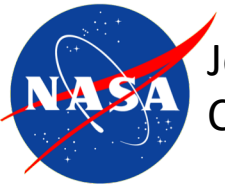

Jet Propulsion Laboratory
California Institute of Technology

Testing and Verification of AIRS 'V7' Development

Qing Yue[1] and Bjorn Lambrigtsen[1]

Contributors: Sun Wong[1], Evan Manning[1], John Blaisdell[2], Adam Milstein[3], Joel Susskind[5], Evan Fishbein[1], Joao Teixeira[1], Eric Fetzer[1], Tom Pagano[1], Bill Irion[1], Peter Kalmus[1], Chris Wilson[4], Ed Olsen[1], Baijun Tian[1], Ruth Monarrez[1], Chris Barnet[6]

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[6]Science and Technology Corporation (STC)

2018 NSSTM

JPL Sounding System Retrieval Data Product Testing

Stage-0

Goal:
Quick general data quality examination on key variables.

Approach

- Comparison between versions/systems
- Comparison with reanalysis

Examples

- Retrieval yield in AIRS V7 and CrIMSS products
- L2 T and Q profile differences with ECMWF
- L3 TPW comparison with AMSR
- L3 Surface skin temperature and 2m temperature comparison with ECMWF

Stage-1

Goal

- Limited validation of key product retrievals
- Identifying possible causes of reduced retrieval performance.

Approach

- Comparison with well-developed reference datasets and tools at JPL
- Pixel-scale collocation
- Cross-relationships of multiple variables

Examples:

- Relationship between retrieval yield and surface condition/cloud condition.
- Comparison with radiosonde measurements on T and Q over land (IGRA) and over ocean (MAGIC).
- L2 near surface T and Q comparison with mesonet (over land) and shiptrack/buoy measurements (over ocean)

Stage-2

Goal

- Validation and quality check of a wider range of variables as requested by users

Approach

- Same with Stage-0 and Stage-1
- Requesting additional reference data collection and tool development.

Examples

- Trace gas products: CO_2, O_3, etc
- Retrieval information content analysis: AK, DOF, vertical reso.
- Longterm trend and climate extreme, physical processes.
- Comparison with new field campaign measurements: HS3 and SOCRATES

Examples of Stage 0 and State 1 Initial Data Product Testing

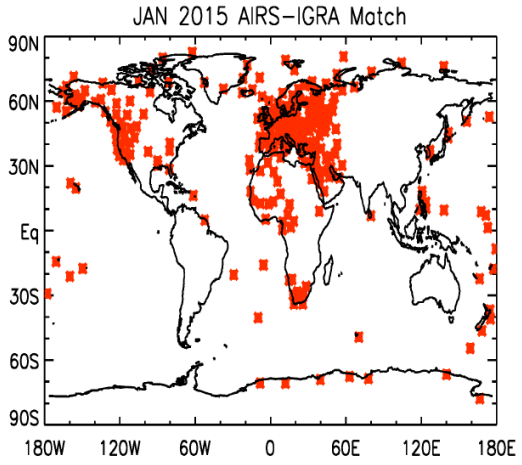
- Quick general data quality examination on key variables
- Limited validation of key product retrievals
- Identifying possible causes of reduced retrieval performance.

- Comparison with reanalysis (Yue et al. 2011, Wong et al. 2015, Hearty et al. 2014)
  - Pixel-scale collocation
  - Yield and Quality control: Yield: percentage of retrievals passing the QC filter
  - Bias analysis on final retrieval and prior:

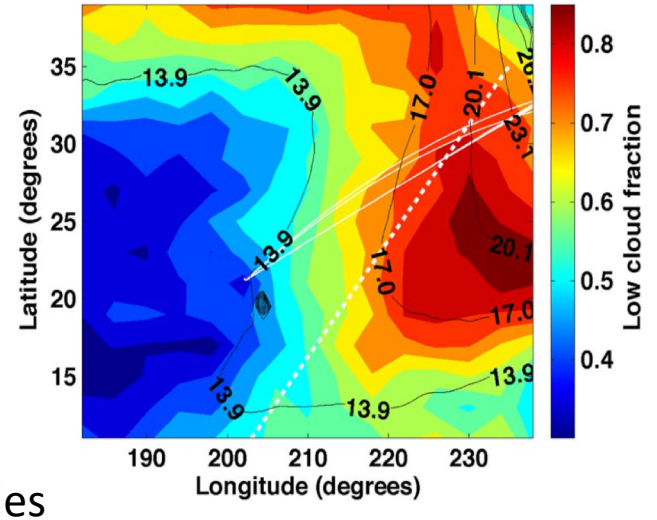
    Retrieval Bias = Retrieval or prior (QC)-Collo.EC(QC)

    Sampling Bias = Collo.EC(QC)-Collo.EC

- Comparison with radiosonde
  - Pixel-scale collocation
  - Over land: IGRA (Wong et al 2015)
  - Over ocean: MAGIC (Kalmus et al. 2015)
  - Field campaigns targeting various climate regimes



Location of collocated IGRA sondes



White lines: MAGIC shiptracks between LA and Hawaii

Extensive Testing and Validation on Target Algorithms and Products

After communication, discussion and identifying the target(s)

1. Testing/validation using new reference data in different climate regimes by applying the collocation and analysis tools already developed.

Campaign	Location	Time	Climate Regimes
HS3 (Hurricane and Severe Storm Sentinel)	Lat: 10 ~ 50 Lon: -160 ~ -19	Aug and Sep from 2011 to 2014	Midlat and Tropic ocean, severe storm
SHOUT (Sensing Hazards with Operational Unmanned Technology)	Lat: 10 ~ 50 Lon: -160 ~ -19	Aug-Sep, 2015 Feb, 2016 Aug-Oct, 2016	Midlat and Tropic ocean, severe storm
WISPAR (the Winter Storms and Pacific Atmospheric Rivers)	Lat: 0 ~ 90 Lon: -170 ~ -120	Feb-March, 2011	Atmospheric Rivers, Arctic environment
VOCALS (VAMOS Ocean-Cloud-Atmosphere-Land Study)	Lat: -30 ~ -15 Lon: -90 ~ -70	Oct-Nov, 2008	Southeastern Pacific low cloud region
SOCRATES (Southern Ocean Clouds Radiation Aerosol Transport Experimental Study)	Lat: -70 ~ -30 Lon: 130 ~ 180	Jan-Feb, 2018	Southern Ocean

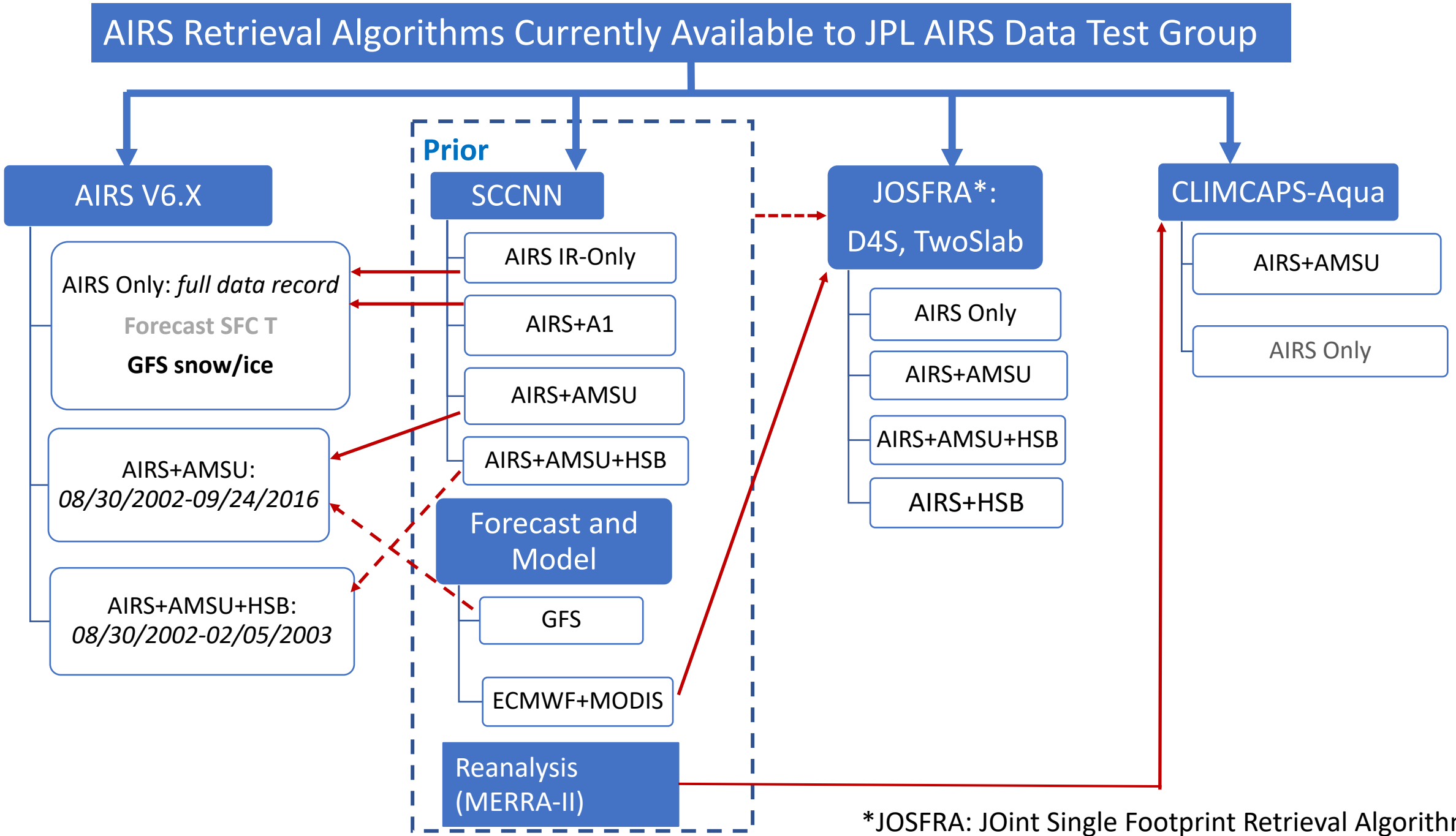
2. Information content analysis: initial guess and spectral sensitivity; vertical resolution; different priors …

3. Climate quality: continuity, anomaly time series, drifting

4. More trace gases (collaboration with Vivienne et al.)

   Example:

   1. total O_3 and O_3 profile tested using O_3 measured by uplooking UV-Visible spectrometer from Dumont d'Urville station By E. Fishbein
   2. Mid-troposphere CO_2 tested using deep profiles from HIPPO aircraft measurements by E. Olsen, S. Licata


AIRS Retrieval Algorithms Currently Available to JPL AIRS Data Test Group
Prior
AIRS V6.X
AIRS Only: full data record
Forecast SFC T
GFS snow/ice
AIRS+AMSU: 08/30/2002-09/24/2016
AIRS+AMSU+HSB: 08/30/2002-02/05/2003
SCCNN
AIRS IR-Only
AIRS+A1
AIRS+AMSU
AIRS+AMSU+HSB
Forecast and Model
GFS
ECMWF+MODIS
Reanalysis (MERRA-II)
JOSFRA*: D4S, TwoSlab
AIRS Only
AIRS+AMSU
AIRS+AMSU+HSB
AIRS+HSB
CLIMCAPS-Aqua
AIRS+AMSU
AIRS Only
*JOSFRA: JOint Single Footprint Retrieval Algorithm

JPL AIRS V6.X Test Summary

V6 to V6.28

- Removed the day-night difference in water vapor.
- Improved Stratospheric SCCNN water vapor
- Reduced 300hPa water vapor bias.
- Improved O3 retrieval.

V6.28 to V6.46

- Assessing the impact of lost of AMSU on V6 product.
- IR-only surface classes by incorporating GFS snow/ice cover.
- Improved O3 retrieval by using new climatology, damping procedure, increasing trapezoid, etc.
- Improved SCCNN:
  - *Addressing discontinuity at 55º*
  - *removing the biased ECMWF in the training data to improve stratospheric T retrieval in polar night*

V6.46 to V6.54

- Improved SCCNN:
  - *increased training dataset to deal with interannual variability (V6.50)*
  - *projected principle component method to reduce SCC errors near sfc (V6.51IR)*
  - *Unified training method for both IR-only and IR+MW (V6.53)*
  - *New AIRS+A1 SCCNN for IRonly retrieval (6.54a1)*
- Modified QC methodology (V6.52, V6.53, V6.54):
  - *QC in PBL over land now relies more on near surface layers*
  - *Tighter QC thresholds for mid and low atmosphere over land and mid atmosphere over frozen surfaces*

V6.56

- Testing the impact of different initial guess: *GFS forecast analysis T, Q, and SFC T.*

Summary of Current AIRS V6.X Test based on Previous V7 Goals

1. Goal zero: good general quality
2. Remove day-night performance difference
3. Better IR-only algorithm than V6IR-only: surface classes, SCCNN, channels,…
4. Better IR only products than V6 IR+MW:
   - Achieved over ocean even in large cloud fraction cases
   - Cold bias with mid-high PBL over land in cold seasons; vertical structure of Q bias and dependence on cloud.
5. Better ozone
6. Improved stratosphere and polar
7. Unified retrieval algorithm for both AIRS/AMSU and CrIMSS: CHART (AIRS V6.46 equivalent) and CLIMCAPS
8. Improved L1B (not included in L2 retrieval, improved RTA)
9. Improved file format: NetCDF4
10. More accurate characterization of errors within our v6 formalism:
    a. More accurate error estimates
    b. Better flagging of bad cases with Q0, Q1, Q2

Met
Partially met or uncertain
Unmet

11. New tests: IR-only retrieval with AIRS+A1 SCCNN and Retrieval using GFS T, Q, SFC_T as prior

Latest Results on AIRS V6.X and CrIMSS Stage 0 and 1 Test

1. Comparisons of V6aa (AIRS+AMSU), V6ao (AIRS-Only), V653aa, V653ao, V654a1 (AIRS-Only with AIRS+A1 SCCNN)

   Retrieval Bias = Retrieval or prior (QC)-Collo.EC(QC)

   Sampling Bias = Collo.EC(QC)-Collo.EC

2. CrIMSS Initial Data Product Testing and Validation by JPL AIRS Team (see the report for detail).

1. Tightening of “Pgood” and Loosening of “Pbest” compared to V6
2. Day-night difference in Yield: ECF=0.1

QC=0 & 1

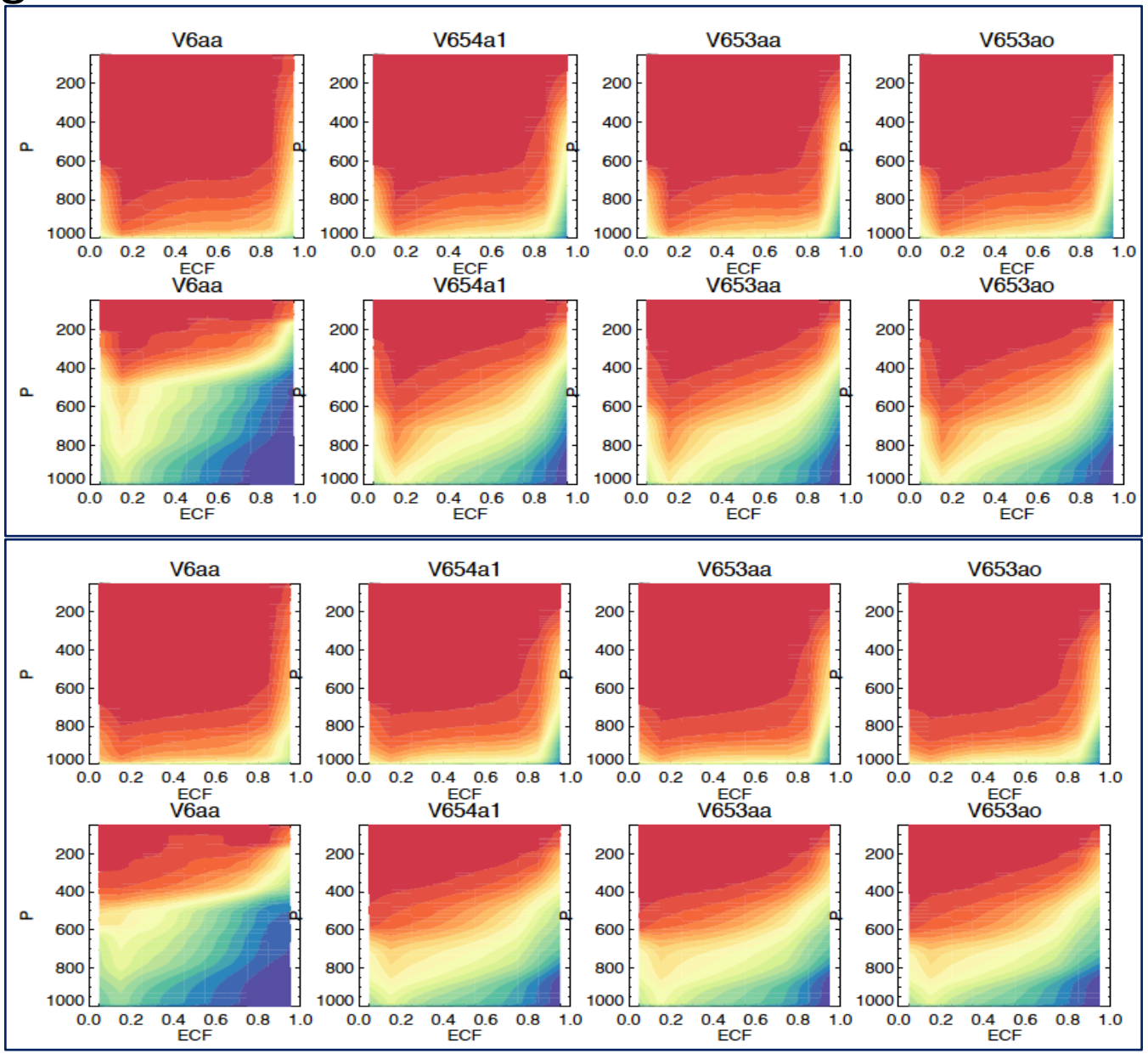
Day

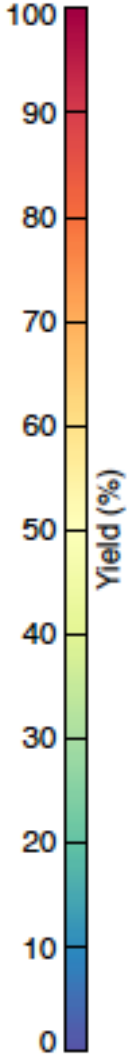
QC=0

QC=0 & 1

Night

QC=0





- V6aa: V6 AIRS+AMSU
- V654a1: AIRS only retrieval with AIRS+A1 SCCNN
- V653aa: V6.53 AIRS+AMSU
- V653ao and V654ao: Latest AIRS IR-Only

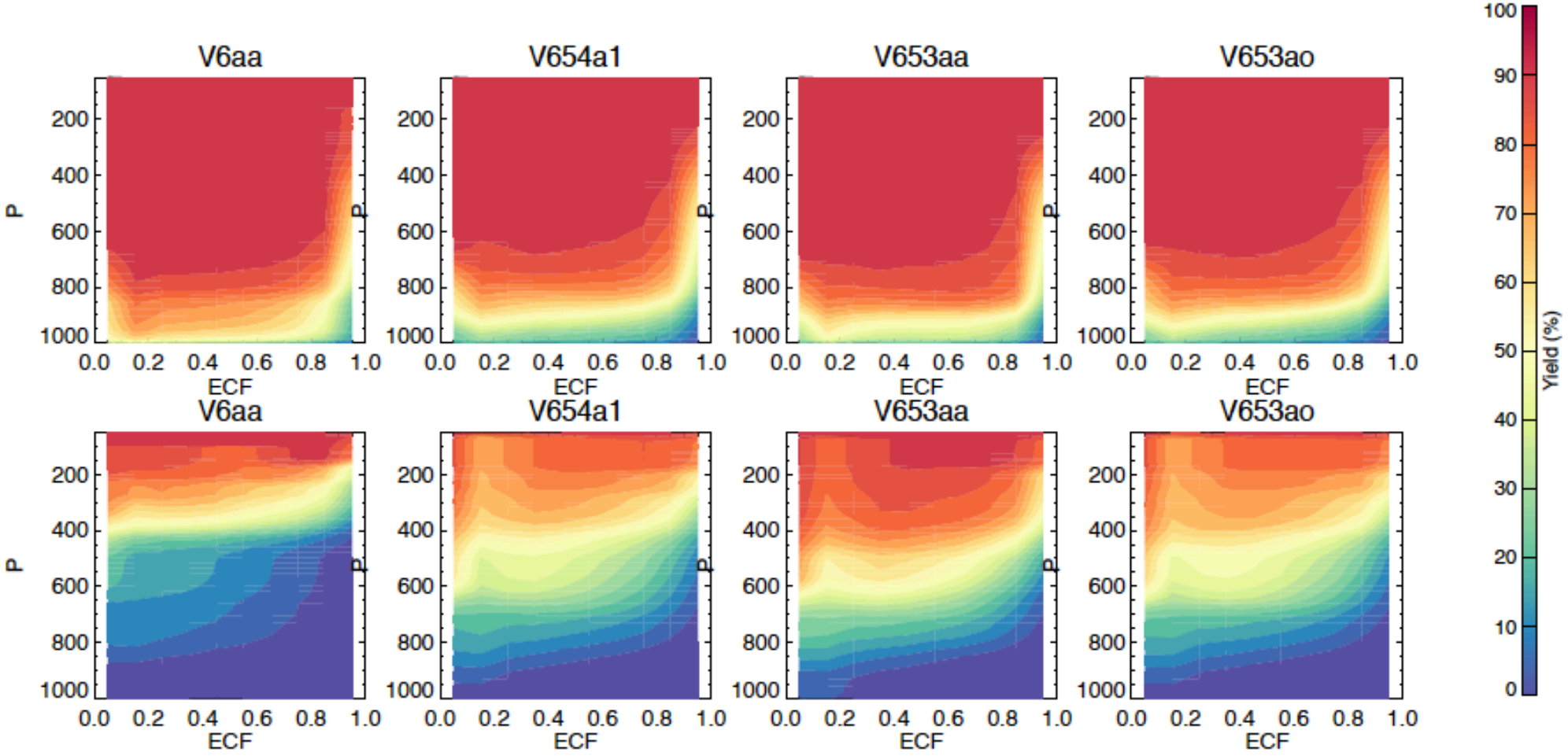
Global, Jan 2015

Sudden increase of Pbest retrieval over Europe at ECF 0.1 over Europe?

Yield over Europe

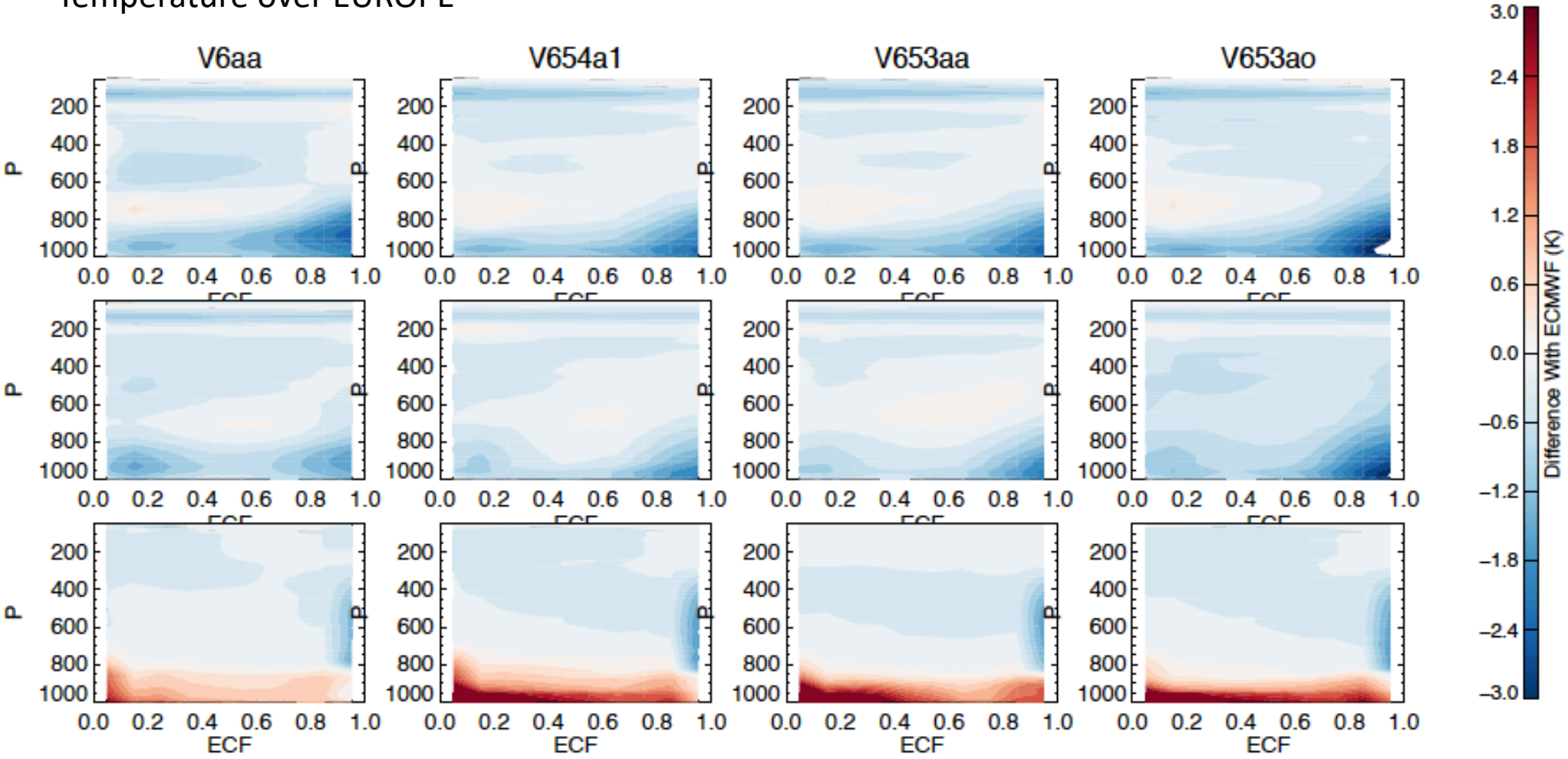
QC=0 & 1

QC=0

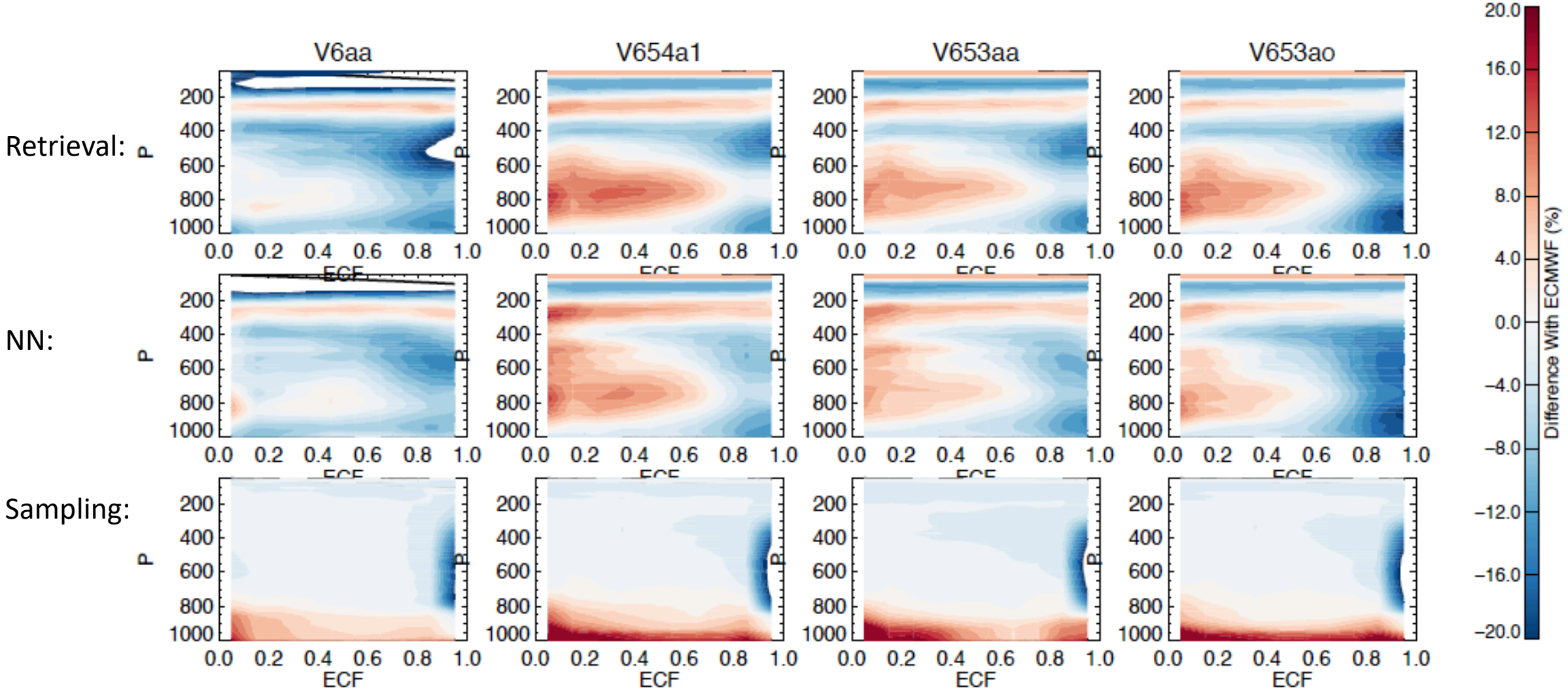


Smaller but persistent PBL cold bias from V6.53aa at all ECF than all other V6.X retrievals.
V654a1 seems to be in-between V653aa and V653ao, but produces a much smaller difference with ECMWF than V653ao when ECF is large or near the surface: statistics from global data and data over Europe

Temperature over EUROPE

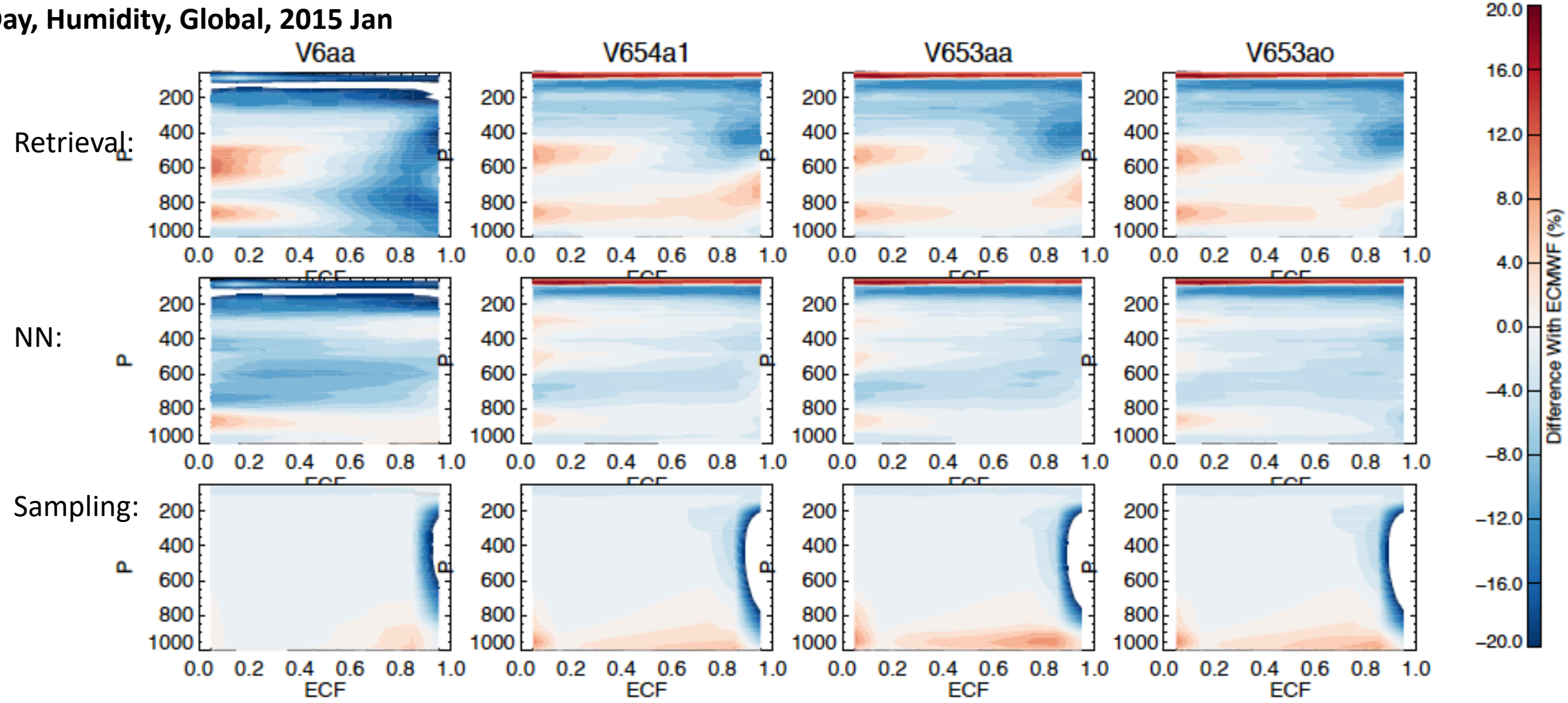


AIRS Humidity Differences with ECMWF Jan 2015: Europe



- Day-Night difference in Humidity retrieval is gone in the new versions
- Larger sampling bias in nighttime
- Final retrieval around 500hPa wetter than NN with small ECF, but dryer than NN in the large ECF
- Final retrieval below 700hPa wetter than NN

Day, Humidity, Global, 2015 Jan



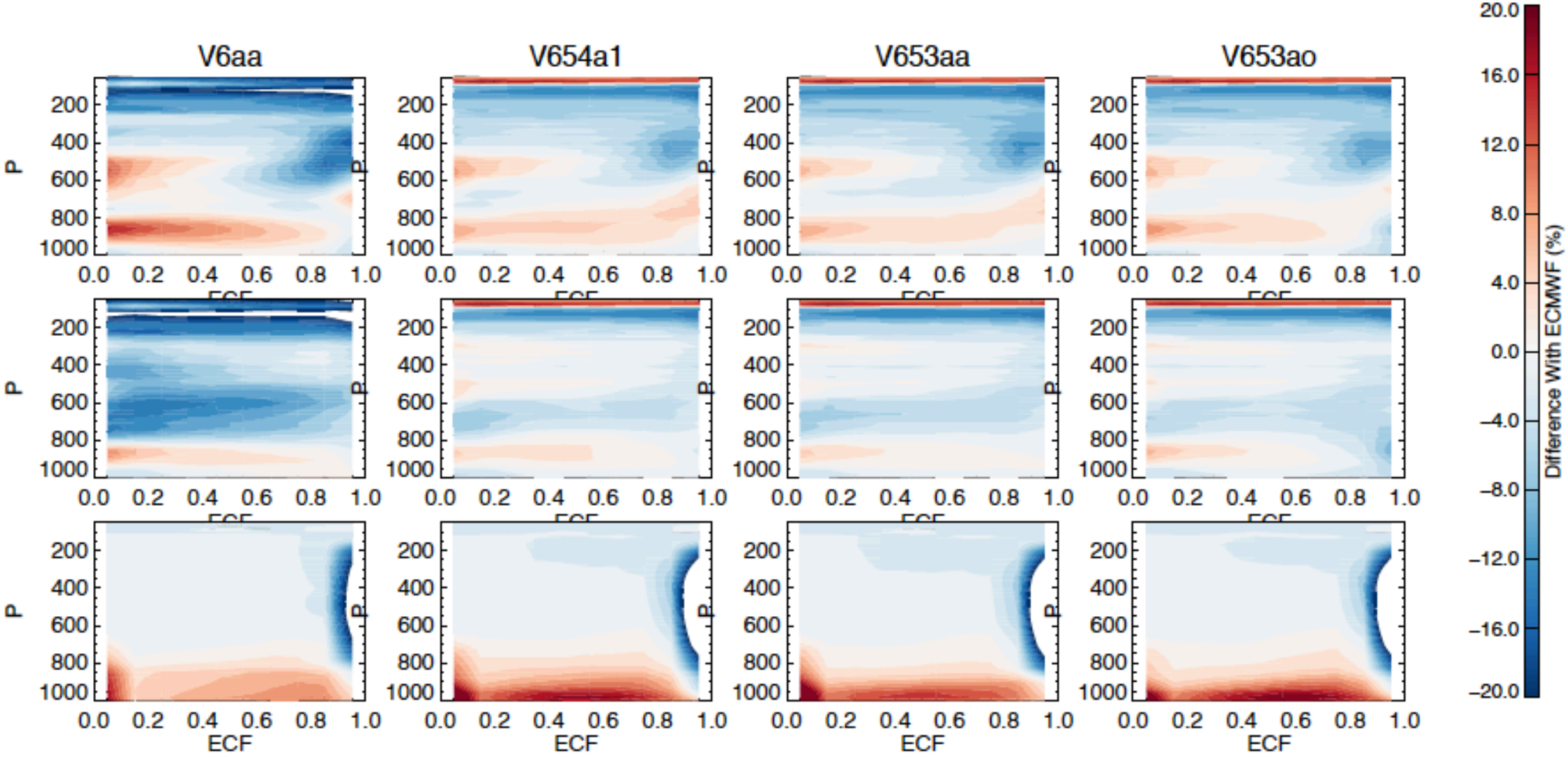
Day-Night difference in Humidity retrieval is gone in the new versions

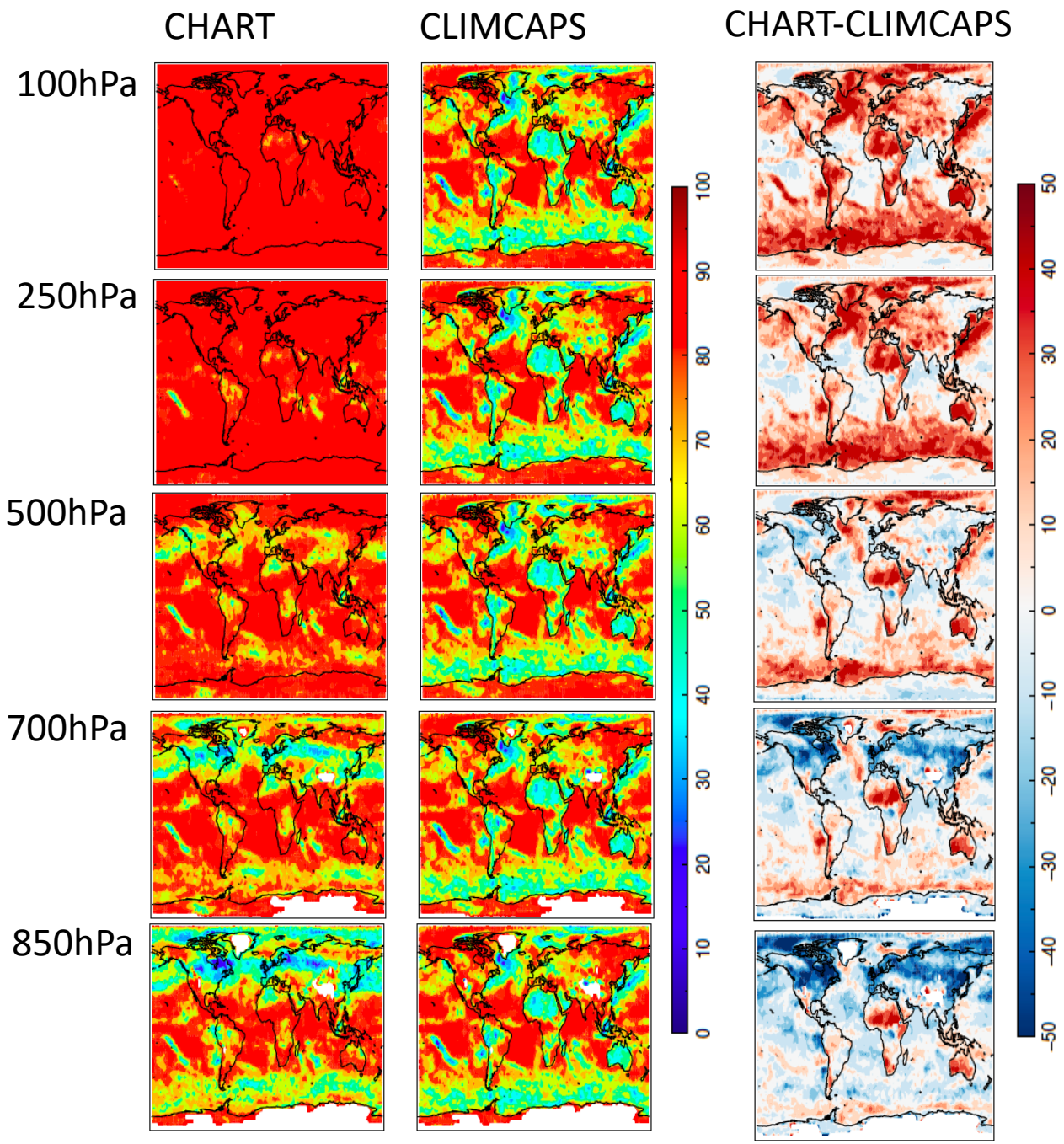
Night, Humidity, Global, 2015 Jan

Retrieval:

NN:

Sampling:





CrIMSS Yield Maps

1. Jan 2015
2. Low yield of CLIMCAPS over desert.
3. CHART yield becomes smaller than CLIMCAPS over high lat land during cold season (Jan 2015 test data).

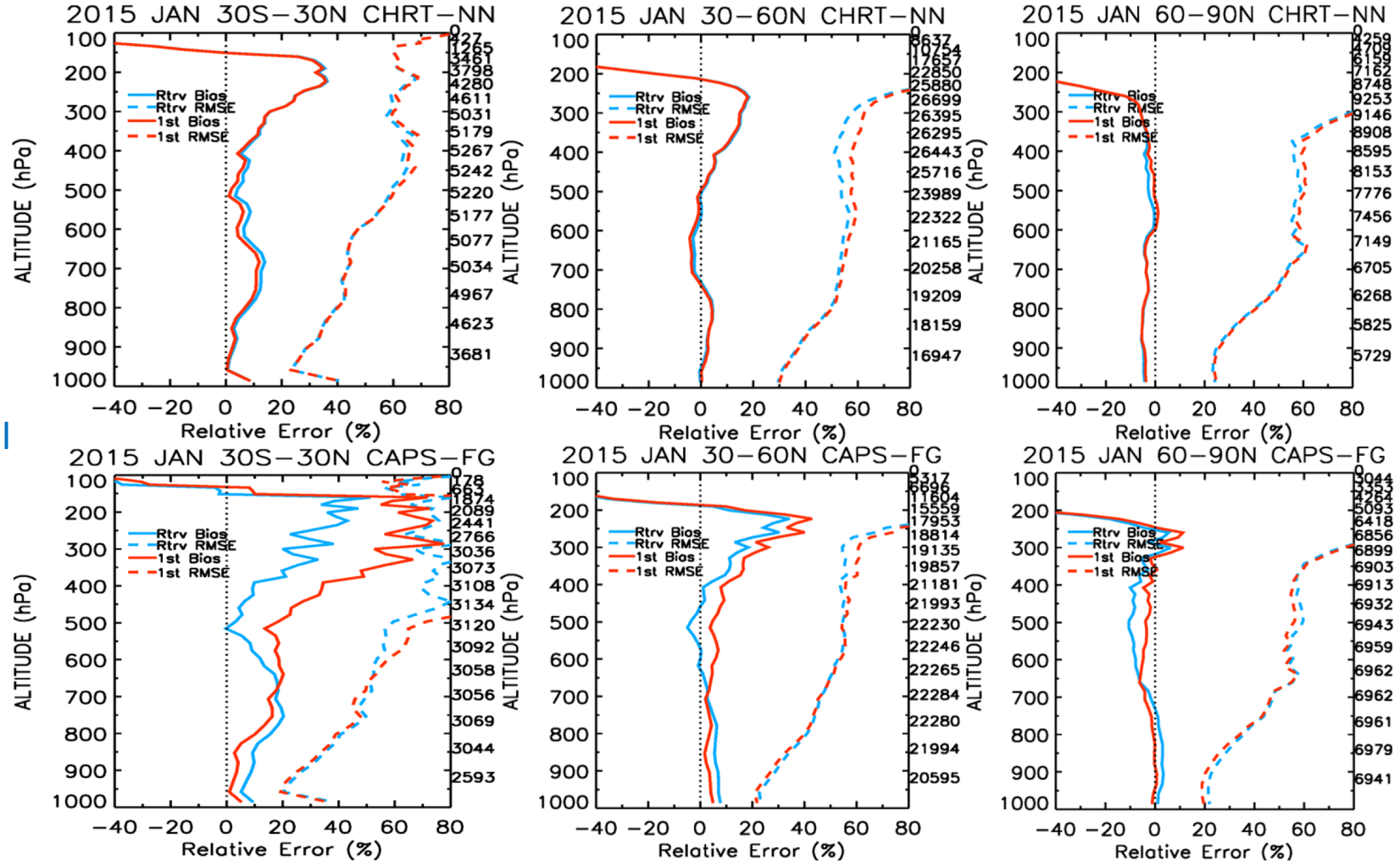
CrIMSS Humidity Retrieval and Prior Comparison with Radiosonde

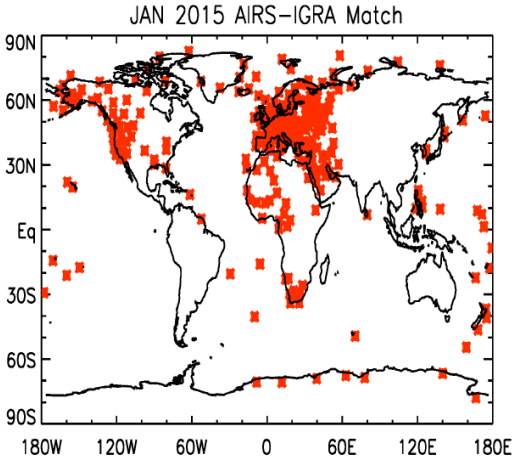
P>600 hPa: higher sonde humidity quality.
CHART's q retrievals are very close to their 1st.
Larger bias from CLIMCAPS than its prior and CHART final retrieval, but smaller RMS in polar and midlat.

CHART

Red: prior
Blue: retrieval

CLIMCAPS



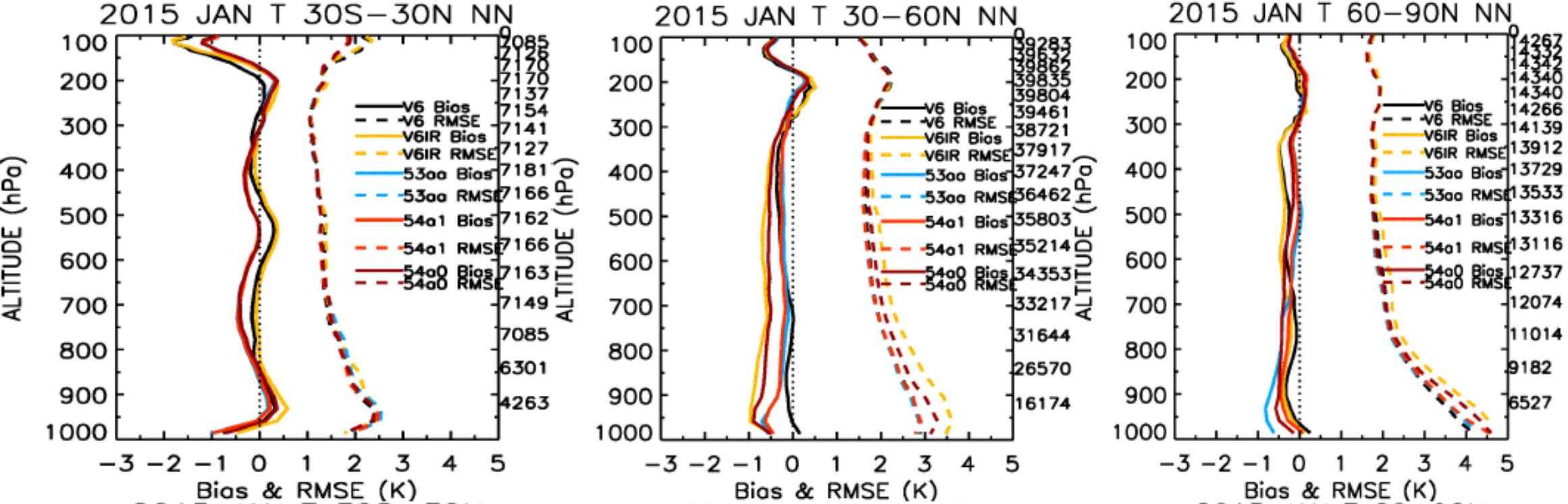


Locations of collocated sondes: These regions have very dense surface observations which are assimilated in the reanalysis

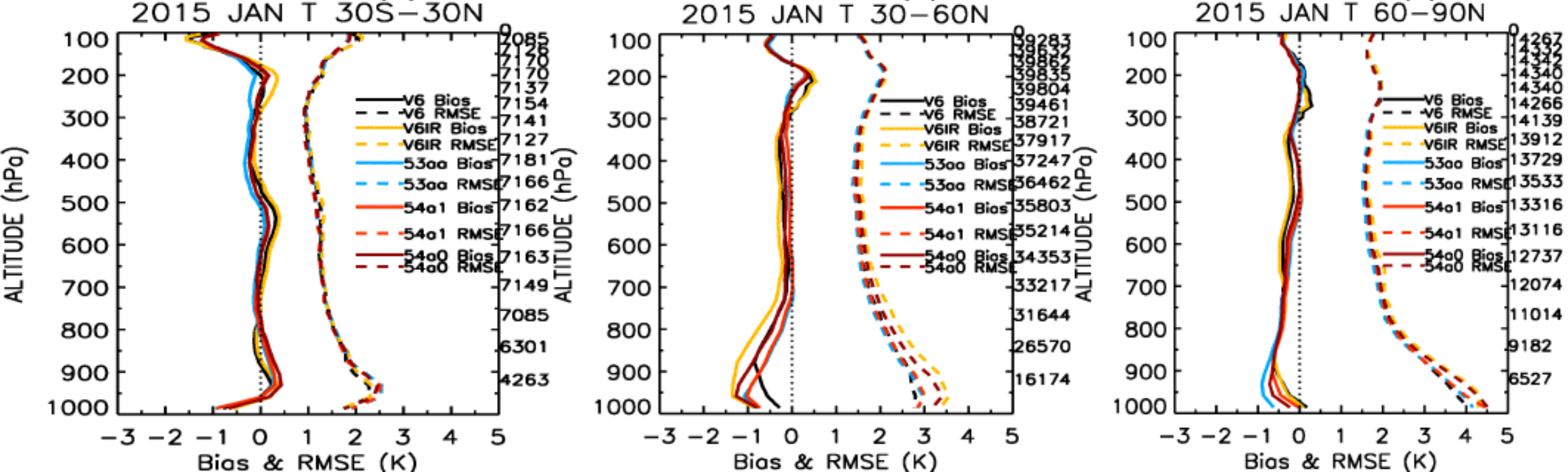
Summary of JPL AIRS 'V7' Testing Analyses

- Sounding system data product testing framework developed at JPL.
- The latest V6.X products that have been tested: V6.54IR only, V6.53IR+MW, V6.54a1
  - *Improved SCCNN:*
    - removing the biased ECMWF in the training data (V6.46)---CHART
    - increased training dataset to deal with interannual variability (V6.50)
    - projected principle component method to reduce SCC errors near sfc (V6.51IR)
    - Improved SCCNN training over polar (V6.53)
  - *Modified QC methodology (V6.52, V6.53, V6.54):*
    - QC in PBL over land now relies more on near surface layers
    - Tighter QC thresholds for mid and low atmosphere over land and mid atmosphere over frozen surfaces
  - *IR-only surface classes:*
    - GFS snow cover and snow water equivalent data used to distinguish non-frozen and frozen surfaces (since V6.46).
  - *Algorithm: Changed channel sets, internal covariance matrix methodology, O_3*: (preV6.4)
  - Test versions:
    - V6.54a1: IR-only retrieval with AIRS+A1 SCCNN
    - V6.56: GFS T, Q, Sfc T as prior

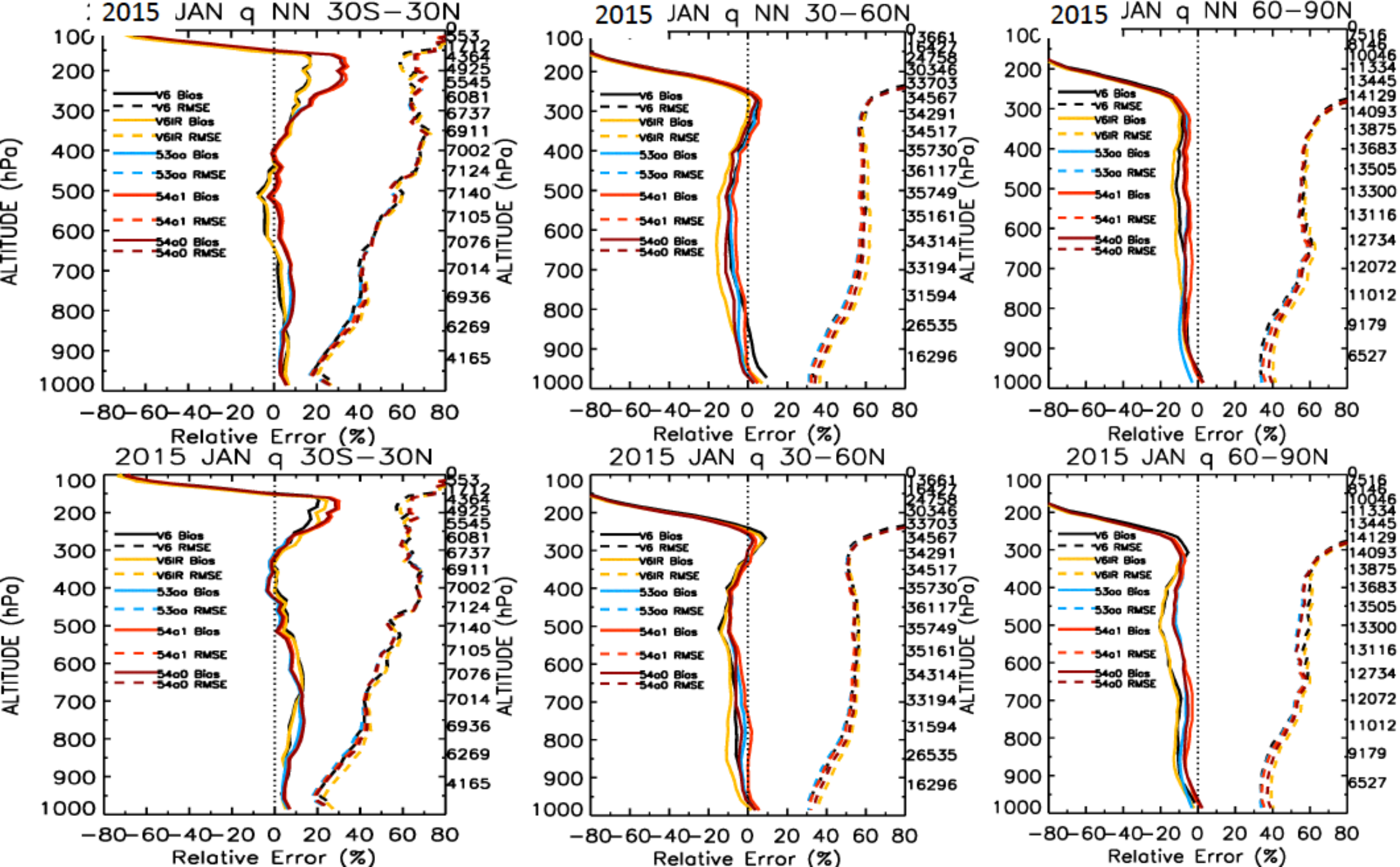
Backup



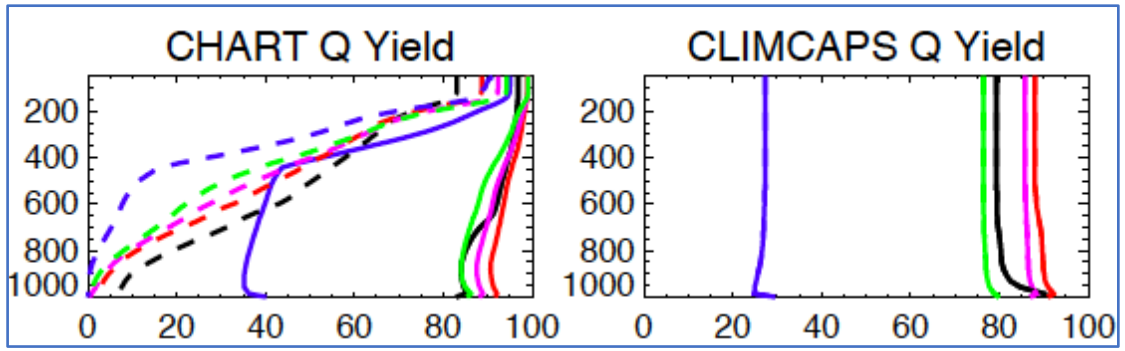
2015 Jan NN T



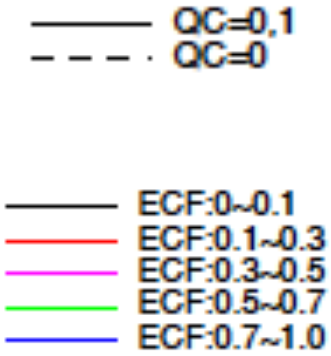
2015 Jan Retrv. T

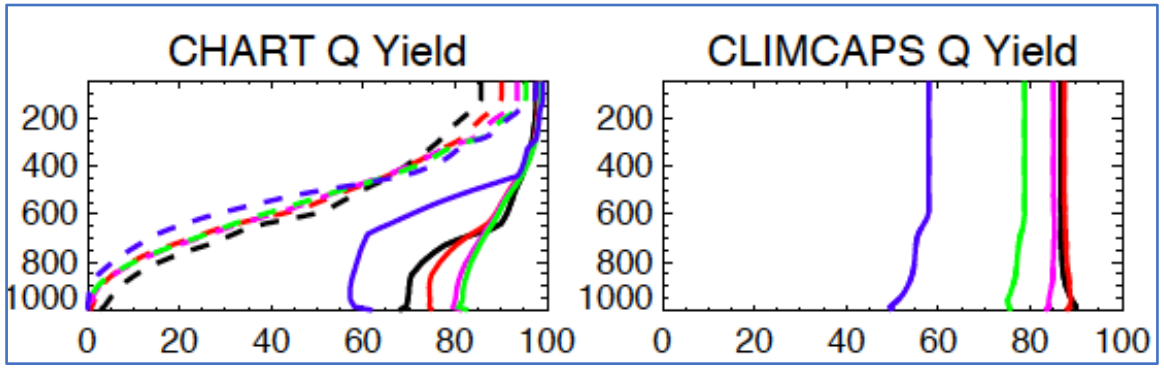

2015 JAN q NN 30S−30N
2015 JAN q NN 30−60N
2015 JAN q NN 60−90N
2015 JAN q 30S−30N
2015 JAN q 30−60N
2015 JAN q 60−90N
V6 Bias
V6 RMSE
V6IR Bias
V6IR RMSE
53oo Bias
53oo RMSE
54o1 Bias
54o1 RMSE
54o0 Bias
54o0 RMSE
ALTITUDE (hPa)
Relative Error (%)
2015 Jan NN q
2015 Jan Retrv. T

CrIMSS Initial Data Product Testing and Validation by JPL AIRS Team



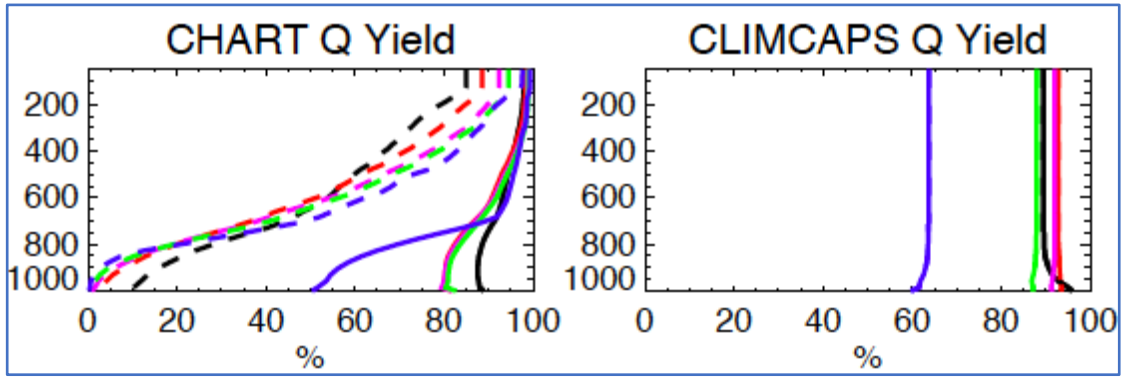
High Cloud: CTP < 440 hPa

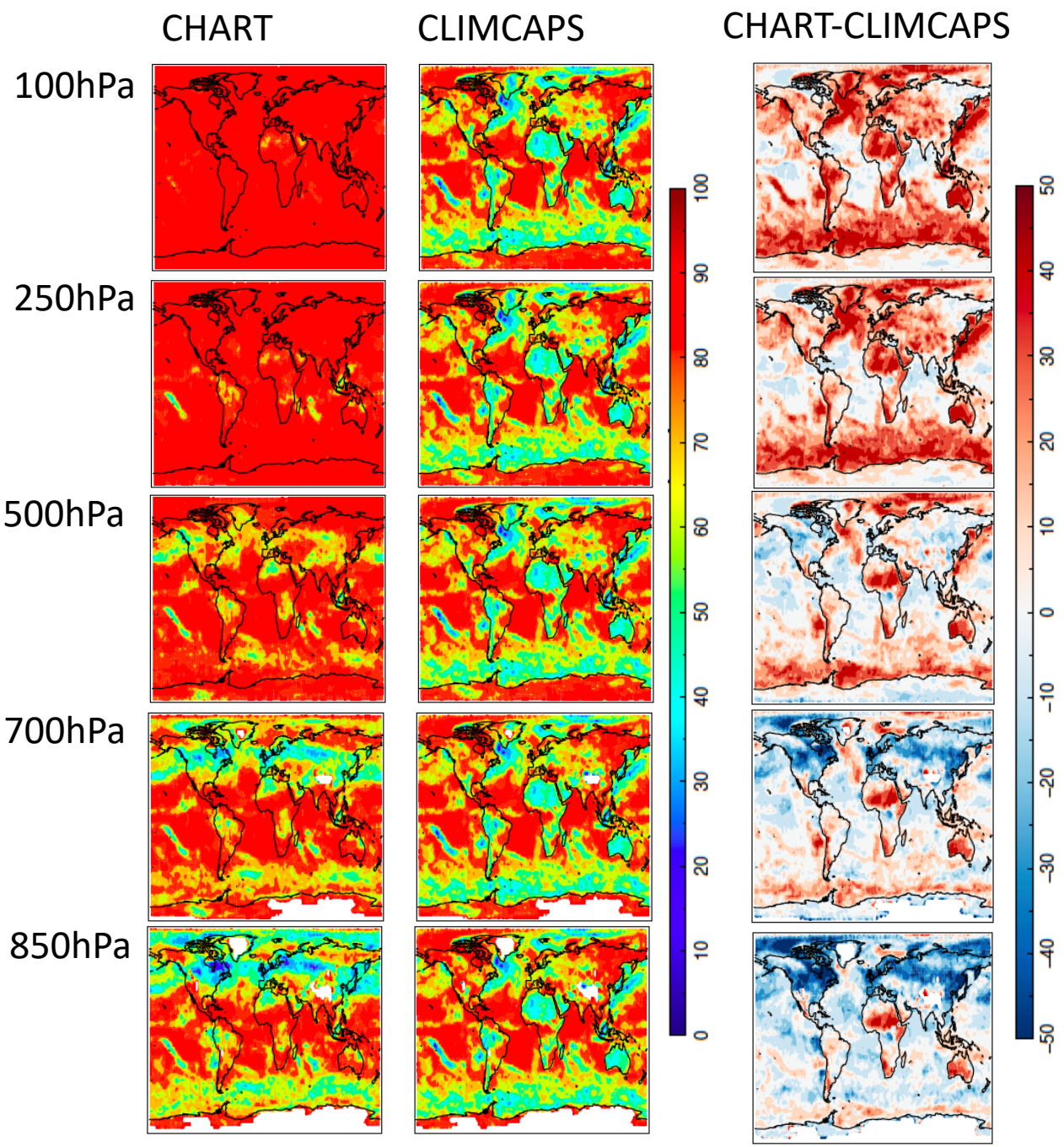




Middle Cloud:
440 hPa < CTP < 680 hPa

Low Cloud: CTP > 680 hPa

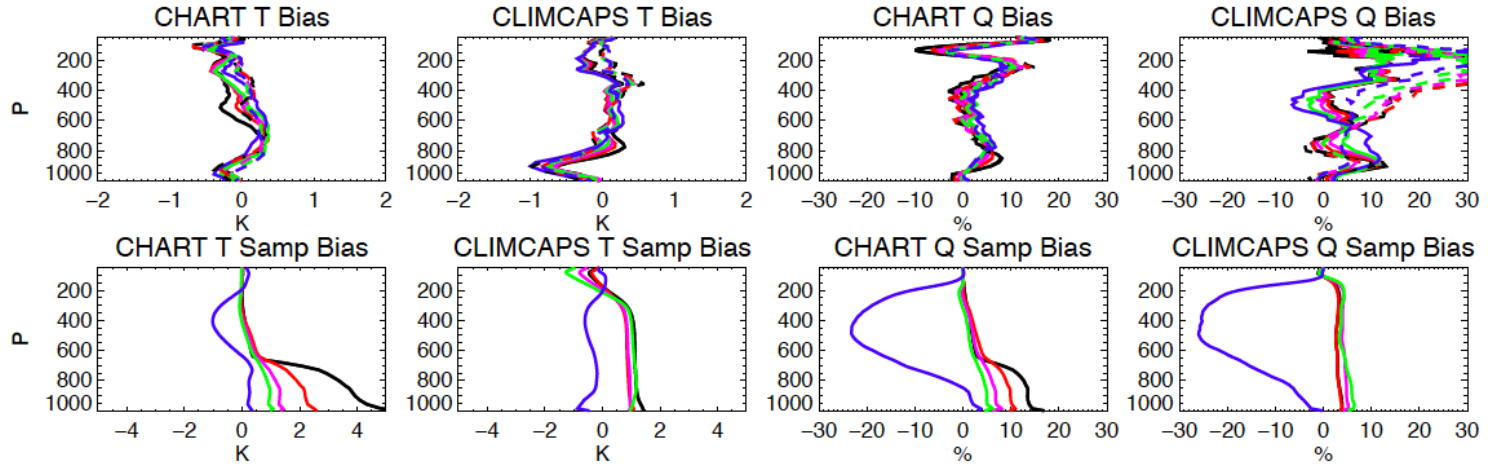




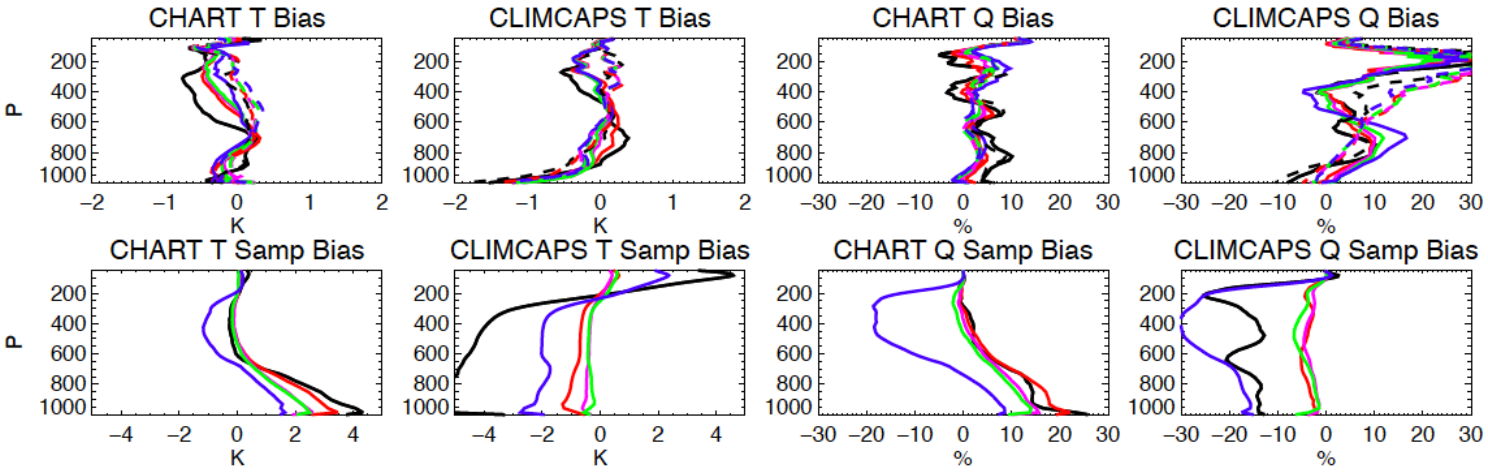
Yield Maps

1. Low yield of CLIMCAPS over desert.
2. CHART yield becomes smaller than CLIMCAPS over high lat land during code season (Jan 2015 test data).

Global Ocean:



Global Land:



ECF:0~0.1
ECF:0.1~0.3
ECF:0.3~0.5
ECF:0.5~0.7
ECF:0.7~1.0

Final retrieval
First Guess

Summary

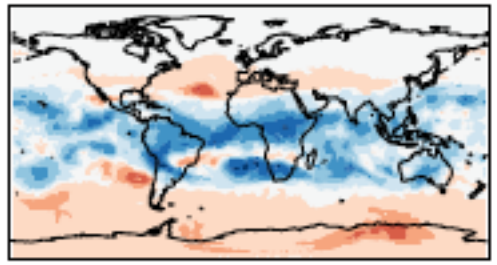
1. CHART and CLIMCAPS retrievals and first guesses (FG) of L2 temperature and water vapor products are compared against collocated ECMWF.
2. Separate QCs are applied to CHART and CLIMCAPS: user point of view, good retrievals by their individual QC flags.
3. For water vapor,
    1. The official level specific humidity (SH) is taken directly from the product and the FGs are provided in the lay_mol goup. In order to compare final retrieval with FG, level SH is derived by log(pres) interpolation from both final retrieval and the FG for CHART and CLIMCAPS (same tool, same pressure vertical bins).
    2. In the derived SH comparison, the difference between CHART and CLIMCAPS retrievals is much smaller than results using the official level SH product, which comes from a much larger change on the CLIMCAPS. Reason is unclear since the same post processing tool is used to derive level SH in the official product.
4. For temperature,
    1. Most of the differences between CHART and CLIMCAPS are from their different FGs.
    2. CHART has biases in N. America and Europe in the PBL where CLIMCAPS produces a nearly zero bias. These regions have very dense surface observations which are assimilated in the reanalysis.
    3. At 500hPa over Antarctic, CHART temperature retrieval is different from their first guess (NN). Reason unclear.
    4. At 100hPa, CHART produces a cold bias against ECMWF, which is from NN.

CHART

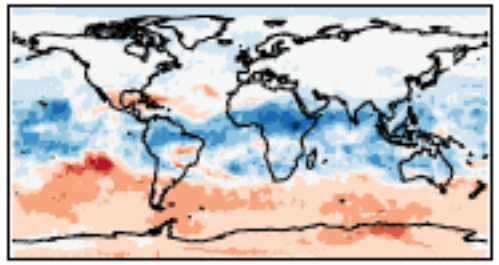
CLIMC

CHART-CLIMC

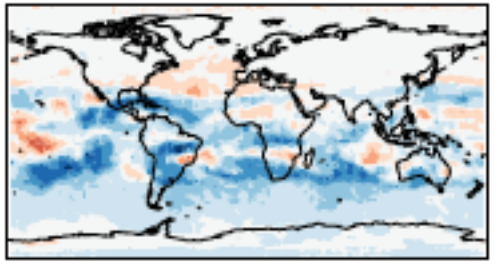
CHART Q Ret Bias



CLIMCAPS Q Ret Bias

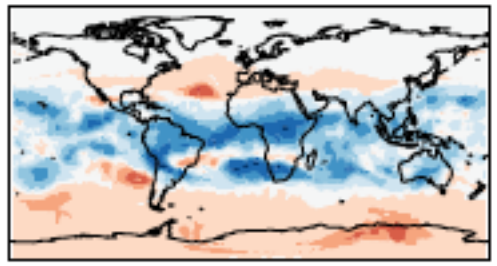


Q Ret: CHART–CLIMCAPS

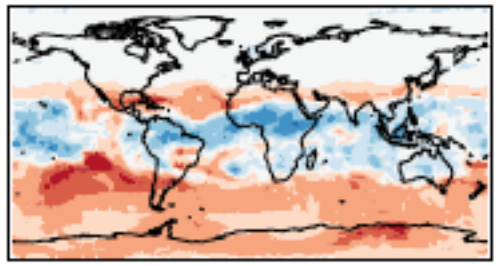


Retrieval: Level SH derived from official layer_mol: log(layer_mol) interpolated from log(air_pres_lay) to log(air_pres)

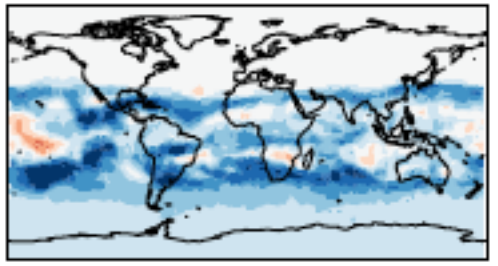
CHART Q FG Bias



CLIMCAPS Q FG Bias

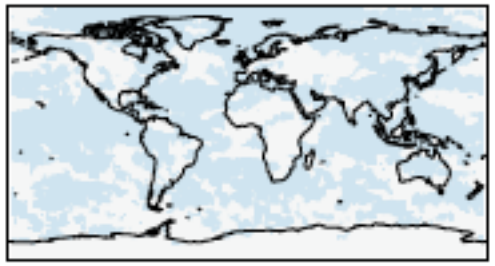


Q FG: CHART–CLIMCAPS

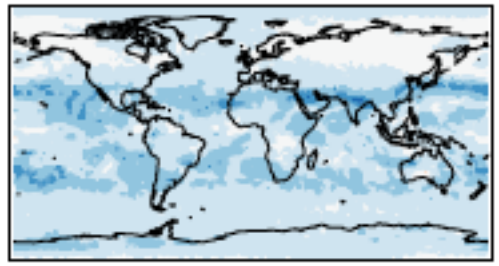


First Guess: Level SH derived from official layer_mol: log(layer_mol) interpolated from log(air_pres_lay) to log(air_pres)

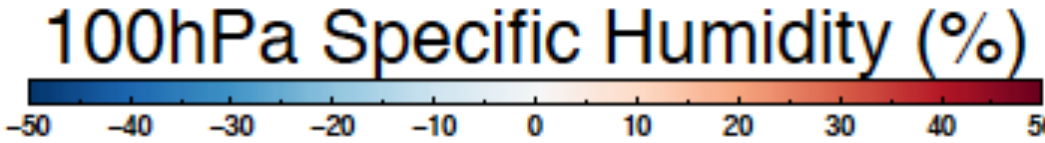
Q CHART: Ret–FG



Q CLIMCAPS: Ret–FG



Retrieval-F. G

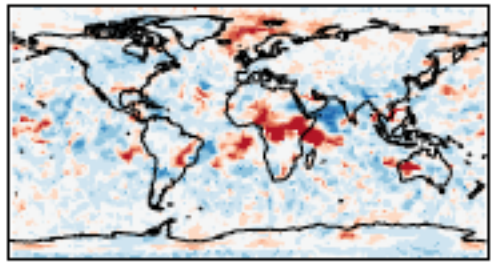


CHART

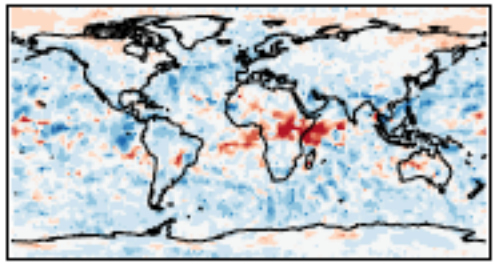
CLIMC

CHART-CLIMC

CHART Q Ret Bias



CLIMCAPS Q Ret Bias



Q Ret: CHART–CLIMCAPS

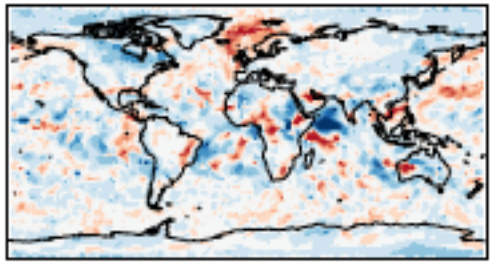
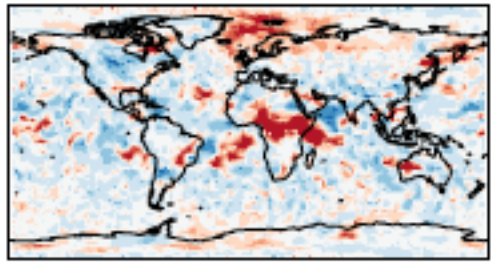


CHART Q FG Bias



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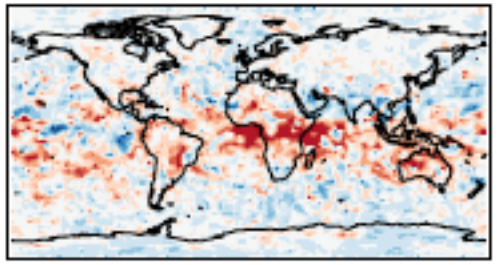

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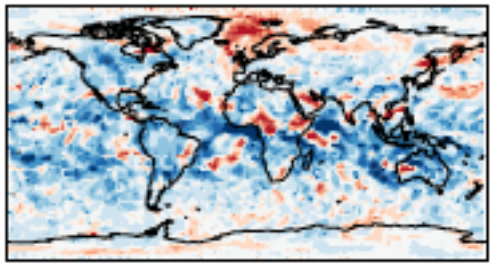

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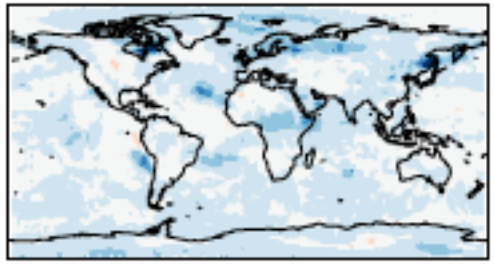

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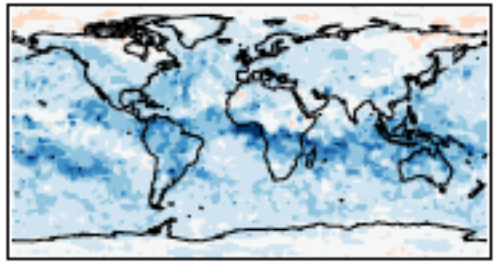
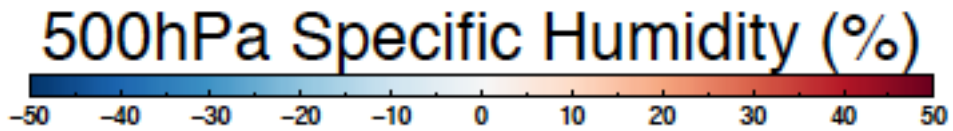


Retrieval: Level SH derived from official layer_mol: log(layer_mol) interpolated from log(air_pres_lay) to log(air_pres)

First Guess: Level SH derived from official layer_mol: log(layer_mol) interpolated from log(air_pres_lay) to log(air_pres)

Retrieval-F. G

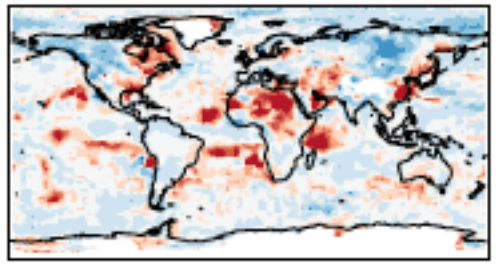


CHART

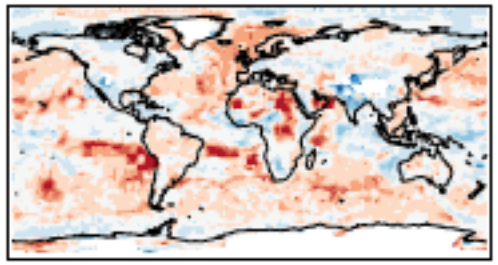
CLIMC

CHART-CLIMC

CHART Q Ret Bias



CLIMCAPS Q Ret Bias



Q Ret: CHART–CLIMCAPS

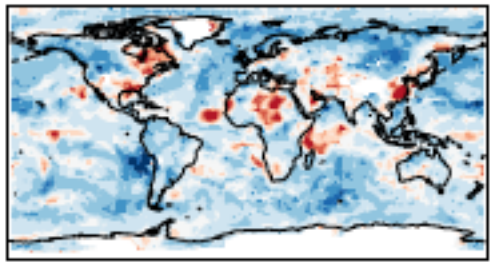
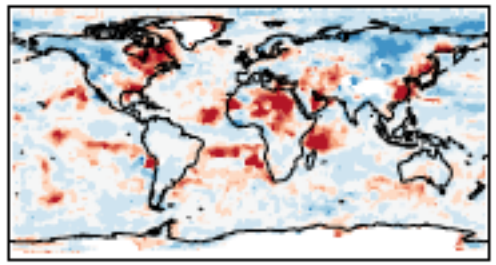
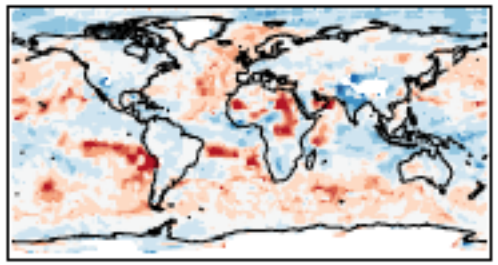


CHART Q FG Bias



CLIMCAPS Q FG Bias



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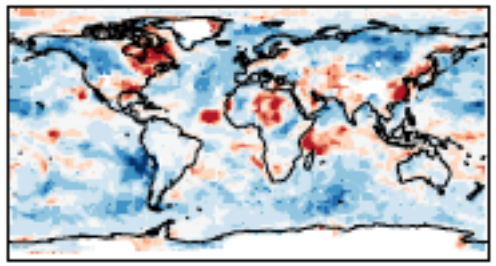
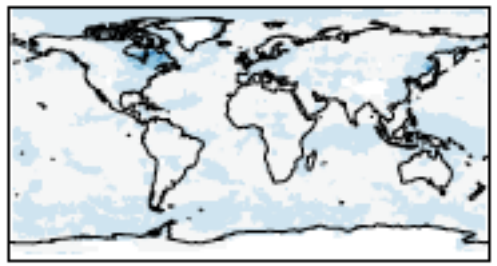
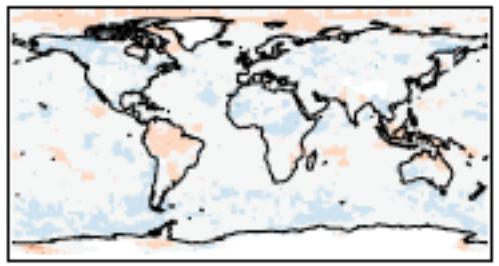


Q CHART: Ret–FG



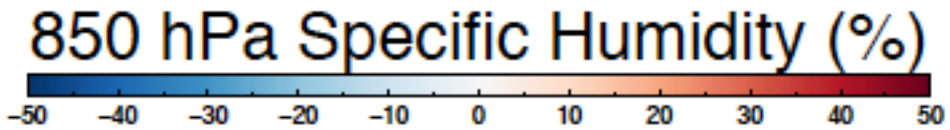
Q CLIMCAPS: Ret–FG



Retrieval: Level SH derived from official layer_mol: log(layer_mol) interpolated from log(air_pres_lay) to log(air_pres)

First Guess: Level SH derived from official layer_mol: log(layer_mol) interpolated from log(air_pres_lay) to log(air_pres)

Retrieval-F. G



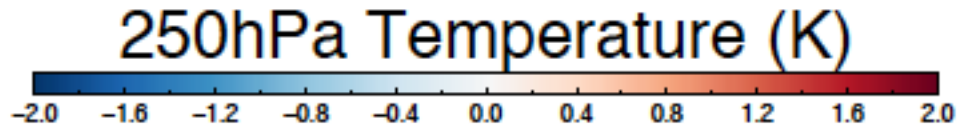
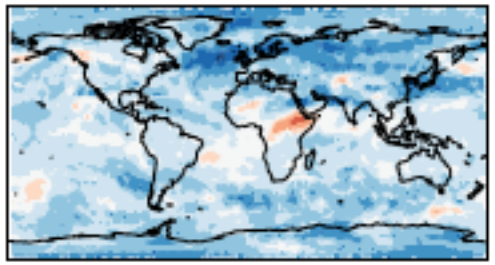
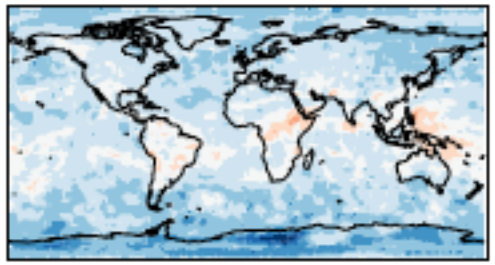


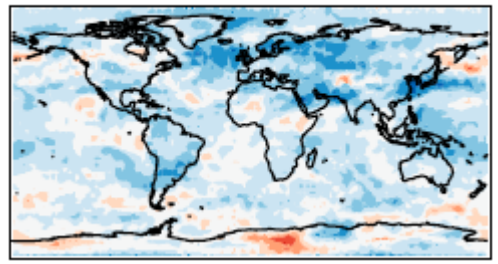
CHART T Ret Bias



CLIMCAPS T Ret Bias

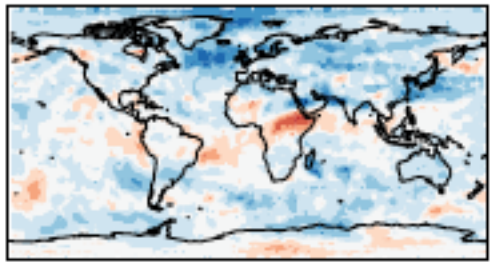


T Ret: CHART–CLIMCAPS

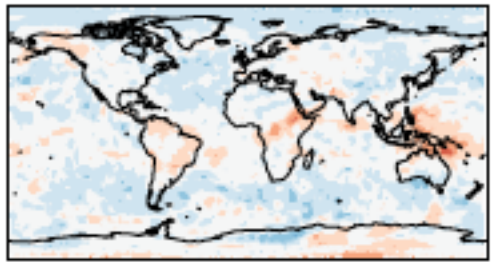


Retrieval

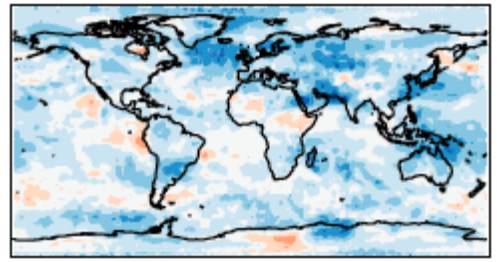
CHART T FG Bias



CLIMCAPS T FG Bias

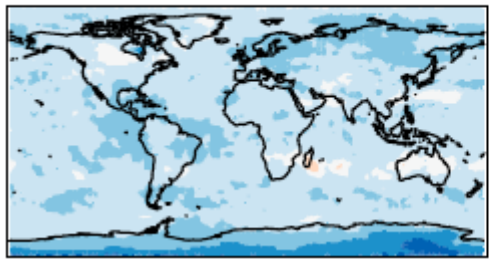


T FG: CHART–CLIMCAPS

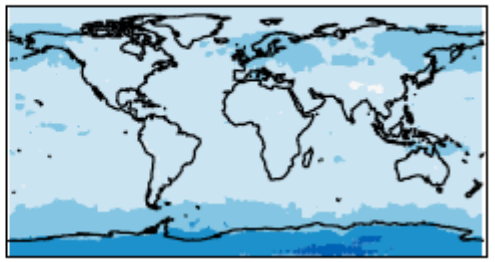


First Guess

T CHART: Ret–FG



T CLIMCAPS: Ret–FG



Retrieval - First Guess

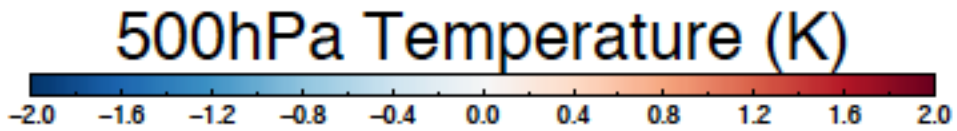
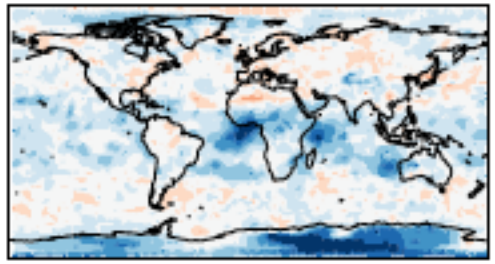
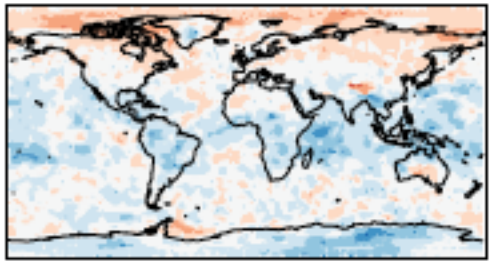


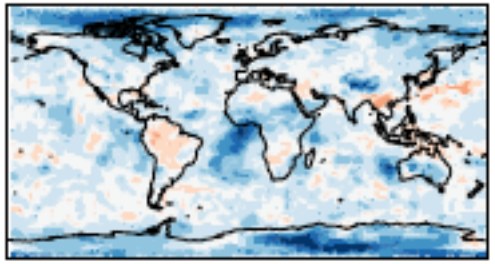
CHART T Ret Bias



CLIMCAPS T Ret Bias

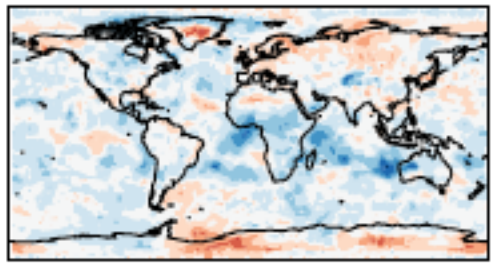


T Ret: CHART−CLIMCAPS

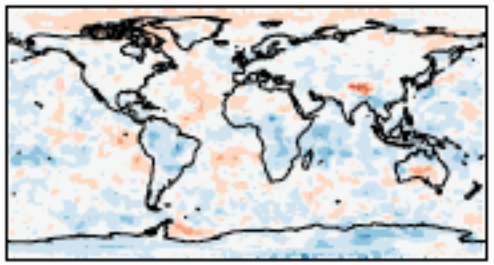


Retrieval

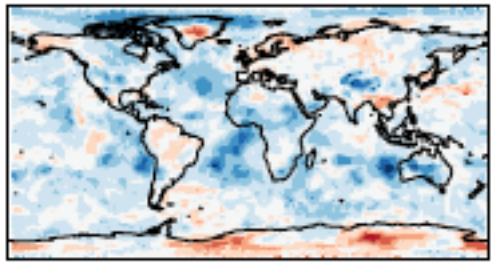
CHART T FG Bias



CLIMCAPS T FG Bias

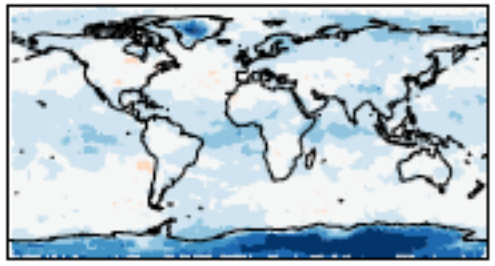


T FG: CHART−CLIMCAPS

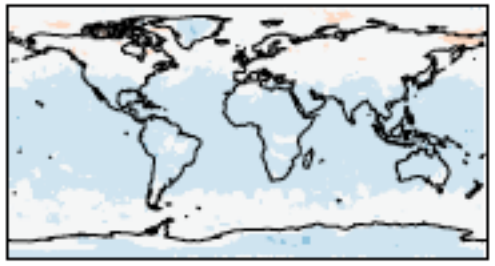


First Guess

T CHART: Ret−FG



T CLIMCAPS: Ret−FG



Retrieval - First Guess

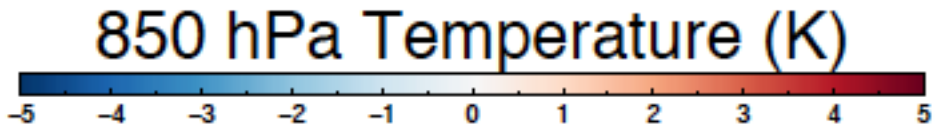
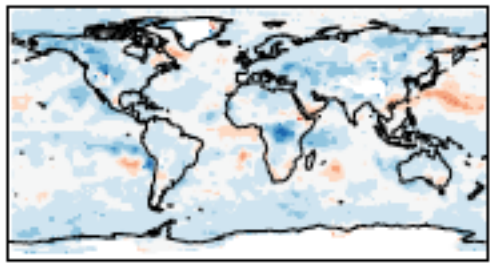
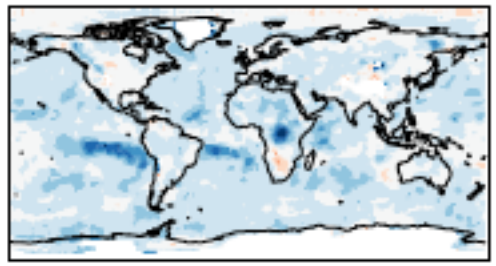


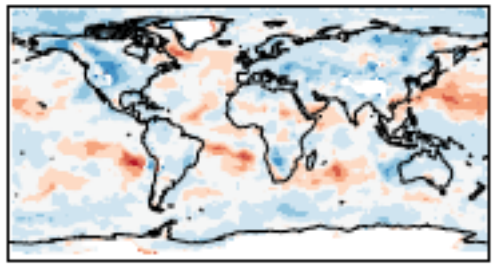
CHART T Ret Bias



CLIMCAPS T Ret Bias

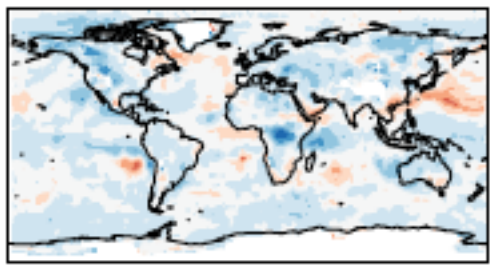


T Ret: CHART–CLIMCAPS

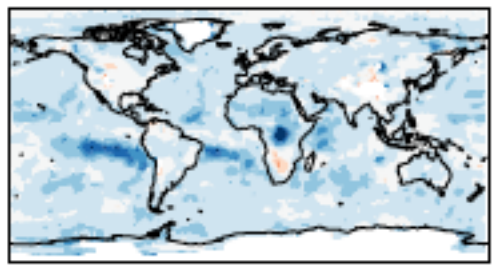


Retrieval

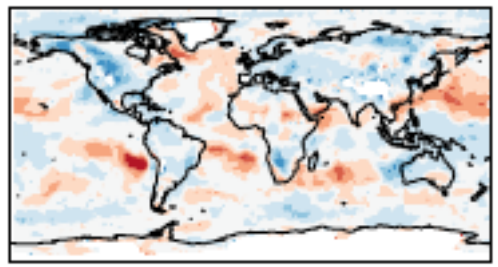
CHART T FG Bias



CLIMCAPS T FG Bias

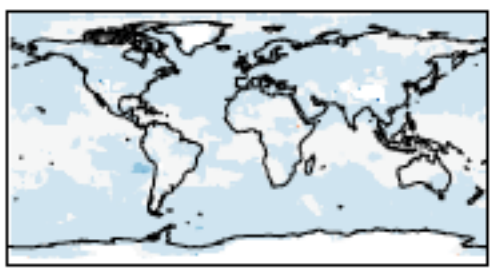


T FG: CHART–CLIMCAPS

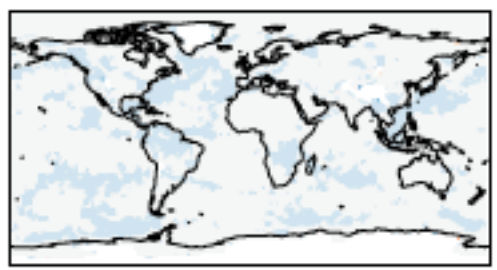


First Guess

T CHART: Ret–FG



T CLIMCAPS: Ret–FG



Retrieval - First Guess

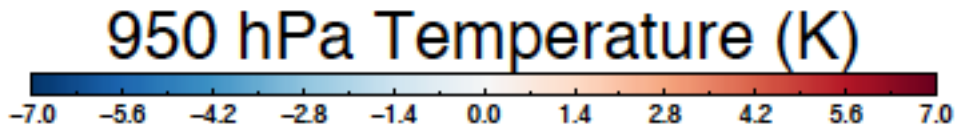
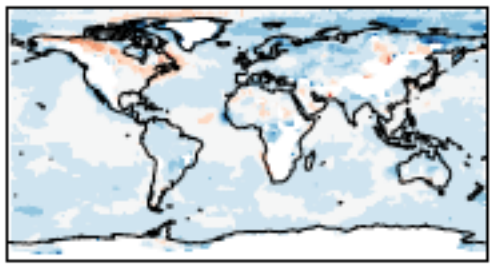
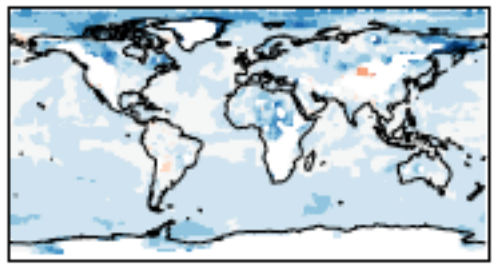


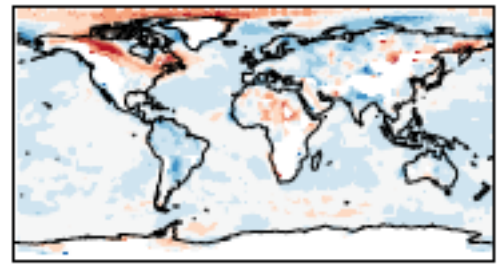
CHART T Ret Bias



CLIMCAPS T Ret Bias

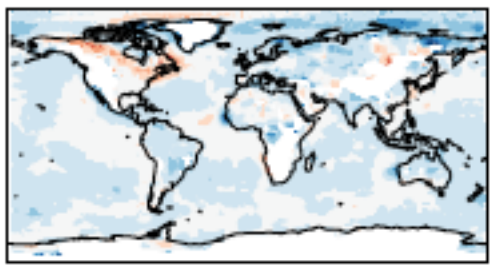


T Ret: CHART−CLIMCAPS

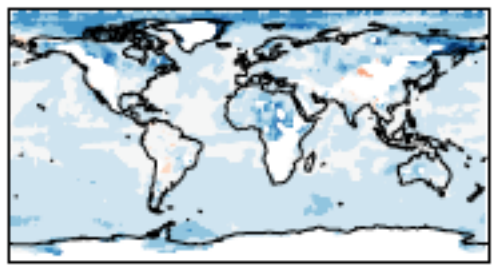


Retrieval

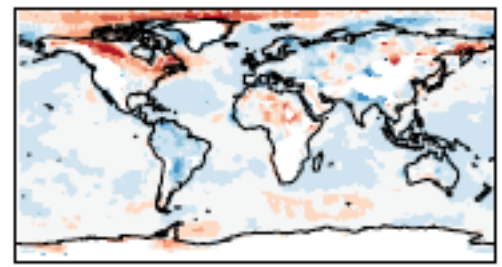
CHART T FG Bias



CLIMCAPS T FG Bias

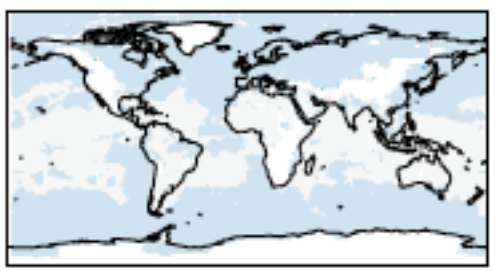


T FG: CHART−CLIMCAPS

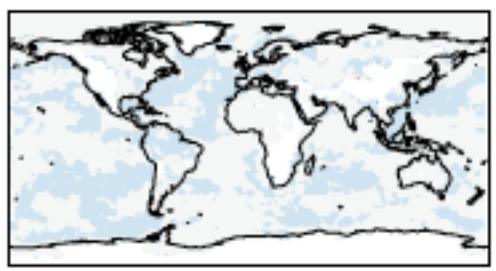


First Guess

T CHART: Ret−FG



T CLIMCAPS: Ret−FG



Retrieval - First Guess

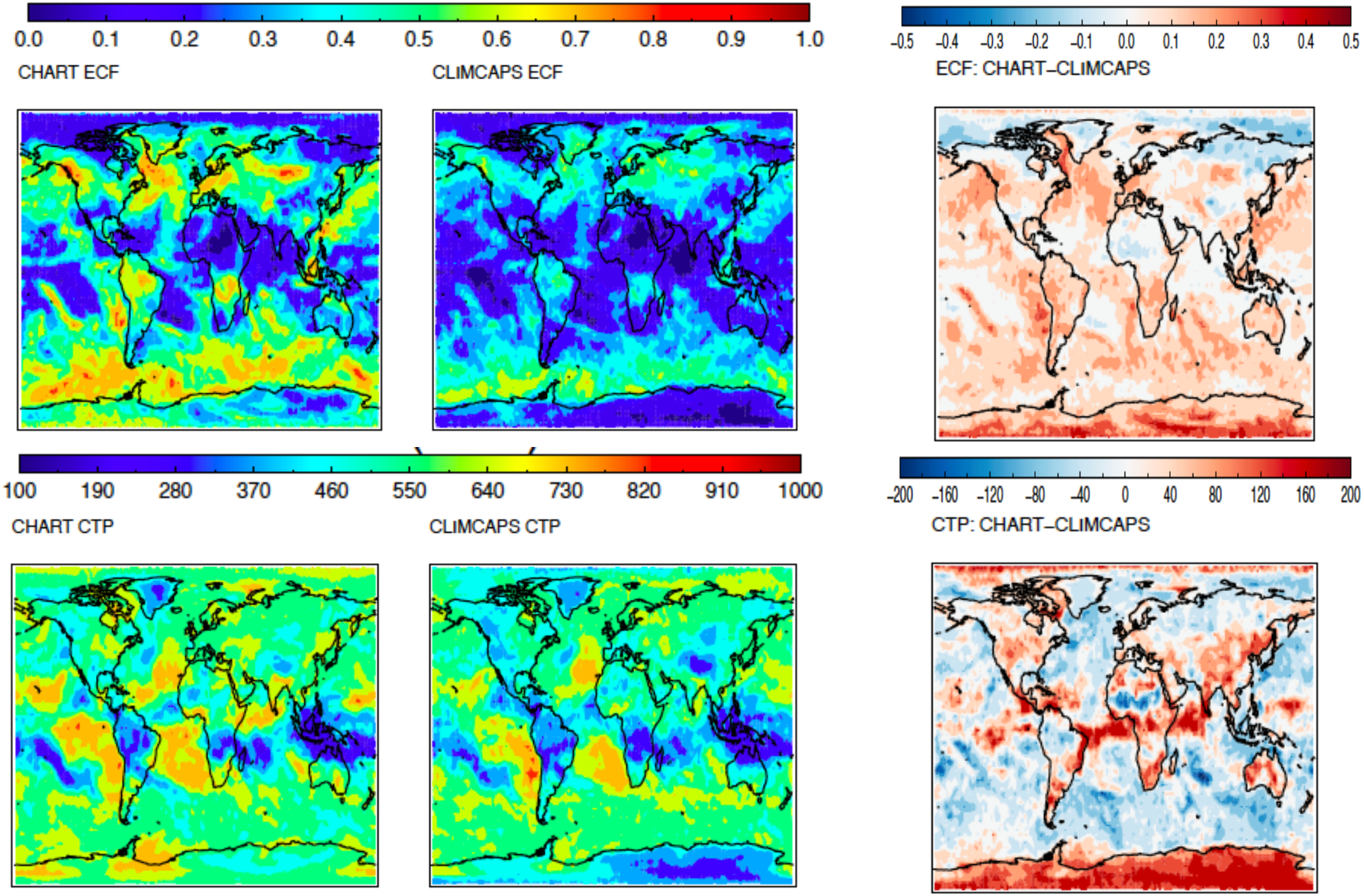

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
CHART ECF
CLIMCAPS ECF
−0.5 −0.4 −0.3 −0.2 −0.1 0.0 0.1 0.2 0.3 0.4 0.5
ECF: CHART−CLIMCAPS
100 190 280 370 460 550 640 730 820 910 1000
CHART CTP
CLIMCAPS CTP
−200 −160 −120 −80 −40 0 40 80 120 160 200
CTP: CHART−CLIMCAPS

Table 1 Summary of Stage 0 Testing Analyses

Var	Reference Data	Contributor	Method	Notes
L2 Temperature and water vapor profiles: T(P) Q(P)	Reanalysis	Qing Yue Evan Fishbein (Yue et al. 2013)	1. Collocation by the nearest neighbor method (with ability of temporal and spatial interpolation to the exact ECMWF data point). 2. Reanalysis profiles are interpolated to AIRS vertical grid. 3. Biases and RMSE are calculated for retrieval and NN from various versions of AIRS against reanalysis.	• Available globally at different time scales • Initial quality check and inter-comparison.
L3 Temperature and water vapor profiles: T(P) Q(P)	Reanalysis	Qing Yue Baijun Tian (Yue et al. 2013, Hearty et al. 2014)	1. Gridded data comparison on daily/monthly mean fields. 2. Yield and sampling biases. 3. Version to version changes	
L3 Total Precipitable Water Vapor (TPW)	AMSR, TMI, GMI, reanalysis	Qing Yue	1. Gridded data comparison on daily/monthly mean fields. 2. Yield and sampling biases. 3. Version to version changes.	• No land data from these microwave instruments.
L3 Surface Skin Temperature and Surface Air Temperature	Reanalysis	Qing Yue Evan Manning	1. Gridded data comparison on daily/monthly mean fields. 2. Yield and sampling biases. 3. Version to version changes.	• Performance on these retrievals link to the surface type and surface emissivity, especially over frozen surfaces.

Table 2 Summary of Stage 1-A Testing Analyses

Var	Reference Data	Contributor	Method	Notes
L2 Temperature and water vapor profiles: T(P) Q(P)	Dedicated sonde, IGRA sonde, and ECMWF mainly over Europe, and N. America	Sun Wong (Wong et al. 2015)	1. Collocate AIRS with reference data using the nearest neighbor method with temporal tolerance of 3 hours and spatial tolerance of 200 km. 2. Radiosonde data are interpolated to AIRS 100 pressure levels. 3. Biases and RMSE are calculated for retrieval and NN from AIRS and ECMWF against sonde. 4. Results are stratified by cloud fraction, surface condition, and latitude bands.	• Stage 1-A • Sonde density see Fig. 1. • Long-term availability of reference data
	MAGIC (9/2012–10/2013) sonde and ECMWF over Pacific subtropical ocean	Peter Kalmus Evan Manning (Kalmus et al. 2015)	1. Collocation by the nearest neighbor method with temporal tolerance of 6 hours and spatial tolerance of 200 km. 2. Radiosonde data are interpolated to AIRS 100 pressure levels. 3. Biases and RMSE are calculated for retrieval and NN from AIRS and ECMWF against sonde. 4. Results are stratified by longitude bins.	• Stage 1-A • Subtropical low cloud region in Northeastern Pacific only (ship tracks shown in Fig. 2). • 9/2012–10/2013
	Reanalysis	Qing Yue Evan Fishbein (Yue et al. 2013)	1. Collocation by the nearest neighbor method (with ability of temporal and spatial interpolation to the exact ECMWF data point). 2. Spatial distribution of differences between AIRS (retrieval and NN) and reanalysis. 3. Sorting differences by multiple conditions: cloud, surface, season, etc to diagnose the cause of changes.	• Stage 1-A

Table 3 Summary of Stage 1-B Testing Analyses

Var	Reference Data	Contributor	Method	Notes
L2 Near surface air temperature and water vapor: NSAT and NSWV	• Ocean: ICOADS, Buoy and shiptrack data • Land: mesonet over land (CONUS)	R. Chris Wilson	1. Collocation by the nearest neighbor method with temporal tolerance of 1 hour and spatial tolerance of 50 km. 2. Biases and RMSE are calculated for retrieval and NN from AIRS against reference data. 3. Results conditioned on cloud and regions.	• Stage 1-B • MesoNet over CONUS (Fig. 3a). • ICOADS distribution over ocean in Fig. 3b). • Long-term availability of reference data.
Ozone: O_3 (Total and profile)	O_3 measured by uplooking UV-Visible spectrometer from Dumont d'Urville station (Fig. 4)	Evan Fishbein	1. Two closest matches in AIRS data by the nearest neighbor method. 2. Location is selected for its largest variability along the edge of the hole, near the Antarctic coast, showing the influence of stratospheric weather on polar vortex isolation and mixing 3. Specific year is identified when O_3 at this location is different from the mean climatology. 4. Time series of total O_3 and individual vertical profiles are examined.	• Stage 1-B • Long-term availability of reference datasets to increase sample size and site numbers.
L2 Total precipitable water: TPW	GPS ground stations	Qing Yue Evan Manning Evan Fishbein	1. Collocation by the nearest neighbor method with temporal tolerance of 0.5 hour and spatial tolerance of 100 km; multi-year 2. Collocation by the box method. 3. Biases and RMSE are calculated for retrieval and NN from AIRS against GPS. 4. Results conditioned on cloud, land-only	• Stage 1-B • Possibility to include more GPS network to cover global land regions. Currently results are over US only (Fig. 5).
CO_2	HIPPO "deep profiles": aircraft measurements extended above the 190hPa pressure level to ensure good coverage of the AIRS CO_2 sensitivity profile (Table 5)	Ed Olsen (?)	1. Collocation by the box method with temporal tolerance of 24 hours and spatial tolerance of 500 km. 2. Convolved HIPPO profiles provide partial column CO_2 measurements to compare with AIRS.	• Stage 1-B • Over ocean (mid-Pacific only), far from emission source

Table 4 Summary of Stage 2 Testing Analyses

Var	Reference Data	Contributor	Method	Notes
L2 Cloud-cleared radiances:CC-Rads	MODIS clear radiances	R. Chris Wilson Mathias Schreier (Schreier et al, 2018)	1. Collocate multiple MODIS pixels within one AIRS FOV and only the clear MODIS pixels as flagged by the MODIS clear 35 flag are used in the analysis. 2. The AIRS CCRs are spectrally convolved to MODIS channels 22, 24, 28, 32, 33, 34, and 35, while clear MODIS radiances are spatially convolved to the AIRS field of regard. 3. Brightness temperature differences between AIRS and MODIS are calculated and compared with the expected errors indicated by the QCs of AIRS CCR product.	• Require collocation between sounder and cloud imager.
L2 Temperature profiles and bias drift with time	PREPQC radiosonde	Fredrick Irion	1. Collocation by the nearest neighbor method with temporal tolerance of 1 hour and spatial tolerance of 100 km. 2. Both direct comparisons based on linear interpolation and the kernel smooth method are used. 3. Both the temperature bias/RMSE and trend of T bias profiles are calculated. 4. Results are stratified by latitude.	• Long-term availability of reference data. • Results are dominated by large samples over Europe (Fig. 6). • Drift of bias tested.
L2 information content and vertical resolution analysis	None	Evan Fishbein Fredrick Irion	1. Information content analysis: averaging kernel, degree of freedom, retrieval error estimation 2. Vertical resolution and sensitivity	• Results on AIRS V6 Ozone are available and can extend to other profile retrievals.
Surface Classes	• Northern Hemisphere: National Ice Center's Interactive Multisensor Snow and Ice Mapping System (IMS) NH Snow and Ice Analysis at 24-km resolution (Daily) • Antarctic Area: NOAA Antarctic Sea Ice Extent Data (Daily).	Qing Yue Evan Manning Bjorn Lambrigtsen	1. Reference data at daily scale. 2. Compare daily surface classes from AIRS with reference data.	
L3 Tropopause height, pressure, and temperature	GPS RO	Baijun Tian	1. Mean field and yield analysis 2. Version to version changes	
Cloud Properties	None	Brian Kahn	1. Pixel-scale comparisons on cloud properties including thermodynamic phase, cloud fraction, cloud top pressure among different versions.	
L3 Total Column Ozone (Daytime)	OMI	Fredrick Irion	1. Mean field and yield analysis 2. Version to version changes	
Other trace gases	unknown	Vivienne Payne	Collaboration with the composition group	