A uniform calibration approach using multiple invariant Earth targets for the 35-year AVHRR visible record

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Introduction / Calibration Strategy

- The 35-year AVHRR record is the longest series of overlapping consistent imager data with global coverage suitable for climate studies
  - Observed the Mt. Pinatubo (1993) and El Chichon (1982) eruptions
  - Observed the 1982 and 1998 El Ninos
  - These events occurred before the MODIS record in 2000, the MODIS record has been quiet climatologically
- The AVHRR instrument has no onboard visible calibration
- Use Earth invariant targets to transfer the Aqua-MODIS Collection 6 calibration
  - Use multiple invariant targets: Libya-4, Libya-1, Niger-1, Arabia-1, Dome-C, Greenland summit, and deep convective clouds (DCC)
  - Combine the individual invariant target calibration by the inverse of the variance about the trend to minimize the effect of invariant target reflectance drifts

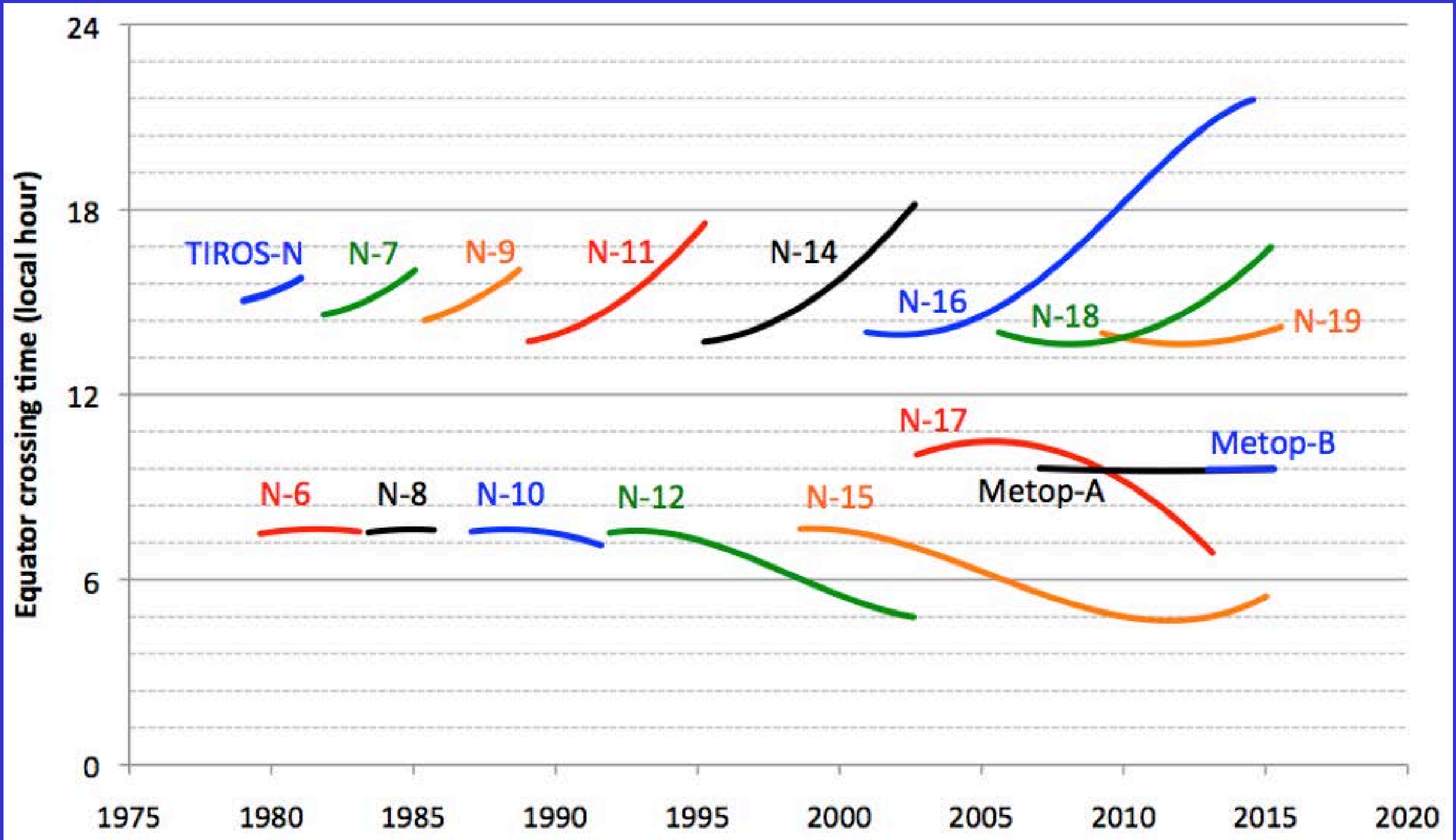
AVHRR instrument

- NOAA orbits are at ~850 km altitude
- Swath width of 2600 km, scans the whole Earth daily
- Nominal pixel resolution of 1.1 km in the scan direction and 3-km in the along track , available in the HRPT or LAC format, but does not provide continuous coverage
- The GAC format sub-samples every 4 out of every 15 LAC pixels and has a nominal pixel resolution of 4-km, and provides continuous coverage
- AVHRR/1 (1978-1991), 0.58-0.68 μm, 0.725-1.10 μm, 3.55-3.93 μm, 10.50-11.50 μm
- AVHRR/2 (1981-2002) and includes the 11.50-12.50μm
- AVHRR/3 (1998 to present) can switch between channel 3A 3.55-3.93 μm and channel 3B 1.58-1.64 μm
- AVHRR/3 has a dual gain sensor response in the visible bands

Calibration Strategy

- The calibration challenge is the NOAA degrading orbit, which culminates in to a terminator orbit
- Characterize the invariant target nadir reflectance with solar zenith angle using the NOAA-16 AVHRR sensor, which drifts completely into a terminator orbit
- First transfer the Aqua-MODIS calibration to the NOAA-16 AVHRR sensor using Simultaneous Nadir Overpass (SNO) radiance pairs over the poles

NOAA degrading orbits



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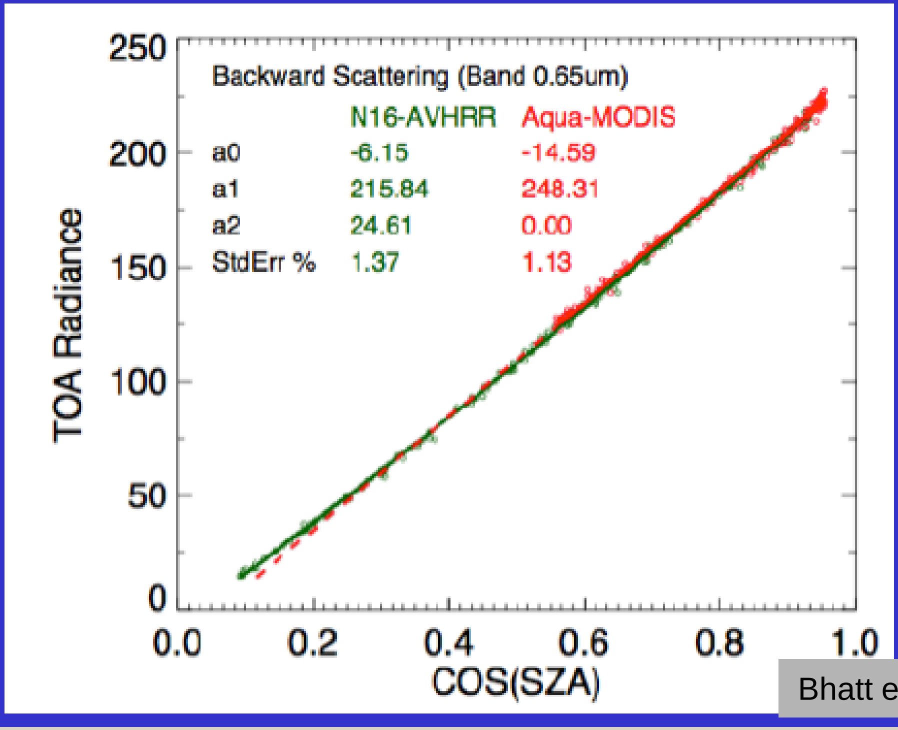
- All NOAA orbits eventually drift into a terminator orbit
- NOAA-16 chosen as reference instrument, since it drifts completely into a terminator and then into a morning orbit, during the MODIS record

Libya-4 Aqua-MODIS and N16 AVHRR directional models

• Characterize the Libya-4 site by regressing TOA radiance and cosine SZA for near nadir (VZA< 10°)
• For desert sites there is a distinct radiance difference between forward and backscatter conditions



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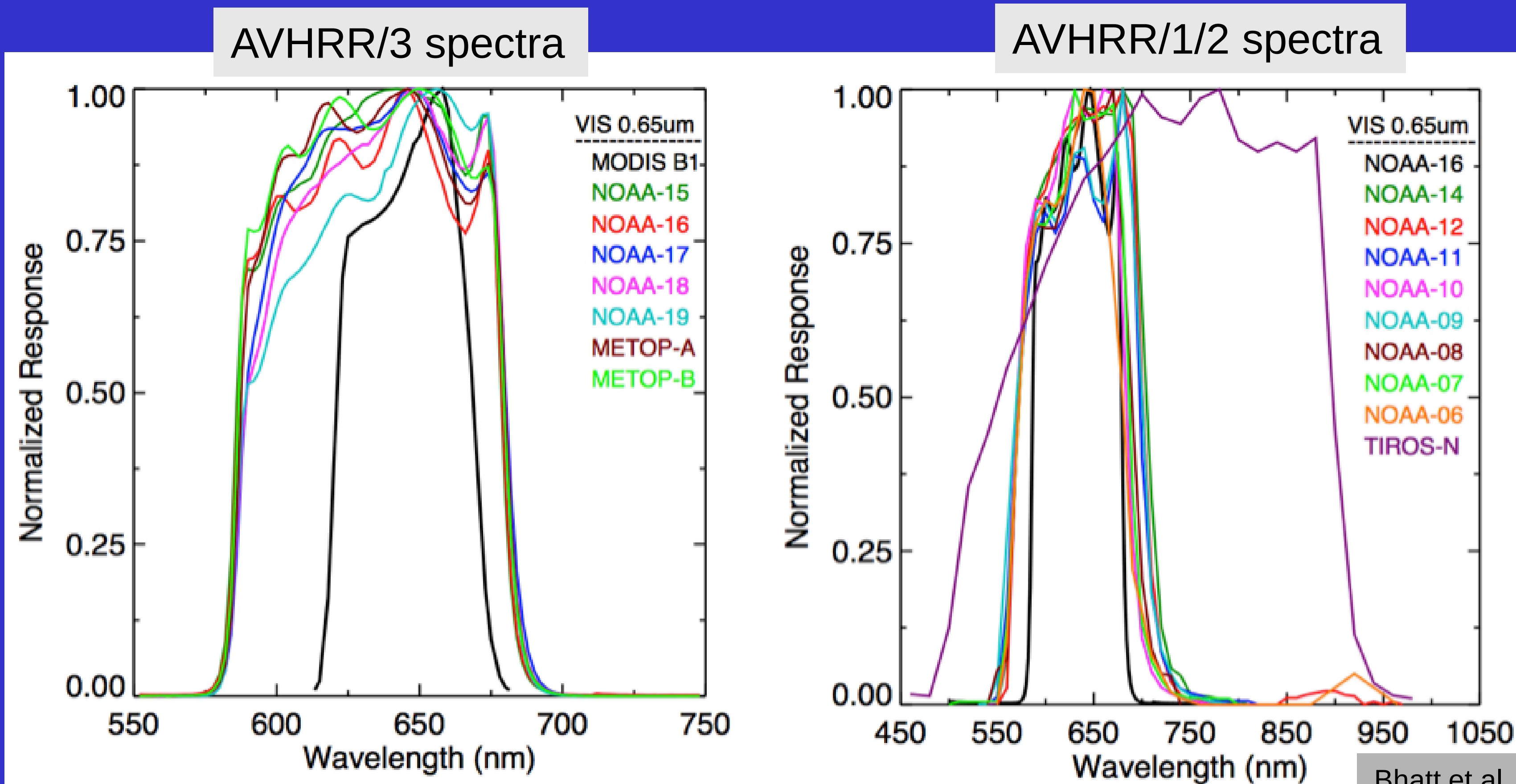
• The NOAA-16 model is not linear with cosine SZA for large SZA
• If the Aqua-MODIS model is extrapolated there will be a bias with the N16 model

Spectral Band Adjustment Factor

- The calibration advantage is that the AVHRR sensor spectral response function (SRF) are similar
- The spectral band adjustment factor (SBAF) between NOAA-16 and other AVHRR sensors are smaller than with Aqua-MODIS bands
- The SBAFs are computed over each invariant target using SCIAMACHY pseudo radiances

AVHRR Sensor Spectral Response Fuctions



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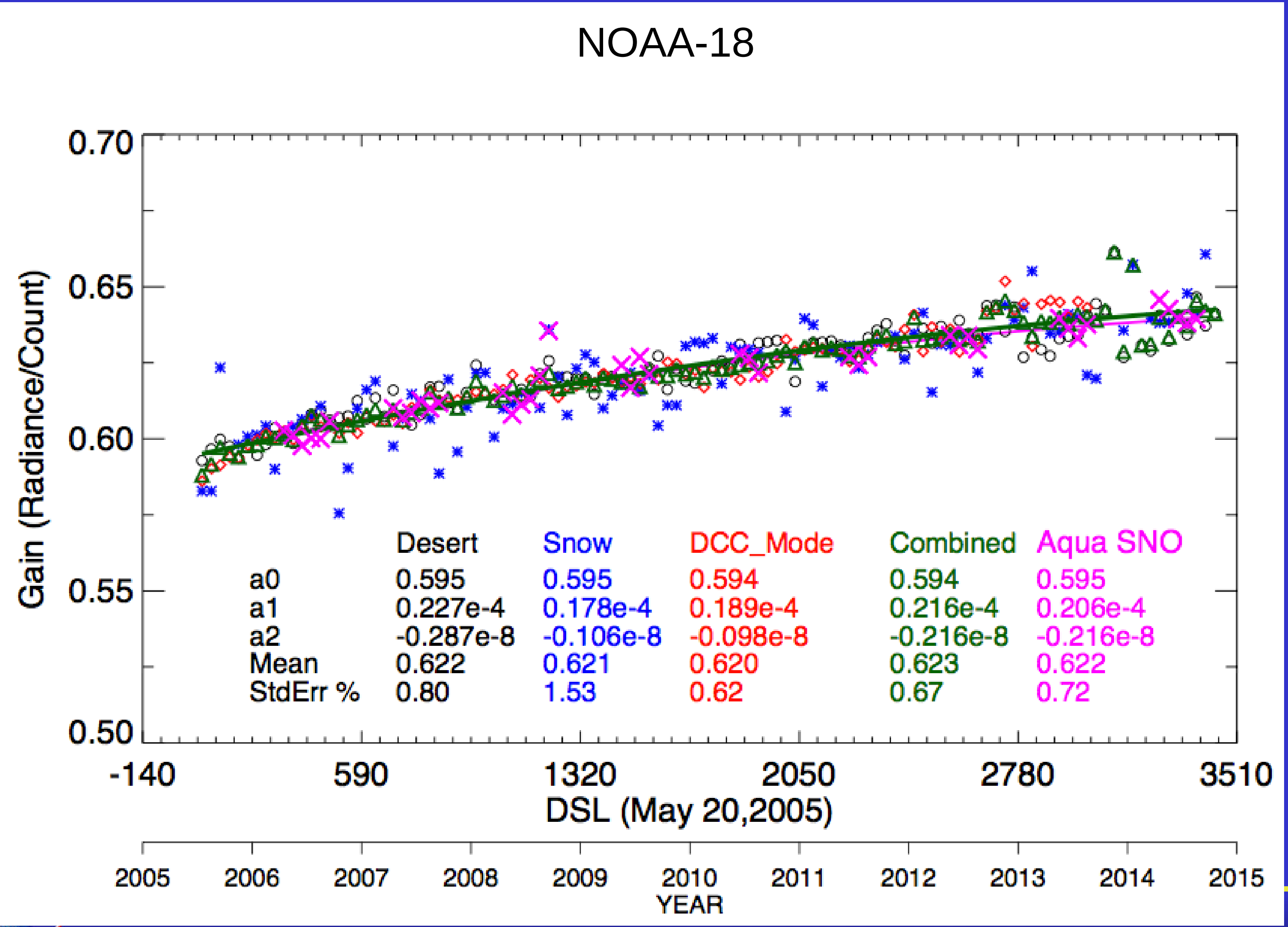
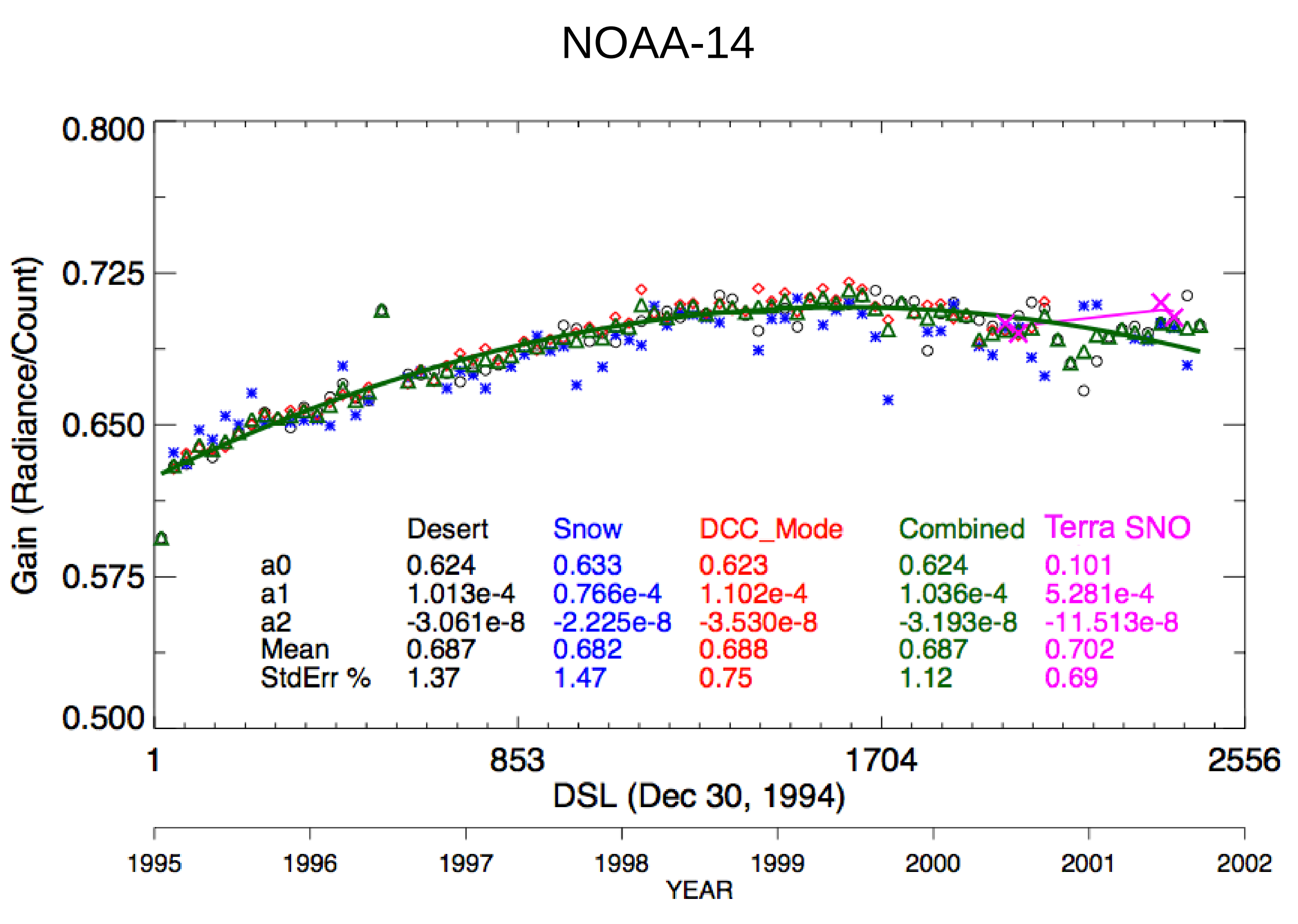
- The AVHRR spectral bands are very similar, except for TIROS-N
- the MODIS spectral band is half of the width

Individual Invariant Target and Combined Trends



Individual Invariant Target and Combined Trends



Error Analysis

- Aqua-MODIS band 1 absolute calibration uncertainty
  - 1.6% mostly from the uncertainty of the mirror BRDF
- Aqua-MODIS/NOAA-16 SNO calibration transfer uncertainty, based on the temporal standard error of the temporal fit
- The SZA radiance NOAA-16 model uncertainty, is the standard error of the regression
- The invariant target stability and temporal regression noise, is the standard error of the monthly gains about the trend
- SBAF uncertainty
- Band 1 combined fit uncertainty is between 1.5 to 2.5% (MODIS uncertainty not included), individual targets are larger

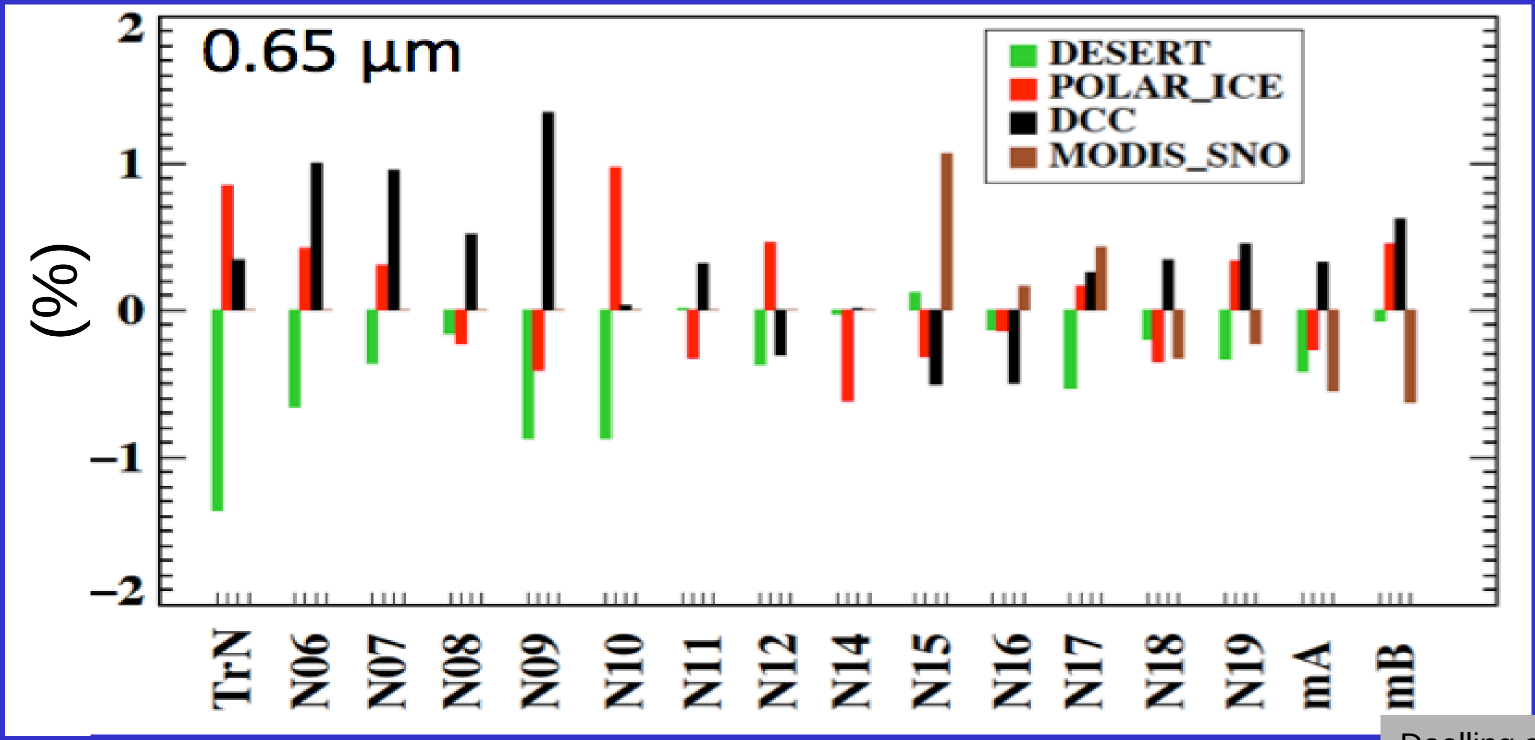
- The confidence of the trend is based on the time record, the magnitude of the trend, and the variability of the data

Validation Strategy

- Validate the combined invariant target calibration with Aqua-MODIS SNOs during the MODIS era
- Compare the consistency of the individual target calibration
- Compare the invariant target inter-sensor nadir reflectance (constant SZA) consistency

Calibration difference with the combined fit

- Compute the mean gain over the sensor record from all the monthly gains
- Compare the calibration difference with respect to the combined gain



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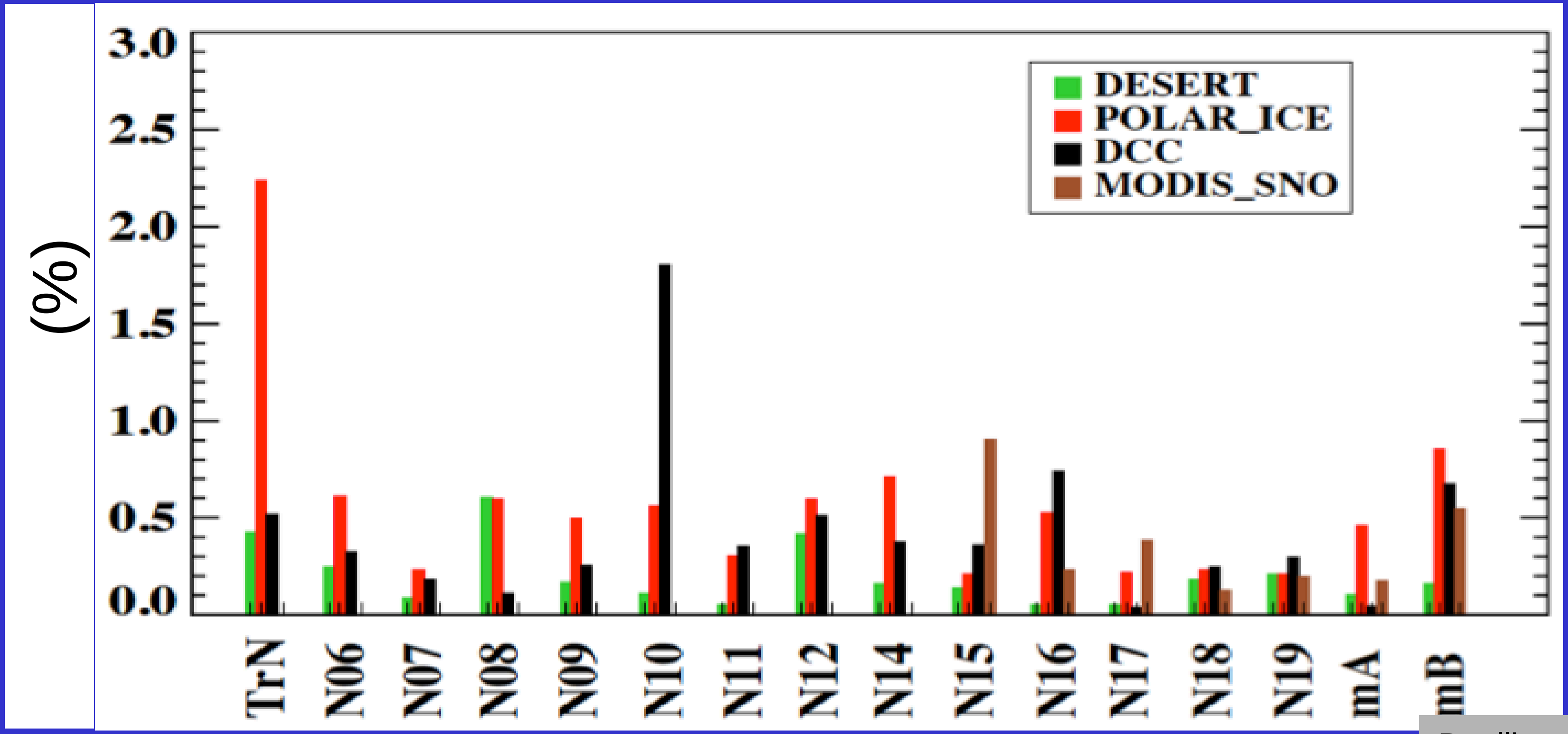
- The combined calibration is mostly within 0.5% of the MODIS SNO calibration
- NOAA-15 spent years in a near terminator orbit
- During the MODIS era most invariant target calibration are consistent within 0.5%
- During the pre-MODIS the invariant target calibration are consistent within 1%

Calibration trend compared with the combined fit

• Compute the RMS error from the monthly gains with respect to the combined gain after removing the mean timeline gain



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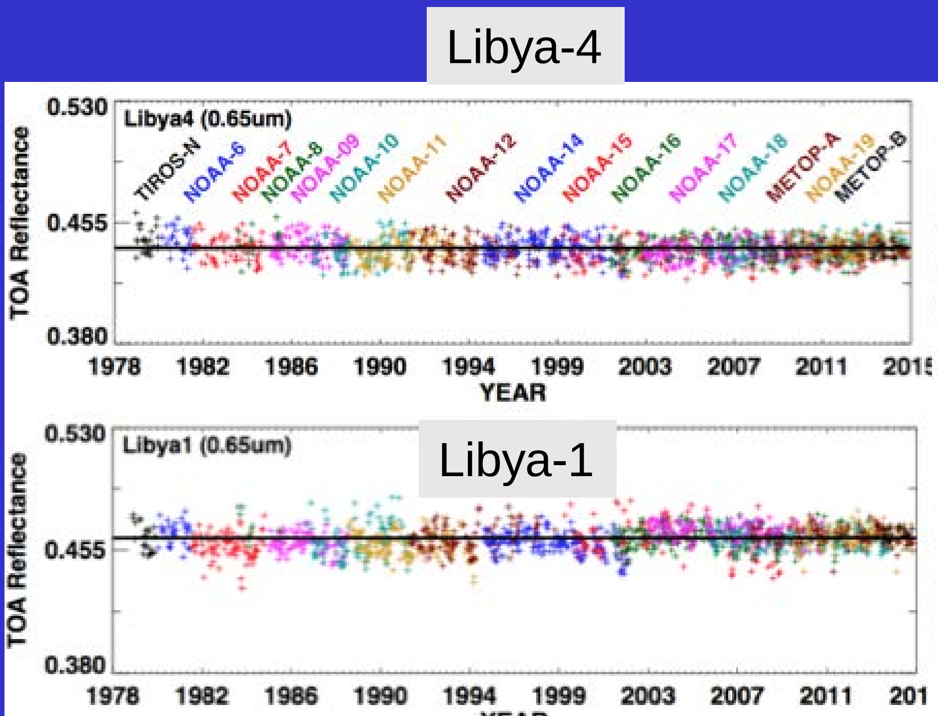
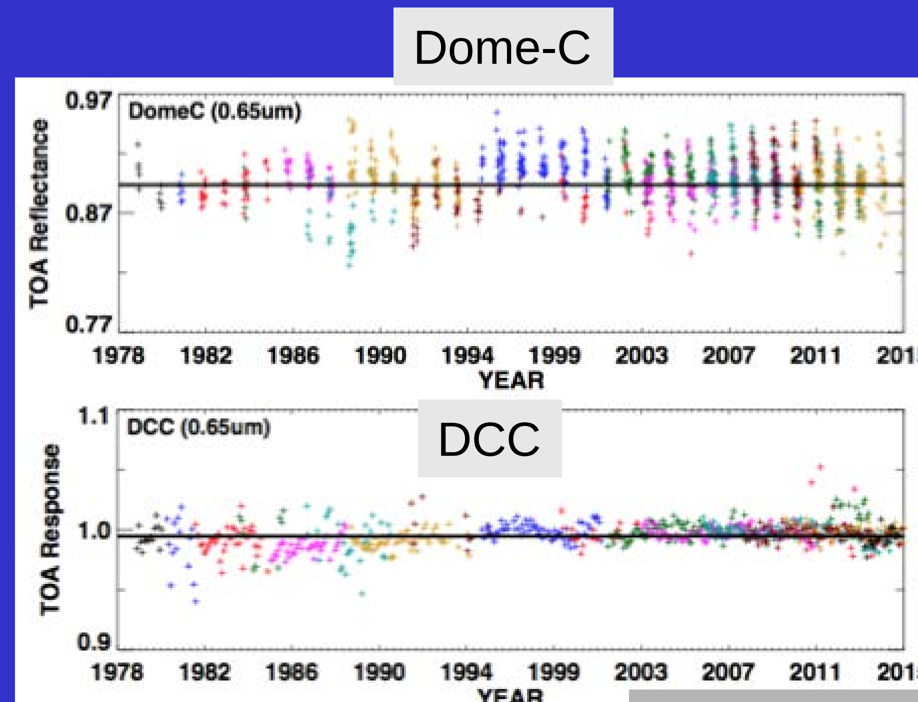
• Most trends are within 0.5% of the combined trend
• The combined trend is within 0.25% with the SNO trend for afternoon sensors
• DCC is only reliable to 60° SZA under current approach

Invariant Target Inter-Sensor Consistency

• For each sensor observations, apply the combined calibration and convert the nadir reflectance to a common SZA using the invariant target characterization model and convert to the NOAA-16 SRF using the site SBAF





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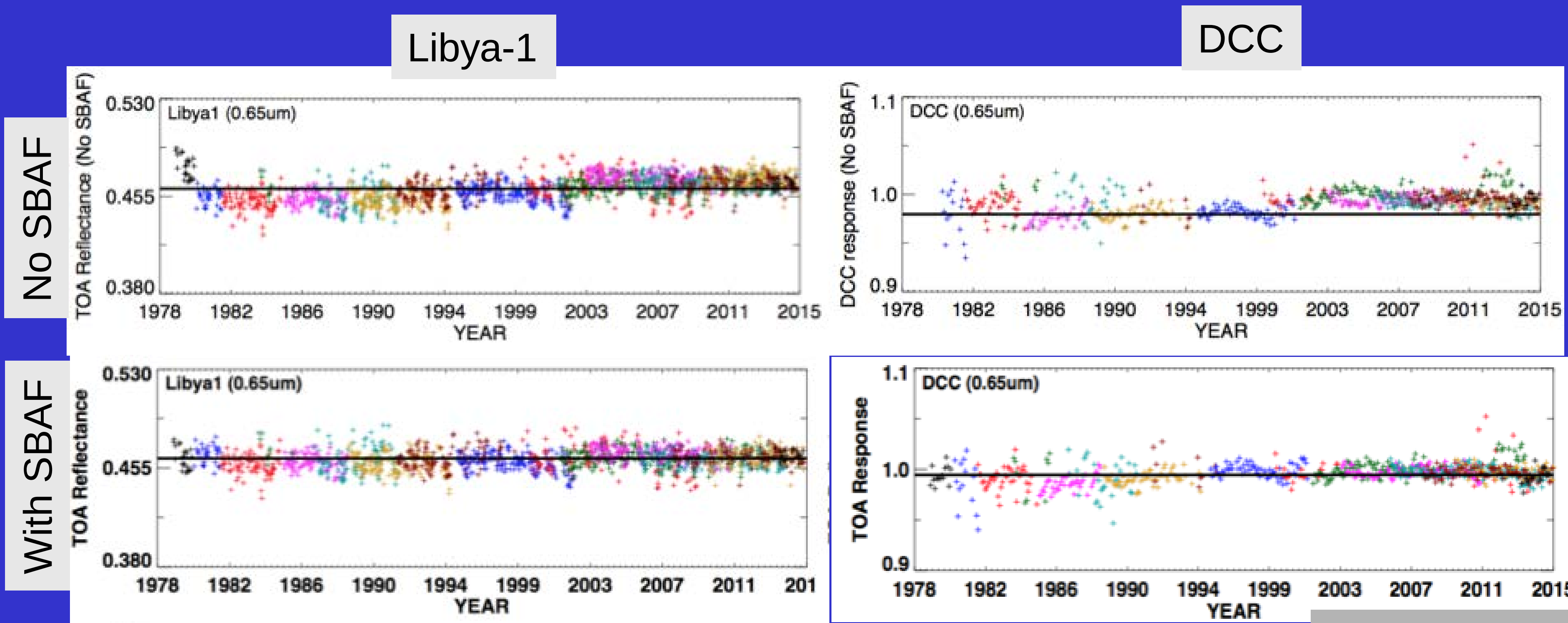
• Most sensors agree within 1 standard deviation with the 35-year average invariant target reflectance

Invariant Target Inter-Sensor Consistency
Validation of the target SBAFs



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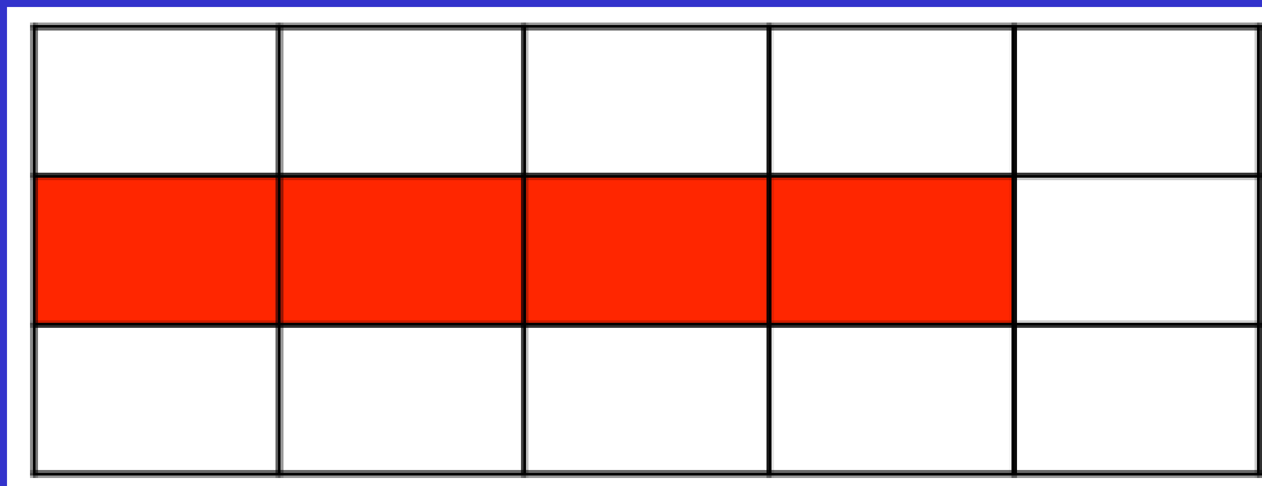
- Note the improved consistency after applying SBAF
- Each invariant has its own unique SCIAMACHY based SBAF

GAC Format Product

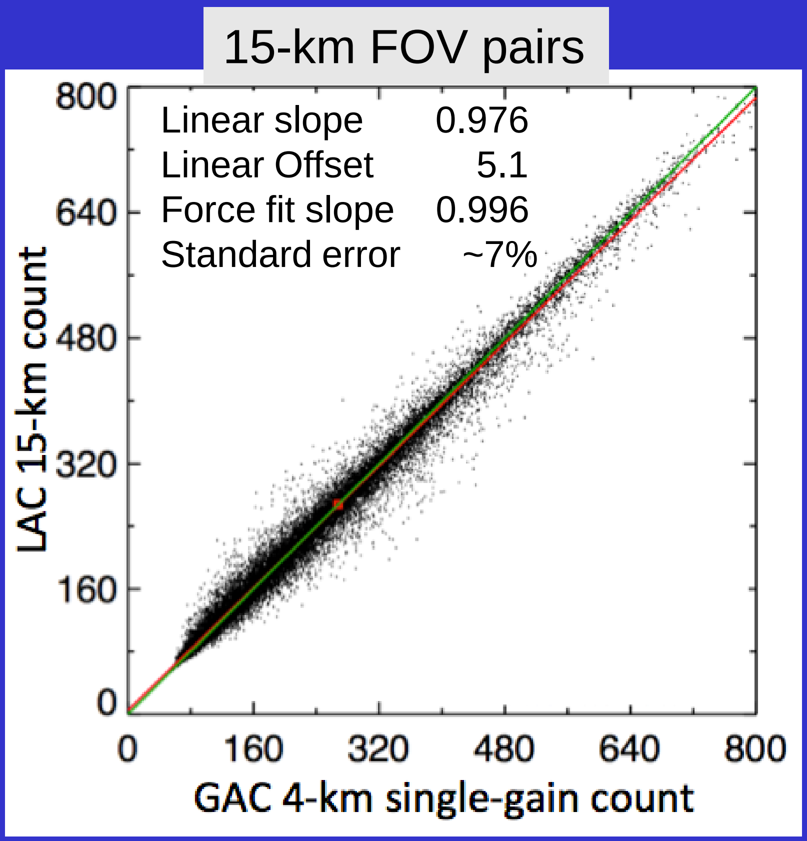
• The GAC formatted 15-km FOV product, simply averages 4 1-km nominal resolution pixel level counts
• For AVHRR/3 dual gain sensors, pixel counts are averaged without accounting for low or high gain

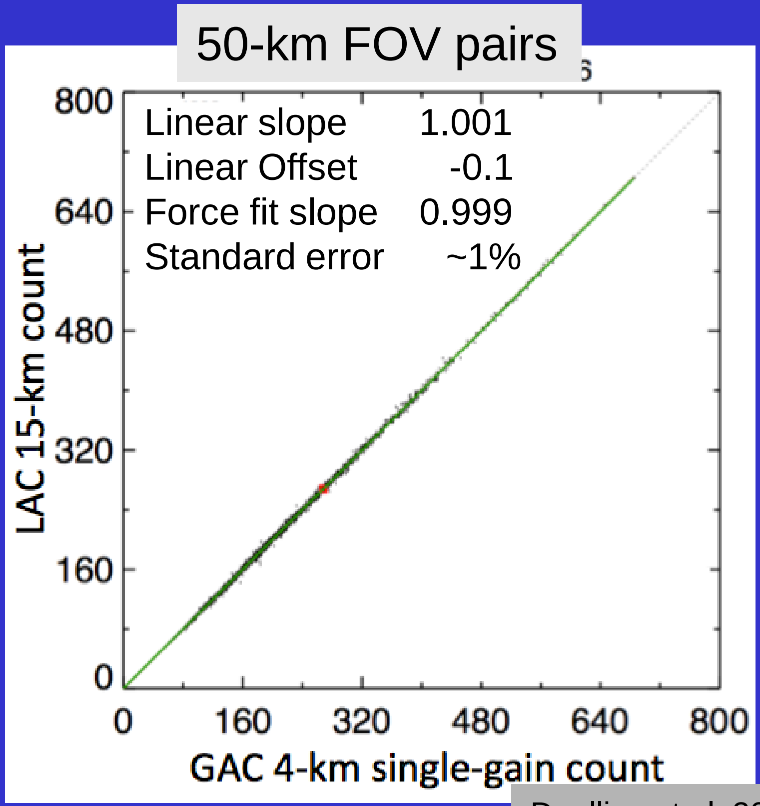


• The GAC format sub-samples 4 out of every 15 pixels, this causes sampling noise
• However, does the GAC format bias the calibration, since it averages both high and low gain counts?

GAC sub-sampling noise for linear response sensors

• Using a tropical LAC image, compute the GAC count and compare to the 15-km LAC equivalent count, no time or navigation miss-matches





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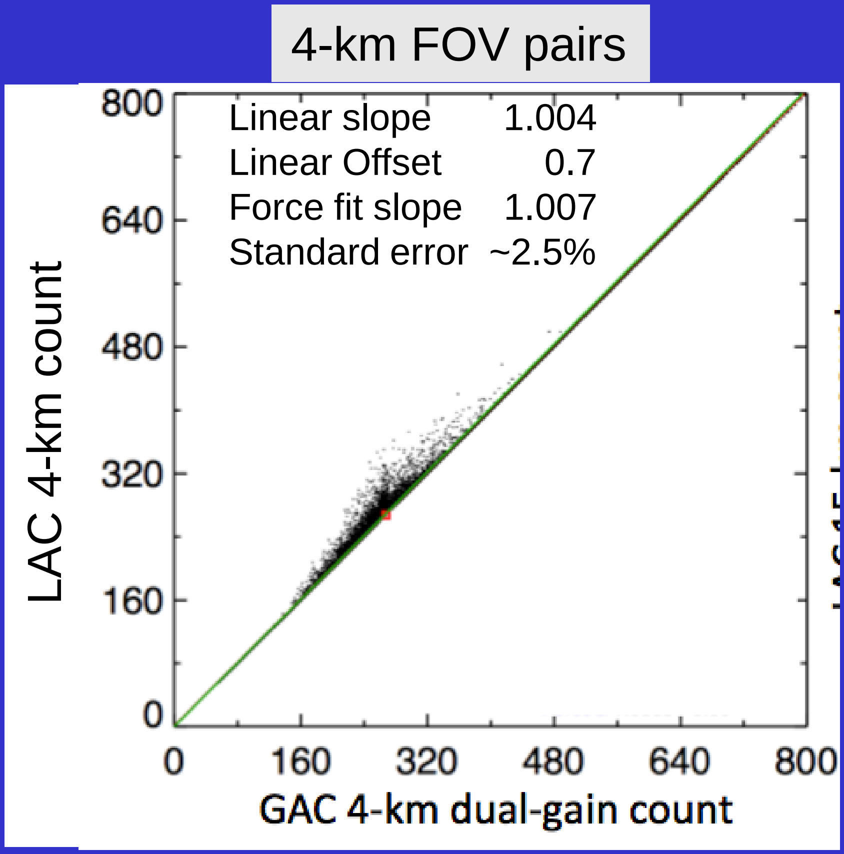
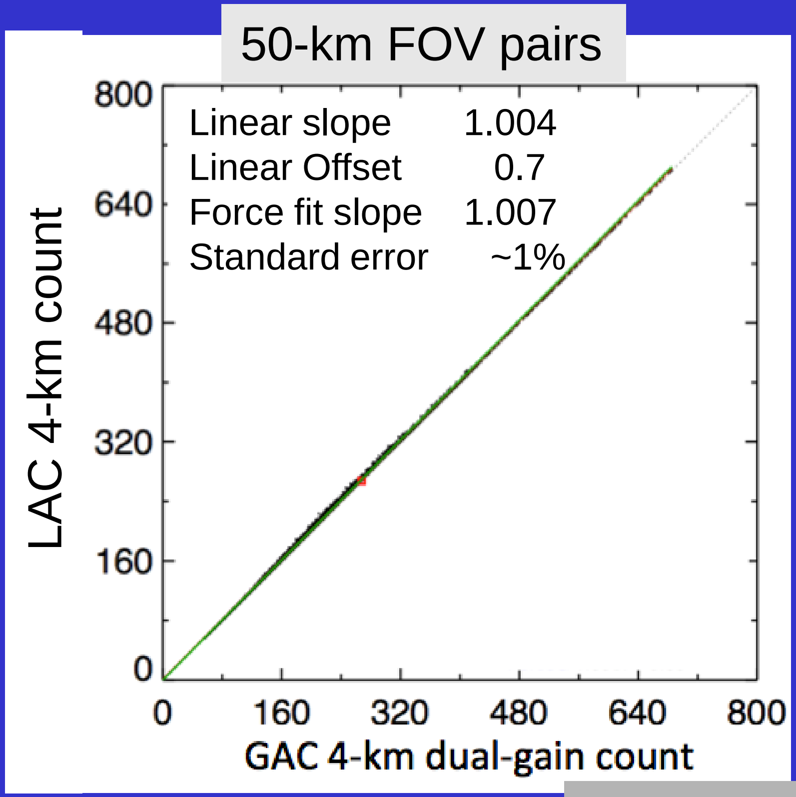
• The GAC sub-sampling noise can easily be mitigated by either using the force fit through the space count or by using large FOV

GAC count bias for dual gain response sensors

- Using a tropical LAC image, compute the LAC and GAC 4-pixel count
- Does not contain the sub-sampling noise, no time or navigation miss-matches





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- The resulting GAC count is always lower than the LAC count
- The LAC/GAC ratio is > 1

GAC format statistics

Dataset	FOV	Linear Regression			Force Fit	
		Slope	Offset	Stderr	Slope	Stderr
Sub-Sampled	15-km	0.9762	5.07	6.89	0.9996	7.04
	50-km	1.0005	-0.12	1.01	0.9999	1.01
Dual Gain	15-km	1.0037	0.67	2.53	1.0068	2.63
	50-km	1.0038	0.77	0.85	1.0074	1.14
Sub-Sampled Dual Gain	15-km	0.9803	5.62	7.07	1.0064	7.20
	50-km	1.0028	0.98	1.31	1.0075	1.31
	50-km, <σ15%	1.0006	0.34	0.82	1.0021	0.85

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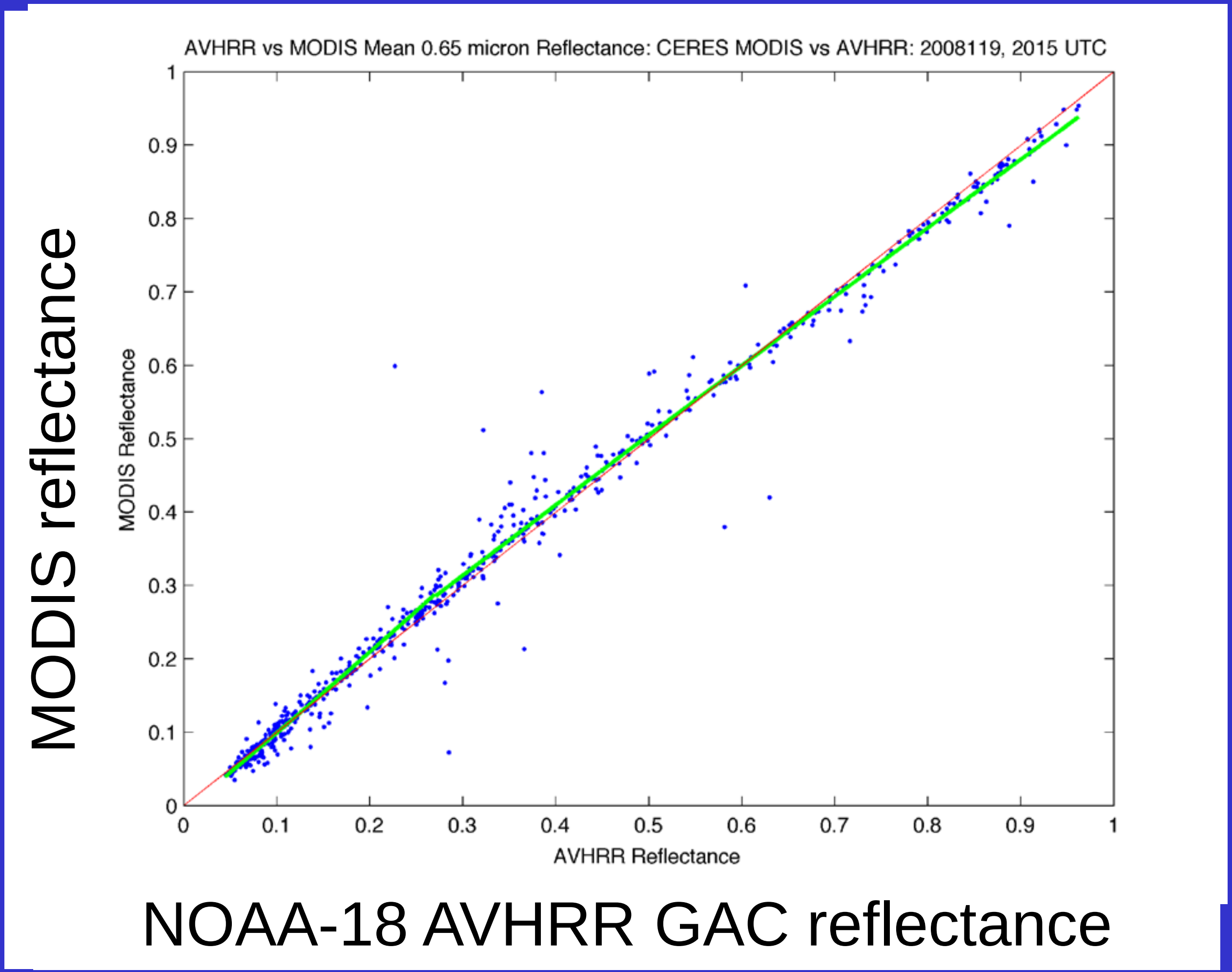
- The AVHRR invariant target calibration uses spatial homogeneity threshold to identify clear-sky desert and snow targets, and DCC cores
- When the GAC footprint has a uniform count, the GAC/LAC slope is nearly 1.
- However, when computing cloud properties over tropical conditions there is a 0.7% residual GAC/LAC slope bias, the GAC retrieved cloud properties are darker than for LAC

Compare MODIS and N18 AVHRR reflectances nearly SNO over the tropics



- The GAC retrieved reflectances are darker than for MODIS
- Need to increase the GAC dual gain calibration by 0.7% to mitigate effect

Conclusions

- The challenge of the NOAA degrading orbits was overcome by using NOAA-16 calibration as a reference
- Validation
  - The invariant target calibrations and MODIS SNOs agree within 0.5% during the MODIS era
  - The invariant target calibrations are consistent within 1.0% during the pre-MODIS era
  - The invariant inter-sensor consistency are within 1 sigma of the mean 35-year reflectance
- Non-uniform dual gain GAC pixels tropical reflectances maybe underestimated
- Future
  - Reassess the selection of the temporal trend
  - Validate with AVHRR AM/PM SNOs
  - Monitor the global mean optical depth