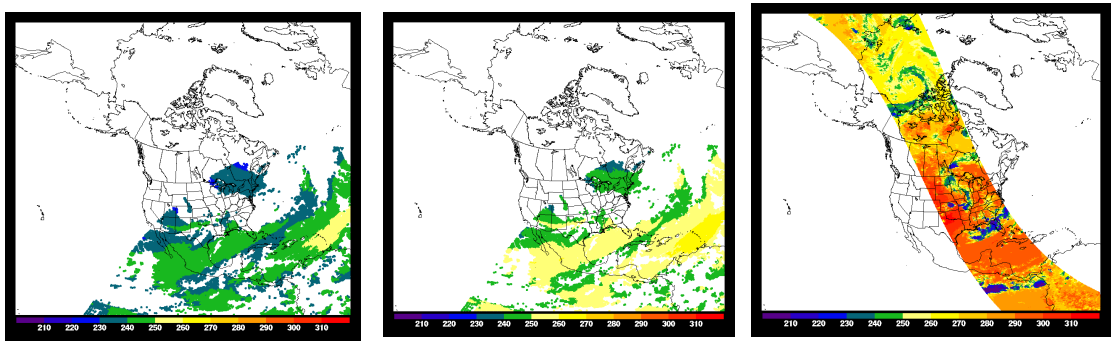
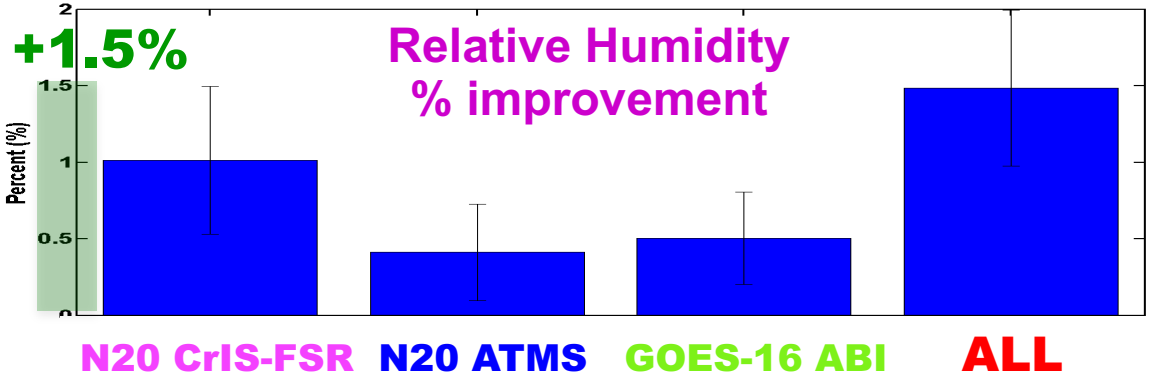
Satellite Radiance Assimilation Enhancements for the Upcoming NCEP Operational Rapid Refresh Upgrade





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NOAA/NCEP's hourly updated models:
RAPv5 / HRRRv4 operational upgrade

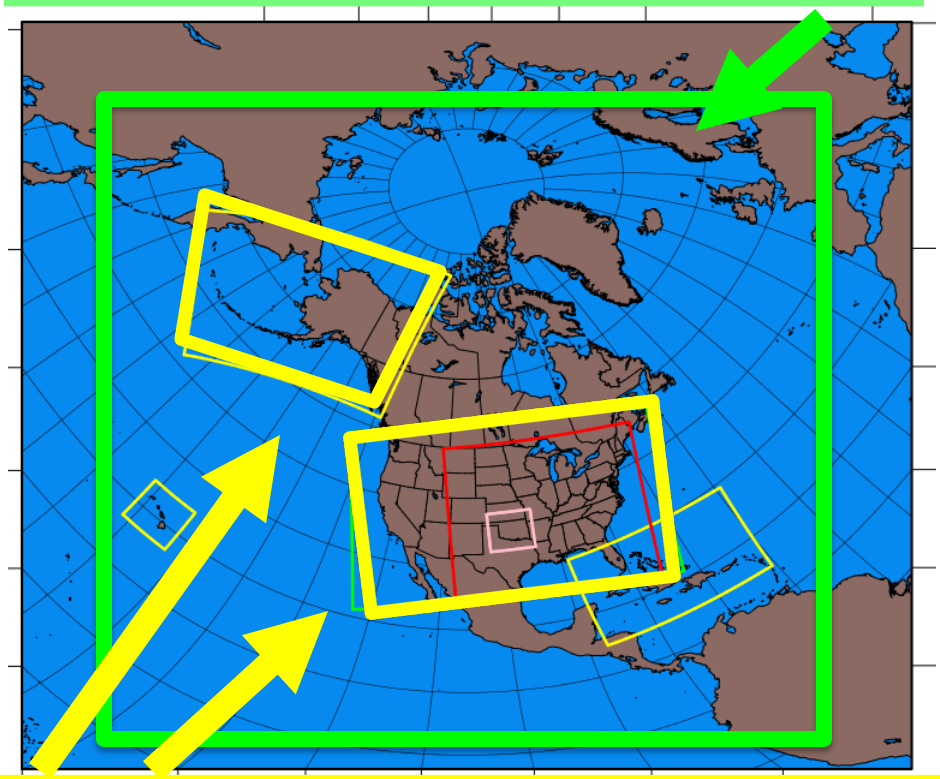
RAPv4 / HRRRv3
NCEP implementation:
July 2018

- ➔ Key features for short-range "situational awareness"
- ➔ RAP/HRRR guidance for aviation, severe weather, energy applications

RAPv5 / HRRRv4
Planned implementation:
June 2020

- – ABI from GOES-16
- – CrIS-FSR, ATMS from N20 with DB/RARS feeds
- – VIIRS fire radiative power for "HRRR-smoke"

Rapid Refresh
21 h hourly, 39 h every 6h



High-Resolution Rapid Refresh
CONUS : 18h hourly, 36h every 6h
AK: 18h every 3h, 36h every 6h

Use of satellite data in RAP / HRRR

Geostationary

- GOES cloud-top pressure
- GOES-15 sounder data
- AMVs
- SEVIRI
- GOES-16 ABI data WV channels
- GLM Lightning data (via LH)
- Cloud-top cooling rate data

Polar Orbiter

- AMSU (RARS)
- MHS (RARS)
- IASI (DB, RARS)
- AIRS
- ATMS (DB, RARS, NPP, N20)
- CrIS (DB, RARS, NPP, NPP/N20 FSR)
- SSMIS
- VIIRS/MODIS fire radiative power
- VIIRS greenness vegetation fraction

DB = Direct Broadcast
RARS = Regional ATOVS Retransmission Services

RAPv4 (2018)
RAPv5 (2020)
RRFS (FV3, ~2022)

RAP data cutoff ~30 min.
Very little polar orbiter radiance data available in time without DB/RARS

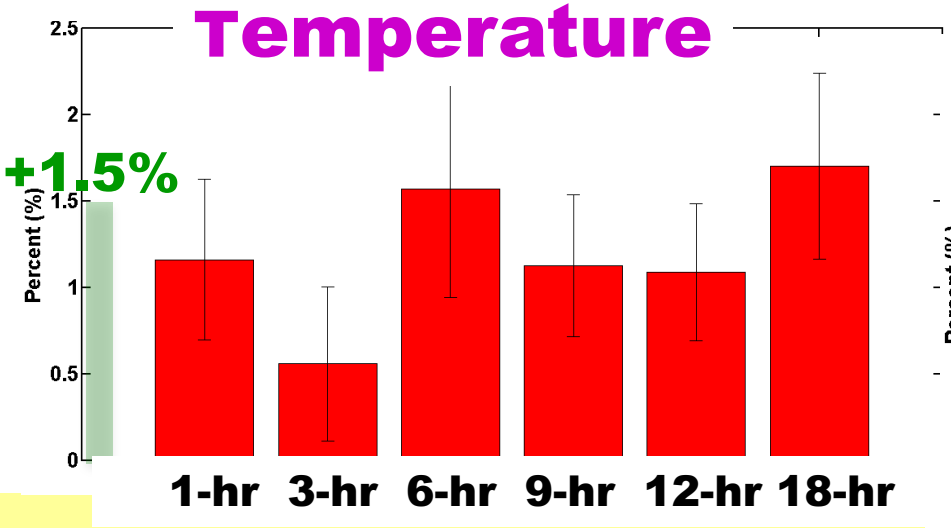
Radiance Channels in RAPv3/earlier, RAPv4, RAPv5

RAPv3 / earlier
RAPv4 (2018)
RAPv5 (2020)

- **AMSU-A**
  - NOAA_n15: channels 1-5, 7-10, 15;
  - NOAA_n18: channels 1-10,15; (removed channels 5, 8)
  - NOAA_n19: channels 1-9,10, 15; (removed channel 7)
  - METOP-a: channels 1-6, 9,10,15;
  - METOP-b: channels 1-10,15; (removed channels 1-7, 15)
  - AQUA: channels 6, 8-10;
- **MHS**
  - NOAA_n18, METOP-A, and METOP-B:1-5
  - NOAA-19: 1-5 (removed channel 3)
- **GOES**
  - GOES-15 (sndrD1,sndrD2,sndrD3,sndrD4): channels 3-8, 10-15
- **SEVIRI**: channels 5,6 from M10
- **ATMS**: channels 1-11, 16-22 from S-NPP
- **CrIS-NSR**: 66 channels from S-NPP (replaced by CrIS-FSR)
- **SSMIS** : channels 1-2, 5-7 from DMSP-17
- **AIRS**: 66 channels from AQUA
- **IASI**: 98 channels (longwave) from METOP-A and METOP-B
- **CrIS-FSR**: 72 channels from S-NPP and NOAA-20
- **ATMS**: channels 1-11, 16-22 from NOAA-20
- **ABI** : three water vapor channels (channels 8-10) from GOES-16

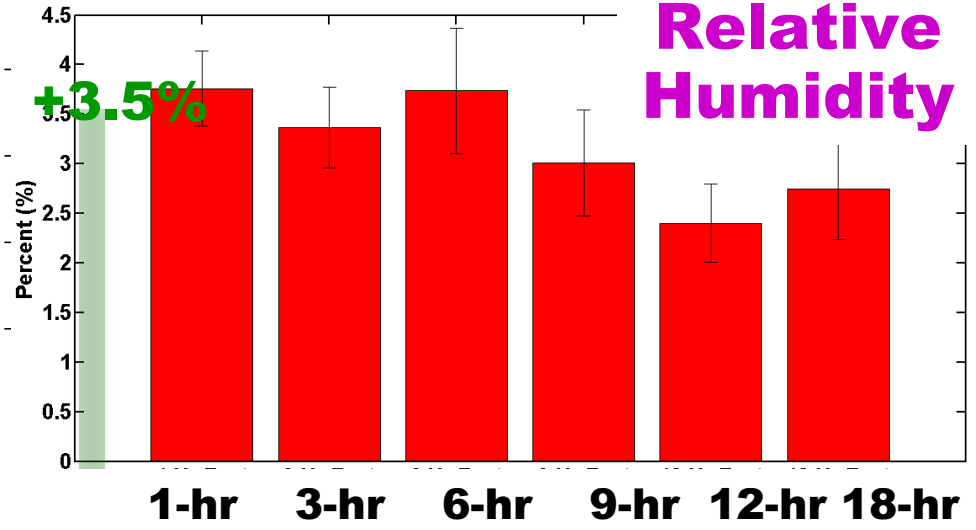
% improvement: ALL radiance data (through RAPv4)

Temperature



4-week Retro averaged

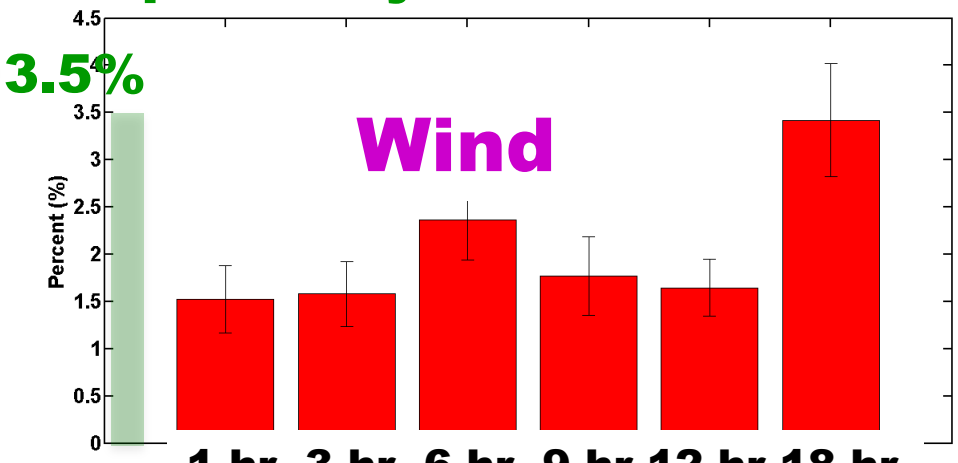
Relative Humidity



Init Hour	11,23z	9,21z	6,18z	3,15z	0,12z	18,6z
Fcst length	1	3	6	9	12	18
Hrs since GFS	2	0	9	6	3	9

GFS partial cycle at 09z and 21z

% impact from denying ALL radiance data



Normalized Errors

$$E_N = \frac{(EXPT - CNTL)}{CNTL}$$

Radiosonde verification

100-1000 hPa RMS mean

Radiance assimilation updates for RAPv5

- Includes new sensors/data
  - ABI infrared data from GOES-16 (3 channels)
  - CrIS-FSR data from S-NPP (72 channels) (and removes CrIS-NSR from S-NPP)
  - CrIS-FSR data from NOAA-20 (72 channels)
  - ATMS data from NOAA-20 (18 channels)
- Uses direct broadcast (DB) and RARS data from NOAA-20

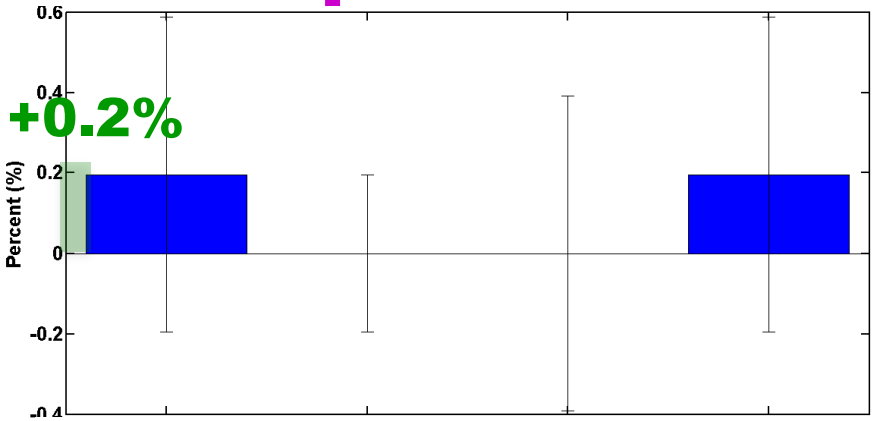
Evaluate FURTHER improvement for **RAPv5** beyond the improvement seen in **RAPv4**

Retrospective Experiments

- **Control run (CNTL) – (All data in RAPv4)**
  - **1-h cycling, 7-day retro run (September 09 –15 2018) using RAPv4**
  - **All data used in operational RAPv4 (conventional + satellite radiance data)**
- **Experiment runs (NCEP real-time hourly data)**
  - **CNTL + N20 CrIS-FSR (72 channels)**
  - **CNTL + N20 ATMS (18 channels)**
  - **CNTL + GOES-16 ABI (3 channels) (NCEP baseline cloud mask data)**
  - **CNTL + All above new data sets**

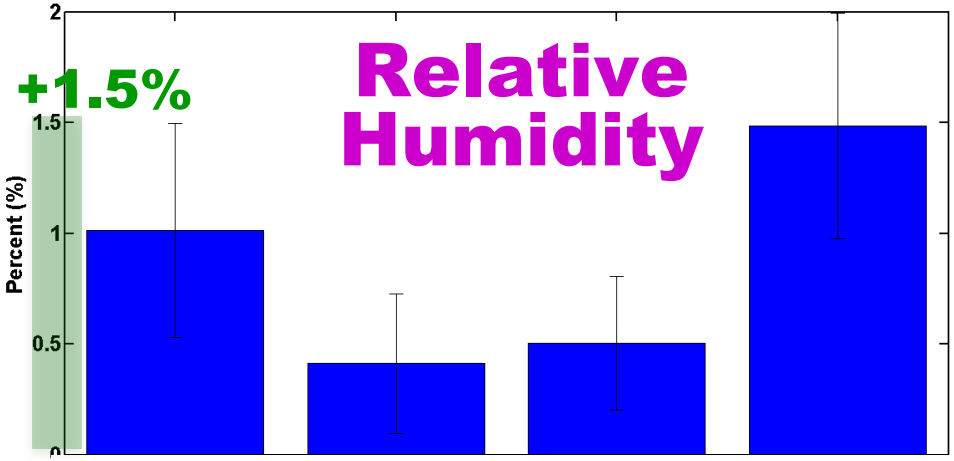
12-h fcst. Normalized Errors from New Data Sets

Temperature



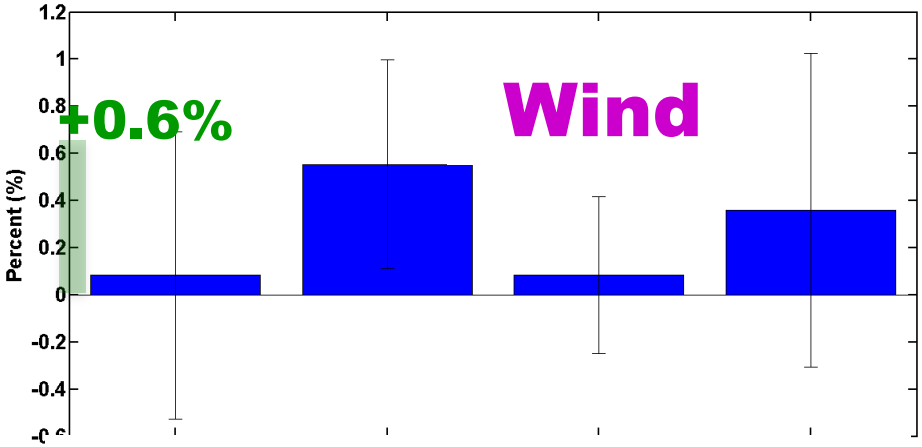
N20 CrIS-FSR N20 ATMS GOES-16 ABI ALL

Relative Humidity



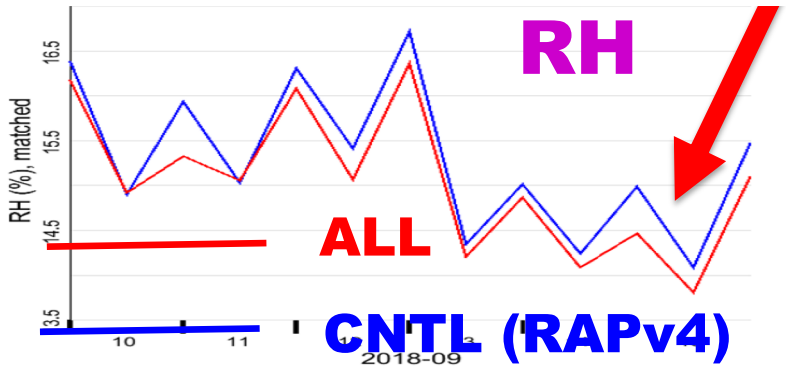
N20 CrIS-FSR N20 ATMS GOES-16 ABI ALL

Wind



N20 CrIS-FSR N20 ATMS GOES-16 ABI ALL

RH



Normalized Errors

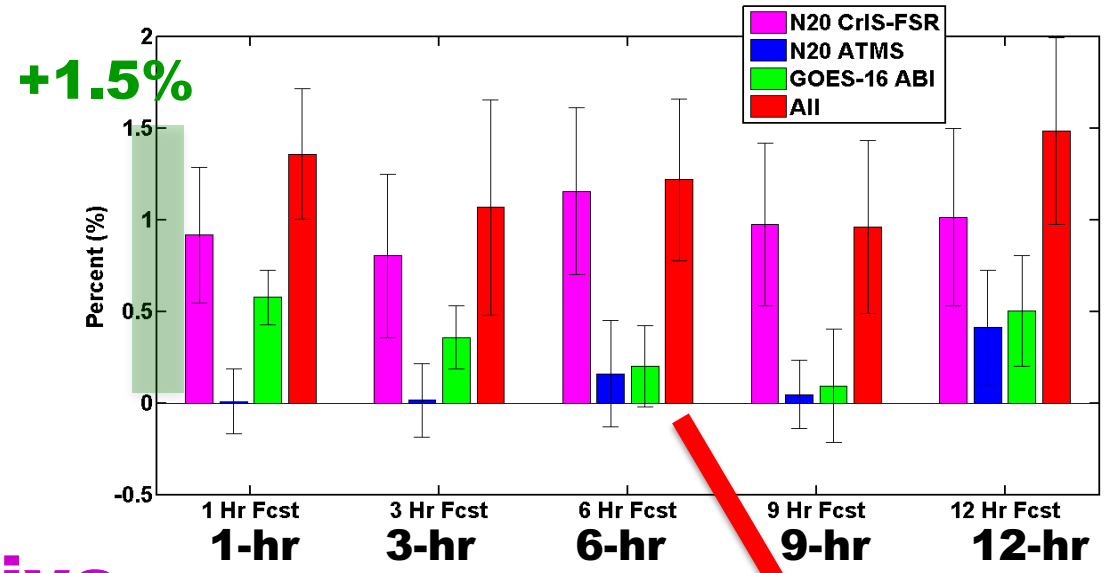
$$E_N = \frac{(CNTL - EXPT)}{CNTL}$$

Radiosonde verification

100-1000 hPa RMS mean
one-week hourly RAP retro run
averaged (Sep09-Sep15 2018)

Control run has all operational data in RAPv4

1-12 fcst. relative humidity verification



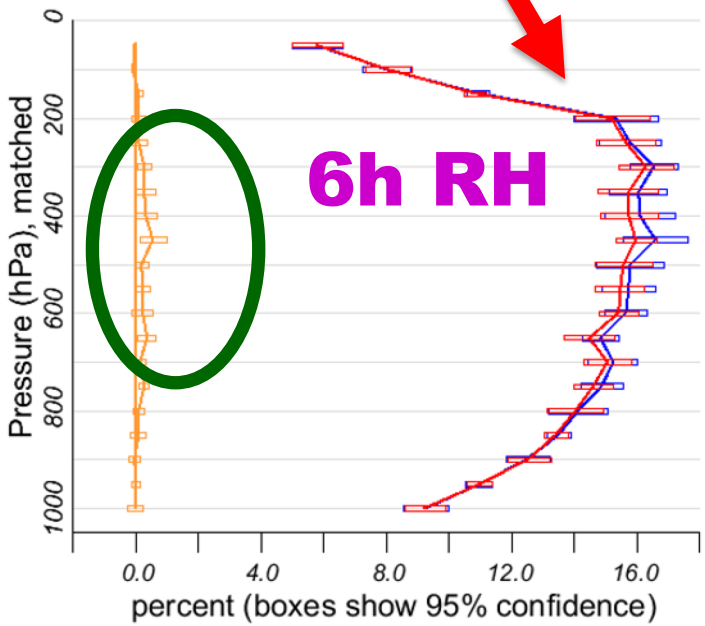
N20 CrIS-FSR

N20 ATMS

GOES-16 ABI

All

Relative Humidity



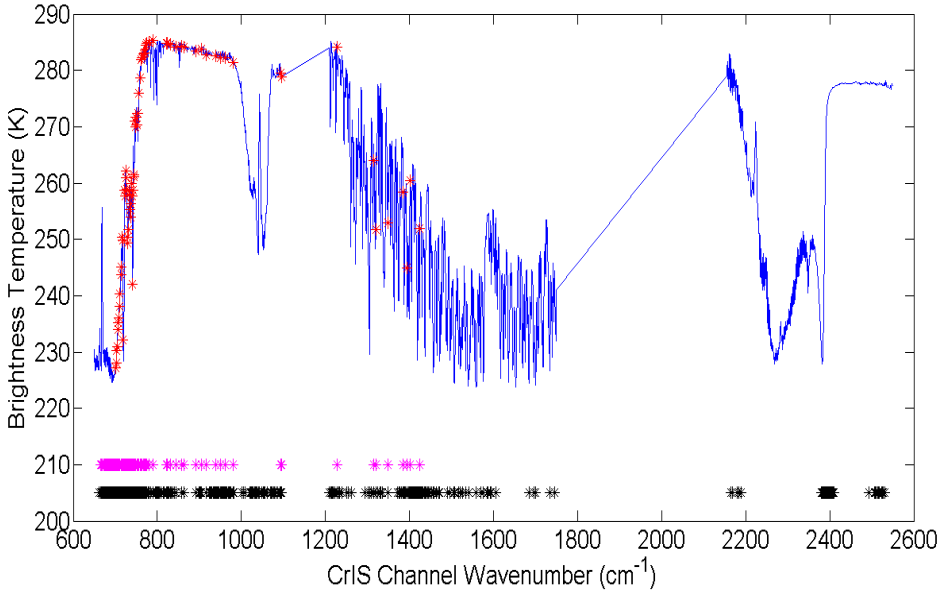
All

CNTL (RAPv4)

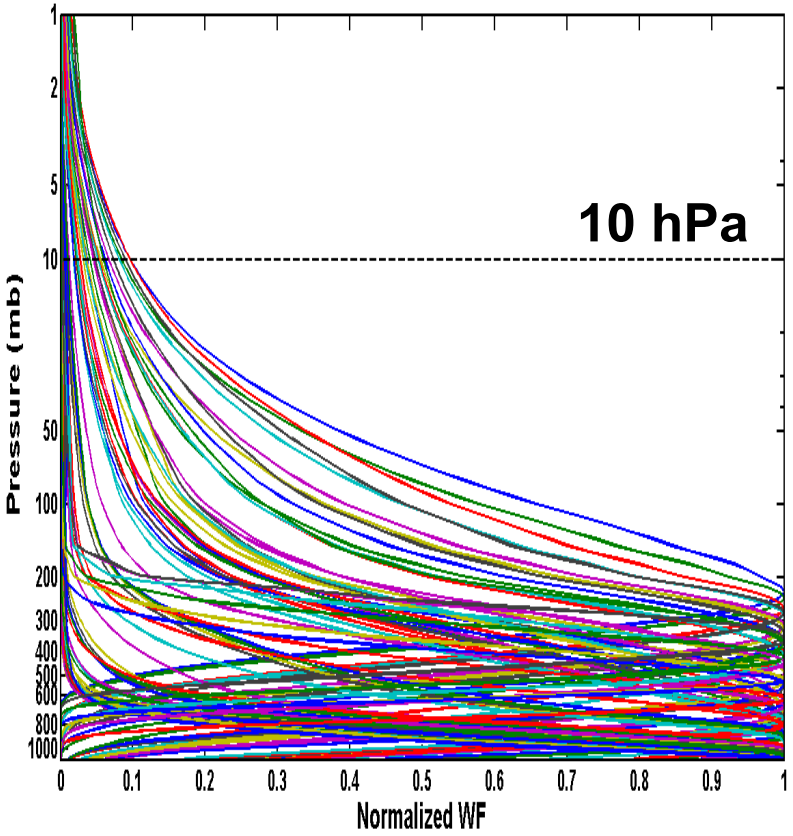
Radiosonde verification

7-day retro runs(Sep09-Sep15 2018) averaged

N20 CrIS-FSR channel selection for RAP



Simulated BT for CrIS-FSR 2211 channels



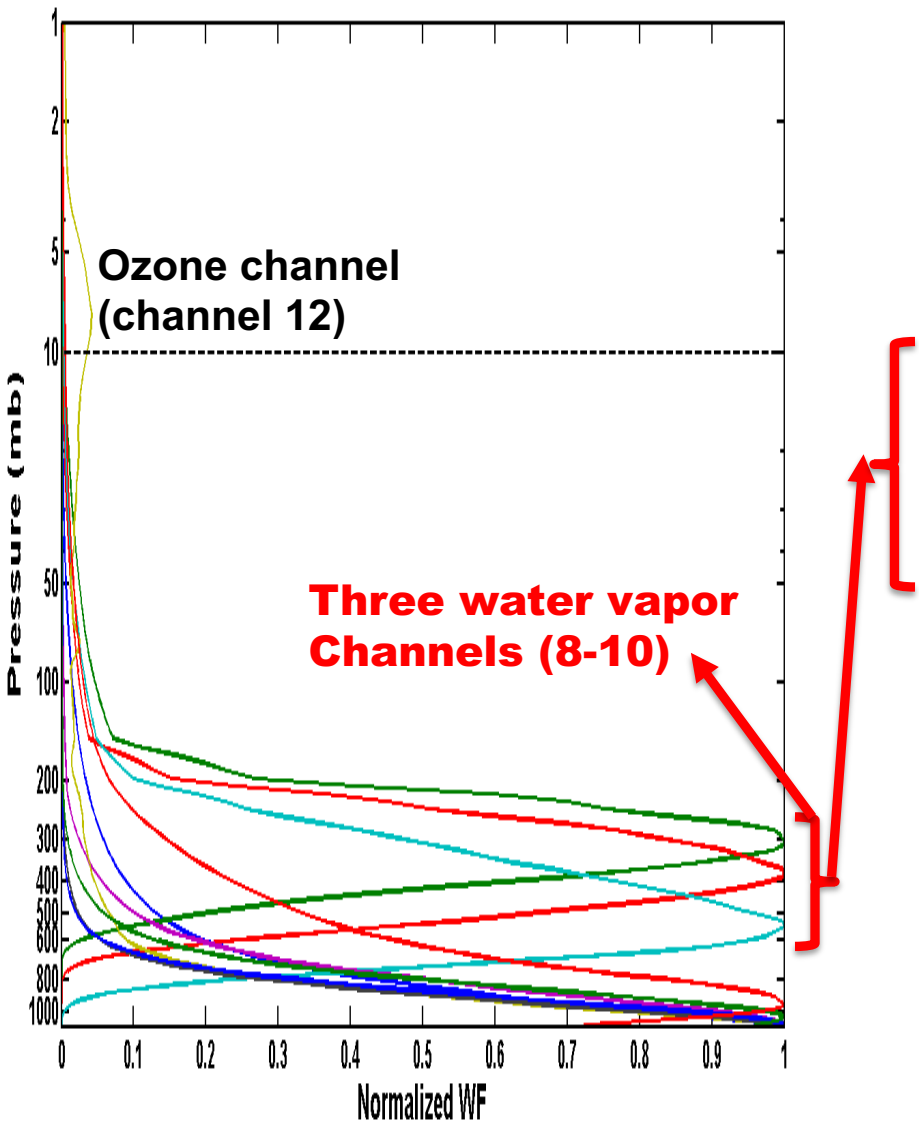
CrIS 2211 channels

NESDIS 431-channel set

GDAS 100-channel set

RAP selected 72-channel set (64 longwave+8 WV)

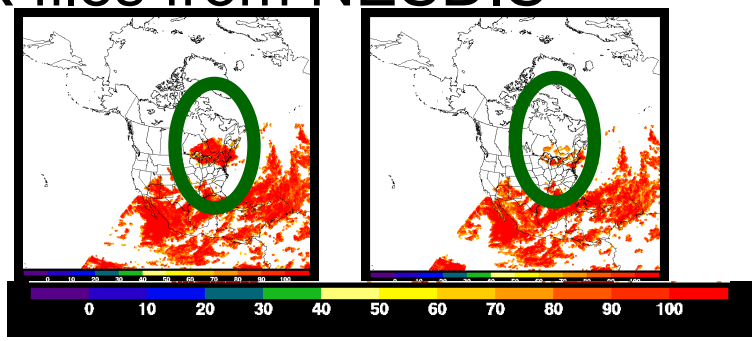
Some details on ABI channels



Channel Number	Central Wavelength	Contribution Primary usage
7	3.90 μm	windows (shortwave band, fire detection)
8	**6.19 μm**	**Upper troposphere water (340 mb)**
9	**6.95 μm**	**Mid-level water (440 mb)**
10	**7.34 μm**	**Low-level water (615 mb)**
11	8.40 μm	cloud-top phase, SO_2
12	9.61 μm	O_3
13	10.35 μm	window (clean IR)
14	11.20 μm	window (low stratus detection with 3.9 μm channel)
15	12.30 μm	window (dirty IR)
16	13.30 μm	CO_2 (low level temperature)

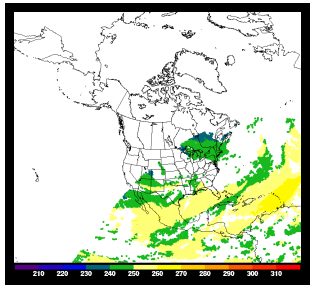
ABI Radiance BUFR files

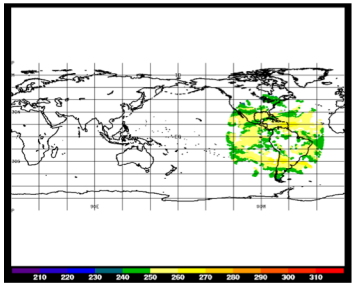
- ABI Clear Sky Radiance (CSR) BUFR files from NESDIS
  - Baseline cloud mask
  - NOAA enterprise cloud mask
  - 15-min Full Disk (FD) data
- NCEP ABI hourly BUFR files for RAP
  - Baseline and enterprise cloud mask data
- CSR BUFR files
  - 15 X 15 box data (30 km resolution with 362x362 full disk data; original ABI infrared data with 2 km resolution 5425x5425)
  - BT standard deviation within a 15x15 box, could provide additional information for cloud detection
  - Satellite zenith angle less than 60 degree

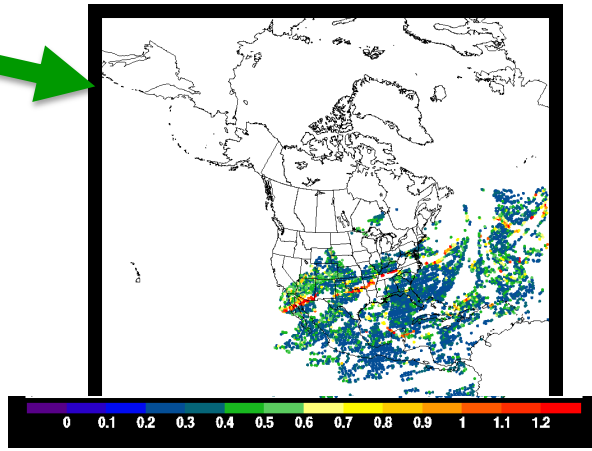


baseline mask

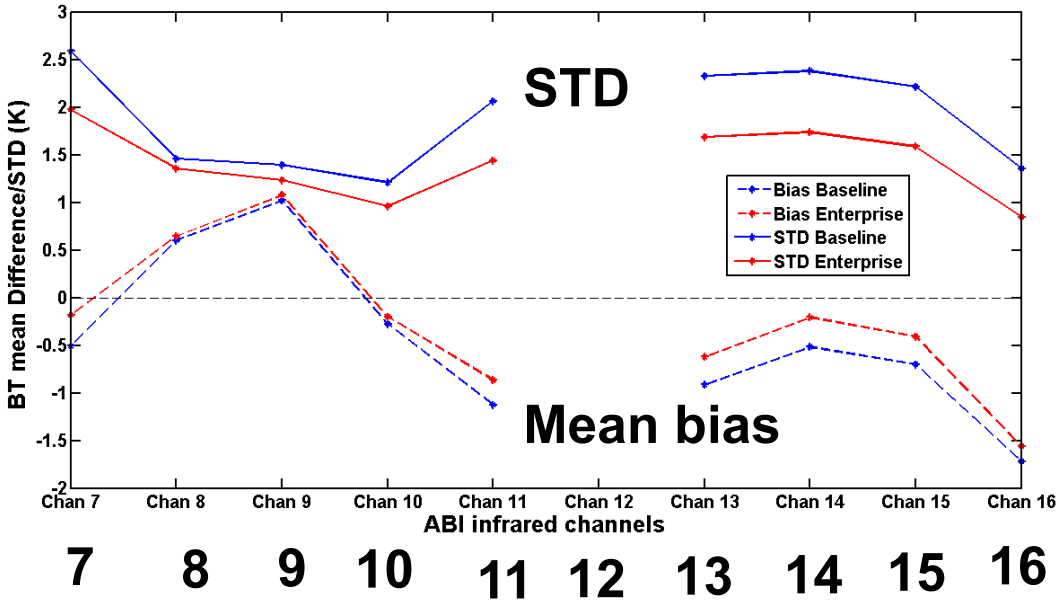
enterprise mask







One-month ABI O-B evaluation

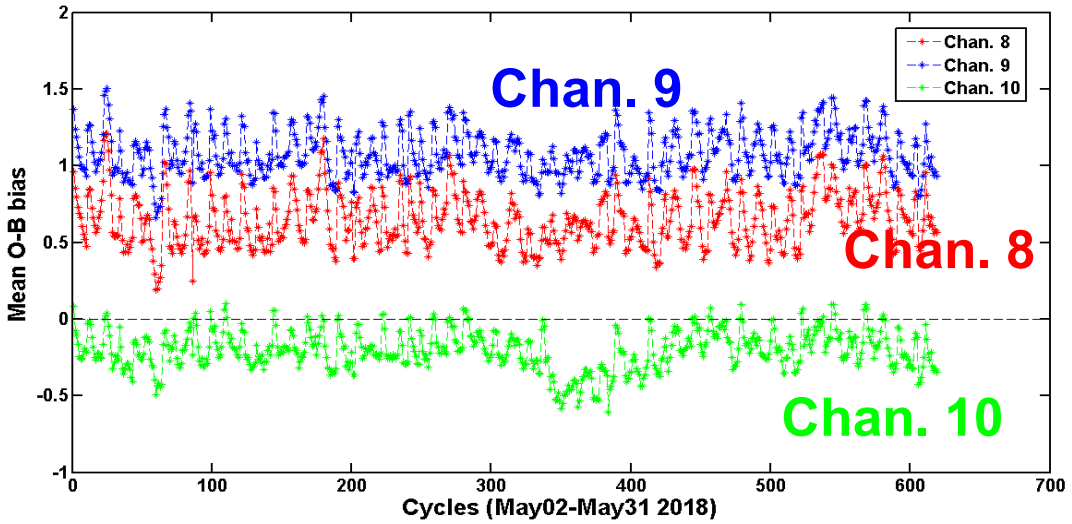


Enterprise cloud mask

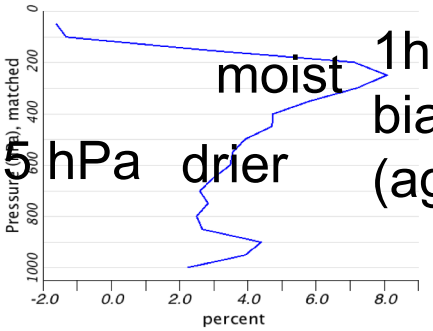
Baseline cloud mask

One-month (May02-May31) RAP 1h forecast (background) are used in GSI/CRTM to calculate the O-B with co-located ABI radiance data(baseline vs. enterprise)

Channel 10 (615 hPa PWF) has the smallest bias (negative), drier background around 615 hPa; more moist background above 450 hPa



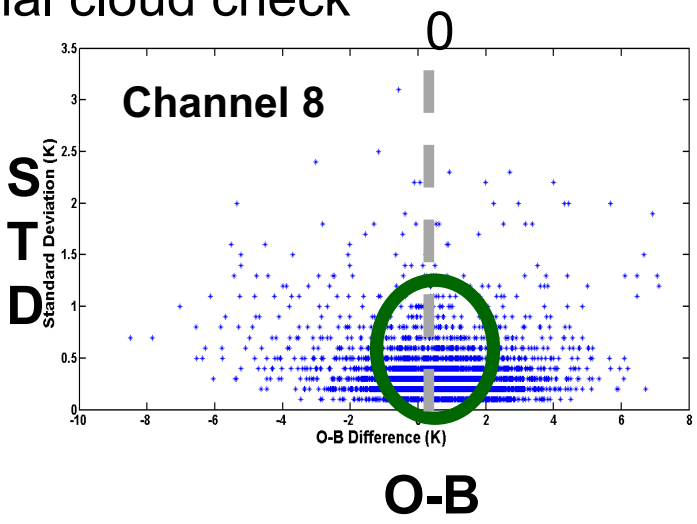
Time series mean O-B for enterprise cloud mask data



1h forecast bias(May2018) (against raob.)

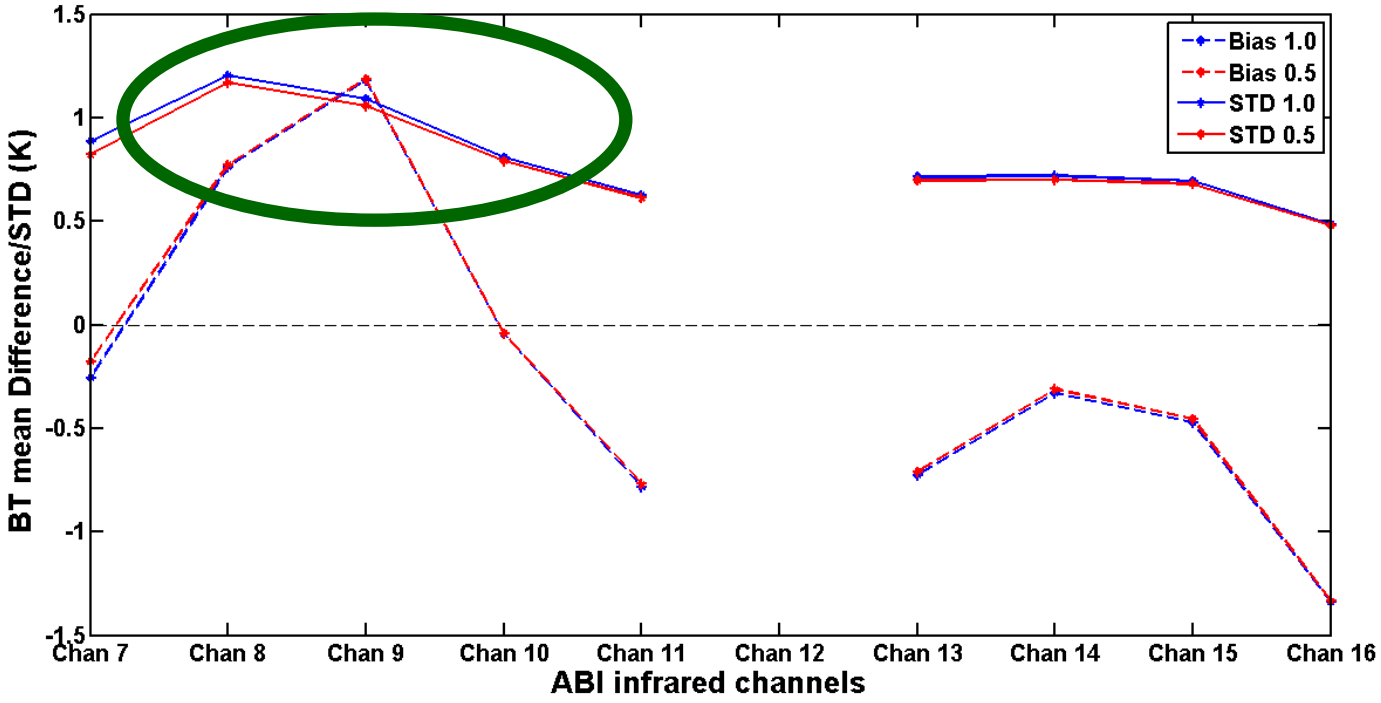
Ongoing different data sets, QC, and error tuning work

- Baseline vs. enterprise cloud mask radiance data
  - Enterprise seems better from one-month O-B evaluation
- QC work
  - Gross check (2K vs. 4K)
  - STD of BT in the 15x15 box as additional cloud check
    - Removed BT STD > 0.4 K
    - 0.4 K could be larger?
    - 0.5 vs. 1.0
  - Amount segment cloud free
    - Currently < 70%, rejected
    - Could be larger
    - 70% vs. 100% ?



- Error tuning
  - Initially three water vapor channels assigned 2.2 K error
  - Changed to the calculated O-B standard deviation
  - Inflated errors could be safer

4-month ABI O-B evaluation (STD 0.5 vs. 1.0)



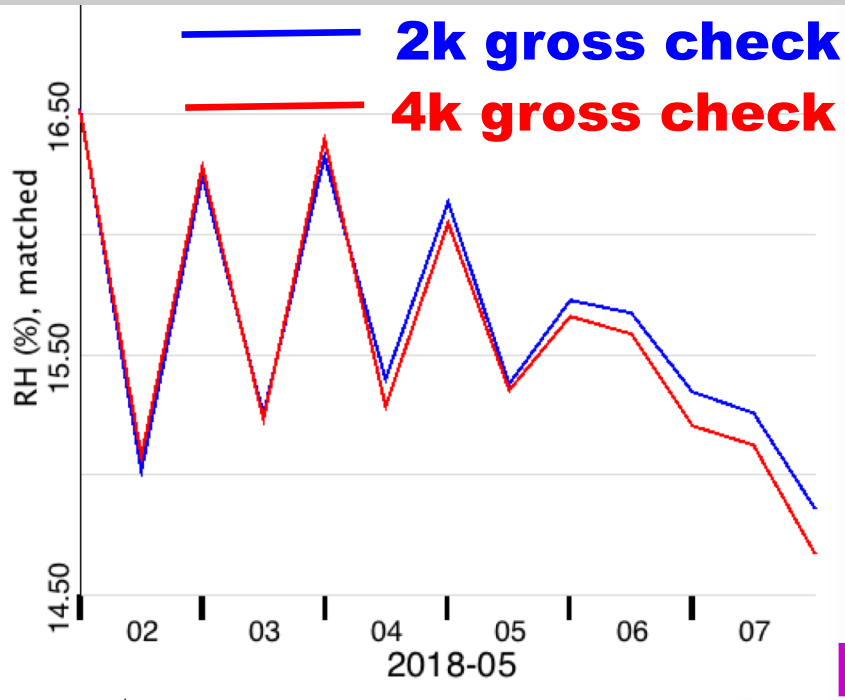
STD less than 1.0

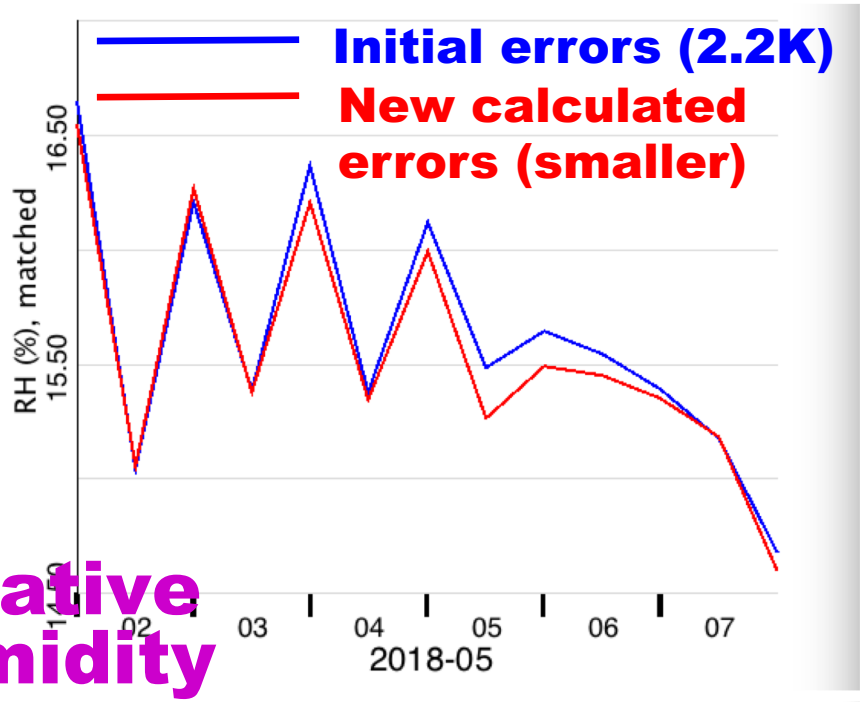
STD less than 0.5

4-month RAP hourly O-B: May 2018, July 2018, October 2018, and January 2019

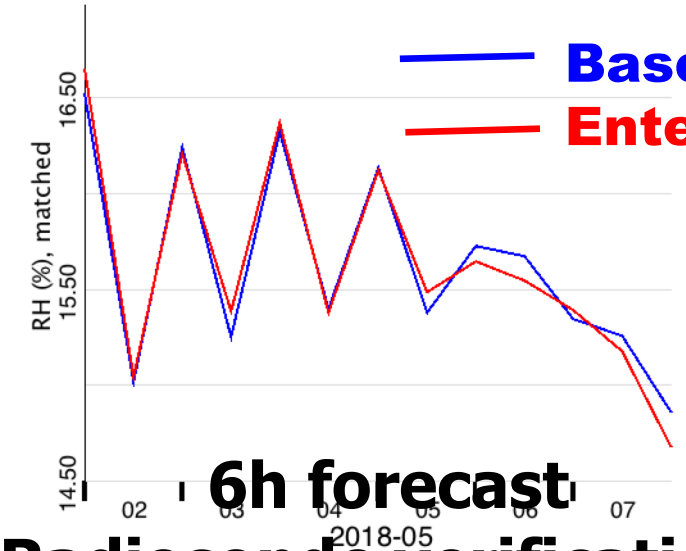
100% clear baseline data

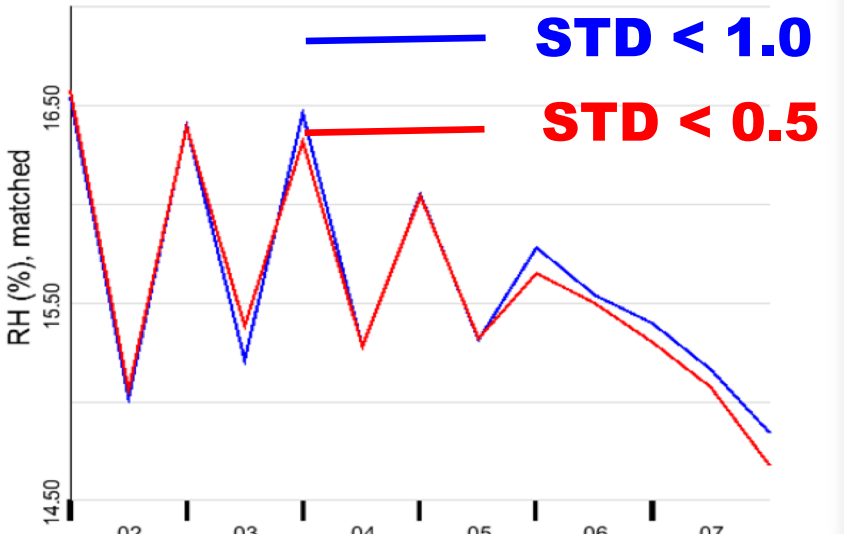
ABI experiments with QC/error tuning





Relative Humidity



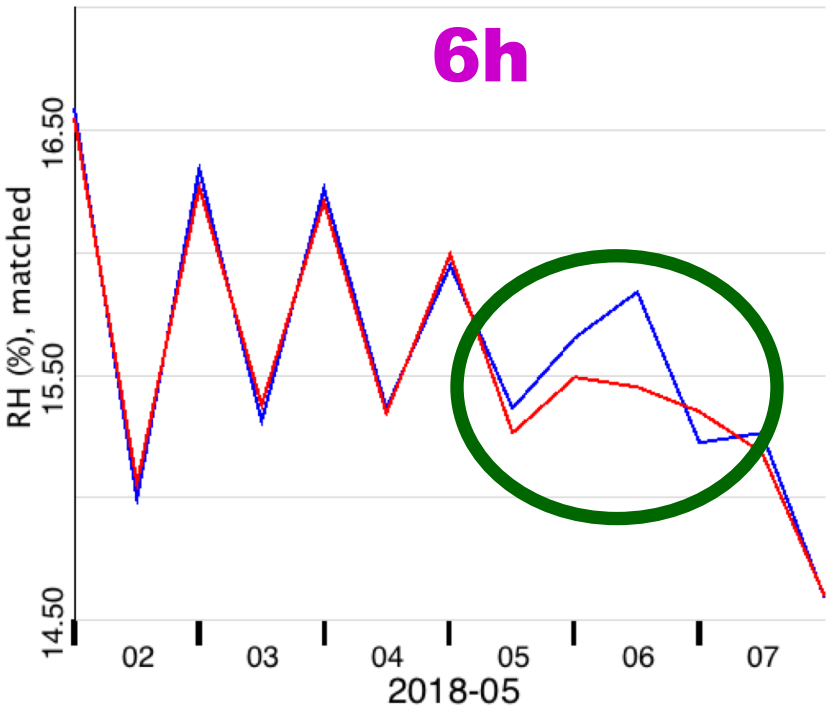


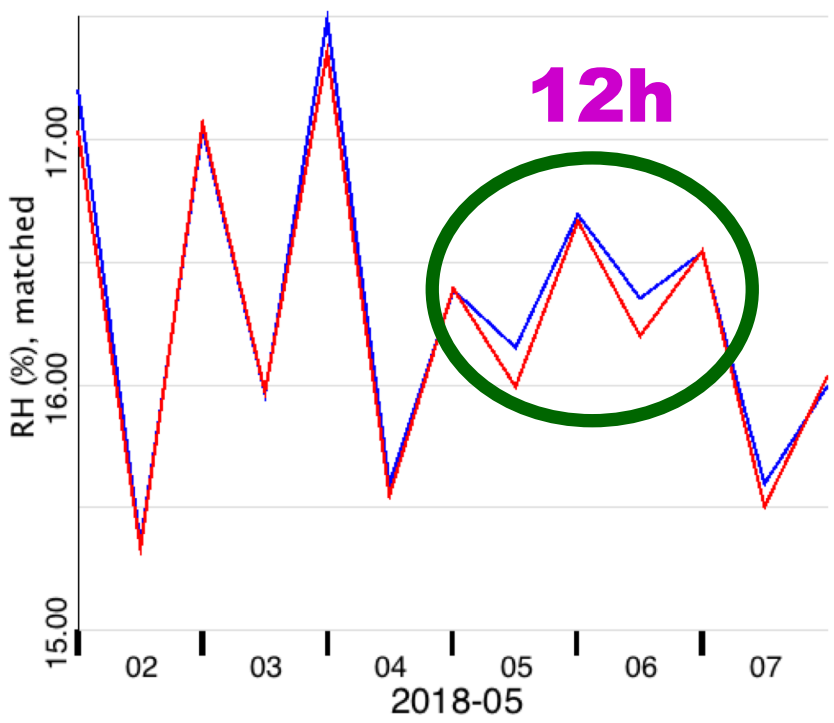
6h forecast

Radiosonde verification

7-day retro run (May01-May07 2018)

ABI assimilation vs. CNTL





Relative Humidity

CNTL

ABI added

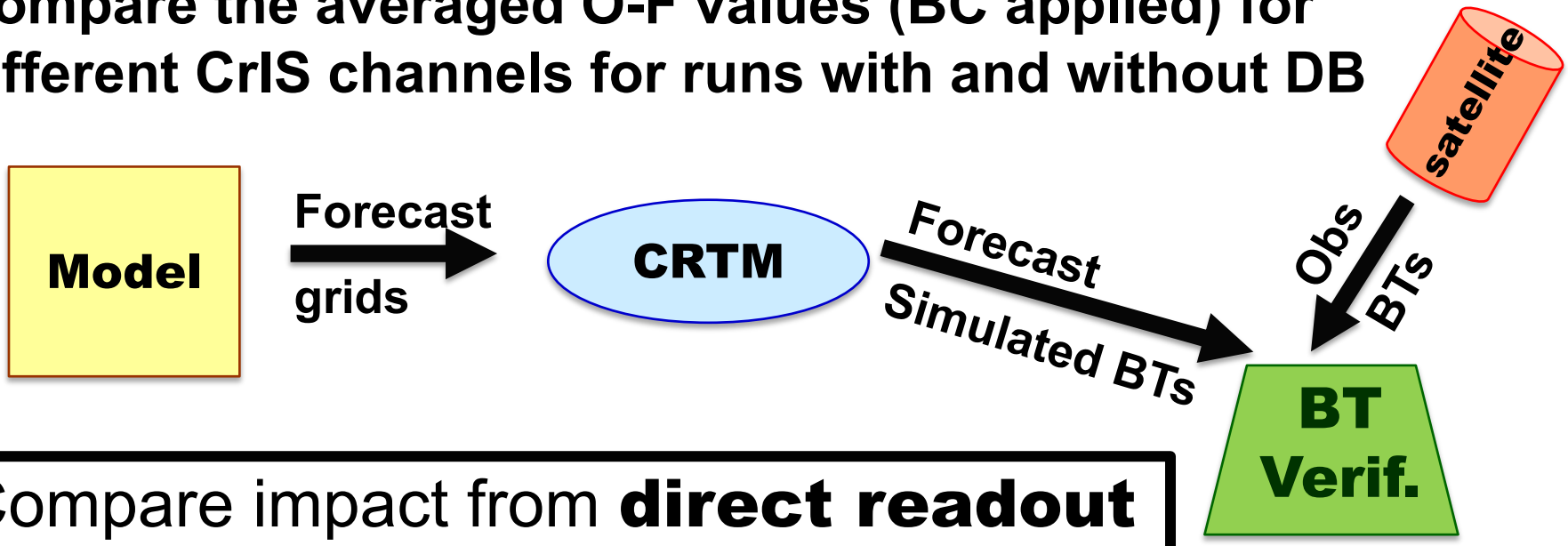
New errors
STD < 0.4
2k gross check

Enterprise cloud mask data

7-day retro run (May01-Mah07 2018)

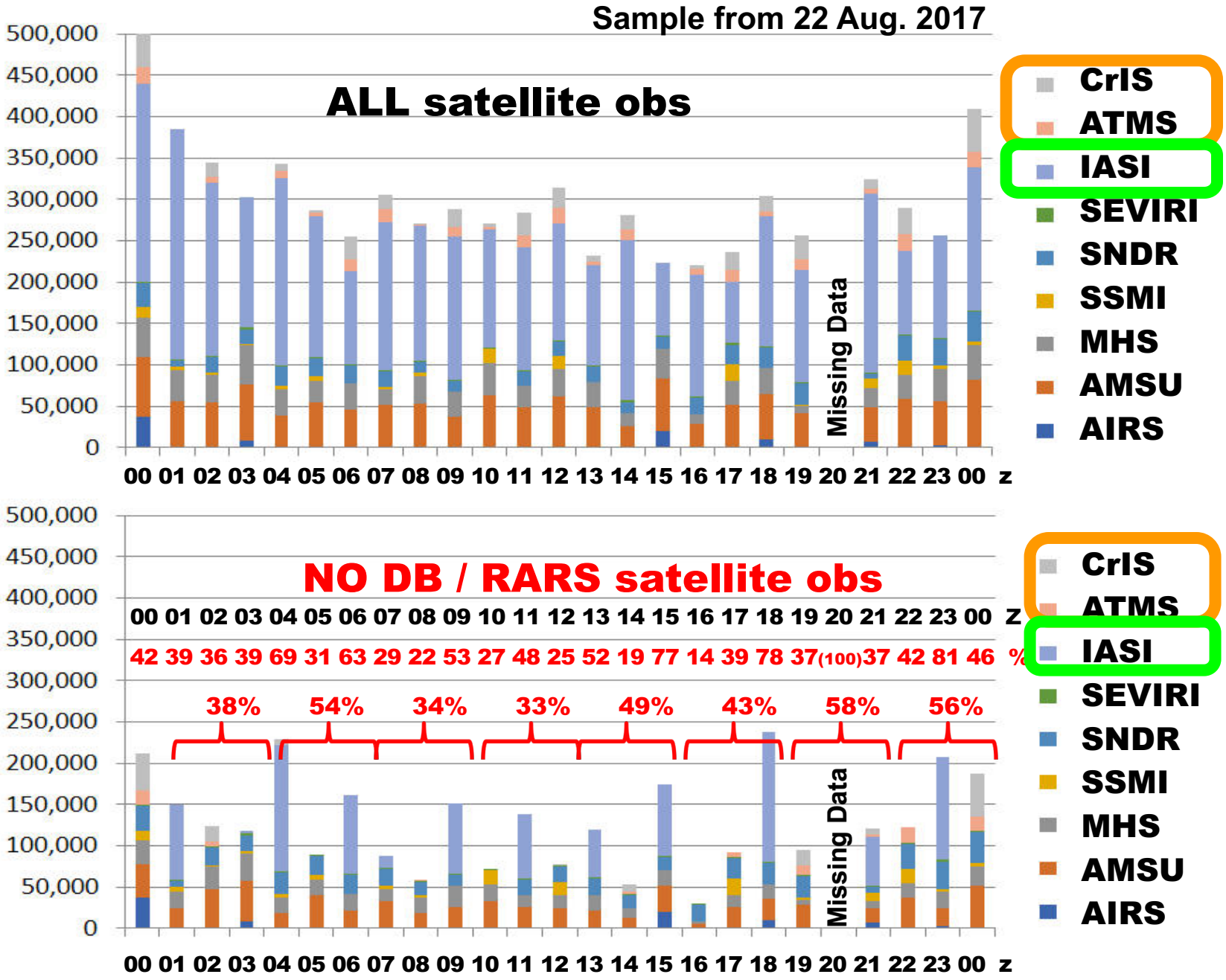
Forecast verification against CrIS BT

- **Use RAP WRF NETCDF forecast files and matched CrIS radiance BUFR files as input to GSI**
- **Use GSI/CRTM to calculate the space and time (< 30 min.) co-located O-Fs with bias correction**
- **Compare the averaged O-F values (BC applied) for different CrIS channels for runs with and without DB**



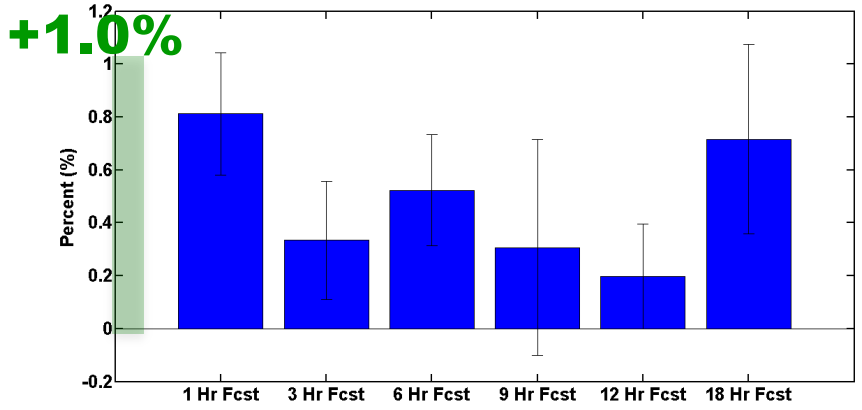
Compare impact from **direct readout** data with **radiosonde** vs. **radiance** verification

Sample radiance ob counts w/ and w/o DB/RARS data



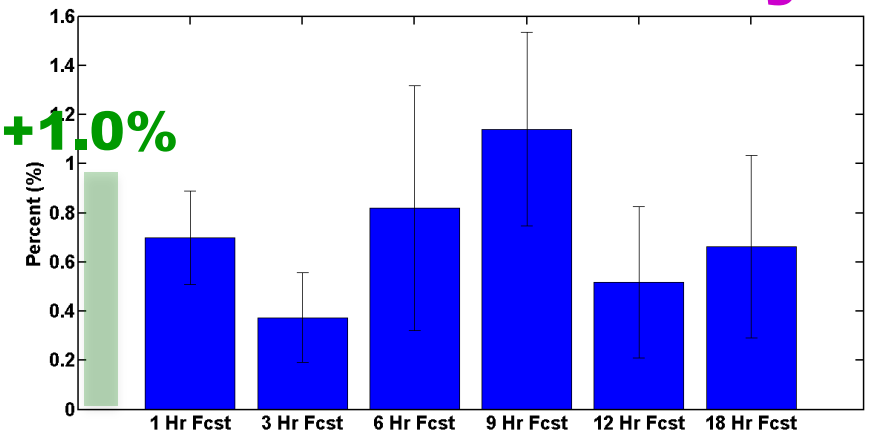
% improvement from direct readout

Temperature



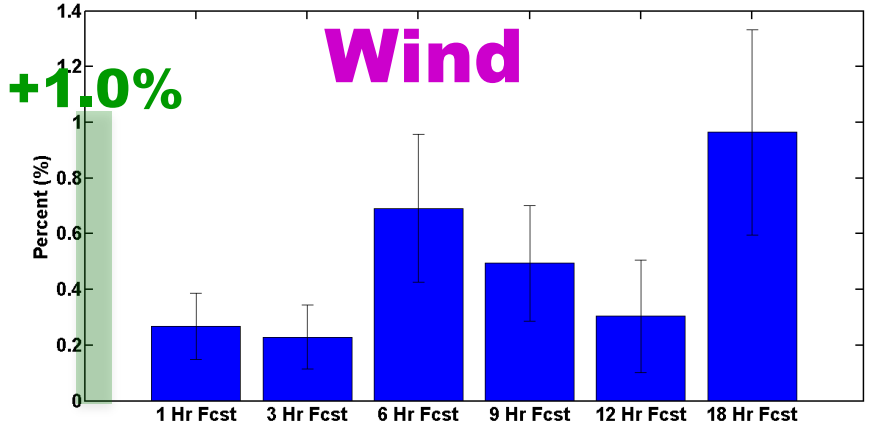
1-hr 3-hr 6-hr 9-hr 12-hr 18-hr

Relative Humidity



1-hr 3-hr 6-hr 9-hr 12-hr 18-hr

Wind



1-hr 3-hr 6-hr 9-hr 12-hr 18-hr

Impact from GFS partial cycle

Init Hour	11,23z	9,21z	6,18z	3,15z	0,12z	18,6z
Fcst length	1	3	6	9	12	18
Hrs since GFS	2	0	9	6	3	9

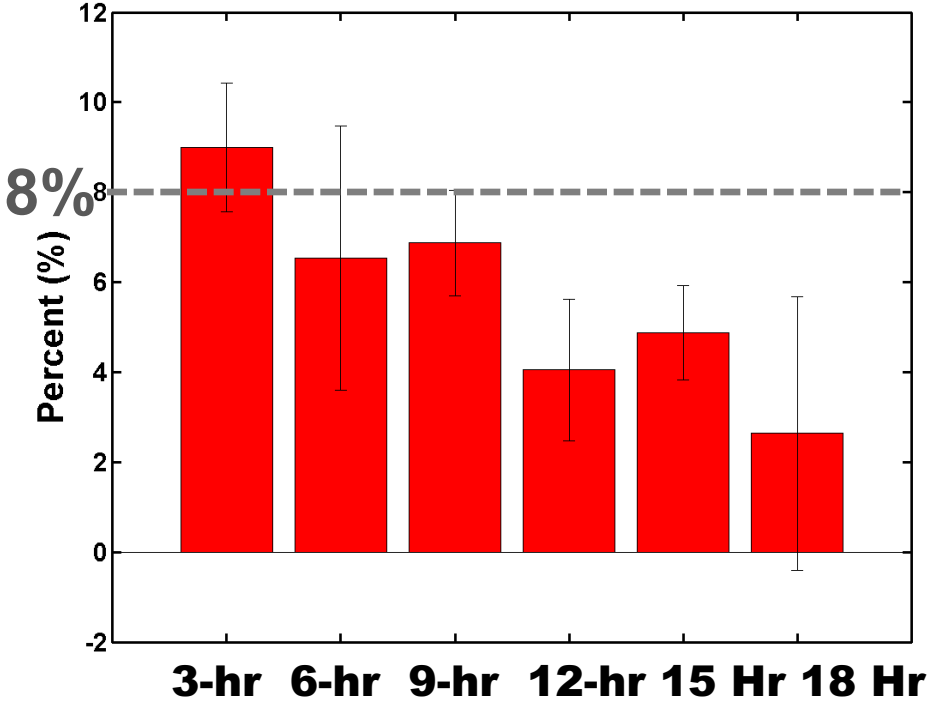
Normalized Errors

$$E_N = \frac{(EXPT - CNTL)}{CNTL}$$

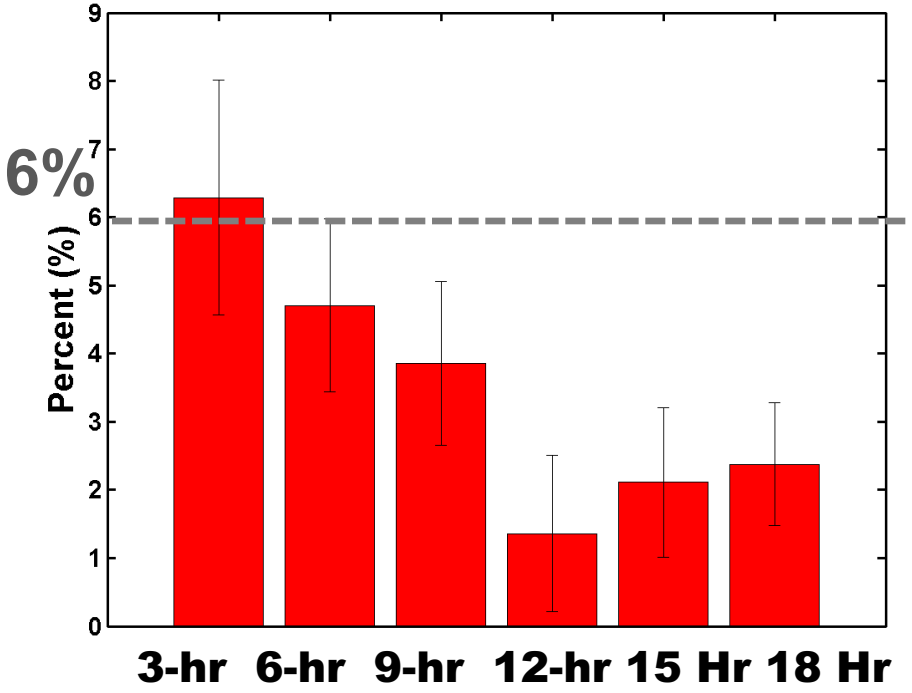
4-week retro run averaged

100-1000 hPa RMS mean

Normalized fcst. improvement from DB data verified against CrIS Obs.



Chan. 83
PWF 218 hPa



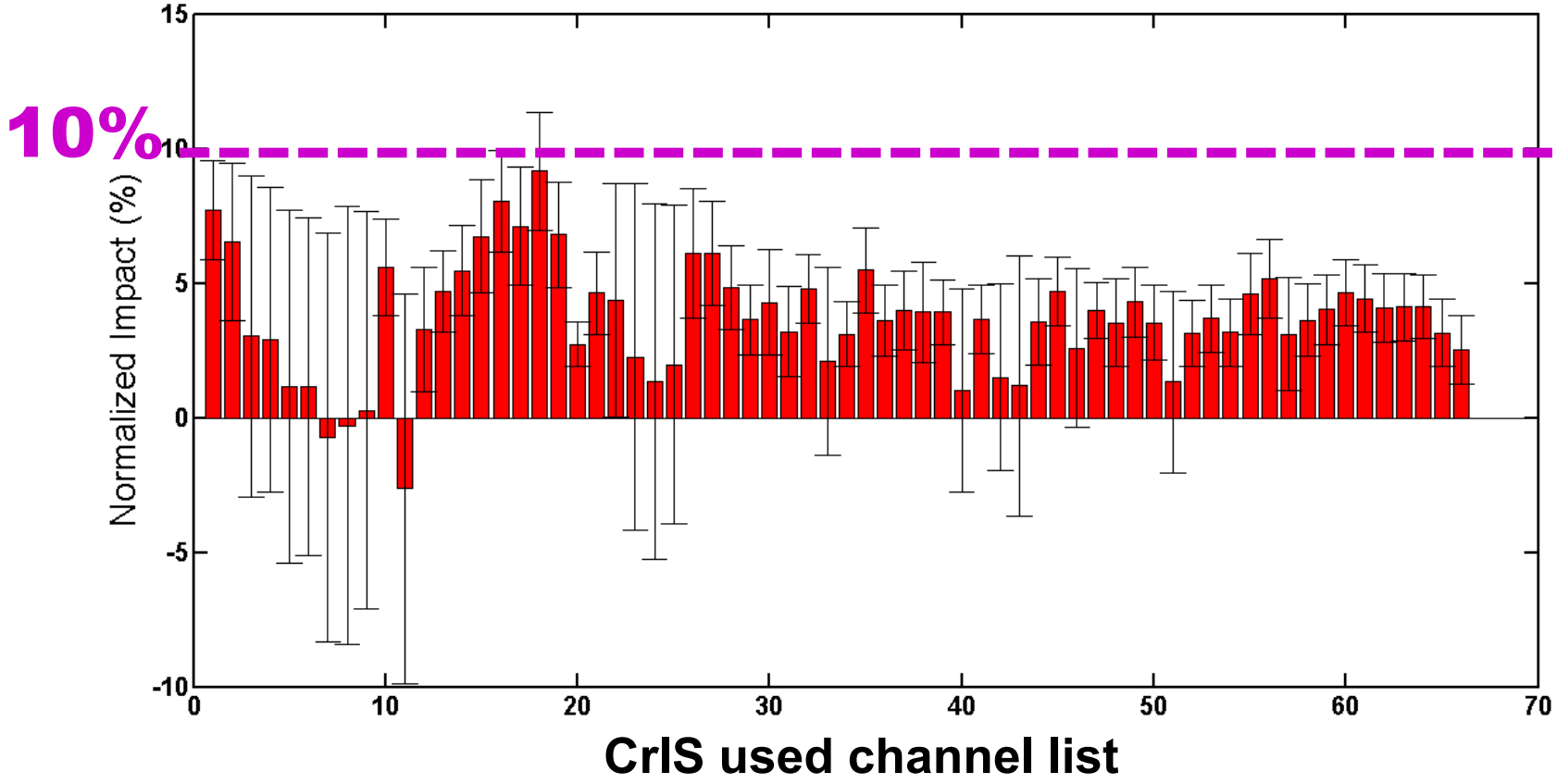
Chan. 165
PWF 814 hPa

% impact from denying DB and RARS data

Normalized Errors

$$E_N = \frac{(EXPT - CNTL)}{CNTL}$$

Normalized 6-h fcst. improvement from DB data verified against CrIS BT obs.



% impact verified against each used CrIS channel from denying DB and RARS data

Normalized Errors

$$E_N = \frac{(EXPT - CNTL)}{CNTL}$$

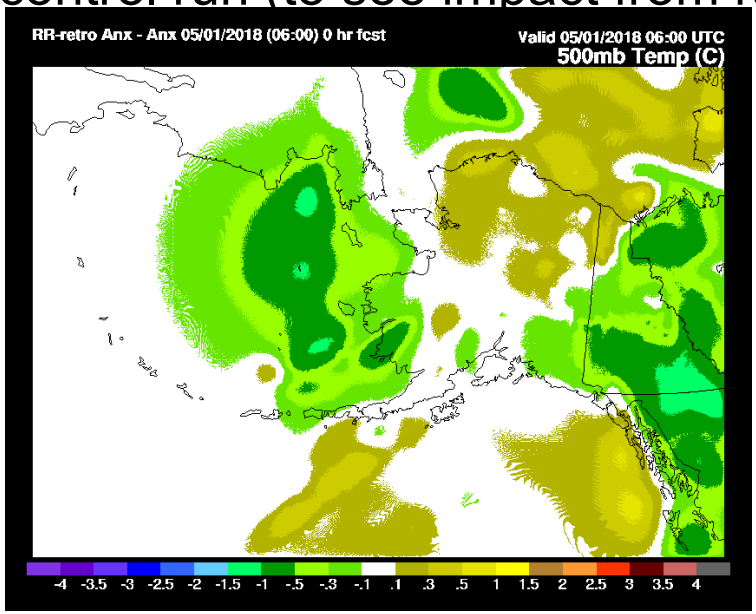
Single Case HRRR/AK GSI run with and without radiance data

Single case HRRR/AK GSI runs (06Z 05/01/2018) with and without radiance data

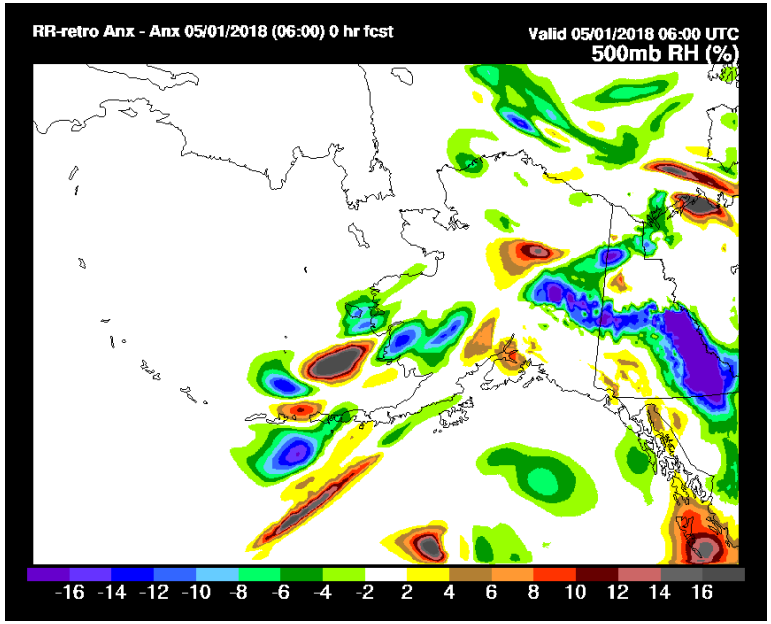
Control run: all available conventional data in operation HRRR/AK

Radiance run: control run adds all radiance data available for RAPv4, only amsua, mhs and IASI data are available for this cycle

Analysis difference: Analysis from radiance run minus analysis from the control run (to see impact from radiance data



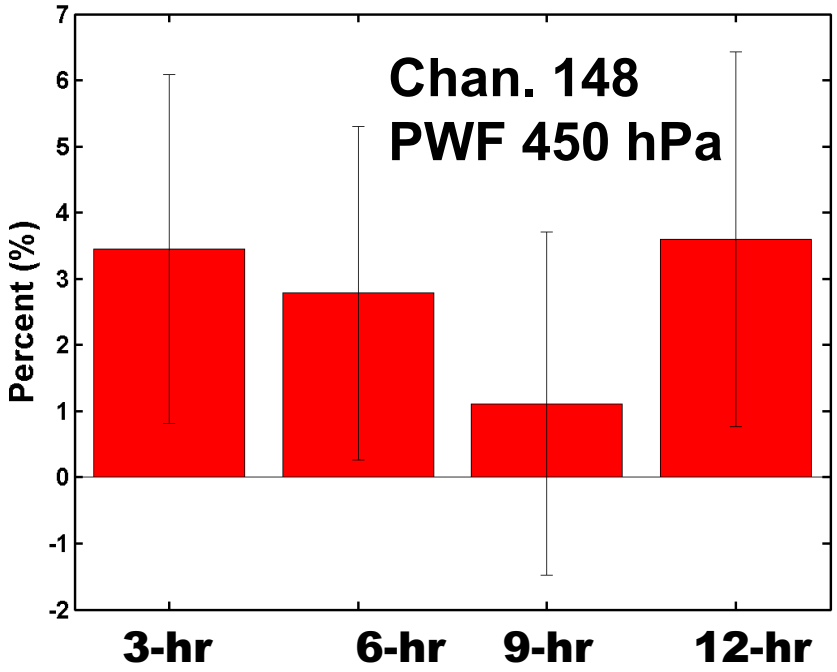
500 hPa Temperature

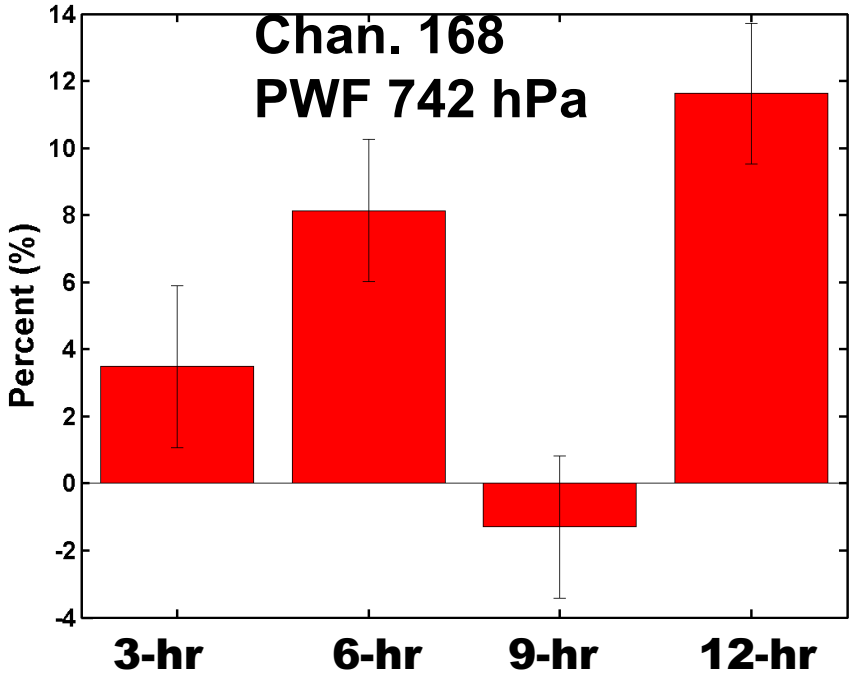


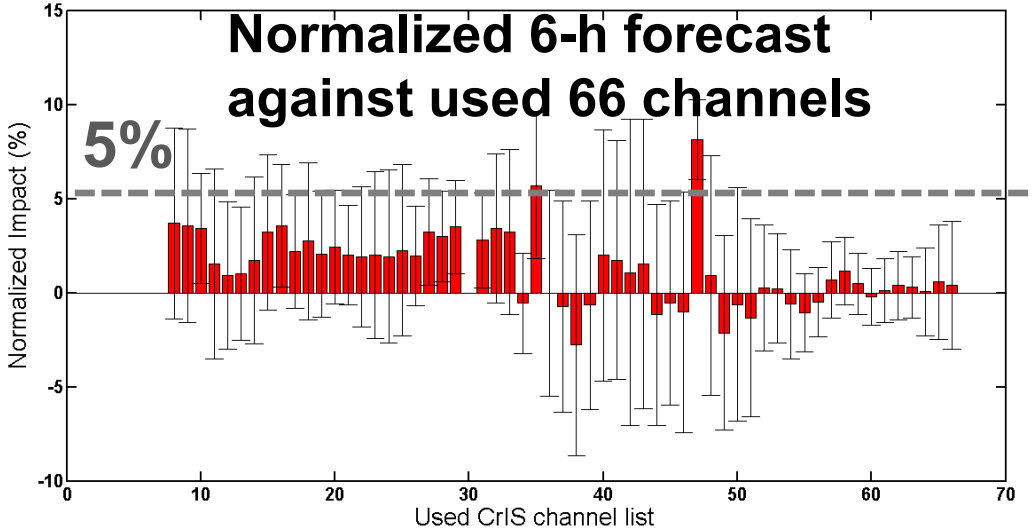
500 hPa RH

Analysis difference (A-A)

Forecast verification against CrIs Obs.







One-week 3h cycled HRRR/AK retro runs (May01-May07 2018) averaged

Summary

- RAPv5 upgrade radiance package (GOES-16 ABI, N20 CrIS-FSR/ATMS) with overall up to 1.5% normalized improvement (against raob.) for RH
- GOES-16 ABI RAP retro results (3 water vapor channels): neutral impact → slight positive impact with additional error tuning and QC
- ABI one-month RAP O-B comparison: smaller errors for enterprise cloud mask than baseline cloud mask
- N20 CrIS-FSR/ATMS RAP retro experiments: CrIS-FSR small positive impact for RH, ATMS small positive impact for RH and wind
- Greater positive impact from DB data for verification against CrIS BT than for radiosonde verification

Ongoing and Future Work

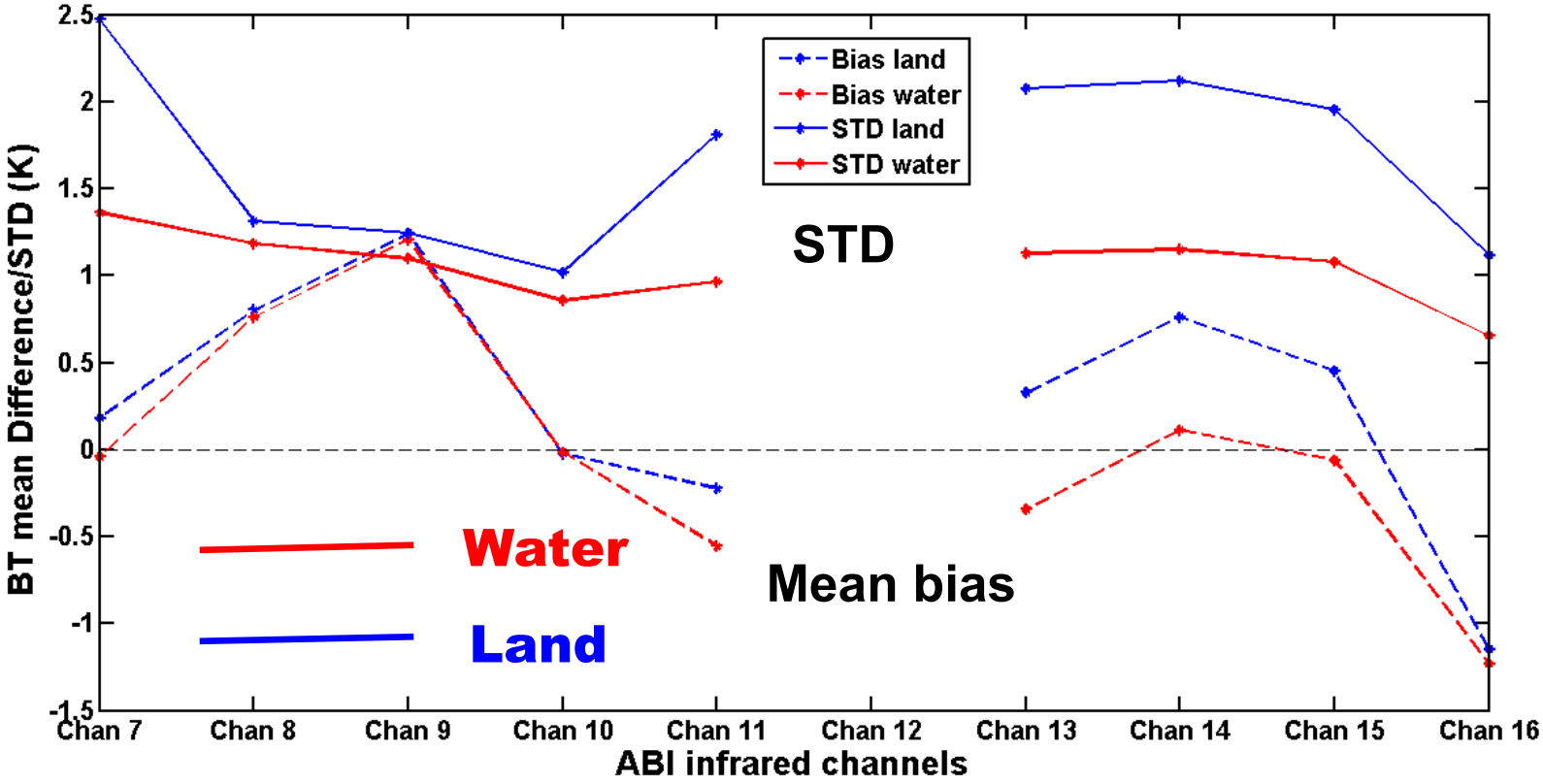
- Finalizing radiance upgrade package for RAPv5, completion of real-time testing at GSD and code transfer to EMC (initial code hand-off June 2019), RAPv5/HRRR4 NCEP planned operational implementation target June 2020
- Continue GOES-16 ABI radiance assimilation work
  - More QC work for cloud detection
  - Add more ABI infrared channels
  - ABI data assimilation in HRRR (sub-hourly ABI assimilation in HRRR?)
- ATMS/CrIS-FSR DB data from NOAA-20
- HRRR/AK – continue radiance assimilation testing
- Begin FSOI obs. impact assessments
- Begin all-sky radiance assimilation and inter channel correlation work

Acknowledgment

- Thanks Qiang Zhao, Peter Keehn, Walter Wolf, and Thomas King from NESDIS for providing the ABI radiance BUFR files
- Thanks Yangrong Ling, Shelley Melchior, and Sudhir Nadiga at NCEP for processing and providing real-time experimental hourly ABI/CrIS-FSR/ATMS data for RAP
- Thanks NCEP decorder group (Jeff Ator etc.) for working on dumping CrIS-FSR DB data for RAP;
- Thanks Jim Jung for the information about DB data and discussion on the CrIS-FSR and ABI data
- Thanks Haixia Liu for discussion on ABI data

Thank you!

4-month ABI O-B evaluation (land vs. water)

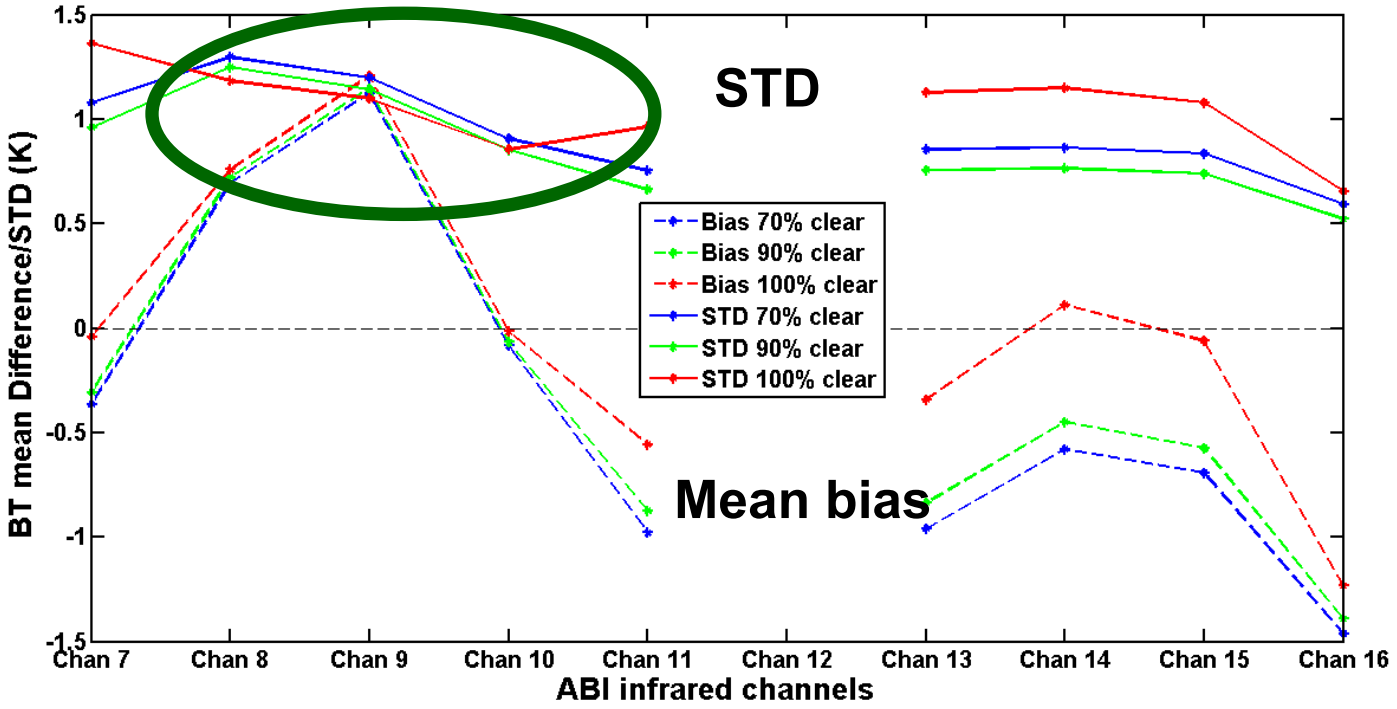


4-month RAP hourly O-B : May 2018, July 2018, October 2018, and January 2019

100% clear baseline data

RAP 1h forecast (background) are used in GSI/CRTM to calculate the O-B with co-located ABI radiance data(water surface vs. land surface)

4-month ABI O-B evaluation (100% clear vs. 90% vs. 70%)



more than 70% clear

more than 90% clear

100% clear

4-month RAP hourly O-B : May 2018, July 2018, October 2018, and January 2019

Baseline cloud mask data

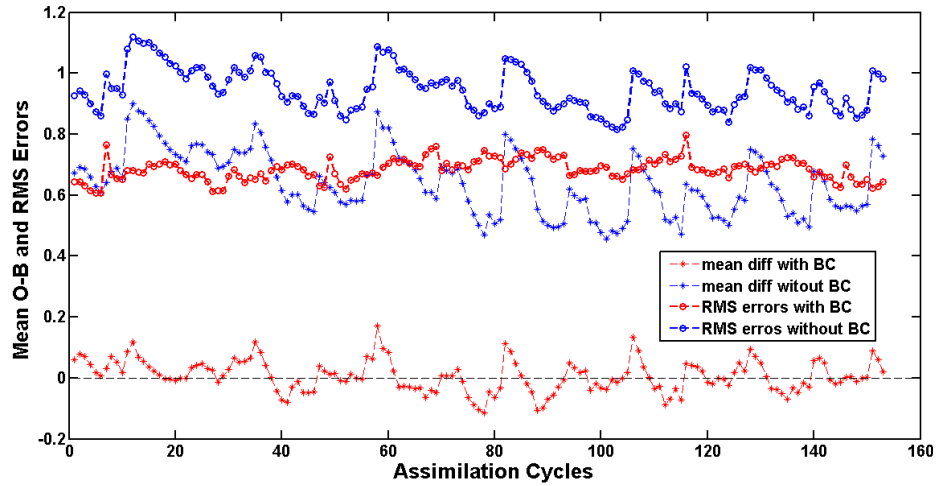
Radiance Channel List for HRRR (20 hPa model top)

- **AMSU-A**
  - NOAA_n15: channels 1-5, 7-9 15;
  - NOAA_n18: channels 1-4, 6-7,15;
  - NOAA_n19: channels 1-6, 9, 15;
  - METOP-a: channels 1-6, 9,15;
  - METOP-b: channels 8-9;
  - AQUA: channels 6, 8-9**;**
- **MHS**
  - NOAA_n18, METOP-A, and METOP-B:1-5
  - NOAA-19: 1, 2, 4, 5
- **GOES**
  - GOES-15 (sndrD1,sndrD2,sndrD3,sndrD4): channels 3-8, 10-15
- **ATMS**: channels 1-10, 16-22 from S-NPP
- **CrIS**: 58 channels (list omitted) from S-NPP (66 in RAP)
- **SSMIS** : channels 1-2, 5-6 from DMSP-17
- **AIRS**: 59 channels from AQUA (66 in RAP)
- **IASI**: 74 channels (longwave) from METOP-A and METOP-B) (98 in RAP)

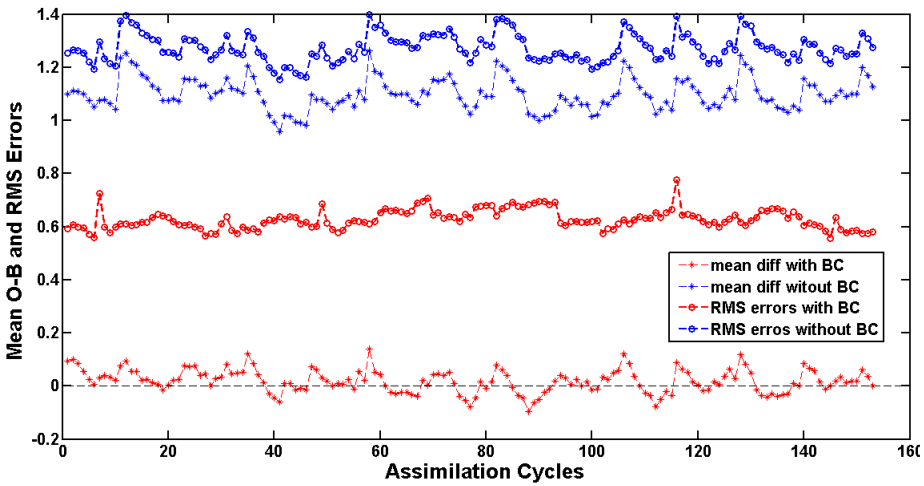
Initial ABI retrospective experiments

- **Control run (CNTL) – (All data in RAPv4)**
  - 1-h cycling run, one-week (May 01 –07 2018) using RAPv4 version (newer GSI version and CRTMv2.3.0)
  - All data used in operational RAPv4 (conventional + radiance)
- **Clear-sky ABI radiance (baseline) experiment**
  - Added three ABI radiance water vapor channels
  - Thinning 60 km
  - Amount segment cloud free less than 70% are rejected
  - Satellite zenith angle larger than 60 degree are rejected
  - GSI gross check (O-B with BC less than 2 K, rejected)
  - Assigned error 2.2 K for all water vapor channels
  - GSI variational bias correction scheme is applied with hourly cycling

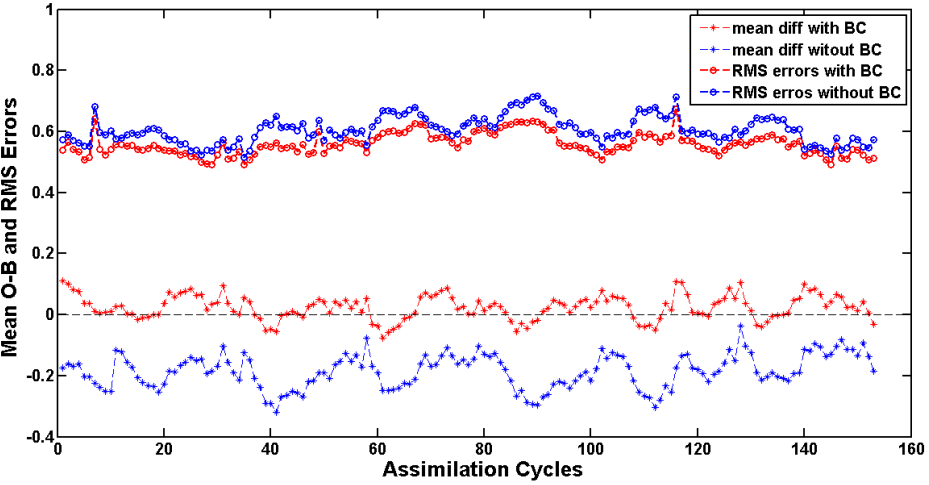
Time series O-B with and without BC



Channel 8



Channel 9

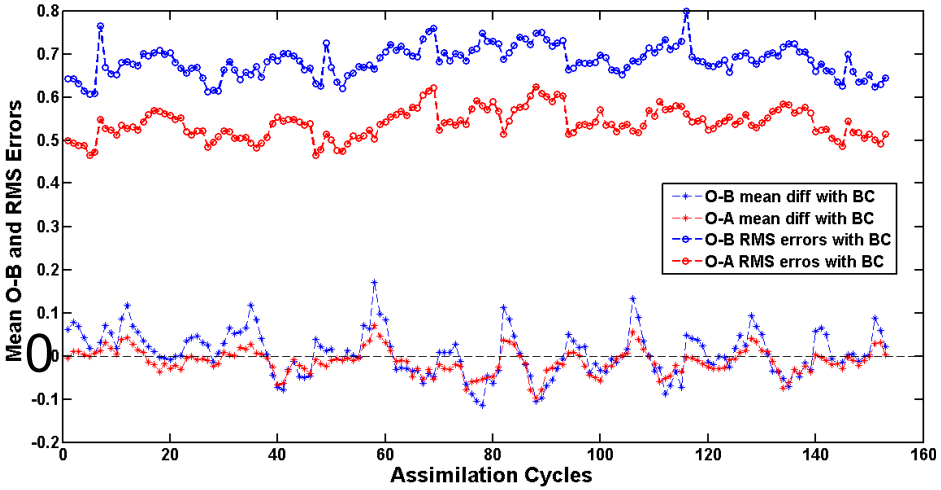


Channel 10

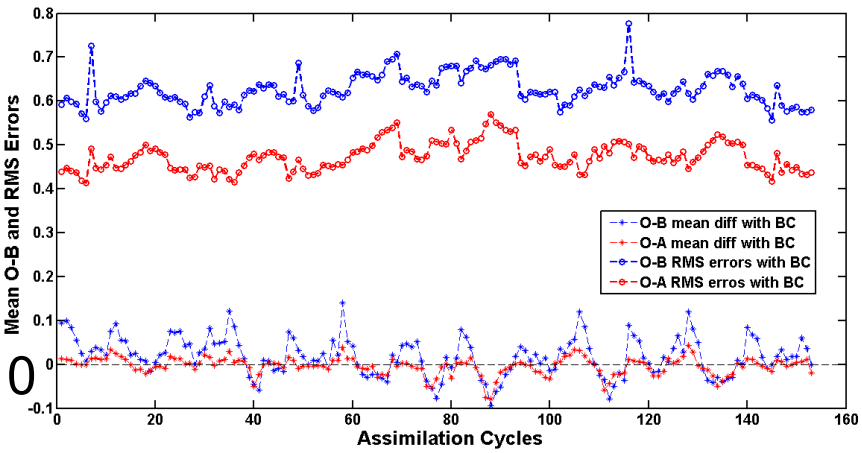
- ○ RMS errors with BC
- ○ RMS errors without BC
- * Mean bias with BC
- * Mean bias without BC

01--07 May 2018

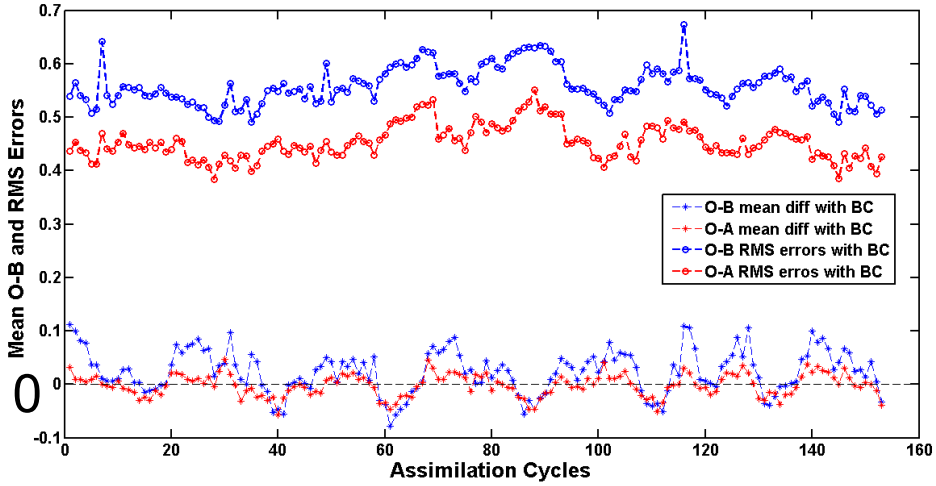
Time series O-B and O-A with BC



Channel 8



Channel 9

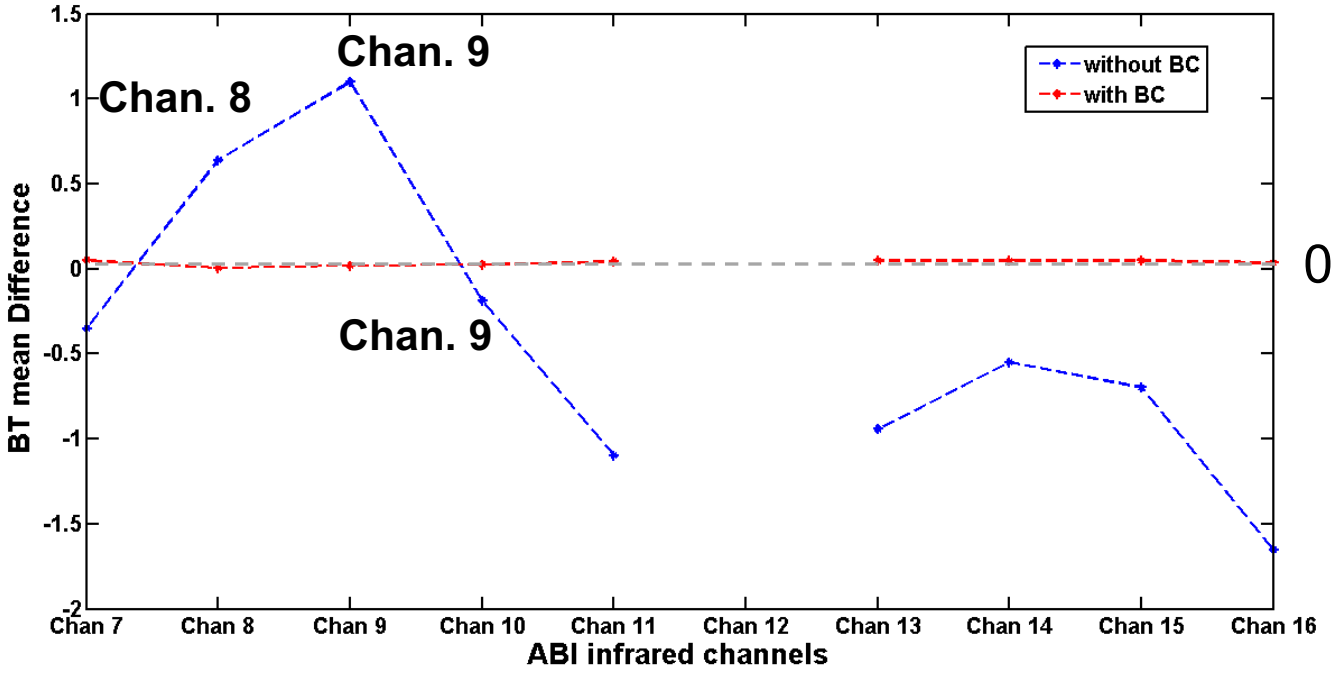


Channel 10

* O-B mean diff. with BC
* O-A mean diff. with BC
- O-B RMS errors with BC
- O-A RMS errors with BC

01--07 May 2018

Mean O-B for 9 infrared channels



---------- With BC

---------- Without BC

Mean O-B averaged from 7-day RAP ABI retrospective experiment