10.04

Global all-sky radiance assimilation for IASI

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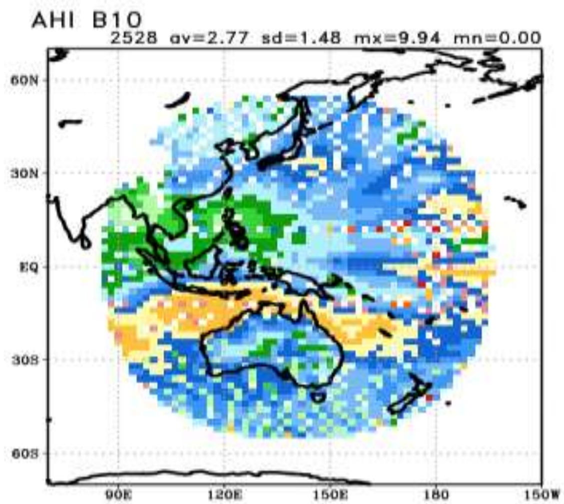
1. Background

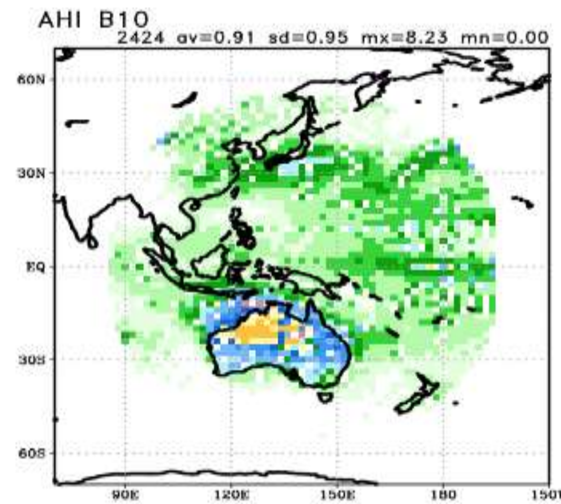
- IR radiance assimilation is significantly beneficial for NWP
  - Mostly limited to clear-sky radiances (CSR)
- IR all-sky radiance (ASR) assimilation will be more beneficial because
  - Increasing obs coverage (homogeneous spatial and temporal distribution)
  - Reducing sampling bias (e.g. dry bias)
  - Exploiting cloud and unique obs info
- Challenges of ASR assimilation (compared with CSR assimilation)
  - Poorer representation in radiative transfer model (RTM) and forecast model
  - Stronger situation-dependency of obs statistics
  - Higher non-Gaussianity and non-linearity
- Encouraging results in many recent studies
  - Otkin (2010, 2012, JGR), Zhang et al. (2016, GRL), Honda et al.(2018 MWR; 2018 MWR, JGR), Minamide & Zhang (2017 MWR; 2018 MWR), Okamoto et al. 2019, QJRMS), Sawada et al. (2019, JGR)
- However, few studies in global DA system, except Geer et al. (2019, AMT) for IASI

1. Objective

- Objective: Improve analysis & forecast by assimilating IR ASR in a global NWP system
- ASR of Himawari/AHI successfully assimilated (Okamoto et al. 2023, QJRMS)
  - Assimilated mid- and upper-tropospheric Water Vapor (WV) ch: (6.2~7.3µm)
  - Developed cloud-dependent QC, BC and observation error covariance
  - Increased obs by almost 3 times and improve Q and T ain the mid- and upper-troposphere over CSR assimilation
- Extend to IASI ASR assimilation

AHI band10

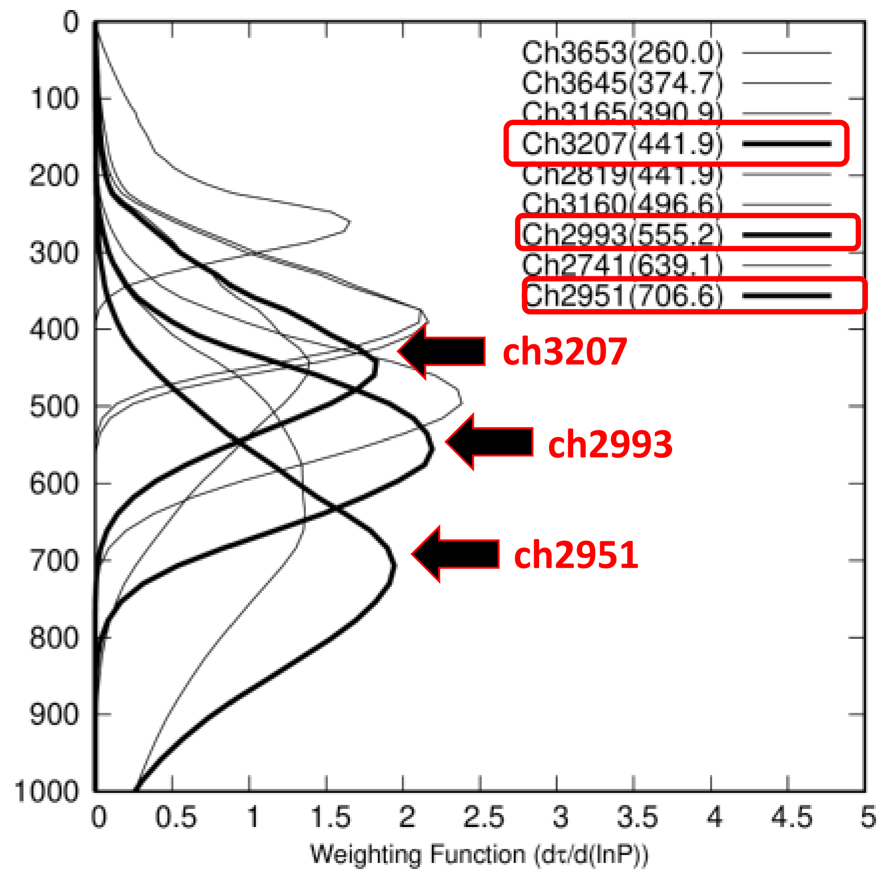




2. ASR assimilation processing

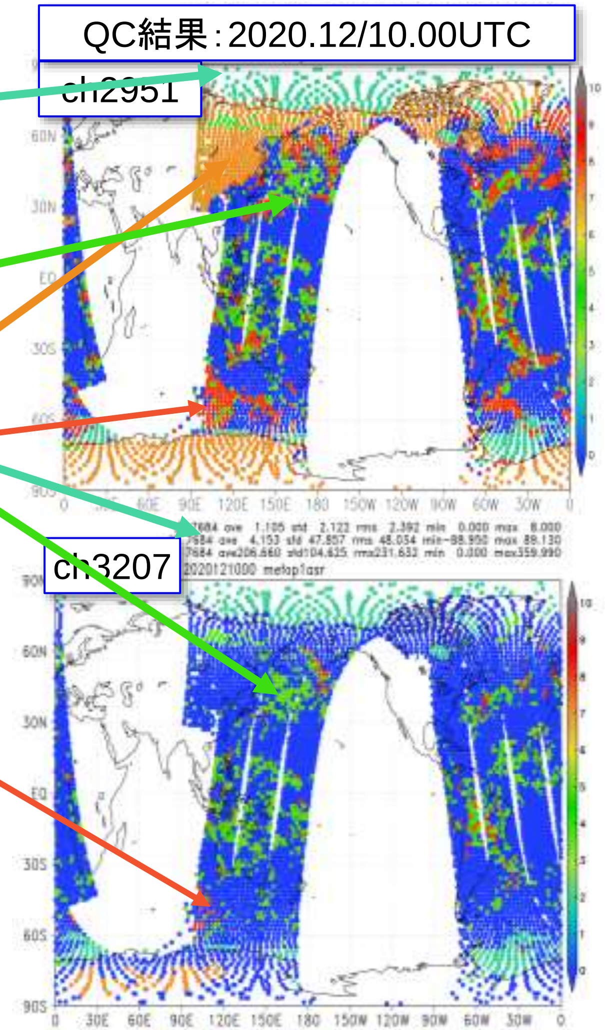
ch	frequency cm^{-1} (μm)	WF peak height [hPa]
2951	1382 (7.23)	633
2993	1392 (7.18)	516
3207	1446 (6.91)	395

- Processings are the same as AHI ASR except for
  - Additional QC: no sea ice, index of spatial homogeneity
- 3 ch sensitive to mid- and upper-tropospheric WV
  - Selected among ch operationally used



2-1. QC (Quality Control)

- Remove scenes poorly simulated where
  - over sea ice
  - Deeply developed clouds (window ch obs < 230K)
  - High inhomogeneity (SD-QC):SD>5K
  - Affected by land surface (transmittance>0.1)
  - large cloud effect (CA>5K)
  - large O-B: |O-B|>3*obs error SD
  - large difference btw linearized and nonlinear BT simulation



Cloud effect parameter:
CA=(|B-Bclr|+|O-Bclr|)/2,
Bclr=clear-sky first-guess
(Okamoto et al. 2014, QJRMS)

2-2. observation error covariance R_{ij}

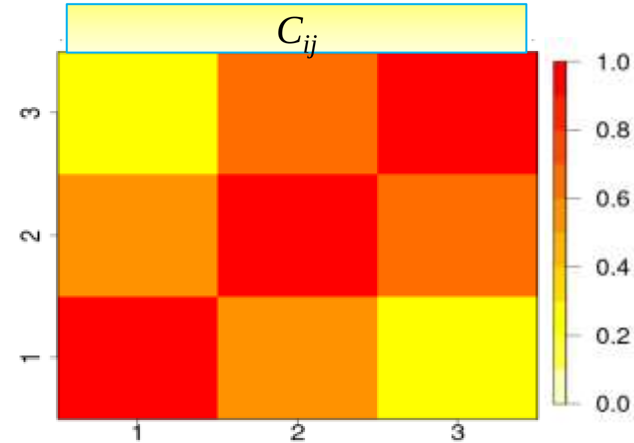
- Observation error covariance

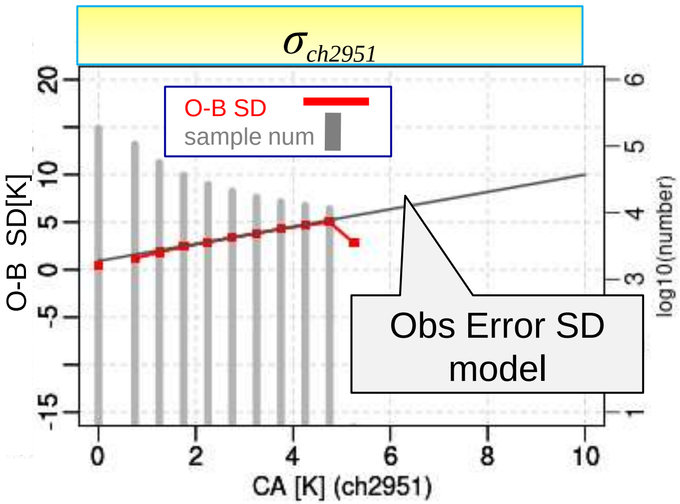
$$R_{ij} = f^2 \sigma_i \sigma_j C_{ij}$$

- f : inflation factor (=1.5)
- σi: observation error standard deviation (SD) of ch i
  - Estimated as a linear function of CA → cloud dependent

$$\sigma = g(C_A) = \begin{cases} g_{clr} & \text{for } C_A \le C_{A clr} \\ g_{clr} + \frac{g_{cld}-g_{clr}}{C_{Acld}-C_{Aclr}}(C_A - C_{Aclr}) & \text{for } C_{Aclr} < C_A < C_{Acld}, \\ g_{cld} & \text{for } C_A \ge C_{Acld} \end{cases}$$

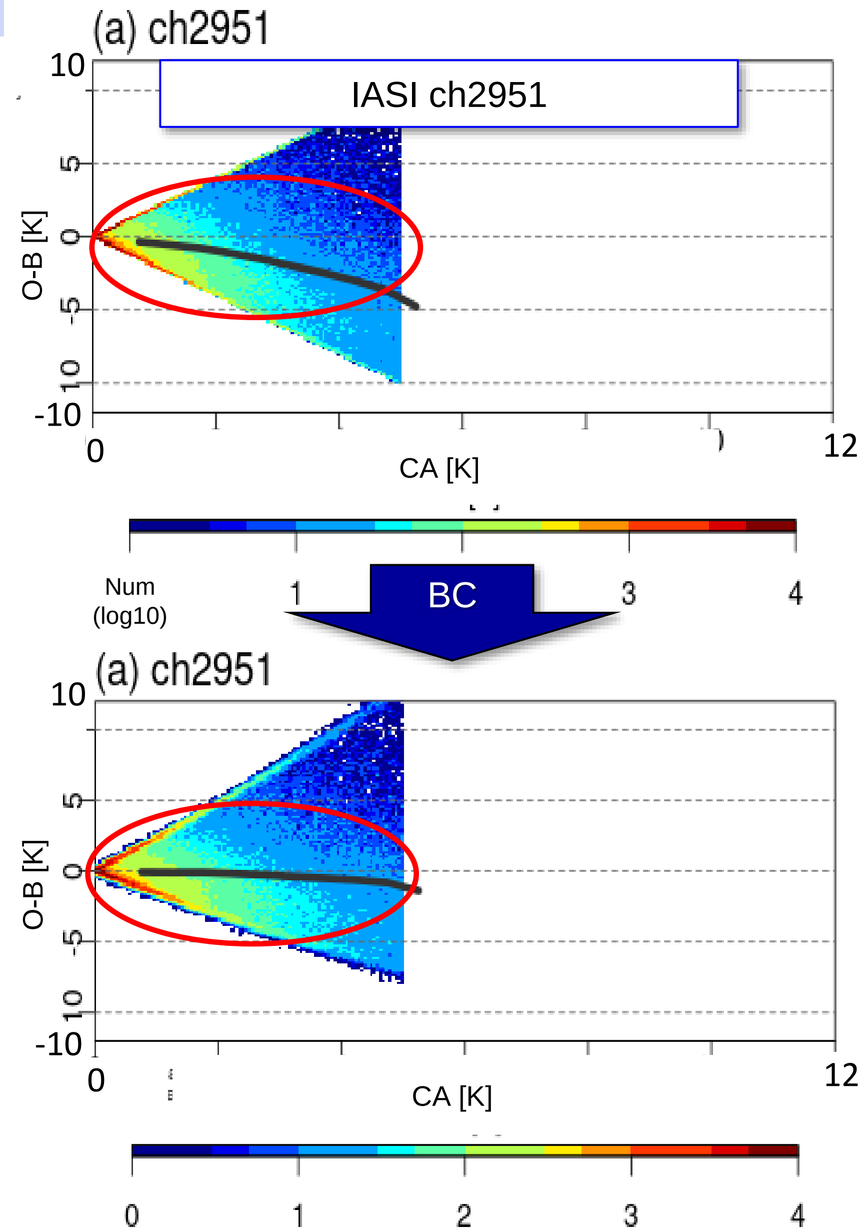
- C_{ij}: Correlation between ch i and j
  - Need to account for the correlation
  - Depend on cloud effect but cloud-dependent Cij did not show positive impacts (at the moment)





2-3. BC (Bias Correction)

- Need to correct cloud-dependent bias
  - Significant negative bias (O-B<0) due to cloud underestimation in model
  - Some biases remain even after strict QC
  - The remaining negative bias produce excessive analysis increments (too moist)
- Apply Variational BC (VarBC) that adds cloud effect predictors to CSR predictors
  - After removing scan dependent bias
  - BC = c_1*dZ850 + c_2* dZ200 + c_3* dZ50 + c_4* dZ10 + c_5 $+ c_6{*}CA + c_7{*}CA^2$



3. Data assimilation experiments

Assimilation system

- Operational global DA system of JMA (as of Dec. 2019) + RTTOV13.0
- Hybrid-4DVar: 4DVar+LETKF
  - outer-loop:20km, inner-loop:55km, 100 layers

Experiment configurations

- CNT: 77 ch CSR from IASI on Metop-1 and -2
- ASR: 3 WV-ch ASR and 74 ch CSR
- ASR9: 9 WV-ch ASR and 74 ch CSR
- ASRQT: 3 WV-ch and 40 T-ch ASR and 34 ch CSR

Okamoto et al. 2024 (QJRMS)

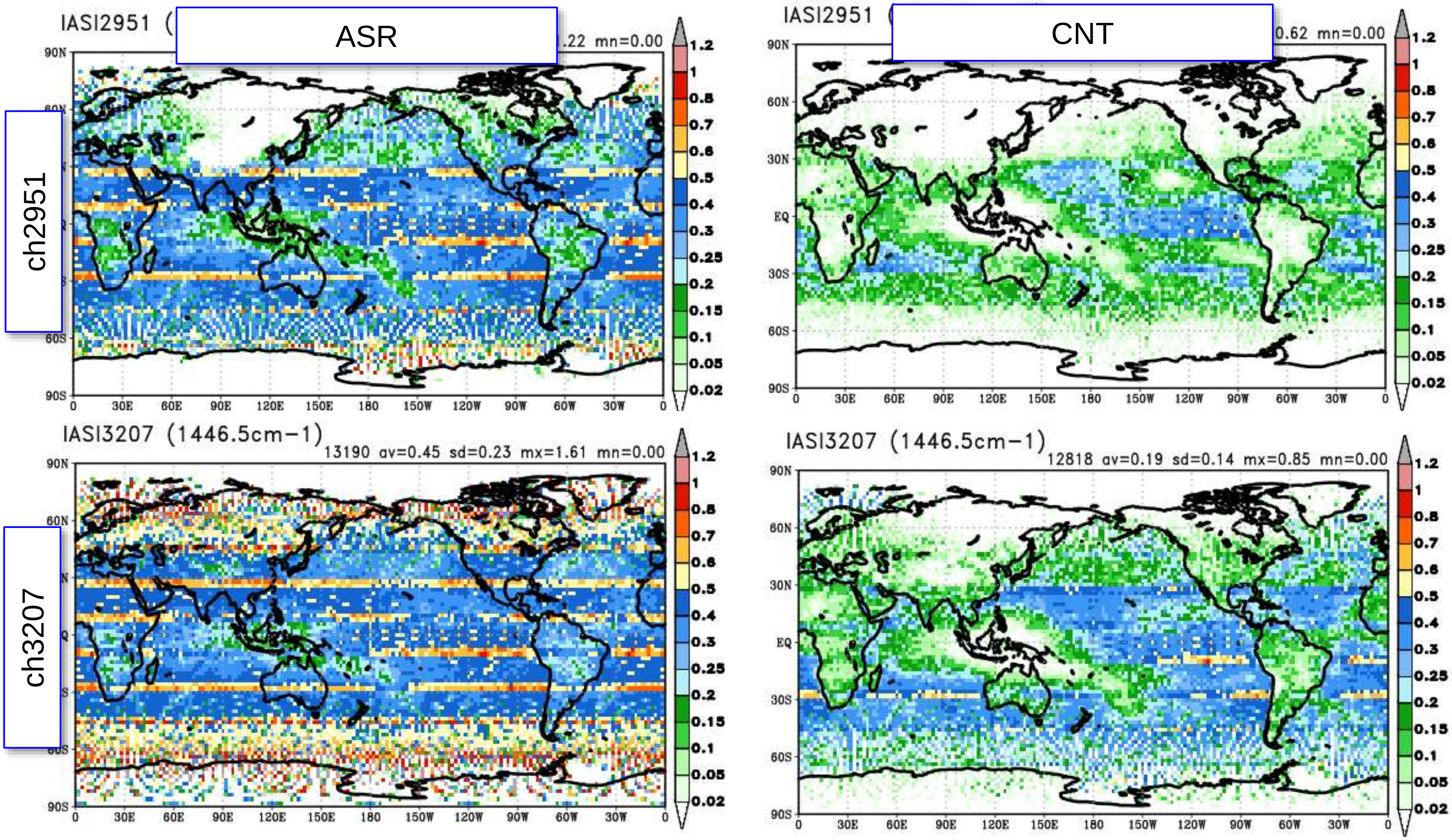
	CSR	ASR
CNT	3WV+74T	0
ASR	74T	3WV
ASR9	74T	9WV
ASRQT	34T	3WV+40T

Period

- Assimilation : 10 Jul. – 17 Sep. 2020 (Aug.Exp),
  10 Dec. 2020 – 11 Feb. 2021 (Jan.Exp)
- Forecast : 20 Jul. - 6 Sep. 2020 (Aug.Exp),
  20 Dec. 2020 – 31 Jan. 2021 (Jan.Exp)

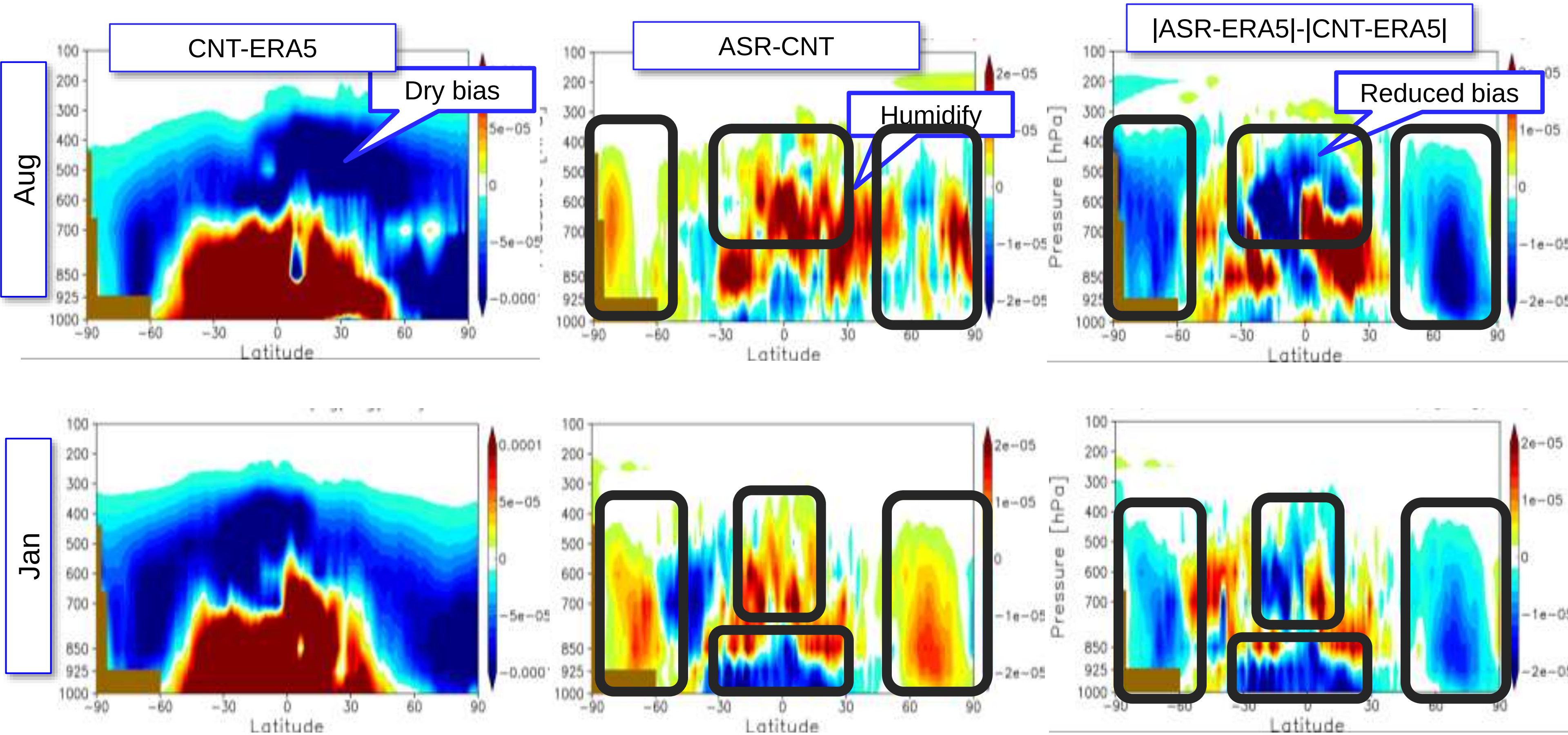
Monthly averaged number of obs assimilated

- 1 -31 Jan. 2021
  - Monthly average in 6-h analysis in 2x2 degree box
- Assimilated obs in ASR increases by 2.77 times over the 3 ch



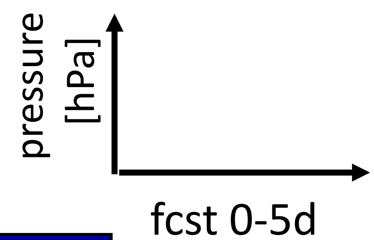
Change in humidity analysis

- ASR mostly increase mid- & upper tropospheric humidity more than CSR, reducing dry bias



Forecast impact (ASR vs CNT)

- Global forecast improvement ratio up to day 5
  - Relative change reduction in forecast error verified against ERA5
- Significant improvement in wind, temperature and relative humidity
  - Greater improvement than AHI ASR assimilation, especially in wind
  - Degradation in RT at 200hPa



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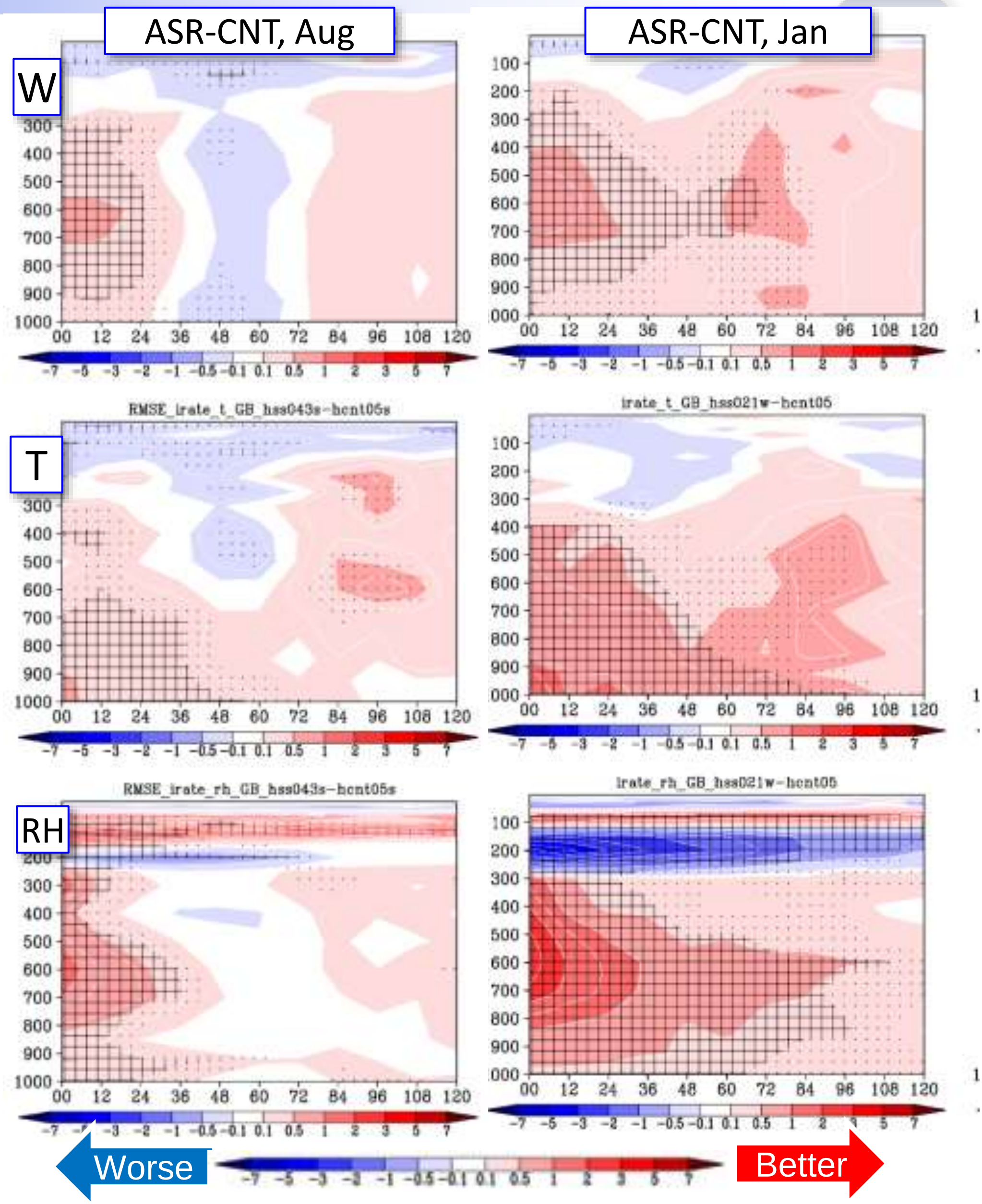
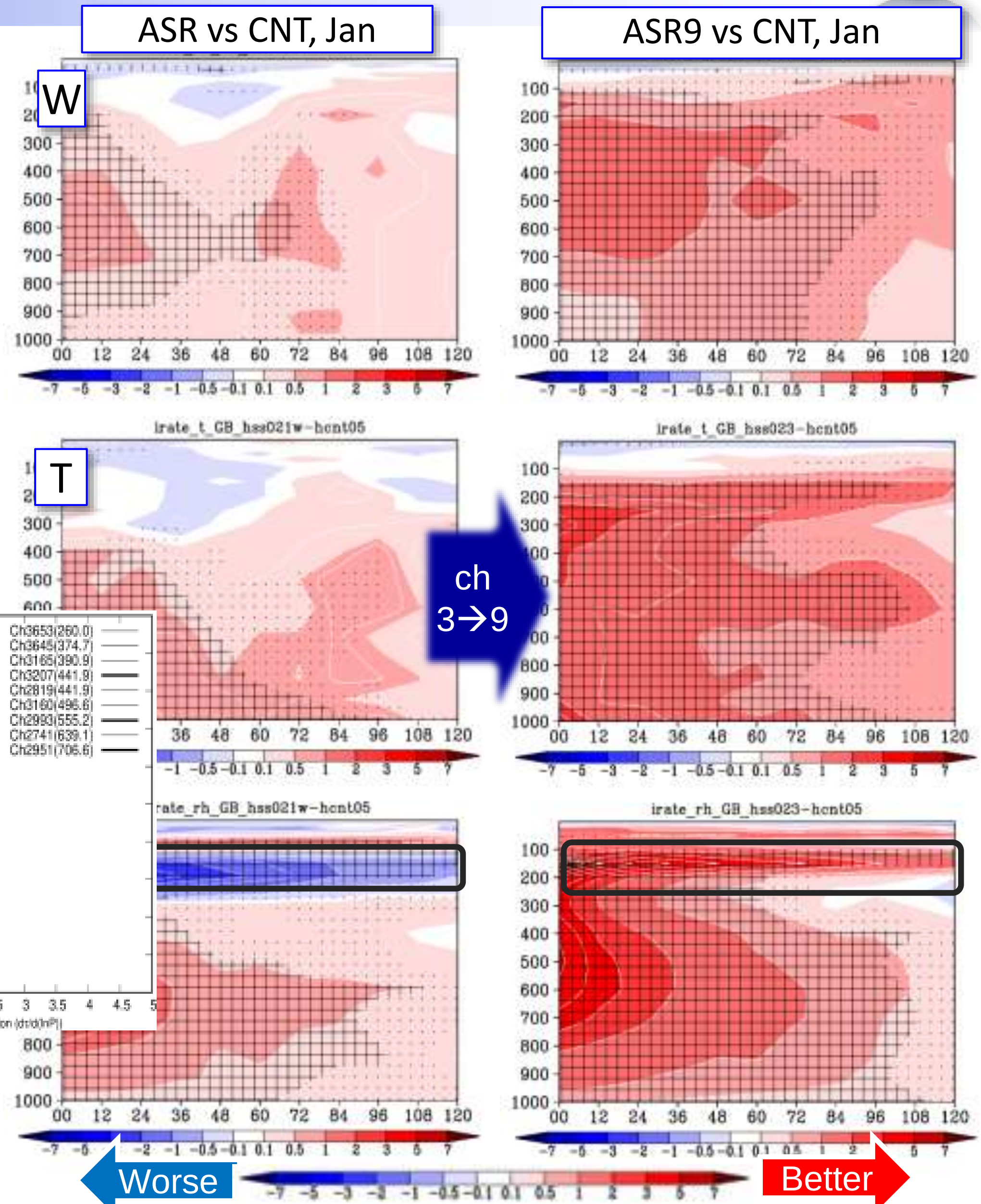
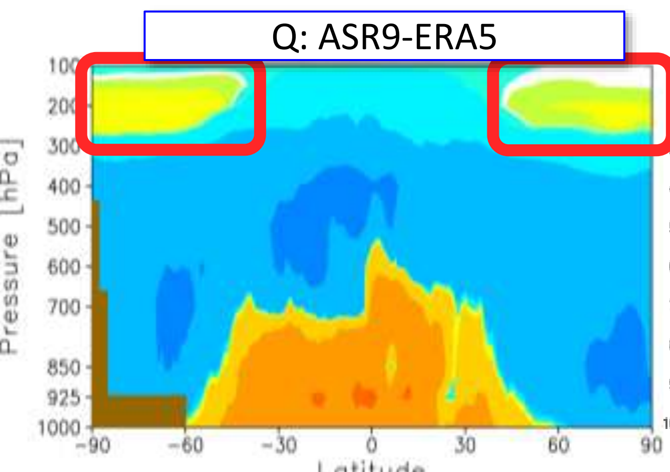
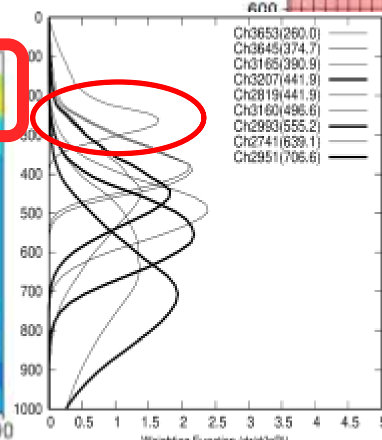


Impact of additional WV-ch (ASR9 vs CNT)

- Add 6 WV ch further improve forecast
- Notably RH at 200hPa also improved
  - Adding the ch sensitive to upper most tropospheric humidity help correct complex model bias



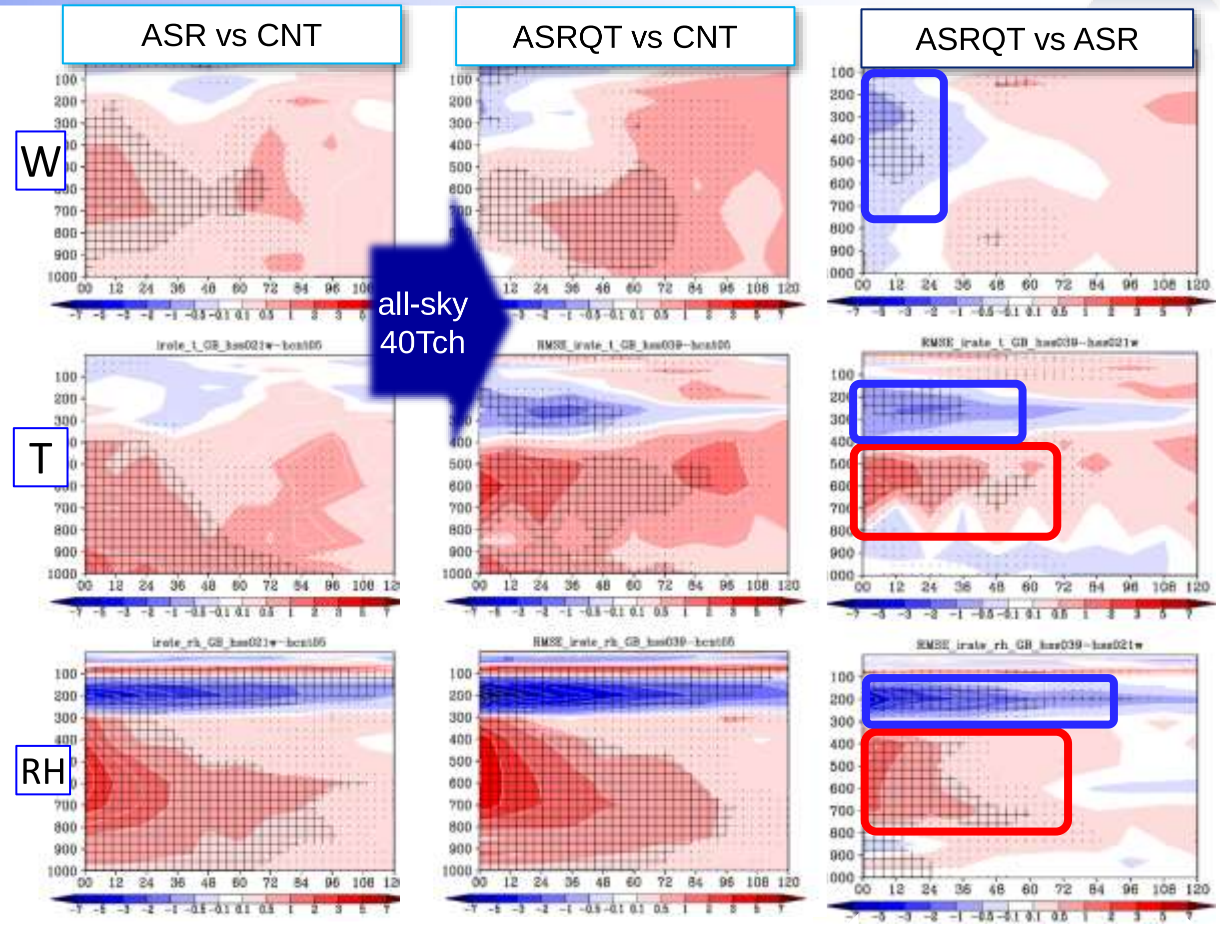




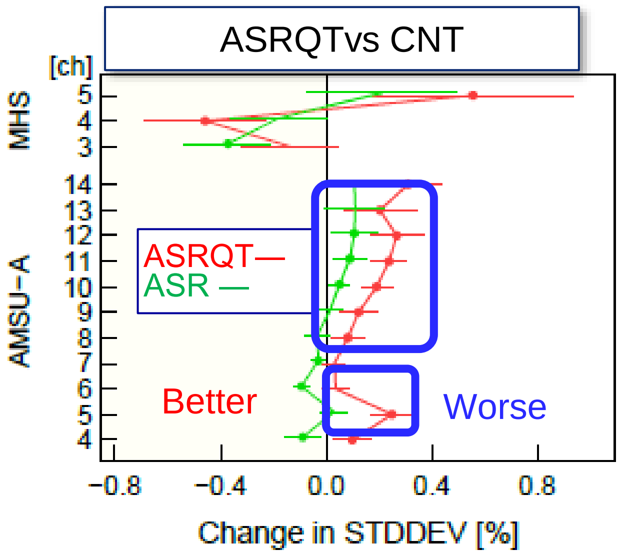
ASR9	74T	9WV
ASRQT	34T	3WV+40T

Impact of ASR of Temperature ch (T-ch) : ASRQT vs CNT

- Compared with 3 WV-ch ASR, further improve forecasts in mid-T & RH
- But upper-T & RH, and wind is degraded
  - Worsen first-guess fit in temperature



Worse Better



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Summary and plans

- All-sky radiance (ASR) assimilation of AHI was extended to IASI
  - No major changes in cloud-dependent QC, BC and obs error model
- Compared with CSR assimilation, IASI ASR assimilation
  - Uses more observations by 2.8 times
  - Reduces dry bias in analysis and improves forecasts T,W, RH
  - Further improves forecast skills by Increasing WV-ch from 3 to 9
  - Mixed impacts from 40 T-ch ASR assimilation

Take Home Message

Our approach may not be really "all-sky" and our forecast model has non-negligible cloud bias, but IR all-sky assimilation works!

- Plans
  - Continue investigation on more effective use or selection of T-ch
  - Increase availability: relaxing cloud QC and extending to other sounders
  - Examine applicability to Reconstructed Radiance (RR)