Impact of GOES Spacecraft Stabilization on Instrument Calibration

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RTI

- NOAA-EUMETSAT Future Geostationary Programs, NSOF, 30 Oct 2007
- Lessons learned during a major transition are useful to both MTG and GOES-R

Unblinking Digital Camera in Space*

… needs a platform to mount on, which must be:

- Geosynchronous
  - Orbit period equal to the Earth's rotation
- Geostationary
  - Zero inclination and eccentricity
- 3-Axis Stabilized
  - Satellite rotates at the same rate of the Earth's rotation but in opposite direction

* W. Smith

Geosynchronous

- Orbit height such that period ≈ 24 hours
  - Law of Universal Gravitation:

$$F = G\frac{Mm}{r^2}$$

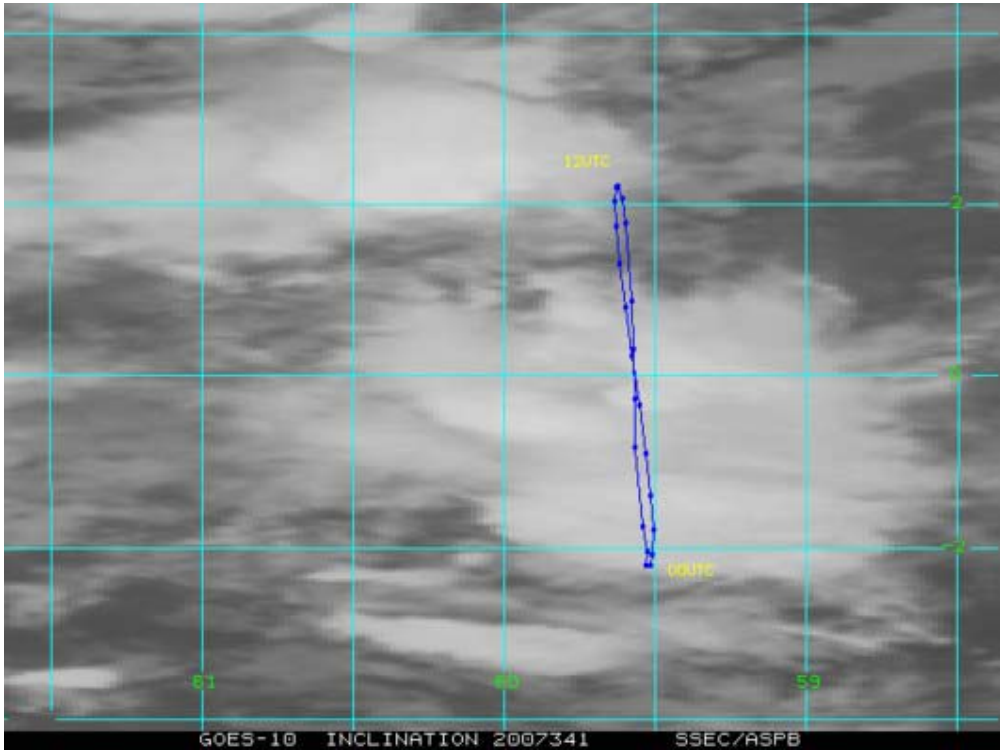
  - Assume circular orbit

$$G\frac{Mm}{(R_e + h)^2} = m\omega^2(R_e + h)$$

$$h = \sqrt[3]{\frac{GM(86400)^2}{4\pi^2}} - R_e = 42241 - 6371 = 35870(km)$$

Geostationary

- Zero inclination and eccentricity
  - Stationkeeping
    - N-S, early Dec. for G12, Sun/Moon
    - E-W, today for G11, Earth
  - Out of control when out of fuel (GOES-10)
    - Tracking
    - Remapping

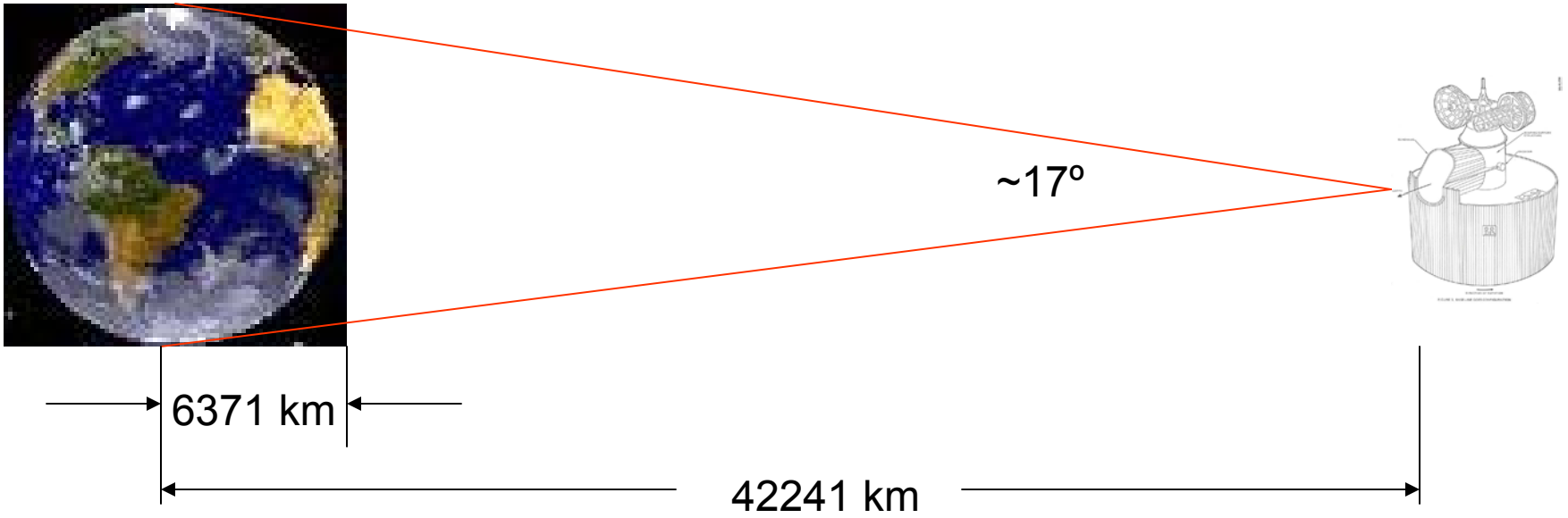


T. Schmit

http://celestrak.com/columns/v04n07/

3-Axis Stabilized

- Constantly staring at the Earth



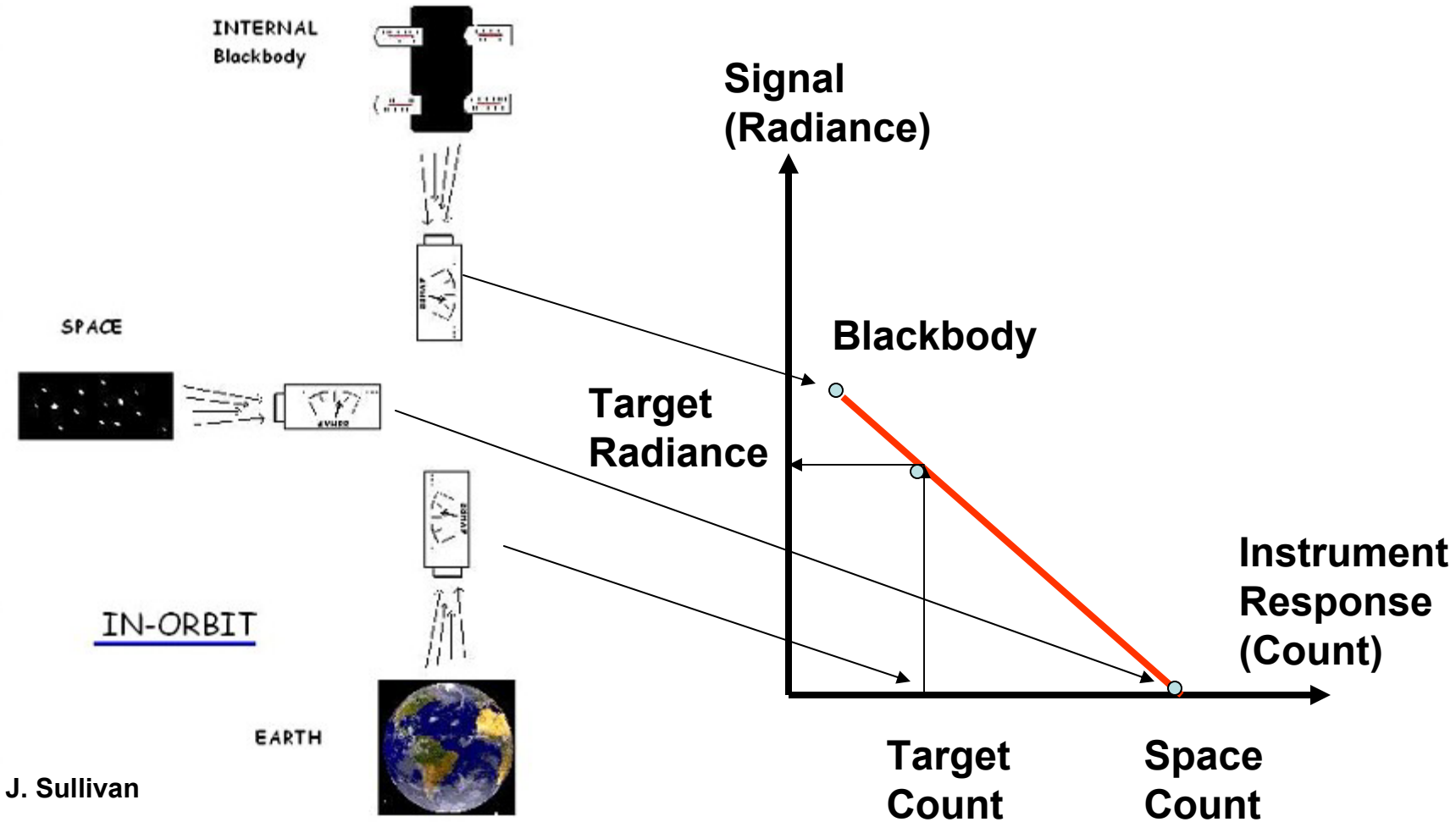
Spinner looks at space 95% of time

Instrument Calibration

The process of quantitatively defining the system response to known, controlled signal inputs

From CEOS/WGCV

Illustration of Radiometer Calibration



Impact 1:
Enable Onboard IR Calibration

- By definition, we need to know the system response to calibrate the system.
- For IR channels on spinner, only part of the aperture and optical chain is illuminated
  - Only the response of a partial system is known

VISSR (GOES 1-3) and VAS (4-7)

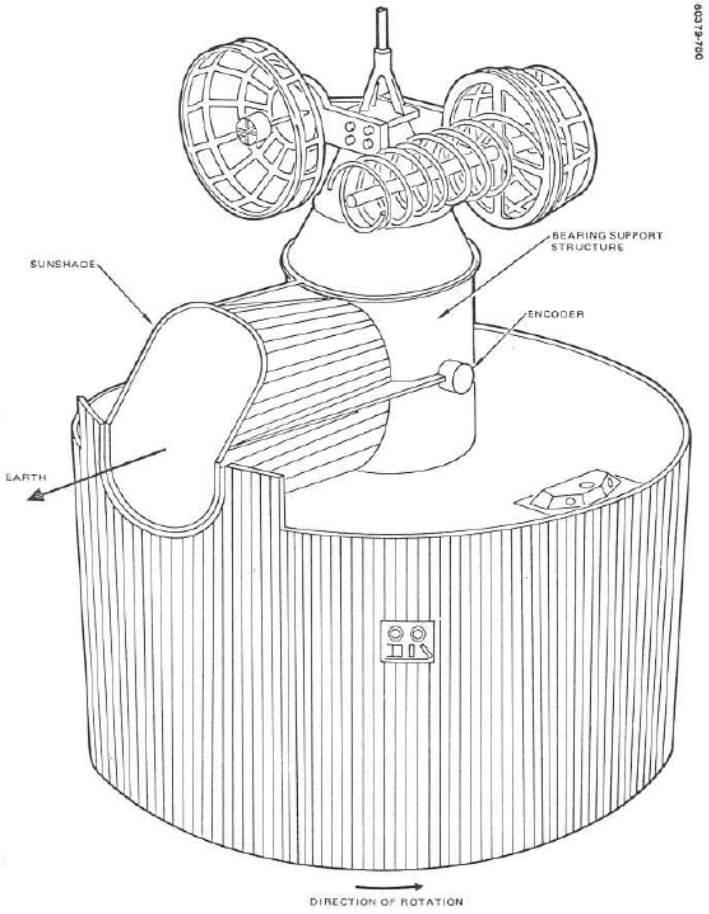


FIGURE 3. BASELINE GOES CONFIGURATION

Have to model radiation from these optical components based on temperature, reflectivity, emissivity, and obscuration fractions. (Menzel 1980)

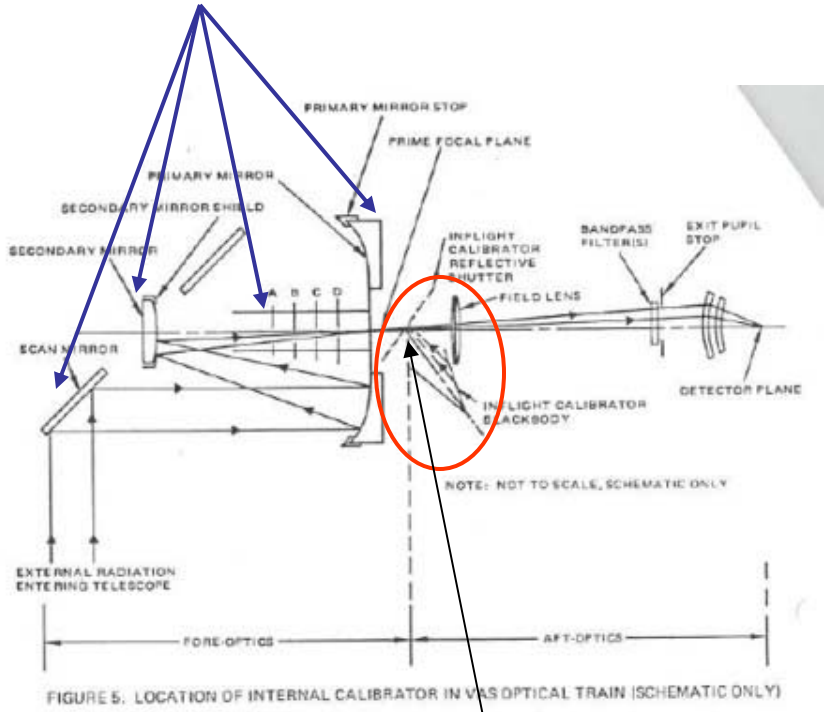
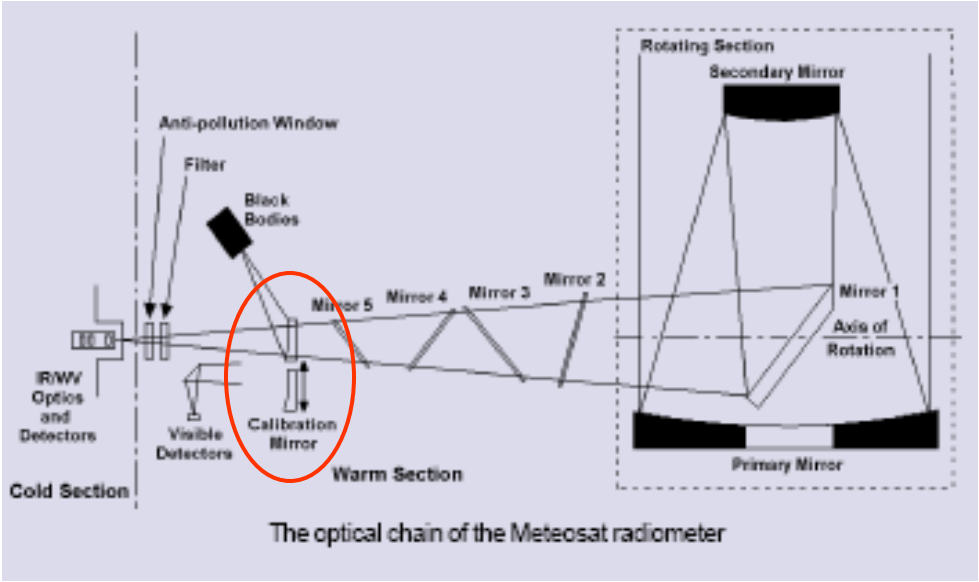


FIGURE 5. LOCATION OF INTERNAL CALIBRATOR IN VAS OPTICAL TRAIN (SCHEMATIC ONLY)

Emitting Shutter for VISSR

METEOSAT 1st Generation (4-7)

Figure 3.1 Meteosat



The optical chain of the Meteosat radiometer

METEOSAT 2nd Generation (8-11)

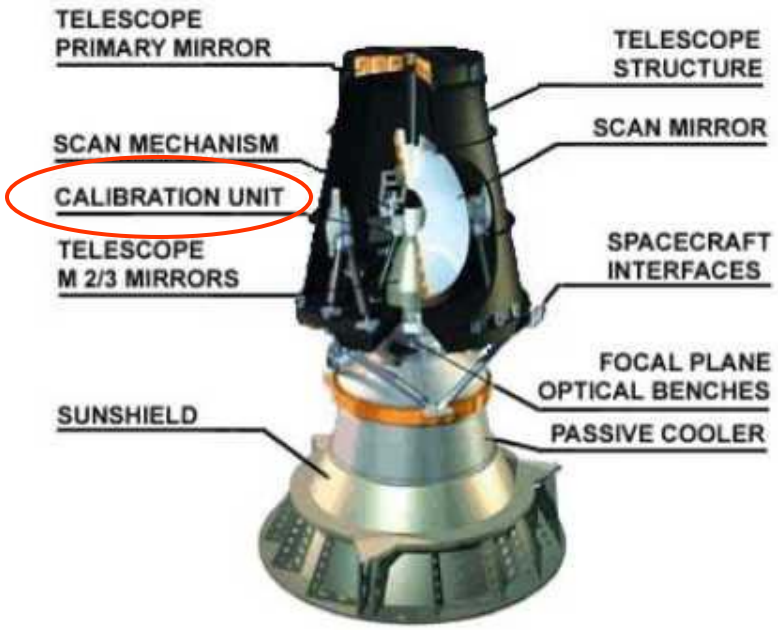
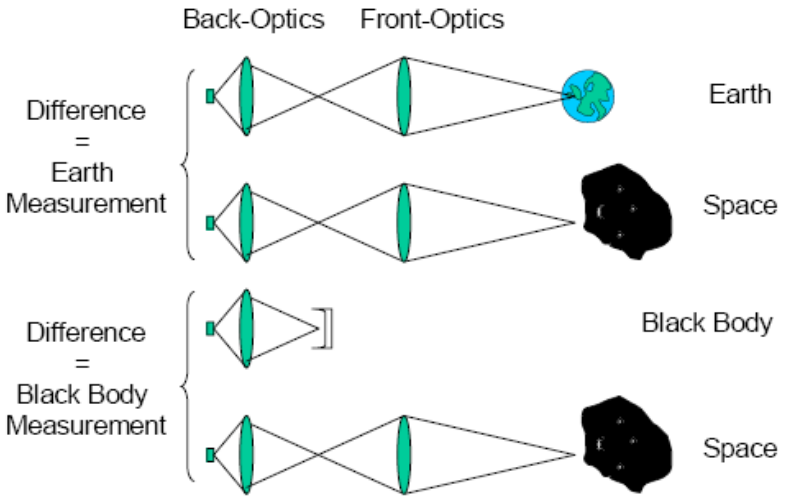
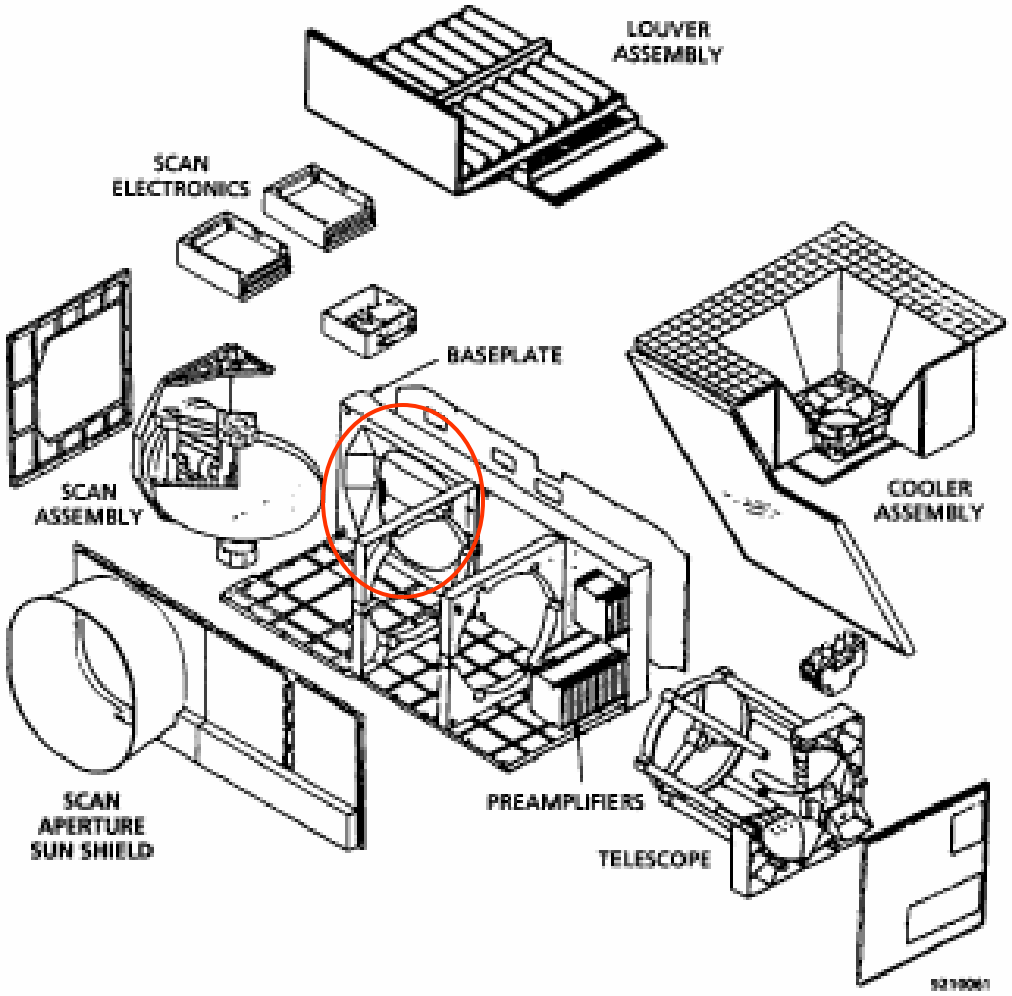


Figure 4.3 Illustration of the SEVIRI instrument



Imager/Sounder (GOES 8-15)



Full-System

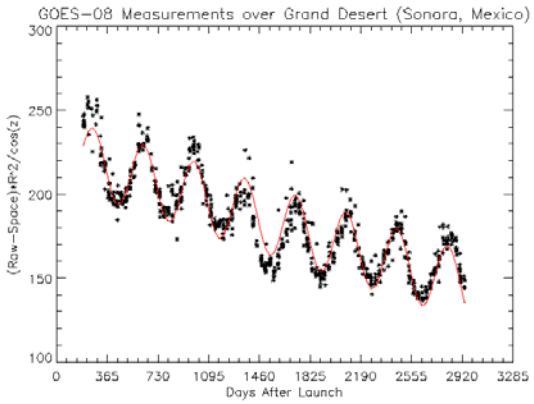
Full-Aperture

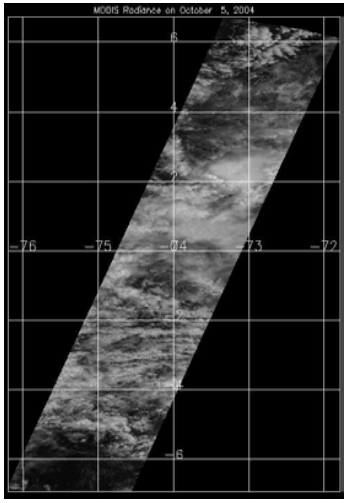
Impact 1:
Enable Onboard IR Calibration

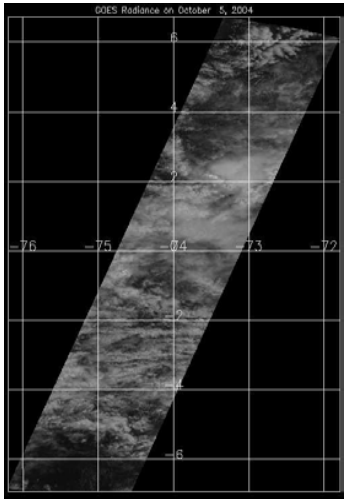
- By definition, we need to know the system response to calibrate the system.
- For IR channels on spinner, only part of the aperture and optical chain is illuminated
  - Probably difficult to build, install, and operate large blackbody (20” vs. 12”)
    - Choice for photo-multiplier over CCD was for similar reason, causing serious striping in visible image before correction
  - Only the response of a partial system is known
  - The most serious and fundamental limitation

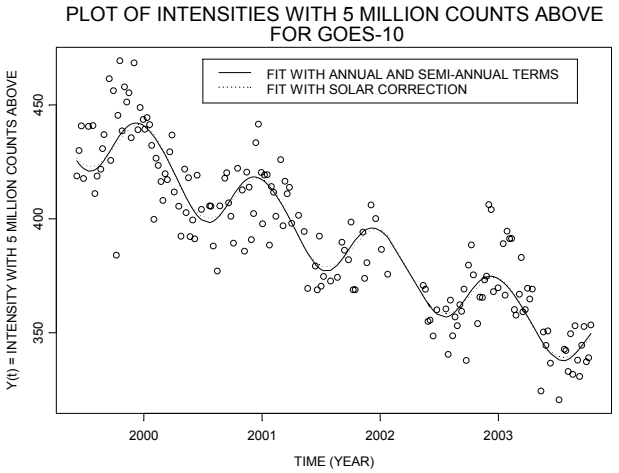
Impact 2:
Enable Advanced Solar Calibration

- Vicarious Calibration based on
  - Earth Target
    - Desert
    - Deep Convective Clouds (EDF)
  - Calibrated Radiometer
    - MODIS, VIIRS









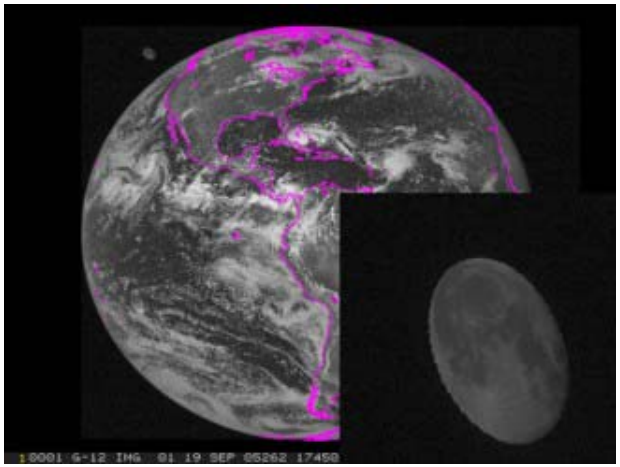
Impact 2:
Enable Advanced Solar Calibration

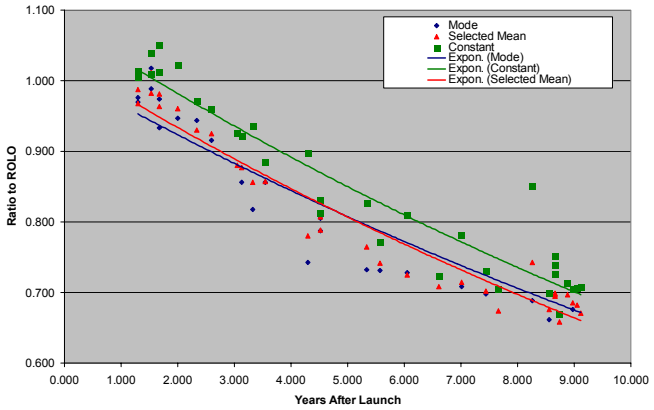
- Vicarious Calibration based on
  - Earth Target
    - Desert
    - Deep Convective Clouds (EDF)
  - Calibrated Radiometer
    - MODIS, VIIRS
  - Stellar bodies
    - Moon
    - Star

Difficult or impossible for spinner

- Onboard Calibration (GOES-R)
  - Solar Diffuser

Lunar Calibration

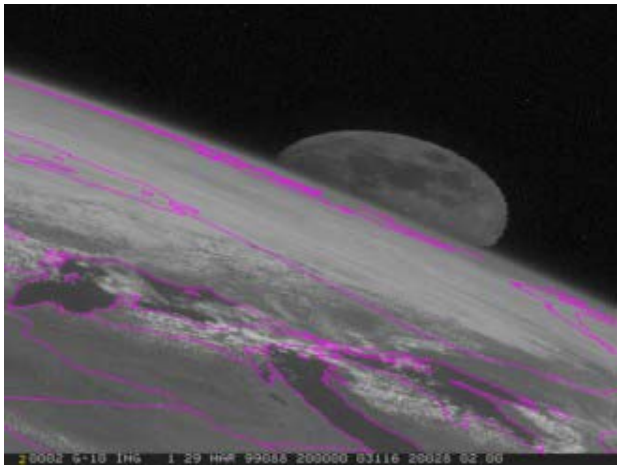


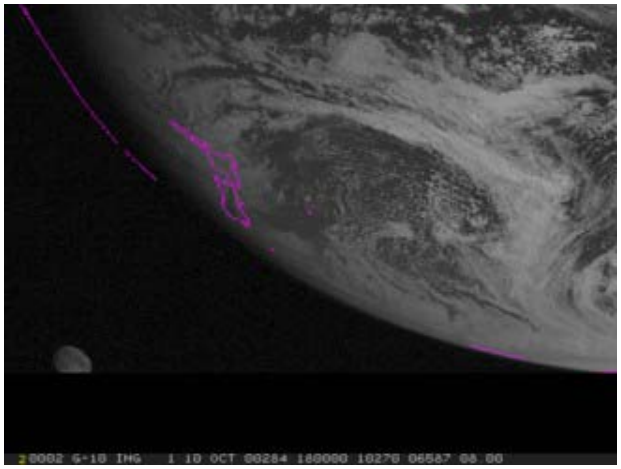


Unscheduled: ~3 per year. Takes years to beat down the noise

Scheduled (since Nov 2005): Once a month. Will be substantially more for GOES-R.

Impractical to schedule for spinners



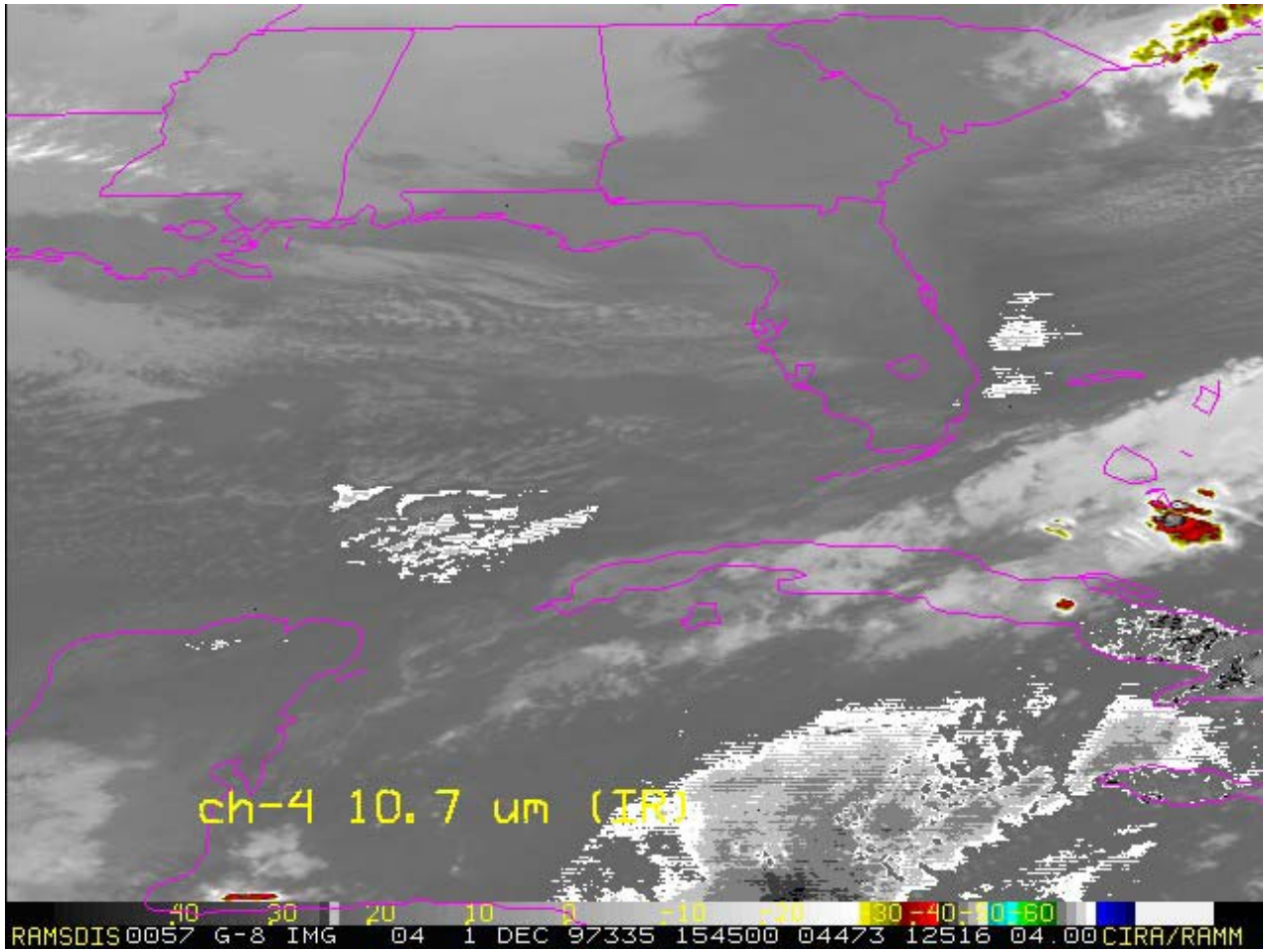


Impact 3:
Reduce Calibration Cycles

- Spinner looks at the space ~95% of time
  - Do all the calibration you want
- 3-axis doesn't have to …
  - But still need to control 1/f noise and thermal drifts
  - Initially underestimated this need – view space every 120 sec
  - Inadequate, but a bit too late with other commitments
  - Implemented "scan clamp" for Imager to view space every 2.2 sec in FD scan and 36.6 sec otherwise
  - Sounder still views space every 120 sec – need remedy at certain time

Infrequent Calibration Contributes to Striping

Illustration only – not all striping are caused by 1/f noise

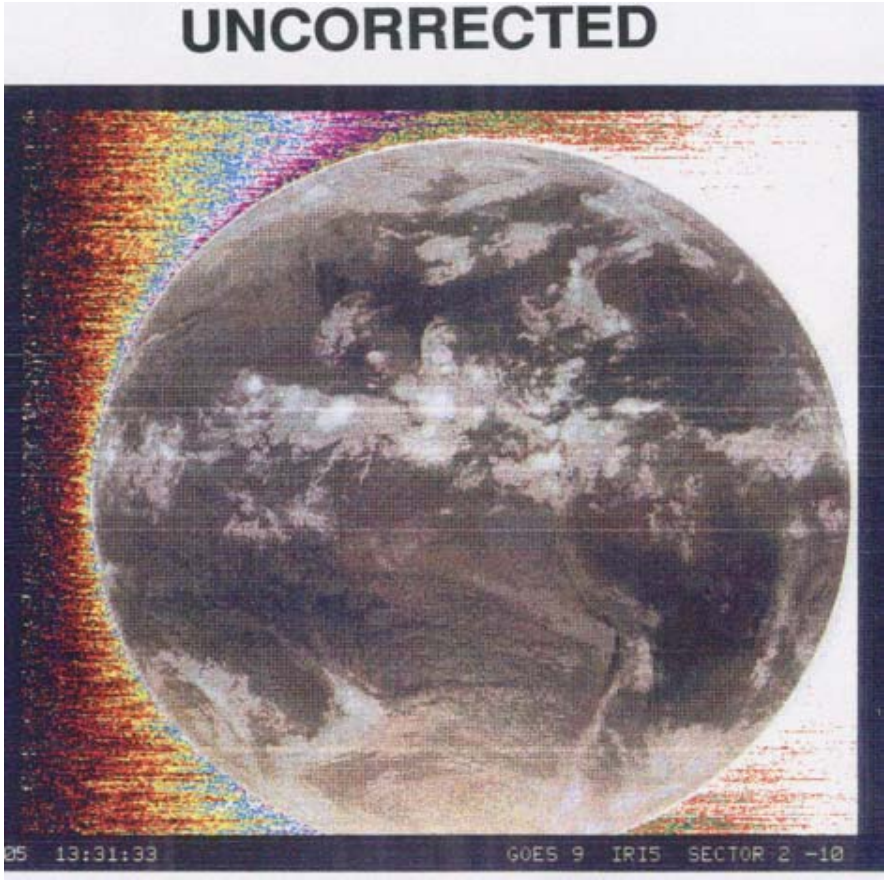


Impact 4:
Demand Better Characterization

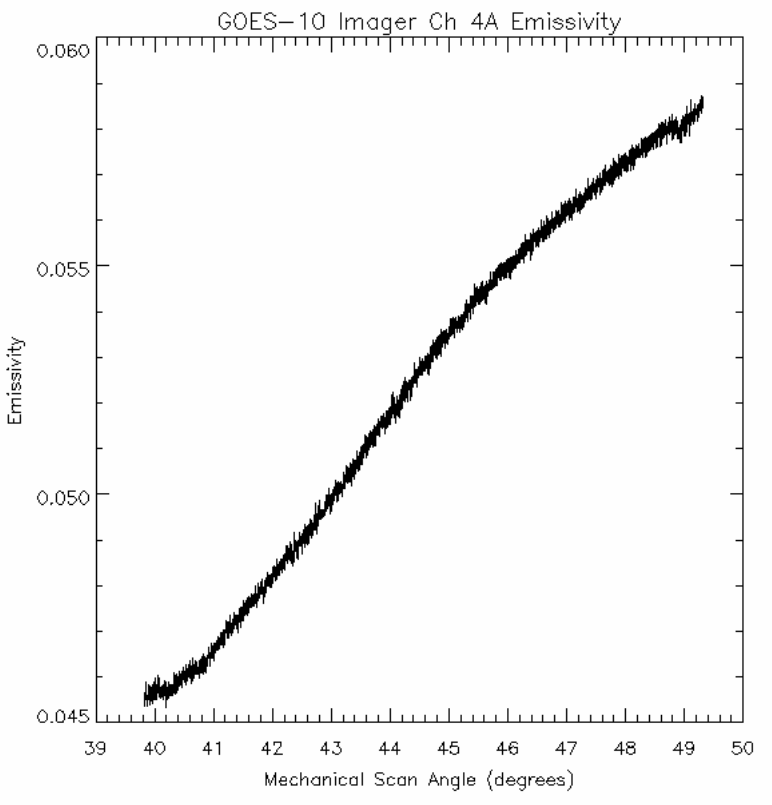
Example 1: Scan Mirror Emissivity

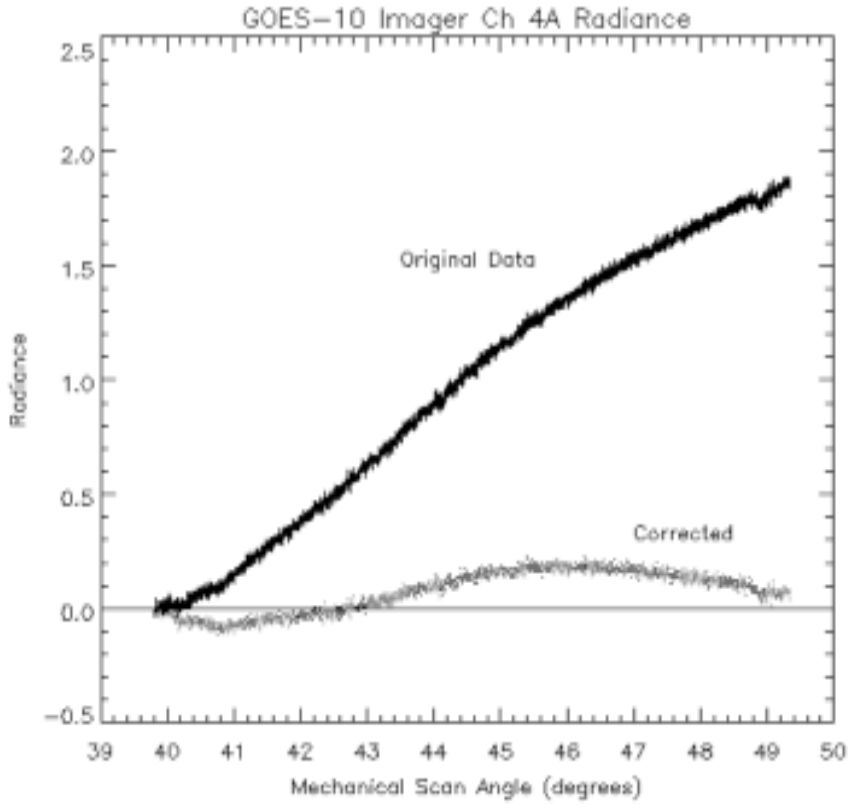
- Spinner scans N-S only
  - No change in Angle-Of-Incidence (AOI)
- 3-axis (GOES-I/P) must also scan E-W
  - AOI changes with scan position
  - Emissivity of scan mirror coating varies with angle
  - Variation is spectrally dependent
  - Affects both Imager and Sounder

Effect and Correction of Scan Mirror Emissivity Dependence on AOI

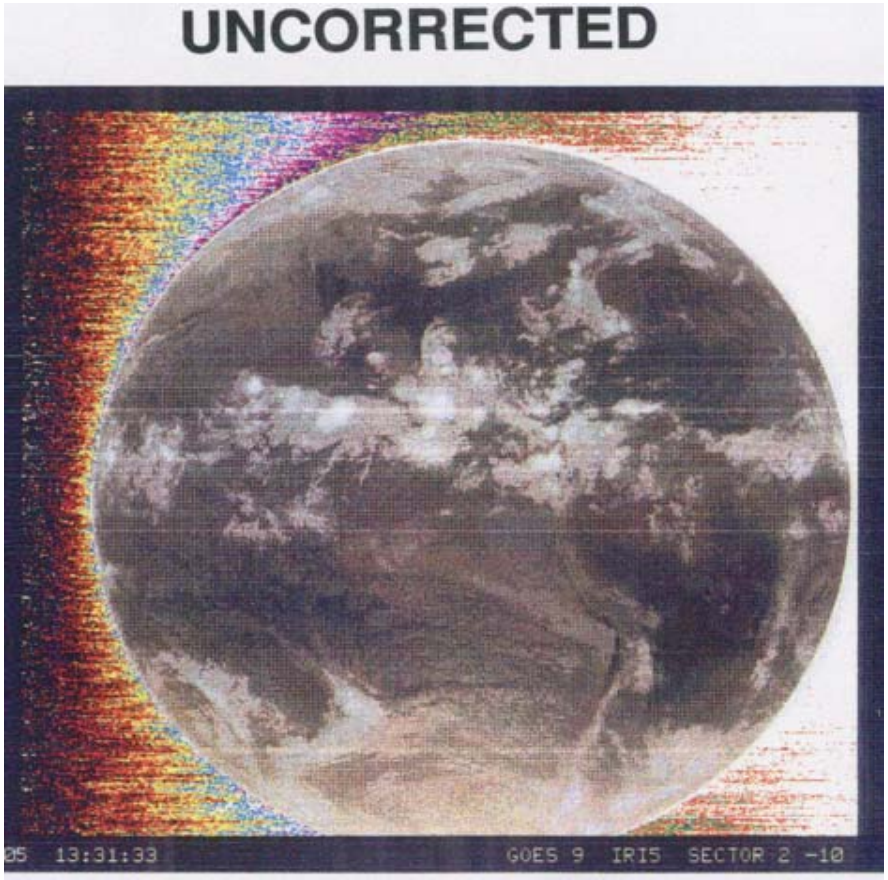


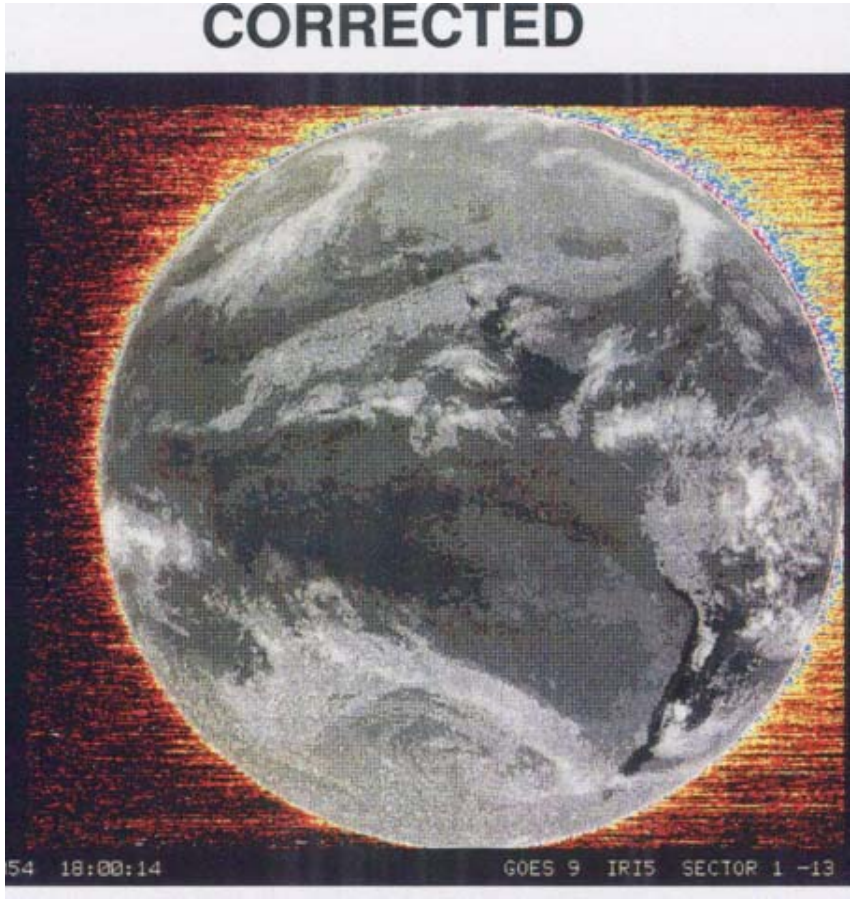
Example of Scan Mirror Emissivity (left) and Space Radiance (right) as Function of AOI





Effect and Correction of Scan Mirror Emissivity Dependence on AOI



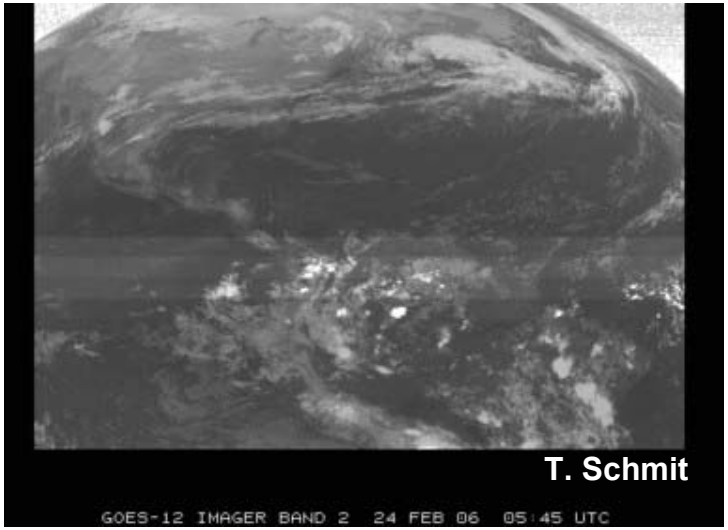


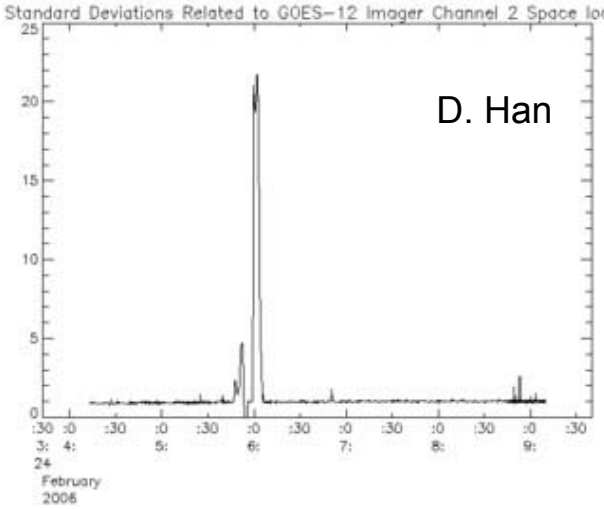
Impact 4:
Demand Better Characterization

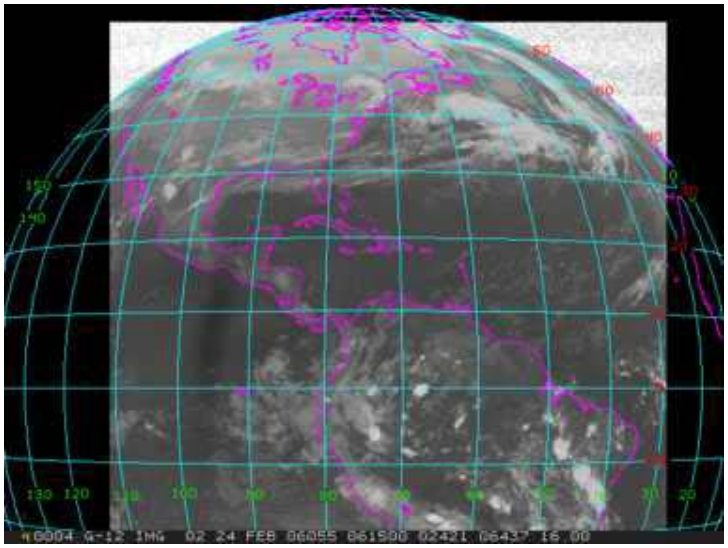
Example 2: Stray Light

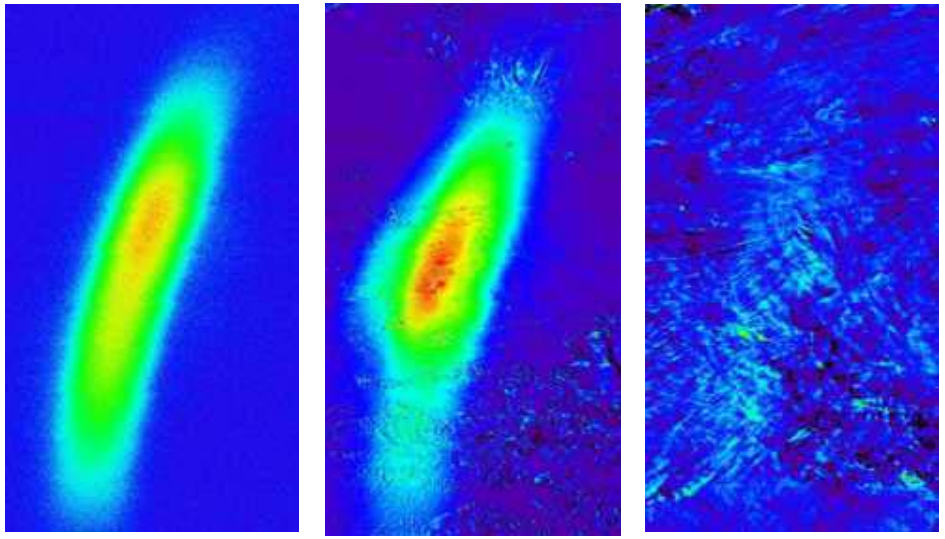
- Stray light rejection is easier to instrument on spinner
  - Needs only narrow East-West opening
- More complicated for those on 3-axis stabilized platform
  - Relatively minor, as far as complaints are concerned
  - But always there, and never fully investigated
  - Known characteristics are consistent with indirect stray light:
    - Around equinox;
    - After midnight before equinox, and vice versa
- Could be a major issue for onboard calibration on geostationary spacecraft

Example and Impact of Stray Light









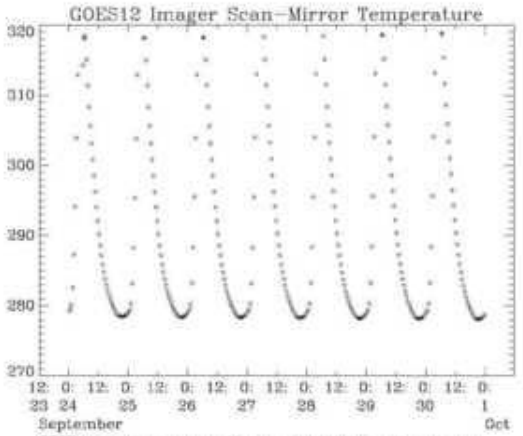
Impact 5:
Impose Large Diurnal Heating

- By far the most serious concern
  - Deserves more attention in future design
  - Reduce the diurnal heating if possible, instead of correcting for its effect
- Impact is profound
- Will demonstrate with three examples:
  - Midnight Blackbody Calibration Errors
  - Banding
  - Intra-annual variation of star signal

Time Series of Scan Mirror Temperature

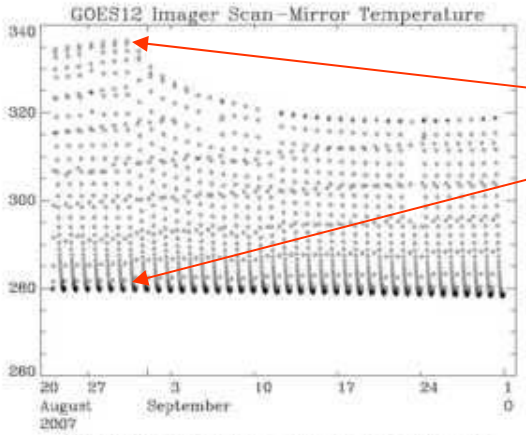
An order of magnitude larger than spinners

One Week



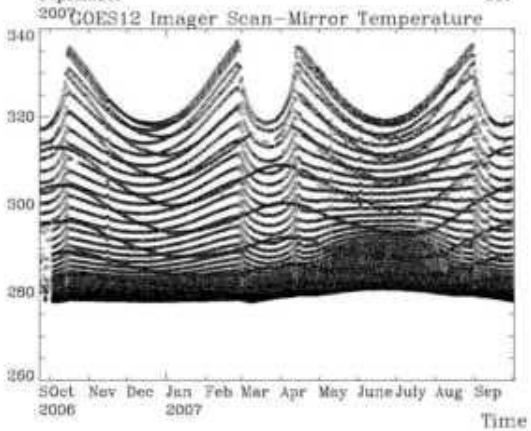
~40ºK
"now"

One Month

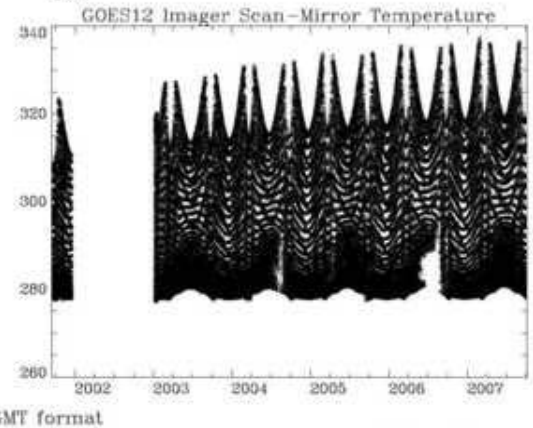


~60ºK some other days

Complicated seasonal variations of diurnal heating



One Year



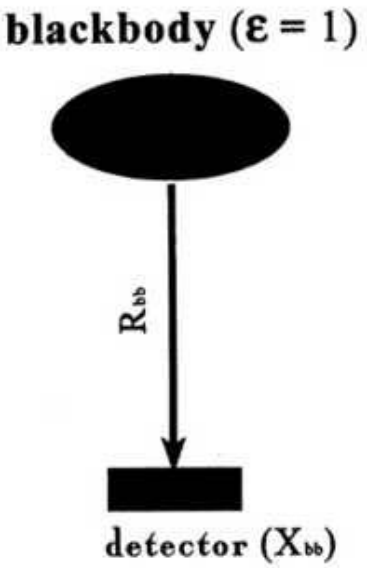
One Satellite

Time in GMT format

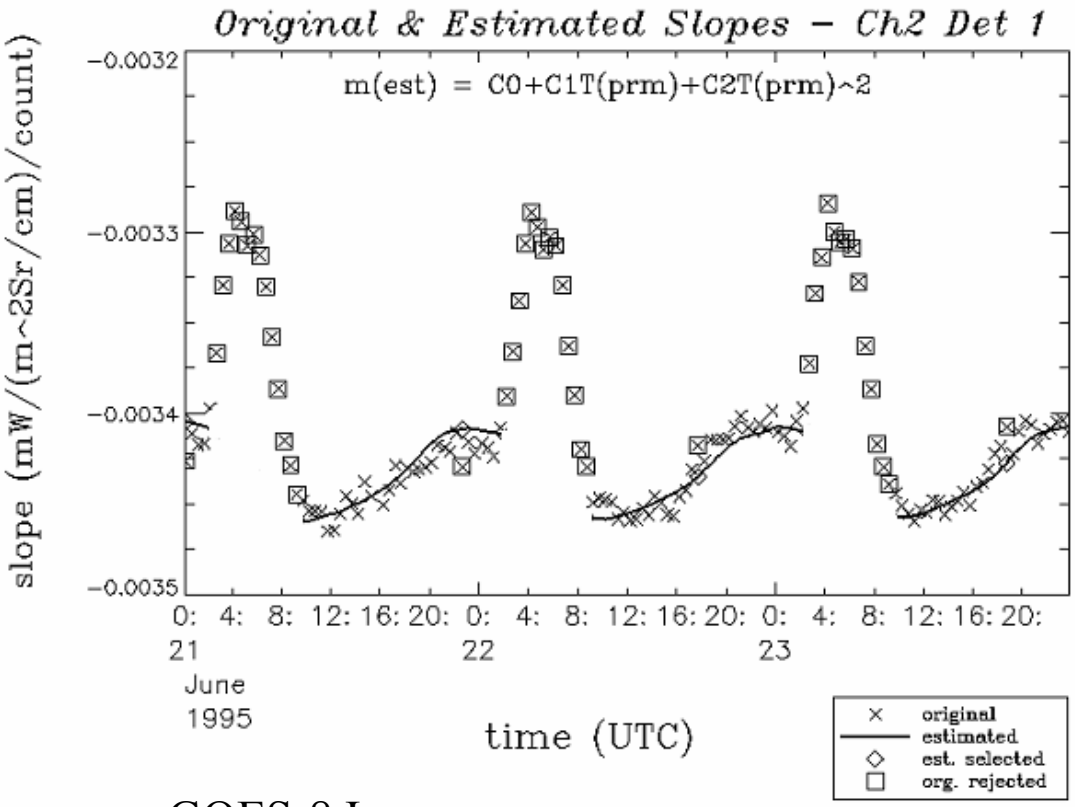
Long term trend

D. Han

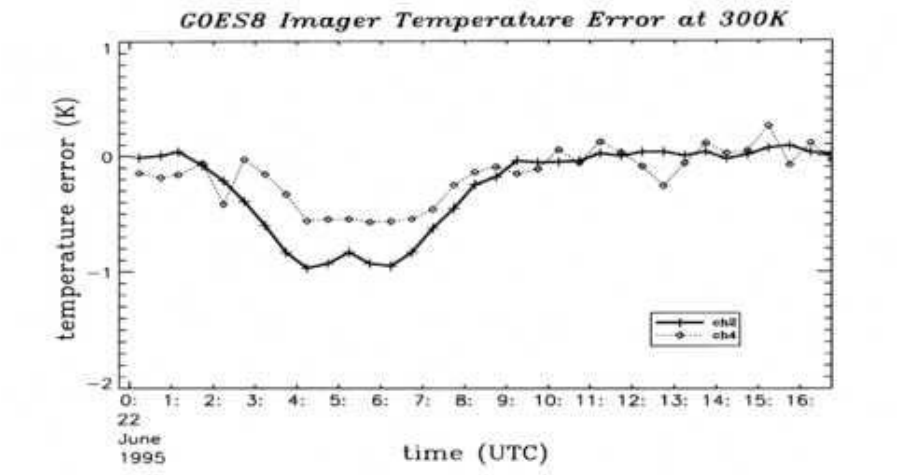
1. Midnight Blackbody Calibration Error

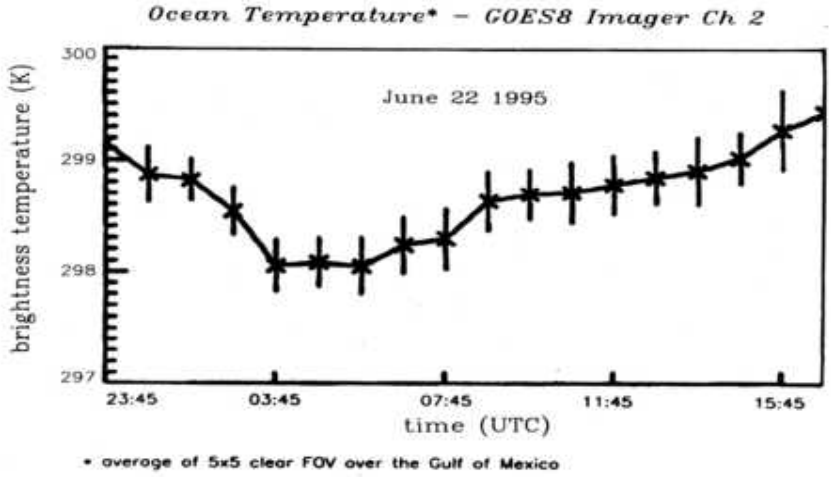


$$m = \frac{R_{bb}}{X_{bb} - X_{sp}}$$

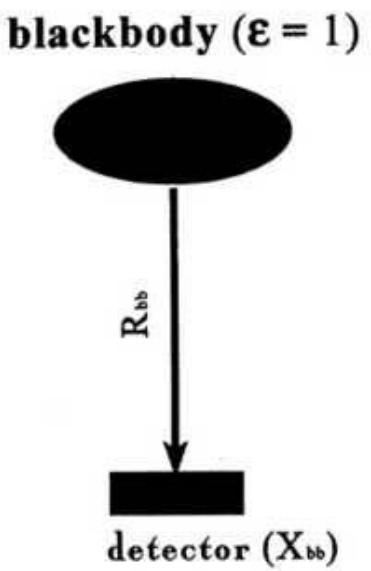


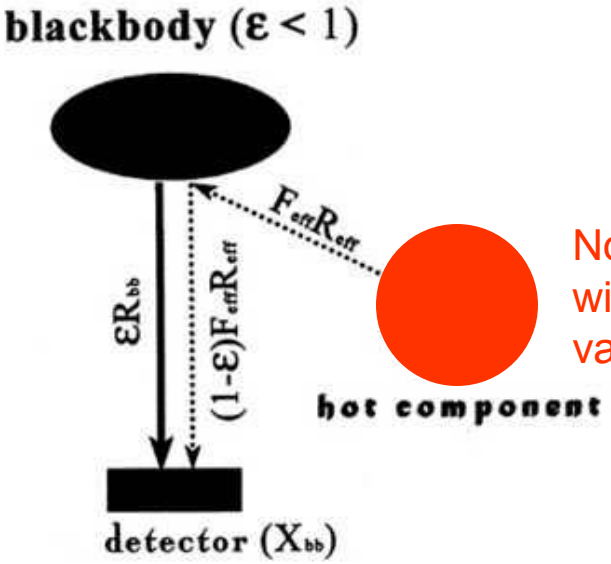
GOES-8 Imager


GOES8 Imager Temperature Error at 300K
temperature error (K)
1
0
−1
−2
ch2
ch4
0: 1: 2: 3: 4: 5: 6: 7: 8: 9: 10: 11: 12: 13: 14: 15: 16:
22
June
1995
time (UTC)


Ocean Temperature* − GOES8 Imager Ch 2
brightness temperature (K)
300
299
298
297
June 22 1995
23:45
03:45
07:45
11:45
15:45
time (UTC)
* average of 5x5 clear FOV over the Gulf of Mexico

1. Midnight Blackbody Calibration Error

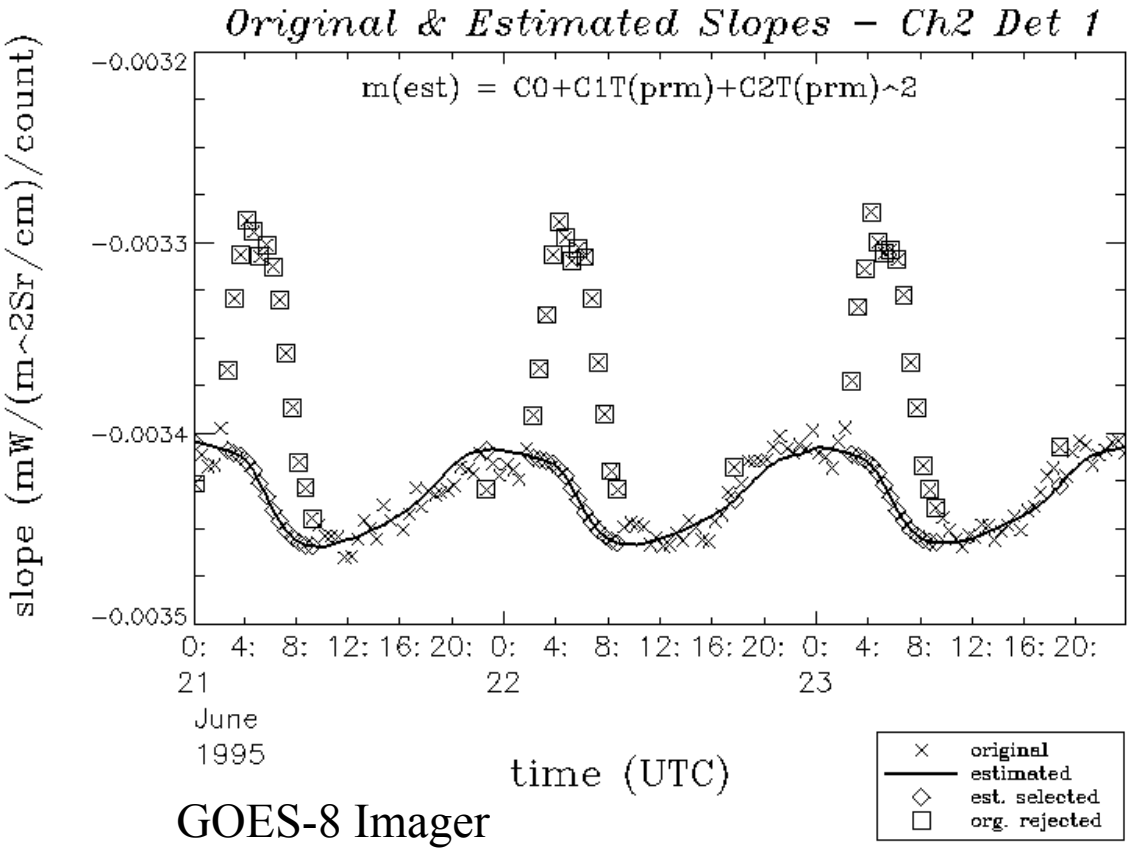




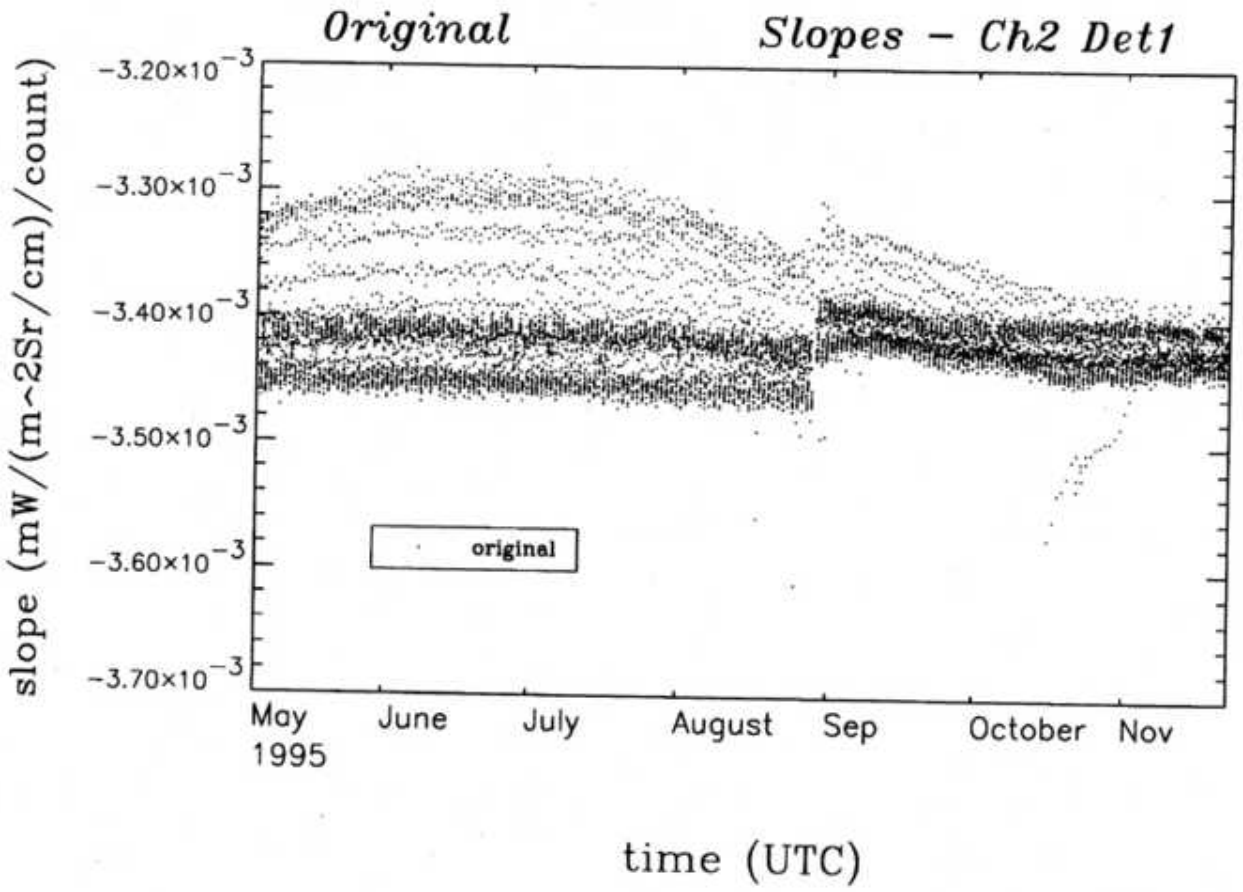
Not a problem without this varying radiator

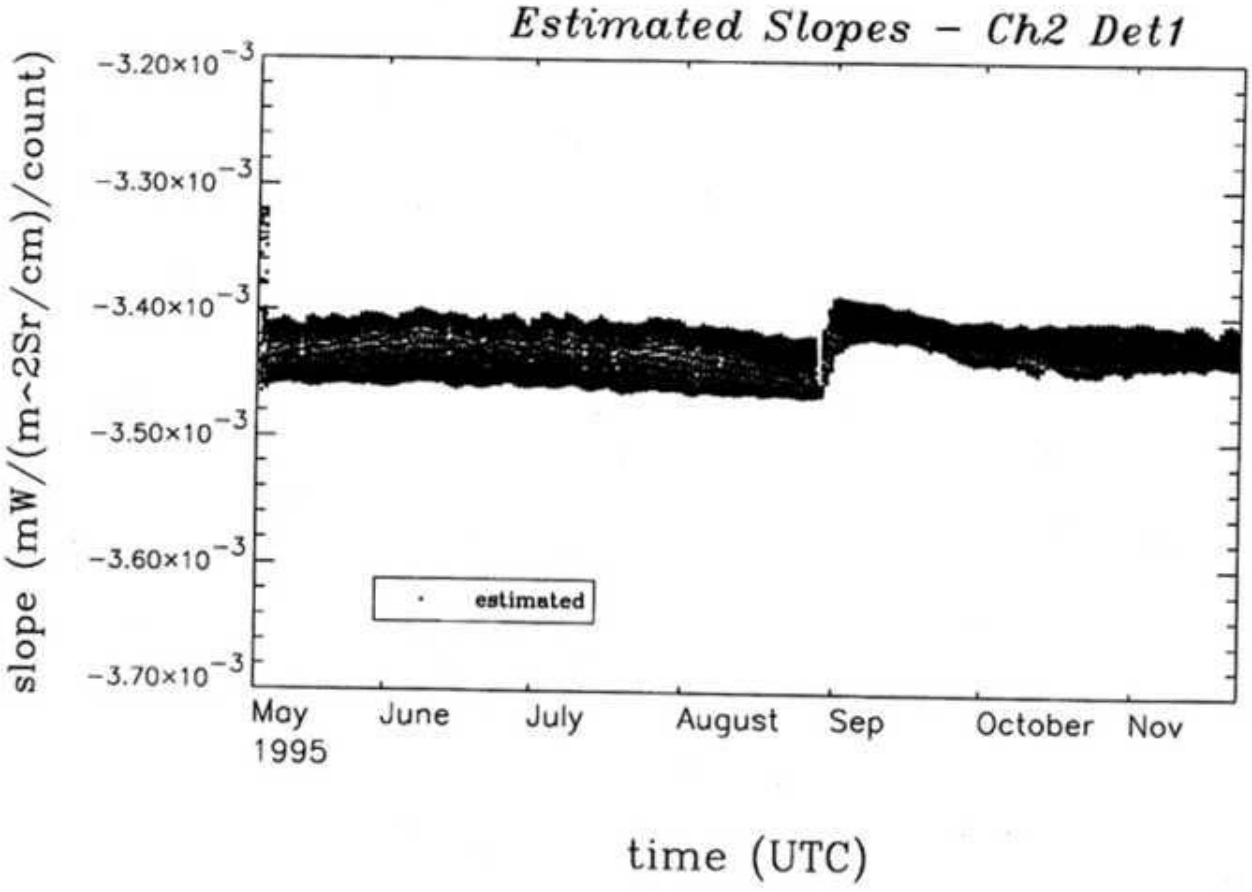
$$m = \frac{R_{bb}}{X_{bb} - X_{sp}}$$

$$m_{true} = \frac{\epsilon R_{bb} + (1-\epsilon) F_{eff} R_{eff}}{X_{bb} - X_{sp}}$$



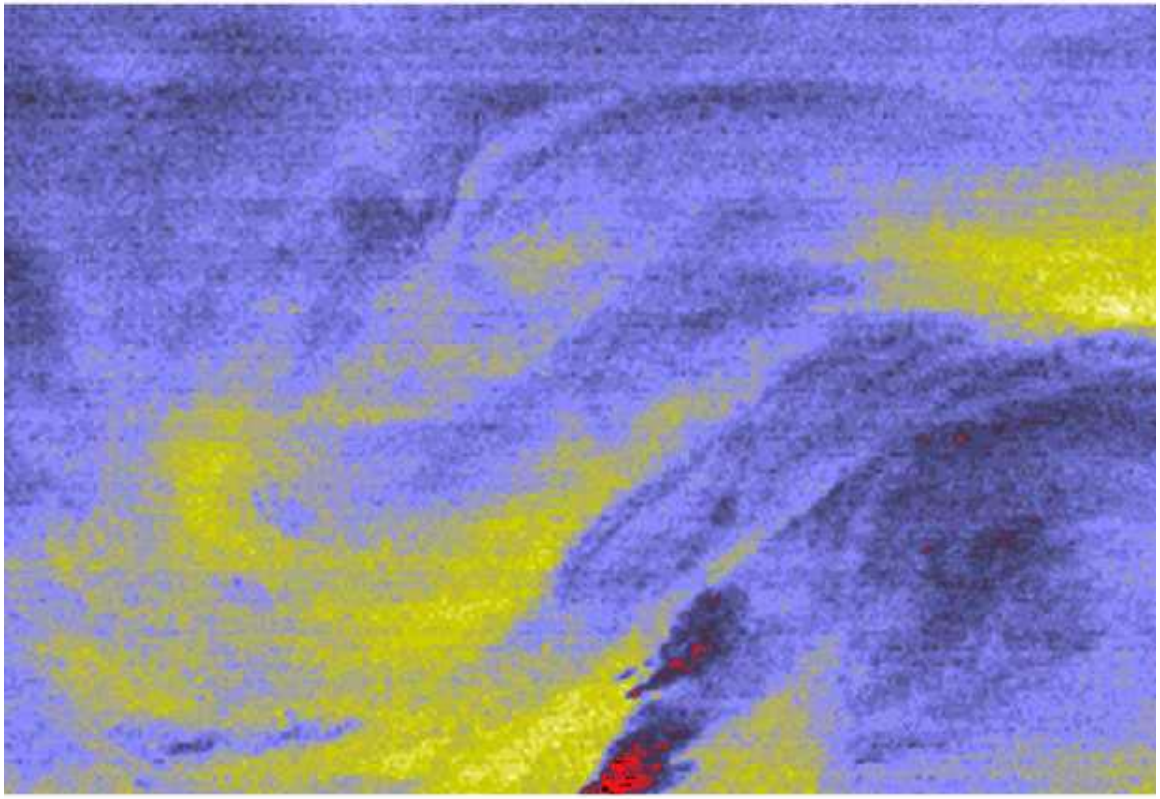
GOES-8 Imager


Original
Slopes – Ch2 Det1
slope (mW/(m^2Sr/cm)/count)
−3.20×10−3
−3.30×10−3
−3.40×10−3
−3.50×10−3
−3.60×10−3
−3.70×10−3
original
May
1995
June
July
August
Sep
October
Nov
time (UTC)


Estimated Slopes – Ch2 Det1
slope (mW/(m^2Sr/cm)/count)
−3.20×10^−3
−3.30×10^−3
−3.40×10^−3
−3.50×10^−3
−3.60×10^−3
−3.70×10^−3
estimated
May
1995
June
July
August
Sep
October
Nov
time (UTC)

2. Banding

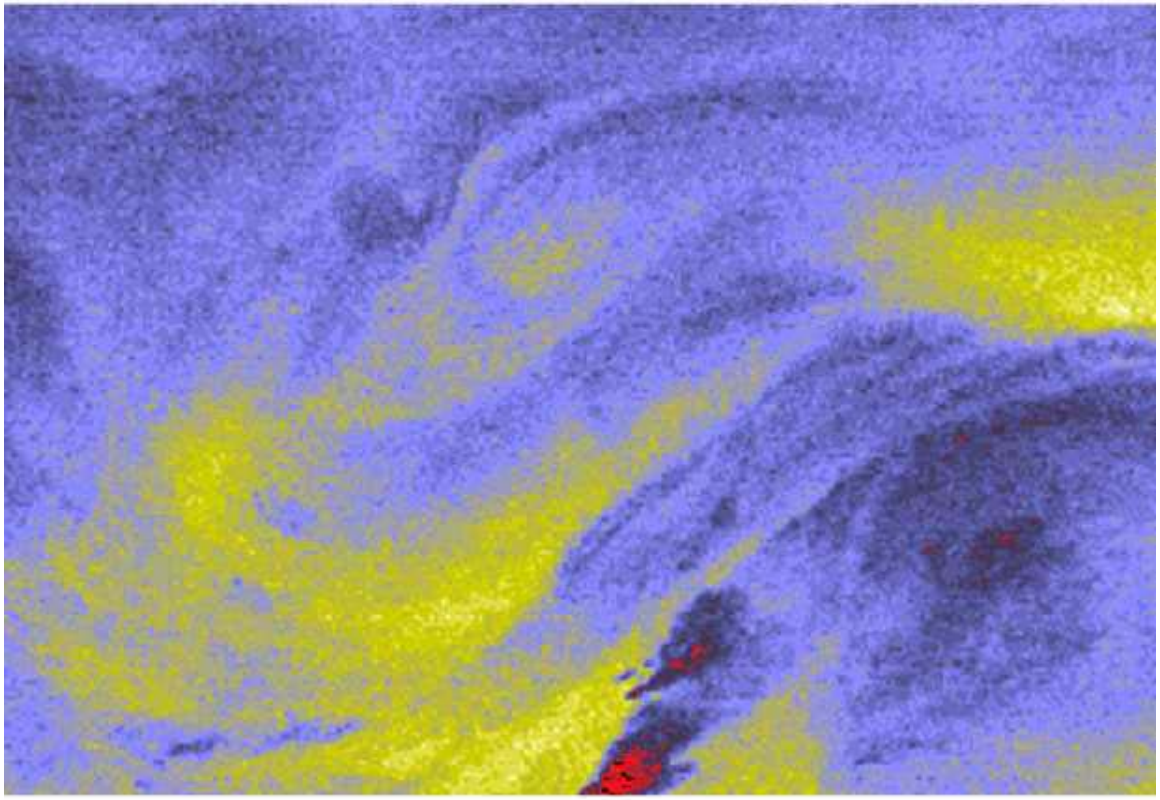
GOES-12 Sounder Ch. 12, 05May05, 0546 UTC, Mode 1



Cause: Calibration frequency (space look every 2 minute) inadequate when instrument temperature changes fast (satellite midnight)

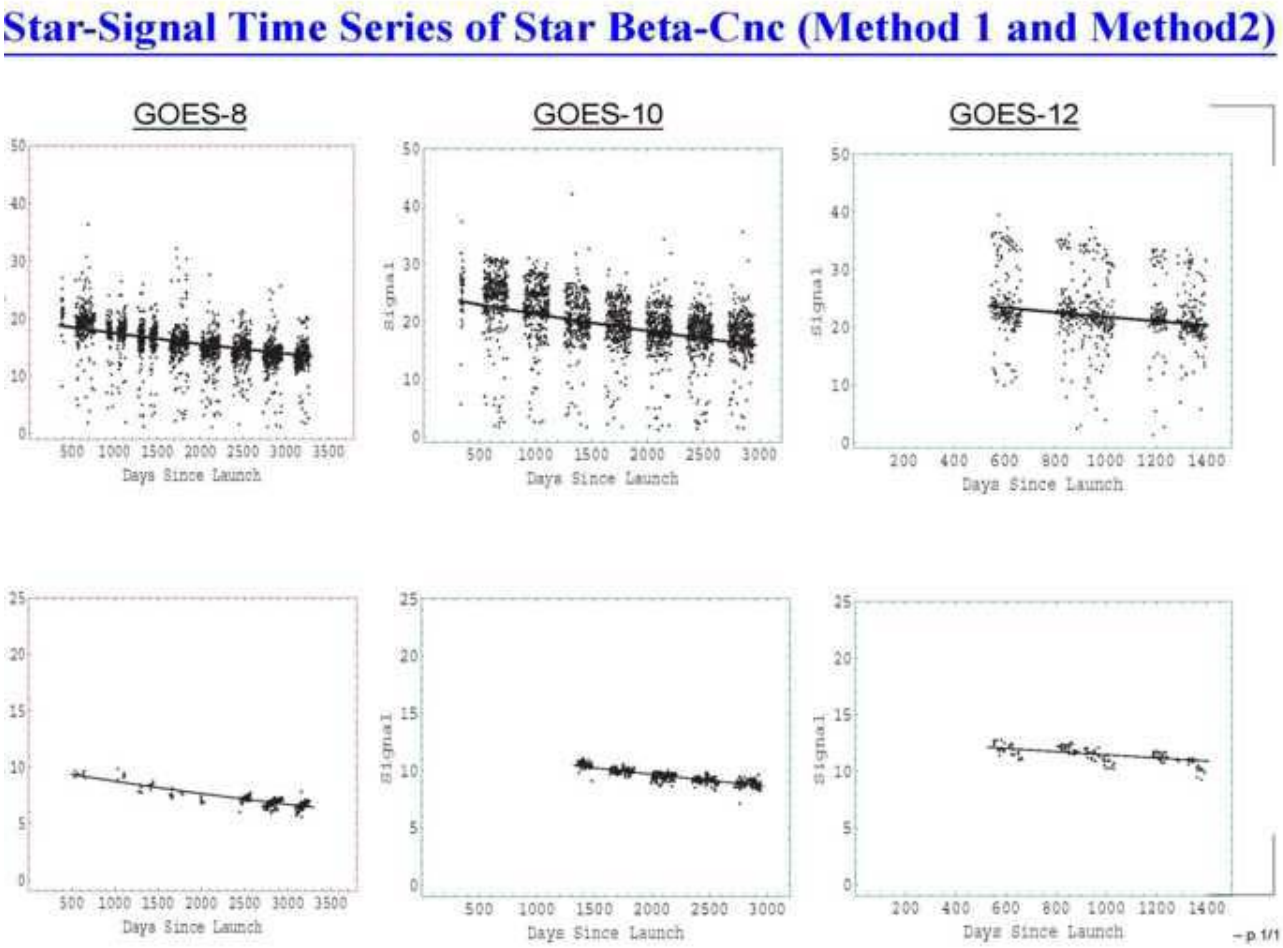
2. Banding

GOES-12 Sounder Ch. 12, 05May05, 0546 UTC, Mode 2 (interpolation)



Solution: Interpolate the offset

3. Intra-Annual Variation of Star Sense



Conclusions

- Benefits
  - Enable full-optical calibration for IR channels
  - Helpful or critical for lunar, stellar, and solar (onboard) calibration
- Lessons Learned
  - Minimize diurnal heating. Pay attention to the instability it causes
    - Midnight Blackbody Calibration Error
    - Banding
    - Alignment/Focusing
  - Adequate calibration frequency
    - 1/f noise
    - Rapid temperature variation
  - Thorough pre-launch characterization, backup with witness sample
    - AOI dependence of scan mirror emissivity
    - Stray light
- Overall impact – positive!