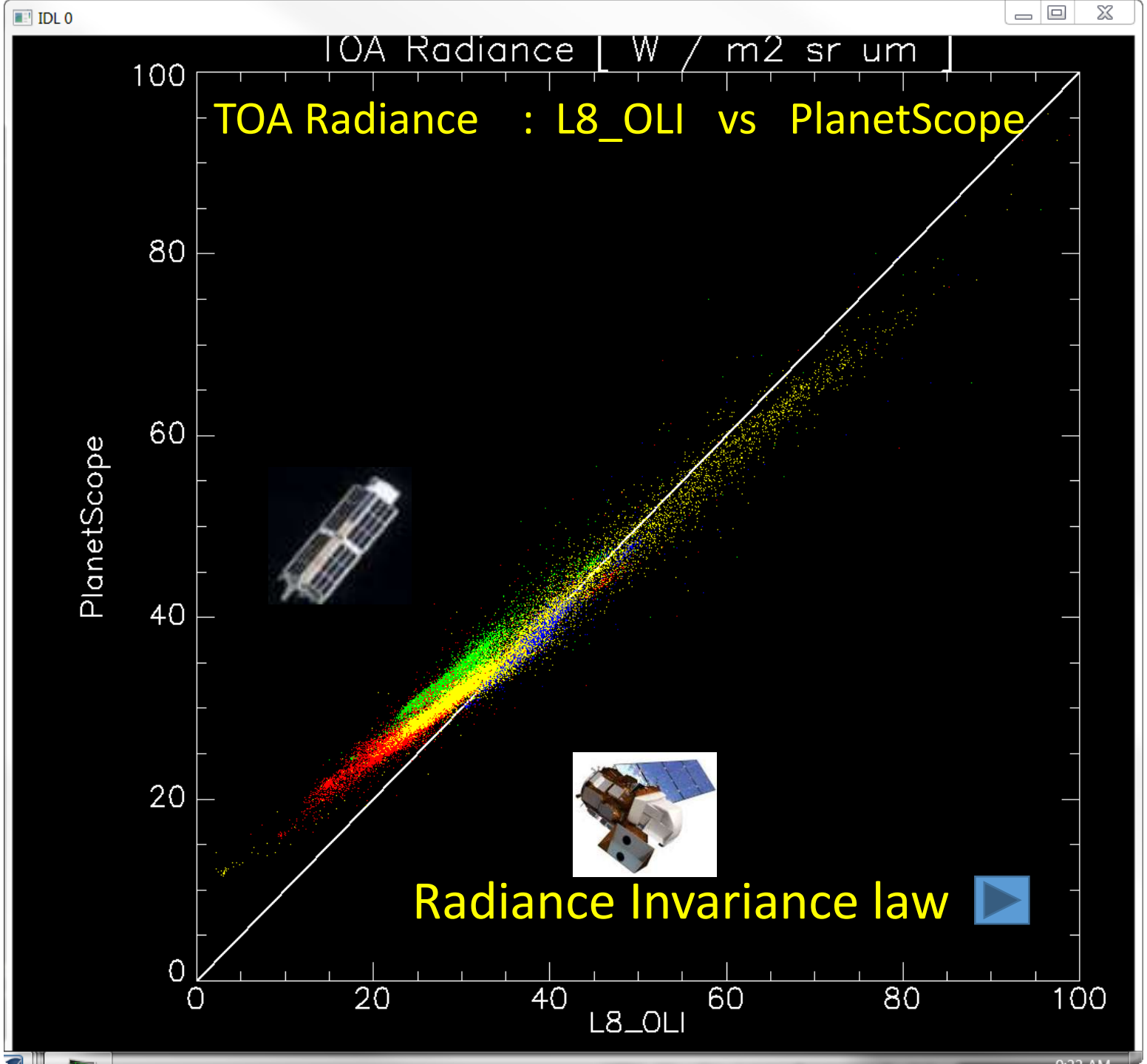
TOAR


IDL 0
TOAR
0.3
0.2
0.1
0.0
PlanetScope
0.0
0.1
0.2
0.3
L8_OLI

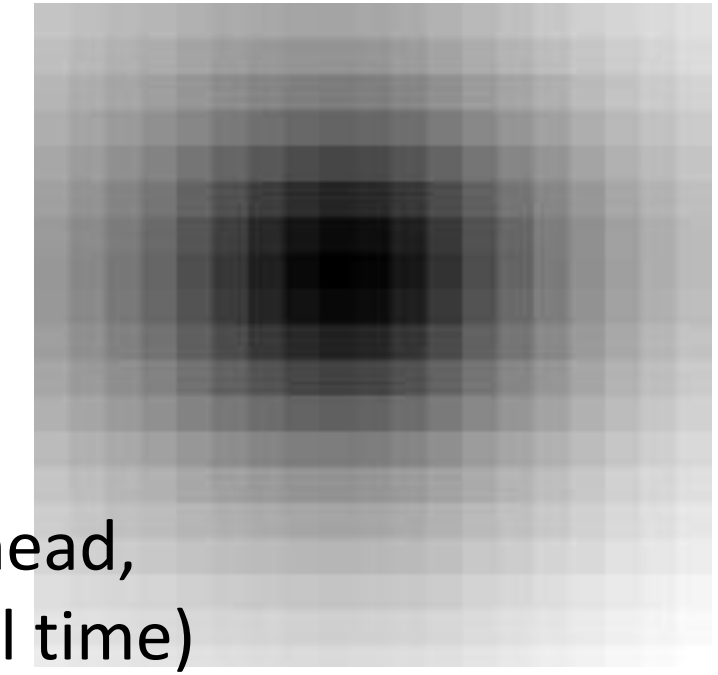
SR


IDL 0
Surf. Refl., AERONET : aot= 0.0355, cwv= 0.4038
0.3
0.2
0.1
0.0
Planet : aot= 0.0142, cwv= 0.5189, ozone= 0.2925
0.0
0.1
0.2
0.3
L8_OLI : aot= 0.0182, cwv= 0.4700, ozone= 0.2925

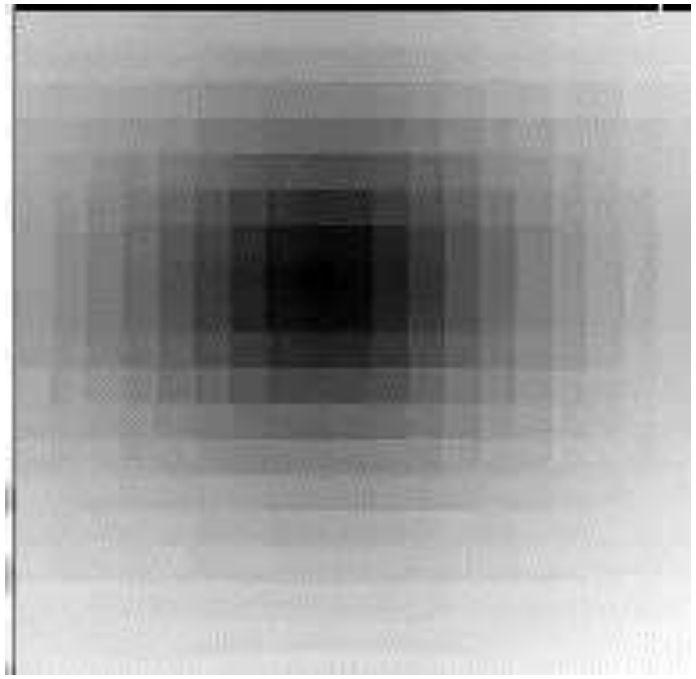

IDL 3
Planet (aot Used & AERONET------)
OLI (aot Used & AERONET------)
0.3
0.2
0.1
0.0
0.4
0.5
0.6
0.7
0.8
0.9
Veg
Soil
TOAR
SR
Root cause is
not AC,
but Radiometry


IDL 0
TOA Radiance [W / m2 sr um]
TOA Radiance : L8_OLI vs PlanetScope
PlanetScope
L8_OLI
0
20
40
60
80
100
Radiance Invariance law

Spatial shift : L8_OLI vs MSI



(One day ahead,
similar local time)



OLI vs MSI

Easting : -1 pixel (-10 m)

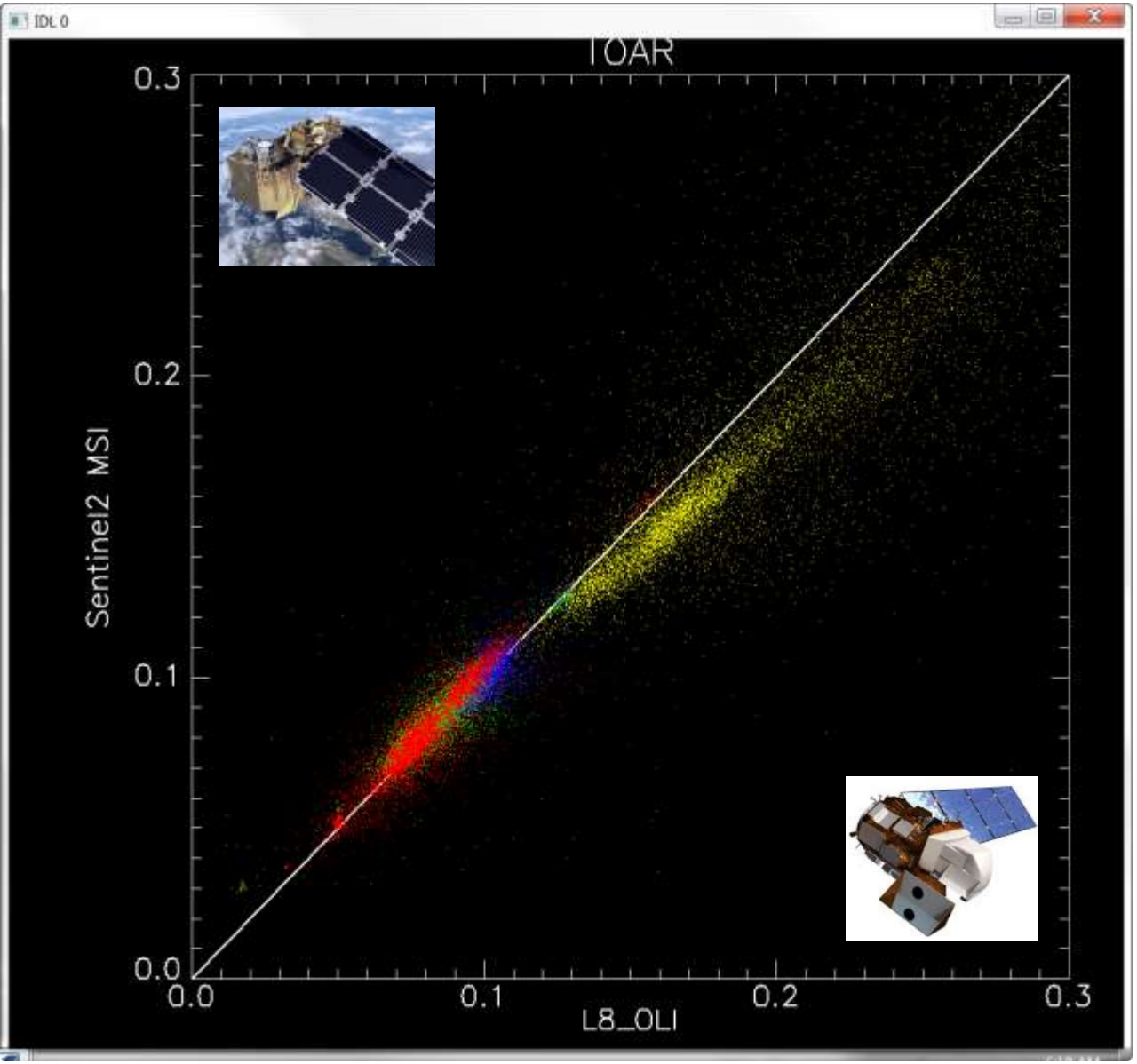
Northing : 2 pixel (20 m)

OLI vs Planet

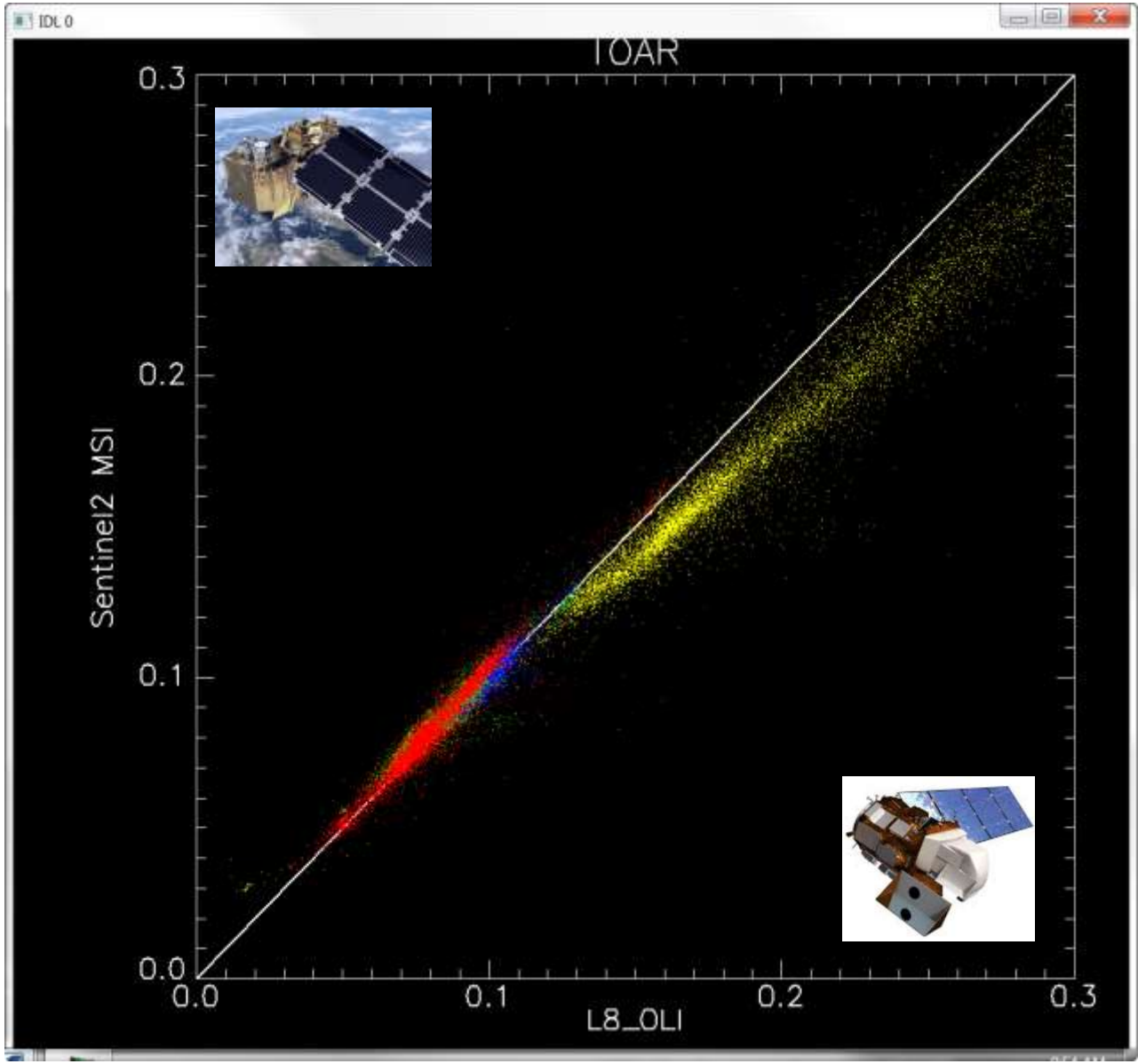
Easting : -3 pixel (- 9 m)

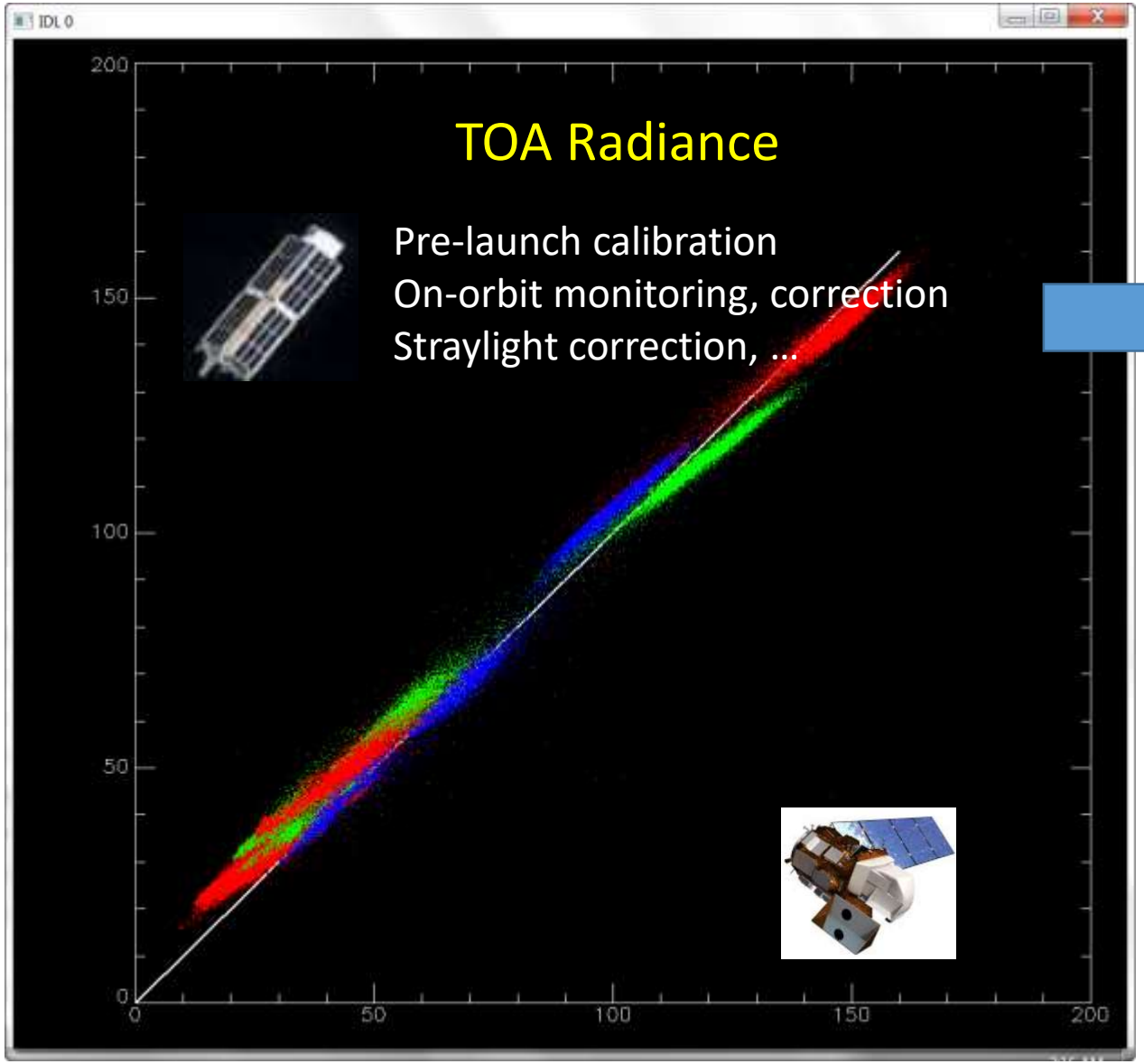
Northing : 8 pixel (24 m)

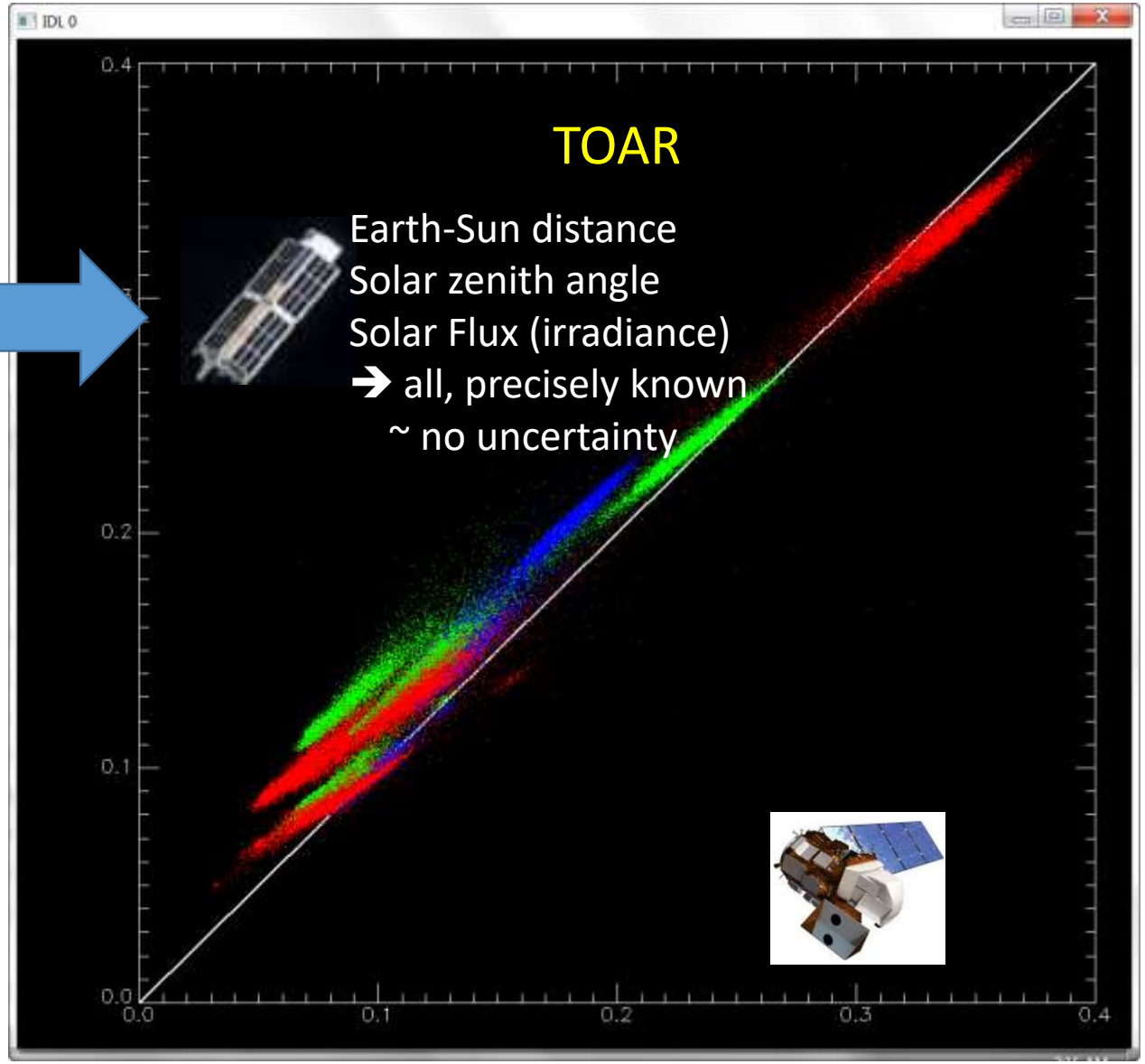
(0, 0) No Image Shift

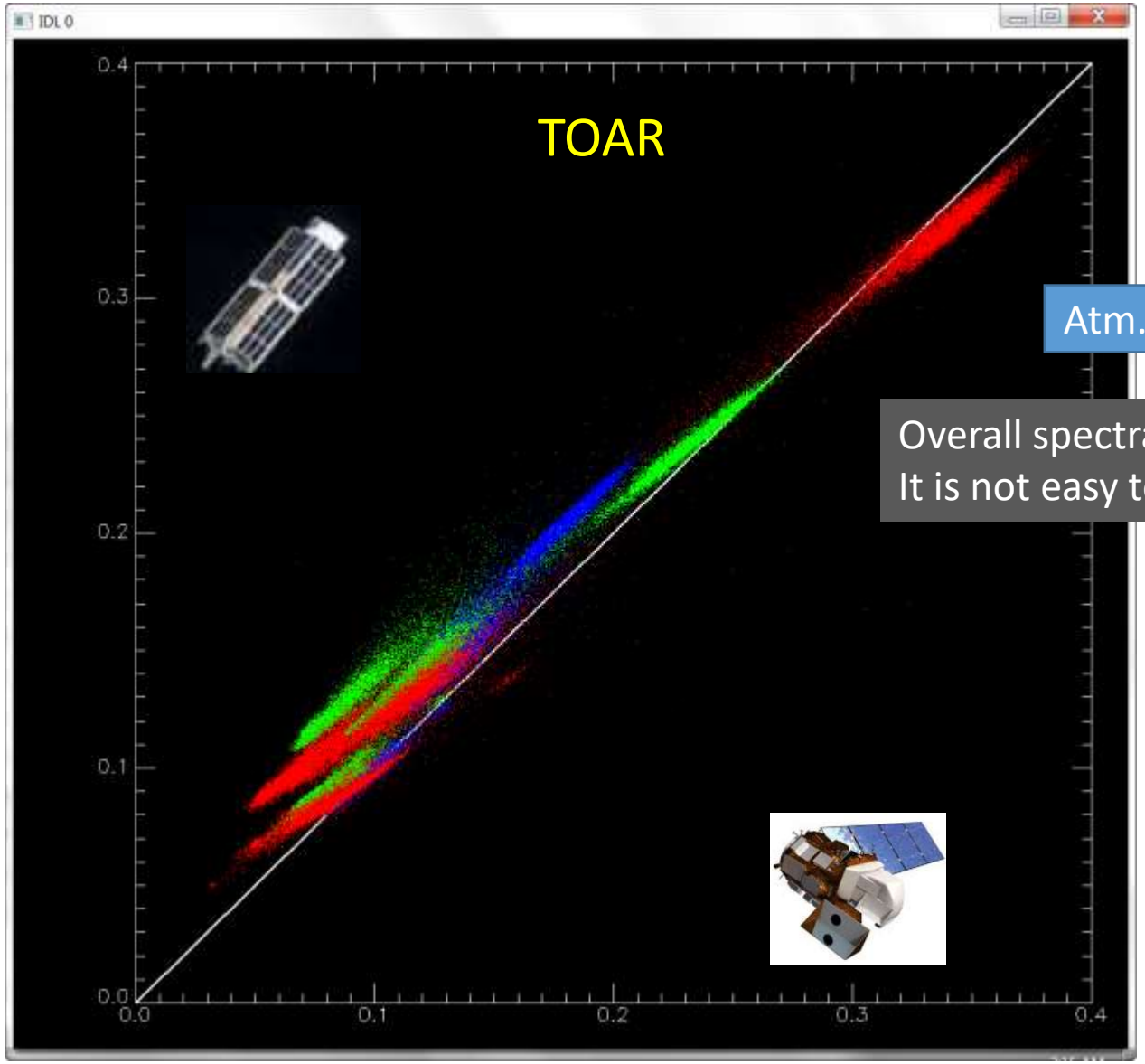


(-1, 2) → (-10m, 20m) Image Shift



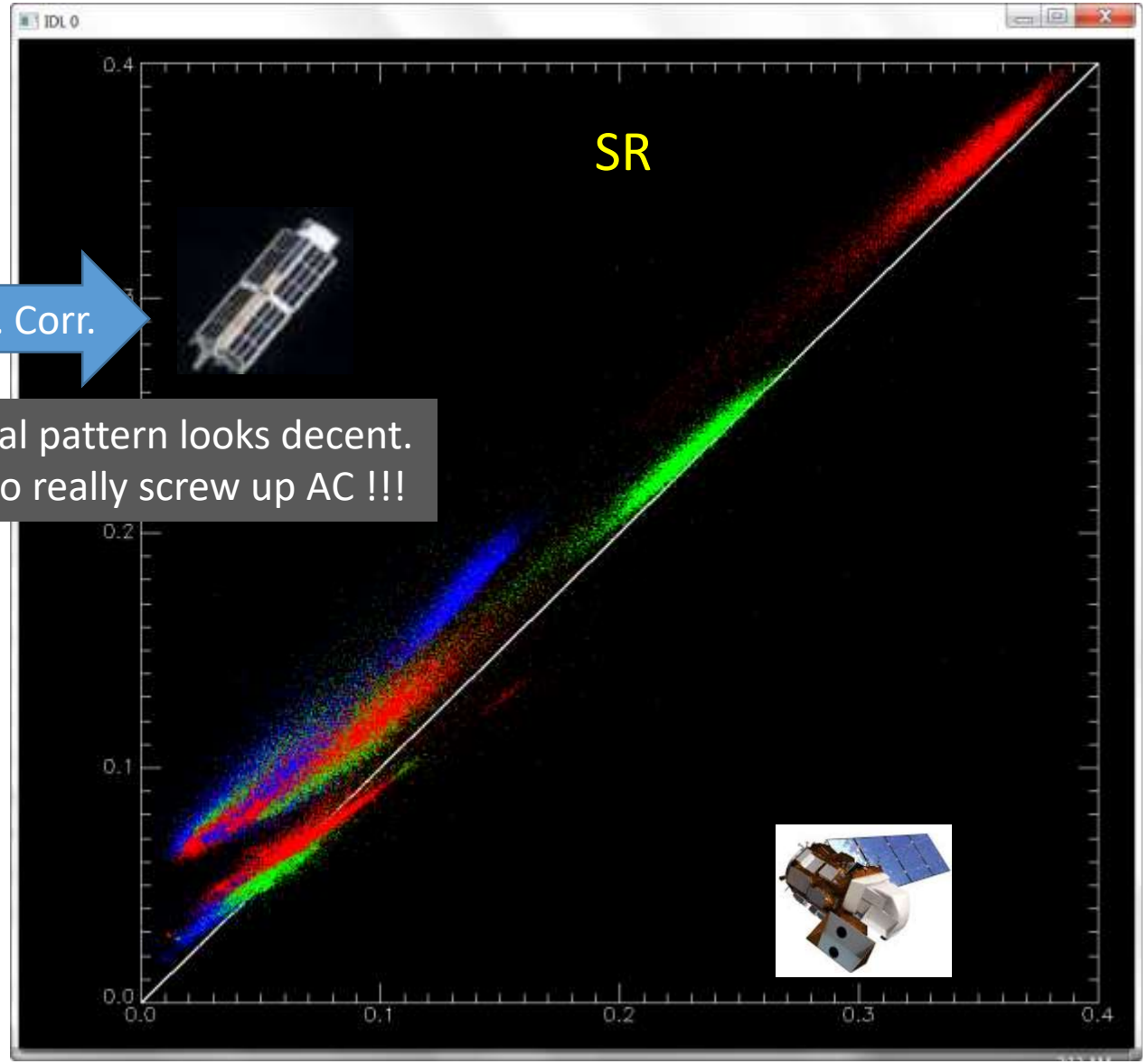

IDL 0
TOA Radiance
Pre-launch calibration
On-orbit monitoring, correction
Straylight correction, …
200
150
100
50
0
0
50
100
150
200

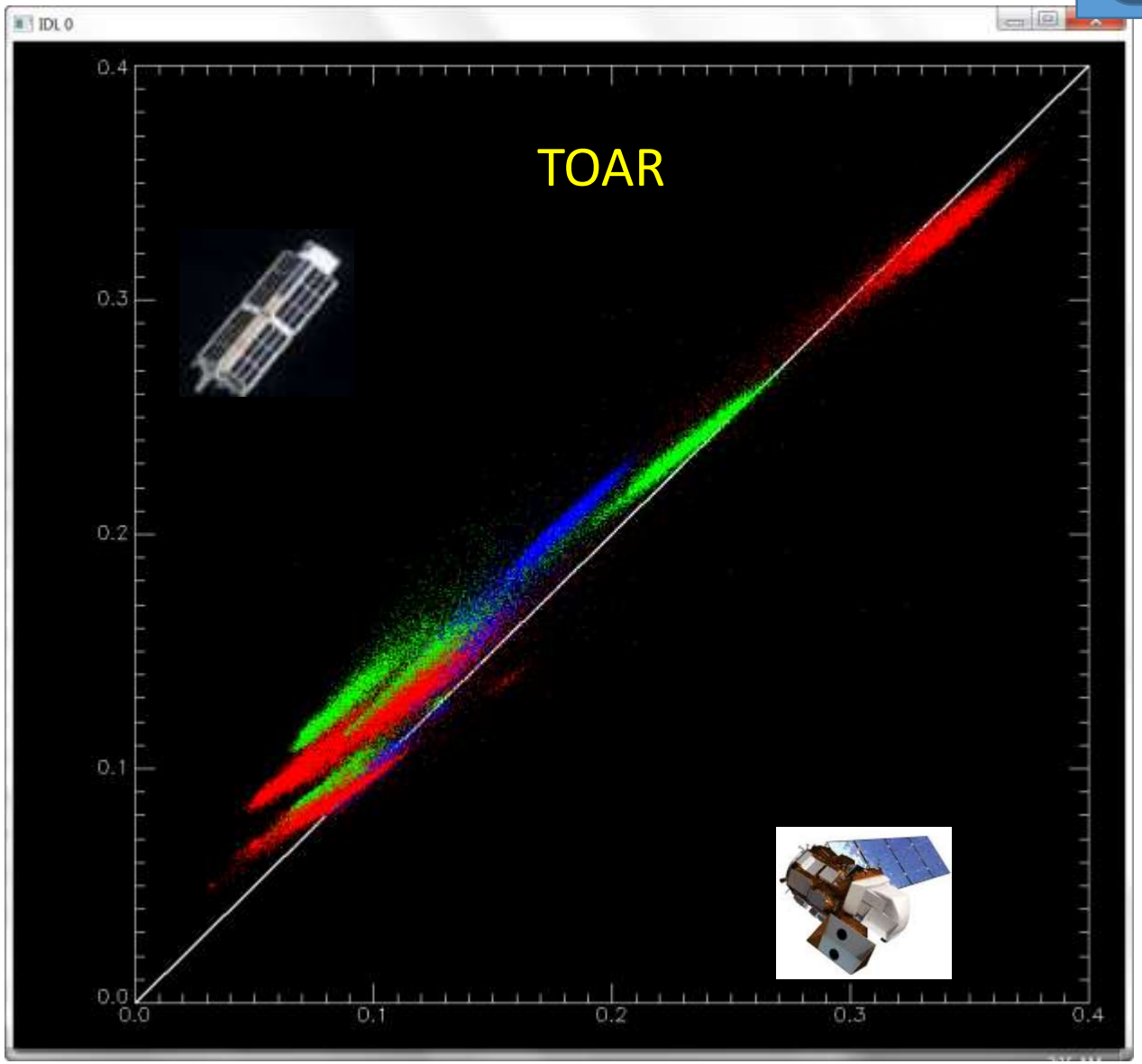

IDL 0
TOAR
Earth-Sun distance
Solar zenith angle
Solar Flux (irradiance)
➔ all, precisely known
~ no uncertainty
0.4
0.2
0.1
0.0
0.0
0.1
0.2
0.3
0.4

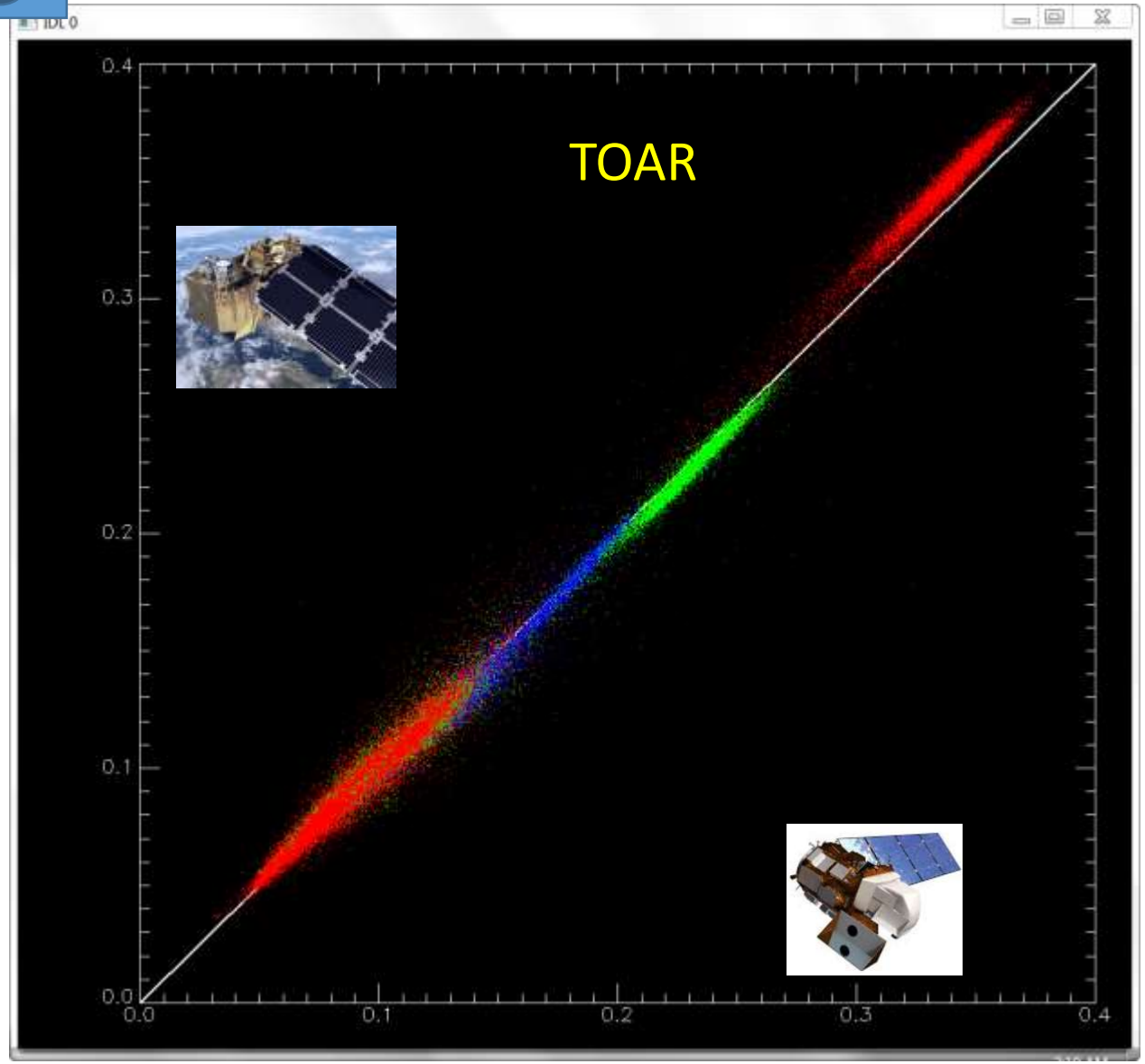


Atm. Corr.

Overall spectral pattern looks decent.
It is not easy to really screw up AC !!!




IDL 0
TOAR
0.0
0.1
0.2
0.3
0.4


IDL 0
TOAR
0.0
0.1
0.2
0.3
0.4

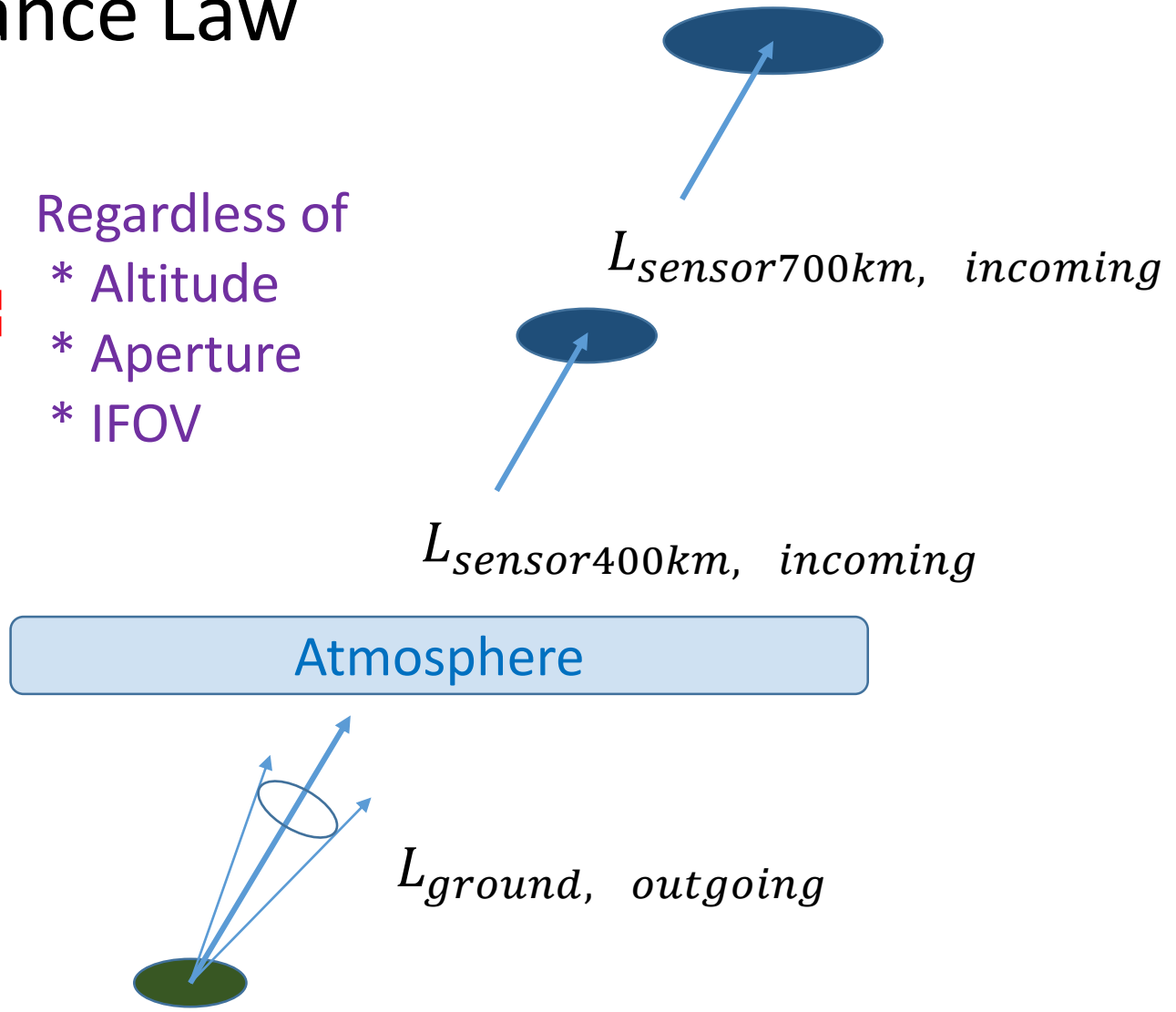
Radiance Invariance Law

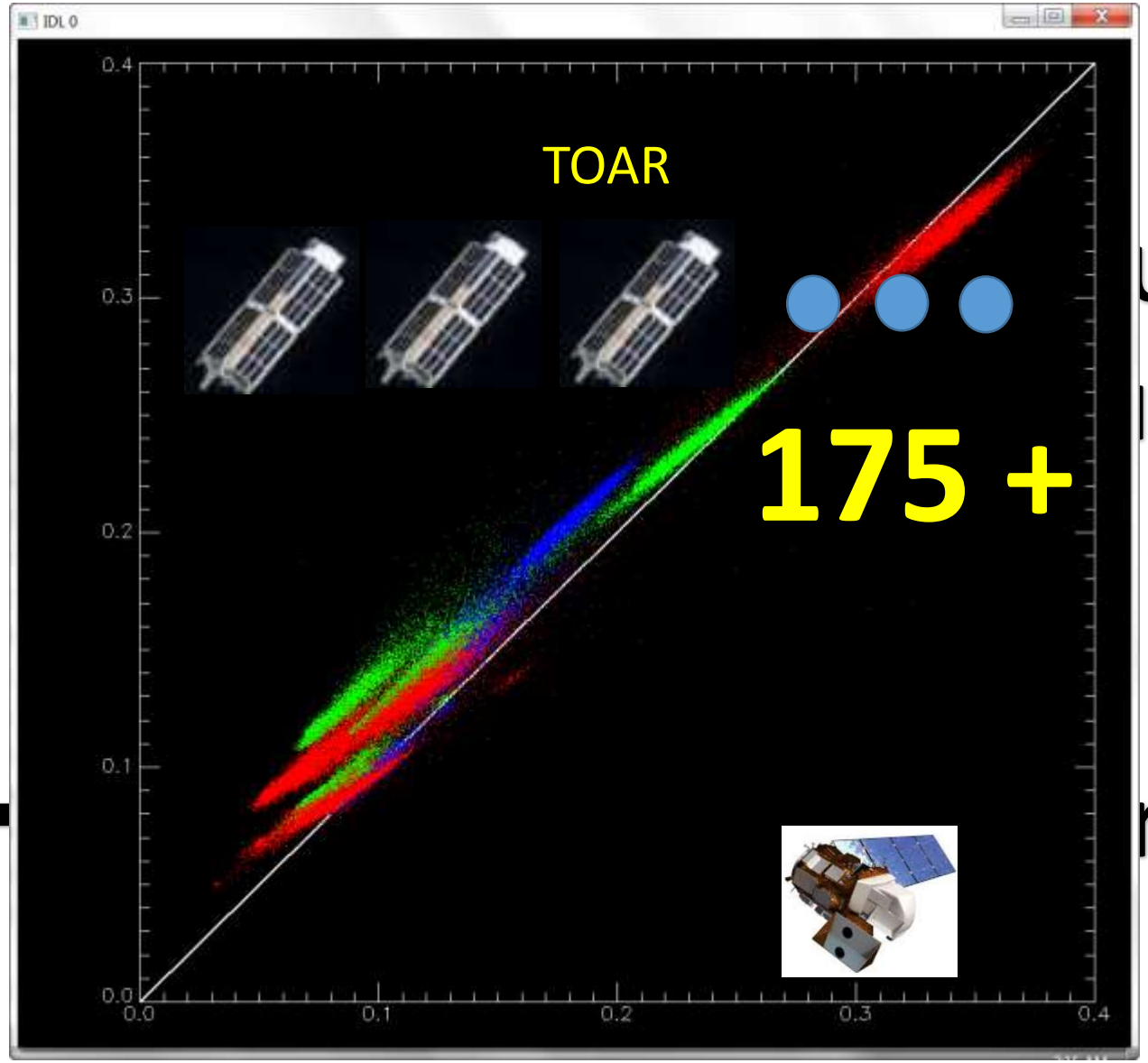
$$L_g^2 \cdot f = L_{400}^2$$

$$L_g^2 \cdot f = L_{700}^2$$

Regardless of
* Altitude
* Aperture
* IFOV

$$f \approx 1/n^2$$



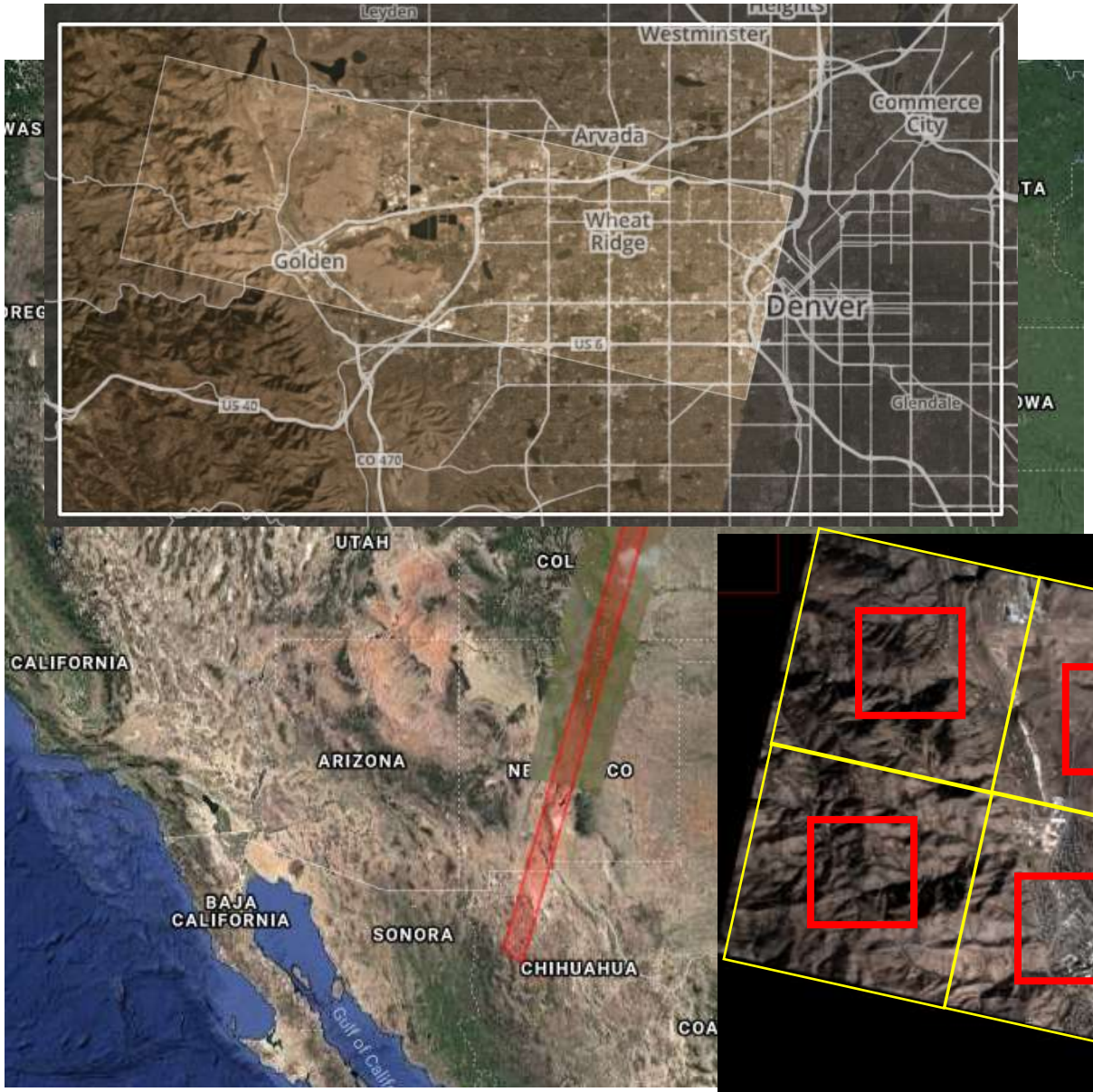


ution

ency

quality

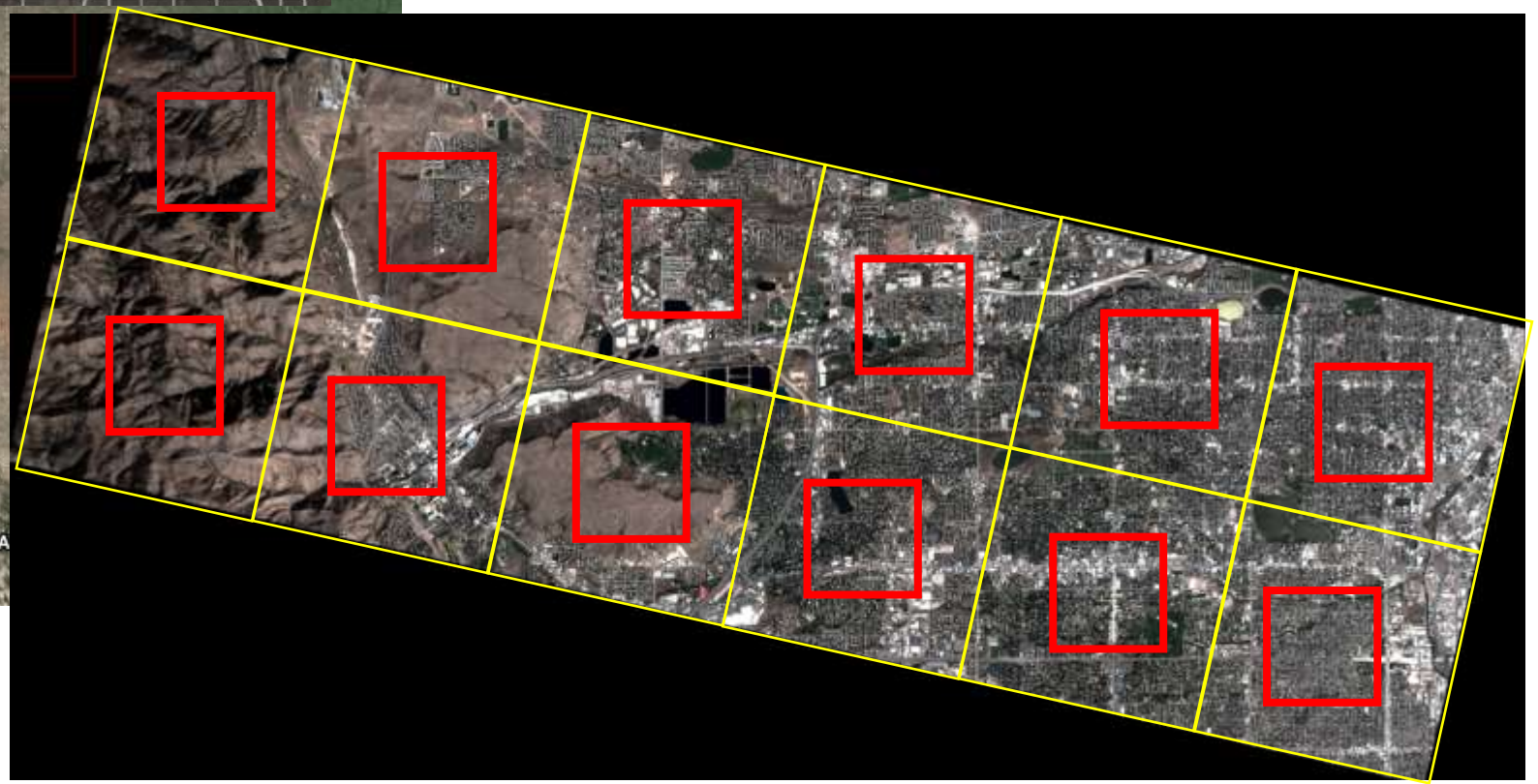
rrection??



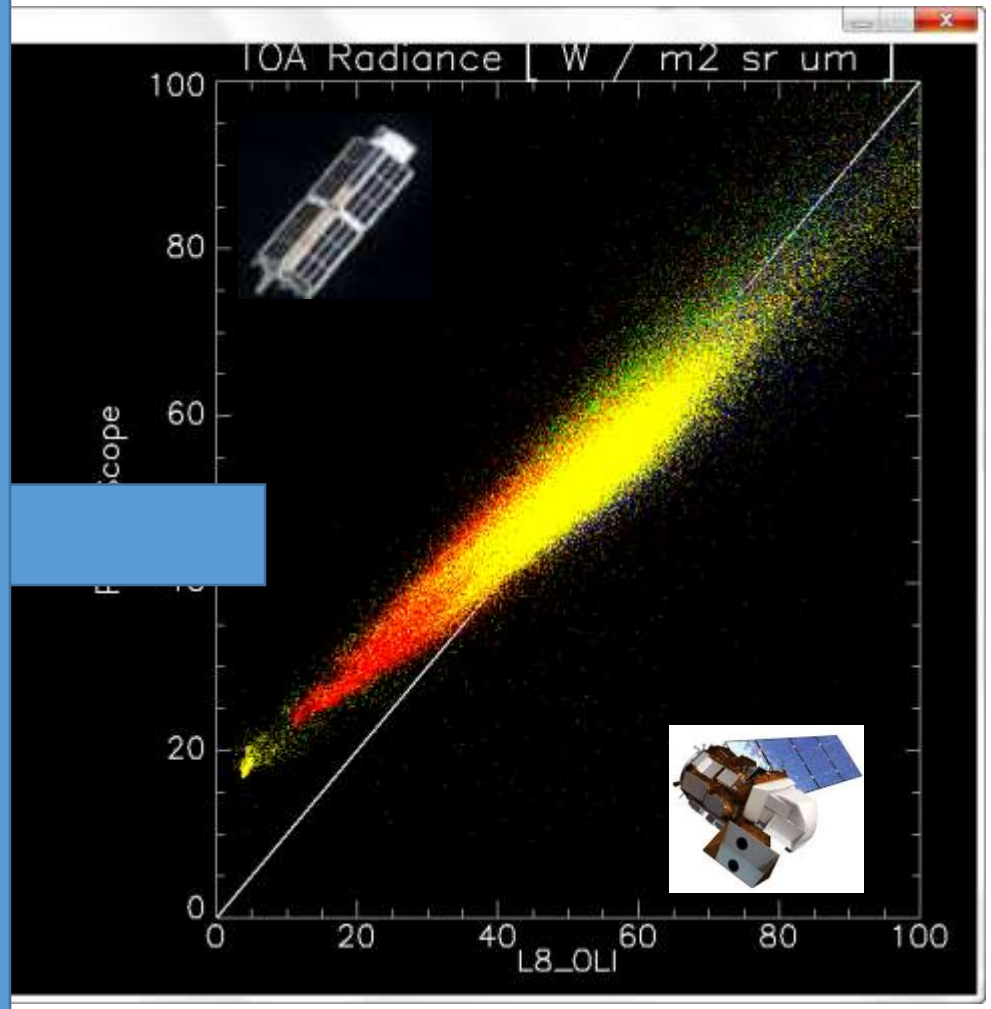
ID=1018

Sep. 8 2018

WRS2 (Path=033)

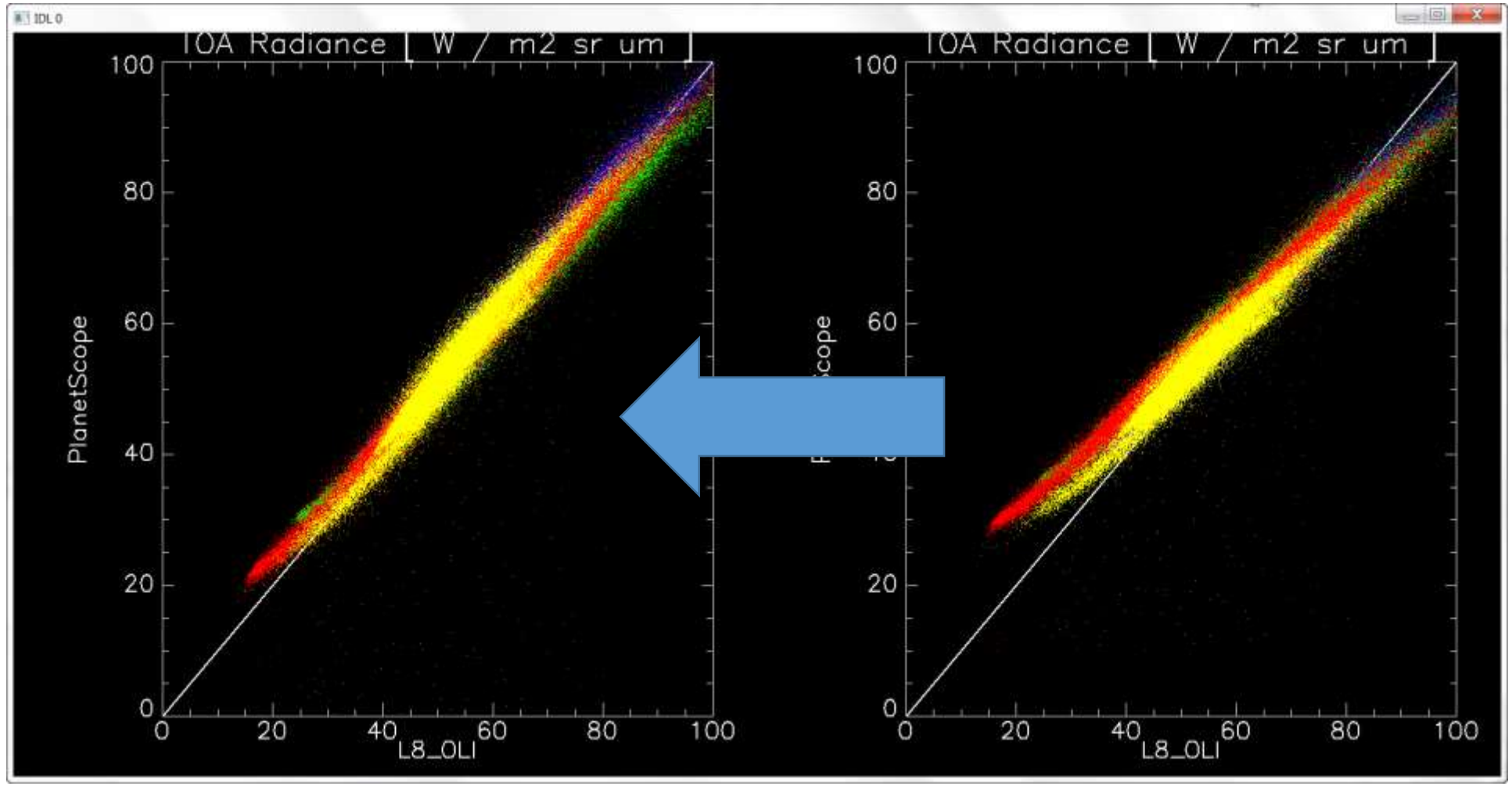


Denver, CO

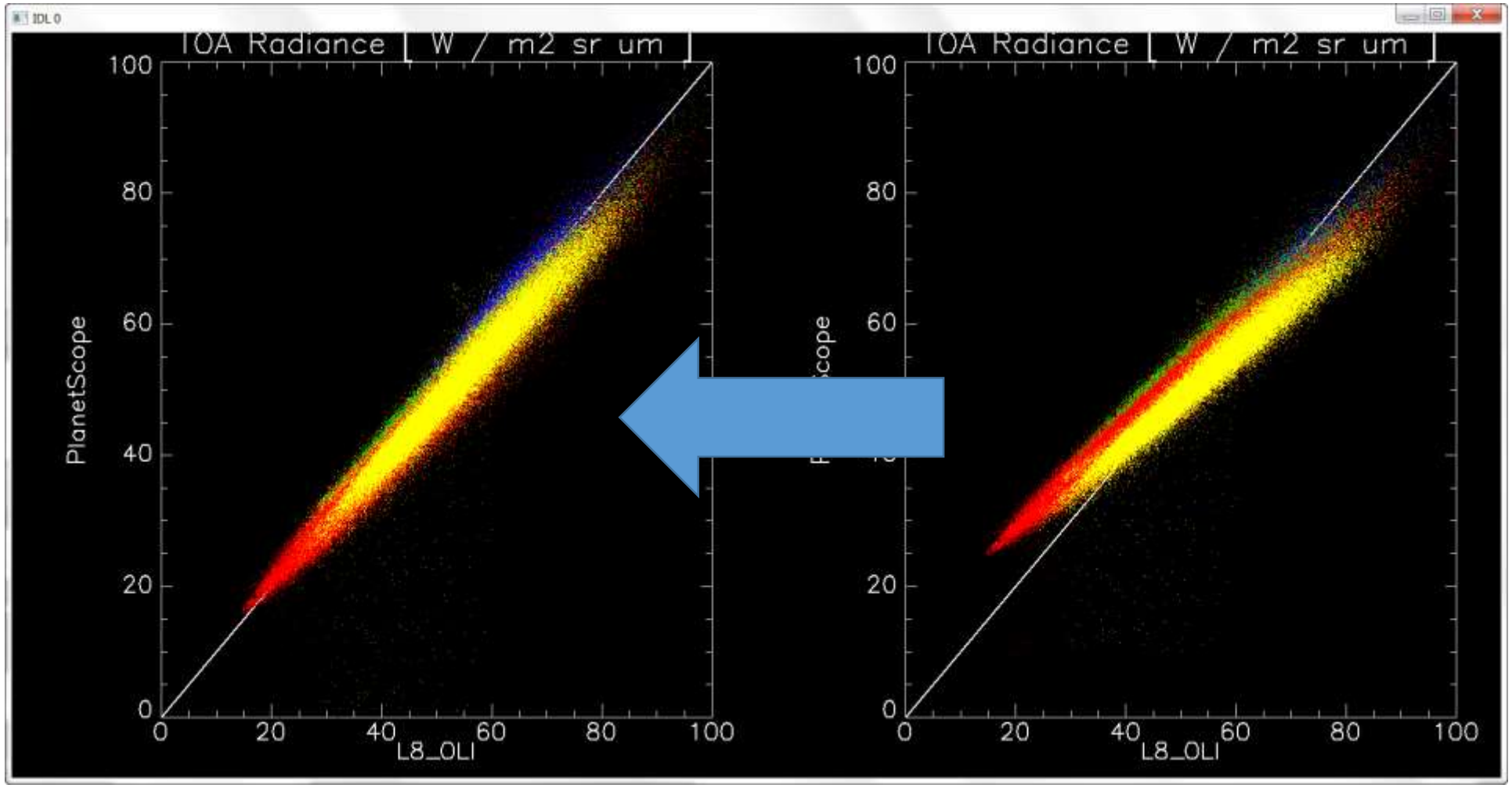


Correction coefficients ← derived from Denver image for Camera ID 1018

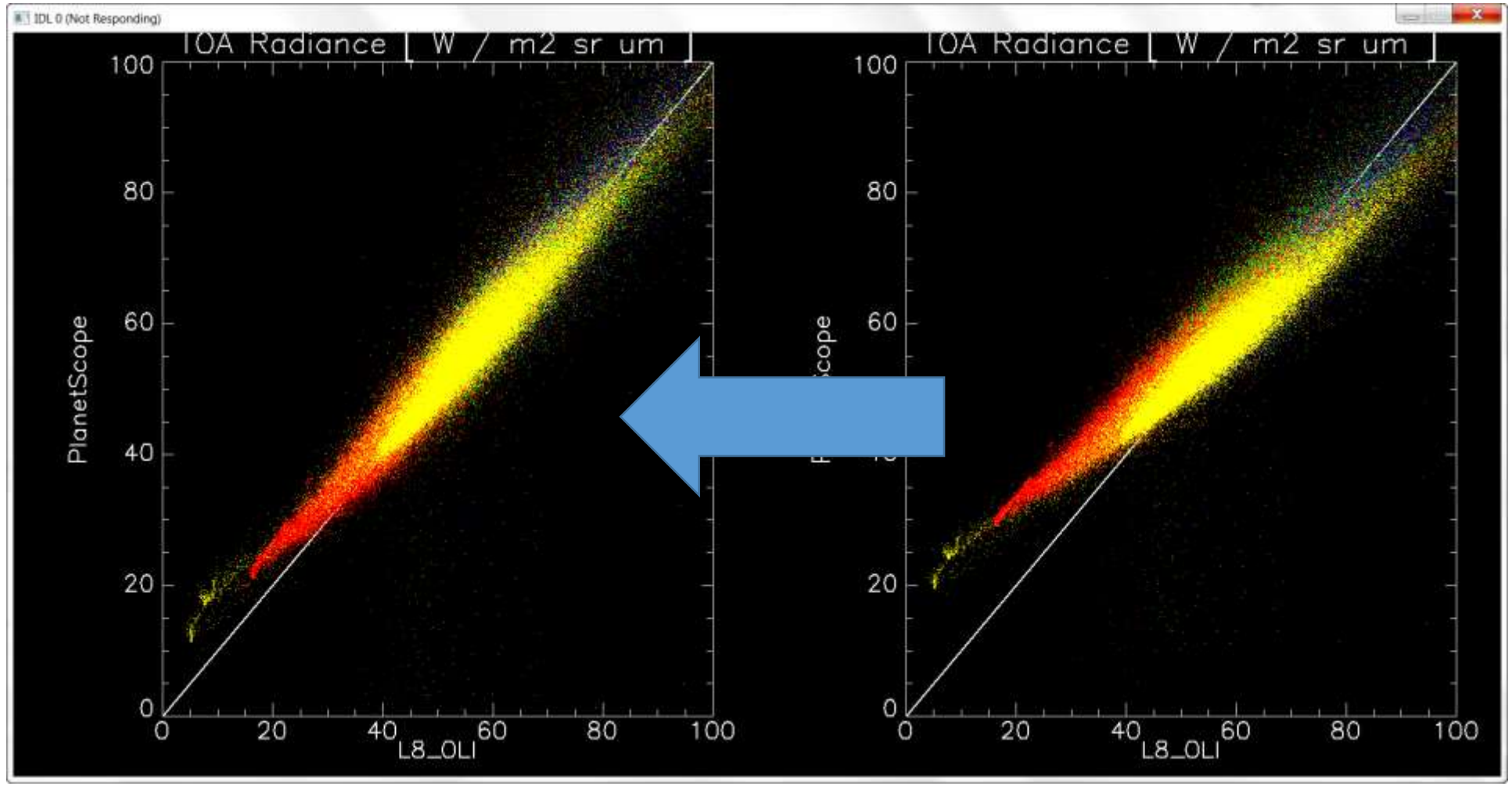
Crestone, CO


IDL 0
TOA Radiance [W / m2 sr um]
PlanetScope
L8_OLI
0
20
40
60
80
100
TOA Radiance [W / m2 sr um]
L8_OLI

Rapid City, SD



Cheyene, WY

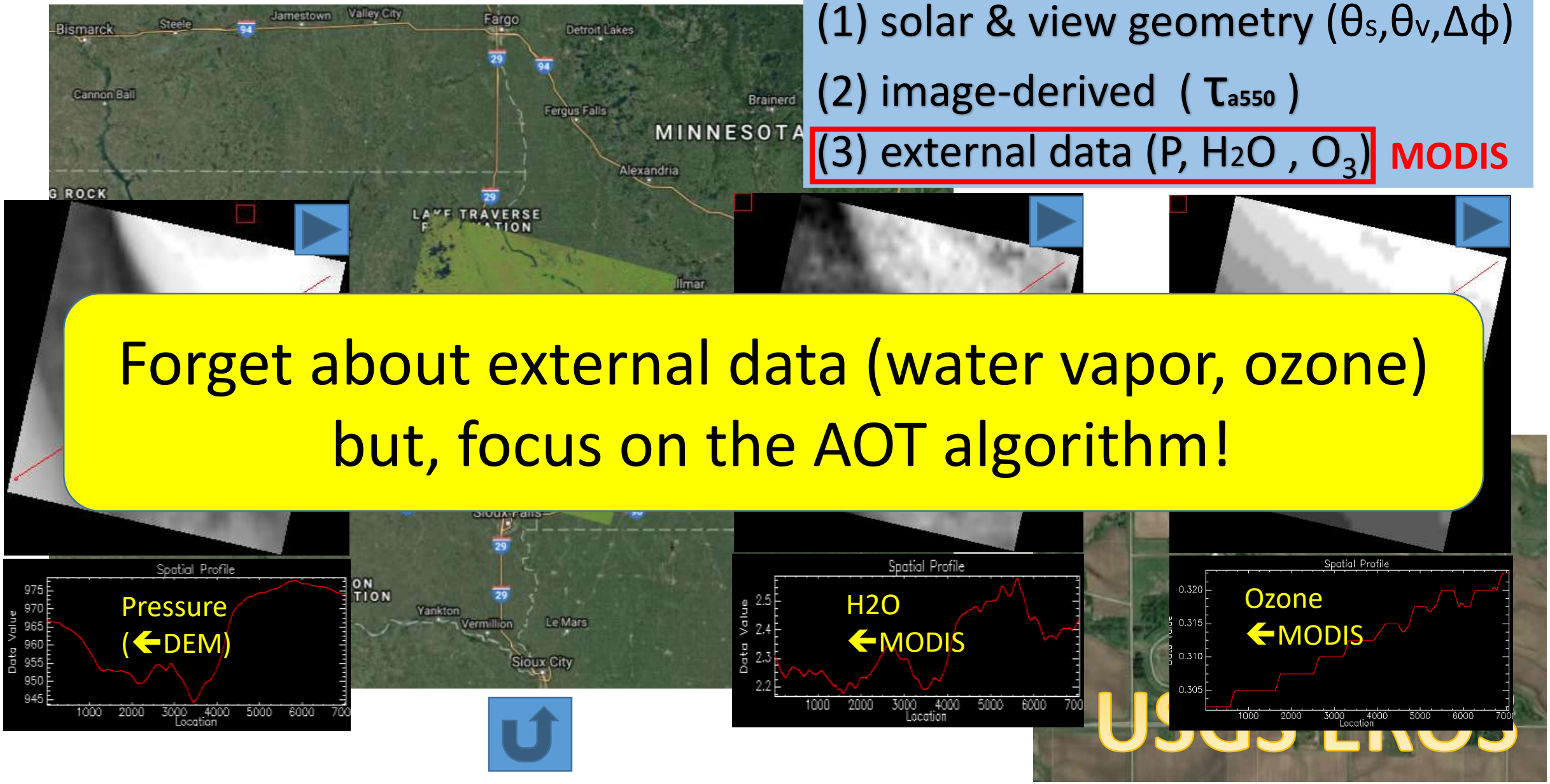

IDL 0 (Not Responding)
TOA Radiance [W / m2 sr um]
PlanetScope
L8_OLI
0
20
40
60
80
100
TOA Radiance [W / m2 sr um]
L8_OLI

LaSRC (OLI AC) :

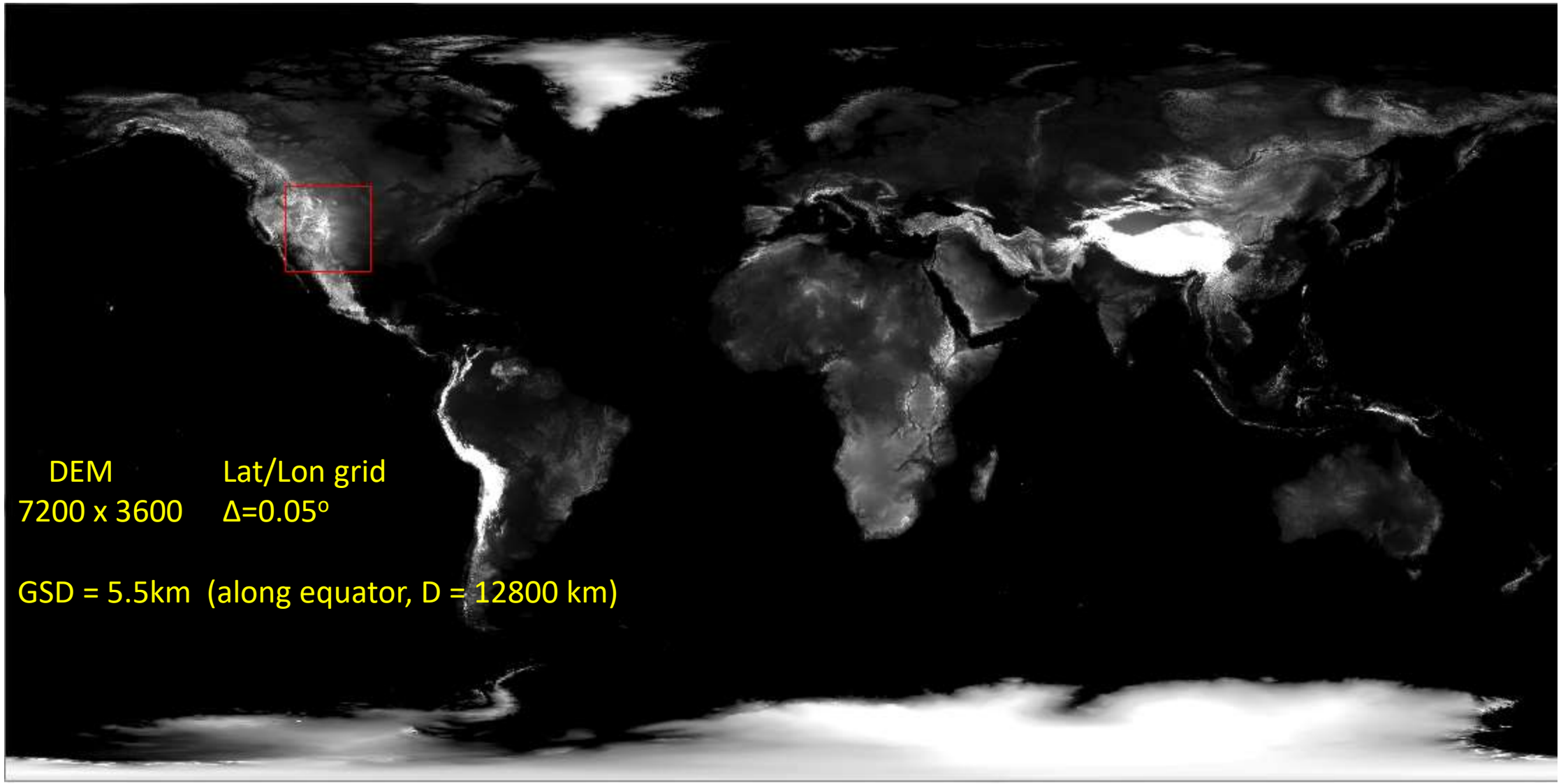
(1) solar & view geometry ($\theta_s, \theta_v, \Delta\phi$)

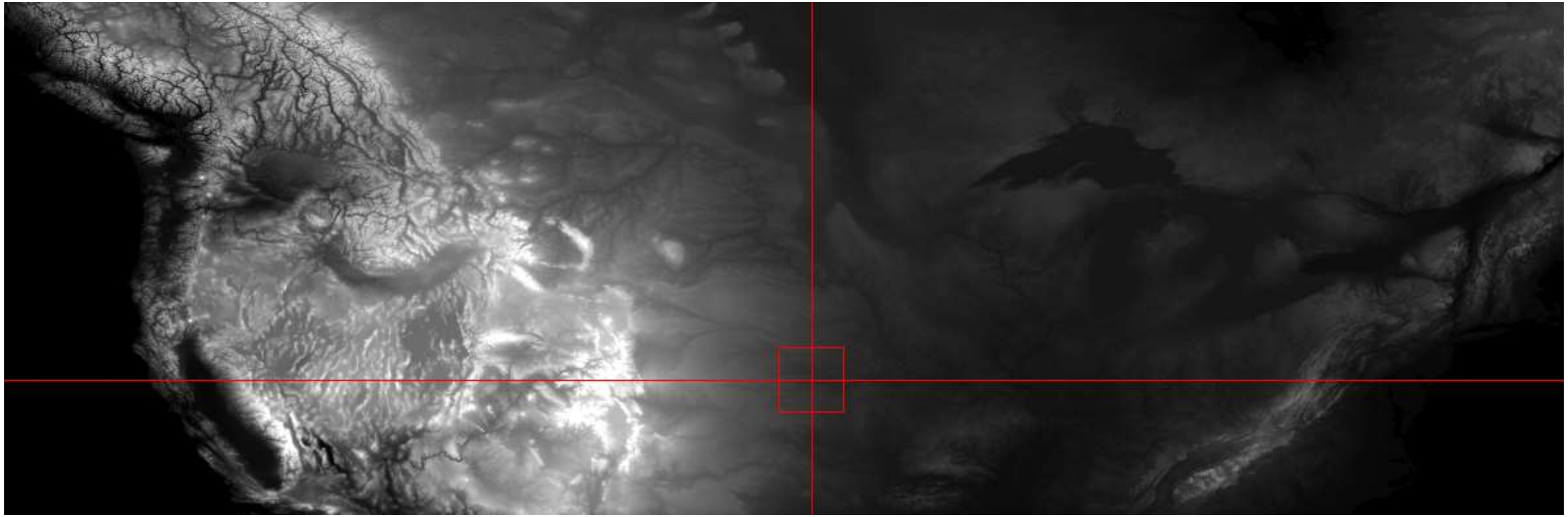
(2) image-derived (τ_{a550})

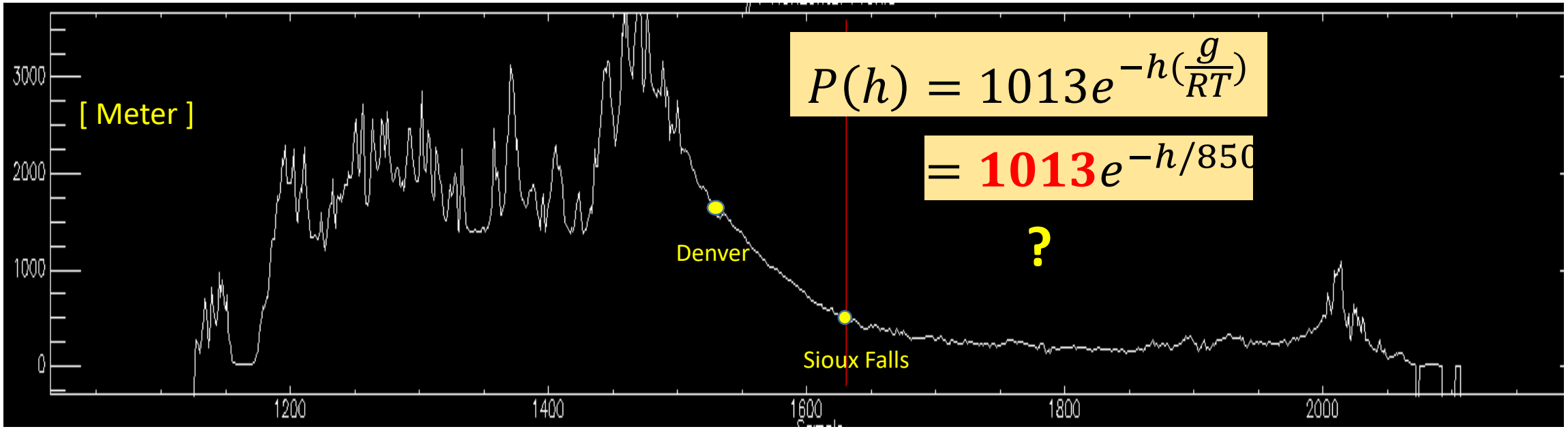
(3) external data (P, H_2O , O_3) **MODIS**



Forget about external data (water vapor, ozone) but, focus on the AOT algorithm!


DEM
7200 x 3600
Lat/Lon grid
Δ=0.05°
GSD = 5.5km (along equator, D = 12800 km)



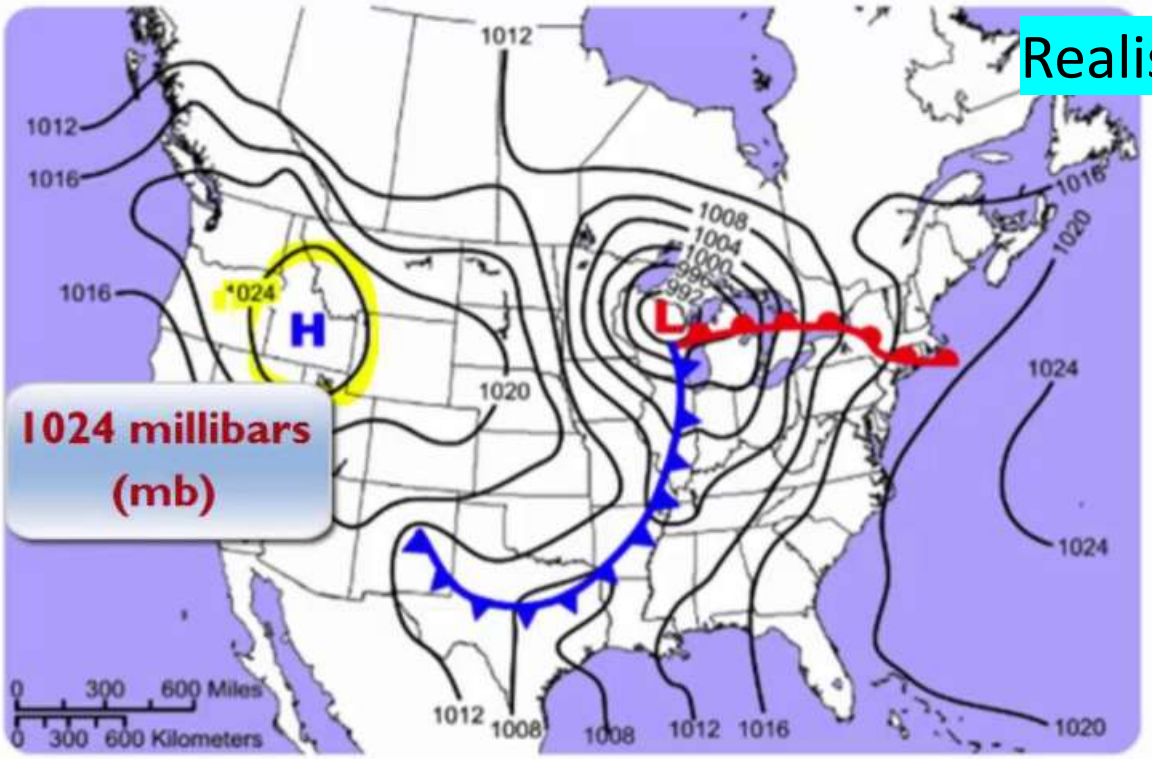


$$P(h) = 1013e^{-h(\frac{g}{RT})}$$

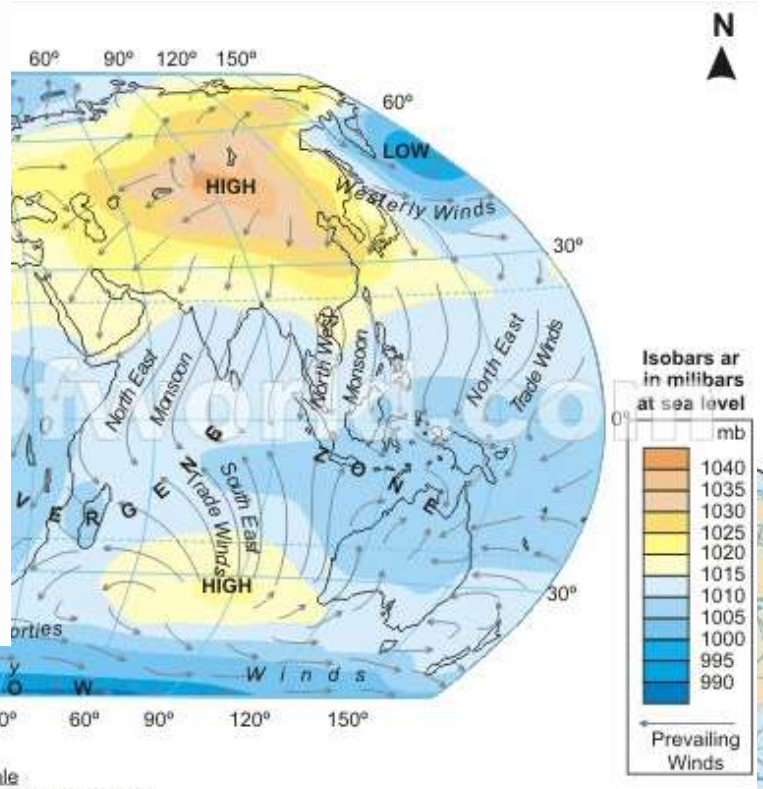
$$= \mathbf{1013}e^{-h/850}$$

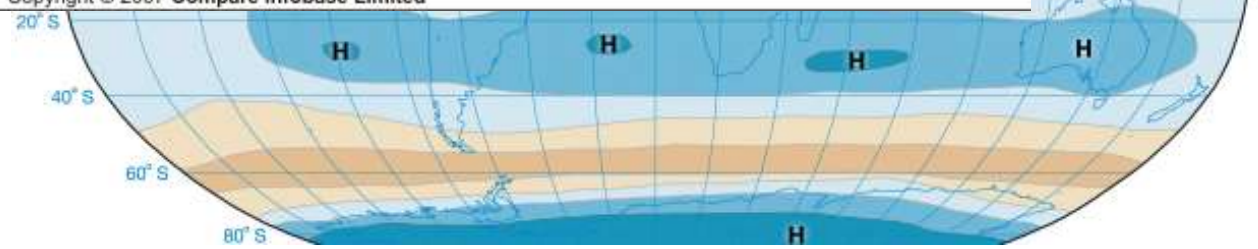
?

Realistic sea-level pressure range (1010 – 1030 mb)



Key: L = low-pressure center — warm front — 1008 isobar — H = high-pressure center — cold front

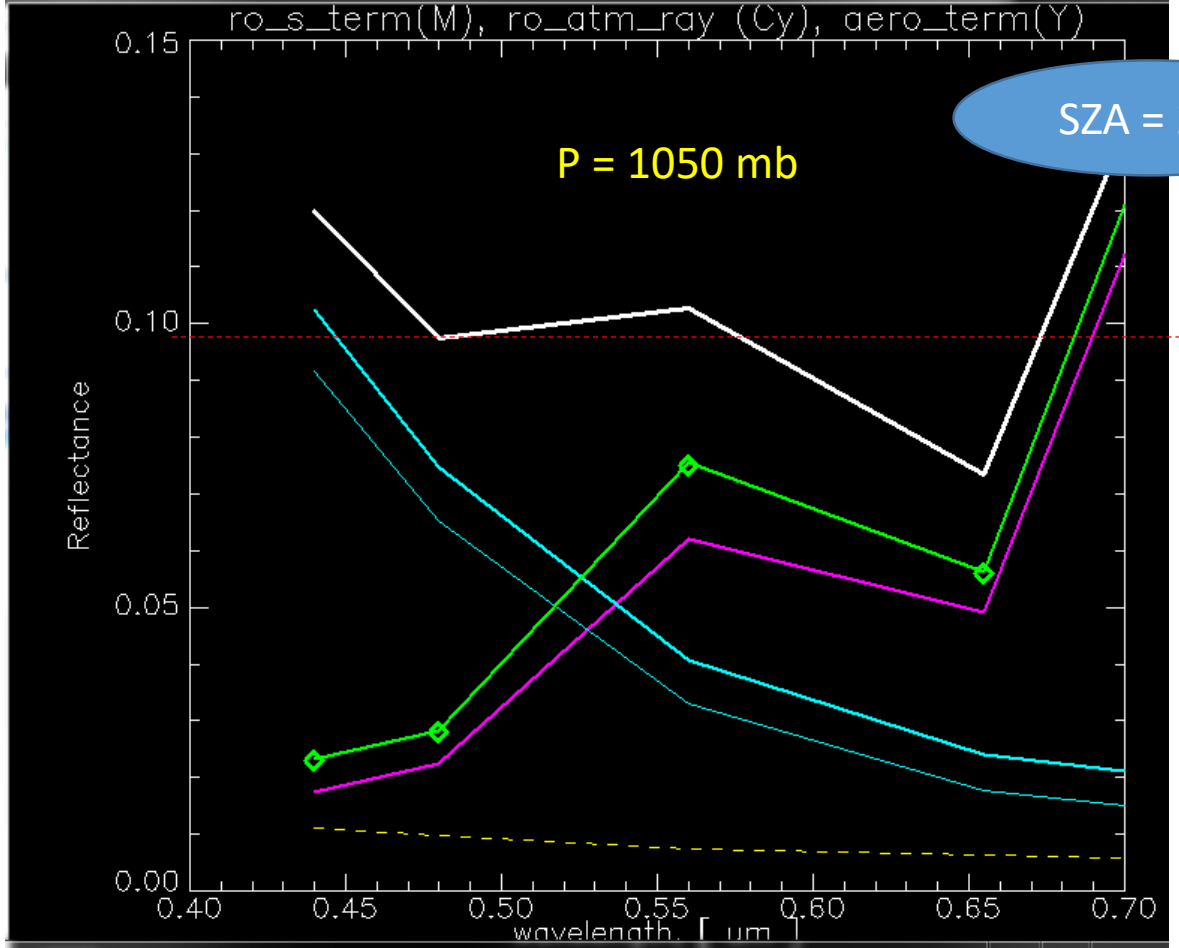


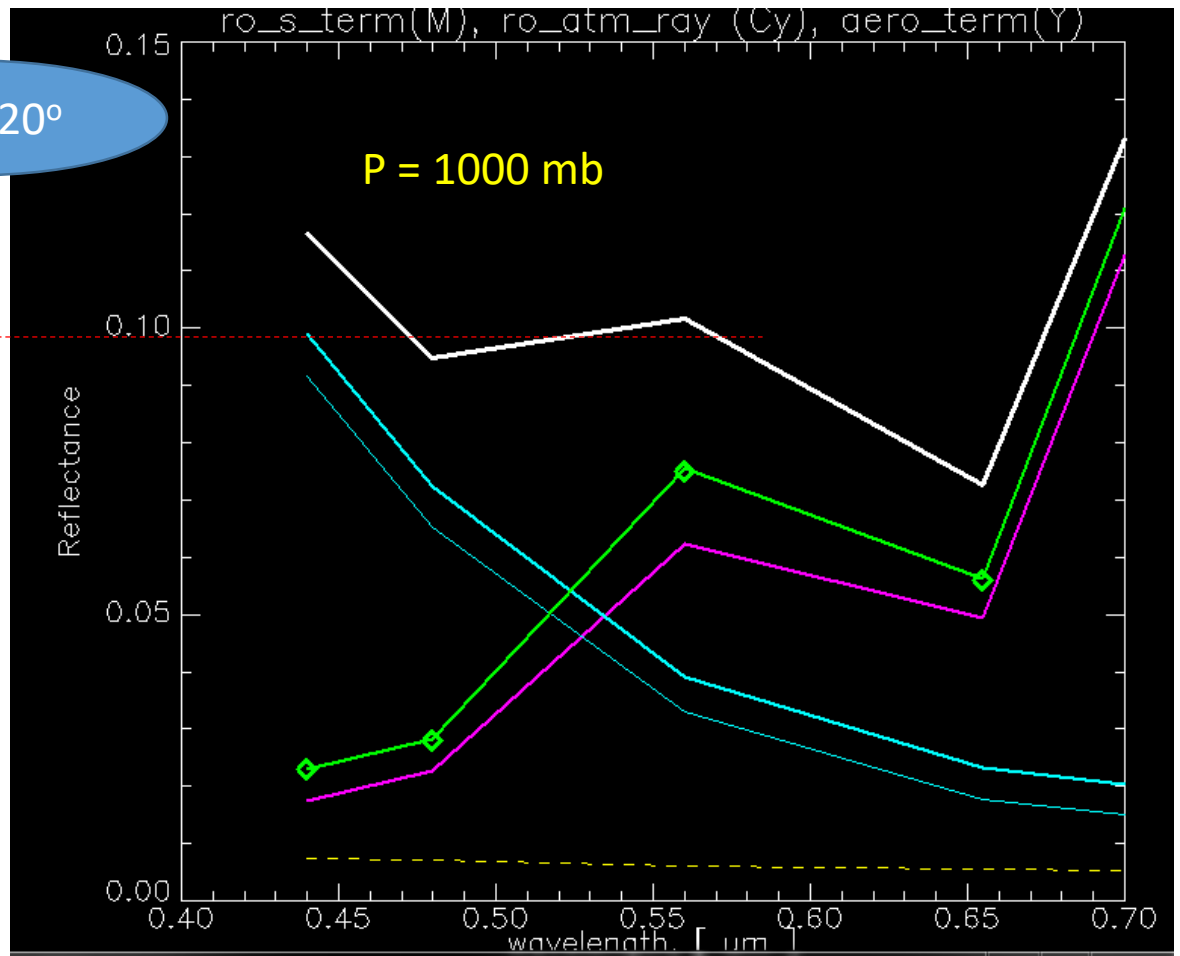


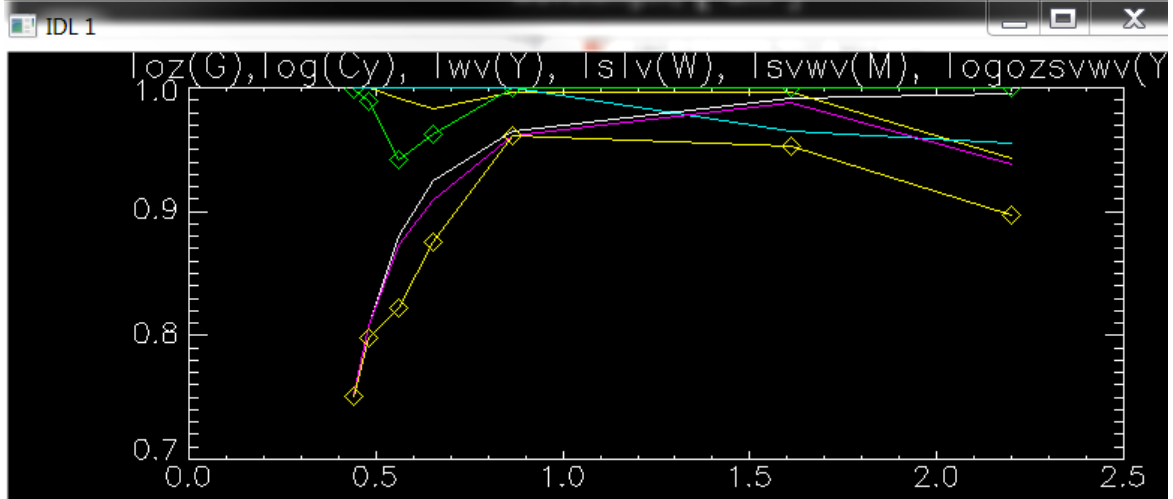
AVERAGE SEA-LEVEL ATMOSPHERIC PRESSURES IN JULY

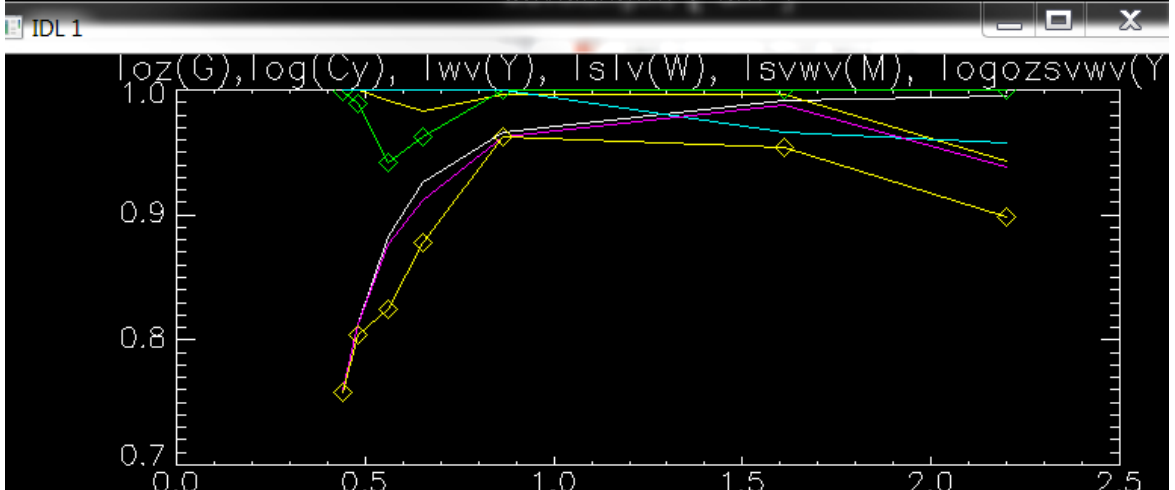
Millibars of Pressure

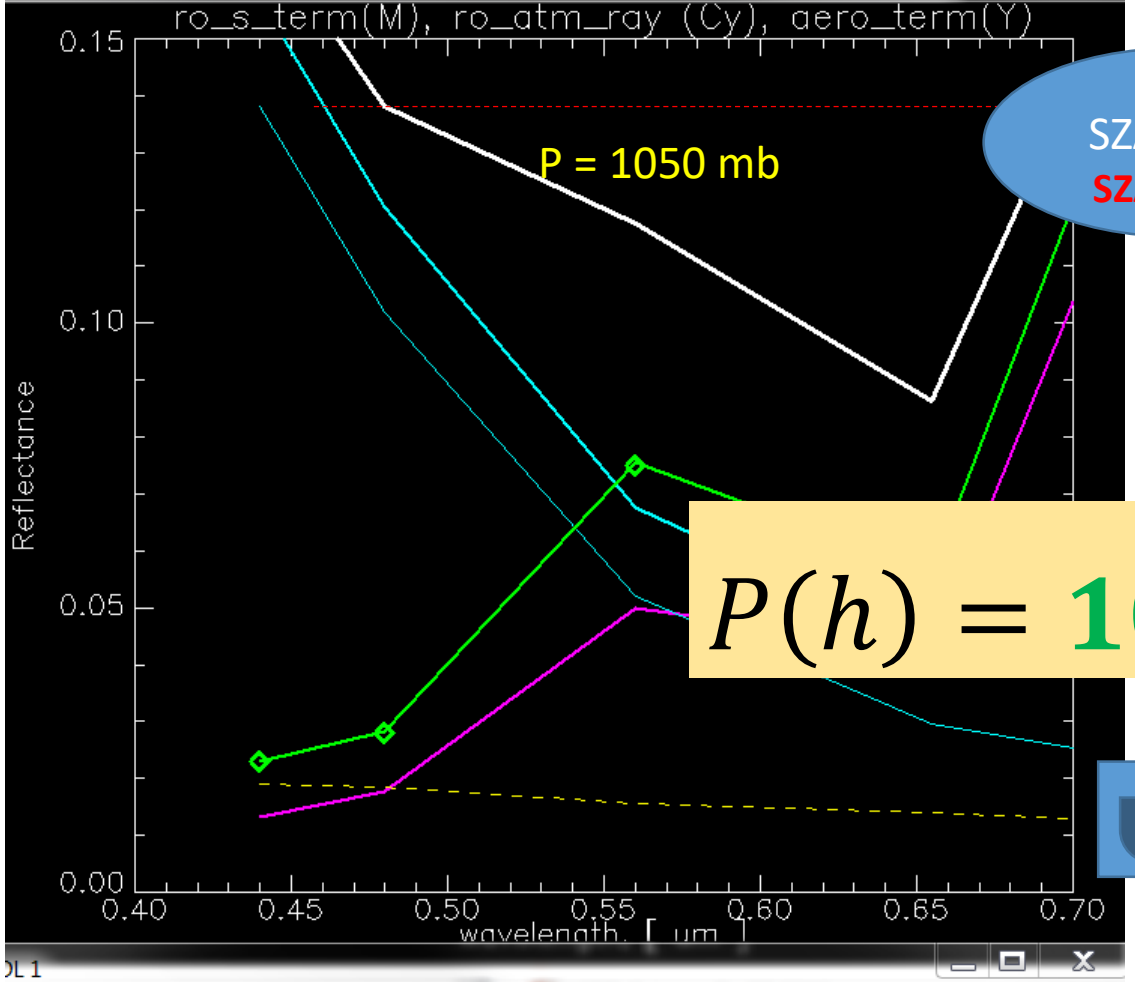
- Over 1,024
- 1,016 to 1,024
- 1,008 to 1,016
- 1,000 to 1,008
- Under 1,000
- H High-Pressure Cell
- L Low-Pressure Cell


ro_s_term(M), ro_atm_ray (Cy), aero_term(Y)
SZA = 20°
P = 1050 mb
Reflectance
0.15
0.10
0.05
0.00
0.40
0.45
0.50
0.55
0.60
0.65
0.70
wavelength [um]


ro_s_term(M), ro_atm_ray (Cy), aero_term(Y)
P = 1000 mb
Reflectance
0.15
0.10
0.05
0.00
0.40
0.45
0.50
0.55
0.60
0.65
0.70
wavelength [um]

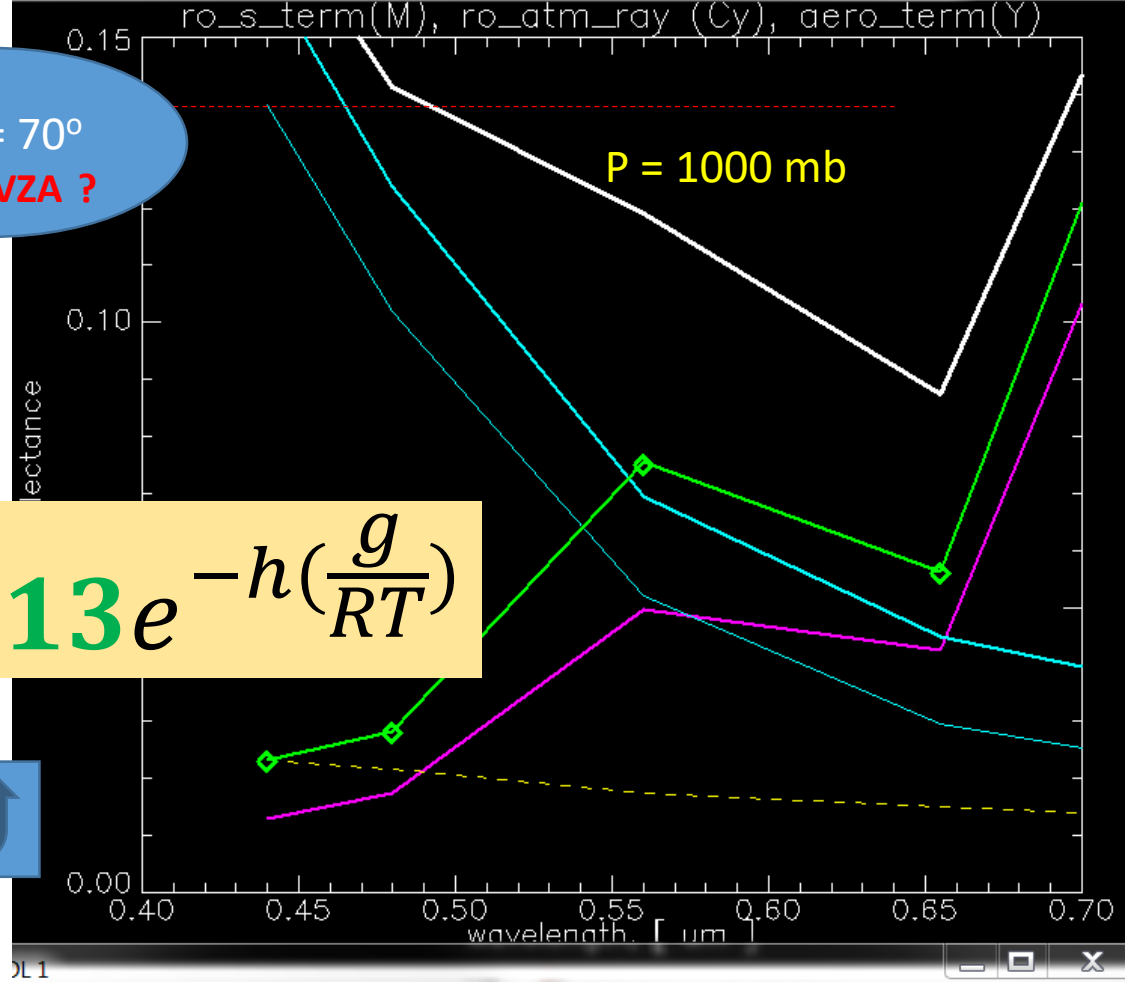

IDL 1
loz(G),log(Cy), lwv(Y), lslv(W), lsvwv(M), logozsvwv(Y
1.0
0.9
0.8
0.7
0.0
0.5
1.0
1.5
2.0
2.5


IDL 1
loz(G),log(Cy), lwv(Y), lslv(W), lsvwv(M), logozsvwv(Y
1.0
0.9
0.8
0.7
0.0
0.5
1.0
1.5
2.0
2.5

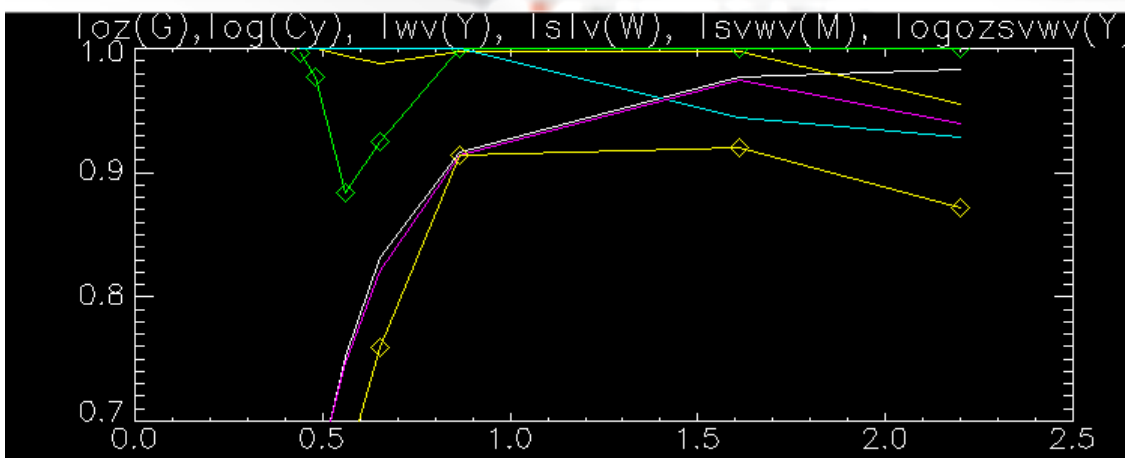


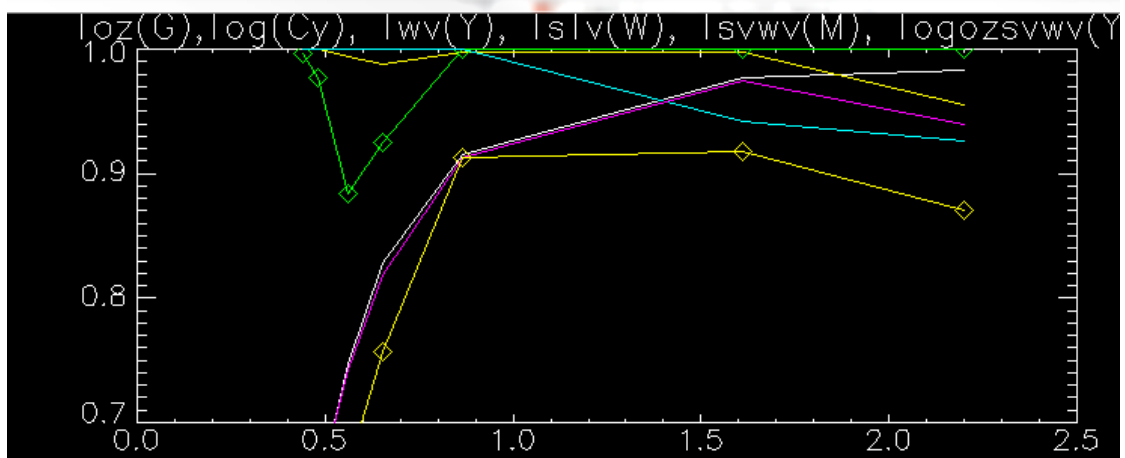
SZA = 70º

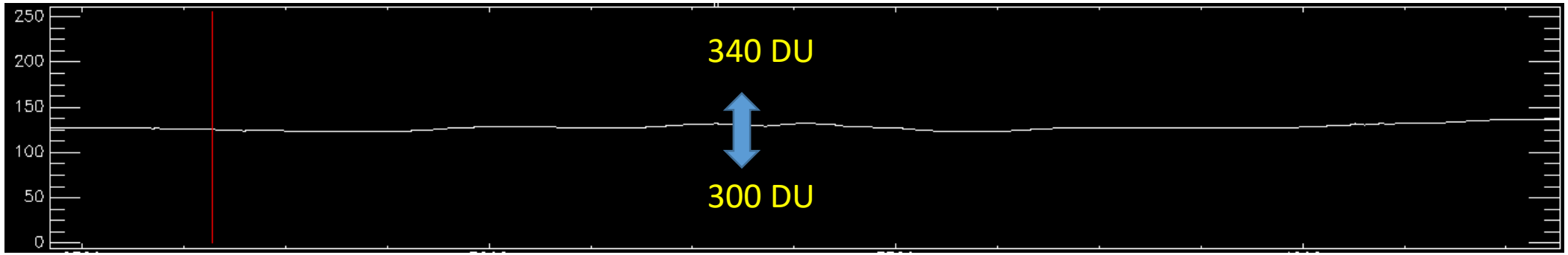
SZA, VZA ?



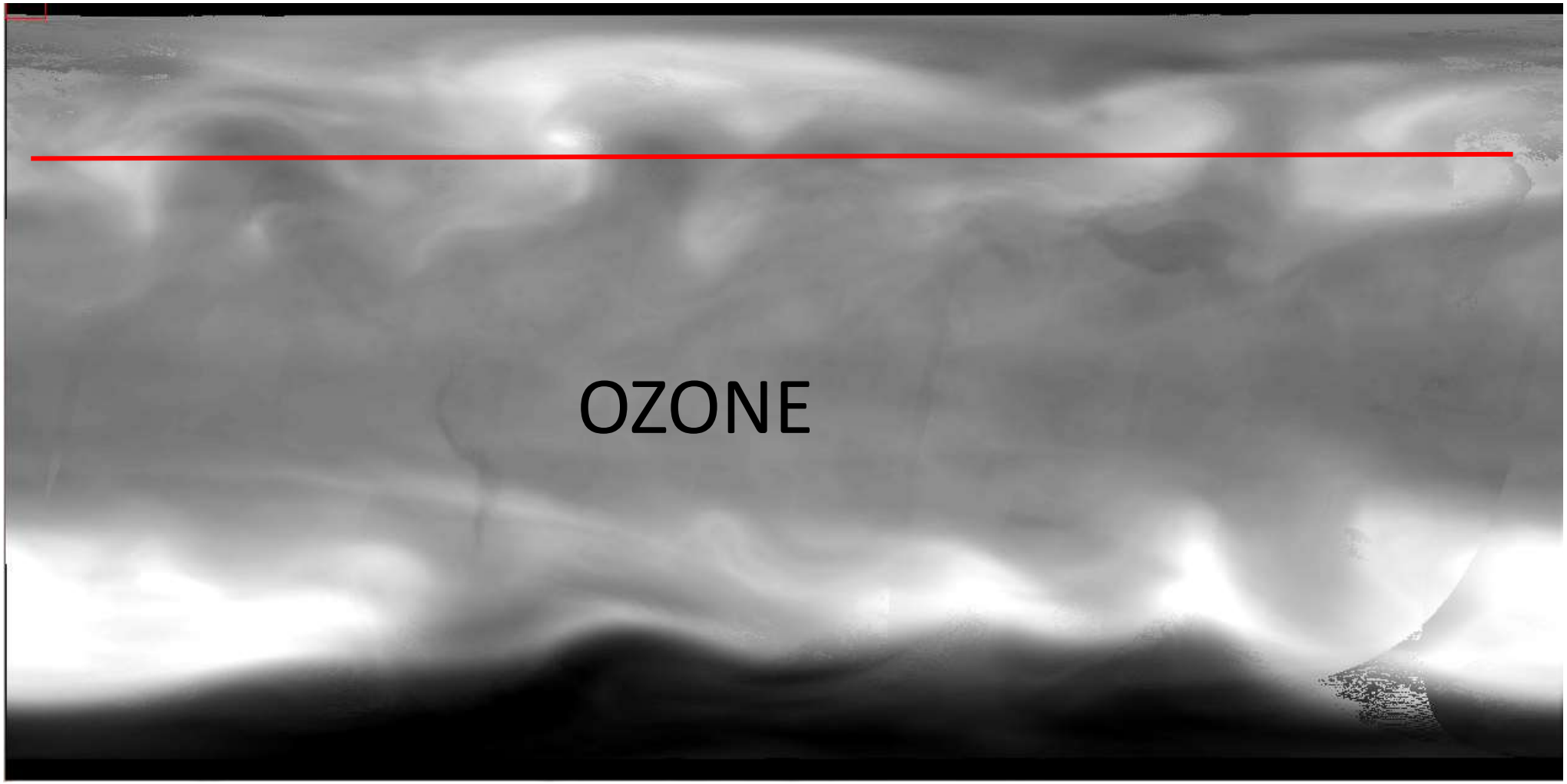
$$P(h) = 1013e^{-h(\frac{g}{RT})}$$



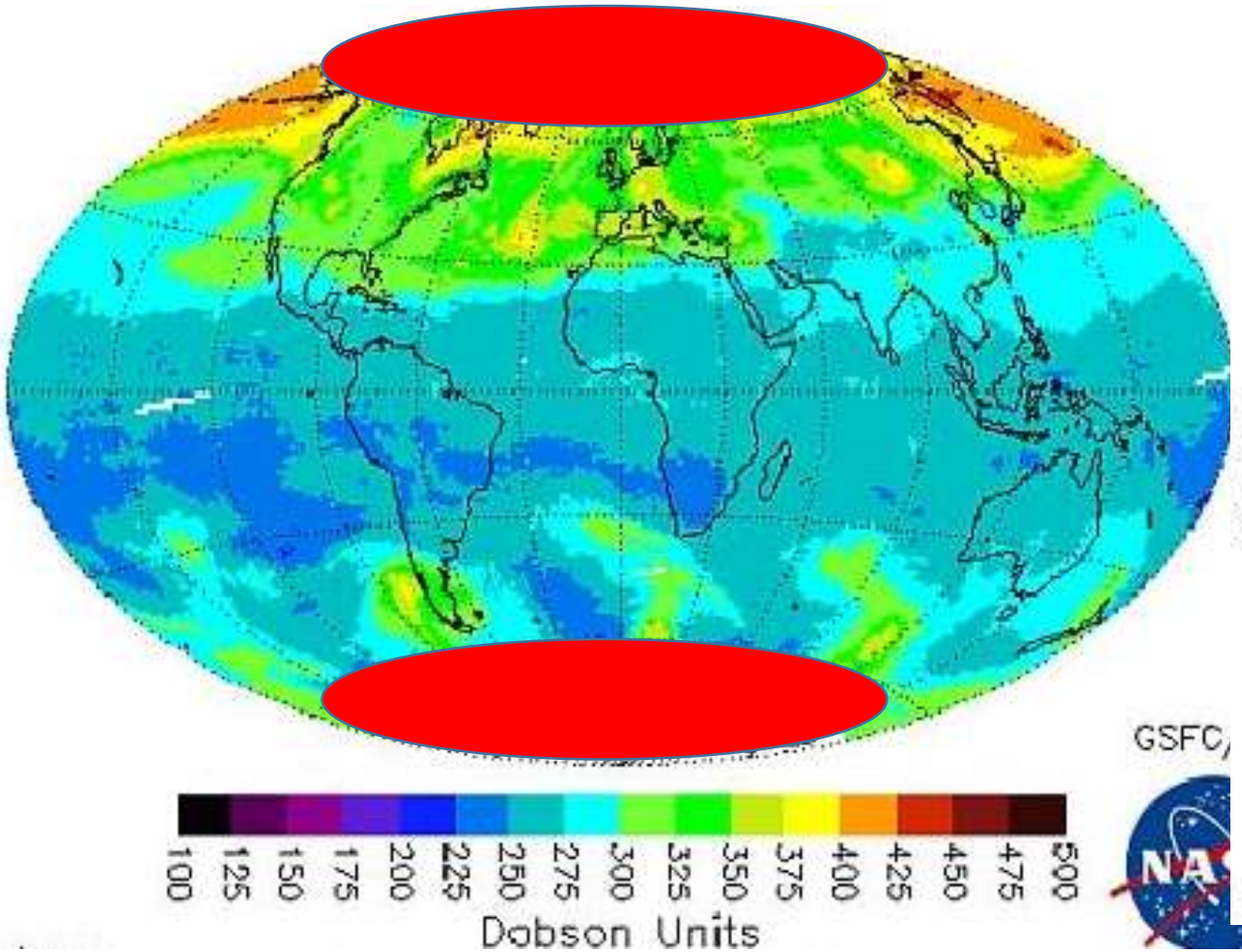


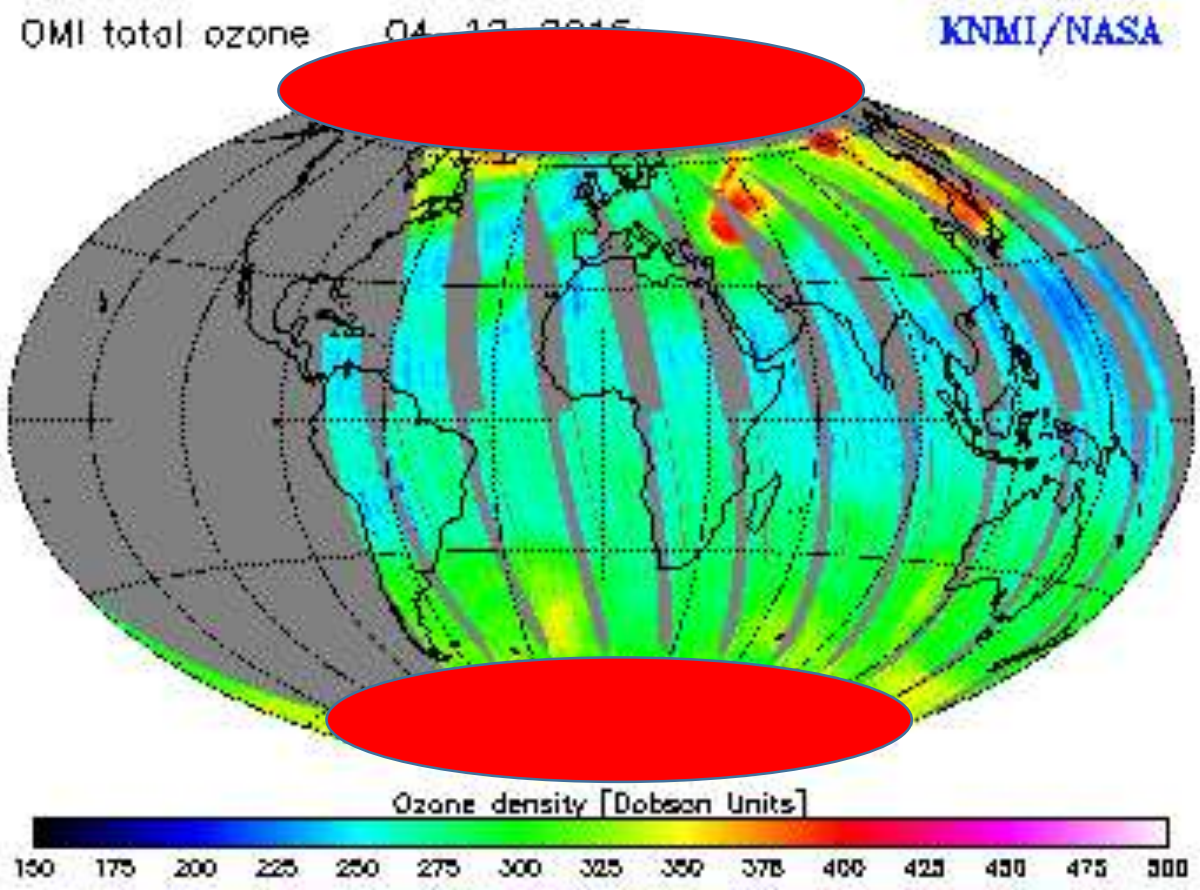


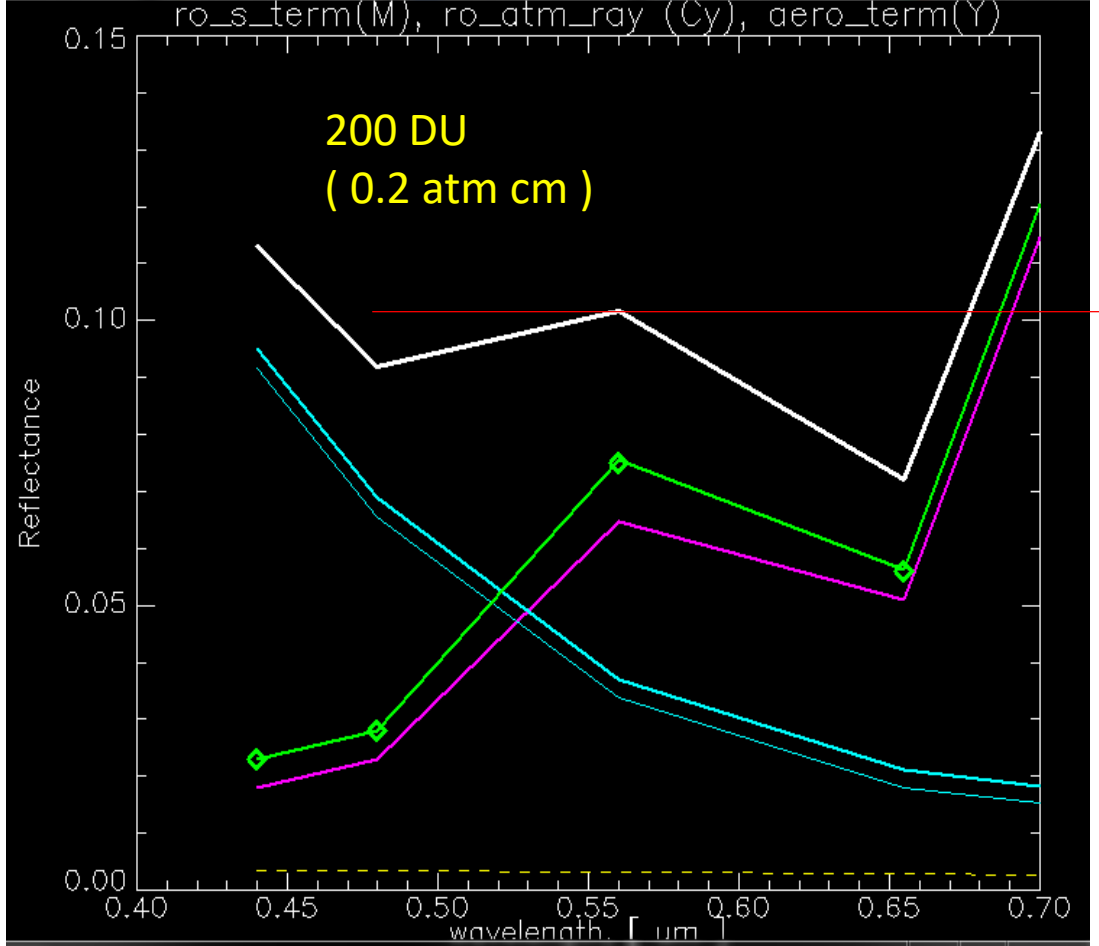
Scale factor
: 400

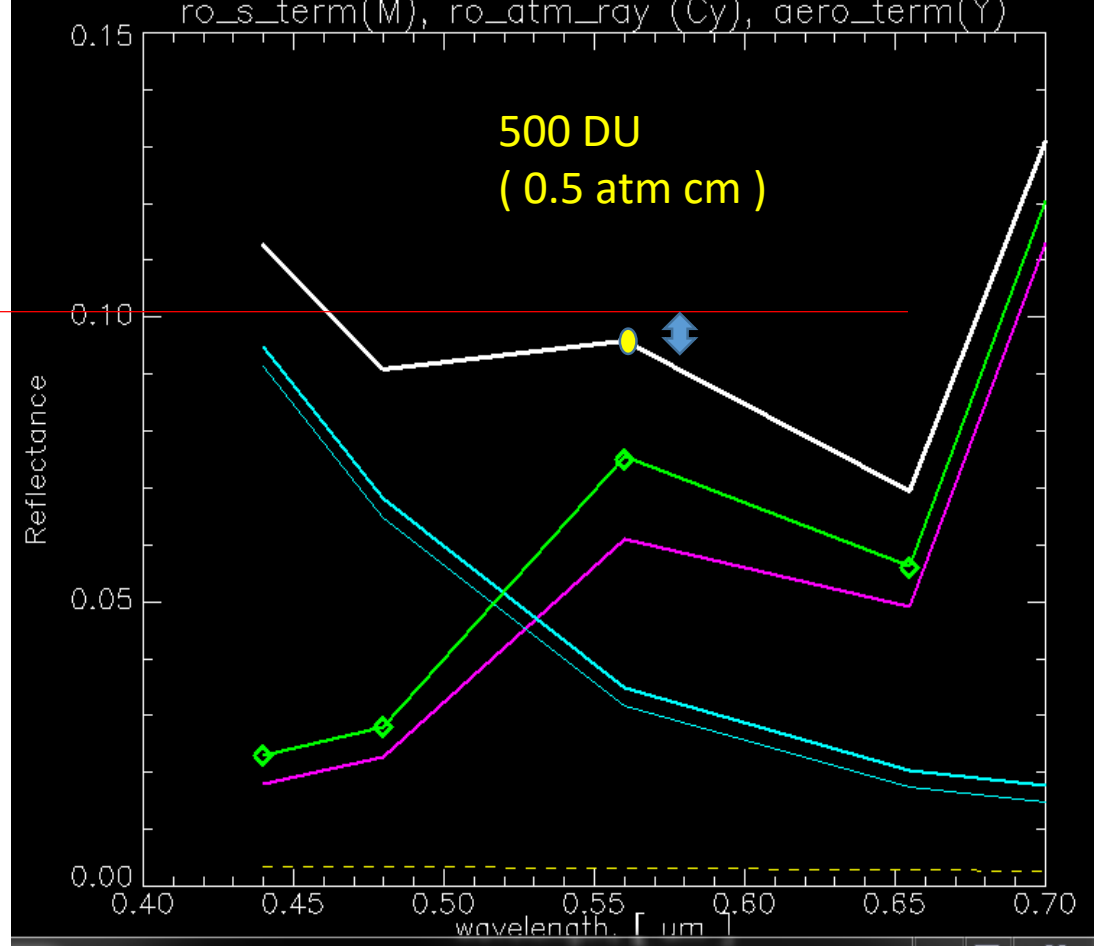


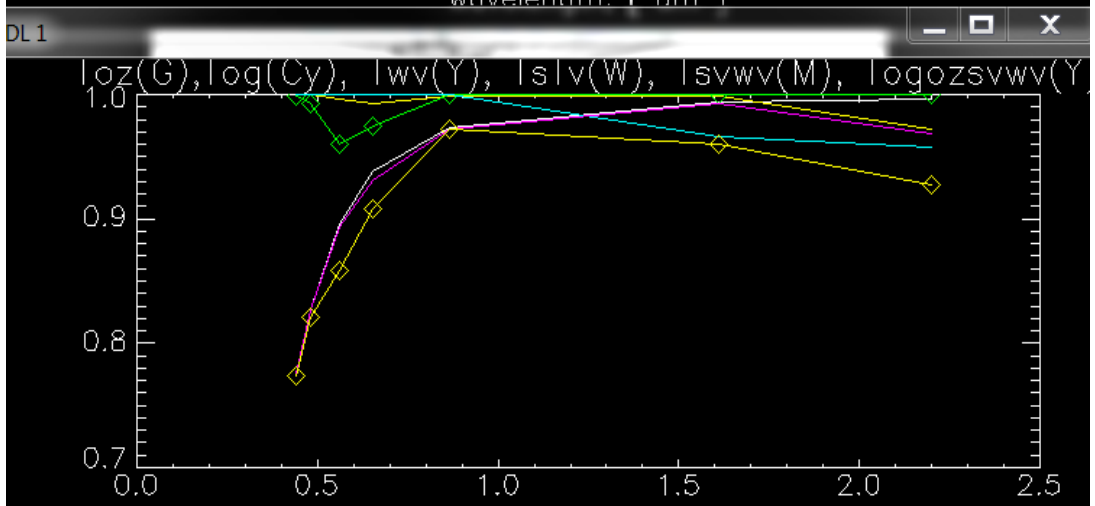
[cm atm]

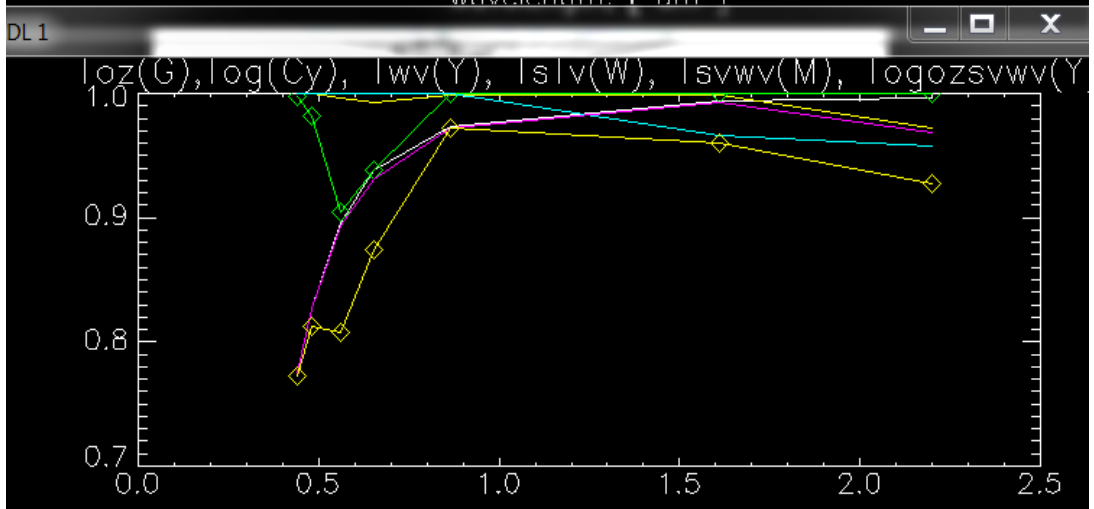

GSFC/
100 125 150 175 200 225 250 275 300 325 350 375 400 425 450 475 500
Dobson Units

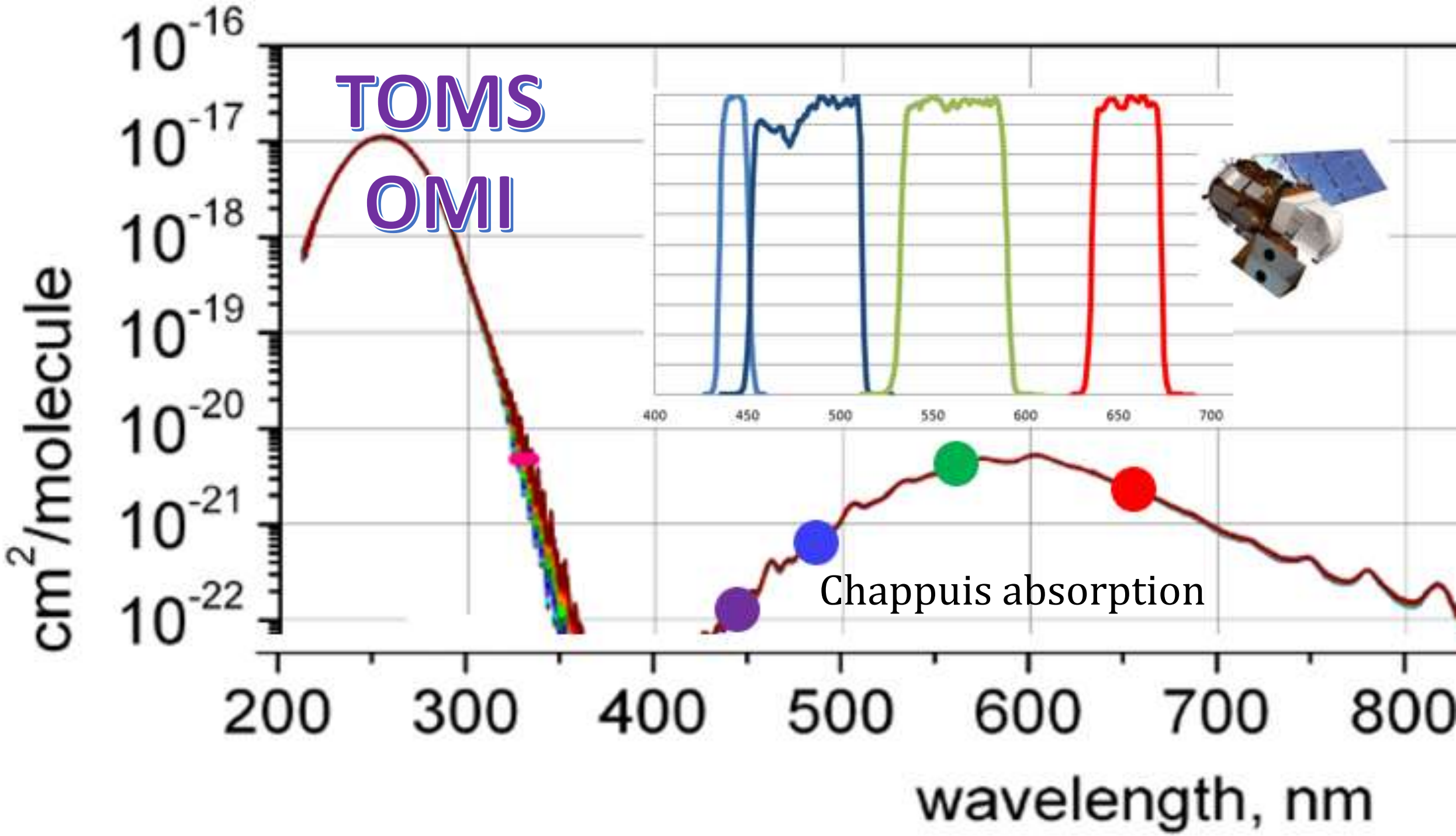

OMI total ozone
KNMI/NASA
Ozone density [Dobson Units]
150 175 200 225 250 275 300 325 350 375 400 425 450 475 500

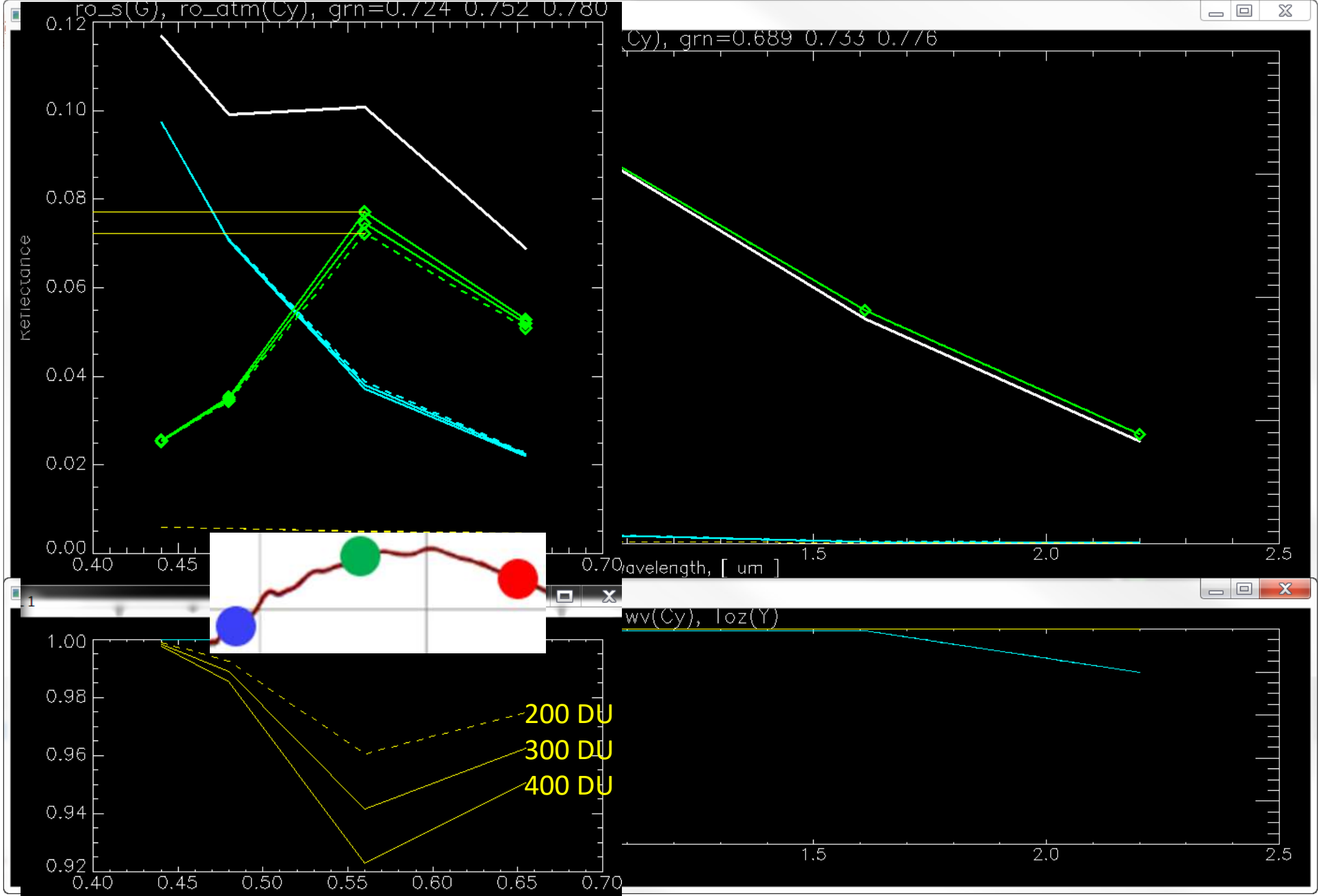

ro_s_term(M), ro_atm_ray (Cy), aero_term(Y)
200 DU
(0.2 atm cm)
Reflectance
0.15
0.10
0.05
0.00
0.40
0.45
0.50
0.55
0.60
0.65
0.70
wavelength [um]

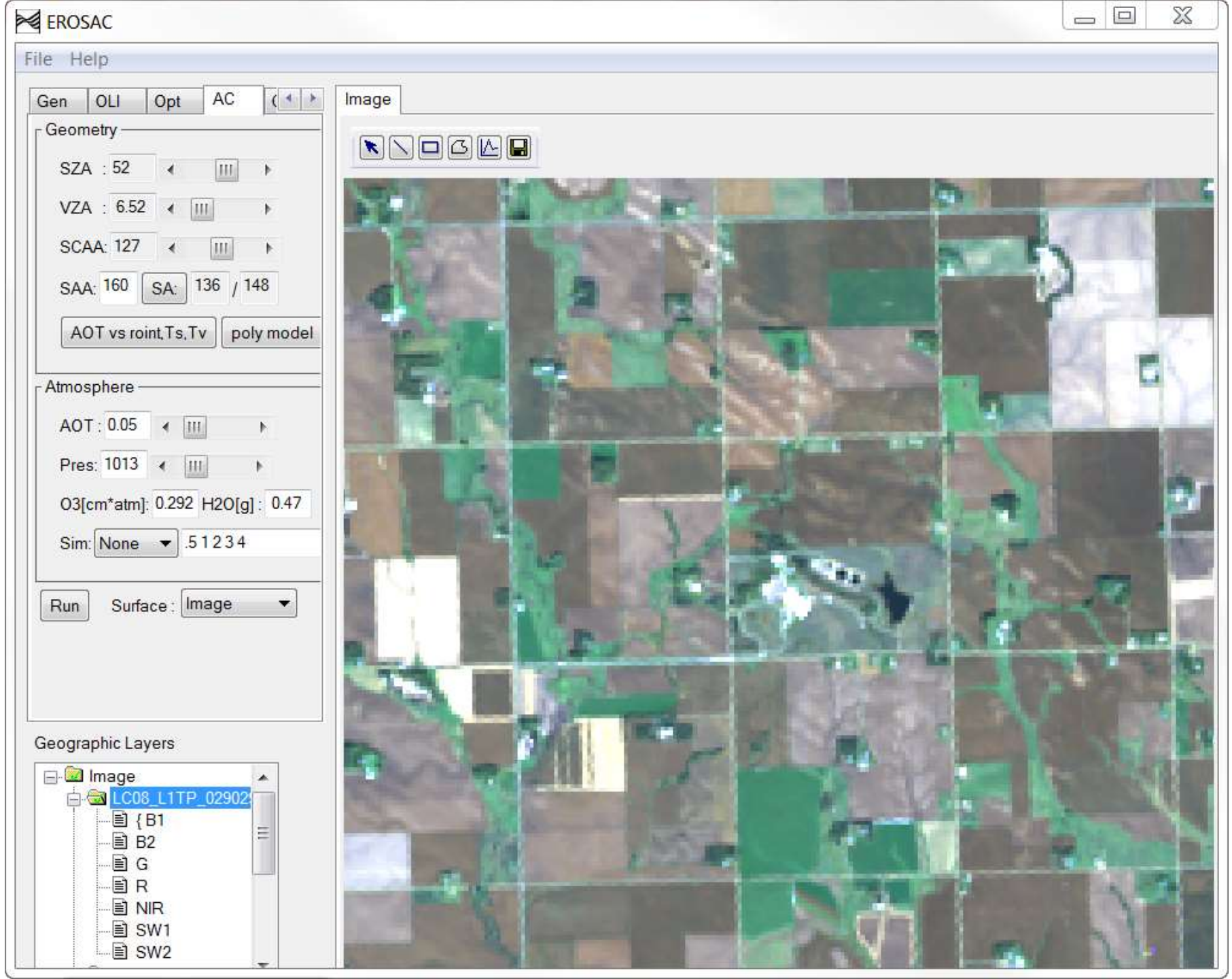

ro_s_term(M), ro_atm_ray (Cy), aero_term(Y)
500 DU
(0.5 atm cm)
Reflectance
0.15
0.10
0.05
0.00
0.40
0.45
0.50
0.55
0.60
0.65
0.70
wavelength [um]


DL 1
loz(G),log(Cy), lwv(Y), lslv(W), lsvwv(M), logozsvwv(Y
1.0
0.9
0.8
0.7
0.0
0.5
1.0
1.5
2.0
2.5

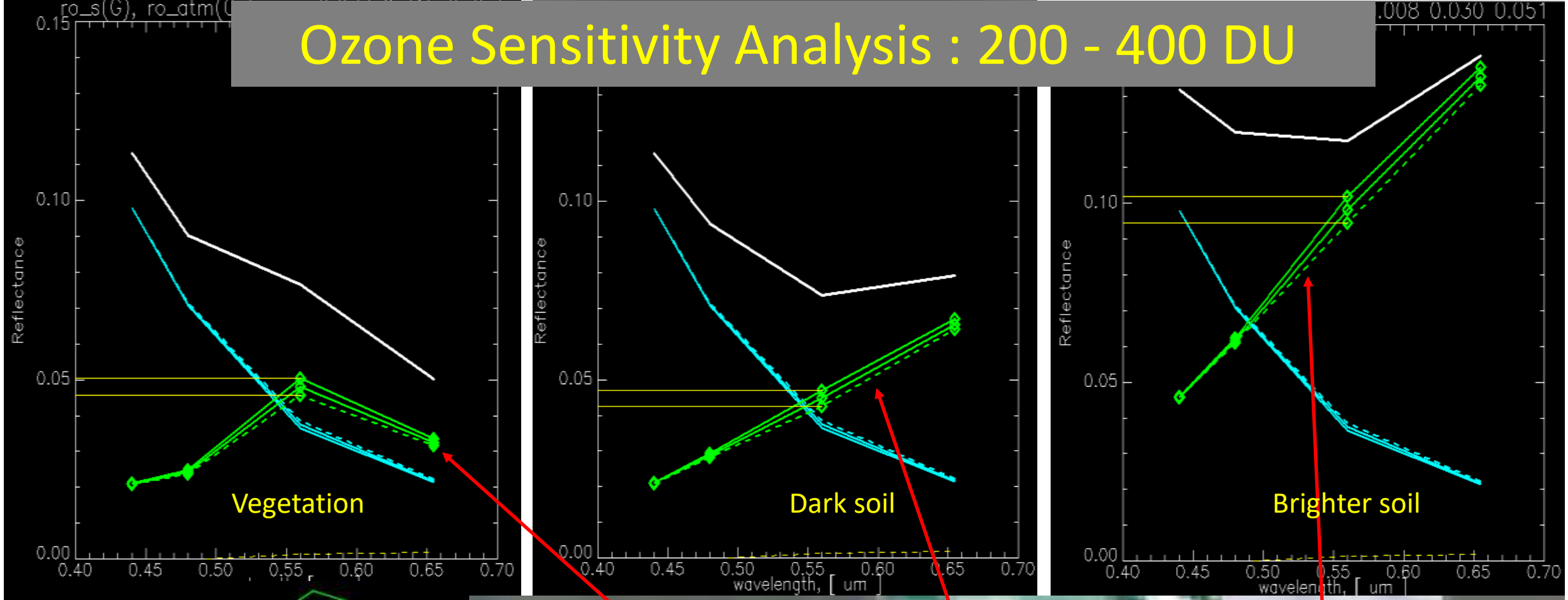

DL 1
loz(G),log(Cy), lwv(Y), lslv(W), lsvwv(M), logozsvwv(Y
1.0
0.9
0.8
0.7
0.0
0.5
1.0
1.5
2.0
2.5

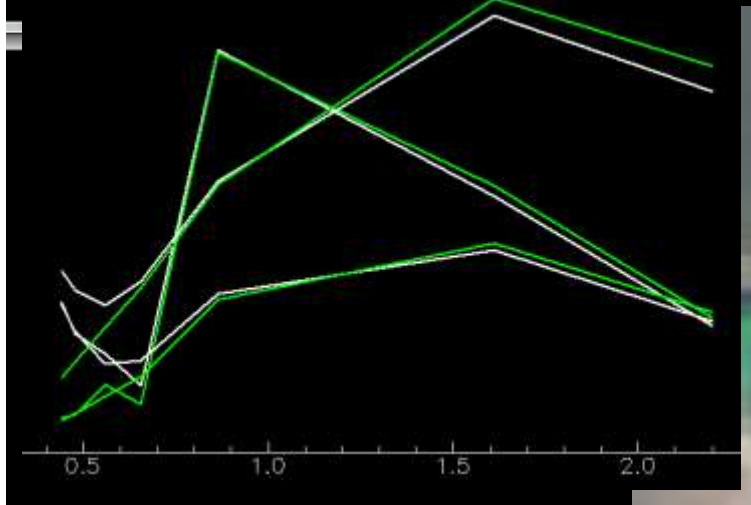

TOMS
OMI
Chappuis absorption
cm²/molecule
10-16
10-17
10-18
10-19
10-20
10-21
10-22
200
300
400
500
600
700
800
wavelength, nm
400
450
500
550
600
650
700

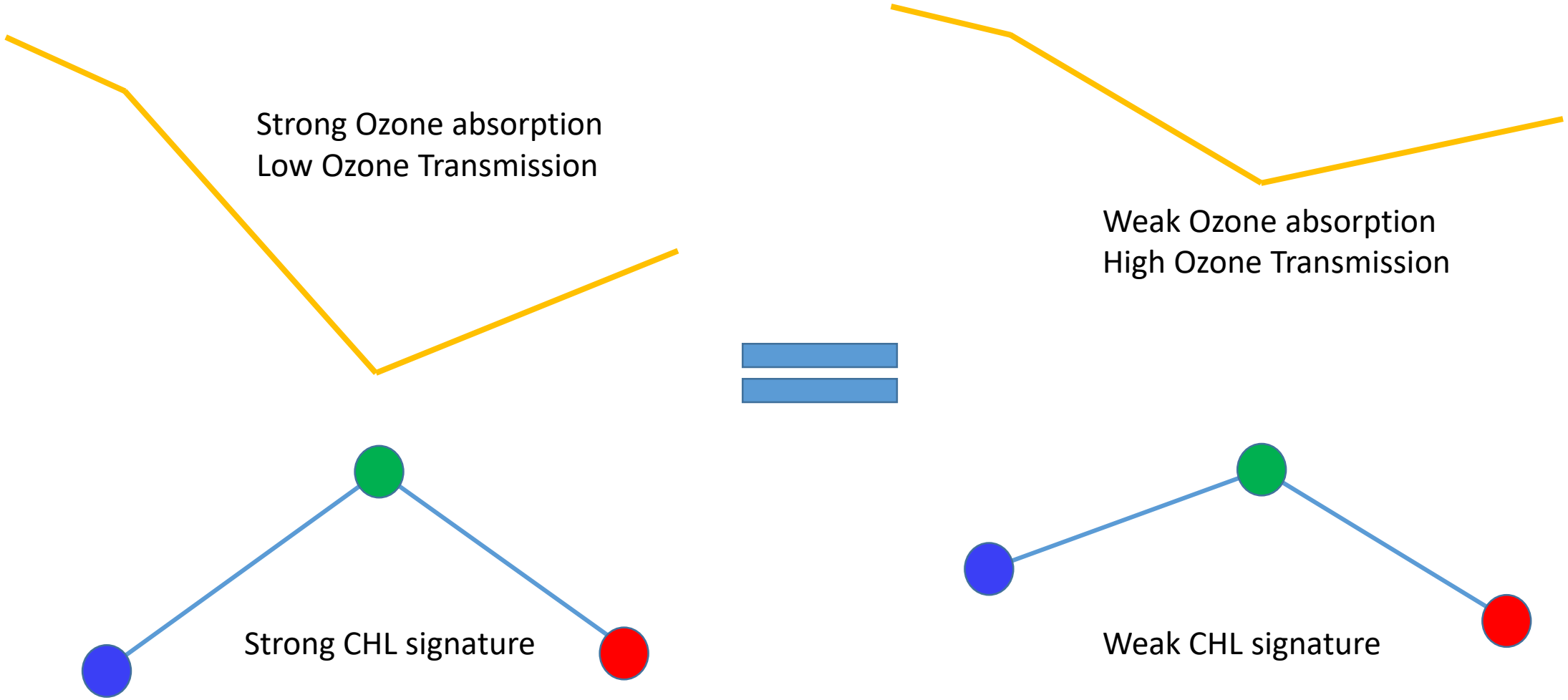

ro_s(G), ro_atm(Cy), grn=0.724 0.752 0.780
Cy), grn=0.689 0.733 0.776
Reflectance
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.40
0.45
0.70
1.5
2.0
2.5
avelength, [um]
wv(Cy), Toz(Y)
1.00
0.98
0.96
0.94
0.92
0.40
0.45
0.50
0.55
0.60
0.65
0.70
200 DU
300 DU
400 DU
1.5
2.0
2.5


EROSAC
File Help
Gen
OLI
Opt
AC
Image
Geometry
SZA : 52
VZA : 6.52
SCAA: 127
SAA: 160
SA: 136 / 148
AOT vs roint,Ts,Tv
poly model
Atmosphere
AOT : 0.05
Pres: 1013
O3[cm*atm]: 0.292
H2O[g] : 0.47
Sim: None
.5 1 2 3 4
Run
Surface : Image
Geographic Layers
Image
LC08_L1TP_02902
{ B1
B2
G
R
NIR
SW1
SW2

Ozone Sensitivity Analysis : 200 - 400 DU



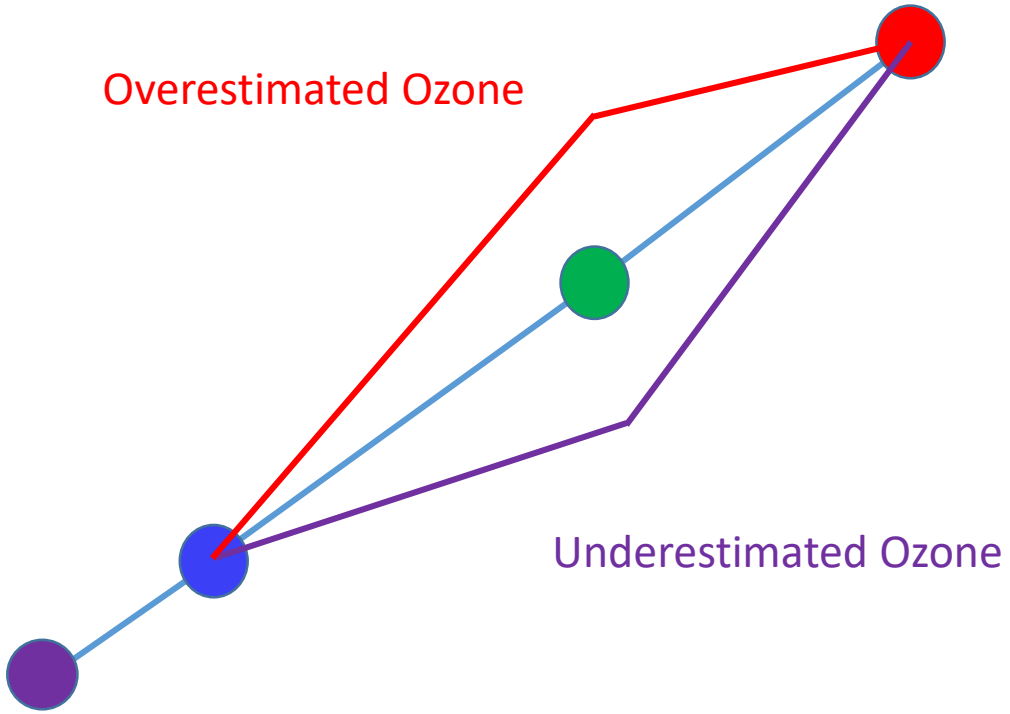




Varying vegetation signature strength (spatio-temporal)
& varying ozone amount mutually compensate!
No unique ozone solution ! → infinite solutions
Vegetation pixel is not useful for ozone inversion !

Sand (soil, road, asphalt, …) with **straight** spectral feature

➔ may provide a chance to estimate ozone!



4 known bands : B1, B2, G, R
2 unknowns : AOT, ozone

⬇

Non-liner optimization

⬇

Simultaneous solution of AOT & ozone

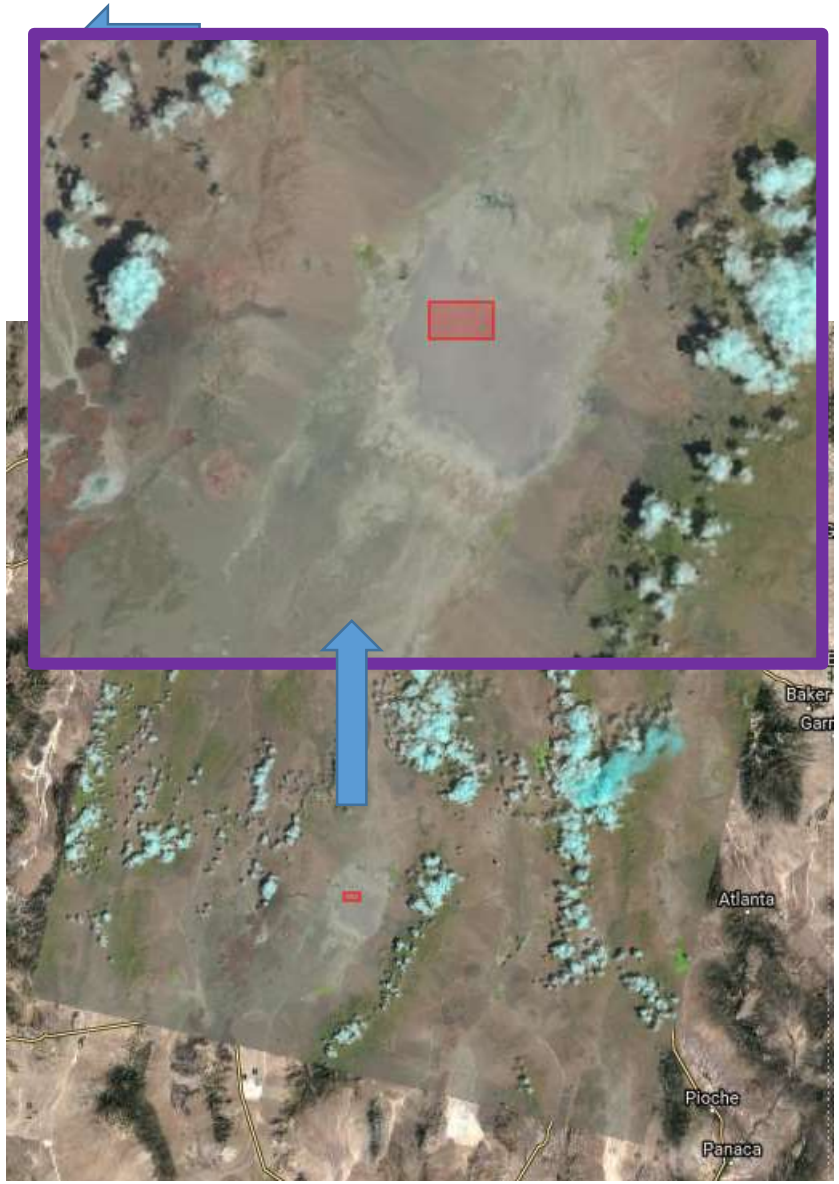
The question is :
Does a (sand, soil-like) spectra have a straight or constant universal spectral curvature ?

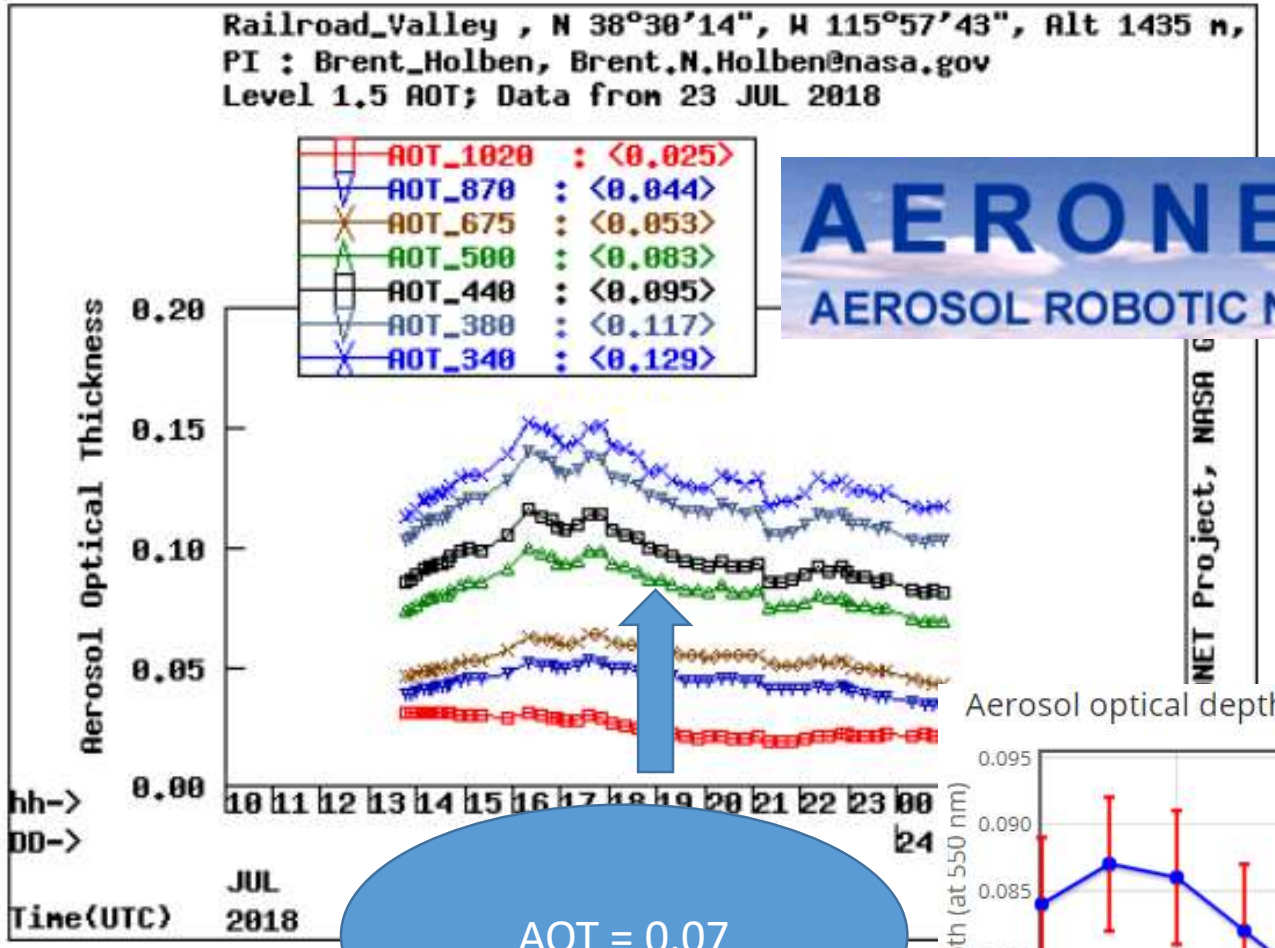
RadCalNet

Railroad Valley Playa

RadCalNet 2018

July 23, 2018

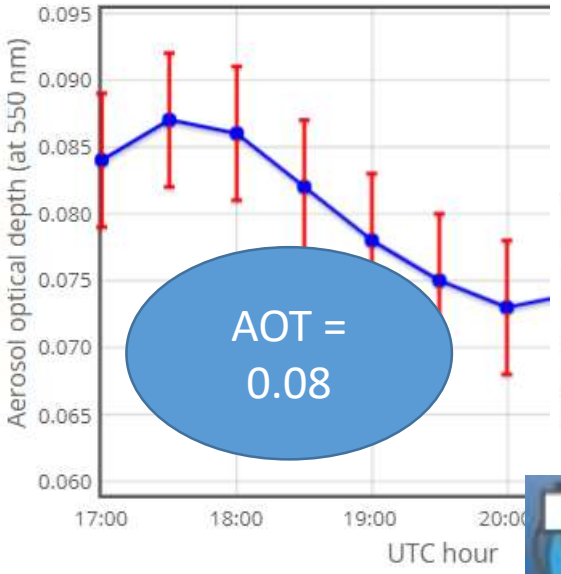




AOT = 0.07

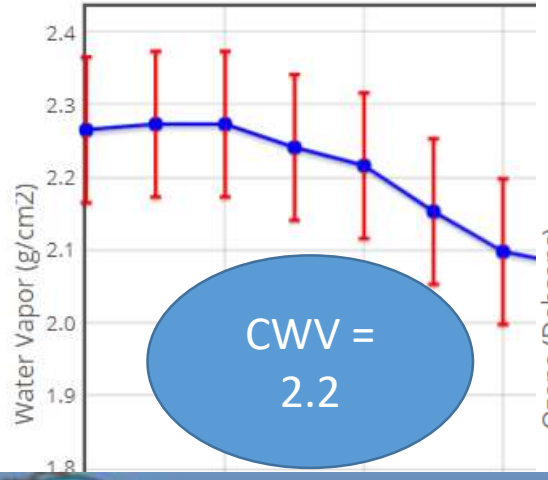
AERONET
AEROSOL ROBOTIC NETWORK

Aerosol optical depth at 550 nm



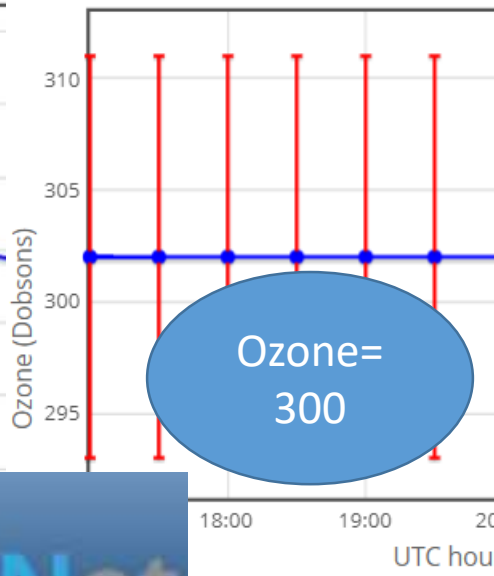
AOT = 0.08

Water vapor content



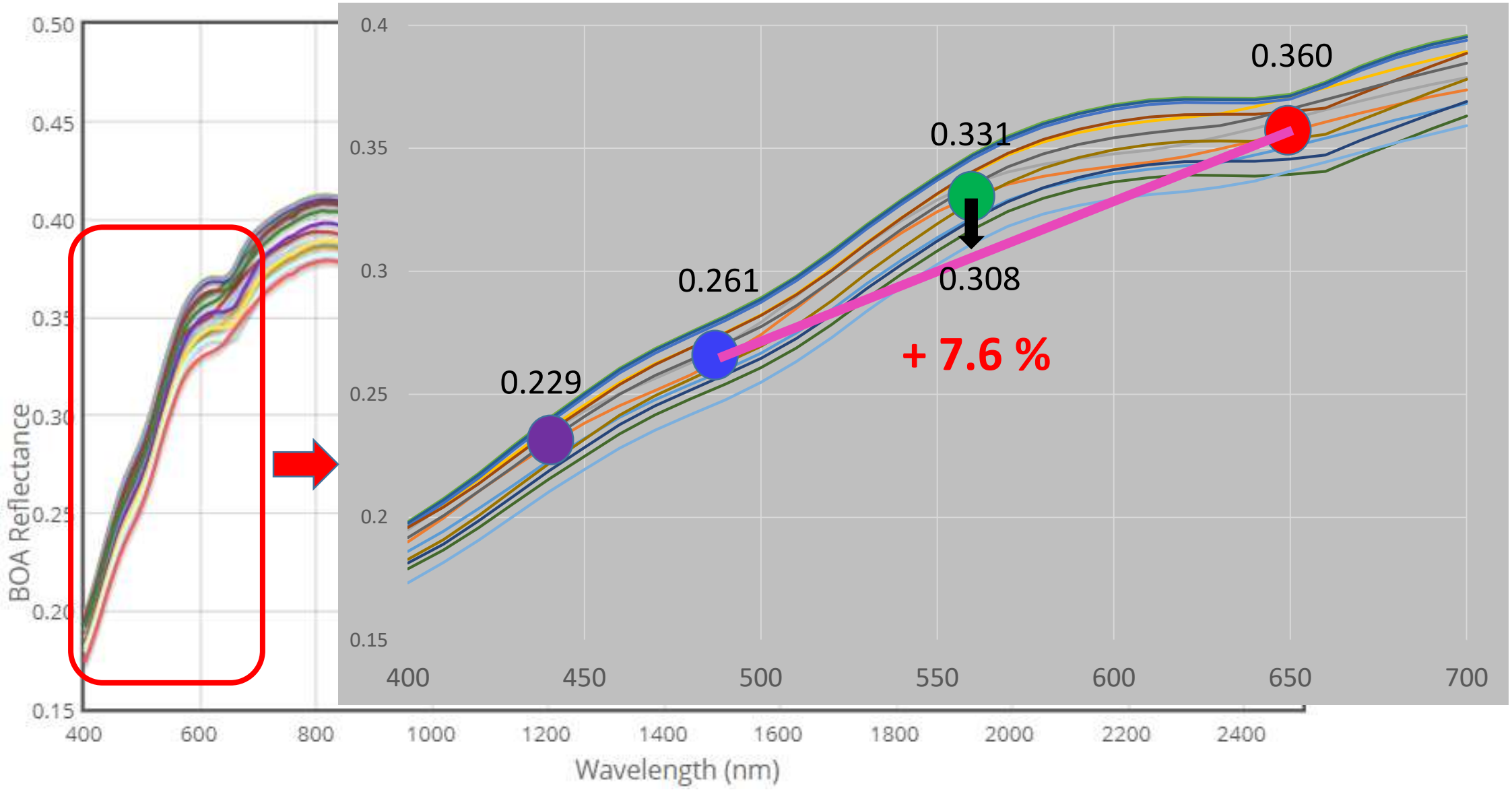
CWV = 2.2

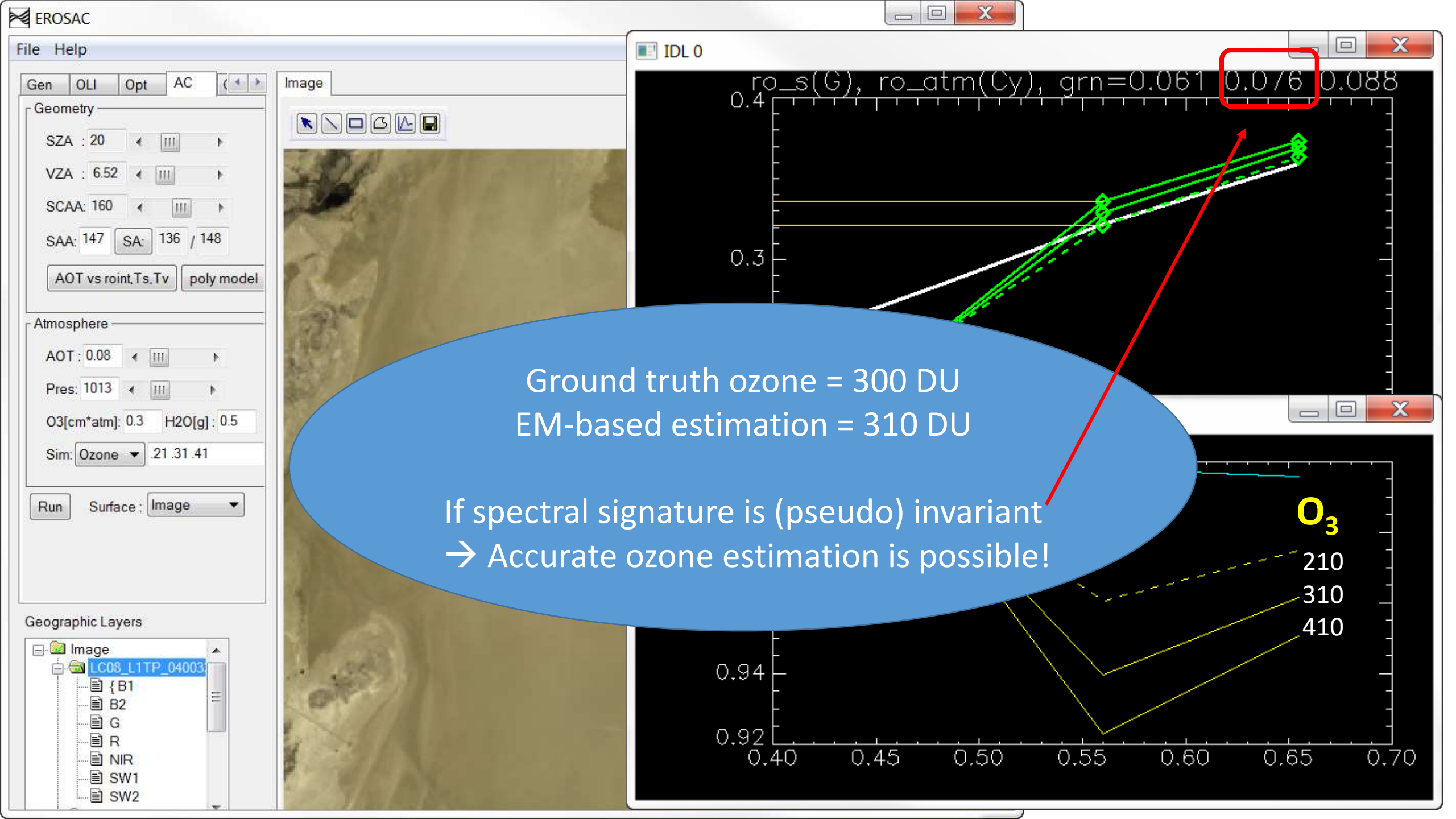
Ozone column



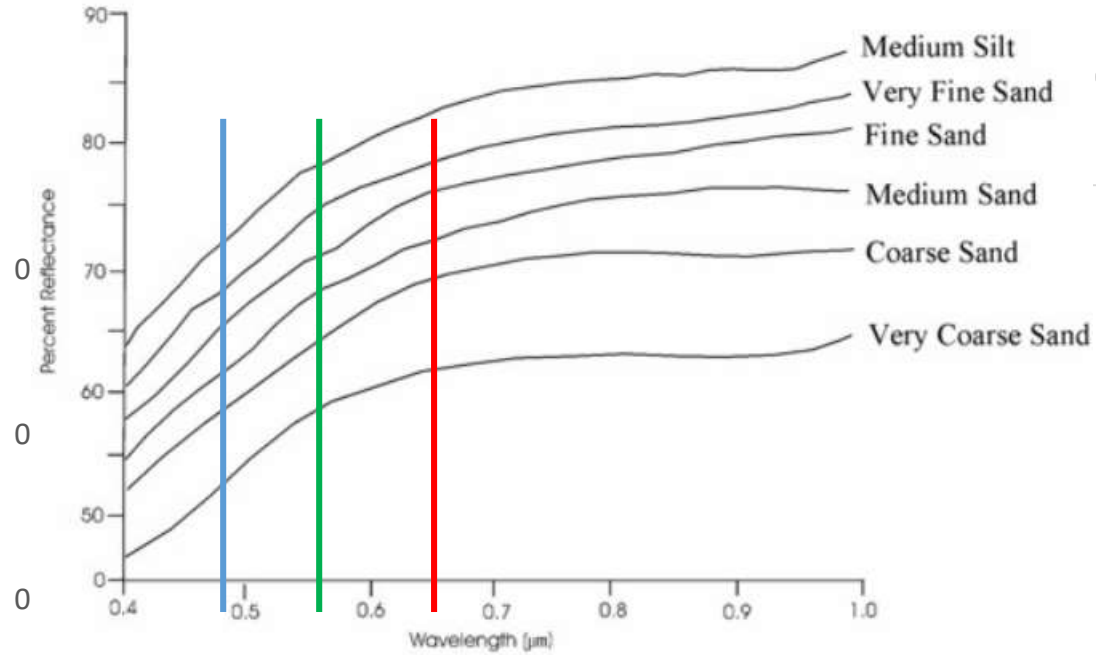
Ozone= 300

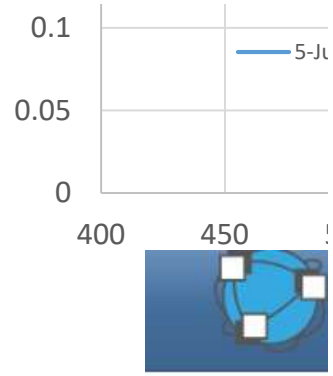
RadCalNet

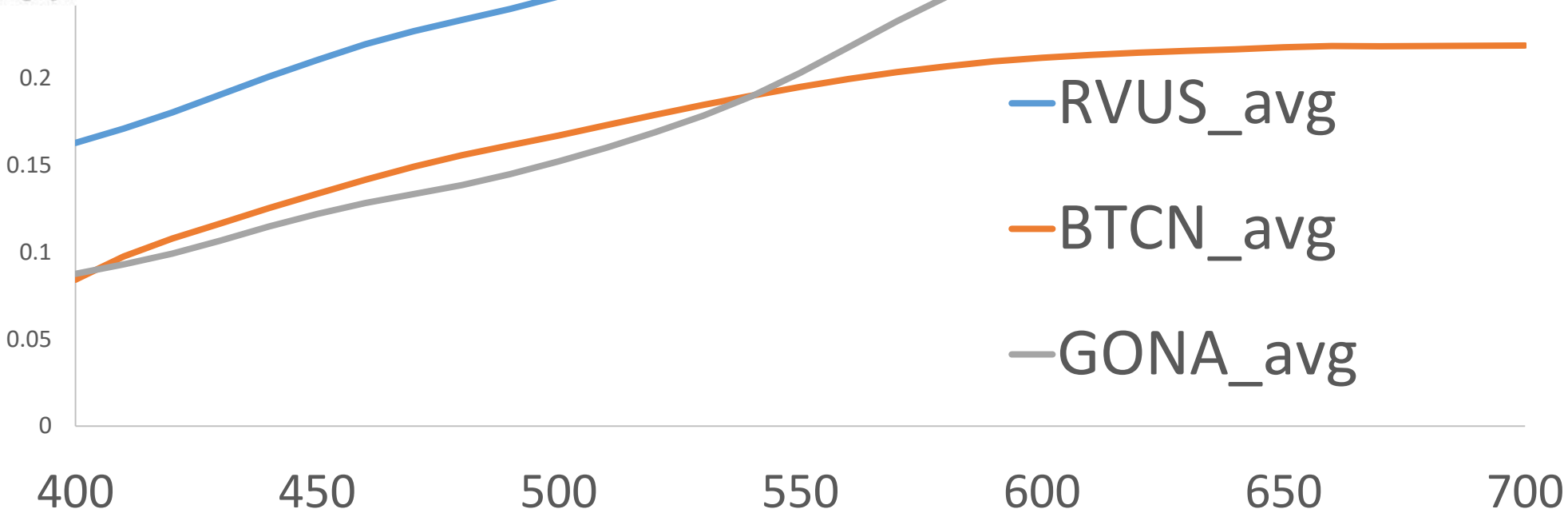

RadCalNet
BOA Reflectance
Wavelength (nm)
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
0.4
0.35
0.3
0.25
0.2
0.15
400
450
500
550
600
650
700
0.229
0.261
0.331
0.308
0.360
+ 7.6 %


EROSAC
File Help
Gen OLI Opt AC
Geometry
SZA : 20
VZA : 6.52
SCAA: 160
SAA: 147 SA: 136 / 148
AOT vs roint,Ts,Tv
poly model
Atmosphere
AOT : 0.08
Pres: 1013
O3[cm*atm]: 0.3 H2O[g] : 0.5
Sim: Ozone .21 .31 .41
Run Surface : Image
Geographic Layers
Image
LC08_L1TP_04003
B1
B2
G
R
NIR
SW1
SW2
Image
IDL 0
ro_s(G), ro_atm(Cy), grn=0.061 0.076 0.088
0.4
0.3
0.94
0.92
0.40 0.45 0.50 0.55 0.60 0.65 0.70
O3
210
310
410
Ground truth ozone = 300 DU
EM-based estimation = 310 DU
If spectral signature is (pseudo) invariant
→ Accurate ozone estimation is possible!

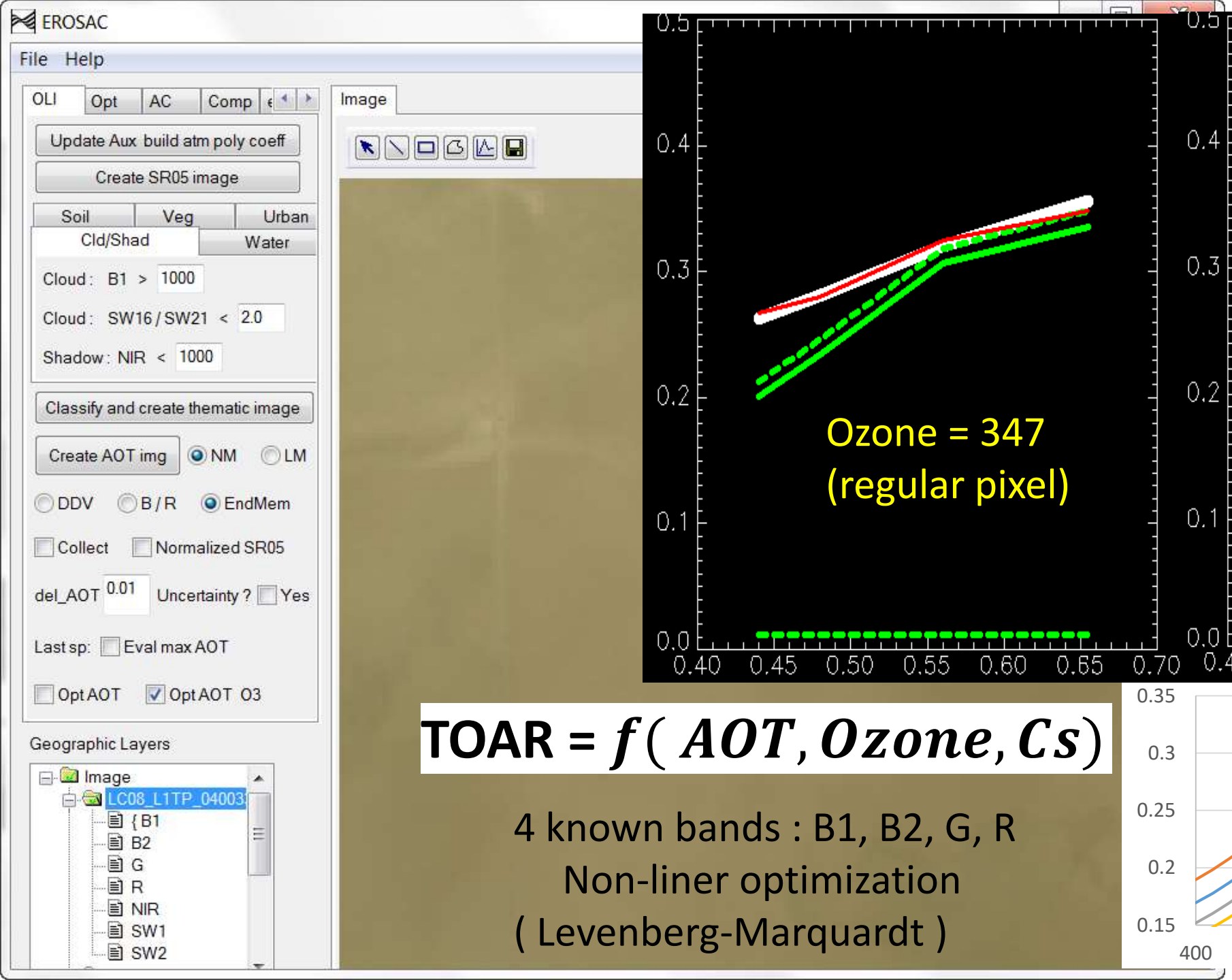
e Reflectance

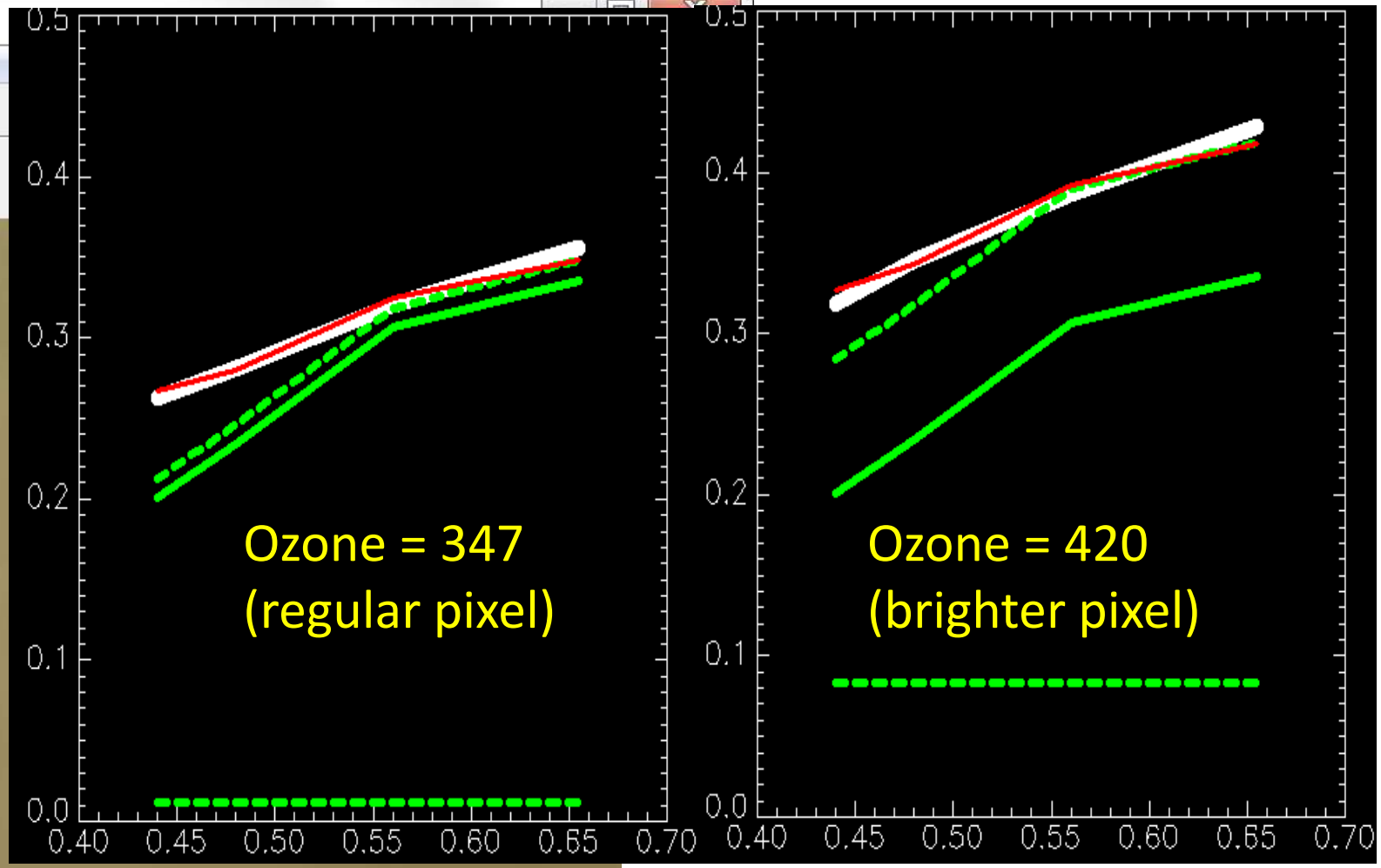






Railro



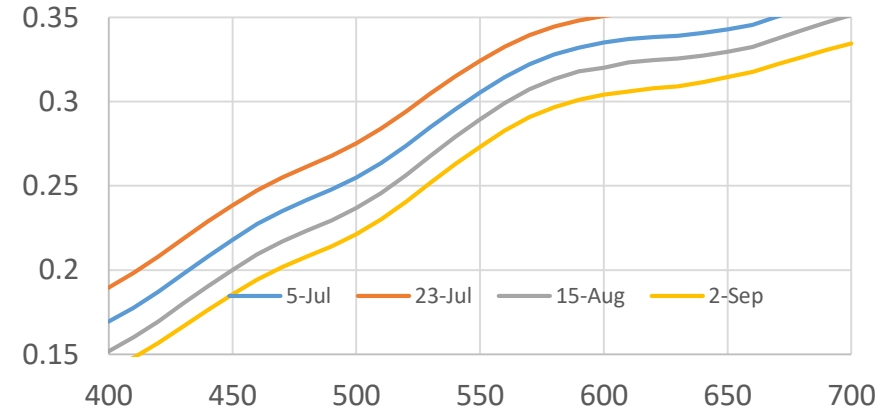


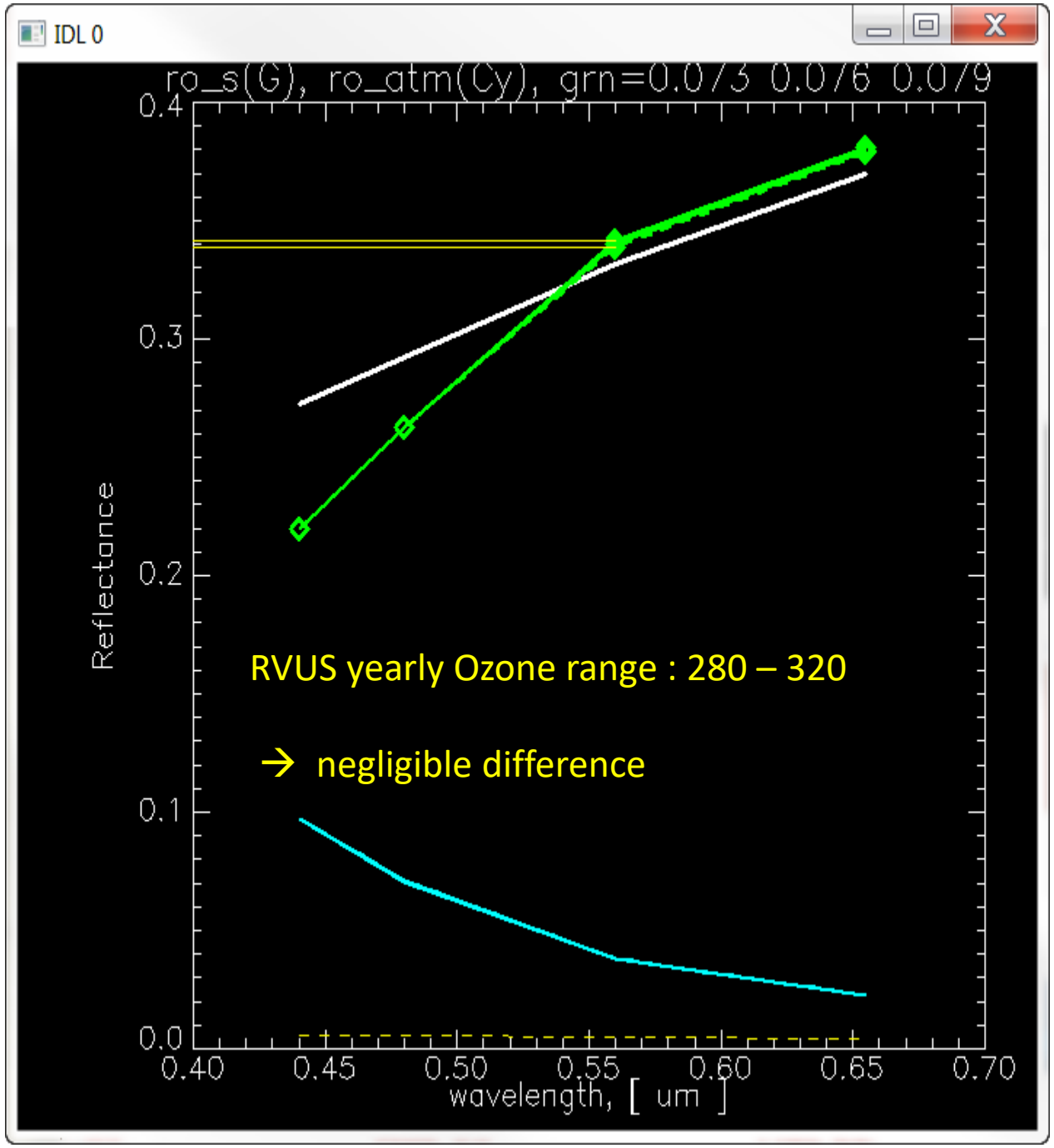
$$\text{TOAR} = f(\,AOT, Ozone, Cs)$$

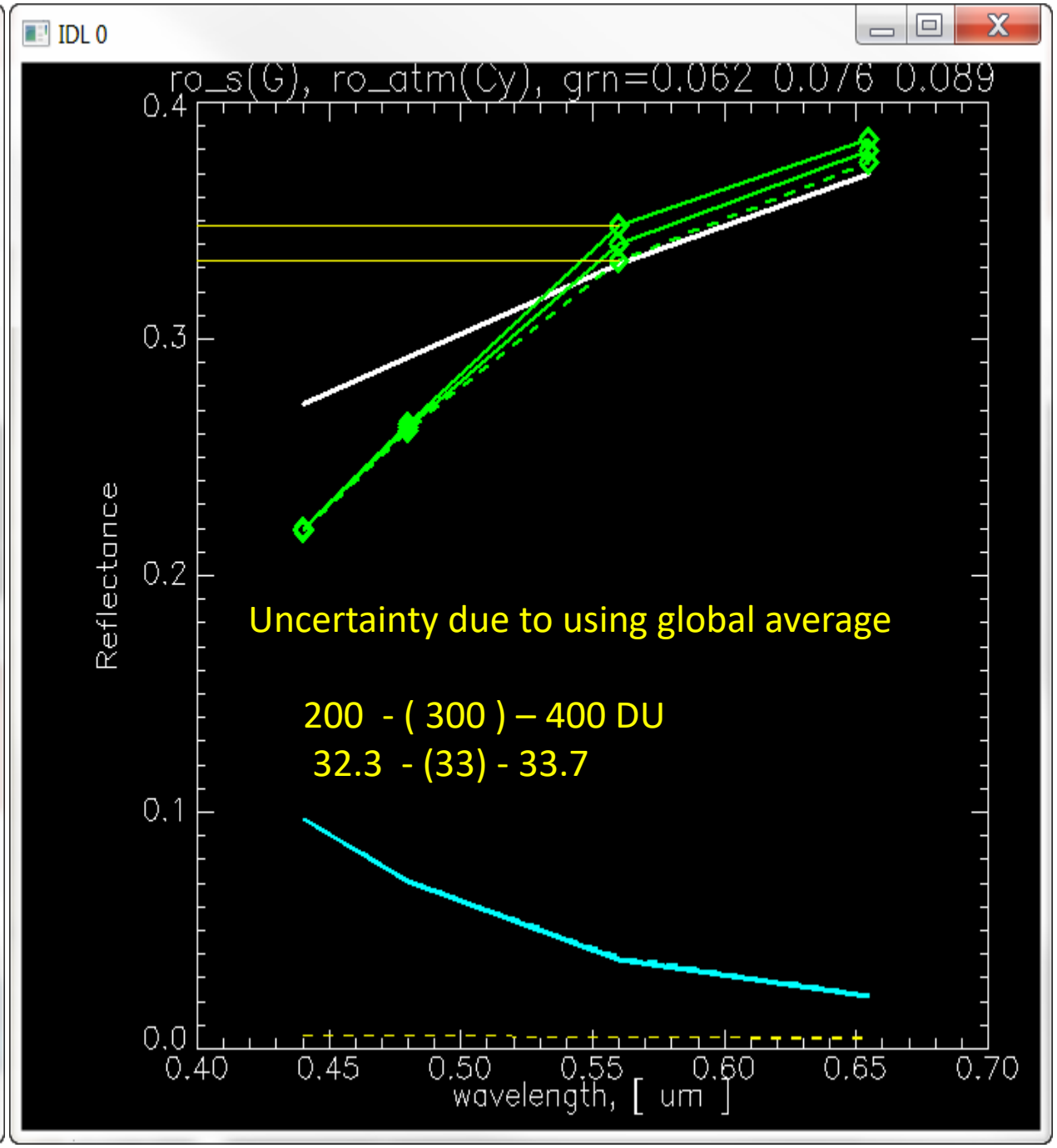
4 known bands : B1, B2, G, R

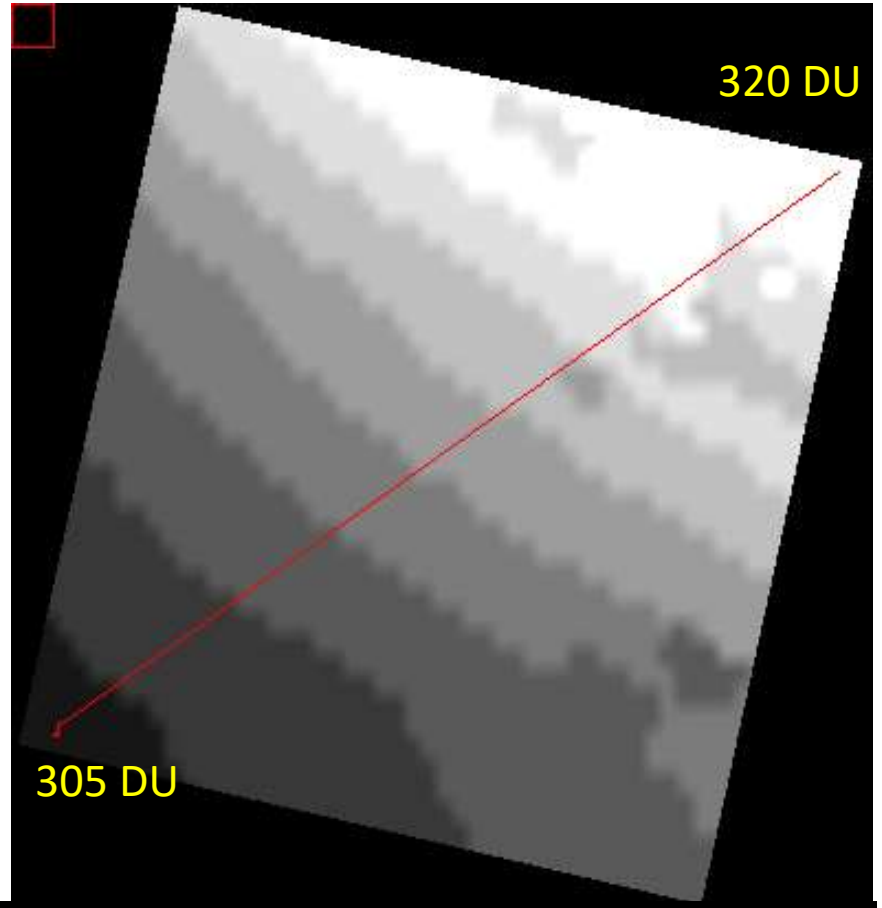
Non-liner optimization

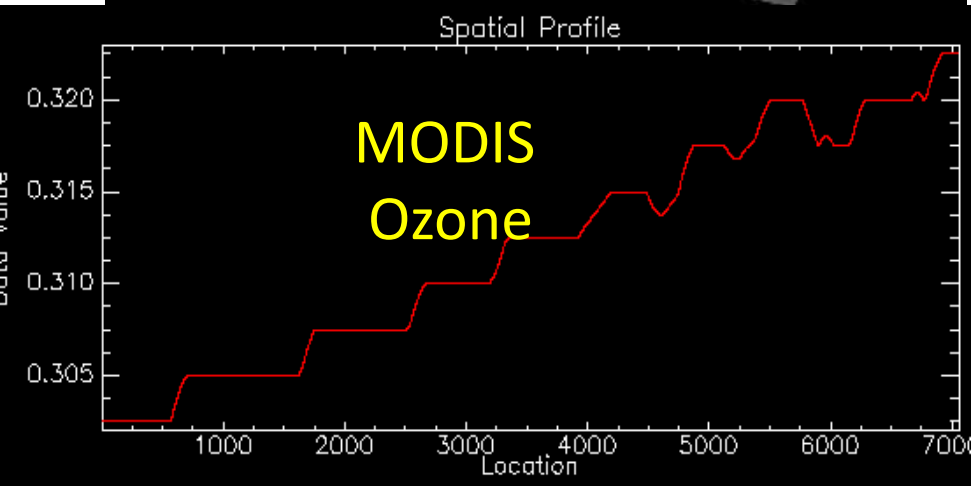
(Levenberg-Marquardt)

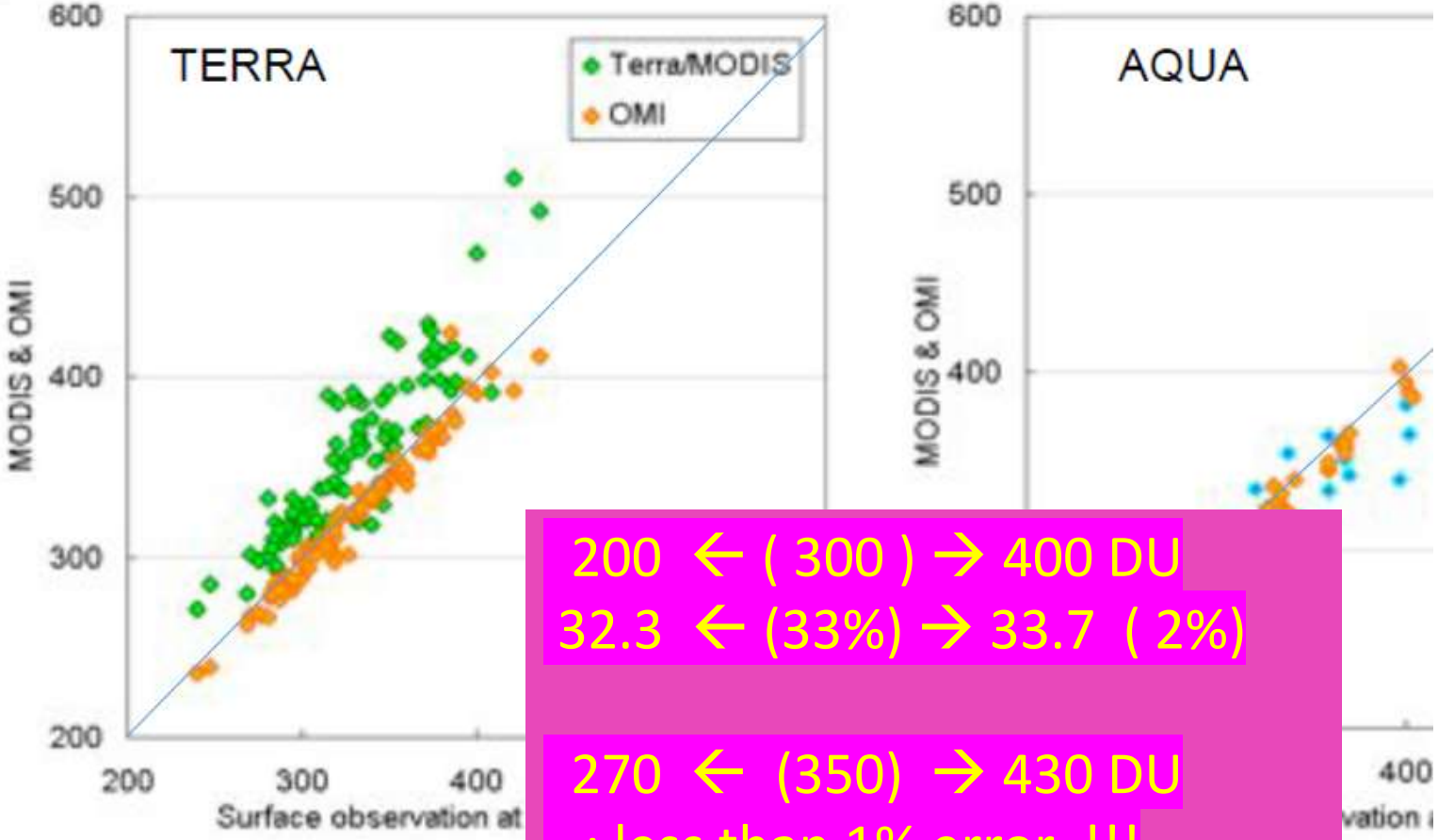



IDL 0
ro_s(G), ro_atm(Cy), grn=0.073 0.076 0.079
Reflectance
0.0
0.1
0.2
0.3
0.4
0.40
0.45
0.50
0.55
0.60
0.65
0.70
wavelength, [um]
RVUS yearly Ozone range : 280 – 320
→ negligible difference


IDL 0
ro_s(G), ro_atm(Cy), grn=0.062 0.076 0.089
Reflectance
0.0
0.1
0.2
0.3
0.4
0.40
0.45
0.50
0.55
0.60
0.65
0.70
wavelength, [um]
Uncertainty due to using global average
200 - (300) – 400 DU
32.3 - (33) - 33.7







200 ← (300) → 400 DU
32.3 ← (33%) → 33.7 (2%)

270 ← (350) → 430 DU
: less than 1% error !!!

Status of the MOD07 atmospheric profile algorithm

Éva E. Borbás[1], Suzanne W. Seemann[1], W. Paul Menzel[1], Anikó Kern[2], K. Strabala[1] and L. Moy[1]

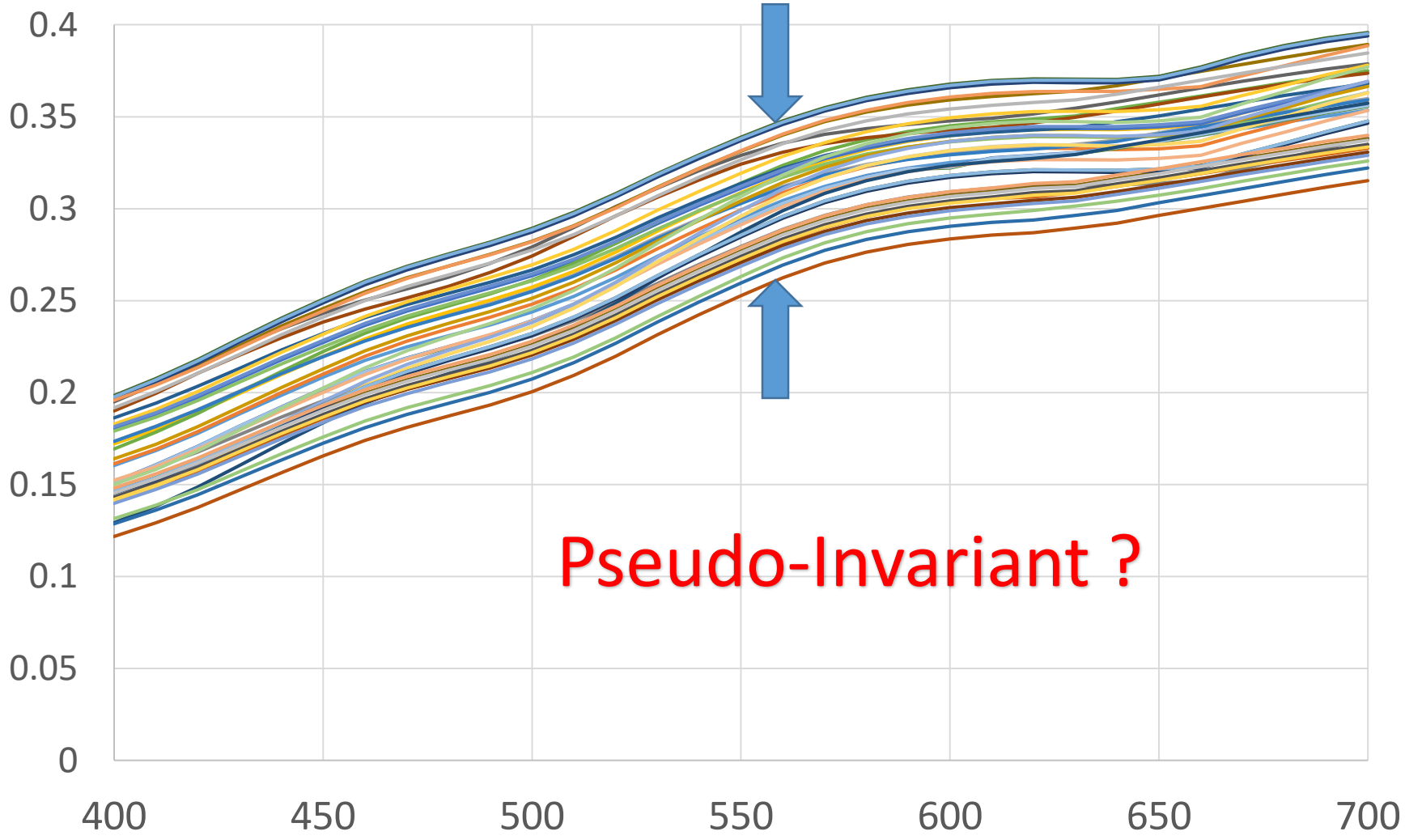
Final Uncertainty Associated with RadCalNet Data

Channel Wavelength (nm)	C1 400	C2 450	C3 500	C4 550	C5 650	C6 850	C7 1000	C8 1550
Combined uncertainty associated with BOA reflectance from GVR	3.5%	3.4%	3.4%	3.3%	3.2%	3.3%	3.2%	3.2%
Uncertainty associated with picking the spectrum	4.0%	3.1%	2.6%	2.2%	2.0%	1.8%	1.8%	1.7%
Combined uncertainty associated with BOA RadCalNet product	5.3%	4.6%	4.3%	4.0%	3.8%	3.8%	3.7%	3.6%

T2-UncertaintySummaryReport-RVUS.pdf

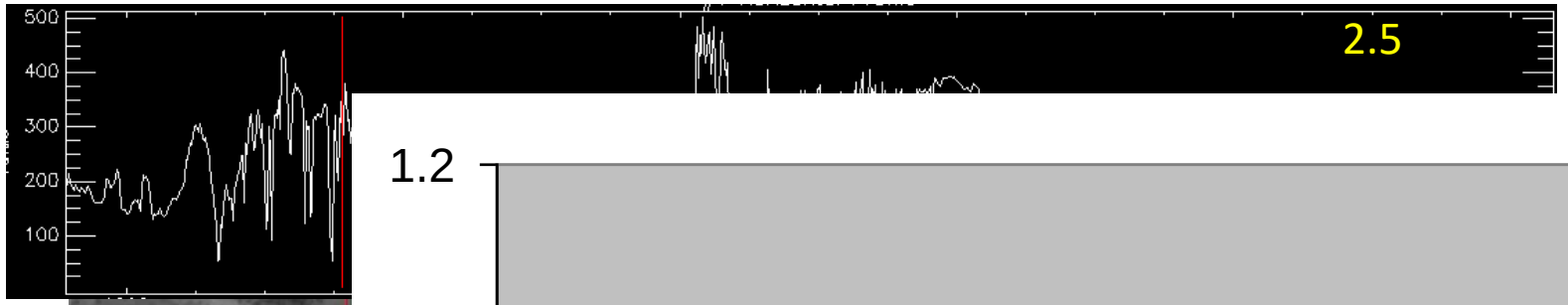
BOA Reflectance (Railroad Valley Playa)

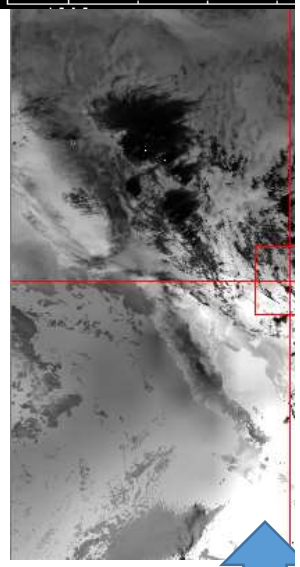
(Intra-day & daily variation combined)

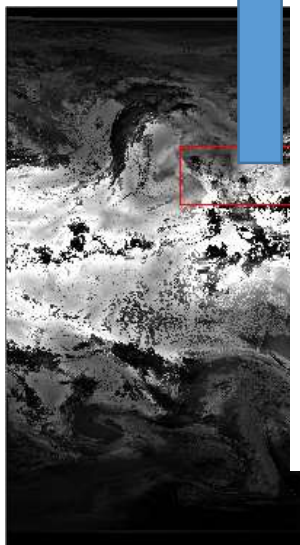


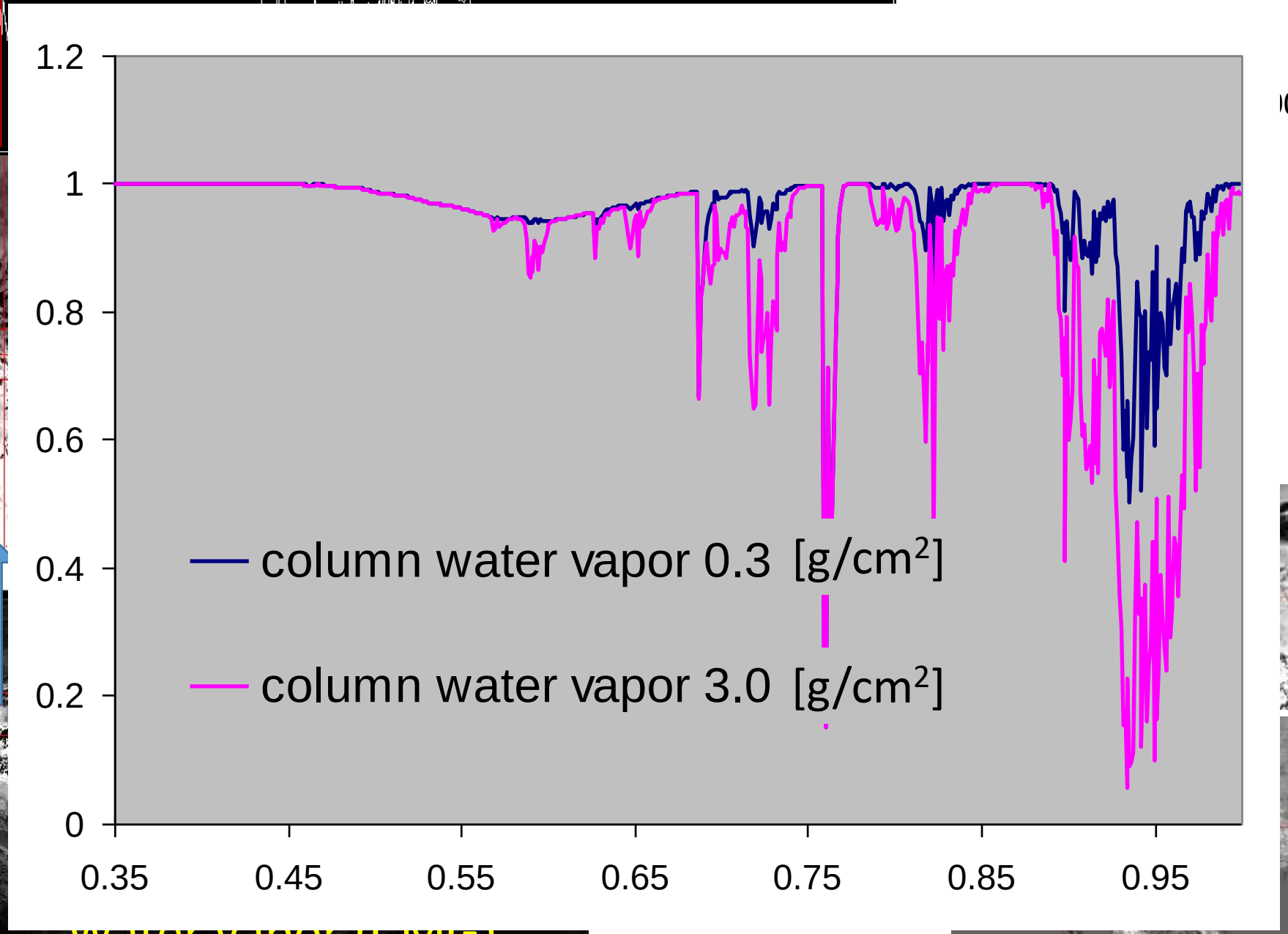
Summary : Ozone mitigation

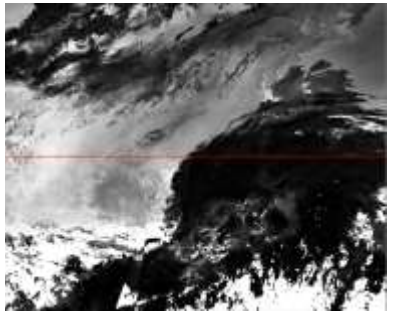
(1) Sand-like EM-based approach allows ozone estimation
(2) Unique spectral curvature does not exist (only site specific PI)
(3) Blind use of global average (300-350 DU) creates
acceptable error (~ 1% relative error)
(4) Considering TOA & BOA measurement uncertainty (~4-5%)
1% relative reflectance error is definitely acceptable!
(5) No worry, there always will be ozone satellite!

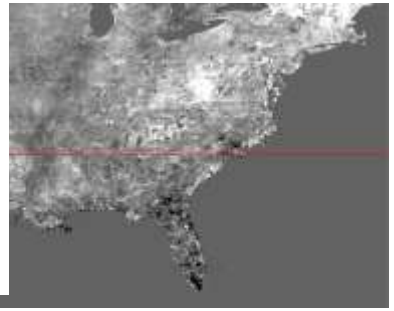

500
400
300
200
100
2.5

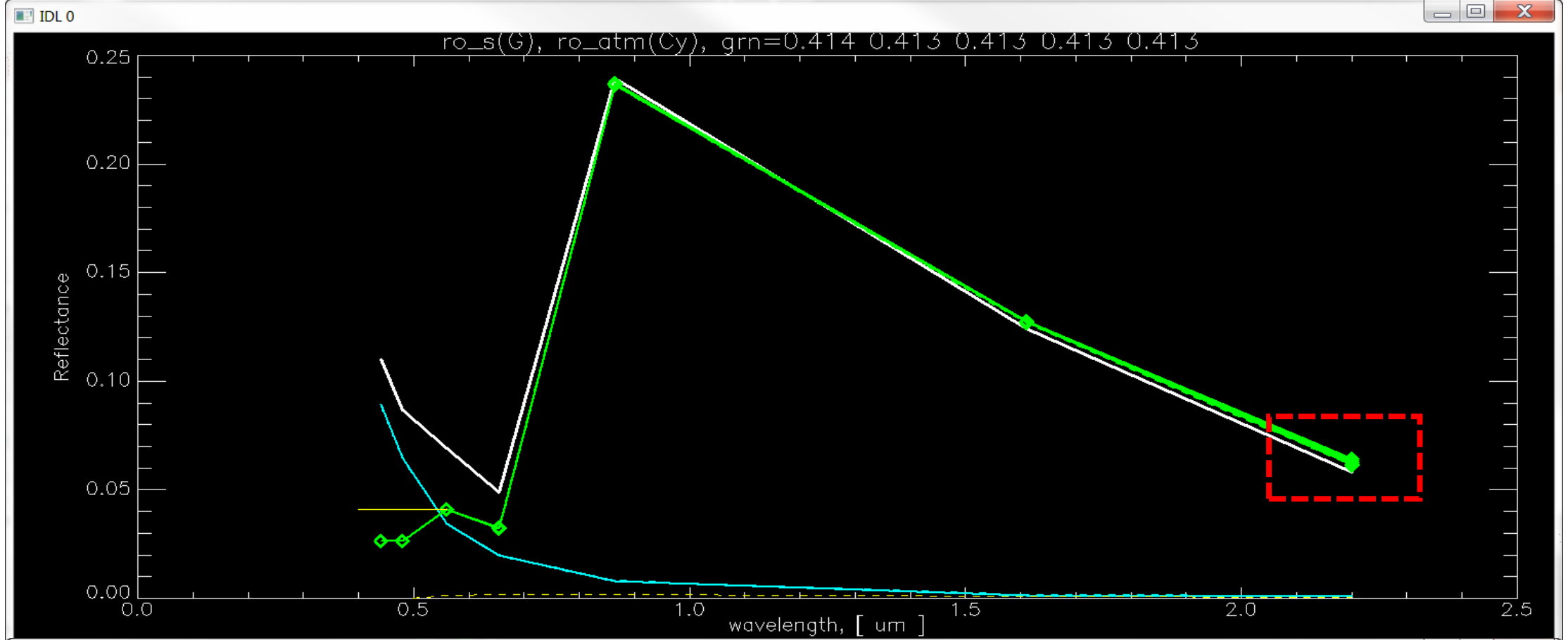


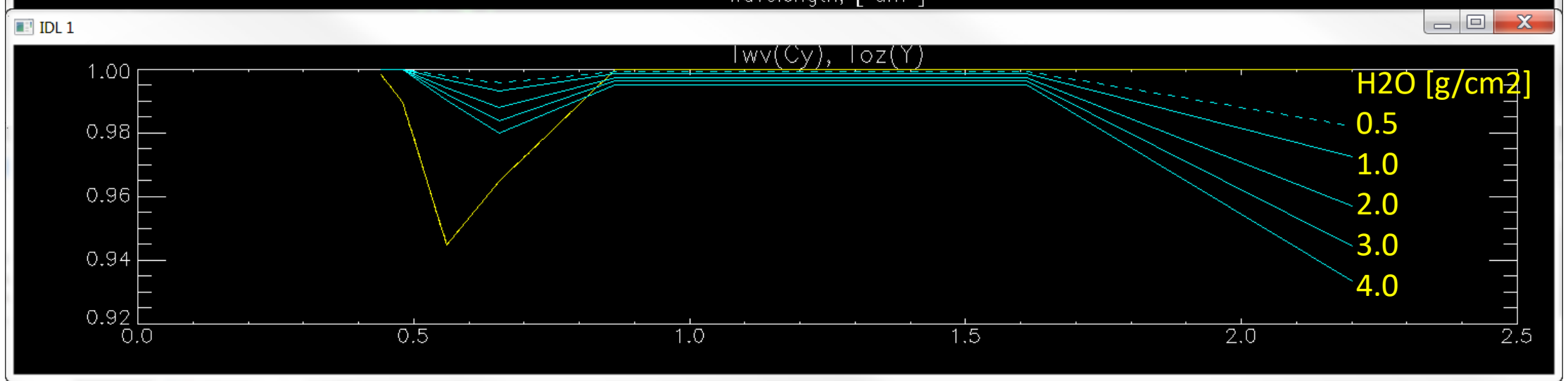


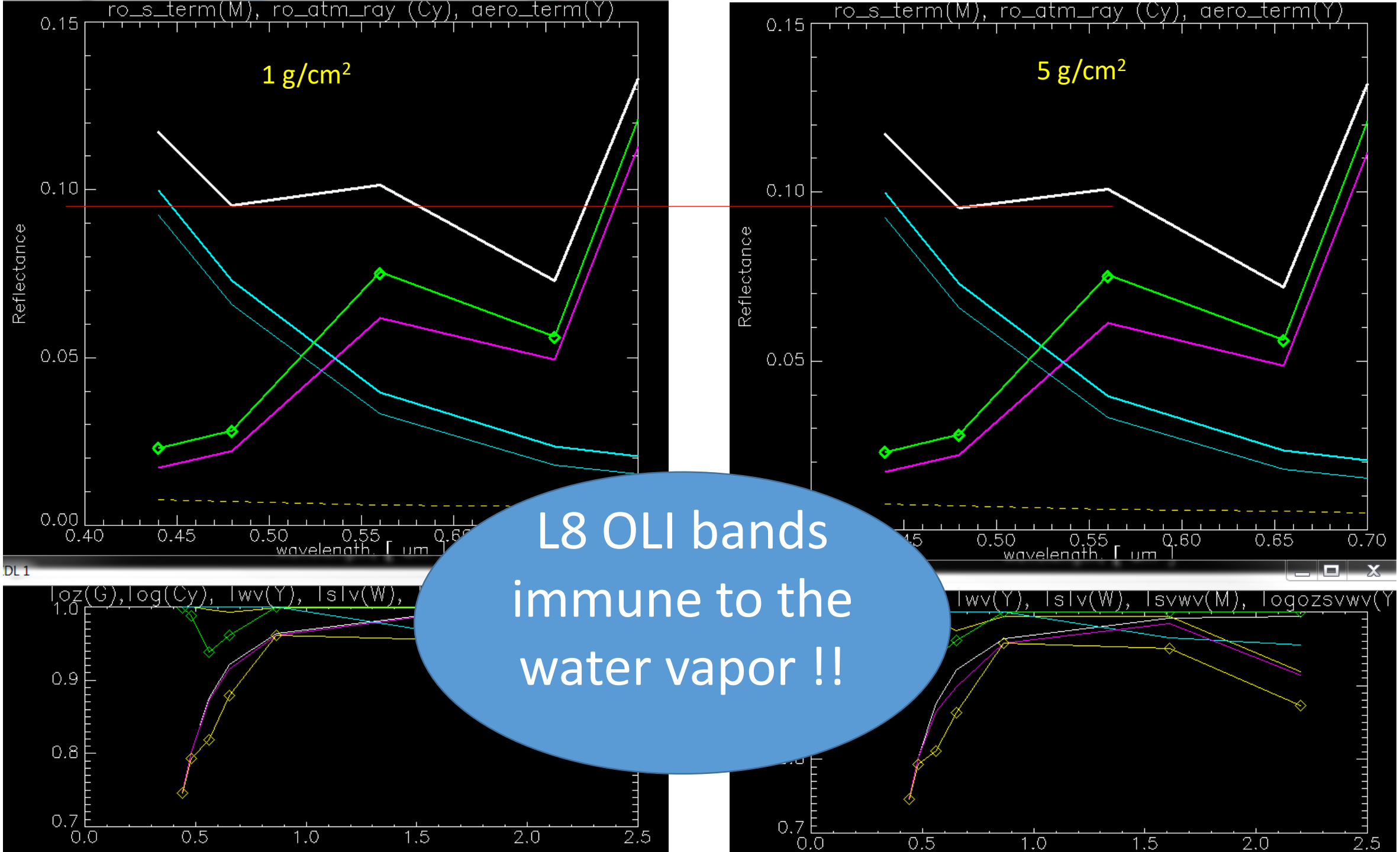

1.2
1
0.8
0.6
0.4
0.2
0
0.35
0.45
0.55
0.65
0.75
0.85
0.95
column water vapor 0.3 [g/cm²]
column water vapor 3.0 [g/cm²]



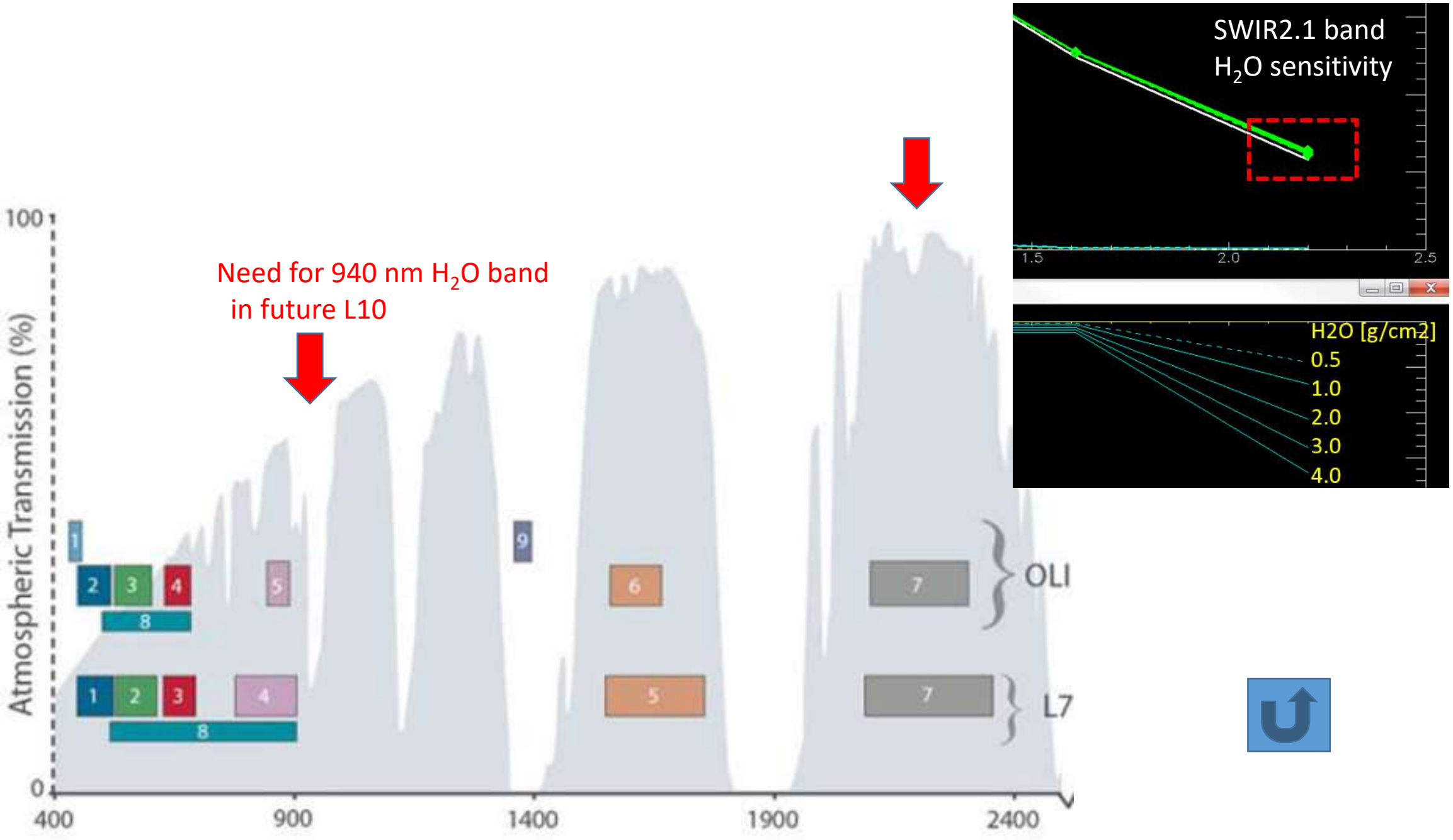



IDL 0
ro_s(G), ro_atm(Cy), grn=0.414 0.413 0.413 0.413 0.413
Reflectance
0.25
0.20
0.15
0.10
0.05
0.00
0.0
0.5
1.0
1.5
2.0
2.5
wavelength, [um]


IDL 1
Twv(Cy), Toz(Y)
1.00
0.98
0.96
0.94
0.92
0.0
0.5
1.0
1.5
2.0
2.5
H2O [g/cm2]
0.5
1.0
2.0
3.0
4.0



L8 OLI bands immune to the water vapor !!


Need for 940 nm H_2O band in future L10
Atmospheric Transmission (%)
100
0
400
900
1400
1900
2400
1
2
3
4
5
6
7
8
9
OLI
L7
SWIR2.1 band
H_2O sensitivity
1.5
2.0
2.5
H2O [g/cm2]
0.5
1.0
2.0
3.0
4.0