Status and Results from CLIMCAPS-SNPP and CLIMCAPS-Aqua

Thursday, Oct. 4, 2018

Session.8: 11:30 EDT

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Creating a hyperspectral sounding continuity product

- We have 5 operational thermal sounder suites at this time

Satellite	Instruments	Overpass	Launch dates
Aqua	AIRS, AMSU	1:30	2002
Metop	IASI, AMSU, MHS	9:30	2008, 2012, …
S-NPP, JPSS	CrIS, ATMS	1:30	2011, 2017, …

- There are numerous differences in these sounding suites
  - Instruments are different
    - Spectra resolution, sampling and noise
    - Spatial sampling
    - Degradation over time
  - Algorithm differences
    - NOAA algorithms became operational ~1 year after launch and have asynchronous maintenance schedules (e.g., training datasets are different)
    - 9:30/1:30 orbits co-location w/ insitu is different (affects regression training and makes validation more difficult)
  - Sensitivity to a-priori assumptions
    - Sensitivity to meteorology (e.g., clouds at 9:30 vs 1:30 am/pm)
    - Sensitivity to seasonal and climate changes (e.g., 8% increase in CO_2, 2002-2017)

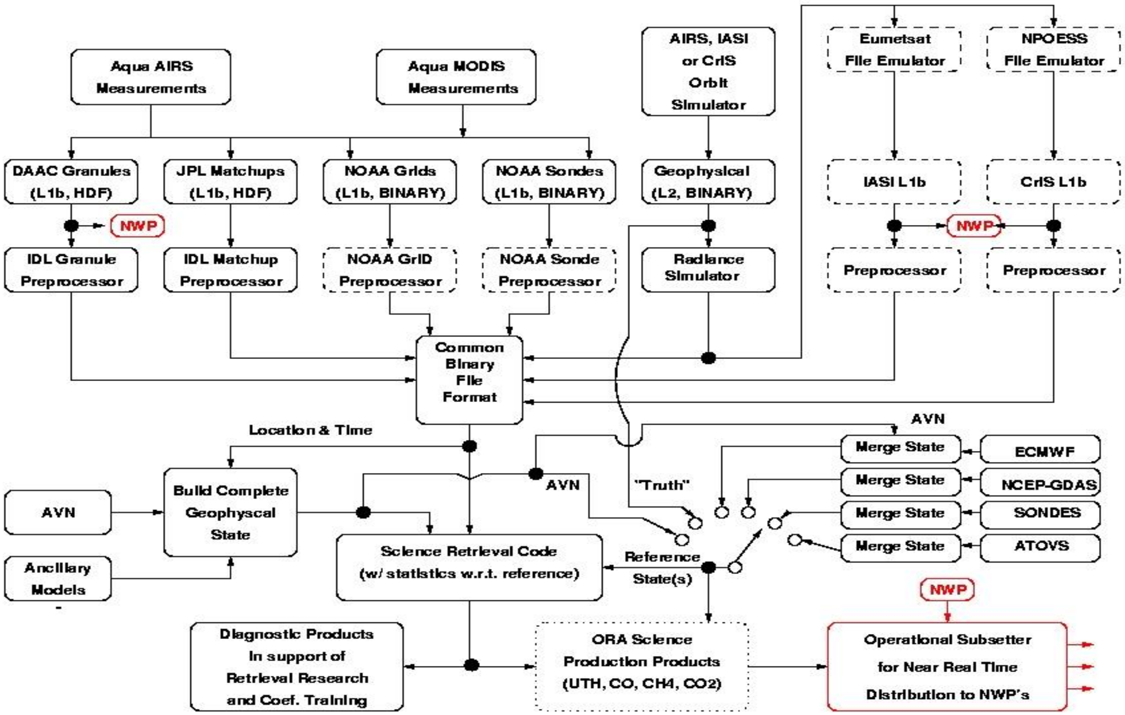
> Continuity was not the primary design criteria of the modern satellite sounding suite

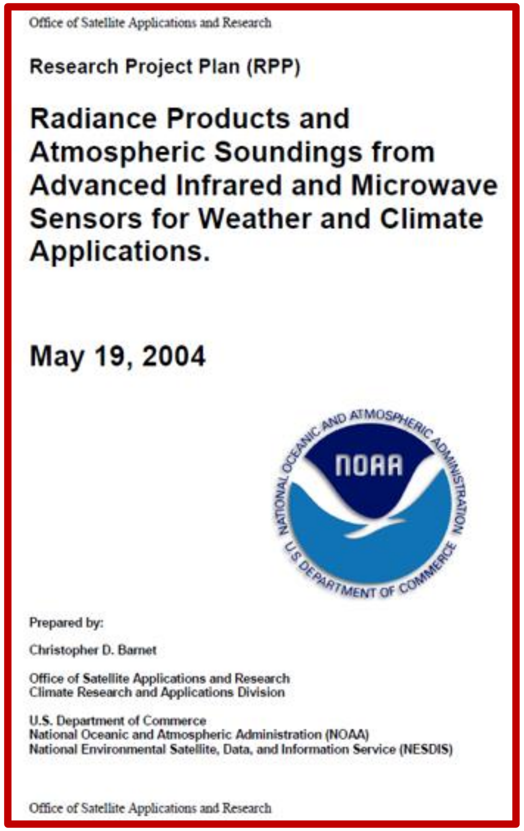
Operational versions of our *x*CAPS retrieval algorithm

- NOAA-Unique Combined Atmospheric Processing System (NUCAPS)
  - Forecast-independent system (uses linear regression)
  - Real-time processing via direct broadcast.
  - Operational for S-NPP, NOAA-20, Metop-A, Metop-B
- Community Long-term Infrared Microwave Coupled Atmospheric Product System (CLIMCAPS)
  - Climate-model independent system
    - Uses Merra-2 for T(p), q(p), and O3(p) a-priori
  - Full error propagation (partition a-priori and measurement).
  - Hind-sight processing (~1 month latency)
  - Implemented at SIPS for S-NPP (ATMS+CrIS-NSR & FSR), NOAA-20, Aqua (both AIRS+AMSU and AIRS-only)
- The same code is used for all satellites (Metop, Aqua, S-NPP, NOAA-20) and configurations (IR-only, NSR/FSR)

CLIMCAPS has a Operations to Research (O2R) component

- NUCAPS was designed – from the beginning - to support multi-satellite missions
  - Leveraged NASA AIRS R2O





Office of Satellite Applications and Research

Research Project Plan (RPP)

Radiance Products and Atmospheric Soundings from Advanced Infrared and Microwave Sensors for Weather and Climate Applications.

May 19, 2004

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NOAA
U.S. DEPARTMENT OF COMMERCE

Prepared by:

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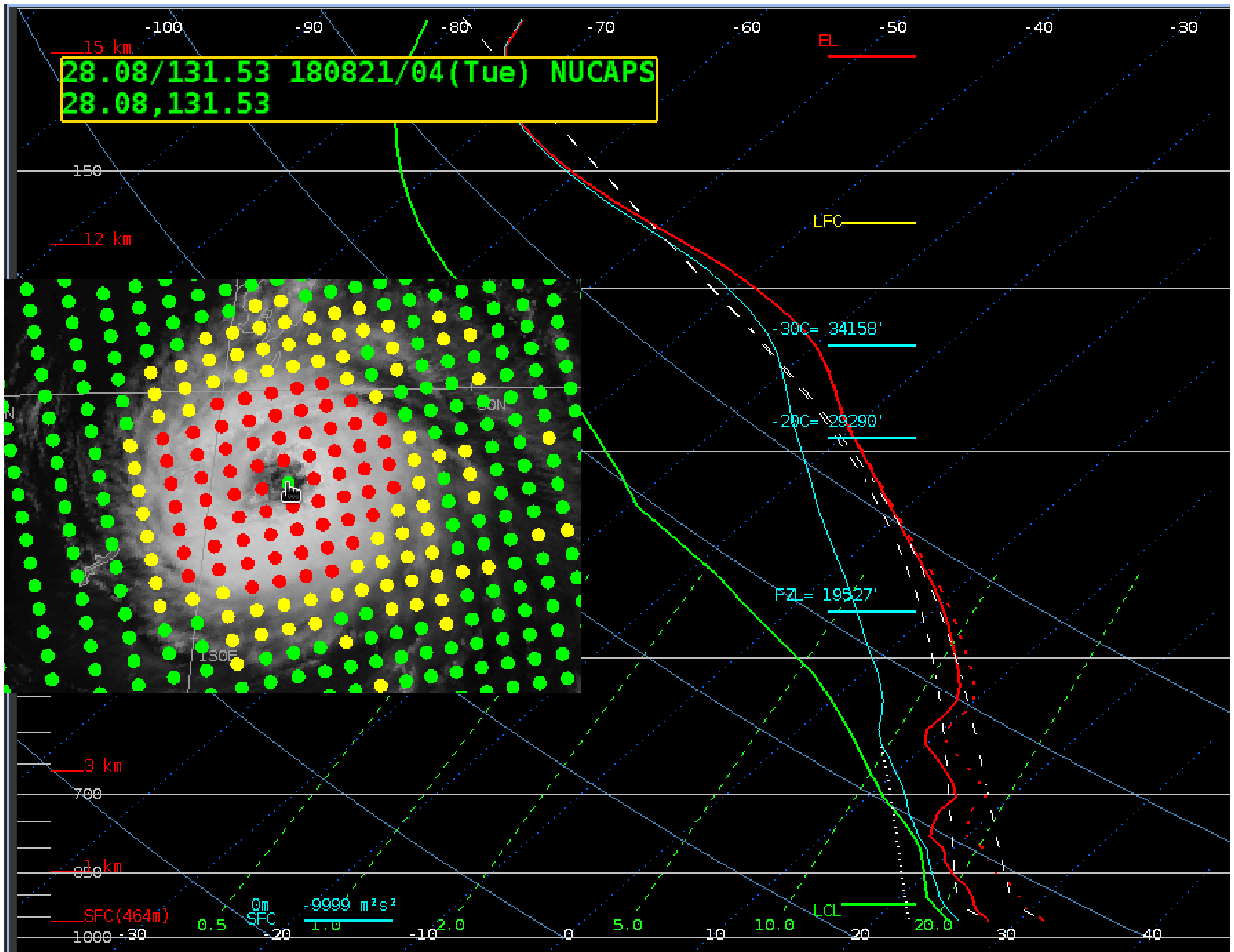
Office of Satellite Applications and Research
Climate Research and Applications Division

U.S. Department of Commerce
National Oceanic and Atmospheric Administration (NOAA)
National Environmental Satellite, Data, and Information Service (NESDIS)

Office of Satellite Applications and Research

NUCAPS in Operations (View in AWIPS-2)



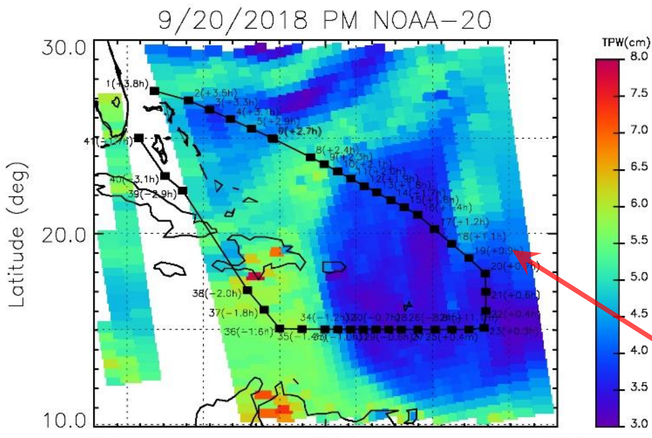
Typhoon Soulik
Aug. 21, 2018

Screen shot sent by forecaster in Guam (Landon Aydlett)

Graphic to the left processed by Scott Lindstrom (SSEC)

What impresses me most is that the community is now excited by what they see in NUCAPS.

Saharan Air Layer field campaign 2-weeks ago

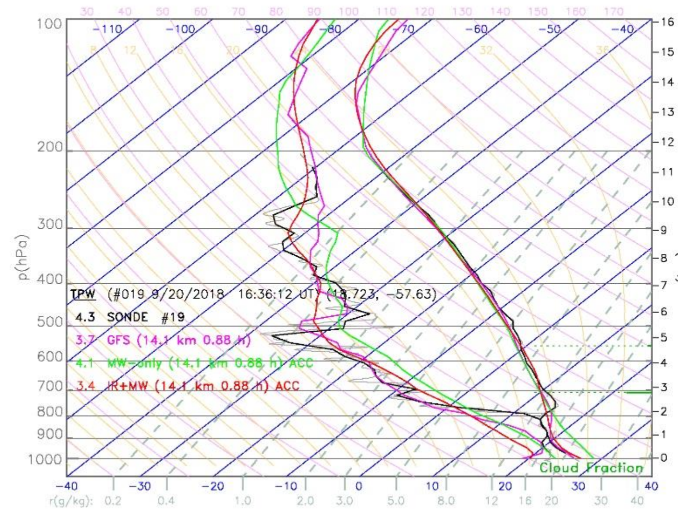


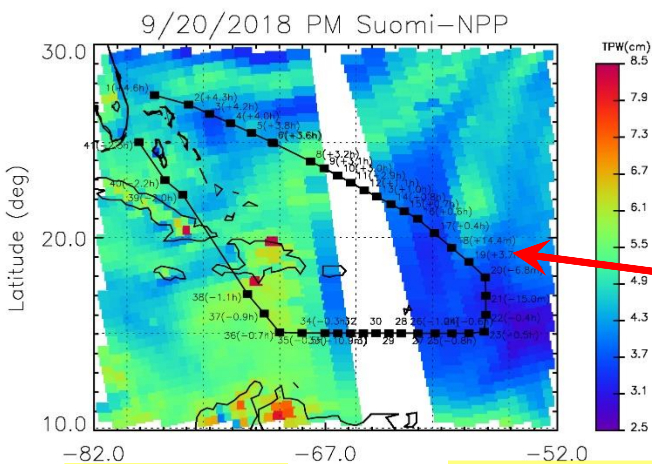
19:10 UT

17:30 UT

Sonde #19/41 16:36 UT

NOAA-20 NUCAPS 14.1 km +54 min

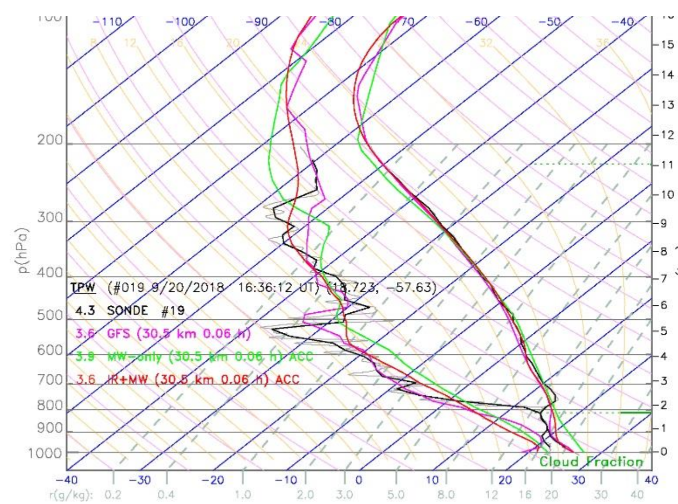




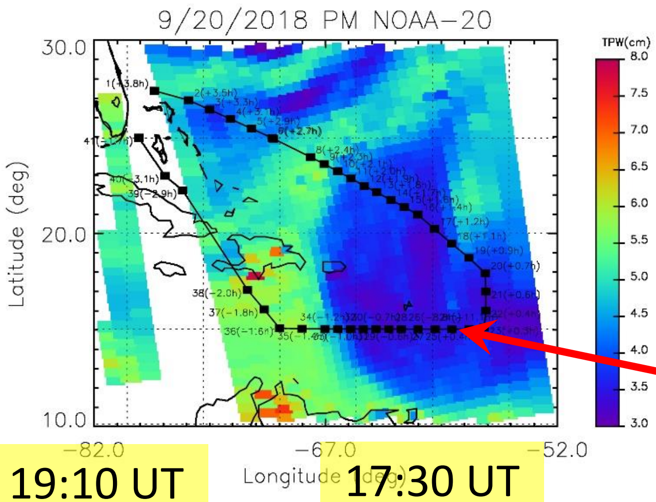
18:20 UT

16:40 UT

S-NPP NUCAPS 30.5 km +3.7 min



Saharan Air Layer field campaign 2-weeks ago

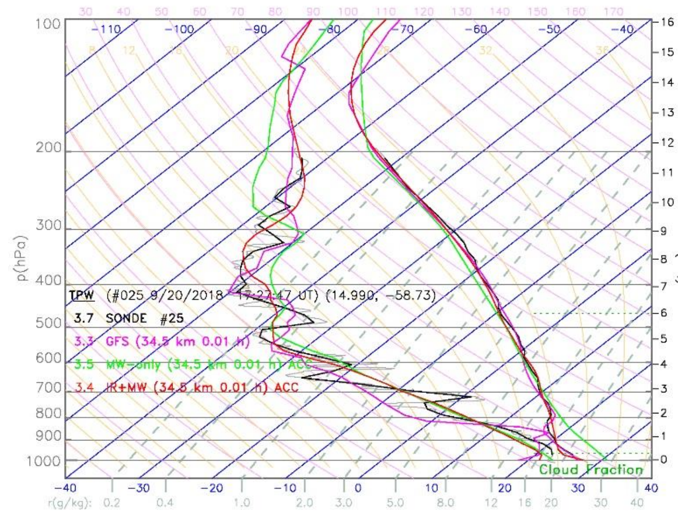


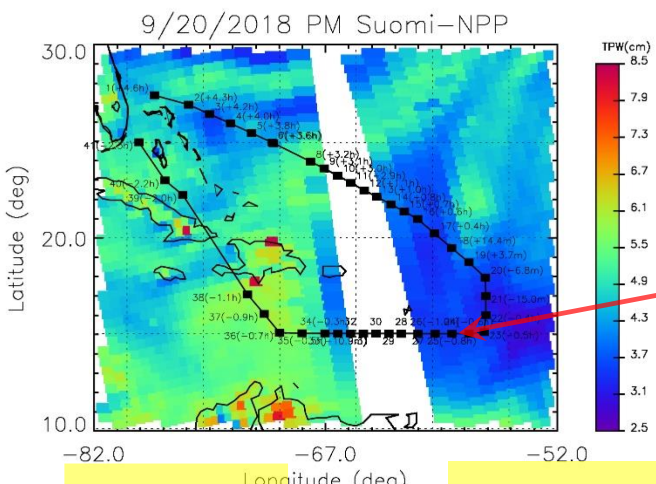
19:10 UT

17:30 UT

Sonde #25/41 17:28 UT

NOAA-20 NUCAPS 34.8 km +0.4 min

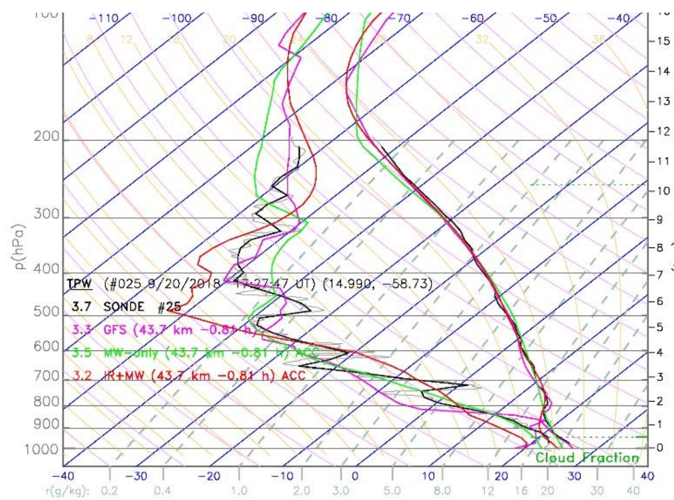




18:20 UT

16:40 UT

S-NPP NUCAPS 43.7 km -49 min



Which a-priori is best for these applications?

Concern	Statistical Model	Re-analysis model
Satellite data is used twice	YES: All channels are used in NN and regressions. Subset of the same exact channels are re-used.	→zero Weight of obs is extremely small w.r.t. 6 hour window and all other instruments.
Vertical sub-structure	Derived from ECMWF statistics and only our obs. The a-priori contribution in the solution cannot be quantified.	Derived from ensemble of many instruments and model dynamics. Contribution is partitioned via error propagation, $dXdX^T$
Latency	Zero – it is a static training	Re-analysis: ~1 month GMAO FP: ~4 to 7 hours
Spatial consistency	Clouds and other signals cause "spatial speckle" that can induce large gradients at 100 km scale.	Constrained by model dynamics (including thermal wind) and is spatially consistent.
Temporal consistency (NOTE NN and regressions are "trained" from specific instruments within specific year(s).)	Non-graceful response to instrument changes (e.g. , degradation, AIRS/CrIS transition) and state changes (climate, volcanoes, or anything outside the domain of its training)	Stated goal is to mitigate obs. discontinuities. Can have artifacts due to instrument changes: O3: MLS in 10/2004; T/q: Metop 2009, 2013, S-NPP 2012, etc.

CLIMCAPS retains many components of the AIRS Methodology

- (see Sep. 14, 2016 and Oct. 26, 2017 NASA STM presentation) for additional details **… and … detailed derivations for NUCAPS are in rs_notes.pdf available on my google drive at http://goo.gl/pJfYAo**
  - **Details of CLIMCAPS theory will be added in soon**
- Cloud clearing
  - Uses spatial information to correct for clouds
  - Allows other state components (SST/LST, T(p), q(p), $\varepsilon(\upsilon)$, O_3(p), CO(p), etc.) to be derived *independently* of clouds from spectral information
  - But, a-priori used for cloud clearing is extremely important.
    - Iteration of cloud clearing causes biases and confounds error characterization … CLIMCAPS currently has 2 steps
- Uses all space sounding assets
  - Microwave radiances used for both for information content and quality control
  - Imager data is implicitly used via emissivity a-priori

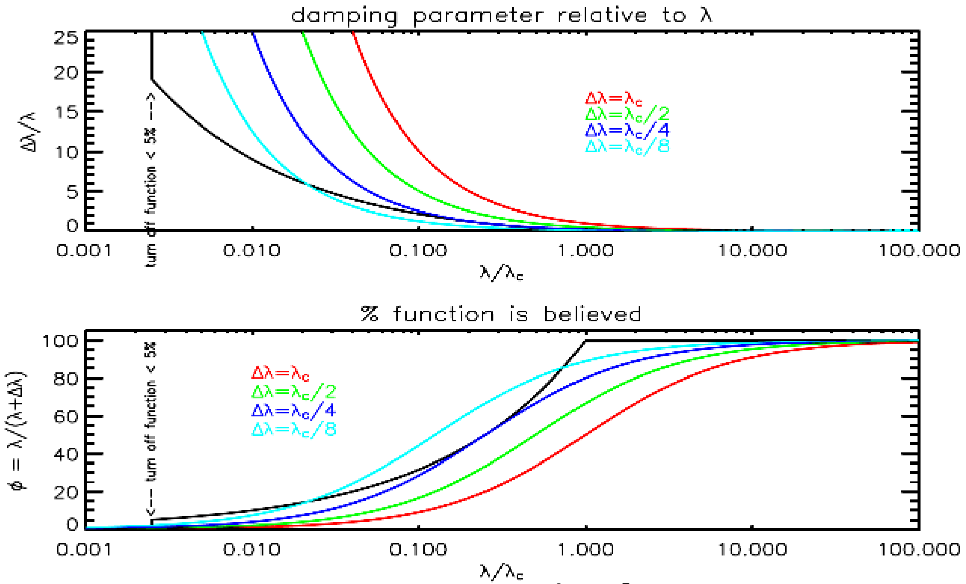
CLIMCAPS retains the AIRS information content analysis

- Embedded information content (IC) analysis
  - Retain components that have high signal-to-noise, S/N
  - *Requires accurate estimates of **all** noise terms, N*
  - Single optimization parameter, $1/\lambda_c$, defines S/N threshold
    - e.g., T(p) retrieval uses $1/\sqrt{\lambda_c} = 5$, $\lambda = (S/N)^2$

Top Panel: shows the damping parameter as a function of λ/λ_c for a AIRS methodology (black) and minimum variance methods (colors)

Bottom Panel: Same curves but shown as percent believed.

Embedded IC allows retaining high S/N components 100% (without damping) while dramatically reducing the impact of low S/N components.



Higher S/N →

CLIMCAPS differs from AIRS Science Team and NUCAPS

- For 20+ years the sounder community has attempted to make a model-independent system.
  - NUCAPS and AIRS v.6 use statistical models as the a-priori.
- CLIMCAPS uses Merra-2 reanalysis as a-priori for T(p) and q(p).
  - Hypothesis: the statistical step in AIRS Science Team methodology does not provide a stable or well characterized a-priori for continuity.
  - Merra-2 is a data driven system, does an incredible job with T(p).
  - Retrieval can benefit from the stability provided by the reanalysis dynamics.
  - For water vapor, hyperspectral infrared IC is high, fixes problems with re-analysis.
- CLIMCAPS uses the Combined ASTER & MODIS Emissivity over Land (CAMEL) as a-priori over land
  - CAMEL database has scene dependent uncertainties
  - Effectively brings in imager IC and high spectral resolution laboratory data
- Numerous other improvements in the estimate of geophysical errors *and their propagation* through the retrieval process
- **Detailed derivations for NUCAPS are in rs_notes.pdf available on my google drive at http://goo.gl/pJfYAo**
  - **Details of CLIMCAPS theory are being added now**

CLIMCAPS algorithm components designed to improve stability (continuity) over time and space

*x*CAPS is both an R2O and an O2R engine

- NUCAPS is based on AIRS Science Team (AST) methodology (version 5.9) and leverages a NASA research investment to support NOAA operations (R2O)
  - NUCAPS-Metop has been operational since 2008
    - 2008 to present Metop-A/IASI+AMSU+MHS + AVHRR
    - 2012 to present Metop-B/IASI+AMSU+MHS
  - NUCAPS/S-NPP went operational in early 2013
  - NUCAPS/NOAA-20 will be operational soon (in DB now)
  - *NUCAPS is fully capable of running AIRS+AMSU*
    - *But it is not a NOAA operational product at this time*
  - NUCAPS has many operational users (T, q, O_3, CO, and CH_4)
- CLIMCAPS leverages NUCAPS & AST development (O2R)
  - NOAA requires diurnal continuity of Metop/S-NPP/NOAA-2x

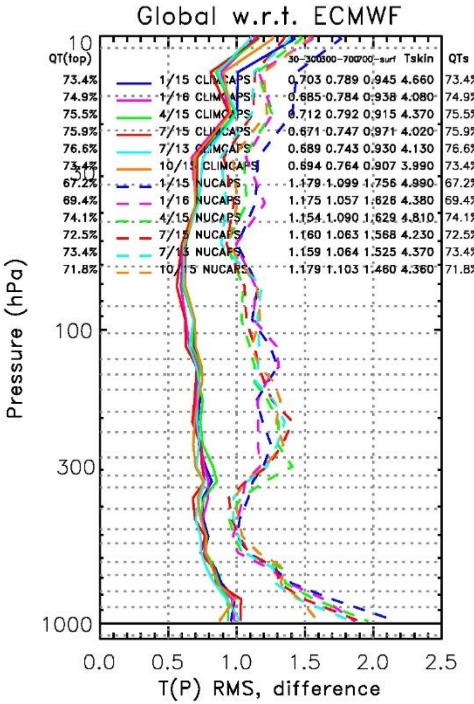
CLIMCAPS has benefited from NUCAPS O2R investment
NUCAPS can benefit from CLIMCAPS R2O investment

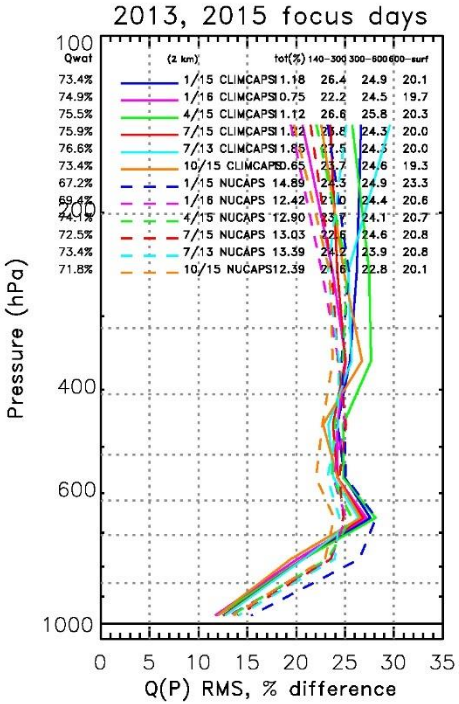
Climate applications require **seasonal**, **inter-annual** and **inter-satellite** stability that is climate model independent (Aqua vs. SNPP, IR-only vs. IR+MW)

Weather applications require real time, forecast independent and PBL skill.

CLIMCAPS-SNPP vs. NUCAPS-SNPP (Global RMS for 6 focus days)

- RMS of retrieval minus ECMWF for July 1, 2013, Jan. 1, 2015, Apr. 1, 2015, Jul. 1, 2015, Oct. 1, 2015, and Jan. 14, 2016 are shown.
- CLIMCAPS-SNPP RMS is better than ~1K throughout troposphere for all seasons ***with ~75% yield in PBL***
- BIAS (backup slides) is less than 0.5 K in PBL versus ~1 K with NUCAPS
- CLIMCAPS T(p) is dramatically improved
  - Retrieval is optimized to believe radiances, not a-priori, so it will adjust Merra-2, if needed
- CLIMCAPS q(p) is ≈ same as NUCAPS
  - Measurement IC dominates solution
  - Merra2 RMS is larger than regression but a-priori is more stable
- **CLIMCAPS statistics are more stable seasonally and interannually.**



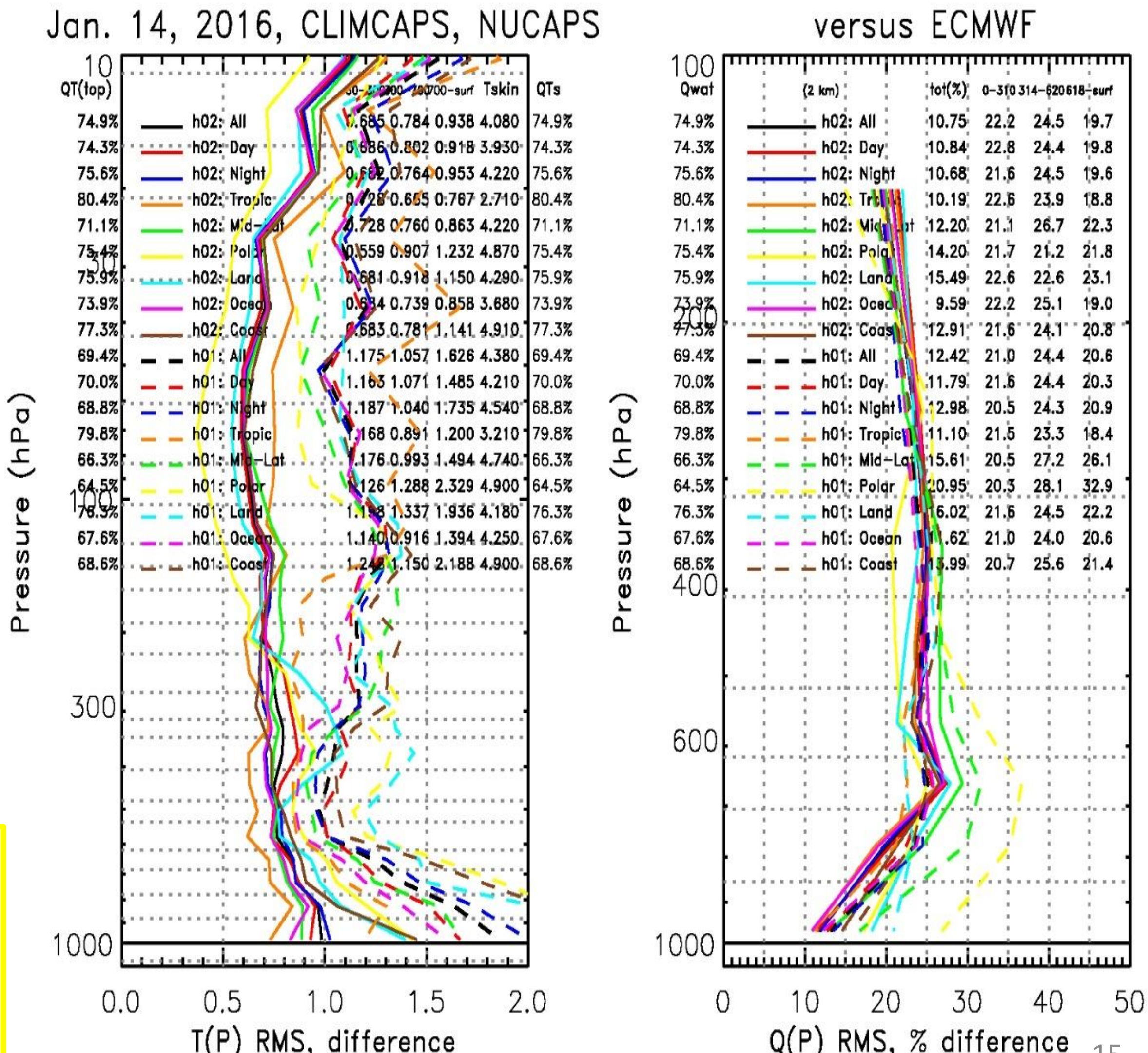


- **CLIMCAPS-SNPP system (solid lines)**
- **NUCAPS-SNPP system (dashed lines)**

These RMS statistics are not sufficient to quantify uncertainty in our level-3 products. CLIMCAPS error propagation will enable the necessary traceability.

CLIMCAPS-SNPP vs. NUCAPS-SNPP statistics for various regimes

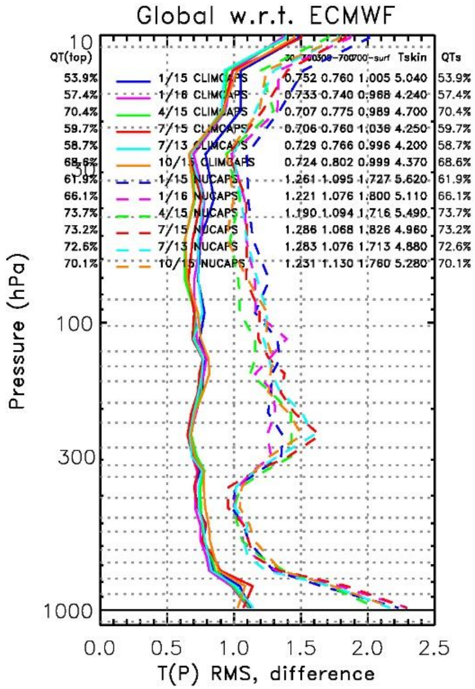
- CLIMCAPS and NUCAPS statistics for Jan. 14, 2016 focus day are shown as a function of regime.
- CLIMCAPS PBL is most difficult in Polar (1.23K), Land (1.15K) and Coastal (1.14K) regimes.
- **CLIMCAPS is stable in different regimes.**

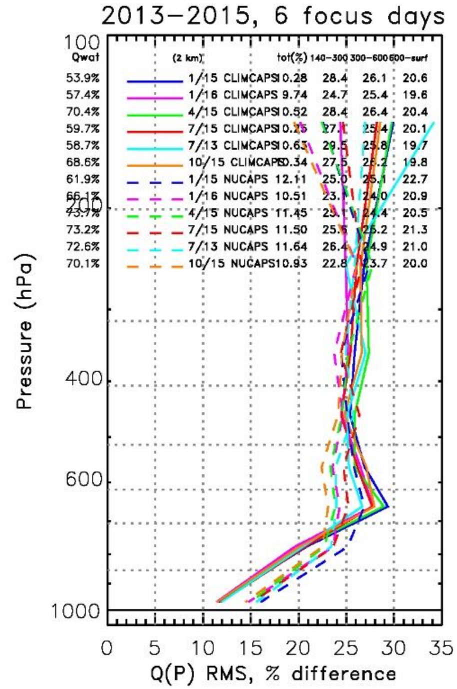


Minimal sampling bias is required for a climate product (i.e., should relax to a known a-priori)

CLIMCAPS-Aqua vs. NUCAPS-Aqua (Global RMS for 6 focus days)

- RMS of retrieval minus ECMWF for July 1, 2013, Jan. 1, 2015, Apr. 1, 2015, Jul. 1, 2015, Oct. 1, 2015, and Jan. 14, 2016 are shown.
- CLIMCAPS-Aqua RMS is better than ~1K throughout troposphere for all seasons ***with ~60% yield in PBL (not optimized yet)***
- BIAS (backup slides) is less than 0.5 K in PBL versus ~1 K with NUCAPS
- CLIMCAPS T(p) is dramatically improved
  - Retrieval is optimized to believe radiances, not a-priori, so it will adjust Merra2, if needed
- CLIMCAPS q(p) is ≈ same as NUCAPS
  - Measurement IC dominates solution
  - Merra2 RMS is larger than regression but a-priori is more stable
- **CLIMCAPS statistics for Aqua have same characteristics as S-NPP**



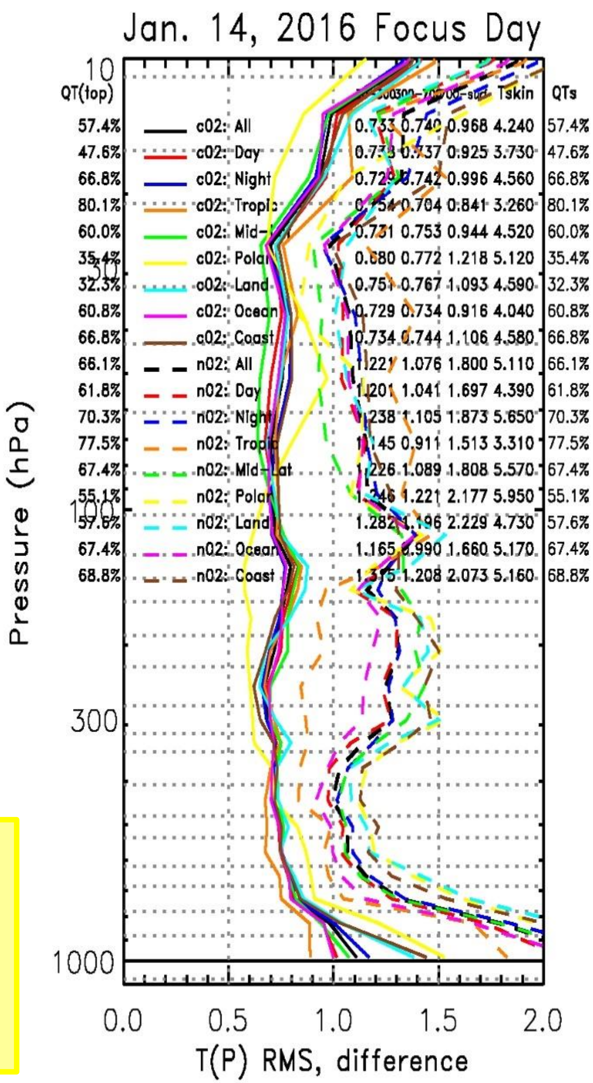


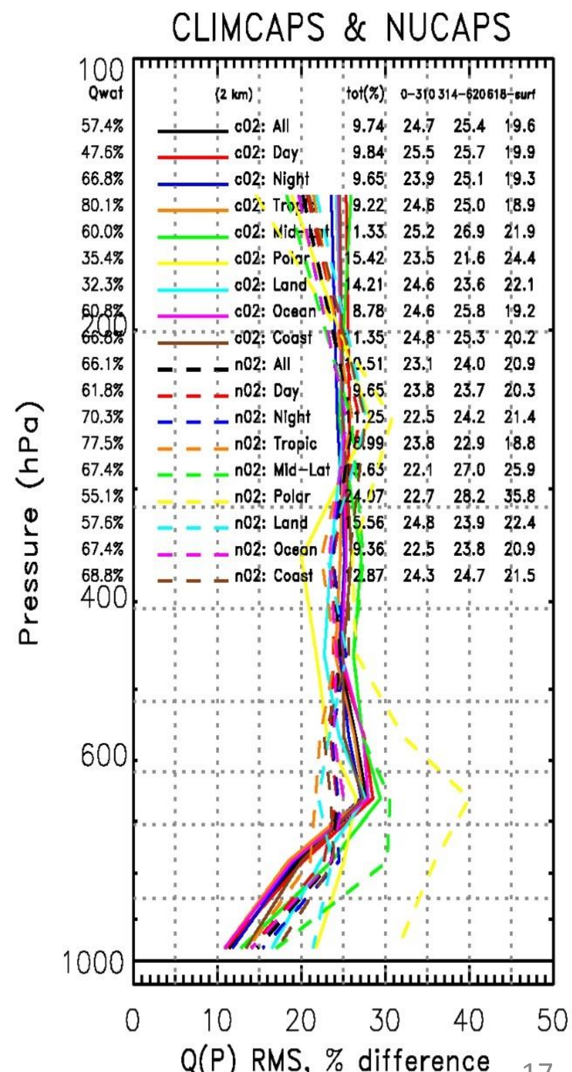
- **CLIMCAPS-Aqua system (solid lines)**
- **NUCAPS-Aqua system (dashed lines)**

These RMS statistics are not sufficient to quantify uncertainty in our level-3 products. CLIMCAPS error propagation will enable the necessary traceability.

CLIMCAPS-Aqua vs NUCAPS-Aqua statistics for various regimes

- CLIMCAPS and NUCAPS statistics for Jan. 14, 2016 focus day are shown as a function of regime.
- CLIMCAPS PBL is most difficult in Polar (1.22K), Land (1.09K) and Coastal (1.11K) regimes.
- **CLIMCAPS is stable in different regimes.**

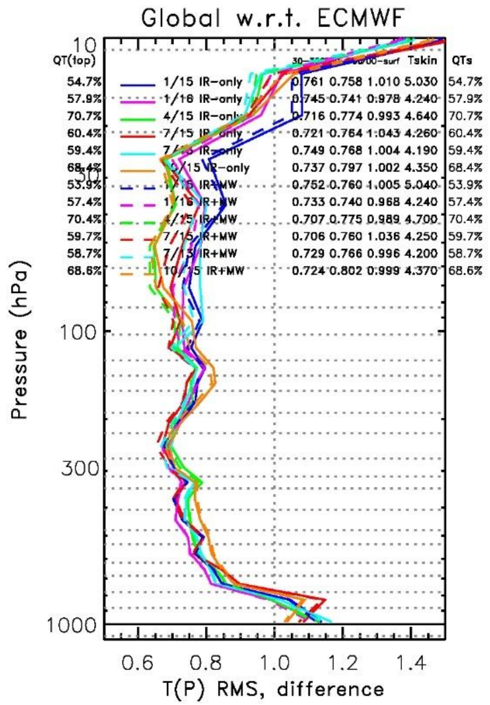


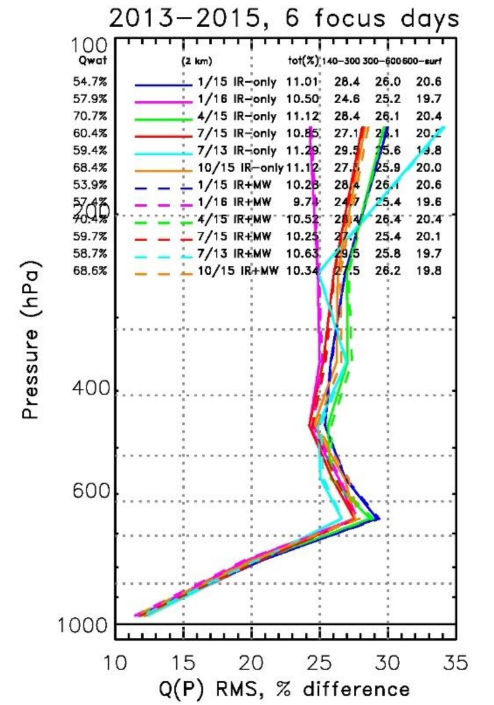


Minimal sampling bias is required for a climate product (i.e., should relax to a known a-priori)

CLIMCAPS-AIRS-only vs AIRS+AMSU (Global RMS for 6 focus days)

- RMS of retrieval minus ECMWF for July 1, 2013, Jan. 1, 2015, Apr. 1, 2015, Jul. 1, 2015, Oct. 1, 2015, and Jan. 14, 2016 are shown.
- CLIMCAPS-Aqua AIRS-only and AIRS+AMSU RMS agree with each other and are less than ~1K throughout troposphere for all seasons
  - ***Aqua yield is less (60%) but these runs are NOT optimized***
- CLIMCAPS T(p) is stable
  - Retrieval is optimized to believe radiances, not a-priori, so it will adjust Merra2, if needed
- CLIMCAPS-AIRS-only q(p) is ≈ same as AIRS+AMSU
  - Measurement IC dominates solution
  - Merra2 RMS is larger than regression but a-priori is more stable
- **CLIMCAPS statistics are not sensitive to loss of AMSU**



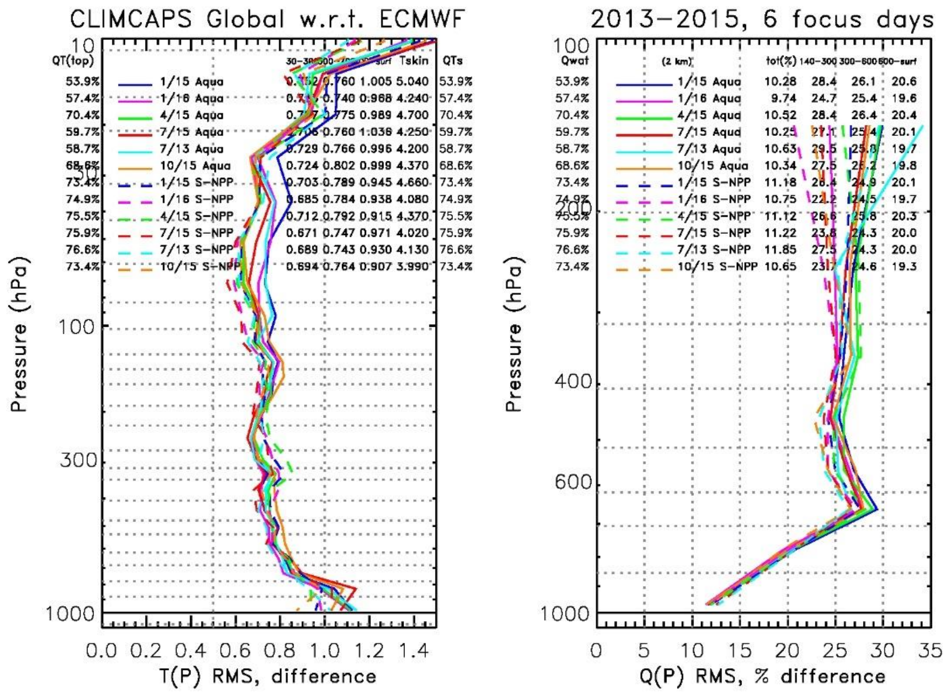


- **CLIMCAPS-Aqua-IR-only system (solid lines)**
- **CLIMCAPS-Aqua-IR+MW system (dashed lines)**

These RMS statistics are not sufficient to quantify uncertainty in our level-3 products. CLIMCAPS error propagation will enable the necessary traceability.

CLIMCAPS-Aqua vs. CLIMCAPS-SNPP (Global RMS for 6 focus days)

- RMS of retrieval minus ECMWF for July 1, 2013, Jan. 1, 2015, Apr. 1, 2015, Jul. 1, 2015, Oct. 1, 2015, and Jan. 14, 2016 are shown.
- CLIMCAPS-SNPP and Aqua RMS agree with each other and are less than ~1K throughout troposphere for all seasons
  - ***Aqua yield is less (60% vs. ~75%) but these runs are NOT optimized***
- CLIMCAPS T(p) is stable
  - Retrieval is optimized to believe radiances, not a-priori, so it will adjust Merra2, if needed
- CLIMCAPS-SNPP q(p) is ≈ same as Aqua
  - Measurement IC dominates solution
  - Merra2 RMS is larger than regression but a-priori is more stable
- **CLIMCAPS should help mitigate kinks in an Aqua/S-NPP (and JPSS) sounding data record.**



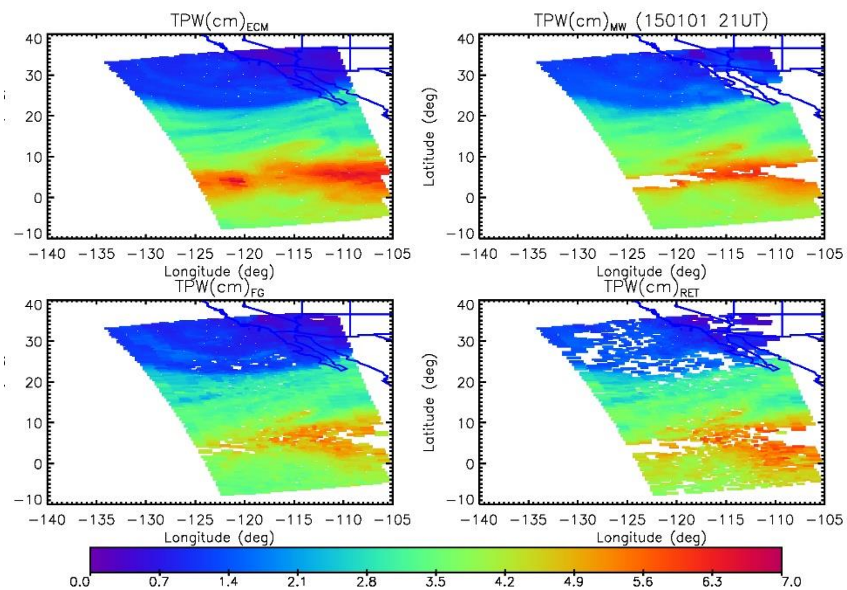
- **CLIMCAPS-Aqua system (solid lines)**
- **CLIMCAPS-SNPP system (dashed lines)**

These RMS statistics are not sufficient to quantify uncertainty in our level-3 products. CLIMCAPS error propagation will enable the necessary traceability.

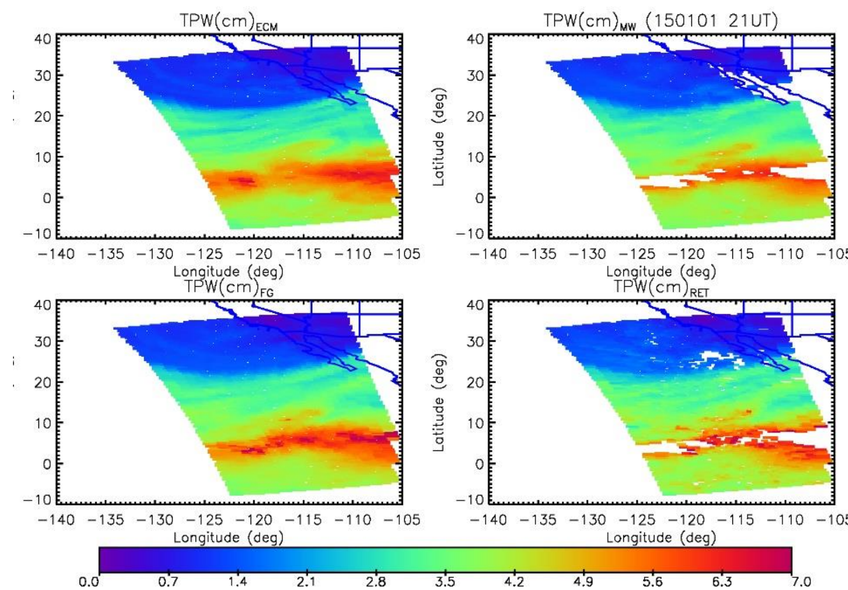
CLIMCAPS has less spatial “speckle”

- Upper left: ECMWF is spatially smooth due to model physics
- Upper right: MIT retrieval is also relatively smooth
- Lower Left: Regression for NUCAPS and Merra2 for CLIMCAPS
- Lower Right: Physical system (believes ~50% of a-priori)

NUCAPS System



CLIMCAPS System

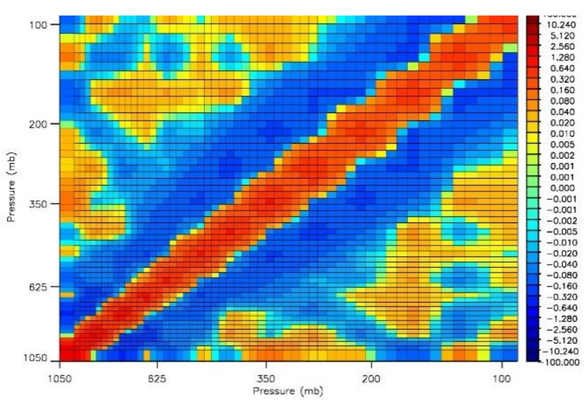


CLIMCAPS propagates a-priori error estimates and reports the error characteristics as either averaging kernals or error covariances

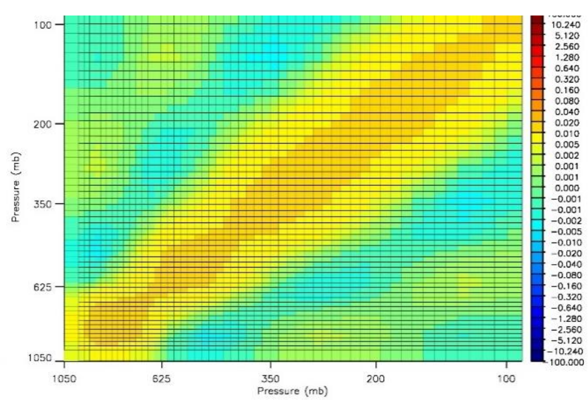
Error covariance of the T(p) retrieval, $\delta T \delta T^T$

- Error covariance & averaging kernels are related through the a-priori covariance
- Error can be mapped through our physical retrieval such that the amount of the a-priori in our solution can be known and analyzed
  - The left panel is how much of the a-priori leaks through (~50% in this case)
  - Middle panel is the error covariance of the measurements
  - Right panel is the total error covariance of the temperature retrieval
- Most of the scene-to-scene variability in the error will be from the fraction of the a-priori that leaks through – ***and that is a strong function of cloud homogeneity***

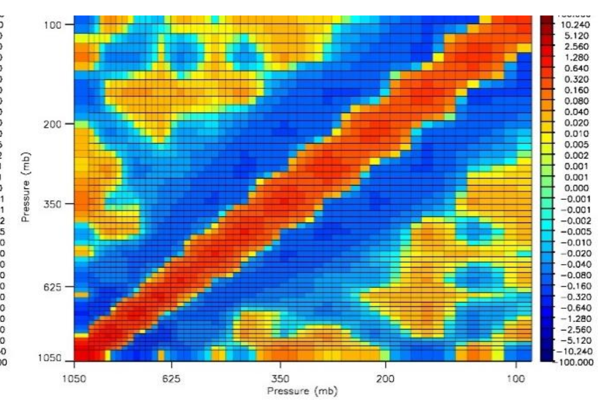
Merra2 error in solution, $(\delta T \delta T^T)^A$



Error in solution, from radiances $(\delta T \delta T^T)^O$



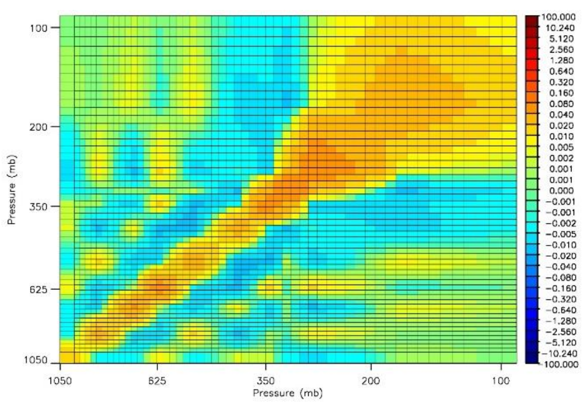
Retrieval error: $\delta T \delta T^T = (\delta T \delta T^T)^A + (\delta T \delta T^T)^O$



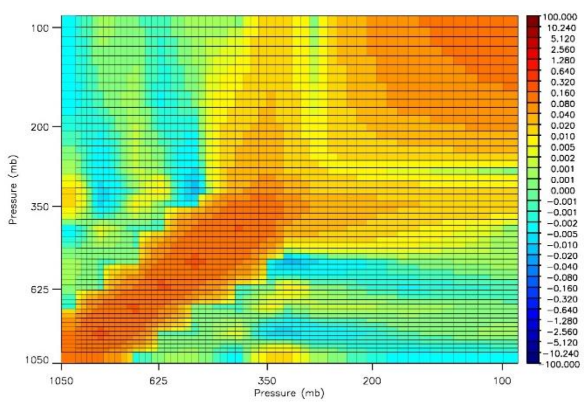
Error covariance of the q(p) retrieval, $\delta q \delta q^T$

- The error from T(p) retrieval, $\delta T \delta T^T$, is used as error source when solving for water vapor, q(p)
  - In the case of water vapor, a greater fraction of the measurements are believed (i.e., ~25% of a-priori error propagates to solution)
  - Higher errors (e.g., cloud clearing or $\delta T \delta T^T$) will cause more of the water a-priori to leak through, especially near the surface
- With CLIMCAPS we can quantify the sources of error in our retrieval.

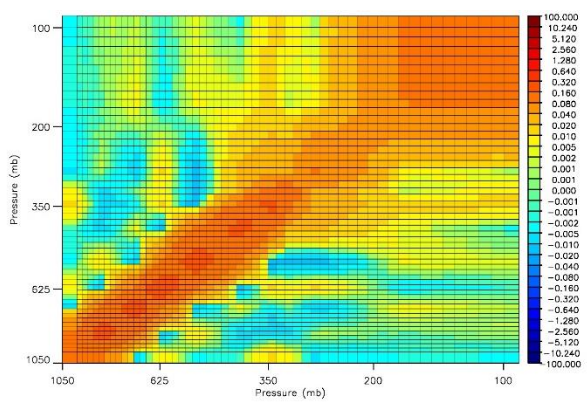
Merra2 error in solution, $(\delta q \delta q^T)^A$



Error in solution, from radiances $(\delta q \delta q^T)^O$



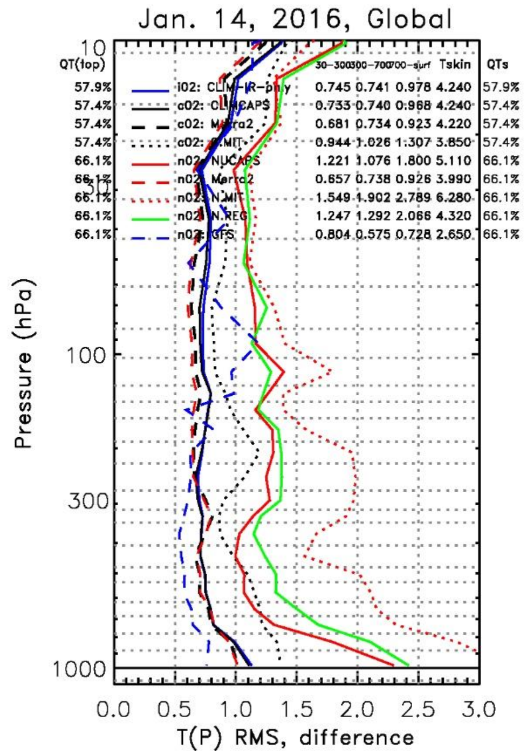
Total retrieval error: $\delta q \delta q^T = (\delta q \delta q^T)^A + (\delta q \delta q^T)^O$

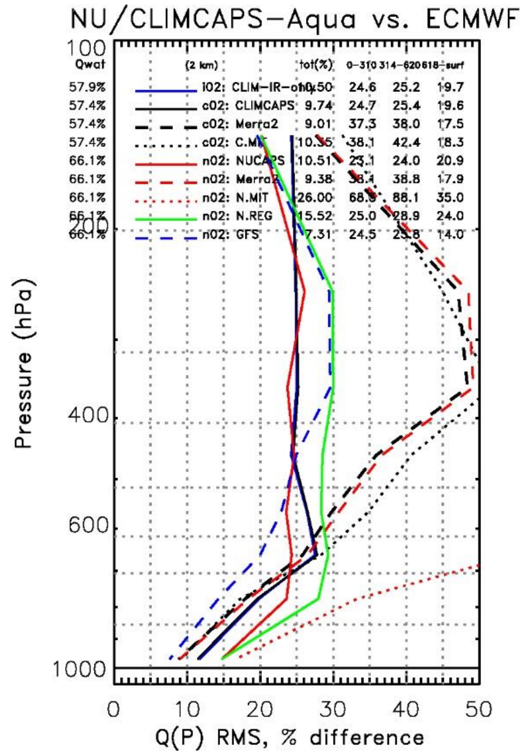


We must be able to interrogate our scene dependent information content in order to understand it impact on level-3 or averaged products.

How much do we improve over Merra-2?

- Statistics for the Jan. 14, 2016 focus day
- CLIMCAPS T(p) is ~= MERRA T(p)
- But CLIMCAPS q(p) ends up in same place as NUCAPS q(p) even though Merra-2 start-up significantly worse than NUCAPS regression.
- **AIRS (and S-NPP) DOES NOT add significant information content to T(p)**
- **AIRS (and S-NPP) DOES add significant IC to q(p)**





Black: CLIMCAPS-Aqua, Solid = AIRS+AMSU dotted: AMSU-only
Blue: CLIMCAPS-Aqua, Solid = AIRS-only
Red: NUCAPS-Aqua, Solid = AIRS+AMSU, dotted: AMSU-only
Green: NUCAPS-Aqua, Solid = AIRS+AMSU LINEAR regression
Dashed Black: Merra-2 for CLIMCAPS-Aqua QC
Dashed Red: Merra-2 / Blue: GFS for NUCAPS-Aqua QC

Preliminary assessment of using Merra-2 as a-priori

Product	How much does Merra-2 help?
CCR’s	Merra-2 T(p) stabilizes cloud clearing.
T(p)	Merra-2 ≈50-75% of IC, CLIMCAPS $dXdX^T$(H_2O,CO_2, O_3,…)
q(p)	Merra-2 contributes ≈25% of IC, CLIMCAPS $dXdX^T$(T,CH_4,…)
O3(p)	≈1.5 d.o.f. in LS/UT Merra-2 O3(p) provides shape
CO	≈1 d.o.f. in mid-trop, Merra-2 T(p) adds stability
CH4, CO2, N2O	≈0.5 d.o.f. in mid-trop, Merra-2 T(p) adds stability
HNO3	≈1 d.o.f. in LS, MERRA-T(p) stabilizes the solution

A-priori is necessary because our solution is under-determined
Merra-2 is more stable than statistical operators
Merra-2 has less discontinuities than forecast models
Retrieval departures from Merra-2 are valuable in the context of continuity because we are exploiting more of the IC of the Aqua/S-NPP/NOAA-20 infrared/microwave satellites and account for $dXdX^T$ of trace gases

CLIMCAPS is a sensor-agnostic product system tailored to the data needs of the climate and composition **communities**

The Value of CLIMCAPS

- The CLIMCAPS T(p) product is dependent on Merra2
  - T(p) departures mostly reflect a "correction" to our satellite time and line of sight observation geometry
  - Most of the NUCAPS/CLIMCAPS difference is in our null-space
- Merra-2 stabilizes our cloud clearing and T(p) retrieval
  - Spatial and vertical structures are more reasonable since they satisfy Merra-2 dynamics, continuity, & thermodynamic eqns.
  - **No longer need to iterate cloud clearing**
  - T(p) statistics are dramatically improved w.r.t. NUCAPS
- The value of CLIMCAPS will be the impact of transparent partitioning of the propagated error to the downstream steps.
  - For the 1st time we have a stable a-priori (T(p), q(p), O_3(p), and $\varepsilon(\upsilon)$) to retrieve these constituent products.
  - For O3(p) we expect Merra-2 dynamics and instruments (e.g., MLS) will provide dramatic improvements.
  - All the structure in our other trace gas products (CO, CH_4, CO_2, HNO_3, N_2O, and SO_2) comes from the radiances

CLIMCAPS trace gas products are both direct and indirect climate products

What are the areas of our current sounding research?

- NOAA-Unique Combined Atmospheric Processing System (NUCAPS) can handle the real-time weather and air quality applications (Metop 9:30 and S-NPP/JPSS 1:30 orbits).
  - Air traffic safety.
  - Pre-convective forecasting
  - Wildfire management and air quality.
  - Hurricane forecasting.
  - Ozone recovery and use of ozone at STE indicator.
- The NASA Continuity product should focus on developing a long-term (2002-2040’s and beyond) record for Aqua/AIRS and S-NPP/JPSS CrIS
  - Study how to build *<u>and document</u>* continuity records.
    - Transparent, instrument agnostic approaches.
    - Choose the appropriate a-priori for NASA applications.
  - Communicate the strengths and caveats of the product

We desire a paradigm shift in communication

- In the past the sounding community has had a “build it and they will come” approach. It did not work.
- With NUCAPS we now have the community fully engaged and openly evaluating the product.
  - It is critical that this is an independent characterization
- With CLIMCAPS we want to engage the NASA communities in much the same way.

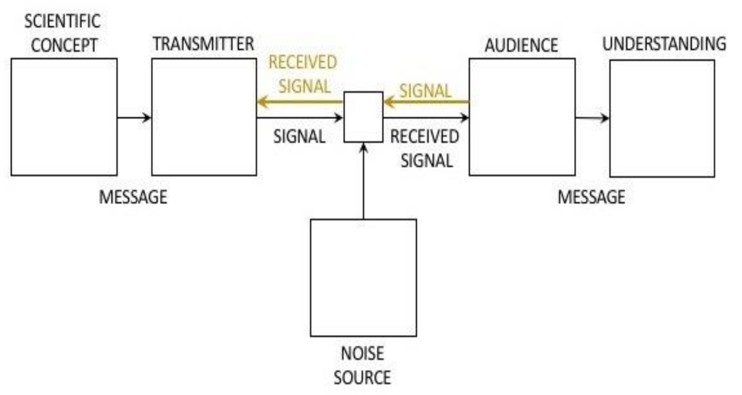
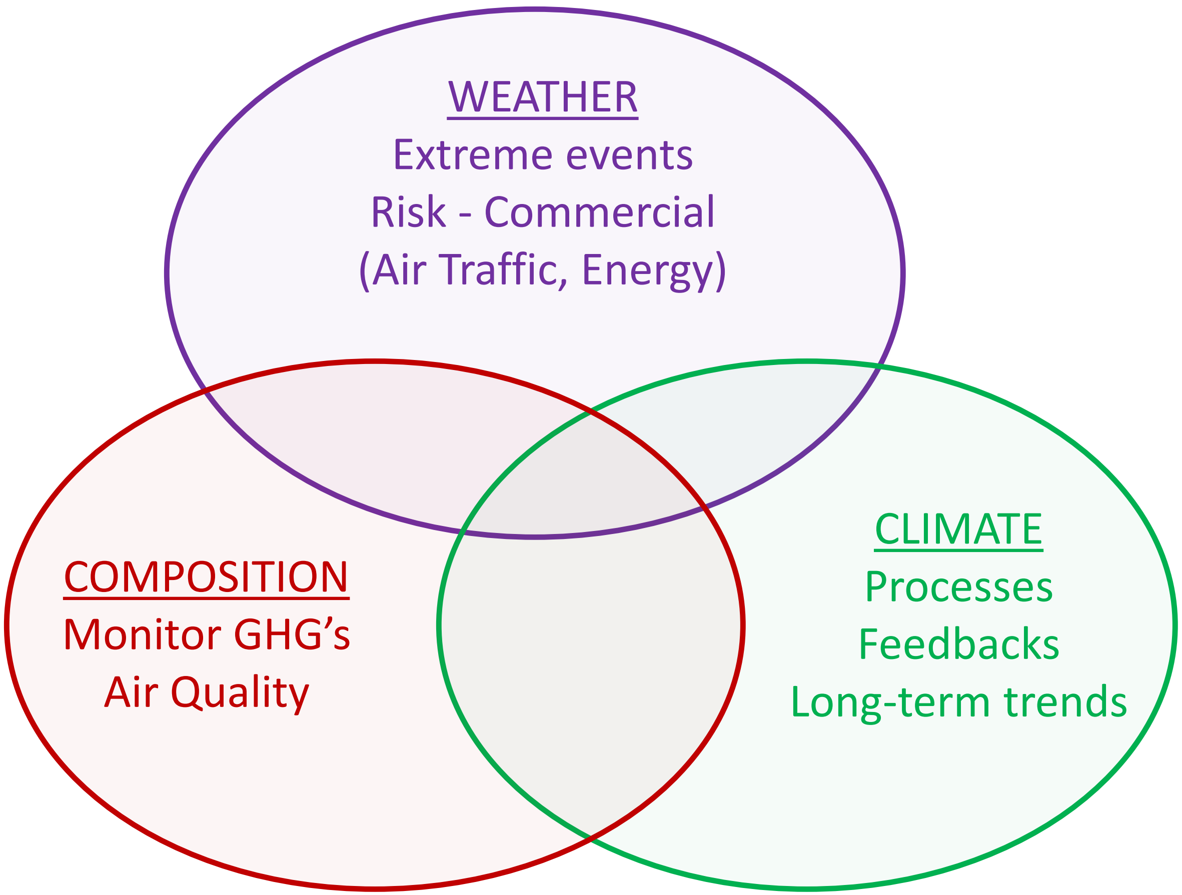


Fig. 2: Reinterpreting Fig. 1 with a focus on scientific communication

Smith, N., C.D. Barnet and K. Shontz 2018. What is a satellite measurement? Communicating abstract satellite science concepts to the world. AMS 14th Symposium on New Gen. Env. Sat., 3 pgs

We are attempting to meet the needs of 3 communities



Applications we should target for the NASA continuity product.

Topic	Potential applications for thermal sounding products
Fingerprinting (e.g., Santer 2018 Science, Pierrehumbert 2011 Phys. Today)	Improved stratosphere/troposphere allows better separate of O3 hole from GHG's, N.H./S.H. gradients, polar amplification (downwelling thermal), Arctic moisture budget (Boisvert 2015 JGR)
PBL (Fetzer 2004 GRL, Hoogewind 2017 J.Clim)	Capping layer inversions, convection and stability. Most important for a thermal sounder is knowledge of when we have skill (i.e., averaging kernels).
UTH, double ITCZ (Tian 2015 GRL), ENSO, MJO	Stable and seasonally consistent T(p) will stabilize cloud clearing and q(p). Departures from Merra-2 will be more valuable than a derived state.
Ozone	Ozone hole; Intrusions and mid-trop O3 (Langford 2018 Atmos. Env); LS O3 trends (Ball 2018 ACP, Wargan 2018 GRL); CO/O3 ratio (Anderson 2016 Nat.Comm)
Carbon Dioxide (CO2)	Contribute to discussion of seasonal cycle amplitude (Barnes 2016 JGR), clear bias of OCO (Corbin 2008 JGR)., and stratospheric/troposphere CO2 gradient. (Separability of T/CO2 is improved with use of Merra-2 and AMSU/ATMS.
Carbon Monoxide	Long-term trends of CO (Worden 2013 ACP). Impact on OH (Gaubert 2017 GRL), Seasonal cycle (Park 2015 JGR) and CO/CO2 emission factors (Wang 2009 ACP)
Methane (CH4)	Monitoring of Amazon CH4 (Bloom 2016 ACP), Changes to Arctic emissions (Shakhova 2010 Science, Thornton 2016 GRL)
Other trace gases	Nitric Acid, Nitrous Oxide, Sulfur Dioxide, Isoprene, PAN, Acetylene, Methanol, etc – all benefit from stable cloud clearing and upstream derived T(p), q(p), etc.

CLIMCAPS supports building a continuity dataset *NOW*

- Provide the best archive of these measurements as a baseline for the future.
  - Reasonable mitigation of instrument artifacts.
  - Full suite of trace gases, error propagation.
- Build a long-term record so that TASNPP researchers can
  - Use the record for understanding climate processes and change
  - Document our best understanding of the information content of these measurements
  - 9/2002-8/2016 AIRS + AMSU → 9/2016-8/2035 CrIS-FSR + ATMS
    - 5 satellites and 2 instrument types at 1:30 am/pm
    - With sufficient overlap period of 2012-present
- Future work (next ROSES cycle?)
  - 2007-2020’s IASI/AMSU/MHS → 2021-2040 IASI-NG
    - Metop-A, -B, -C at 9:30 am/pm with IASI, AMSU, MHS
    - Follow-on (EPS-SG/IASI-NG) has been approved for 2021-2040
  - Reprocessing using a Common Hyperspectral InfraRed Product (CHIRP) dataset (AIRS, IASI, CrIS to common spectrum).

Questions?

1. CLIMCAPS is a NASA continuity product system
2. CLIMCAPS uses Merra-2 as a-priori for T(p) and q(p), CAMEL for $\varepsilon(\nu)$, static climatologies for trace gases.
3. CLIMCAPS retrieves soundings in clear and partly cloudy scenes.
4. CLIMCAPS has diurnal, seasonal and inter-annual and inter-satellite stability.
5. CLIMCAPS propagates partitions a-priori and retrieval error estimates.
6. CLIMCAPS is designed to support **community needs.**
7. **So …. How can CLIMCAPS support your research?**

Sequential Retrieval Equations

$$
\begin{aligned}
T^i \quad = \quad T^A \quad + \quad & \left[K_T^T \cdot N^{-1} \cdot K_T + (\delta T \delta T^T)^{-1}\right]^{-1} \cdot K_T^T \cdot N^{-1} \cdot \\
& \left[R^{obs} - R(T, q, O_3, \epsilon, \dots) + K_T \cdot (T^{i-1} - T^A)\right]
\end{aligned}
$$

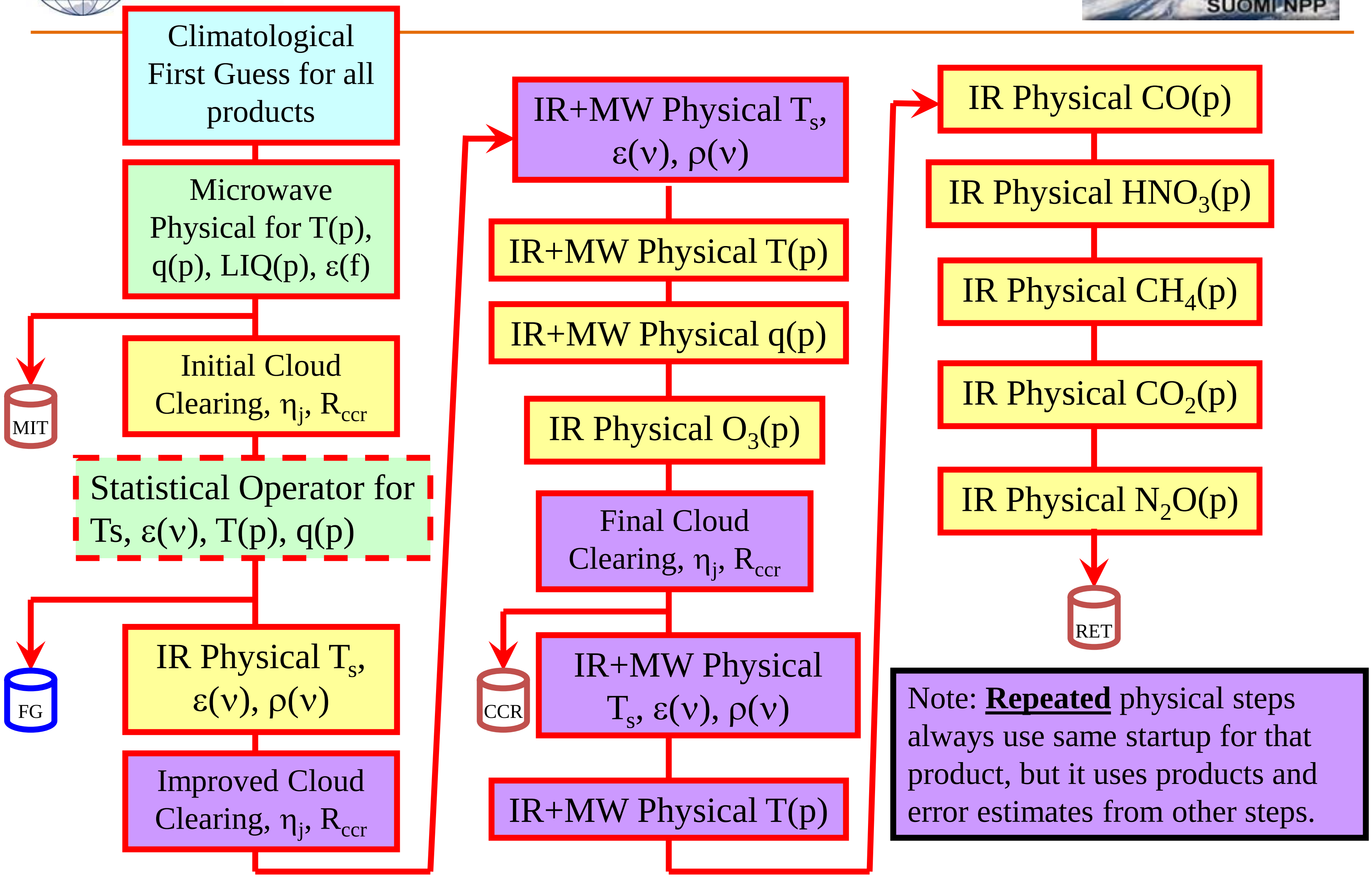
$$
K_X \equiv \frac{\partial R\,(T, q, O_3, \epsilon, \dots)}{\partial X}
$$

$$
\begin{aligned}
N \; = \; & \partial R \partial R^T + K_q \cdot \delta q \delta q^T \cdot K_q^T \\
+ \; & K_{O_3} \cdot \delta O_3 \delta O_3^T \cdot K_{O_3}^T + K_\epsilon \cdot \delta \epsilon \delta \epsilon^T \cdot K_\epsilon^T + \dots
\end{aligned}
$$

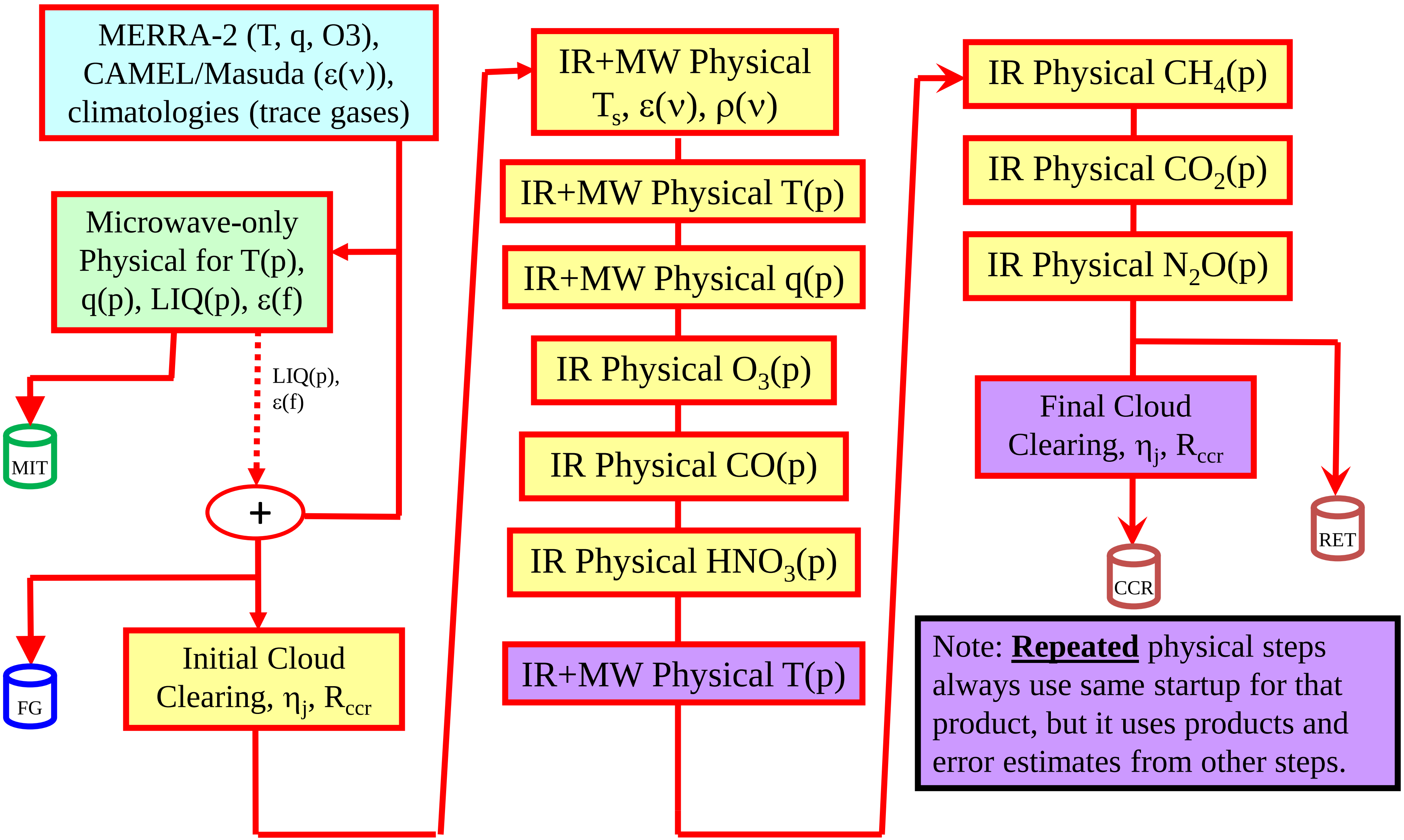
$$
\begin{aligned}
q^i \quad = \quad q^A \quad + \quad & \left[K_q^T \cdot N^{-1} \cdot K_q + (\partial q \partial q^T)_{j,j}^{-1}\right]^{-1} \cdot K_q^T \cdot N^{-1} \cdot \\
& \left[R^{obs} - R(T, q, O_3, \epsilon, \dots) + K_q \cdot \left(q_j^{i-1} - q_j^A\right)\right]
\end{aligned}
$$

$$
\begin{aligned}
N \; = \; & \partial R \partial R^T + K_T \cdot \delta T \delta T^T \cdot K_T^T \\
+ \; & K_{O_3} \cdot \delta O_3 \delta O_3^T \cdot K_{O_3}^T + K_\epsilon \cdot \delta \epsilon \delta \epsilon^T \cdot K_\epsilon^T + \dots
\end{aligned}
$$

Simplified Flow Diagram of the NUCAPS Algorithm

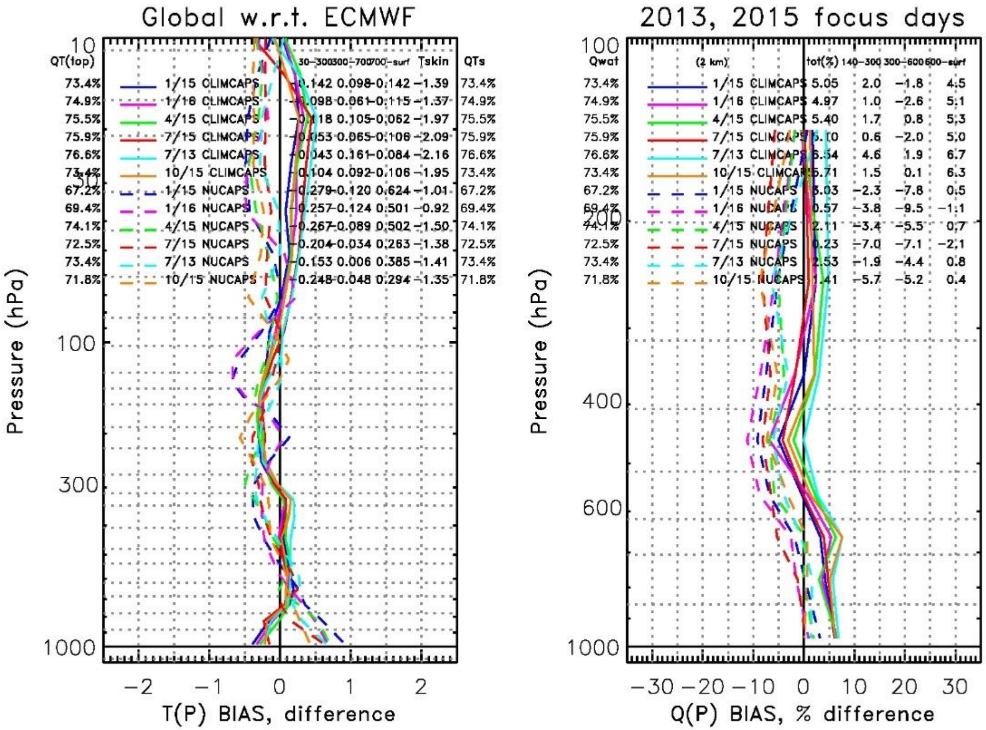


Simplified Flow Diagram of the CLIMCAPS Algorithm



CLIMCAPS-SNPP vs. NUCAPS-SNPP (Global BIAS for 6 focus days)

- Bias of retrieval minus ECMWF for July 1, 2013, Jan. 1, 2015, Apr. 1, 2015, Jul. 1, 2015, Oct. 1, 2015, and Jan. 14, 2016 are shown.
- CLIMCAPS BIAS is better than ~0.5K throughout troposphere for all years
  - 75% yield in PBL
- There is less seasonal variability in the bias
- CLIMCAPS statistics are more similar seasonally, interannually

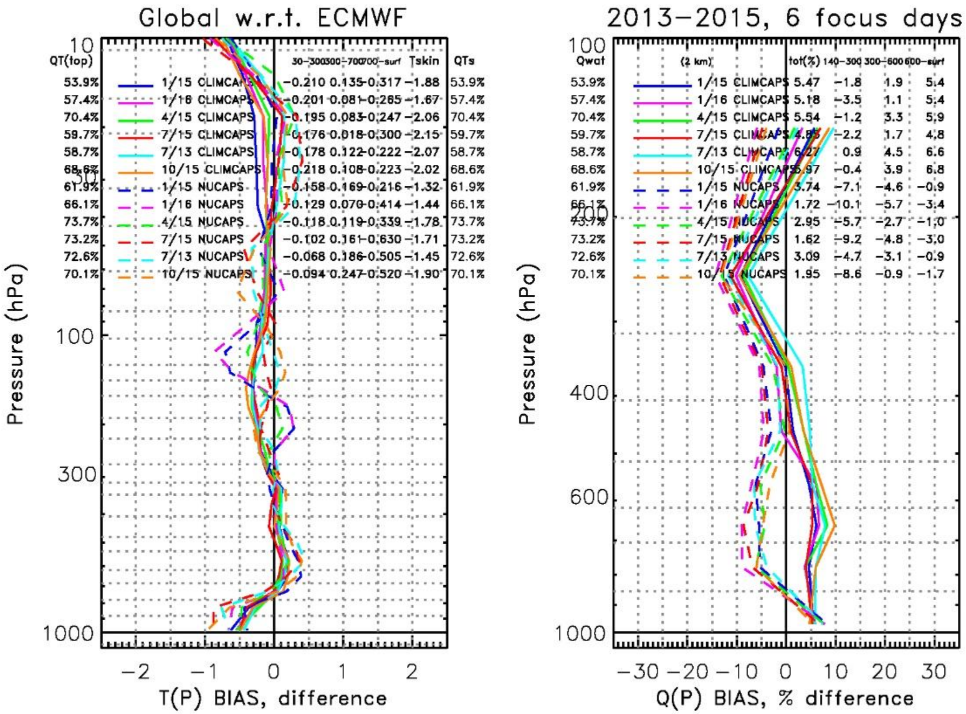


- **CLIMCAPS-SNPP system (solid lines)**
- **NUCAPS-SNPP system (dashed lines)**

Stability is required for a climate product

Performance of CLIMCAPS-Aqua (Global BIAS for 5 focus days)

- Bias of retrieval minus ECMWF for July 1, 2013, Jan. 1, 2015, Apr. 1, 2015, Jul. 1, 2015, Oct. 1, 2015, and Jan. 14, 2016 are shown.
- CLIMCAPS BIAS is better than ~0.5K throughout troposphere for all years
  - 60% yield in PBL
  - (not optimized yet)
- There is less seasonal variability in the bias
- CLIMCAPS statistics are more similar seasonally, interannually



- **CLIMCAPS system (solid lines)**
- **NUCAPS system (dashed lines)**

Stability is required for a climate product