# Vicarious Calibrations of GOES Imager Visible Channels

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Calcon 2014 @ Logan, Utah

# Motivations

- A variety of vicarious calibration methods are available for the GOES Imager visible channels
  - No onboard calibration device for GOES Imager visible channels
  - Different stable reference for each method
  - Reference characterization: Relative vs. absolute calibrations
  - Independently evaluate the sensor performance & cross verifications
- Request for high quality of calibrated radiance/reflectance
  - Reliable absolute calibration accuracy for the climate studies
  - High relative calibration accuracy for early change(trend) detection
- Applications:
  - GSICS re-analysis product
  - GOES-R ABI in-orbit radiometric calibration accuracy validation

# Objectives

- **Evaluate the individual vicarious calibration method implemented in-house for GOES Imager visible channel at NOAA/NESDIS**

- **Integrate the different vicarious calibration methods to improve the calibration accuracy**
  - **Improve the relative calibration accuracy**
  - **Evaluate the difference between different absolute calibration results**

# GOES Imager Visible Vicarious Calibration Methods

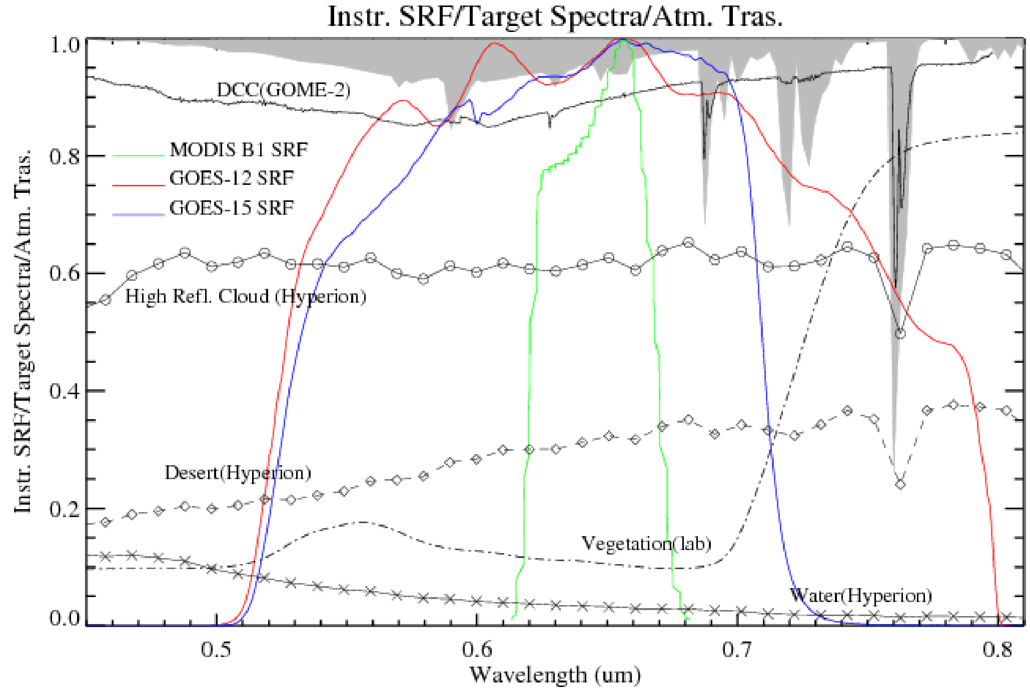
- Reference targets:
  - Stars – relative cal.
  - Ray-matching – relative cal.
  - Sonoran desert – absolute cal.
  - Deep Convective Cloud (DCC) – absolute cal.
  - Moon – expected to be implemented soon once the GSICS Implemented ROLO (GIRO) model is publically available

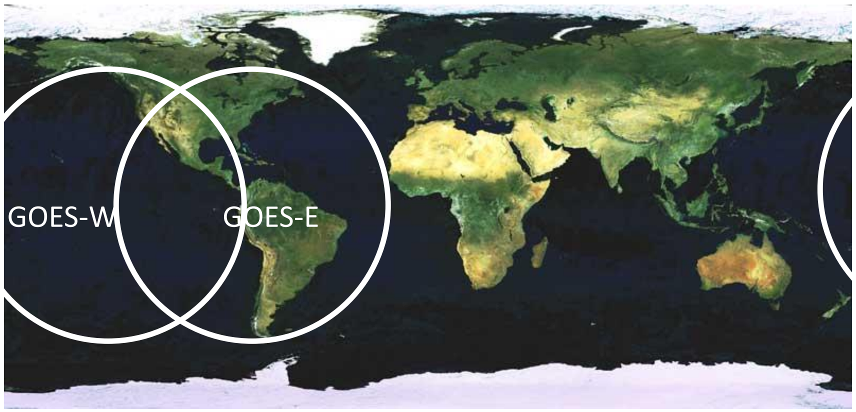
In-house implemented algorithms

- Absolute calibration accuracy was achieved by calibrating the GOES Imager visible data traceable to Aqua MODIS Band 1 C6 standard
  - Recommended by the GSICS research working group vis/nir sub-group

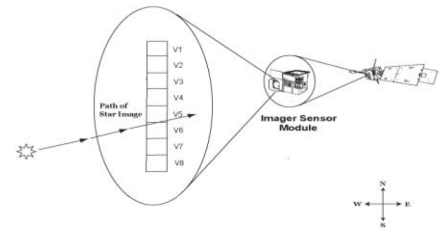
- GOES-15 (GOES-West, 135W) and GOES-12 (GOES-East, 75W) as examples

# Spectral Response Functions & Desert/Clouds/Vegetation/Water Spectra



# Stellar Calibration

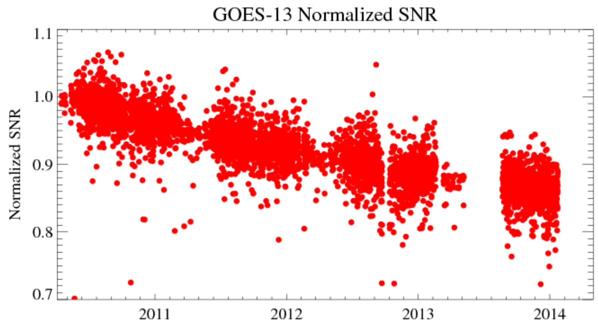


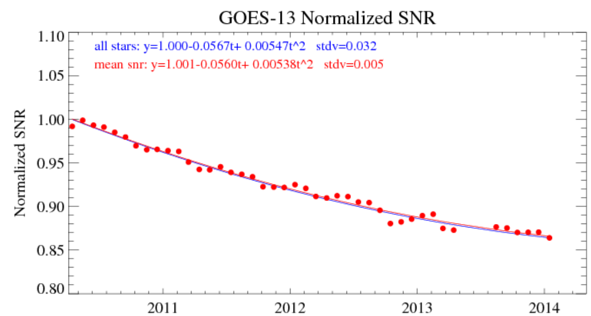

Courtesy of I. Chang

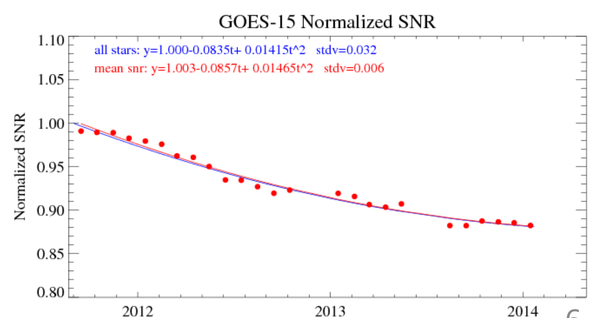
- **Extremely stable reference**
  - Used for image navigation purpose
  - Many stars available
  - Bremer et al. (1998) & Chang et al. (2012)

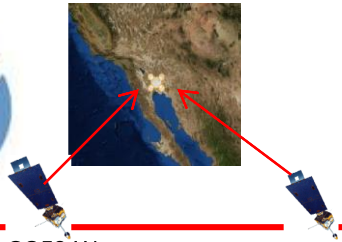
- **Challenges**
  - Relatively low Signal-to-Noise Ratio (SNR)
  - Each star has observation gap in a year
  - Sensitive to instrument diurnal/seasonal optics' temperature variation
  - Subject to the ground system on the INR signal processing

- **Relative calibration**
  - Chang et al. 2012 & Dean et al. 2012
  - Select bright stars
  - Exclude the midnight effect (filtering out the data falling in satellite midnight time ± 5hours)
  - Normalize the time-series SNR to Day1 data
  - Combine the normalize the SNR values
  - Average the combined SNR at monthly interval



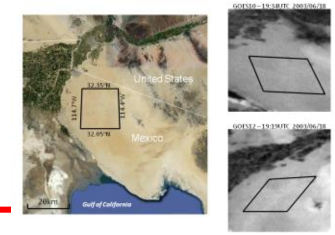



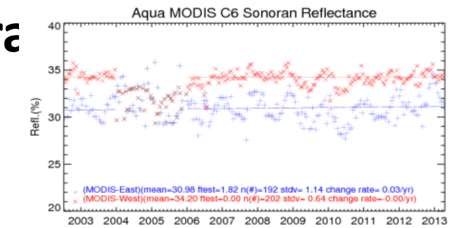



# Sonoran Desert

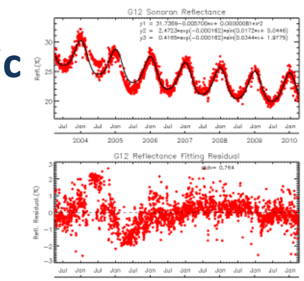
[32.05N-32.25N, 114.7W-114.4W]




- **Target is long-term radiometrically, spatially and spectra stable at GOES viewing geometries.**



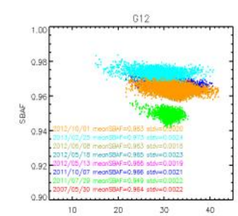

- **Challenges:**
  - Impact of seasonal variation of solar zenith angle
  - Impacts of daily dynamic atmospheric components and periodic climatic variations e.g. ENSO events
  - Different SRFs
  - No strict GEO-LEO ray-matching pixels for absolute cal.

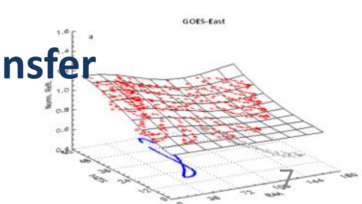



- **Absolute Calibration:**
  - Quadratic fitting for sensor degradation + two sine functions for the impacts of seasonal changes of solar zenith angle and atmospheric components.

$$R_{pre,t} = a + bt + ct^2 + m_1 e^{dt} \sin(\alpha t + \beta_1) + m_2 e^{dt} \sin(2\alpha t + \beta_2)$$

  - Hyperion data for the spectral correction
  - One year of satellite measurements to develop the BRDF model to transfer the Aqua MODIS data to GOES viewing geometries



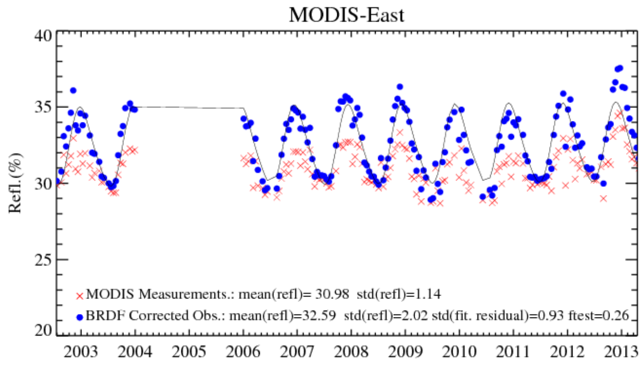



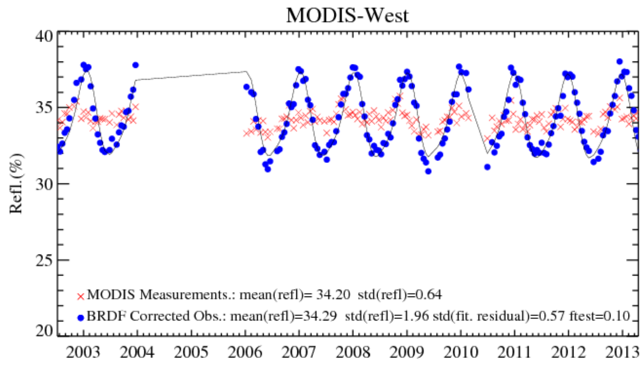

Yu, F. et al. (2014) JGR doi:10.1002/2013JD020702

# Reference reflectance of Sonoran Desert

**Desert Reference Reflectance, traceable to Aqua MODIS**

| | GOES-12 (East) | GOES-15 (West) |
|---|---|---|
| Desert MODIS long-term reflectance (%) | 32.59 | 34.29 |
| SBAF (GOES/MODIS, Hyperion data derived) | 0.949 | 0.929 |




Daily median MODIS reflectance

↓

Removal of contaminated pixels

↓

Average the daily clear-sky pixel reflectance at monthly interval

↓

Trend fitting

$$R_{pre,t} = a + bt + ct^2 + m_1 e^{dt} \sin(\omega t + \beta_1) + m_2 e^{dt} \sin(2\omega t + \beta_2)$$



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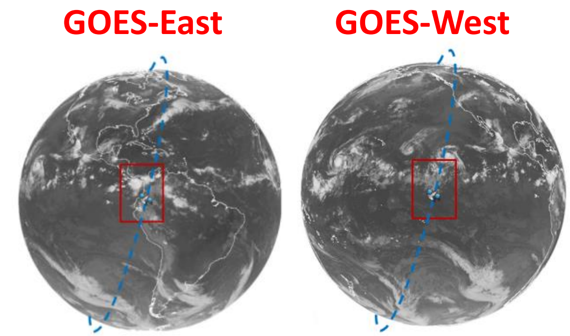
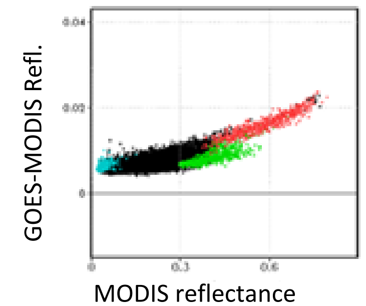
# Ray-matching

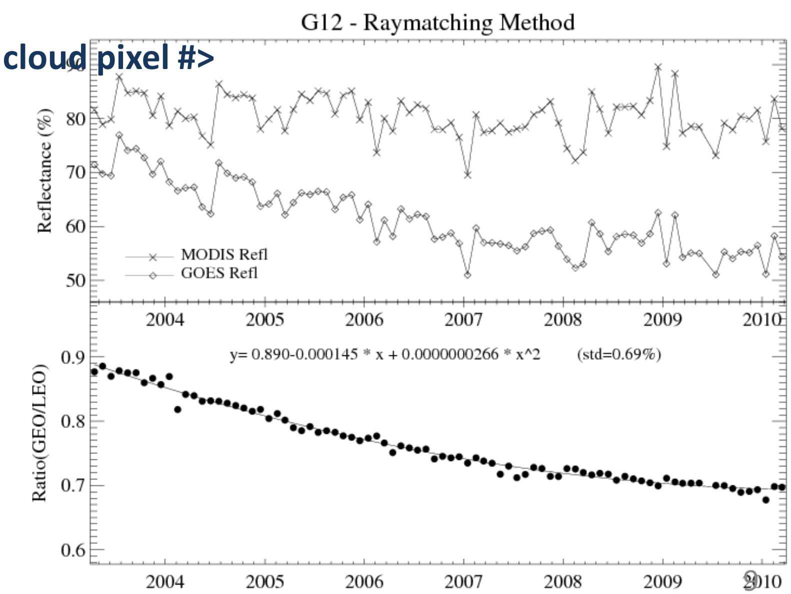


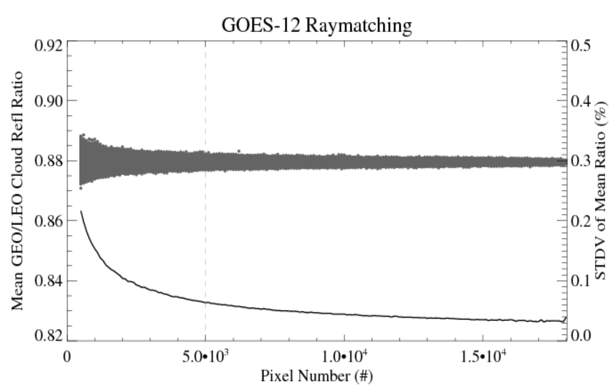

- Direct satellite-to-satellite inter-comparison to minimize the impacts of BRDF and different atmospheric components
  - Doelling, D. et al. (2004)
- Challenges
  - Lack of coincident hyper-spectral radiometric measurements in result in large uncertainty in spectral correction
  - Few collocations with same relative azimuth angles - BRDF
- Relative Calibration
  - Collocations at sub-satellite regions within ±10º lat/lon
  - Viewing angle difference < 1%
  - High reflectance cloud collocations: MODIS reflectance > 50%
  - Reflectance ratio for sensor trending purpose
  - Statistically stable ratio with monthly high reflectance cloud pixel #> 5,000

GOME-2 Simulated G14 and MODIS Refl.




Wu, X. et al. (2011)IGARSS

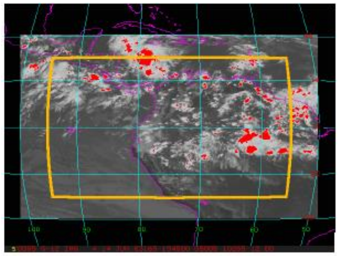


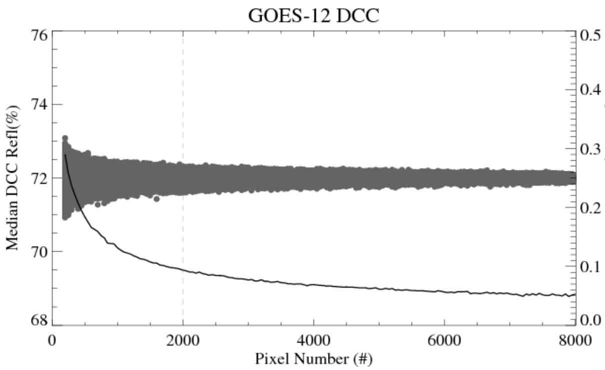

Yu, F. and X. Wu (2014) Remote Sensing of Environment, Submitted

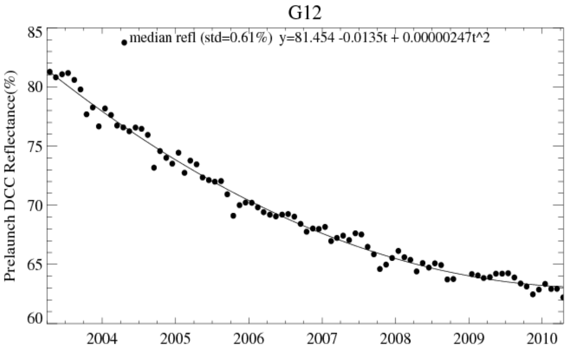
# Deep Convective Cloud (DCC)

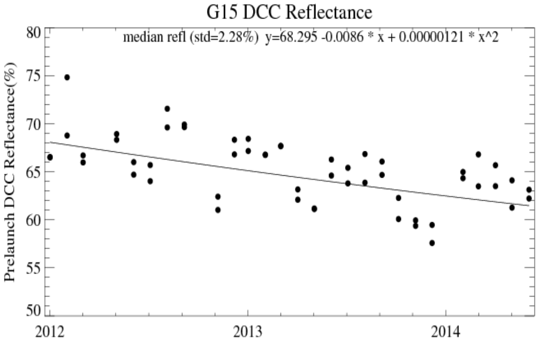
- **Stable, spectrally flat, high reflectance and common to all the satellites**
  - **Doelling, D. et al. (2004)**
  - **Reflectance is represented with monthly identified DCC pixels**
- **Challenges**
  - **Slight variation in reflectance**
  - **Occasional insufficient DCC pixels may lead to relatively large reflectance deviation for GOES-West Satellites**
- **Absolute Calibration**
  - **Use mode or median reflectance of the monthly DCC pixels to represent the DCC reflectance**
  - **At least 2,000 DCC pixels are needed to generate a statistically reliable monthly DCC reflectance value**
  - **Use Ray-matching collocated DCC pixels to determine the reference reflectance**



Courtesy of D. Doelling



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# Reference Reflectance of DCC

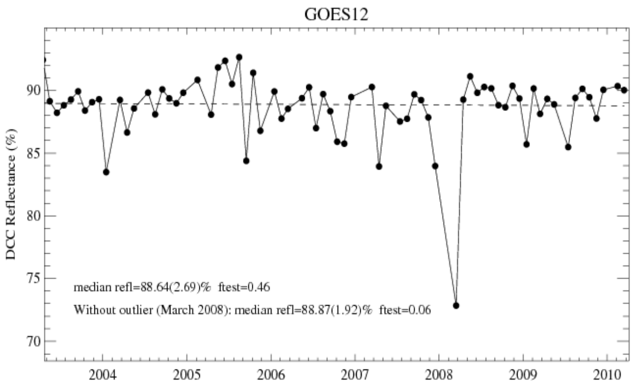
**DCC Reference Reflectance, traceable to Aqua MODIS**

| | GOES-12 (East) | GOES-15 (West) |
|---|---|---|
| DCC MODIS long-term reflectance (%) | 88.87 | 90.38 |
| SBAF (GOES/MODIS) | 0.991[1] | 0.994[2] |

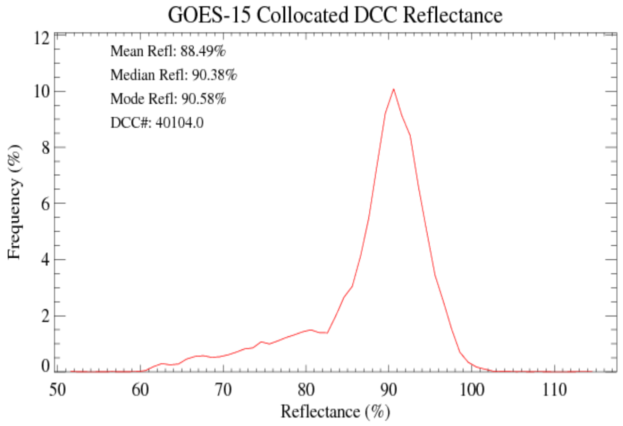
1: SCIAMACHY data derived provided by D. Doelling, 2: GOME-2 data derived

## DCC Reference Reflectance Derived from Ray-matching Collocated MODIS DCC Pixels

**Time-series of monthly MODIS DCC reflectance for GOES-12**




**Histogram of MODIS DCC Reflectance for GOES-15 (Dec 2011 – March 2014)**



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# Combination of the Different Vicarious Calibration Results

**Monthly average reflectance**

↓

**Trending fitting**

$$R_{pre,t,\,fitting} = a + bt + ct^2$$

↓

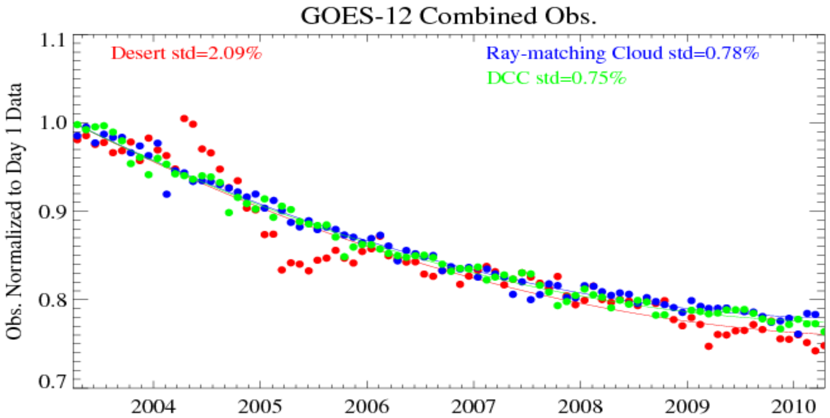
**Normalized to the estimated Day1 reflectance**

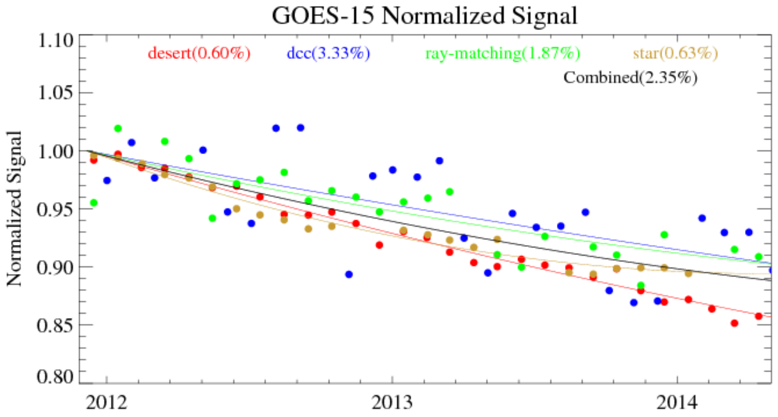
$$Normalized\_Reflectance_t = \frac{R_{pre,t,observation}}{R_{pre,t=1,\,fitting}}$$

$$R_{pre,t=1,\,fitting} = a + b*1 + c*1^2$$

↓

**Combine the Normalized Data**

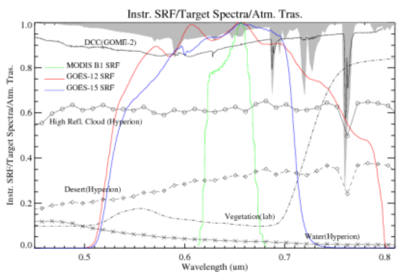


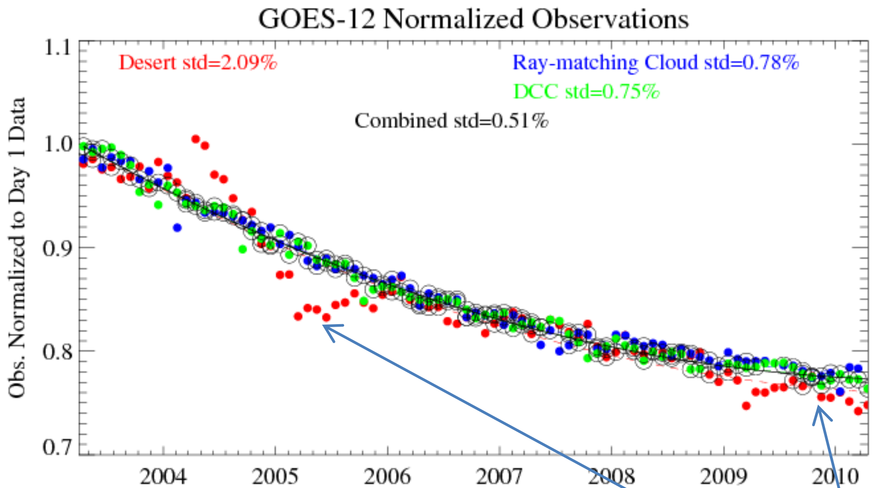



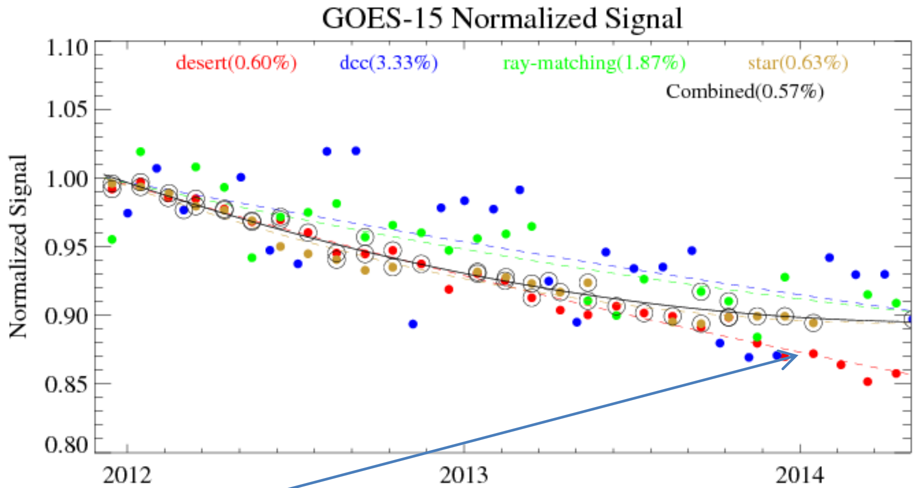
# Integrated Vicarious Calibration

**Similar degradation patterns over different reference targets may indicate that the spectral response function degradation, if any, is very small and negligible**

- **Where is the truth of sensor degradation?**
  - **The truth should exist where most observations converge**
- **Recursive filtering to remove the observations away from the "truth" - the fitting curve**




*Relative calibration accuracy improved to 0.41% when only ray-matching and DCC methods are combined

ENSO effects?

# Absolute Calibration Correction Comparisons

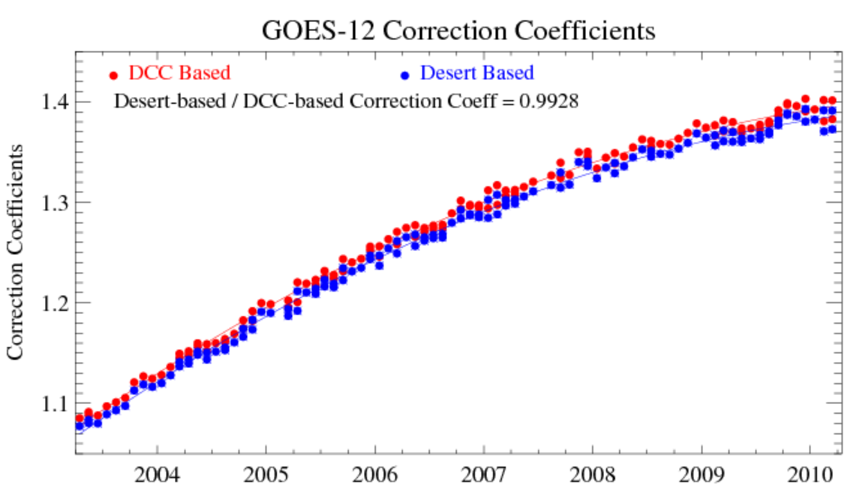
$$Correction\_Coefficient_{t,i} = \frac{\mathrm{Re}f\_R_{t=1,i}}{R_{t,i}} * \frac{\hat{S}_{t=1,\mathrm{int}}}{\hat{S}_{t=1,i}}$$

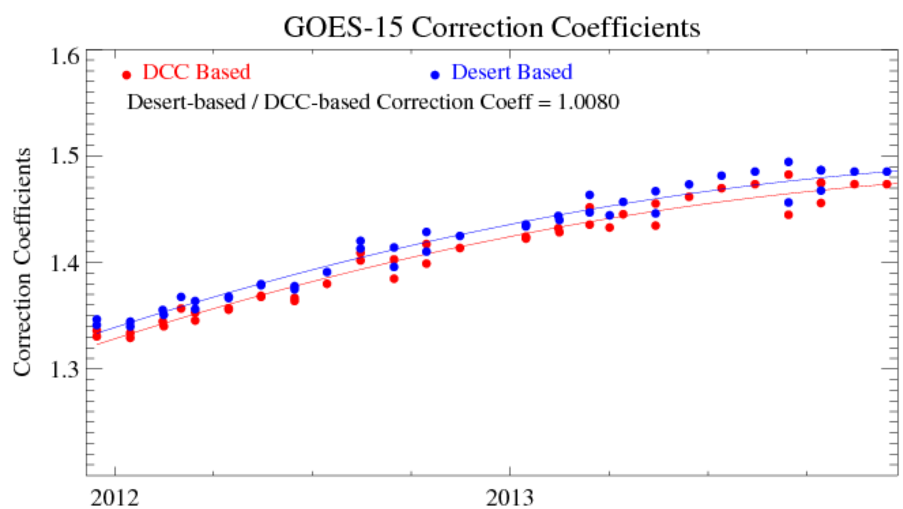
where, $R_{t,i} = \hat{R}_{t=1,i} \times Normal\_Observation_{t,\mathrm{int}}$

$$\hat{S}_{t,i} = a_i + b_i t + c_i t^2$$

**Sonoran Desert:** $\mathrm{Re}f\_R_{t,i=desert} = \overline{R}_{\mathrm{modis},i=desert} \times SBAF_{desert} + m_1 \sin(\alpha t + \beta_1) + m_2 \sin(2\alpha t + \beta_2)$

**DCC :** $\mathrm{Re}f\_R_{t,i=dcc} = \overline{R}_{\mathrm{modis},i=dcc} \times SBAF_{dcc}$



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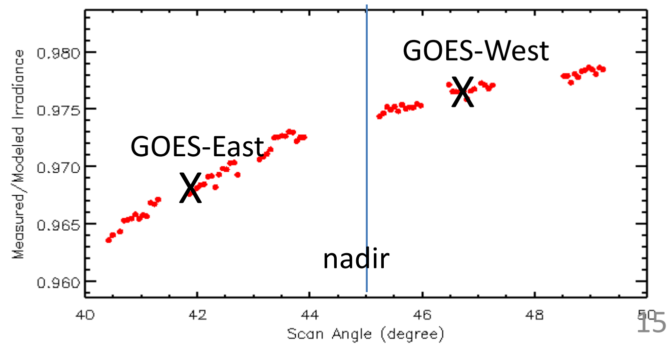
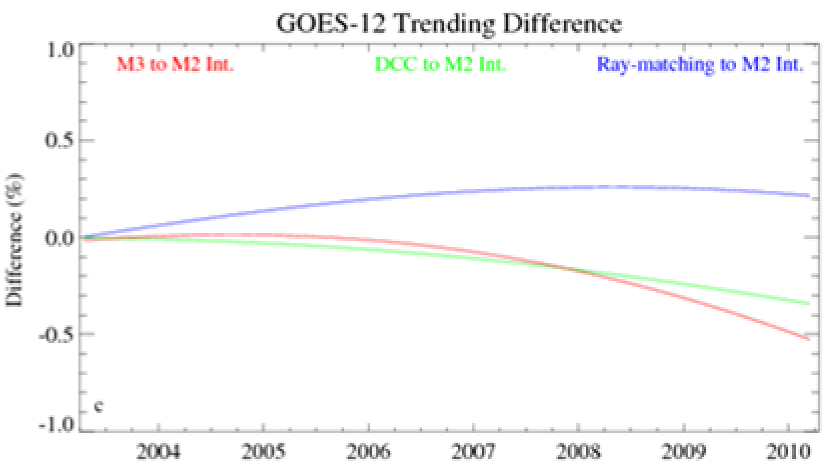
# Possible Causes to the Bias

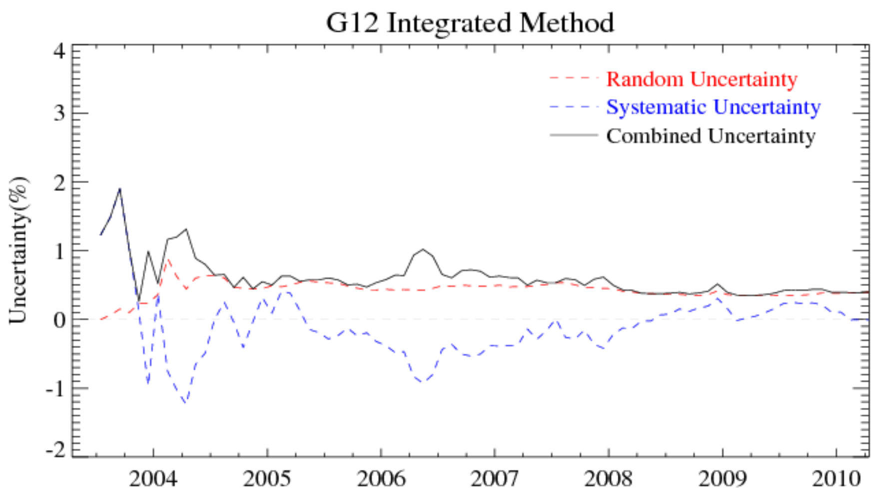
- **Reference reflectance, especially at Day1 ,is critical to determine the absolute calibration correction coefficients**
  - **Need long-term desert observation to ensure the accurate desert Day1 reflectance value**
- **Possible reflectance difference between overall DCC pixels (±20ºfrom sub-satellite point) and subset DCC pixels (±10ºfrom sub-satellite)**
  - **Slight Land/ocean DCC difference?**
  - **Slight difference at different viewing angle, residual of DCC ADM correction?**
- **Impact of GOES scan mirror reflectivity between nadir (DCC) and off-nadir (Sonoran desert) observations.**



Yu et al. (2013), GSICS QL

# Time-Series of G12 Error Budget




$\max(U_t) = 0.75\%$

$U_{r,longterm} = 0.41\%$

$\max(U_r) = 2.0\%$

Integrated method uncertainty

$$U = \sqrt{U_t^2 + U_r^2}$$

$$U_{\max} = \sqrt{(0.75\%)^2 + (2.0\%)^2} = 2.14\%$$

$$U_{longterm} = \sqrt{(0.75\%)^2 + (0.41\%)^2} = 0.85\%$$



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# Conclusions

- **The integrated method can improve the relative calibration accuracy for the GOES Imager visible channels (GOES-East)**
  - Maximum overall uncertainty is about 2% in the first one year with long-term accuracy <0.5%
  - After about 2 years, the relative calibration accuracy is generally stable at <1%
  - Same error budget assessment is needed for the GOES-West satellites

- **For the GOES-West satellites, the stellar calibration is expected to play a critical role to improve the relative calibration accuracy**
  - Especially in the early stage of the satellite mission life

- **For the GOES-East satellites, the ray-matching and DCC results play almost equally important roles in the integrated method**
  - The stellar observations are expected to further improve the relative calibration accuracy

- **The difference between desert- and DCC- based absolute calibration accuracy is less than 1%**
  - Bias may be reduced with the correction of scan angle dependent reflectivity

- **Tools and knowledge/experience will continue evolving and will be applied to validate the radiometric calibration accuracy of GOES-R ABI solar reflectance channels.**