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

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http://rapidrefresh.noaa.gov
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”
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

### 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

Relative Humidity

Wind

4-week Retro averaged

Normalized Errors

E_N = \frac{(\text{EXPT} - \text{CNTL})}{\text{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 + \textbf{N20 CrIS-FSR} (72 channels)
  • CNTL + \textbf{N20 ATMS} (18 channels)
  • CNTL + \textbf{GOES-16 ABI} (3 channels) (NCEP baseline cloud mask data)
  • CNTL + \textbf{All above new data sets}
12-h fcst. Normalized Errors from New Data Sets

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

Normalized Errors

\[ E_N = \frac{(\text{CNTL} - \text{EXPT})}{\text{CNTL}} \]

Control run has all operational data in RAPv4.
1-12 fcst. relative humidity verification

+1.5%

Relative Humidity

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**

<table>
<thead>
<tr>
<th>Channel Number</th>
<th>Central Wavelength</th>
<th>Contribution Primary usage</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>3.90 µm</td>
<td>windows (shortwave band, fire detection)</td>
</tr>
<tr>
<td>8</td>
<td>6.19 µm</td>
<td>Upper troposphere water (340 mb)</td>
</tr>
<tr>
<td>9</td>
<td>6.95 µm</td>
<td>Mid-level water (440 mb)</td>
</tr>
<tr>
<td>10</td>
<td>7.34 µm</td>
<td>Low-level water (615 mb)</td>
</tr>
<tr>
<td>11</td>
<td>8.40 µm</td>
<td>cloud-top phase, SO₂</td>
</tr>
<tr>
<td>12</td>
<td>9.61 µm</td>
<td>O₃</td>
</tr>
<tr>
<td>13</td>
<td>10.35 µm</td>
<td>window (clean IR)</td>
</tr>
<tr>
<td>14</td>
<td>11.20 µm</td>
<td>window (low stratus detection with 3.9 µm channel)</td>
</tr>
<tr>
<td>15</td>
<td>12.30 µm</td>
<td>window (dirty IR)</td>
</tr>
<tr>
<td>16</td>
<td>13.30 µm</td>
<td>CO₂ (low level temperature)</td>
</tr>
</tbody>
</table>
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
One-month ABI O-B evaluation

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.
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)

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

2k gross check
4k gross check

Relative Humidity

Baseline
Enterprise

6h forecast
Radiosonde verification

Initial errors (2.2K)
New calculated errors (smaller)

STD < 1.0
STD < 0.5

7-day retro run (May01-May07 2018)
ABI assimilation vs. CNTL

**Relative Humidity**

6h

12h

New errors
STD < 0.4
2k gross check

Enterprise cloud mask data
7-day retro run (May01-Mah07 2018)
• 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

Sample from 22 Aug. 2017

ALL satellite obs

NO DB / RARS satellite obs

Sample from 22 Aug. 2017
% improvement from direct readout

Temperature

Relative Humidity

Wind

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

\[ E_N = \frac{(EXPT - CNTL)}{CNTL} \]
Normalized fcst. improvement from DB data verified against CrIS Obs.

Normalized Errors

\[ E_N = \frac{(\text{EXPT} - \text{CNTL})}{\text{CNTL}} \]

% impact from denying DB and RARS data

Chan. 83
PWF 218 hPa

Chan. 165
PWF 814 hPa
Normalized 6-h fcst. improvement from DB data verified against CrIS BT obs.

\[ E_N = \frac{(EXPT - CNTL)}{CNTL} \]

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

10%
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)
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
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
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• Thanks NCEP decoder 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%)

- **STD**
- **Mean bias**

**BT mean Difference/STD (K)**

**ABI infrared channels**

- **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 + radiances)

- **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

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

Channel 10

01--07 May 2018
Time series O-B and O-A with BC

Channel 8

Channel 9

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

Channel 10

01--07 May 2018
Mean O-B for 9 infrared channels

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