All-sky infrared assimilation overview

Kozo Okamoto (JMA/MRI)

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M.Takahashi, M.Hayashi

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- 3. Challenges of all-sky IR assimilation
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- 5. Recent research progress
- 6. Concluding remarks

Assimilate cloud-affected IR radiances

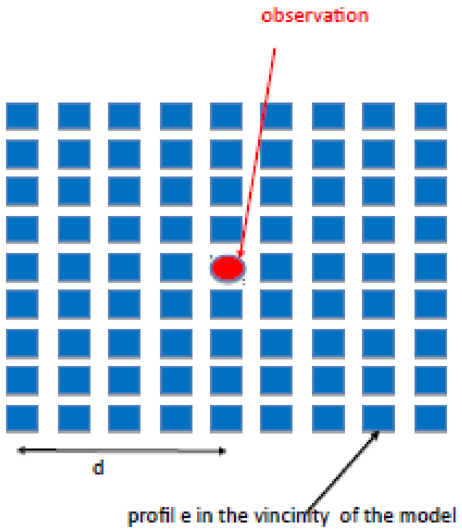
- 1. Retrieval products from cloud-affected radiances
  - (Traditional retrieval implemented outside assimilations system)
    - Cloud top height (temperature),cloud fraction, cloud water path, optical thickness,,,
  - 1D + 4D-Var : 1D-Var or 1D-Bay in preprocessing
    - $h(x) = \sum Q_k$, Q_k, ,,, in main analysis, but general RTM can be used in 1D step
- 2. Cloud-cleared radiance (CCR)
  - Construct pseudo clear-sky rad using ancillary data
  - $h(x) = RTM(T_k, Q_k)$
- 3. Simple cloud radiance (SCR)
  - Use simple RTM for homogeneous single-layer cloud
  - $h(x) = RTM(T_k, Q_k, N, P_{CloudTop})$
- 4. All-sky radiance (ASR)
  - Handle general clouds (multi-layer, thin to opaque, partial to overcast)
  - $h(x) = RTM(T_k, Q_k, F_k, C_k)$

T_k: Temperature
Q_k: Humidity
N or F_k: Cloud fraction
C_k: Cloud content
k: vertical level

1. 1D-Bay + 4D-Var (Meteo-France)

- 2-step technique, already used for radar and MW rainy radiance assimilation
  - Caumont et al. 2010, Tellus; Wattrelot et al. 2014, MWR; Duruisseau et al. 2019, QJRMS
- Retrieve RH profiles from cloudy IR rad based on 1D Bayesian approach
  - Weighted average of 81 surrounding profiles
  - $h(x) = RTM(T_k, Q_k, F_k, C_k)$
- Additional route of the current clear-sky radiance assimilation

Farouk et al. 2019 ITSC22



Weight assigned to each neighbour

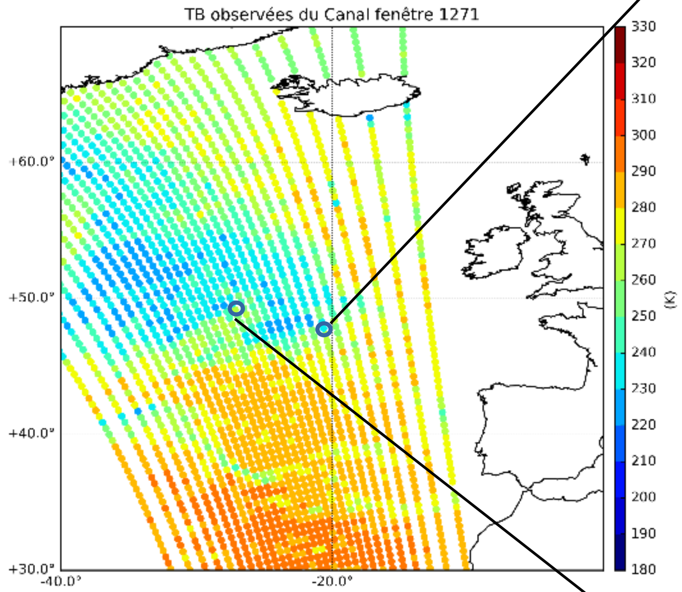
$$w_j = e^{-\frac{1}{2}\sum_i^{Nchan}\left(\frac{H(x_j)-TB_{obs\,i}}{R_I}\right)^2}$$

Investigating the 1D-Bay+4D-Var technique for IASI cloudy observations

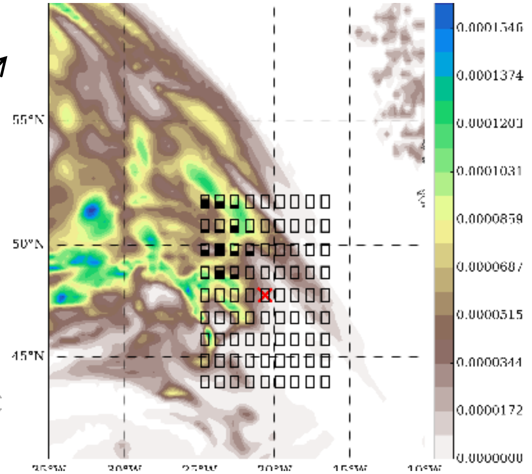
(PhD of Imane Farouk 2015-2018)

Meteo-France
from N. Fourrie

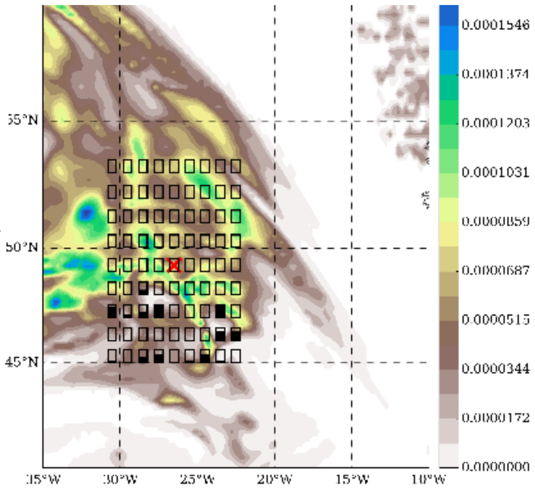
Single observation experiments with a subset of 83 IASI channels



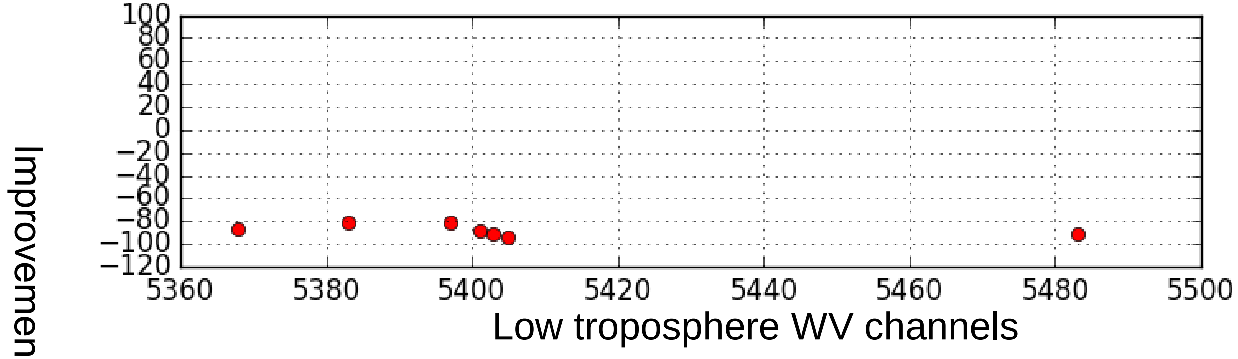
Observation is cloud affected



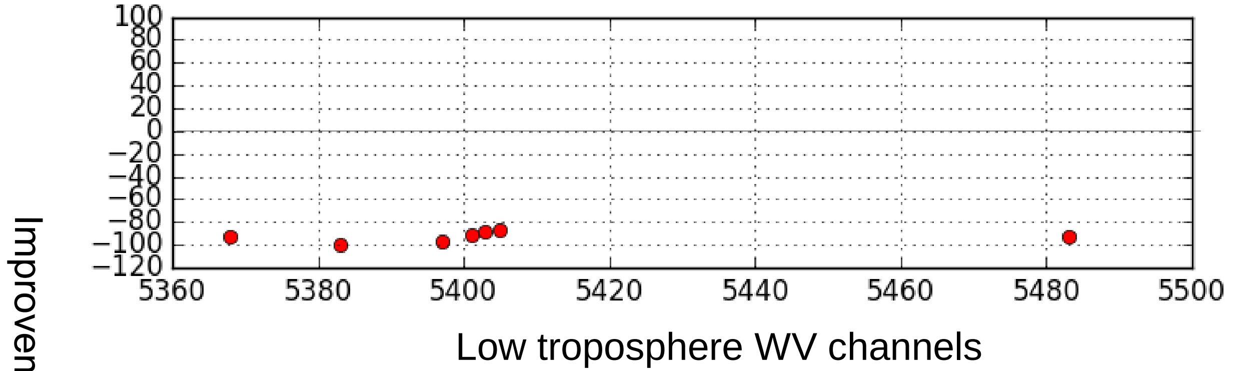
First guess is cloud affected



27/12/2017 00UTC ARPEGE guess cloudy ice content @200 hPa



The retrieval of full state vector (RH, Cli, Ciw, …) leads to a better forward simulation close to observations



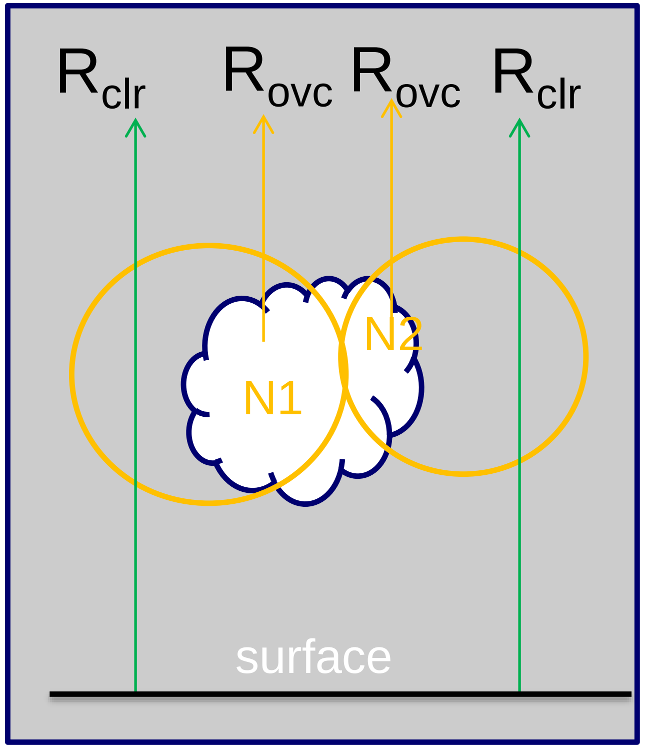
The retrieved RH profiles are used within the 4D-Var assimilation like for MW observations (Duruisseau et al., 2018) => tests are ongoing

2. Cloud Cleared Radiance (CCR)

- Construct pseudo clear-sky rad using collocated obs or DA from partial cloud rad
- Algorithm
  - FOV1: $R_1 = (1-N_1).R_{clr} + N_1.R_{ovc}$
    FOV2: $R_2 = (1-N_2).R_{clr} + N_2.R_{ovc}$
  - Assume: R_{clr} and R_{ovc} in the 2 adjacent FOVs are same
  - Eliminating R_{ovc} from above 2 equations leads to
    $R_{ccr} = R_{clr} = R_1 + \eta.(R_1-R_2)$ or $(R_1-R_2N^*)/(1-N^*)$
    where $\eta = N_1/(N_2-N_1)$ and $N_1 \neq N_1$
    $N^* = N_1/N_2$
- 3 approaches to obtain η or N*

1. Use collocated high res. imager (Li et al. 2005, IEEE)
2. Use collocated MW sounder (Susskind et al. 2006, JGR)
3. Constrained by DA system (Liu et al. 2015, AMS)

Adapted from Liu et al. 2015, AMS



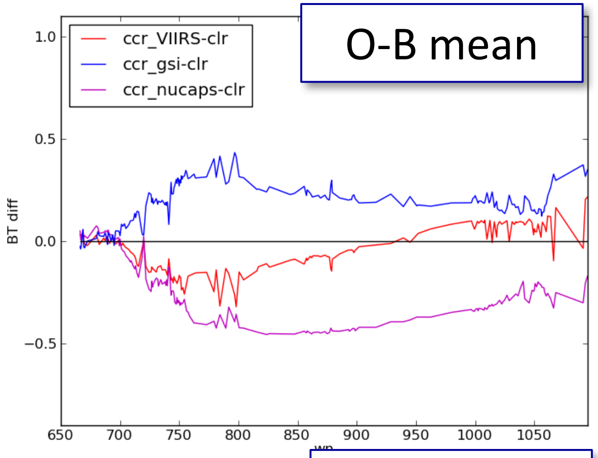
CCR assimilation development at NCEP

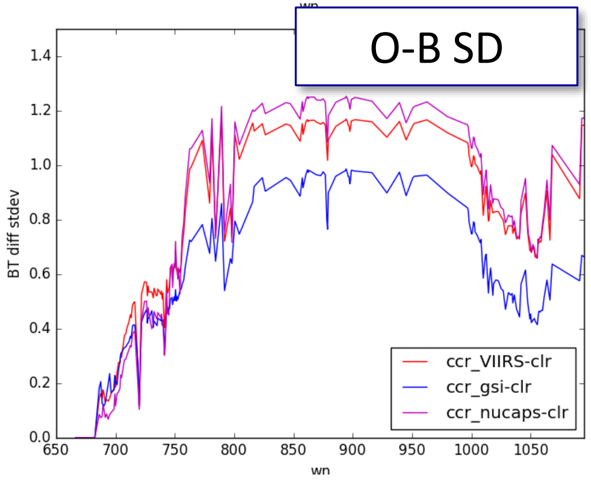
NCEP
from H. Liu

Liu et al. 2017, ITSC21

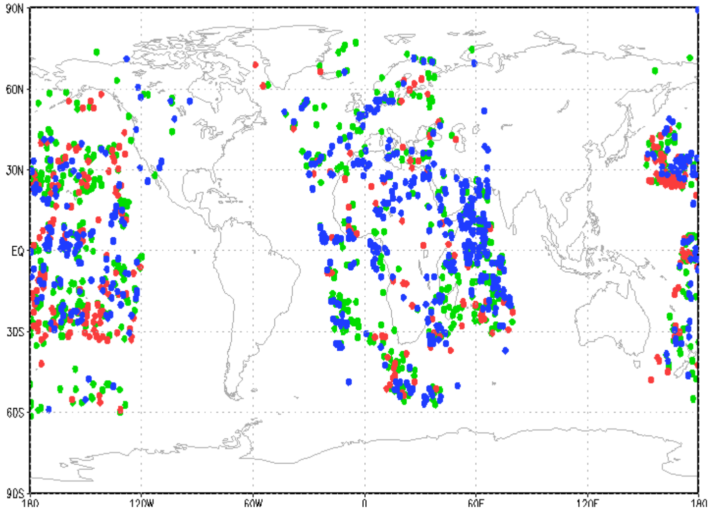
- The three CCRs were comparable in quality compared to the clear-sky data identified by VIIRS cloud mask
- The impact of the CrIS CCR_VIIRS on the global forecast score was neutral so far
- Obs error assigned was hard to tune

Red CCR_viirs
Blue CCR_gsi
Purple CCR_atms



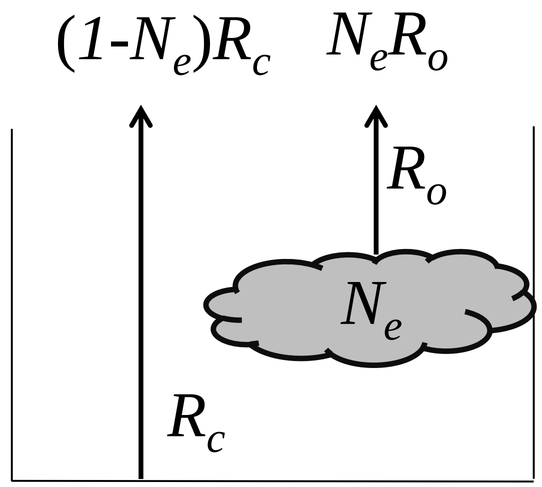


Blue clear-sky (CSR)
Red: CSR + CCR_viirs
Green: CSR+CCRviirs, modified thinn



3. Simple Cloud Radiance (SCR)

- Assume cloud is homogeneous & single-layer (or at most 2 layers to avoid complexity)
- Assimilate SCR in addition to clear-sky rad
- Cloud effect is included using only effective cloud fraction N_e and cloud top pressure P_c
  - $R^i = R^i_{clr}(1 - N) + R^i_{ovc} N$
    - R^i_{clr} : clear-sky radiance of channel I
    - R^i_{ovc} : completely overcast radiance from a blackbody cloud at P_c
  - N & P_c are given from obs products, estimate using FG, or control variables
- Problems
  - Limited availability (few increasing obs)
  - Hard to relate the obtained cloud info with other variables



4. All-sky Radiance (ASR)

- "use all observations directly as radiances whether they are clear, cloudy or precipitating using models (for both radiative transfer and forecasting) that are capable of simulating cloud and precipitation with sufficient accuracy" (Geer et al. 2019, AMT)

- Against CCR
  - Directly handle clouds
- Against SCR
  - Handle general clouds, no need to take a separate clear-sky path

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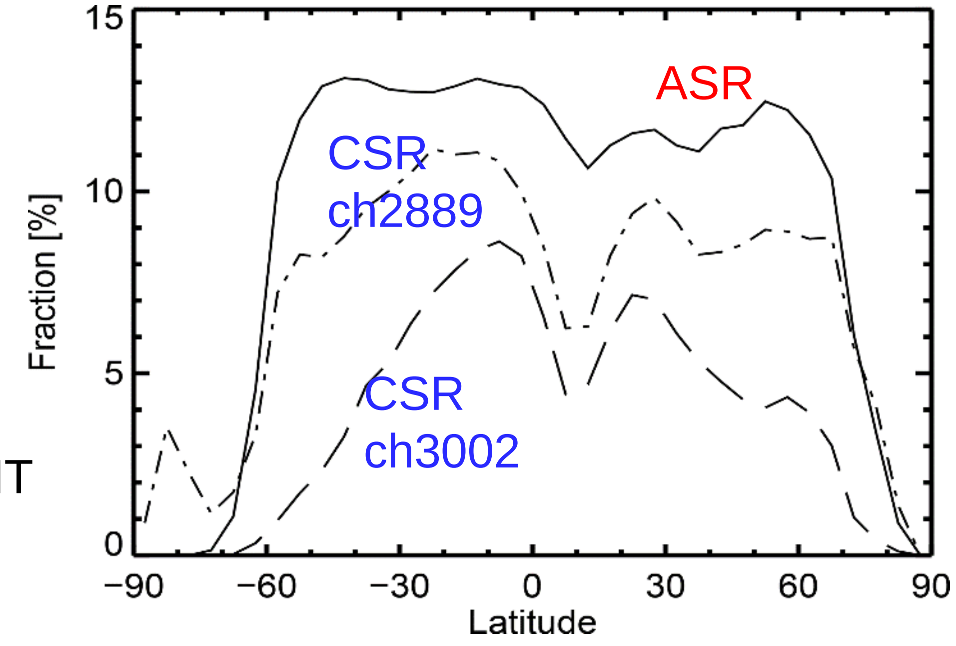
Benefit of all-sky IR assimilation

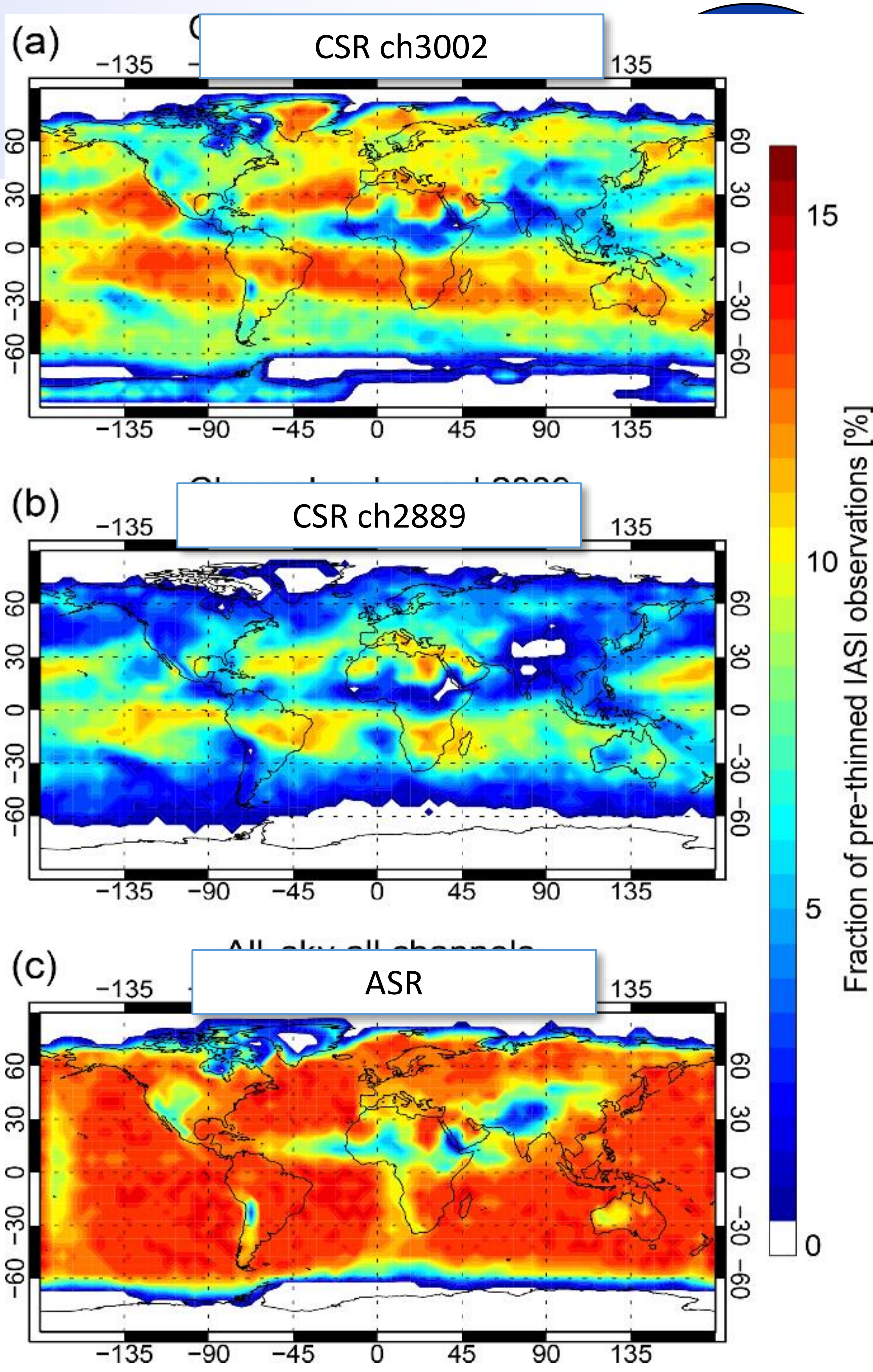
- What benefit can we add to clear-sky IR and all-sky MW assimilation?
- Advantage over clear-sky IR
  - Increase observation coverage
    - More horizontally and vertically homogeneous coverage
    - Available inside and below thin clouds
  - Exploit cloud information
  - Reduce sampling bias, such as dry bias
  - No need to develop a cloud detection scheme
  - Help evaluation of model cloud process
- Advantage over MW all-sky
  - More frequently available obs from geo imagers/sounders
  - More vertically resolved information from hyperspectral sounders
  - Higher sensitivity to cloud → thin cloud

Advantage: Increase coverage

- Example of Geer et al. 2019, AMT
  - Percentage of actively assimilated IASI all-sky and clear-sky obs from 1 to 20 June 2017
- More uniform coverage
  - Especially mid-lat stom track area and tropics
  - 1.3 (2.3) times more obs with higher (lower)-peaking ch in this period

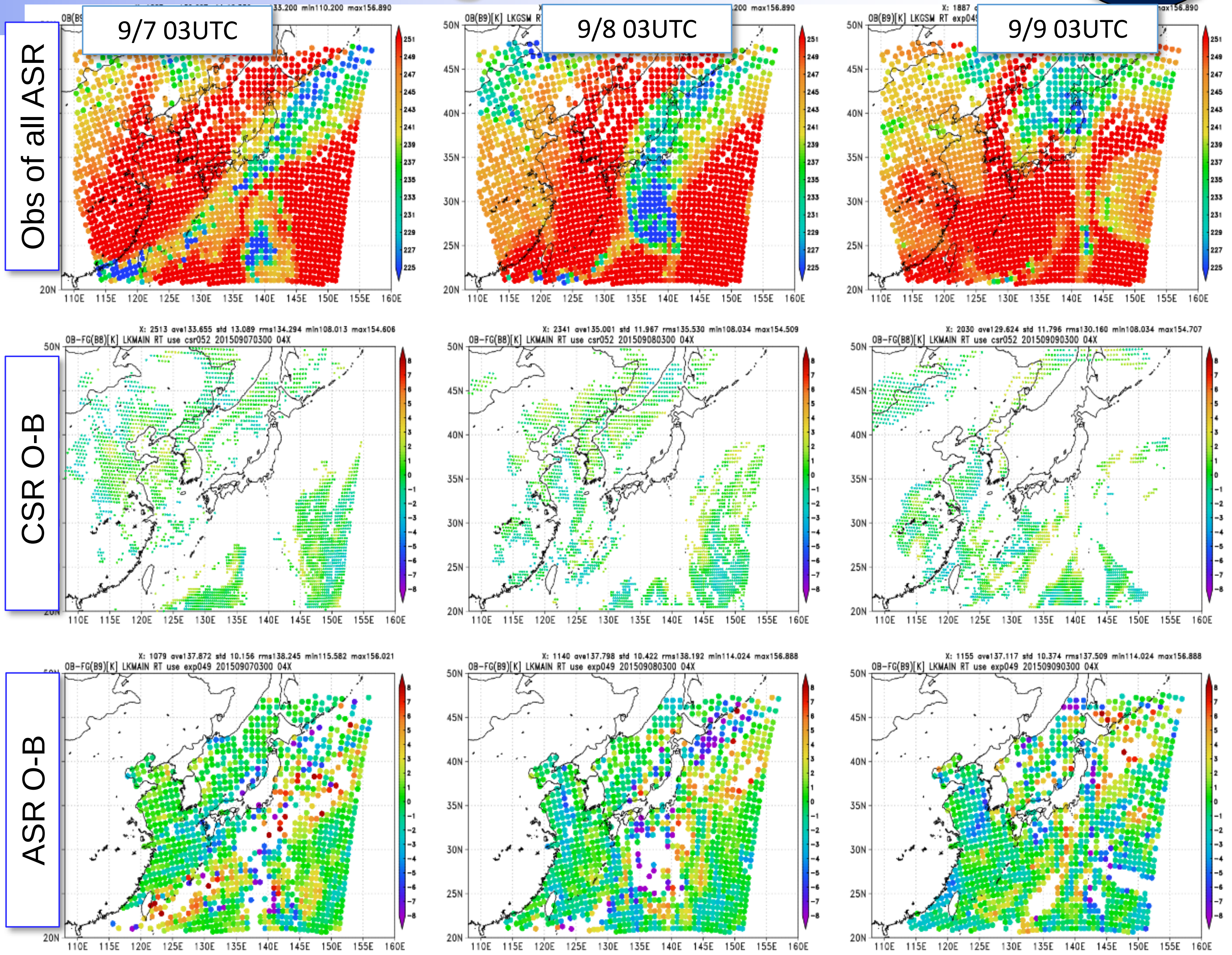


Geer et al. 2019, AMT



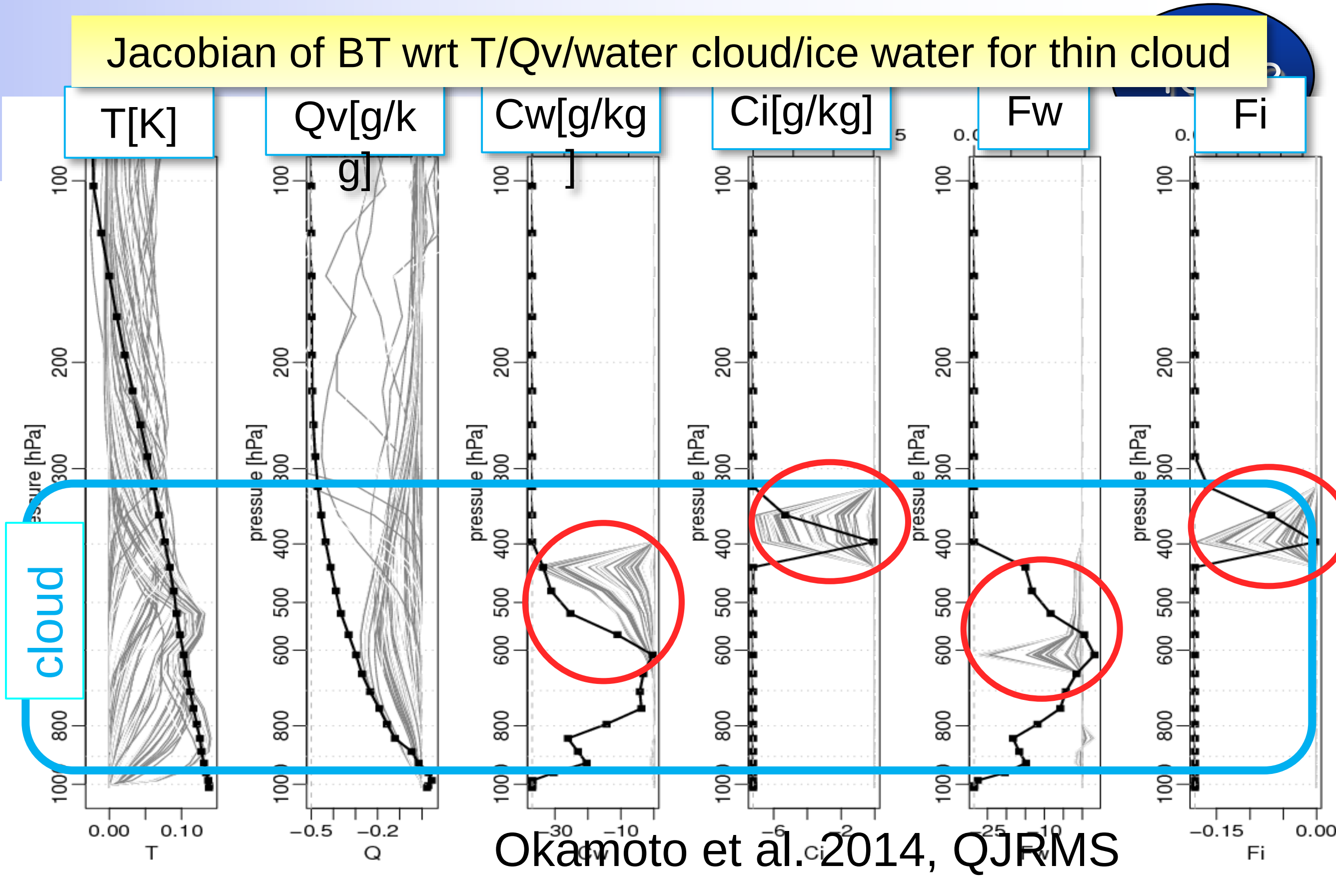
Advantage: Increase coverage

- Example of regional DAS around Japan
  - Actively assimilated AHI for 3 analyses when TC passed Japan in Sep. 2015
- CSR coverage is limited and much varies according to clouds
- More homogeneous availability with ASR
  - Despite rejection in highly developed cloud regions and over land

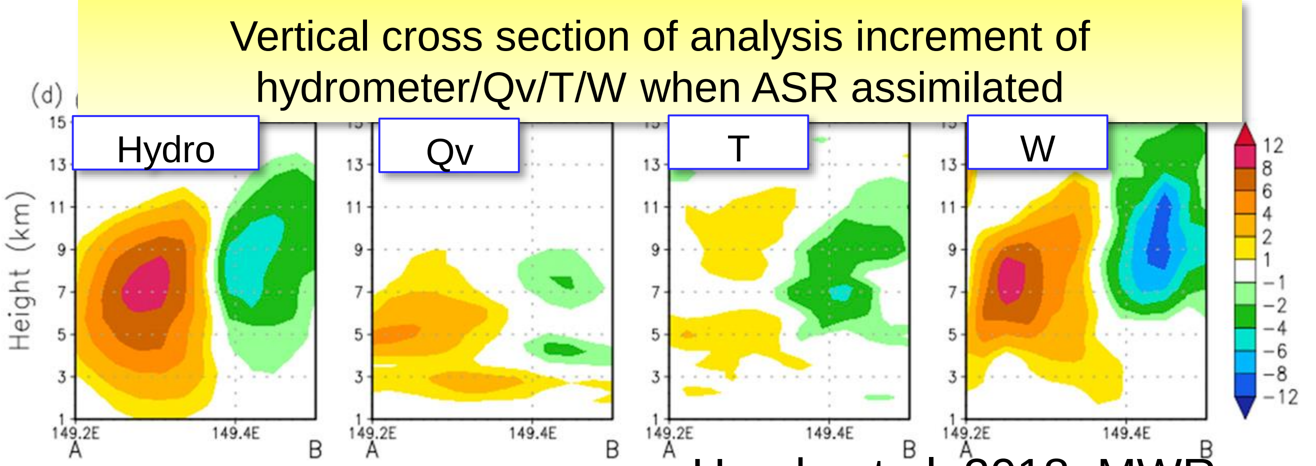


Advantage: Cloud info

- Through RTM Jacobians, error correlation and adjoint of forecast model
  - Cloud control variables are not necessarily needed
  - Error correlation & adjoint can produce cloud analysis increment even inside and below (thick) cloud
  - Extract wind info from tracer effect of cloud (& humidity)
- Analyze and initialize cloud
  - Beneficial especially for convective-permitting models, cloud analysis studies and applications using cloud-related products



Okamoto et al. 2014, QJRMS



Honda et al. 2018, MWR

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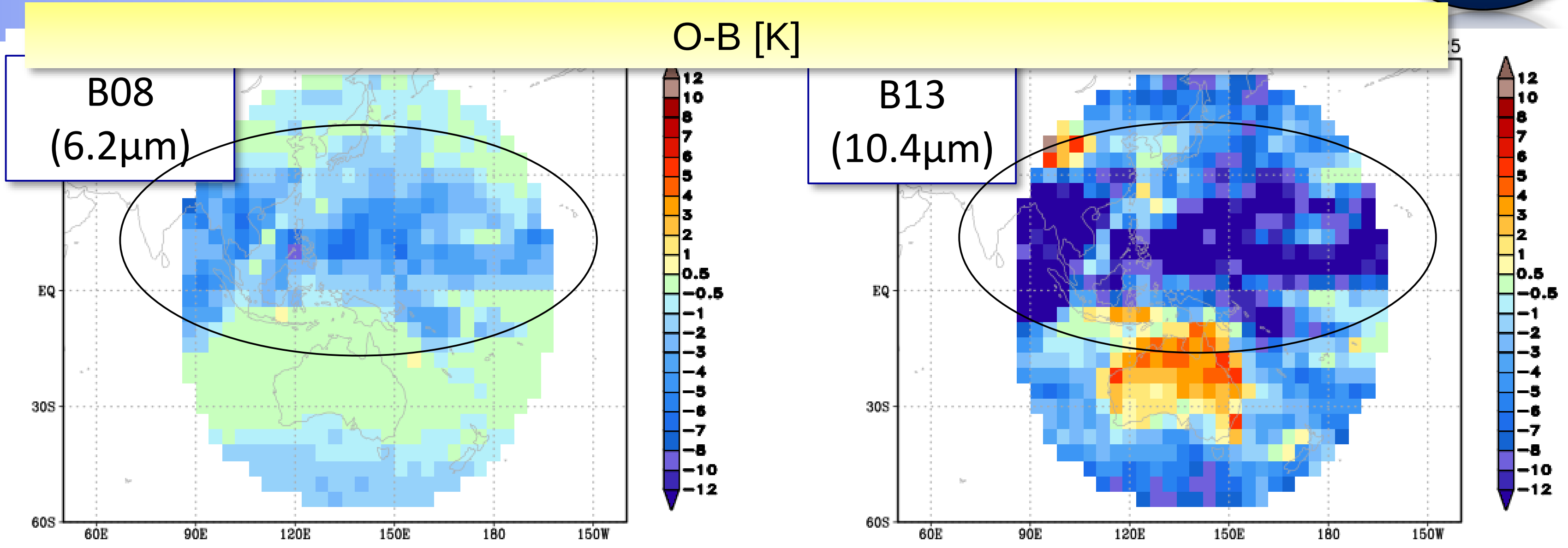
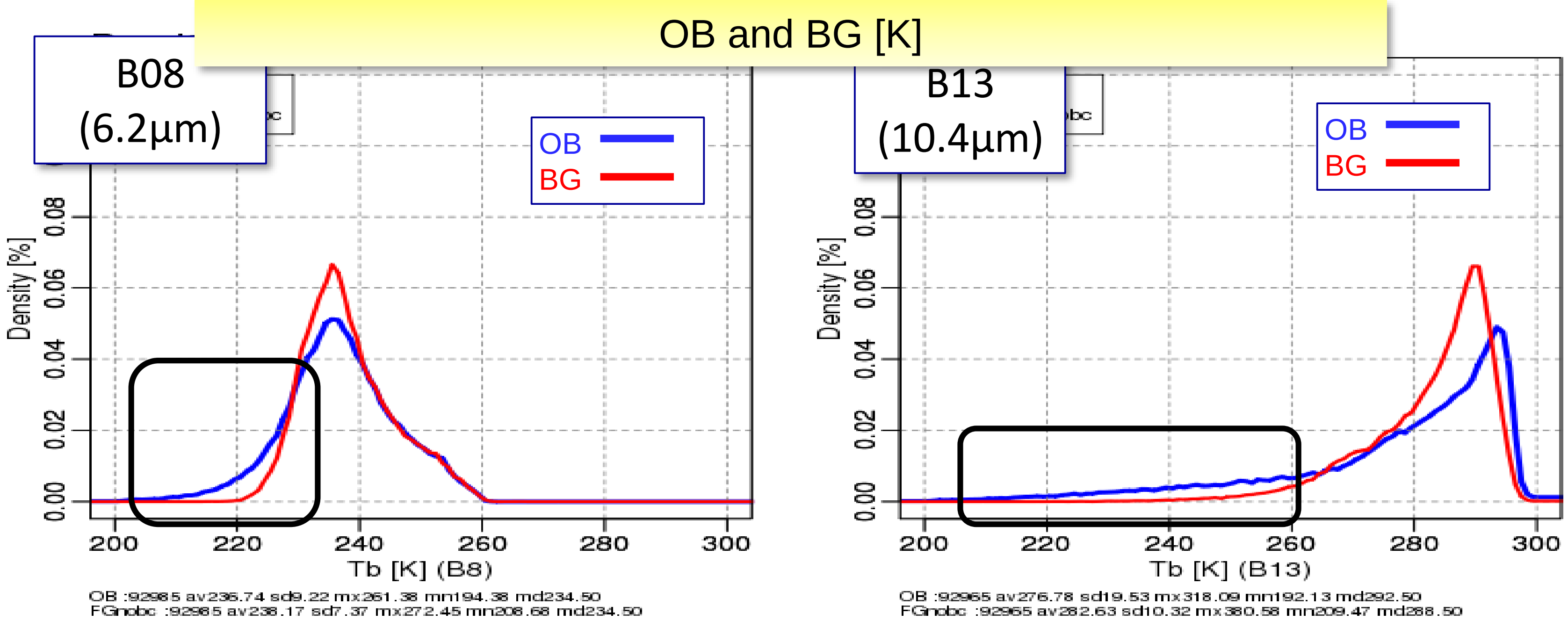
Challenges of all-sky IR assimilation

- Modeling cloud processes
  - Large unpredictability
  - → Relatively low representation (mislocation, bias,,,)
- RTM
  - Large variability in optical parameters
  - Sub-grid process (multiple column, overlap)
- Observations
  - Calibration
- DA
  - Large scene-dependent error
  - Strong non-Gaussianity and non-linearity
  - Zero-gradient (Var) or zero-spread (Ens) for cloud

Challenges: model

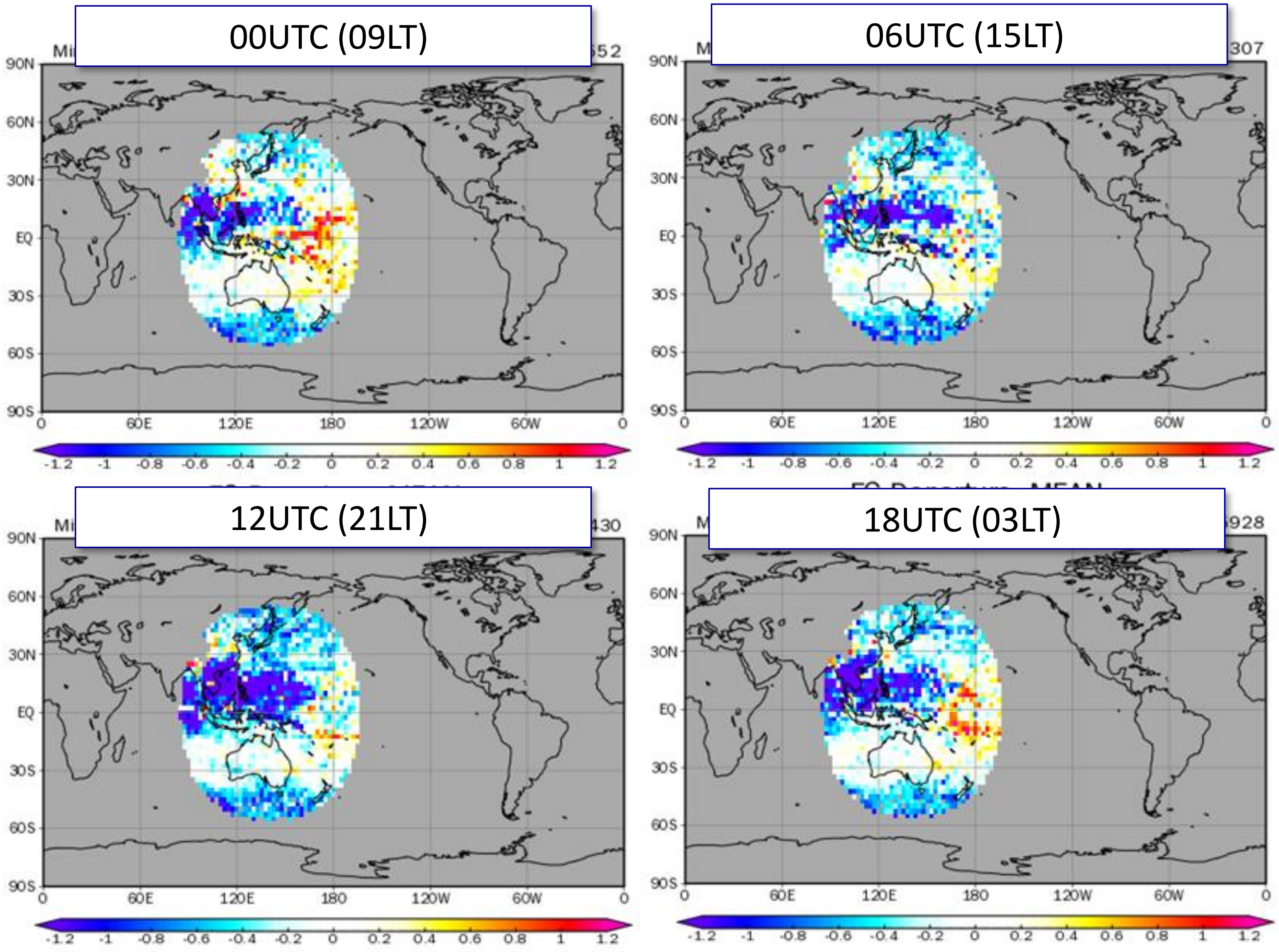
- Example of JMA's global model
  - O-B of Himawari-8/AHI for 21-30 July 2018
  - RTTOV10.2
    - Wyser ice scheme
  - No QC
  - Super-obbed (16x16 pix)
- Model underpredicts high clouds





Challenges: model

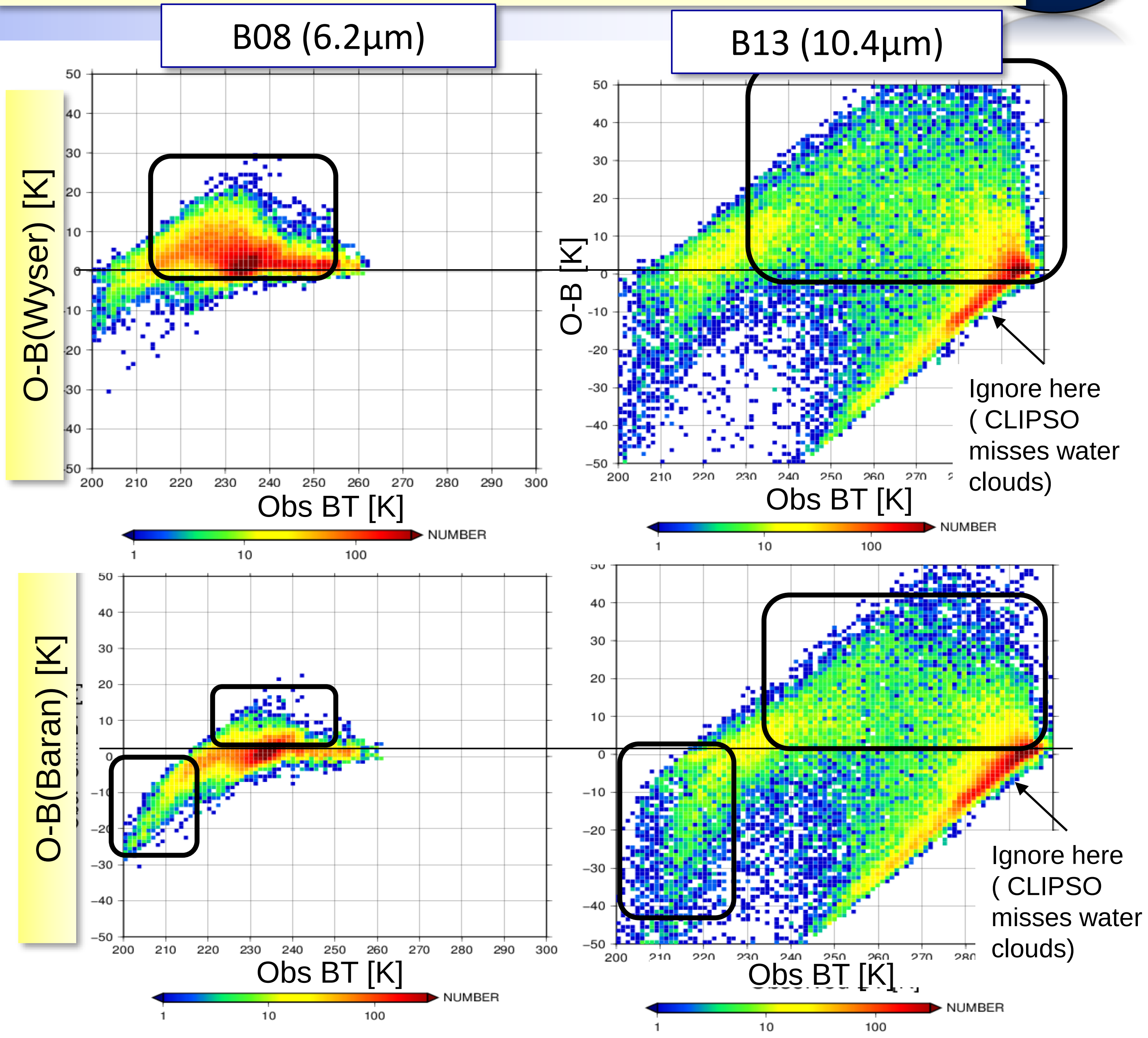
- Example of JMA's global model bias
  - O-B at Himwari8/AHI band 08 (6.2µm) in August 2018
- Model does not well represent diurnal variation of high clouds
  - Wider and thicker around the convective region in the evening



Challenges: RTM

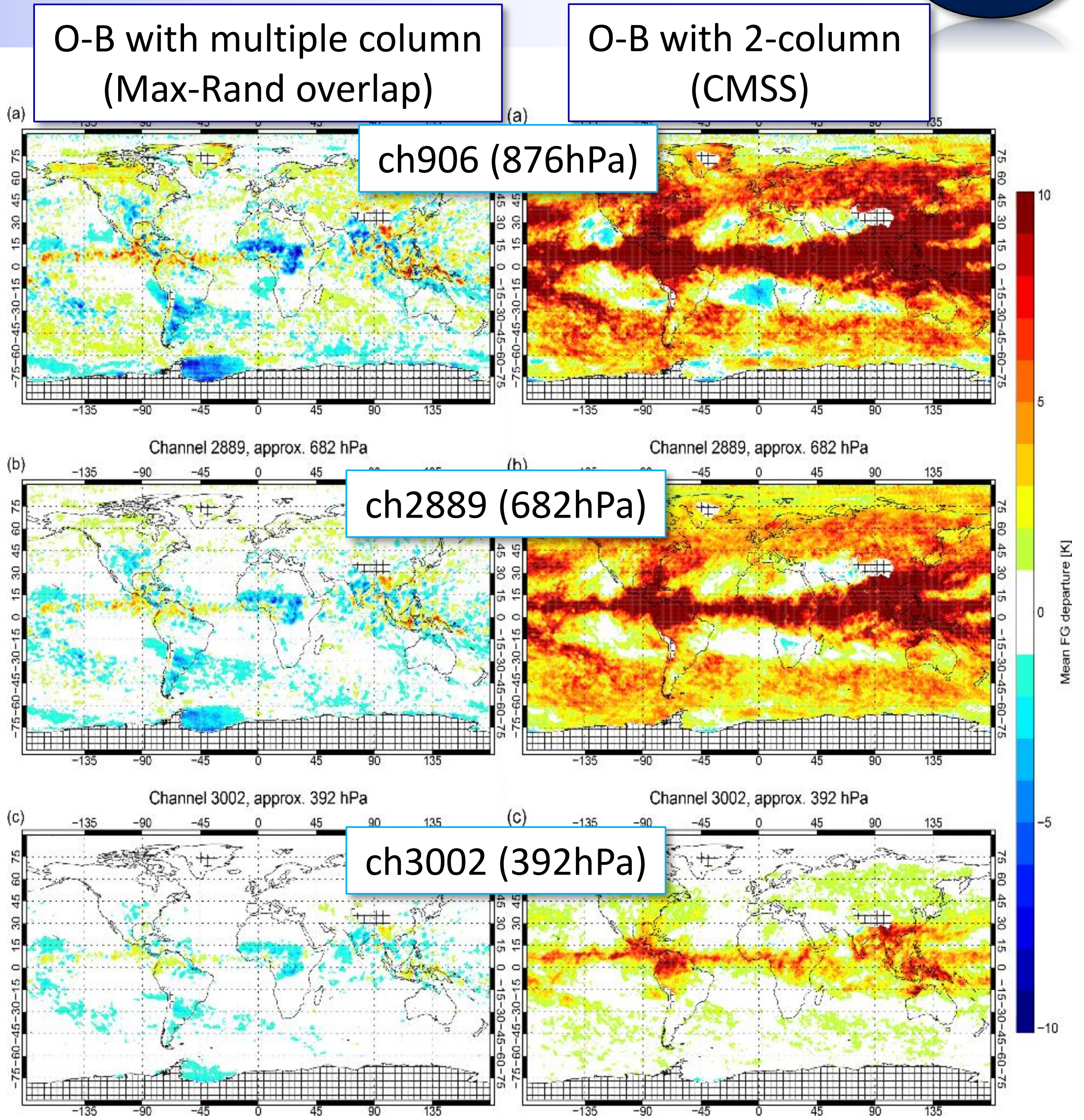
- Simulation with RTTOV12.2 using CALIPSO cloud profile
  - Himawari8/AHI band 8 and 10
- Baran scheme relative to Wyser scheme
  - Reduce +ve O-B bias
    - educe overestimation of cloud abs
  - But still have temperature dependent bias
  - Note that missing water clouds in CALIPSO makes –ve O-B at high BT
- Need to improve optical parameters and/or provide cloud microphysical parameters

Obs vs O-B



Challenges: RTM

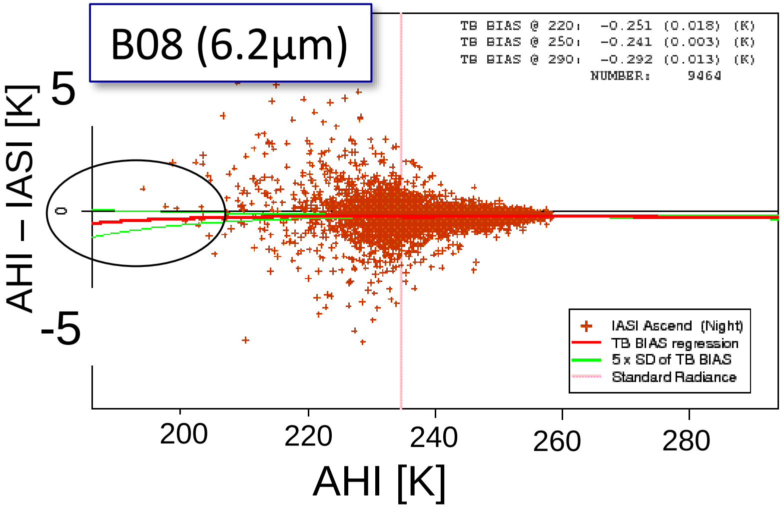
- How to treat subgrid cloud variation?
  - Deploy fractional clouds at each vertical layer under a overlap assumption
- Need multiple independent column approach (Geer et al. 2019, AMT)
  - Simplified 2-column approach generates large errors even for upper-tropospheric ch
    - Different from all-sky MW
  - Increase computational cost with the number of columns
    - 34 times more than clear-sky calculation at ECMWF
  - How do Jacobians wrt cloud behave?

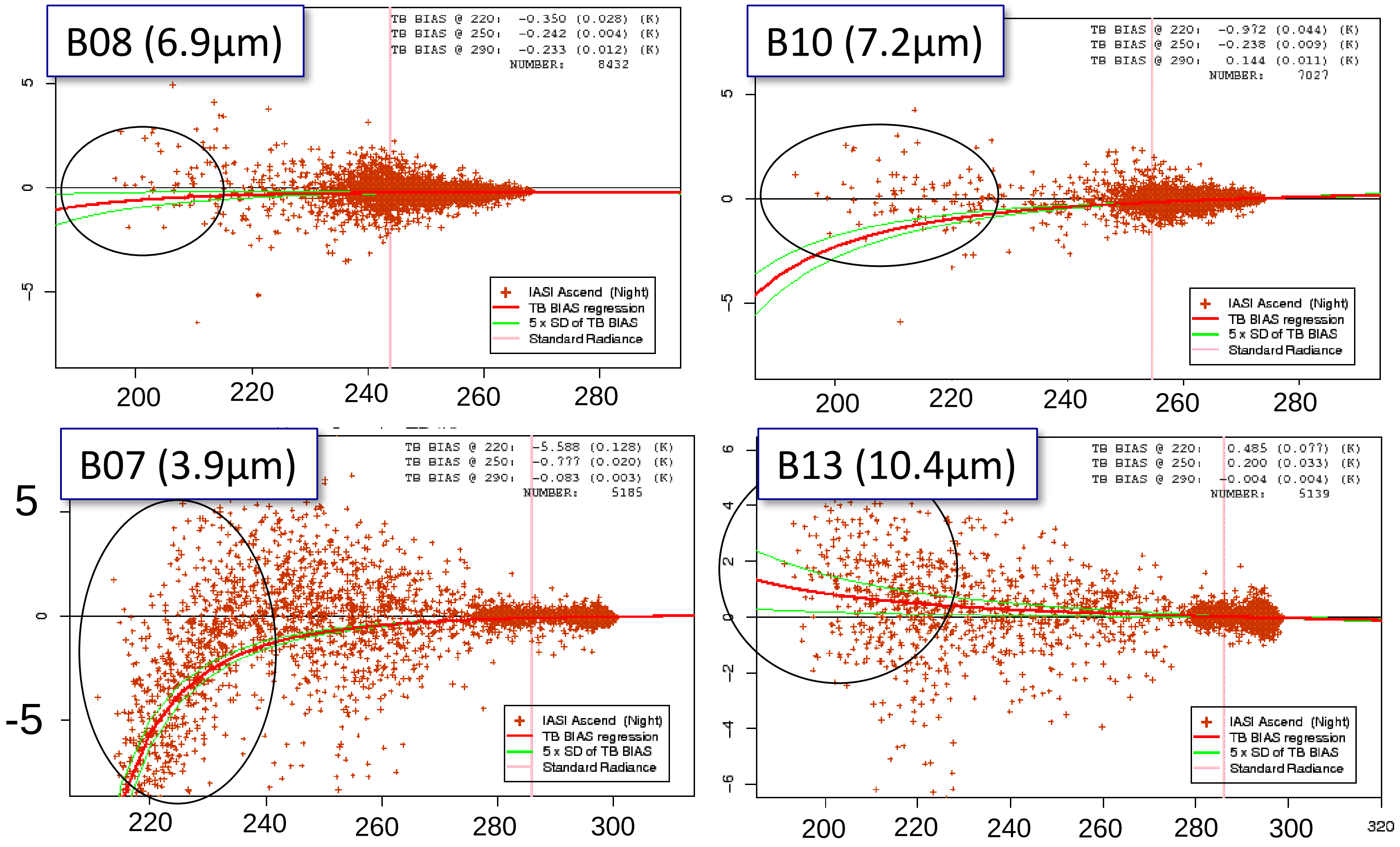


Geer et al. 2019, AMT

Challenges: observations

- Larger BT bias in cold region due to increasing calibration uncertainty
  - In particular, large at short wavelength (3.9 μm)



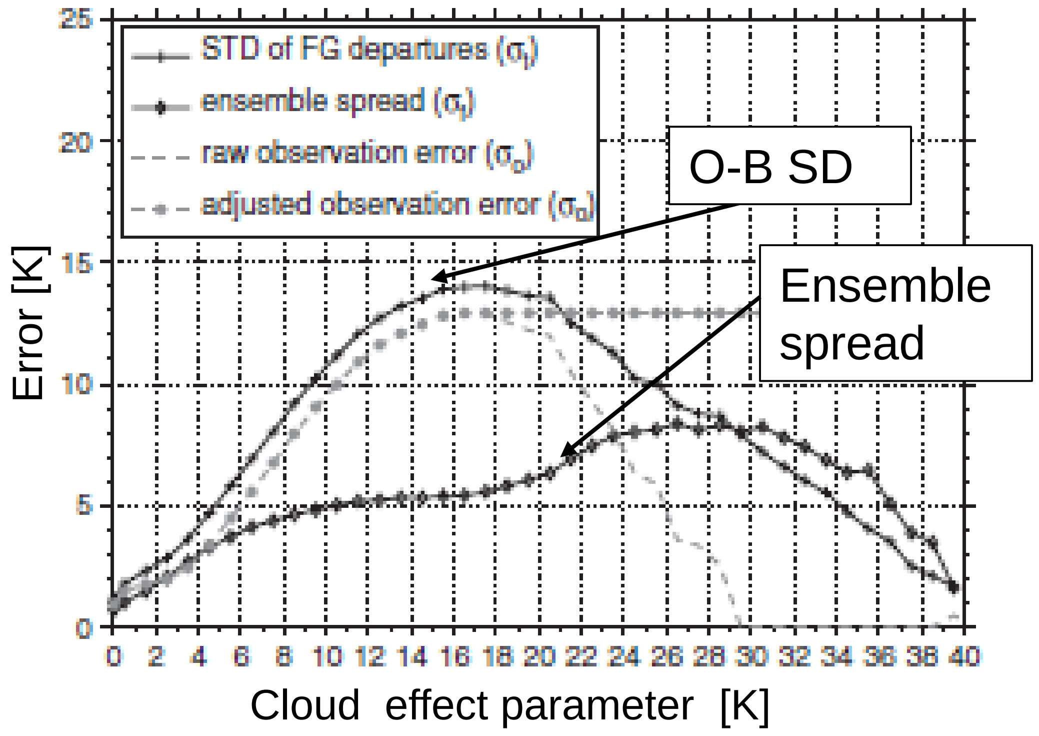


HImawari8/AHI intercalibration with IASI super-ch in GSICS

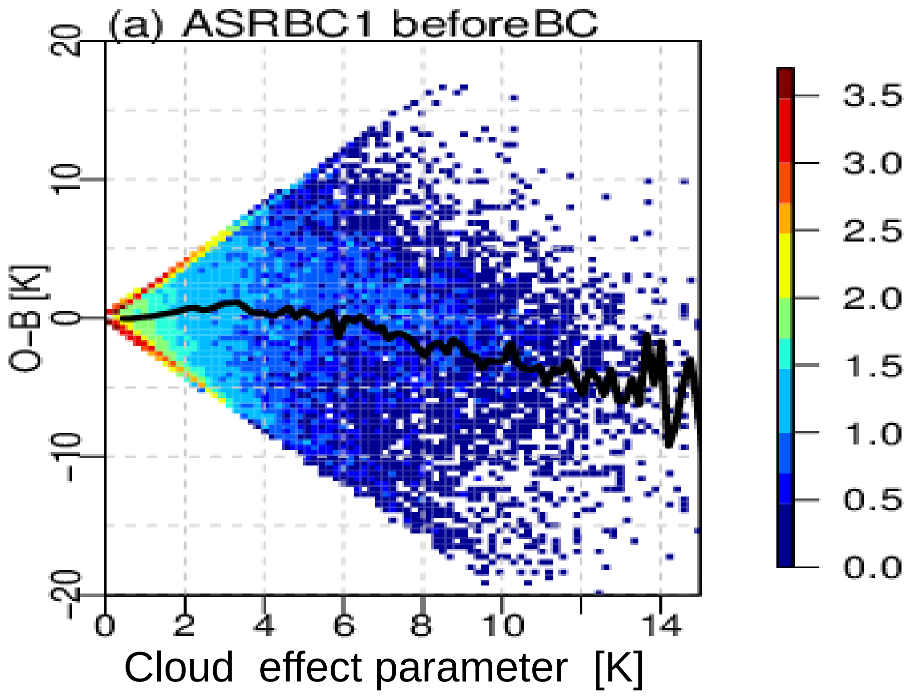
Takahashi et al. 2015,
EUMETSAT conference

Challenges: DA: Large scene dependent error

- O-B variability and bias significantly varies with cloud due to low predictability
- Observation error (covariance) should be scaled according to cloud effect or model unpredictability
  - To account for dominant “representation error”



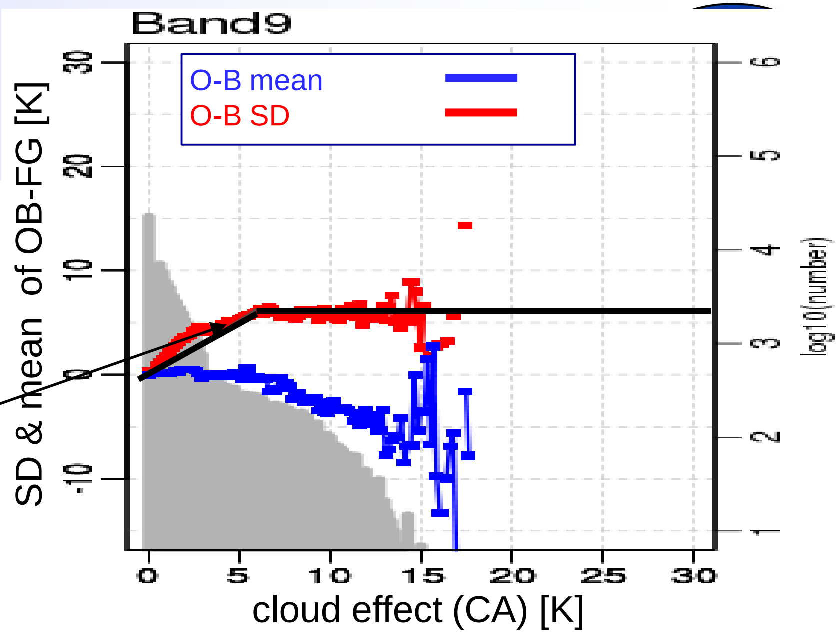
Harnisch et al. 2016, QJRMS

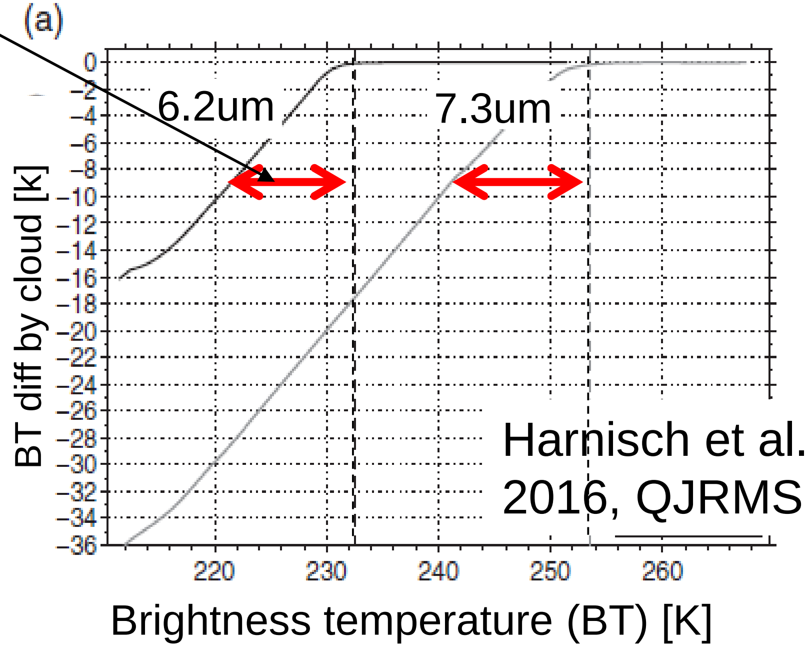


Okamoto et al. 2019, QJRMS

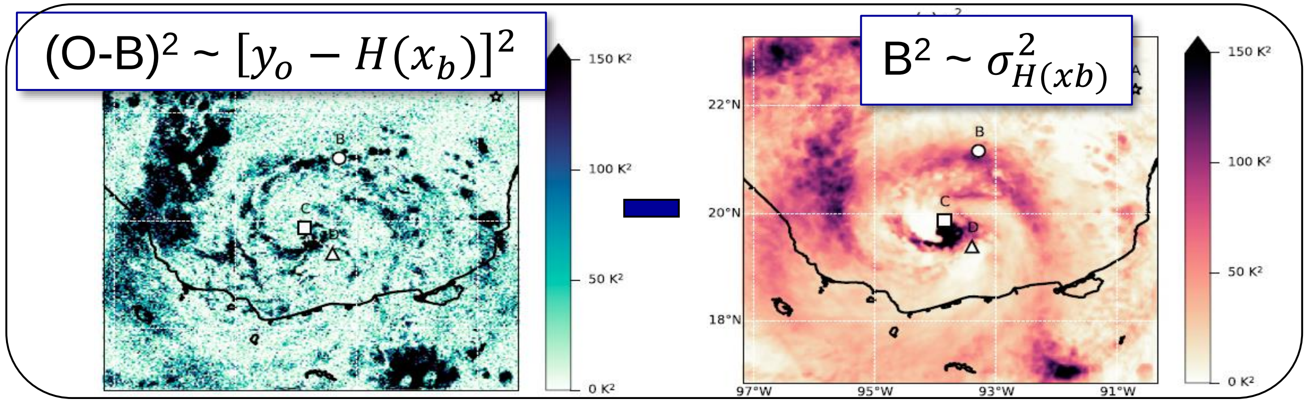
Observation error model

- 1. Empirical climatological model based on a symmetric cloud parameter
  - Extend the original Geer and Bauer approach to all-sky IR
  - Obs error is a linear function of cloud effect parameter Ca
    - Okamoto et al. (2014, QJRMS) : Ca = ½{|O-Bclear|+|B-Bclear|}
    - Harnisch et al. (2016, QJRMS) : Ca = ½{(Tlim-B)+(Tlim-O)}
- 2. Adaptive model based on O-B and ensemble spread
  - AOEI (adaptive observation-error inflation; Minamide and Zhang 2017, MWR)
  - $\sigma_o^2 = max\{\sigma_{min}^2, [y_o - H(x_b)]^2 - \sigma_{H(xb)}^2\}$





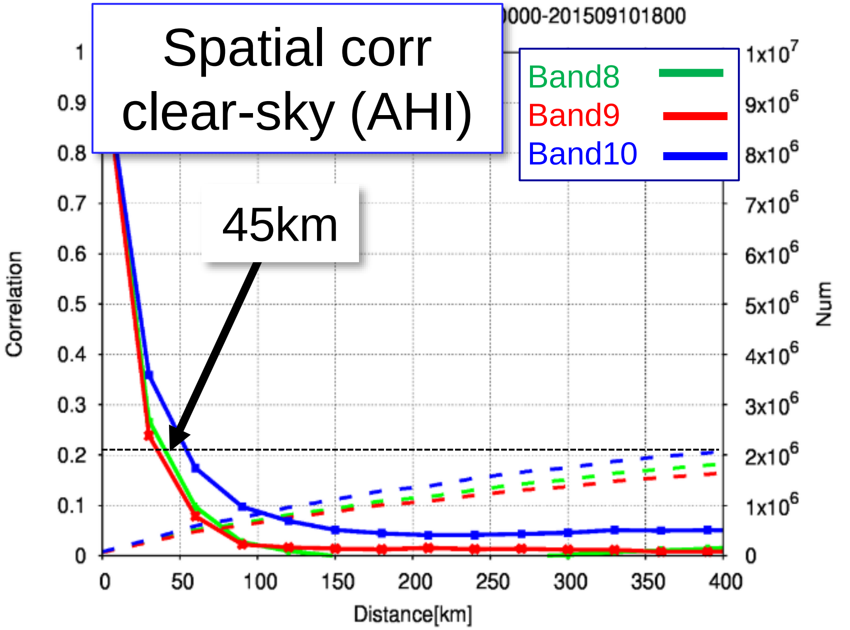
Harnisch et al. 2016, QJRMS

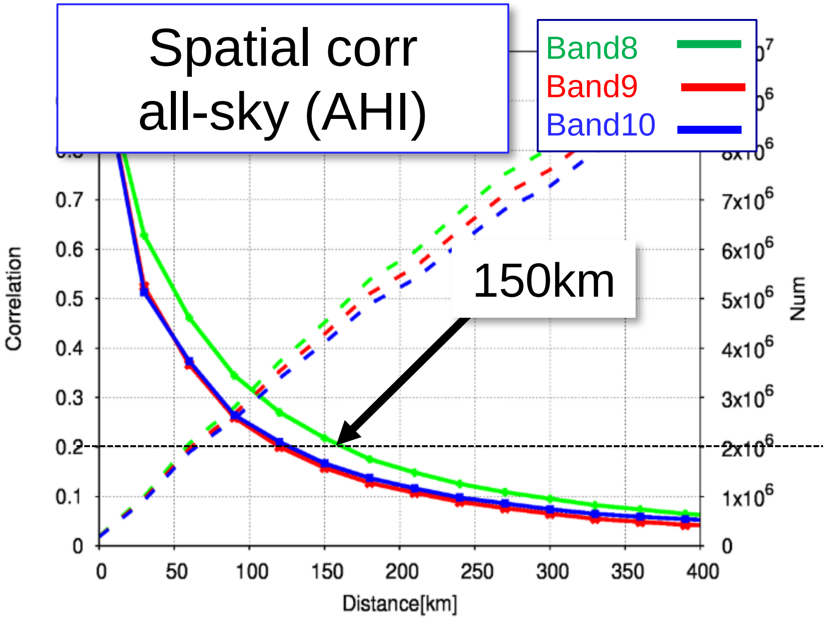


Minamide & Zhang 2017, MWR

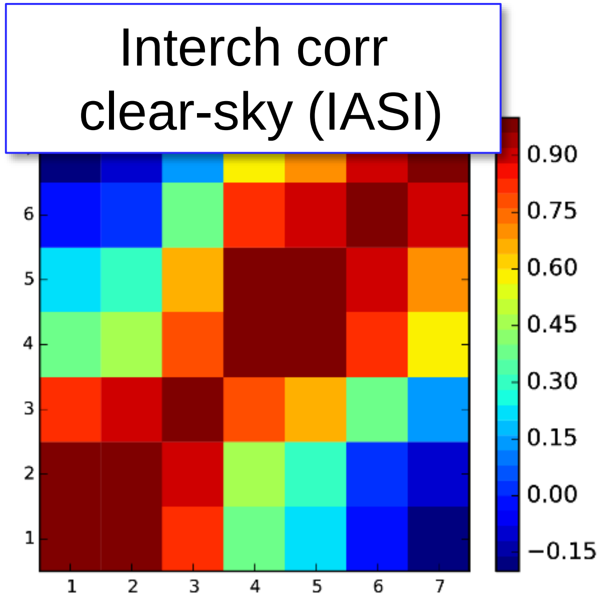
Challenges: DA: Large scene-dependent error

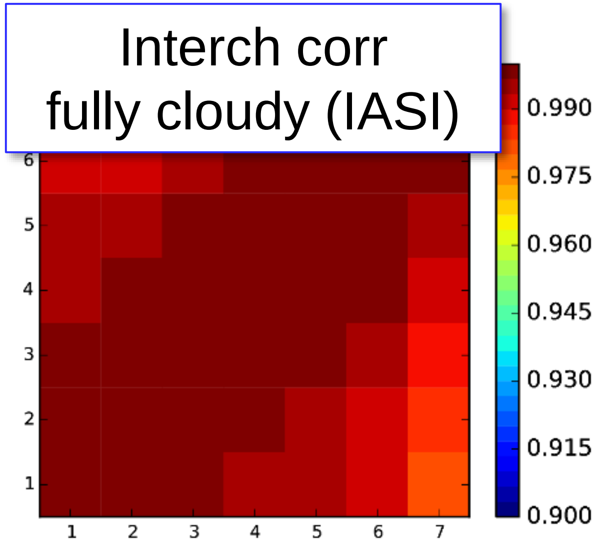
- Spatial and spectral observation error correlation becomes larger in the presence of cloud
- Including interchannel correlation in clear-sky radiance brings big positive impacts for hyperspectral sounders
- All-sky MW has not yet introduced the error correlation
- Geer (2019, AMT) shows greater positive impacts by properly including interchannel error correlation with eigenvalue adjustment





Okamoto et al. 2019, QJRMS





Geer 2019, AMT

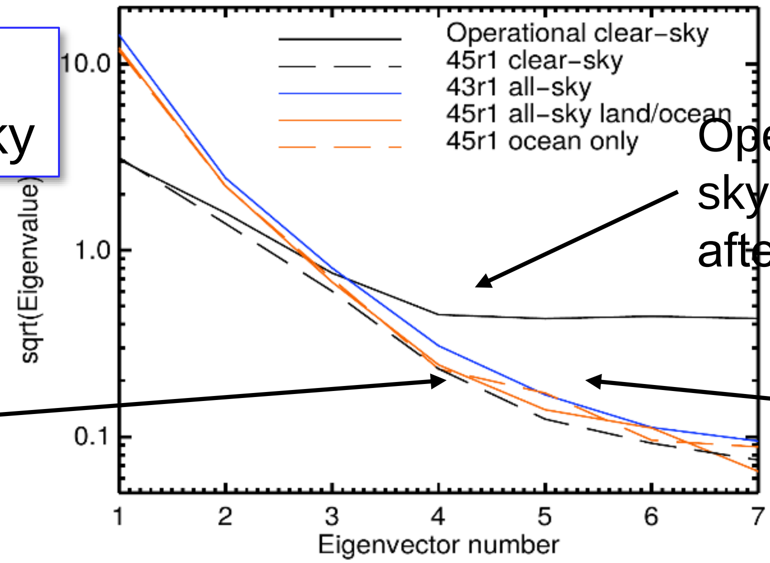
Obs error correlation at ECMWF

Adapted From Geer (2019, esas)

Geer 2019, AMT

- How to handle the interchannel obs error correlation?
  - Apply eigenvector decomposition of obs error covariance matrices
  - Scale eigenvalues according to cloud effects using the obs error model
  - Tune trailing eigenvalues (set minimum value)
    - To suppress weird biases, T-sensitivity in the stratosphere, and vertical T oscillations
    - Small trailing eigenvalues amplify sensitivity to high-order combination of ch

Eigenvalues of clear-sky and all-sky



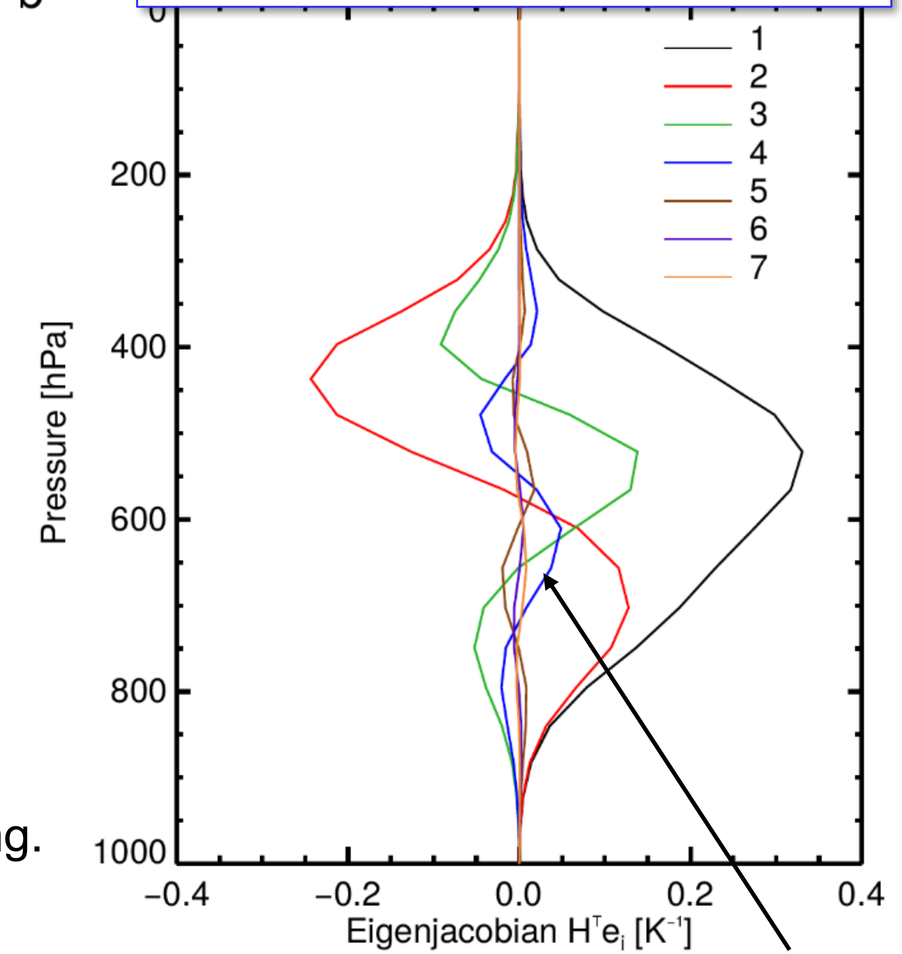
Operational clear-sky eigenvalues after “floor” retuning.

Strong amplification of high-order combinations of channels

Clear-sky and all-sky eigenvalues before any tuning

EigenJacobian = $H^T ej$

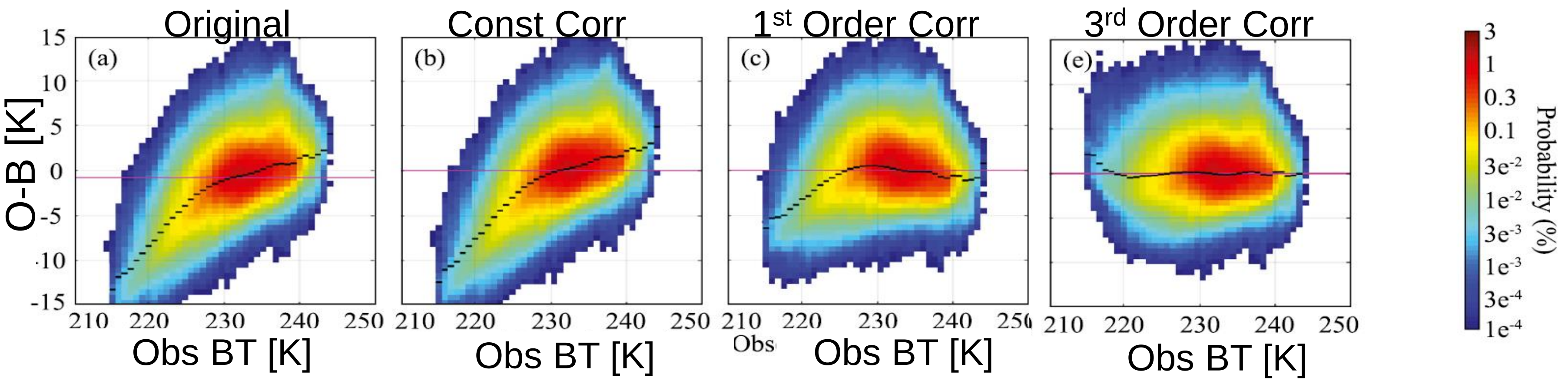
b



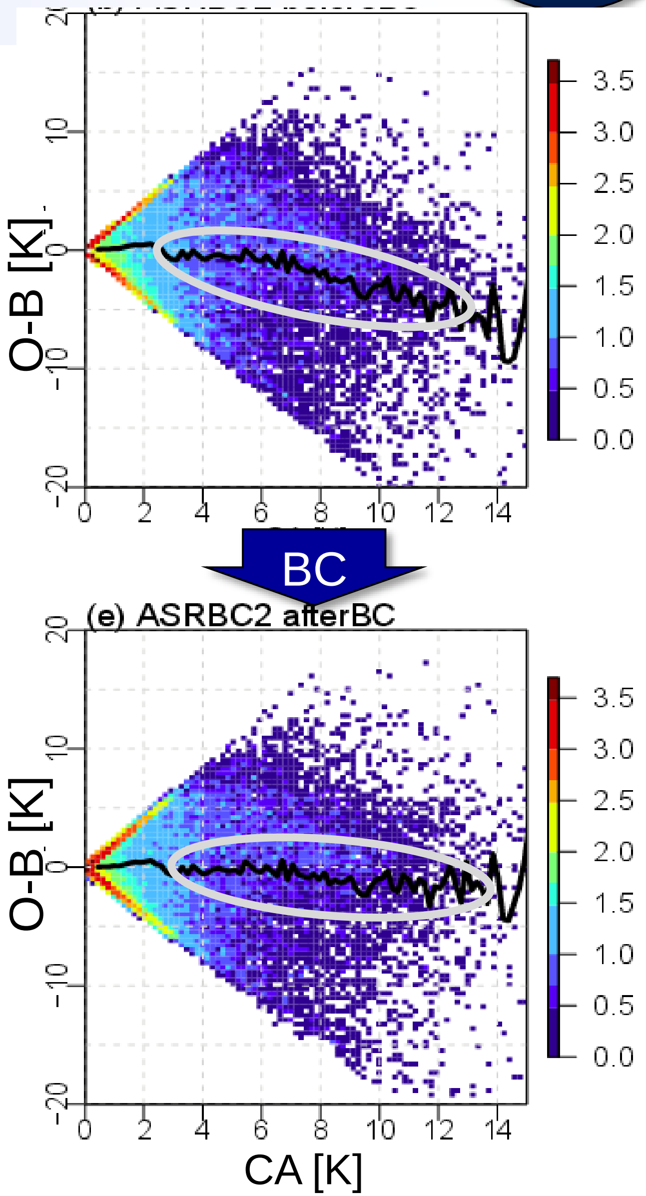
non-localised oscillatory T features

Challenges: DA: bias

- Biased obs should be removed (QC), underweighted (inflate obs errors) or corrected (bias correction: BC)
  - Depend on relative magnitude to obs error
- How to BC? What BC predictors should be used?
  - Cloud-independent BC (e.g. same as CSR predictors of thickness and scan position: Geer et al. 2019, AMT)
  - Cloud dependent BC
    - Observed CTH or BT (Otkin et al. 2018, MWR)
    - Symmetric cloud effect parameters (Ca)
- How to handle a forecast model bias?
  - Model bias can be a major bias source

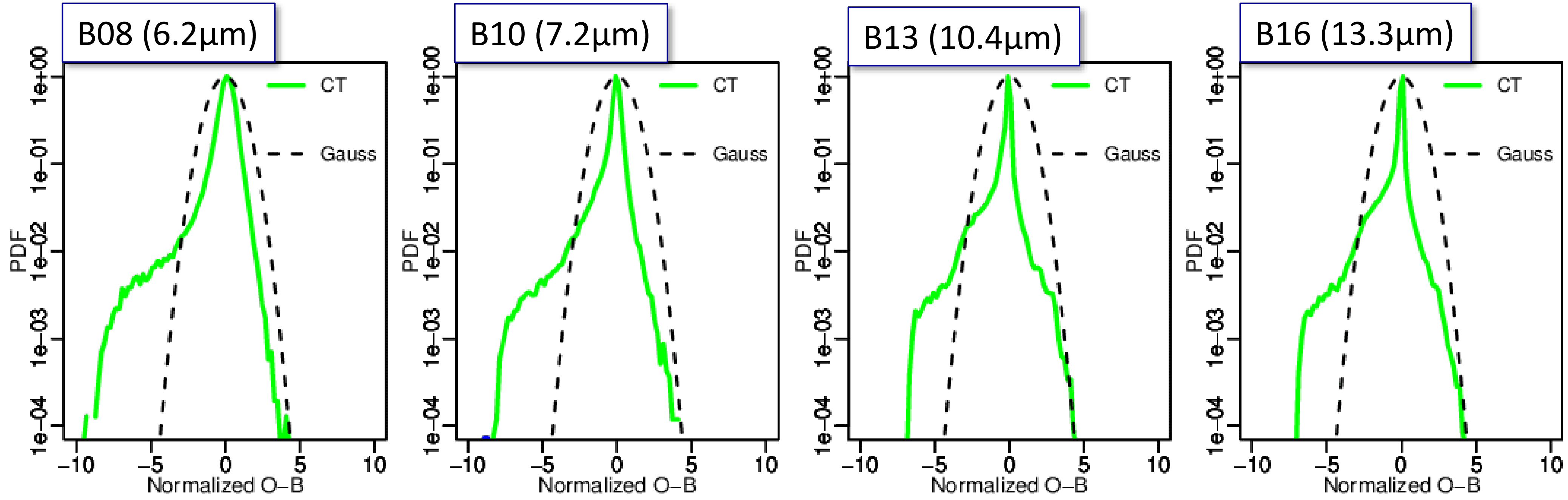


Otkin et al. 2018, MWR



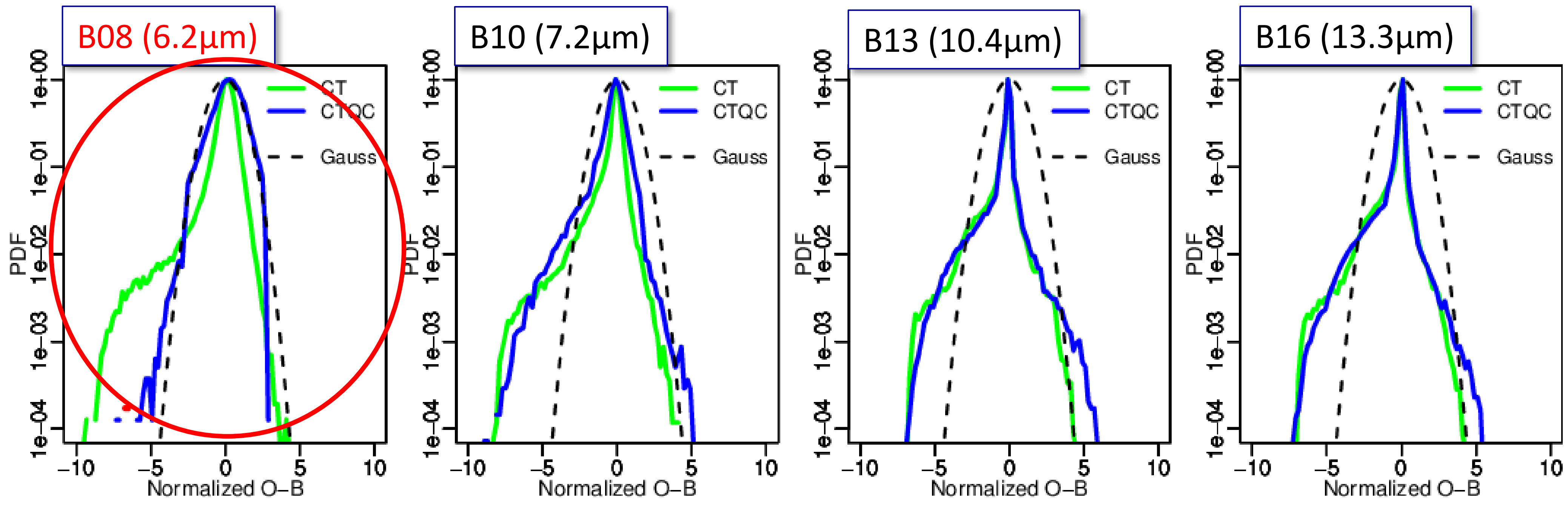
Okamoto et al. 2019 QJRMS

Challenges: DA: Non-Gaussianity



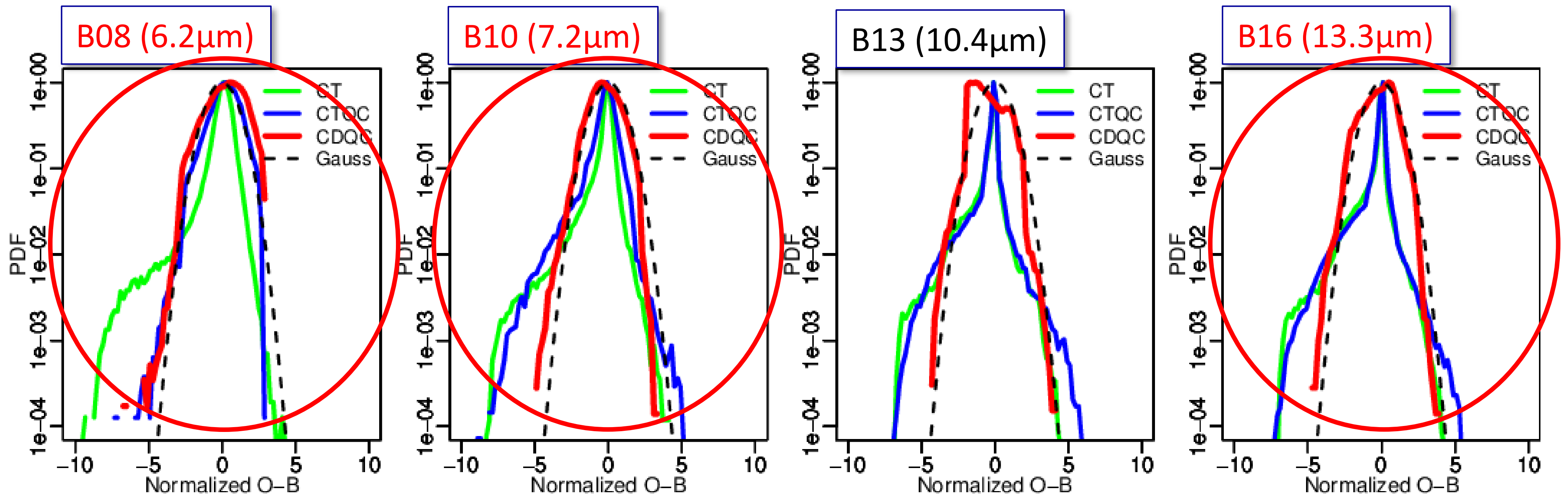
- O-B normalized with (constant) O-B SD after minimum QC in Sep 2015
  - Remove high inhomogeneous data
- No bands show Gaussian PDF in this case
  - Negative long tail and too peaked

Challenges: DA: Non-Gaussianity



- O-B normalized with (constant) O-B SD after stricter QC in Sep. 2015
  - Remove data of high inhomogeneity, too low-BT, or too large O-B
- The most WV-sensitive (least cloud-sensitive) band (B08) shows Gaussianity
- Still non-gaussian for other bands

Challenges: DA: Non-Gaussianity

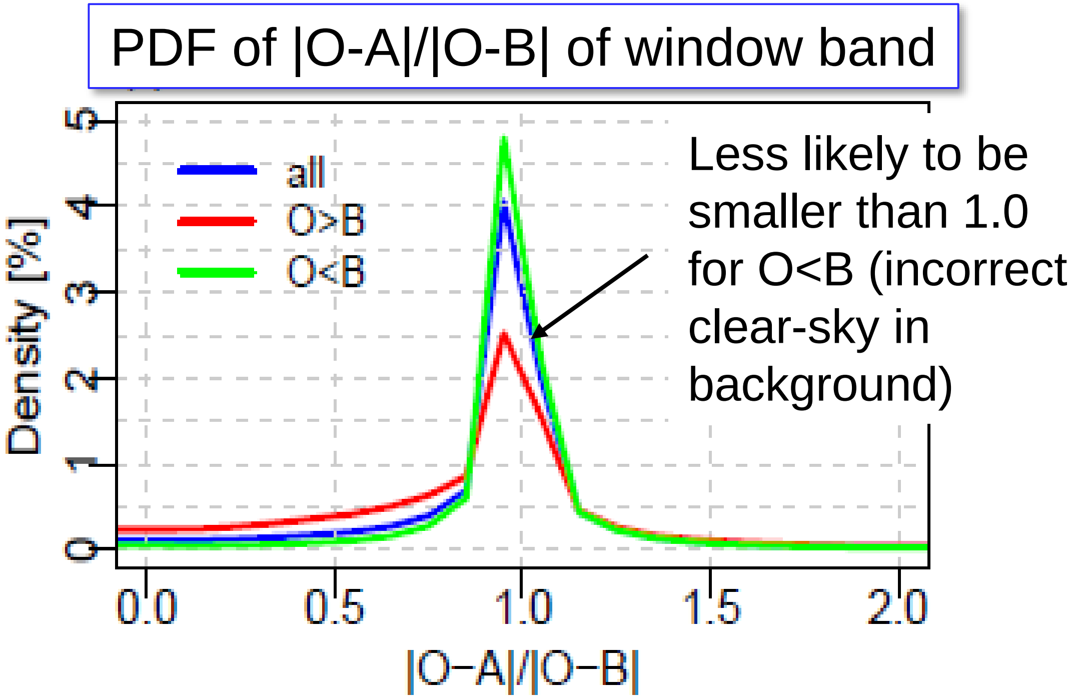


- O-B normalized with cloud-dependent O-B SD after stricter QC in Sep. 2015
- All WV-sensitive bands (B08 & 10) show Gaussianity
- Still non-gaussian for window band (B13)
- Acceptable for low tropospheric T band (B16)

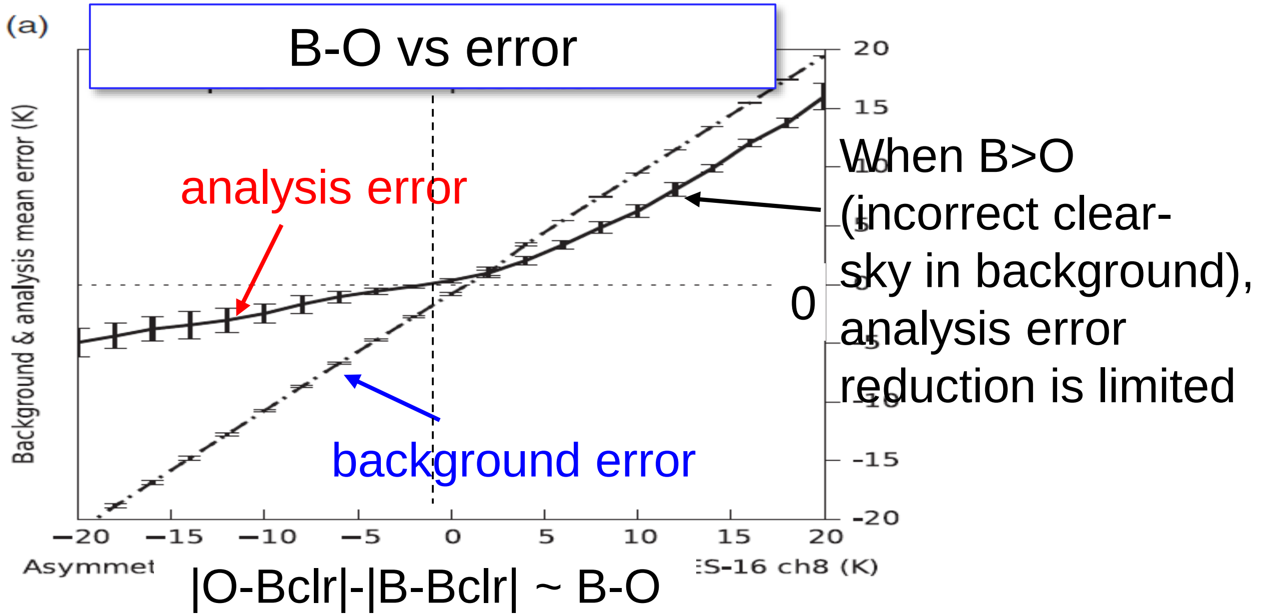
Okamoto 2017, QJRMS

Challenges: DA: Zero-gradient/zero-spread

- More difficult to produce clouds than to reduce clouds
  - Under no cloud background condition, developing clouds in analysis is difficult due to zero-gradient (Jacobian) or zero-spread of ens members wrt clouds
- Update background (e.g. outer-loop), inflate spread (ABEI: Minamide & Zhang 2019, QJRMS), or select obs with similar sensitivity to clouds (e.g.WV ch)



Okamoto et al. 2019, QJRMS



Minamide & Zhang, 2019, QJRMS

Challenges: all-sky IR

- “I knew the challenges, but I want to start to do it. What should I do first?”
- → WV ch is good for all-sky IR as initial development (Geer et al. 2019 AMT)
  - Compared with window and temperature sounding channels

1. Moderate sensitivity to clouds → More Gaussian, smaller non-linearity
   - Easier to characterize error statistics, then making obs error model
2. Change in the same direction as clouds → Avoid zero-gradient/zero-spread and aliasing cloud errors
   - Eg. -ve O-B leads to reducing humidity (clouds), and then clouds (humidity)
   - Eg. For T-ch, –ve O-B leads to reducing temperature or increasing clouds
3. Limited sensitivity to other variables (e.g. surface emissivity)
4. Exploit experience of all-sky MW assimilation of WV sounding-ch

- Actually, most recent studies chose WV ch of hypersounders and geo imagers

4

- 1. Assimilation of cloud-affected IR radiances
- 2. Benefit of all-sky IR assimilation
- 3. Challenges of all-sky IR assimilation
- **4. Developments of operational centers**
- 5. Recent research progress
- 6. Concluding remarks

Development of operational centers (1/3)

- No operational centers have implemented all-sky IR assimilation in the operational systems as of Dec 2019

- UKMO
  - Developing all-sky for IASI and MTG/IRS
  - Aim1: Increase the number of IR rad assimilation in cloudy areas
    - Semi-transparent cloud and partial cloud cover
  - Aim2. Get the most out of geo hypersounders, potentially by improving wind fields through the tracer advection effect
- GMAO
  - Suspend developing all-sky IR assimilation because DA system is not fully ready to assimilate imagery IR data yet
- ECCC
  - Started testing all-sky MW assimilation
  - Planning to extend the same methodology to all-sky IR

Development of operational centers (2/3)

- Meteo-France
  - Developing 1D-Bay + 4D-Var
    - Also working on vertical subsampling of the retrieved profile to pressure levels where the IASI channels have information content within the clouds.
  - In the longer term, all-sky radiance assimilation in EnVar
- DWD
  - Developing all-sky IR in both global ICON and regional COSMO-KENDA system
  - Experiments with COSMO-KENDA uses WV-channels of MSG/SEVIRI based on Harnisch et al. (2016, QJRMS)
    - The system is being transferred into the new regional system LAM-KENDA
  - Non-linear BC is looked into based on Otkin & Potthast (2019, MWR)
- NRL
  - Testing all-sky IR of geo with COAMPS-TC/EnKF
  - Not doing all-sky IR for global and regional system at this point

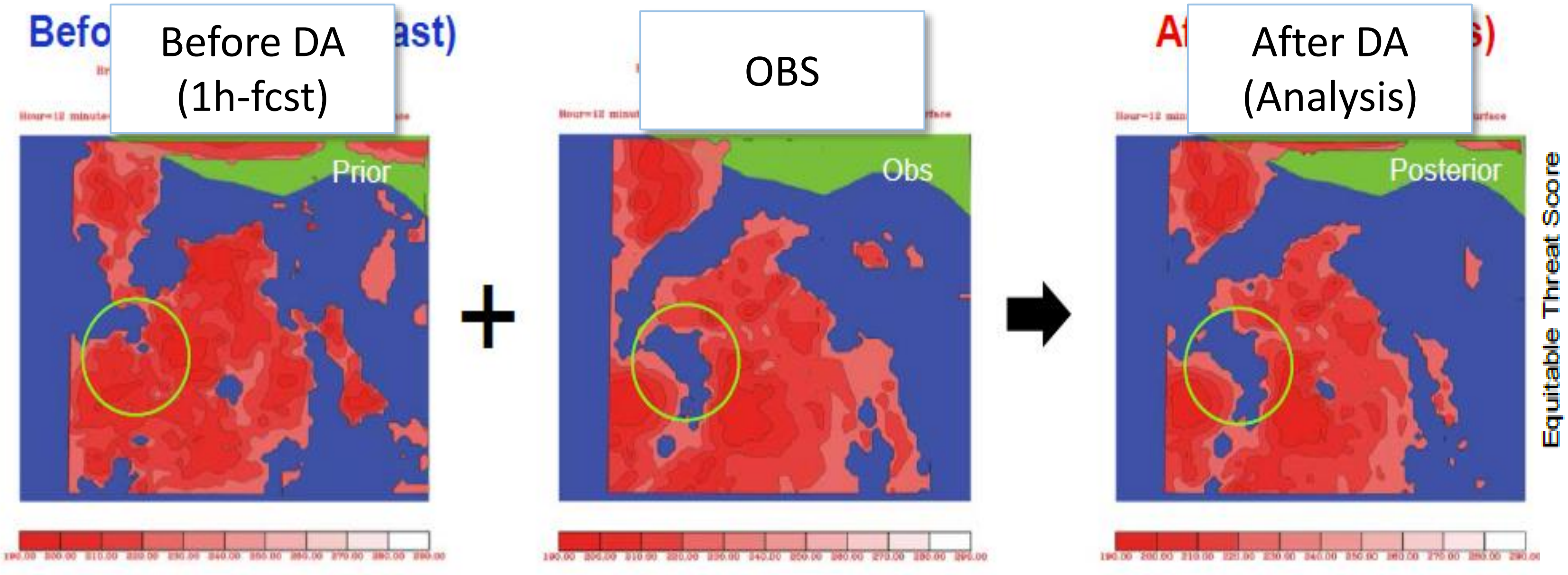
Development at NRL

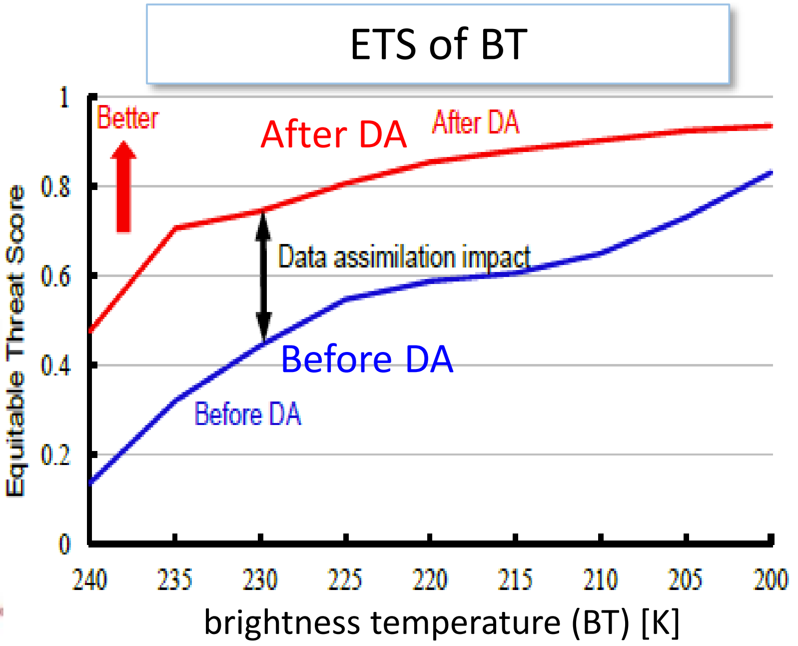
Baker et al. 2019, ITSC22

NRL
From N. Baker

- NRL is testing ASR assimilation for TC cases with COAMPS-TC/EnKF in collaboration with scientists from Penn State University
  - the Coupled Ocean/Atmosphere Mesoscale Prediction System for Tropical Cyclones
  - Hourly GOES-13(16) WV band (6.55um) assimilated
  - Obs error model: AOEI (Adaptive Observation Error Inflation)
- Improve initial TC structure, and then TC intensity and track forecasts with the impacts lasting more than 3 days

1200 UTC 21 Oct. 2019



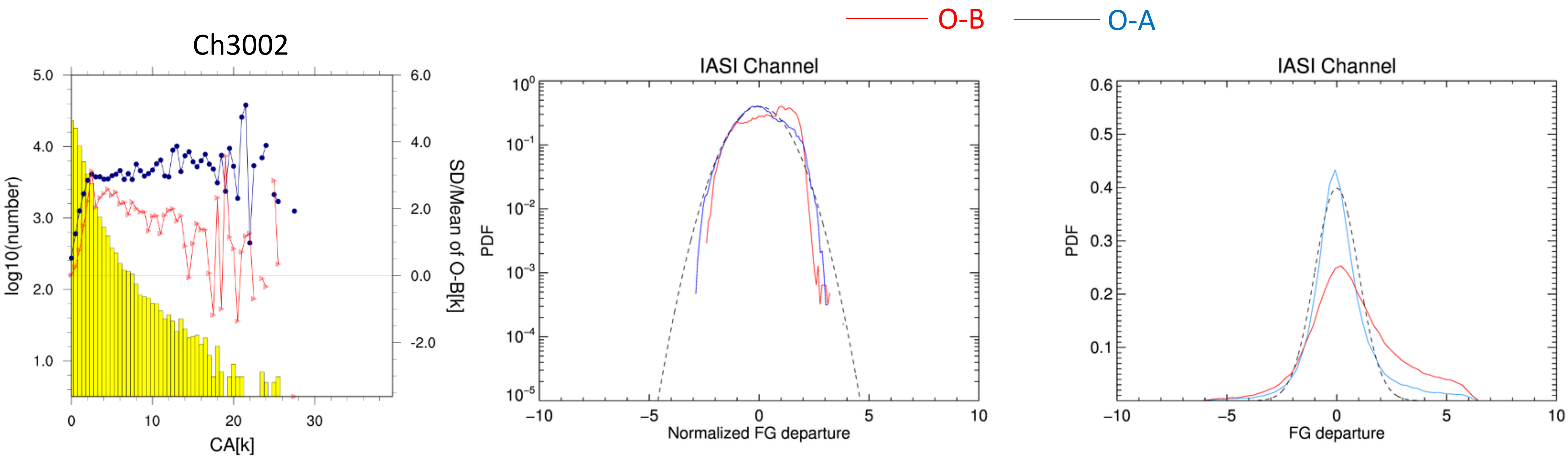


Development of operational centers (3/3)

- NCEP
  - Tested 3 approaches: CCR, SCR, ASR → ASR as extension of all-sky MW
  - Assimilating all-sky IASI WV ch shows reduction of O-B/O-A bias for MHS and slight positive/neutral impact
    - Need reevaluation after significant forecast model changes
  - Cloud fraction is concerns because simple 2-stream model is used
    - Motivate the use of geo rad with smaller FOV size
- JMA
  - Developed all-sky assimilation for a Himawari8 WV band and compared impacts with CSR in a research-based regional system with LETKF (Okamoto et al. 2019, QJRMS)
  - Developing all-sky assimilation for Himawari8 WV bands in the operational global system with 4D-Var
- ECMWF
  - Developed all-sky assimilation of additional IASI WV ch and compared clear-sky assimilation (Geer et al. 2019 AMT)
  - Developed cloud-dependent observation error correlation and found positive impacts from IASI all-sky assimilation (Geer 2019 AMT)

NCEP
From A. Collard and L. Bi

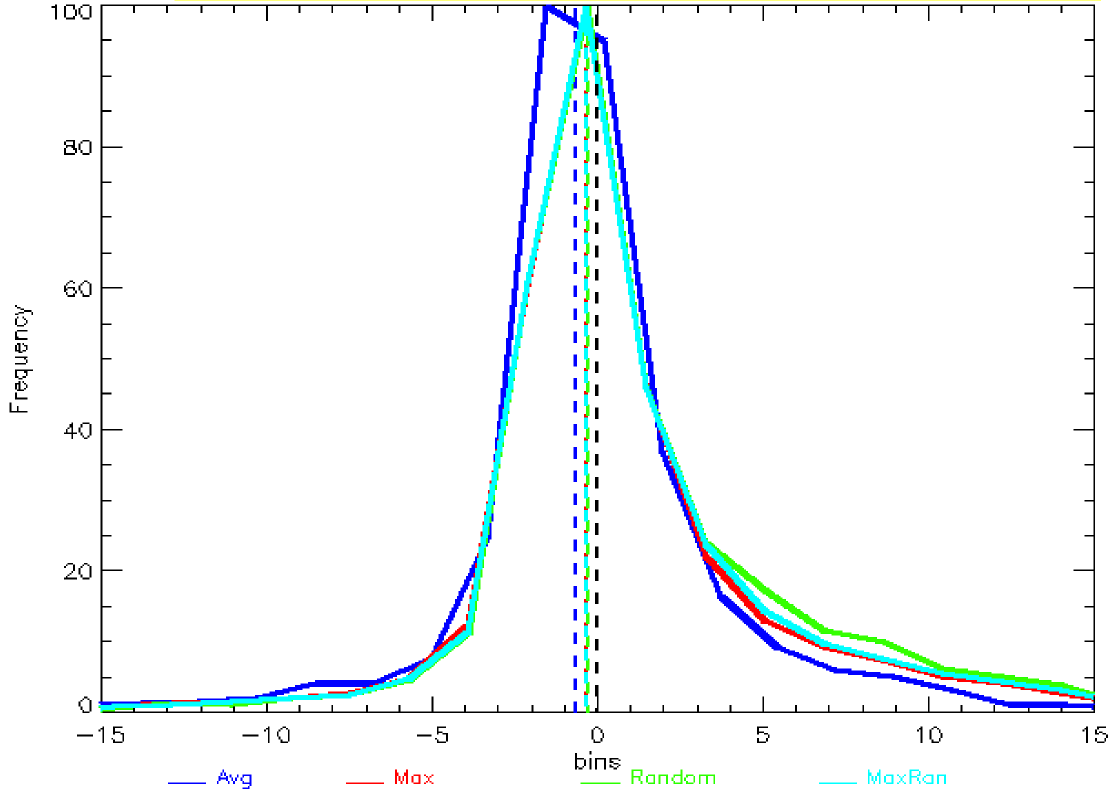
2015052506 – 2015052918 after QC



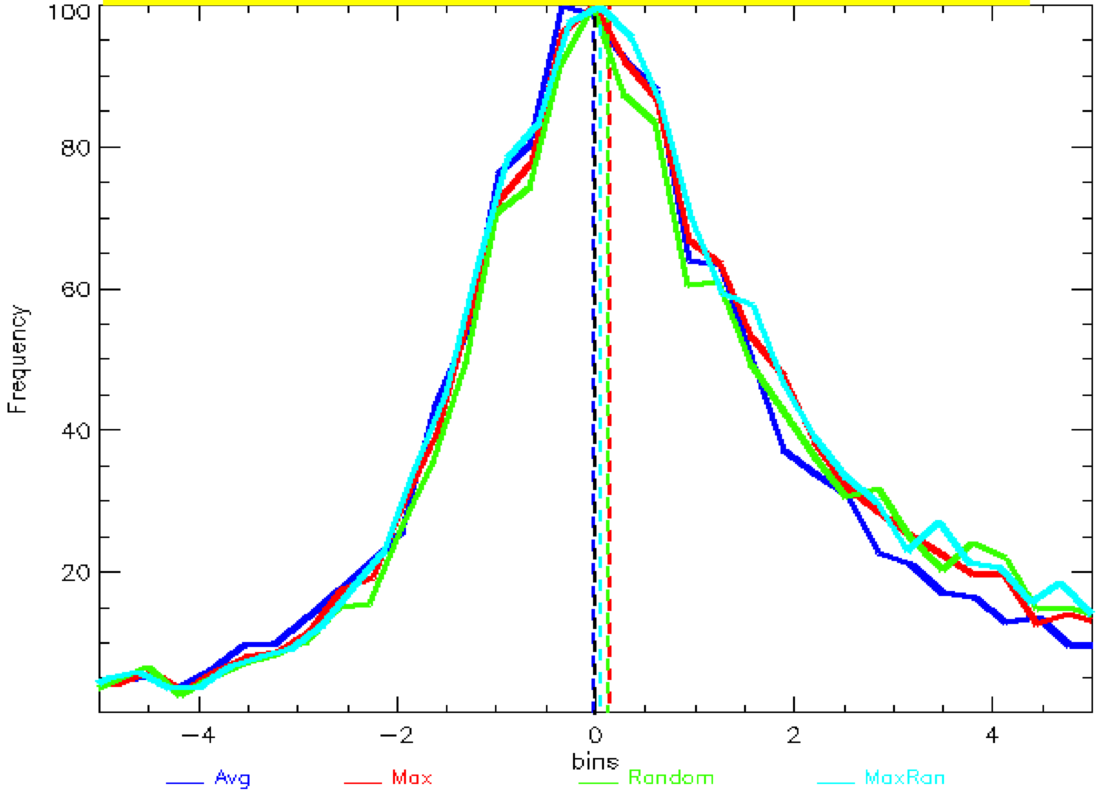
Analysis PDFs response well by including cloud effect and model's cloud fraction

NCEP
From A. Collard and L. Bi

All the points over ocean



All the points over ocean with QC



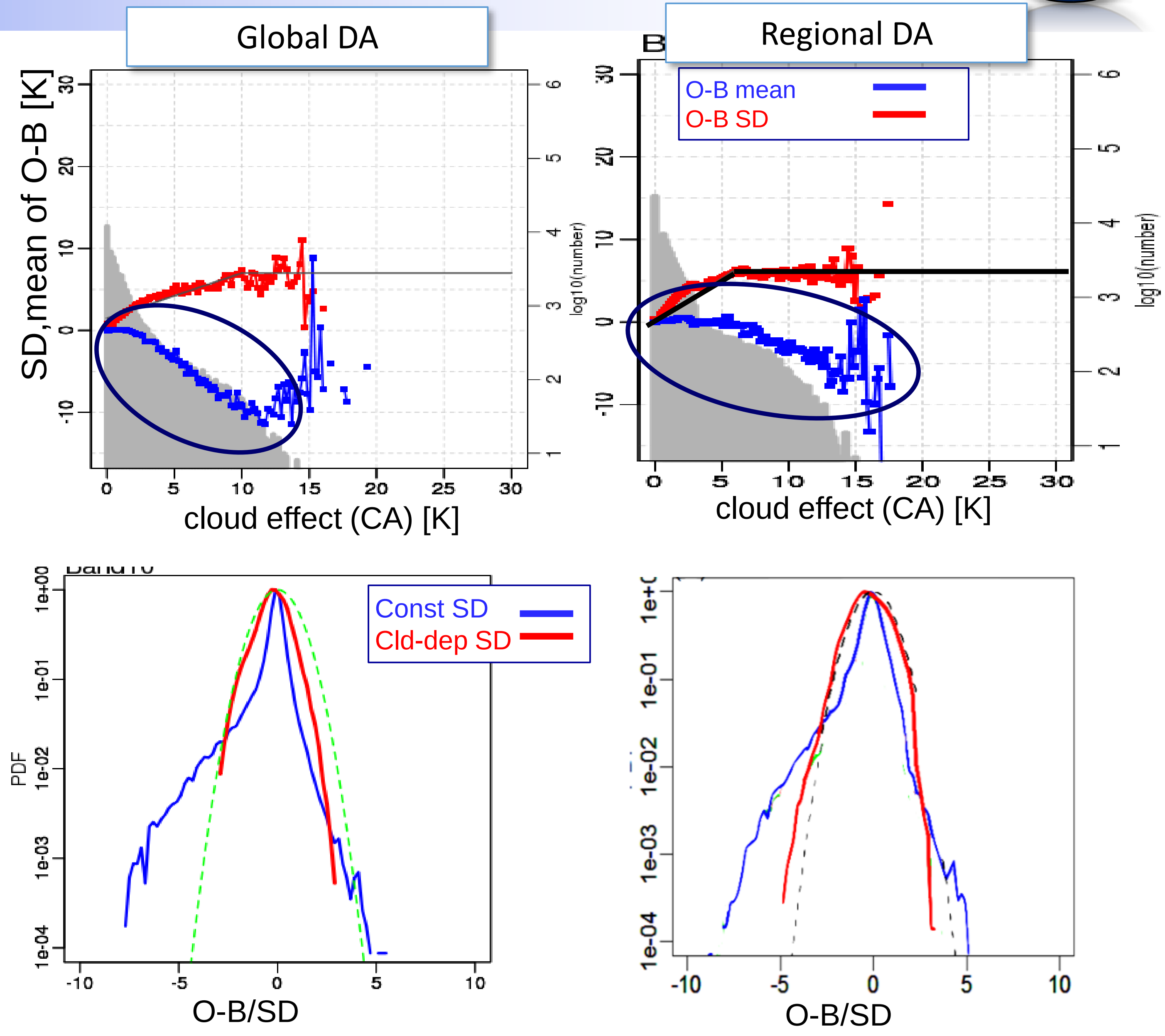
- O-B GSI stats (no bias correction) for different overlap assumptions:

Avg: 0.3981826 Max: 0.5500953 Ran: 0.6193535 MaxRan: 0.5777849

Four CRTM cloud cover schemes were tested in this study and the average overlap scheme was selected.

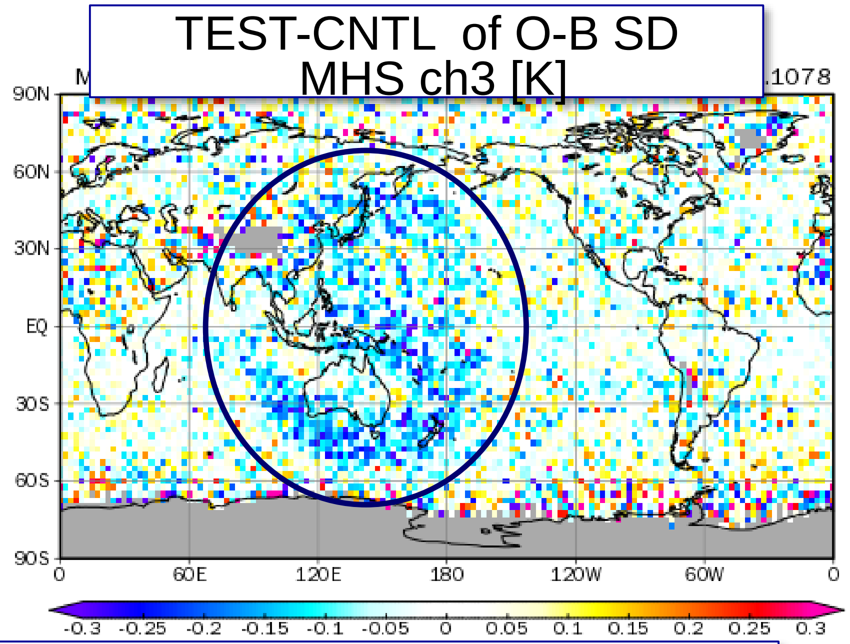
Development at JMA

- Developed cloud dependent obs error model and QC using cloud effect parameter Ca
  - Okamoto et al. 2014, QJRMS; Okamoto 2017, QJRMS
- The same approach is applied to regional and global DA with adjusted parameters and additional QC
- Bias correction is under evaluation

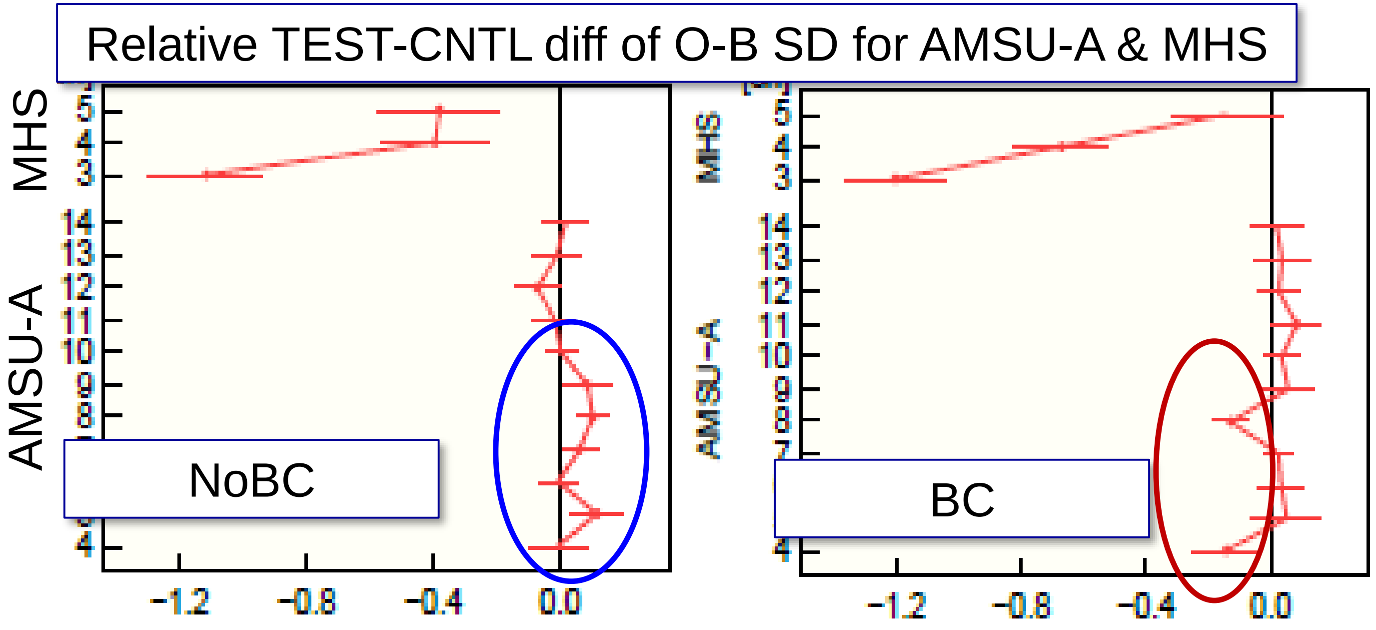


Development at JMA: impact on global DA

- ASR assimilation of Himwari8
  - 3 WV bands, cloud-dependent obs error (diagonal)
  - Reduce dry bias in the mid- & upper troposphere and improve fit to MW WV-sounders
  - Improve mid-range forecast of winds
  - Degrade fit to AMSU-A T-ch and MW imager 22GHz in the tropics



- Applying cloud-dependent BC (predictors of Ca,Ca^2,Ca^3)
  - Remove the degradation of fit
  - But reduce mid-range forecast improvement

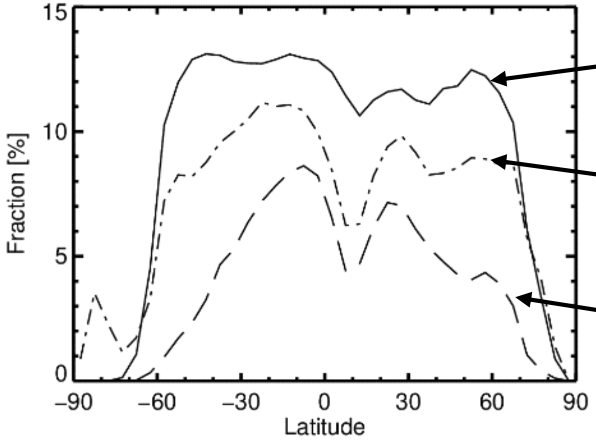


Effects of all-sky assimilation of 7 IASI IR WV channels

ECMWF
From A. Geer

1 – More observations

Percentage of all data that was actually assimilated (main loss: spatial thinning)



All-sky WV (all 7 channels)

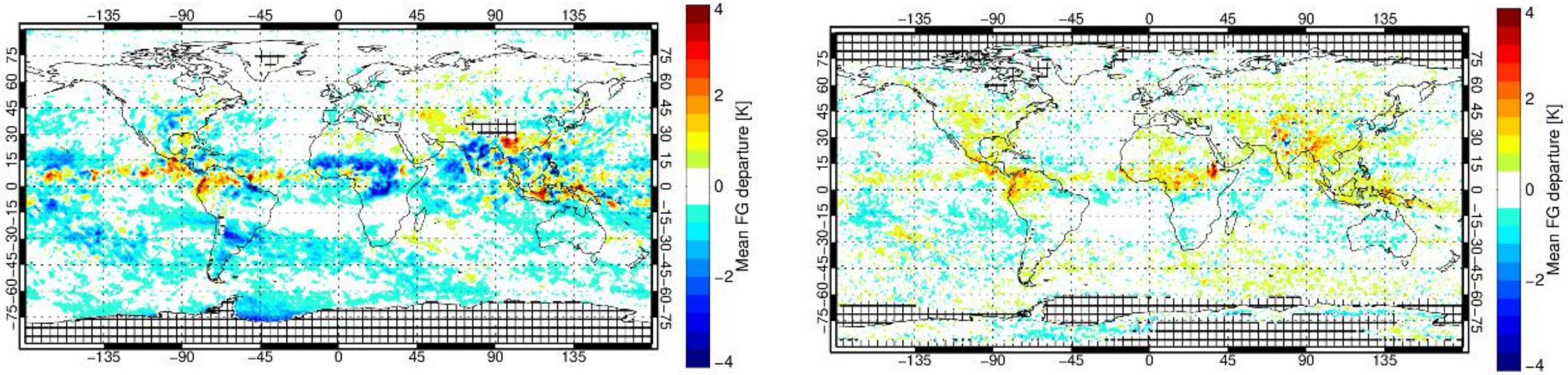
Clear-sky (highest-peaking WV channel)

Clear-sky (lowest-peaking WV channel)

2 – Biases are not much larger than clear-sky, at least in upper channels

Background departures 1-20 June 2017,
channel 3110 (highest-peaking WV channel)

All-sky: all observations (but excluding high orography)



Clear-sky: actively assimilated observations only

Effects of all-sky assimilation of 7 IASI IR WV channels

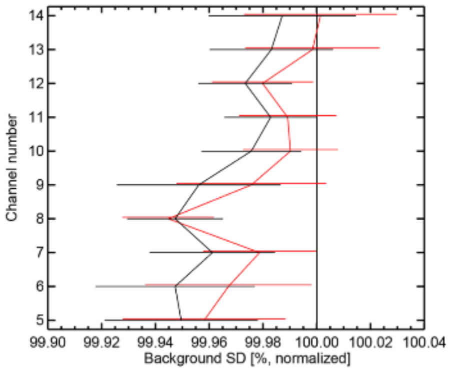
ECMWF
From A. Geer

3 – Neutral benefits to forecasts in extratropics, positive benefits in tropics

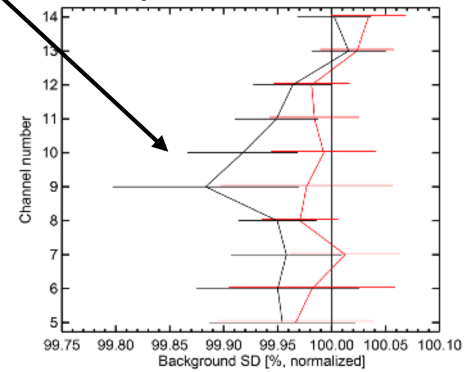
Impact on background fits (full system experiments)

Tropical UTLS temperatures are better in all-sky experiments; midlatitude WV fits are slightly worse

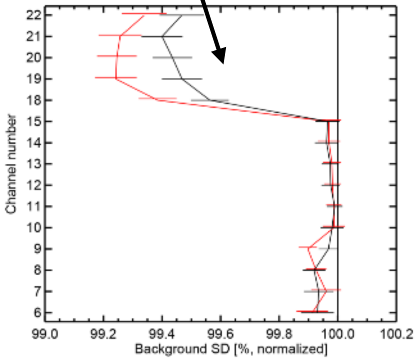
Global AMSU-A



Tropical AMSU-A



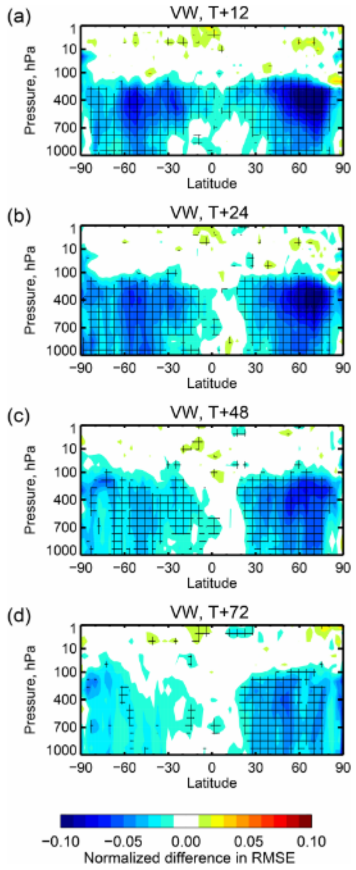
Global ATMS



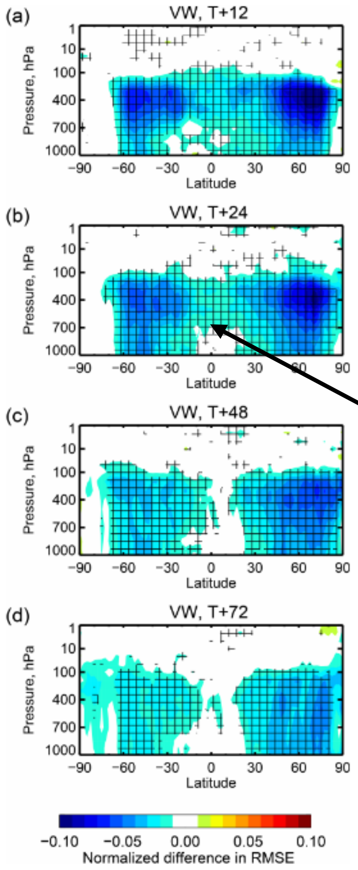
All-sky WV (black)

Clear-sky WV (red)

Clear-sky WV



All-sky WV



Impact on wind vector forecasts in the absence of other observations (reinitialization framework)

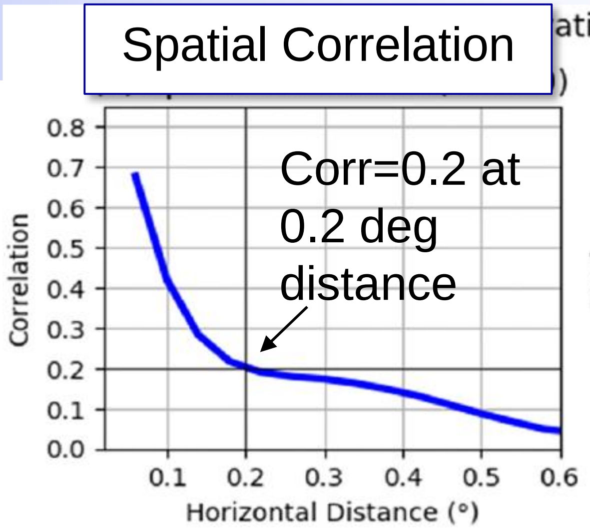
All-sky improves over clear-sky mainly in the tropics

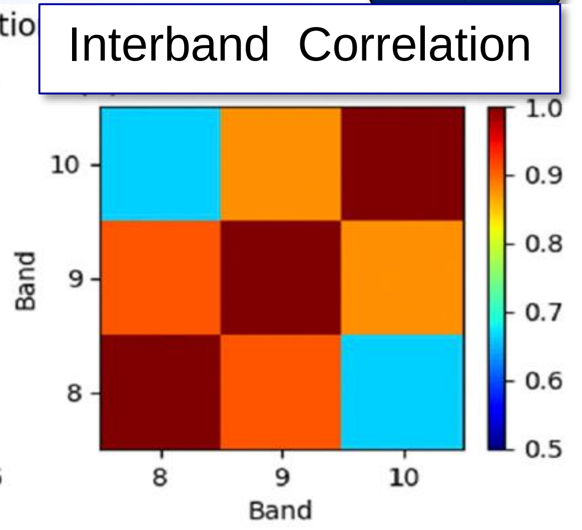
5

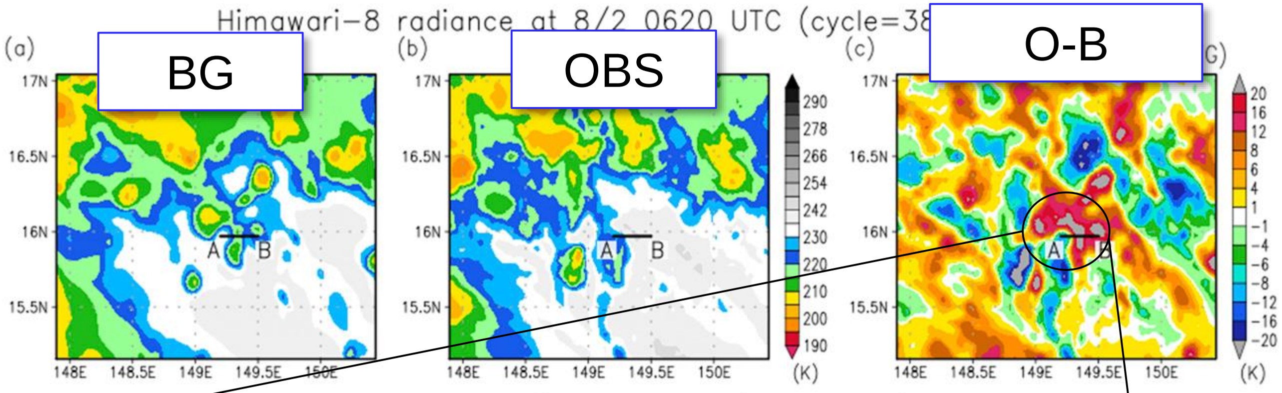
- 1. Assimilation of cloud-affected IR radiances
- 2. Benefit of all-sky IR assimilation
- 3. Challenges of all-sky IR assimilation
- 4. Developments of operational centers
- **5. Recent research progress**
- 6. Concluding remarks

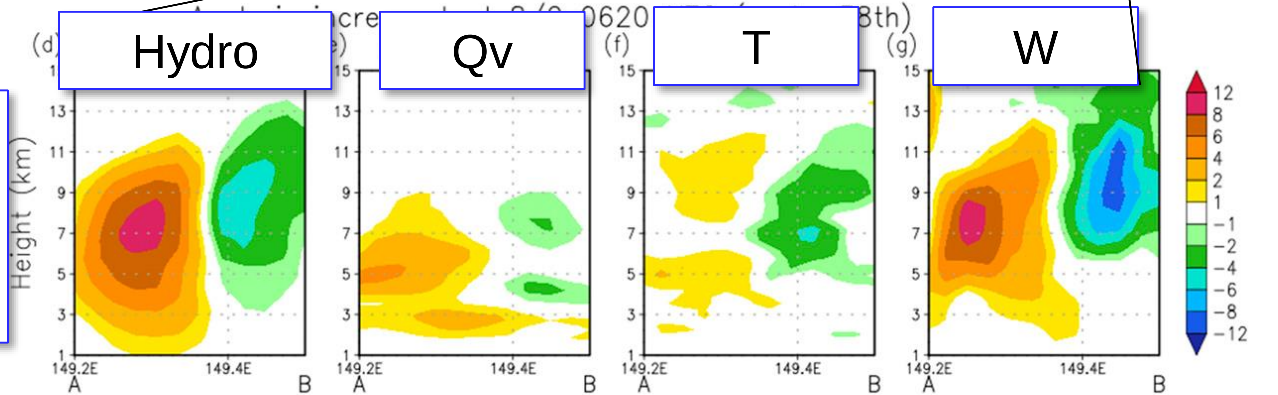
All-sky IR assimilation for geo
Honda et al. 2018, MWR (1/2)

- Assimilate Himawari8 ASR every 10 min for TC with LETKF
  - Only band9 (avoid including obs error corr)
  - Obs error: 3K for clear-sky or 6K for cloudy
  - No bias correction ← small O-B
  - Thin to 0.2x0.2 deg ← small spatial corr
- Modify different variables not only around the cloud top but also lower levels
  - Through correlation resulted from model convective process







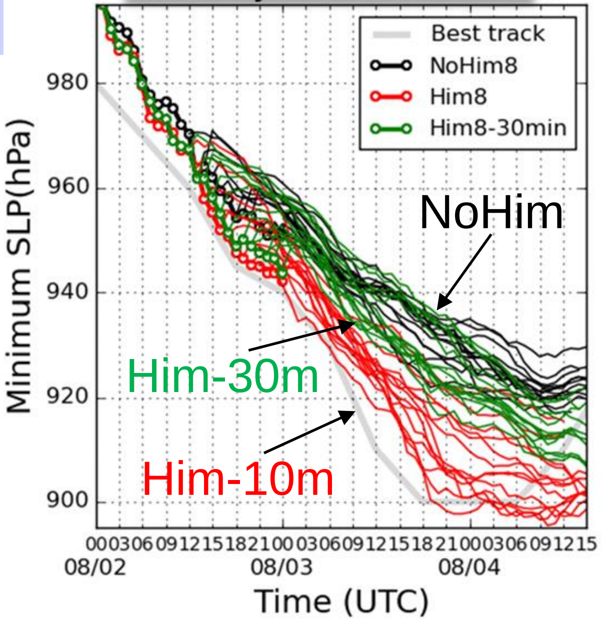


Analysis Increment Cross Section

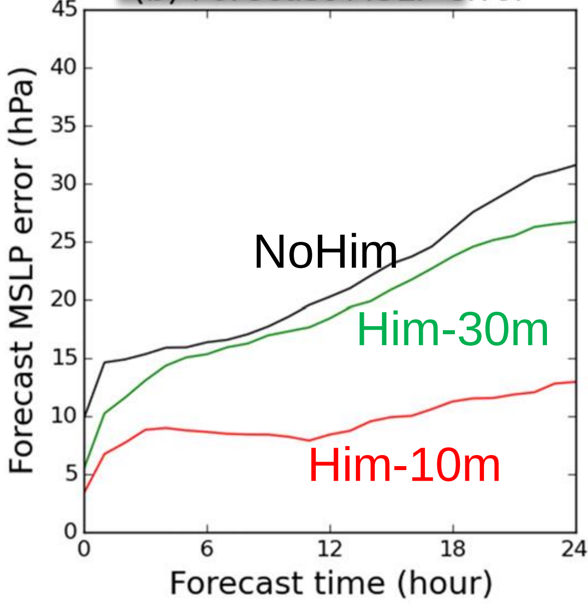
All-sky IR assimilation for geo Honda et al. 2018, MWR (2/2)

- Better reproduce radiances and hydrometeor distribution
- Better analyze TC structure
  - Upper-lev warm core, contracted eye, inner-core moisture
- Improve rapid intensification forecast
- Greater benefit from 10-min obs than 30-min obs

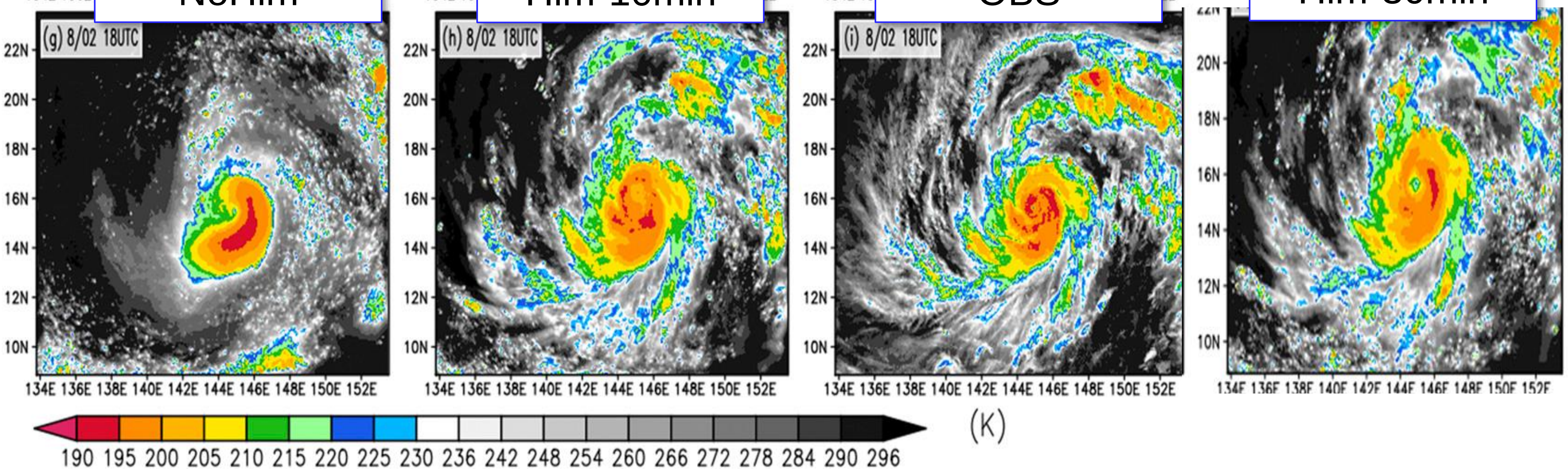
Analysis & Forecast MSLP



Forecast MSLP error

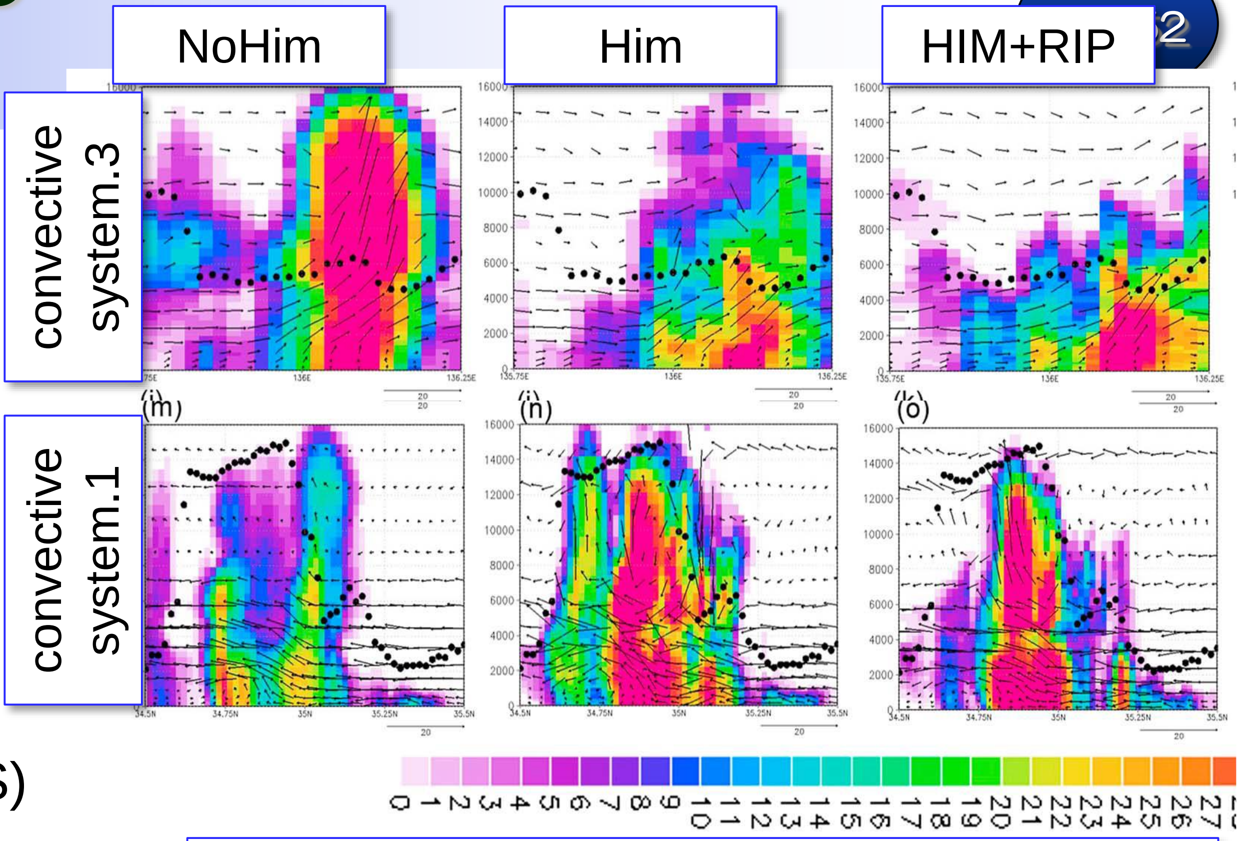


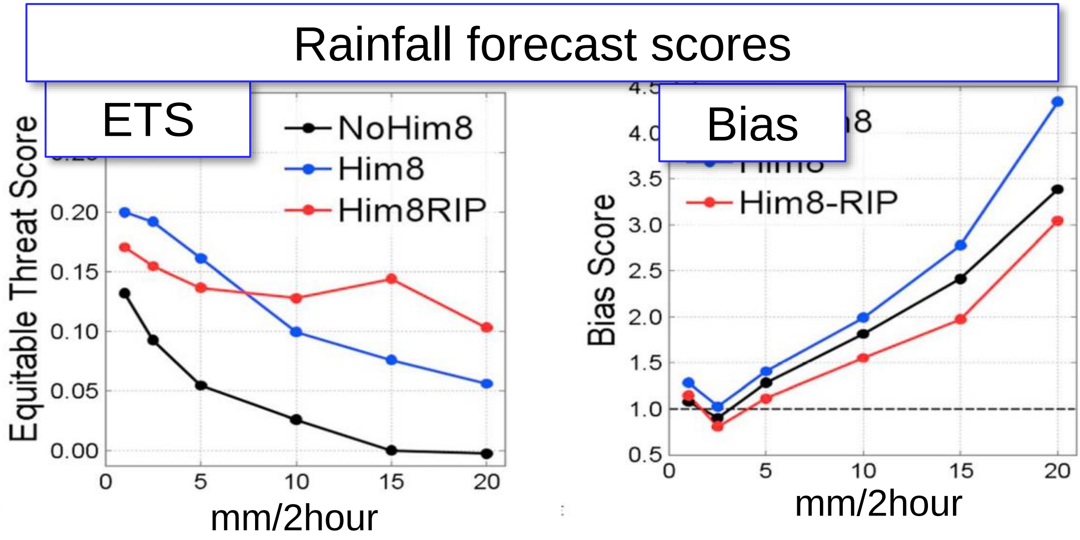
NoHim | Him-10min | OBS | Him-30min



All-sky IR assimilation for geo
Sawada et al. 2019, JGR

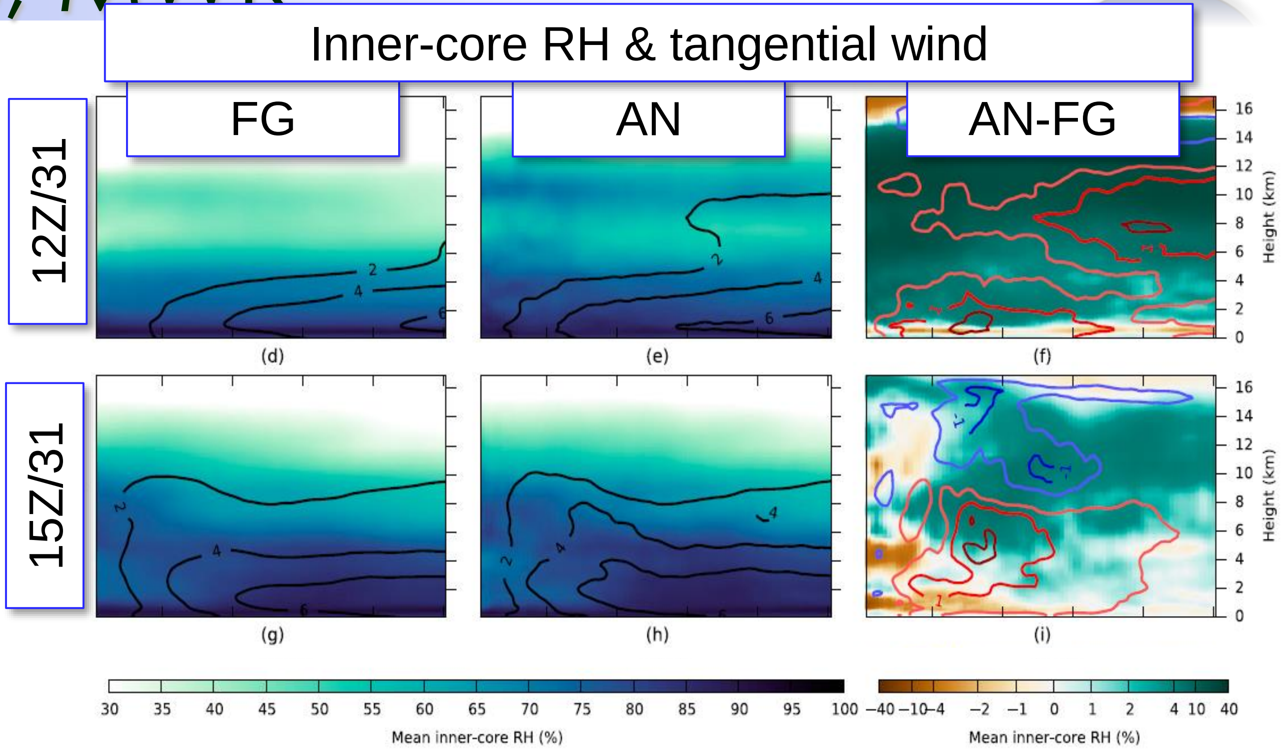
- 10min Himawari8 ASR assimilation with LETKF for unorganized convective cells
  - Band 8 (6.2µm) and 10 (7.3µm), but not considering obs error corr
  - Obs error: 5 & 7 K (inflate Desroziers' estimate)
  - No BC
- Employ RIP to better handle nonlinear dynamics and shorten spin-up time
  - Running-in-place (Kalnay & Yang 2010, QJRMS)
- Improves analysis and forecasts of the unorganized systems and rainfall
- Smaller spatially thinning distance (every other~5km) is crucial to capture the small-scale convective structures even if obs error correlation is not explicitly treated

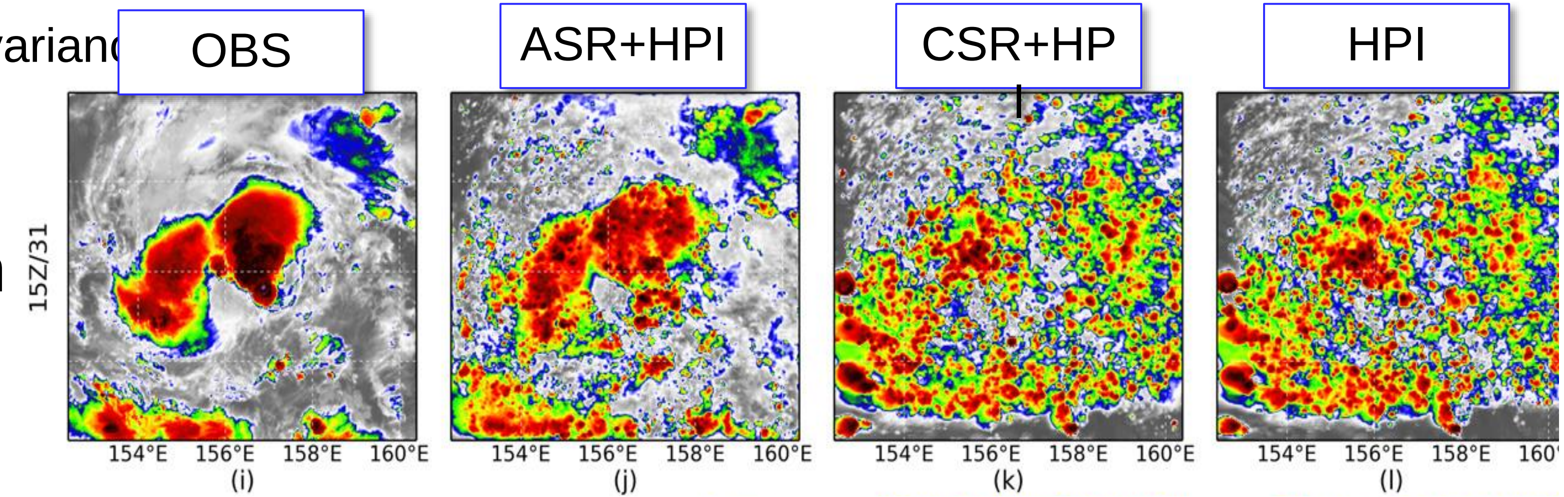




All-sky IR assimilation for geo
Minamide & Zhang 2018, MWR

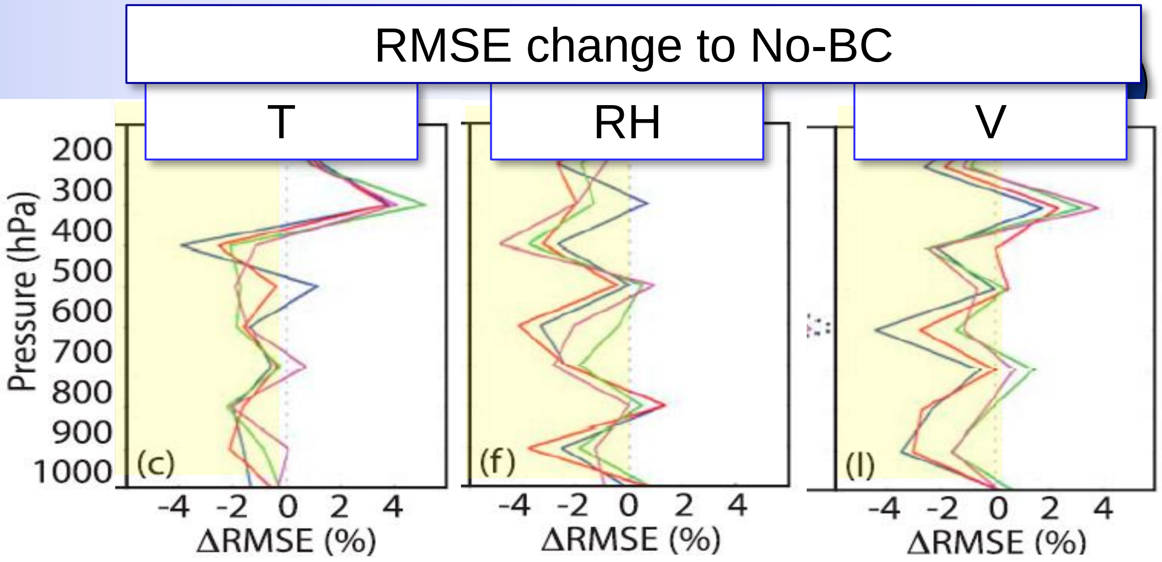
- Hourly Himawari8 ASR assimilation for TC with LETKF
  - WV band8 (6.2 μm), Thinning 12km
  - Obs error model using ensemble spread
    - AOEI (Adaptive Obs Error Inflation; Minamide & Zhan, 2017; MWR)
- Results: ASR assimilation
  - Better constrains not only temperature and moisture, but also TC vortex even inside the inner core
    - Through flow-dep ens-based covarianc
  - Successfully predicts rapid intensification
- CSR assimilation is not enough to improve TC structure

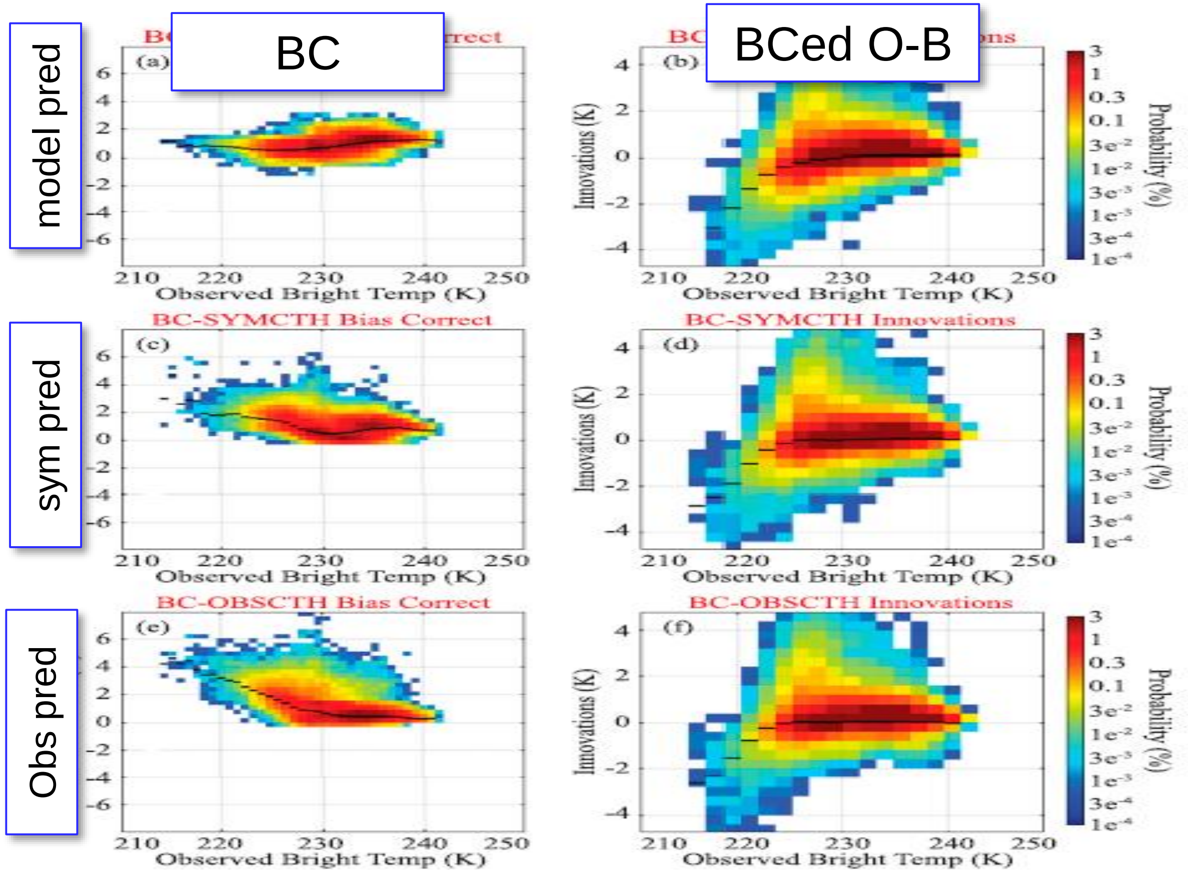




All-sky IR assimilation for geo
Otkin & Potthast 2019, MWR

- Examine bias correction (BC) effect on BT and RAOB fit
  - MSG 6.2µm band, obs error: 4K
  - Hourly update cycle with KENDA for 3 days
  - Longer range forecasts is to be verified
- BC employs linear and nonlinear predictors
  - Observed BT or cloud-top-height are recommended as predictors
- Assimilating ASR with BC improves the fit
  - BC remove –ve bias in low BT
  - No-BC improves BT fit but worsens RAOB fit especially for RH
- Symmetric (or model-based) parameter may not be an effective BC predictor





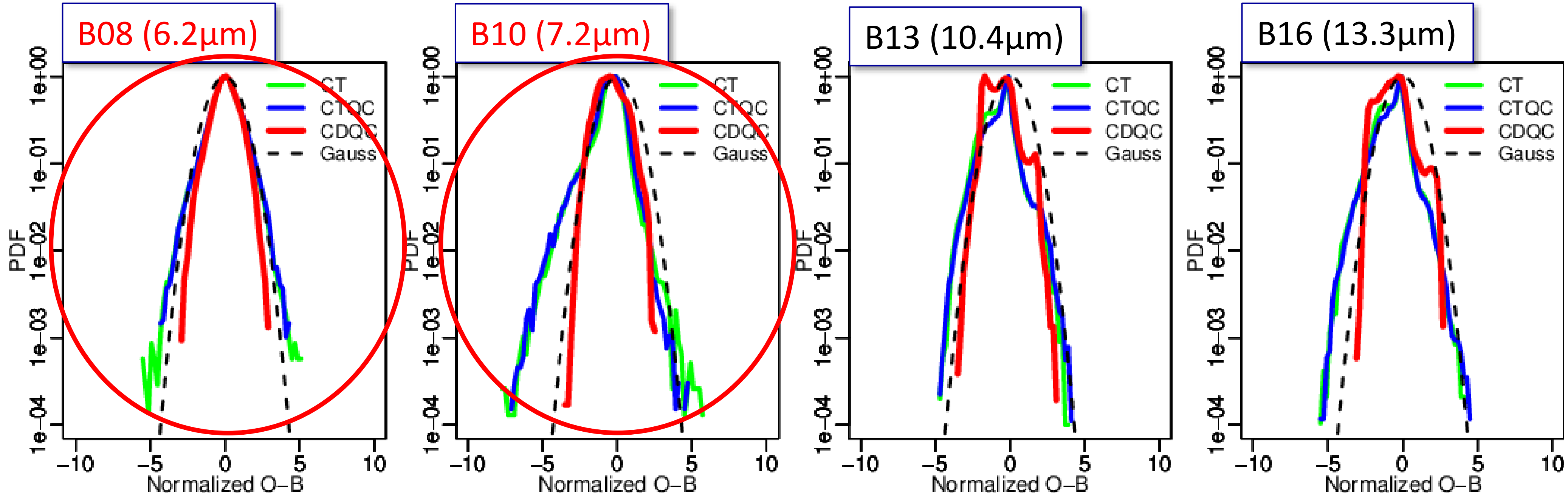
6. Concluding Remarks

- All-sky IR assimilation has been recently significantly progressed
  - But no operational assimilation has started yet, probably because operational centers prioritize all-sky MW
  - Many published researches demonstrate benefit of all-sky IR, especially from geo satellite obs with wide coverage and frequent availability
- Additional benefits to clear-sky IR and all-sky MW should be gained if
  - The challenges discussed here are (partially) addressed
  - Computational cost is allowed
  - Model bias is well handled (by improving moist process, correcting bias, keeping away from biased regions,,,)

Acknowledgements

- Attending the workshop is partially supported by ECMWF
- This study was partly supported by
  - JSPS KAKENHI Grant Number 19H01973
  - JAXA 2nd Research Announcement on the Earth Observations

Challenges: DA: Non-Gaussianity

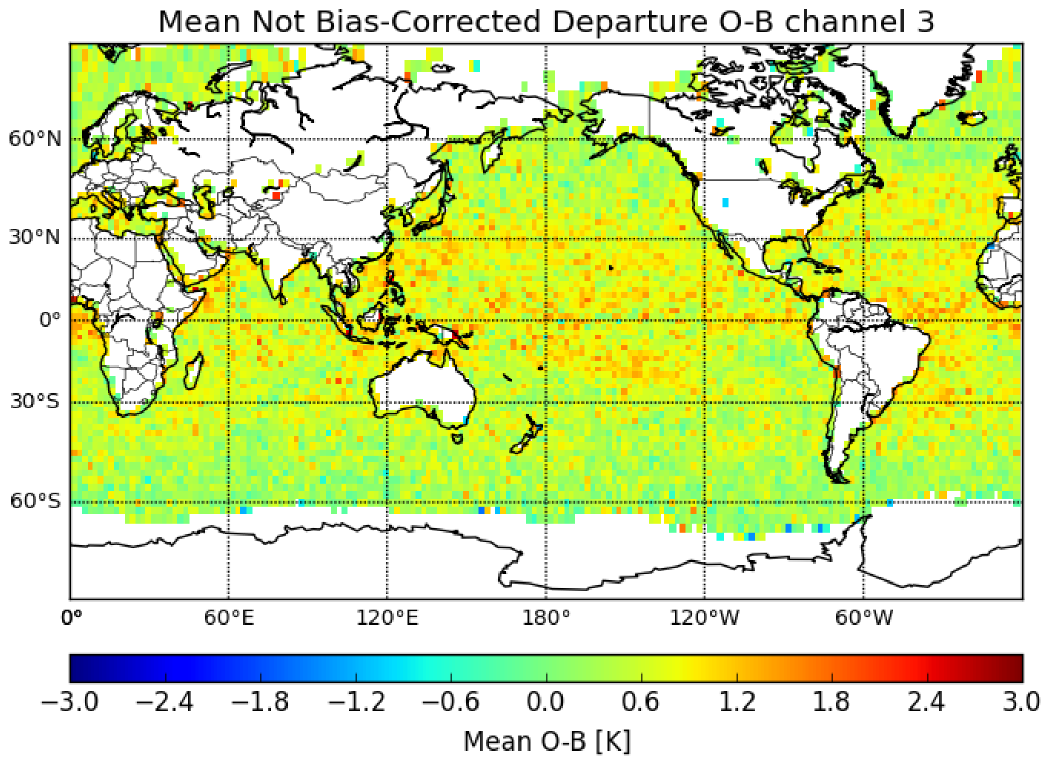


- O-B normalized with cloud-dependent O-B SD after QC in different case (Jan 2016)
- WV-sensitive bands show Gaussianity
- Non-gaussian for window band (B13) and low tropospheric T band (B16)
  - Gaussianity is dependent on scene (cloud) for low tropospheric T band

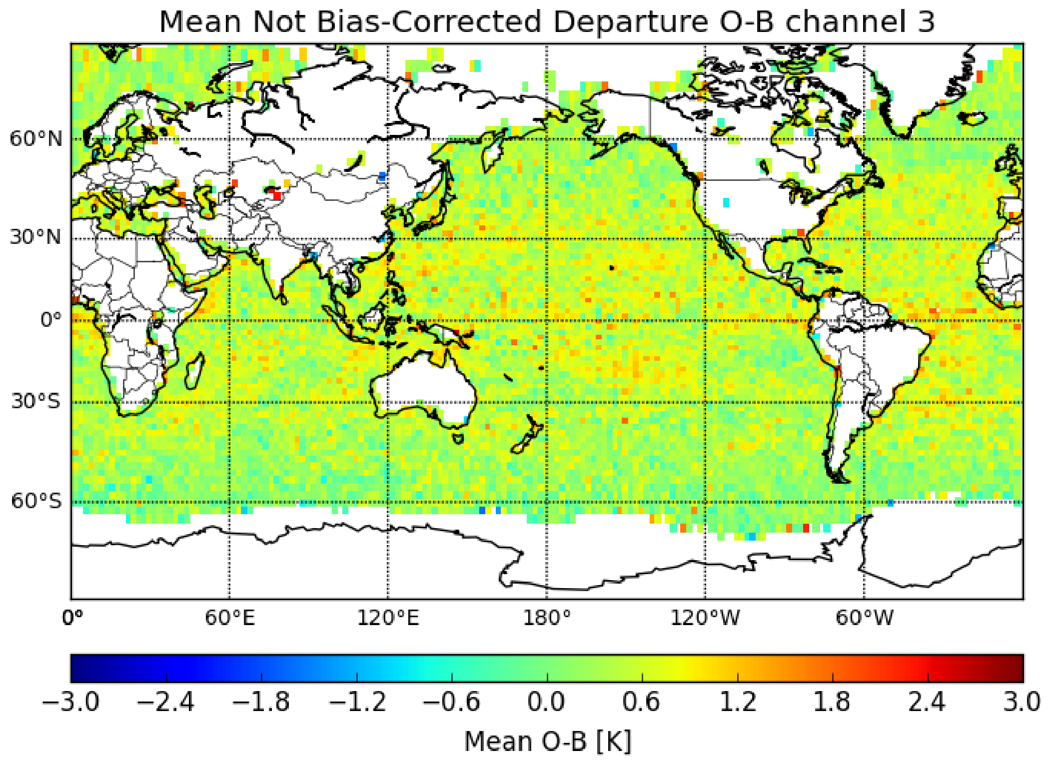
Okamoto 2017, QJRMS

MHS channel 3 unbias corrected mean O-B for control and experiment

Clear sky IASI experiment???



All sky IASI experiment

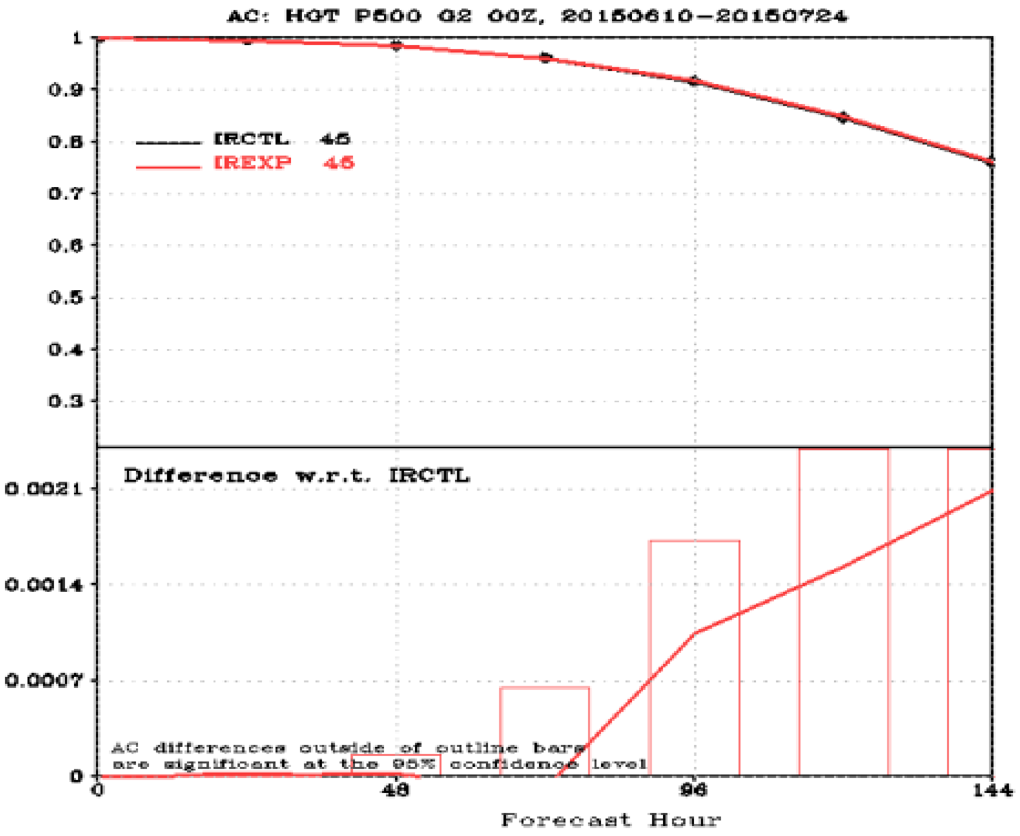


IASI All-sky radiances assimilation reduced the bias of other satellite instrument.

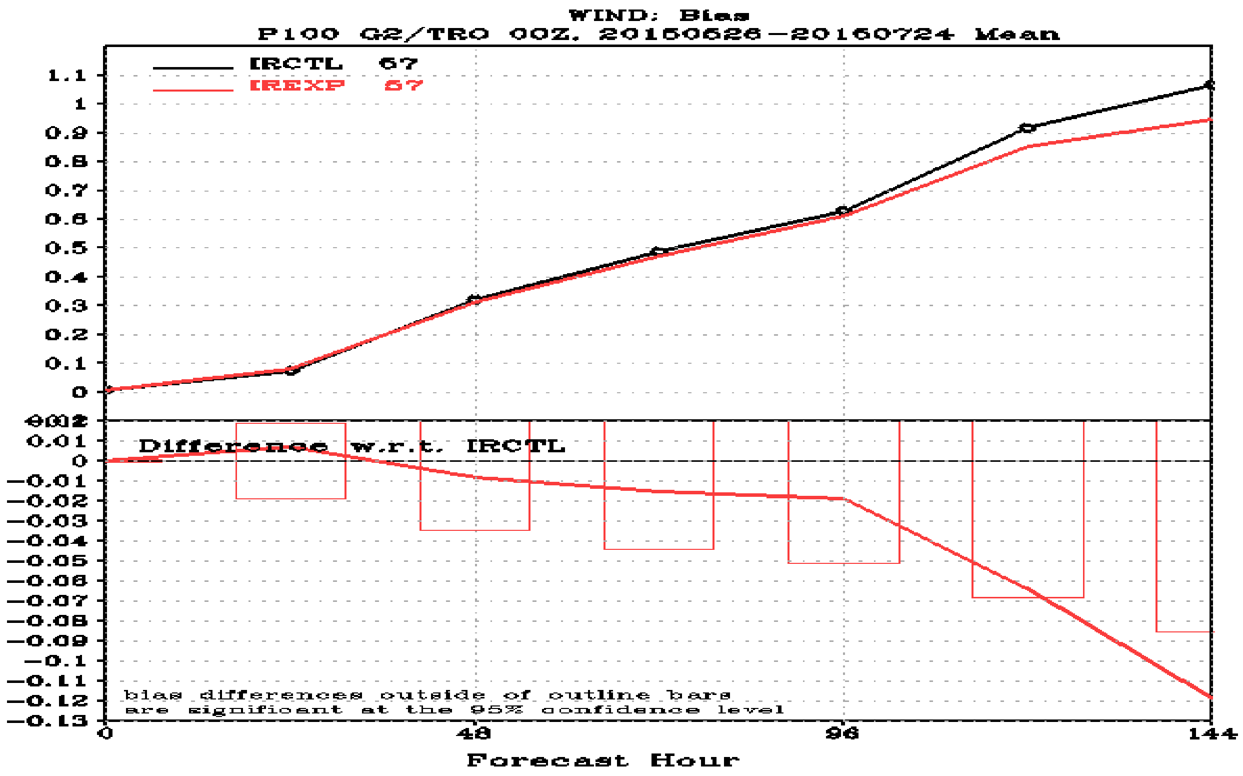
NCEP
From A. Collard and L. Bi

Results from parallel experiment : 2015052500-2015072400

500Z Anomaly Correlation



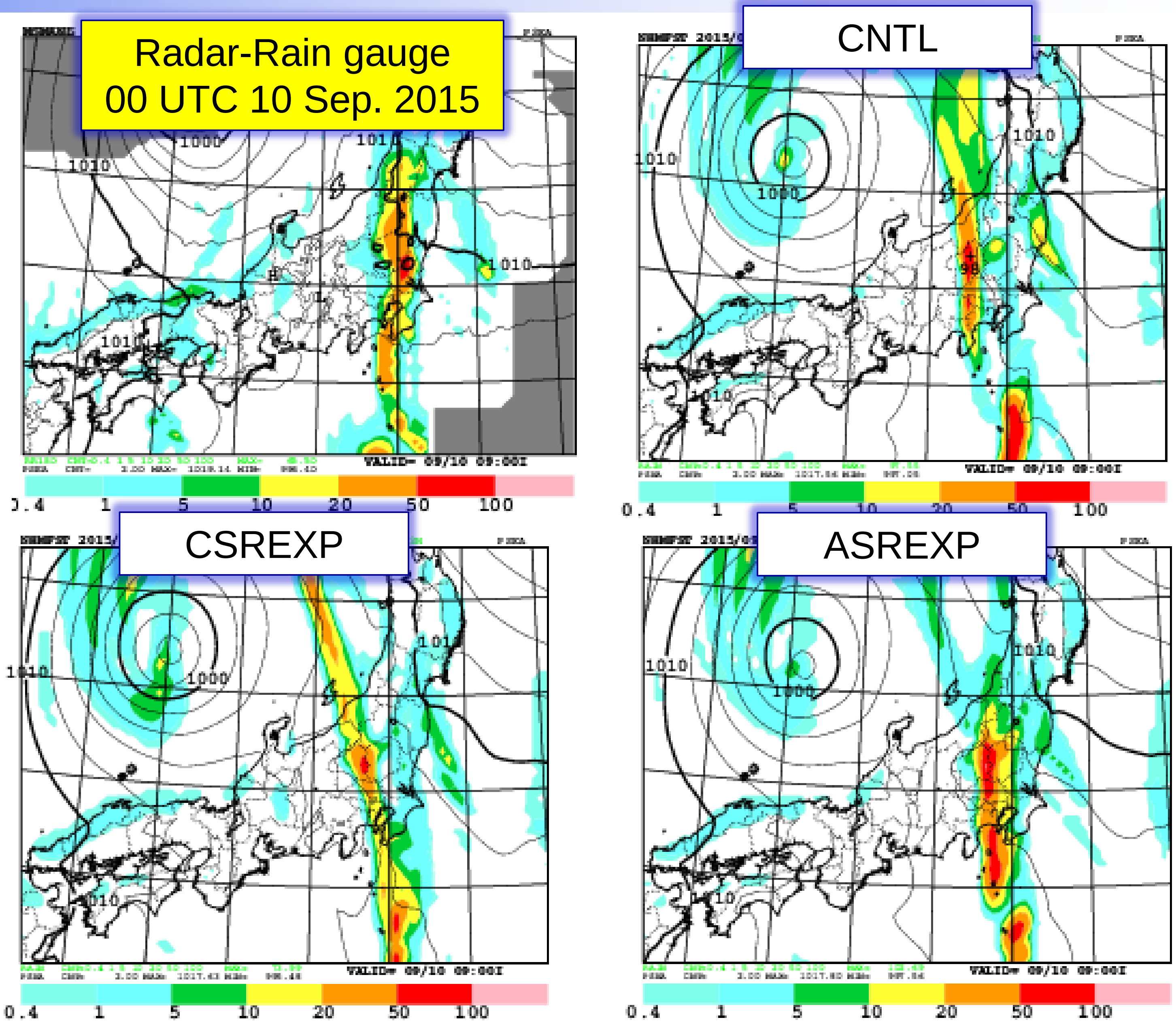
Wind Bias



Assimilating IASI water vapor sensitive channels in all-sky condition show slight positive/neutral impact.

Development at JMA: impact on regional DA

- Compare assimilation of ASR and CSR of Himwari8/AHI WV band with LETKF
  - 3h rainfall at 24 h fcst, initialized at 00 UTC 9 Sep
- CNTL (no rad) and CSR assimilation predict the heavy rainfall shifted to the west at this analysis
- ASR assimilation brings more stable improvement due to better spatial and temporal availability



Okamoto et al. 2019, QJRMS