The NOAA Unique CrIS/ATMS Processing System (NUCAPS): algorithm description and validation results after 2 years in orbit

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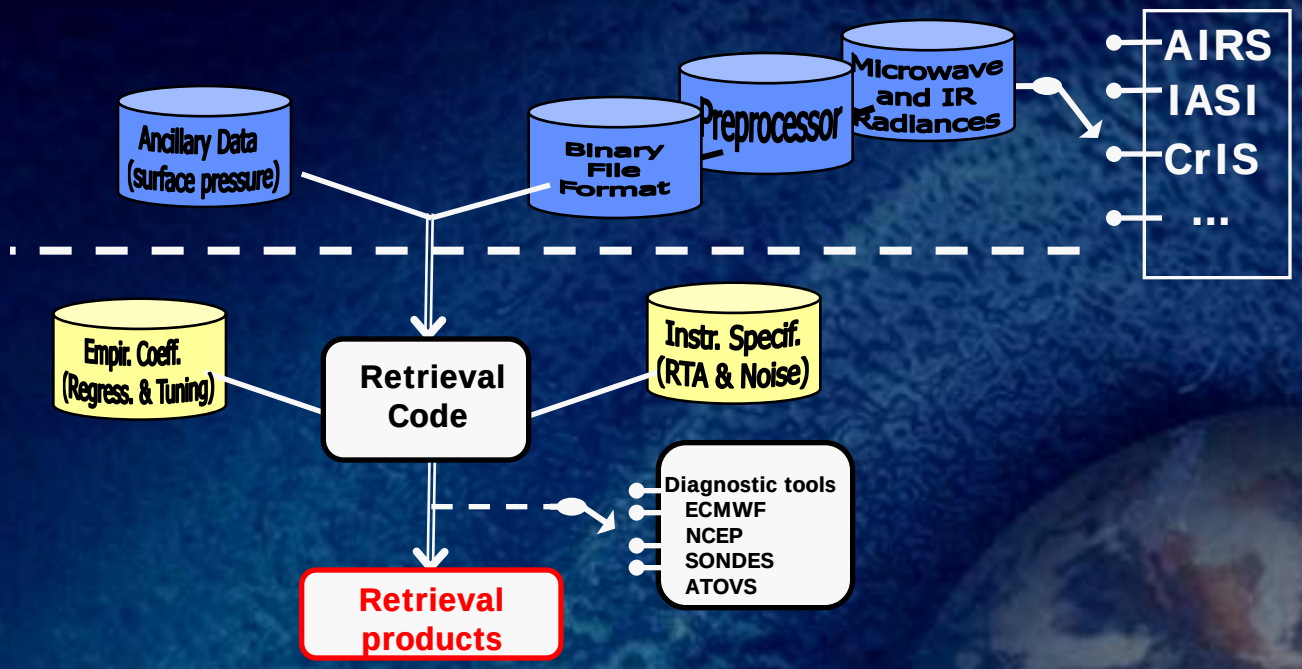
Outline

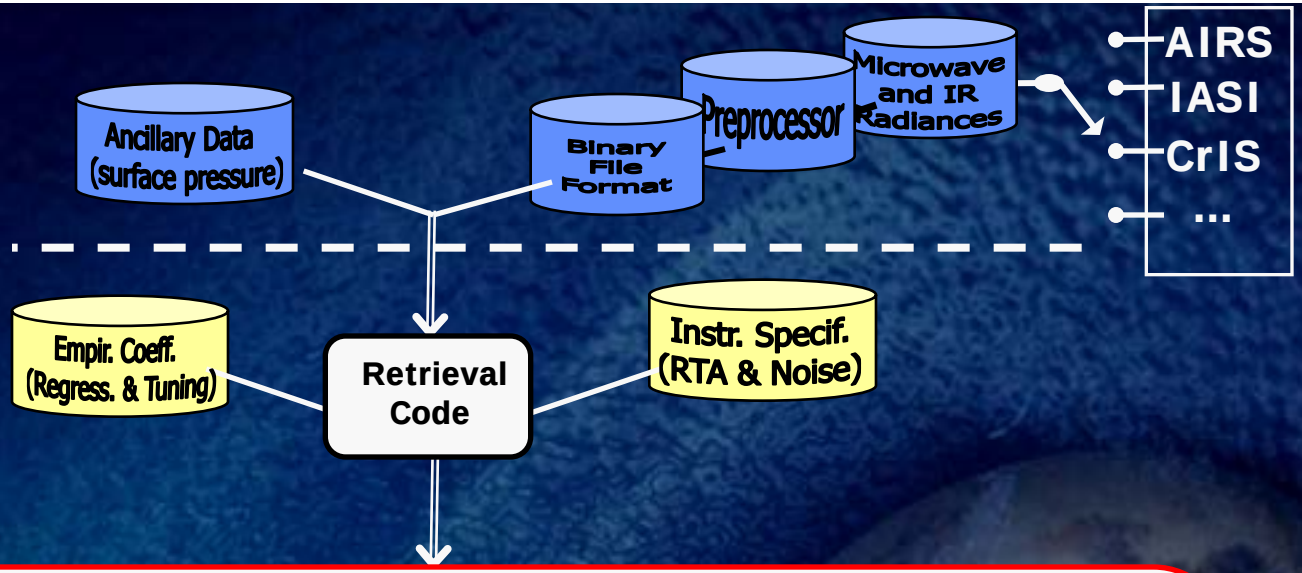
- Status of the NOAA Unique CrIS/ATMS Processing System
  - » Part I: Algorithm architecture and product description
  - » Part II: Inter-consistency among CrIS/ATMS, AIRS/AMSU, IASI/AMSU/MHS retrieval products
    - – Temperature and water vapor validation error characteristics and validation strategy
    - – Demonstration experiment using CrIS high resolution radiances to retrieve atmospheric trace gases (impact study on CO)
  - » Final conclusions and future work

The NOAA Unique CrIS/ATMS Processing System is a modular design compatible with multiple instruments



- This system is a heritage algorithm of the AIRS Science Team and is currently used to operationally process the Aqua AIRS/AMSU (since 2003), the Metop A and B IASI/AMSU/MHS (since 2006 and 2013) and the *NOAA Unique CrIS/ATMS Processing System (NUCAPS*) (since 2013).
- Modular design – same retrieval algorithm code, same underlying spectroscopy - is key for a long term homogeneous multi-satellite integrated dataset of environmental data records.

The NOAA Unique CrIS/ATMS Processing System is a modular design compatible with multiple instruments



Retrieval Products

Cloud Cleared Radiances Cloud fraction Cloud Top Pressure	Surface temperature Vertical Temperature Profile Vertical Water Vapor Profile	Trace gases vertical profiles: O3, CH4, CO, CO2, N2O, SO2, HNO3

Near Real Time (~3 hours) data availability:
www.class.noaa.gov

Applications

- **Direct broadcast of temperature and water vapor retrievals from hyper spectral sounders are suitable for NowCasting applications.**
  - » AMS 2014 talk: Barnet et al., 9:00, Wednesday, February 5th, Room C111

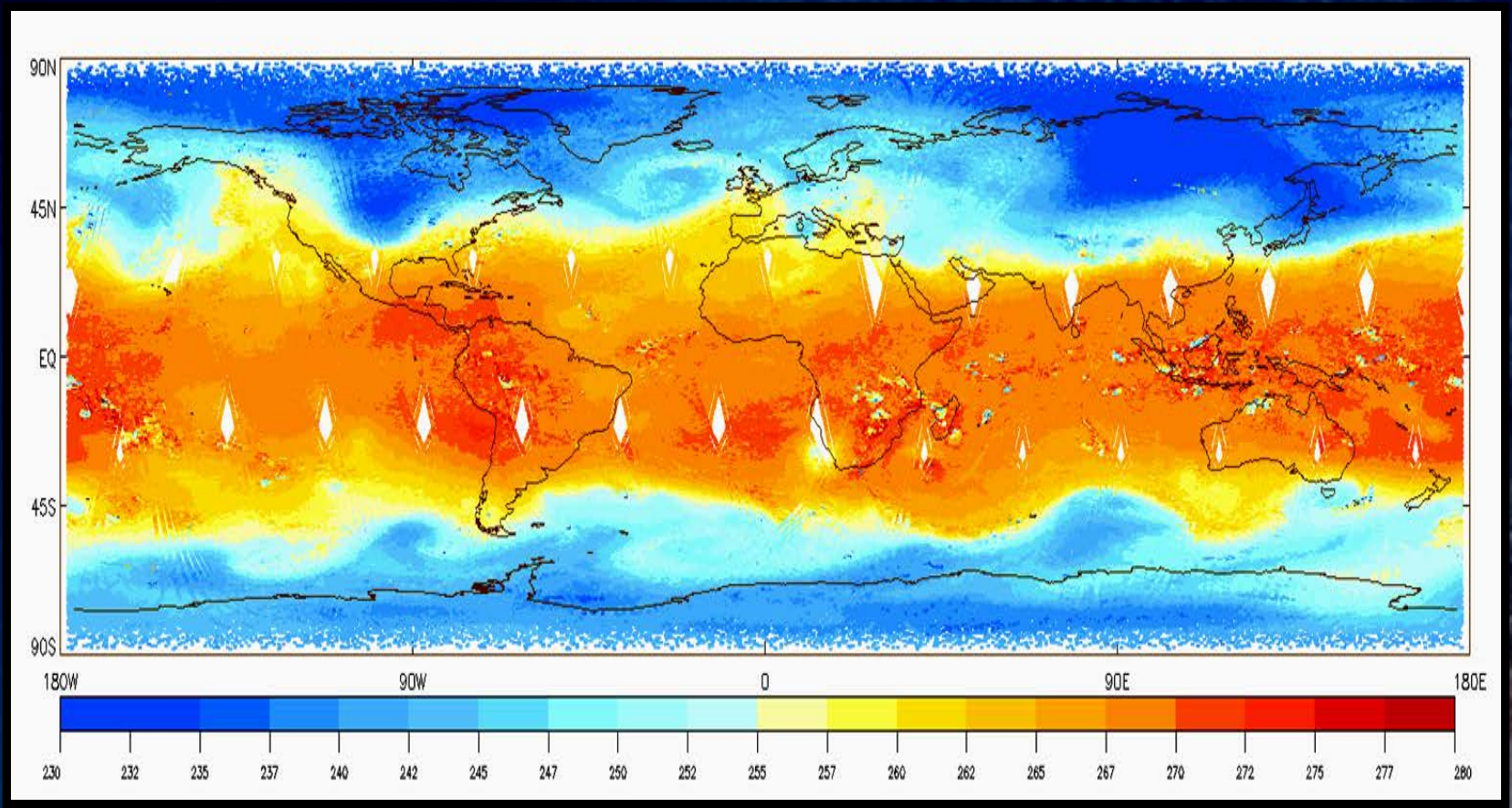
  Implementation of NUCAPS within the Community Satellite Processing Package (CSPP), Session "New Capabilities in Satellite Ground Processing Systems".

- **Assimilation of temperature and water vapor profiles in Numerical Weather Prediction has shown significant positive impact**
  - » AMS 2014 talks during session "Application of Data Assimilation in Numerical Weather Prediction" Wednesday, February 5th, Room C202.

- **AIRS, IASI, CrIS homogeneous retrieval data record re-processing for climate study applications and in support of climate models.**
  - » AMS 2014 talk: Goldberg et al., 13:30 Tuesday February 4th, Room C111

  JPSS Data and applications in support of forecasting and environmental assessments, Session " Preparing User Communities for the New Generation of LEO and GEO Environmental Satellites".

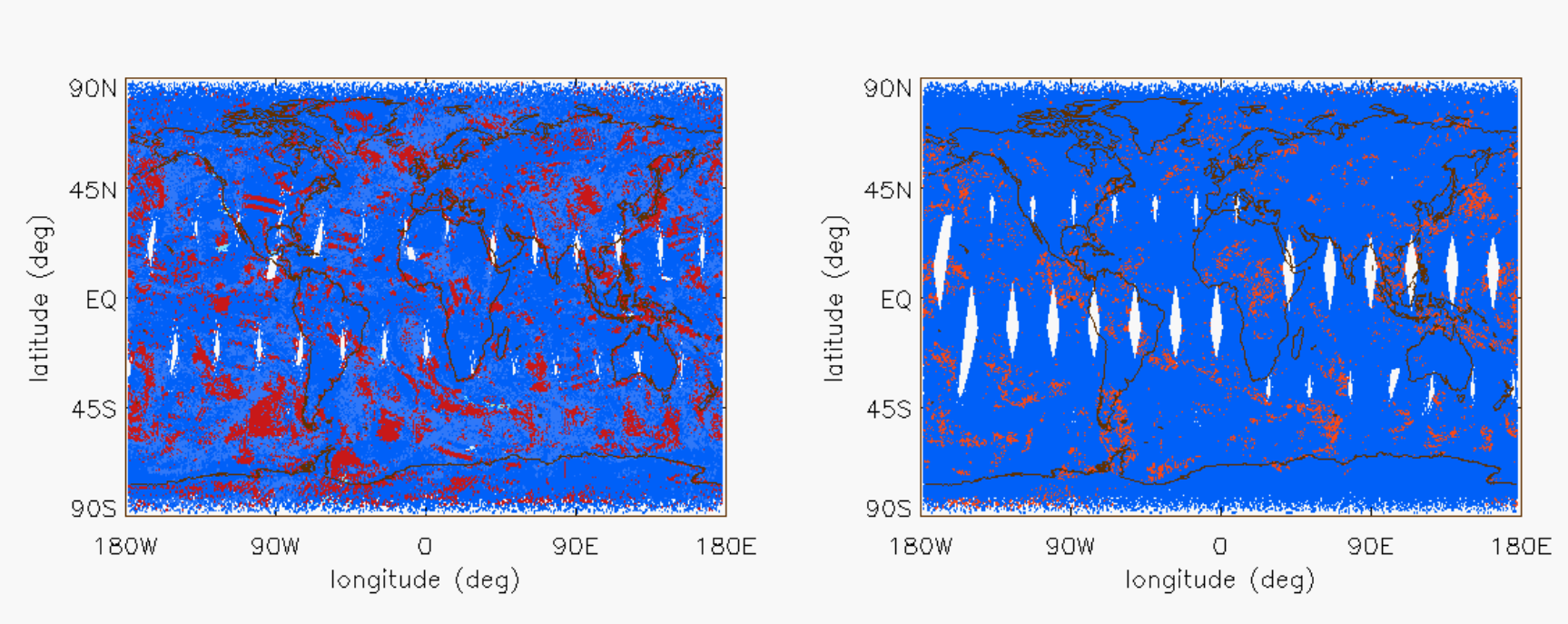
NOAA Unique CrIS/ATMS Processing System (NUCAPS)
Temperature retrieval @ 500mb
January 5th 2014 (Polar Vortex Anomaly)



NUCAPS vs NOAA AIRS retrieval acceptance yield

BLUE= accepted RED = rejected

NUCAPS **NOAA AIRS**



- NUCAPS global acceptance yield is ~60% (focus day 2012/05/15)
- NOAA AIRS global acceptance yield is ~75% (focus day 2012/05/15)
- Work in progress: optimization of retrieval configuration in order to increase yield

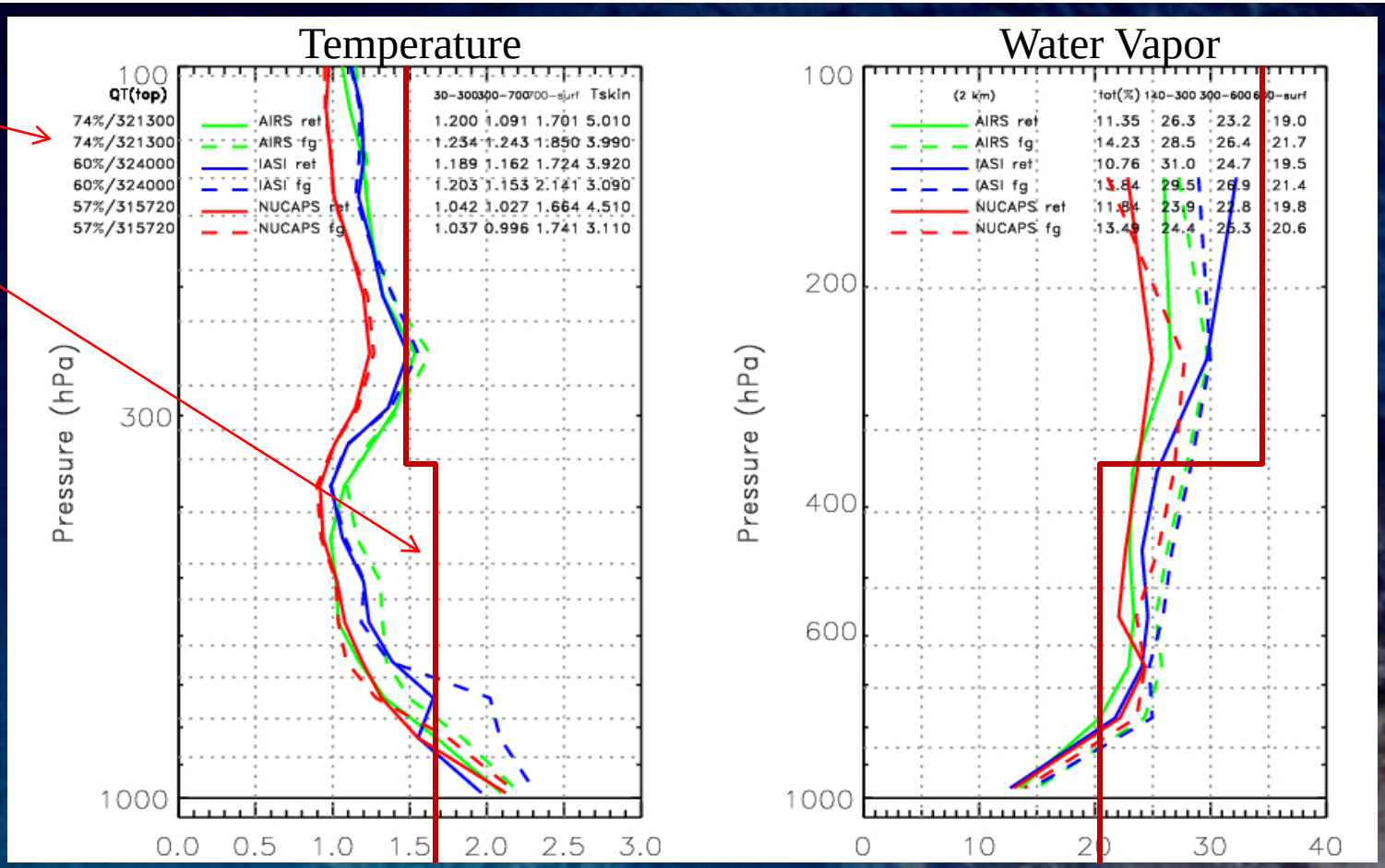
NUCAPS IASI AIRS

Global RMS Statistics vs ECMWF Analysis

(dash lines = first guess)

QA Acceptance Yield

Vertical red bars indicate JPSS specification requirements



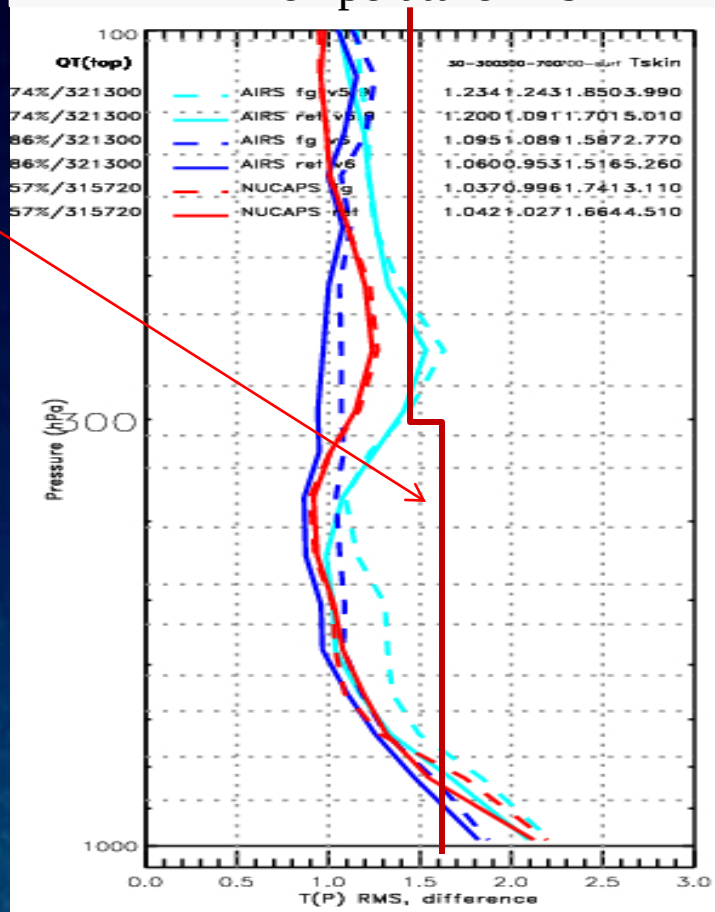
- Retrieval performance is stable and consistent across the three platforms.
- NUCAPS comparable to AIRS and IASI (10+ year maturity systems)

NUCAPS NOAA AIRS (v5.9) NASA AIRS(v6)
Global RMS Statistics vs ECMWF Analysis
(dash lines = first guess)

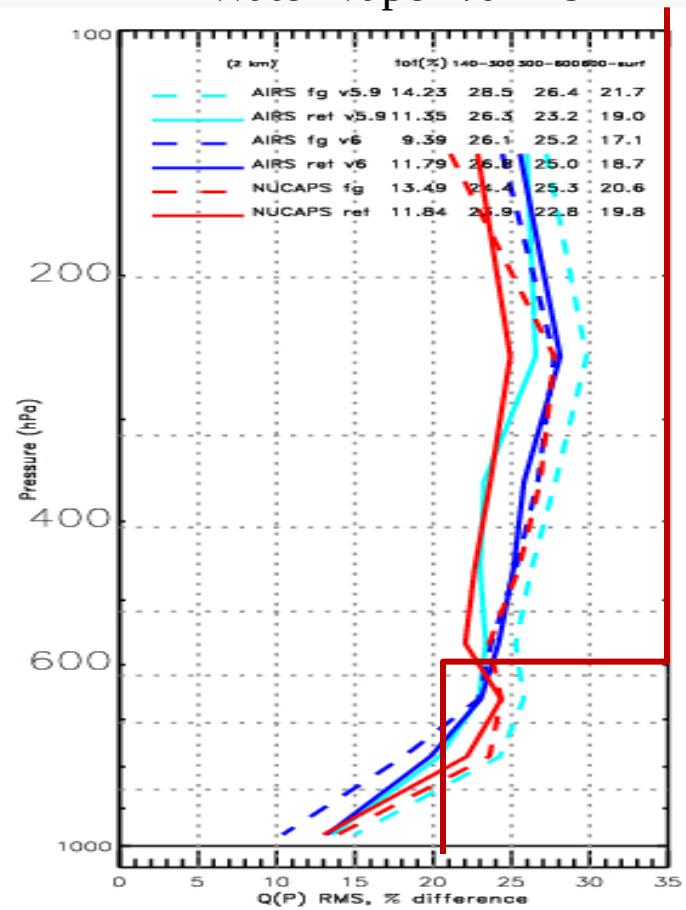
QA Acceptance Yield

Vertical red bars indicate JPSS specification requirements

Temperature rms

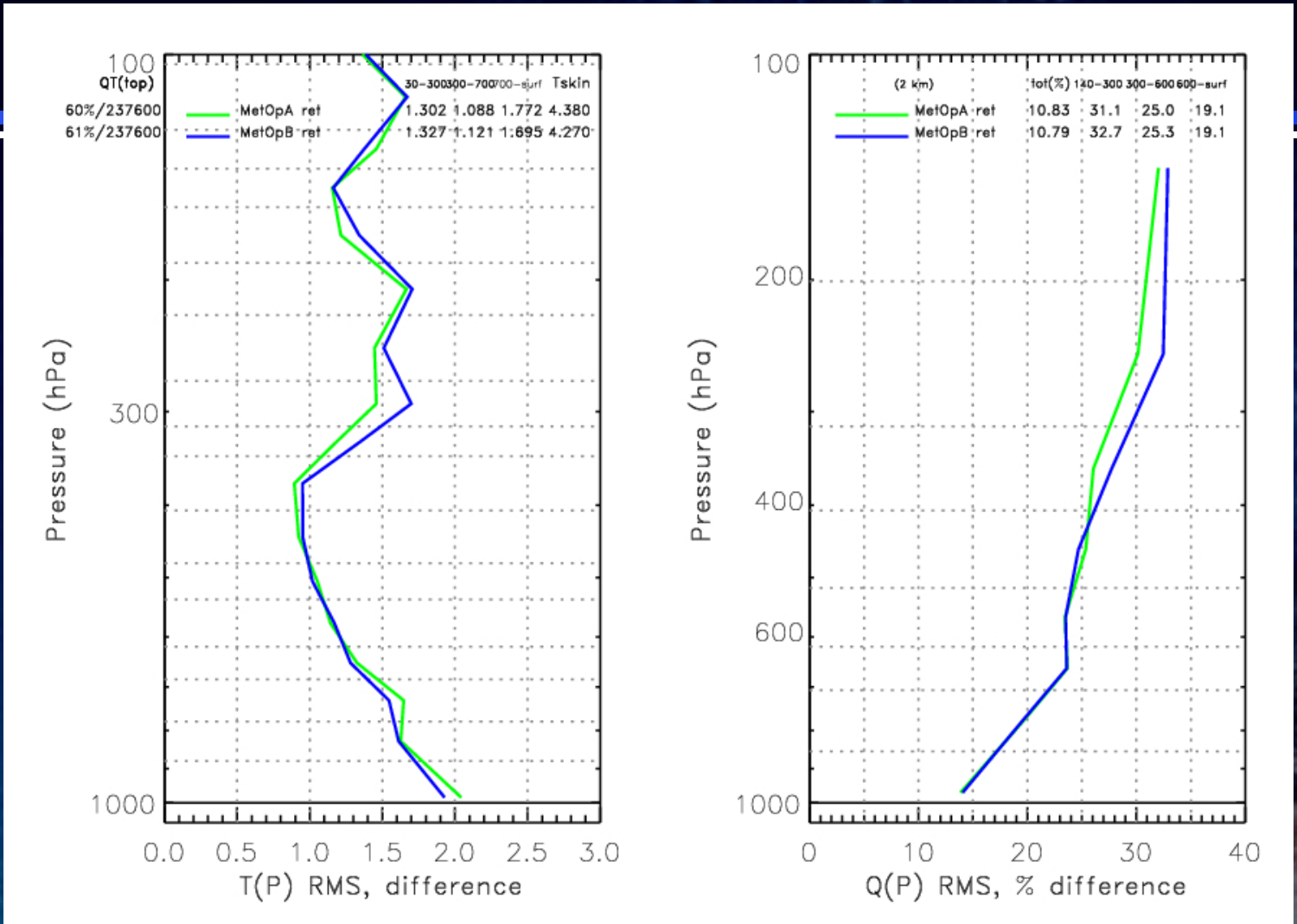


Water Vapor % rms



- Retrieval performance is stable and consistent across the three systems.
- NUCAPS comparable to both existing AIRS systems.

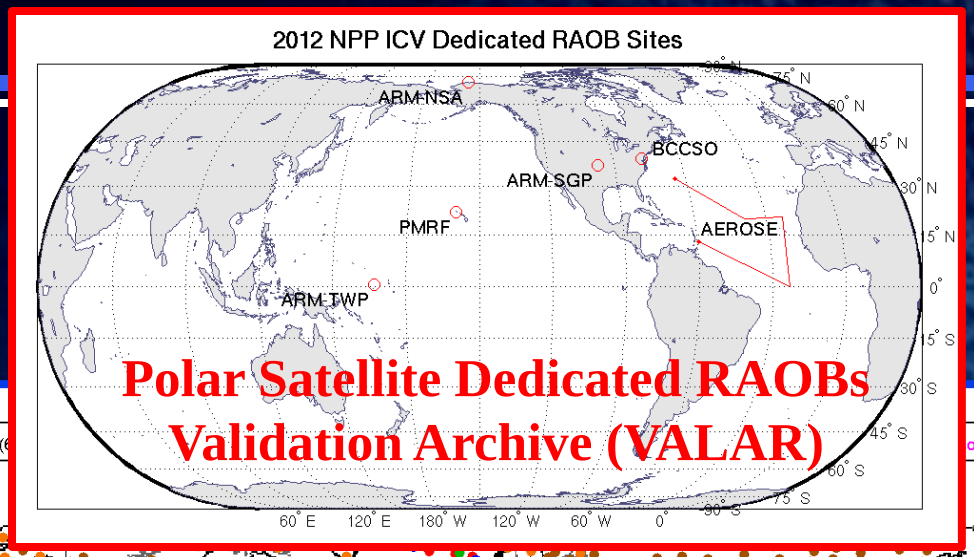
IASI MetOp A IASI MetOp B
Global RMS Statistics vs ECMWF Analysis



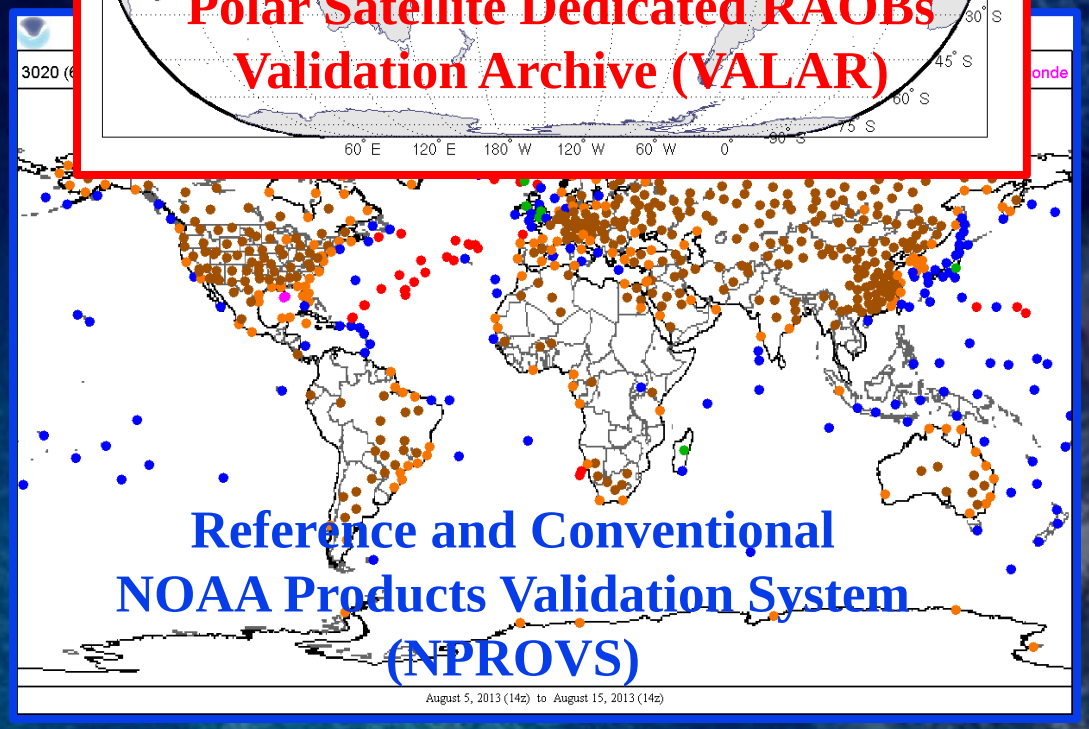
- Retrieval performance is stable and consistent between IASI MetOp A and B systems.
- Same exact *code, spectroscopy and look up tables* are used for both.
- Results are consistent with EUMETSAT partners.

Ongoing Retrieval Validation Strategy

Validation Data Sample Yield



Polar Satellite Dedicated RAOBs Validation Archive (VALAR)



Reference and Conventional NOAA Products Validation System (NPROVS)

Validation Data Sample Quality

Ongoing Retrieval Validation Strategy

- AMS 2014 cal/val related talks and posters of interest:
  - » Nalli et al., 9.3: "Validation of Satellite Sounder Environmental Data Records: Application to S-NPP“
  - » Nalli Poster 681: "NOAA Aerosols and Ocean Science Expeditions (AEROSE) and Satellite Sounder EDR Validation“
  - » Divakarla et al., 10.4: "Validation of CrIMSS AVTP and AVMP Retrievals with PMRF RAOBs, ECMWF Analysis Fields, and the Retrieval Products from Heritage Algorithms“
  - » Divakarla et al., Poster 353: "The CrIMSS EDR Algorithm Assessment: Provisional Maturity and Beyond“
  - » Pettey et al., poster 677---"Graphic programs for the validation of satellite sounding products with the NOAA Products Validation System (NPROVS)“
  - » Sun B. et al, poster 675---"Using NPROVS for evaluation of Suomi-NPP atmospheric soinding retrievals against conventional radiosonde observations“
  - » Reale A. et al, poster 673 ---"Using NPROVS+ to validate Suomi-NPP derived atmospheric sounding versus ref/dedicated RAOBs"

An experiment using higher resolution NPP CrIS measurements: impact on the retrieval of atmospheric trace gases

- **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 *L* of 0.8 cm (LW), 0.4 cm (MW) and 0.2 cm (SW)
  - » Spectral resolution: 0.625 cm-1, 1.25 cm-1 and 2.5 cm-1 (Fourier Transform is Nyquist sampled at *1/2L)*

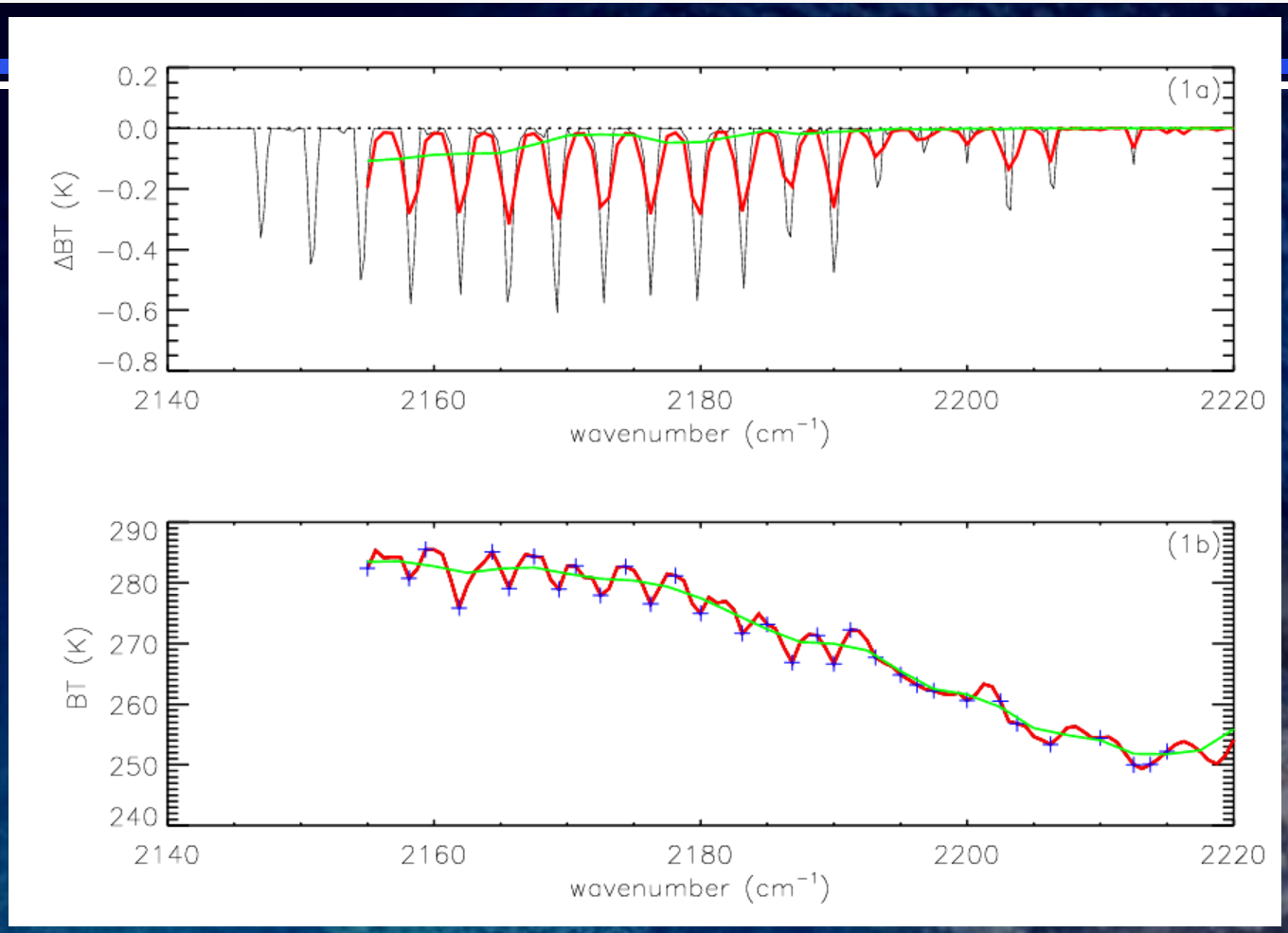
- **Experimental set up** (5 orbits from March 12th 2013)
  - » Maximum geometrical path *L* of 0.8 cm in all three bands
  - » Spectral resolution: 0.625 cm-1 in all three bands (Fourier Transform is Nyquist sampled at *1/2L)*

- **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.

- **REF: A. Gambacorta et al.,** “*An experiment using CrIS high spectral resolution measurement for trace gas retrievals: CO retrieval impact study*”, IEEE Letters, in press, 2014. & Poster 676 AMS 2014

CO Sensitivity Analysis to 1% CO perturbation

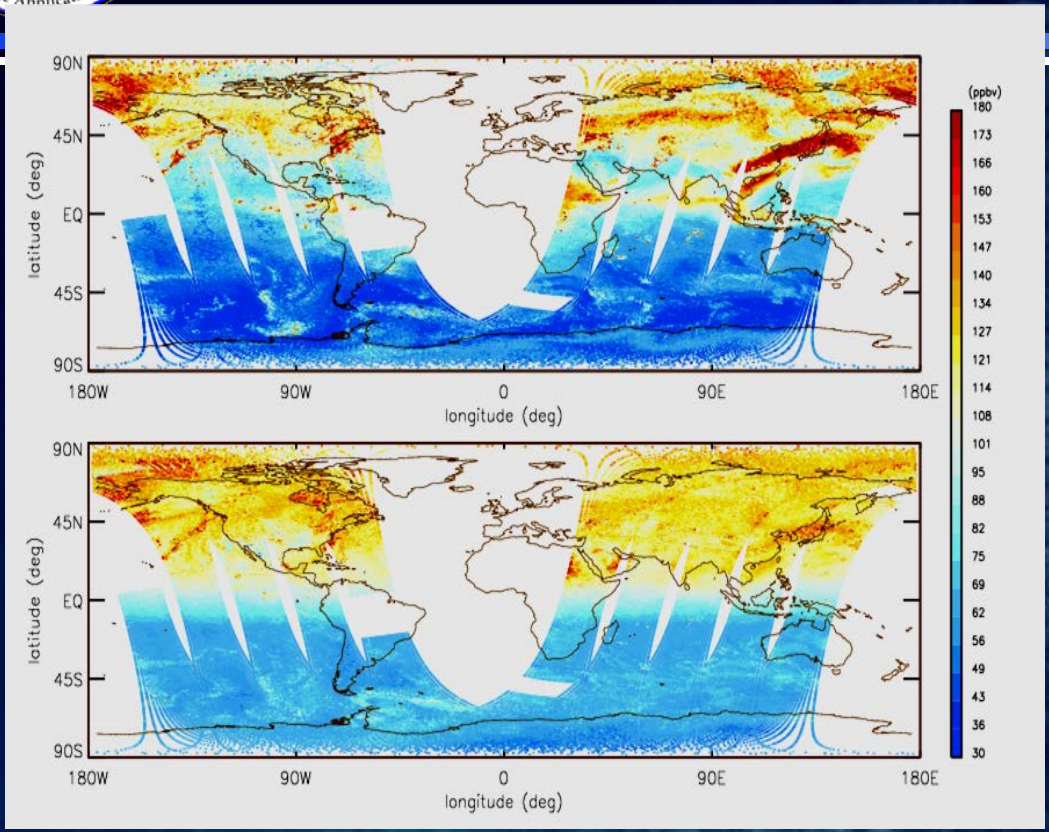
2.5cm^-1 res 0.625 cm^-1 res 0.25cm ^-1 res



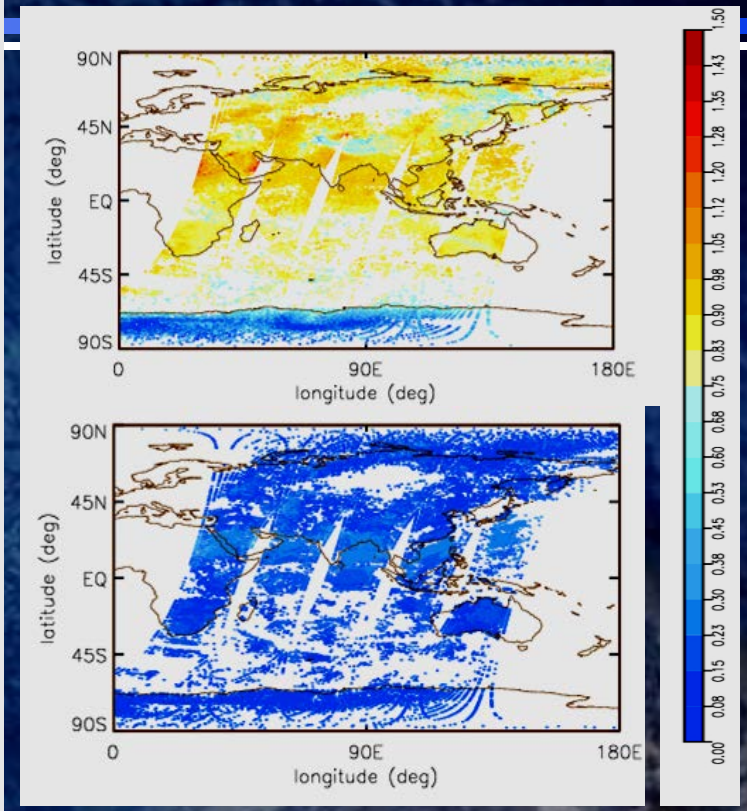
- The large structure present in the high resolution spectrum carries the distinctive signature of the CO absorption lines (top). The high resolution CO channel selection (blue cross symbols, 32 in total) captures the cores and wings of the CO absorption lines, enabling full sounding of the CO absorption curve of growth.

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

NUCAPS CO retrieval (~450mb)



CO DOF



- High resolution mode retrievals show significantly more structure in the global distribution of CO abundance with respect to the low resolution mode.
- NUCAPS high spectral resolution CO DOFS (top right) are observed to consistently improve across all latitudinal regimes, up to one order of magnitude wrt the low resolution DOFS (bottom right).
- This higher information content enables a larger departure from the a priori, hence the increased spatial variability observed in the high spectral resolution map wrt the low resolution map.

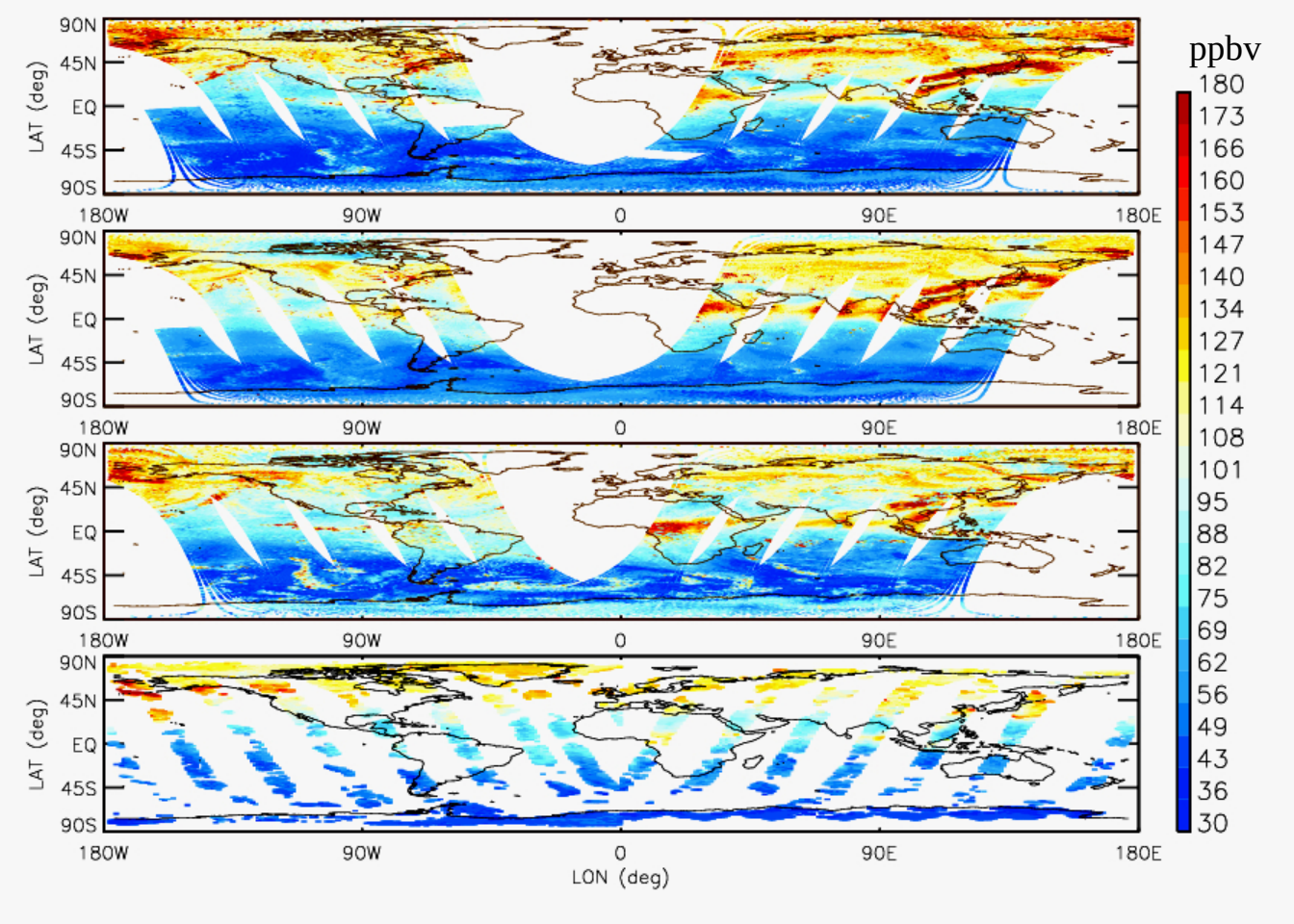
NUCAPS High RES (top), AIRS (second), IASI (third) and MOPITT (bottom) CO retrievals

NUCAPS High RES

AIRS

IASI

MOPITT



- NUCAPS high resolution CO retrievals show a significantly improved agreement to all three operational 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.

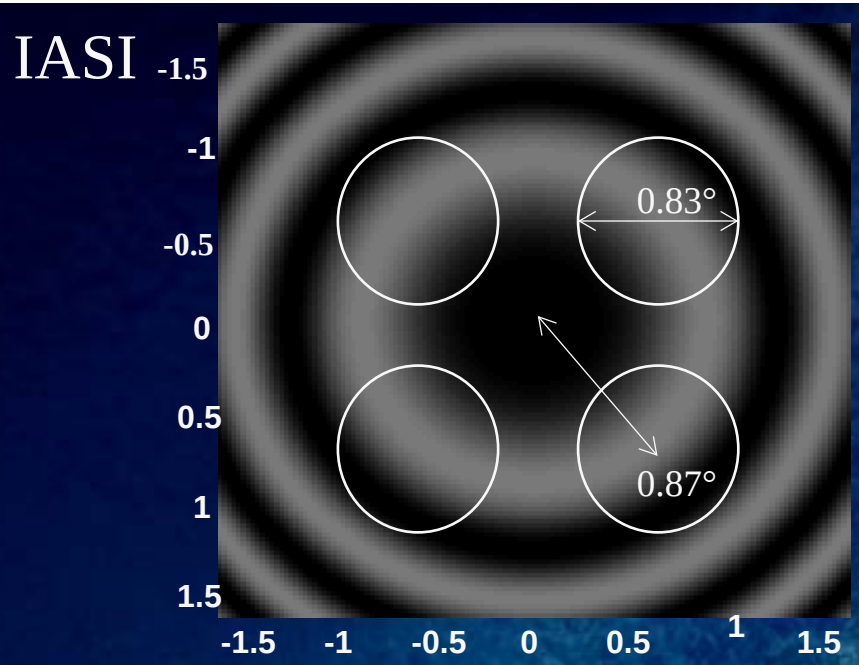
NUCAPS Project Plan: Task and Schedules

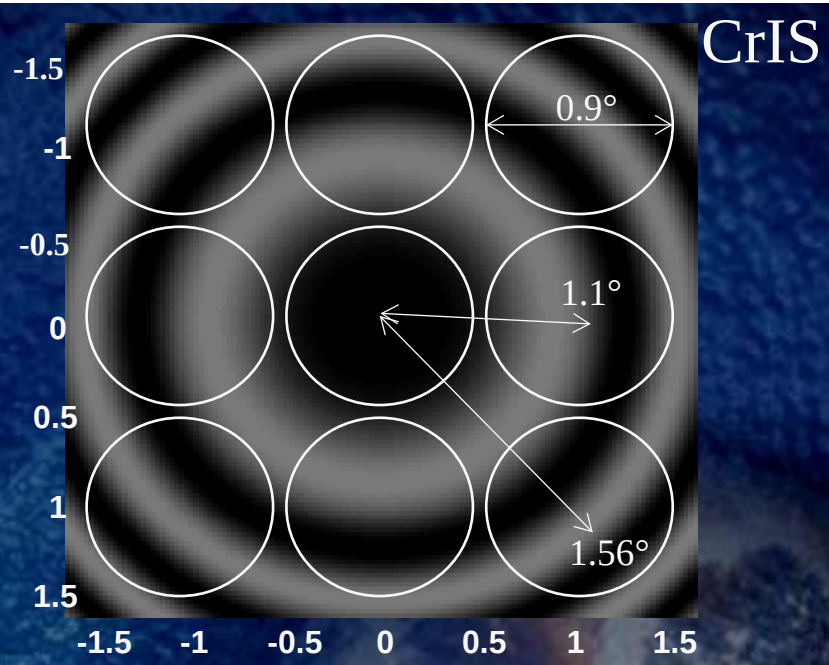
- Schedule (key milestones):
  - » Preliminary Design Review – May 9, 2007
  - » Critical Design Review – Sep. 29, 2008
  - » Test Readiness Review – Sep. 29, 2010
  - » Code Unit Test Review – Oct. 20, 2010
  - » Phase 1 Algorithm Readiness Review – Mar. 14, 2012
  - » NUCAPS Phase 1 Delivery – Mar. 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
    - – ILS shift in presence of scene in-homogeneities
    - – OLR product delivery
    - – 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

IASI vs CrIS FOV geometry and ILS distortion in presence of surface in-homogeneities





- IASI FOVs are arranged in a 2x2 grid on a α=0.87° radius circle from the optical axis.
- CrIS FOVs are arranged on a 3x3 grid on a α=0 °, 1.1 ° and 1.56 ° radius circle from the optical axis.
- Work in progress to assess the impact of the ILS distortion in presence of surface in-homogeneities.

Conclusion Remarks

- The NOAA Unique CrIS/ATMS Processing System suite of retrieval products (temperature, water vapor, cloud clearing, cloud and surface products, trace gases) has been declared fully operational in September 2013
- Performance is robust and consistent across all three platforms: 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, 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.
- New products can be developed: cloud parameters, ammonia, OLR.
- New instruments can be integrated to improve cloud clearing: VIIRS.
- Assessment of the impact of the ILS shift in presence of surface in-homogeneities is underway.
- The results of this effort will guarantee continuity to the afternoon orbit sounding as part of a multi-satellite, uniformly integrated, long term data record of atmospheric variables and will also serve in preparation of future advanced satellite missions under the Joint Polar Satellite System and IASI Next Generation.

Back Up slides

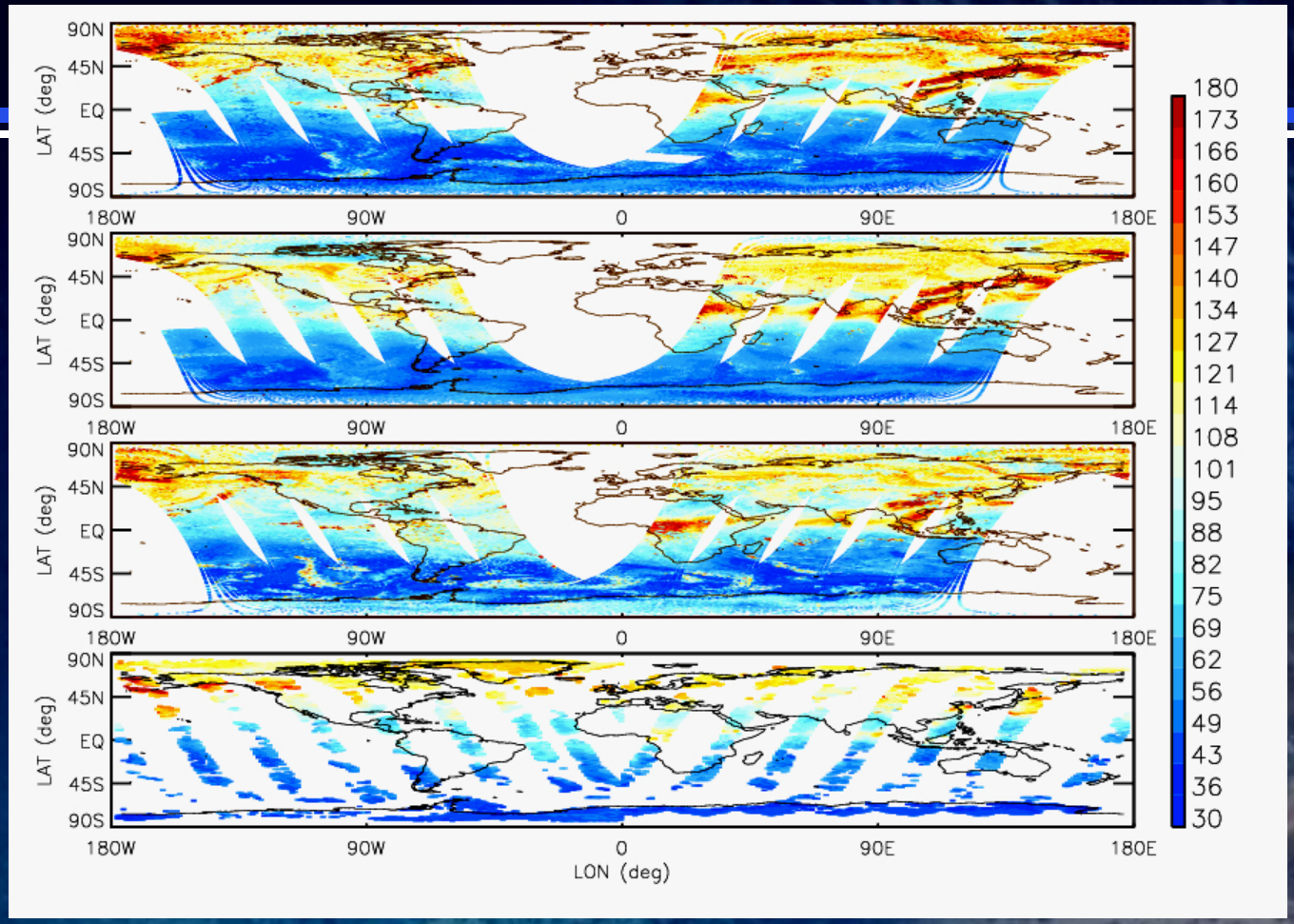
NUCAPS High RES (top), AIRS (second), IASI (third) and MOPITT (bottom) CO retrievals

NUCAPS High RES

AIRS

IASI

MOPITT



- 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.

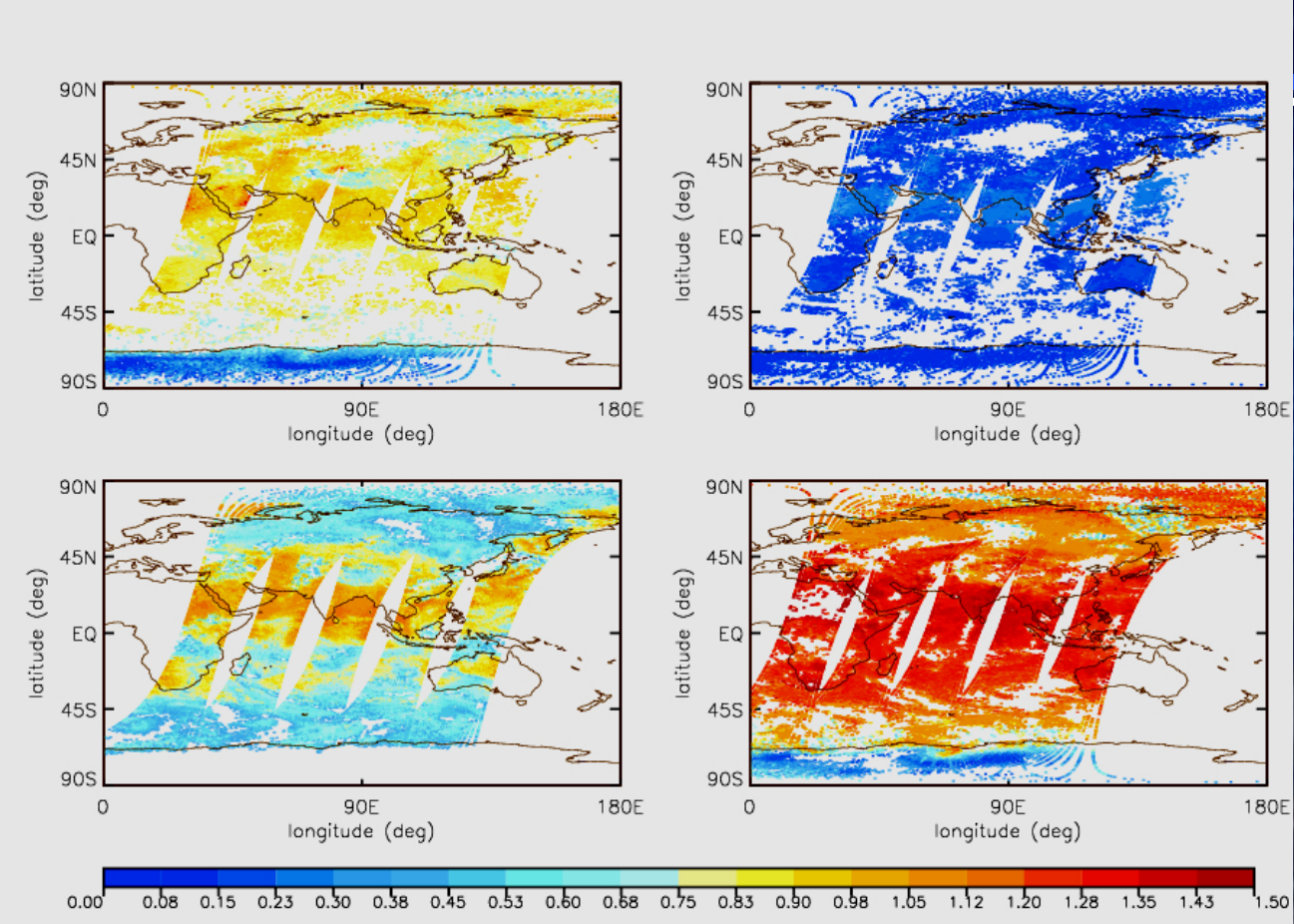
NUCAPS High Res (top left), NUCAPS Low Res (top right) AIRS (bottom left) and IASI (bottom right) CO DOF comparison

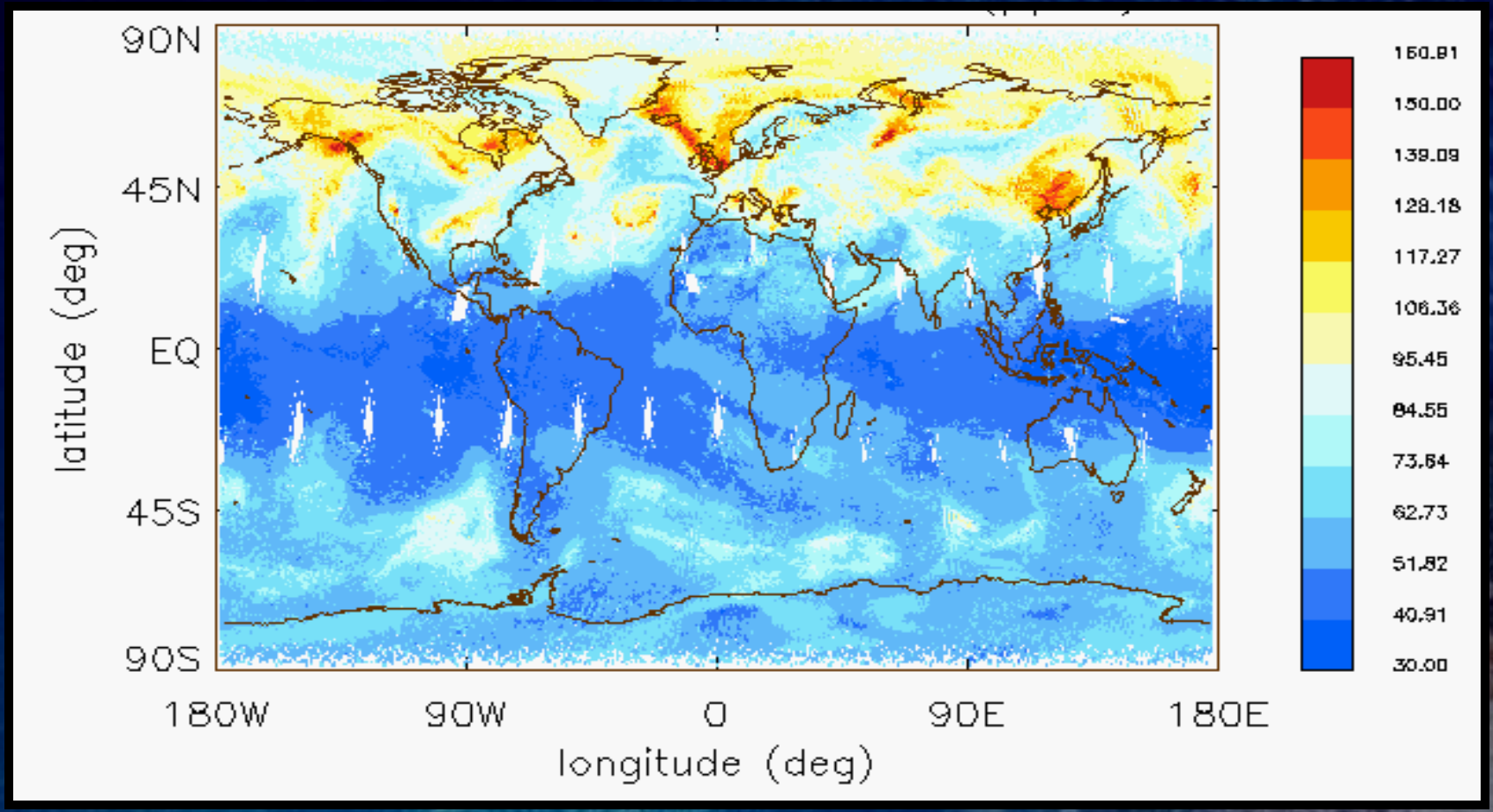
NUCAPS High Res DOF

NUCAPS Low Res DOF

AIRS DOF

IASI DOF



- NUCAPS high resolution CO DOFS (top left) are observed to consistently improve across all latitudinal regimes, up to one order of magnitude, with respect to the low resolution mode (top right). The higher information content enables for a larger departure from the first guess, hence the increased spatial variability observed in the high resolution retrieval map.
- NUCAPS high resolution CO DOFS performance appears by far more comparable to both the AIRS and IASI CO DOFS performance.

NOAA Unique CrIS/ATMS Processing System (NUCAPS)
Ozone retrieval @ 450mb on May 15th 2013