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Cross Calibration and Validation using CLARREO

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JPL IR Cross-cal and validation Study Activity

- Study Questions
  - Focus on MW/LW
  - Error Sources: What can be expected?
  - Validation: How will validation be performed? What resolution is required?
  - Cross-Calibration: What spatial resolution is required?
- Study Effort:
  - Empirical Approach: Examine AIRS, IASI and MODIS Cross-Calibration methods already in place
  - Estimate number of clear and Dome C observations possible vs spatial resolution
- Study Result:
  - 5000 Samples Per Cross-Calibration Recommended
  - Insufficient cloud free and Dome C AWS observations for cross-cal and validation at 100km
  - < 20 km IFOV at 100 km swath needed to achieve sufficient samples for cross-calibration of CLARREO

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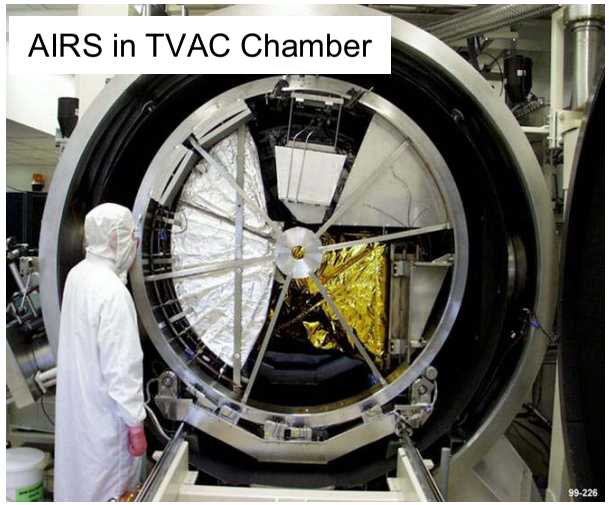
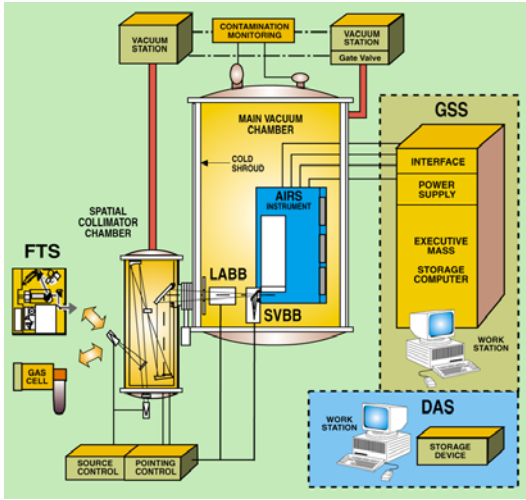
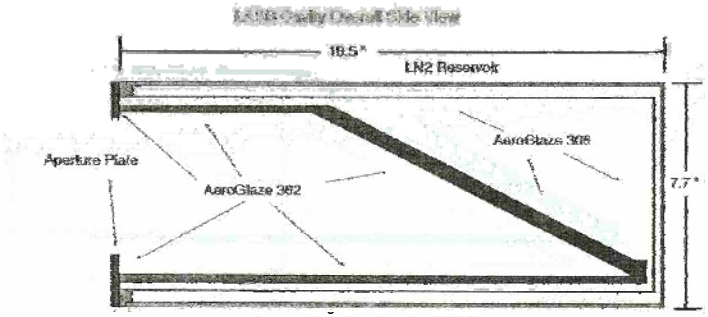
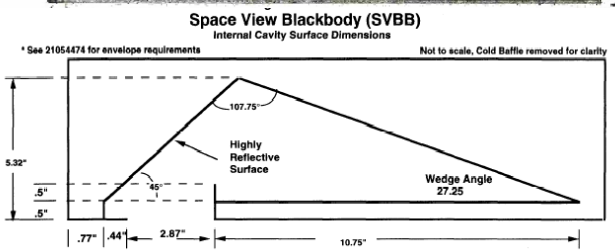
AIRS Pre-Flight Calibration Transferred LABB to OBC Blackbody





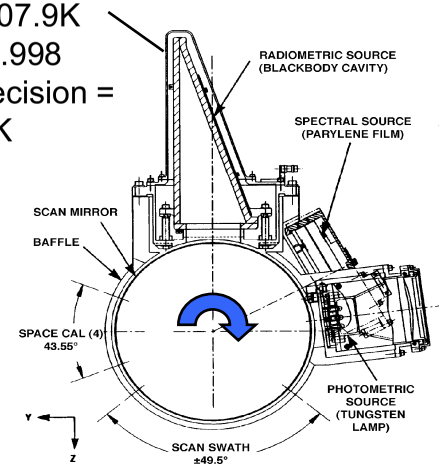


- Large Area Blackbody (LABB)
- T = 190K to 360K
- ε > 0.99998
- NIST Traceable PRTs (Rosemont)
- T_precision = 0.01K
- T_accuracy = 0.027K



- Space View Blackbody (SVBB)
- T < 80 K
- ε > 0.99998
- T_precision = 0.01K
- T_accuracy = 0.5K

- OBC Blackbody (OBC)
- T = 307.9K
- ε > 0.998
- T_precision = 0.01K



AIRS Scan Geometry

- AIRS Space View Blackbody and Large Area Blackbody (SVBB & LABB) User's Manual, Bomem, AI-BOM-022/96 Revision A, 14 August 1996

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Radiometric Transfer Equations for AIRS (Grating Spectrometer)

Radiometric Transfer Equations

$$N_{sc,i,j} = \frac{a_o(\theta_j) + a_{1,i}(dn_{i,j} - dn_{sv,i}) + a_2(dn_{i,j} - dn_{sv,i})^2}{1 + p_r p_t \cos 2(\theta_j - \delta)}$$

$$a_o(\theta_j) = P_{sm}\, p_r p_t [\cos 2(\theta_j - \delta) + \cos 2\delta]$$

$$a_{1,i} = \frac{N_{OBC,i}(1 + p_r p_t \cos 2\delta) - a_o(\theta_{OBC}) - a_2(dn_{obc,i} - dn_{sv,i})^2}{(dn_{obc,i} - dn_{sv,i})}$$

$N_{sc,i,j}$ = Scene Radiance (mW/m^2-sr-cm^{-1})
P_{sm} = Planck radiation function at scan mirror temp
$N_{OBC,i}$ = Radiance of the On-Board Calibrator Blackbody
i = Scan Index, j = Footprint Index
θ = Scan Angle. θ = 0 is nadir.

$dn_{i,j}$ = Raw Digital Number in the Earth View
$dn_{sv,i}$ = Space view counts offset.
a_o = Radiometric offset. a1,i = Radiometric gain.
a_2 = Nonlinearity
$p_r p_t$ = Polarization Factor Product
δ = Phase of the polarization

T. Pagano et al., “Pre-Launch and In-flight Radiometric Calibration of the Atmospheric Infrared Sounder (AIRS),” IEEE TGRS, Volume 41, No. 2, February 2003, p. 265

T. Pagano, H. Aumann, K. Overoye, “Level 1B Products from the Atmospheric Infrared Sounder (AIRS) on the EOS Aqua Spacecraft", Proc. ITOVS, October 2003

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Radiometric Uncertainties*

- *Differentiate radiometric transfer equation to get uncertainty terms*

$$\partial N_{SC}^{\ 2} = \left(\frac{\partial N_{SC}}{\partial p_r p_t}\Delta p_r p_t\right)^2 + \left(\frac{\partial N_{SC}}{\partial T_{sm}}\Delta T_{sm}\right)^2 + \left(\frac{\partial N_{SC}}{\partial \theta}\Delta\theta\right)^2 + \left(\frac{\partial N_{SC}}{\partial \varepsilon_{OBC}}\Delta\varepsilon_{OBC}\right)^2 + \left(\frac{\partial N_{SC}}{\partial T_{OBC}}\Delta T_{OBC}\right)^2 + \left(\frac{\partial N_{SC}}{\partial a_2}\Delta a_2\right)^2 + \left(\frac{\partial N_{SC}}{\partial dn}\Delta dn\right)^2$$

PRELIMINARY

Parameter	Uncertainty	Error (K)
Polarization Factors Uncertainty	4.13E-04	0.016
Scan Mirror Temperature Uncertainty	5 K	0.005
Scan Mirror Angle Uncertainty	0 deg	0.000
OBC BB Emissivity Uncertainty	4.26E-04	0.023
OBC BB Temperature Uncertainty	0.03 K	0.022
Nonlinearity Uncertainty	5.9903E-10 Rad/dn^2	0.015
Low Frequency Drift within Scan	0.01 dn	0.006
LABB Temperature Uncertainty	0.03 K	0.030
LABB Emissivity Uncertainty	0.0001 -	0.004
Spectrometer Phase Uncertainty	5 deg	0.000
OBC BB Emissivity End of Life	0.0002	0.008
OBC BB Reflected Energy Uncertainty	7.40E-04	0.027
Gain Drift	4.8258E-06 Rad/dn	0.000
Other (Unknown)		0.040
RSS Radiometric Error		0.070

*T. S. Pagano, H. Aumann, R. Schindler, D. Elliott, S. Broberg , K. Overoye, M. Weiler, "Absolute Radiometric Calibration Accuracy of the Atmospheric Infrared Sounder", Proc SPIE, 7081-46, August 2008-(With Revisions)

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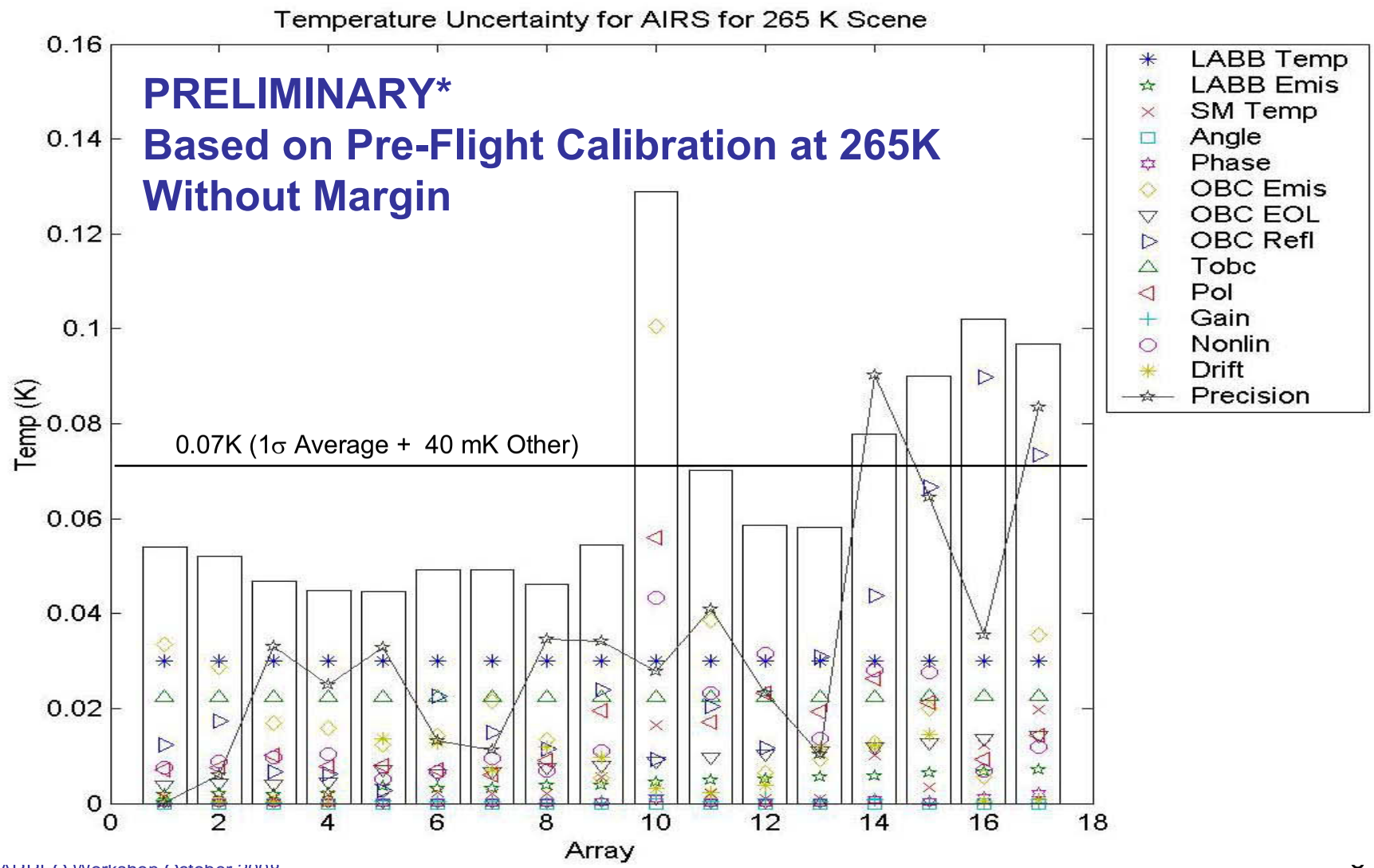
AIRS Radiometric Uncertainty Estimate at 265K



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Accuracy Budget for CLARREO

Dominant Error Sources	AIRS* (mK)	CLARREO (Budget. mK)
• External BB Standard Temperature: T	30	0
• External BB Standard Emissivity: ε	4	0
• Nonlinearity Uncertainty	15	15
• Internal BB Temperature: T	22	10
• Internal BB Emissivity: ε, ε_{EOL}	23, 8	10, 0
• Internal BB Reflectance: ρ	27	27
• Scan Mirror Temperature: T	5	0
• Scan Mirror Polarization: ε_s , ε_p	16	0
• 1/f Noise within Scan	6	6
• Other (Unknown)	40	0
• Total Bias Uncertainty (1 sigma)	70	34

*Average over all channels at 265K

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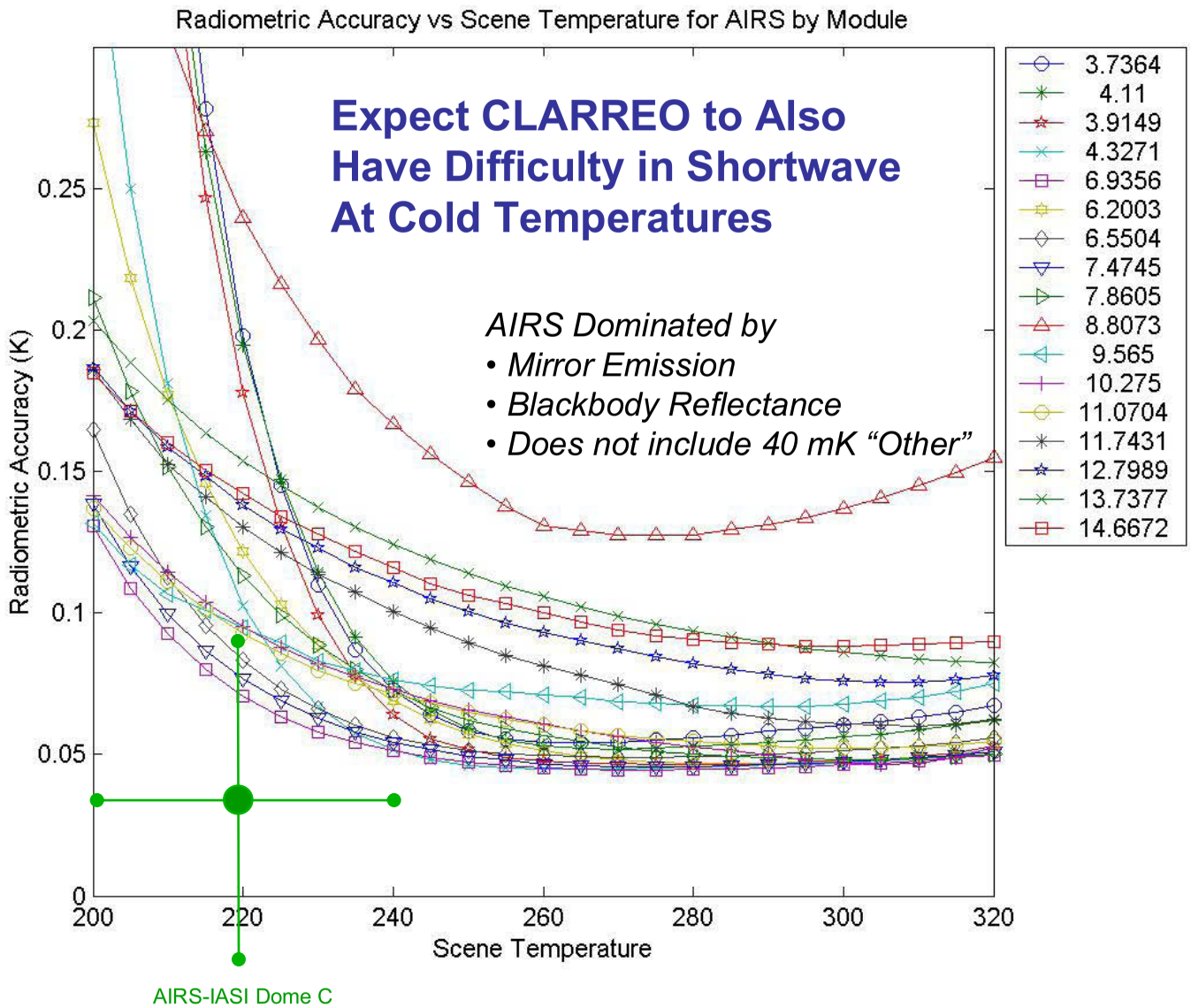
Temperature and Wavelength Dependence of Radiometric Errors Expected



Expect CLARREO to Also Have Difficulty in Shortwave At Cold Temperatures

AIRS Dominated by
- *Mirror Emission*
- *Blackbody Reflectance*
- *Does not include 40 mK "Other"*

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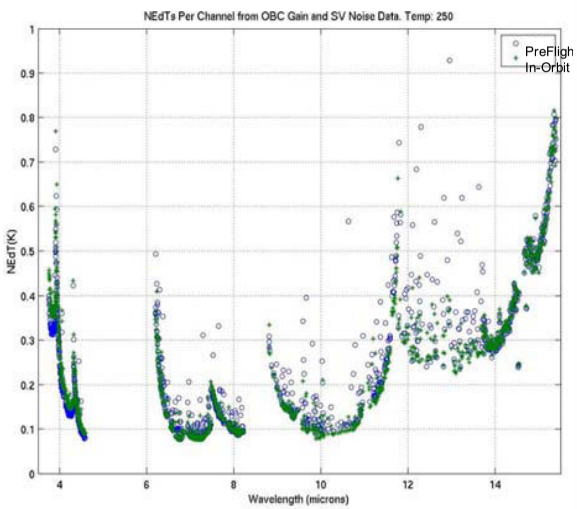
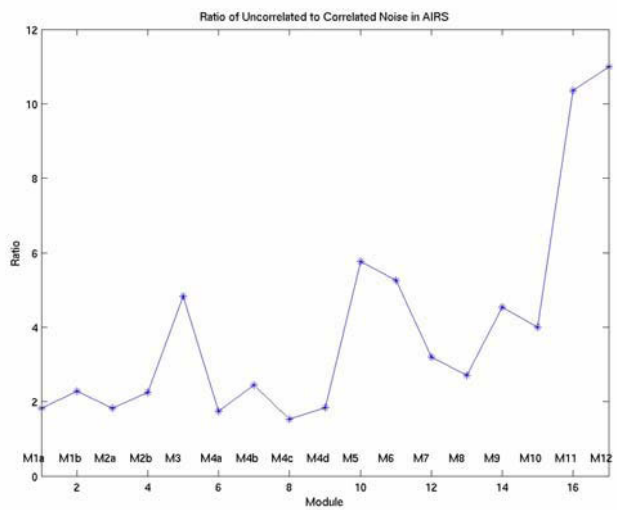
Not included in the Accuracy Predictions

Random Noise



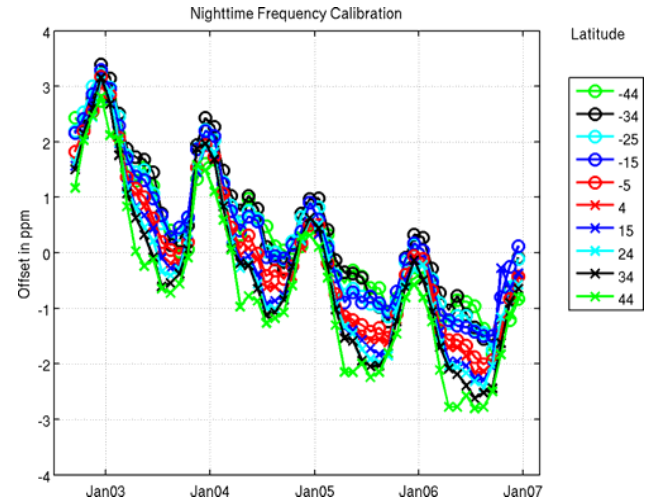
Random noise is averaged out when obtaining climate signals but must be included when estimating individual sample uncertainty

Correlated Noise



Correlated noise must be included separately because accuracy will depend on the combination of channels used

Spectral Uncertainty



Spectral uncertainty is a scene dependent error and must be included separately in science climate accuracy estimates

Importance of Validation

- Claims of Accuracy must be substantiated by independent observations made by independent scientists
  - Standard Methods Include: Aircraft, Upwelling FTS, Ocean Buoys
- Stability is critical to meeting and measuring accuracy
  - Instability will cause errors when trying to validate
  - Instability uncertainty will contribute to radiometric uncertainty
  - Methods to measure stability: Ocean Buoys, Cross-Calibration on a frequent (weekly or daily) basis
- Primary methods for validation and stability verification used on AIRS require clear observations

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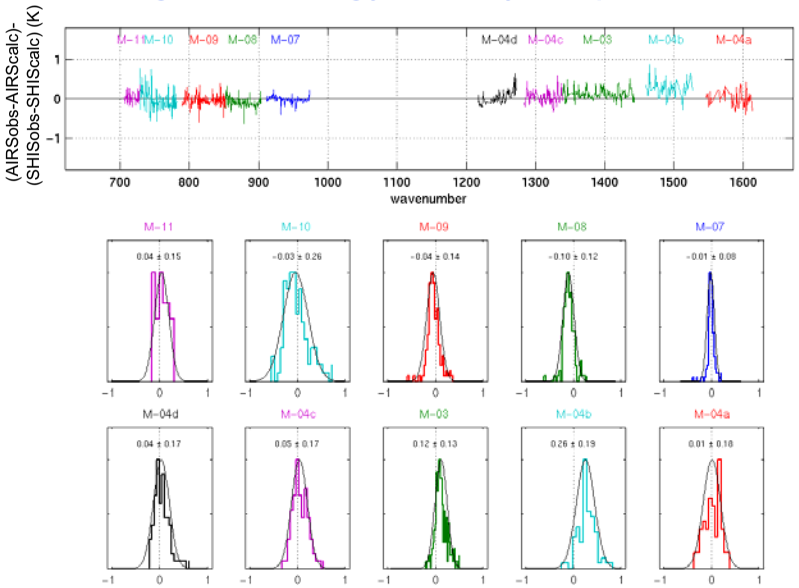
Key Validation Techniques Performed Under Clear Conditions

Radiometric Accuracy

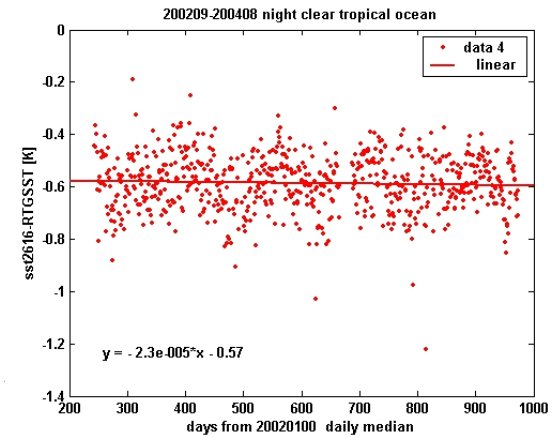
Scanning HIS Validates Rad Accy to 0.2K – H. Revercomb (UW)

Final "Comparison 2" (21 November 2002)
Excluding channels strongly affected by atmosphere above ER2



Radiometric Stability

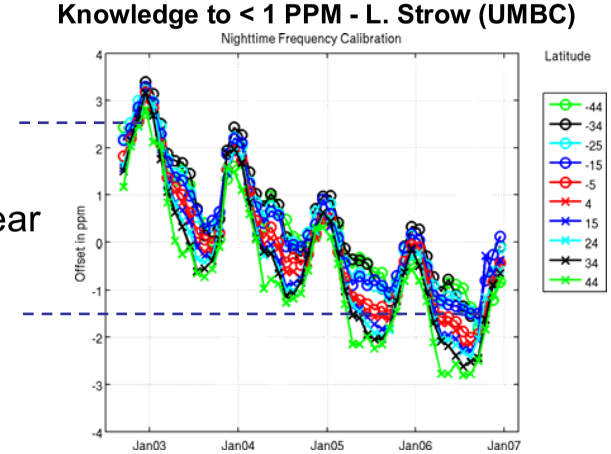
Stable to <8mK/Y – H. Aumann (JPL)



Spectral Accuracy/Stability

Knowledge to < 1 PPM - L. Strow (UMBC)

< 1 ppm/year



Reference: JGR, VOL. 111, April 2006

Cross-Calibration Techniques Proven using AIRS Data to Accuracies Needed

- Comparison with Ocean Buoys
  - Performed under clear conditions
  - Double Difference (AIRS-SST)-(IASI-SST)
  - Over 10,000 clear observations per day
  - Sensitive to less than 30 mK Bias, <20 mK/year
- Comparison with Dome C Automated Weather Station (AWS)
  - Performed under clear and cloudy conditions
  - Double difference (AIRS-Dome C)-(IASI-Dome C)
  - Over 50,000 Observations Per Year
  - Sensitive to less than < 30 mK Bias, 60 mK/year

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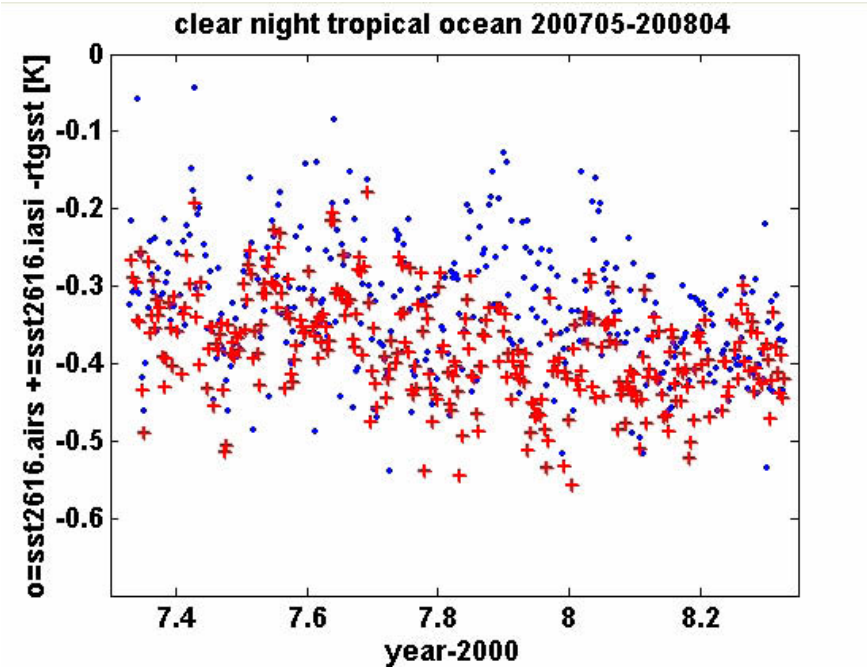
IASI-AIRS DD SST Comparisons
Accuracy depends on Atmos. Correction

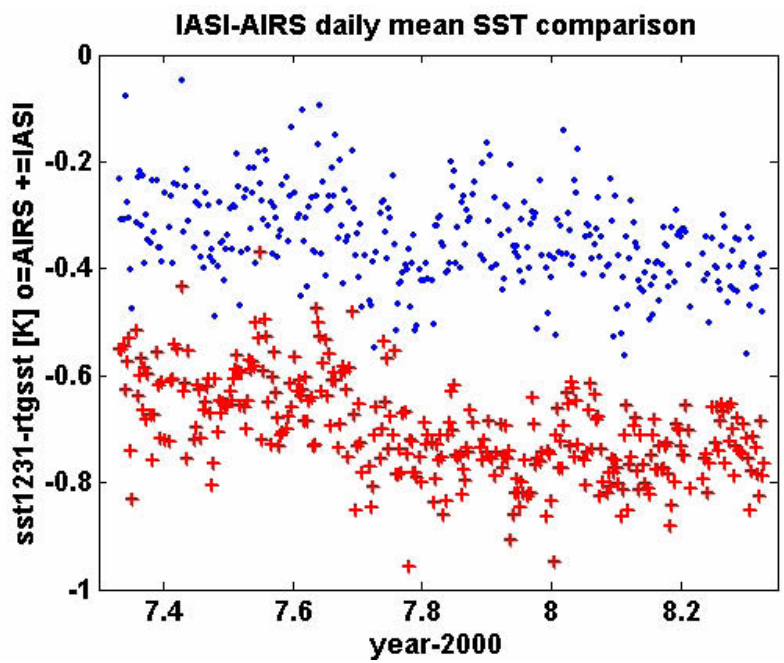
2616 cm^{-1}, T_{corr} = 0.4K



Bias: 45 mK ± 30 mK
Trend is +11 +/- 11 mK/year

AIRS and IASI have a small cold bias due to cloud leak

1231 cm^{-1}, T_{corr} ~ 4K



Bias: 350 mK ± 30 mK
Trend is -52 ± 17 mK/year

The bias difference of 0.35 K is due to a difference in the definition of what is clear

~10,000 Points Per Day

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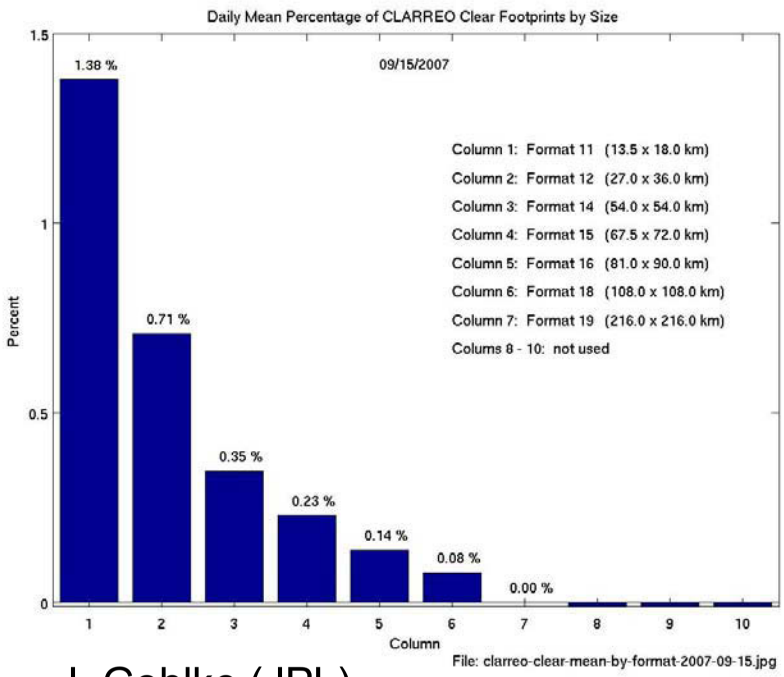
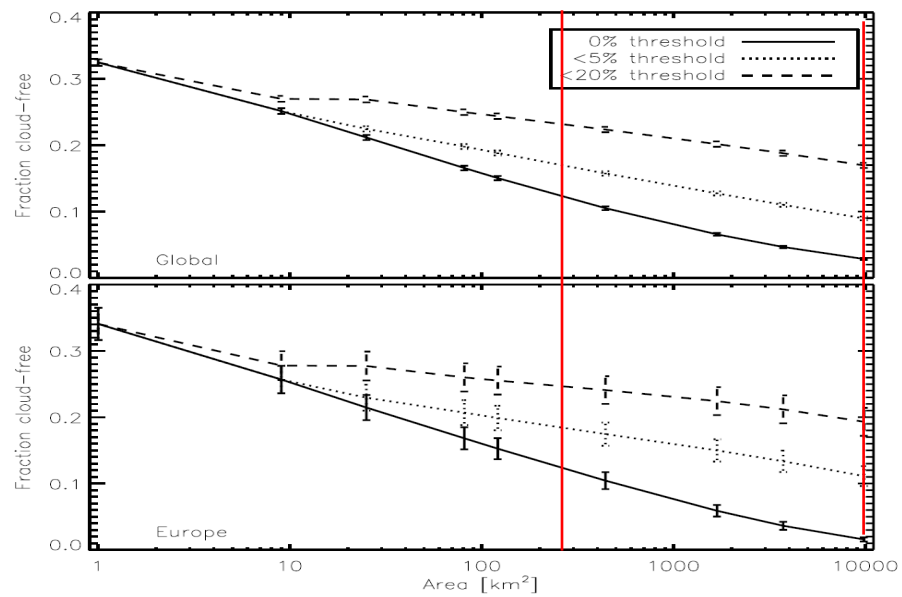
Fractional Clear Drops with Spatial Resolution

CLARREO Simulated Data Show
Rapid Fall-off of Clear vs Spatial Res.
CLEAR = < 0.2k Cloud Contamination



J. Gohlke (JPL)

Similar Result Seen in Literature
CLEAR = < 1k Cloud Contamination



15 km, 12% 100 km, 2%

[1]J. Krijger et. al, The effect of sensor resolution on the number of cloud-free observations from space, Atmos. Chem. Phys. Discuss., 6, 4465-4499, 2006, www.atmos-chem-phys-discuss.net/6/4465/2006

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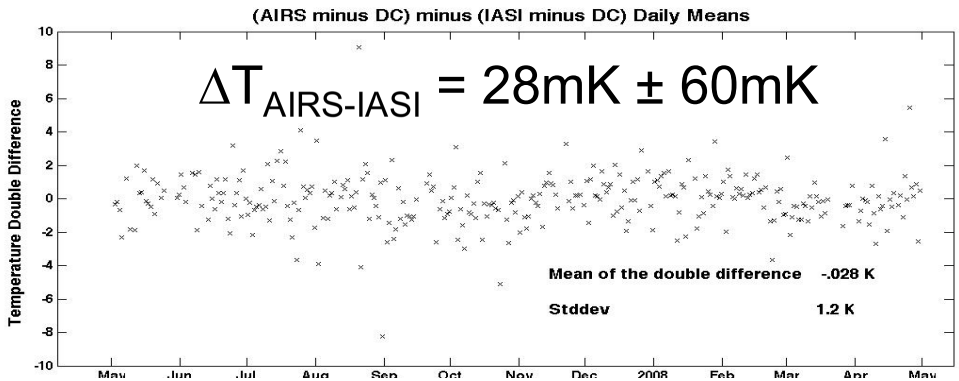
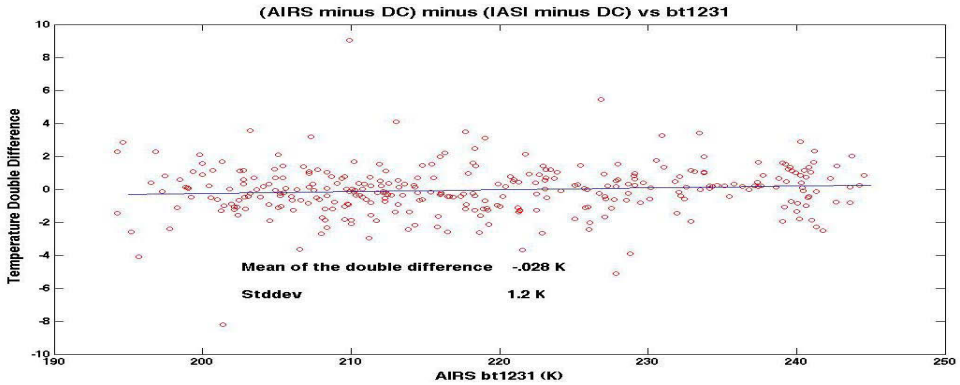
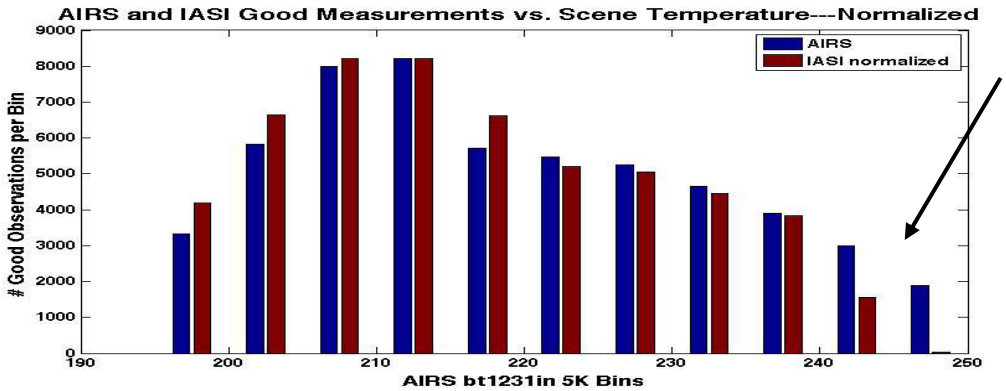
All-Sky Double Difference (DD) AIRS and IASI Identifies Low Bias and Trend







No Apparent Seasonal Drift over 1 Year
(Clear Conditions)

No Temperature Dependent Biases

Yield Loss at Mid Temperature Range viewing Dome C

- **>50000 Points Used**
- **Over 1 Year Period**
- **Daily Observations**

D. Elliott

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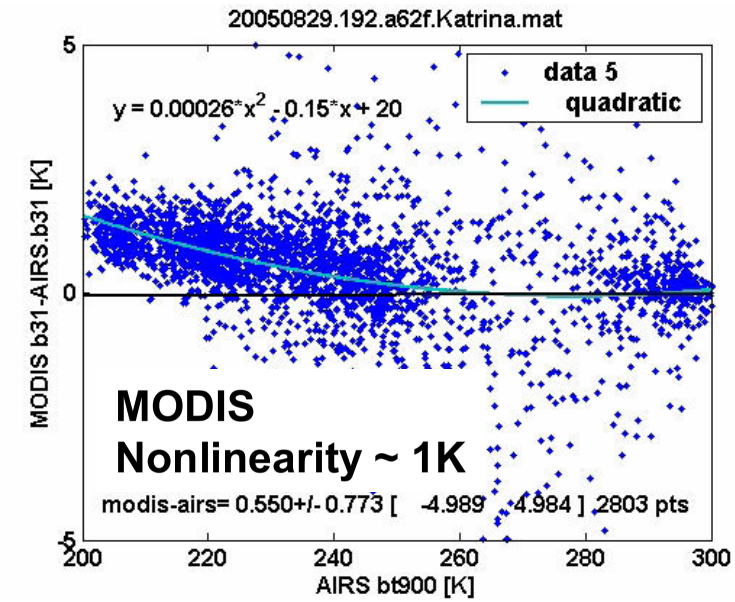
All-Sky Comparison Globally Works but Noisy

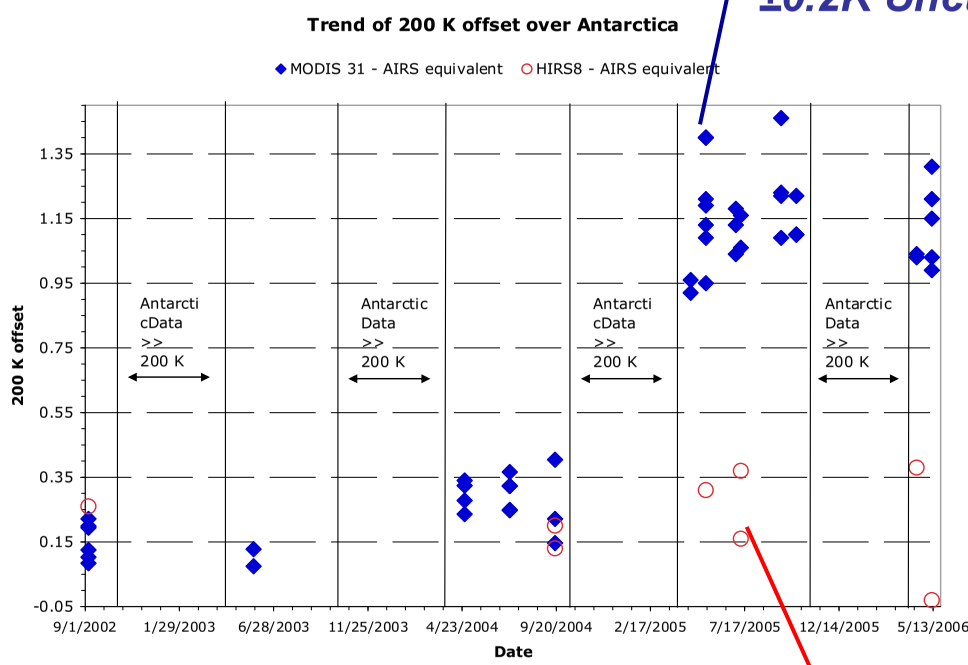
Direct Comparison Katrina Granule MODIS-AIRS All Sky



2803 Samples

Direct Comparison Antarctic Granule MODIS-AIRS All Sky

Shift in MODIS Calibration Algorithm V4 to V5 ±0.2K Uncty



HIRS Stable

S. Broberg, Evaluation of AIRS, MODIS, and HIRS 11 micron brightness temperature difference changes from 2002 through 2006, SPIE 6296-22, August 2006

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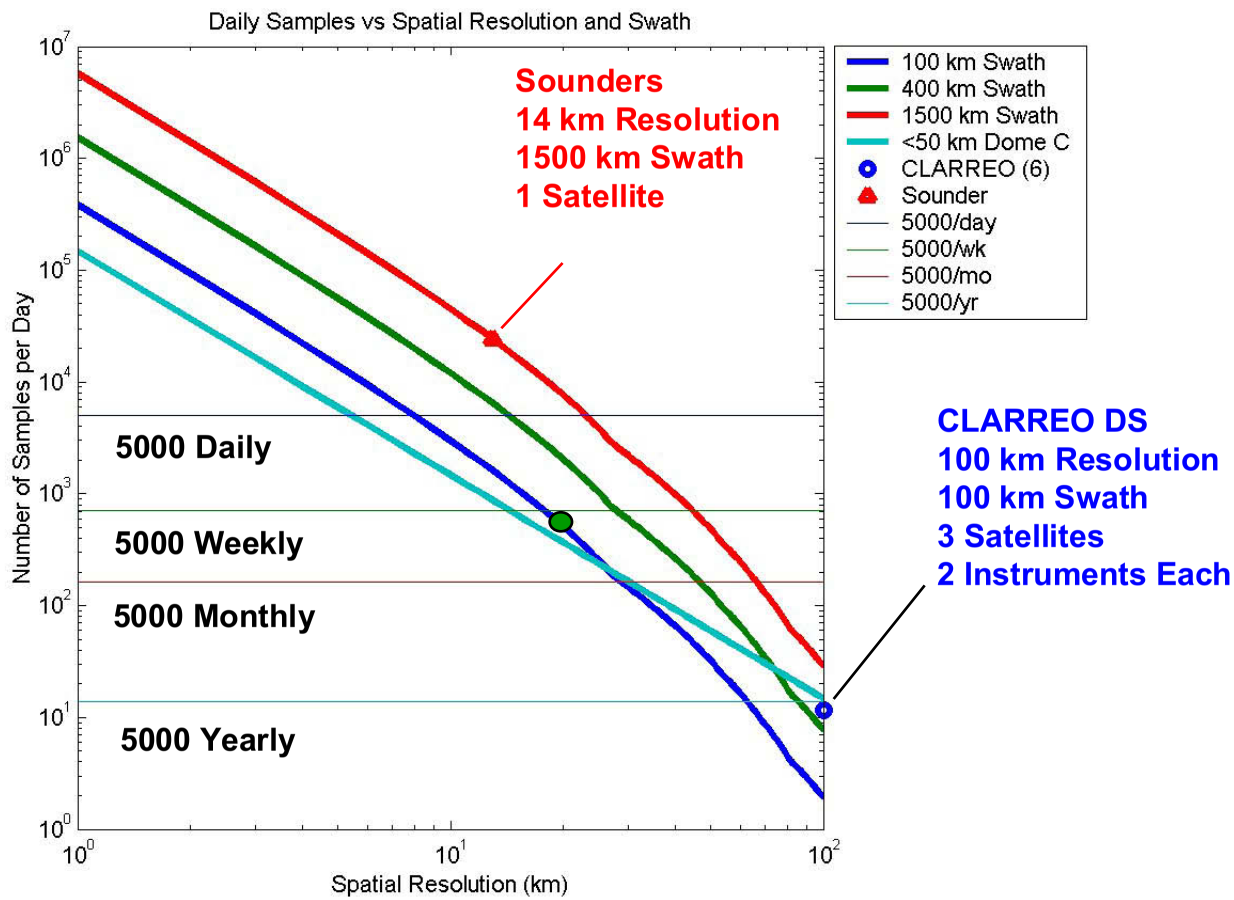
Number of Tropical Clear Ocean and Dome C Observations Per Day vs IFOV

Tropical Clear
(R, G, B)

Dome C
All Weather

CLARREO should be < 20 km with >100 km swath to get sufficient clear for calibration and validation



To first order…

$$N_{tropical/day} = \frac{2\pi R_e}{S}\frac{SW}{S}\frac{60^o}{180^o}N_{orbits/day}F_{clear}$$

$$N_{DomeC/day} = \left[\frac{50km}{(S/2)}\right]^2 N_{orbits/day}$$

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Results and Recommendations CLARREO MW/LW

- Validation and Stability Monitoring Requires Clear Observations
  - Comparison to Buoy Observations (SST)
  - Comparison to Aircraft: Usually Co-location to within 50 km
- Cross-Calibration Best Performed with Clear Observations
  - Double Difference with SST or Dome C
- All-Sky Considerations for Cross-Calibration
  - Must have sufficient number of samples to calibrate linearity curve
  - Tends to be more noisy than clear cross-calibration
  - Subject to spectral noise due to cloud effects on FTS
  - Must be performed often to allow differentiating instrument calibration from instability
- Fractional Clear Drops Rapidly with Spatial Resolution
- Higher Spatial Resolution provides more clear improving validation and cross-calibration capability
- Recommendation: CLARREO MW/LW horizontal resolution should be < 20 km to be effective as a calibration laboratory in space.