Status of the NOAA Operational Hyper Spectral IR + Microwave Retrieval Algorithm

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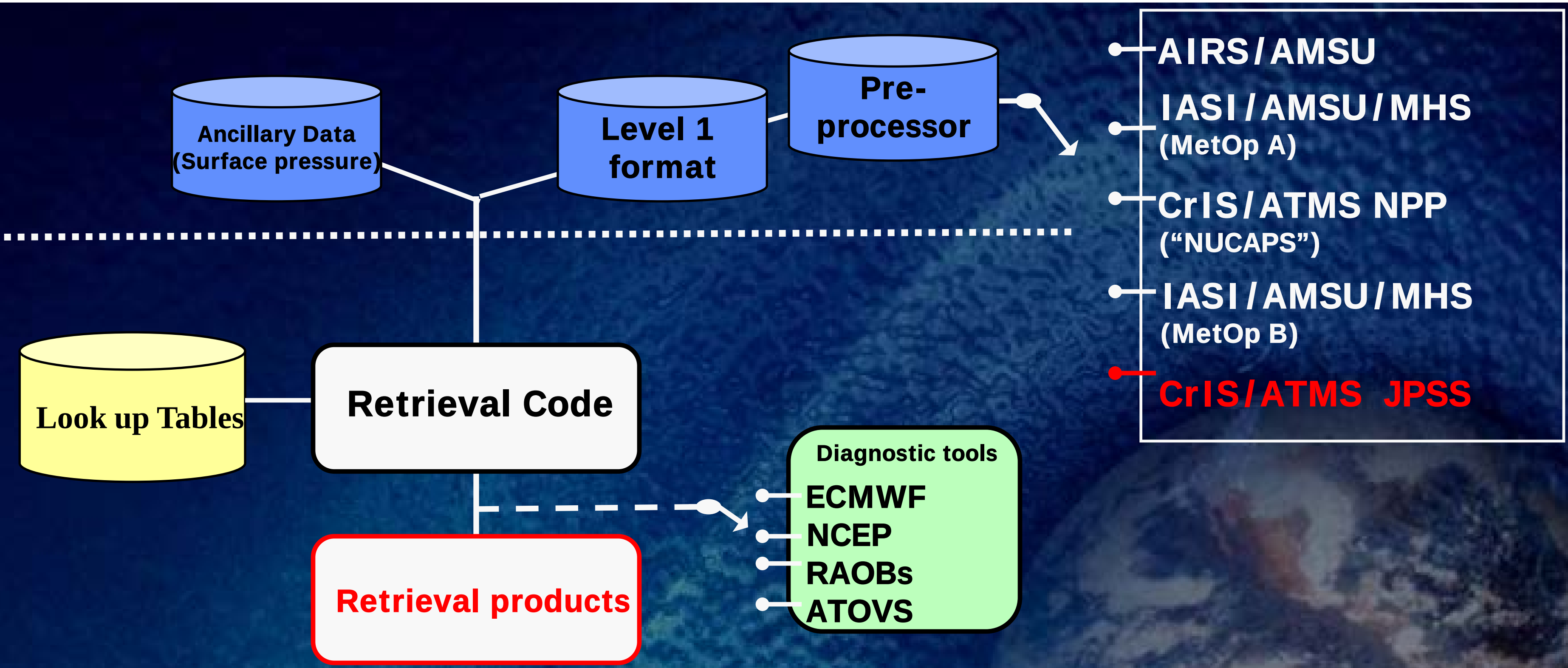
Outline

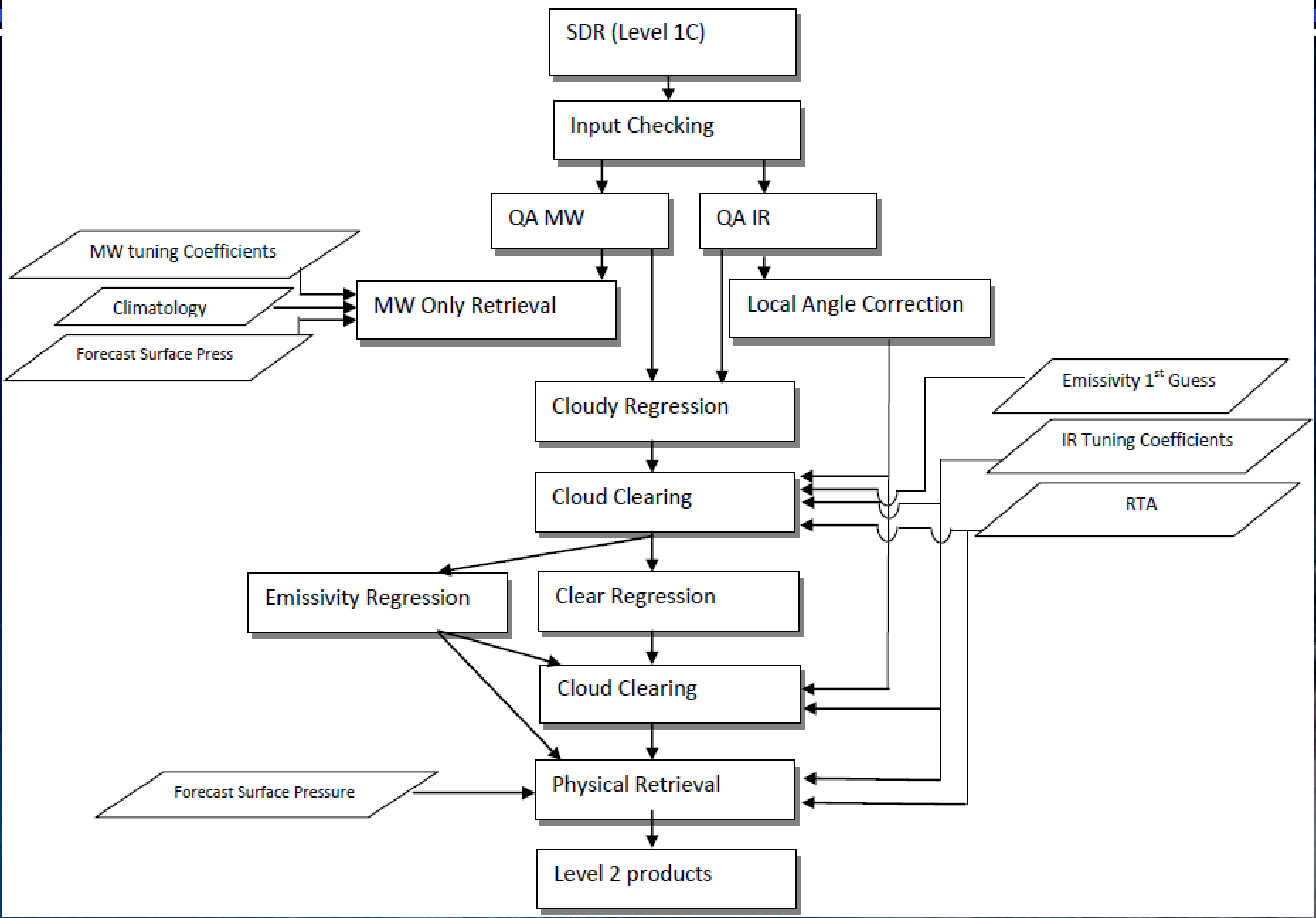
- Architecture of the NOAA operational hyper spectral retrieval algorithm
- Performance assessment: global, ocean, latitudinal regimes
- Cross-comparison of the performance of the CrIS/ATMS, IASI/AMSU/MHS and AIRS/AMSU retrieval systems
- Demonstration experiment of CrIS high resolution retrieval capabilities (CO impact study
- IASI and CrIS ILS distortion effects in presence of scene in-homogeneities
- NUCAPS Project Plan
- Conclusions and future work

The NOAA MW+IR retrieval system



- Using the same retrieval algorithm, same underlying spectroscopy, same set of assumptions and same look up table methodology is a key strategy for a homogeneous multi-satellite integrated dataset of environmental data records.

The NOAA MW+IR retrieval system



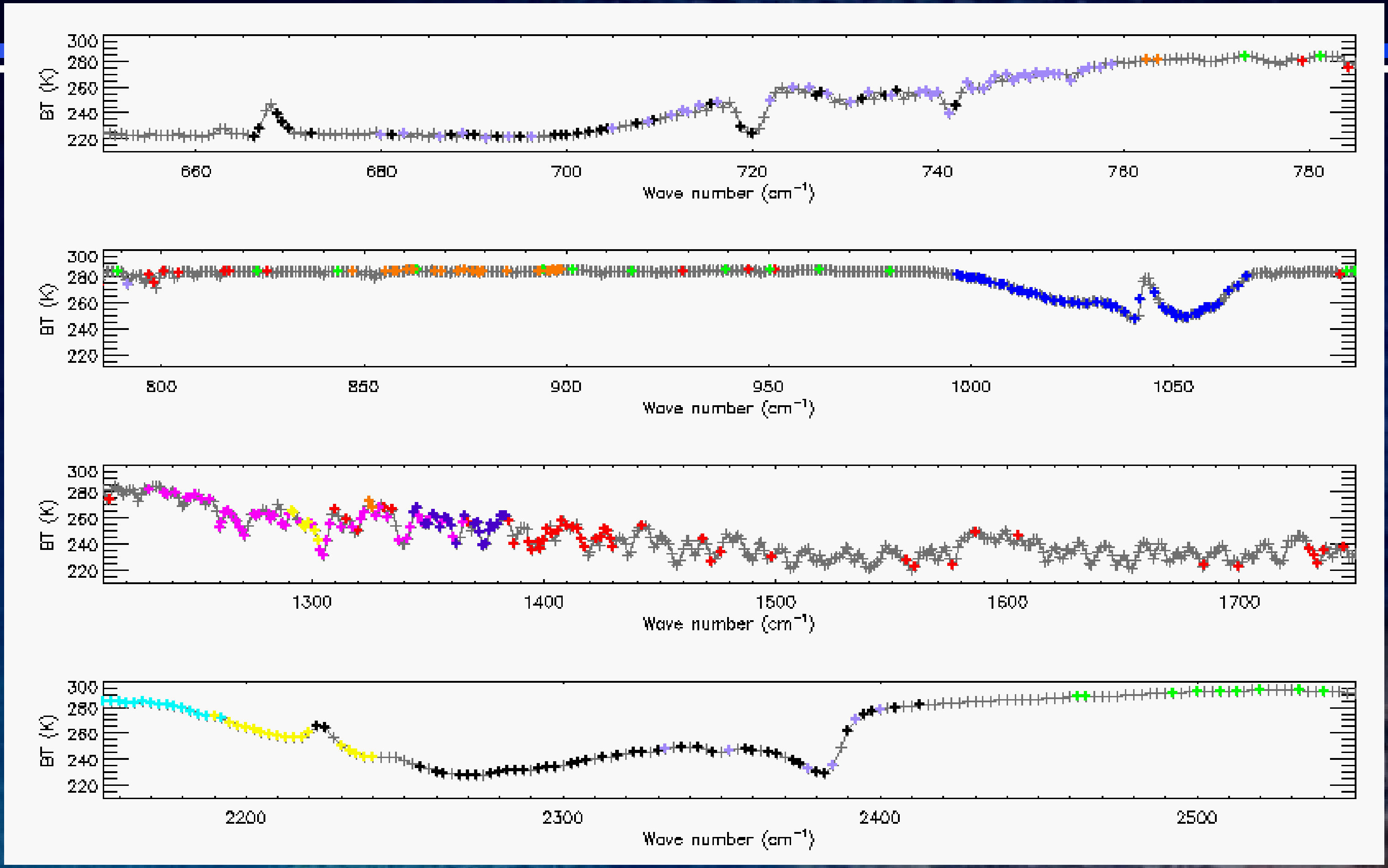
The NOAA MW+IR retrieval system

•A multi-step retrieval algorithm, heritage of the AIRS Science Team Retrieval Algorithm, made of the following main steps:

- 1) a microwave retrieval module which derives cloud liquid water flags
- 2) a fast eigenvector regression retrieval that is trained against the European Center for Medium-Range Weather Forecasts (ECMWF) analysis and CrIS all sky radiances
- 3) a cloud clearing module
- 4) a second fast eigenvector regression retrieval that is trained against ECMWF analysis and CrIS cloud cleared radiances
- 5) the final infrared physical retrieval based on a regularized iterated least square minimization

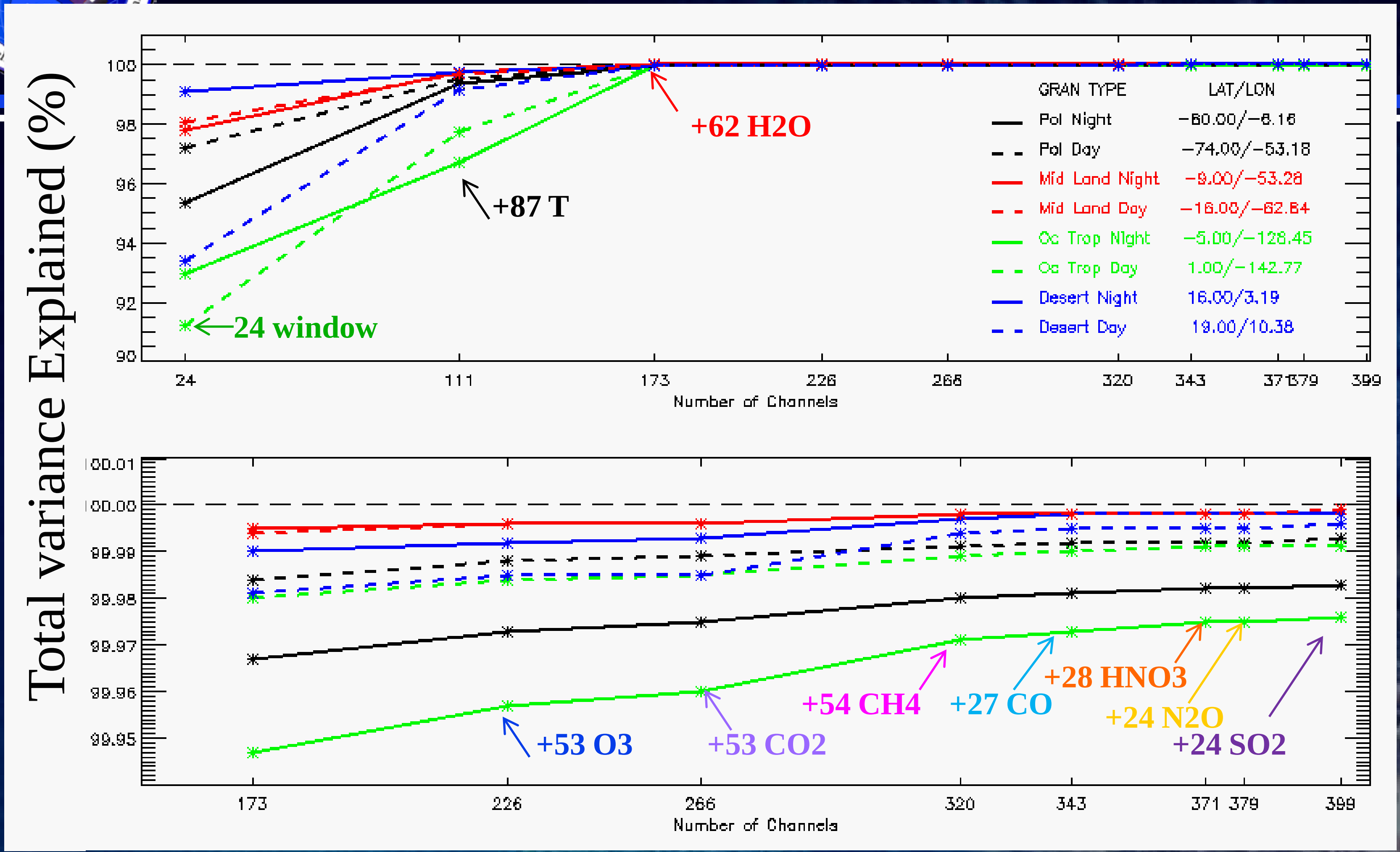
CrIS Operational Channel Selection (Total # of Channels: 399)

EDR	#chns
T	87
Surf	24
HO2	62
O3	53
CO	27
CH4	54
N2O	24
SO2	54
HNO3	28
CO2	53



REF: Gambacorta et al., Methodology and information content of the NOAA NESDIS operational channel selection for the Cross-Track Infrared Sounder (CrIS), IEEE, Vol. 51, Issue 6, 2013

Total Variance Explained



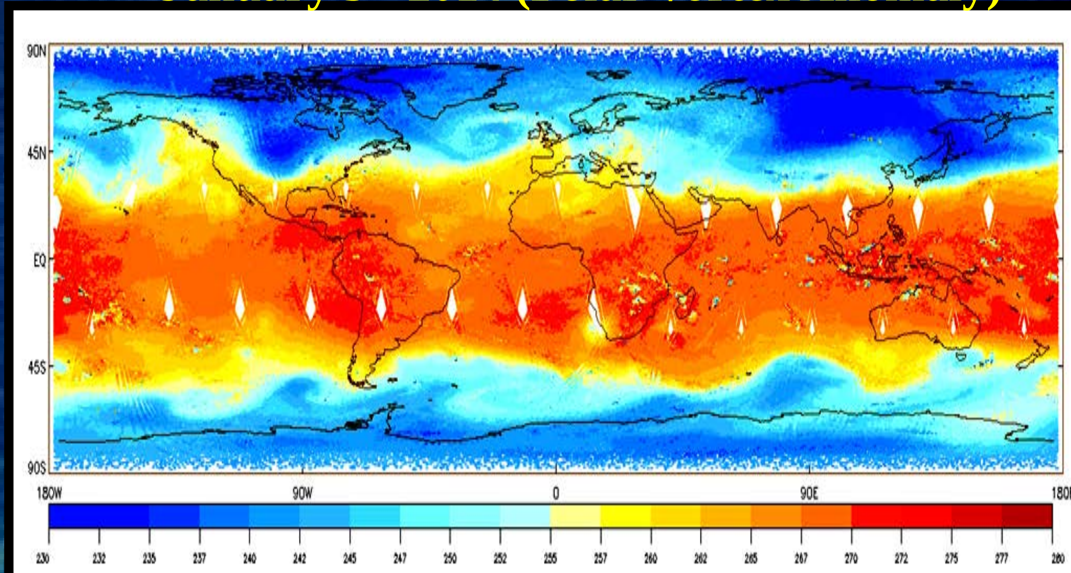
- The full list of 399 selected channels explains ~99.9% of the total atmospheric variance, consistently across all geophysical regimes.
- The first 173 channels (window, temperature and water vapor channels) alone explain ~ 99% of the total atmospheric variance. REF: Gambacorta et al., IEEE, 2013

Operational Retrieval Products

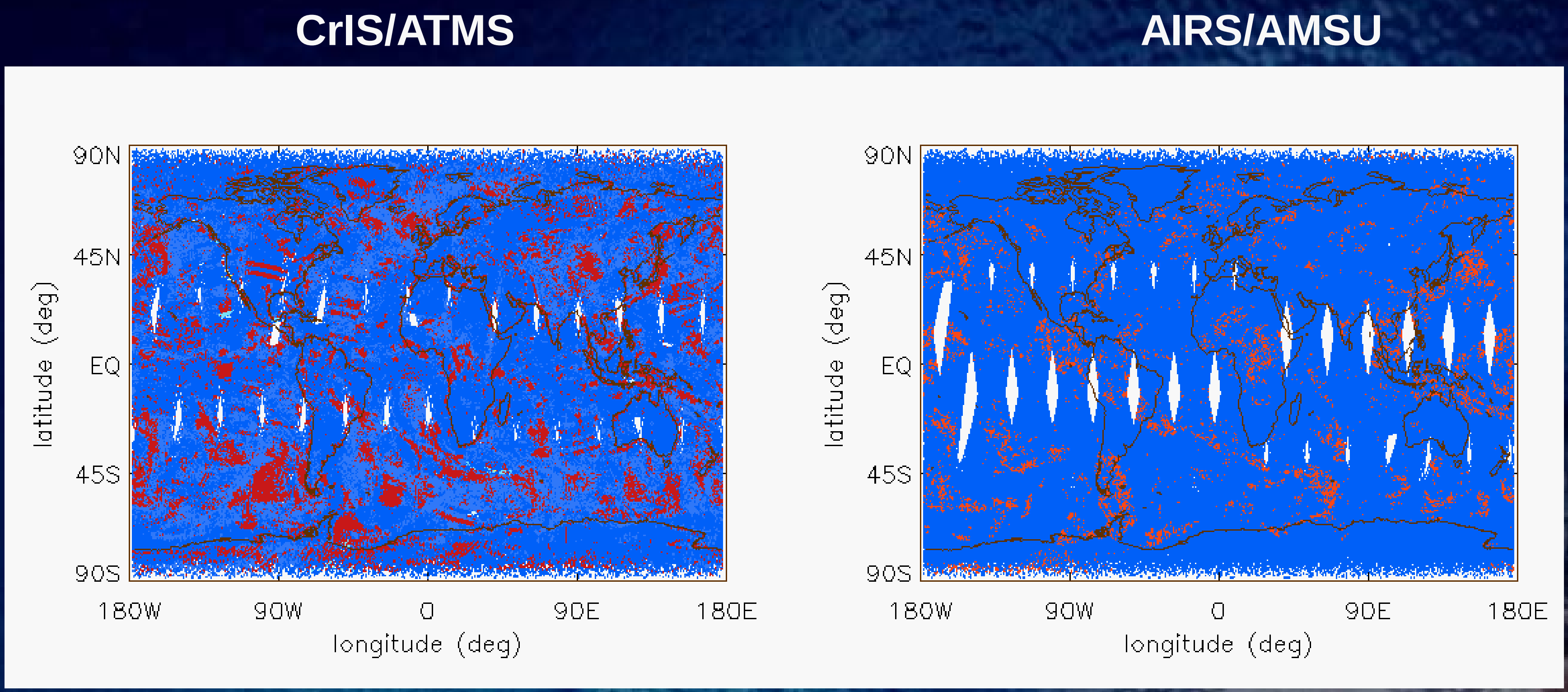
Retrieval Products

Cloud Cleared Radiances	660-750 cm-1 2200-2400 cm-1
Cloud fraction and Top Pressure	660-750 cm-1
Surface temperature	window
Temperature	660-750 cm-1 2200-2400 cm-1
Water Vapor	780 – 1090 cm-1 1200-1750 cm-1
O3	990 – 1070 cm-1
CO	2155 – 2220 cm-1
CH4	1220-1350 cm-1
N2O	1290-1300cm-1 2190-2240cm-1
HNO3	760-1320cm-1
SO2	1343-1383cm-1

NUCAPS Temperature retrieval @ 500mb January 5th 2014 (Polar Vortex Anomaly)

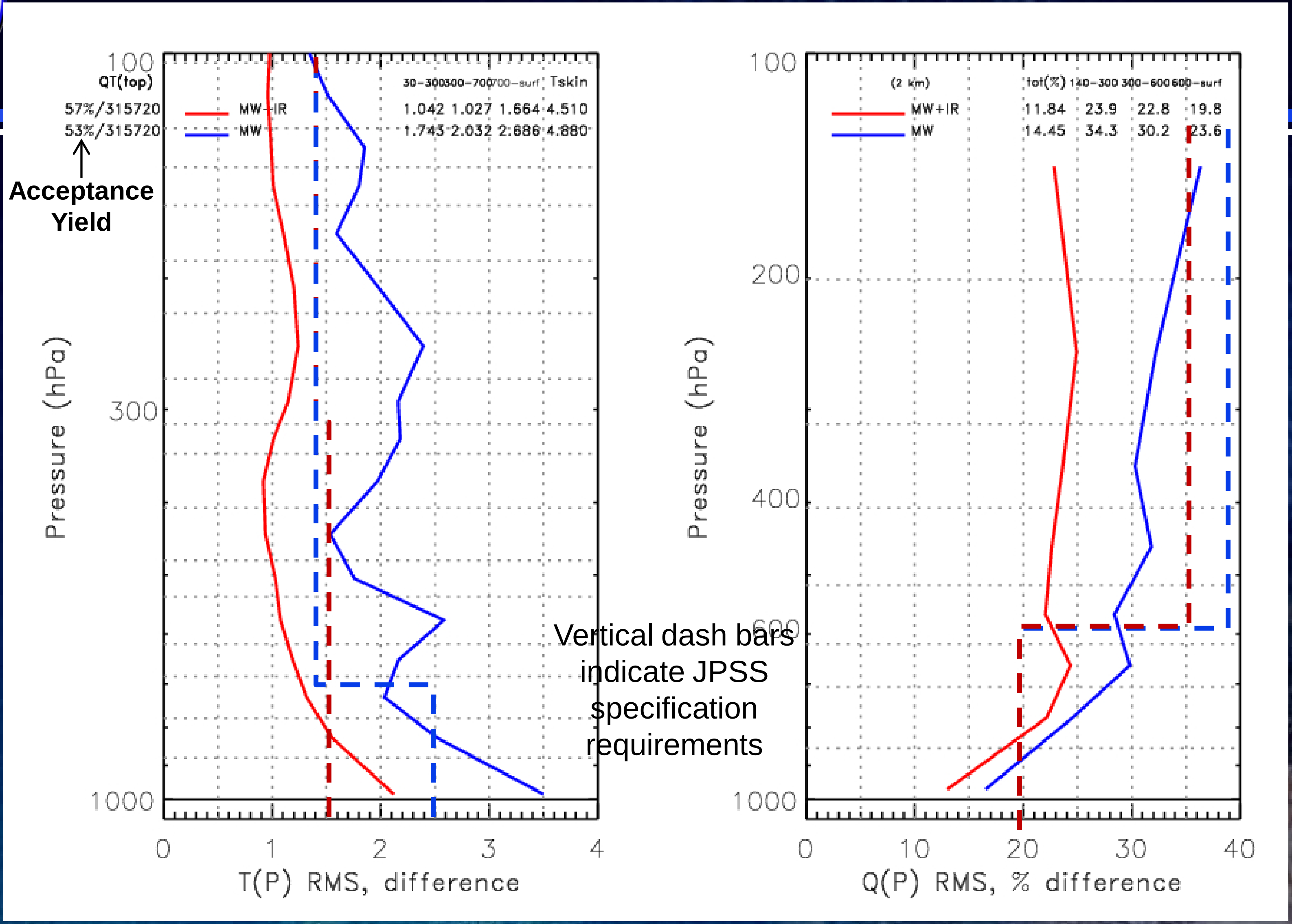


CrIS/ATMS vs AIRS/AMSU retrieval acceptance yield
BLUE= accepted RED = rejected



- AIRS/AMSU global acceptance yield is ~75%
- CrIS/ATMS global acceptance yield is ~60% (retrieval parameters and QC optimization is in progress)

NUCAPS MW+IR & MW Only
Global RMS Statistics vs ECMWF Analysis



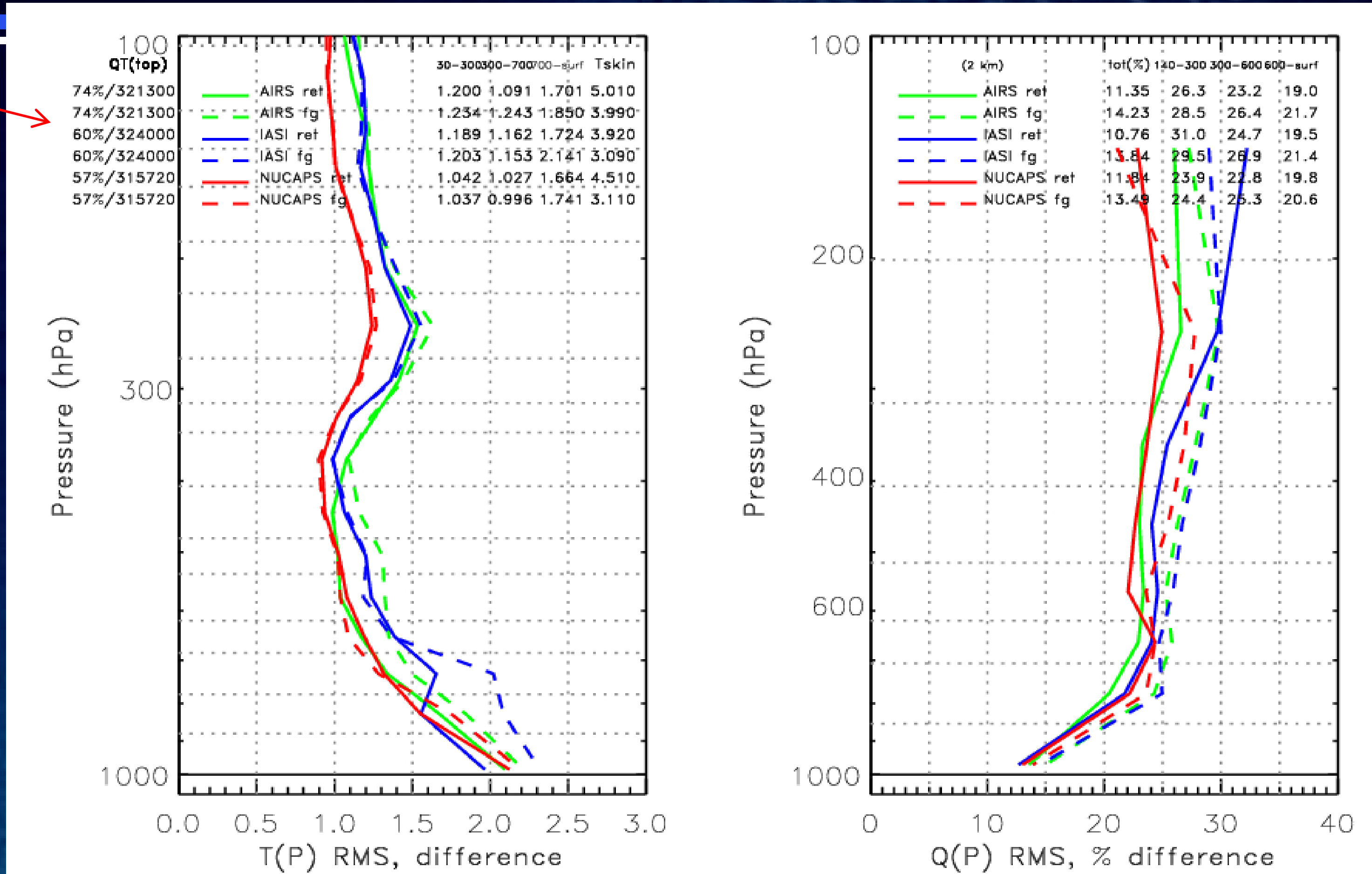
- NUCAPS MW+IR temperature and water vapor generally meet requirements
- NUCAPS MW-Only water vapor meets requirements; temperature needs further optimization

CrIS IASI AIRS

Global RMS Statistics vs ECMWF Analysis

(dash lines = first guess)

QA Acceptance Yield



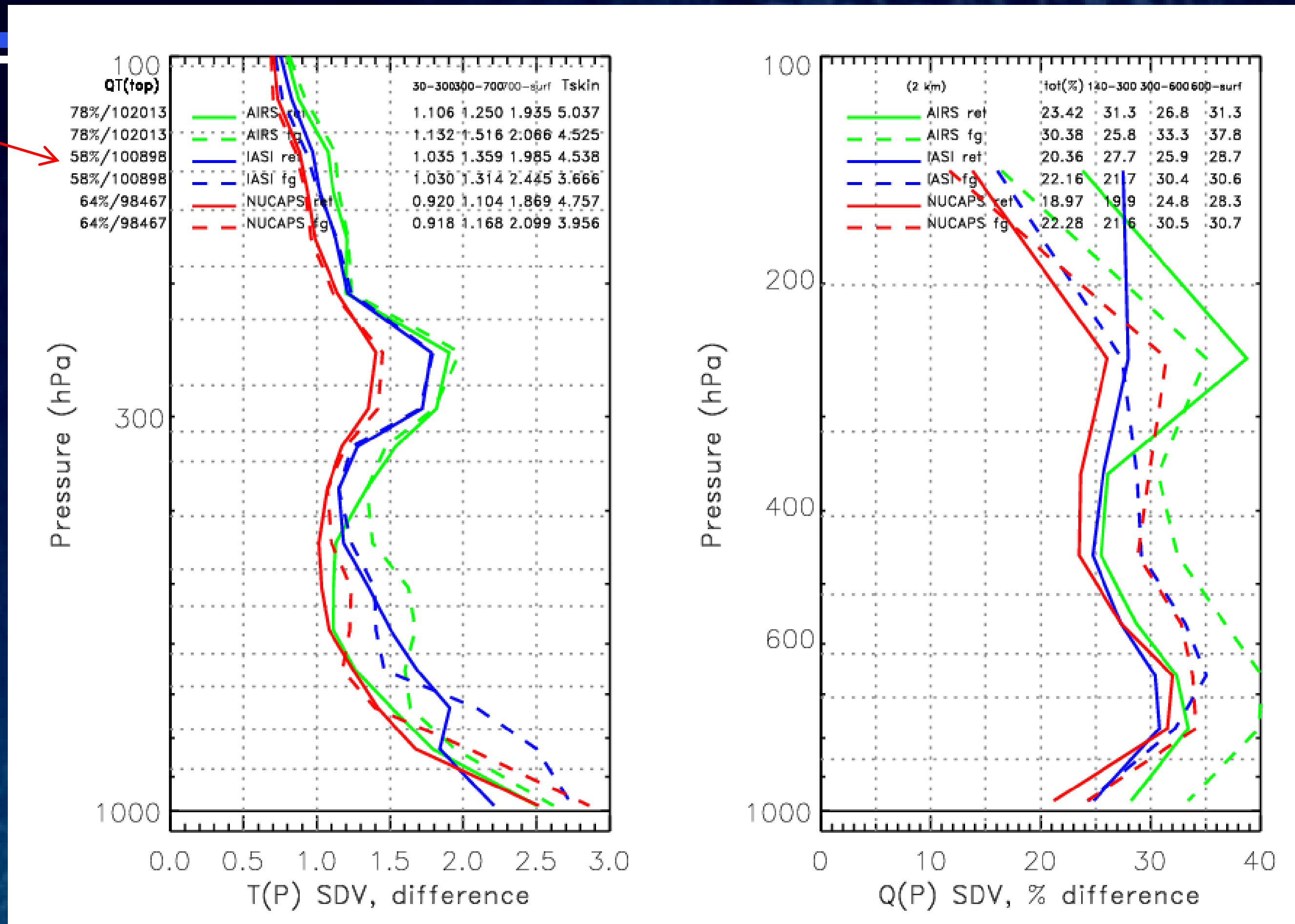
- Retrieval performance is stable and consistent across the three platforms.
- CrIS comparable to AIRS and IASI (10+ year maturity systems)
- Physical retrieval (solid) shows significant departure from first guess (dash line)

CrIS IASI AIRS

SDV Statistics vs ECMWF Analysis – Polar Regime

(dash lines = first guess)

QA Acceptance Yield



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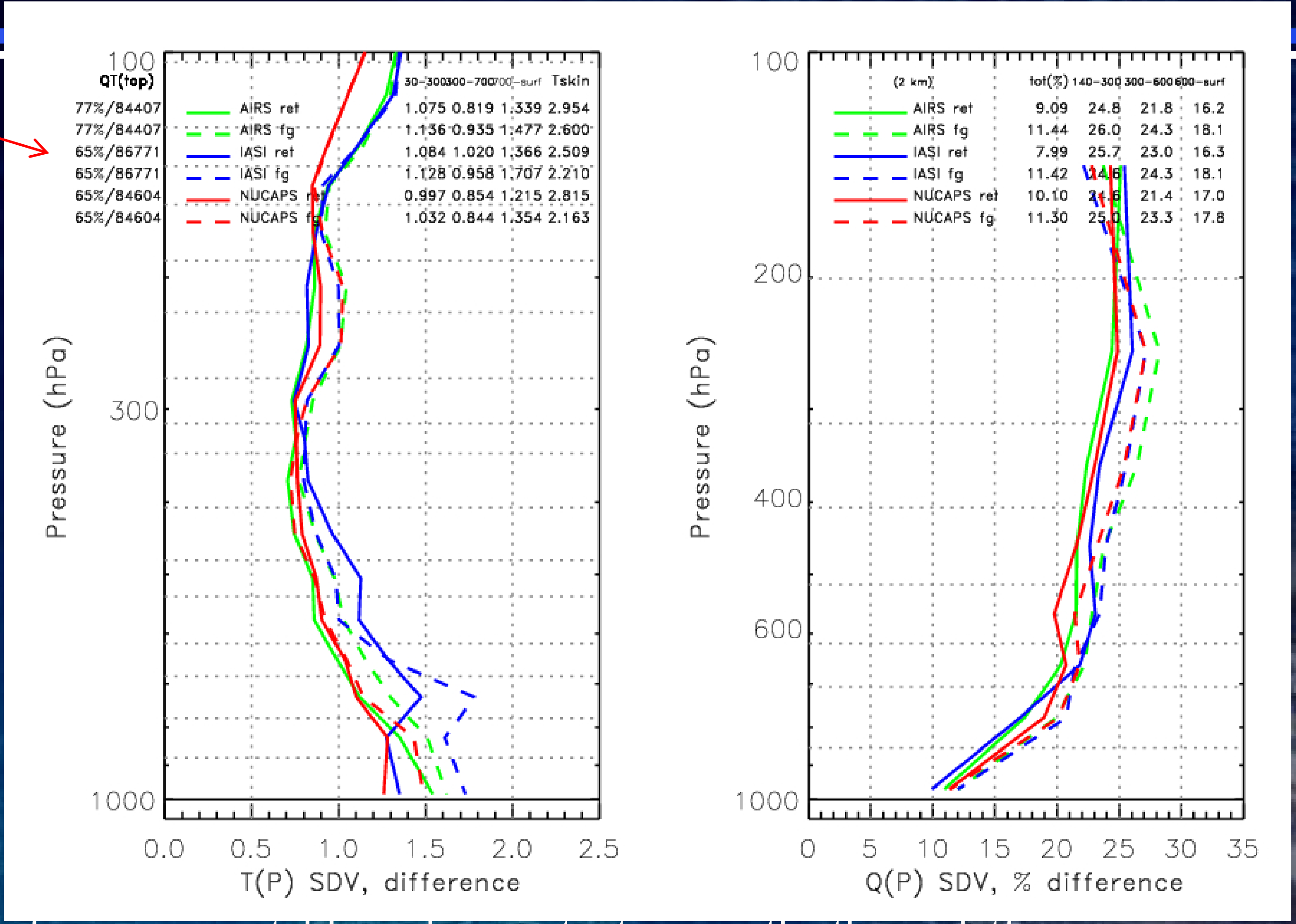
CrIS IASI AIRS

SDV Statistics vs ECMWF Analysis – Tropical Regime

(dash lines = first guess)

QA Acceptance Yield



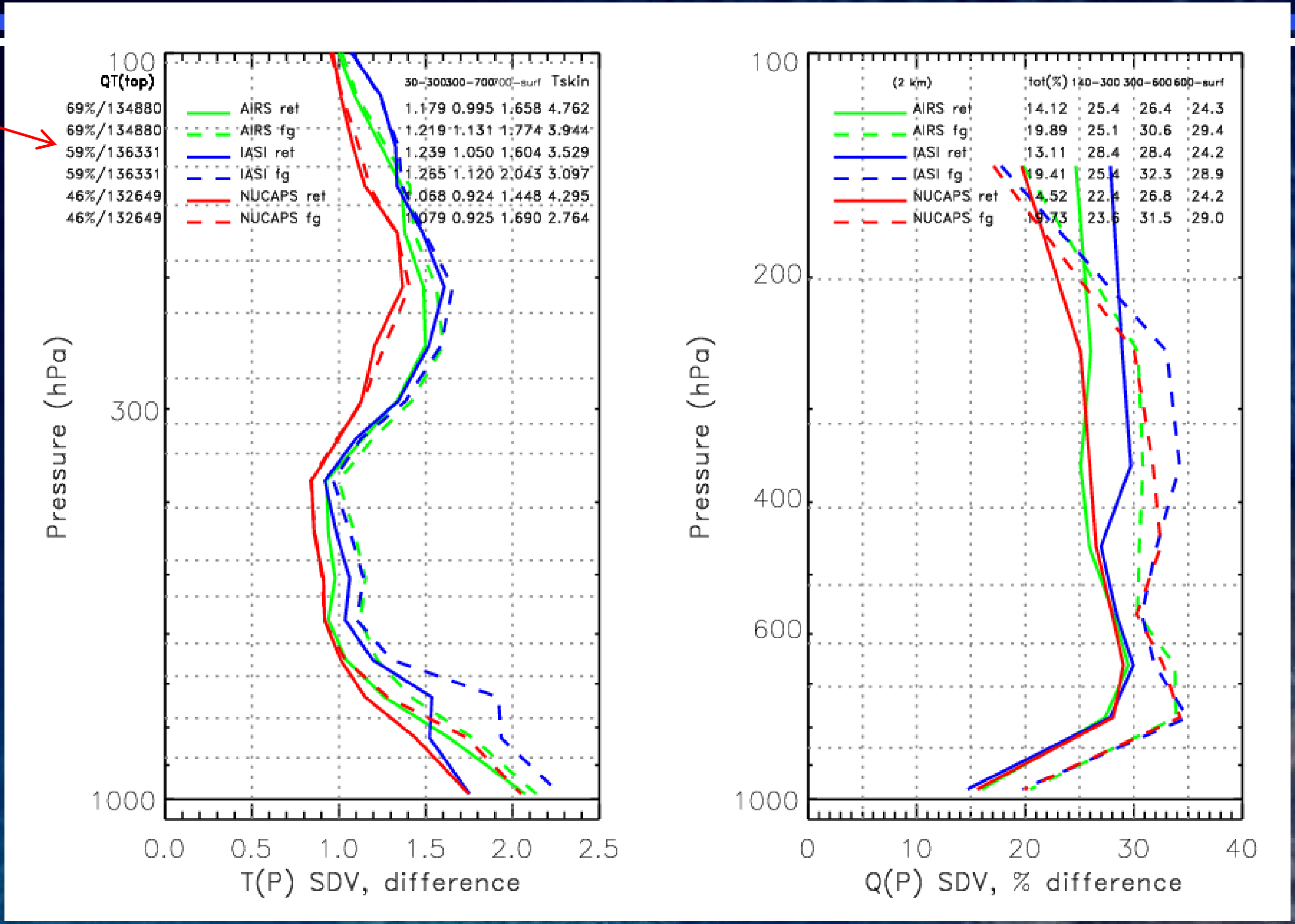
- Retrieval performance is stable and consistent across the three platforms.
- CrIS comparable to AIRS and IASI (10+ year maturity systems)
- Physical retrieval (solid) shows significant departure from first guess (dash line)

CrIS IASI AIRS

SDV Statistics vs ECMWF Analysis – MID LAT Regime

(dash lines = first guess)

QA Acceptance Yield



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An experiment using higher resolution NPP CrIS measurements: impact on carbon monoxide retrievals

- **The Cross-Track Infrared Sounder (CrIS)** is a Fourier spectrometer covering the longwave (655-1095 cm-1, "LW"), midwave (1210-1750 cm-1, "MW"), and shortwave (2155-2550 cm-1, "SW") infrared spectral regions.

- **Current operations:**
  - Maximum geometrical path difference *L* = 0.8 cm (LW), 0.4 cm (MW) and 0.2 cm (SW)
  - Nyquist spectral sampling (*1/2L*): 0.625 cm-1, 1.25 cm-1 and 2.5 cm-1

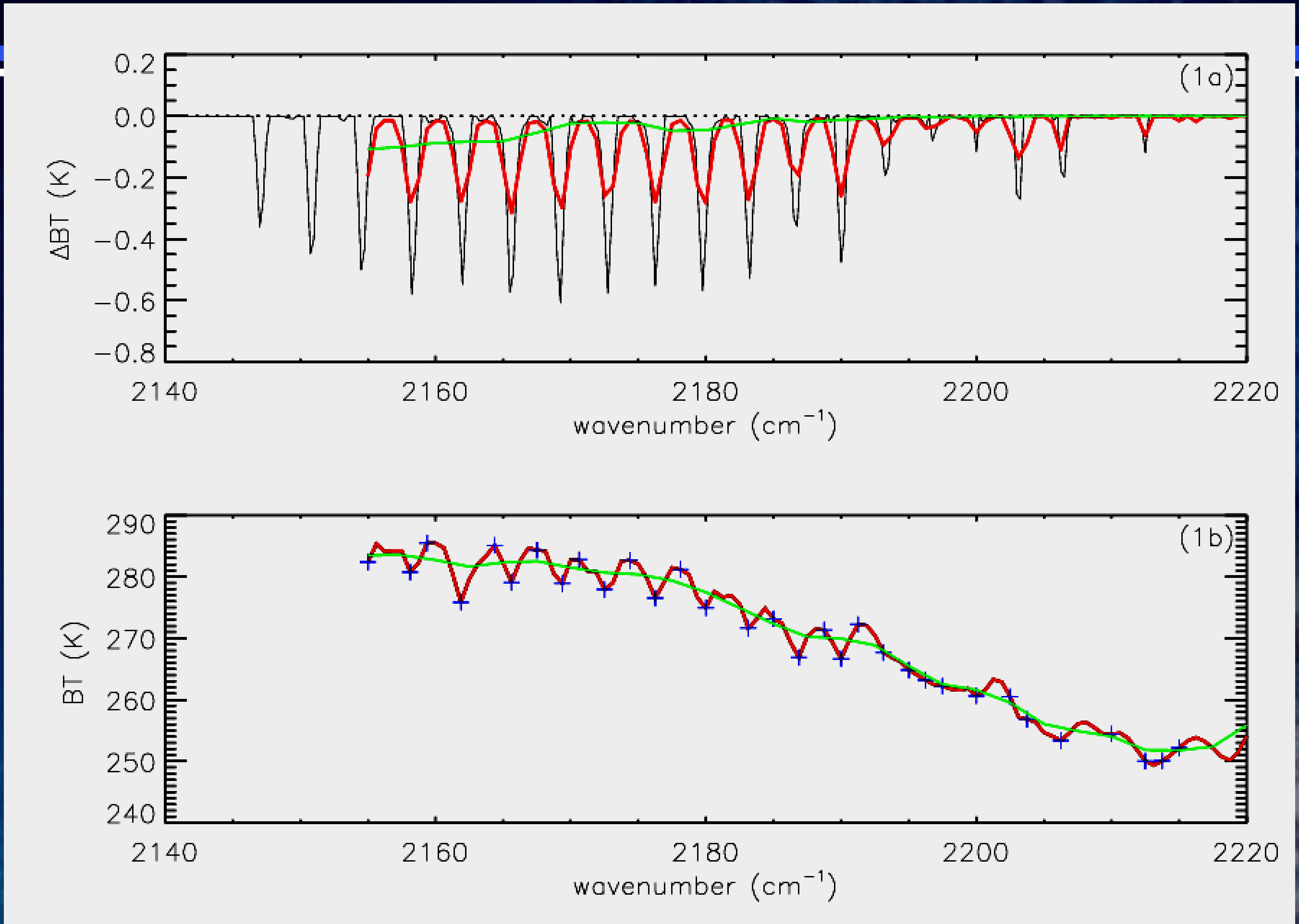
- **Experimental set up** (5 orbits from March 12th 2013)
  - Maximum geometrical path difference *L* = 0.8 cm in all three bands
  - Nyquist spectral sampling (*1/2L*): 0.625 cm-1 in all three bands

- **CO retrieval impact study**: CO is expected to benefit the most from the high resolution mode, now increased by a factor of 4 with respect to the operational resolution.

- **Reference:** ***Gambacorta et al., "An experiment using CrIS high spectral resolution measurement for trace gas retrievals: CO retrieval impact study", IEEE Letters, 2014.***

Sensitivity Analysis to 1% CO perturbation

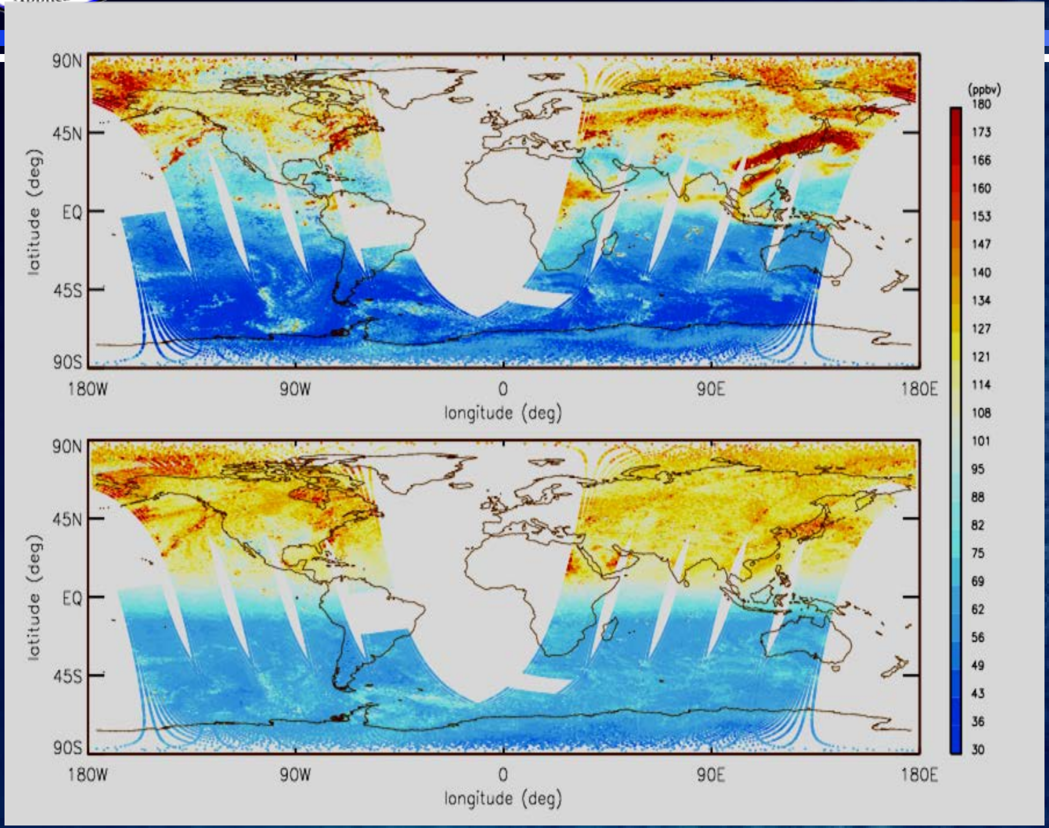
2.5cm^-1   0.625 cm^-1   0.25cm ^-1



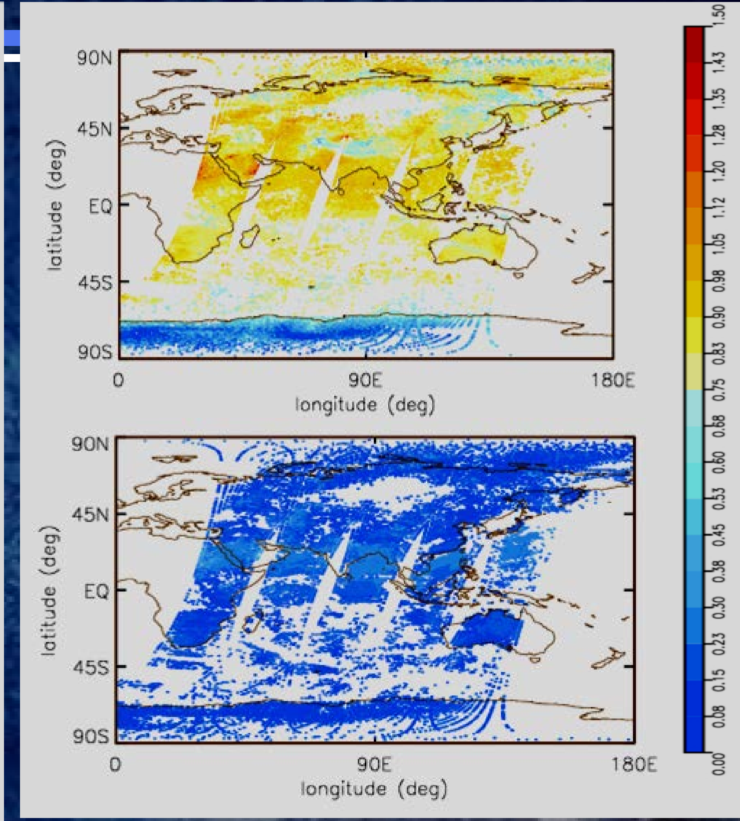
- Only when switched to high spectral resolution, CrIS spectrum (red curve, bottom part) shows the distinctive signature of CO absorption (red and black curve, top figure).
- Blue cross symbols: CO high resolution channel selection.

CO high resolution (top) vs operational low resolution results (bottom)

NUCAPS CO retrieval (~450mb)

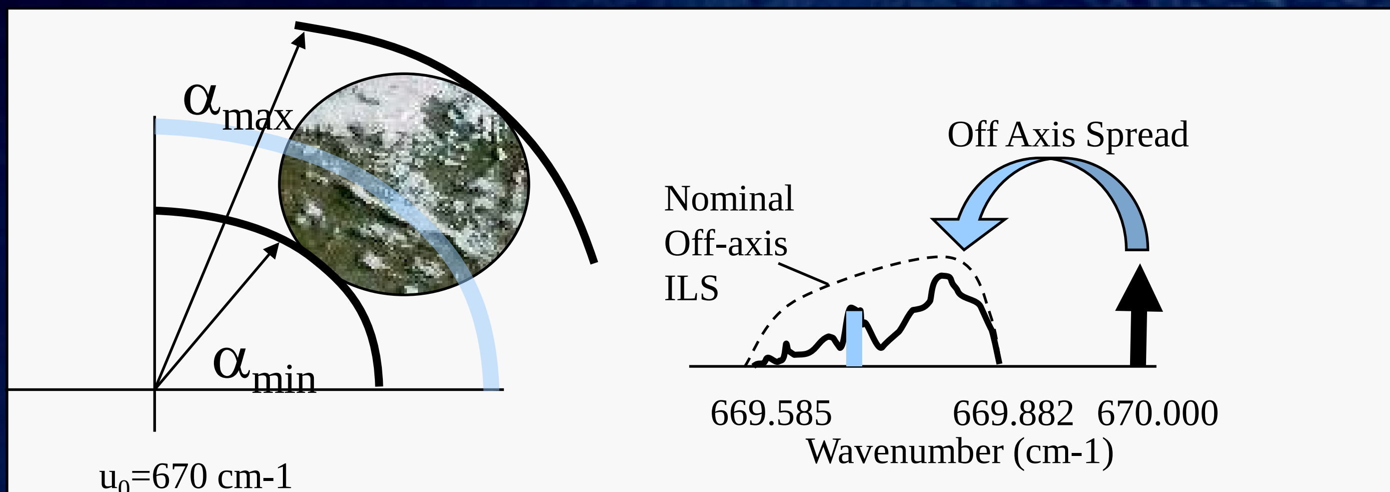


CO DOF



- The higher information content enables a larger departure from the a priori, hence the increased spatial variability observed in the high spectral resolution map (top left) compared to the low resolution (bottom left).
- A demonstration experiment in support for the need of high spectral resolution CrIS measurements.
- NUCAPS modular architecture has proven that there is no risk of disruption to the operational processing upon switching to high spectral sampling.

FOV ILS Distortion in Presence of Scene Inhomogeneities

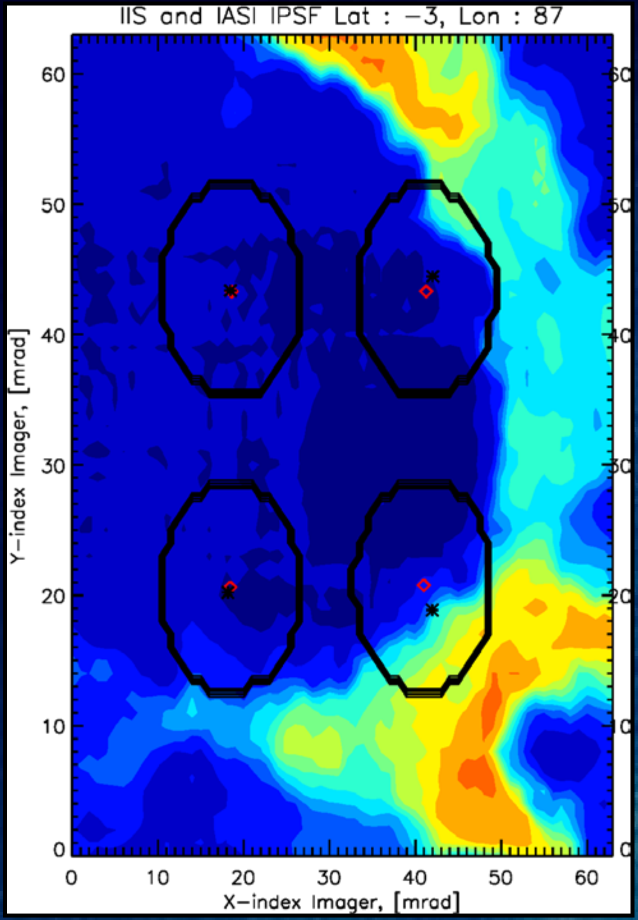


Picture courtesy of Dan Mooney

- Sub pixel scene in-homogeneities (clouds, surface variability, et.) are responsible for a distortion of the nominal off-axis ILS (mainly a frequency shift), introducing an error in the parameterization of the self apodization matrix.
- This error is propagated through the off-axis correction (inversion of the self apodization matrix) introducing an error in the radiance spectrum.

ILS frequency shift computation in presence of scene inhomogeneities: lessons learned from IASI

IIS Imager (64x64 pixels) and IASI FOVs (black contour)



- The ILS distortion due to the presence of scence inhomogeneities is mainly a frequency shift effect, $\delta\nu$, resulting from the angular offset, $\delta\alpha$, between the geometric and radiometric centers of the FOV.

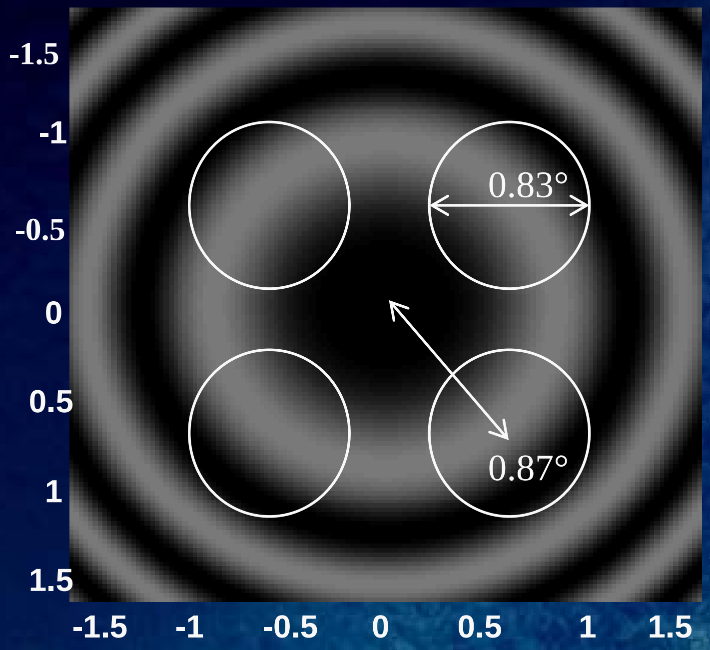
$$\frac{\delta\nu}{\nu} \sim \alpha_0 \delta\alpha$$

Lessons learned from IASI + IIS:

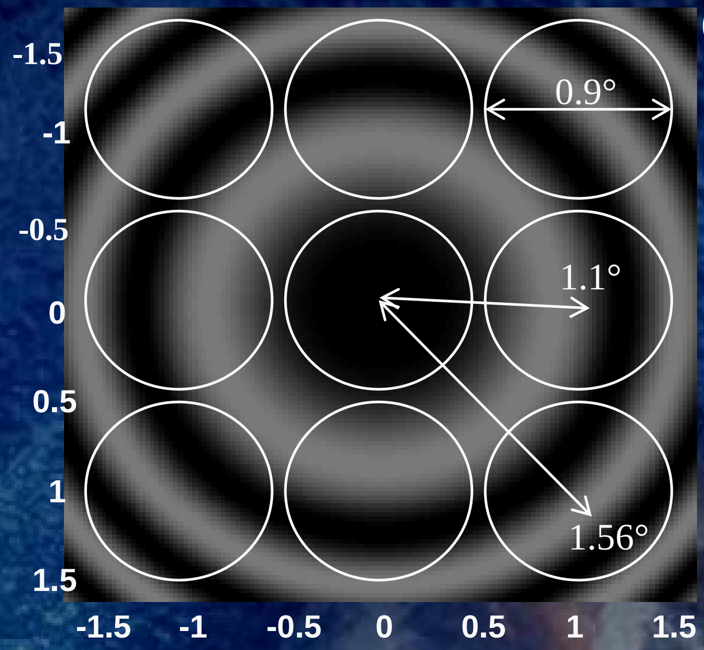
- $\delta\alpha$ distribution results:
  mean = 0.001mrad; 1 sigma = 0.1 mrad
- $\delta\nu/\nu$ =1.5 ppm across the three bands
- Radiance error lower than NEDN across the three bands, hence is negligible.
- Reference: Gambacorta et al.; Proceedings of 2nd IASI International Meeting, Sevrier, 2010.

IASI vs CrIS FOV geometry

IASI



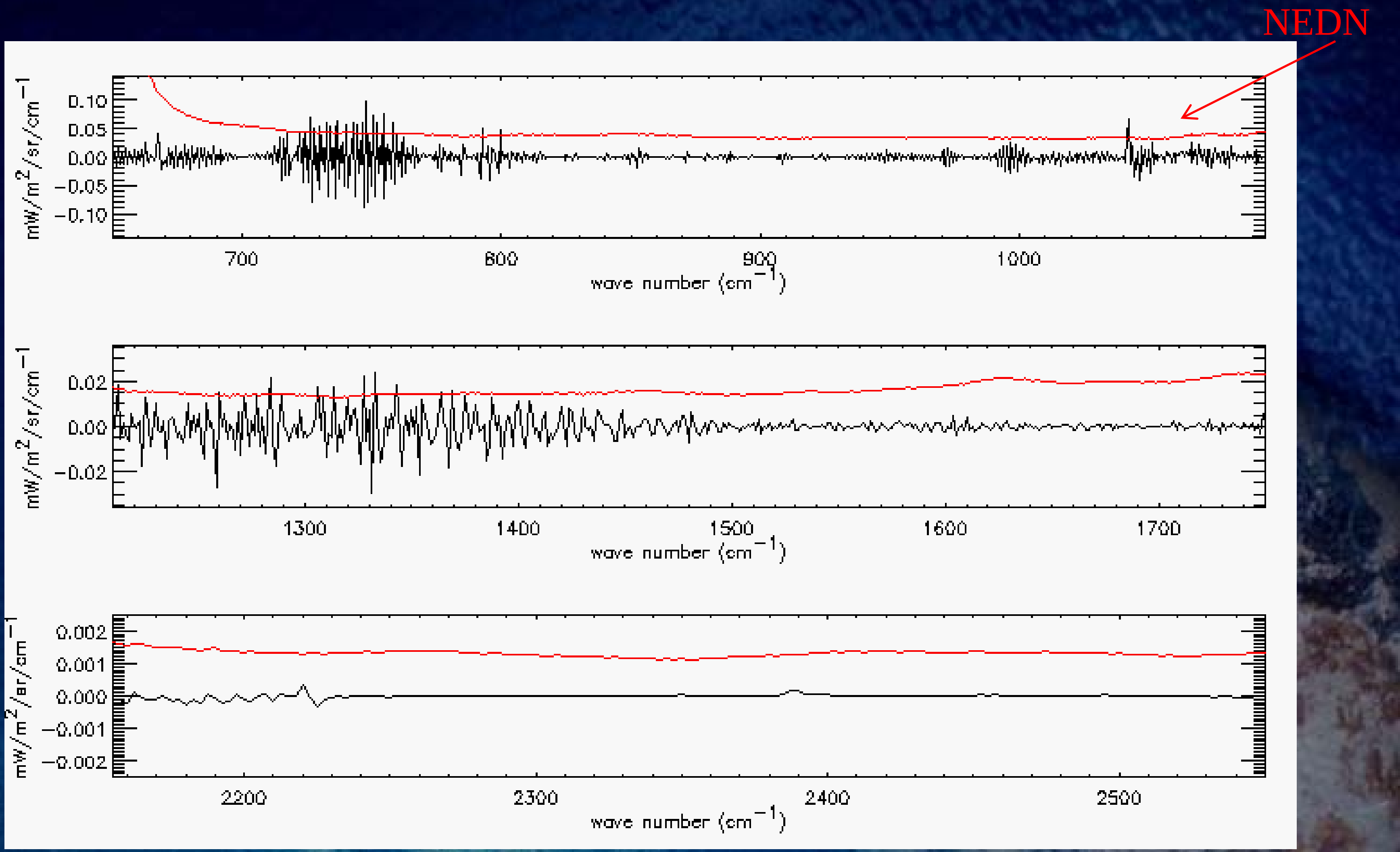
CrIS



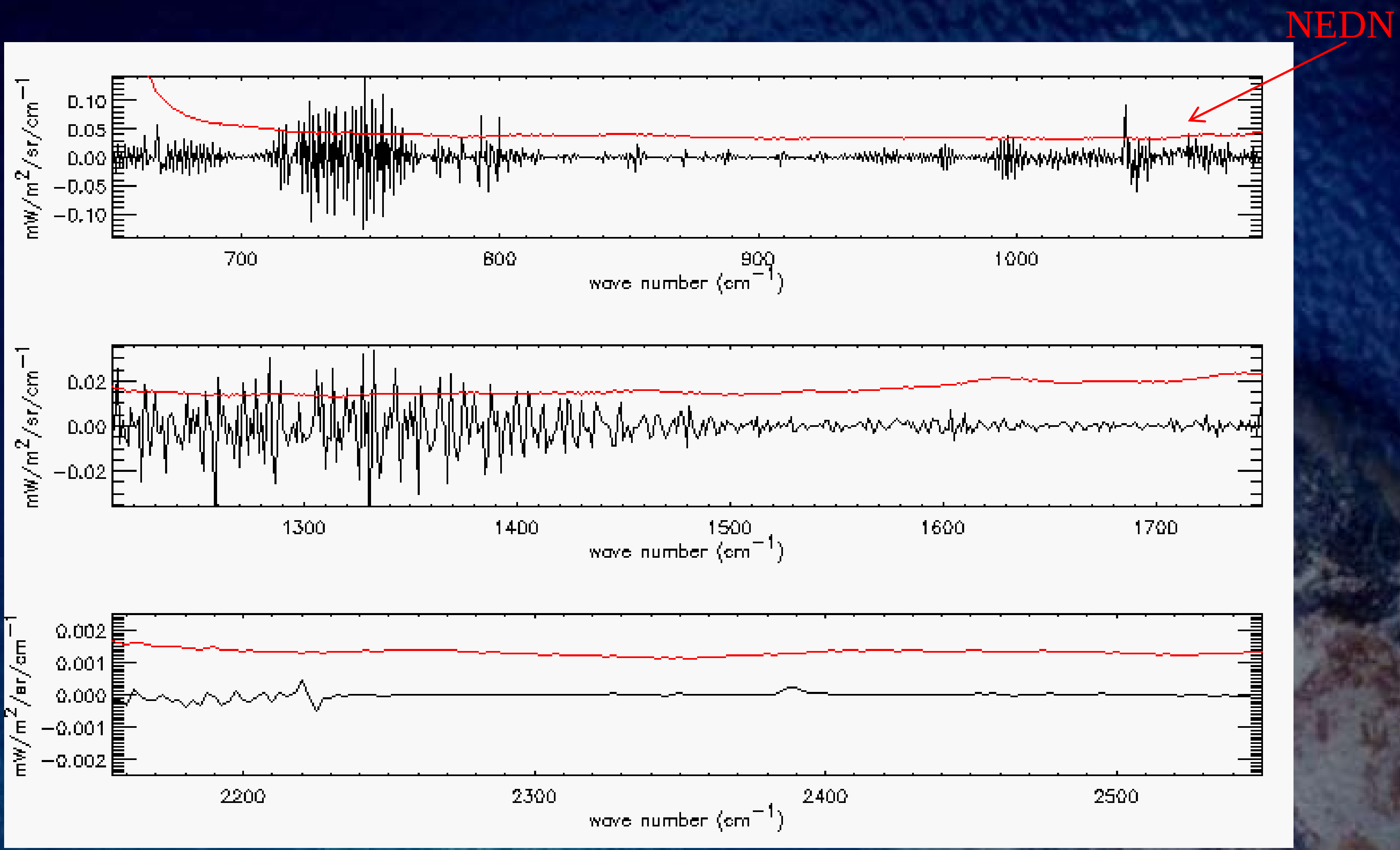
- Applying IASI's $\delta\alpha$ results to CrIS (assuming surface inhomogeneity and interference ringing are close enough between the two instruments):
  - CrIS Side Cube (α=1.1°=0.019rad): $\delta\nu/\nu \sim \alpha\delta\alpha$ = **1.91e-6**
  - CrIS Corner Cube (α=1.56°=0.027rad): $\delta\nu/\nu \sim \alpha\delta\alpha$ = **2.72e-6**

< 3ppm

Radiance error induced by ILS shift - Side cube -



Radiance error induced by ILS shift
- corner cube -



NUCAPS Project Plan: Task and Schedules

- Schedule (key milestones):
  - » Preliminary Design Review – May 9, 2007
  - » Critical Design Review – Sep. 29, 2008
  - » Test Readiness Review – Sep. 29, 2010
  - » Code Unit Test Review – Oct. 20, 2010
  - » Phase 1 Algorithm Readiness Review – Mar. 14, 2012
  - » NUCAPS Phase 1 Delivery – Mar. 19, 2012
  - » NUCAPS Phase 2 Delivery – Dec. 3, 2012
  - » Phase 2 Algorithm Readiness Review – Jan. 14, 2013
  - » Satellite Product Services Review Board (SPSRB) Briefing for Phase 1 – Jul. 17, 2013
    - – Declared NUCAPS trace gases operational; approved funding.
  - » NUCAPS Phase 1 Operations Commence – Sep. 19, 2013
  - » SPSRB Briefing for Phase 2 – Sep. 18, 2013
    - – Declared NUCAPS T, q, operational in replacement of CrIMSS IDPS; approved funding.
  - » NUCAPS Phase 2 Operations Commence – Oct. 2013

NUCAPS Project Plan:
Task and Schedules

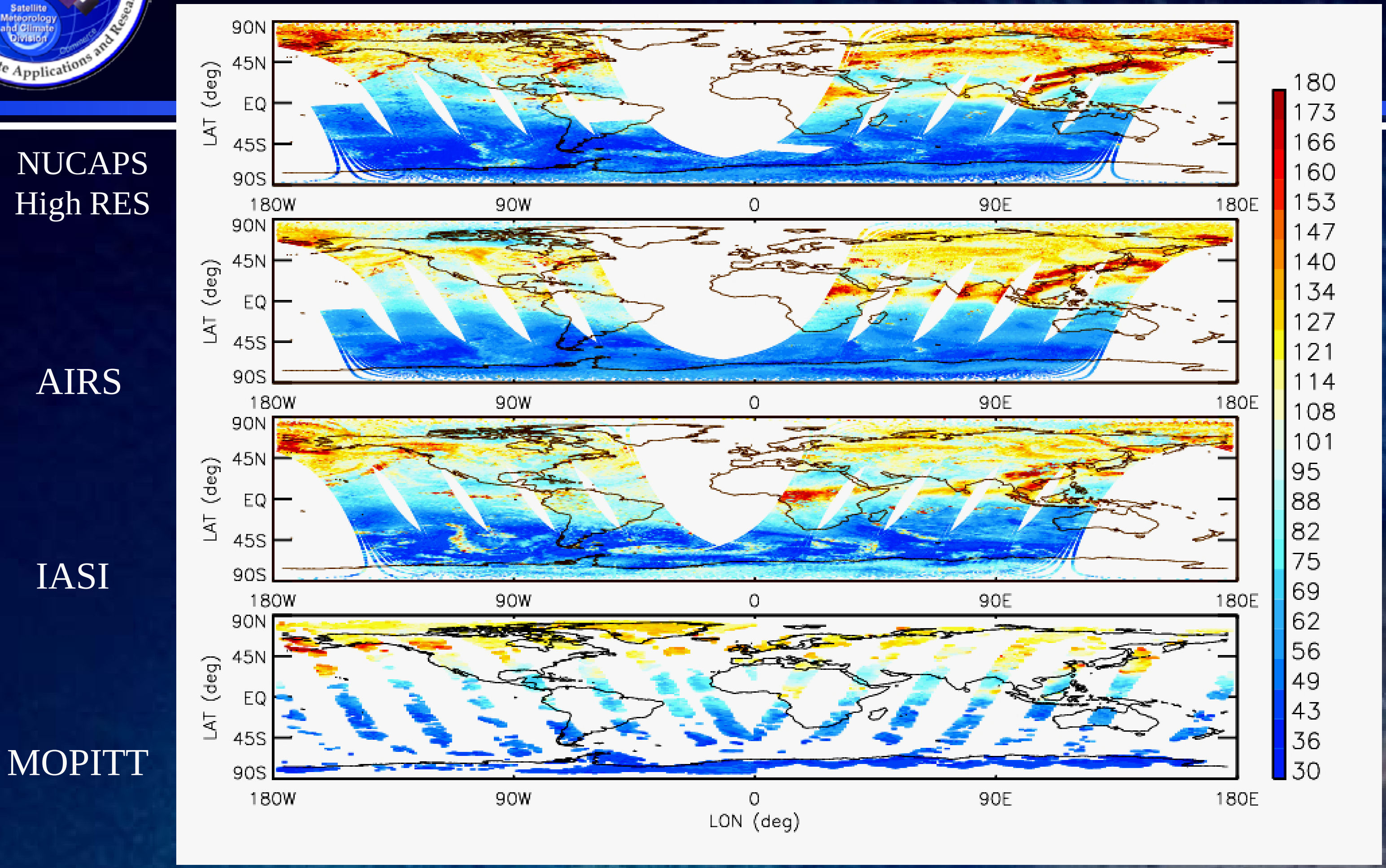
- Schedule (key milestones) continued:
  - » NUCAPS Phase 3 Critical Design Review – Nov. 2013
    - OLR product delivery
    - ILS shift in presence of scene in-homogeneities
    - VIIRS/CrIS collocation
  - » NUCAPS Phase 3 Code Test Review – Mar. 2014
  - » NUCAPS Phase 3 Algorithm Readiness Review – Aug. 2014
  - » NUCAPS Phase 3 DAP Delivery – Sep. 2014
  - » SPSRB Phase 3 briefing – Oct. 2014
  - » NUCAPS Phase 3 Operations Commence – Oct. 2014
  - » AIRS, IASI, CrIS full data record reprocessing for science application ~2015

Conclusion Remarks and ongoing work

- NUCAPS MW+IR retrievals performance:
  - **MW+IR temperature and water vapor generally meet requirements**
  - **MW-Only water vapor meets requirements; temperature needs further optimization**
- Cross – comparison validation efforts have shown consistency across all three systems: CrIS/ATMS, IASI/AMSU/MHS and AIRS/AMSU.
- On going validation and development activity involves the improvement of the intermediate modules of the retrieval algorithm: mw-only retrieval step, first guess, a priori, regularization parameters, rta bias correction,etc.
- We have provided evidence to support the need for high spectral resolution CrIS measurements. The modular architecture of NUCAPS has proven that there is no risk of disruption to the operational processing upon switching to high spectral resolution mode.
- Assessment of the impact of the ILS shift in presence of surface in-homogeneities has been proven negligible for both the IASI and CrIS instruments.
- The results of this effort guarantee continuity to the afternoon orbit sounding as part of a multi-satellite, uniformly integrated, long term data record of atmospheric variables and also serve in preparation of future advanced satellite missions under the Joint Polar Satellite System and IASI Next Generation.

Back Up slides

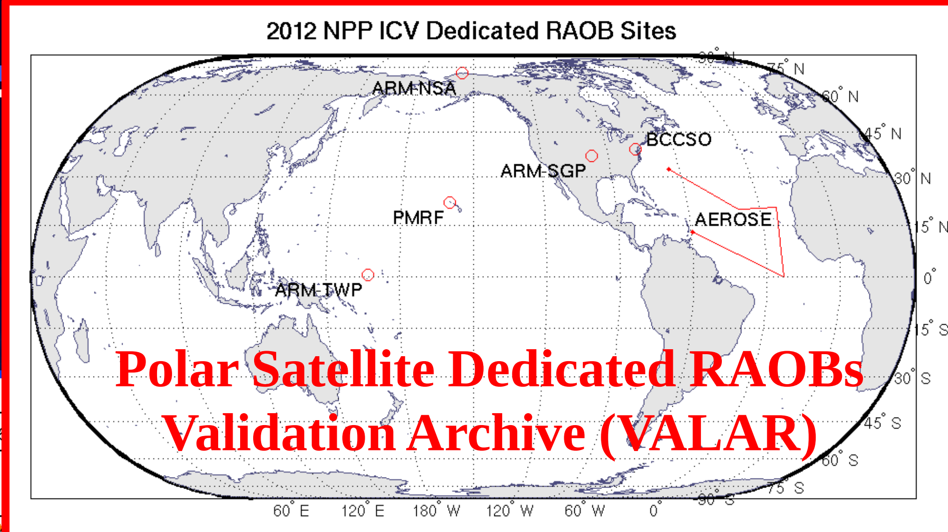
NUCAPS High RES (top), AIRS (second), IASI (third) and MOPITT (bottom) CO retrievals

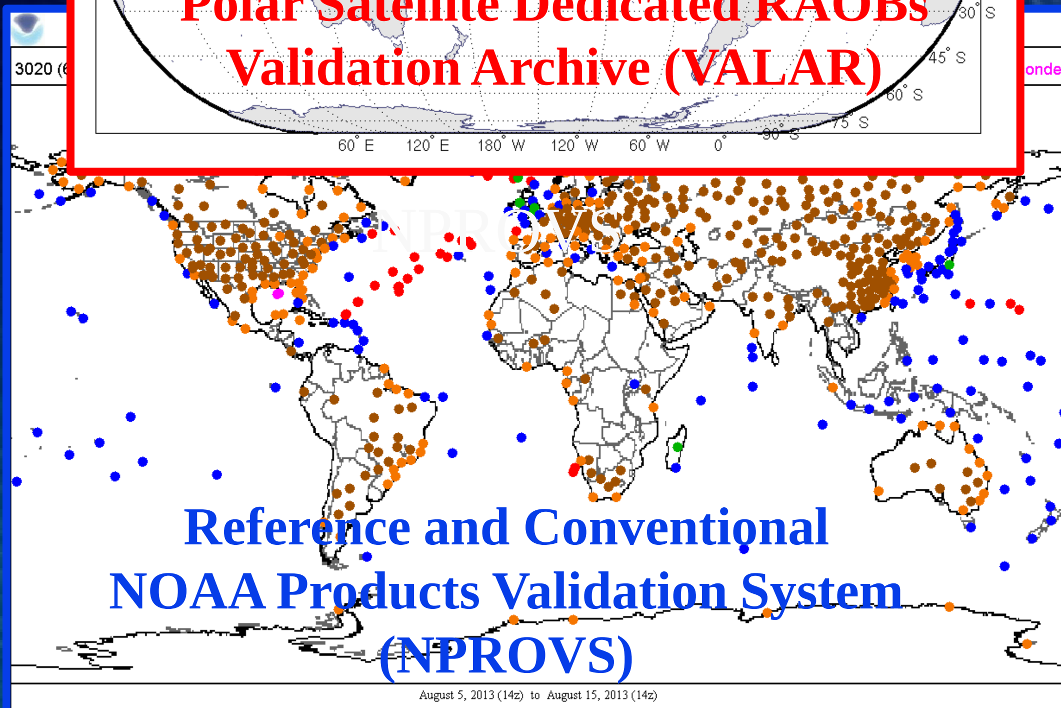


- NUCAPS high resolution CO retrievals show a significantly improved agreement to all three CO satellite products. The observed differences among the four instruments are consistent with what has been previously observed and have been mainly attributed to differences in instrumental spectral resolution, retrieval methods, a priori and thermal contrast diurnal cycle.
- This analysis intended to provide a performance demonstration of the NUCAPS high resolution CO product, in terms of both spatial variability and order of magnitude, in support for the need of high resolution radiance measurements.

Ongoing Retrieval Validation Strategy

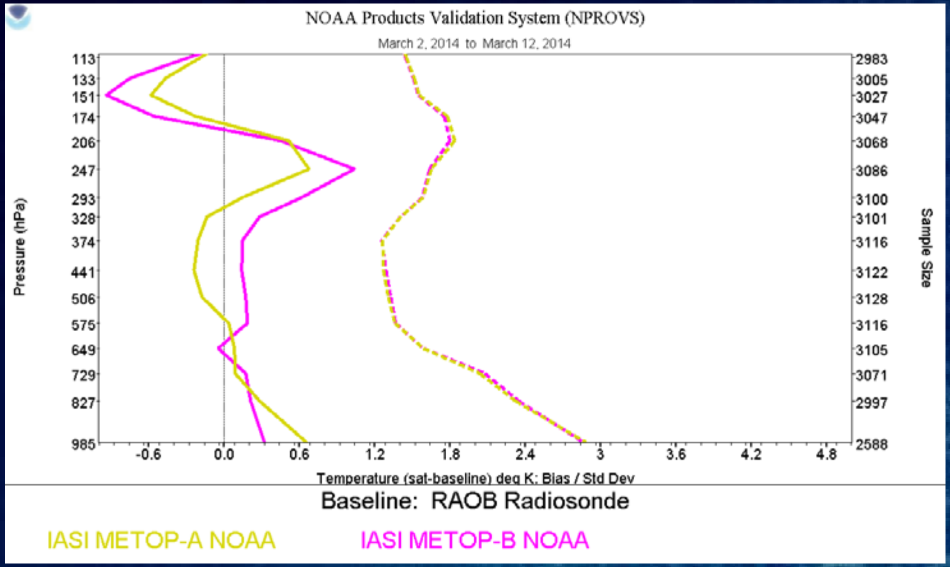
Validation Data Sample Yield

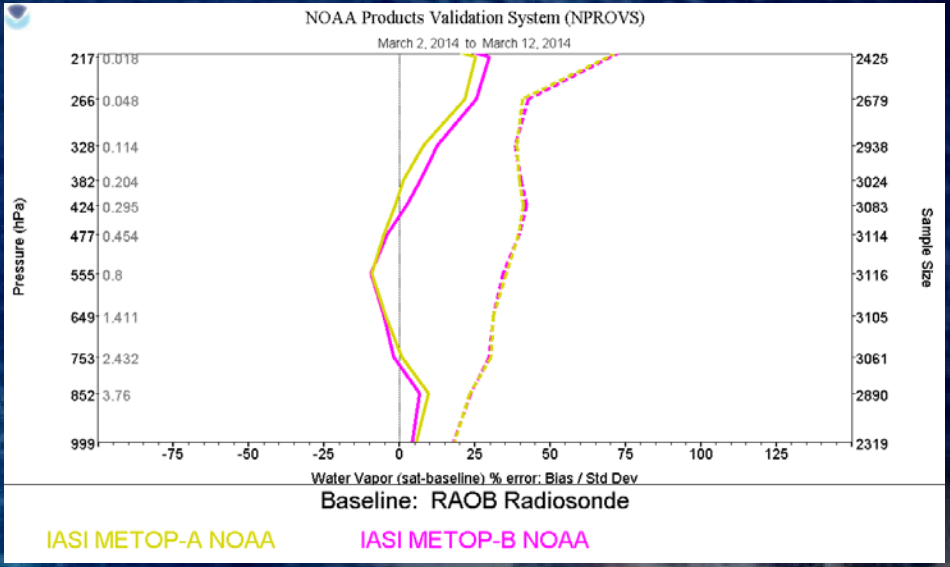




Validation Data Sample Quality

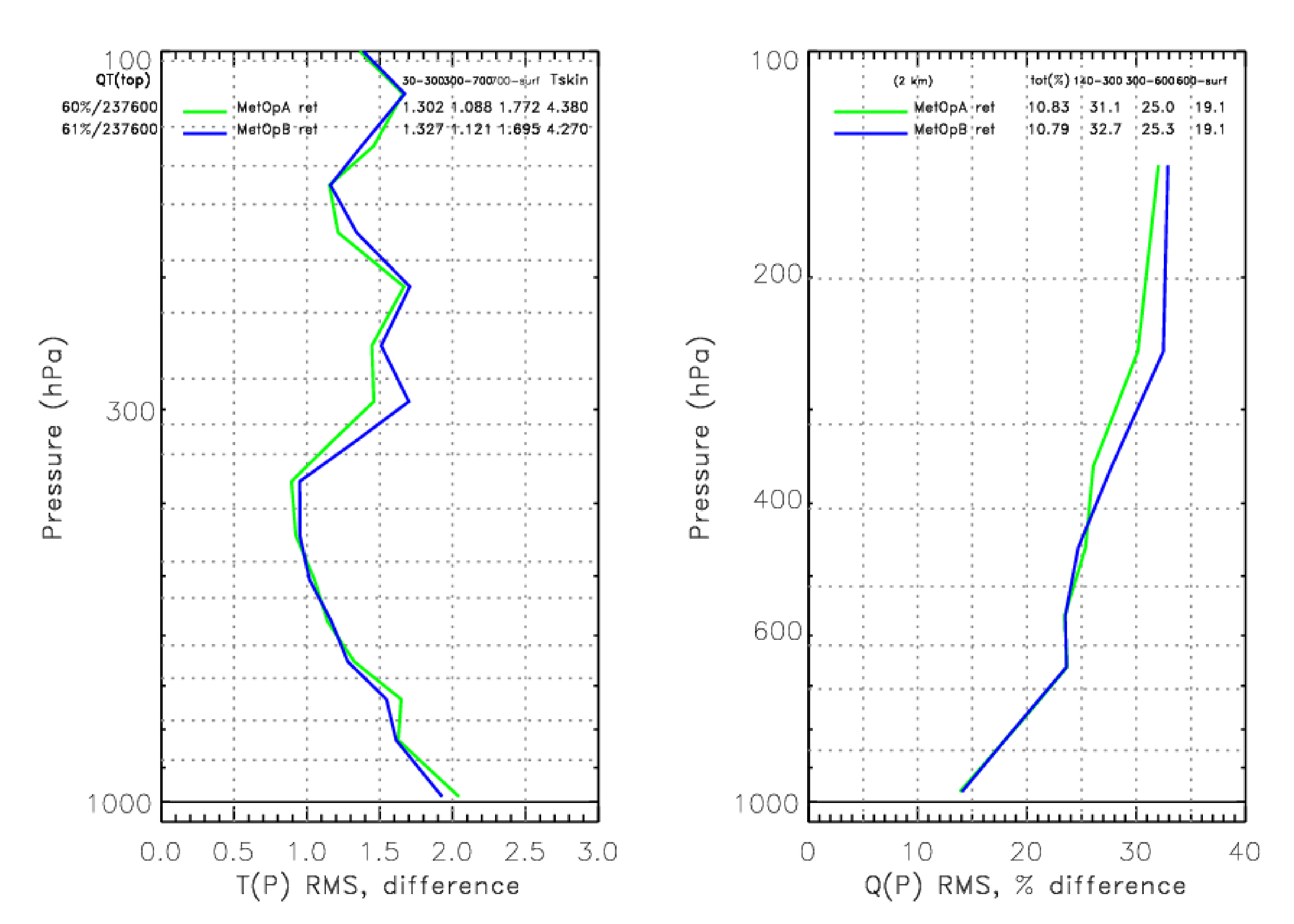
IASI MetOp A vs IASI MetOp B





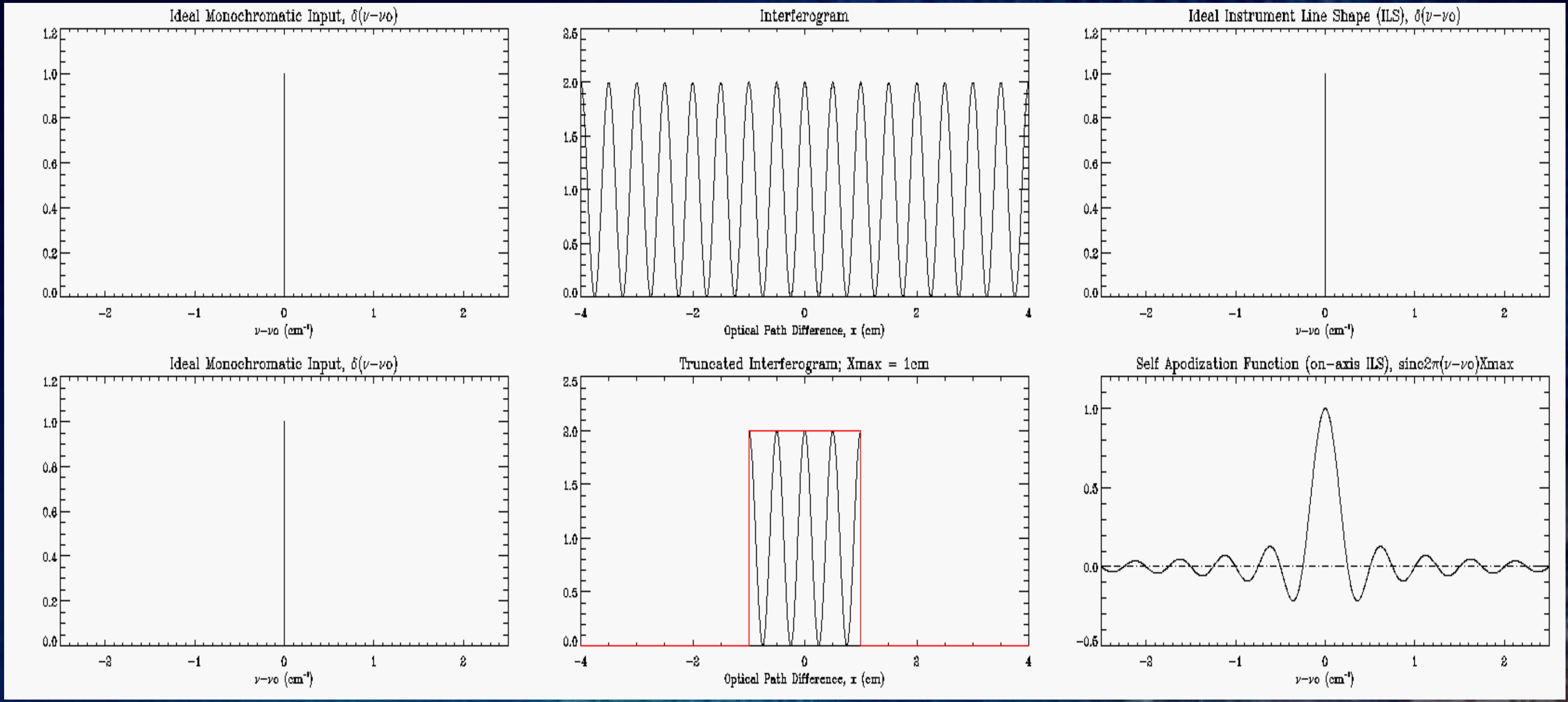
- Same exact code and look up tables used for both systems
- Consistency between the two systems is remarkable

IASI MetOp A IASI MetOp B
Global RMS Statistics vs ECMWF Analysis



- Retrieval performance is stable and consistent between IASI MetOp A and B systems.
- Same exact *code, spectroscopy and look up tables* are used for both.
- Results are consistent with findings from EUMETSAT partners.

Truncation of the Interferogram & Resulting Instrument Line Shape



The Instrument Line Shape resulting from the box-car truncation is a sinc function with pronounced side lobe effects.

Parameter	JPSS Requirements (6/27/2013)
AVMP Clear, surface to 600 mb	20% or 0.2 g/kg
AVMP Clear, 600 to 300 mb	35% or 0.1 g/kg
AVMP Clear, 300 to 100 mb	35% or 0.1 g/kg
AVMP Cloudy, surface to 600 mb	20% of 0.2 g/kg
AVMP Cloudy, 600 mb to 400 mb	40% or 0.1 g/kg
AVMP Cloudy, 400 mb to 100 mb	40% or 0.1 g/kg
AVTP Clear, surface to 300 mb	1.6 K/1-km layer
AVTP Clear, 300 to 30 mb	1.5 K/3-km layer
AVTP Clear, 30 mb to 1 mb	1.5 K/5-km layer
AVTP Clear, 1 mb to 0.01 mb	3.5 K/5-km layer
AVTP Cloudy , surface to 700 mb	2.5 K/1-km layer
AVTP Cloudy, 700 mb to 300 mb	1.5 K/1-km layer (clear=1.6)
AVTP Cloudy, 300 mb to 30 mb	1.5 K/3-km layer
AVTP Cloudy, 30 mb to 1 mb	1.5 K/5-km layer
AVTP Cloudy, 1 mb to 0.01 mb	3.5 K/5-km layer
CH4 (methane) column	1% precision, ±5% accuracy
CO (carbon monoxide) column	3% precision, ±5% accuracy