The NOAA operational hyper spectral retrieval system: algorithm description and inter-consistency among the CrIS/ATMS, IASI/AMSU/MHS and AIRS/AMSU systems.

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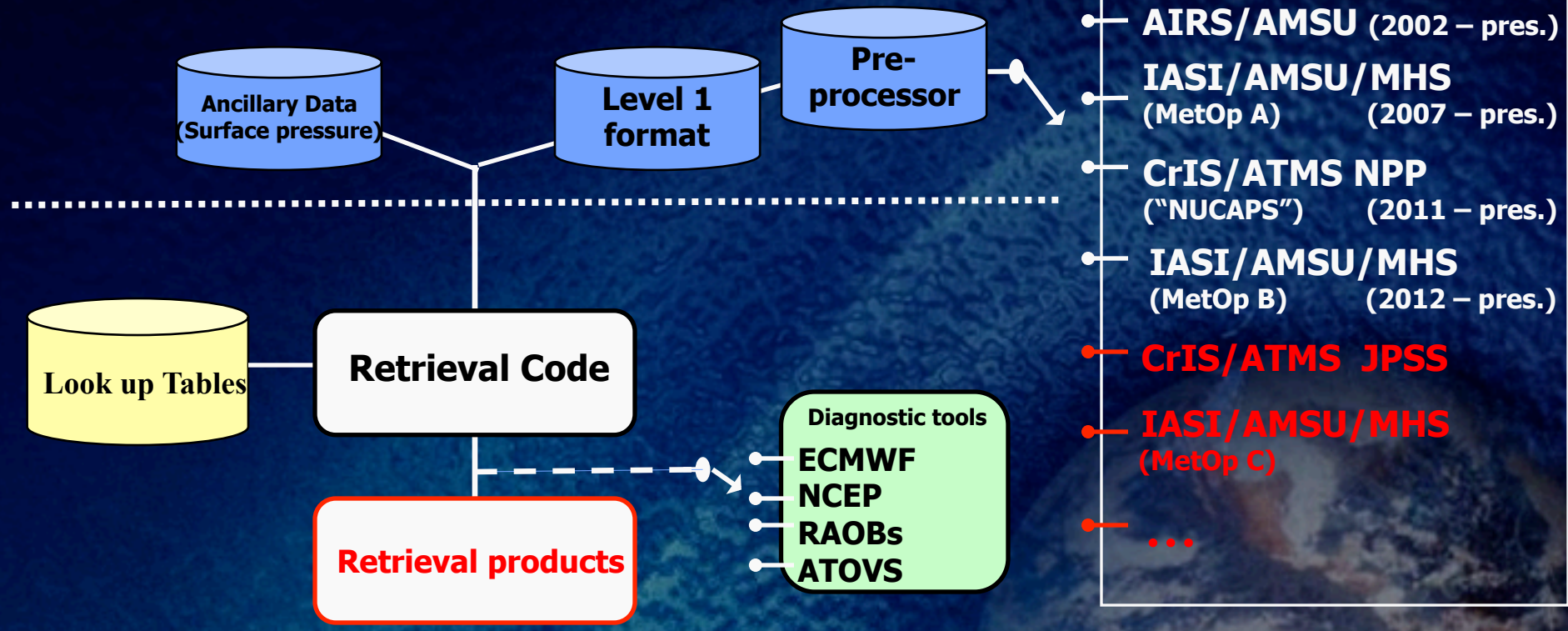
(3) NOAA/NESDIS/STAR
(4) NOAA JPSS Office

Contents

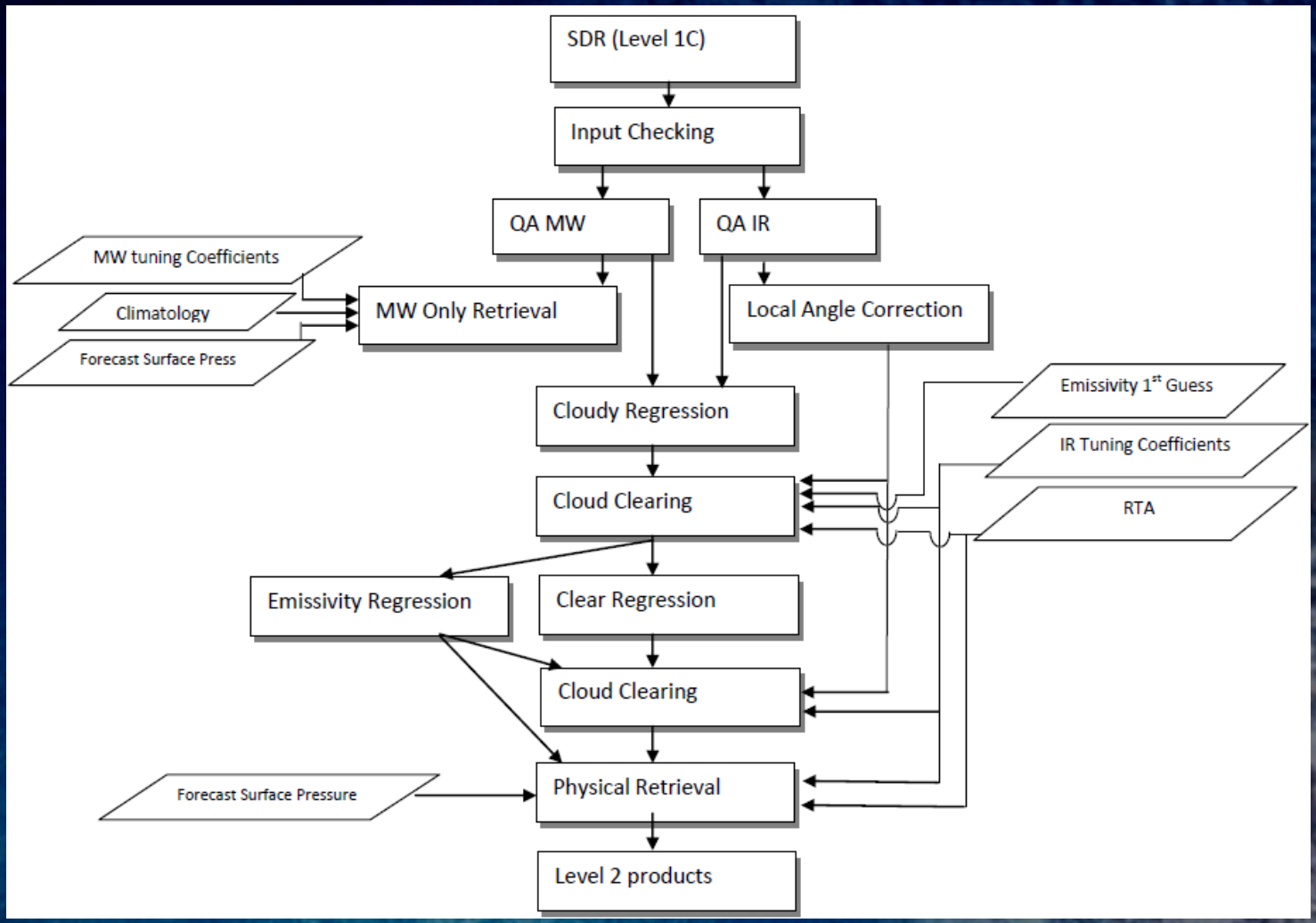
- Architecture of the NOAA operational hyper spectral retrieval algorithm
- Cross-comparison of the performance of the CrIS/ATMS, IASI/AMSU/MHS and AIRS/AMSU retrieval systems
- Focus on the NOAA Unique CrIS/ATMS Processing System (NUCAPS)
- NUCAPS Project Plan
  - » CrIS high resolution experiments: impact study on CO retrievals
  - » ILS distortion in presence of scene in-homogeneities: radiance errors and impact on retrievals (tomorrow's talk)
- Conclusions and future work

The NOAA hyper spectral 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 hyper spectral retrieval system



The NOAA hyper spectral 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 computes temperature and water vapor retrievals from the MW sensor (Rosenkranz, 2000)

- 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 (Goldberg et al., 2003)

- 3) a radiance cloud clearing module (Chahine, 1974)

- 4) a second fast eigenvector regression retrieval that is trained against ECMWF analysis and CrIS cloud cleared radiances (Goldberg et al., 2003)

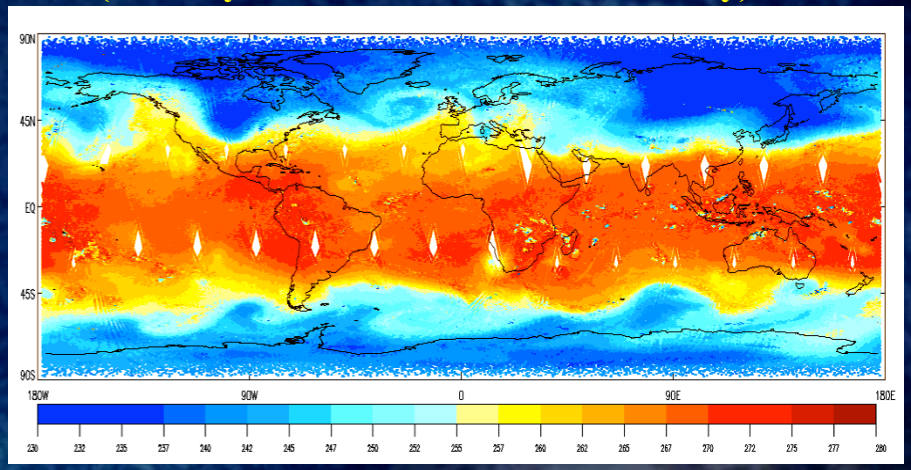
- 5) the final infrared physical retrieval based on a regularized iterated least square minimization (Susskind, Barnet, Blaisdell, 2003)

List of operational retrieval products

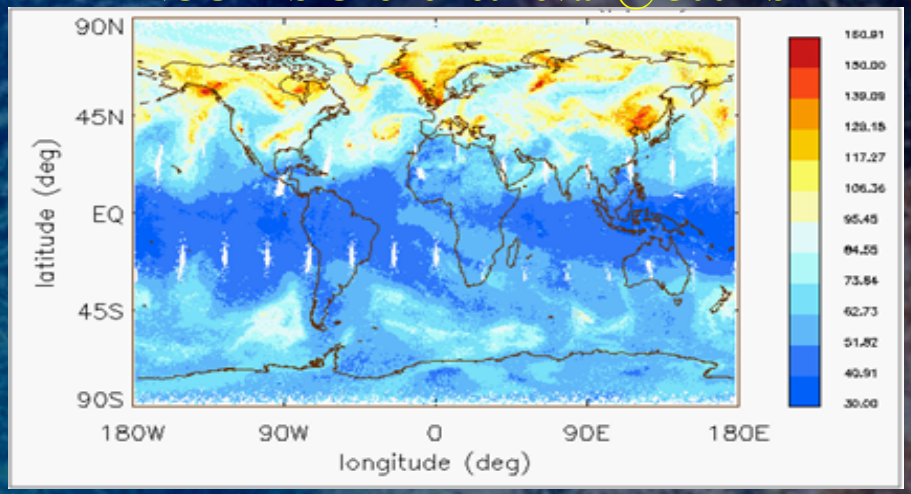
Retrieval Products

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
CO2	660-760 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)

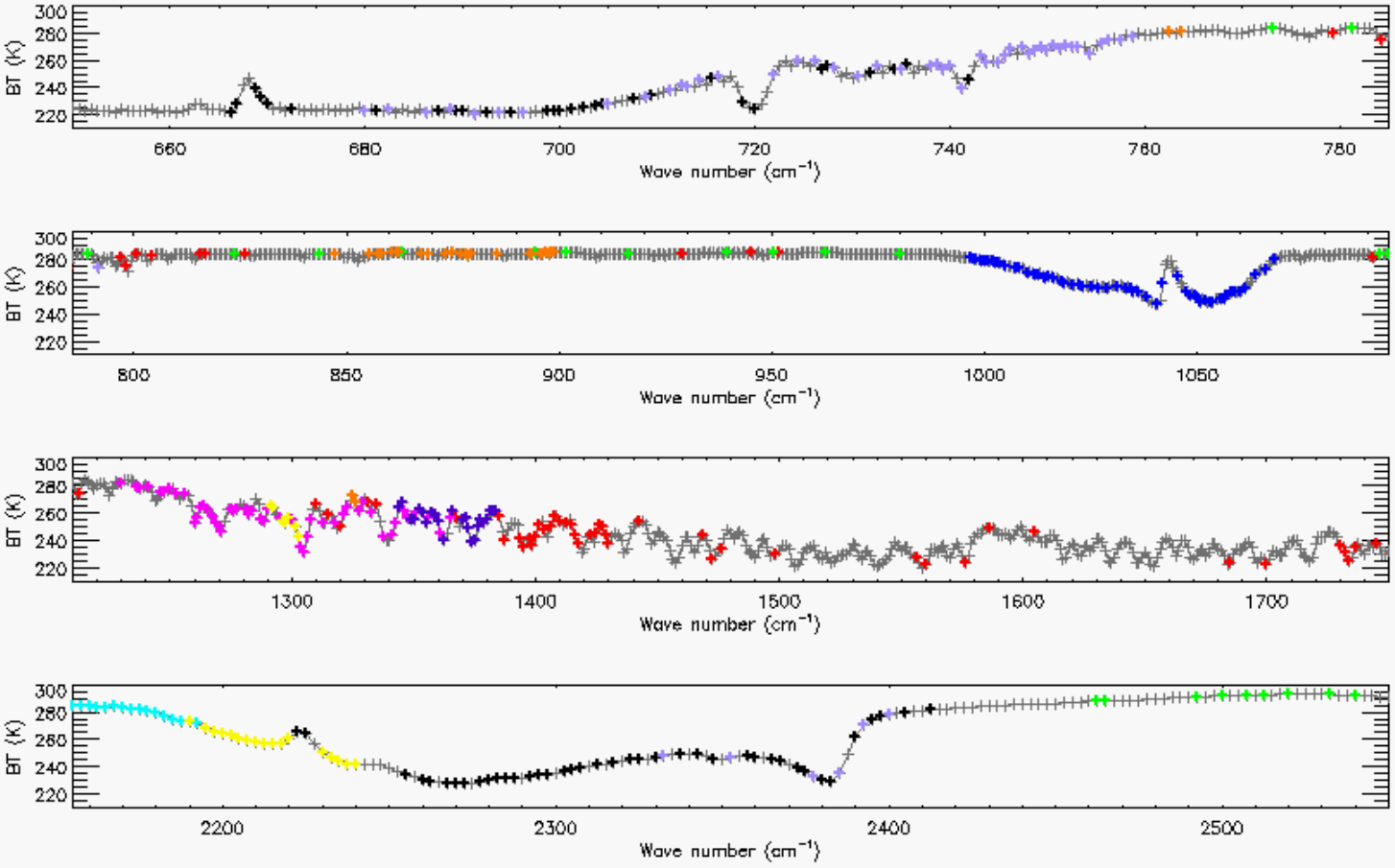


NUCAPS Ozone retrieval @ 500mb



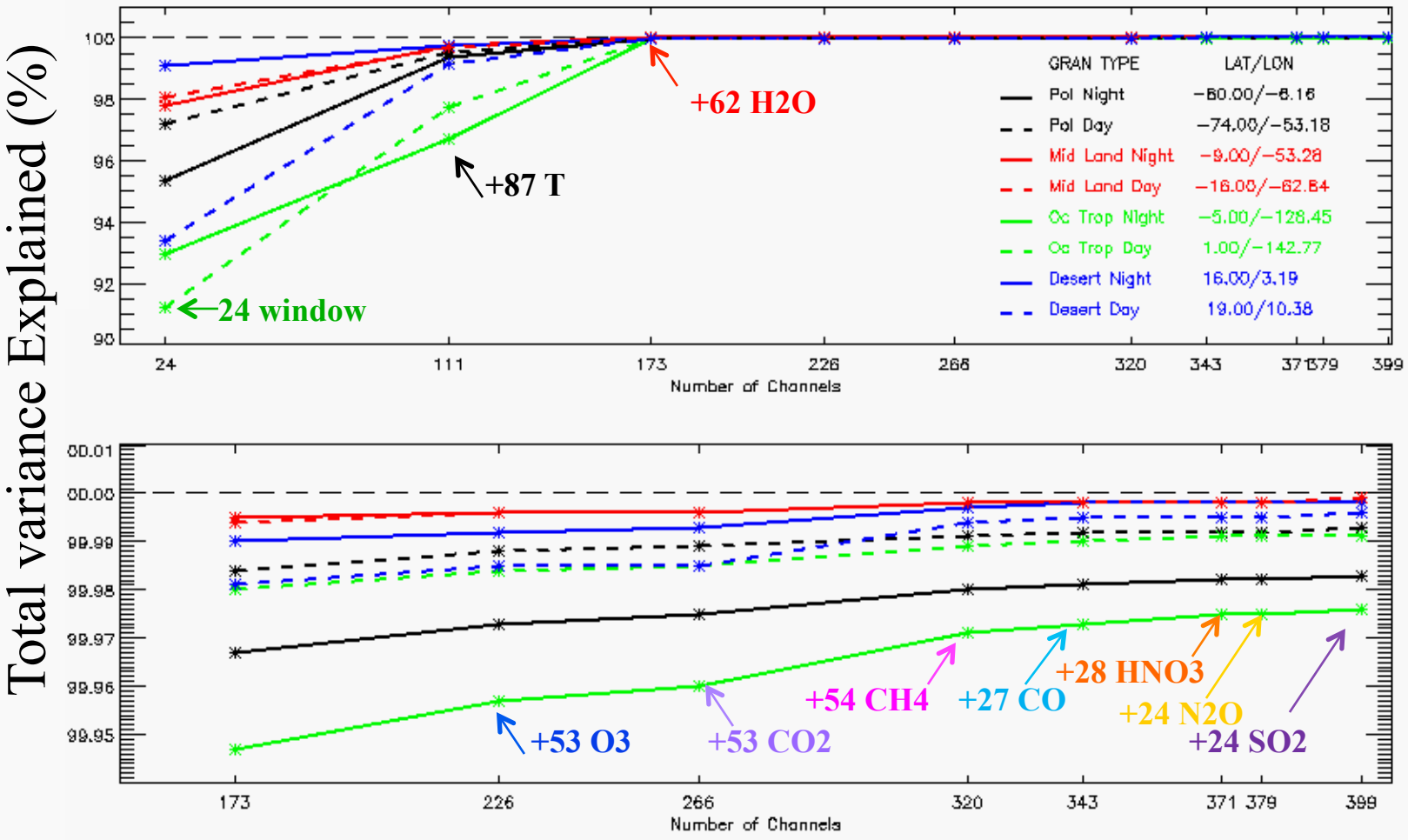
CrIS Operational Channel Selection (Total # of Channels: 399)

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



REF: A.Gambacorta and C.Barnet, 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

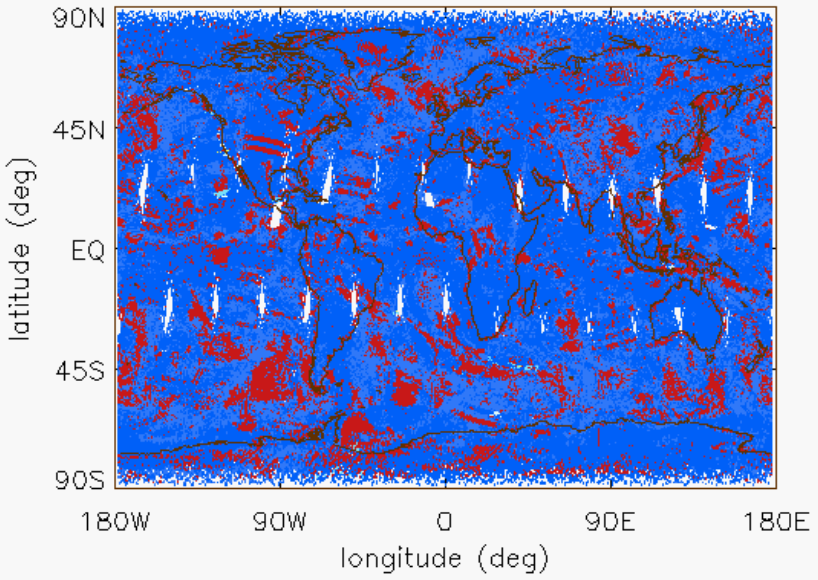


- The full list of 399 selected channels explains ~99.9% of the total atmospheric variance, consistently across all geophysical regimes.
- The first 173 channels (window, temperature and water vapor channels) alone explain ~ 99% of the total atmospheric variance.

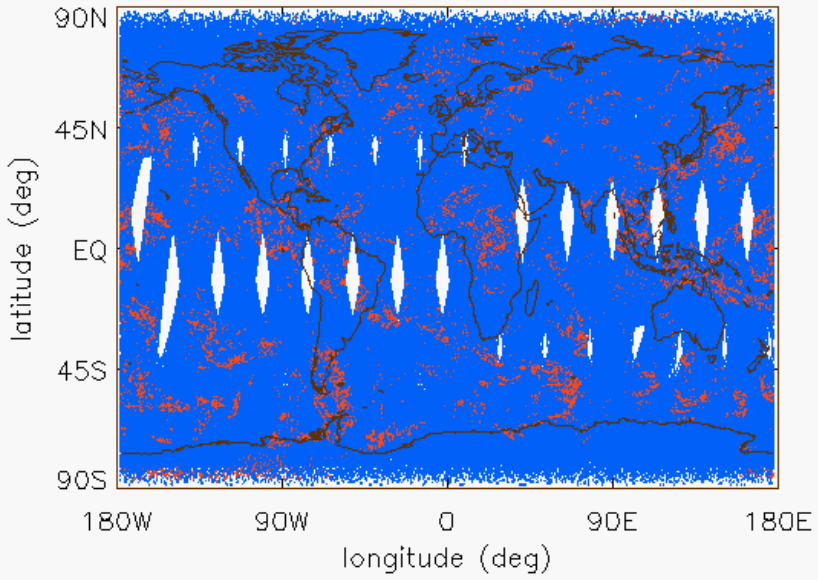
CrIS/ATMS vs AIRS/AMSU retrieval acceptance yield

BLUE= accepted RED = rejected

CrIS/ATMS



AIRS/AMSU

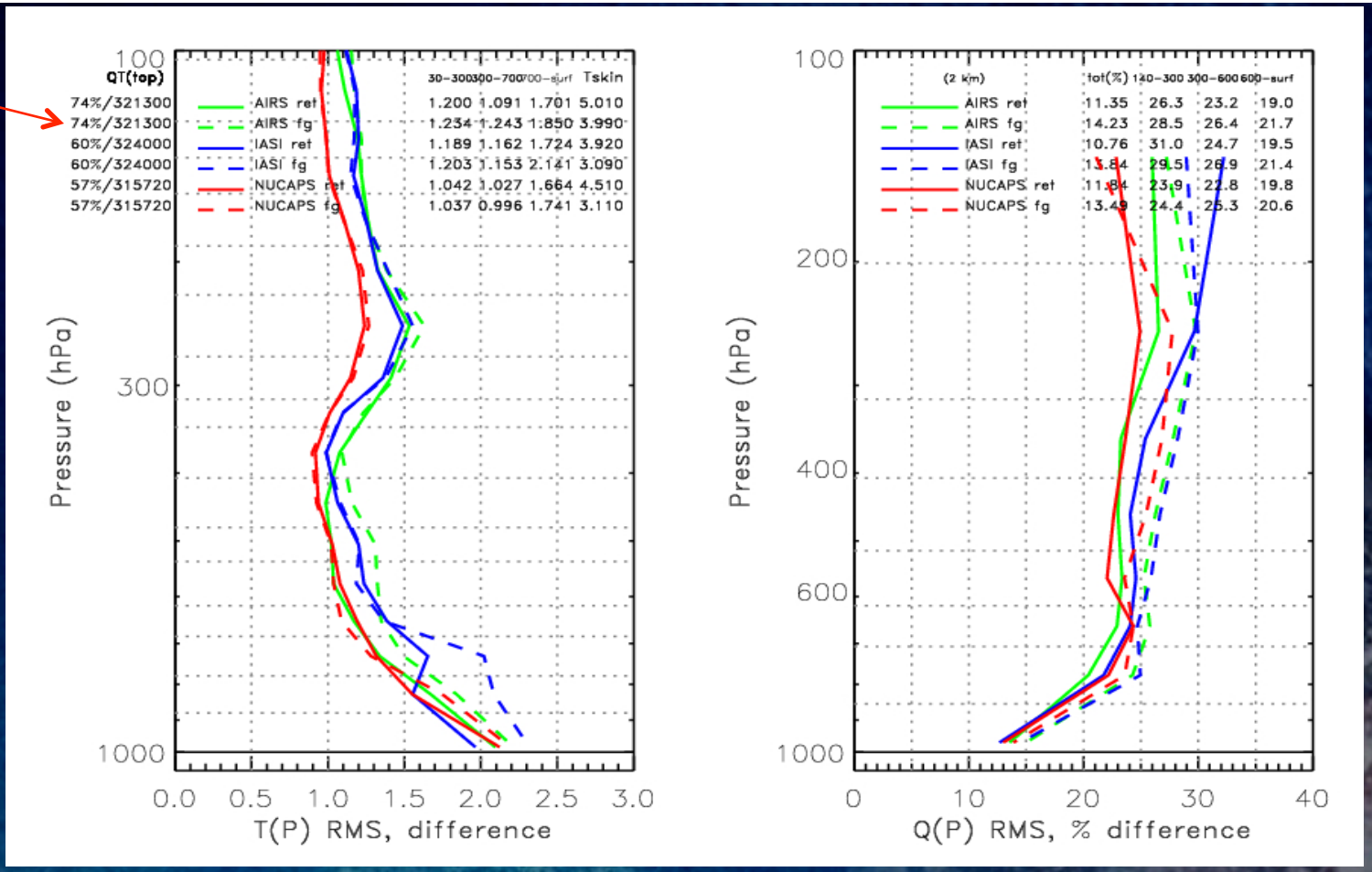


CrIS IASI AIRS

Global RMS Statistics vs ECMWF Analysis

(dash lines = first guess)

Acceptance Yield



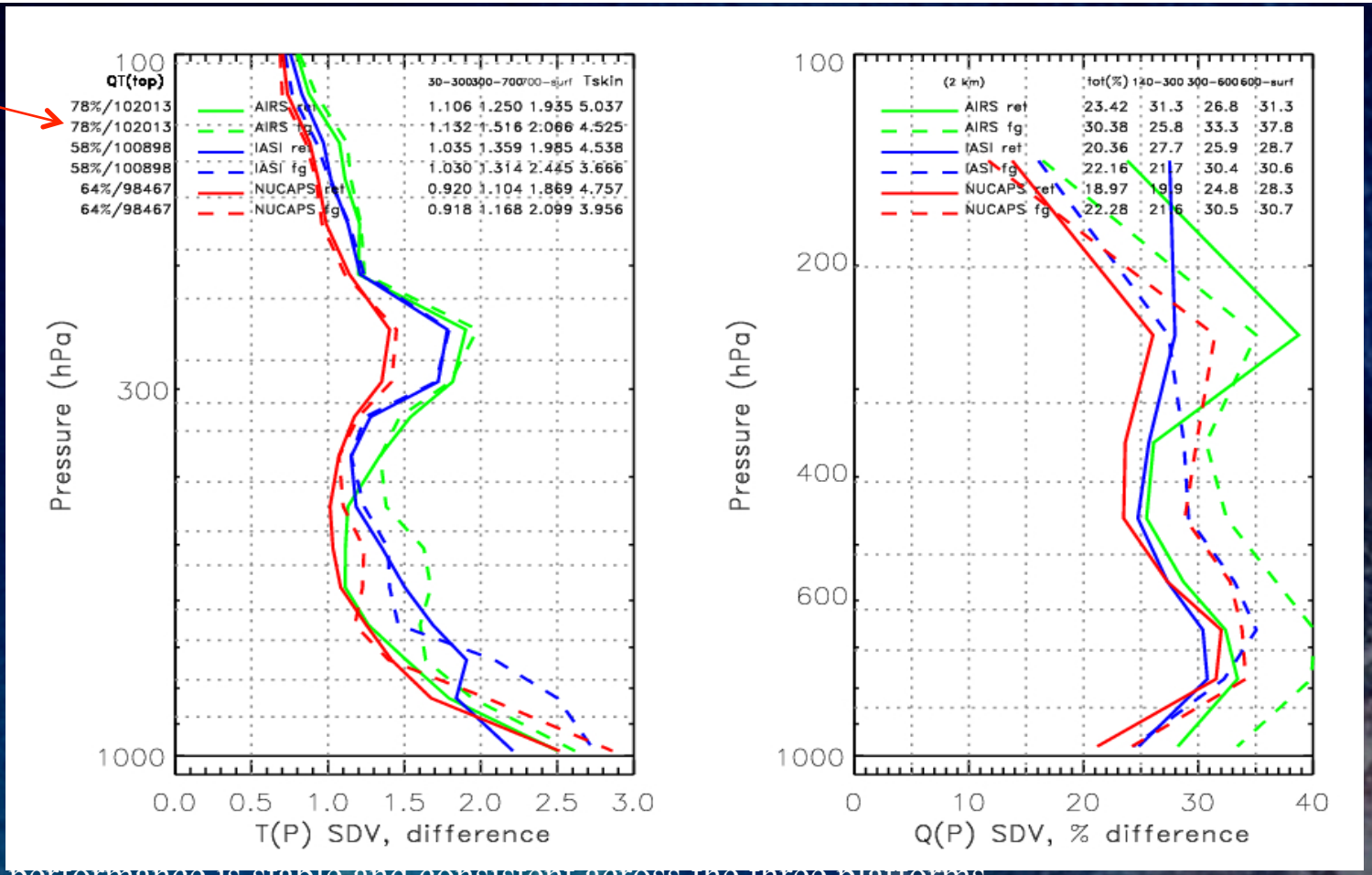
- Retrieval performance is stable and consistent across the three platforms.
- CrIS comparable to AIRS and IASI (10+ year maturity systems)
- Physical retrieval (solid) shows significant departure from first guess (dash line)

CrIS IASI AIRS

SDV Statistics vs ECMWF Analysis – Polar Regime

(dash lines = first guess)

Acceptance Yield



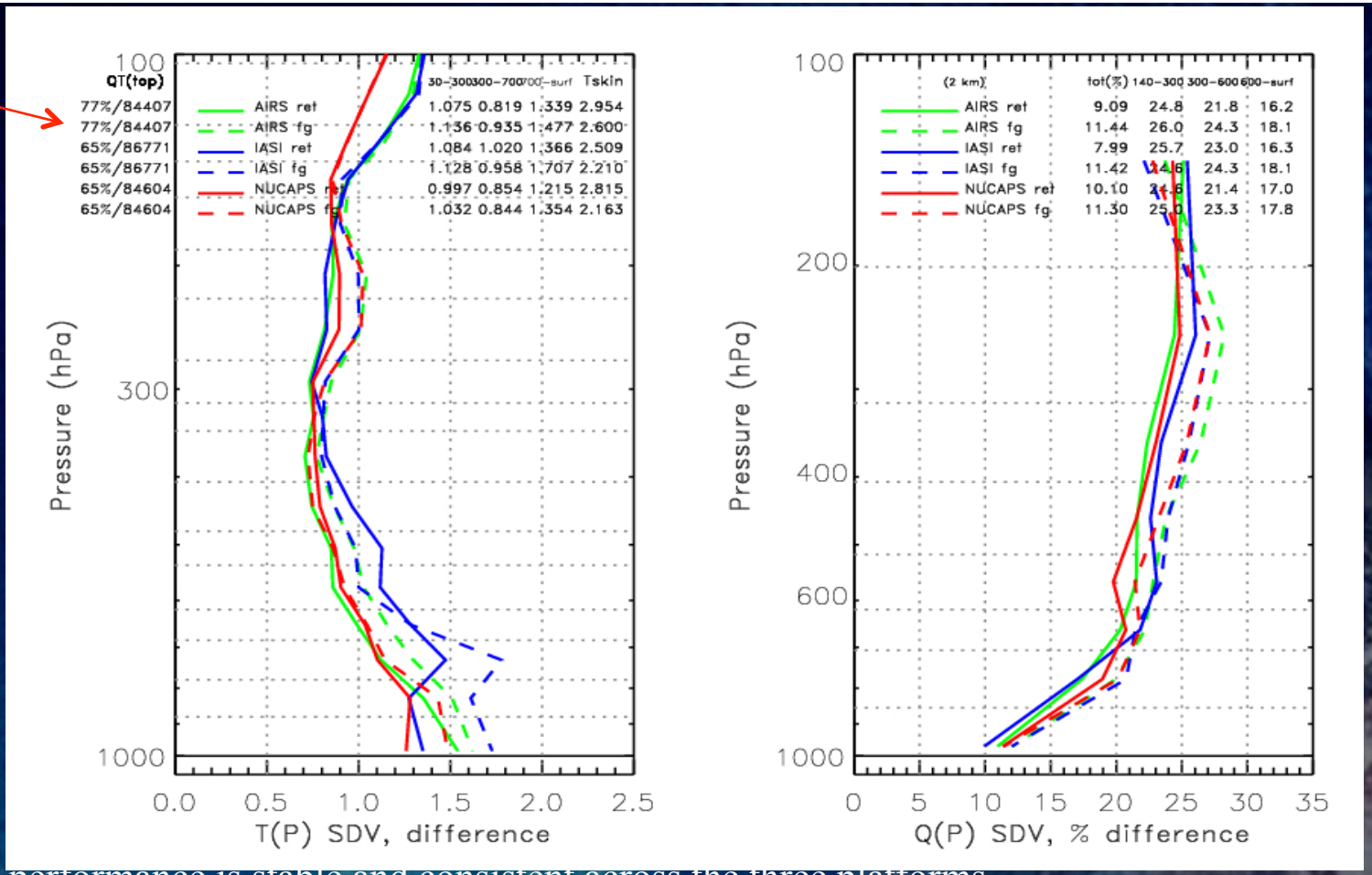
- Retrieval performance is stable and consistent across the three platforms.
- CrIS comparable to AIRS and IASI (10+ year maturity systems)
- Physical retrieval (solid) shows significant departure from first guess (dash line)

CrIS IASI AIRS

SDV Statistics vs ECMWF Analysis – Tropical Regime

(dash lines = first guess)

Acceptance Yield



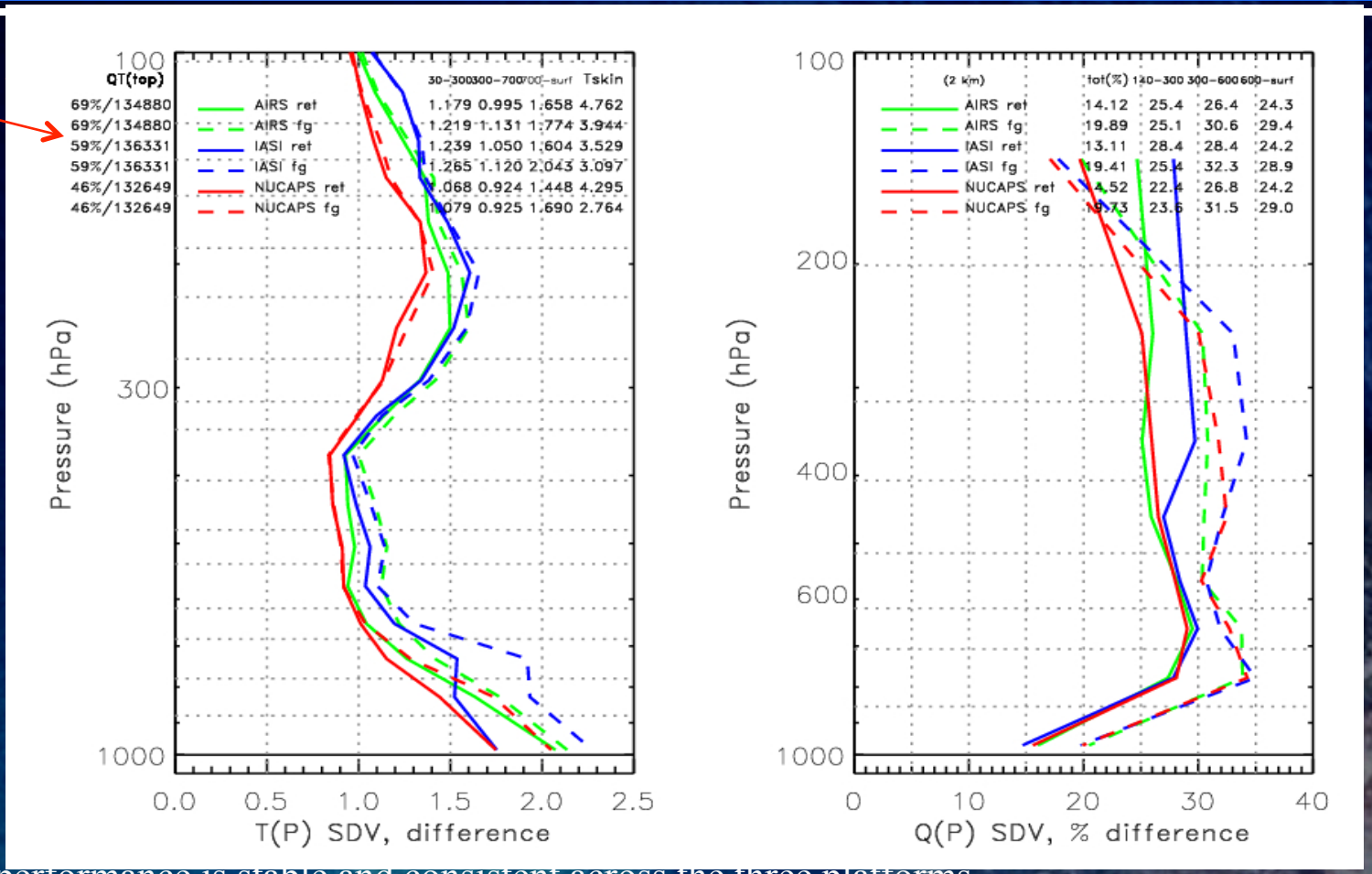
- Retrieval performance is stable and consistent across the three platforms.
- CrIS comparable to AIRS and IASI (10+ year maturity systems)
- Physical retrieval (solid) shows significant departure from first guess (dash line)

CrIS IASI AIRS

SDV Statistics vs ECMWF Analysis – MID LAT Regime

(dash lines = first guess)

Acceptance Yield



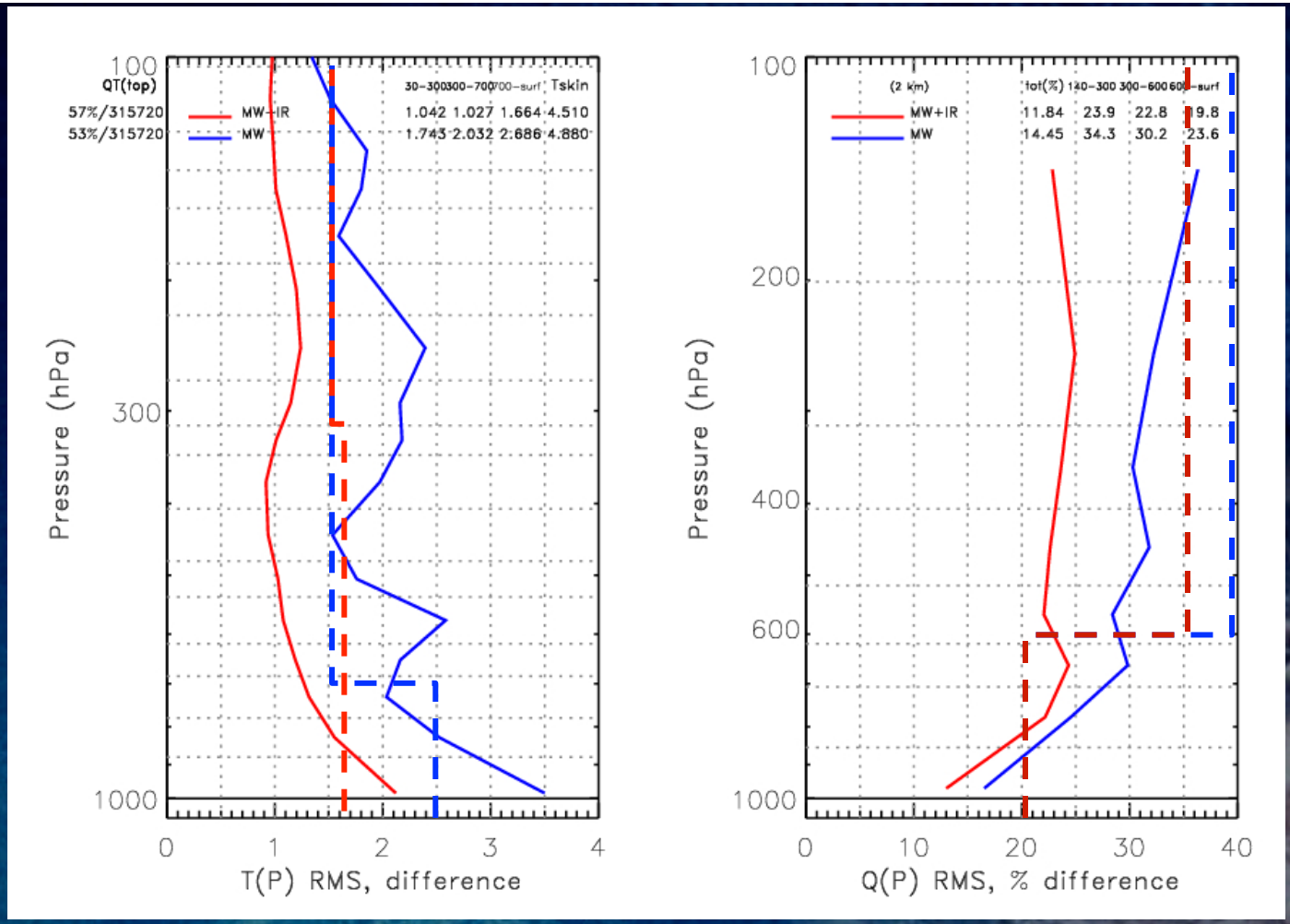
- Retrieval performance is stable and consistent across the three platforms.
- CrIS comparable to AIRS and IASI (10+ year maturity systems)
- Physical retrieval (solid) shows significant departure from first guess (dash line)

September 3rd 2014: NUCAPS passed JPSS review on stage 1 validation

Temperature	Threshold (Global)	Objective
MW+IR: Surface to 300 mb	1.6 K per km layer	0.5 K per km layer
300 to 30 mb	1.5 K per 3 km layer	0.5 K per 3 km layer
30 to 1 mb	1.5 K per 5 km layer	0.5 K per 5 km layer
1 to 0.5 mb	3.5 K per 5 km layer	0.5 K per 5 km layer
MW-Only: Surface to 700mb	2.5 K per km layer	0.5 K per km layer
700 to 300 mb	1.5 K per km layer	0.5 K per km layer
300 to 30 mb	1.5 K per 3 km layer	0.5 K per 3 km layer
30 to 1 mb	1.5 K per 5 km layer	0.5 K per 5 km layer
1 to 0.5 mb	3.5 K per 5 km layer	0.5 K per 5 km layer

Water Vapor	Threshold (Global)	Objective
MW+IR: Surface to 600 mb	Greater of 20% or 0.2 g/kg	10%
600 to 300 mb	Greater of 35% or 0.1 g/kg	10%
300 to 100 mb	Greater of 35% or 0.1 g/kg	10%
MW-Only: Surface to 600mb	Greater of 20% or 0.2 g/kg	10%
600 to 300 mb	Greater of 40% or 0.1 g/kg	10%
300 to 100 mb	Greater of 40% or 0.1 g/kg	10%

NUCAPS MW+IR & MW Only
Global (land+ocean) vs ECMWF Analysis
(focus day 2012-05-15)



- See next slide for performance summary

Summary on GLOBAL validation vs ECMWF
green = passed yellow = close red = failed

SUMMARY ON MW+IR RESULTS vs JPSS L1RD REQUIREMENTS					
MW+IR TEMPERATURE	RESULTS	JPSS L1RD	MW+IR WATER VAPOR	RESULTS	JPSS L1RD
30 – 300mb	1.04K	1.5K	100 - 600mb	23.3%	35%
300mb - SURF	1.34K	1.6K	600mb -SURF	19.8%	20%
SUMMARY ON MW-ONLY RESULTS vs JPSS L1RD REQUIREMENTS					
MW-ONLY TEMPERATURE	RESULTS	JPSS L1RD	MW-ONLY WATER VAPOR	RESULTS	JPSS L1RD
30 – 700mb	1.88K	1.5K	100 - 600mb	32.2%	40%
700mb - SURF	2.68K	2.5K	600mb -SURF	23.6%	20%

- **NUCAPS MW+IR fully meets requirements globally**
- **NUCAPS MW-Only is close to fully meets spec.**
  - **Possible issues are**:
    - Residual temporal and spatial mismatch between retrievals and model: ECMWF mismatch is +/- 1.5 hour and +/- 0.25 deg and we use both forecast and analysis depending on UT time.
    - Uncertainty in the ECMWF model analysis; Uncertainty in the NUCAPS retrievals
  - **Ongoing activity:**
    - Improve NUCAPS look up tables (RTA tuning, first guess, QC)
    - Improve validation methodology by using dedicated RAOBs: **see ahead**

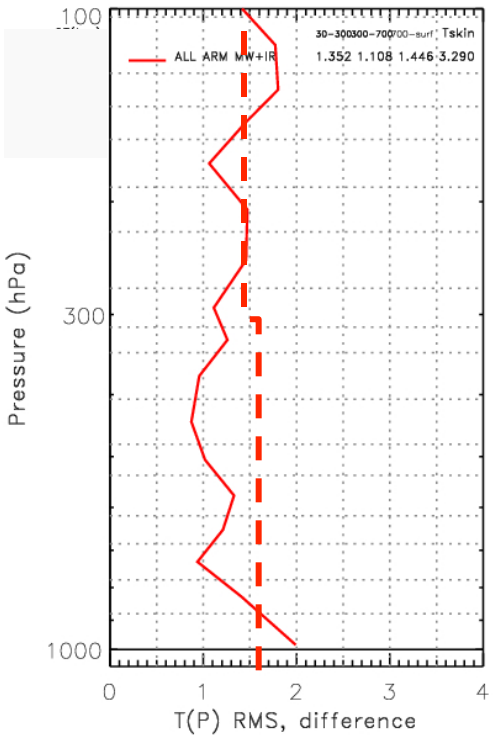
NUCAPS validation vs ARM Site Dedicated RAOBs

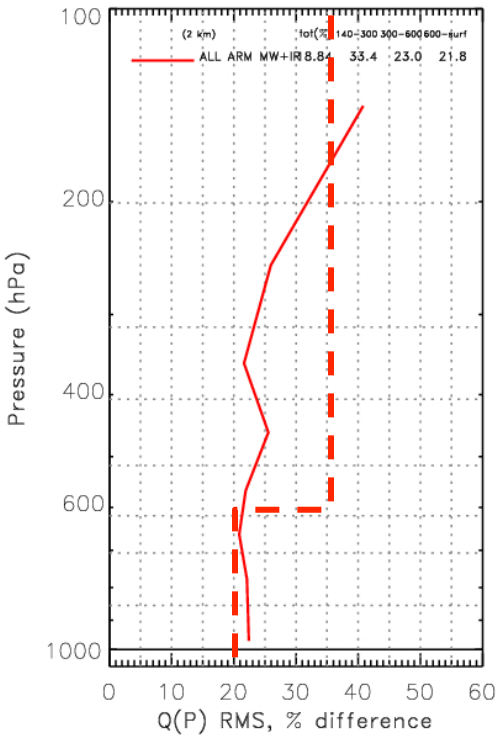
- JPSS funded dedicated (time and location) wrt NPP overpass
- ***Global*** ensemble, ~ 3 month field campaign (2012):
  - » Tropical Western Pacific (TWP) – *tropical regime*
  - » Southern Great Plans (SGP) – *mid latitude regime*
  - » North Slope of Alaska (NSA) – *polar regime*

RAOB Site	Lat (deg)	Lon (deg)	Collocation strategy	Ensemble size
ARM-SGP	36.6	-97.5	**<50km**	**~400 matches**
ARM-NSA	71.3	-156.6	**<50km**	**~200 matches**
ARM-TWP	2.06	147.43	**<75km**	**~50 matches**

Ref.: N. Nalli et al., JGR, 2013; D. Tobin et al., JGR, 2005

NUCAPS MW+IR
RMS Statistics vs ARM TWP, SGP, NSA Dedicated RAOBs



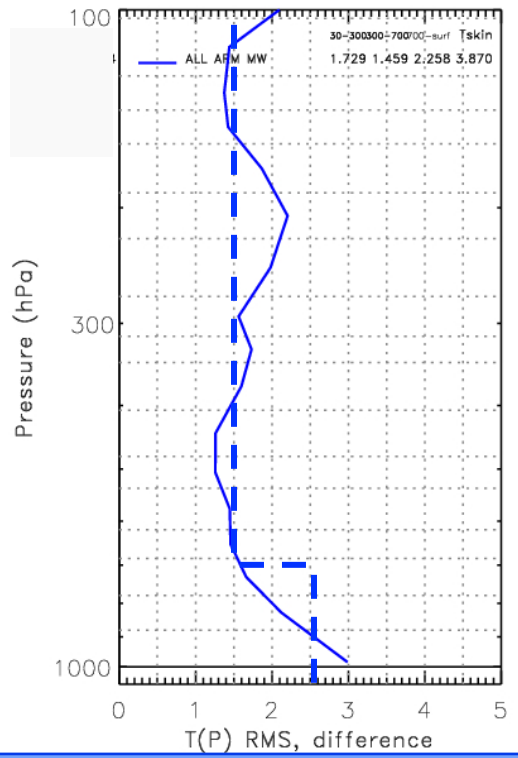


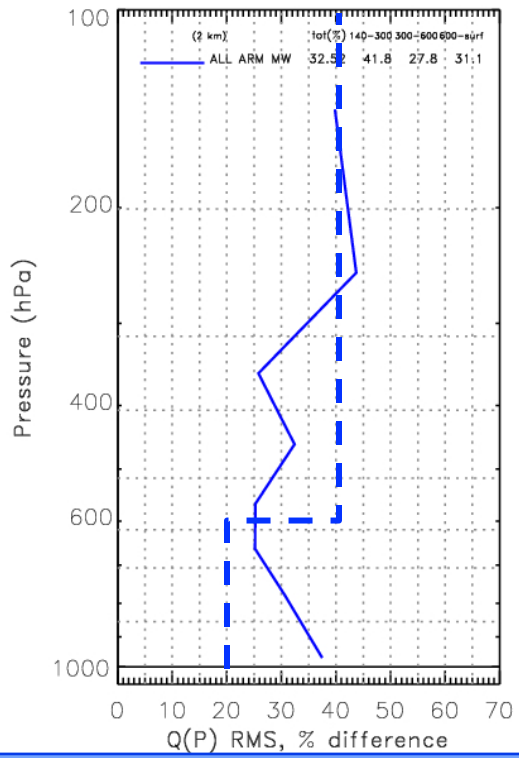
SUMMARY ON MW+IR RESULTS vs JPSS L1RD REQUIREMENTS

MW+IR TEMPERATURE	RESULTS	JPSS L1RD	MW+IR WATER VAPOR	RESULTS	JPSS L1RD
30 – 300mb	1.35K	1.5K	100 - 600mb	28.2%	35%
300mb - SURF	1.25K	1.6K	600mb -SURF	21.8%	20%

NUCAPS MW Only

RMS Statistics vs ARM TWP, SGP, NSA Dedicated RAOBs





SUMMARY ON MW-ONLY RESULTS vs JPSS L1RD REQUIREMENTS					
MW-ONLY TEMPERATURE	**RESULTS**	**JPSS L1RD**	**MW-ONLY WATER VAPOR**	**RESULTS**	**JPSS L1RD**
30 – 700mb	1.59K	1.5K	100 - 600mb	34.8%	40%
700mb - SURF	2.25K	2.5K	600mb -SURF	31.1%	20%

Summary on global validation vs ARM dedicated RAOBs
green = passed yellow = close red = failed

SUMMARY ON MW+IR RESULTS vs JPSS L1RD REQUIREMENTS					
MW+IR TEMPERATURE	RESULTS	JPSS L1RD	MW+IR WATER VAPOR	RESULTS	JPSS L1RD
30 – 300mb	1.35K	1.5K	100 - 600mb	28.2%	35%
300mb - SURF	1.25K	1.6K	600mb -SURF	21.8%	20%

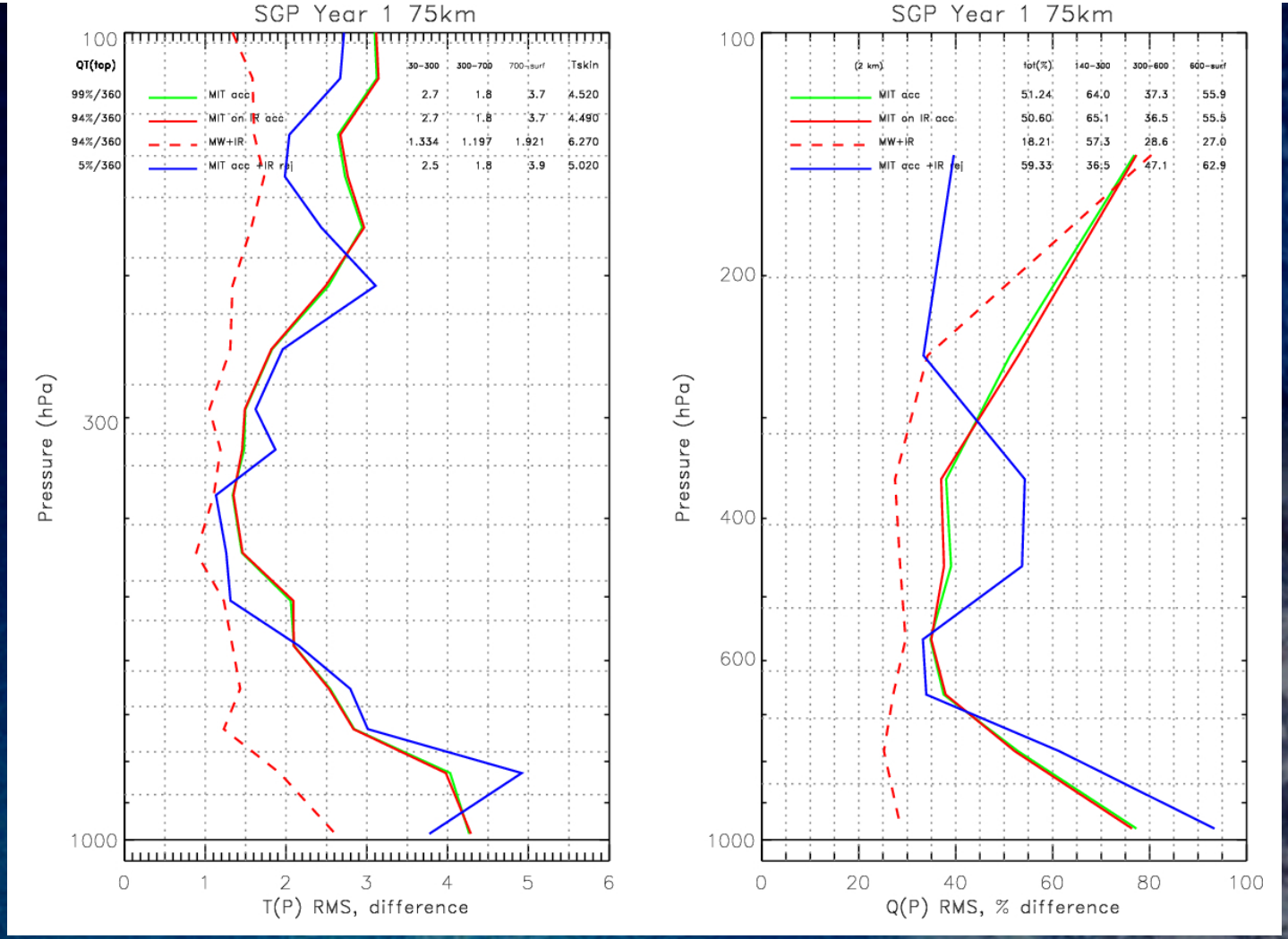
SUMMARY ON MW-ONLY RESULTS vs JPSS L1RD REQUIREMENTS					
MW-ONLY TEMPERATURE	RESULTS	JPSS L1RD	MW-ONLY WATER VAPOR	RESULTS	JPSS L1RD
30 – 700mb	1.59K	1.5K	100 - 600mb	34.8%	40%
700mb - SURF	2.25K	2.5K	600mb -SURF	31.1%	20%

- The NUCAPS system meets requirements globally except for water vapor MW-only (31.1% vs 20%) in the layer 600mb – surface and the water vapor MW+IR (21.8% vs 20%) in the layer 600mb - surface .
- Possible issues are:
  - Residual temporal and spatial mismatch (up to 75km) between retrievals and RAOBs considerably affects water vapor statistics (up to 10% for a 50km mismatch, especially in the UTH due to RAOB drift)
  - Uncertainty in the RAOBs (super saturation, calibration uncertainty)
  - Uncertainty in the retrievals (ongoing work)

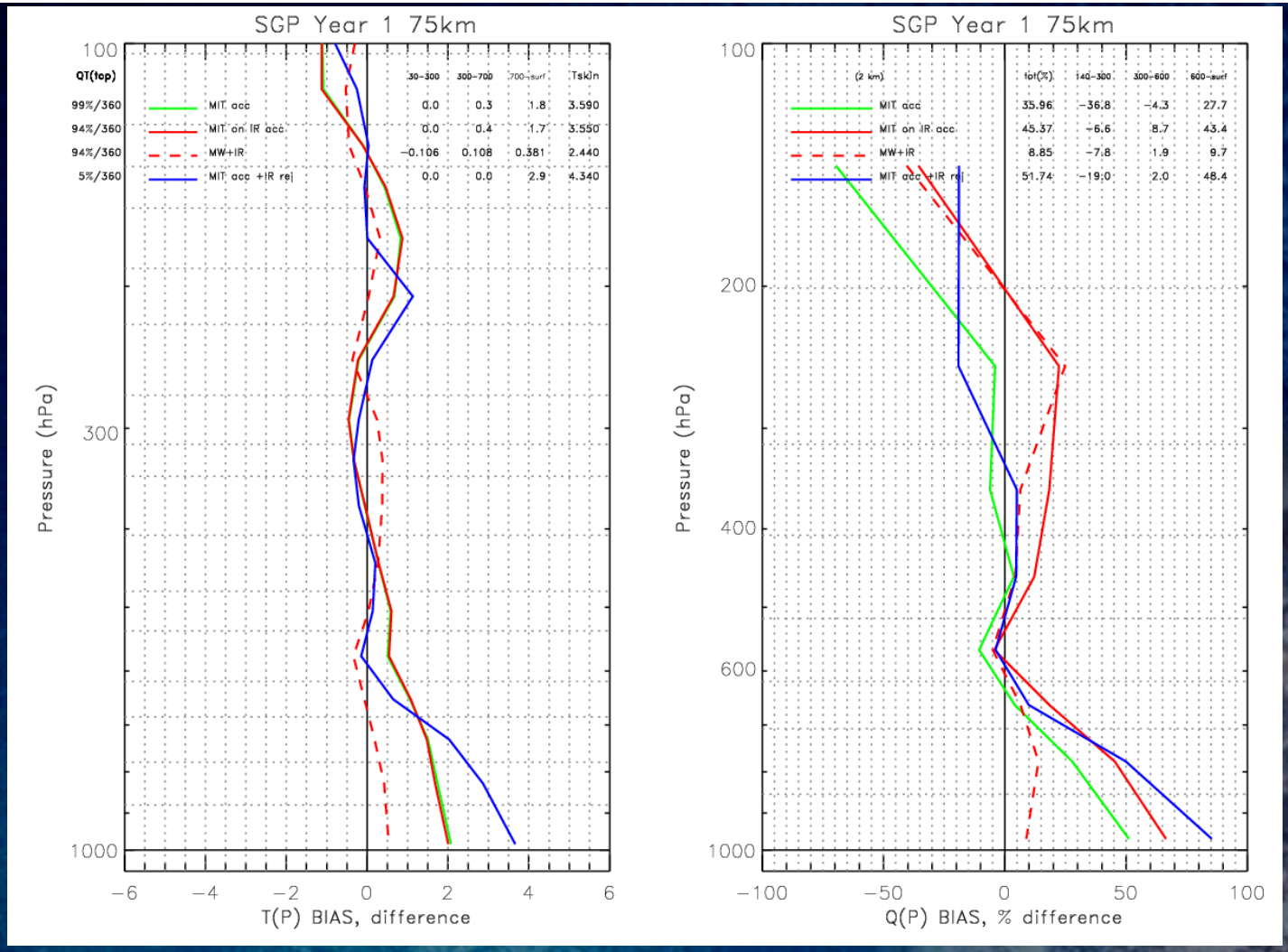
MW – only retrieval plans

- A new SDR pre-processor has been implemented in operations. This pre-processor is now able to appropriately co-locate the 9 FOV clusters of ATMS radiance observations to the CrIS center FOV and to the ECMWF field.
- A newly implemented precipitation flag (Ferraro et al.) to improve training ensemble for radiance bias tuning

MW Acc; MW on IR Acc (dashed is MW+IR); MW Acc on IR Rej



MW Acc; MW on IR Acc (dashed is MW+IR); MW Acc on IR Rej



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

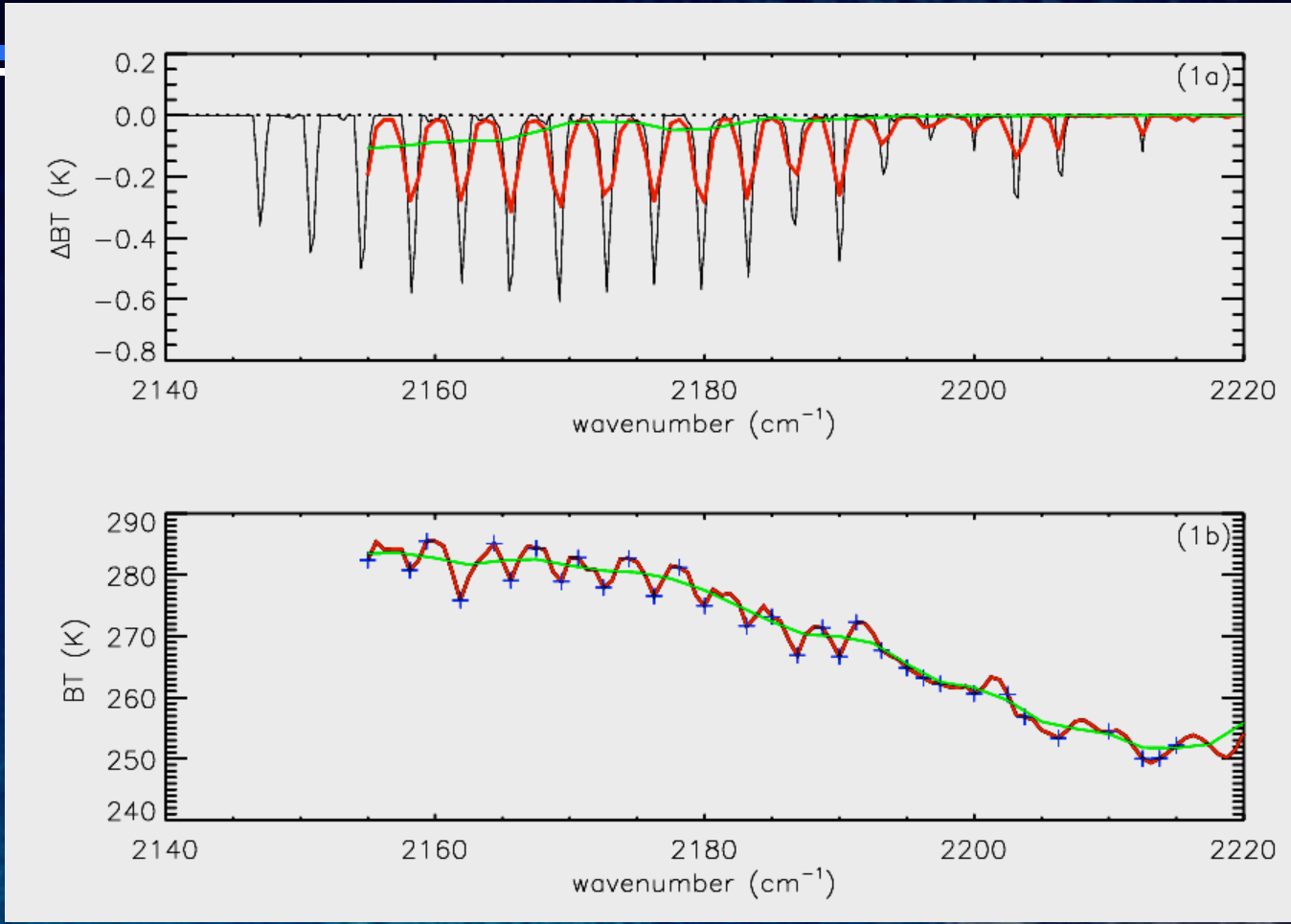
- **Experimental set up** (5 orbits from March 12th 2013)
  - Maximum geometrical path difference L = 0.8 cm in all three bands
  - Nyquist spectral sampling ($1/2L$): 0.625 cm-1 in all three bands

- **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

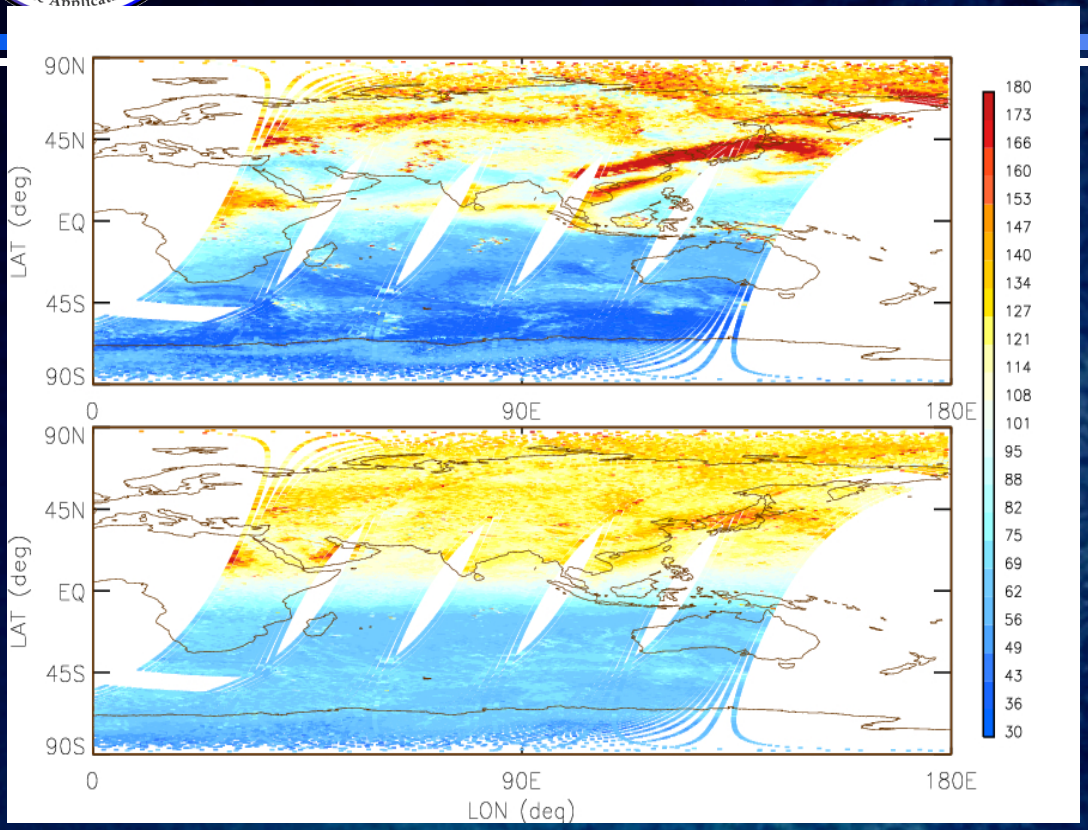
2.5cm^-1 0.625 cm^-1 0.25cm ^-1



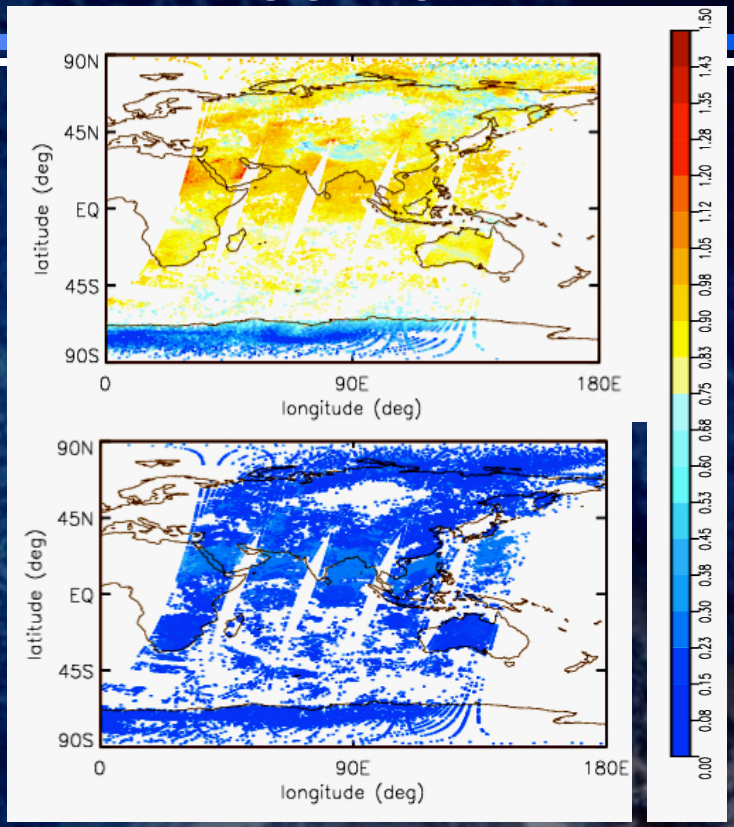
- Only when switched to high spectral resolution, CrIS spectrum (red curve, bottom part) shows the distinctive signature of CO absorption (red and black curve, top figure).
- Blue cross symbols: CO high resolution channel selection.

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.

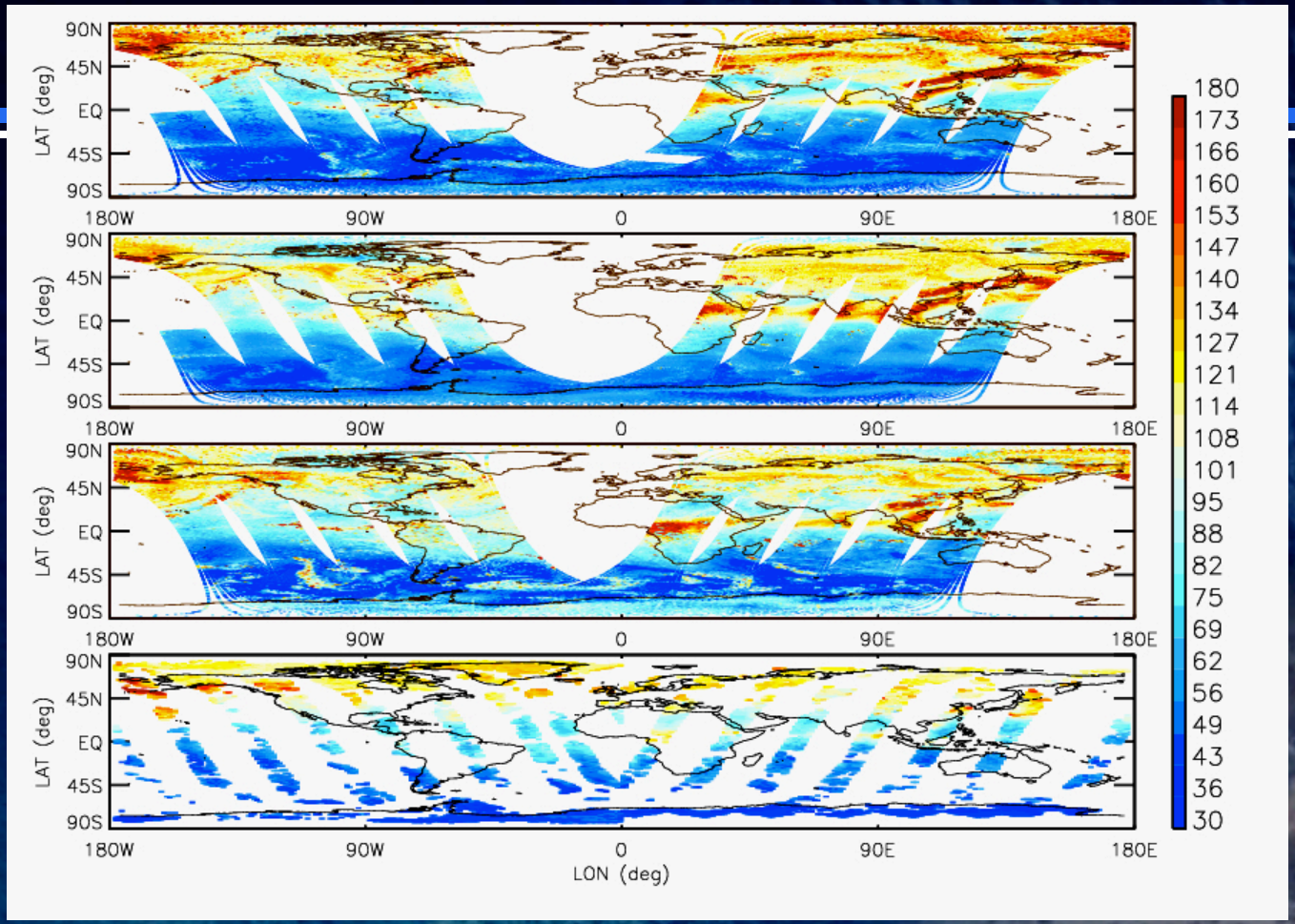
NUCAPS High RES (top), AIRS (second), IASI (third) and MOPITT (bottom) CO retrievals

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 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
  - NUCAPS Phase 3 Code Test Review – Mar. 2014
  - NUCAPS JPSS review on stage 1 validation – Sep. 2014
  - **NUCAPS Phase 3 Algorithm Readiness Review – Nov. 2014**
    - ILS shift in presence of scene in-homogeneities
    - VIIRS/CrIS collocation
    - OLR product delivery
  - **NUCAPS Phase 3 DAP Delivery – Nov. 2014**
  - **SPSRB Phase 3 briefing – Dec. 2014**
  - **NUCAPS Phase 3 Operations Commence – Dec. 2014**

Conclusion remarks and ongoing work

- Cross – comparison validation efforts have shown consistency of the NOAA hyper spectral retrieval system across all three platform: CrIS/ATMS, IASI/AMSU/MHS and AIRS/AMSU.

- September 3rd, 2014: NUCAPS passed the JPSS review for stage 1 validation.
  - » Stage 2 validation: performance evaluation over selected areas
  - » Stage 3 validation: performance evaluation in stability and long term trends

- We have provided evidence in support for the need of 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.

- 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

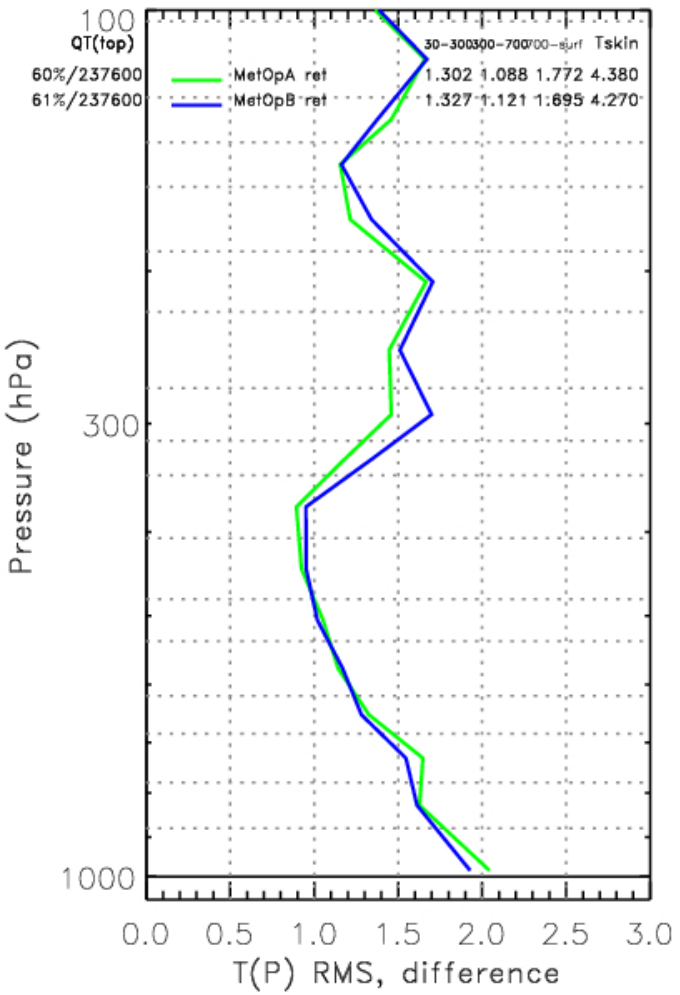
NUCAPS VALIDATION SUMMARY

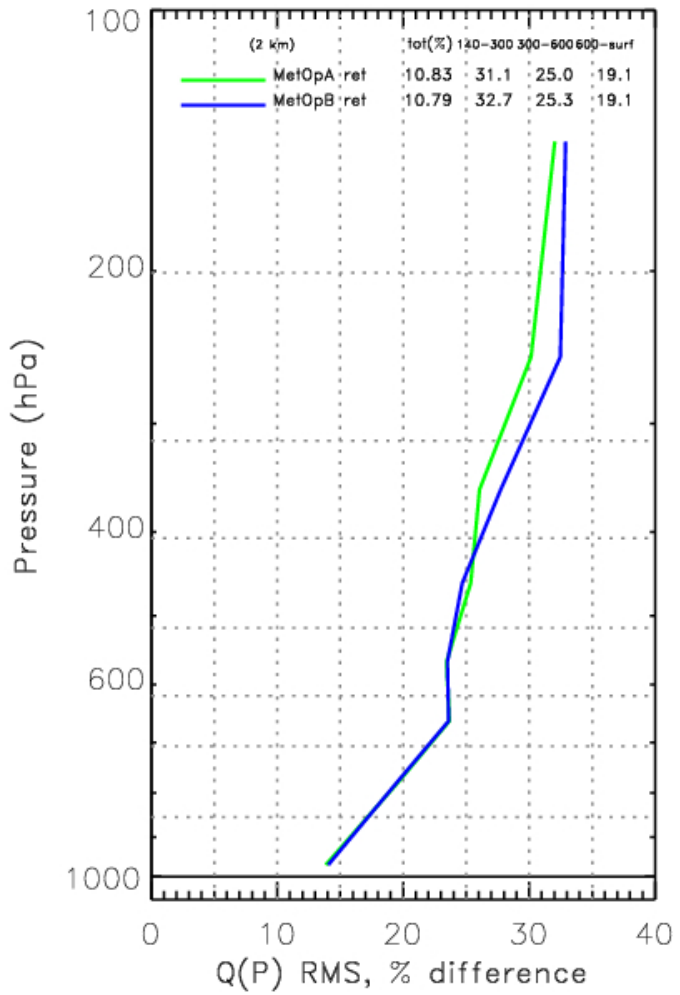
- **NUCAPS MW+IR**
  - **meets requirements globally vs ECMWF**
  - **meets requirements over ocean vs ECMWF**
  - **Close to meet requirements globally and over selected areas vs Dedicated RAOBs**

- **NUCAPS MW – Only**
  - **NUCAPS MW Only close to meet requirements globally vs ECMWF**
  - **NUCAPS MW only close to meet requirements over ocean vs ECMWF**
  - **meets requirements over tropical western pacific dedicated RAOBs**

- **Present issues in the validation truth:**
  - Residual temporal and spatial mismatch between retrievals and model: ECMWF mismatch is +/- 1.5 hour and +/- 0.25 deg and we use both forecast and analysis depending on UT time.
  - Uncertainty in the ECMWF model
  - Residual temporal and spatial mismatch (75km) between retrievals and RAOBs considerably affects water vapor statistics (up to 10% due to 50km mismatch, especially in the UTH due to RAOB drift)
  - Uncertainty in the RAOBs (supersaturation, calibration uncertainty)
- **Ongoing activity:**
  - We are aware that there is a need for updating the look up tables for both the MW-Only and MW+IR retrieval:
    - A priori, First guess, radiance bias correction

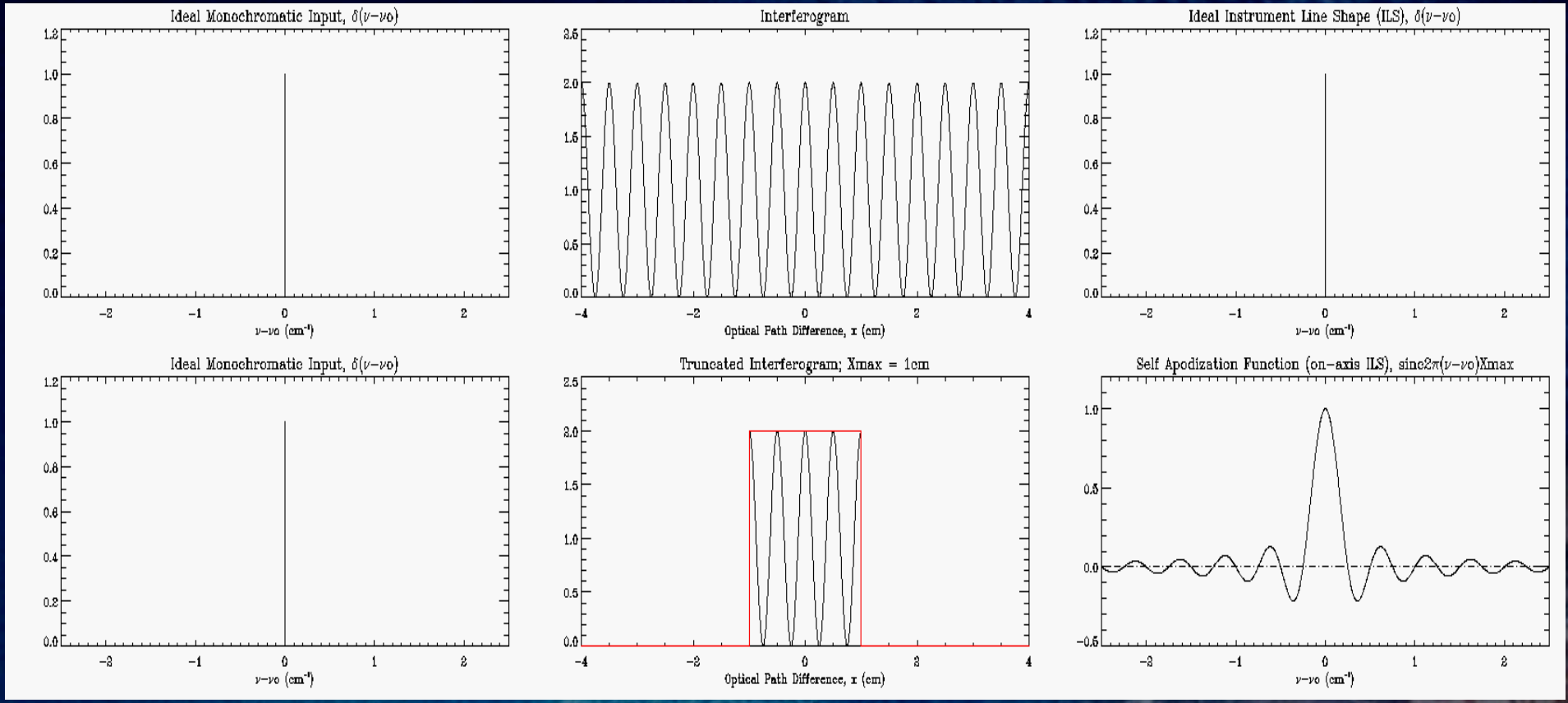
IASI MetOp A IASI MetOp B
Global RMS Statistics vs ECMWF Analysis





- 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.

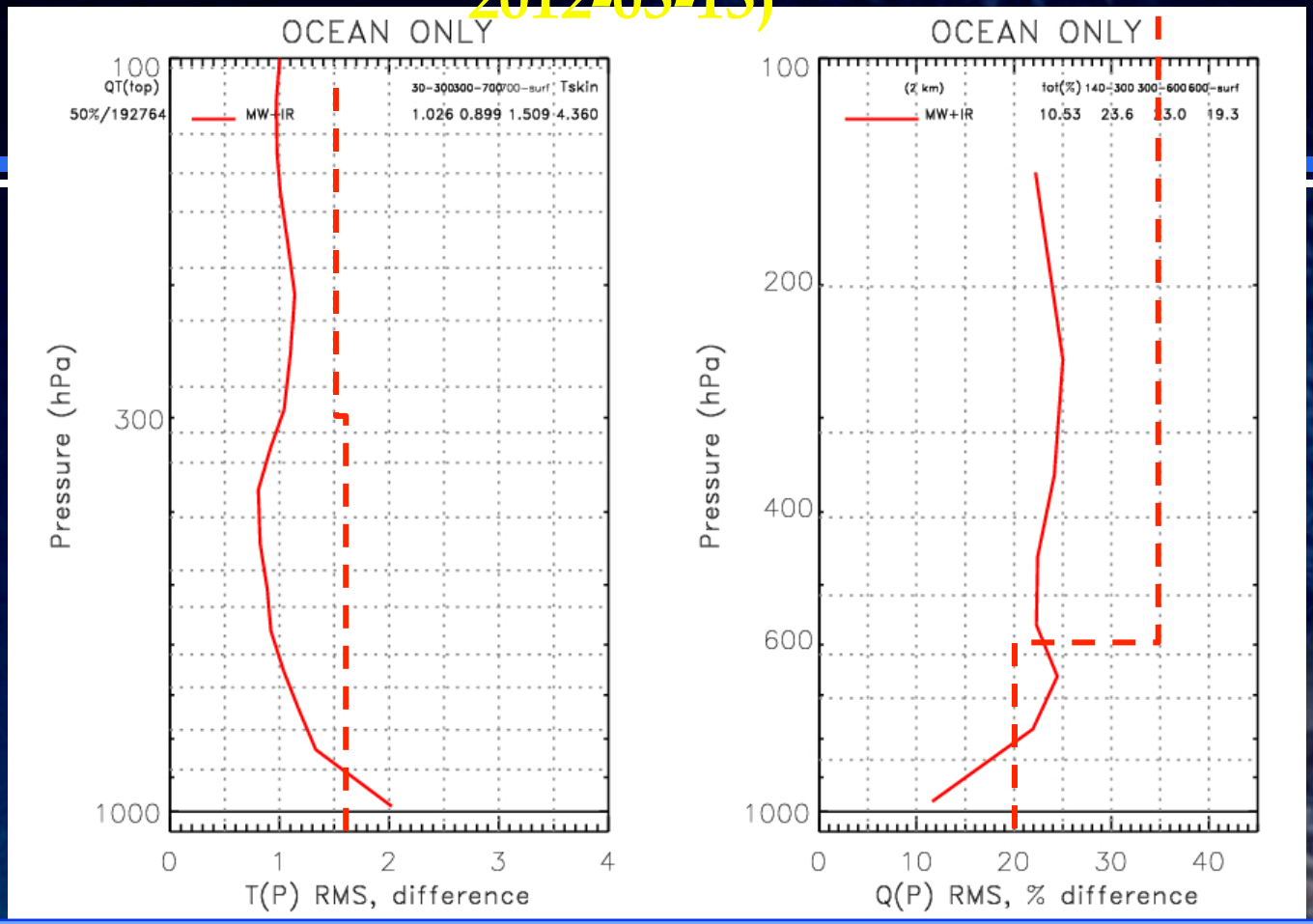
Truncation of the Interferogram & Resulting Instrument Line Shape



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

GLOBAL OCEAN VALIDATION

NUCAPS MW+IR vs ECMWF Analysis (focus day 2012-05-15)

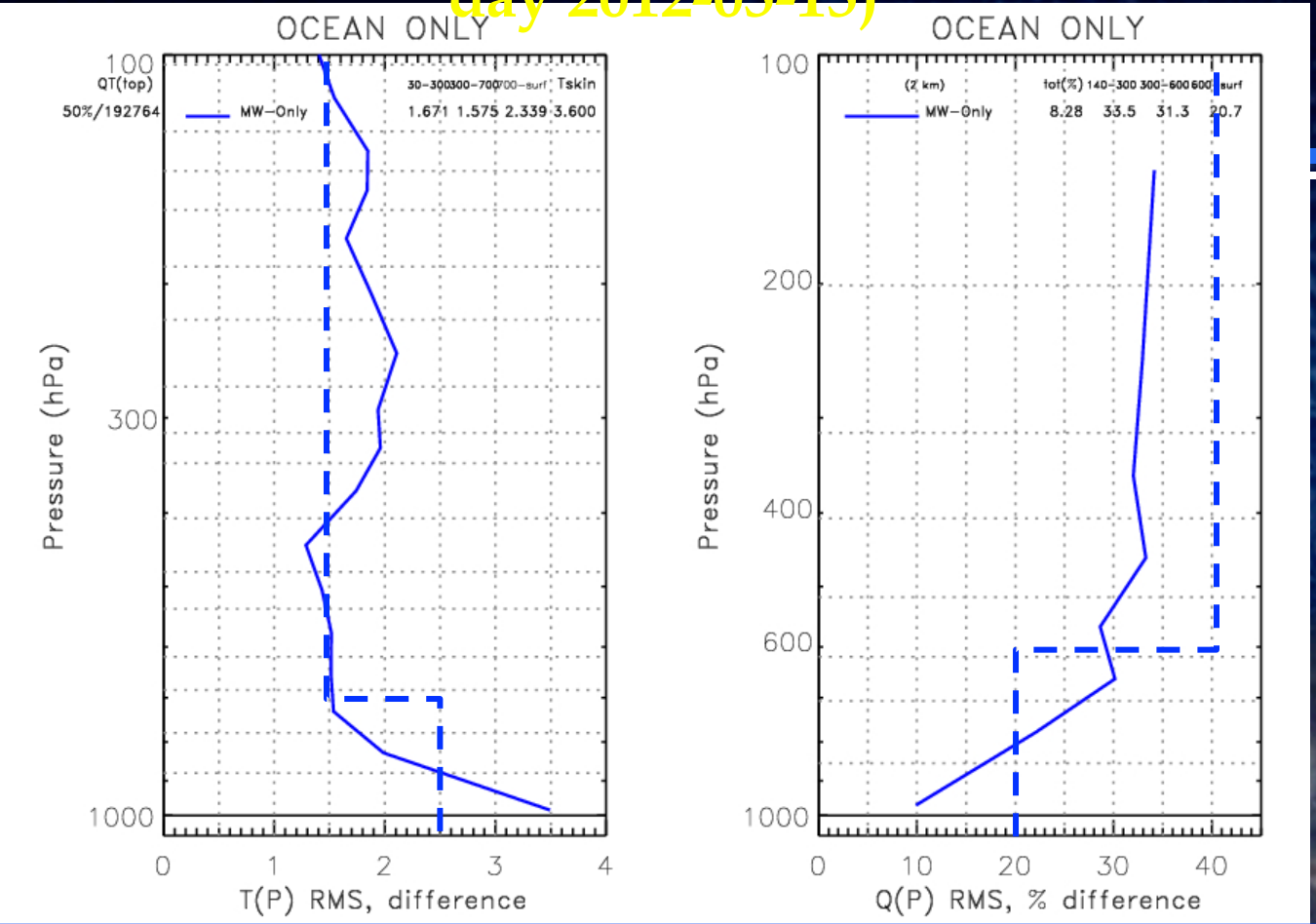


SUMMARY ON OCEAN MW+IR RESULTS vs JPSS L1RD REQUIREMENTS

MW+IR TEMPERATURE	RESULTS	JPSS L1RD	MW+IR WATER VAPOR	RESULTS	JPSS L1RD
30 – 300mb	1.02K	1.5K	100 - 600mb	23.3%	35%
300mb - SURF	1.20K	1.6K	600mb - SURF	19.3%	20%

GLOBAL OCEAN VALIDATION

NUCAPS MW Only vs ECMWF Analysis (focus day 2012-05-15)



SUMMARY ON OCEAN MW-ONLY RESULTS vs JPSS L1RD REQUIREMENTS

MW-ONLY TEMPERATURE	RESULTS	JPSS L1RD	MW-ONLY WATER VAPOR	RESULTS	JPSS L1RD
30 – 700mb	1.55K	1.5K	100 - 600mb	32.4%	40%
700mb - SURF	2.33K	2.5K	600mb - SURF	20.7%	20%

green = passed yellow = close red = failed

SUMMARY ON OCEAN MW+IR RESULTS vs JPSS L1RD REQUIREMENTS					
MW+IR TEMPERATURE	RESULTS	JPSS L1RD	MW+IR WATER VAPOR	RESULTS	JPSS L1RD
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- **NUCAPS MW+IR fully meets requirements over ocean**
- **NUCAPS MW-Only is close to fully meet spec.**
  - **Possible issues are:**
    - Residual temporal and spatial mismatch between retrievals and model: ECMWF mismatch is +/- 1.5 hour and +/- 0.25 deg and we use both forecast and analysis depending on UT time.
    - Uncertainty in the ECMWF model
    - Uncertainty in the retrievals
  - **Ongoing NUCAPS improvement activity:**
    - Improve NUCAPS look up tables (RTA tuning and first guess)
    - Improve validation methodology by using dedicated RAOBs: **see ahead**