# First SNPP Cal/Val Campaign: Satellite and Aircraft Sounding Retrieval Inter-Comparison

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## Introduction

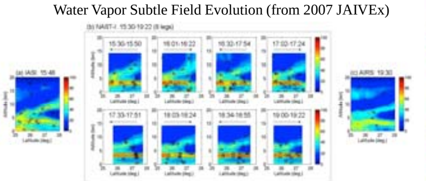
Satellite ultraspectral infrared sensors provide key data records essential for weather forecasting and climate change science. The Suomi National Polar-orbiting Partnership (SNPP) satellite Environmental Data Record (EDR) is retrieved from calibrated ultraspectral radiance so called Sensor Data Record (SDR). *The CrIS/ATMS temp. requirement is 1.5K (3-21km), 1.6K (surf-3km); water vapor requirement is 35% (4-9km), 20% (surf-4km).* It is critical to understand the accuracy of retrieved EDRs, which mainly depends on SDR accuracy (e.g., instrument random noise and absolute accuracy), an ill-posed retrieval system, and radiative transfer model errors. There are few approaches to validate EDR products, e.g., some common methods are to rely on radiosonde measurements, ground-based measurements, and dedicated aircraft campaign providing in-situ measurements of atmosphere and/or employing similar ultraspectral interferometer sounders.

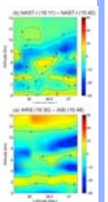
Ultraspectral interferometer sounder aboard aircraft measures SDR to retrieve EDR, which is often used to validate satellite measurements of SDR and EDR. The first SNPP Calibration/Validation Campaign was conducted during May 2013. The NASA high-altitude aircraft ER-2 that carried ultraspectral interferometer sounders such as the NASA Atmospheric Sounder Testbed-Interferometer (NAST-I) flew under the SNPP satellite that carries the Cross-track Infrared Sounder (CrIS). Here we inter-compare the EDRs produced with different retrieval algorithms from SDRs measured by the sensors from satellite and aircraft. The available dropsonde and radiosonde measurements together with the European Centre for Medium-Range Weather Forecasts (ECMWF) analysis were also used to draw the conclusion from this experiment.

## Traditional Satellite Sounding Evaluation

- The common approaches to validate environmental data record (EDR) products:
  1. Radiosonde measurement.
  2. Ground-based measurements (ground based Raman Lidar data, ground-based FTS system).
  3. Numerical Weather Prediction (NWP) models (e.g., ECMWF analysis).
  4. The "best estimate" atmospheric state from combined-measurements.
  5. Dedicated aircraft campaign providing:
     - in-situ measurement,
     - dropsonde measurement,
     - employing similar ultraspectral interferometer sounders (sounding retrievals).
- Validation depends on other independent measurements (i.e., radiosonde, dropsonde), and the accuracy of these independent measurements.
- The vertical and horizontal resolutions of the measurements have to be taken into account.
- Retrieval error/uncertainty needs to be estimated and taken into account.
- They must be "*coincidental*" measurements, e.g., measurement-derived "truths" are *at the same time and location*.

Water Vapor Subtle Field Evolution (from 2007 JAIVEx)



## S/C and A/C Retrieval Inter-Comparison

The *validation* activity consists of comparing the products to be validated with similar products derived from other independent sources. There are two distinct methods to validate the products.

- The first, known as the direct method, directly compares the satellite-derived products with validated products. This requires "coincidental" measurements with very similar vertical and horizontal resolutions.
- The second, known as the indirect method, indirectly validates the non-validated satellite product with the other coincidental satellite and/or aircraft products, or other information and applications (e.g., model simulations).

**Here we demonstrate an indirect validation method using retrieved atmospheric profiles from satellite and aircraft measurements.**

For an indirect method, here we use 4 retrieval algorithms providing us confidence on the accuracy of the EDR products without any other validated measurements. They are 2 algorithms for satellite sensors CrIS/ATMS (CrIMSS & NUCAPS) and 2 algorithms for aircraft sensor (NAST-I Channel-base & PC-based algorithms).

Since the EDR (or retrieval products from satellite and aircraft) are not directly measured but are outcomes of an ill-posed problem, the retrieval algorithms also need to be evaluated (i.e., inter-compared or cross-checked).

The advantages of this study are:
- to have a very similar vertical profile resolution from satellite and aircraft profiles
- to have a very similar horizontal resolution (e.g., aircraft smaller FOVs profiles are averaged within satellite FOR)
- to have aircraft underflow the satellite with a very close time, and at a same location
- to cross-check algorithms using 2 different algorithms for the same measurement
- to evaluate both satellite and aircraft retrievals simultaneously.

And the disadvantages are:
- all retrievals suffer an ill-posed problem; retrievals could agree with each other but have a possibility of being all wrong. This possibility is very small, and NWP model analysis can always be used to have another perspective.
- estimated retrieval accuracy is not an absolute value, but relative to the mean of retrievals from different A/C and S/C algorithms.

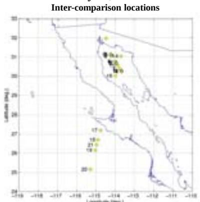
## Retrieval Methodologies: Major Similarities & Differences

| | **CrIS/ATMS retrieval algorithms (IR+MW)** | | **NAST-I retrieval algorithms (IR only)** | |
|---|---|---|---|---|
| | CrIMSS [1] | NUCAPS [2] | PC-based [3] | Channel-based [4] |
| IR forward model | OSS | SARTA | PCRTM + Cld. model | OSS + Cld. model |
| Ret. horizontal resolution | CrIS FOR (50 km) | CrIS FOR (50 km) | NAST-I FOV (<2.5 km) | NAST-I FOV (<2.5 km) |
| Initial ret. methodology | None | EOF reg. ret. with IR/MW | None | EOF reg. ret. |
| Initial. ret. training | None | NOAA88 | None | UW SeeBor + Cld. + Suf. |
| Training radiance | None | Model simulated | None | Model simulated |
| Dealing with cloud | Cld. clearing with ATMS | Cld. clearing with ATMS | Ret. cld. properties | Ret. cloud properties |
| Cloud property | Retrieved from MW | Not retrieved | Retrieved from IR | Retrieved from IR |
| Retrieved cloud property | Cld. top height, cld. amount | None | Cld. top height, optical depth, particle size, cld. phase | Cld. top height, optical depth, particle size, cld. phase |
| Emissivity ret. | Hinge points | Hinge points | PC scores | PC scores |
| Retrieval domain | Channel radiance | Channel radiance | PC score | Channel radiance |
| Phy. ret. methodology | Regularization | Regularization | Regularization | Regularization |
| Phy. ret. channel number | 1305 | 399 | 160 EOFs (5664 channels) | 1201 channels |
| First gauss | MW-only ret. or NWP | EOF reg. ret. | Climatology | EOF reg. ret. |
| Phy. ret. procedure | Simultaneous | Sequential | Simultaneous | Simultaneous |

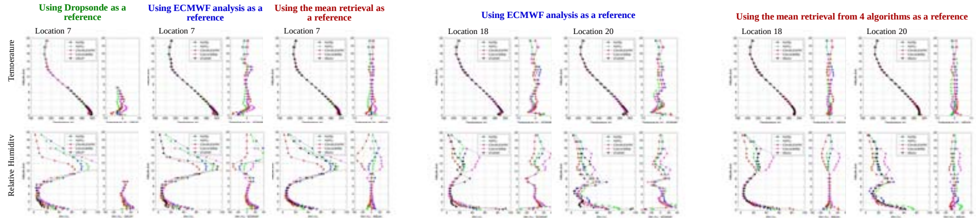
[1] Divakarla, M., et al. (2014), The CrIMSS EDR Algorithm: Characterization, Optimization, and Validation, *J. Geophys. Res. Atmos.*, **119**, 4953–4977, doi:10.1002/2013JD020438.
[2] Gambacorta, A. et al. (2014), The NOAA Operational Hyper Spectral Retrieval Algorithm: a cross-comparison among the CrIS, IASI and AIRS processing system, International TOVS Study Conference paper Proceedings, Jeju Island, South Korea.
[3] Liu, X., D. K. Zhou, A. M. Larar, W. L. Smith, and S. A. Mango (2007), Case study of a principal-component-based radiative transfer forward model and retrieval algorithm using EAQUATE data, *Q. J. R. Meteorol. Soc.*, **133**, 243–256, doi:10.1002/qj.156.
[4] Zhou, D. K., W. L. Smith, Sr., X. Liu, A. M. Larar, S. A. Mango, and H.-L. Huang (2007), Physically retrieving cloud and thermodynamic parameters from ultraspectral IR measurements, *J. Atmos. Sci.*, **64**, 969–982, doi:10.1175/JAS3877.1.

## Selected Retrieval Inter-Comparison

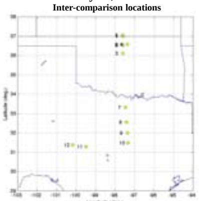
**May 16, 2013**
**Inter-comparison locations**



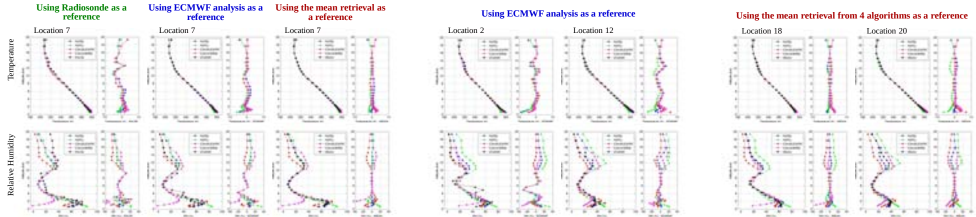
Using Dropsonde as a reference | Using ECMWF analysis as a reference | Using the mean retrieval as a reference | Using ECMWF analysis as a reference | Using the mean retrieval from 4 algorithms as a reference



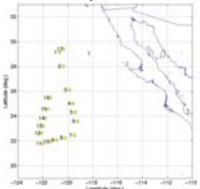

**May 20, 2013**
**Inter-comparison locations**



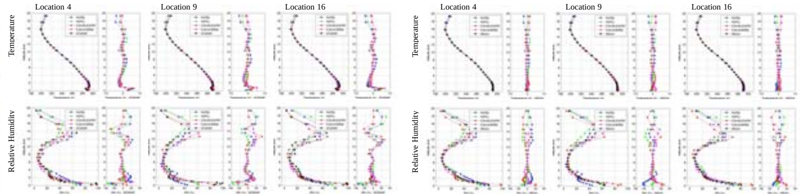
Using Radiosonde as a reference | Using ECMWF analysis as a reference | Using the mean retrieval as a reference | Using ECMWF analysis as a reference | Using the mean retrieval from 4 algorithms as a reference




**May 30, 2013**
**Inter-comparison locations**



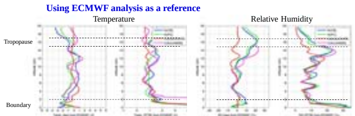
Using ECMWF analysis as a reference | Using the mean retrieval from 4 algorithms as a reference



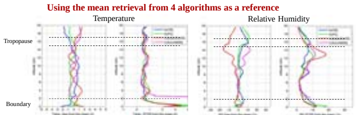

Note:
- NAST-I retrievals (~2 km FOV) are averaged within SNPP CrIS/ATMS FOR (~50 km).
- NAST-I retrievals from Channel-based & PC-based algorithms are compared with CrIS/ATMS retrievals from NUCAPS & CrIMSS algorithms.
- ECMWF and the mean of 4 retrievals are used as references. Dropsonde is used for a selected location

## Discussion and Conclusions

Using ECMWF analysis as a reference




Using the mean retrieval from 4 algorithms as a reference




**Temperature profile:**
- There is a difference between CrIS and NAST-I retrievals above the tropopause, CrIS is warmer than NAST-I by ~3K.
- Above the boundary and below the tropopause, temperature bias is within ±2.0K (ECMWF) and ±1.5K (RTV mean), and the STDE is between 0.5 to 1.0K.
- Within the boundary, the STDE is significantly larger than the CrIS/ATMS requirement (1.6K).
- CrIMSS deviates significantly from the others at ~3 km and below.

**Relative humidity profile:**
- There should be no water vapor retrieval sensitivity above the tropopause, the error might just be introduced by different first guess profile (i.e., the null-space error).
- Above the boundary and below the tropopause, the RH bias increased as the altitude increased but stayed within ±15%, and the STDE is below ~20% (ECMWF) and 15% (RTV mean).
- Within the boundary, the both bias and STDE is under 30% (ECMWF) and ~15% (RTV mean)

- A direct validation method for retrieval profile was performed by using dropsonde and radiosonde measurements; a relatively large discrepancy between the retrievals and dropsonde/radiosonde is pronounced in the boundary layer. No statistical conclusion can be drawn with limited dropsonde/radiosonde.
- An indirect validation method for retrieval profile is demonstrated using the different retrieval algorithms applying to the data collected from both satellite and aircraft. Similar comparison is also performed with ECMWF model analysis.
- **Above the boundary layer, retrieval differences from different algorithms are within expected range, indicating these algorithms can produce retrievals satisfying operational requirements (e.g., temperature 1.5K & water vapor 20%).**
- **In the boundary layer, retrieval deviation is relatively larger than what s expected. The retrieval algorithms should be further studied to improve the outcomes.** We have less confidence on retrieval accuracy in the boundary layer than that in the region above.
- These conclusions were drawn from the 1st SNPP Cal/Val campaign having limited dataset (i.e., at a specific region and season); more aircraft campaigns will benefit this type of EDR inter-comparison. The 2nd SNPP Cal/Val campaign have been conducted in March 2015 over Greenland will provide data for SNPP CrIS data evaluation in a different environment.