Characterization of Deep Convective Clouds as Absolute Calibration Targets for Visible Sensors

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Daniel Morstad[a], David Doelling[b], Benjamin Scarino[a], Rajendra Bhatt[a], Arun Gopalan[a],
[a]SSAI, One Enterprise Pkwy Ste 200, Hampton, VA 23666 USA
[b]NASA Langley Research Center, 21 Langley Blvd MS 420, Hampton, VA 23681-2199 USA

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Inter-calibration and Validation of Operational Sensors -- Oral Session

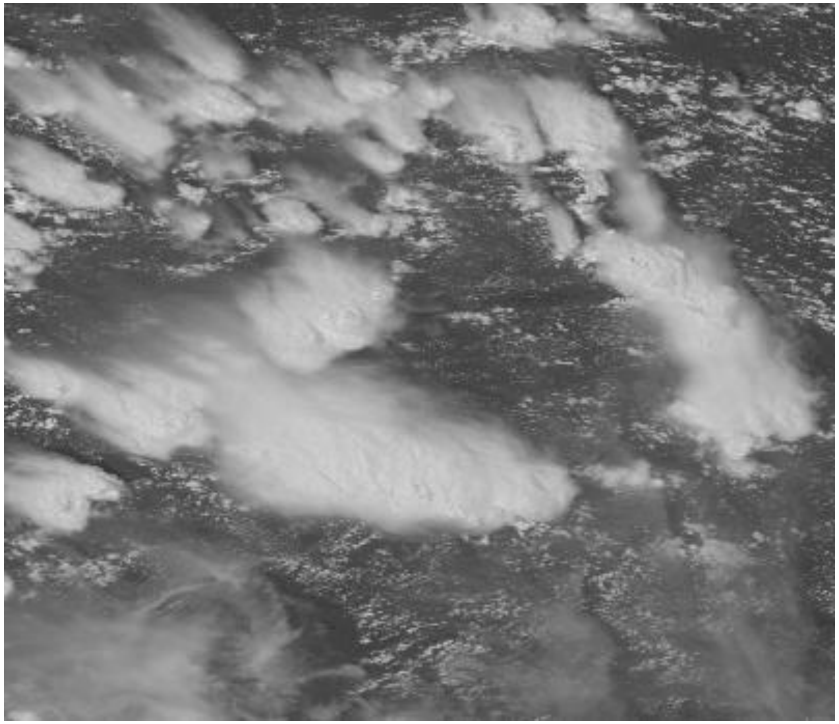
Background

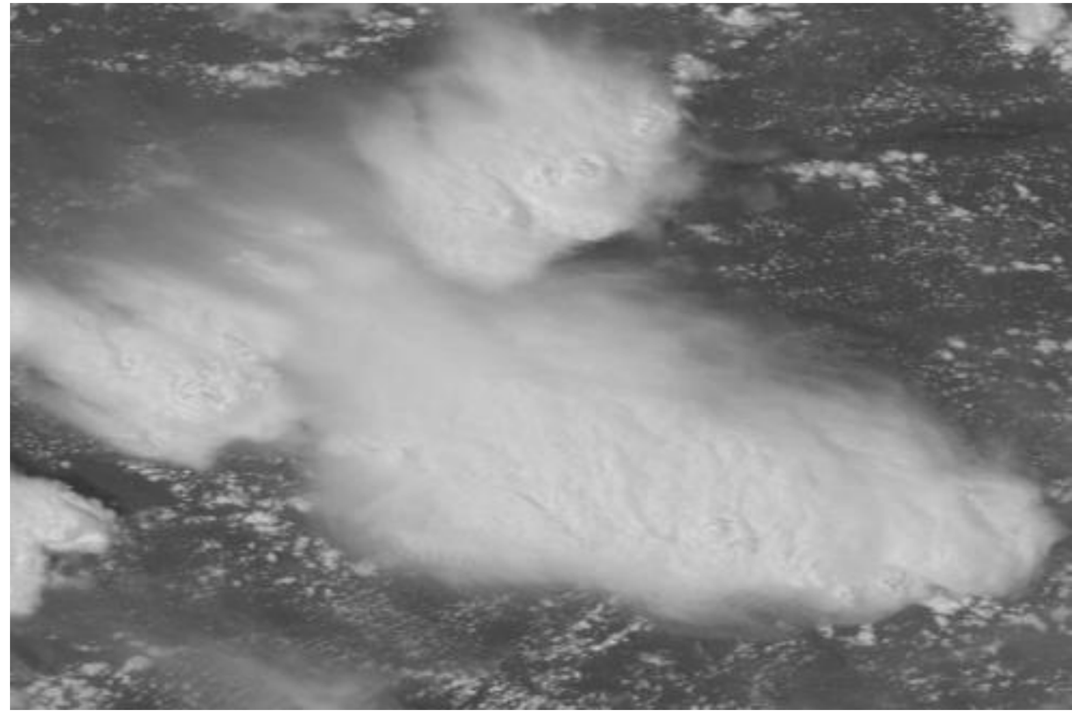
- Deep Convective Clouds (DCC) are cold, bright, and stable targets that are observed by nearly all geostationary and polar orbiting satellites
  - 90% reflectance at the lowest possible SZA
  - Predictable DCC reflectance at low SZA and VZA
  - Located near equator at the tropopause level
- DCC are easily identified by a simple IR threshold.
  - IR imagers are historically well calibrated with onboard blackbodies
  - Only good visible and IR co-registration is needed, good navigation is not a requirement
- DCC have historically been used to monitor degradation of visible sensors. To be used for transferring absolute calibration, they must be better characterized.

Objective: Characterize DCC for use as absolute calibration targets

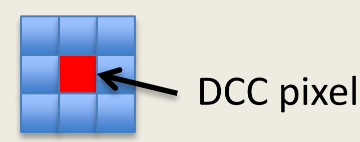
- Use Aqua-MODIS as reference sensor to evaluate how the following criteria affect DCC reflectivity:
  - IR temperature threshold
  - Spatial standard deviations (Visible/IR)
  - Geolocation
- Use SCIAMACHY and Hyperion to evaluate hyper-spectral characteristics of DCC reflectivity
  - Compare DCC to other cloud type

DCC Identification





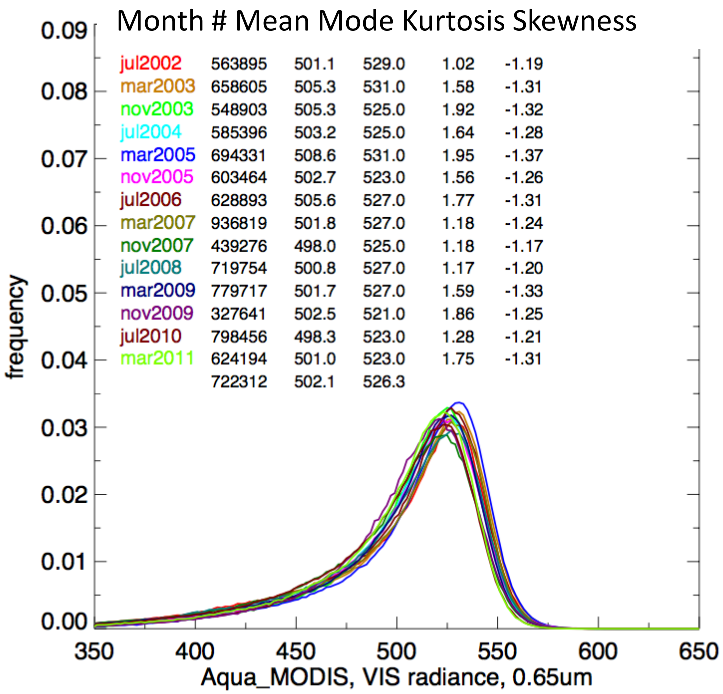
Parameters	DCC Identification Threshold
Geographical Extent	30°N to 30°S all surface types
Angular Range	SZA<40°, VZA<40°
11µm Temperature	BT11µm < 205°K
11µm Spatial Homogeneity	Standard deviation $BT_{11\mu m}$ <1°K
0.65µm Spatial Homogeneity	Standard deviation $R_{0.6\mu m}$<3%



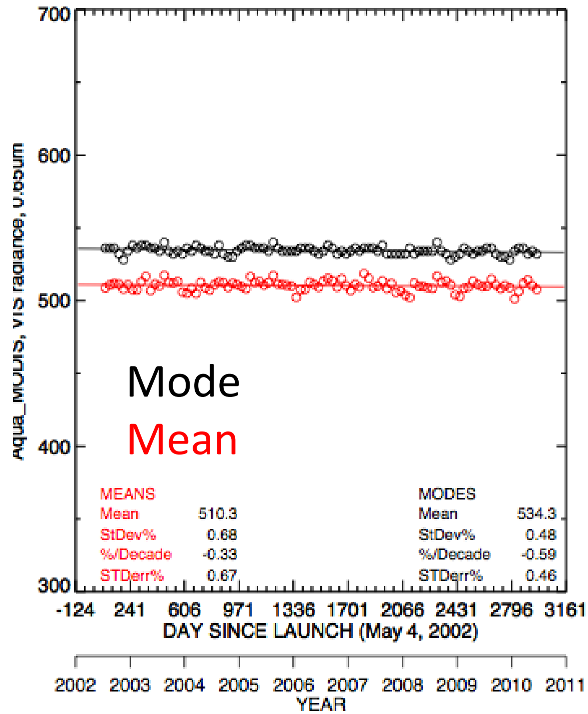
Standard deviation based on all 9 pixels

Baseline Aqua-MODIS 0.65µm DCC method

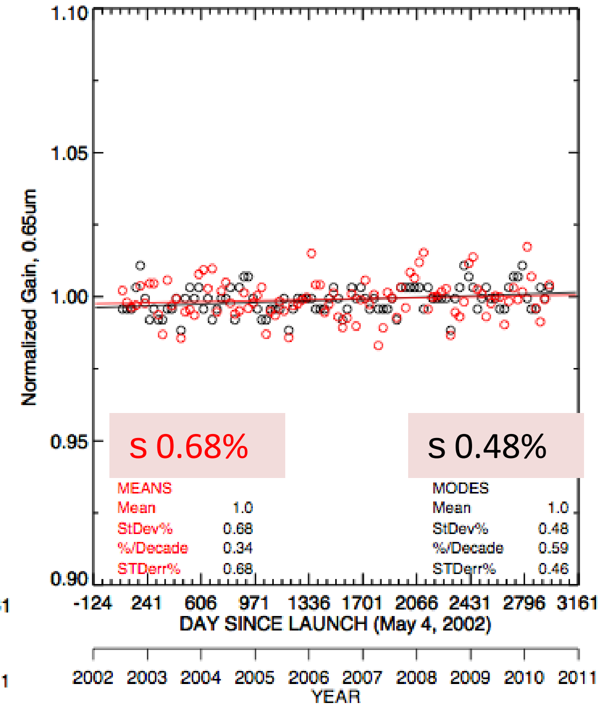
Monthly frequency PDFs



Monthly PDF Rad_{AC}



Monthly normalized trend

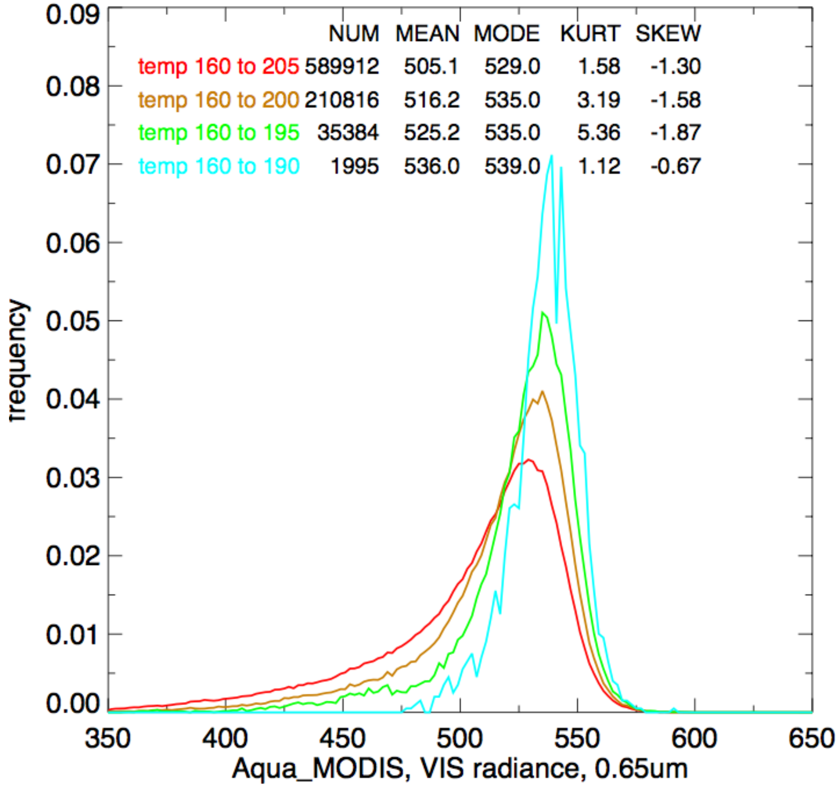


- Apply BRDF model to derive DCC anisotropic corrected (AC) radiance
- Compute monthly histogram
- Perform temporal trend

IR Temperature Threshold for DCC Identification

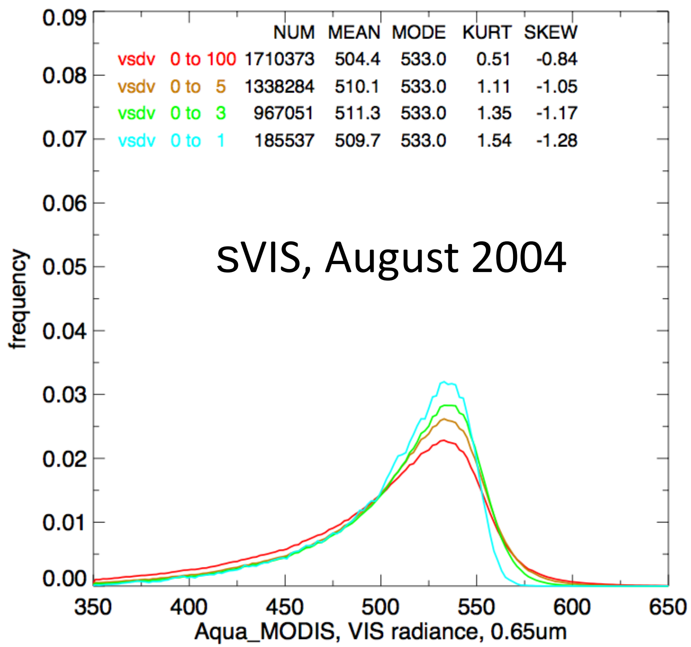
August 2004

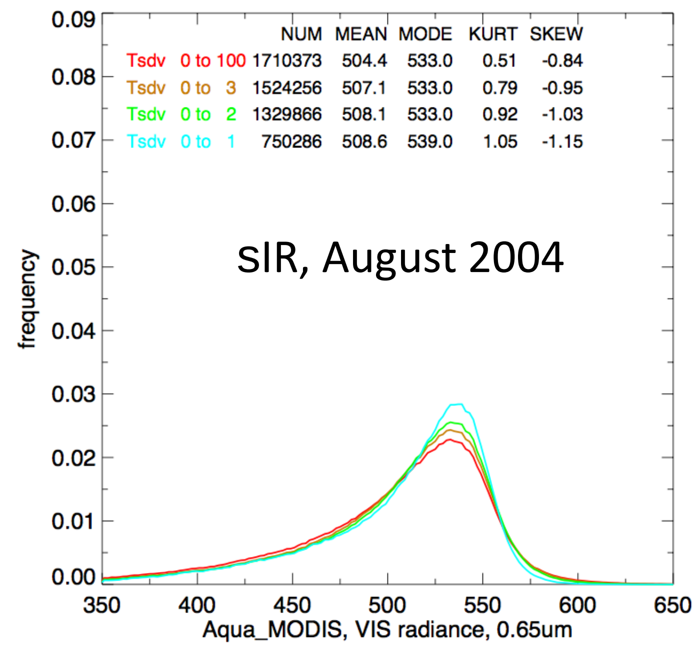
Temperature Threshold (K)	Mode DCC radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$)	Mean DCC radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$)	Monthly Mode standard deviation (%)	Mode trend (%/decade)
205	525.9	502.6	0.49	-0.43
200	529.3	513.2	0.50	-0.55
195	532.9	522.7	0.49	-0.57
190	536.6	531.5	0.77	-0.95
185	540.7	540.8	1.27	0.03
180	521.8	523.1	3.09	-8.34



- 2%, 0.6% increase in the mean, mode PDF Rad_{AC} with each 5° decrease
- 64%, 94%, 99.7% data reduction between 205°K and 200°K, 195°K, 190°K
- Sufficient samples with IR threshold between 205°K and 195°K

Spatial Thresholds for DCC Identification



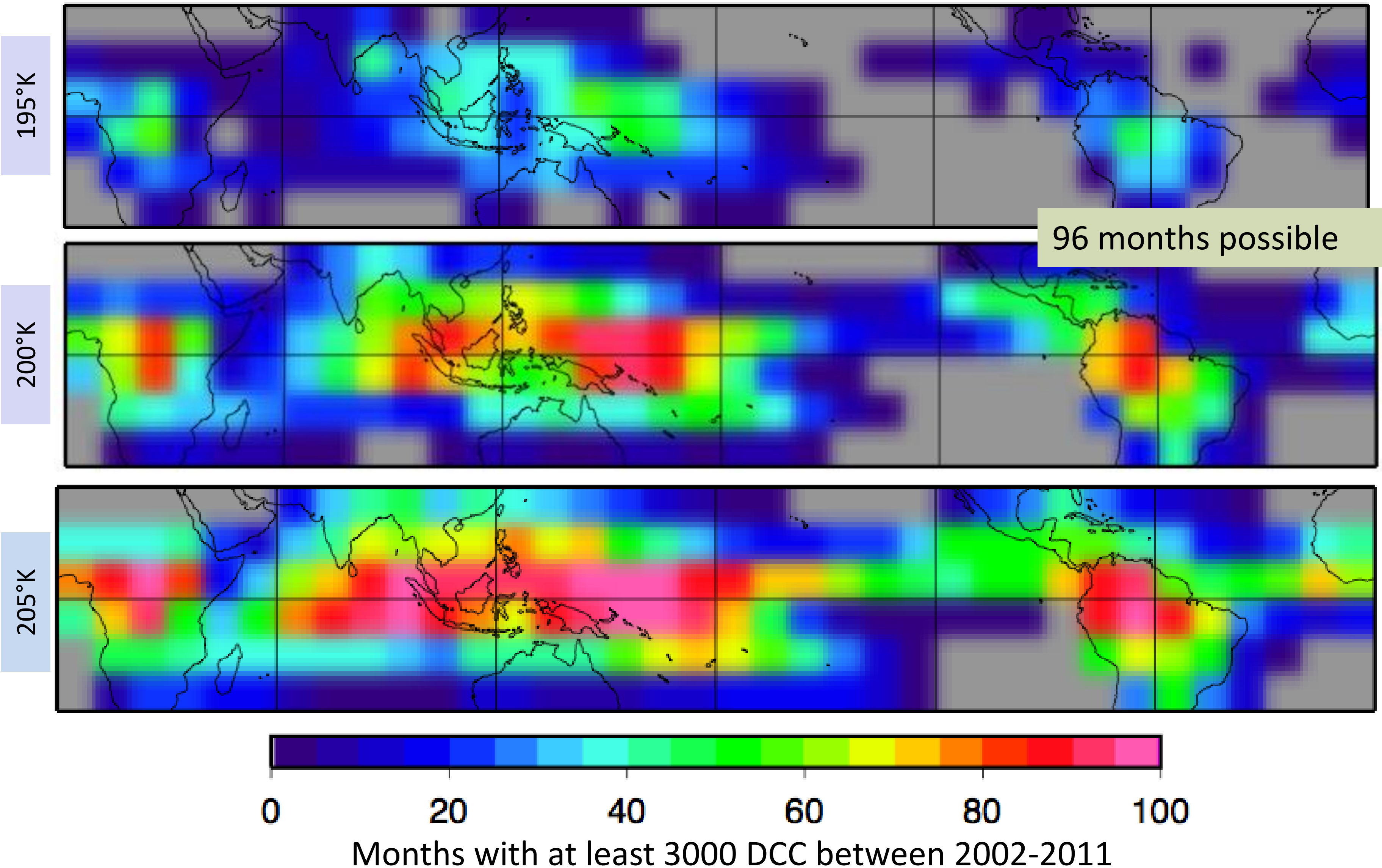


0.65µm StDev threshold (%)	Mode DCC radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$)	Mean DCC radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$)	Monthly Mode standard deviation (%)	Mode trend (%/decade)
None	530.4	501.4	0.51	-0.60
5	531.7	507.9	0.47	-0.61
3	532.8	509.3	0.51	-0.66
1	532.6	509.4	0.55	-0.73

11µm StDev Threshold (K°)	Mode DCC radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$)	Mean DCC radiance ($Wm^{-2}sr^{-1}\mu m^{-1}$)	Monthly Mode standard deviation (%)	Mode trend (%/decade)
None	530.4	501.4	0.51	-0.60
3	530.9	504.3	0.50	-0.79
2	531.6	505.2	0.51	-0.64
1	533.4	505.5	0.51	-0.71

- Spatial standard deviation has little to no effect on Mode or Mean reflectivity
- 56% data reduction when applying both spatial thresholds

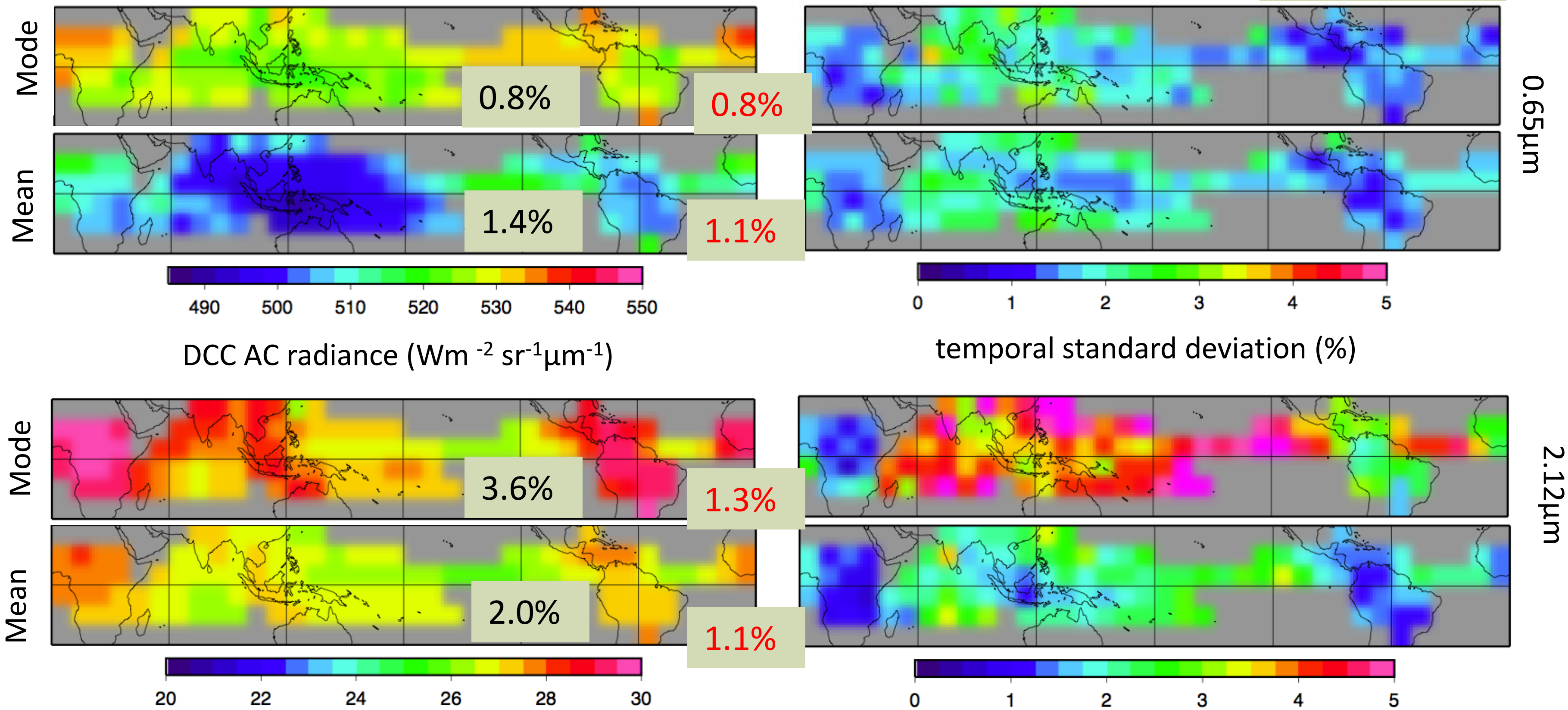
Aqua-MODIS DCC Frequency



147 regions with 30 valid months

205°K

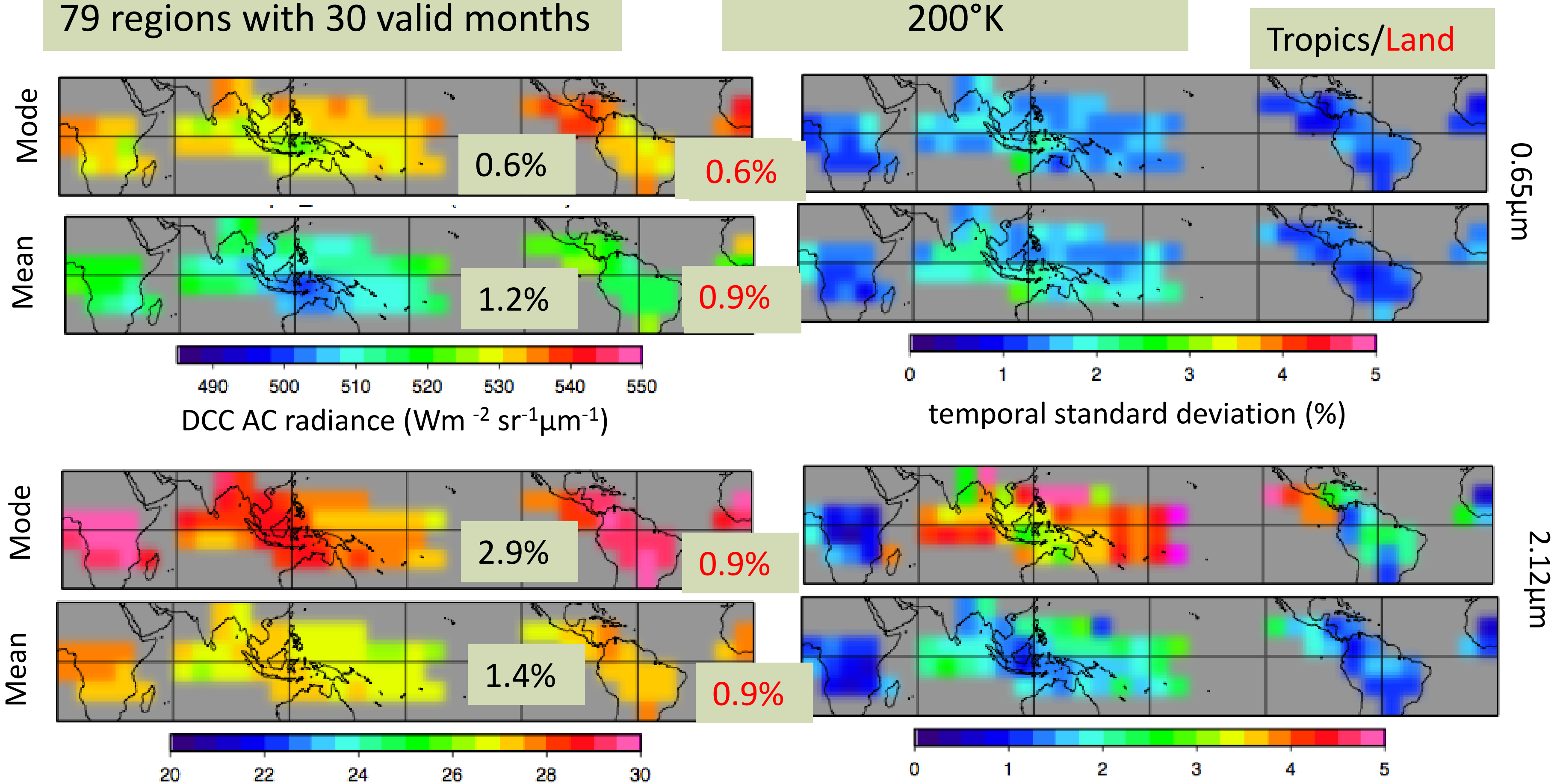
Tropics/Land



- For 0.65µm the mode is more consistent in space
- For 2.12µm the mean is more consistent in space and time
- 0.65µm land not necessarily brighter than ocean, for 2.12µm it is
- For 2.12µm land has less temporal uncertainty

79 regions with 30 valid months

200°K

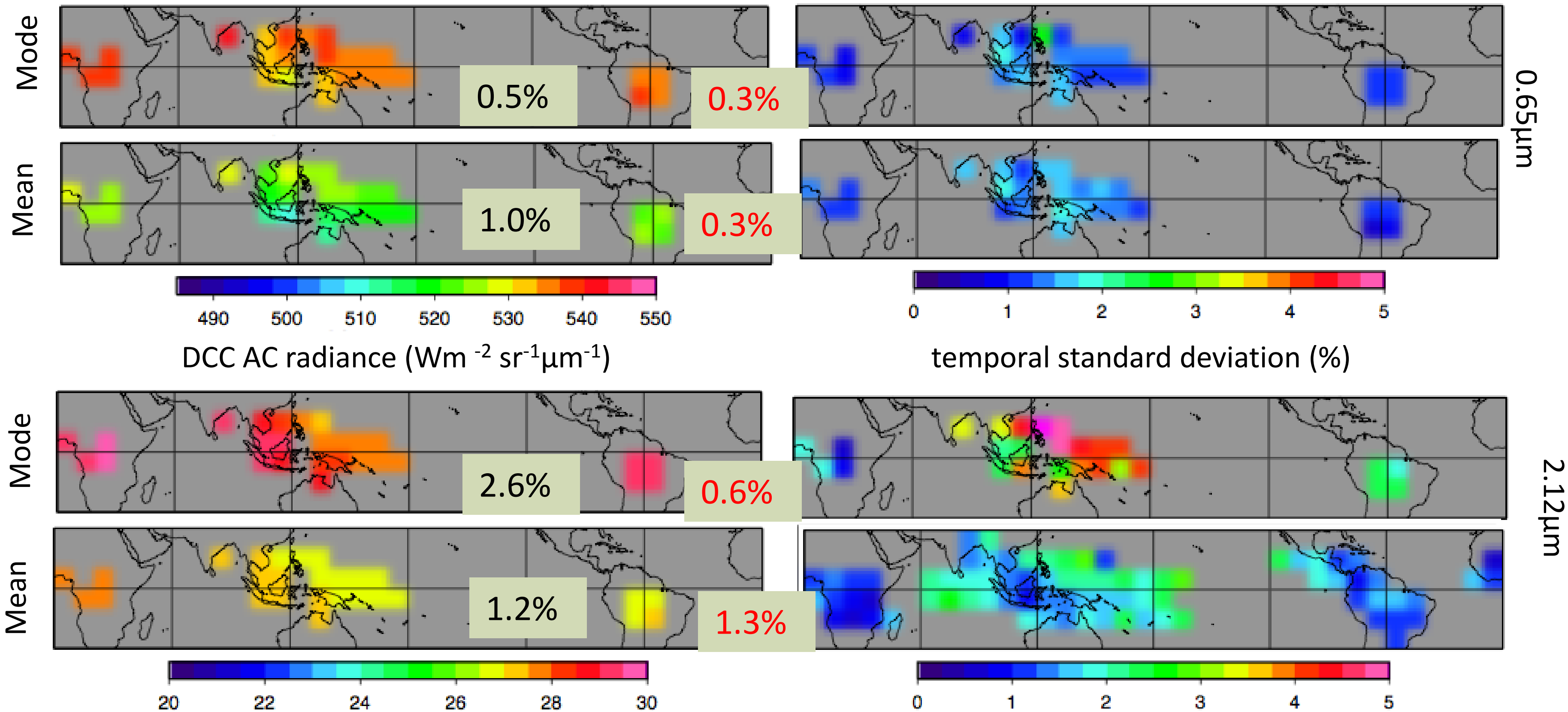


- DCC AC radiance regional standard deviation decreased for both tropics and land for both channels as compared to 205°K maps

27 regions with 30 valid months

195°K

Tropics/Land



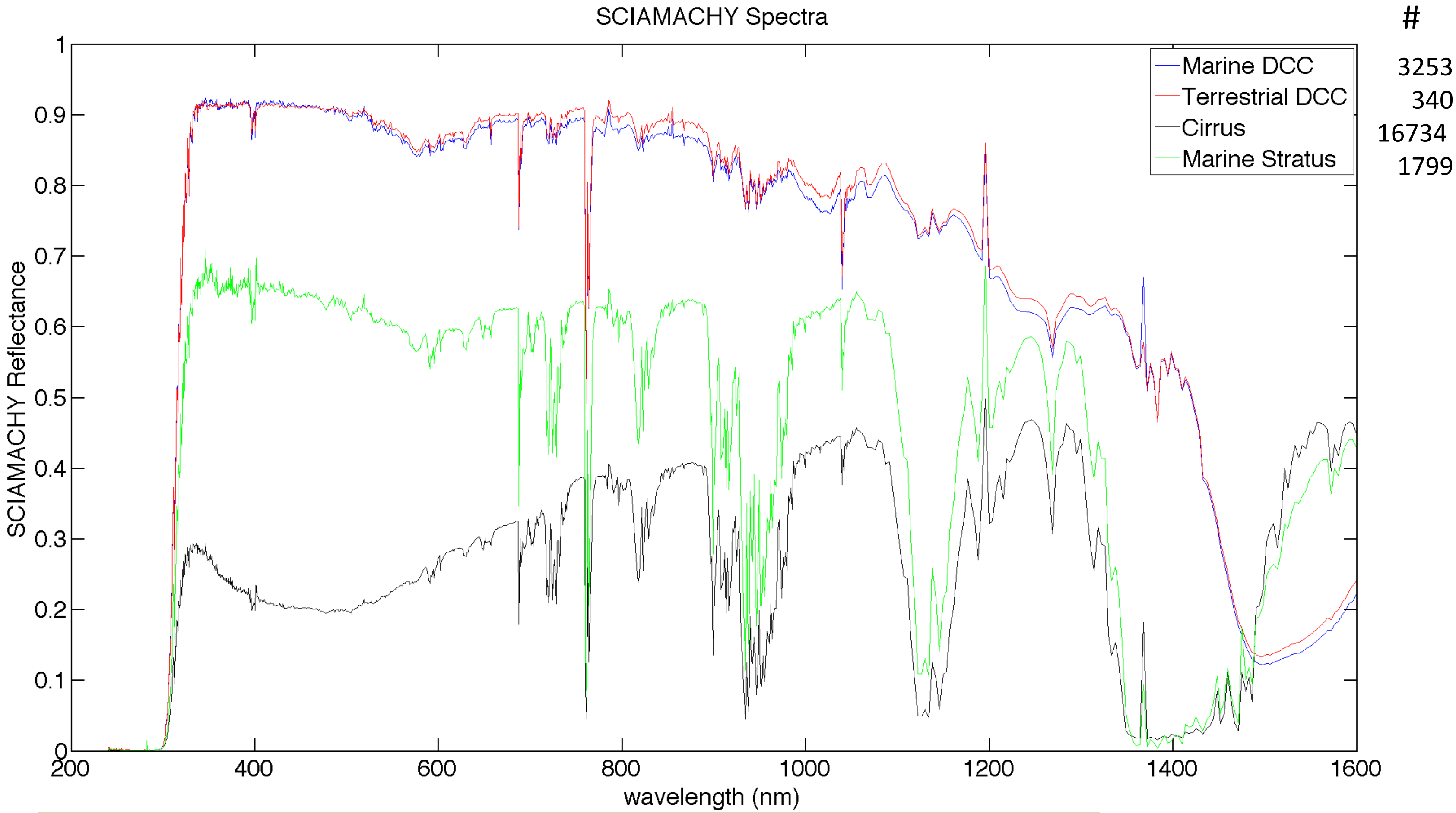
- DCC AC radiance regional standard deviation decreased for both tropics and land for both channels as compared to 205°K and 200°K maps but severely limited available calibration domains

200°K and spatial threshold

Tropics/Land	MODE			MEAN		
MODIS BAND (µm)	Spatial (%)	Month (%)	Annual (%)	Spatial (%)	Month (%)	Annual (%)
1 (0.65)	0.5/0.3	1.2/1.0	0.6/0.5	1.1/0.3	1.6/1.2	0.8/0.6
3 (0.47)	0.5/0.4	1.3/1.1	0.6/0.5	1.1/0.3	1.7/1.2	0.8/0.5
4 (0.55)	0.5/0.3	1.3/1.1	0.6/0.5	1.1/0.3	1.7/1.2	0.8/0.6
5 (1.24)	1.2/0.7	1.3/1.0	0.6/0.5	1.3/0.7	1.0/0.8	0.5/0.4
6 (2.12)	2.5/1.2	3.4/1.9	2.0/1.7	1.8/0.7	1.8/1.1	1.1/1.0
26 (1.37)	2.0/1.1	2.7/1.9	1.2/0.9	2.3/0.9	2.0/1.5	1.0/0.6

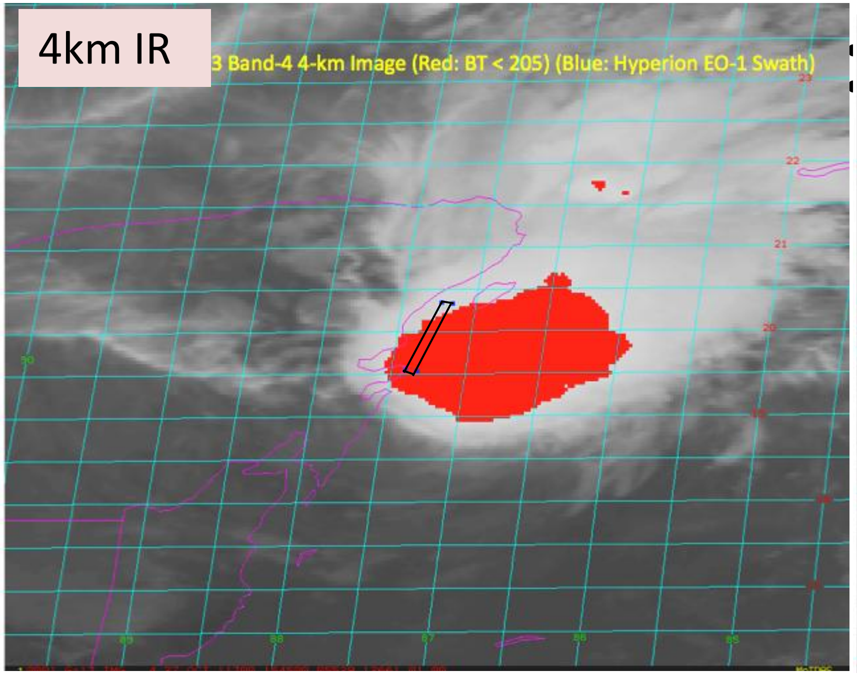
- Use PDF mode statistic for <0.65µm
- Use PDF mean statistic for >1.0µm
- Land has less temporal uncertainty than over ocean

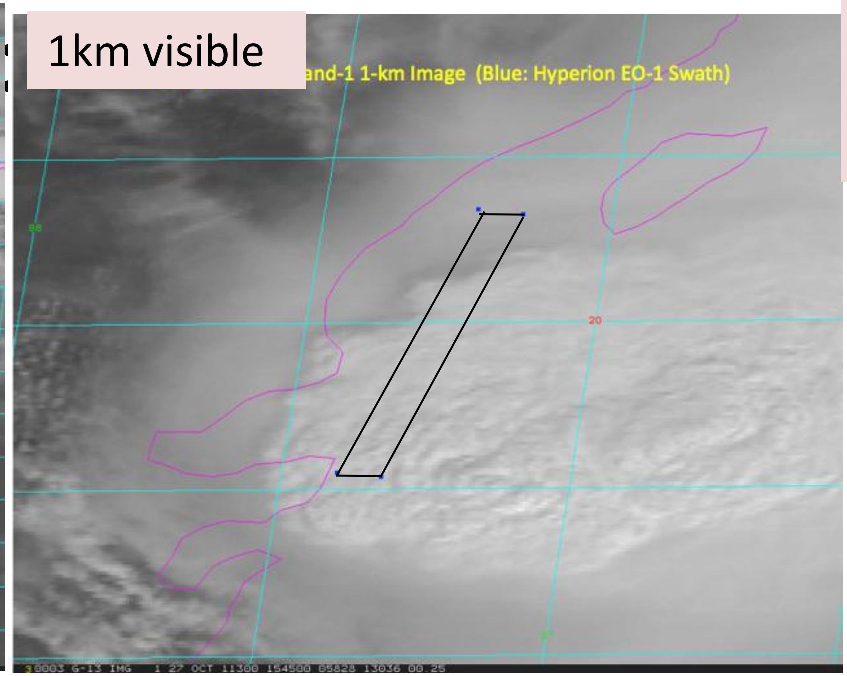
SCIAMACHY reflectance spectra



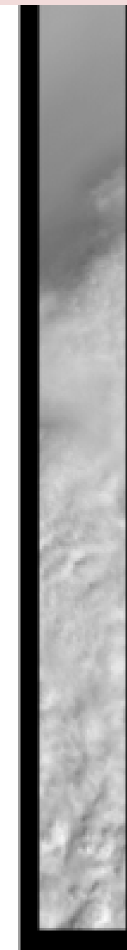
- DCC not effected by water vapor absorption bands
- Land footprints slightly brighter than ocean >0.65µm

GOES-13 and Hyperion image over hurricane Rina, October 27, 2011



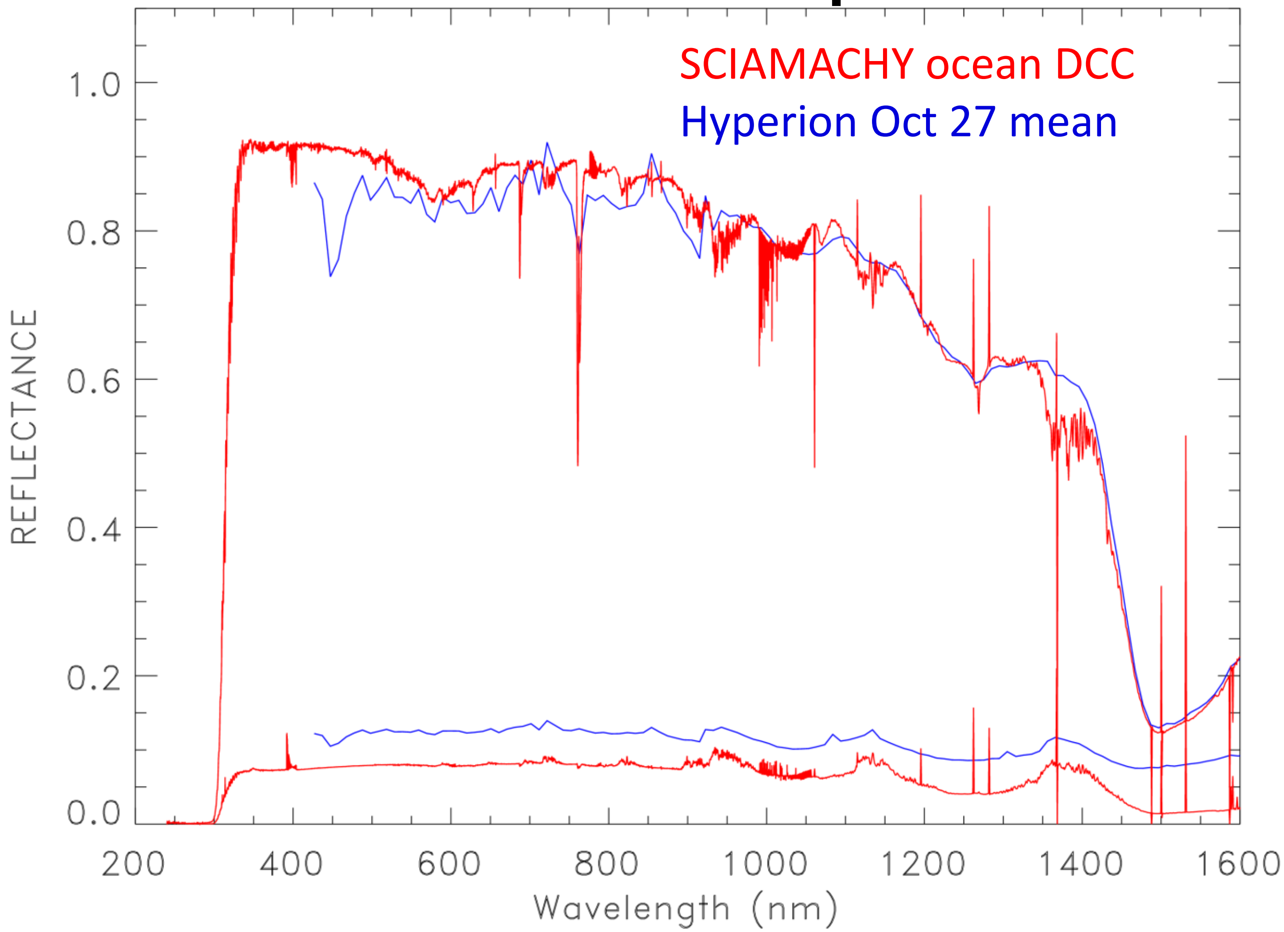


Hyperion
30 meter
0.6 µm



- Hyperion on EO-1 10:00AM,
- 220 spectral bands from 0.4µm to 2.5µm at 10nm increments
- 7.5 by 100km spatial image

Comparison of Hyperion and SCIAMACHY spectra



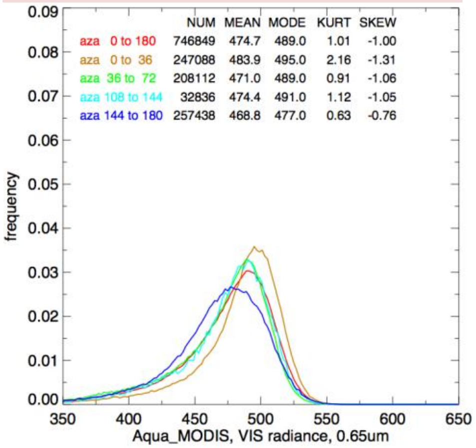
- The reflectance spectra are similar, except maybe at 1.4µm
- Hyperion reflectance based on the USGS Hyperion solar spectra

Conclusions

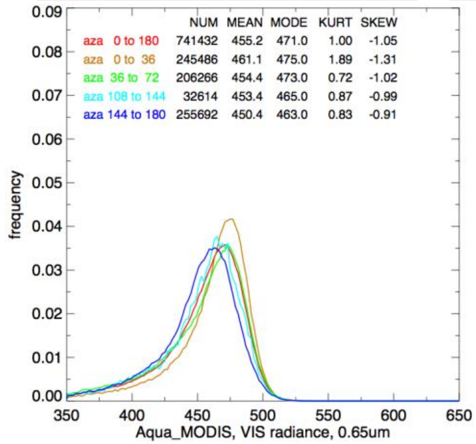
- DCC calibration is most successful if the monthly PDF shape is consistent from month to month
  - Must balance the most stringent threshold with sample size
  - TWP, Africa and South America have the most DCC
  - PDF mode best for wavelengths < 0.7µm
  - PDF mean best for wavelengths > 1.0µm
  - Possible to calibrate wavelengths < 2.2µm
- DCC over land provides a more predictable reflectance and less uncertainty than over ocean
- DCC not impacted by water vapor bands between 0.4 and 1.6µm as with other cloud types

DCC ADMs

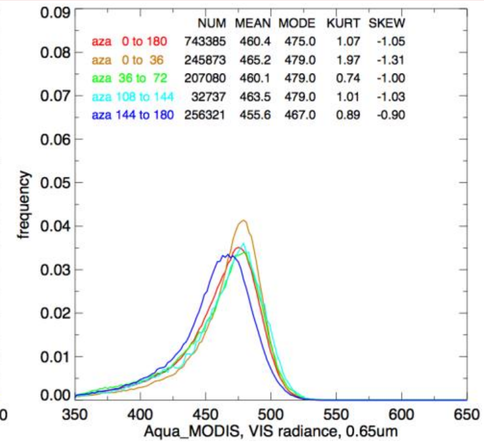
No BRDF Model



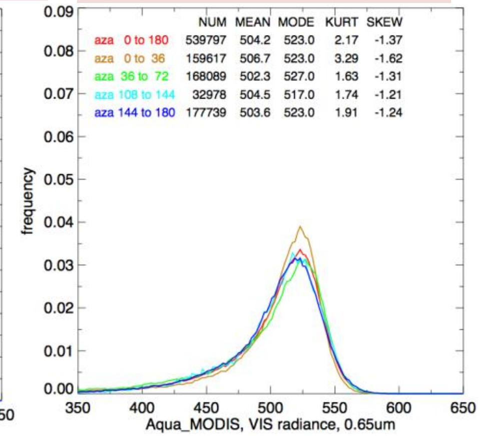
Hu Model



CERES - Broadband



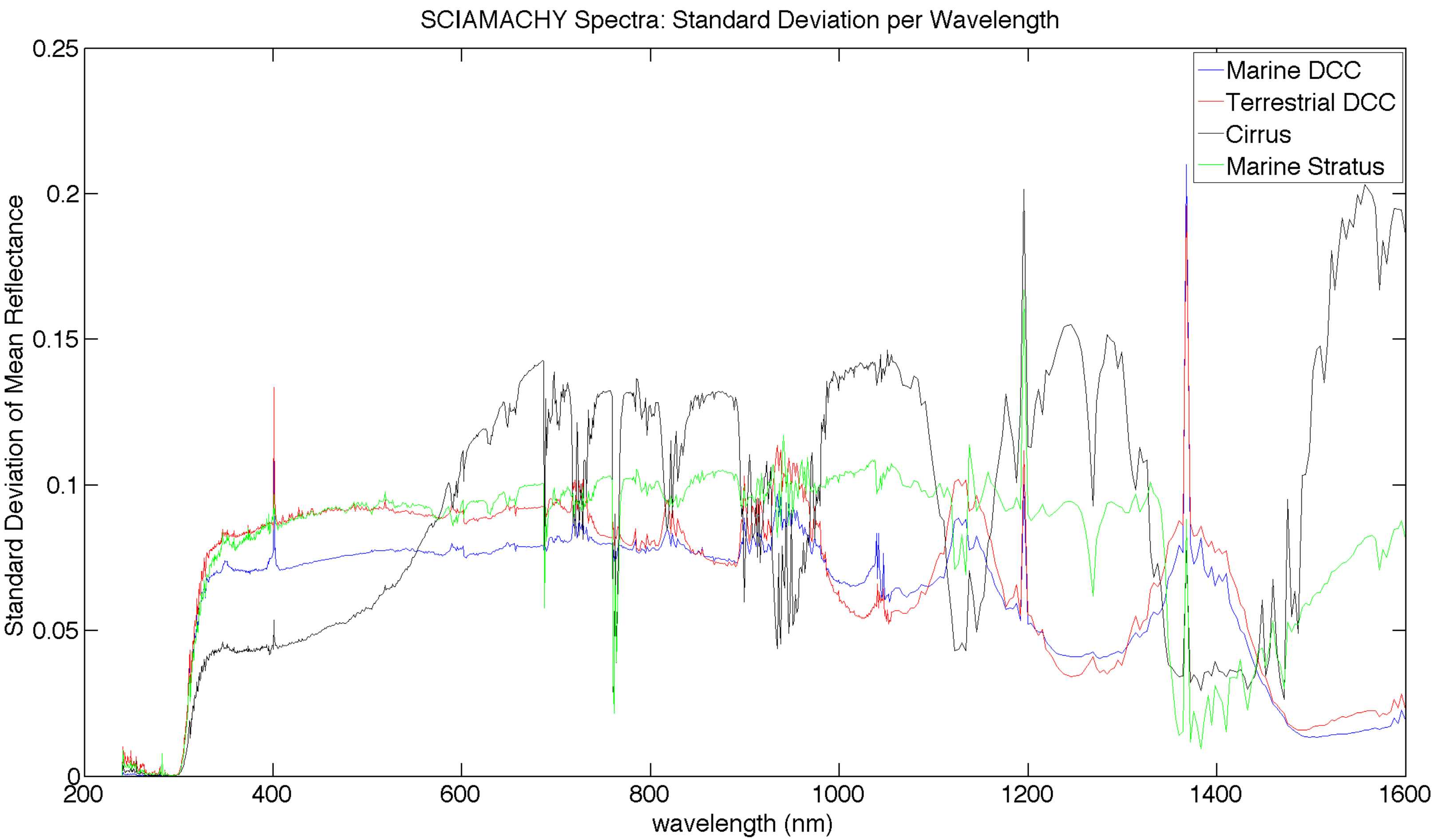
MODIS based



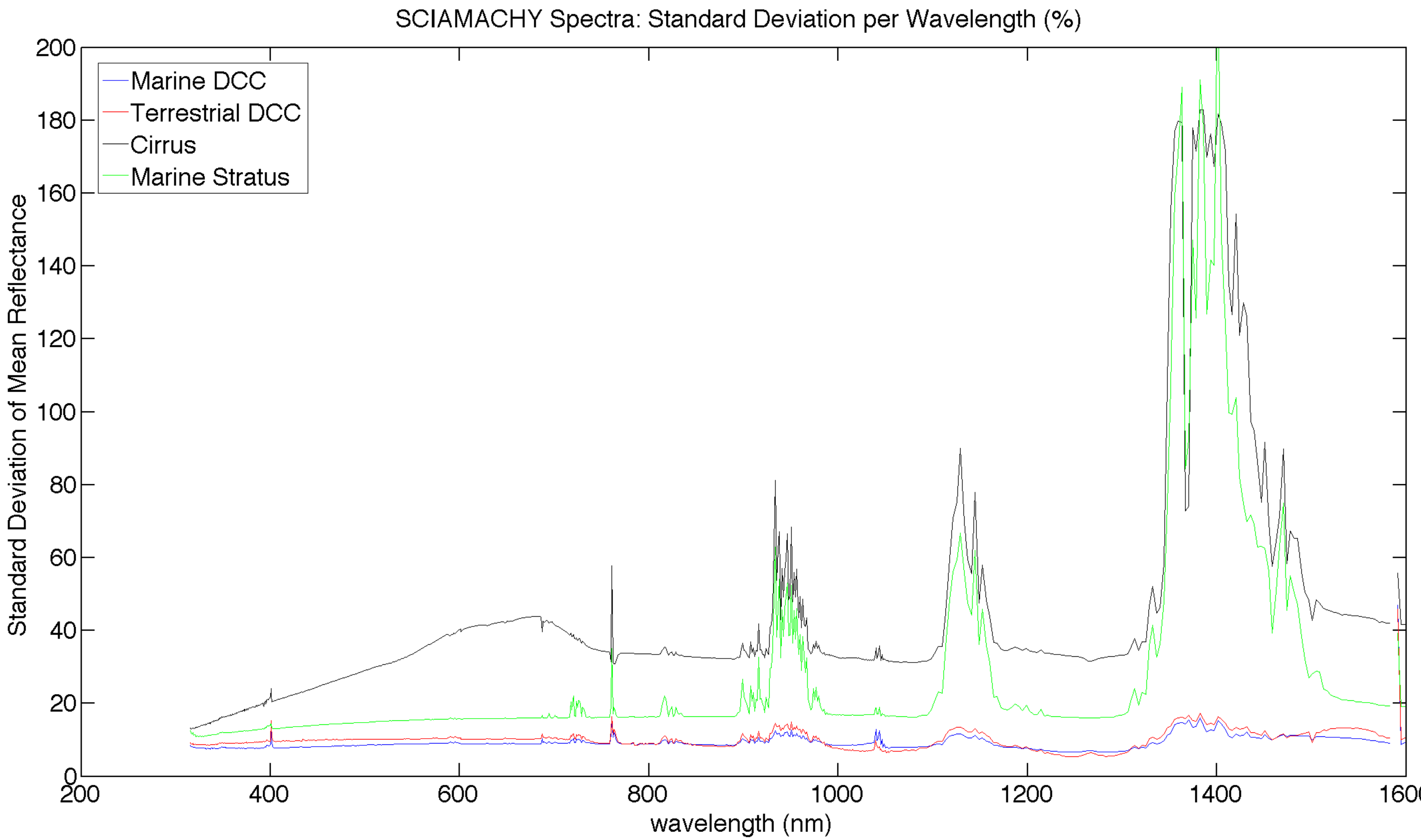
ADM	Monthly Mode standard deviation (%)	Trend (%/decade)
Lambertian	0.67	-0.86
Hu (theory)	0.37	-0.51
CERES (BB)	0.46	-0.27
MODIS (NB)	0.49	-0.43

- The DCC ADM is nearly isotropic within 40° SZA and VZA
- If the Aqua orbit is maintained, and DCC consistent in space and time, then viewing geometry is replicated annually and less dependency on ADM

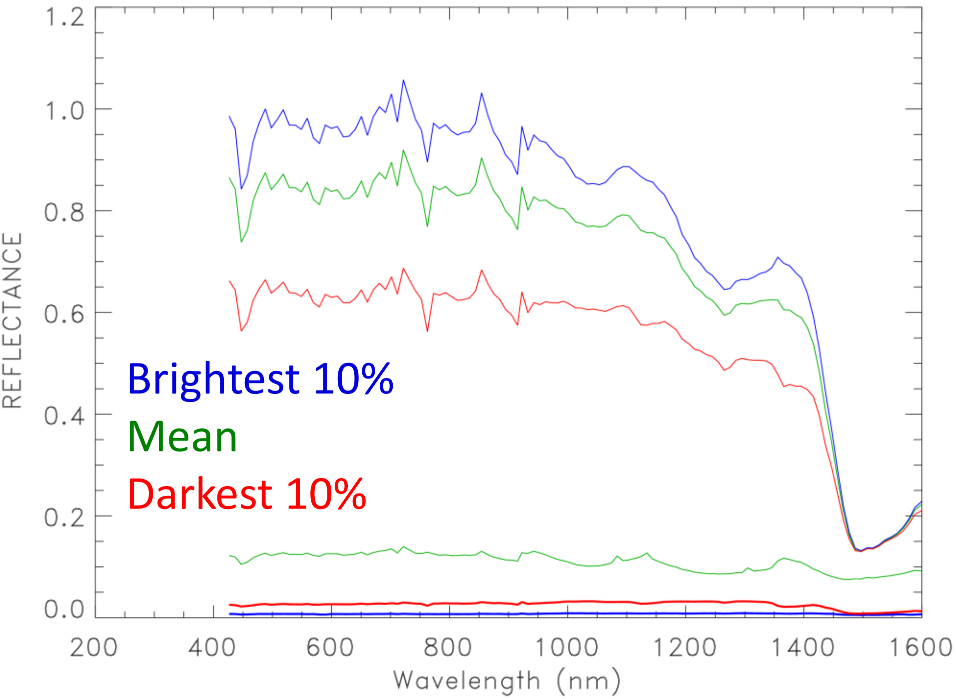
SCIAMACHY reflectance standard deviation

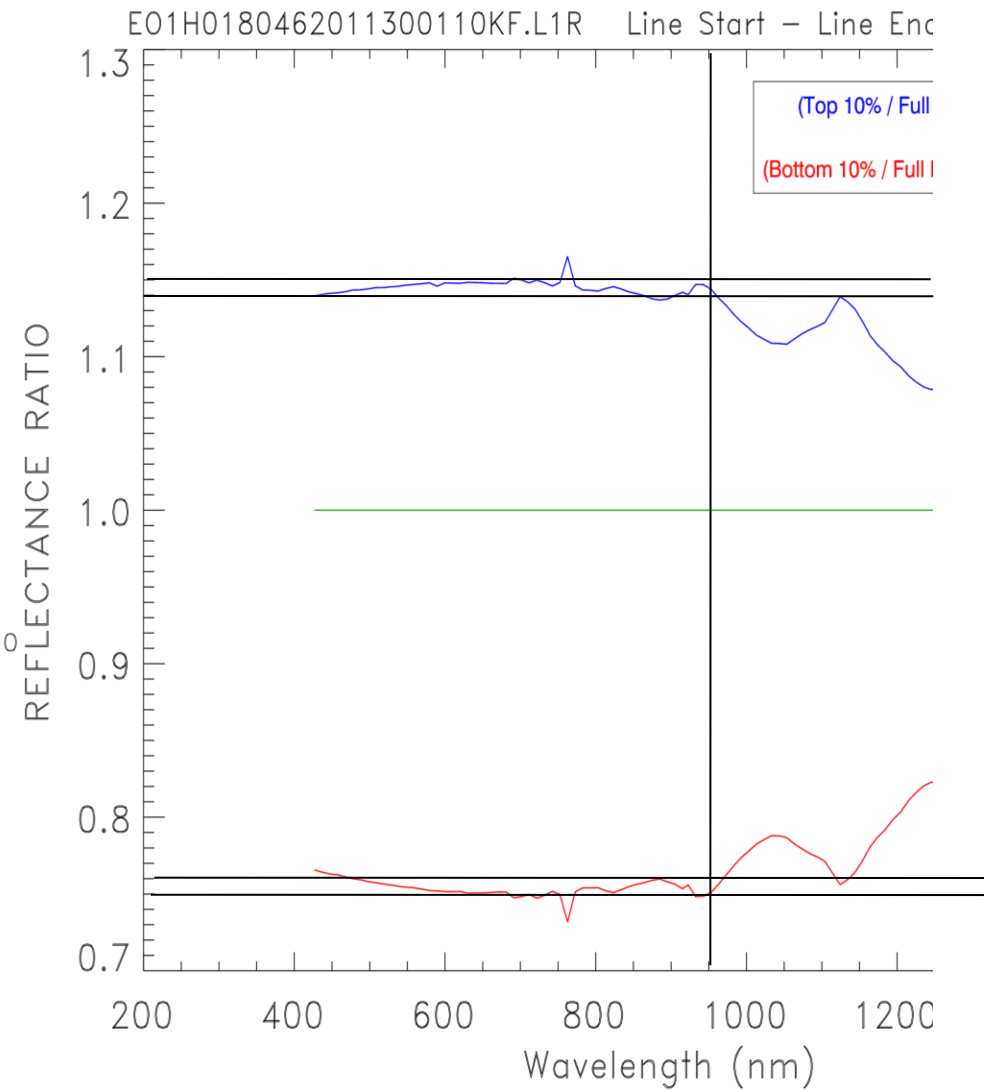


SCIAMACHY reflectance standard deviation (%)

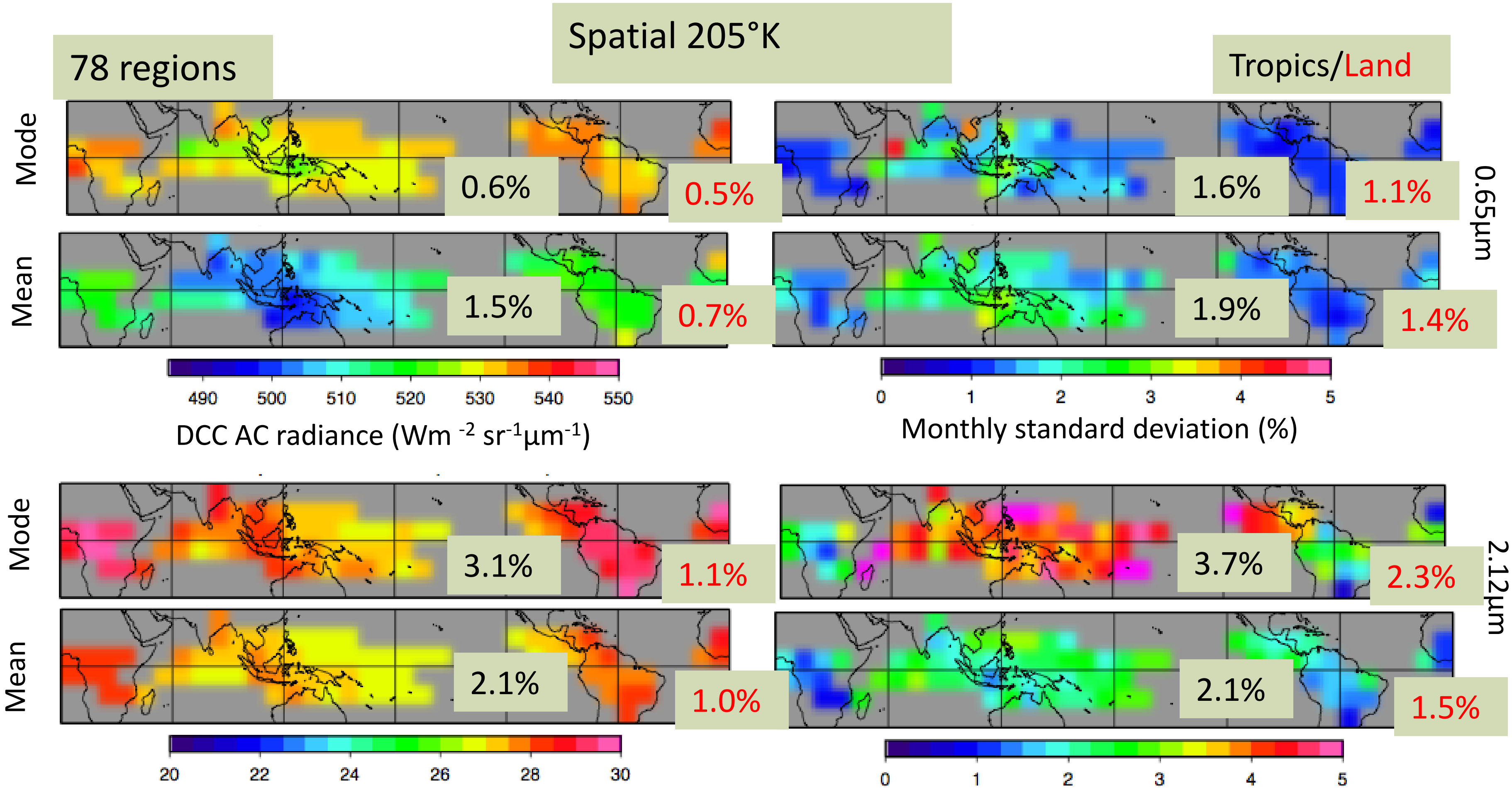


Hyperion reflectance ratios

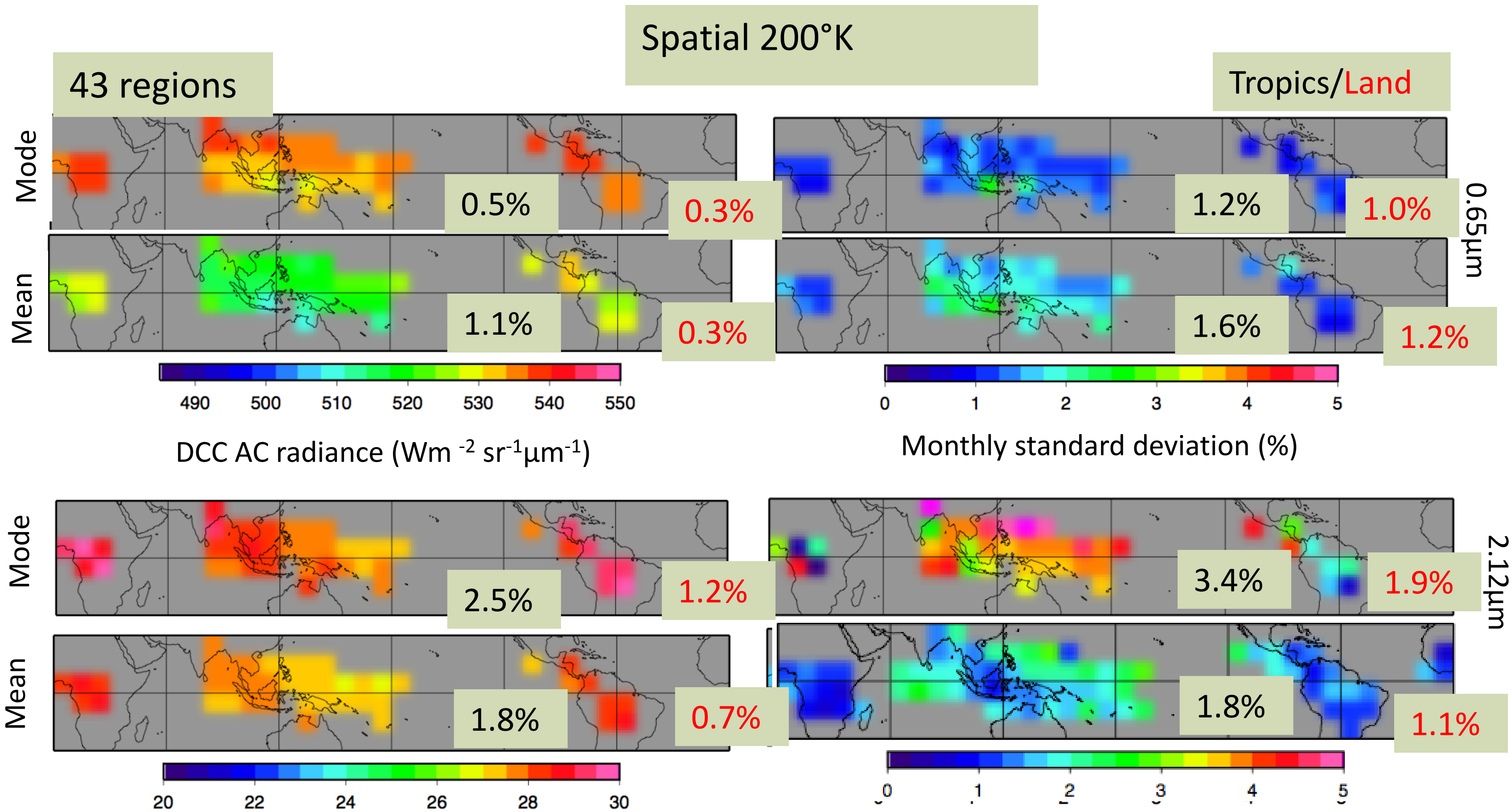




- The spectral reflectance shape is independent of brightness and nearly flat < 0.9µm
- Brightest/mean or darkest/mean is within 1% between 0.4 to 0.9µm
- The standard deviation of the Hyperion reflectances are <2%



Spatial 205°K
78 regions
Tropics/Land
Mode
Mean
0.6%
0.5%
1.6%
1.1%
1.5%
0.7%
1.9%
1.4%
0.65µm
490 500 510 520 530 540 550
DCC AC radiance (Wm -2 sr-1µm-1)
0 1 2 3 4 5
Monthly standard deviation (%)
Mode
Mean
3.1%
1.1%
3.7%
2.3%
2.1%
1.0%
2.1%
1.5%
2.12µm
20 22 24 26 28 30
0 1 2 3 4 5


Spatial 200°K
43 regions
Tropics/Land
Mode
Mean
0.5%
0.3%
1.1%
0.3%
1.2%
1.0%
1.6%
1.2%
0.65µm
490 500 510 520 530 540 550
DCC AC radiance (Wm -2 sr-1µm-1)
0 1 2 3 4 5
Monthly standard deviation (%)
Mode
Mean
2.5%
1.2%
1.8%
0.7%
3.4%
1.9%
1.8%
1.1%
2.12µm
20 22 24 26 28 30
0 1 2 3 4 5

DCC threshold characteristics

0.65µm	threshold			MODE			MEAN		
Surface	Temp (K°)	Spatial	#	Spatial (%)	Month (%)	Annual (%)	Spatial (%)	Month (%)	Annual (%)
Tropics	205		117	0.8	1.8	0.7	1.4	1.8	0.8
	205	Y	78	0.6	1.6	0.7	1.5	1.9	0.9
	200		78	0.6	1.4	0.6	1.2	1.6	0.7
	200	Y	43	0.5	1.2	0.6	1.1	1.6	0.8
	195		27	0.5	1.3	0.7	1.0	1.4	0.8
Land	205		29	0.8	1.5	0.6	1.1	1.5	0.6
	205	Y	22	0.5	1.1	0.5	0.7	1.4	0.7
	200		24	0.6	1.3	0.6	0.9	1.3	0.6
	200	Y	11	0.3	1.0	0.5	0.3	1.2	0.6
	195		8	0.3	1.1	0.5	0.3	1.1	0.6

- Spatial thresholds work better over land
- Temperature thresholds work better over ocean