The use of temperature and water vapor profiles for weather applications: recent activities in the NOAA/JPSS Proving Ground

Chris Barnet, Antonia Gambacorta, and Mitch Goldberg

NASA Sounder Meeting

Wednesday, Oct. 14, 2015

Motivation

- For decades, algorithm developers have argued pro's and con's of various retrieval methods
  - Cloud clearing versus hole hunting or single FOV
  - SVD (minimum variance) versus O-E
  - Choice of a-priori (climatology, microwave-only, global regression, regional neural networks, etc.)
- *Operational* users have unique needs
  - Focus tends to be on using individual scenes
  - Confused by multiple products from multiple sources, each with claims that theirs is significantly better than the others
- NOAA-Unique CrIS/ATMS Processing System (NUCAPS)
  - became operational at NOAA on Apr. 8, 2014
  - based on the AIRS version 5.9 system
  - Connection to traditional forecaster tools, such as AWIPS

Availability of NUCAPS (with latency)

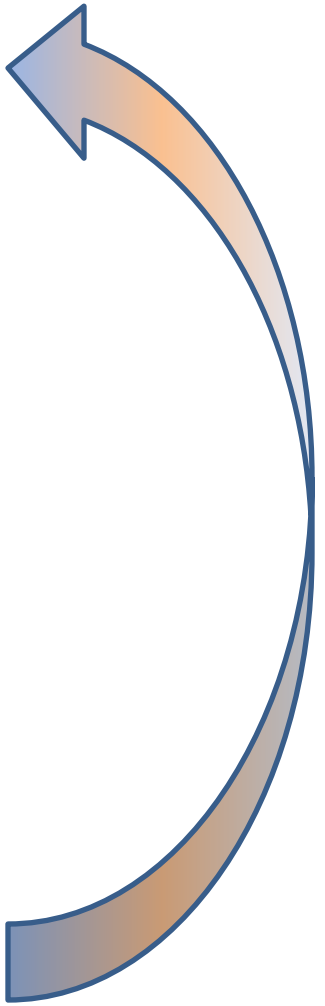
- Apr. 18, 2014 NUCAPS operational at OSPO
  - Via DDS subscription in near real time (≤ 3h)
  - Via CLASS interactive webpage (~ 6h)
  - On-line/downloadable TAR files via CLASS ftp site (~48h)
- Sep. 2014 AWIPS-II implementation begins
  - NUCAPS T(p) and H_2O(p) products can be displayed as skew-T and manipulated within AWIPS (≤ 3h)
- Feb. 24, 2015 NUCAPS operational at CSPP direct broadcast stations
  - Much better latency (~ minutes, if priority processing is done)
  - CSPP = Community Satellite Processing Package
  - Support field campaigns and science evaluations
- Reprocessing of full mission CrIS+ATMS SDRs and NUCAPS at Univ. Wisconsin (JPSS funded)
  - V1.0 (2014 operational system) completed in Aug. 2015
  - V1.5 will be run in near future (Dec. timeframe) and available via CLASS

NOAA/JPSS Application Team Initiatives for Sounding

- Sounding applications team
  - Primary goal is to promote new applications.
  - Secondary goal is to encourage interaction between developers and users to tailor NUCAPS to applications
- We currently have a number of active initiatives for sounding
  1. Hydrometeorology Testbed (HMT): Atmospheric Rivers
  2. Aviation Weather Testbed (AWT): Cold Air Aloft
  3. AWIPS-II NUCAPS and training module & improvements
  4. Hazardous Weather Testbed (HWT): Convective Initiation
  5. NUCAPS Trace Gas Product Evaluation
  6. Evaluation of products in NWP model applications

Why Study Retrievals?

- Data assimilation (DA) ingests many instruments
  - Microwave (*e.g.*, ATMS) is easier (more linear) to assimilate
  - Infrared (*e.g.*, CrIS) is under-utilized in all NWP models
    - Avoid clouds , so must sub-sample FOVs and channels
  - Therefore, CrIS/ATMS obs. are sparse and have low weight w.r.t. model
    - Assumes obs. will nudge model in the right direction over many cycles
- Retrievals operate on single satellite field of regard
  - Can afford to do detailed calculations
    - More channels, including trace gas state and covariance
    - off-diagonal covariance can be used
  - CrIS+ATMS can provide soundings in ~70% of scenes
    - Use of cloud clearing significantly increases the number of scenes
    - Use of microwave improves lower trop soundings in cloudy scenes
    - Likely to be of more value to local forecasters
  - Many lessons learned can be incorporated into global models
- But there are many applications where profiles have value



Initiative #1 / 5

Hydrometeorology Testbed: CalWater-2015

POCs: Chris Barnet (JPSS) & Ryan Spackman (NOAA/ESRL/PSD)

CalWater-2015 was topic in recent JPSS focus article

- In JPSS Quarterly Newsletter (Issue 2, Apr-June 2015)
- On JPSS webpage:
  http://www.jpss.noaa.gov/media.html?story=news-61

NUCAPS sees entire field campaign domain

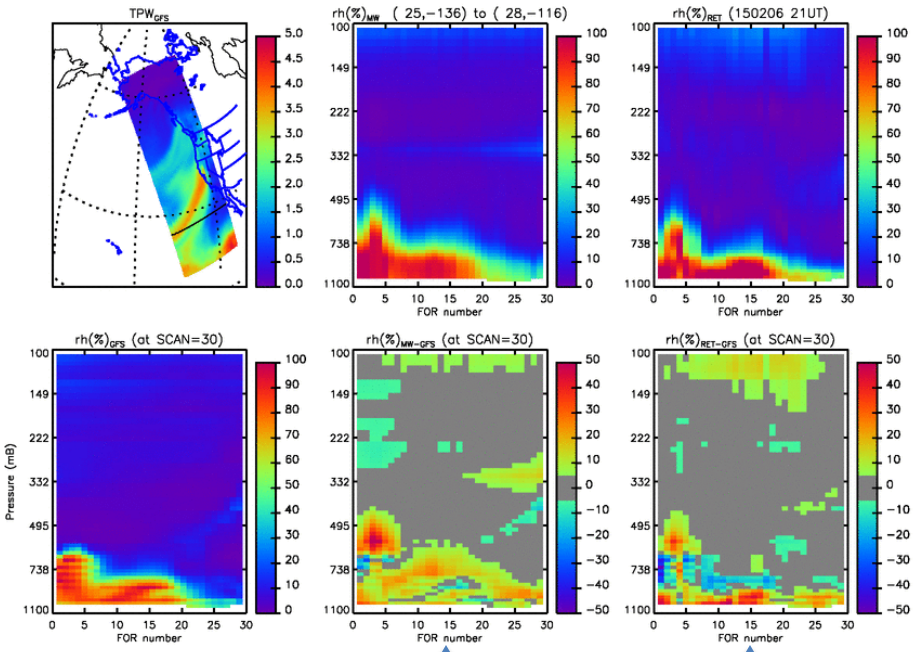
- NUCAPS 2200 km wide "scanset" is acquired in 8 seconds
- 30 retrievals with spatial resolution of ~50 km at nadir and ~70x134 km at edges of scan
- In many cases these retrievals reveal structures many hours in advance of a model analysis (i.e., CrIS/ATMS have not been ingested)
- Differences shown at in lower panels could be due to retrieval errors or GFS errors

NUCAPS Microwave RH Retrieval cross section along scanset shown as black-line in top left figure. Insensitive to non-precipitating clouds

NUCAPS Microwave + Infrared RH retrieval along same scanset. More sensitive to clouds but higher vertical resolution

GFS TPW
Feb. 6, 2015

GFS RH cross section (along scanset indicated on top left



NUCAPS Microwave retrieval – GFS

NUCAPS Microwave + Infrared retrieval – GFS

CalWater-2015 time line

- Campaign began Jan. 12
- Jan. 12 to Feb. 12 we used Corvallis Oregon DB data
  - Processing with NUCAPS science code
  - Provided forecasters the Pacific west coast overpass (10:00 UT ≅ 2 am PST = 5 am EST) in real time
    - Considered in 7 am PST flight planning meeting
  - Provided 22:00 UT (14:00 PST = 5 pm EST) overpass while field campaign aircraft were in the air
- Feb. 14, 2015 we used Univ. of Hawaii DB data
  - Field campaign is winding down
    - G-IV ferried to Hawaii
    - R.H. Brown departed 2/13
    - NOAA P-3 departed 2/15
  - Provided forecasters the Hawaii overpass in real time (24 UT) while G-IV was in the air.

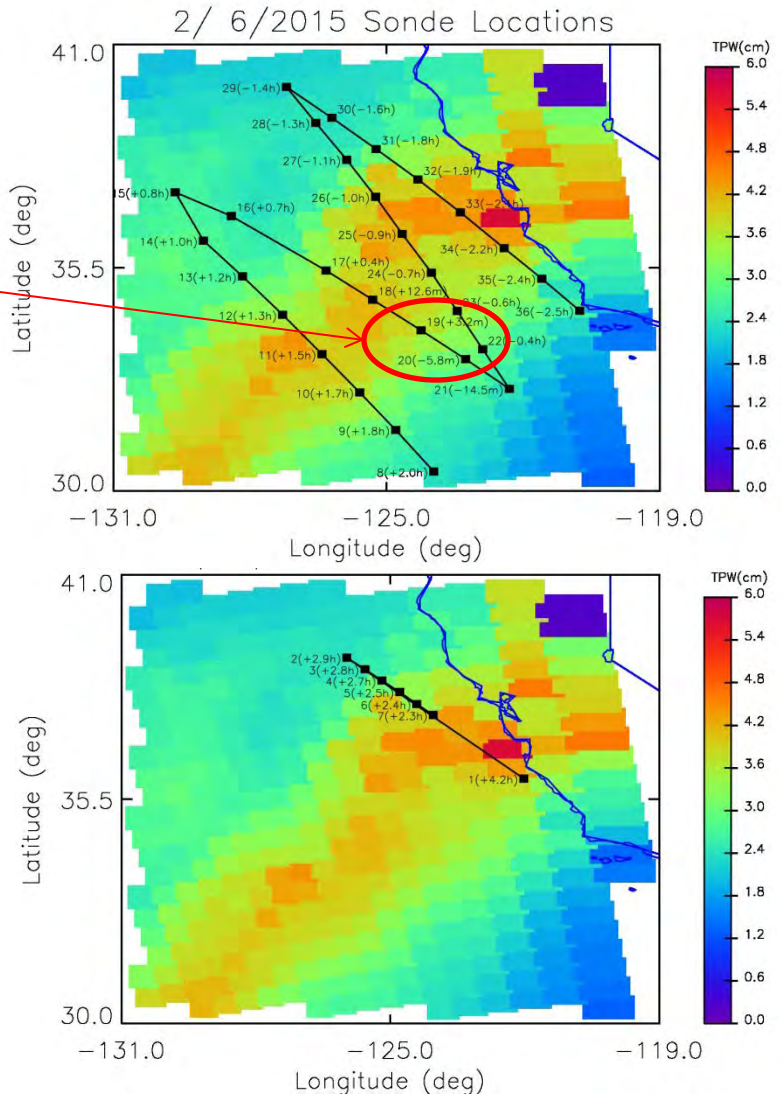
What JPSS program gained from CalWater 2015

- CalWater-2015 was an opportunity for NUCAPS product validation
  - Over 435 dropsondes were acquired
  - Test NUCAPS in extreme weather that is of national and societal interest
- As algorithm developers, we need these kinds of scenes to improve the retrieval skill and tailor the quality control.
  - Can test experimental versions of NUCAPS
  - Gain the expertise of the entire CalWater science team to characterize the underlying science and meteorology.
  - Other *in-situ* measurements (CO, O_3, CO_2, aerosols) will help the NPP validation,
  - Demonstrate the value and shortcomings of NUCAPS in the field

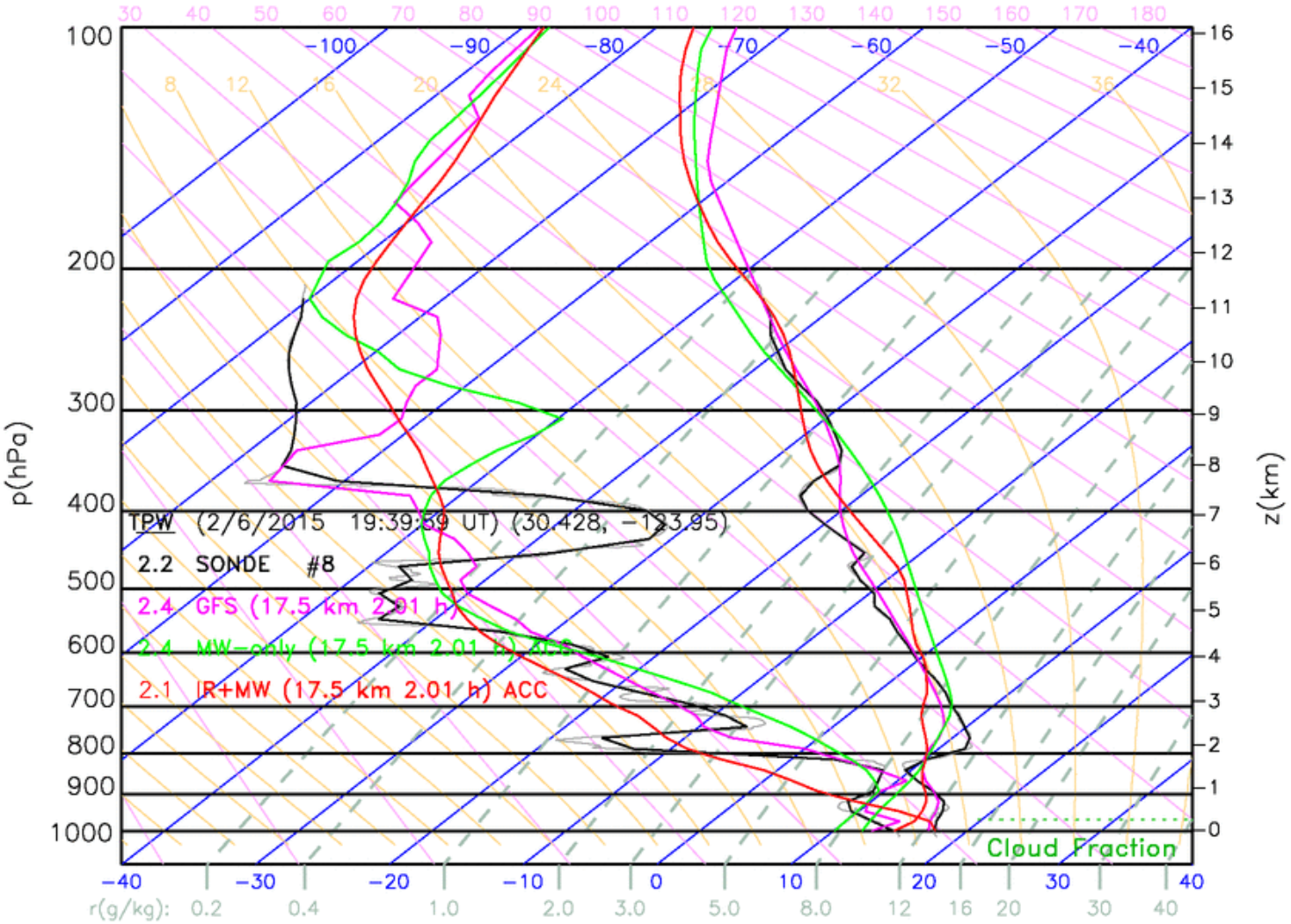
Date	G-IV	P-3
1/15	25	
1/17	29	
1/22	13	
1/24	23	
1/27		22
1/31		24
2/5	35	
2/6	30	7
2/7		9
2/8	32	
2/9		16
2/14	41	
2/19	37	
2/20	35	
2/22	30	
2/24	35	
total	365	78

Example of Feb. 6 dropsondes

- NOAA G-IV did a saw-tooth pattern across the AR
  - NPP Overpass occurred between sondes #19 and #20
  - Capture pre-AR, AR, and post-AR regimes on 4 crossings
  - Pre-AR is relatively warm and dry
  - AR is wet, cloudy, warm, and most likely raining
  - Post-AR is wet and cooler
- NOAA P-3 was flying at 800 mb
  - Sampling same region as G-IV
  - ~4 hours later



wide range of pre-AR, AR, and post-AR conditions



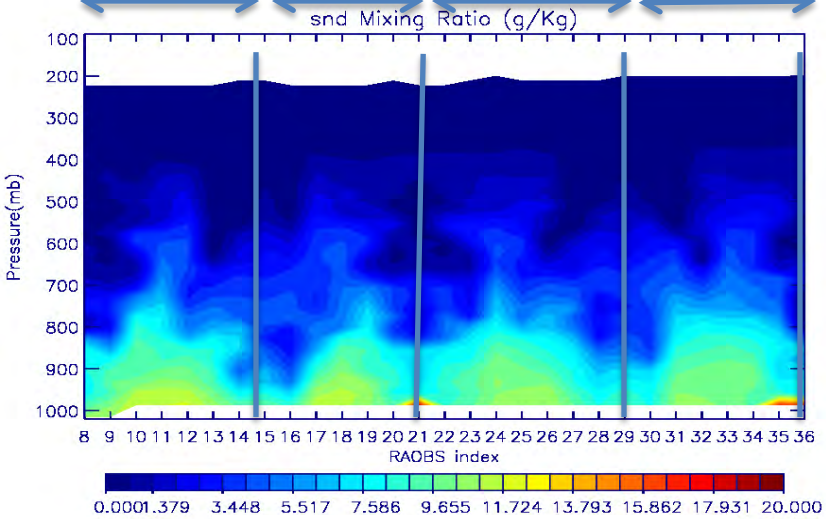
Pre-AR:
#8, 9, 20, 21, 22

AR:
#10, 19

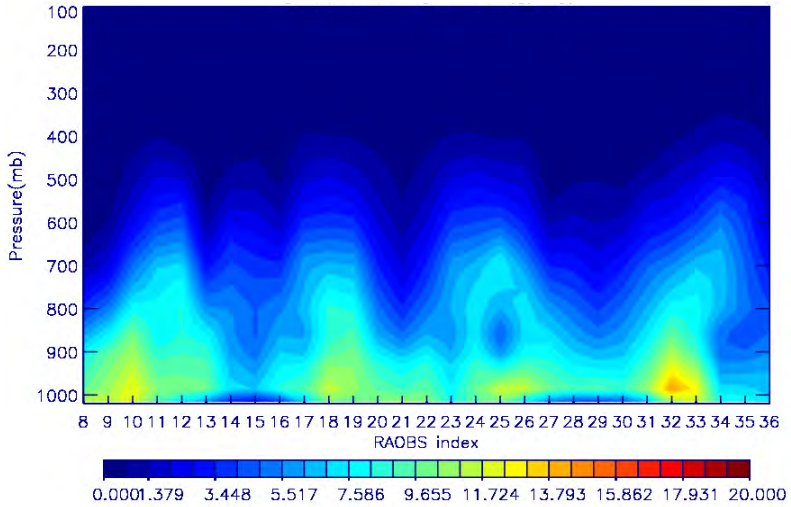
Post-AR:
#13, 27,28,29,30

Dropsonde and retrieval cross section along flight

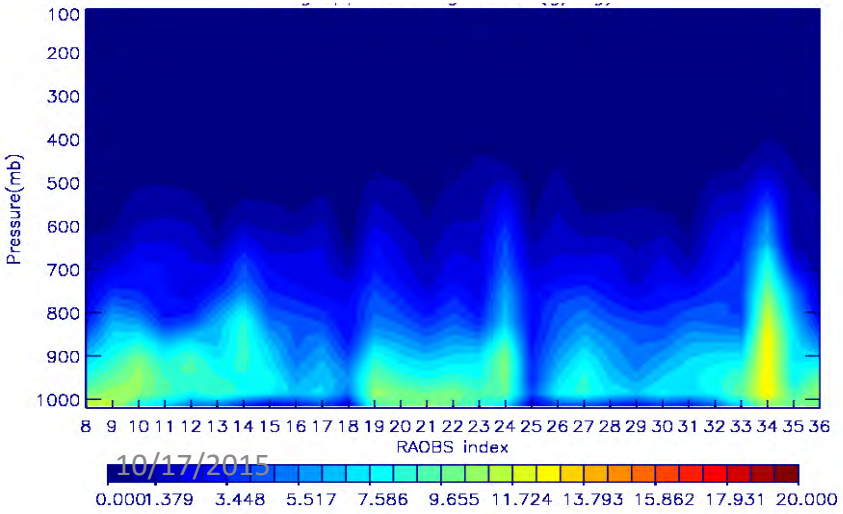
Transect 1 Transect 2 Transect 3 Transect 4



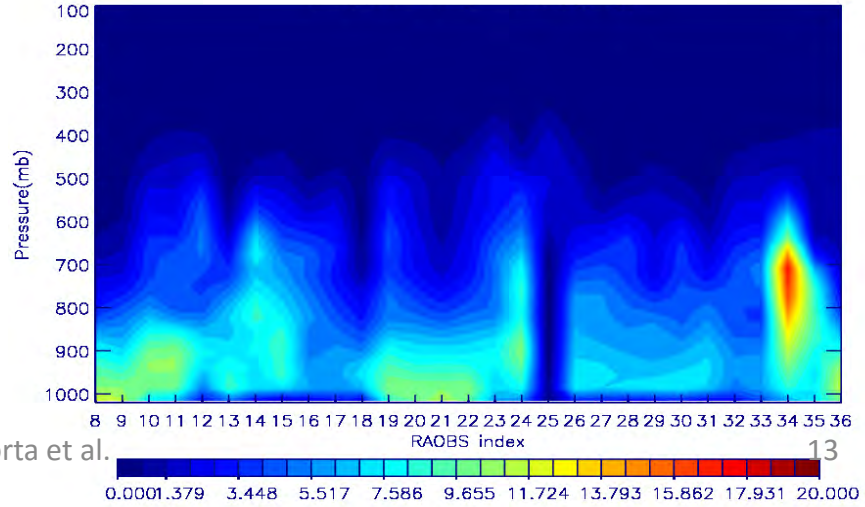
Micro-wave only



Regression first guess



MW+IR (final) retrieval



Summary of CalWater-2015

- We demonstrated the value of NUCAPS soundings in defining crucial moisture structure (position, water vapor content, amplitude) in the vicinity of sparsely sampled but high impact mesoscale events.
  - Low latency (direct broadcast) access is valuable for field campaign logistical support and understanding the context of *in-situ* data
  - Synergistic validation yields a large sample of *in-situ* data in regimes that are traditionally difficult to validate
- Ongoing and future work:
  - We are using these dropsondes to improve performance (better radiance bias tuning, first guess, etc.)
    - Re-run retrieval with proposed changes and compared to original retrieval and in-situ data before promoting to operations
  - Publish an analysis of NUCAPS capabilities in AR environments

Initiative #2 / 5

Aviation Weather Testbed: Cold Air Aloft

POC: Brad Zavodsky (NASA/SPoRT), Kristine Nelson (NWS/AR/ARS/CWSU/ANCHORAGE AK)

Aviation Weather Testbed
Cold Air Aloft

In Alaska, forecasters must rely on analysis and model fields and limited radiosonde observations (~4/day) to determine the 3D extent of the cold air aloft

- Airline fuel begins to freeze below -65 degC, need to issue pilot advisories
- Forecasters need to know spatial and vertical location of “bubble” of cold air aloft

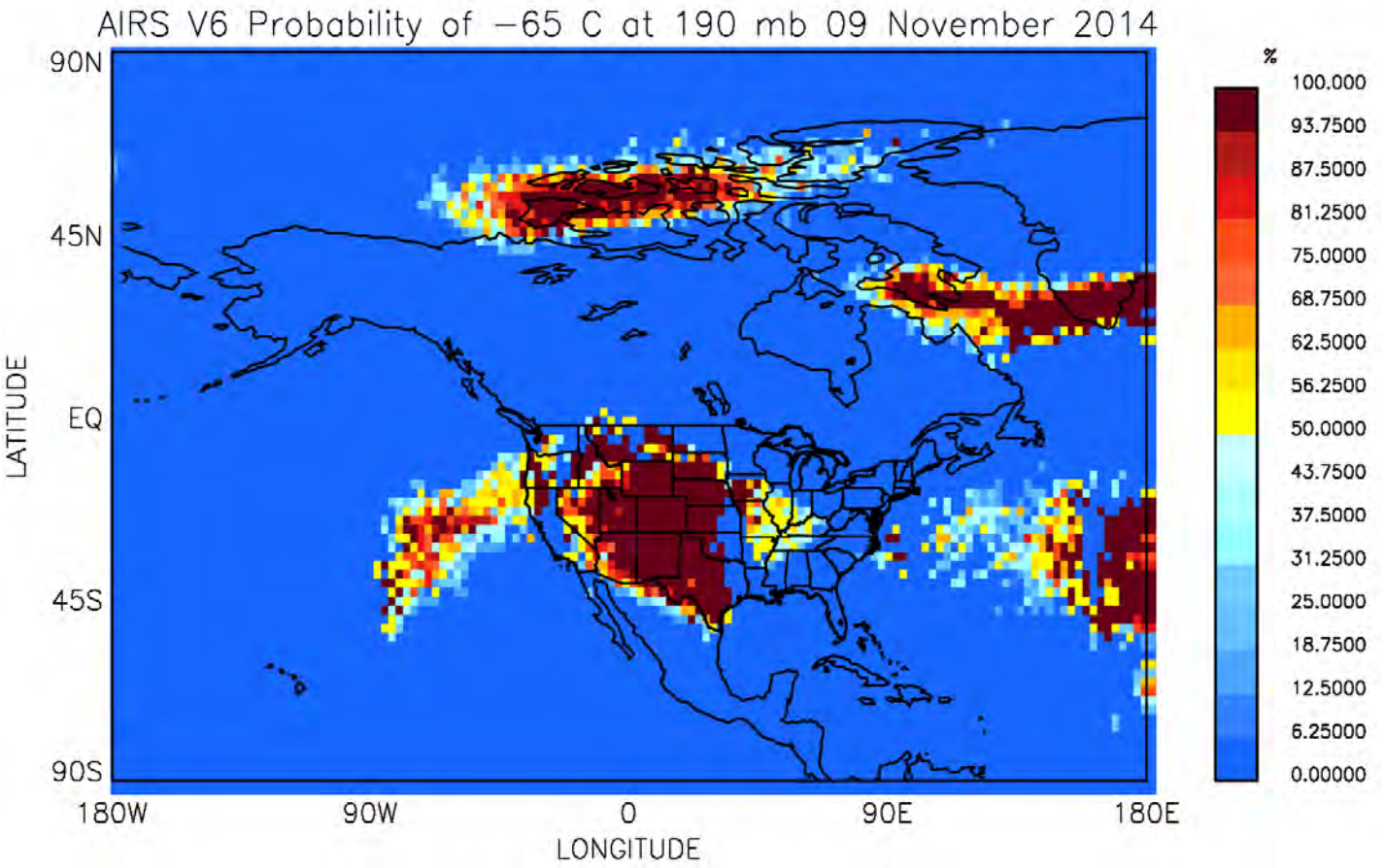
- Anchorage Flight Information Area (FIR) encompasses 2.4 square million miles
- Anchorage Airport was ranked 3rd worldwide for throughput cargo (90% of China to USA) and 1st in the USA for cargo poundage (5.9 Billion lbs)

Daily Cold Air Loft frequency of occurrence at 190 mbar

Used AIRS Level.2 Support Product

Counted occurrences of T(190mb) ≤ -65 degC in a 1x1 deg grid

Anchorage Center Weather Service Unit (CWSU) issues warnings on Nov. 11th to 14th



Analysis and graphics by C. Francoeur, STC

Summary of Aviation Weather initiative

- CrIS/ATMS easily sees the cold air aloft in our cross-sections and skew-T plots
  - Product has +/- 4 K differences f/GFS and is smoother
    - Vertical location is different
  - Goal is to work with Alaska AWT/CWSU to develop better visualization of cold air aloft and to evaluate Suomi-NPP soundings in this context.
    - Forecasters can account for biases
- GFS ingests CrIS and ATMS, is it good enough?
  - At 200 mbar many CrIS channels/scenes are used
  - Real time NUCAPS (8, 9.5, 11 and 20, 21.5, 23 Z) adds information between the model analysis times (0, 6, 12, 18Z) and gives forecaster more confidence

Initiative # 3 / 5

AWIPS-II NUCAPS training module & AWIPS improvements

POCs: Brian Motta (NWS), Scott Lindstrom (CIMSS)

AWIPS-NUCAPS training module and improvements

- Articulate Presenter modules are available at:
  - V1: https://www.youtube.com/watch?v=91ORWNreXLI
  - V2: https://www.youtube.com/watch?v=U-w6EBnOzb0
- NUCAPS was installed without QC
  - QC exists in NUCAPS file ingested by AWIPS
  - DR submitted to fix the problem
- Recent upgrades to AWIPS-II causes NUCAPS data to be deleted
  - WFO installed patch until problem can be fixed
- Improved Visualization
  - “Plan View” and “Volume Browser“ displays

Initiative #4 / 5

Hazardous Weather Testbed: 2015 Spring Experiment

Will be discussed in next presentation by Dan Nietfeld (SOO at Omaha WFO)

Initiative #5 / 5

NUCAPS Trace Gas Product Evaluation

POCs: Greg Frost (NOAA/ESRL/GSD),
Brad Pierce (NOAA/STAR)

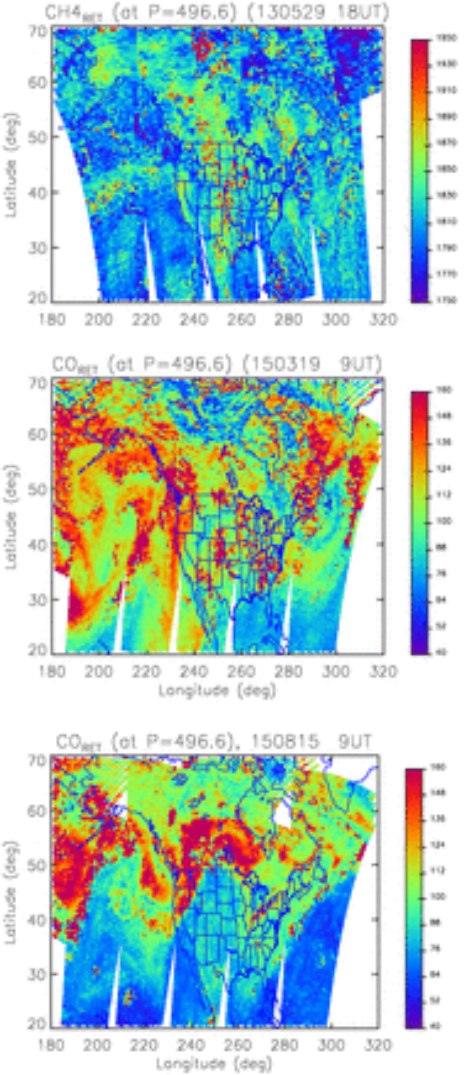
NUCAPS Trace Gas Product Evaluation

- This initiative is based on two recently funded JPSS proposals.
  1. Greg Frost: “Understanding emissions and tropospheric chemistry using NUCAPS and VIIRS”
  2. Brad Pierce: “High Resolution Trajectory-Based Smoke Forecasts using VIIRS Aerosol Optical Depth and NUCAPS Carbon Monoxide Retrievals “
- Models are used to interpolate the sparse aircraft observations to the satellite temporal, spatial, and vertical sampling characteristics for detailed validation
- NUCAPS (and AOD f/ VIIRS) will be used within IDEA (Infusing Satellite Data into Envir. AQ Applications)

  http://www.star.nesdis.noaa.gov/smcd/spb/aq/

NUCAPS Trace Gas Product Evaluation

- We selected two field campaigns
  - Senex: http://www.esrl.noaa.gov/csd/projects/senex
    - Senex ≡ Southeast Nexus
    - Summer 2013, SE USA
    - Focus on methane emissions associated with wildfires.
  - Songex: http://esrl.noaa.gov/csd/projects/songnex/
    - Songex ≡ Shale Oil and Natural Gas Nexus
    - Spring 2014, Northwest USA
    - Begin with NUCAPS Carbon Monoxide
      - Requires full spectral resolution CrIS data
      - Use experimental version of NUCAPS
    - Also, methane emissions from oil and gas
- Recent wildfire activity in western USA



Future Plans for NUCAPS
and
The Path Forward

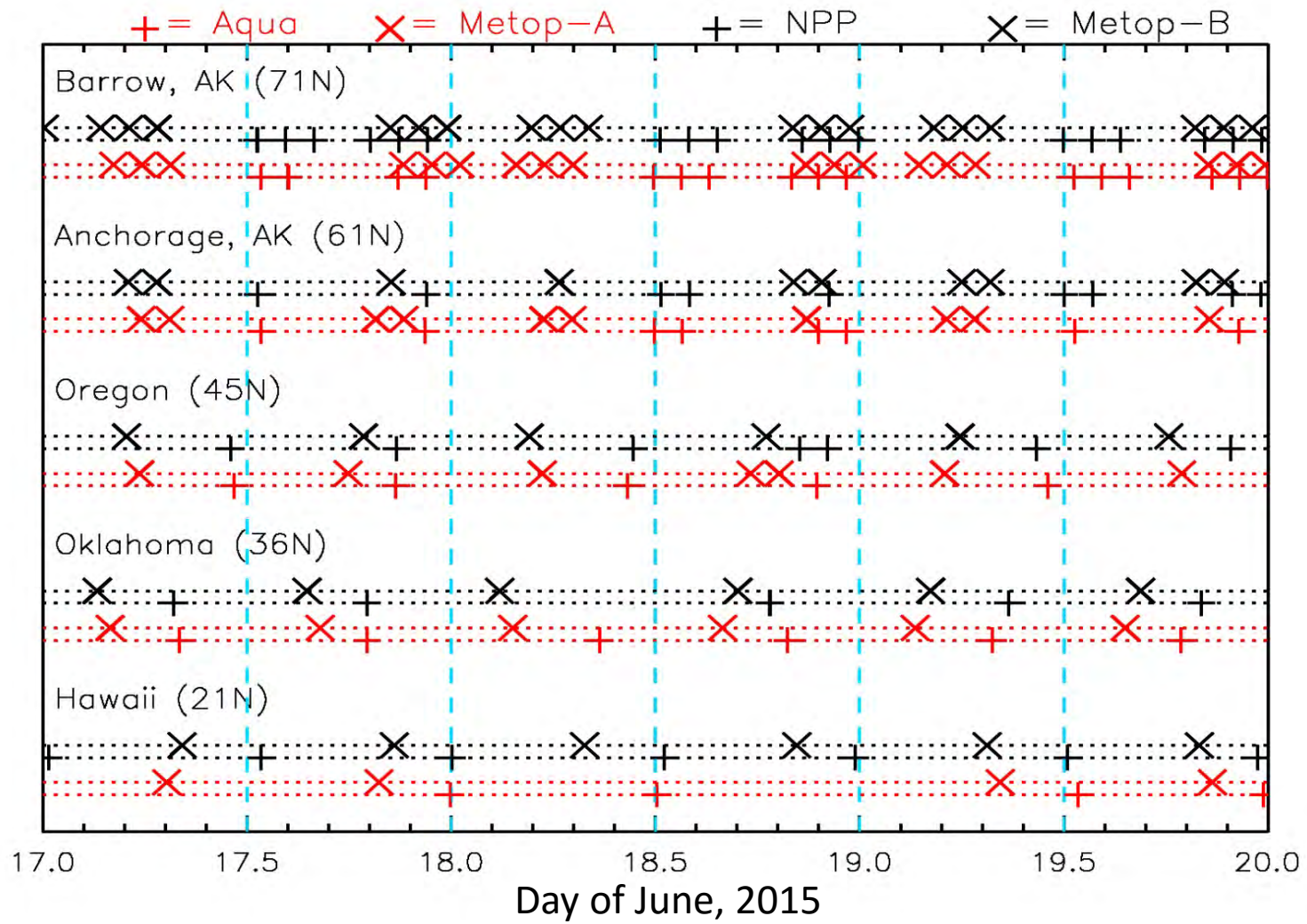
A number of funded initiatives with a NWS modeling focus

- Much of the NUCAPS retrieval skill comes from use of cloud cleared radiances (CCRs)
  - Jun Li (CIMSS) is doing a study of using NUCAPS CCRs
    - Hindsight analysis of H. Sandy (2012) and Typhoon Haiyan (2013)
  - Andrew Collard (NCEP) looking at using our algorithm directly (compute CCRs from CrIS radiances using model background)
- Emily Berndt (SPoRT) investigation of NUCAPS T(p), q(p), and O3(p) to study extratropical transition of hurricanes
  - create an enhanced stratospheric depth product
  - conduct a product demonstration and assessment with the NHC, WPC, OPC forecasters
- Galina Chirokova (CIRA) will investigate use of VIIRS and NUCAPS to improve moisture flux estimates.
  - Detection of dry air intrusions are important for TC forecasting

Future Plans
The way forward

- Improve AWIPS implementation
  - Better training
  - Automate profile modification (funded, Dan Lindsey)
  - Spatial and/or cross-section visualization of T/q
- Metop-A & B retrievals into AWIPS-II
  - Same algorithm as NUCAPS, but 4 hours earlier
- Metop-A & B retrievals into CSPP direct broadcast
  - In work, should be operational in early 2016
- Unfortunately, AIRS is not in the operational flow at NOAA (it is a NASA DAAC product)
  - We are considering putting it into CSPP (FY2017)

Constellation of satellites allows more observations between 0Z & 12Z RAOBS



NPP/J-1 will be phased similar to Metop-A/B approx. 6 months after launch of J-1

If we included NOAA AMSU/HIRS there would be even more soundings

These are overpasses with satellite elevation > 32 deg (all FOR's)

QUESTIONS?

Acronyms

- AIRS = Atmospheric Infrared Sounder
- AMSU = Advanced Microwave Sounding Unit
- AR = Atmospheric River
- ATMS = Advanced Technology Microwave Sounder
- AVHRR = Advanced Very High Resolution Radiometer
- AWIPS = Advanced Weather Interactive Processing System
- AWT = Aviation Weather Testbed
- CrIS = Cross-track Infrared Sounder
- CIMMS = Cooperative Institute for Mesoscale Meteorological Studies
- CIMSS = Cooperative Institute for Meteorological Satellite Studies
- CSPP = (CIMSS) Community Satellite Processing Package
- CWA = (NWS) County Warning Area
- CWSU = (FAA) Center Weather Service Unit
- EUMETSAT = EUropean organization for exploitation of METeorological SATellites
- FOV/FOR = Field Of View/Regard
- GFS = (NCEP) Global Forecast System
- GSFC = (NASA) Goddard Space Flight Center
- HMT = Hydrometeorology Testbed
- HSB = Humidity Sounder Brazil
- HWT = Hazardous Weather Testbed
- IASI = Infrared Atmospheric Sounding Interferometer
- JPSS = Joint Polar Satellite System
- METOP = METeorological Observing Platform
- MHS = Microwave Humidity Sensor
- MODIS = MODerate resolution Imaging Spectroradiometer
- NASA = National Aeronautics and Space Administration
- NCEP = National Centers for Environmental Prediction
- NESDIS = National Environmental Satellite, Data, and Information Service
- NHC = (NCEP) National Hurricane Center
- NOAA = National Oceanographic and Atmospheric Administration
- NPP = National Polar-orbiting Partnership
- NWP = Numerical Weather Prediction
- NWS = National Weather Service
- NUCAPS = NOAA Unique CrIS/ATMS Processing System
- OPC = (NCEP) Ocean Prediction Center
- OSPO = (NESDIS) Office of Satellite and Product Operations
- SOO = Science Operations Officer
- SPC = (NCEP) Storm Prediction Center
- SPoRT = (NASA) Short-term Prediction and Research Transition Center
- STAR = (NESDIS) SaTellite Applications and Research
- STC = Science and Technology Corporation
- UMBC = University of Maryland, Baltimore County
- VIIRS = Visible Infrared Imaging Radiometer Suite
- WFO = (NWS) Weather Forecast Office
- WPC = (NCEP) Weather Prediction Center

Summary of products from NUCAPS (and AWIPS-II)

gas	Precision	d.o.f.	Interfering Parameters	Sensitivity
Temperature Profile, T(p), SST, LST	1.5K/km	6-10	Emissivity, H_2O, O3, N2O	surface to ~1 mb
Water Profile, H_2O(p)	15%	4-6	CH4, HNO3	surface to ~300 mb
Cloud Top Pressure Cloud fraction	25 mbar, 1.5K, 5%	2 18	CO2, H2O	surface to tropopause
Ozone, O_3	10%	1+	H2O, emissivity	Lower stratosphere
Carbon Monoxide, CO	15%	≈ 1	H_2O, N2O	Mid-troposphere
Methane, CH_4	1.5%	≈ 1	H2O, HNO3, N2O	Mid-troposphere
Carbon Dioxide, CO_2	0.5%	≈ 1	H2O, O3, T(p)	Mid-troposphere
Sulfur Dioxide, SO_2	≈ 50%	< 1	H2O, HNO3	Volcanic flag
Nitric Acid, HNO_3	≈ 50%	< 1	emissivity H2O, CH4, N2O	Upper troposphere
Nitrous Oxide, N_2O	≈ 5%	< 1	H2O, CO	Mid-troposphere

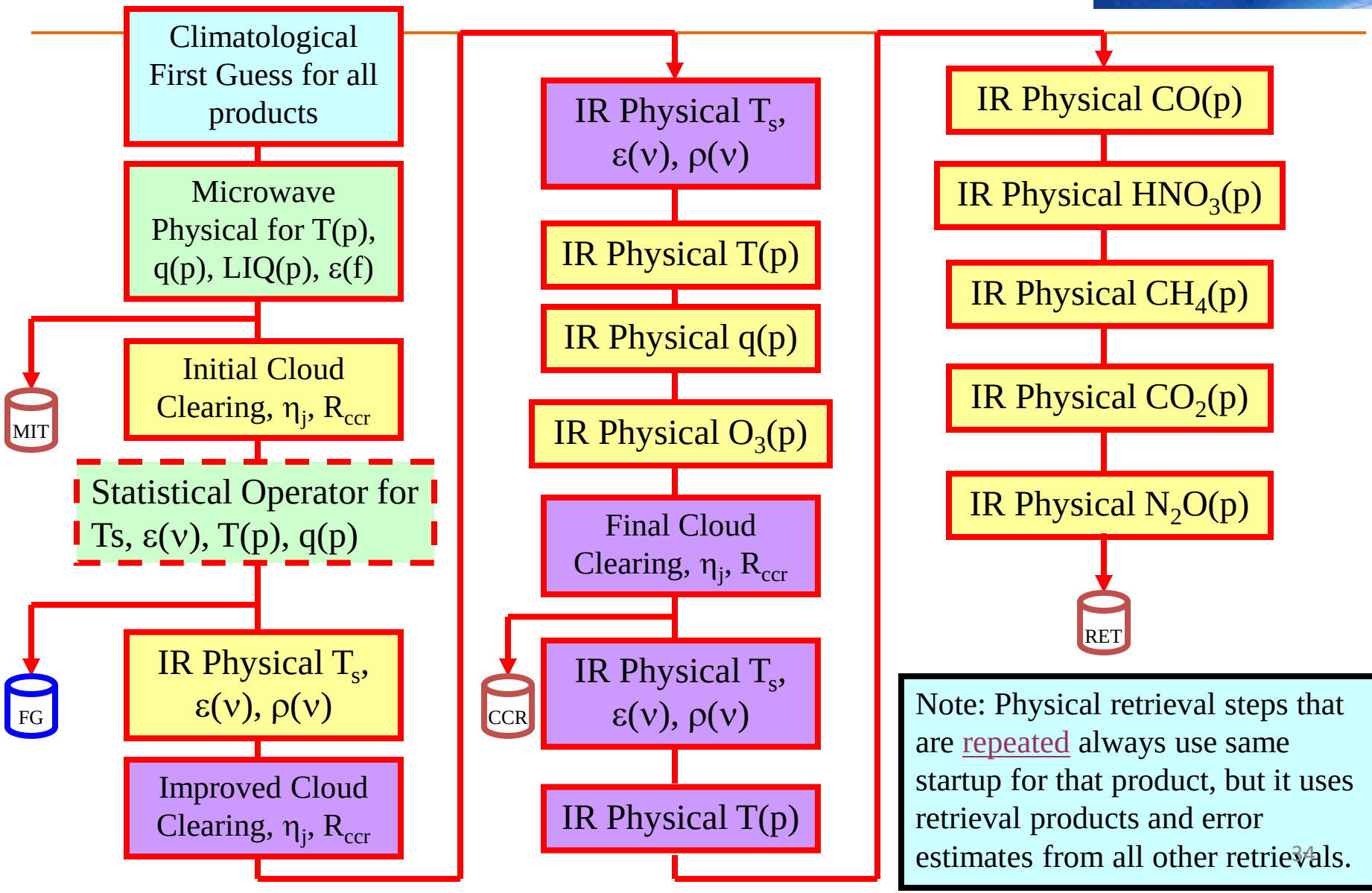
NUCAPS Retrieval File Variables for AWIPS

Variable	Type	Dim	Description	Units
Dice	Long	120	Field of Regard (FOR) number 1-120	NA
Time	Doub	120	UTC Milliseconds since Jan 1, 1970	Millisec
Latitude	Float	120	Latitude of the center of the FOR	Degrees
Longitude	Float	120	Longitude of the center of the FOR	Degrees
View_Angle	Float	120	Instrument view angle	Degrees
Ascend/Descend	Short	120	Ascending /Descending flag (0=Descending, 1=Ascending) for ea FOV	NA
Topography	Float	120	Surface elevation in meters above sea level	m
Surface_Pressure	Float	120	Surface pressure	mb
Skin_Temperature	Float	120	Skin temperature from the final retrieval step	K
Quality_Flag	Long	120	Quality flag for the retrieval (0=good, non zero = bad)	NA
Pressure	Float	120,100	Pressure at each of the 100 retrieval levels	mb
Effective_Pressure	Float	120,100	Effective pressure	mb
Temperature	Float	120,100	Temperature from the final retrieval	K

NUCAPS Retrieval File Variables for AWIPS

Variable	Type	Dim	Description	Units
H2O_MR	Float	120,100	Water vapor mixing ratio from the final retrieval	g/g
O3_MR	Float	120,100	Ozone mixing ratio from the final retrieval	ppb
Liquid_H2O_MR	Float	120,100	Liquid water mixing ratio from the final retrieval	g/g
Ice_Liquid_Flag	Short	120,100	Ice liquid flag 0=water, 1=ice	NA
SO2_MR	Float	120,100	Sulfur Dioxide mixing ratio from the final retrieval	g/g
Stability	Float	120,16	Stability parameters	Varying

Simplified Flow Diagram of the AIRS Science Team Algorithm



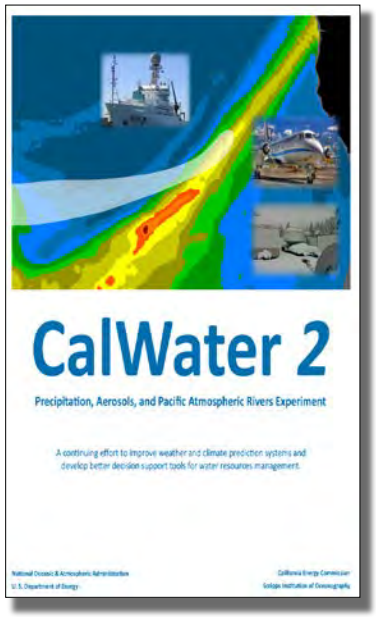
Note: Physical retrieval steps that are repeated always use same startup for that product, but it uses retrieval products and error estimates from all other retrievals.

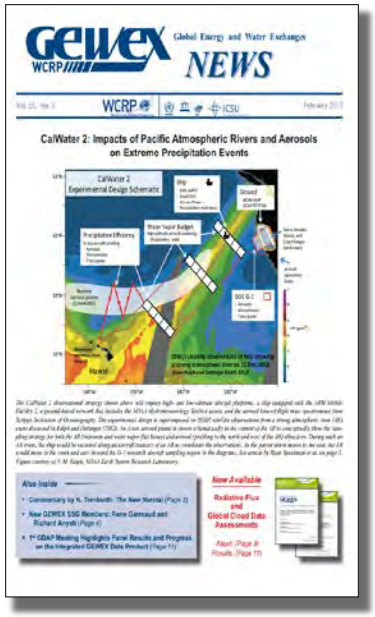
Hydrometeorology Testbed Initiative – CalWater-2015

Science focus of this campaign is to improve forecasting of Atmospheric Rivers (ARs)

- CalWater 2 white paper is at http://esrl.noaa.gov/psd/calwater
  PI is Marty Ralph, Scripps

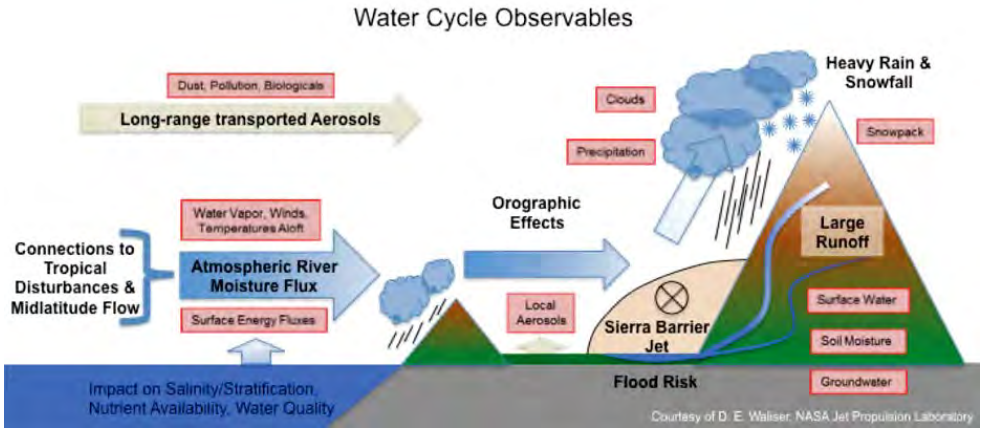
- Coordinated with DOE ACAPEX (ARM Cloud Aerosol Precipitation Experiment)
  PI is L. Ruby Leung, DOE





Understanding Atmospheric Rivers (ARs) has national and societal value

- ARs are narrow filaments of enhanced WV transport
  - responsible for ≈ 90% of mid-latitude transport (Zhu 1998 MWR)
  - 75% is below 2.25 km altitude



30-50% of annual precipitation on USA west coast is associated with ARs

- Typically within a few extreme precipitation events
  - Jan. 6-8, 2009 a strong event damaged the Hansen Dam (White 2012 BAMS)
  - Warm moist conditions in ARs can accelerate snowmelt
- Northwest USA snowfall tends to come in a few powerful winter ARs
  - Winter snowpack provides 70-90% of water supply for western USA
- AR events end ~40% of Northern California droughts (Dettinger 2013 J.Hydro.)
- Large ARs transport 13-26 km^3/day, ~7.5-15 times the average discharge of the Mississippi River (Ralph 2011 Eos)

NUCAPS sees entire field campaign domain (single frame)

- NUCAPS 2200 km wide "scanset" is acquired in 8 seconds
- 30 retrievals with spatial resolution of ~50 km at nadir and ~70x134 km at edges of scan
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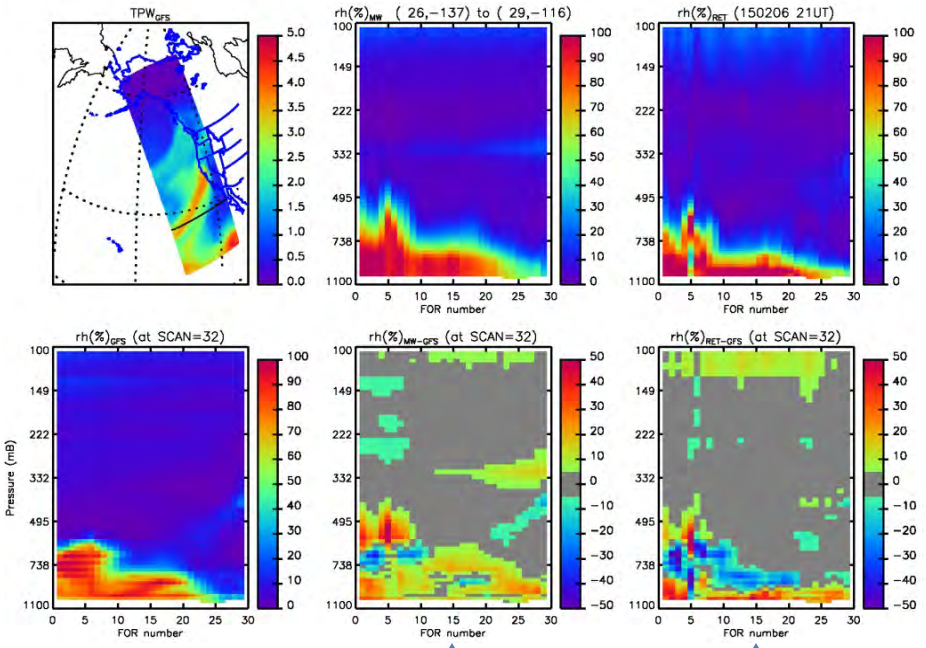

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Daily Cold Air Loft frequency of occurrence (single frame)

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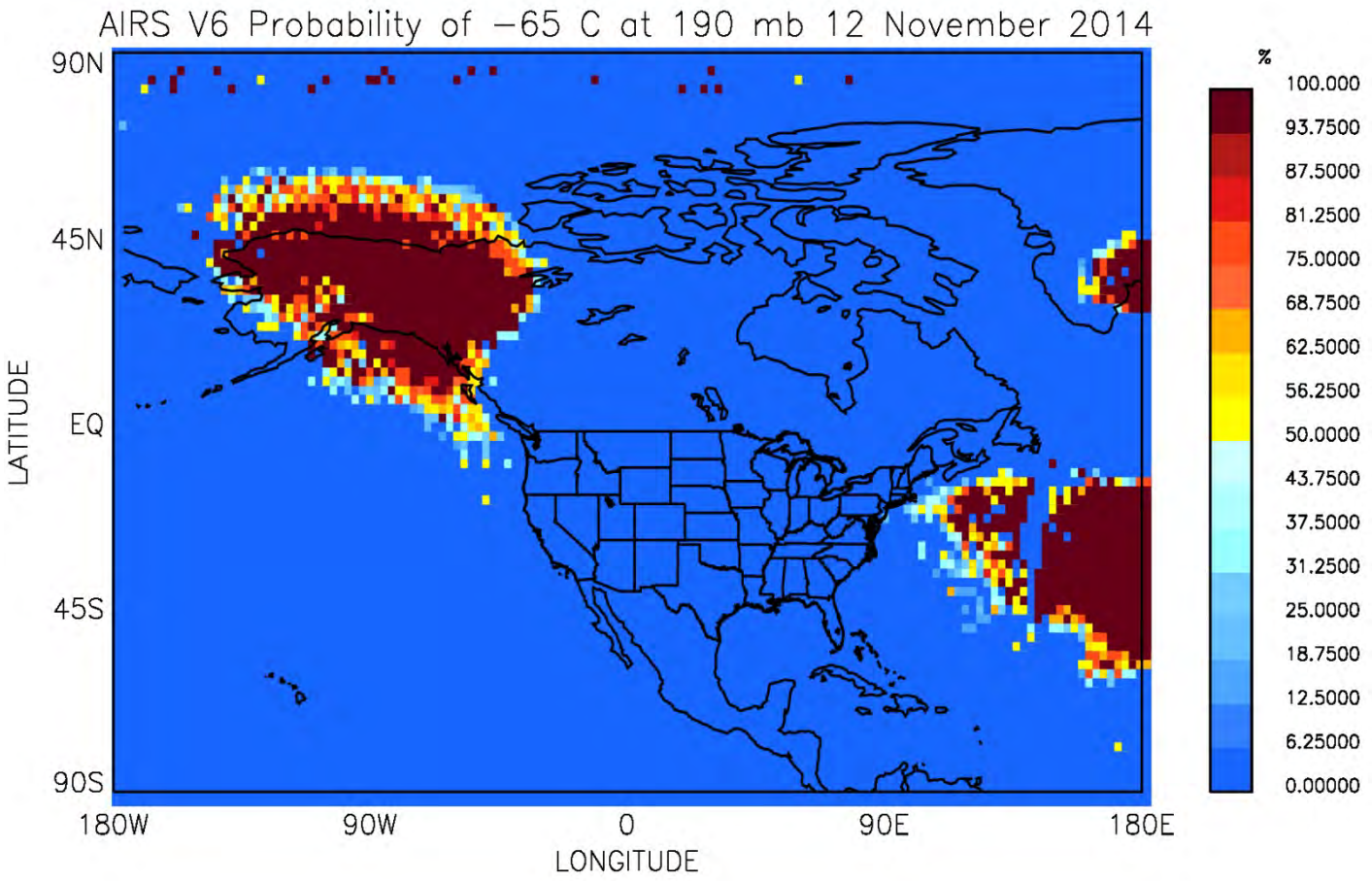
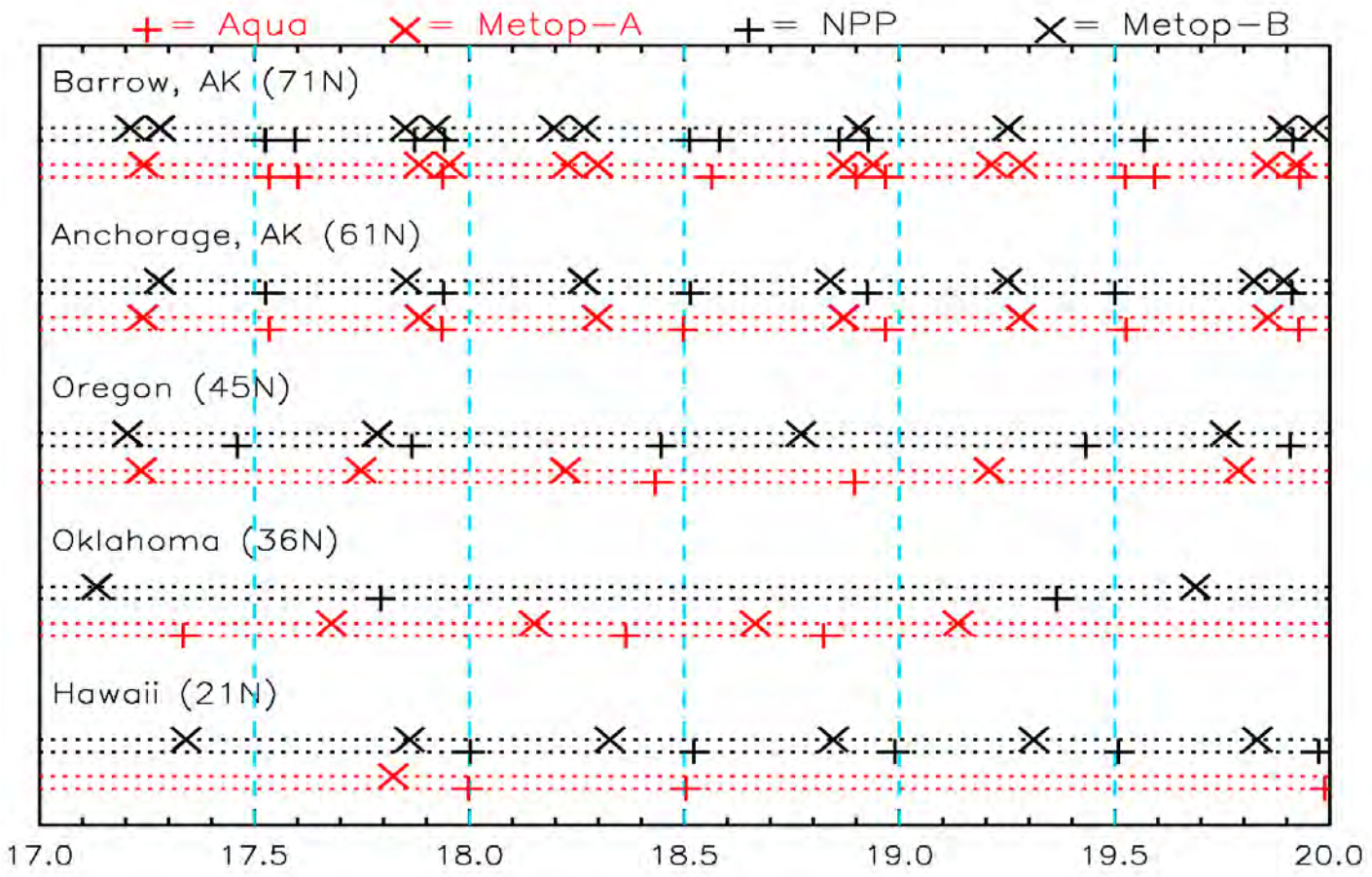
Counted occurrences of T(190mb) ≤ -65 degC in a 1x1 deg grid

Anchorage Center Weather Service Unit (CWSU) issues warnings on Nov. 11th to 14th



Analysis and graphics by C. Francoeur, STC

Constellation of satellites allows more observations between RAOBS



Day of June, 2015

NPP/J-1 will be phased similar to Metop-A/B approx. 6 months after launch of J-1

If we included NOAA AMSU/HIRS there would be even more soundings

These are overpasses with satellite elevation > 45 deg (FOR 4-27)