Vertical localization for the microwave humidity sounder in the ensemble Kalman filter

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Variational scheme vs. Ensemble Kalman filter scheme

- Cost function:

Background error covariance **Observations error covariance**

$$J(x) = (x - x_b)^T \boldsymbol{B}^{-1}(x - x_b) + [y_0 - H(x)]^T \boldsymbol{R}^{-1}[y_0 - H(x)]$$

$$\nabla J(x_a) = 0$$

x_a : model variables
x_b: model background variables
y_0: observations
H: observation operator

- Analysis solution

$$x^a = x^b + \underbrace{\boldsymbol{B}H^T(H\boldsymbol{B}H^T + \boldsymbol{R})^{-1}}_{\text{Kalman gain matrix}}\underbrace{\left[y^o - H\left(x^b\right)\right]}_{\text{Observation increment}}$$

Variational scheme
(e.g., 3D-Var and 4D-Var)

"Static"
Background error covariance (B)

Ensemble Kalman filter scheme
(e.g., EAKF and LETKF)

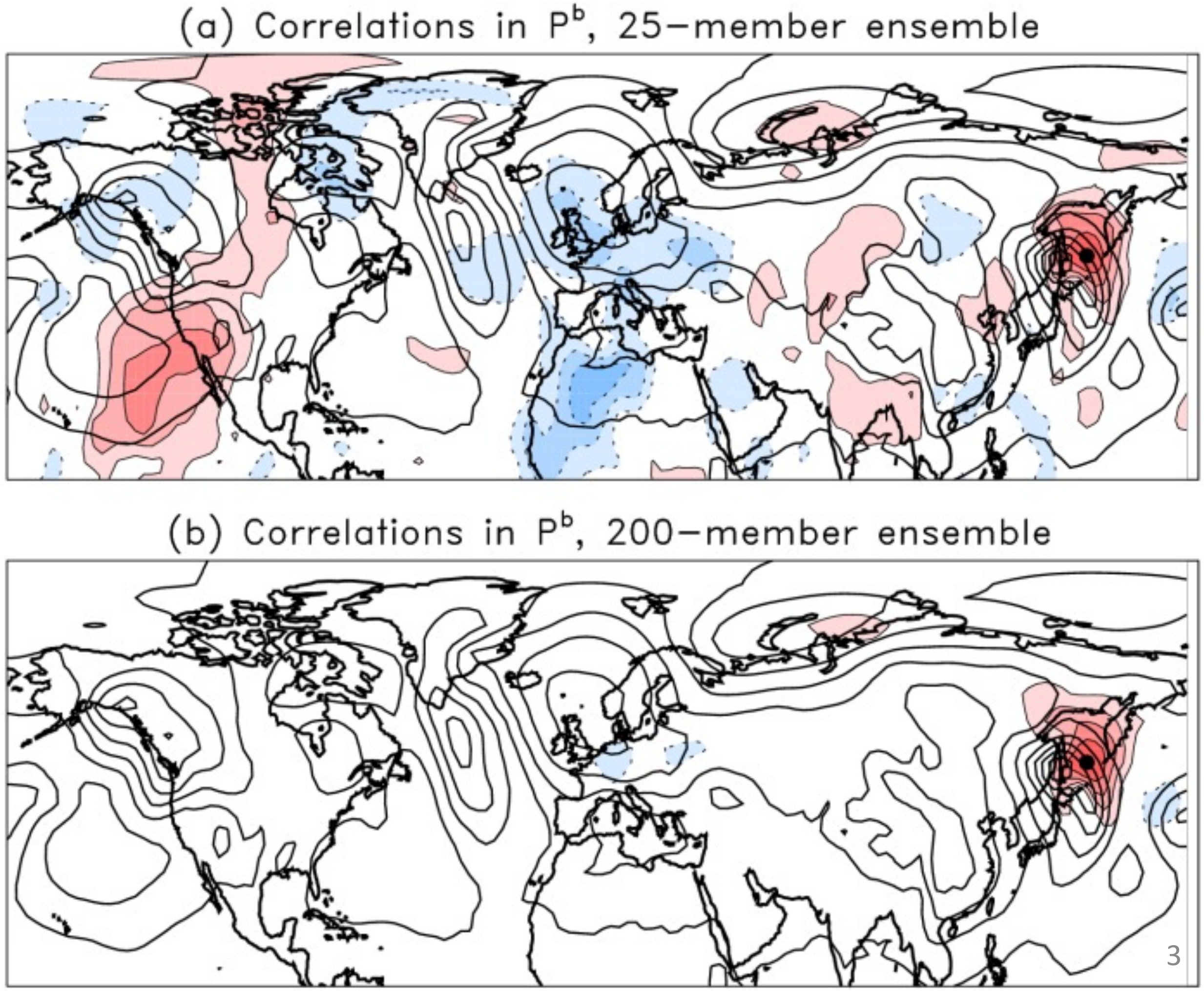
"Flow-dependent"
Background error covariance (B)

Sampling error – Spurious correlation (or covariance)

- # of ensemble members < 50 ····▸ Not capture the true covariance
- To counteract the sampling error, the "localization" function is used.

# of ensemble: 25

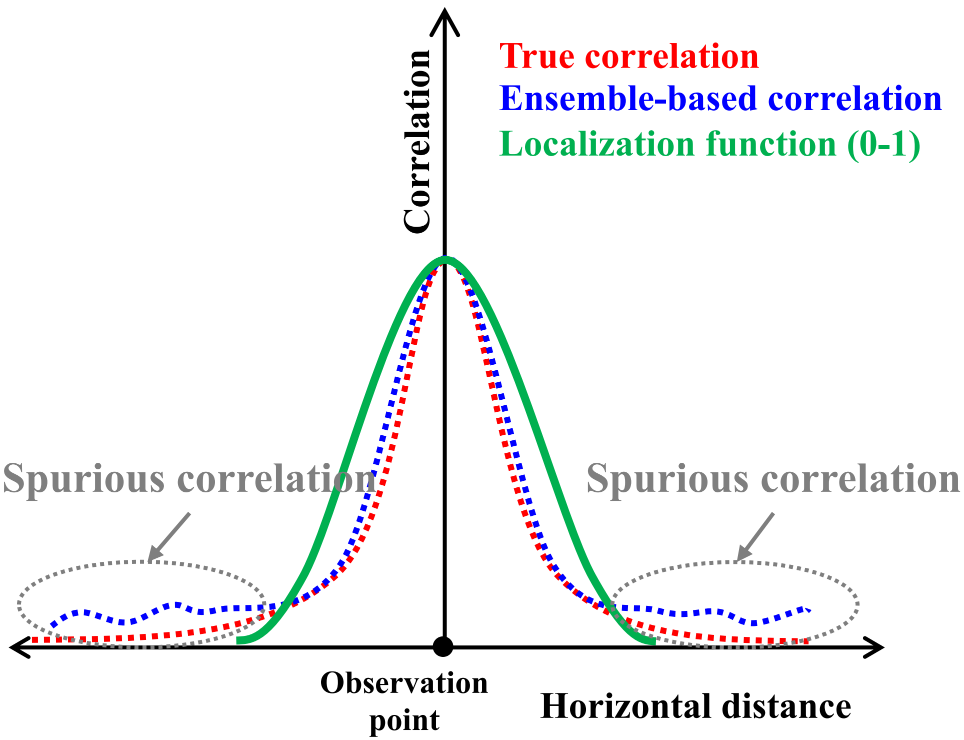
# of ensemble: 200



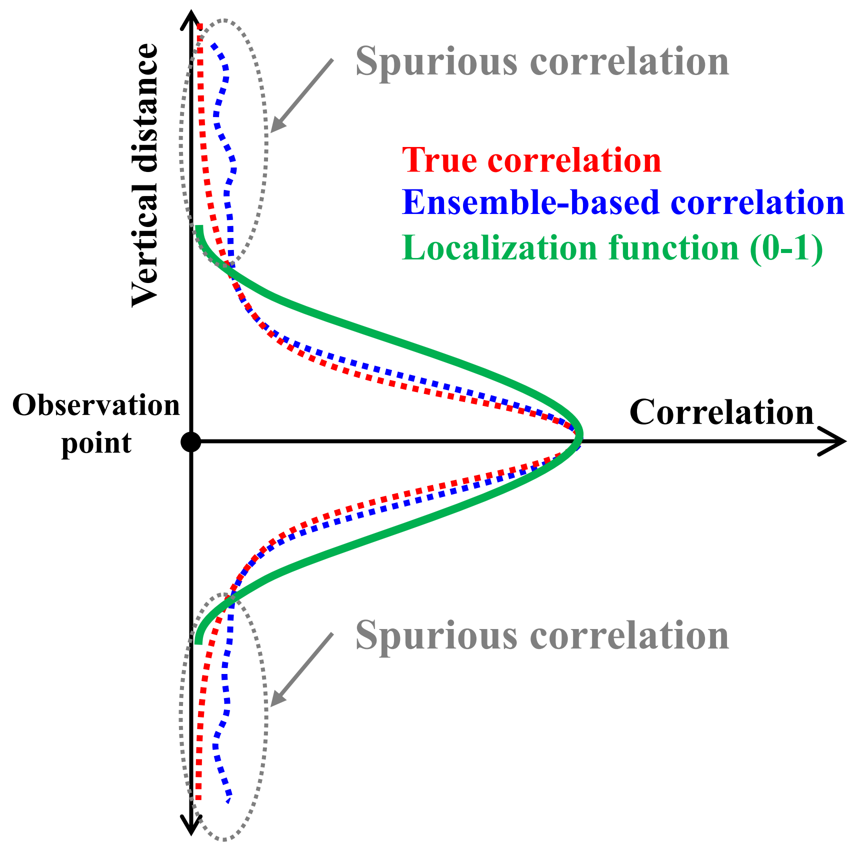
(from Vetra-Carvalho)

“Horizonal” and “vertical” localization in EnKF

Horizontal localization

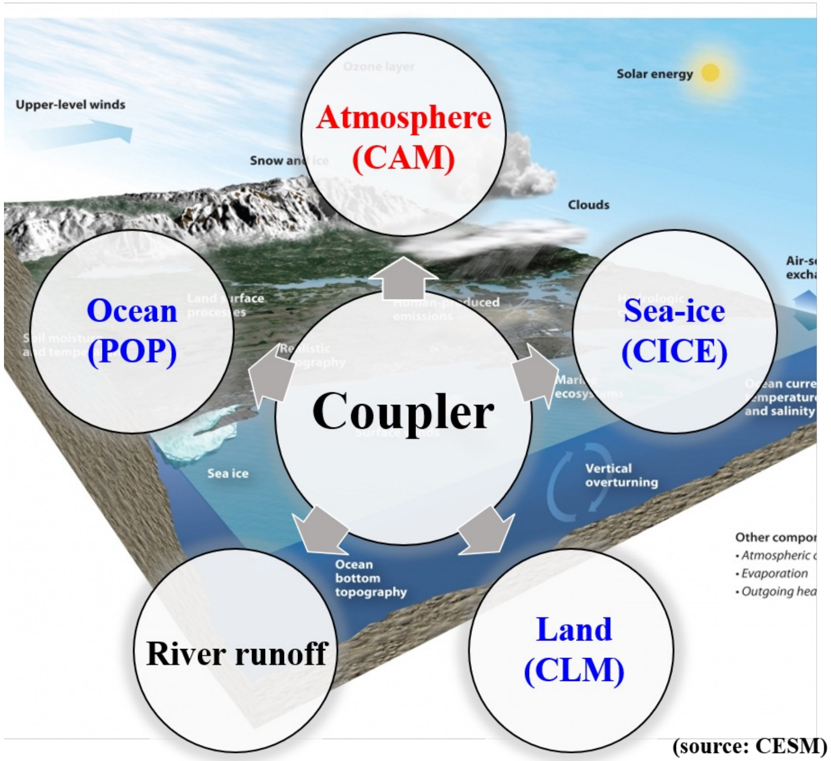


Vertical localization



CESM (Community Earth System Model) + DART (Data Assimilation Research Testbed)

<CESM>



(source: CESM)

<DART>

Ensemble Kalman Filter (EnKF)

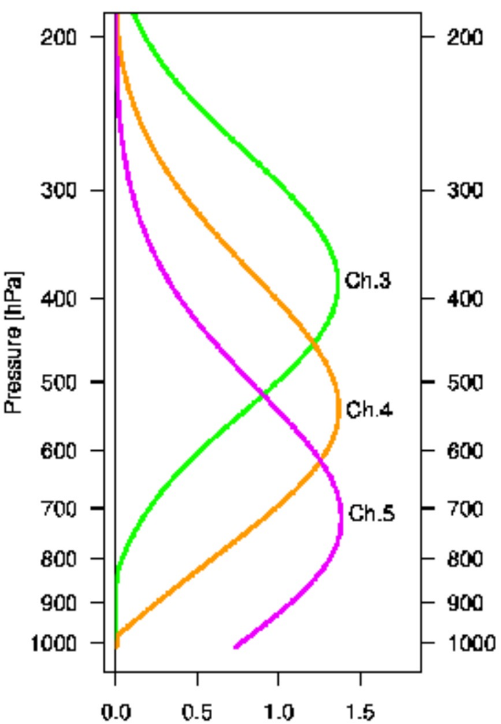
Lower Atmosphere	Upper Atmosphere	Ocean	Cryosphere	Land Surface	Hydrology
CAM	WACCM	POP	CICE	CLM	WRF-Hydro
WRF	GITM	ROMS		NOAH	
WRF-Chem	Open GGCM	MITgcm-ocean		NOAH-MP	
MPAS-Atmosphere	TIE GCM	MPAS-ocean			
AM2	ROSE	FESOM			

- **AMSU-A and MHS radiances are assimilated within the CESM-DART system.**
- **Three localization functions (i.e., Gaspari-Cohn, Boxcar and Ramped Boxcar) are available.**
- **The geolocation information is required for horizontal and vertical localization.**
  - **Horizontal localization: latitude and longitude of observation**
  - **Vertical localization: pressure level or height of observation**
- **The vertical location for the radiances is assigned as the peak height of WF or Jacobian.**

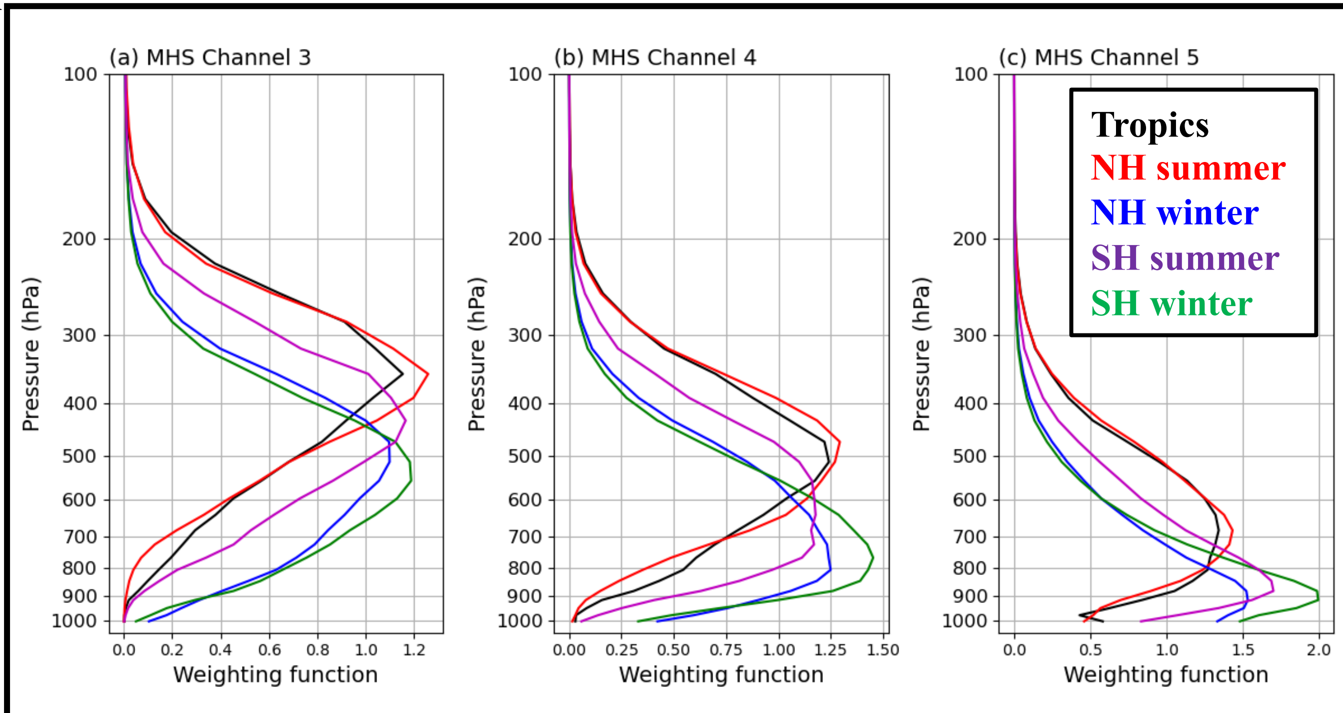
Vertical localization for MHS

- For AMSU-A, the vertical location is assigned as the peak height of mean WF or Jac.
- The peak height of WF or Jacobian vary depending on the water vapor amount.
- For MHS, the vertical localization is not activated in the current DART system.

MHS
“mean” weighing function



MHS
weighing functions depending on the “water vapor amount”



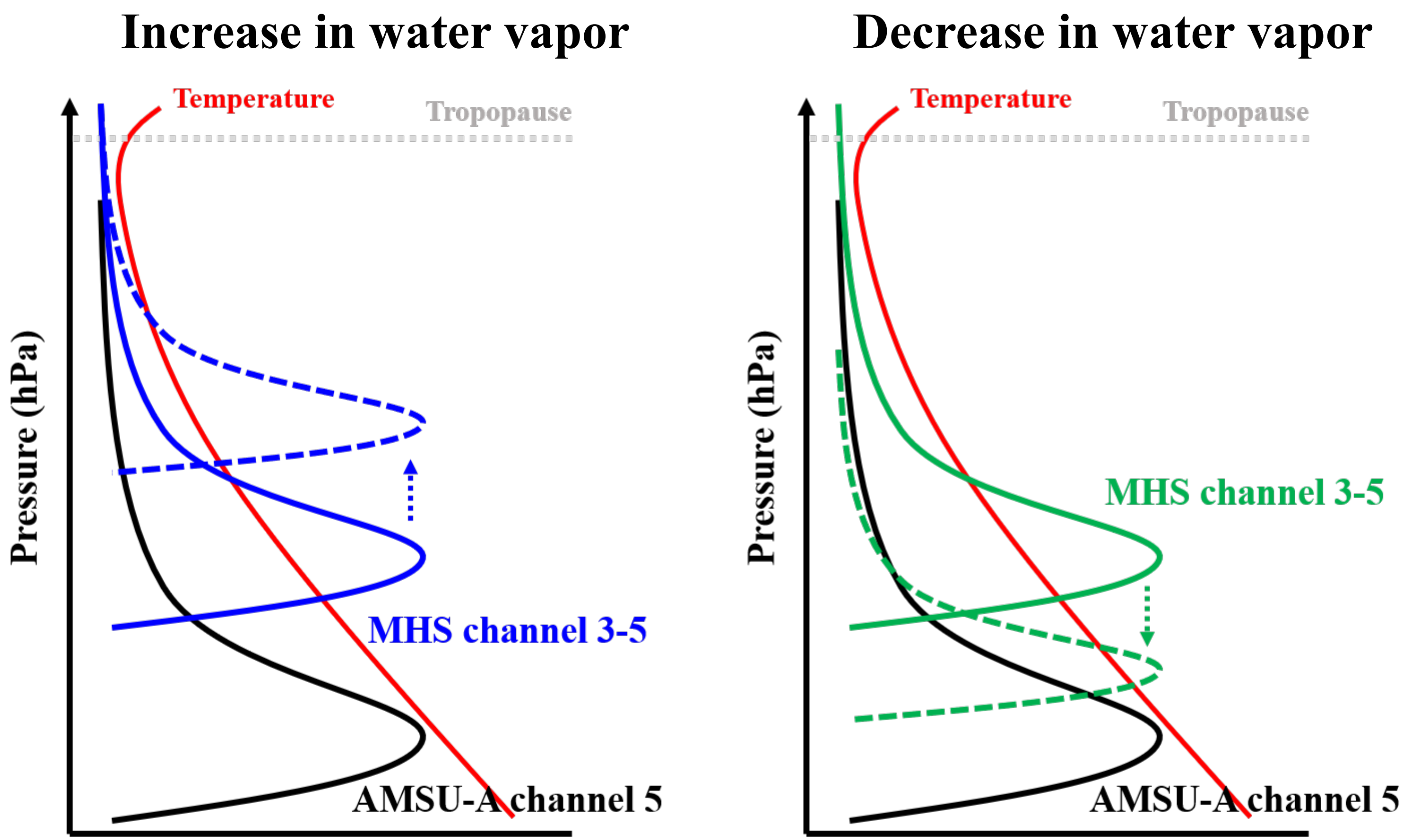
Objectives

- To activate the vertical localization for MHS radiances,
    - Propose a method to provide the “vertical location” for MHS,

      based om “the spectral characteristics” of AMSU-A and MHS
    - Advantages:
        - Only using the AMUS-A and MHS radiances
        - Using the simple regression approach, not sophisticated approach

- Alternative approach: the RTM simulation using the model background
    - However,
    - The error can occur due to the uncertainty of the background moisture.
    - Additional computation cost is required due to the RTM simulation.

Basic concept



- When the WF moves upward due to WV increase, ΔBT (AMSU-A ch 5. – MHS chs.) increases.
- When the WF moves downward due to WV decrease, ΔBT (AMSU-A ch 5. – MHS chs.) decreases.
- ΔBT (AMSU-A – MHS) can provide information on the peak height of WF for MHS radiances.

Training dataset for the regression method

RTTOV simulation

- Input data:

NWP-SAF reference dataset (20,000 profiles)

Total 28 atmospheric parameters

T, q, O_3, cloud liquid water, cloud ice water on 137 pressure levels

Surface parameters (2m T, 2m q, 10m wind, surface pressure, etc)

- Output data:

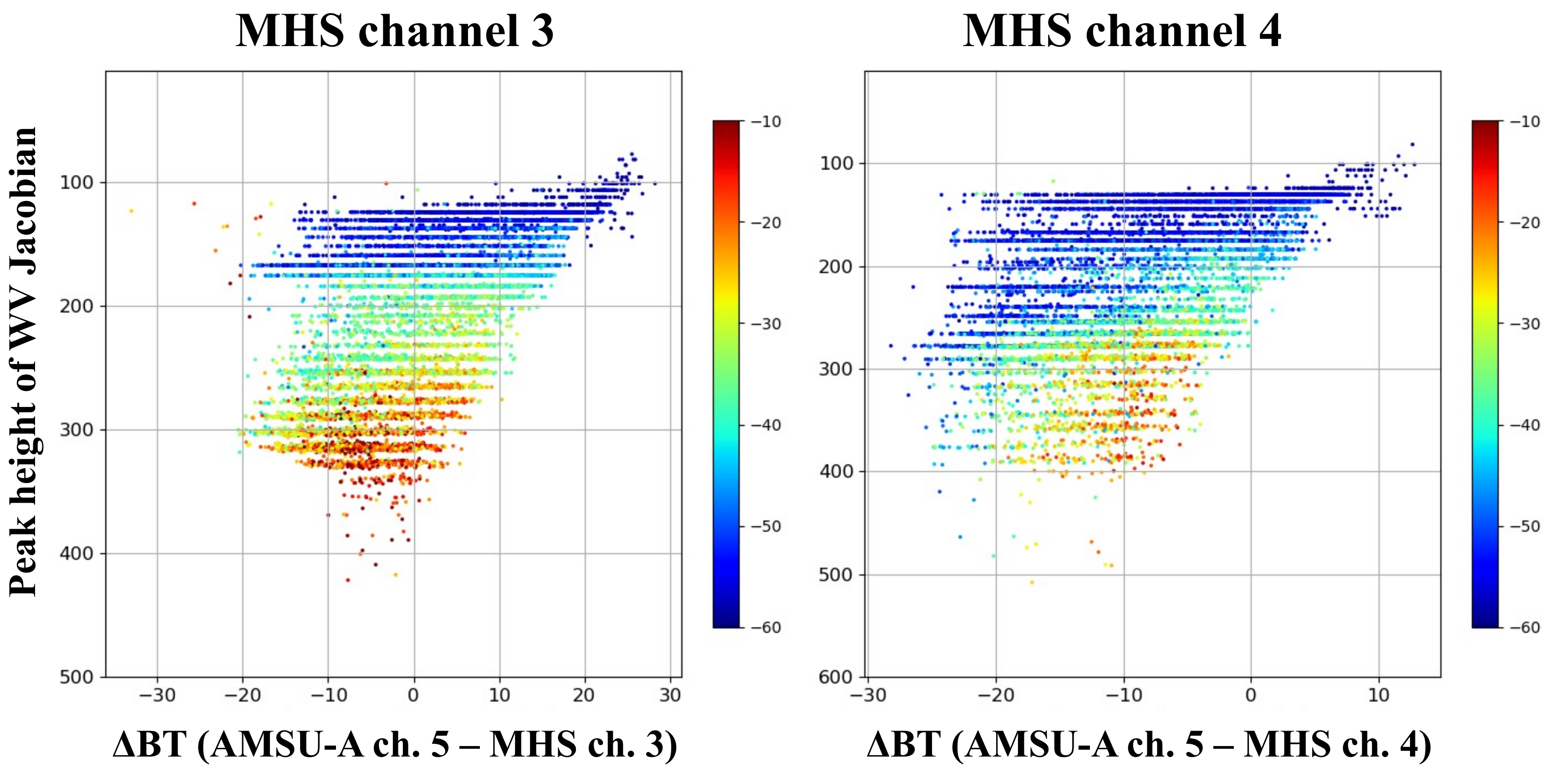
Brightness temperatures (BTs) for AMSU-A and MHS

Weighting functions

Temperature and water vapor Jacobians

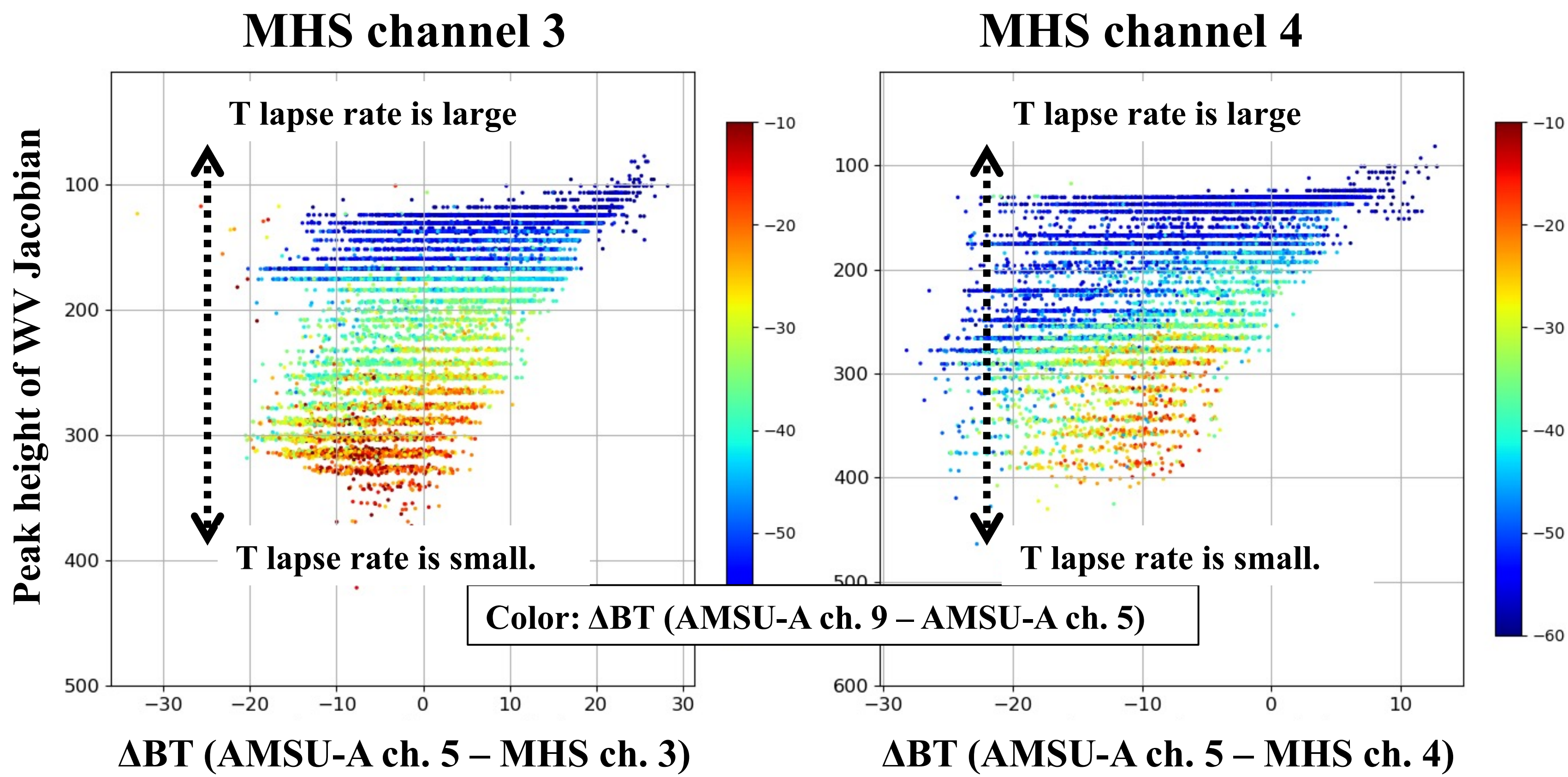
"Reference peak height" is defined as the peak height of "WV Jacobian" for MHS

ΔBT(AMSU-A ch. 5 – MHS chs. 3 and 4) vs. Ref. peak height



- When the peak height is higher, ΔBT (AMSU-A ch. 5 – MHS chs.) increases.
- When the peak height is lower, ΔBT (AMSU-A ch. 5 – MHS chs.) decreases.
- However, the relationship is not linear due to difference temperature vertical structure.

ΔBT(AMSU-A ch 5 – MHS chs 3 and 4) vs. Ref. peak height



- The temperature lapse rate is situation-dependent.
- ΔBT (AMSU-A ch. 9 – AMSU-A ch. 5) provides information on the temperature lapse rate.
- Therefore, two ΔBTs are used to generate the peak height of WV Jacobian for MHS.

Development of multivariate regression model

Step 1. Regression coefficients are calculated via the multivariate regression approach.

<multivariate regression model>

$$p = \beta_0 + \sum_{j=1}^{2} \beta_j \cdot BTD_j$$

Target variable (*p*)

Reference peak height of WV Jacobian for MHS

Predictors (*BTD_j*)

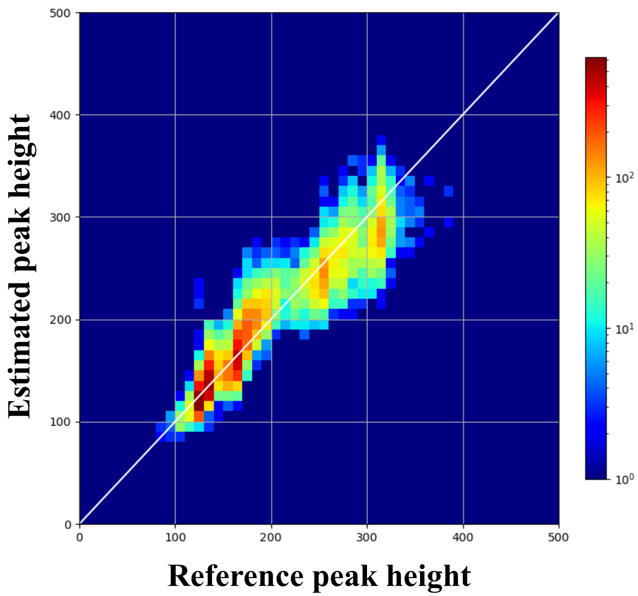
BTD_1 : ΔBT (AMSU-A ch. 5 – MHS chs. 3 and 4)

BTD_2: ΔBT (AMSU-A ch. 9 – AMSU-A ch. 5)

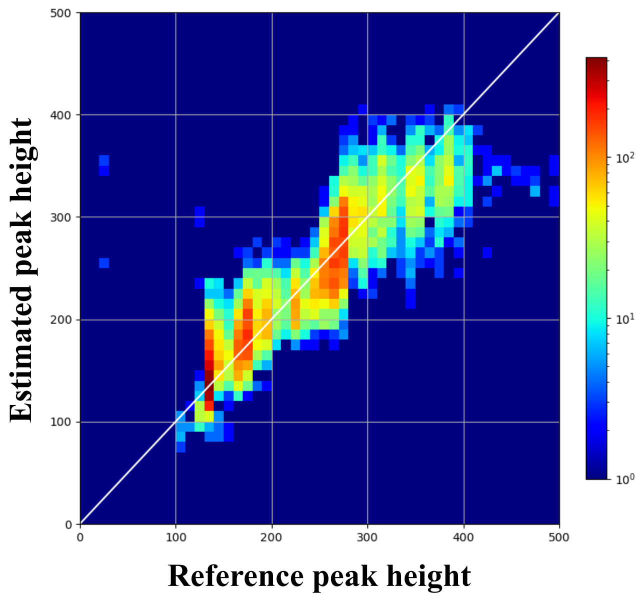
Regression coefficients (β_0, β_j)

Step 2. Using the estimated regression coefficients, the peak height is estimated.

Estimated p vs. Ref. p (MSH channel 3)

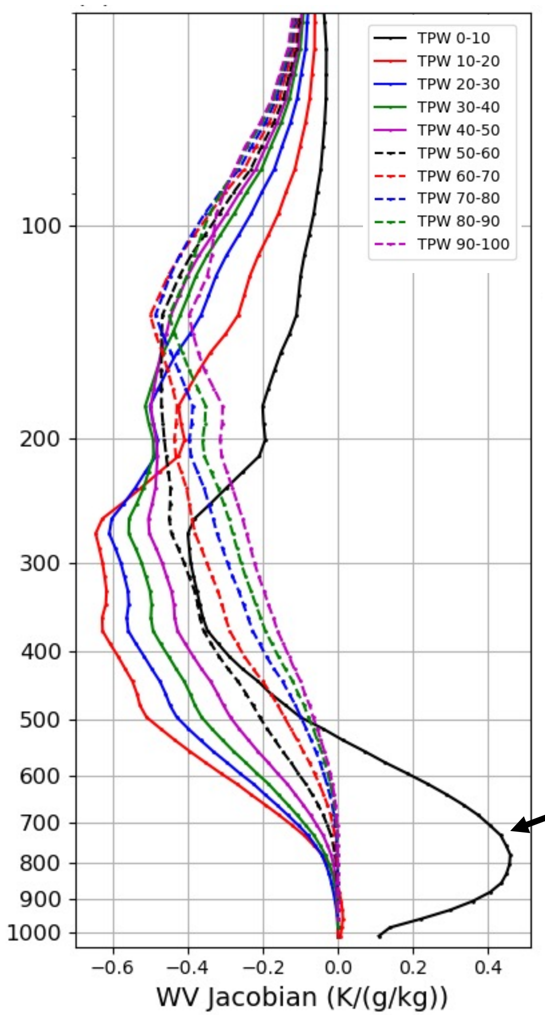


Estimated p vs. Ref. p (MSH channel 4)



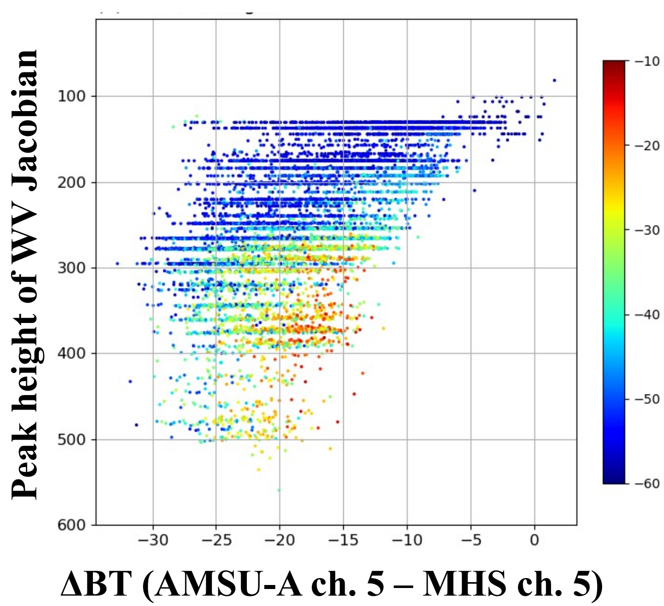
WV Jacobian for MHS ch. 5 depending on TPW

MHS channel 5
WV Jacobian

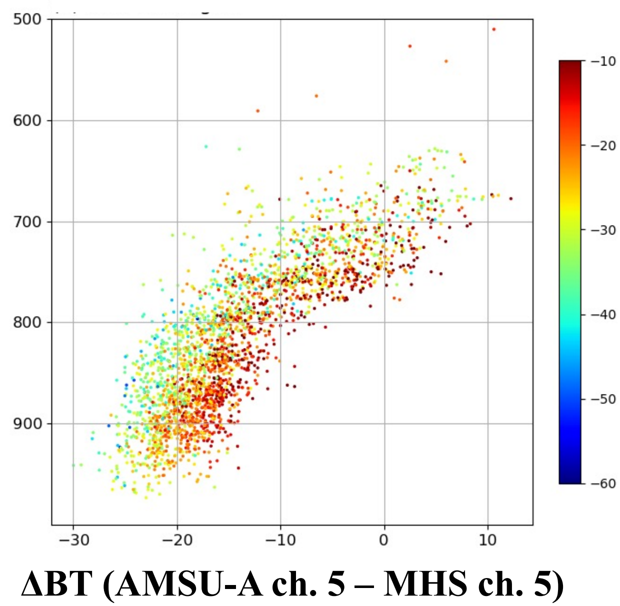


ΔBT(AMSU-A ch 5 – MHS ch 5) vs. Ref. peak height

TPW > 10 kg/m^2



TPW < 10 kg/m^2



TPW < 10 kg/m^2

- **Under dry conditions (TPW < 10 kg/m^2), the positive peak occurs.**
- **This is due to the surface signal over the ocean.**

Development of regression model

Step 1. Regression coefficients are calculated via the multivariate regression approach.

<multivariate regression model>

$$p = \beta_0 + \sum_{j=1}^{2} \beta_j \cdot BTD_j$$

Predictors (*BTD_j*)

if TPW > 10 kg/m^2

BTD_1 : ΔBT (AMSU-A ch 5 – MHS ch 5)

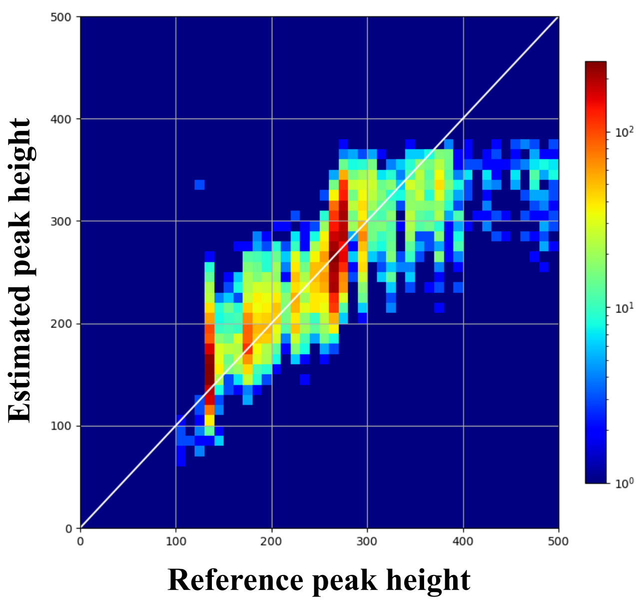
BTD_2: ΔBT (AMSU-A ch 9 – AMSU-A ch 5)

if TPW < 10 kg/m^2

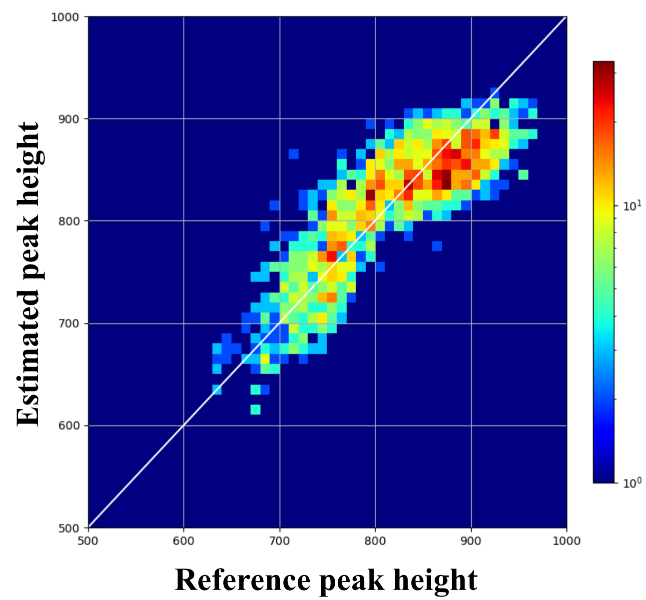
BTD_1 : ΔBT (AMSU-A ch 5 – MHS ch 5)

Step 2. Using the estimated regression coefficients, the peak height is estimated.

Estimated p vs. Ref. p
(TPW > 10 kg/m^2)



Estimated p vs. Ref. p
(TPW < 10 kg/m^2)



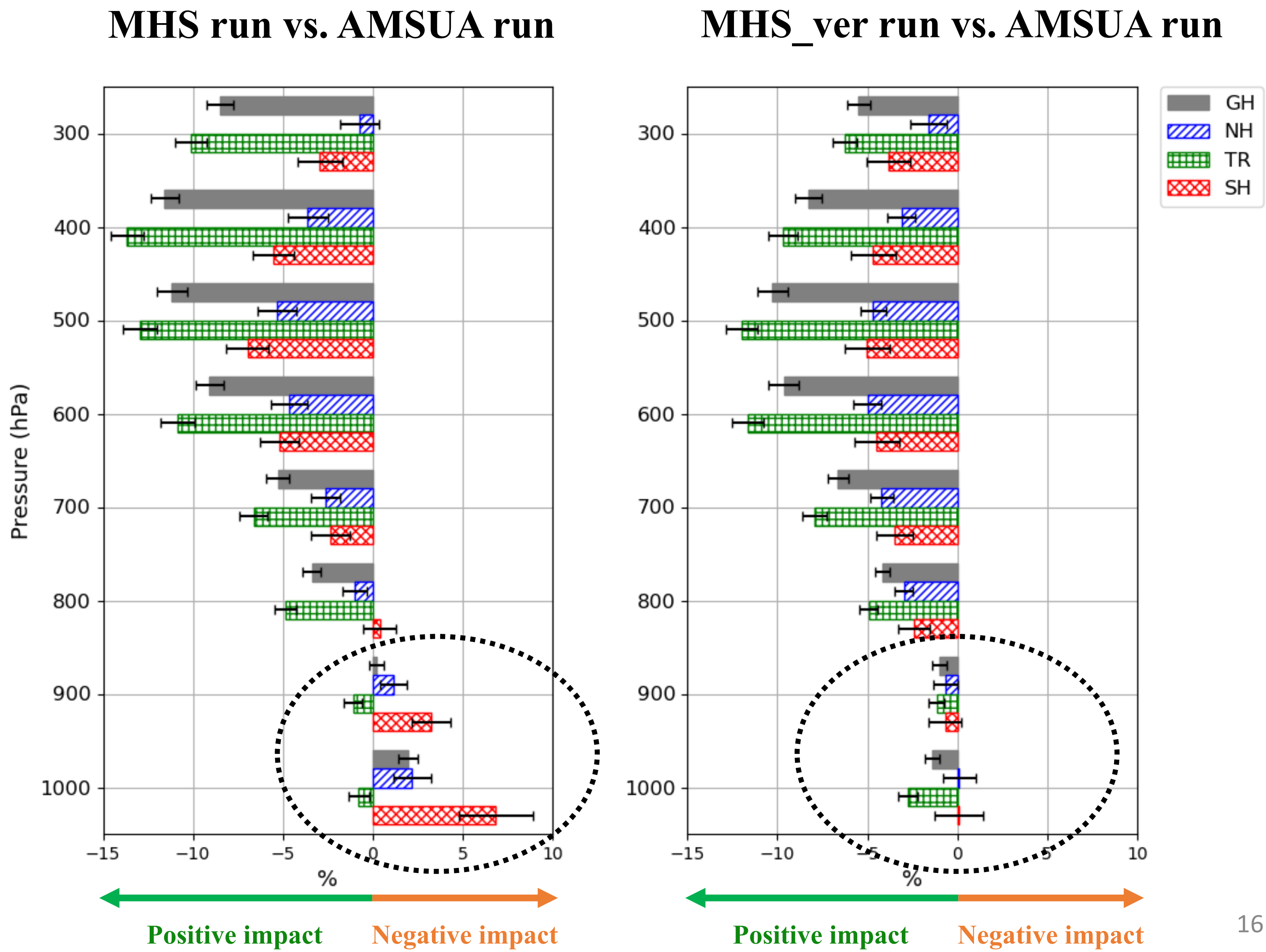
Experimental runs

- **Data assimilation system:** DART (v9.12) and CESM (v2.1.0)
- **Experiment period:** 11 August 2014 – 30 September 2014 (6 hourly)
- **DA scheme:** Ensemble Adjustment Kalman Filter (EAKF)
- **# of ensemble:** 20
- **Trial runs:**
    - **AMSUA run**: assimilating the NCEP conventional data + **AMSU-A radiances**
    - **MHS run**: Same as AMSUA run, but **MHS radiances assimilated**
    - **MHS_ver run**: Same as MHS run, but **vertical localization activated for MHS radiances**
- **Reference:** ECMWF ERA5 reanalysis

Impact on the moisture "analysis"

$$\text{Normalized difference} = \frac{\text{EXP - CNTL}}{\text{CNTL}} \times 100$$

< 0 : positive impact
> 0 : negative impact



Summary

- **Development of the method for the peak height retrieval for MHS**
  - Using the spectral characteristics of AMSU-A and MHS channels
  - Based on the multivariate regression approach
  - Reliable peak heights retrieved

- **Application of the retrieved peak height to the vertical localization in EnKF**
  - Moisture analysis improved
  - In particular, in “the Southern Hemisphere” and in “the lower troposphere”

- **Application of other microwave sounders**
  - MWTS and MWHS on board FY-3 satellite series
  - ATMS on board JPSS satellites (e.g., SNPP, NOAA-20, and NOAA-21)