Implementation of the NOAA Unique CrIS/ATMS processing System (NUCAPS) within the Community Satellite Processing Package (CSPP)

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Session: 1c, New Observations

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Discussion Points

- Why study retrievals?
- Brief Introduction to the NUCAPS algorithm.
  - More details in 8.02 (Dr. Gambacorta)
- Example NowCasting application of NUCAPS.
  - Application with atmospheric rivers.
  - Application with regional WFOs.
- Schedule for implementation into direct broadcast and future Work

Why Study Retrievals?

- Data assimilation ingests ATMS and CrIS radiances
  - Microwave (ATMS) is easier (more linear) to assimilate
  - Infrared (CrIS) is under-utilized in GFS
    - Too many channels, so subsets are used
    - Clouds cause problems, sub-sample fields of view
- Why study retrievals?
  - CrIS+ATMS can provide soundings in ~70% of scenes
    - Use of cloud clearing significantly increases the number of scenes in which infrared can be used
    - Cloudy scenes are more likely to include interesting weather
  - However, everything has to be done correctly
    - Retrievals need to properly model instrument errors
    - Have achieved ~1.5 K RMS errors in lowest 3 km
  - Retrievals are the same science as data assimilation
    - Lessons learned can be incorporated into global models

What is NUCAPS?

- NUCAPS is the operational code for CrIS+ATMS retrievals.
- Goal of this work is use the science version of NUCAPS to improve retrievals and study interesting cases.
  - Science and operational products are identical.
    - Science retrieval code is literally run through a filter to become the operational code.
    - Backward and forward compatibility is maintained.
  - Science version has many enhancements
    - Options for a plethora of diagnostic information
    - Includes trace gases (O_3, CO2, CH_4, CO, HNO_3, N_2O, SO_2, NH_3) CAPE, LI, cloud fraction and cloud height retrievals.

NUCAPS is a "*testbed*" for retrieval science

- NUCAPS was designed to be "*sensor agnostic*"
  - Namelists point to files that specify instrument parameters
  - Designed to avoid hardwiring of any instrument specifics
- The NUCAPS science code was derived from the AIRS Science Team (AST) science code
- The same science code was also used for the NOAA operational Metop (IASI, AMSU, MHS, AVHRR) system.
- Science code can easily be configured for any dataset
  - Science code can be configured to run AIRS, IASI, or CrIS
  - Can be used for simulation of hypothetical instruments
  - Can mix and match sensors (e.g., Aqua AIRS + NPP ATMS)

What makes this algorithm unique?

- Algorithm was designed to use all available ***sounding*** information.
  - Microwave radiances used in microwave-only physical retrieval, “cloudy” regression, “cloud cleared” regression and downstream physical T(p) and q(p) steps.
  - Use a comparison of 4 independent retrieval steps for quality control (QC) in addition to traditional QC (residuals, etc.).
- Algorithm utilizes the high-information content of the hyper-spectral infrared – both radiances and physics.
  - All channels used in *constrained* regression first guesses.
  - Utilize forward model derivatives help constrain the solution.
    - Uses full off-diagonal covariance of (obs-calc) errors.
    - Minimizes arbitrary *a-priori* constraints.

Nowcasting Application of Retrievals within Regional WFOs

- Retrievals can provide *situational awareness.*
- The goal of this work is to install NUCAPS into direct broadcast and study impact of retrievals at local WFOs.
- 1st demonstration of direct broadcast will focus on Alaska.
  - High latitudes have more satellite overpasses.
  - Low spatial density of *in-situ* and upstream measurements.
  - Huge heterogeneous areas.
    - *In-situ* has limited spatial representativeness.
  - North slope of Alaska has good in-situ validation.
    - ARM-Cart site on North slope for T/q validation.
    - Barrow Alaska: Validation of methane products that might be of interest for permafrost monitoring.

Still shot of vertical cross section movie

(Note: differences on 100 layer (~250 meter) profile)

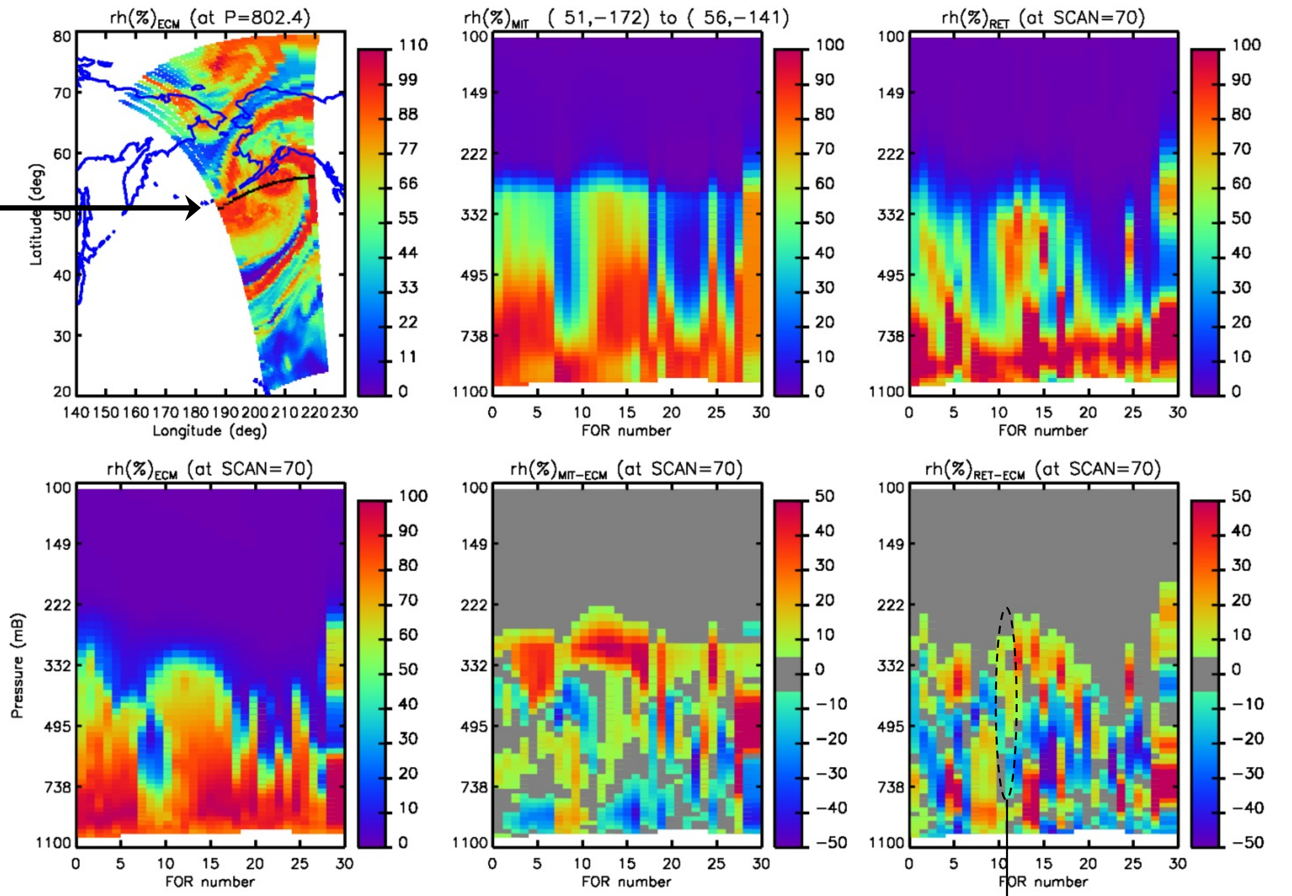
CrIS+ATMS | ATMS-only | CrIS+ATMS

Location of cross-sections

Retrieval

Closest ECMWF Analysis (52 minutes later)

Retrieval minus ECMWF

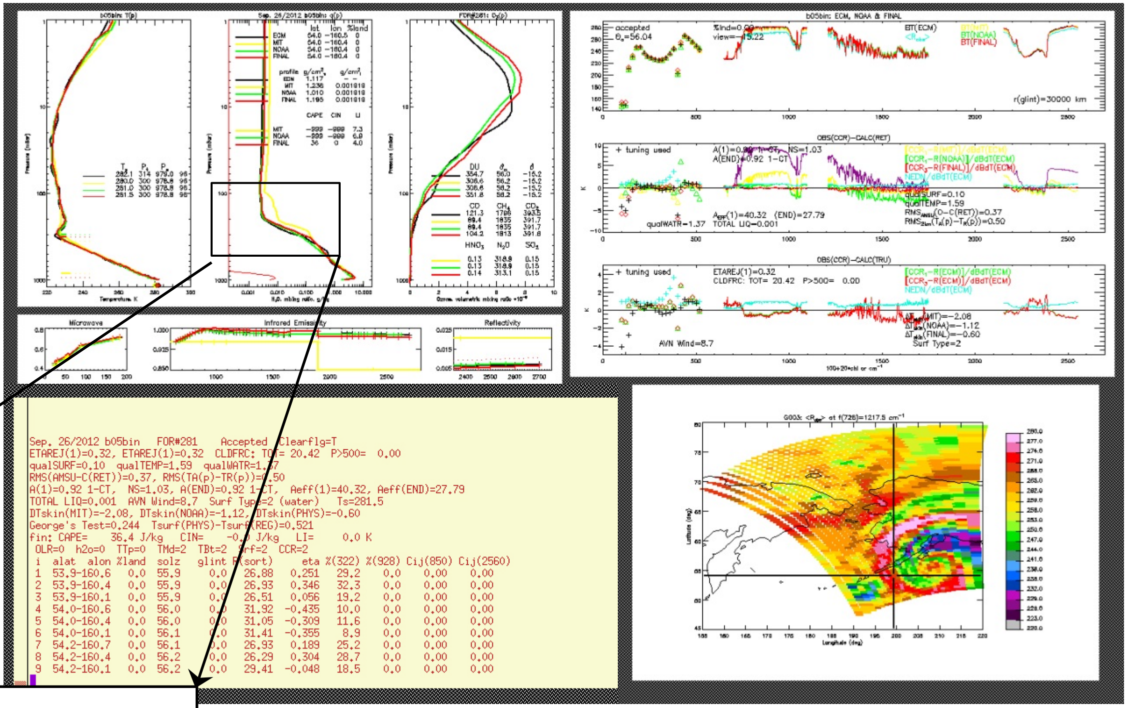


Detail on next page

Screen snapshot of NUCAPS diagnostic output for Scan line 70, FOV #10

T(p), q(p), O3(p)

ε(ν)



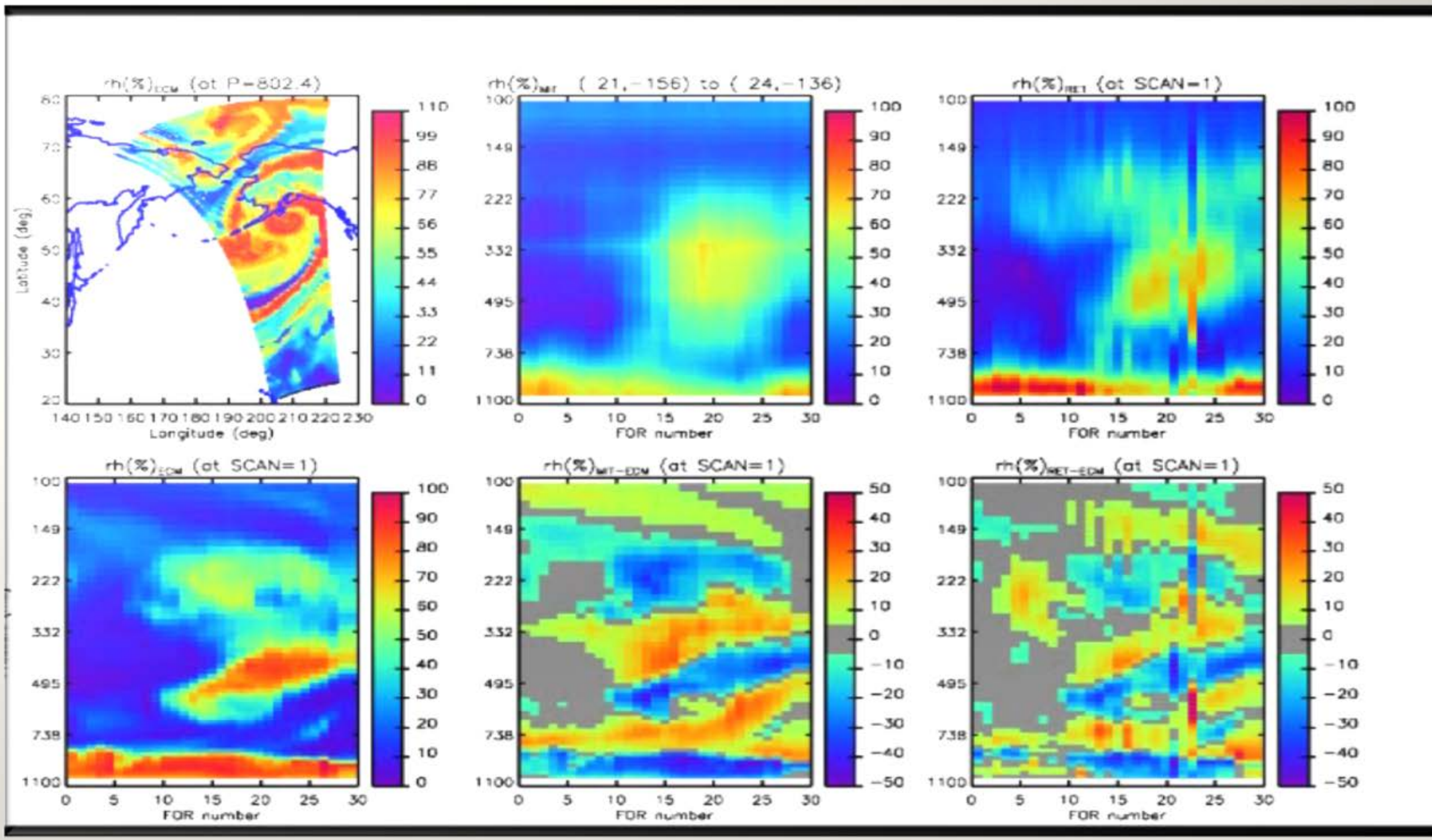
radiances

Obs-calc

calc(ret)-calc(ECM)

Example of a positive ret-ECM (red line minus black line) over a negative ret-ECM difference in the previous plot:
positive difference at 350 mbar
negative difference at 500 mbar)

CrIS/ATMS Relative Humidity Movie
(NOTE: ECMWF analysis is ~1 hour later)

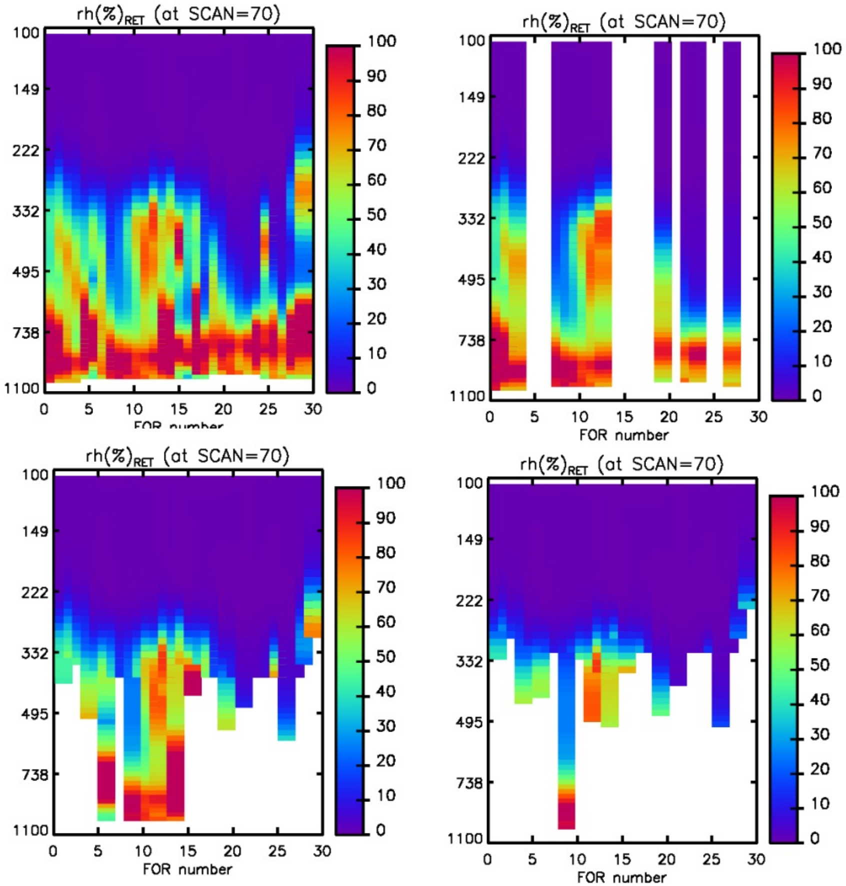


Comments made during movie

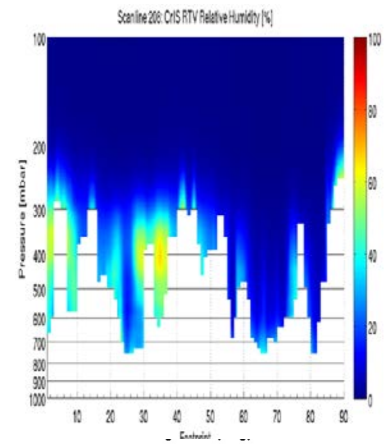
- Movie shows that ATMS-only and CrIS+ATMS retrievals capture a significant amount of the structure in ECMWF in many scenes
  - NOTE: The still shot on previous pages was actually atypical (*i.e.*, has large differences) but was selected for QC discussion on next slides.
- Differences between CrIS+ATMS and ECMWF are smaller and are consistent with higher vertical resolution of the CrIS instrument
- When differences are vertically stacked (*e.g.*, blue on top/below red) it is possible that ECMWF and retrieval only differ in altitude and not the amount of water vapor in the layer (example later)

Compare NUCAPS, ECMWF, and the CSPP dual regression

NUCAPS with 4 types of QC: None, full profile (same as operations), and emulation of AST “Pgood” and “Pbest”

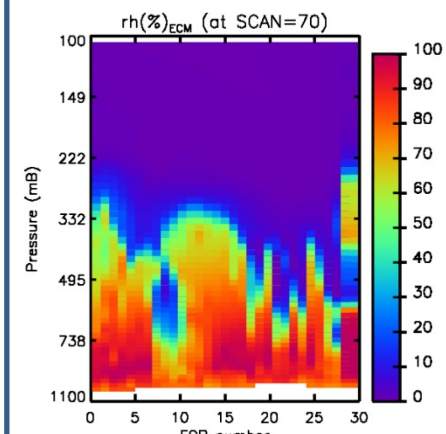


Comparison Datasets



Note: Some of the rejected profiles might be suitable for nowcasting.

CSPP dual-regression retrieval (NOTE: color scale is different)



Closest ECMWF Analysis
(52 minute later)

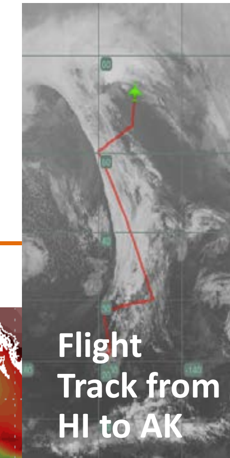
CalWater 2 Early Start – NOAA G-IV Flights

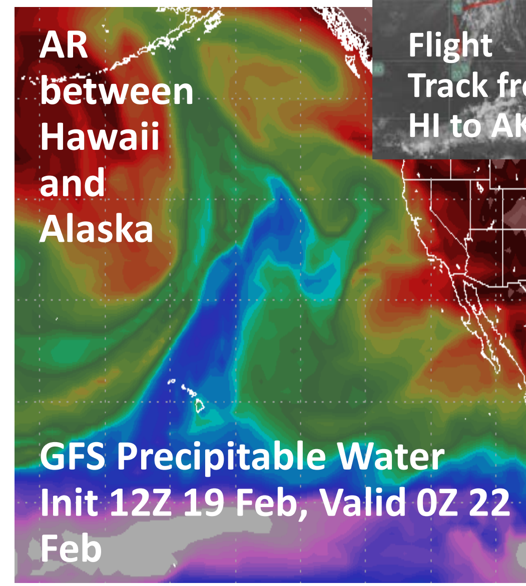
Chris Fairall (ESRL), Marty Ralph (Scripps), Ryan Spackman (STC)

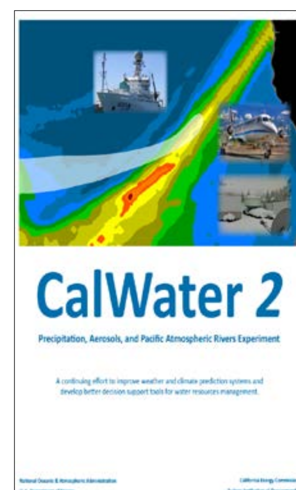
- Objective: Examine the development and structure of atmospheric rivers (ARs) before landfall to improve forecasts of extreme precipitation events along the US West Coast
- Accomplishments:

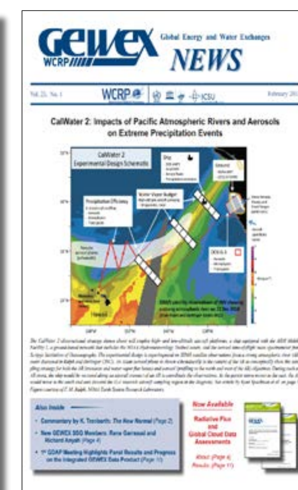
1. 12 research flights in Eastern Pacific in Feb 2014
2. Measurements included 190 dropsondes released between 8°N – 60°N and tail doppler radar
3. Observations included 2 major landfalling AR events along West Coast, a developing AR between Hawaii , Alaska, and the AR source region between Hawaii and the ITCZ

- CalWater 2 is a 5-year broad interagency vision to address key water cycle science gaps along the US West Coast
- CalWater 2 white paper is at http://esrl.noaa.gov/psd/calwater





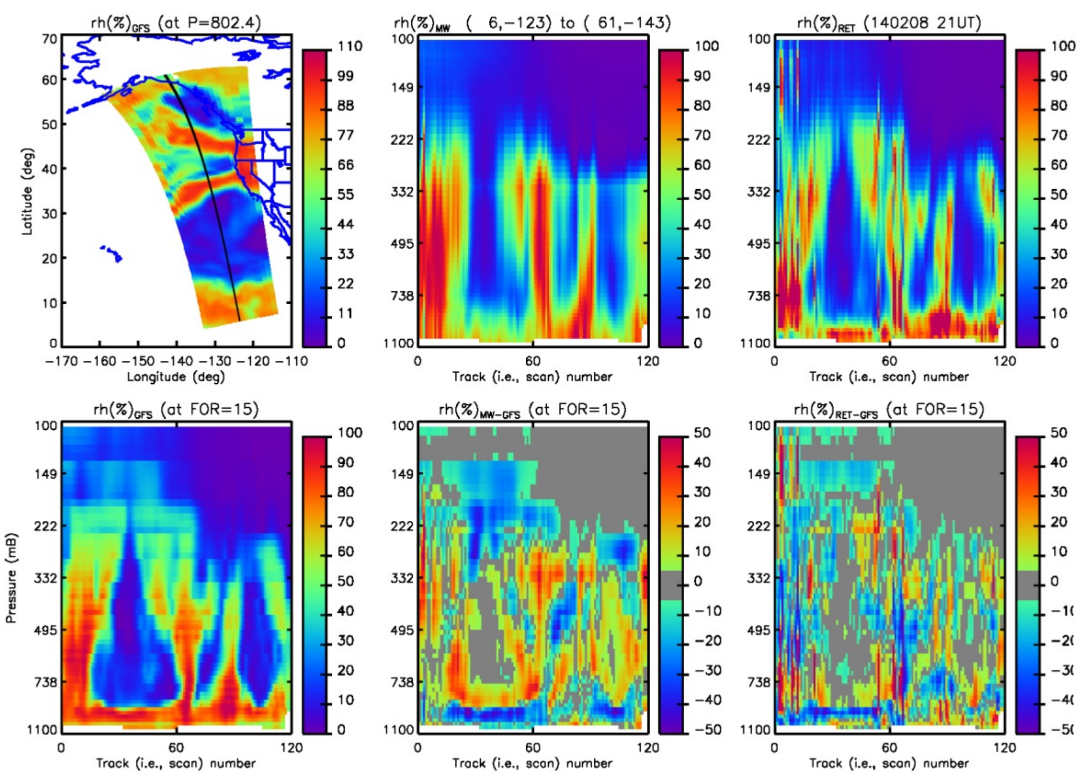




Can Retrievals Improve Forecasts? The Value of CrIS and ATMS

Item 1: AR landfalling forecast errors are large (500 km at 5 day, 200 km at 1 day, Wick et al. 2013)

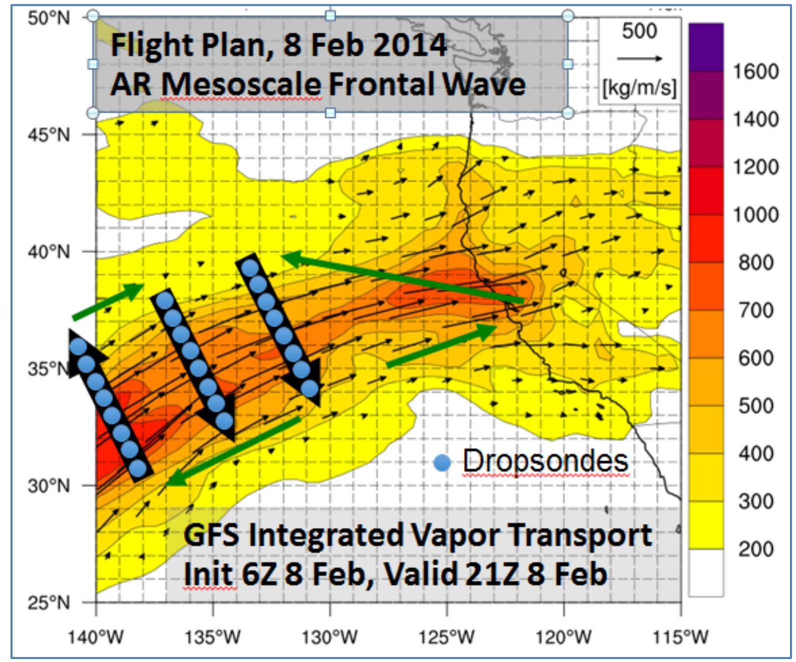
➤ Preliminary analysis suggests retrievals from CrIS and ATMS could improve landfalling forecasts



GFS interpolated to retrieval sampling

ATMS-only retrieval

CrIS+ATMS Retrieval



Item 2: Vertical structure of water vapor in ARs is crucial to getting integrated vapor transport correct

➤ Numerous discrepancies between model and dropsonde data were observed in vertical profiles of water vapor across ARs

Status of the DB version of NUCAPS

- Code is now runnable on small Unix/Linux platforms
  - Operational preprocessor was 1st converted to IDL
    - read HDF5 ATMS and CrIS SDR and GEO files
    - co-location of ATMS and CrIS
    - Get surface altitude and land fraction from Digital Elevation Model
    - Read and co-locate GFS forecast information
      - Surface pressure is used by retrieval (only external variable)
      - T(p), q(p), and O3(p) used for diagnostic and monitoring
    - write binary files for retrieval code
  - Retrieval code compatible with many versions of FORTRAN (*e.g.*, GNU gfortran, Intel, Portland Group, and Absoft compilers)
- Code is now running on Univ. of Wisconsin's PEATE (Product Evaluation and Algorithm Test Element) test machine
  - Preprocessor reads directly from PEATE archive
  - Processing speeds are ~2x (i.e., 4 seconds for 8 second scanset) on a single CPU or 130 milli-second/retrieval

Near term work and schedule

- Implement a tailored QC to enhance product for NowCasting applications
  - In many cases these retrievals reveal structures many hours in advance of a model analysis
  - These cases, with proper error assessment, could be of value for context and early assessment of weather
- Expect to be fully implemented into CSPP direct broadcast by late summer, 2014.
- Focused study on the impact of cloud cleared radiances (CCRs)
  - Collaborate with Jun Li, Univ. of Wisconsin, to study impact of CCRs on Hurricane Sandy regional forecast

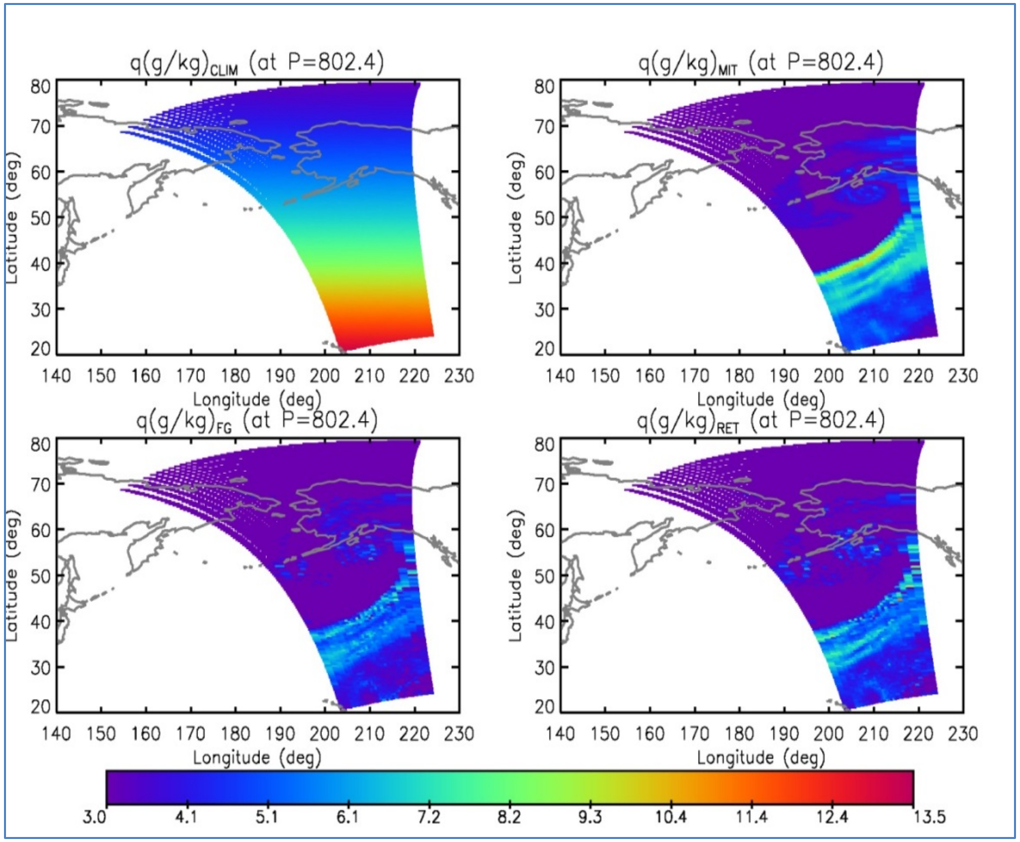
Conclusions

- Simultaneous use of ATMS and CrIS instruments enable sounding closer to the surface
  - Utilizes all available information from sounder investment
  - Utilizes information contained in hyperspectral forward models
- Quality control of the NUCAPS product can be improved.
  - Cross-section display of products demonstrate that we are currently rejected too much information that would be valuable for NowCasting applications.
- CSPP direct broadcast retrieval products are suitable for NowCasting applications
  - Both NUCAPS and Dual-Regression retrievals will be available
  - Users could select either the NUCAPS full profile low spatial resolution or the Dual-Regression high spatial resolution products depending on their application
  - Products will be intercompared in a JPSS Proving Ground study

QUESTIONS?

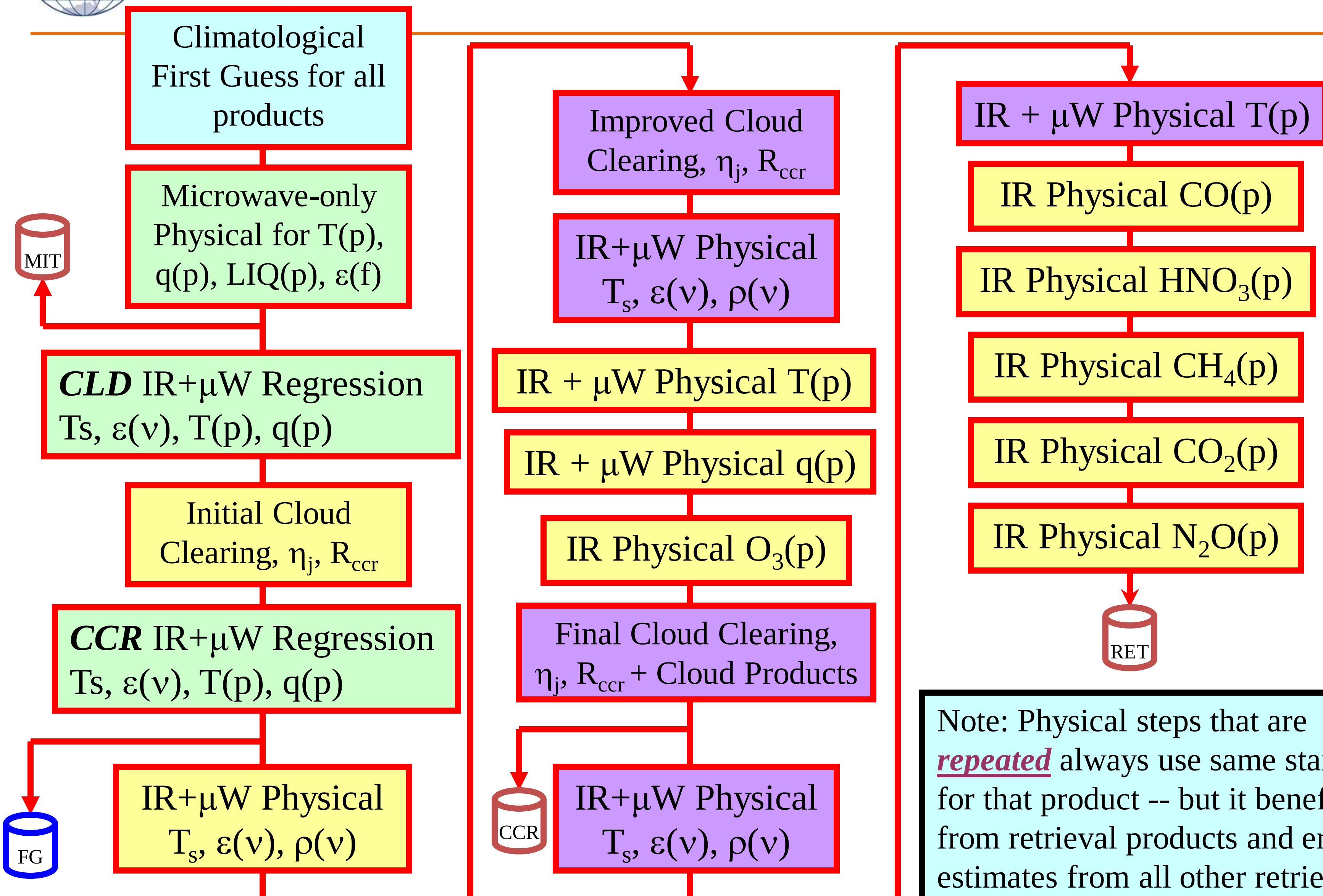
Example of individual retrieval types

- Upper Left: Climatological start-up state for all variables.
- Upper Right: Microwave-only is fall-back state if cloud clearing fails
- CLD Regression is trained on both cloudy radiances and ATMS (not shown, it is similar to CCR regression).
- Lower Left: CCR regression is trained on cloud cleared radiances and ATMS. It is the first guess for the physical algorithm
- Lower Right: CrIS and ATMS radiances are used within the final physical algorithm T(p), q(p), and surface steps. CrIS-only for all other products.



Example of NUCAPS water vapor for Sep. 26, 2012

Sequestion Retrieval Steps in NUCAPS
(A robust and stable methodology)

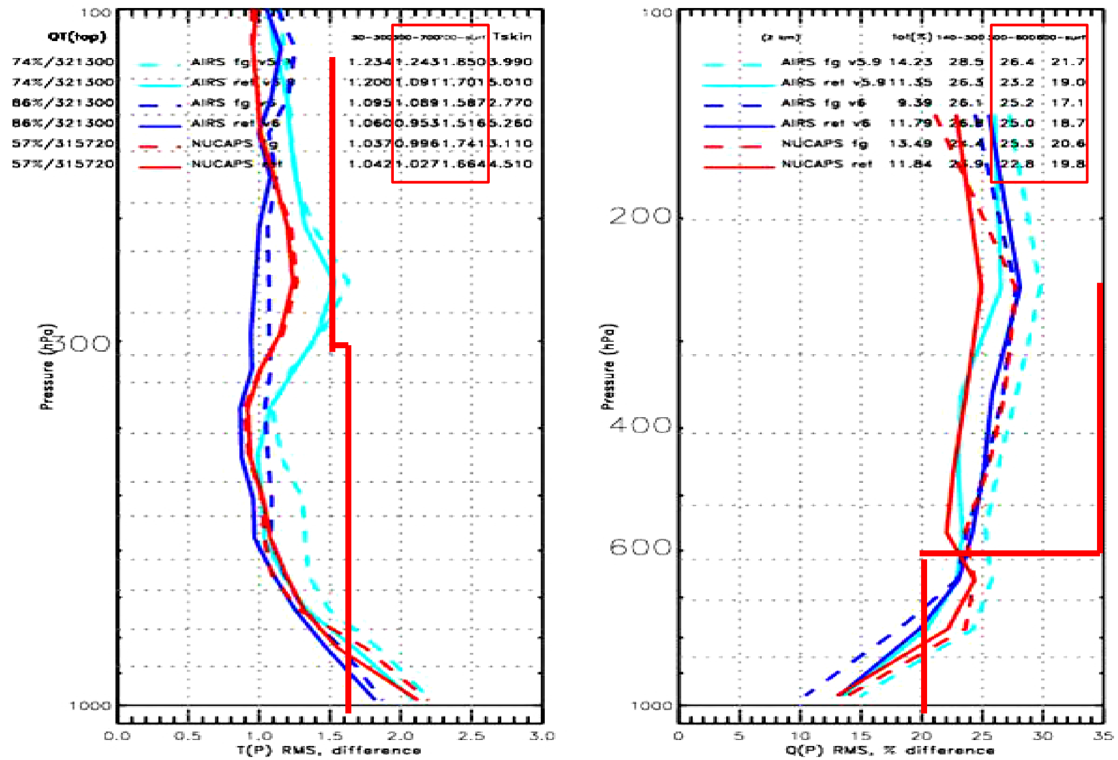


Note: Physical steps that are ***repeated*** always use same startup for that product -- but it benefits from retrieval products and error estimates from all other retrievals.

NUCAPS Performance on Global Ensemble

(difference of Retrievals from ECMWF)

- AIRS/AMSU v5.9 (CYAN) is AIRS v5 with correction for instrument changes.
- AIRS/AMSU v6.0 (BLUE), utilizes a neutral net (NN), and shown for comparison
- NUCAPS (RED) uses CrIS/ATMS and the same spectroscopy and retrieval methodology as AIRS v5.9.
- Both final retrieval (solid) and regression steps (NN in case of AIRS v6) are shown as dashed line



- Statistics for May 15, 2012 focus day in which Aqua and NPP orbits had high coincidence.
- Global requirements shown in dark red (and table of statistics in upper right of each panel)
- AIRS v5.9 and NUCAPS statistics are remarkably close
  - However, yield of NUCAPS is significant lower

Summary of products from Science Code

gas	Range (cm^{-1})	Precision	d.o.f.	Interfering Gases	Science Code
T	**650-800** **2375-2395**	**1K/km**	**6-10**	**H2O,O3,N2O** **emissivity**	**100 levels**
H_2O	**1200-1600**	**15%**	**4-6**	**CH4, HNO3**	**100 layers**
O_3	**1025-1050**	**10%**	**1+**	**H2O,emissivity**	**100 layers**
CO	**2080-2200**	**15%**	**≈ 1**	**H2O,N2O**	**100 layers**
CH_4	**1250-1370**	**1.5%**	**≈ 1**	**H2O,HNO3,N2O**	**100 layers**
CO_2	**680-795** **2375-2395**	**0.5%**	**≈ 1**	**H2O,O3** **T(p)**	**100 layers**
Volcanic **SO_2**	**1340-1380**	**50% ??**	**< 1**	**H2O,HNO3**	**flag**
HNO_3	**860-920** **1320-1330**	**50% ??**	**< 1**	**emissivity** **H2O,CH4,N2O**	**100 layers**
N_2O	**1250-1315** **2180-2250**	**5% ??**	**< 1**	**H2O** **H2O,CO**	**100 layers**
NH_3	**860-875**	**50%**	**<1**	**emissivity**	**BT diff**
CFCs	**790-940**	**20-50%**	**<1**	**emissivity**	**Constant**