Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

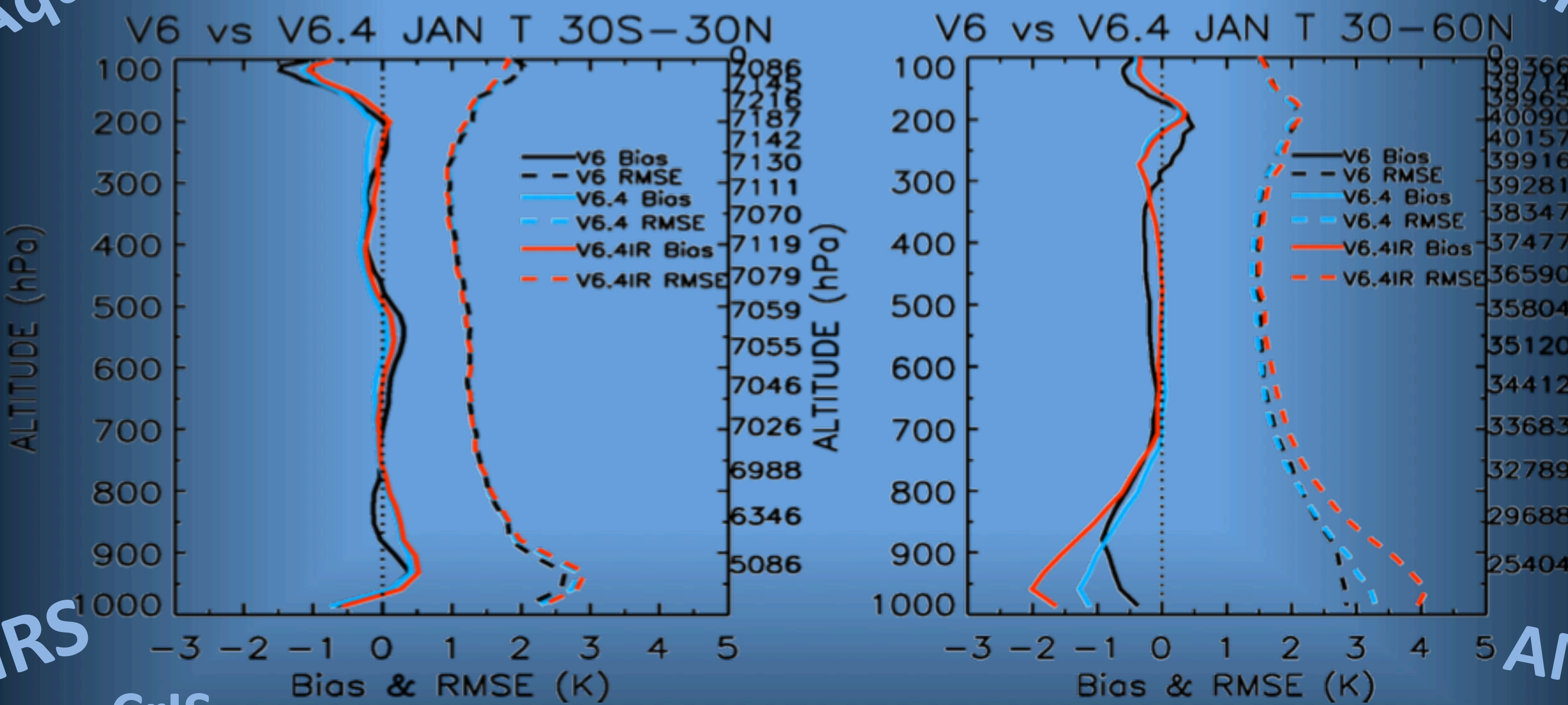
# Assessing Sounder Performance

## Comprehensive capabilities at JPL

Bjorn Lambrigtsen, Jet Propulsion Laboratory, California Institute of Technology

Aqua

S-NPP




AIRS

AMSU

CrIS

ATMS

IASI

MODIS

suborbital

GPSRO

raobs

NASA Sounder Science Team Meeting, Greenbelt, October 24-26, 2017

# Sounding Science Themes

## Focus is on the troposphere

- "Moist thermodynamics": water vapor is the key variable
- Water cycle in the atmosphere: water vapor, clouds, precipitation
- Atmospheric processes controlling weather and climate; severe storms

## Illuminated by tropospheric sounders & related sources

- IR sounders: AIRS, CrIS, IASI etc.; MW sounders: AMSU, ATMS etc.
- CYGNSS, GPSRO, GPS-met, raobs, buoys, airborne

## Science questions

- *How do small-scale weather processes interact with the large-scale thermodynamic environment?*
- *What controls the intensity, distribution and likelihood of convective storms, and how can we use satellite observations to improve modeling and prediction of important weather events?*
- *How well do climate models compare to observations, and how can we use global satellite observations to improve the models?*
- *What phenomena relevant to our research themes are not adequately observed and require new observing strategies and systems to be developed?*

# Sounding Science Groups at JPL

**"Atmospheric Physics and Weather" group: Focus on AIRS**

- *Has provided most of AIRS science support since 1980's*
- Has developed into a significant sounding-science research group
- Funded from R&A, AIRS, NPP and other sources

**Unique capabilities & expertise in Sounding Science**

- *Complete range of expertise, from instruments to atmospheric research*
- Instruments & algorithms: AIRS, AMSU, CrIS, ATMS; L0→L3; climatology
- Data & data products: Thorough understanding; analysis & validation
- Research: Rich research program, high productivity re. published papers

**Related groups: Leverage and collaborations**

- "Aerosols and Clouds" group: built around former MISR group
  - LES simulations; Cloud processes
- "Tropospheric Composition" group: built around former TES group
  - Retrieval algorithms, radiative transfer models
- "Stratosphere and Upper Troposphere" group: former MLS group
  - Upper tropospheric moisture; WRF simulations
- "Statistical Methods" group
  - Data fusion

# Atmospheric Physics and Weather group

## Demographics

– 14 employees; 1 contractor; 3 postdocs (→ 5)

## Business mix and funding base

– 40%: AIRS and CrIMSS science support
– 50%: R&A
– 10%: Field campaigns, new developments, etc.

## Expertise

– Satellite systems; sounders; data characteristics
– Atmospheric science & research
– Retrieval algorithms; radiative transfer models; spectroscopy
– Simulations; OSSEs
– Future instrument & mission development

## Themes & topics

– Water vapor; clouds
– Precipitation
– Tropical cyclones & severe storms
– Water resources/hydrology, droughts, fires
– Climate
– Trace gases & composition; $CO_2$
– Sensor technology & design

# Sounder Analysis Capabilities

**AIRS Project and SNPP-Sounder SIPS provide mission anchor**

- Staff has broad knowledge of AIRS/AMSU and CrIS/ATMS instruments
- Large infrastructure for algorithm development, integration & testing
- Large database supporting product testing & validation
- Supports seamless transition from Aqua to S-NPP to JPSS

**Our goal is to merge data across instruments and platforms**

- Support unified algorithms, data fusion, advanced retrieval methods
- Integrate past/current/future sounder data into long-term record
- Develop collaborations with EUMETSAT and IASI

**Atmospheric Physics and Weather group provides science anchor**

- Broad knowledge and understanding of satellite data & their usage
- Understanding of science user needs from personal research experience

**Partnerships complements local expertise**

- Science teams: Algorithm & product development
- GSFC, NOAA & CIMSS: Instrument expertise, algorithms, mission context

**JPL environment fosters exploration of future directions**

- Specialized sounders: Solve the boundary layer problem
- Geostationary sounders: Provide time resolution of storm environment
- Cubesats & Venture missions: Address the cost & life-cycle problem

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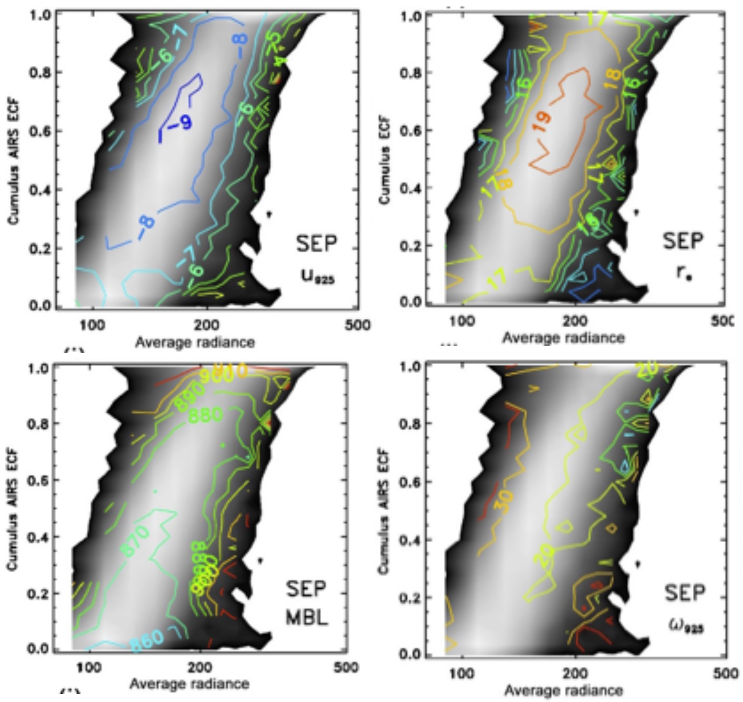
# Research highlight: Brian Kahn

## An A-train and MERRA view of cloud, thermo-dynamic, and dynamic variability




*Joint histograms of MERRA 925 hPa wind speed (upper left), MODIS effective radius (upper right), AIRS MBL depth (lower left), and MERRA 925 hPa vertical velocity (lower right) on top of log counts of visible radiance versus infrared cloud amount*

**Problem:** The global-scale patterns and covariances of subtropical marine boundary layer cloud fraction, atmospheric thermodynamic and dynamic fields remain poorly understood.

**Finding:** A method that uses a combination of A-train and MERRA reanalysis data sets has demonstrated that an increase in effective radius within shallow cumulus is strongly related to higher MBL wind speeds and increased precipitation occurrence that was previously demonstrated with surface observations.

**Significance**: Using remote sensing together with reanalysis, matching at the native pixel and grid scales, an approach that is vastly underutilized, has shown great potential of adding global context to process-level understanding of the strato-cumulus to trade cumulus transition and should be extended to other cloud regimes.

Kahn, B. H., G. Matheou, Q. Yue, T. Fauchez, E. J. Fetzer, M. Lebsock, J. Martins, M. M. Schreier, K. Suzuki, and J. Teixeira (2017), An A-train and MERRA view of cloud, thermodynamic, and dynamic variability within the subtropical marine boundary layer, *Atmos. Chem. Phys.*, **17**, 9451–9468.

*Supported by JPL's R&TD program, the AIRS project at JPL, the NASA Science of Terra and Aqua program under grant NNN13D455T, and the NASA Making Earth Science Data Records for Use in Research Environments (MEaSUREs) programs*

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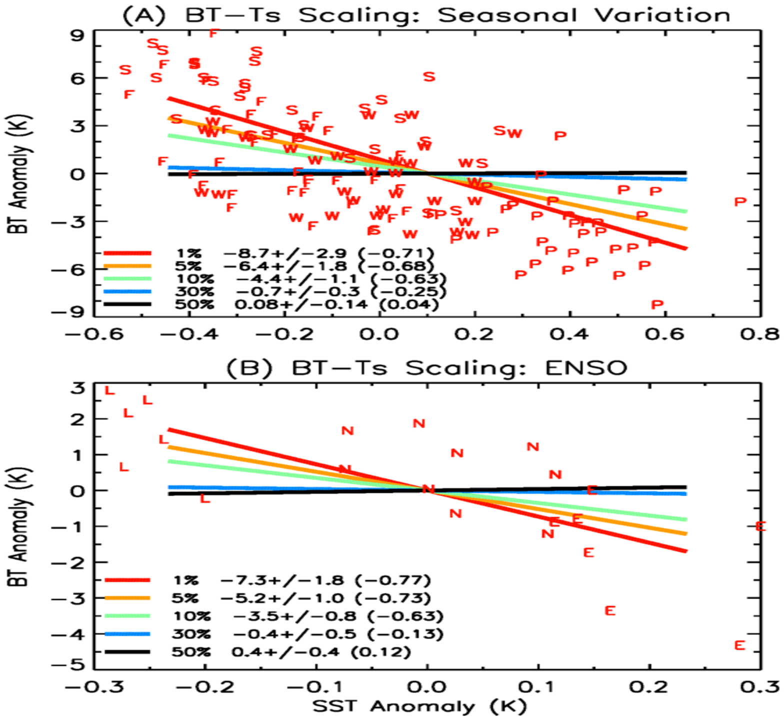
# Research highlight: Sun Wong

*Extreme Convection and Tropical Climate Variability*




Sensitivity of tropical mean over-the-ocean AIRS brightness temperatures (BT) to tropical mean SST for (A) the seasonal variation and (B) the ENSO. Scatter plots are for the 1-st percentile anomalies and the corresponding fitted lines are the red solid lines. The sign of the dots in (A) indicate the Northern Hemispheric seasons with December-January-February as 'W', March-April-May as 'P', June-July-August as 'S', and September-October-December as 'F'. The colors of dots in (B) indicate the El Niño December-January as 'E', La Niña December-January as 'L', and the neutral December-January as 'N'.

How does extreme tropical convection change with sea surface temperature (SST)?

## Finding:

Over the tropical ocean, when convection grows with SST, the more extreme convective events (measured by AIRS window channel brightness temperature) are more sensitive to SST changes, and the median events are insensitive.

## Significance:

Extreme convective events may occur more frequently when SST warms up, in particular over regions where monsoon and tropical storms often occur.

**Sun Wong and João Teixeira (2015): Extreme convection and tropical climate variability: Scaling of cold brightness temperatures to sea surface temperature, *J. Climate,* 29, 3893-3905, doi:10.1175/JCLI-D-15-0214.1.**
**Funding source: AIRS Climate Data Record (PI: João Teixeira).**

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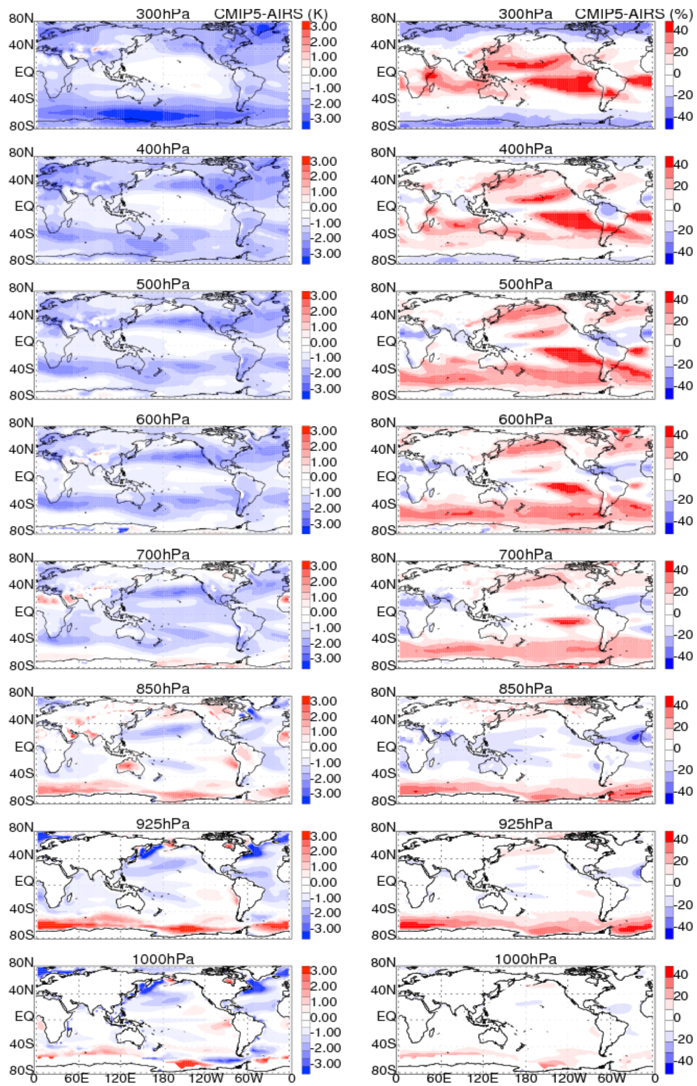
# Research highlight: Baijun Tian

*Evaluating CMIP5 models using AIRS tropospheric air temperature and specific humidity climatology*




## ◆ Problem:

The tropospheric air temperature and specific humidity simulations in CMIP5 climate models have not been well evaluated. Here, we compare the AIRS Obs4MIPs datasets and 16 CMIP5 climate model outputs to evaluate the tropospheric air temperature and specific humidity simulations in CMIP5 climate models.

## ◆ Result:

Based on the AIRS Obs4MIPs datasets, we found two noticeable biases in CMIP5 climate models. The first is a tropospheric cold bias (~2 K) in most CMIP5 climate models (13 of 16). The second is the double-Intertropical Convergence Zone (ITCZ) bias in the troposphere in all CMIP5 climate models.

## ◆ Significance:

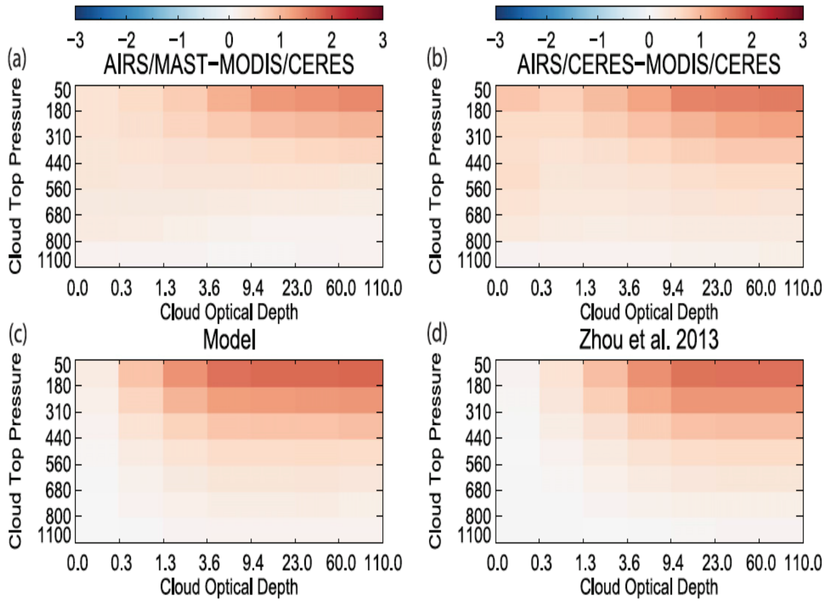
This study demonstrates the strong values of the AIRS Obs4MIPs datasets for CMIP5 model evaluation and the significant biases of the state-of-the-art CMIP5 models.

**Figure**: Systematic biases of tropospheric air temperature (CMIP5−AIRS, K, left) and specific humidity ((CMIP5−AIRS)/AIRS, %, right) climatologies for 16 CMIP5 model ensemble mean.

**Tian et al., 2013, J. Geophys. Res., 118, D50117, doi:10.1029/2012JD018607**

# Research highlight: Qing Yue

*Observation-based Longwave Cloud Radiative Kernels Derived from the A-Train*




**CRKs (W m$^{-2}$ %$^{-1}$) obtained by different data and methods. (a) and (b): Obs.-CRKs using AIRS-MODIS-CERES data for different MODIS retrieval algorithms. (c) and (d): Fu-Liou model calculated CRKs based on satellite and model data as input, respectively.**

**Problem:** Observation-based longwave cloud radiative kernels derived from pixel-scale collocated A-Train and MERRA data to estimate cloud feedback by cloud regime.

**Finding:** The observation-based CRKs show the TOA radiative sensitivity of cloud types to unit cloud fraction change as observed by the A-Train. Observations show a larger TOA radiative sensitivity for optically thin clouds than models.

**Significance:** A combination of observation-based CRKs with cloud changes observed by A-Train provides an estimate of the short-term cloud feedback by maintaining consistency between CRKs and cloud responses to climate variability.

Yue, Q., E. J. Fetzer, B. H. Kahn, M. Schreier, S. Wong, X. Huang, X. Chen, 2016, Observation-based Longwave Cloud Radiative Kernels Derived from the A-Train, J. Climate, 29(6), 2023–2040, doi: http://dx.doi.org/10.1175/JCLI-D-15-0257.1

**Funding source: This work was supported by NASA MEaSUREs (PI: Eric Fetzer), CCST (PI: Qing Yue) and JPL SURP program (PI: Brian Kahn).**

# Integration, Testing, Validation: Approach

**Integration: Support development of new/updated algorithms & SW**

- Functional testing to diagnose problems ← (iterate) → Algorithm dev.
- Performance testing

**Testing: Characterize as-built performance**

- Verify performance claimed by algorithm developers: precision, accuracy
- Verify progress: New versions better than old
- Identify "issues" before users find them
- AIRS V7: Delivery candidate (V6.43) only recently available
  - Preliminary testing done on earlier versions ← Examples on following slides
  - Final testing will proceed shortly

**Validation: Measure performance against "truth"**

- Focused on regions and processes where independent truth is available
  - Independent of data sources used to support and verify algorithm development
- Complete characterization: Uncertainties, information content, etc.
  - Apply "VVUQ" paradigm
- "Absolute" sources: Dedicated raobs, GPSRO, buoys, land met stations, ARM CART, etc.
- "Relative" sources: Other satellite sensors: MODIS, AMSR, etc.
- Comparative analysis: Sounder results vs. reanalysis & forecast models
- Dissemination of results: Peer-reviewed papers; Summary web reports

# AIRS V7 Testing Analysis: Tests, people, data

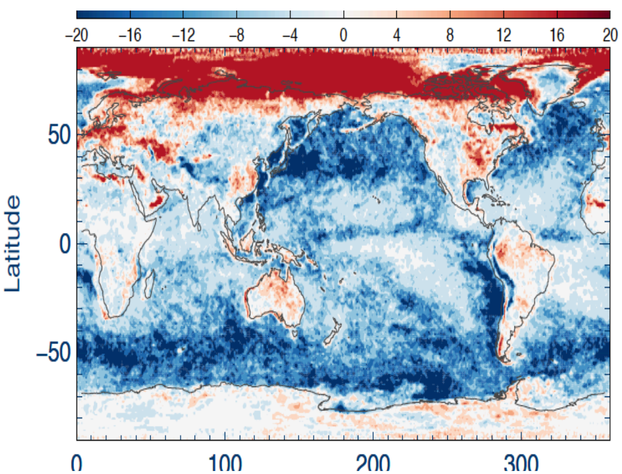
| Variables | POC | Correlative Data | AIRS Data Used |
|---|---|---|---|
| L3 yield, totH2OVap and SST over ocean | Qing Yue | AMSR2 | 01 and 07, 2015 |
| Surface Classes | Evan Manning<br>Qing Yue | Snow and sea ice from National Snow and Ice Center | 01 and 07, 2015 |
| Total ozone and ozone profiles along the edge of the southern ozone hole | Evan Fishbein | 18 ozonesondes launched from Dumont d'Urville station | 18 granules over this station where departures from climatology are observed. |
| L2 temperature and water vapor profiles | Sun Wong | Operational Sonde | 01 and 07, 2015 |
| L2 near surface T and Q over ocean | Luke Chen | ICOADS: Buoy and ship | 01 and 07, 2015 |
| L2 near surface T and Q over ocean | Luke Chen | Meso Net | 01 and 07, 2015 |
| L2 CC-Rad | Chris Wilson | MODIS clear sky radiances | 01 and 07, 2015 |
| L2 and L3 cloud | Brian Kahn | None | 01 and 07, 2015 |

# Example AIRS V7 testing: Yield

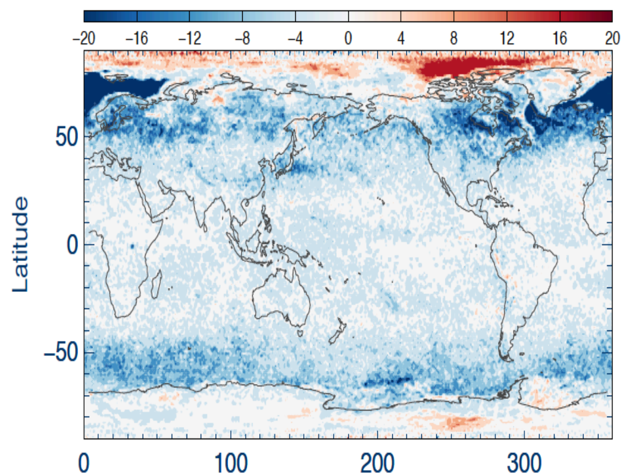
**2015 January TPW Yield:**

- **Decreased yield over ocean in the new versions, especially over subtropical low cloud and storm track regions.**
- **Increased yield in the polar region.**

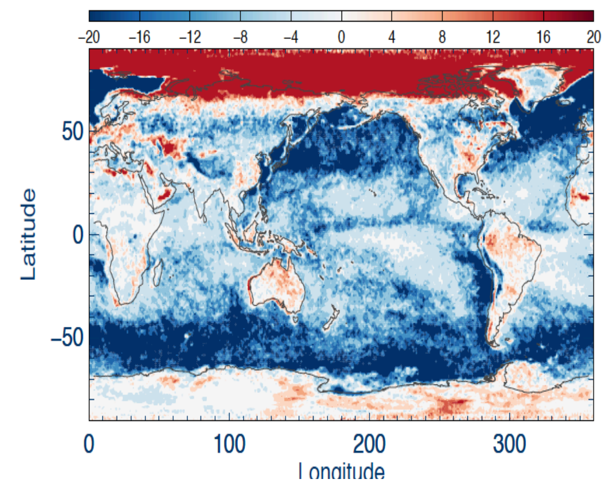
**Asc: V6.46 IR+MW minus V6 IR+MW**



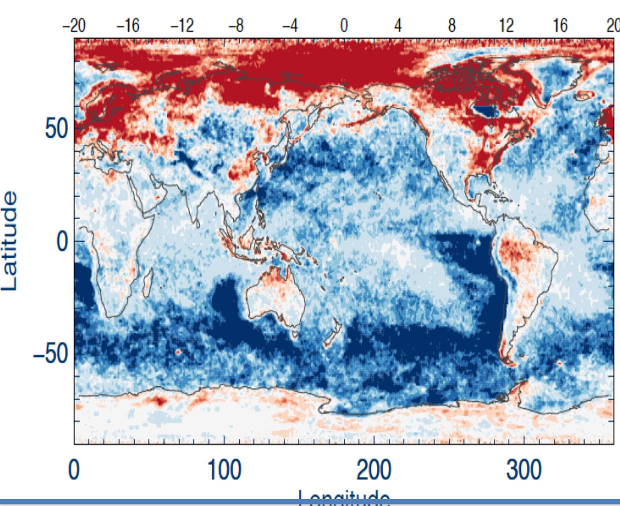

**Asc: V6.46 IR-Only minus V6.46 IR+MW**



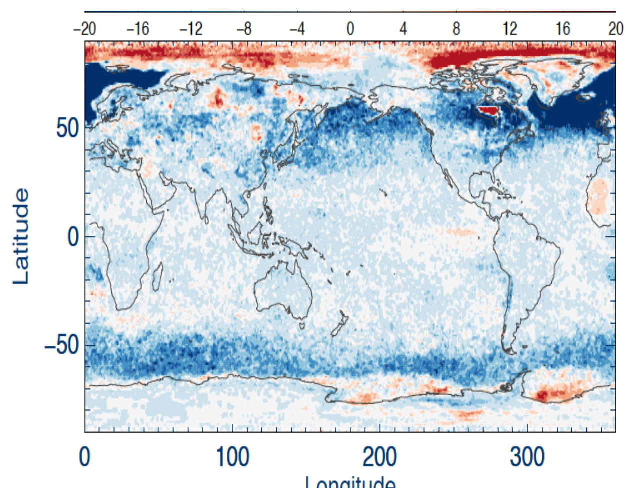

**Asc: V6.46 IR-Only minus V6 IR+MW**



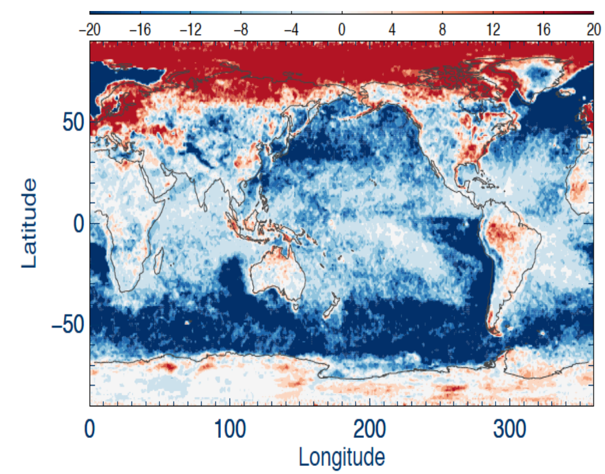

**Dsc: V6.46 IR+MW minus V6 IR+MW**




**Dsc: V6.46 IR-Only minus V6.46 IR+MW**




**Dsc: V6.46 IR-Only minus V6 IR+MW**



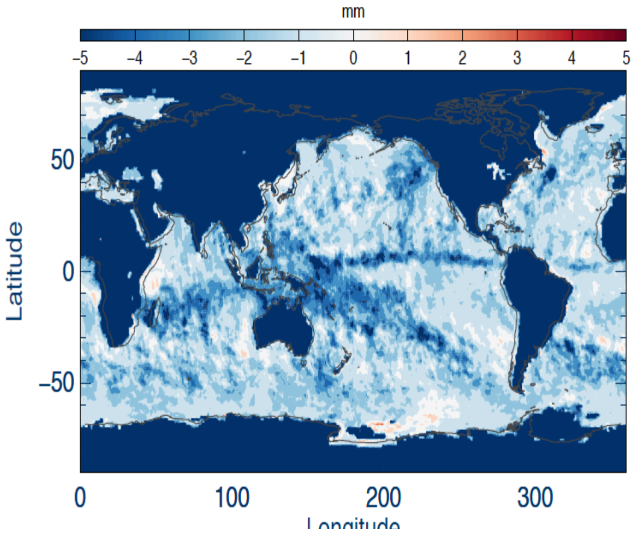
# V7 testing: Yield (2)

2015 January TPW V6.46 IR+MW:

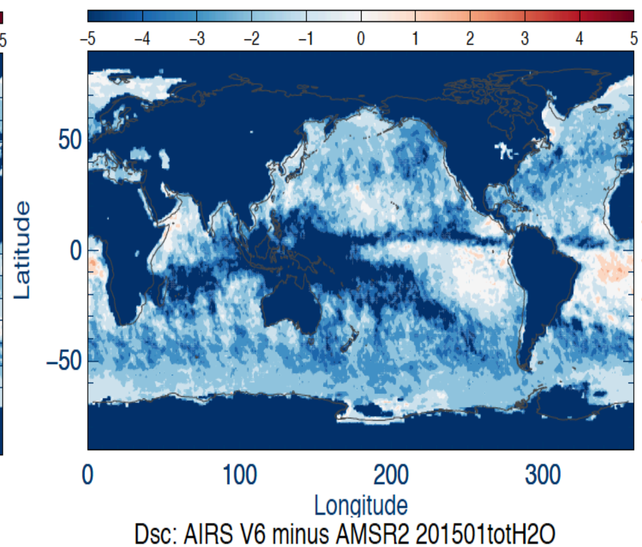
Dry bias in deep convective area improve

Nighttime wet bias in the subtropical low cloud region decreases or changes to small dry bias.

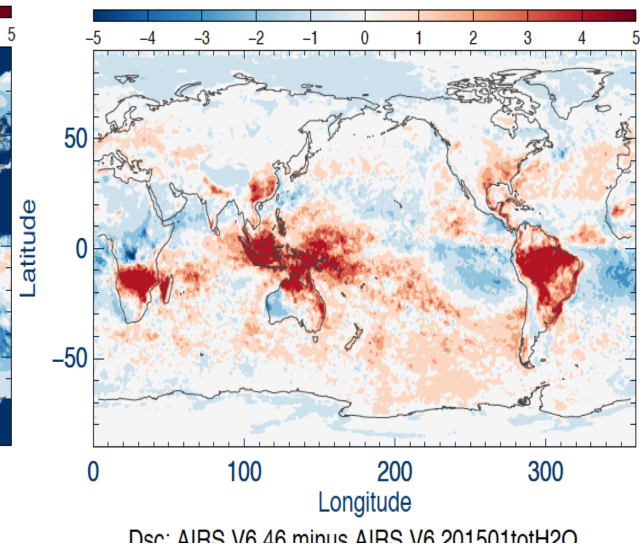
**Asc: V6.46 IR+MW minus AMSR2**



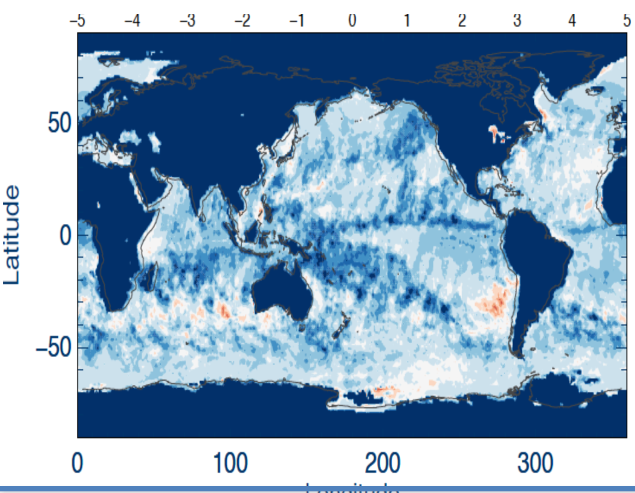

**Asc: V6 IR+MW minus AMSR2**



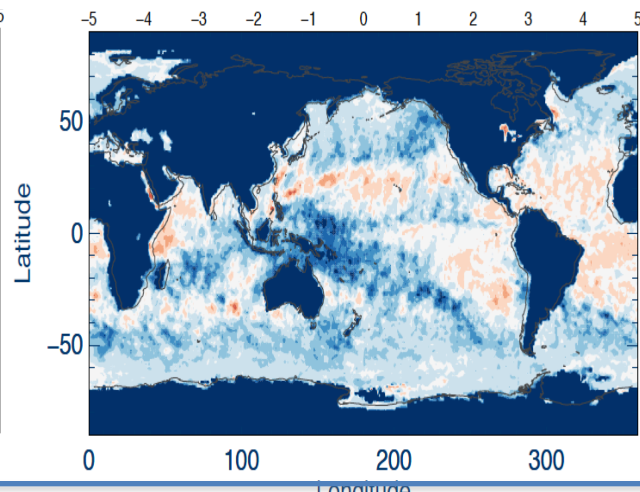

**Asc: V6.46 IR+MW minus V6 IR+MW**



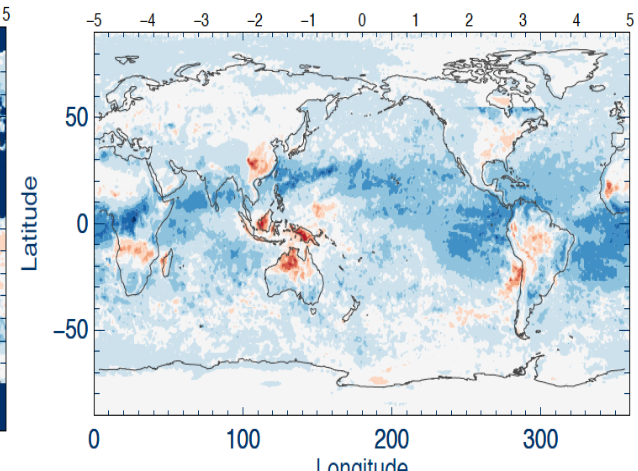

**Dsc: V6.46 IR+MW minus AMSR2**




**Dsc: V6 IR+MW minus AMSR2**



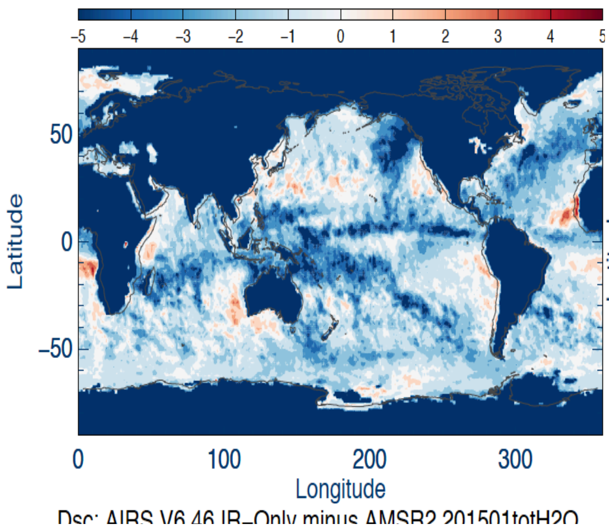

**Dsc: V6.46 IR+MW minus V6 IR+MW**



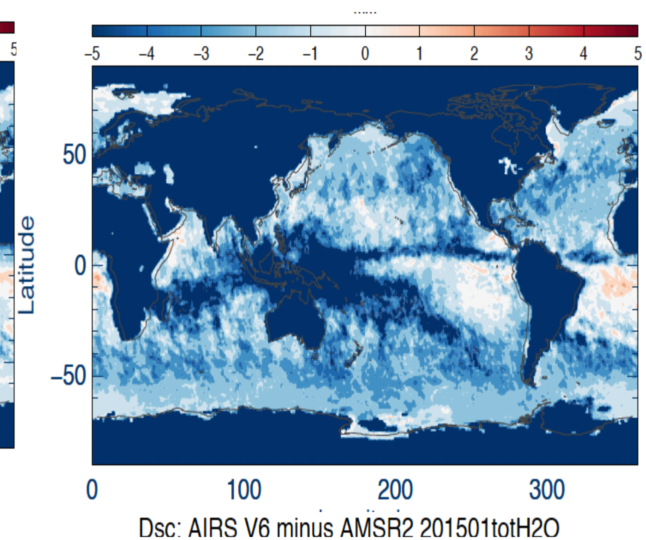
# V7 testing: Yield (3)

2015 January TPW V6.46 IR-Only:
Very similar to V6.46 IR+MW, but wet bias in subtropical low cloud region is larger both in magnitude and in spatial extent, especially in the descending mode.

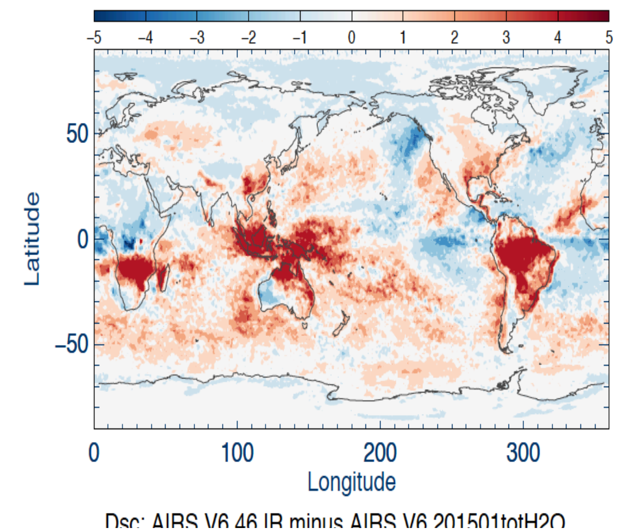
**Asc: V6.46 IR-Only minus AMSR2**



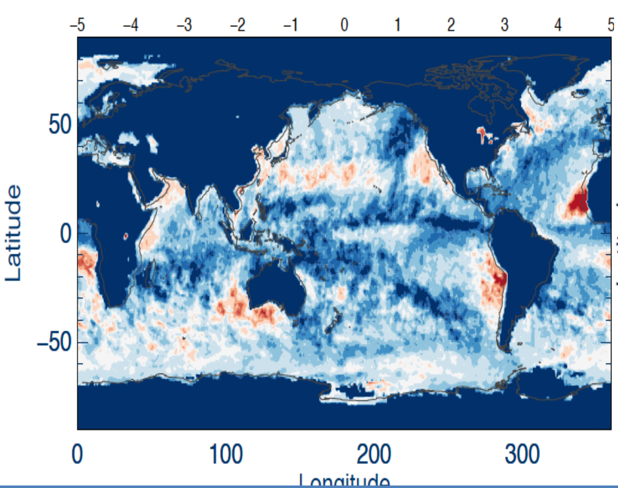

**Asc: V6 IR+MW minus AMSR2**



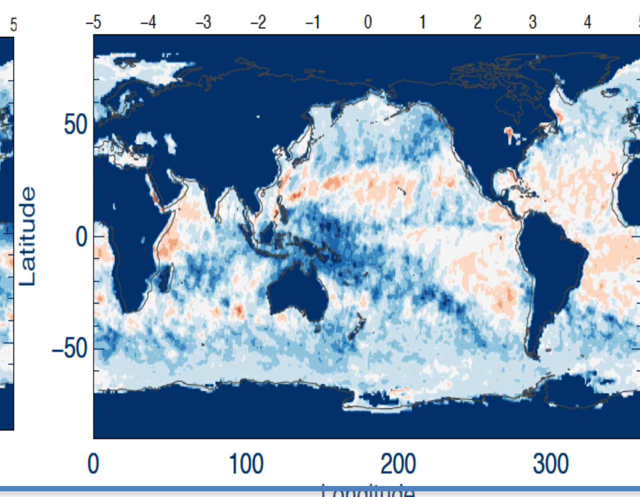

**Asc: V6.46 IR-Only minus V6 IR+MW**



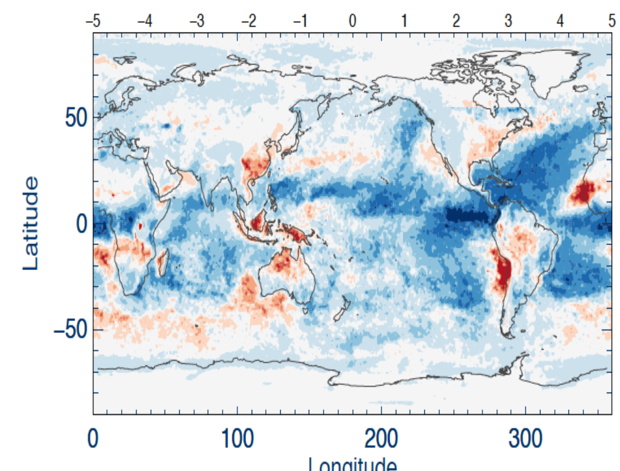

**Dsc: V6.46 IR-Only minus AMSR2**



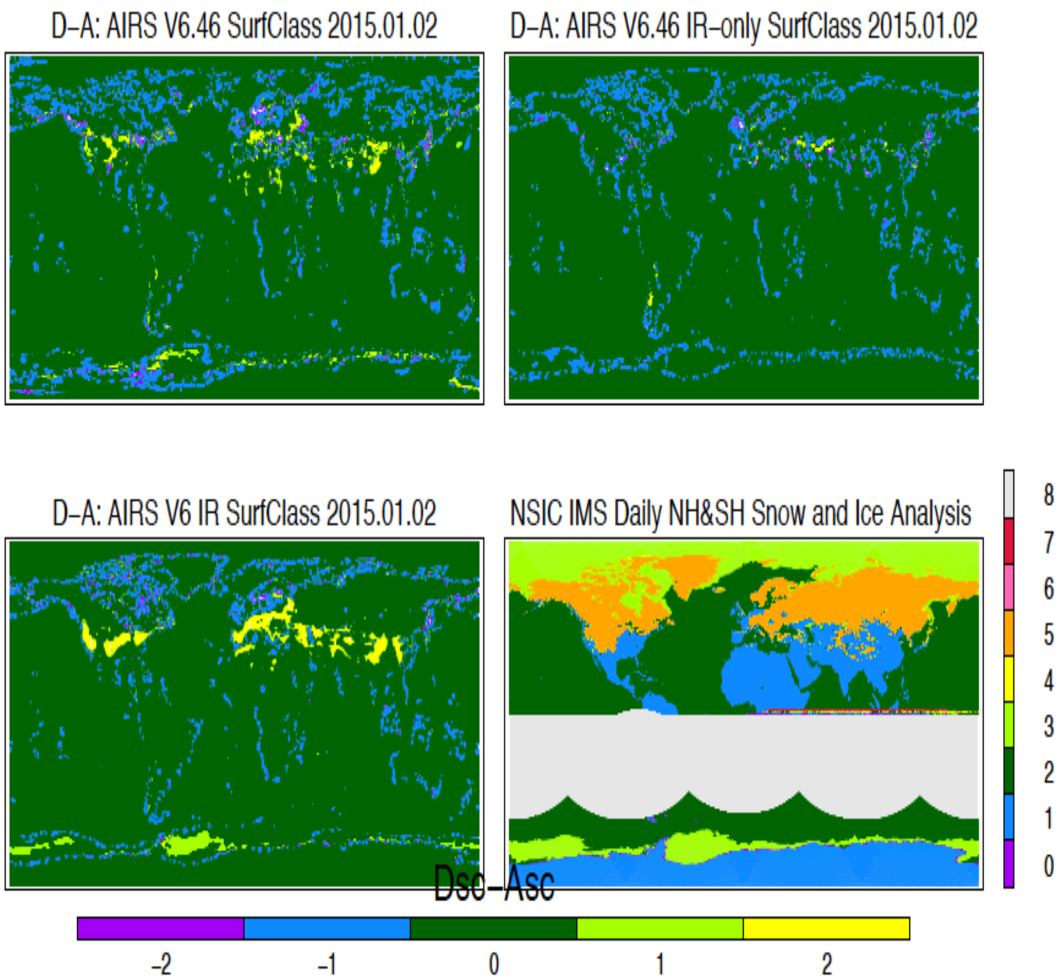

**Dsc: V6 IR+MW minus AMSR2**




**Dsc: V6.46 IR-Only minus V6 IR+MW**



# V7 testing: Surface Classes

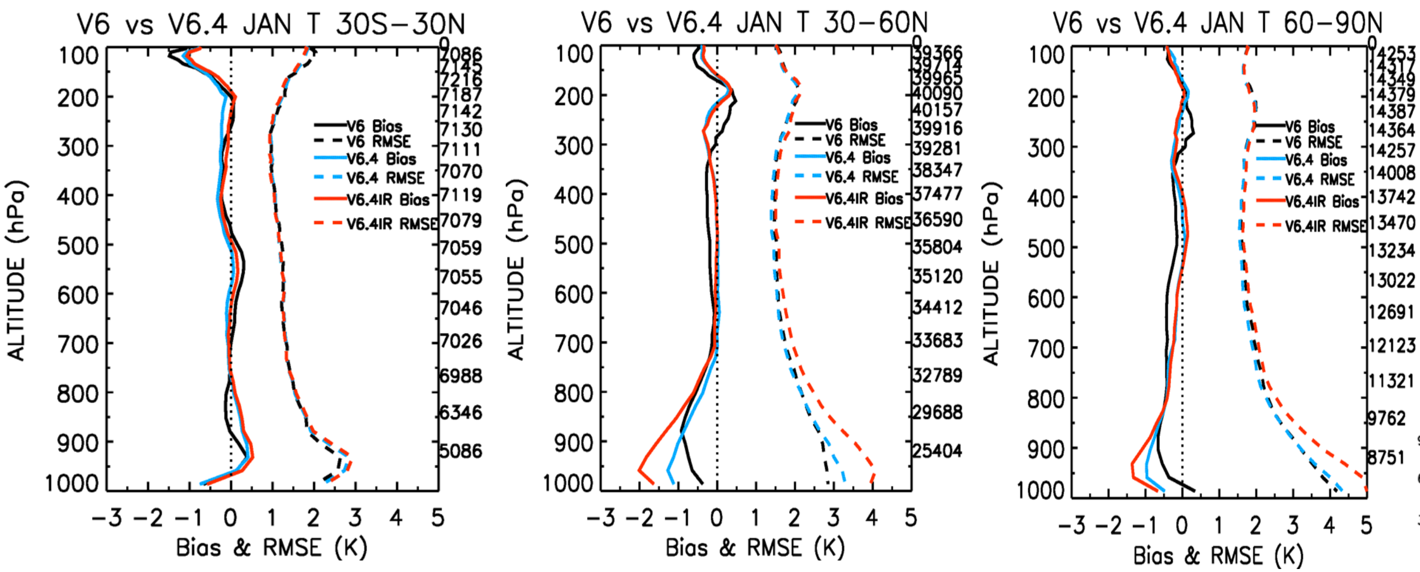


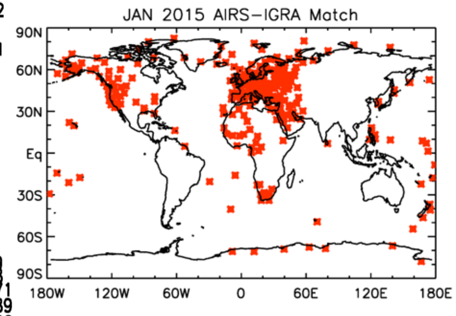

Difference between descending and ascending surface classes in AIRS products. Lower right shows NSIC snow and ice data with the vertical color bar same as previous figures.

- V6.46 IR-only surface is very similar to the NSIC snow and ice extent. Small differences probably due to resolution differences.
- V6.46 IR+MW shows non-frozen land over Europe, where NSIC data shows snow.
- More frozen land in the high-mountain regions in V6.46 IR-only than V6.46 IR+MW.
- The Antarctic region sea ice anomaly in the V6 IR-only products is removed in the new versions.
- The day-night difference in the IR-only algorithm is largely removed in the new versions.

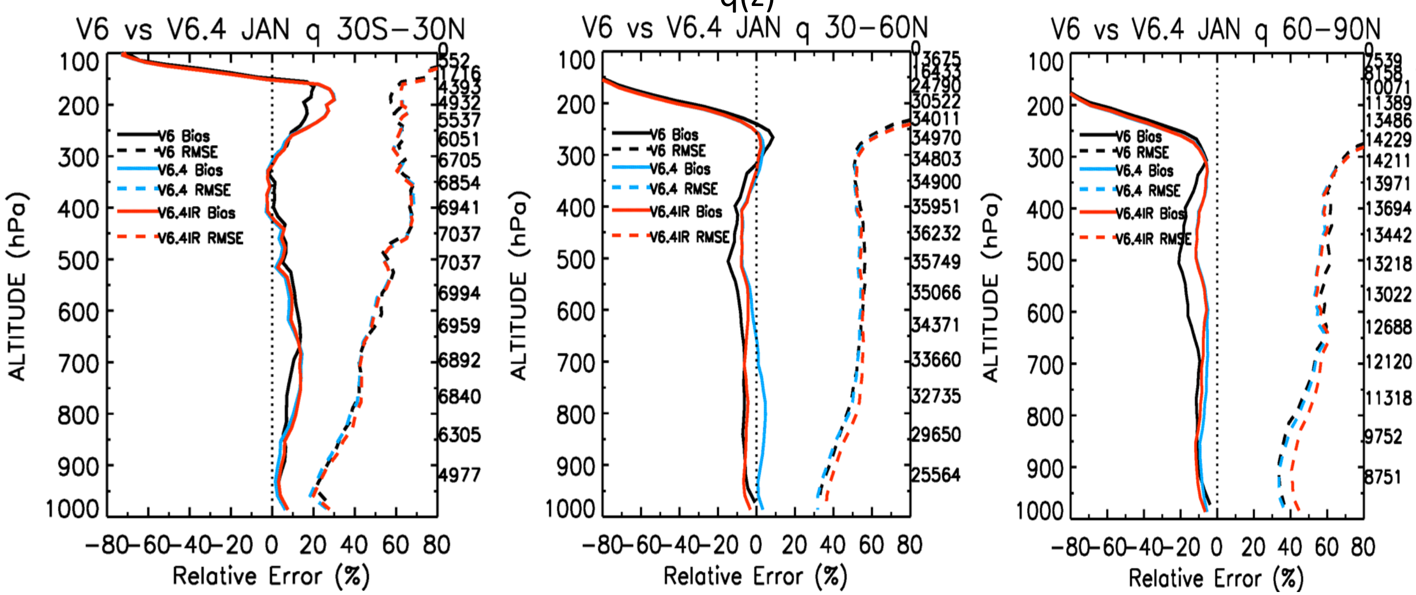
# V7 testing: Profiles

T(z)



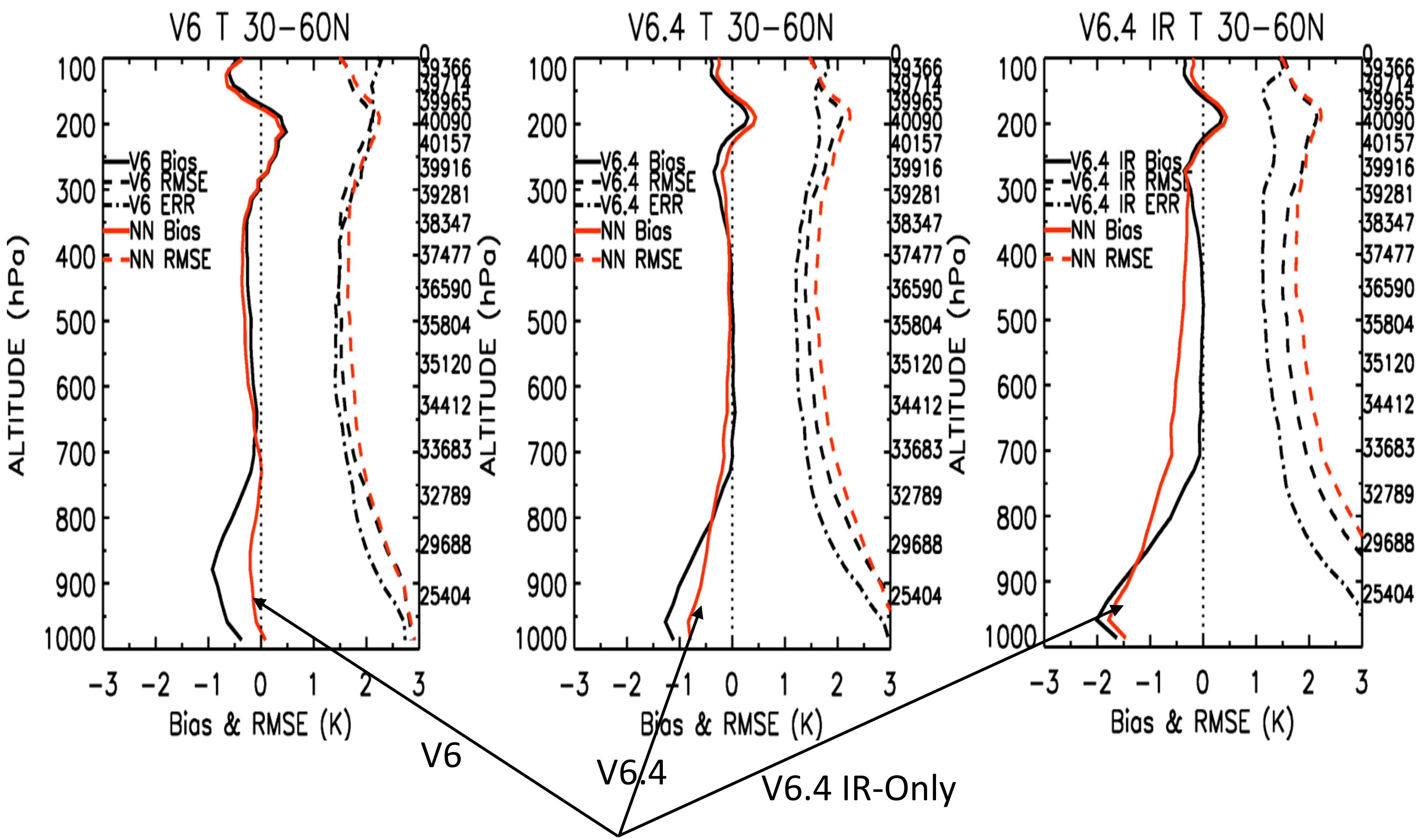




q(z)



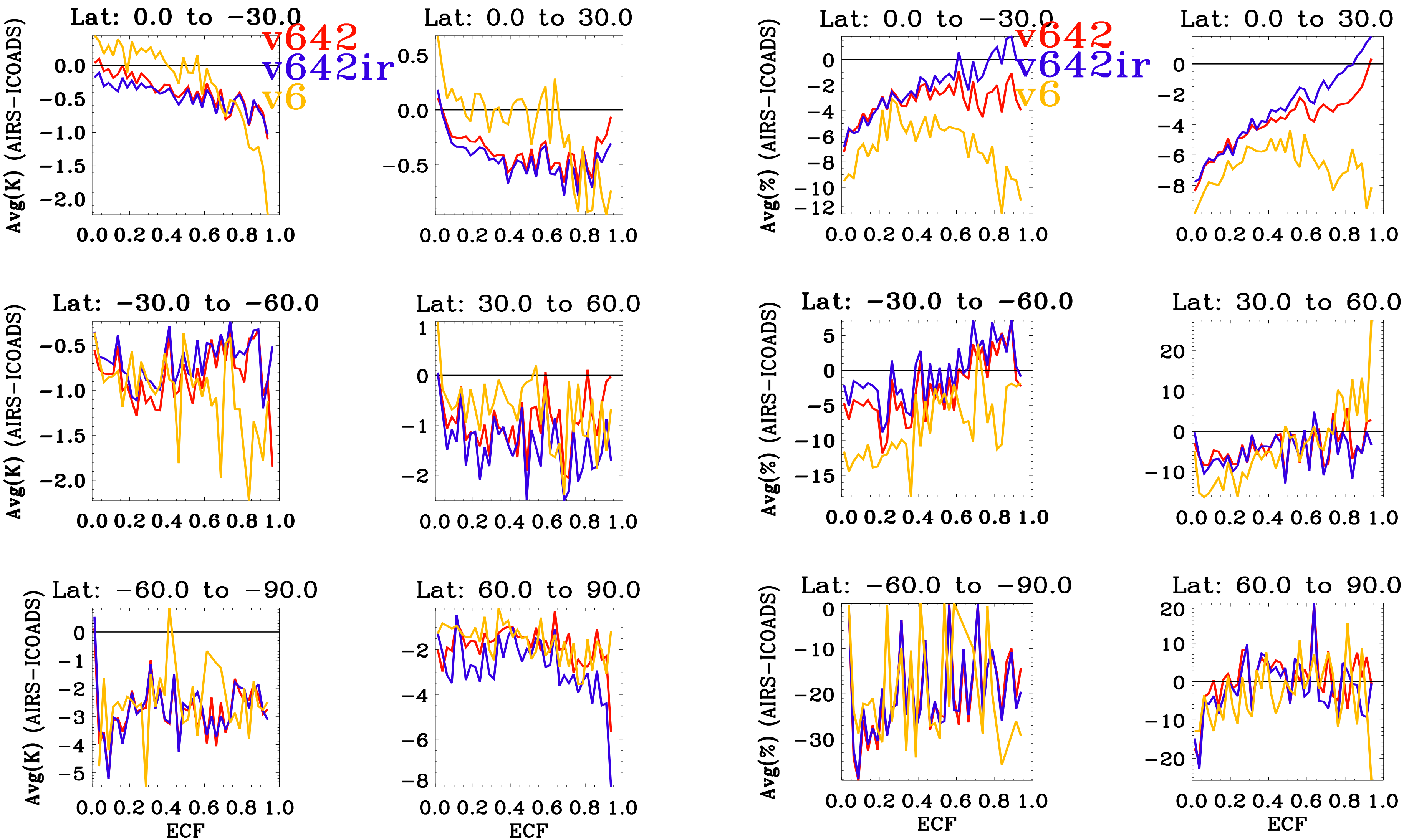
# V7 testing: Finding neural-network problems

## An Example of differences in NN (January 2015)



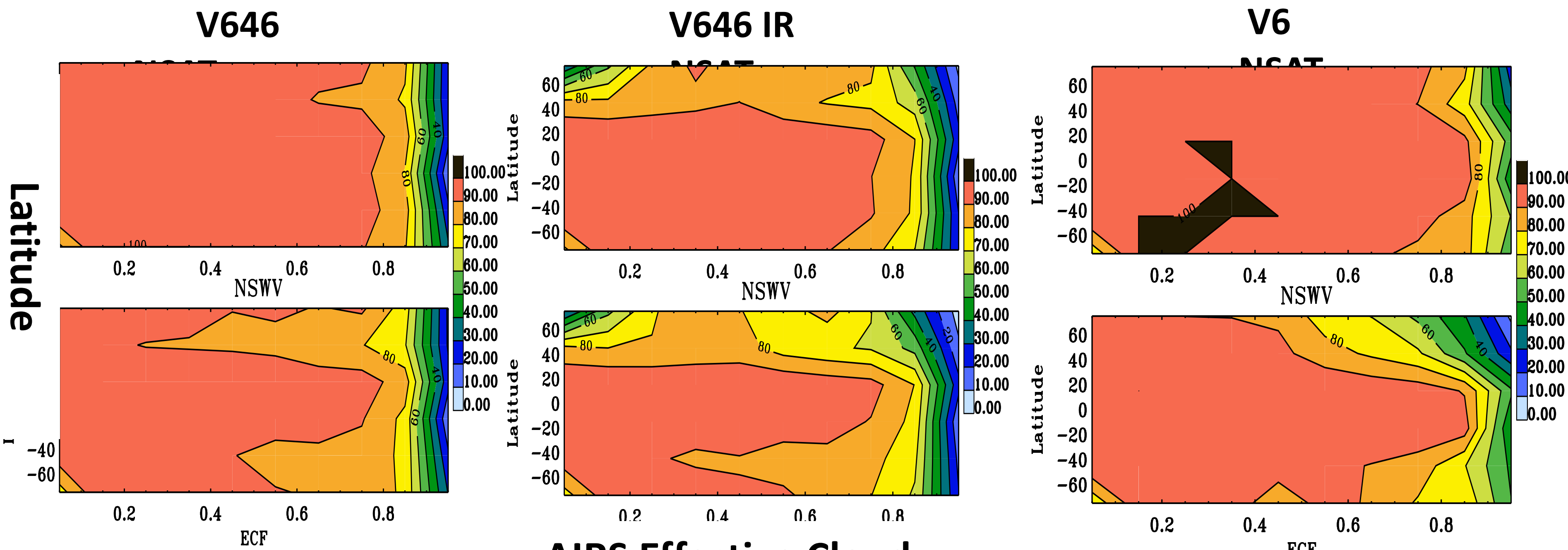

NN biases in the PBL increase from V6 to V6.4, and further increase in V6.4 IR-Only.
Work on identifying and fixing the problems is on-going.

# V7 testing: Near surface T and q



# V7 testing: Near surface T and q Yield

## **Yield(%) NSAT** and **NSWV** Day 2015.01




**AIRS Effective Cloud Fraction (ECF)**

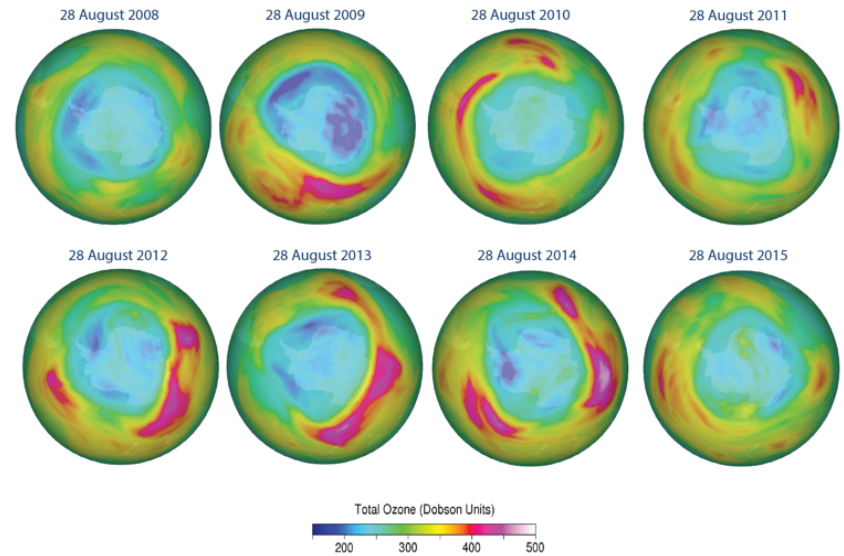
V646 yield is slightly less than V6

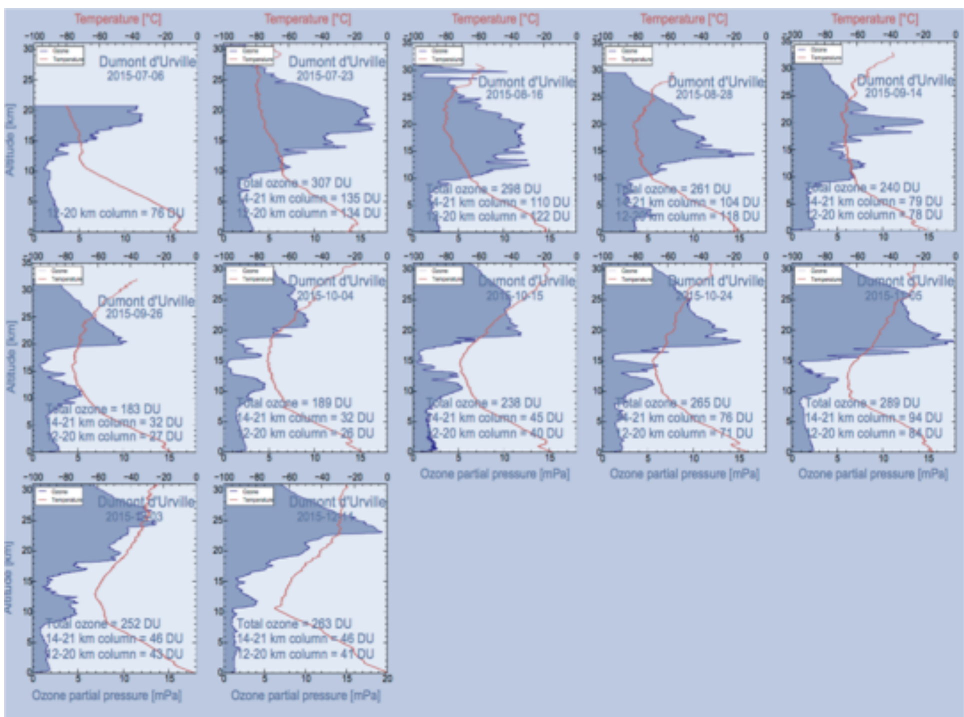
V646IR is lower than V646 in higher latitude.

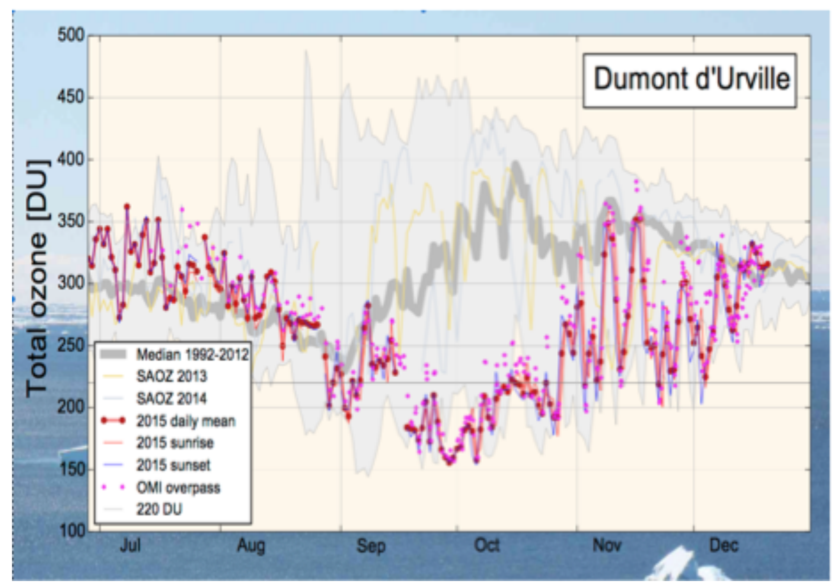
# V7 testing: Ozone hole

The 2015 time series at Dumont d'Urville is well characterized and anomalous compared to climatology

AIRS retrieved ozone will be compared with the ozondesonde profiles below

# Next…

## V7 testing

- Apply preliminary tests to "final" version
- Possibly fix problems revealed & test again
- Develop V7 test report, to be delivered with other V7 documentation

## Validation

- Has been under way for several years (V5, V6) → Published papers
- Identify gaps in published record → Additional validation
- Generate summary of published validation results
- Move on to V7

## AIRS → S-NPP → JPSS continuity

- Test & validate seamless "V7" for AIRS *and* CrIS/S-NPP
- Test & validate single-FOV cloudy retrieval system for AIRS and CrIS

## Multi-sensor/multi-platform analysis

- Pursue data fusion: AIRS, CrIS, MODIS, IASI, etc.
- Collaborations with EUMETSAT/IASI
  - Apply methodologies developed under SCIS etc.

## Support future sounder development

- IR & MW, LEO & GEO, small-sats & large-sats
- Develop science case: requirements, OSSEs, applications, etc.