Inter-Calibration Space/Time/Angle Matching

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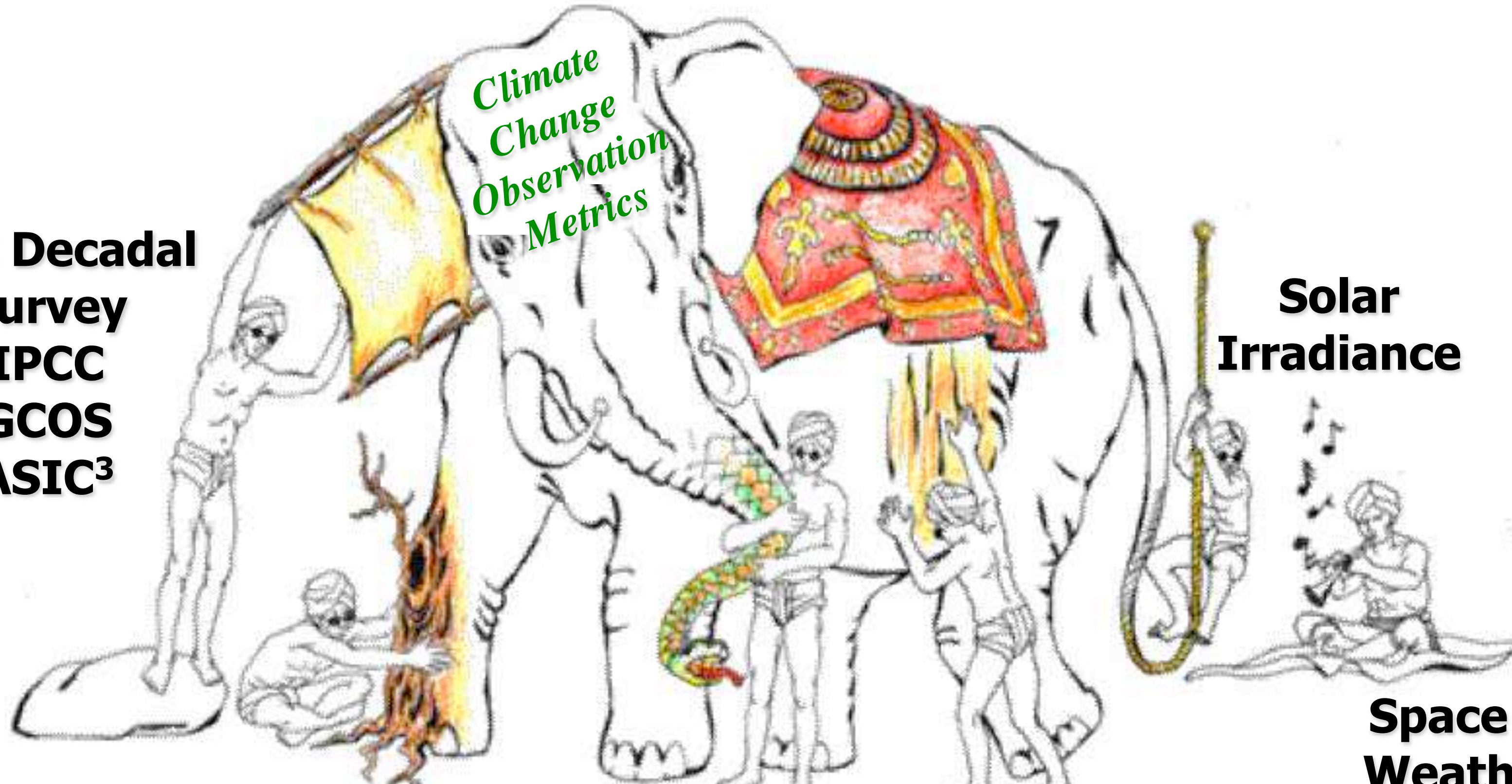
CLARREO and Climate Change

Groping Toward "The Truth, The Whole Truth, and Nothing But The Truth"

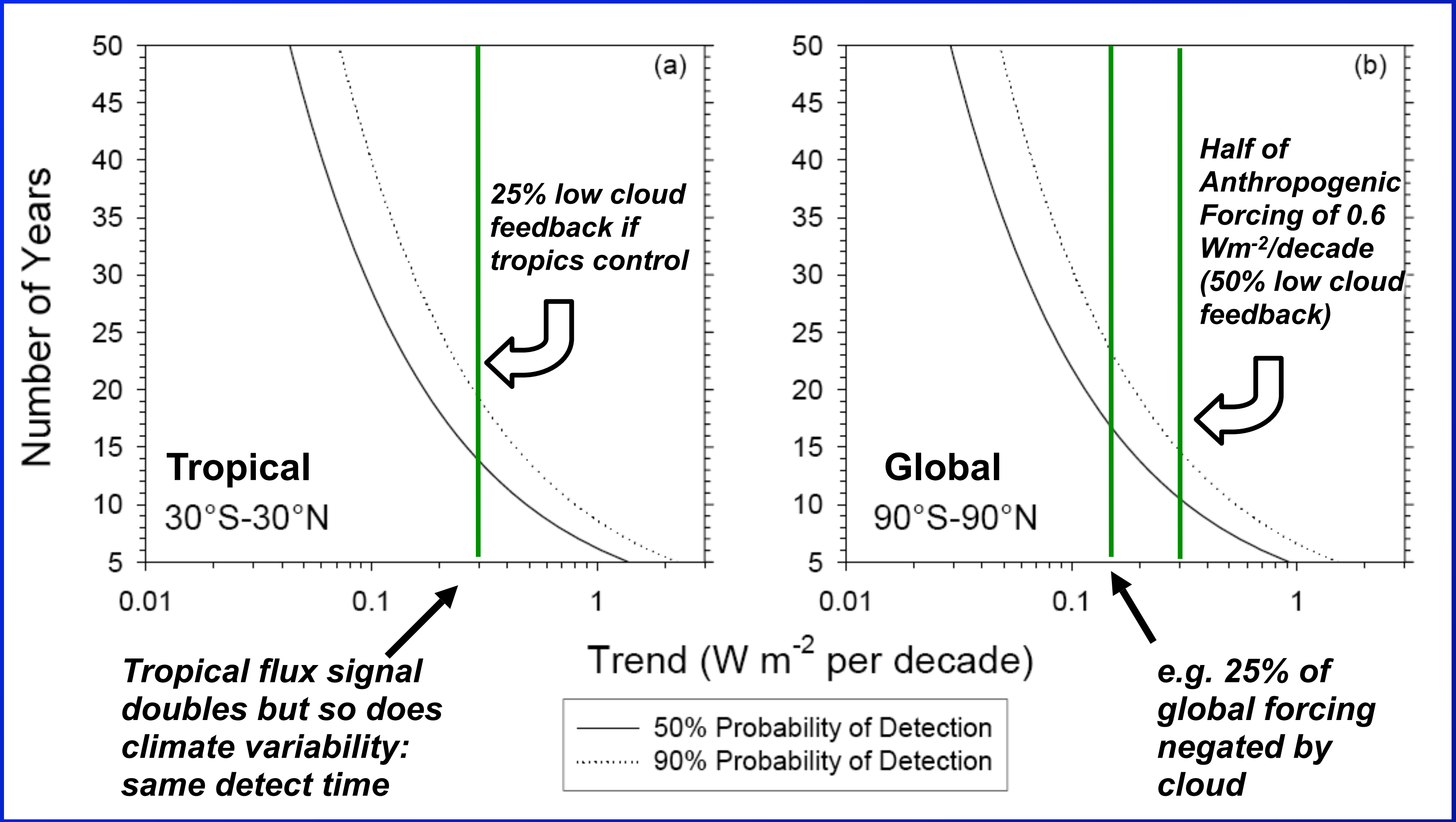


And the first blind man said, "To learn the truth, we must put all the parts together"

IPCC AR4 Report: Low Cloud Feedback Largest Uncertainty

How long to observe a 25% low cloud feedback?

For low clouds: Earth reflected solar flux dominates the feedback

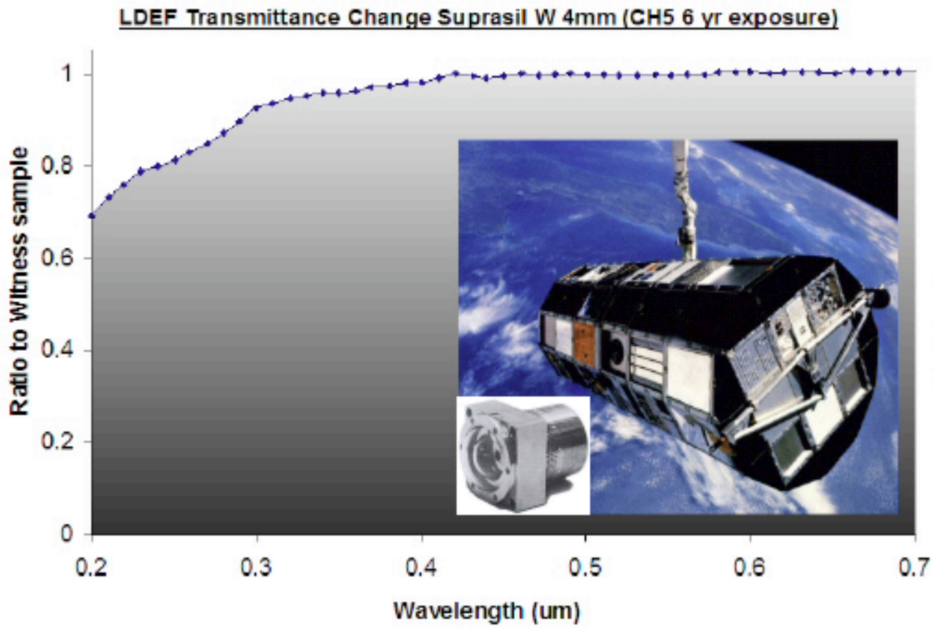


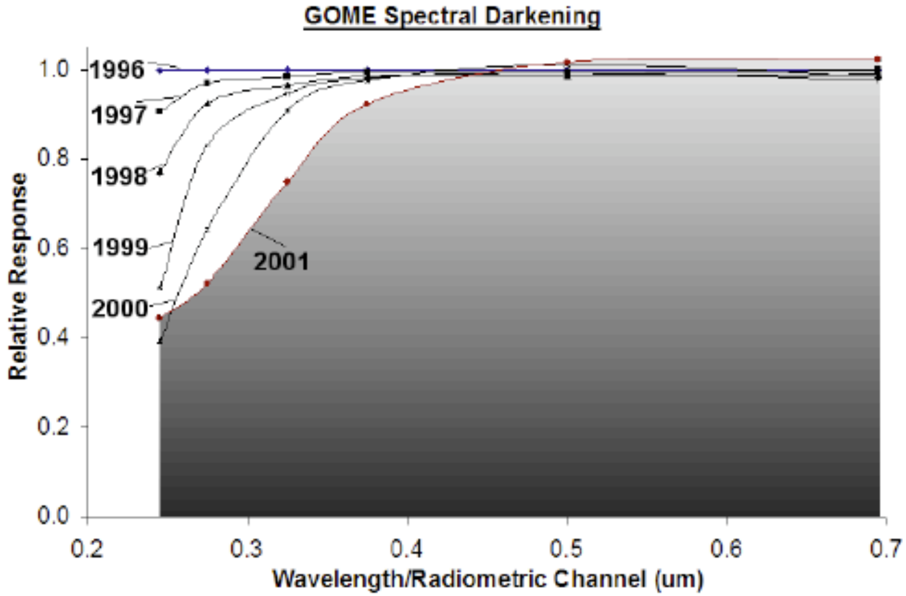
Given climate variability, 15 to 20 years is required to detect cloud feedback trends with 90% confidence. Loeb et al. J. Climate, 2007

Requires cloud radiative forcing calibration stability of 0.3% per decade

Evidence for Solar Optics Contamination in Orbit: Especially below 0.5μm wavelength

This matches the shape of spectral darkening occurring on LDEF and GOME:

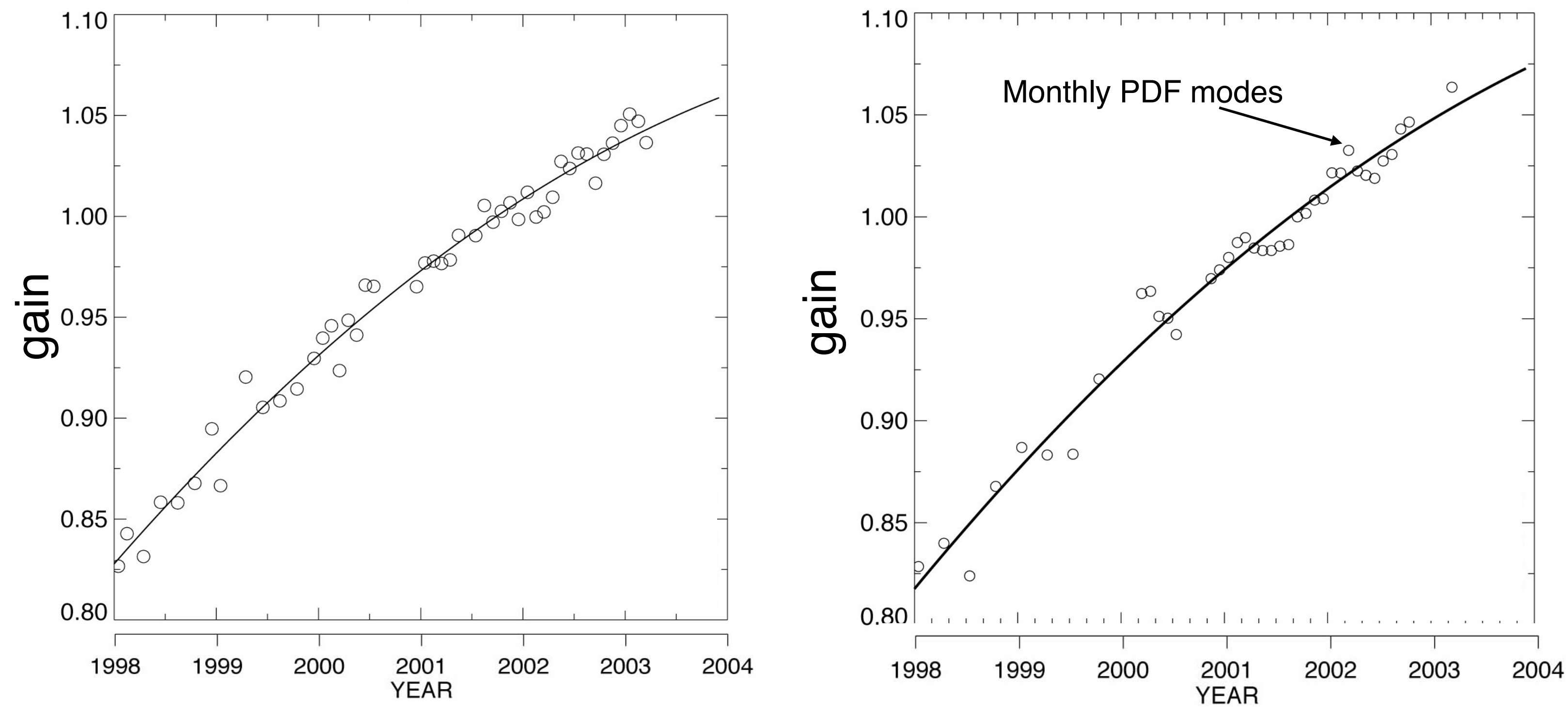




Conclusion: It is critical to provide spectrally dependent calibration to reach climate accuracy for solar reflectance. From G. Matthews, 2007

Comparison of LEO-GEO Intercalibration and that using Deep Convective Clouds: Detector Gain Change

GOES-8 based on VIRS | **GOES-8 based on DCCT**



D. Doelling

Conclusion: Changes of visible channel calibration can be 3 to 5% per year, and normal methods reach consistency of ~ 2 to 3%, a factor of 10 larger than that sought for climate change ~ 0.2%

So how do we reach climate accuracy?

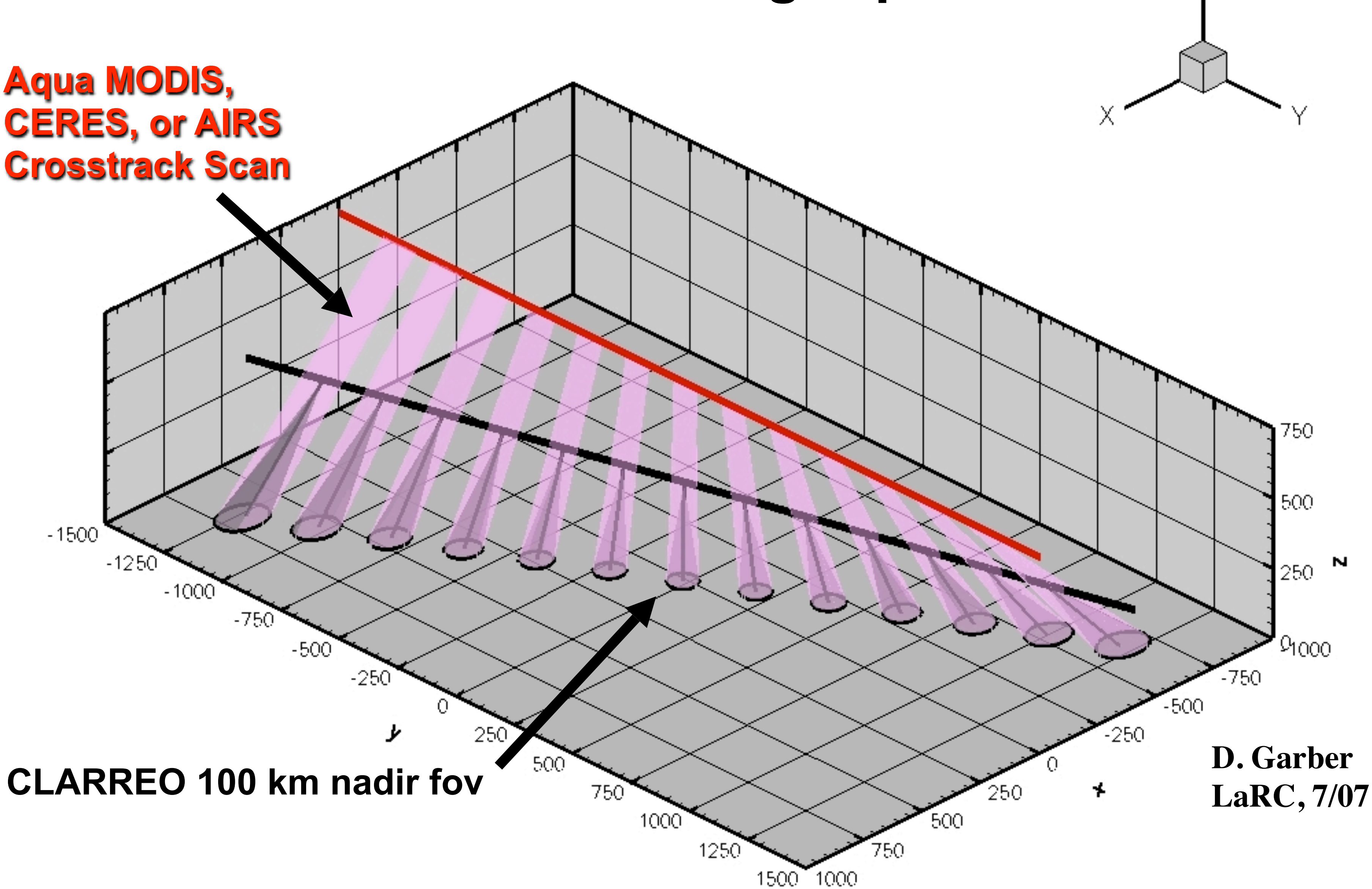
- One way is to make all instruments at climate accuracy of 0.2% solar reflectance, and 0.1K infrared. Much more effort, mass, power, put into on-board calibration sources. NPOESS VIIRS imager will be less well calibrated than MODIS.
- Fly multiple copies of all instruments (like CERES on Terra/ Aqua) to independently confirm surprises.
- Do lunar calibration pitchovers like SeaWiFS (~ monthly) to verify against more stable targets like the moon (NPOESS, NPP and Aqua refuse, Terra did it once, TRMM 6 times).
- CLARREO suggests that a better and more cost effective approach is to fly benchmark solar and infrared spectral radiance records in space: how could these be used to calibrate the other instruments in orbit?

Radiation and Calibration are 8-dimensional Sampling Problems

- Latitude
- Longitude
- Altitude
- Time
- Solar Zenith Angle
- Viewing Zenith Angle
- Viewing Azimuth Angle
- Wavelength

- Radiance signals vary a factor of 2 to 10 with all of these dimensions. Yet key climate change is a few tenths of a percent/decade.
- Climate Change adds a stealth "9th dimension": accuracy

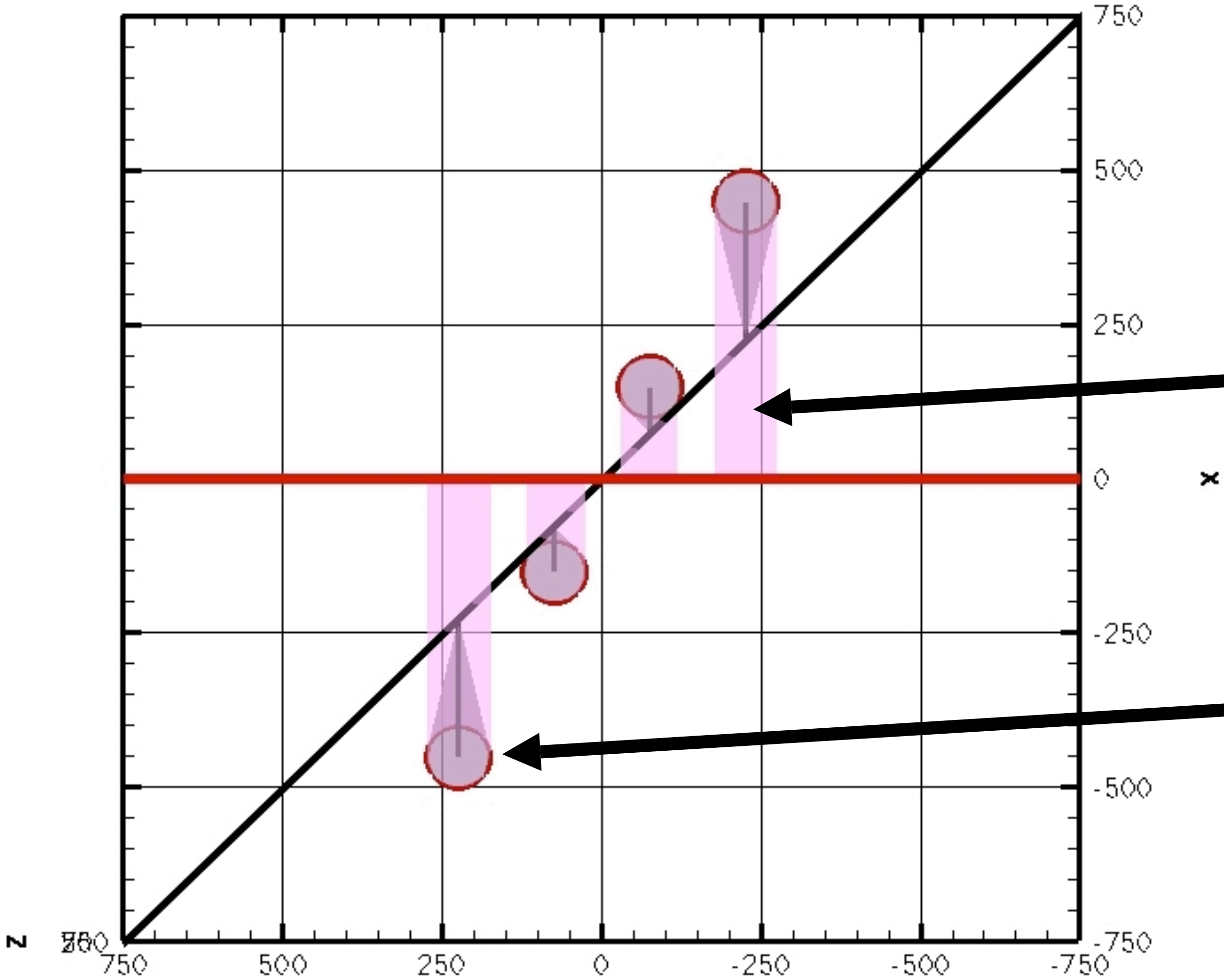
CLARREO 350km Crossing Aqua 700km



D. Garber
LaRC, 7/07

Time to Achieve Viewing Angle Matches:
40 seconds per 100km orbit altitude Difference: 140 seconds above

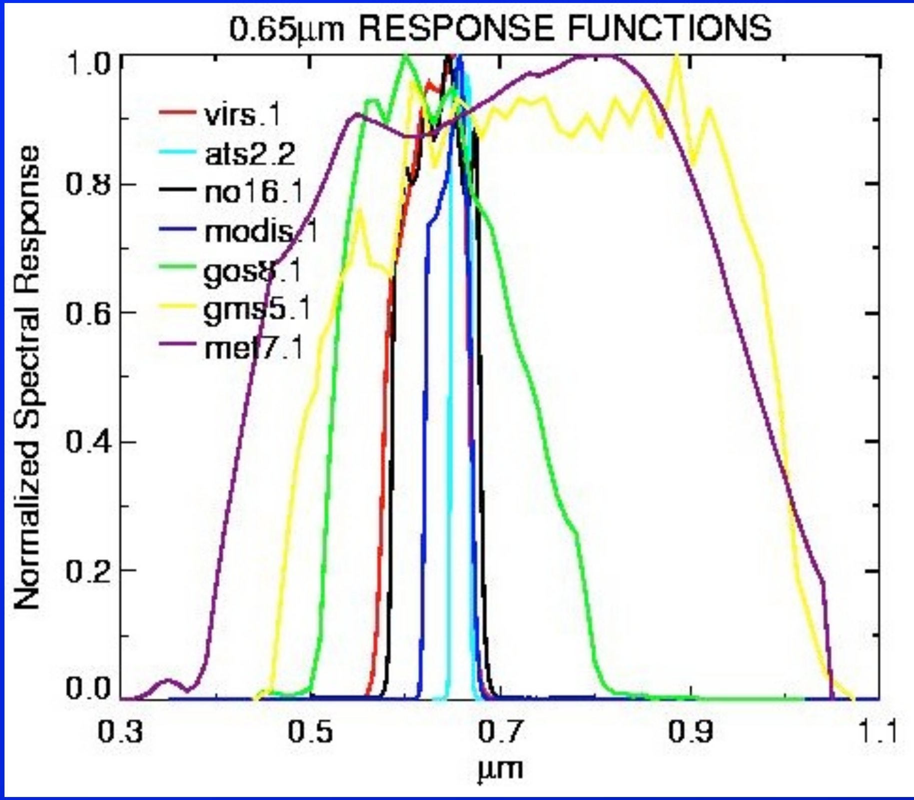
Top View: CLARREO 350km, Aqua 700km

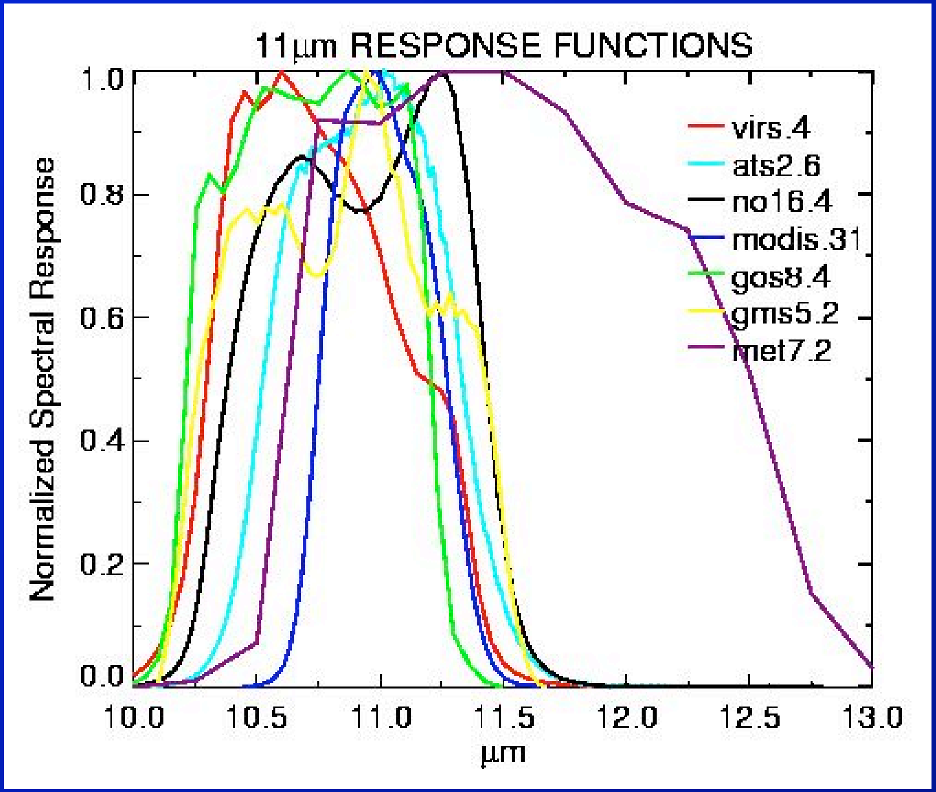


Angle Pointing (zenith, azimuth) is required to obtain any calibration matches beyond those at nadir. Options: pointable instrument, pointing table, or S/C reaction wheels

D. Garber
LaRC, 7/07

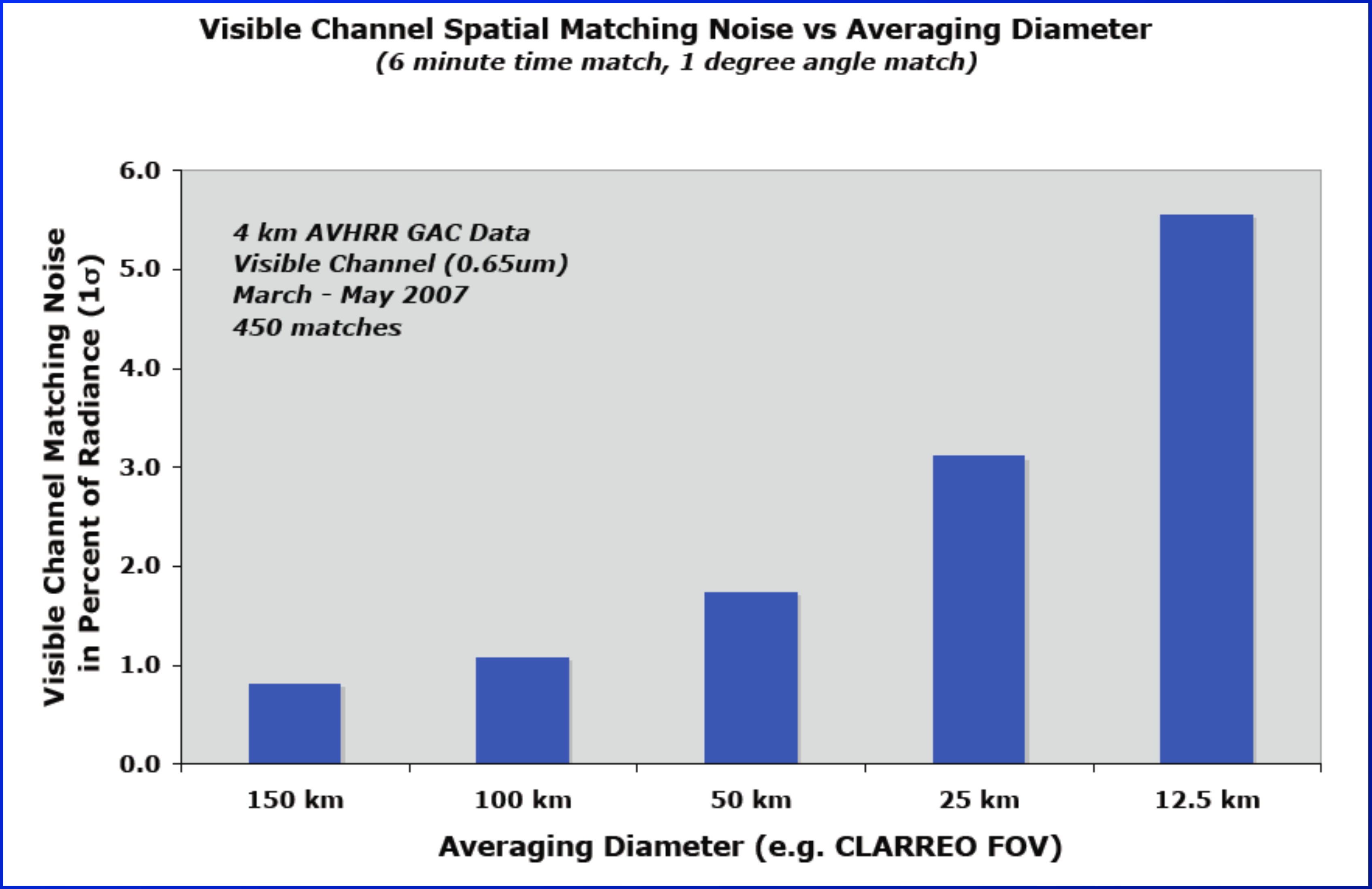
0.65μm & 11μm Channel Spectral Response Functions Vary Greatly





Similar variations seen in other channels..

How Does Field of View Affect Matching?



D. Doelling

Conclusion: 50 to 100km field of view needed to reduce noise.

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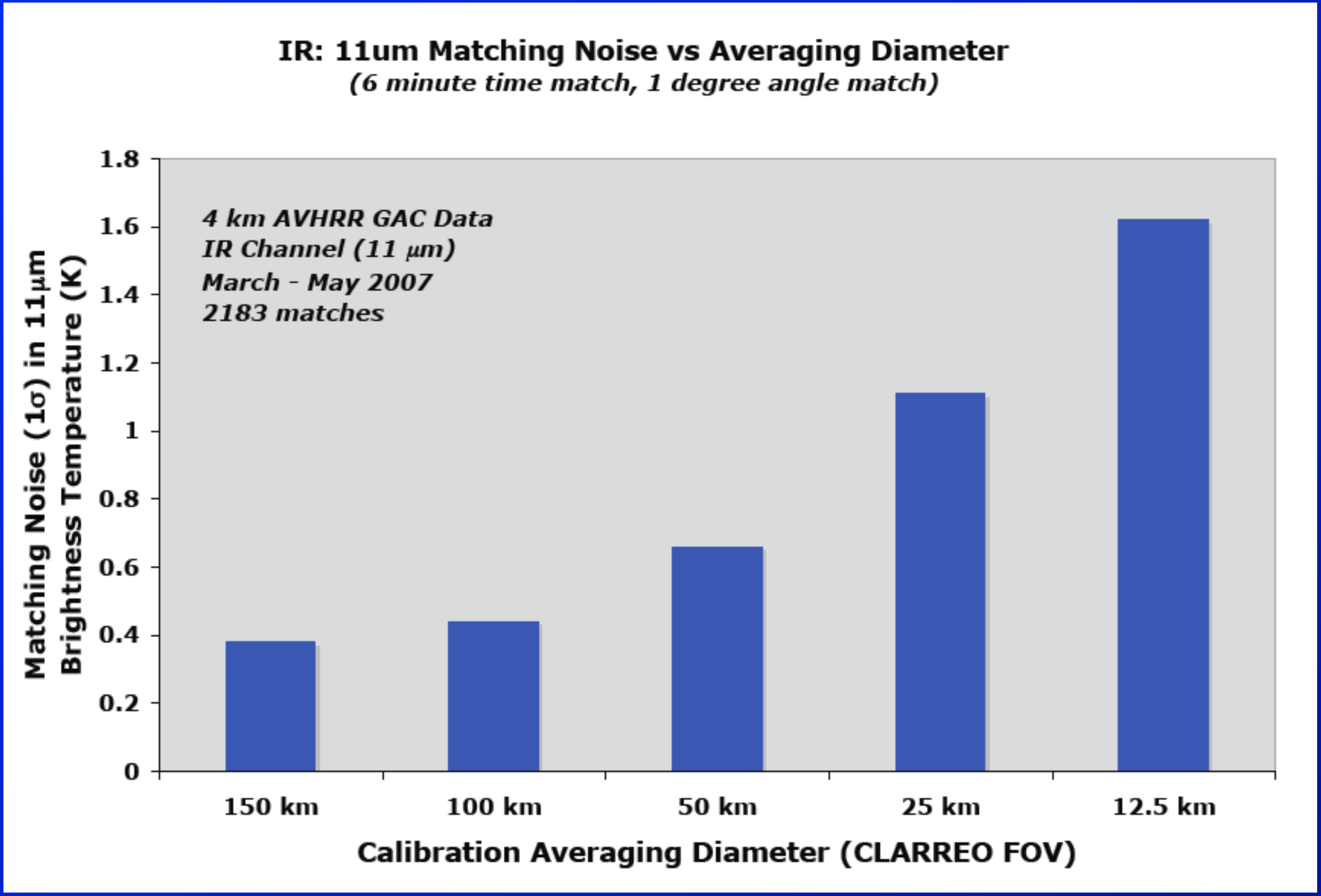

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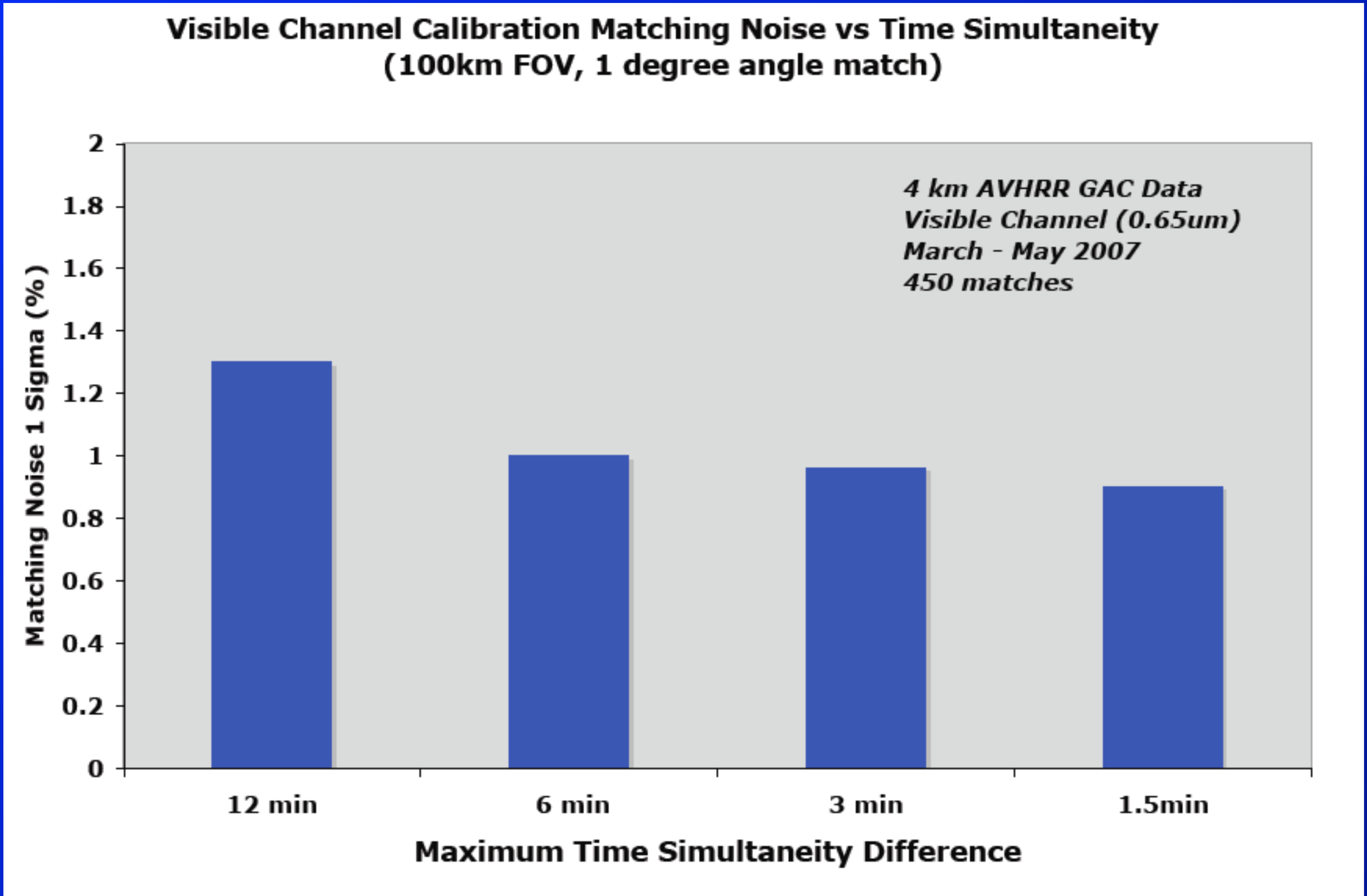
How Does Time Simultaneity Affect Matching?



Conclusion: At 100km fov, 6 minute time simultaneity is sufficient

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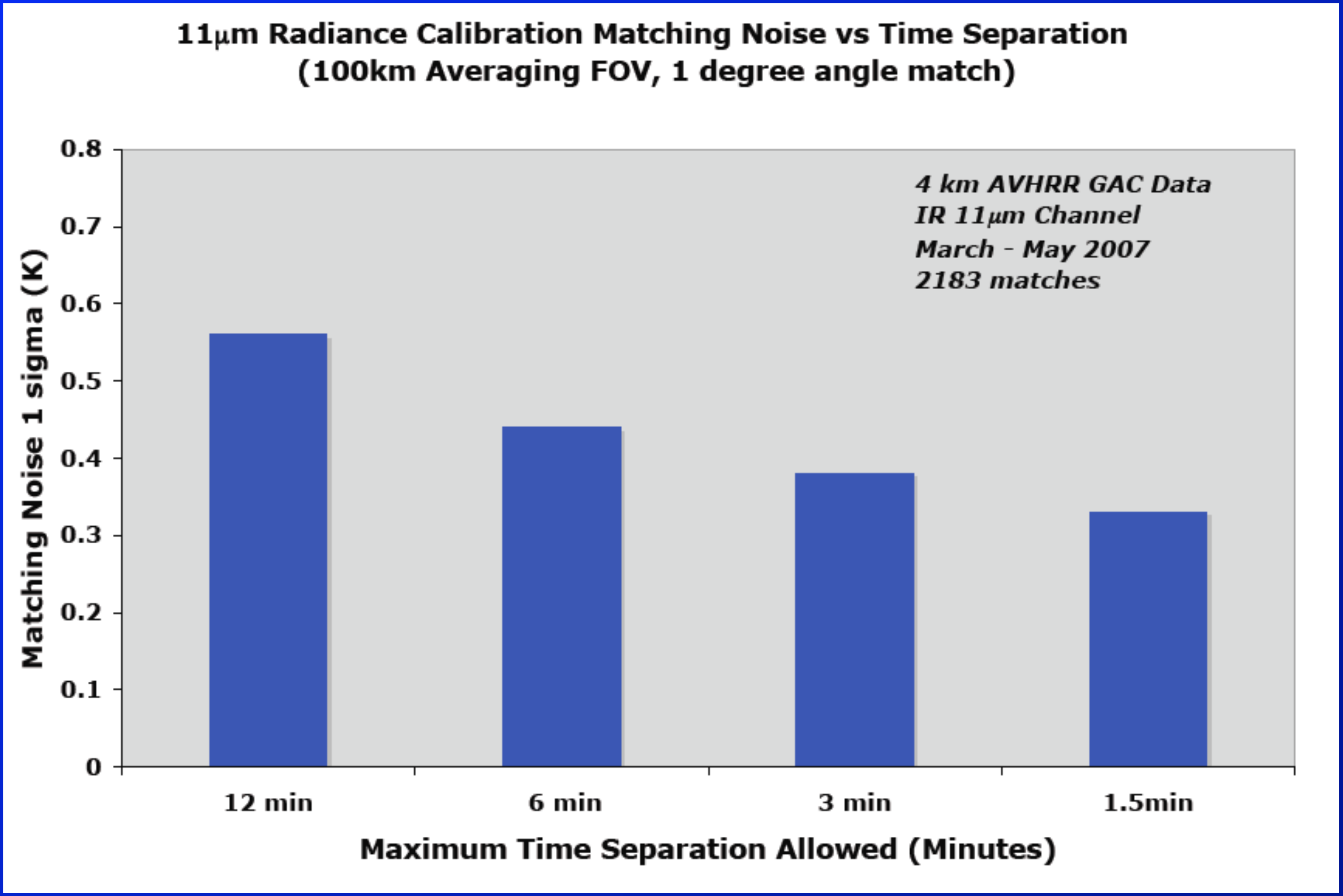

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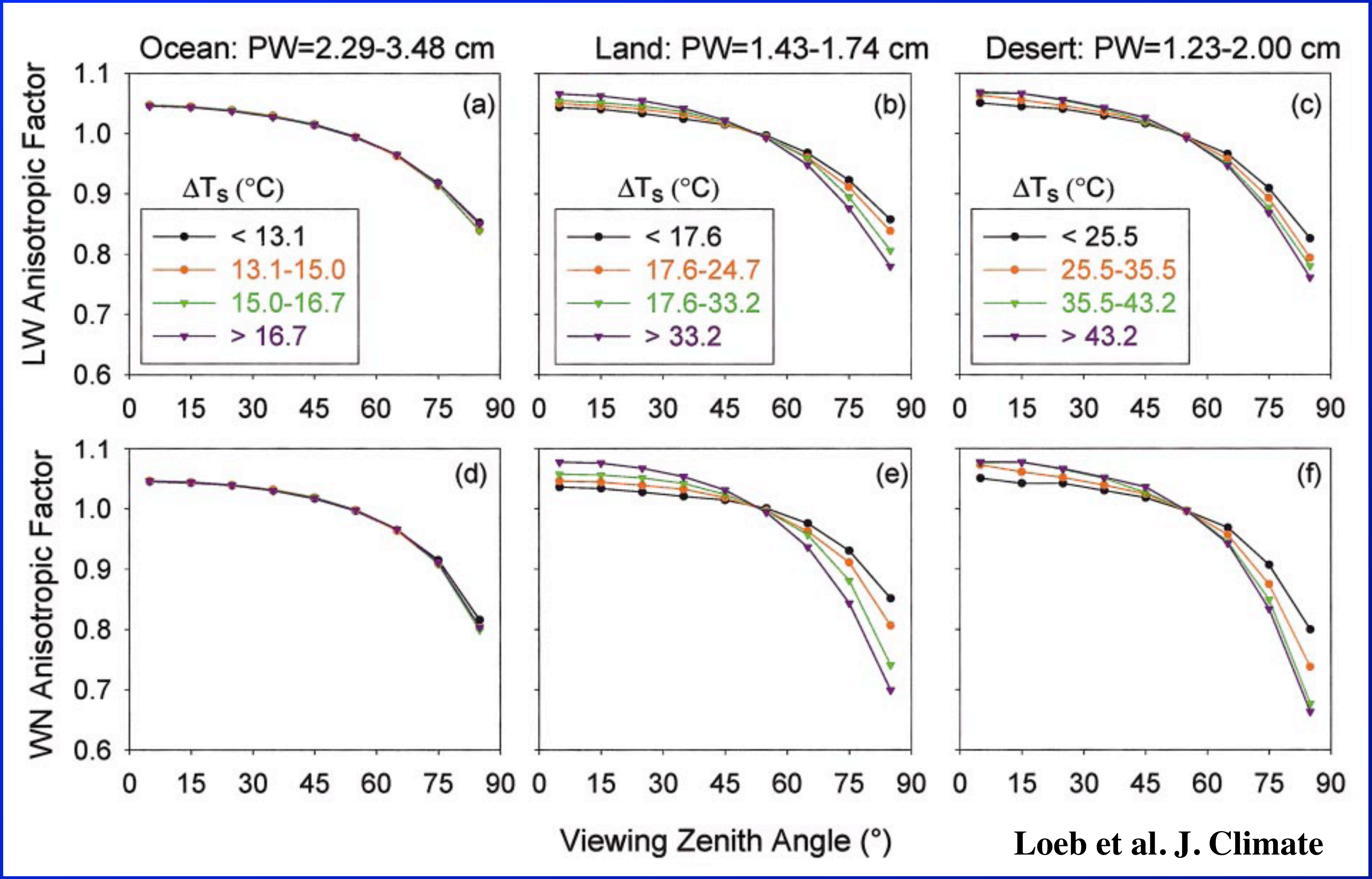
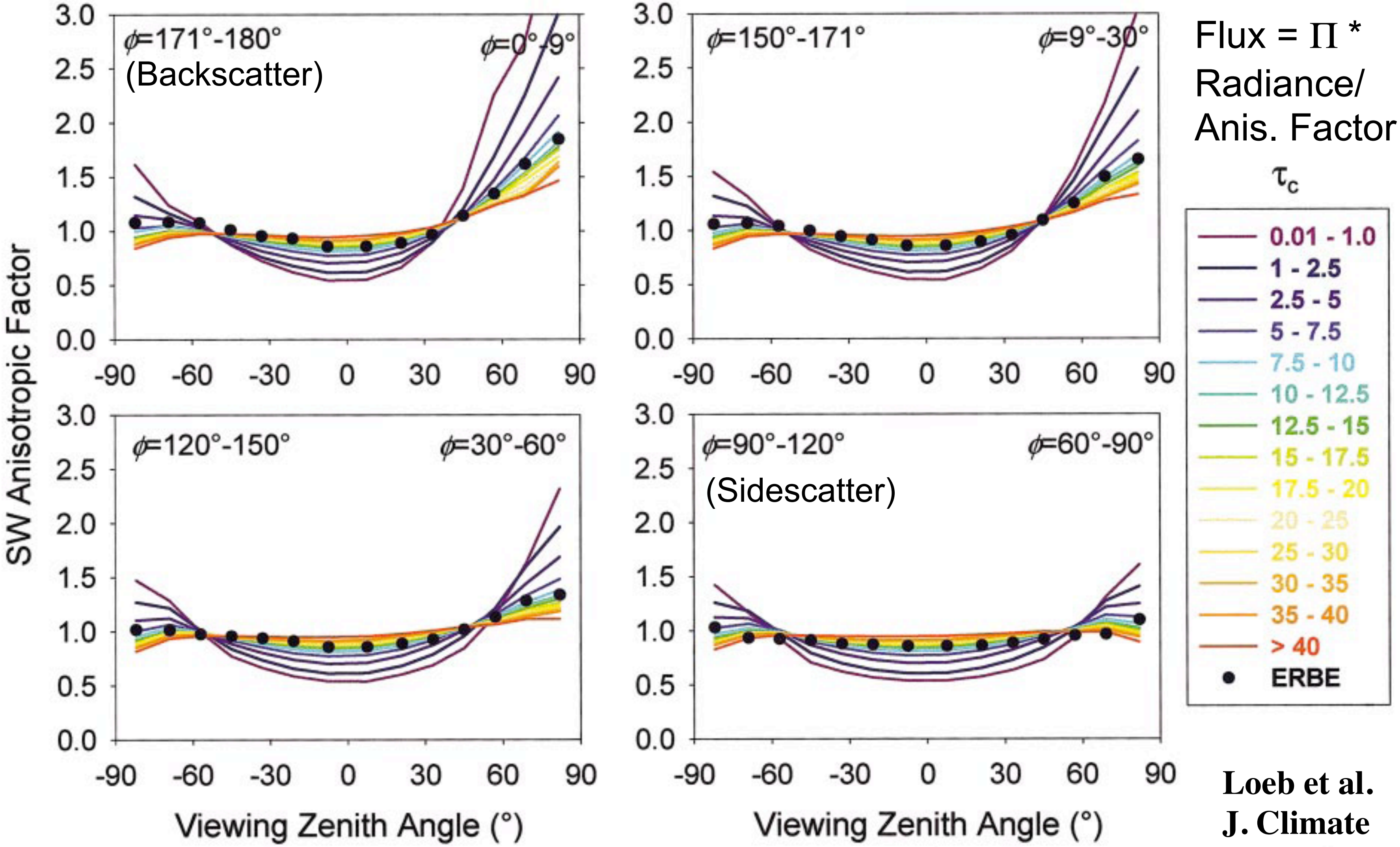
Infrared Anisotropy: Radiance to Flux Ratio



Typical Broadband Longwave Anisotropic effect is ~ 5 to 10%
Typical Atmospheric Window (WN) Anisotropic effect is ~ 10 to 20%.

Solar Reflected Anisotropy: Radiance to Flux Ratio



Loeb et al.
J. Climate

Typical Broadband Shortwave Flux Anisotropic effect is ~ 50 to 200%.
Factor of 10 larger anisotropy issues in solar reflected observations than IR.

Influence of Angle Mismatch in Satellite Instrument Intercalibration

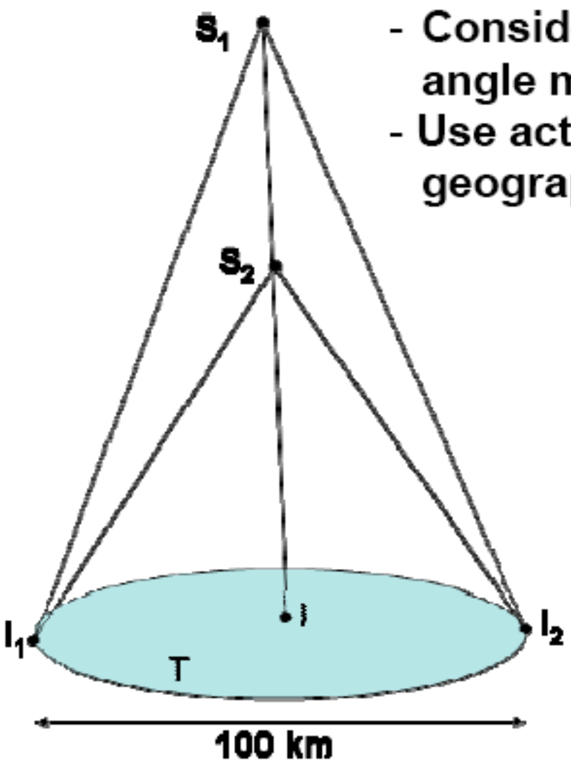
- Over a given region, satellite angle sampling depends upon satellite altitude:

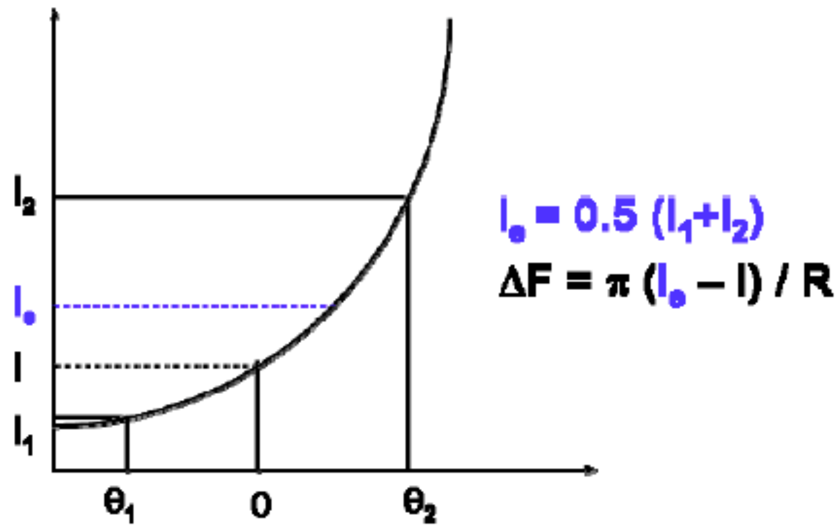
=> For a satellite at 750-km: angle range over 100-km region is ± 4° (about nadir)

For a satellite at 350-km: angle range over 100-km region is ± 8° (about nadir)

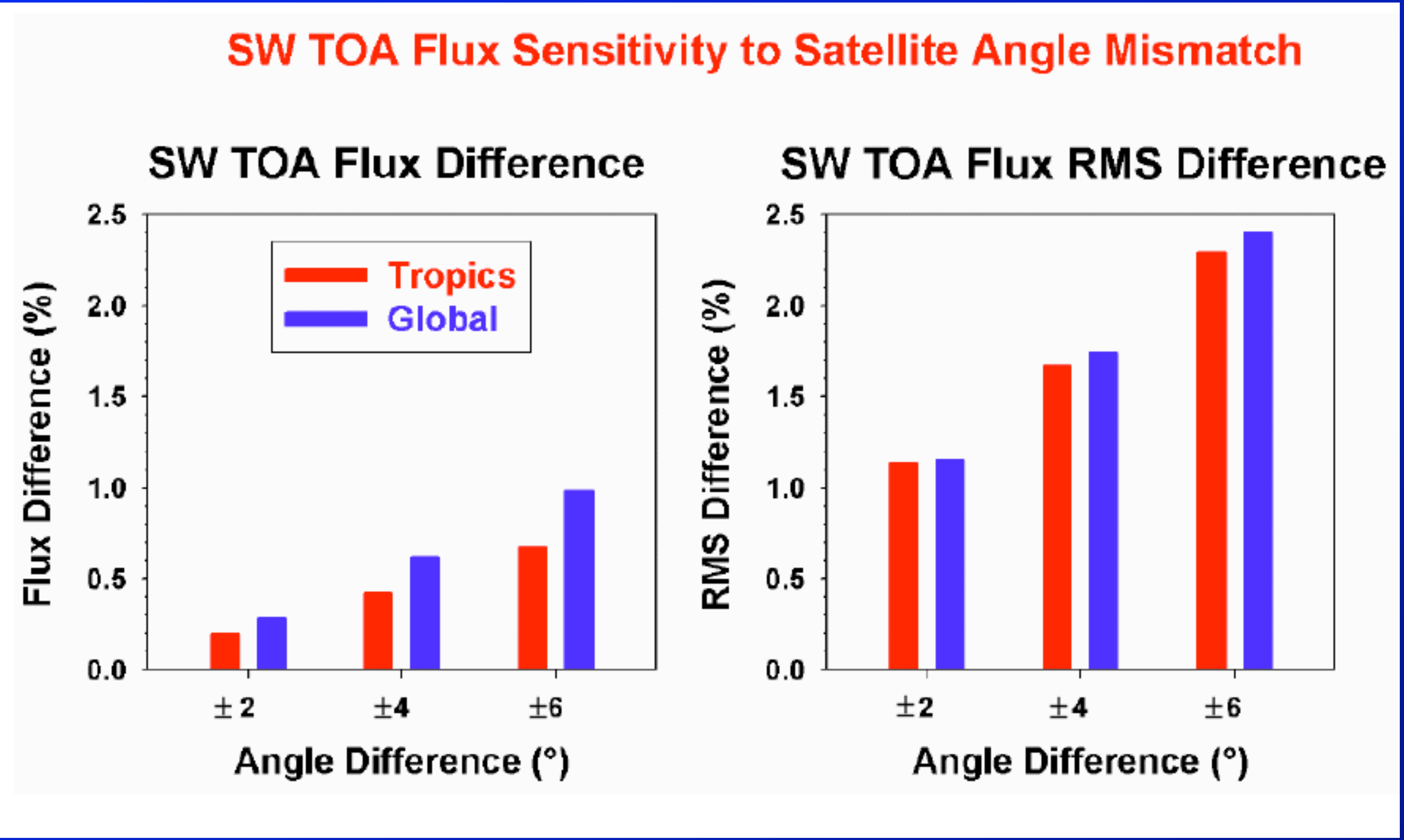
- Assuming satellite views are aligned in the center of the region, what is the impact of angle mismatches in other portions of the region?

- Assume $S_1 >> S_2$ (worst case scenario).
- Use CERES ADMs to infer I_1, I_2 and I at S_2.
- Consider variations in both θ and ϕ for 2°, 4° and 6° angle mismatches.
- Use actual CERES data (5 days) to get representative geographical scene distribution.



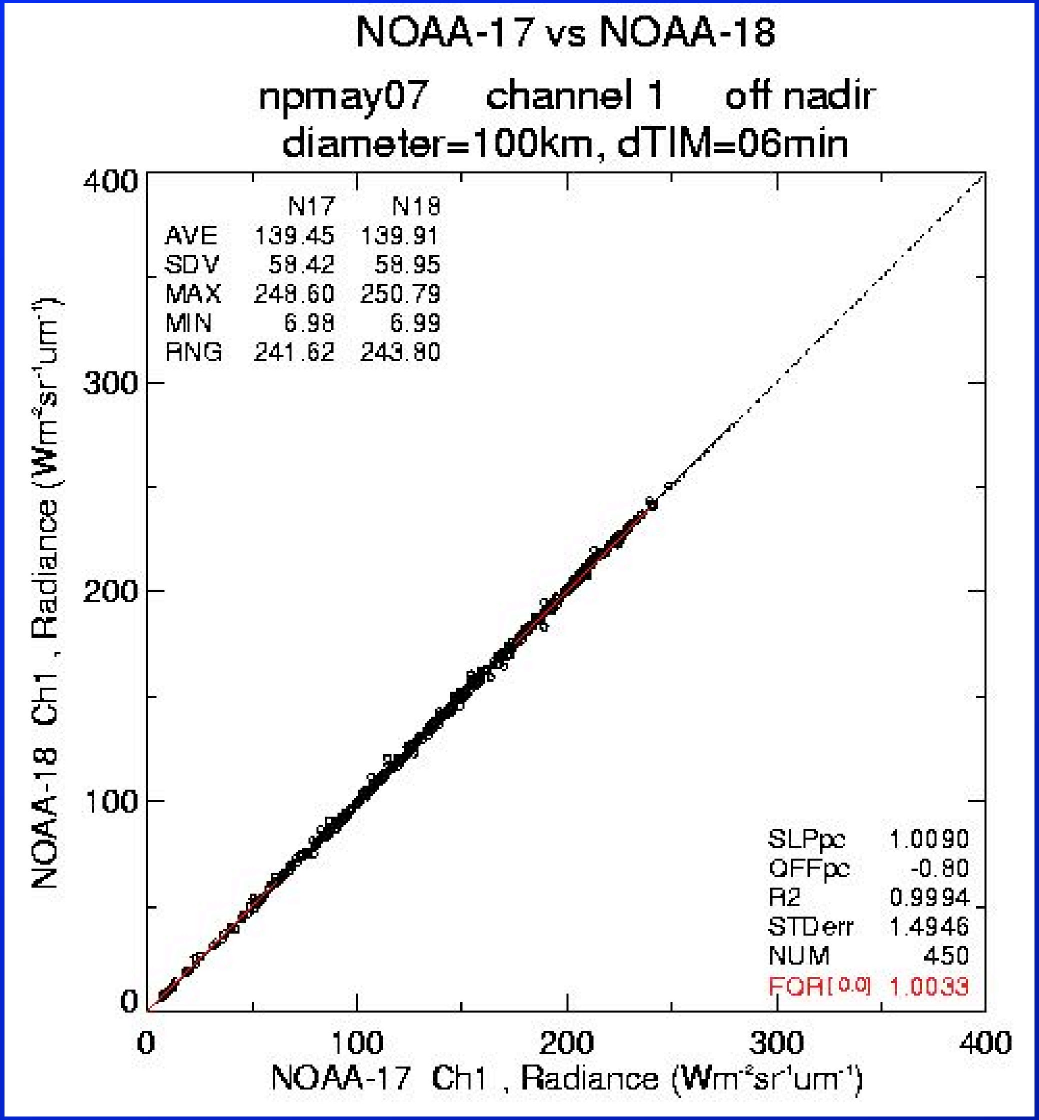


How Close in Viewing Angle to Calibrate?



Conclusion: Close angle matching is critical for bias and noise.

NOAA 17 to 18 AVHRR Visible Channel Intercalibration



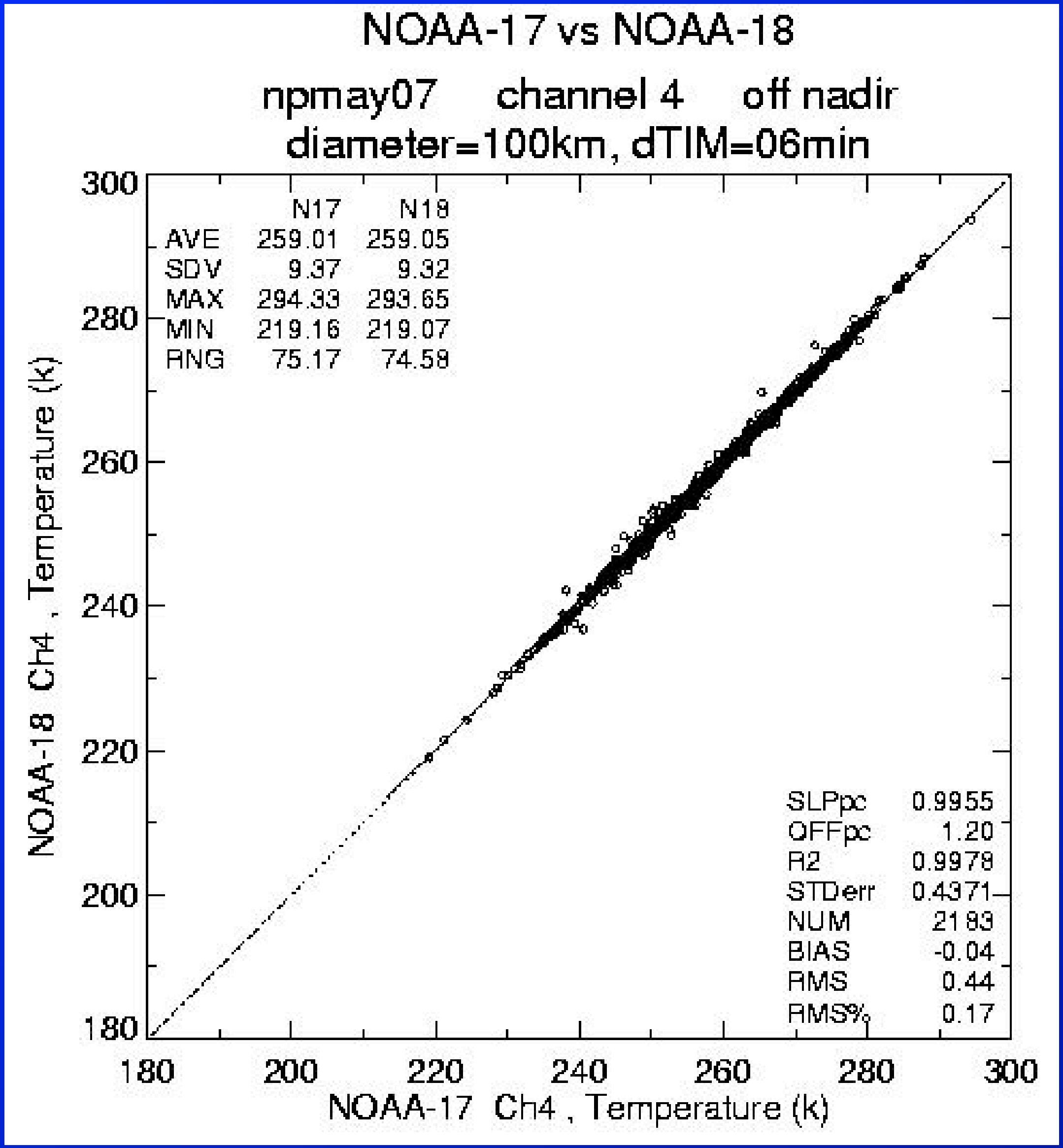
Spectral bandpasses agree,
100-km spatial match
1-degree angle match,
6-minute time match:

Sigma is 1.1% visible radiance
For single 100km fov match.

Data shown is 3 months of matching data (Apr-May07)

Caveat: polar only

NOAA 17 to 18 AVHRR 11μm Window Channel Intercalibration



Spectral bandpasses agree,
100-km spatial match
1-degree angle match,
6-minute time match:

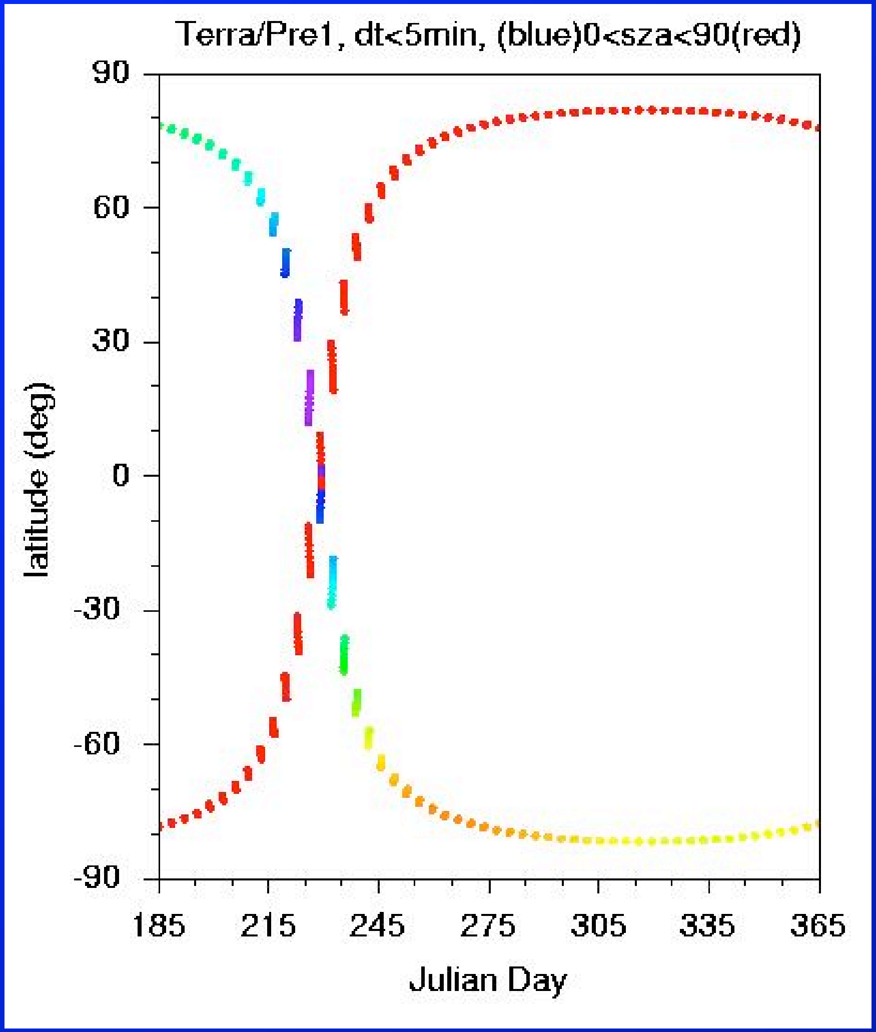
Sigma is 0.44K B. Temp.
For single 100km fov match.

Data shown is 3 months of matching data (Apr-May07)

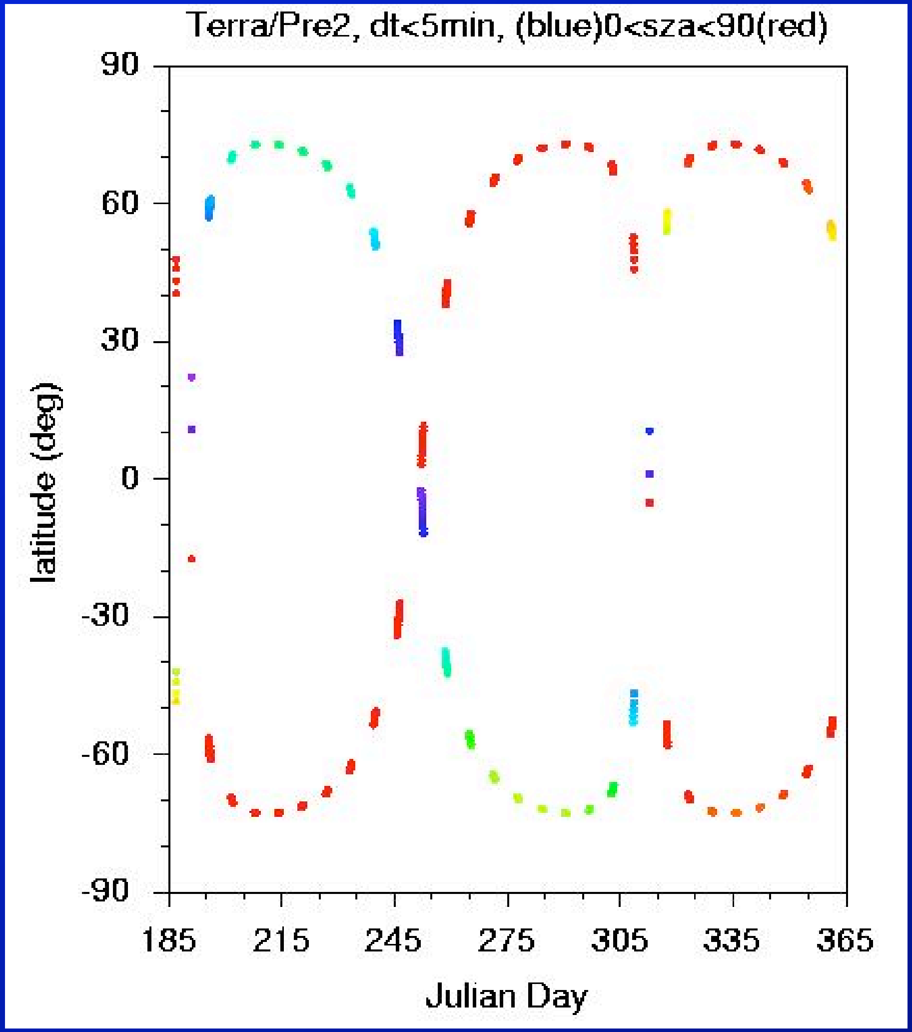
Caveat: polar only

How often and Where will Orbits Cross? June - Dec CLARREO calibrating Terra/Aqua/NPOESS

90 degree Incl. 1 24-hr cycle/yr



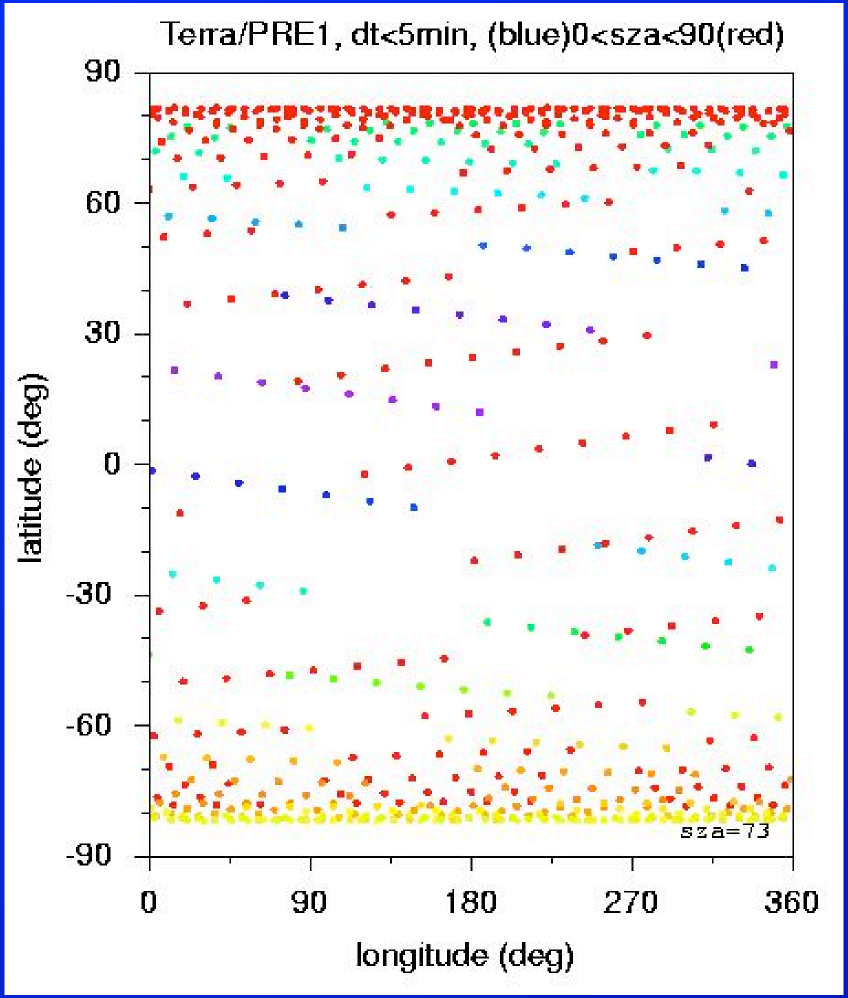
74 degree Incl. 2 24-hr cycles/yr



Conclusion: intercalibration in polar regions is common for leo satellites, tropics less common: precession cycle limits.

How often and Where will Orbits Cross? June - Dec
CLARREO calibrating Terra/Aqua/NPOESS

90 degree Incl. 1 24-hr cycle/yr



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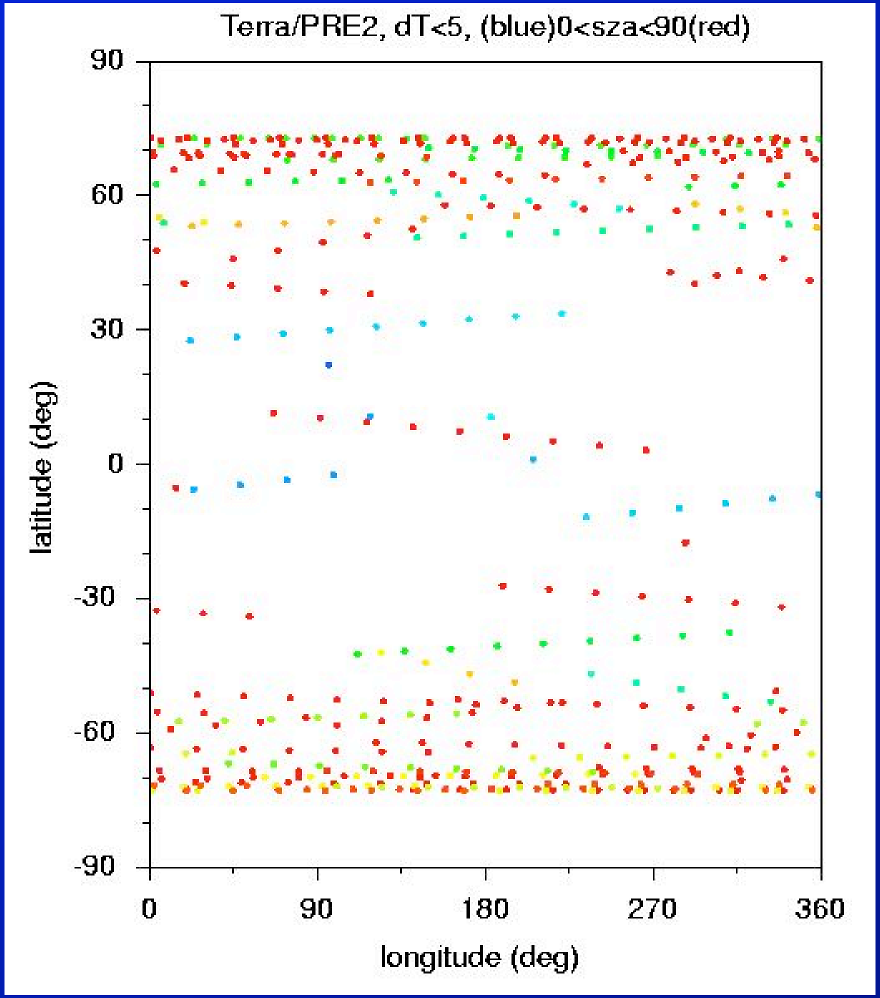
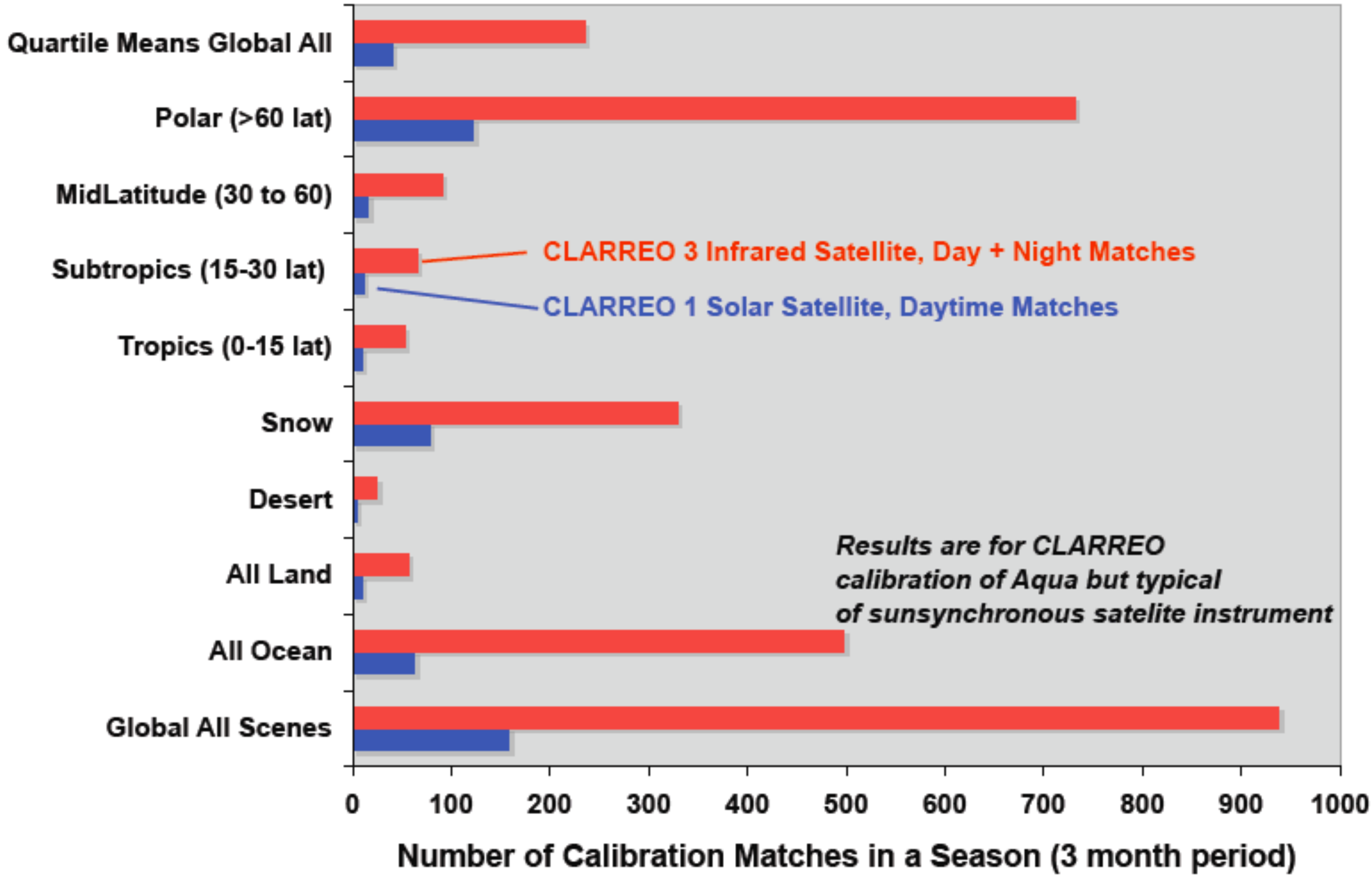


Conclusion: in 6 months can cross-calibrate across the entire Range of climate regimes: equator to pole, ocean to land. But is the sampling enough?

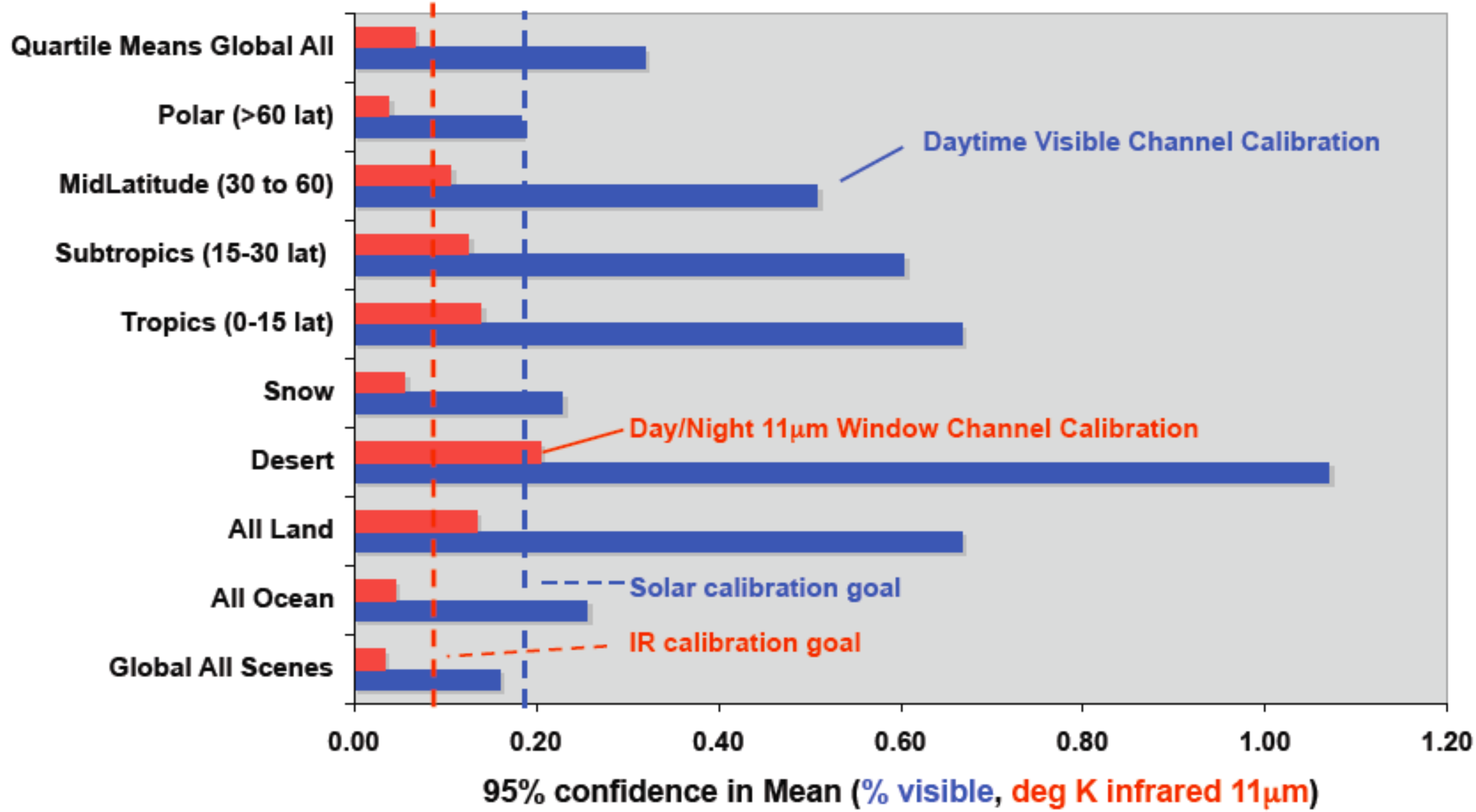
3 CLARREO IR Satellites, 1 CLARREO Solar Sat, Nadir Only 90 Deg Orbits: Number of Calibration Matches for LEO (100km fov, matches within 5 minutes, and within 1 degree viewing angle)



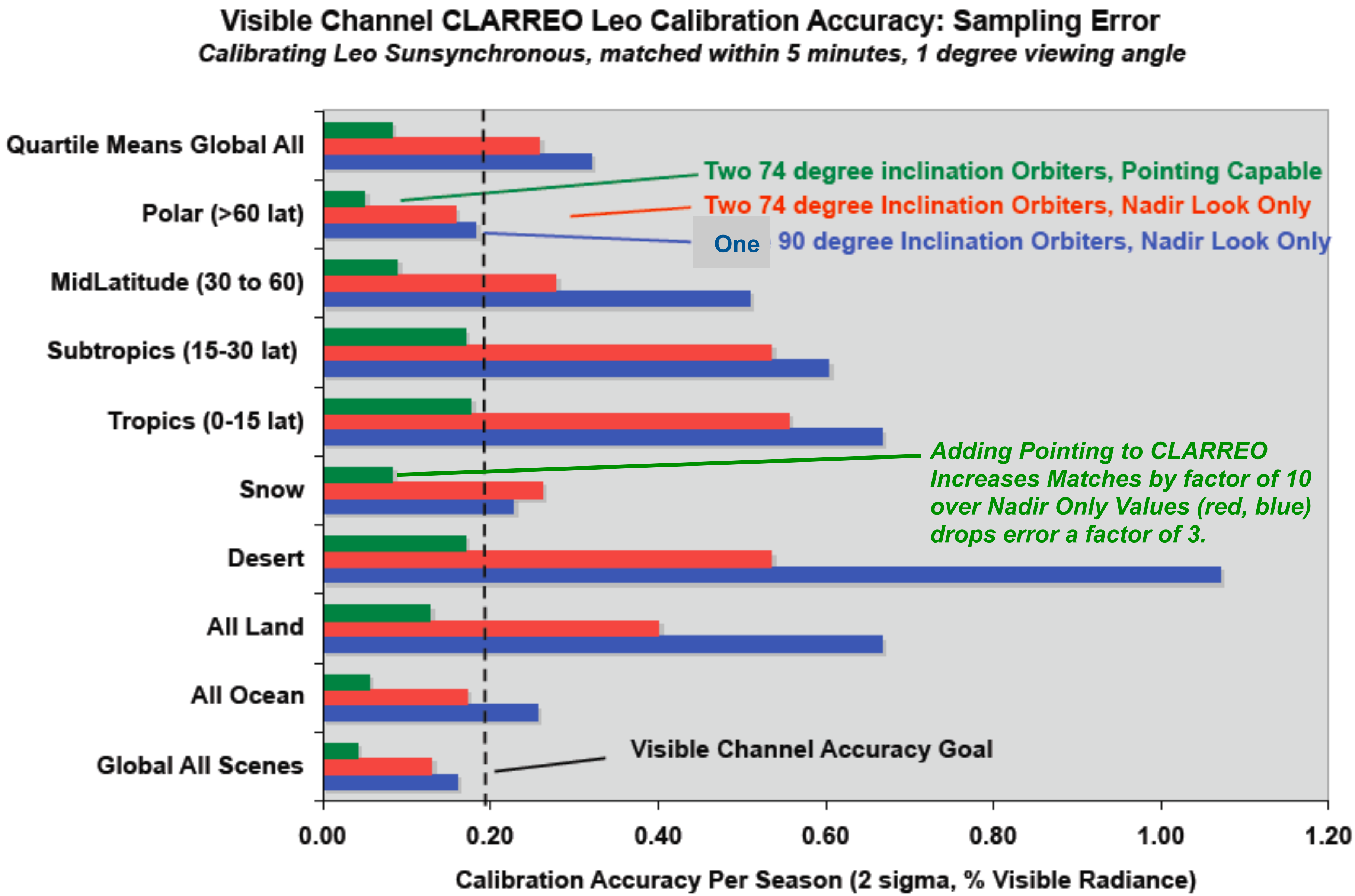
Conclusion: Solar Sampling Much Less: 1 satellite, day only

3 CLARREO IR Sats, 1 Solar Sat, Nadir Only, 90 degree Inclined Orbits
Calibration of Imager in a LEO Sunsynchronous Orbit: e.g. NPOESS

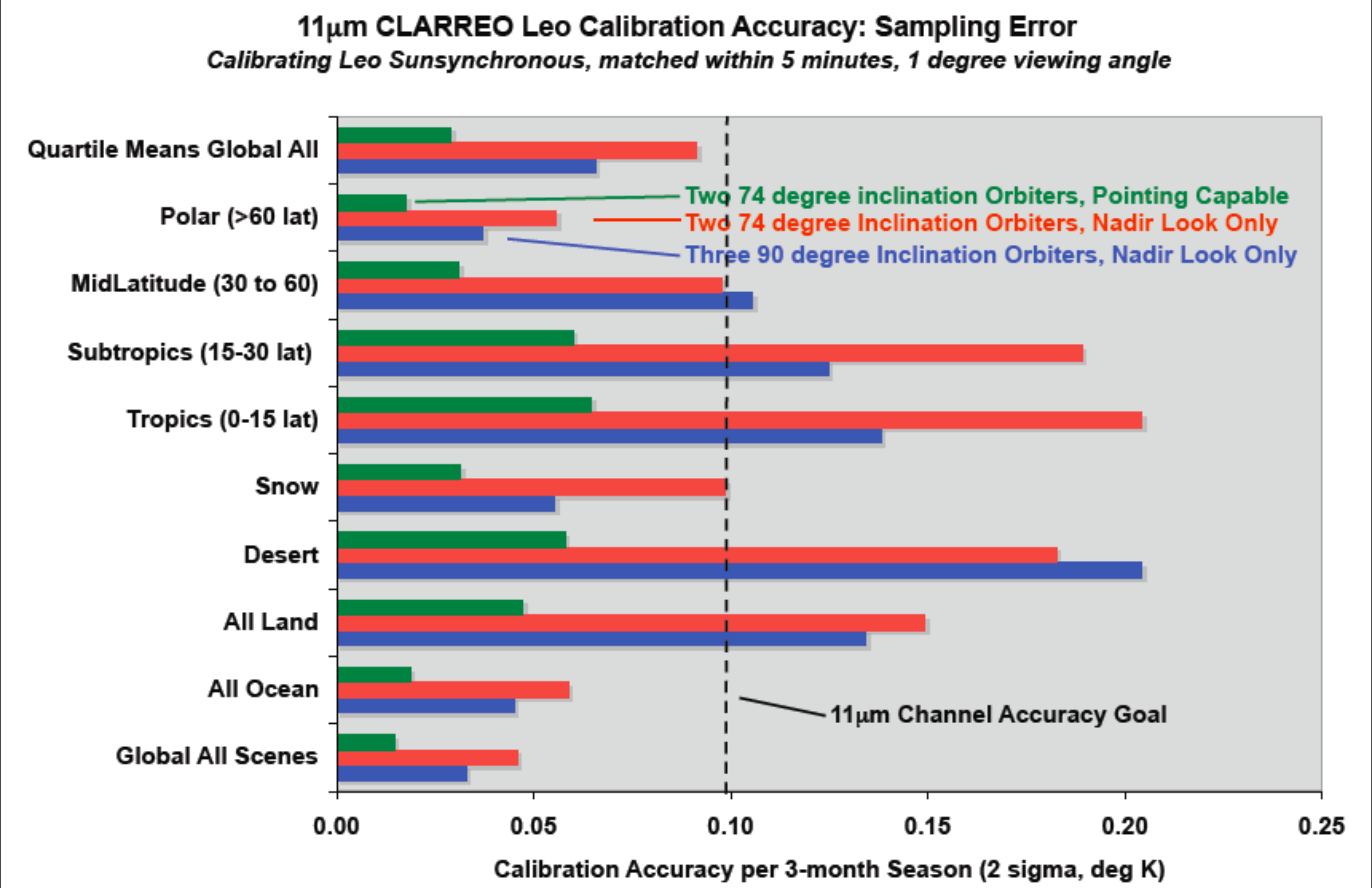
(100km fov, within 5 minute time match, within 1 deg angle match)



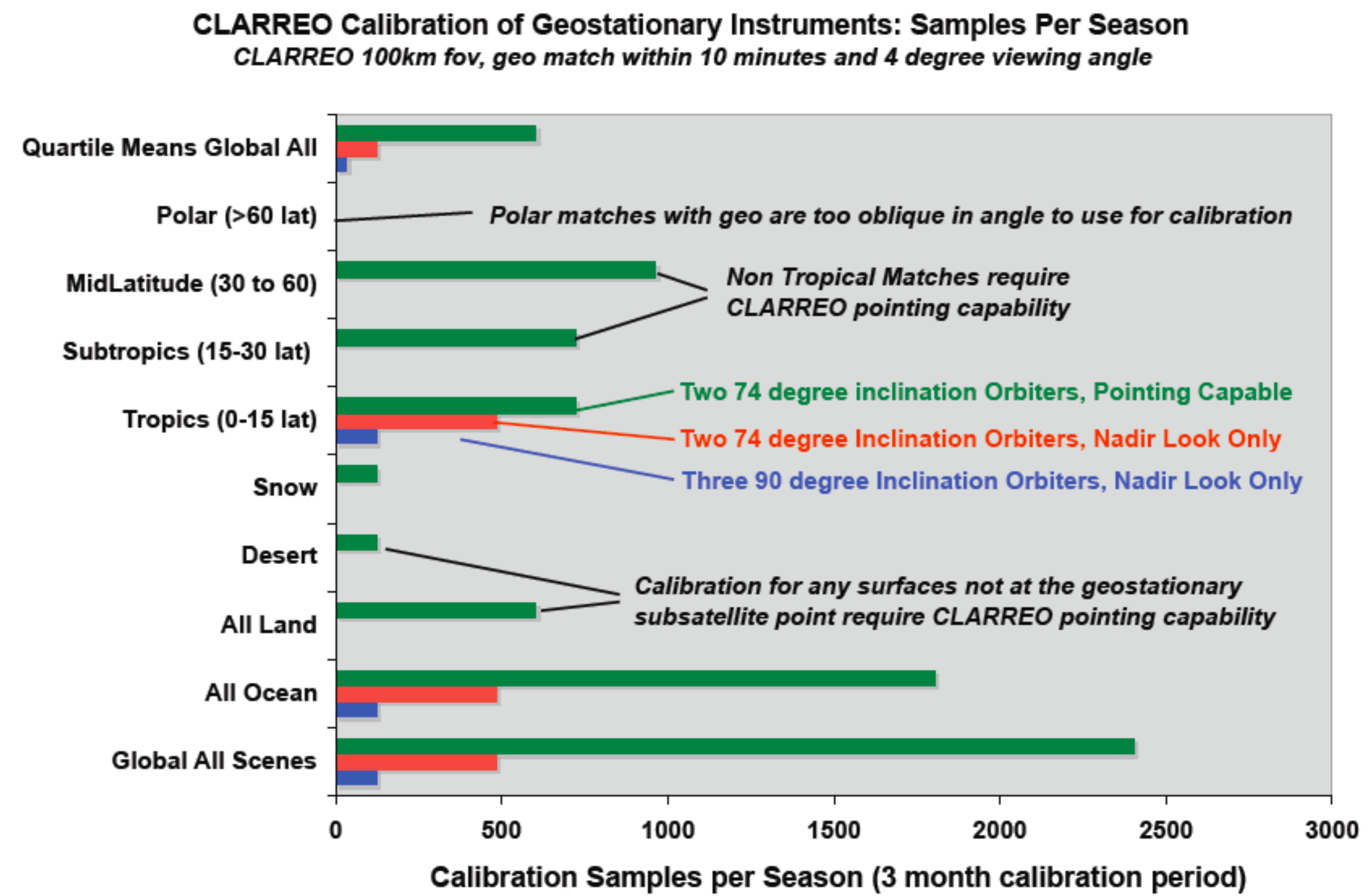
Conclusion: Poor Solar Sampling Doesn't Meet Accuracy Requirement



Conclusion: 2 Solar CLARREO sats and pointing (factor of 10 in samples Is key to meeting solar calibration goals.



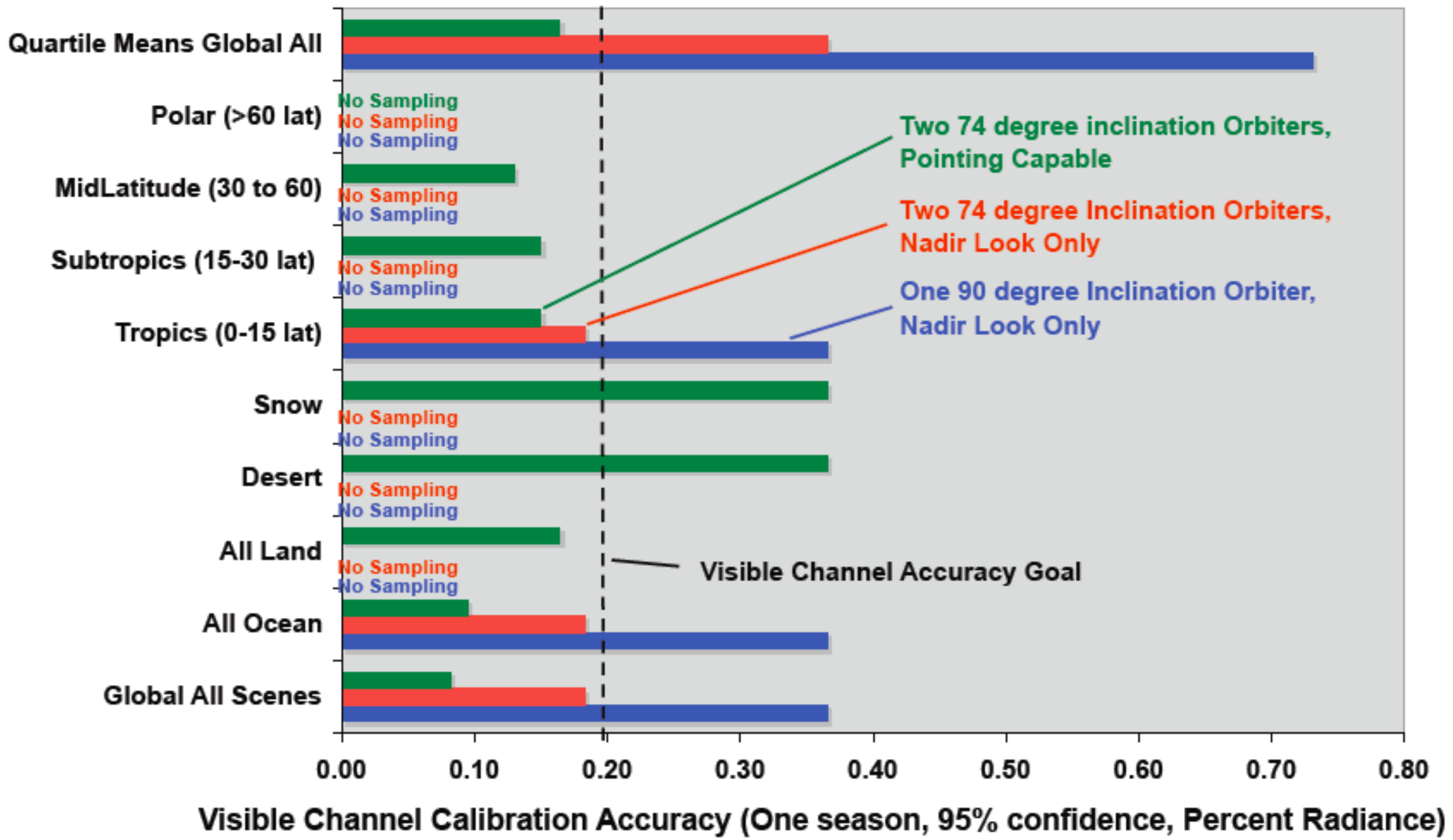
Conclusion: 2 IR CLARREO sats and pointing (factor of 10 in samples Is sufficient to meet all infrared calibration goals.



Conclusion: Pointing capability is critical to calibrate geostationary sensors at any position other than the sub-satellite equatorial point.

Visible Channel CLARREO Geostationary Calibration Accuracy: Sampling Error

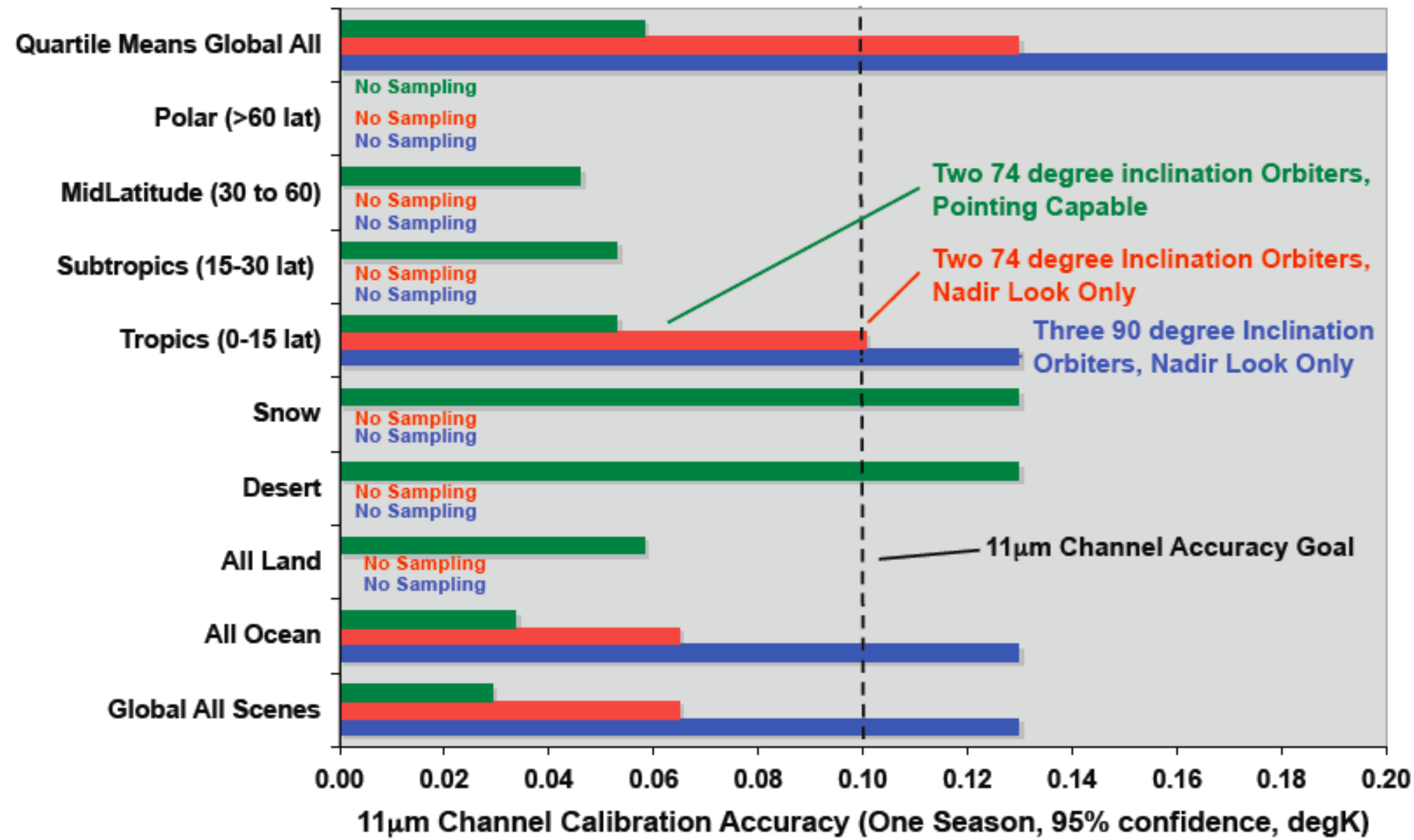
CLARREO 100km fov, geo match within 10 minutes, 4 degree viewing angle



Conclusion: Pointing capability is critical to calibrate geostationary sensors for any solar reflectance channels

11µm Channel CLARREO Geostationary Calibration Accuracy: Sampling Error

CLARREO 100km fov, geo match within 10 minutes, 4 degree viewing angle



Conclusion: Pointing capability is critical to calibrate geostationary infrared sensors for any conditions other than the geo subsatellite pt.

Conclusions

- Using CLARREO to calibrate leo and geo satellite sensors
  - Space/Time/Angle matching noise determines the intercalibration accuracy in any limited period of orbit crossings (e.g. 3 months)
  - Field of view of 100 km appears to be the sweet spot of minimizing both angle and spatial matching error. Could handle 20 km and smaller fovs (e.g. AIRS, CrIS, IASI, CERES). Spatial match noise for fovs > 20 km would rapidly increase.
  - 2 precessing orbits can under-fly all other satellites, and can ensure initial independence checks/overlap until prove absolute accuracy. (90 or 74 degree inclination).
  - The nominal NRC Decadal Survey 90 degree orbits (3) would be sufficient at nadir only for IR leo calibration (CrIS), but not for geo IR calibration.
  - The nominal NRC Decadal Survey 90 degree orbit (1) nadir only solar orbit would not be sufficient for leo or geo solar calibration.
  - Geo calibration will require CLARREO pointing capability: orbit crosses at geostationary sub-satellite points too limited for nadir only pointing.
  - Sampling can be increased a factor of 10 to 20 by allowing CLARREO pointing during orbit crossings: spacecraft or pointing platform or instrument. Note that CLARREO pointing must be in azimuth and zenith (e.g. SORCE, CERES): not just the normal elevation zenith scan of most scanning instruments (MODIS, AIRS, AVHRR, geo).
  - Matching viewing angle between two LEO satellites, 40 seconds is available for every 100 km of difference in orbit altitude: suggests altitudes at 550 to 600 km, or 950 to 1000 km.

Conclusions

- At climate accuracy, simple offset and gain will not be sufficient for CLARREO to calibrate.
  - determine any nonlinearity to instrument response, both intended (multi-gain) and unintended. requires sufficient sampling over wide dynamic range (e.g. quartiles).
  - determine consistency of calibration results over full range of climate regimes (tropics to polar, land to ocean)
  - these second order effects can be determined with longer calibration data sets: ~ 2 years instead of 3 months for simple gain and offset.
- CLARREO has the opportunity to raise the accuracy of many key climate data records: but only if orbit/fov/sampling are designed to achieve it.
- IR is likely to be much easier than solar.
- Solar reflectance instruments are in general less well calibrated than infrared: CLARREO will have a large positive impact on their observation quality for climate change.
- Calibration of instruments like CERES require CLARREO solar and IR instruments to fly in formation or on same spacecraft.

Next Steps

- Verify ability to calibrate nonlinearity in gain: both a few percent unexpected, as well as multiple gain design (AVHRR, VIIRS). Number of independent dynamic range bins needed to verify at climate accuracy? 4? 10?
- Consider the ability to use CLARREO's likely 1 km solar reflectance spectra fov (needed for lunar stability check) to construct arbitrarily sized and aligned larger intercalibration fovs. Analogous to matching MODIS 1 km fov to CERES 20 km point spread function. In a 100 km CLARREO swath of 1 km fovs, could achieve many simulated 20 km fovs, increasing independent samples when spatial sampling noise dominates. As drop fov size of match, however, time simultaneity becomes more critical (e.g. cloud motion). Consider this pointing/fov trade space.
- Test ability to intercalibrate 2 sets of CLARREO instruments on different orbits: for 1km solar resolution, no different than current results. But for CLARREO 100km fov to CLARREO 100km fov, spatial matching noise will increase greatly.