Implementation of GEO-AIRS Inter-Calibration at NESDIS

X. Wu, NOAA/NESDIS

In collaboration with Y. Tahara, K. Kato, M. Gunshor, D. Tobin, M. König, Y. Li, S. Sohn, H. Sun, and F. Yu

- ATBD
- Implementation
- Operation
- Issues

Algorithm Theoretical Basis Document
GSICS GEO-AIRS Inter-Calibration

- **Introduction**
  - Background
  - Scope
  - History
- **Design Principle and Justification**
- **Algorithm Description**
  - Input Data
  - Subsetting
    - *Interior to GEO FOR*
    - *Collocated in Space*
    - *Concurrent in Time*
    - *Subset*
  - Collocation
    - *Collocated in Space*
    - *Concurrent in Time*
    - *Aligned in Line-Of-Sight – Zenith Angle*
    - *Aligned in Line-Of-Sight – Azimuth Angle*
    - *Uniform Environment*
      - BACKGROUND
      - IMPLEMENTATION
      - OVER-SAMPLING
    - *Normal Sample*
    - *Spatial Averaging*
    - *Spectral Convolution*
  - Output Data
- **References**

ATBD Introduction – Scope

- This ATBD is one of many, specifically for the inter-calibration between an imaging instrument on a GEO and AIRS on LEO for GSICS.
  - Not GEO-GEO, LEO-LEO
  - Not visible
  - Not Sounder
  - Many ways for comparison of other purposes.
- This ATBD currently is for data collection only.
  - Analysis is the next step to reach the goal of inter-calibration
  - That is a rapidly developing field.

ATBD Introduction – History

- Version 0, May 2007
  - Not well documented
- Version 1.0, Oct. 2007, initial release
  - ATBD will be amended later
- Version 1.1, Dec. 2007
  - Debugging and expand to more GEO
- Version 1.2, Jan. 2008
  - Some changes. More debugging and expansion.

ATBD Introduction – History

- To be discussed after break
  - Version 1.x as needed
  - Version 2 to incorporate JMA modular design
  - Convention for versions
    - How big a change qualifies for Version 2.x instead of Version 1.x or Version 1.2.x?
    - How little a change qualifies for a new version at all?
    - What if ATBD didn't change, only the implementation?
    - Document what have been changed?
    - Procedure for community feedback and version release
  - Compatibility
    - Encourage innovation and ensure compatibility
    - Baseline algorithm, uniform output

ATBD Design – Definition

- Calibration
  - Wikipedia – The process of verification that an instrument is within its designated accuracy.
  - CEOS – The process of quantitatively defining the system responses to known, controlled signal inputs.
  - It may be obvious which is better, but the main point is the need for common definition
- Inter-Calibration
  - The evaluation of agreement among collocated measurements compared to the expected uncertainty

ATBD Design – Definition

- To be discussed tomorrow
  - If that definition is adopted, need to quantify uncertainty
    - Spatial collocation
    - Temporal concurrence
    - Geometric alignment
    - Spectral convolution
    - Instrument noise
  - Perhaps in a collaborative way

ATBD Design – Goals

- GSICS Goals/Objectives
  - Quantify the difference between measurements by two satellites for the collocations being considered.
    - Minimum goal
    - Useful only if the results can be generalized, albeit often implicitly
  - Evaluate instrument performance
    - Advanced goal
    - Characteristics of the difference
      - Channel, satellite, time, day, angle, scene, …
    - Cause of the difference
- Key (necessary condition) to both goals – **sampling**

ATBD Design – Sampling

- Samples must include all conditions under which the satellites operate, i.e., the normal range of:

Spectral band	All bands
Scene temperature	Single pixel
Geographic location	Off nadir
Viewing geometry	Off nadir
Time of day	Off nadir[1]
Day of year	Continue for long term[2]
Satellite age	Continue for long term[2]

1 Sun-synchronous satellites (most LEOs) always pass the nadir of a geostationary satellite (all GEOs) at the fixed time of day (local time).

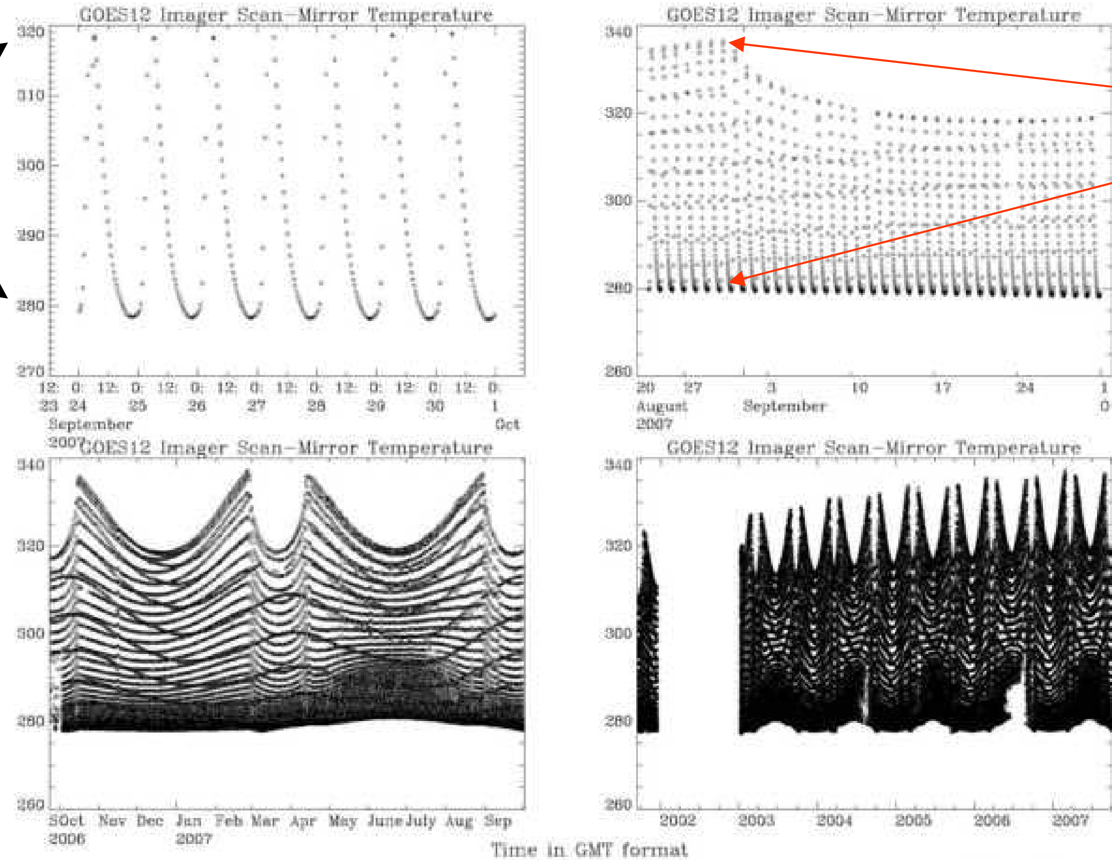
2 GSICS must be a system instead of a campaign

Time Series of Scan Mirror Temperature

An order of magnitude larger than spinners

~40ºK "now"

One Week **One Month**



~60ºK some other days

Complicated seasonal variations of diurnal heating

Long term trend

One Year **One Satellite**

D. Han

ATBD Design – Summary

- GSICS goals require that single pixel collocations anywhere within the GEO field of regard be collected continuously over long term for all bands.

- GSICS should collect all it can to allow future selection and manipulation by users.

Implementation – Input Data

- A complete set of GEO and LEO data within a common period of time (one day)
  - AIRS granules from NASA DAAC
    - Channel validity as of May 2007
    - Leap second as of May 2007
    - Update strategy TBD
  - GOES images from NESDIS server, CLASS, or UW
    - GOES-11/12. Some GOES-13.
    - Need tuning for other GEO.
  - All four IR bands
    - Despite the large spectral gaps and shortage for the 3.9 μm and 6.7 μm channels

Implementation – Intermediate Data

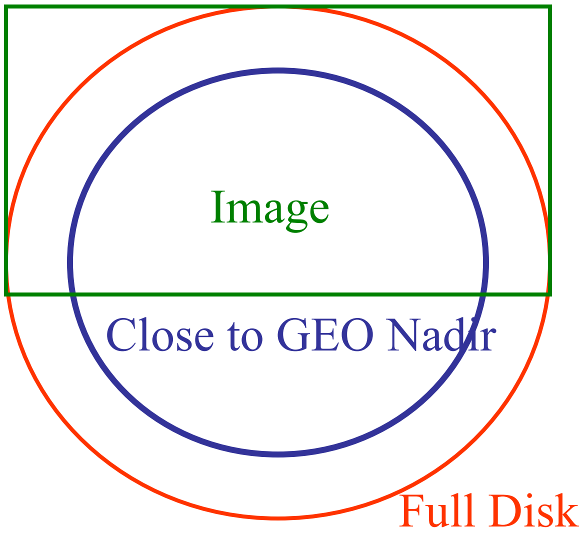
- M. König suggested subsetting at GRWG-II
  - ~95% granules are outside of a GEO FOR or mismatch in time
  - When matched, ~10% of the image covers a granule
- GEO subset image: SSS##.AIRS.yyyy.mm.dd.grn.lat.long.bbb
  - So named such that only this name needs to be saved permanently

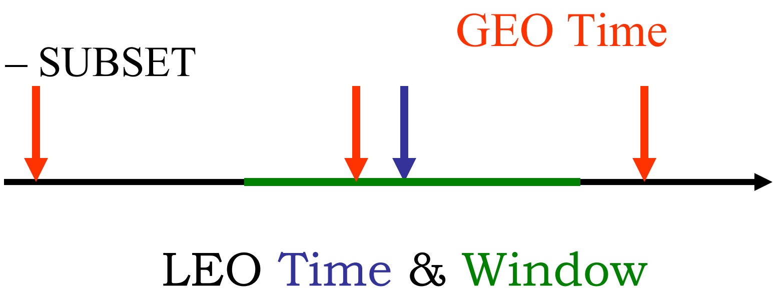
sss	Satellite ID (e.g., GOS, MET, FY_, MTS)
##	Satellite series number (e.g., 07)
yyyy	Year (2007, 2008, ...)
mm	Month (01, 02, ..., 11, 12)
dd	Day (01, 02, ..., 30, 31)
grn	AIRS granule number (001, 002, ..., 239, 240)
lat	Latitude (e.g., N04)
long	Longitude (e.g., W120)
bbb	Band wavelength (µm*10, e.g., 039)

Further discussion after break

Implementation – Subsetting

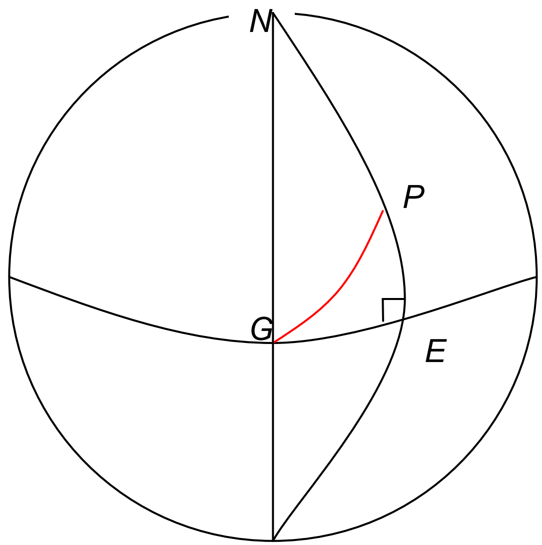
```
for each LEO granule
    for each GEO image
                    CLOSE TO GEO NADIR
        if LEO granule is outside of GEO FOR then next granule
                    WITHIN GEO IMAGE
        if LEO granule is outside of GEO image then next image
                    CONCURRENT IN TIME
        time_diff = LEO_time – GEO_time
        if time_diff > max_sec then
             this image is too early – next image
        else if time_diff < -max_sec then
             this image (and the rest) is too late – next granule
        else
             this image matches the granule – SUBSET
        end
    end (next GEO image)
end (next LEO granule)
```

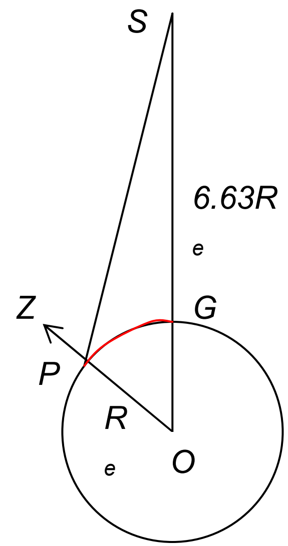




Implementation – Subsetting

Cosine theorem of spherical trigonometry





Cosine and sine theorems of plane trigonometry

GP = ∠SOZ

$$\cos(GP) = \cos(gra\_ctr\_lat)\cos(geo\_nad\_lon - gra\_ctr\_lon)$$

$$SP^2 = SO^2 + OP^2 - 2 * SO * OP\cos(PG)$$

$$\sin(SPZ) = \sin(PG) * SO / SP$$

Implementation – Collocation

for each LEO pixel

COLLOCATED IN SPACE

if LEO pixel is outside of GEO image then next LEO pixel

CONCURRENT IN TIME

if |LEO_time – GEO_time| > max_sec (300 sec) then next LEO pixel

ALIGNED IN LINE-OF-SIGHT

if |cos(geo_zen)/cos(leo_zen)-1| > max_zen (0.01) then next LEO pixel

UNIFORM ENVIRONMENT

if env_stdv > max_stdv (10 count) then next LEO pixel

NORMAL GEO FOV

if |fov_mean – env_mean| > (env_stdv/n)(N-n)/(N-1)*G (3) then next LEO pixel

SPATIAL AVERAGING

simple average of GEO pixels in area comparable of LEO FOV

SPECTRAL CONVOLUTION

several choices

OUTPUT THE RESULTS

list of parameters provided

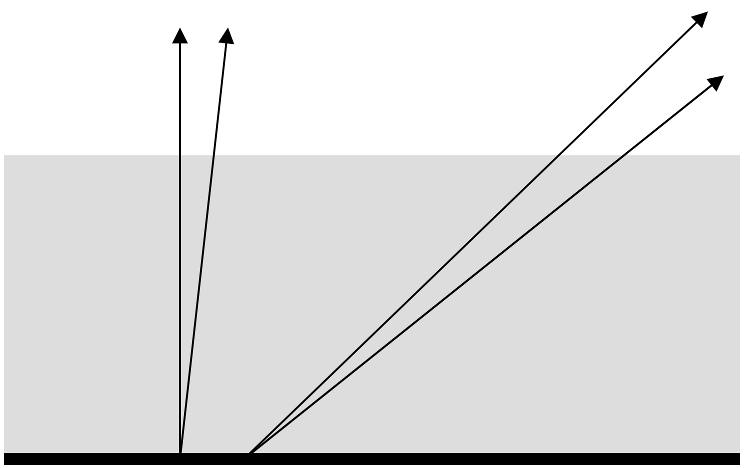
end (next LEO pixel)

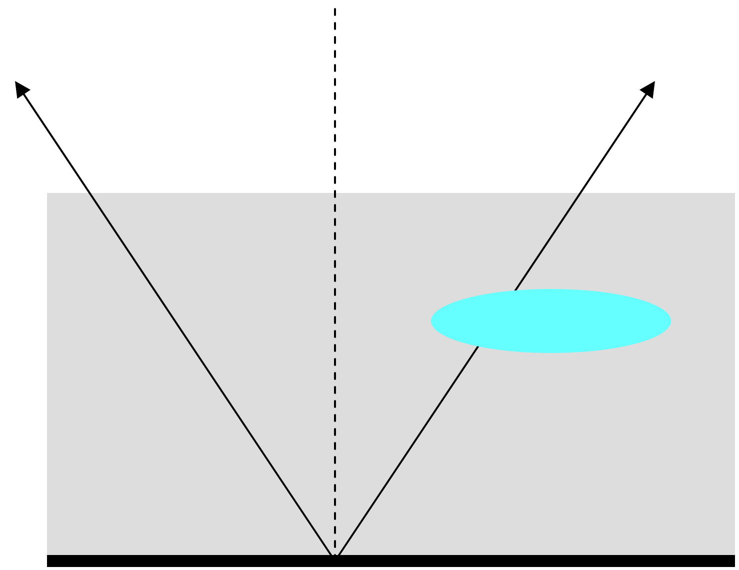
Implementation – Collocation Angle

|geo_zen - leo_zen|

|cos(geo_zen) - cos(leo_zen)|

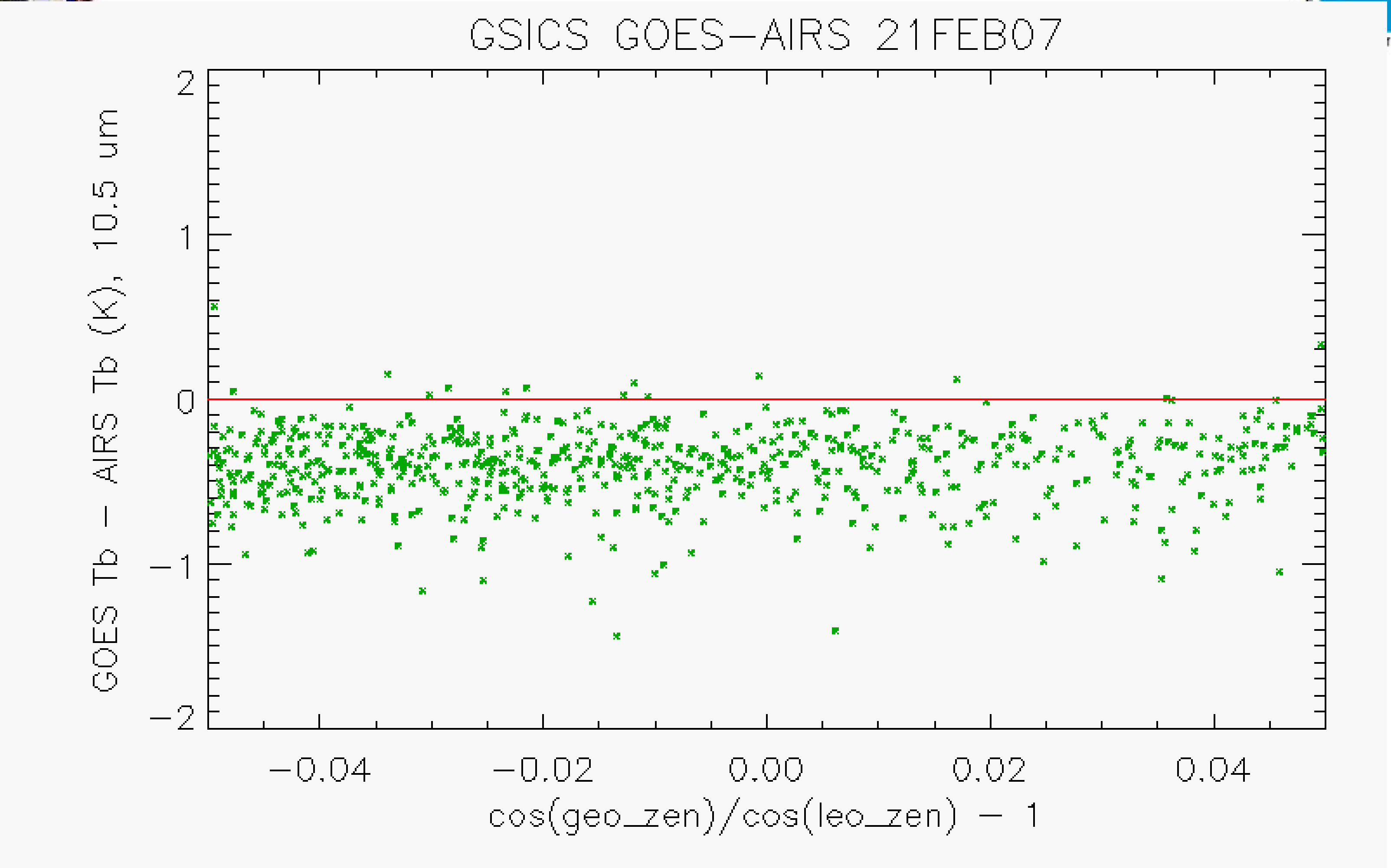
|cos(geo_zen)/cos(leo_zen)-1|



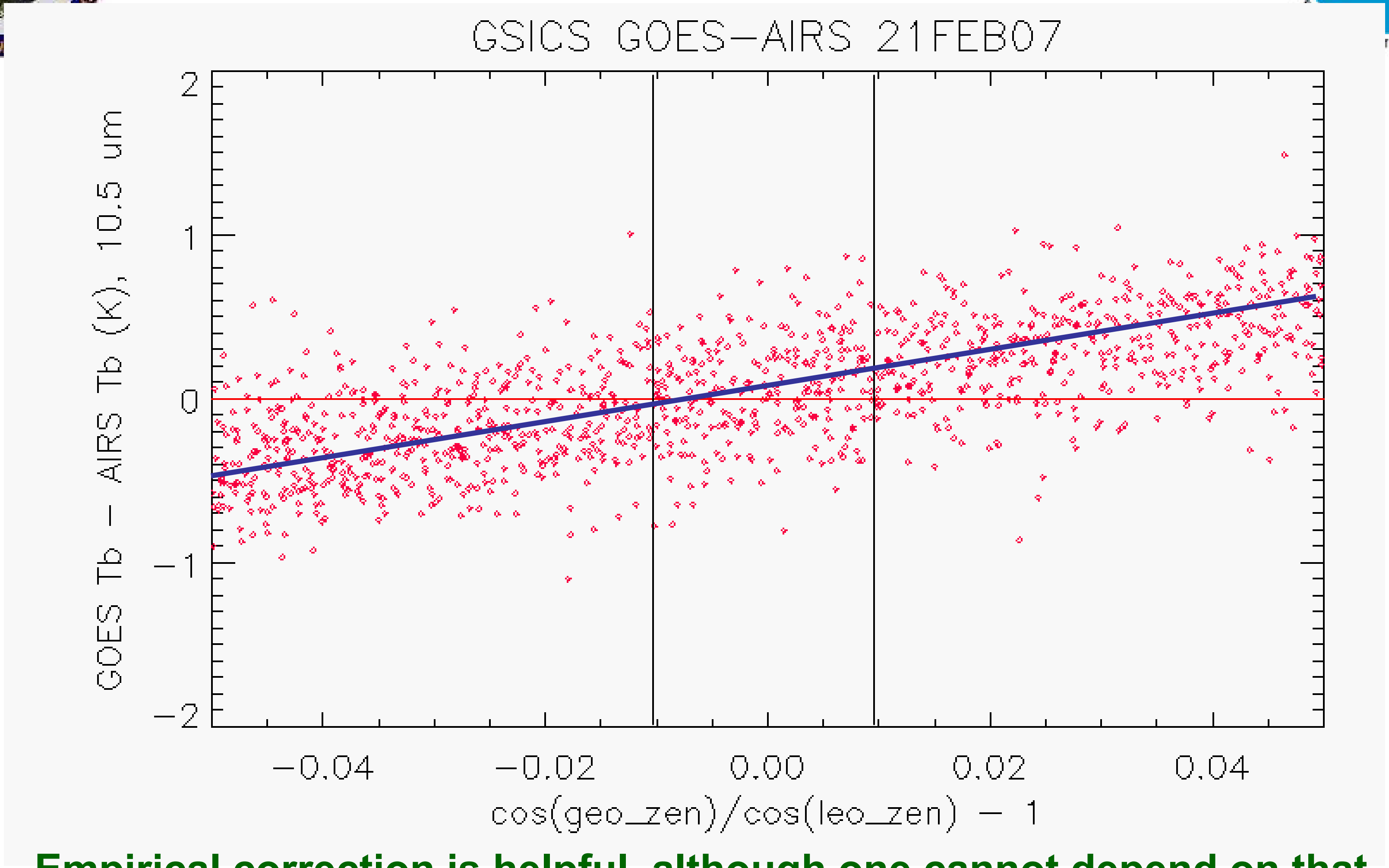


IR channels are often insensitive to difference in azimuth angle

Preliminary Results from Prototype Algorithm

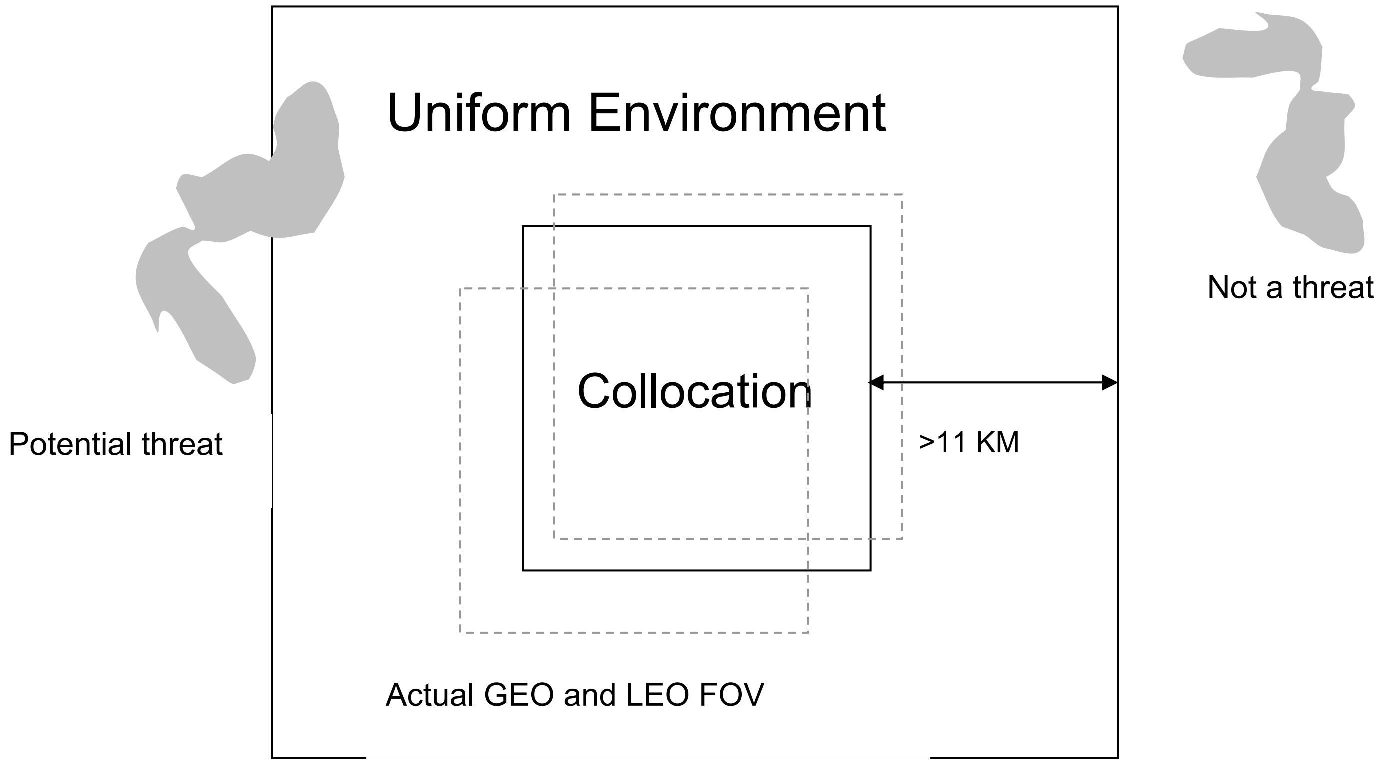


Preliminary Results from Prototype Algorithm

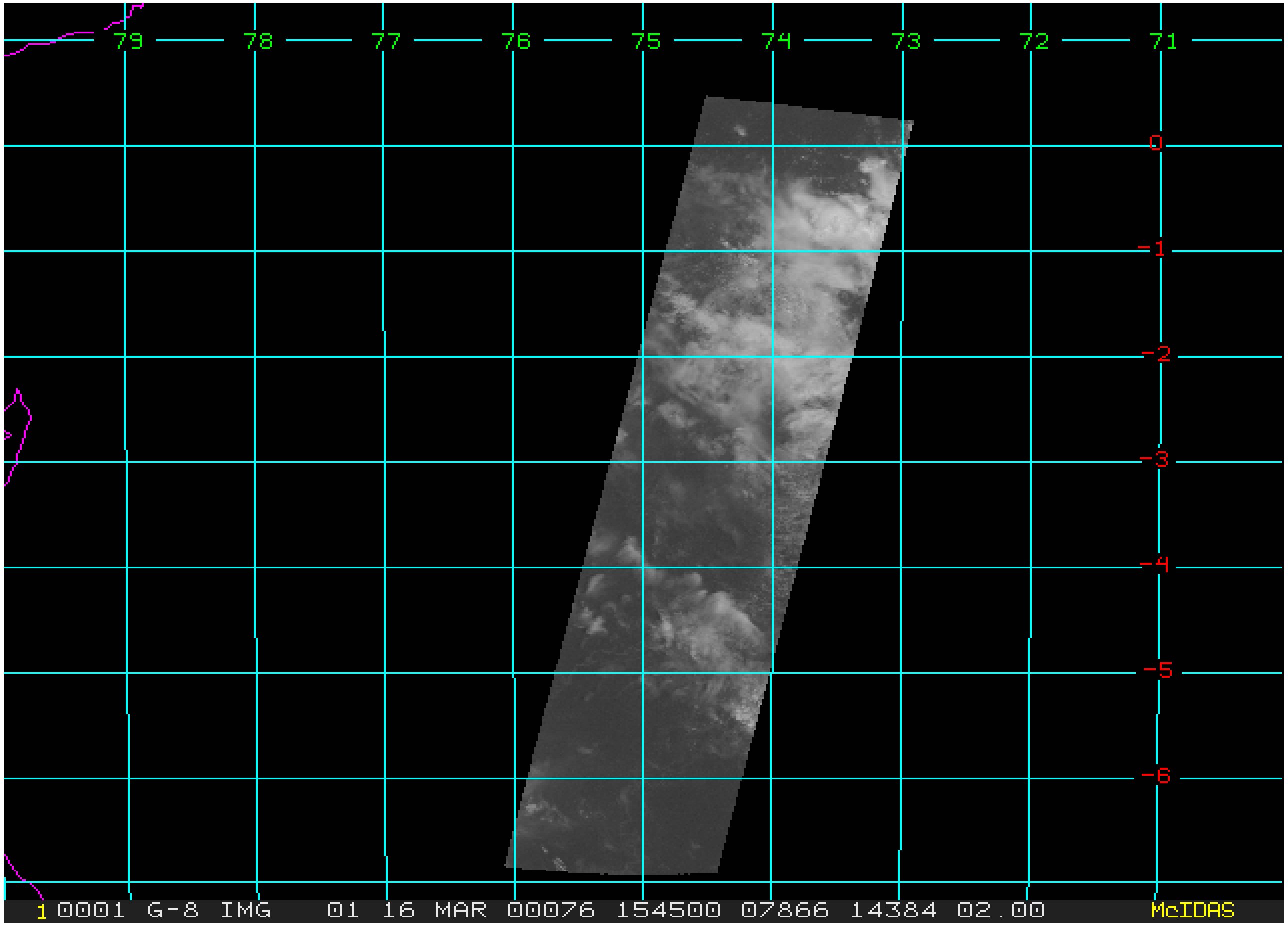


Empirical correction is helpful, although one cannot depend on that too much since this correction depends on the lapse rate

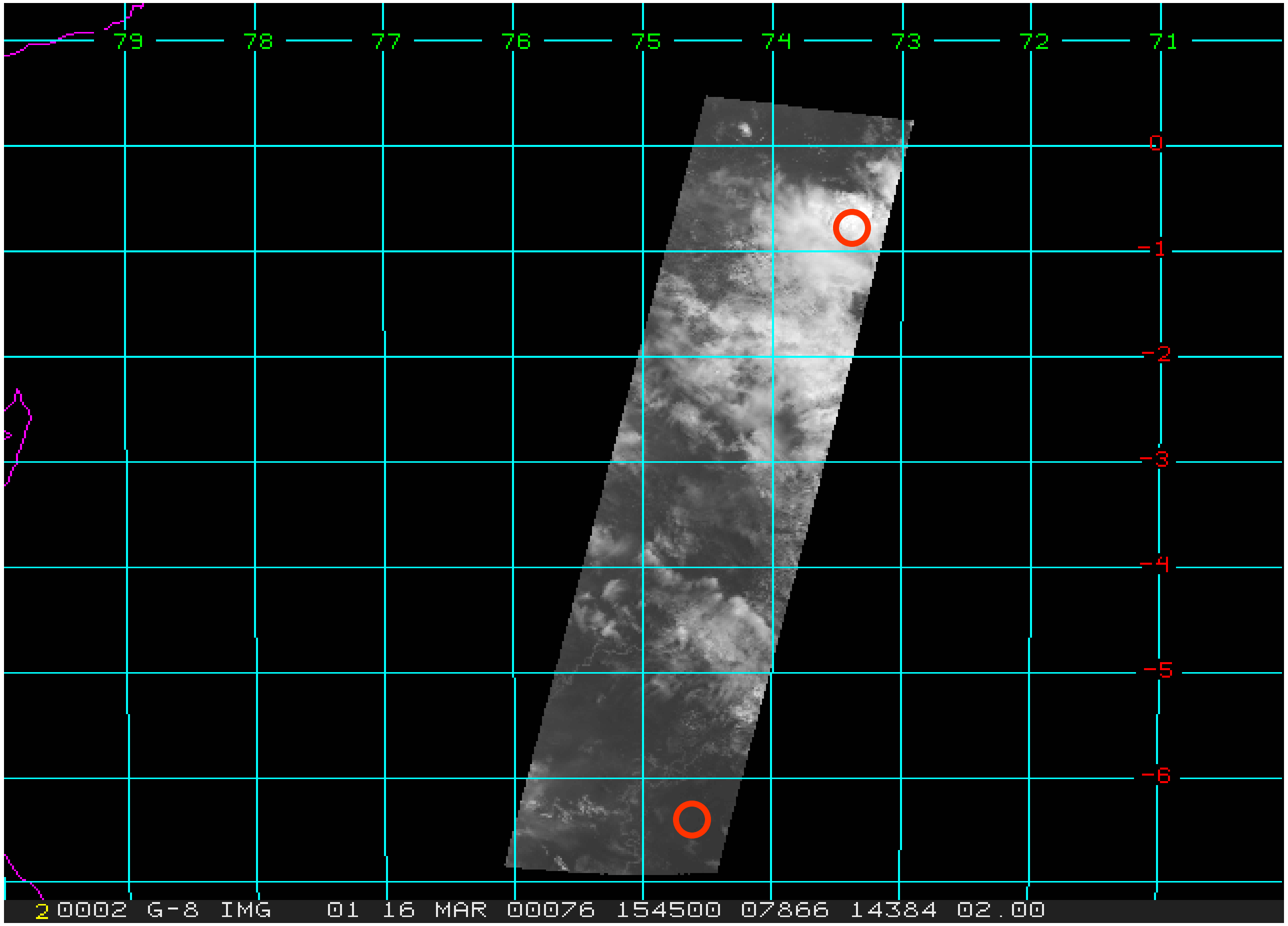
Implementation – Collocation Uniform



Preliminary Results from Prototype Algorithm



Preliminary Results from Prototype Algorithm



Implementation – Collocation Uniform

- Uniformity measured by standard deviation σ
- σ of T_b is a bad choice.
- σ of radiance is better.
  - Varies with scene T_b and wavelength – weighted by mean

Table 1: δT_b in response to 5% δR for GOES IR channels at selected scene temperature.

	3.9 μm	6.6 μm	10.7 μm	12.0 μm	13.3 μm
290ºK	1.2K	2.0K	3.1K	3.6K	3.9K
250ºK	0.9K	1.5K	2.4K	2.7K	2.8K
210ºK	0.6K	1.0K	1.5K	1.8K	2.0K

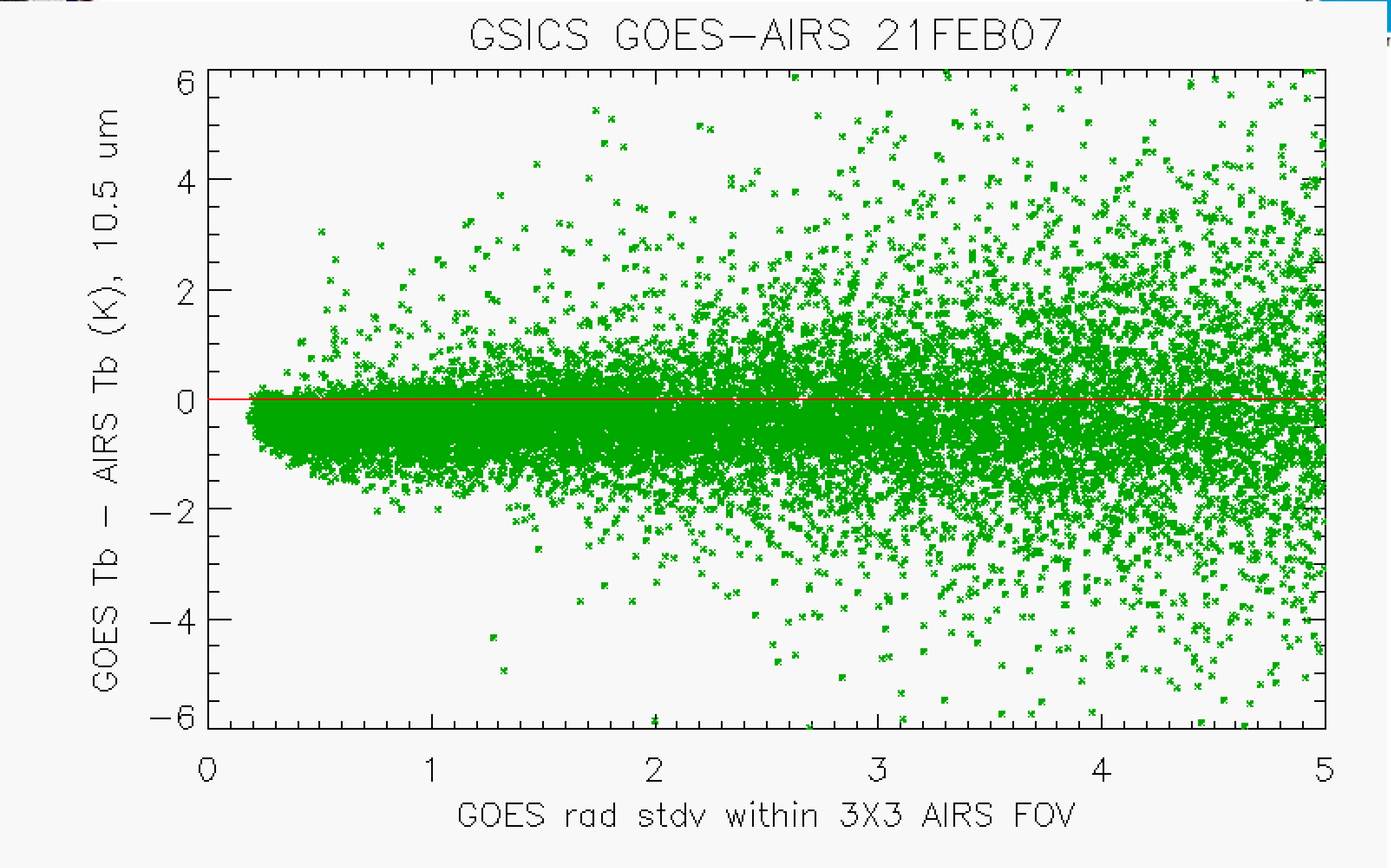
Implementation – Collocation Uniform

- σ of count is the best

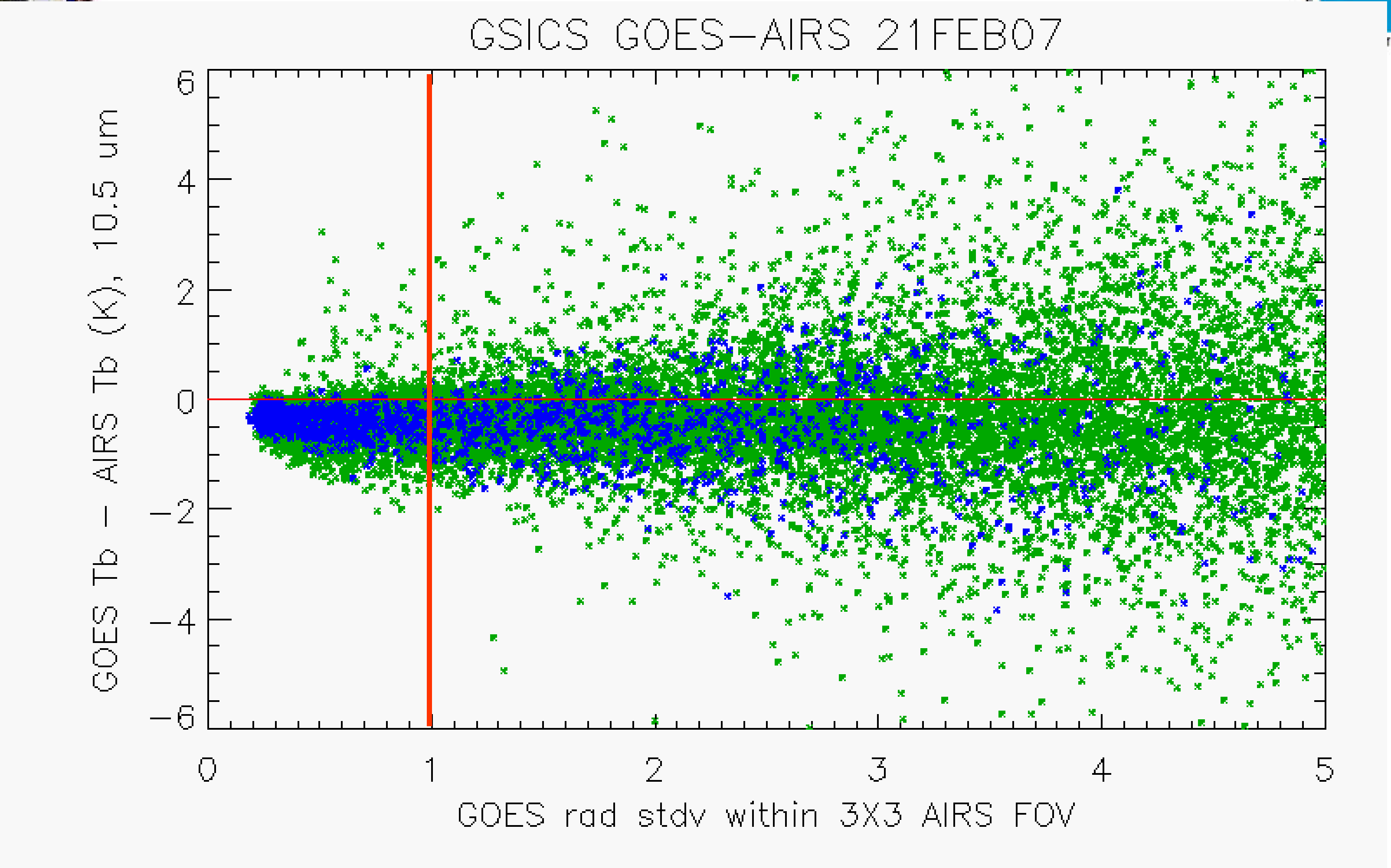
Table 2: δT_b in response to 10 counts for GOES IR channels at selected scene temperature.

	3.9 μm	6.6 μm	10.7 μm	12.0 μm	13.3 μm
290ºK	1.6K	0.5K	1.2K	1.2K	1.1K
250ºK	7.5K	1.1K	1.9K	1.8K	1.5K
210ºK	27K	3.8K	3.7K	3.1K	2.4K

Preliminary Results from Prototype Algorithm

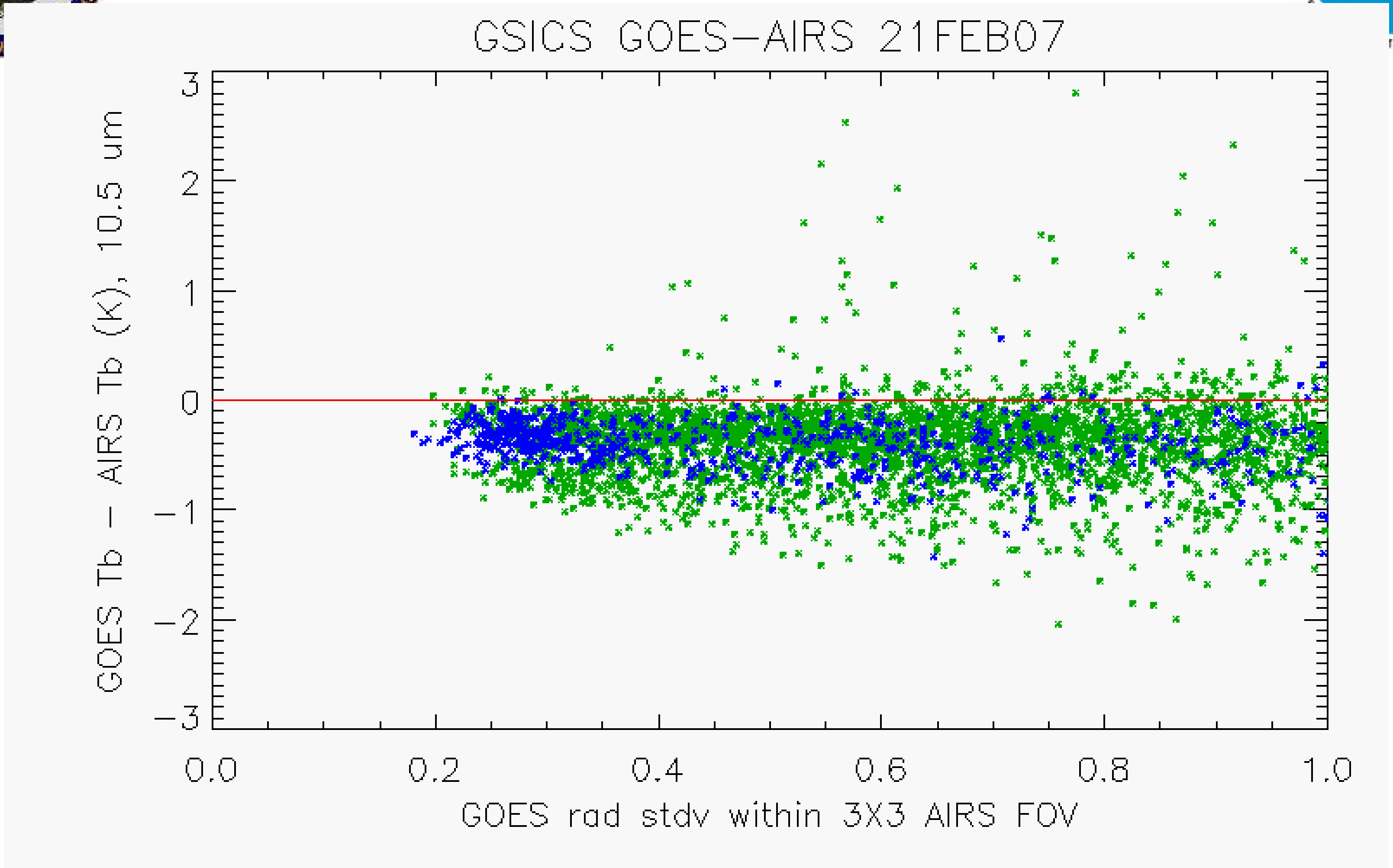


Preliminary Results from Prototype Algorithm



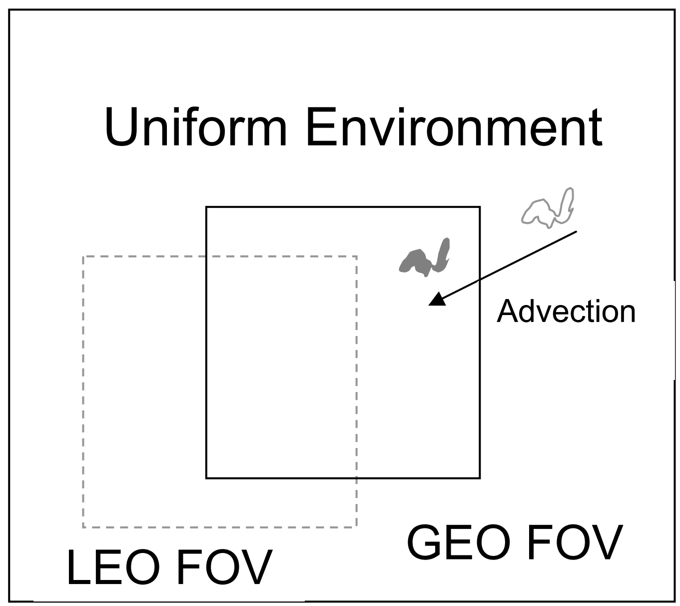
Blue: time difference < 60 seconds

Preliminary Results from Prototype Algorithm



Implementation – Collocation Normal

$$\left|\frac{1}{n^2}\sum_{i=1}^{n^2} R_i - M\right| \le \frac{S}{n}\frac{N-n}{N-1}Gaussian(=3)$$



Implementation – Collocation Averaging and Convolution

- Spatial average of GEO radiances

$$R_{GEO} = \frac{1}{n^2} \sum_{i=1}^{n^2} R_i$$

- Spectral convolution of LEO radiances

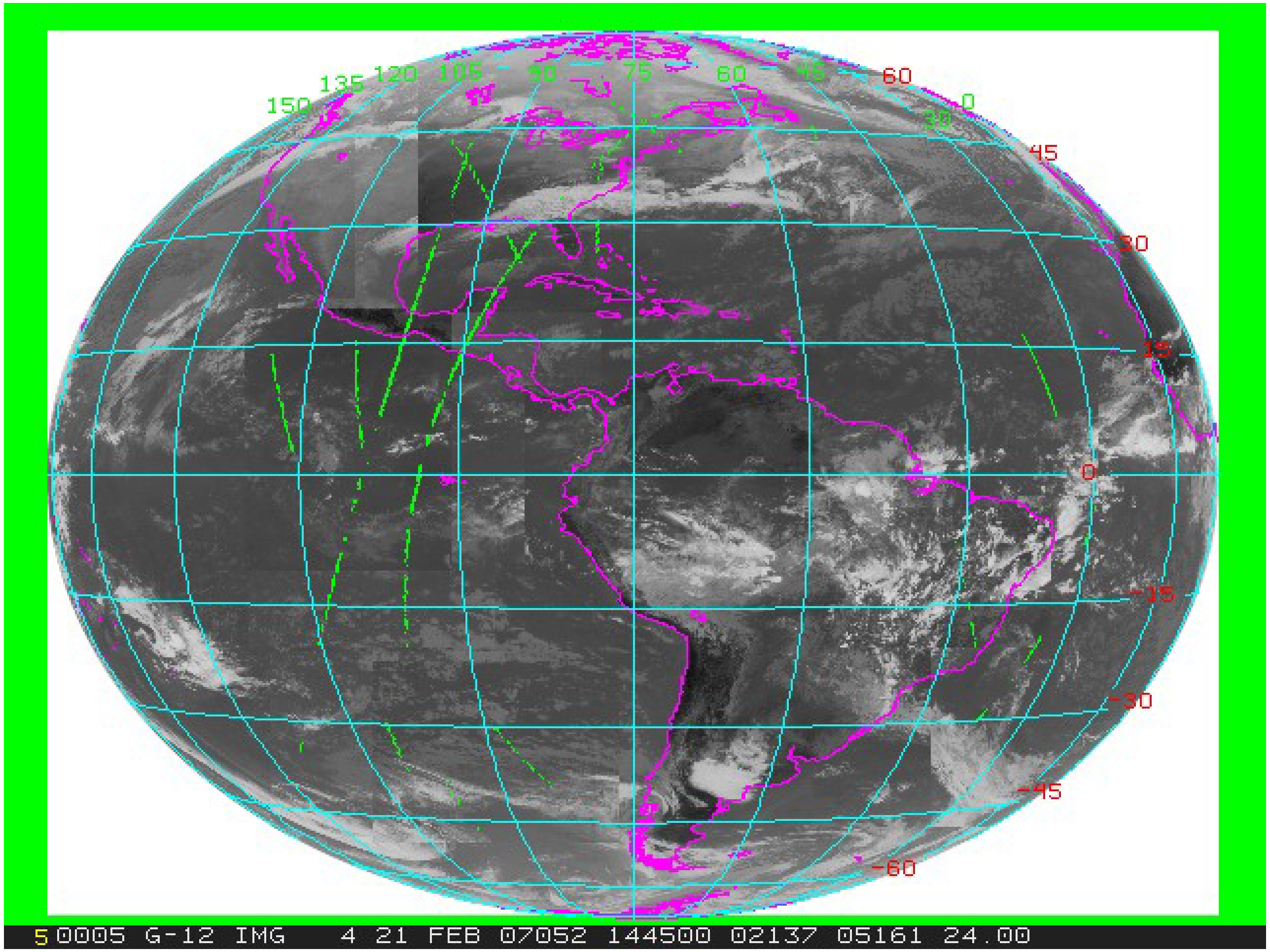
$$R_{GEO}^{'} = \frac{\int_{\nu} R_{\nu} \Phi_{\nu} d\nu}{\int_{\nu} \Phi_{\nu} d\nu}$$

Implementation – Output Results

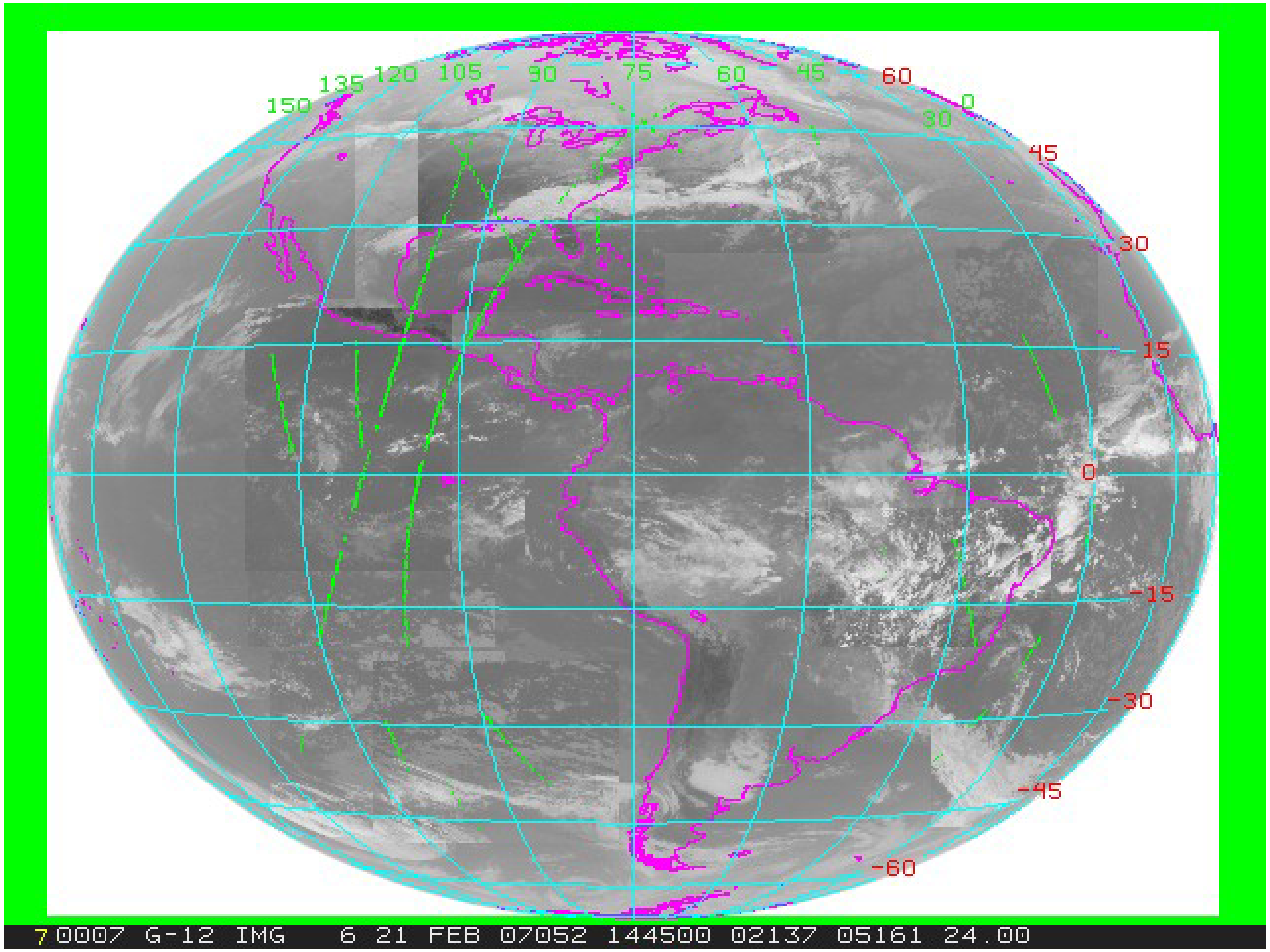
Real * 4	yyddd	year and day of year
Real * 4	hhmmss	hour/minute/sec of GEO observation
Real * 4	time_diff	LEO_time – GEO_time (sec)
Real * 4	zeni_diff	cos(θGEO)/cos(θLEO) - 1
Real * 8	time	LEO time of observation (TAI second)
Real * 4	latitude	collocation latitude (degree east positive)
Real * 4	longitude	collocation longitude (degree north positive)
Real * 4	geo_zen	GEO zenith angle (degree)
Real * 4	leo_zen	LEO zenith angle (degree)
Real * 4	sol_zen	SUN zenith angle (degree)
Real * 4	geo_azi	GEO azimuth angle (degree)
Real * 4	leo_azi	LEO azimuth angle (degree)
Real * 4	sol_azi	SUN azimuth angle (degree)
Real * 4	airs_cnv_shift	Ch6 shift SRF (irrelevant in general – to be deleted)
Real * 4	airs_mmg_shift	Ch6 shift SRF (irrelevant in general – to be deleted)
Real * 4	stat(6,4)	mean & stdv of collocation environment, mean & stdv of collocation target, convoluted AIRS radiance using modified Kato and Gunshor methods, for four channels
Real * 4	leo_rad(2378)	AIRS spectral radiances at 2378 channels
Real * 4	geo_rad(17,9,4)	GEO rad at 17 elements, 9 lines, and 4 channels

Further discussion after break

GOES 10.7 μm Co-locations with AIRS, 21feb02



GOES 13.3 μm Co-locations with AIRS, 21feb02



All bands data saved even if only one band qualifies for collocation

Operation – Input Data

- A complete set of GEO and LEO data within a common period of time (one day)
  - AIRS granules from NASADAAC
    - Take no short-cut – available to the world
    - Run after 3 days – near real time
    - Run again after 10 days – >90% (and presumably no more) data
  - GOES images from NESDIS server, CLASS, or UW
    - GOES-11/12. Some GOES-13.
    - Ready to re-process 2007 GOES-12

Operation – Output Results

- Names of intermediate files
  - Sufficient details to obtain AIRS and GOES data to repeat collocation
  - Insufficient to repeat subsetting
    - One needs all AIRS and GOES data any way for that
- Collocation results
  - One file per day per satellite
  - ~2000 collocations (25 MB) per file
    - ~10 GB per satellite per year

Operation – Reporting

- Nothing operational
  - Evaluation and *ad hoc* analyses as needed

Issues – Algorithm Compatibility

Goal/Balance

- Encourage innovation
- Ensure compatibility

Level of compatibility

- Common output (definition/format)
- Common principle
- Common logic
- Common threshold
- Common code

Less compatible ↕ Completely compatible

Questions

- Where we are and where we want to be?
- Baseline algorithm

Issues – Design Principles

- GSICS goals require that single pixel collocations anywhere within the GEO field of regard be collected continuously over long term for all bands.
- GSICS should collect all it can to allow future selection and manipulation by users.

Issues – Version Control

- Version 2 to incorporate JMA modular design
- Convention for versions
  - How big a change qualifies for Version 2.x instead of Version 1.x or Version 1.2.x?
  - How little a change qualifies for a new version at all?
  - What if ATBD didn't change, only the implementation?
  - Document what have been changed?
  - Procedure for community feedback and version release

Issues – Archiving Strategy

- Name of SSS##.AIRS.yyyy.mm.dd.grn.lat.long.bbb

sss	Satellite ID (e.g., GOS, MET, FY_, MTS)
##	Satellite series number (e.g., 07)
yyyy	Year (2007, 2008, ...)
mm	Month (01, 02, ..., 11, 12)
dd	Day (01, 02, ..., 30, 31)
grn	AIRS granule number (001, 002, ..., 239, 240)
lat	Latitude (e.g., N04)
long	Longitude (e.g., W120)
bbb	Band wavelength (µm*10, e.g., 039)

- Collocations (next page, ~30MB/day/GEO)

Issues – Output Parameters

Real * 4	yyddd	year and day of year
Real * 4	hhmmss	hour/minute/sec of GEO observation
Real * 4	time_diff	LEO_time – GEO_time (sec)
Real * 4	zeni_diff	cos(θGEO)/cos(θLEO) - 1
Real * 8	time	LEO time of observation (TAI second)
Real * 4	pix_lat	collocation latitude (degree east positive)
Real * 4	pix_lon	collocation longitude (degree north positive)
Real * 4	geo_zen	GEO zenith angle (degree)
Real * 4	leo_zen	LEO zenith angle (degree)
Real * 4	sol_zen	SUN zenith angle (degree)
Real * 4	geo_azi	GEO azimuth angle (degree)
Real * 4	leo_azi	LEO azimuth angle (degree)
Real * 4	sol_azi	SUN azimuth angle (degree)
Real * 4	airs_cnv_shift	Ch6 shift SRF (irrelevant in general – to be deleted)
Real * 4	airs_mmg_shift	Ch6 shift SRF (irrelevant in general – to be deleted)
Real * 4	stat(6,4)	mean & stdv of collocation environment, mean & stdv of collocation target, convoluted AIRS radiance using modified Kato and Gunshor methods, for four channels
Real * 4	leo_rad(2378)	AIRS spectral radiances at 2378 channels
Real * 4	geo_rad(17,9,4)	GEO rad at 17 elements, 9 lines, and 4 channels

Real * 4 leo_lat, leo_lon, geo_lat, geo_lon, sun_lat, sun_lon

Issues – Reporting

- Suggestion 1
  - Unified output results
  - Start with something simple, e.g., daily mean bias
  - Improve as we go
- Suggestion 2
  - ?

Issues – Input Data

- A complete set of GEO and LEO data within a common period of time (one day)
  - AIRS granules from NASA DAAC
    - Channel validity as of May 2007
    - Leap second as of May 2007
    - Update strategy TBD
    - Short-cut (e.g., from member of AIRS Science Team)