Effect of GNSS Radio Occultation Data Assimilation in JMA's Global NWP System

Mitsuhiro Shimada, Kazuki Shimoji and Hiromi Owada

Japan Meteorological Agency

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Operational Status at Global NWP System

- JMA operationally assimilates GNSS RO data in Global and Meso-scale NWP systems.
- GNSS RO data assimilation in the Global Analysis
  - Assimilation of bending angle
  - Forward Operator : ROPP (version 8)
  - 1D operator
- Status of usage

Global Spectral Model (GSM) & Analysis	
Grid size	0.1875 deg. (TL959)
Vertical levels/Top	100/0.01 hPa
Forecast range (Initial time)	132 hours (00, 06, 18 UTC) 264 hours (12 UTC)
Initial condition	4D-Var Analysis (TL319)
Assimilation window	6h (-3 to +3 hours)
Data cut off time	Early Analysis : 2h20m Cycle Analysis : 11h50m(00,12UTC), 7h50m(06,18UTC)

Satellite	Current status	Period of operational use (Available for experimental use)
Metop-A	Operational use	30 Nov. 2009 ~
Metop-B		28 Nov. 2013 ~
COSMIC		01 Nov. 2010 ~
TerraSAR-X		18 Dec. 2012 ~
TanDEM-X	Monitoring for the operational use	(01 Jul. 2014 ~)
KOMPSAT-5		(17 Feb. 2017 ~)
FY-3C		(23 Aug. 2017 ~)
Metop-C		(28 Mar. 2019 ~)

Motivation

- Assimilation experiments were performed for the operational use of RO data from TanDEM-X and Metop-C

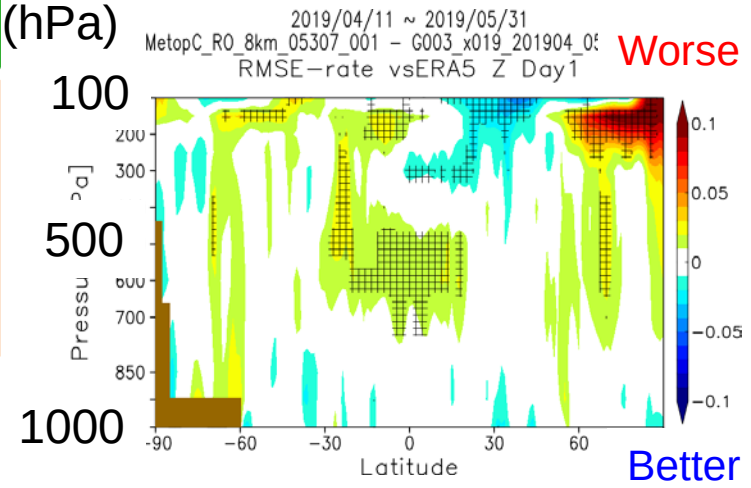
  RO data from these satellites are not used for operational assimilation into JMA 's Global NWP system
  - ➢ Assimilation of these data has negative impacts on 500 hPa geopotential height

TEST:
RO data from Metop-C are assimilated
CNTL:
JMA's Operational Global NWP system

Period: 2019/04/11 – 2019/05/31

Changes of RMSE of 24-hour forecast
(reference ECMWF ERA5)
[TEST: w Metop-C] – [CNTL: w Metop-C]

Geopotential height



Common problem with other satellite platform

We would like to operationally assimilate the new RO data. However, new data are not operationally used due to this negative impact.

It is necessary to solve this problem

Basic Investigation of the effect of RO data assimilation

Outline of Experiments

1. RO data denial experiments

- To investigate how the analysis and forecast fields are affected by the RO data assimilation in JMA's NWP system
- CNTL: JMA's Operational Global NWP system
- BASE: RO data denial experiment

Negative impact on analyzed temperature in lower troposphere

Why is the temperature in the lower troposphere affected?

2. Single observation tests

- To investigate how the assimilation of single RO data changes the analysis fields
- TEST: Single RO data is assimilated.

Increments are raised not only near the RO data height but also below the height such as 850 hPa

Which ajoint have impact in the lower troposhere?

3. Experiments using only the adjoint of one element (4 runs)

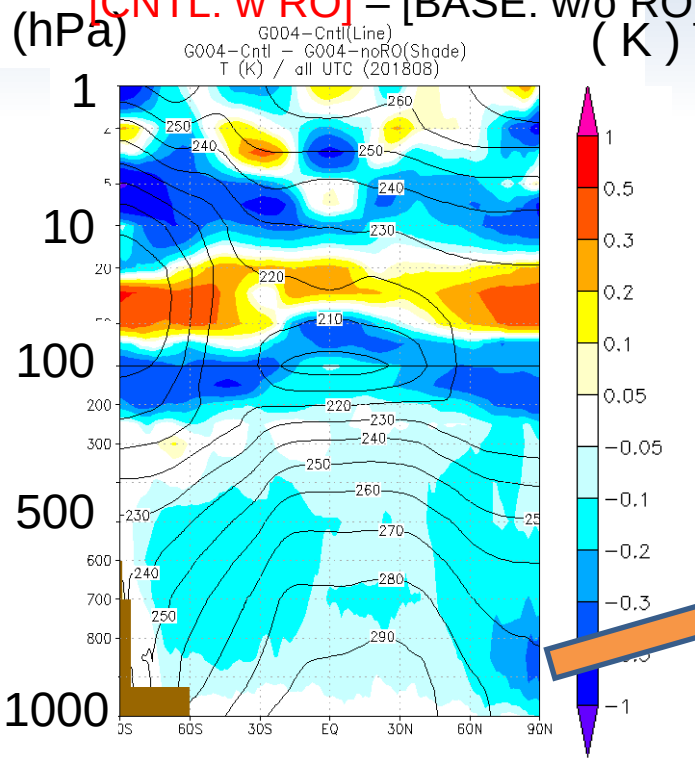
- To investigate the effect of use of adjoint of each element
- TEST: only the adjoint of temperature, specific humidity, pressure or geopotential height is used
- BASE: RO data denial experiment

The use of geopotential height adjoint have negative impact in the lower troposhere

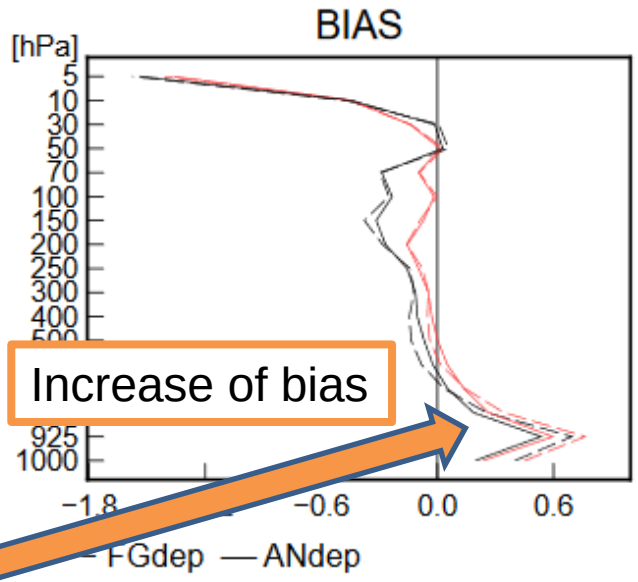
EXP1. RO DATA DENIAL EXPERIMENTS

Impact on Temperature Analysis Field

Diff. of zonal averaged temp.
[CNTL: w RO] – [BASE: w/o RO]



Radiosonde Temp. Bias
[CNTL: w RO] – [BASE: w/o RO]



Increase of bias

CNTL: JMA's Operational Global NWP system Period: Aug. 2018
BASE: RO data denial experiment

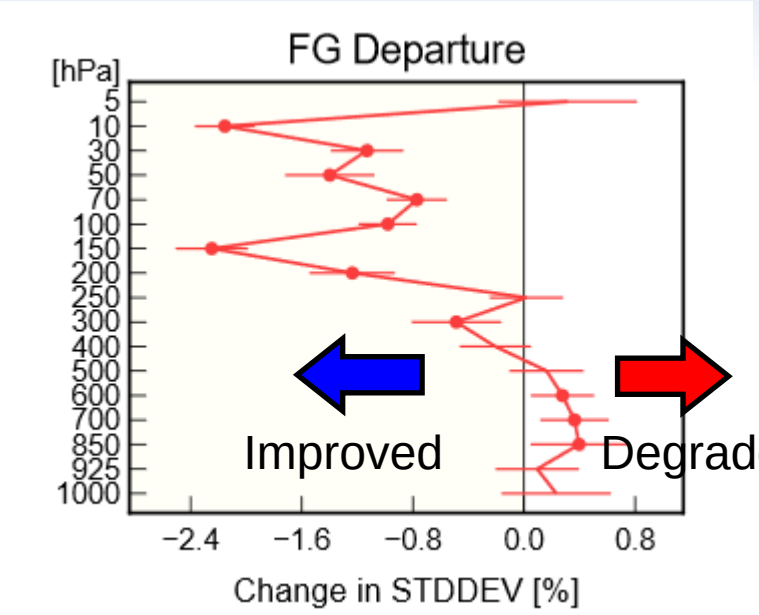
The assimilation of RO data
✓ have large impact on temperature of analysis in the upper troposphere and stratosphere.
- Decrease of the radiosonde temperature bias from 500 hPa to 50 hPa.

✓ decrease analyzed temperature in the lower troposphere, especially in the Arctic region.
- Increase of the radiosonde temperature bias in lower troposphere

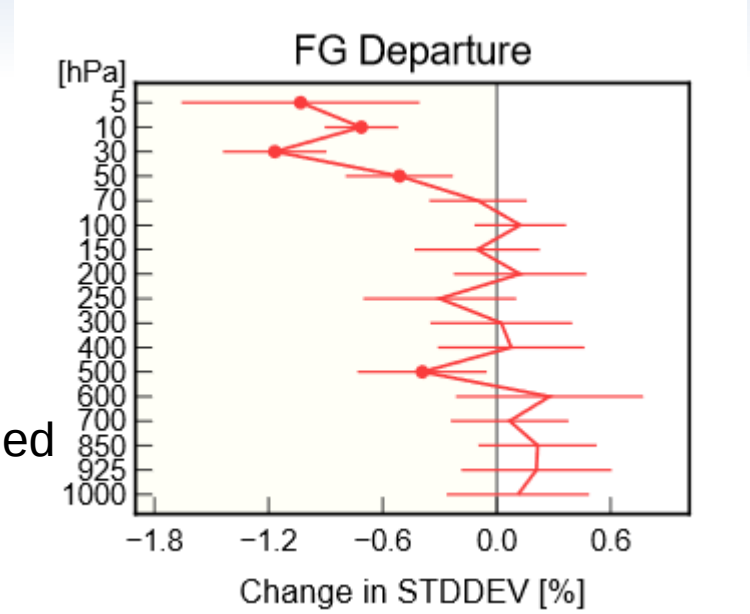
Normalized changes in the STDV of FG departure

[CNTL: w RO] – [BASE: w/o RO]

Radiosonde Temp.



Radiosonde U wind



CNTL: JMA's Operational Global NWP system
BASE: RO data denial

Period: Aug. 2018

- Large positive impact on temperature in the stratosphere and upper troposphere
- Negative impact on temperature in lower troposphere

Accuracy of analysis field below 500 hPa is the most important for the forecast !

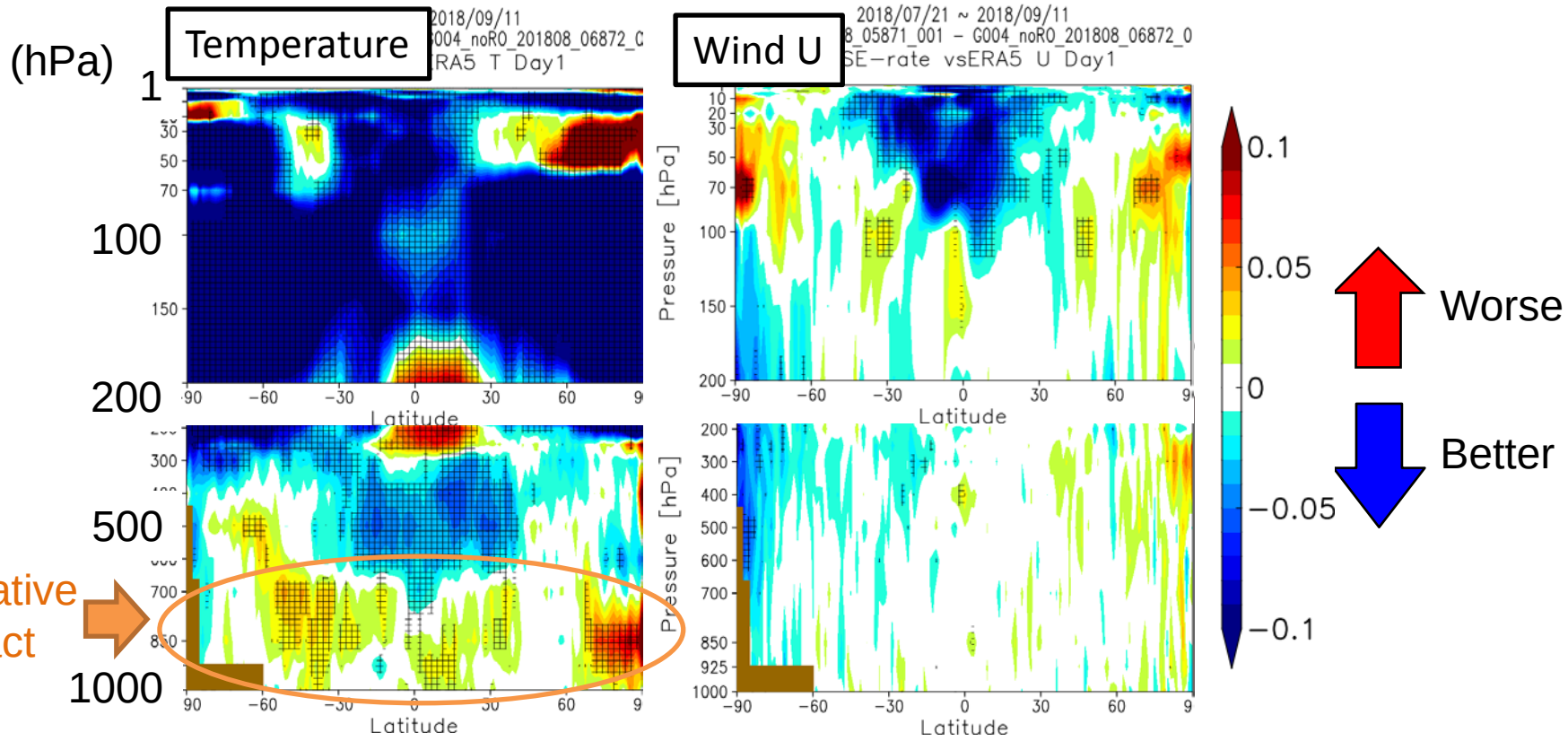
Negative Impacts on Forecast Fields

Changes of zonal averaged RMSE of 24-hour forecast
(reference ECMWF ERA5) (CNTL – BASE)

CNTL: JMA's Operational Global NWP system

BASE: RO data denial

Period: 2019/07/21 – 2019/09/11



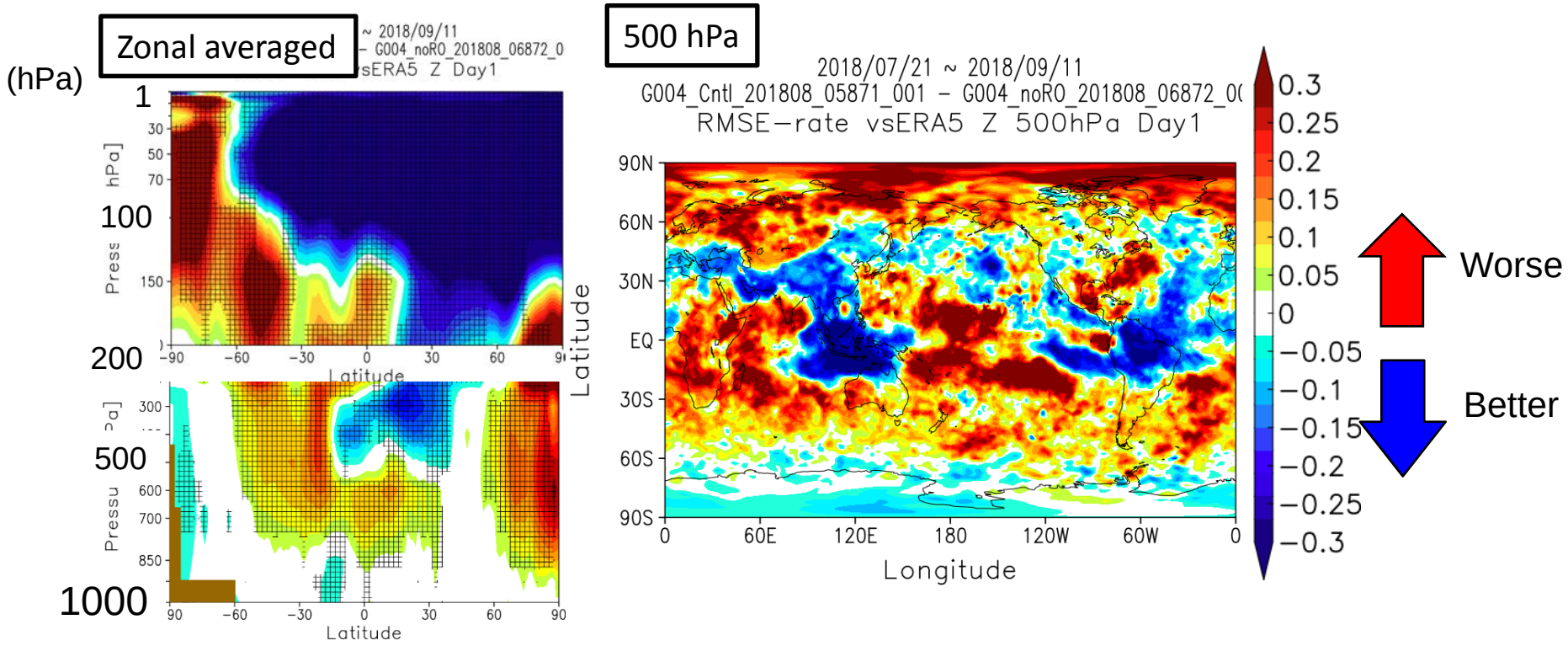
- Significant improvement on temperature in the stratosphere and upper troposphere

- Negative impact on temperature in the lower troposphere, especially for Arctic region

Geopotential height forecast

Changes of RMSE of 24-hour forecast
(reference ECMWF ERA5) (CNTL – BASE)

CNTL: JMA's Operational Global NWP system
BASE: RO data denial
Period: 2019/07/21 – 2019/09/11



The assimilation of RO data has negative impact on 500 hPa geopotential height in JMA's Global NWP system, which is brought from the decrease of analyzed temperature in the lower troposphere.

EXP2. SINGLE OBSERVATION TESTS

Single observation tests

Why is the analyzed temperature in the lower troposphere affected?

To understand the effect of RO data in detail, the single observation tests in the data assimilation were performed.

Single RO data was assimilated at the Arctic region.
No other observation data was assimilated.

Negative impact in the Arctic region was particularly large

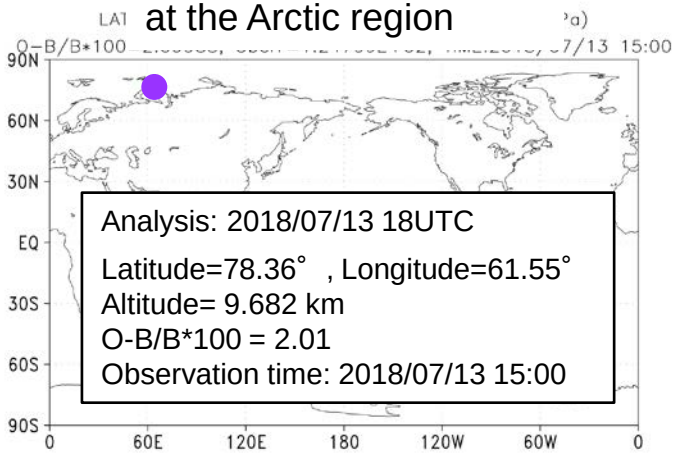
To clearly see the effect of the assimilation of RO data, the following values were changed.

✓(O-B)/B*100 ~ 2

✓ Observation time
(= first window of the time step of 4D var analysis)

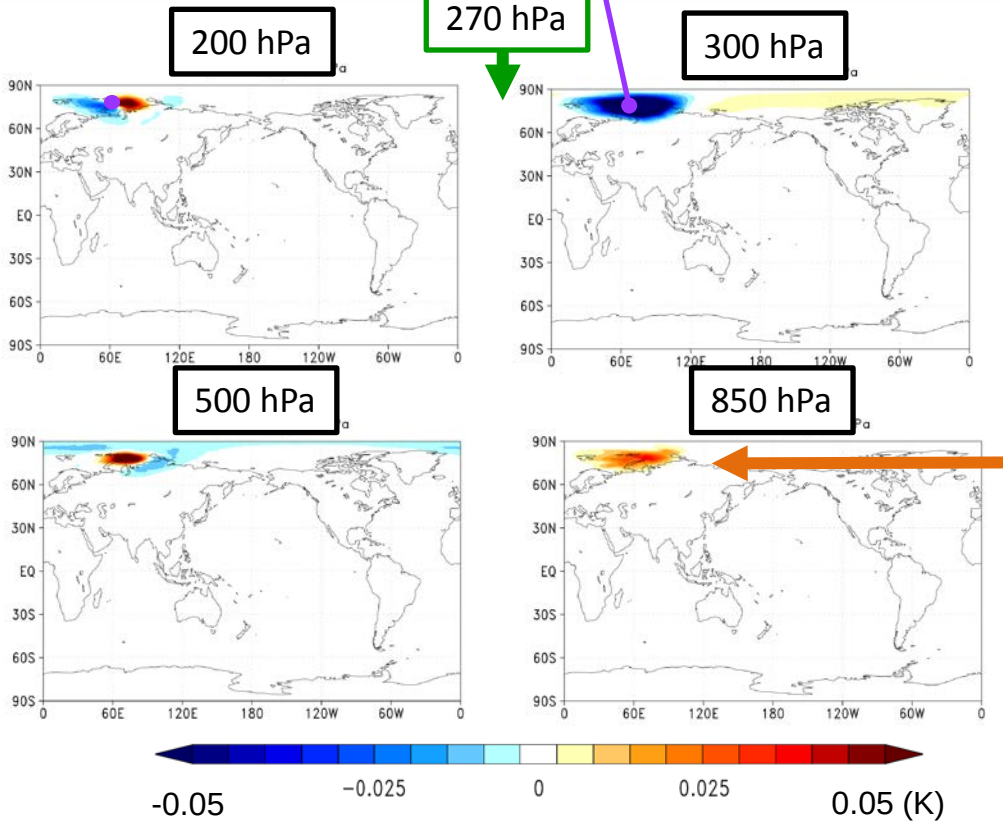
Real data were used for other observation values.

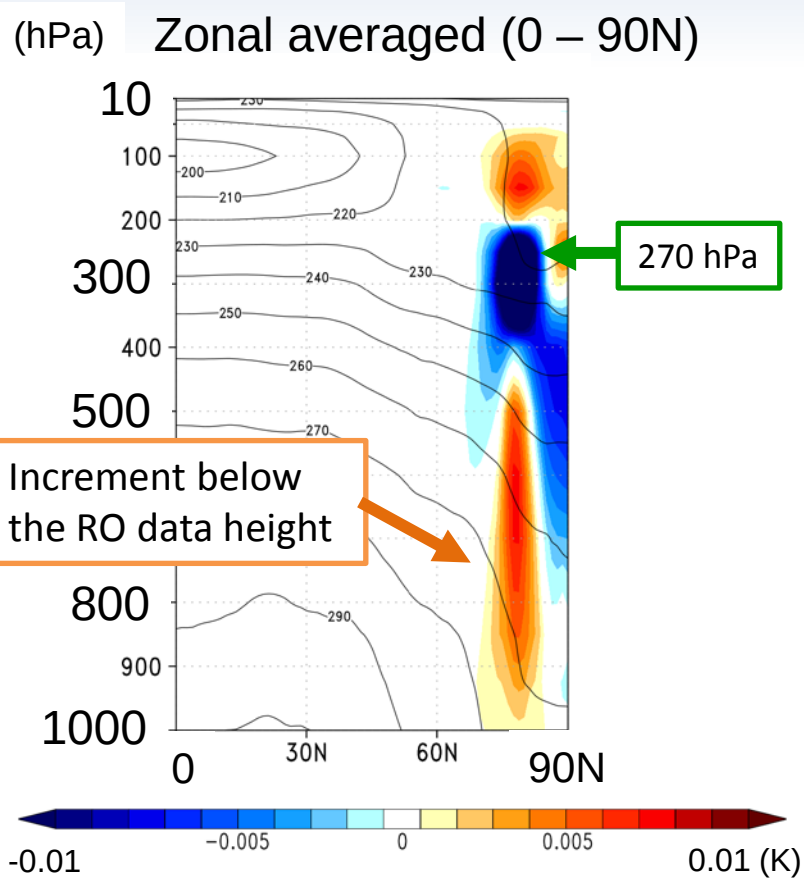
Single observation tests
at the Arctic region



Increments of temperature

- Single observation tests at the Arctic region (Analysis: 2018/07/13 18UTC)
  - Latitude=78.36°, Longitude=61.55°, Altitude=9.682 km (270 hPa)
  - O-B>0, Observation time: 2018/07/13 15:00



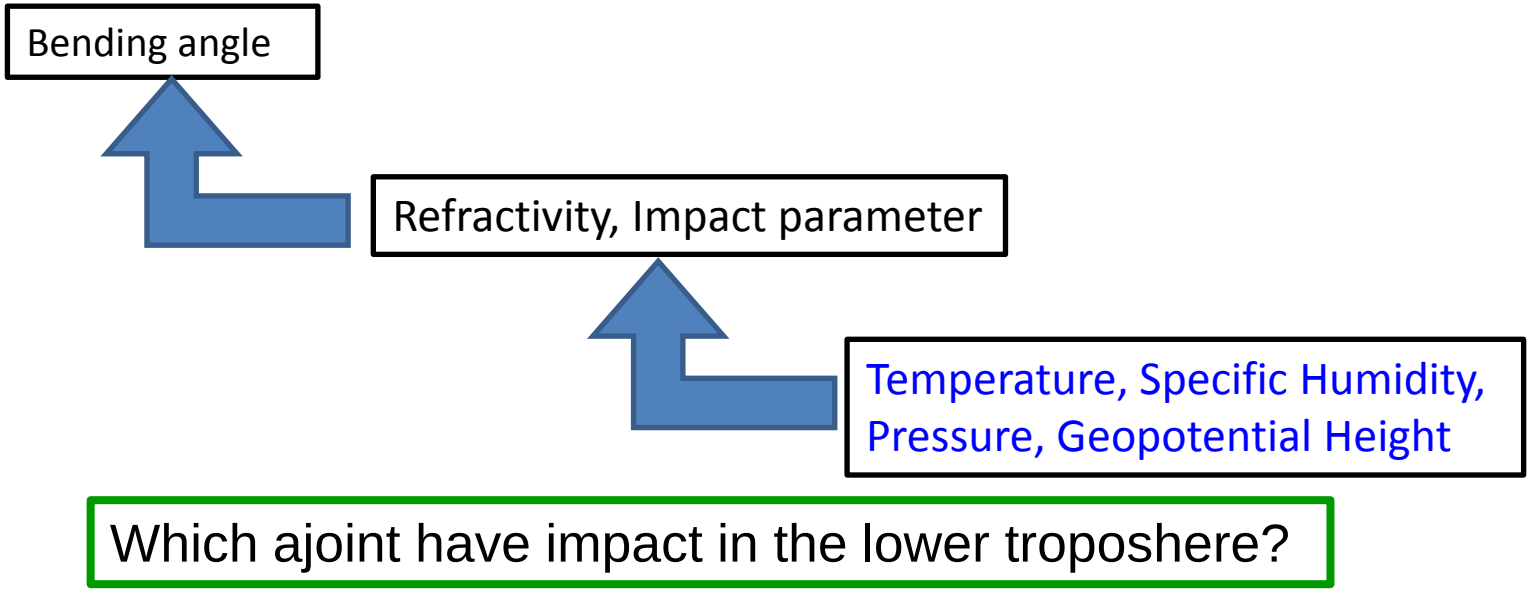


RO data assimilation raised analysis increments of temperature not only near the RO data height but also below the height such as 850 hPa in the JMA's global NWP system.

EXP3. ADJOINT OF ONE ELEMENT

Adjoint from Bending angle

- The Adjoint from bending angle data assimilation
  - Temperature, Specific Humidity, Pressure, Geopotential Height



- To see the effect from the adjoint of each element, the experiments using only the adjoint of one element were performed

Experiments Using Only Adjoint of One Element

- Increment from RO data assimilation are mainly brought from the use of adjoint of temperature and geopotential height.
- The adjoint of geopotential height have larger impact than that for temperature below RO assimilation height such as 850 hPa.

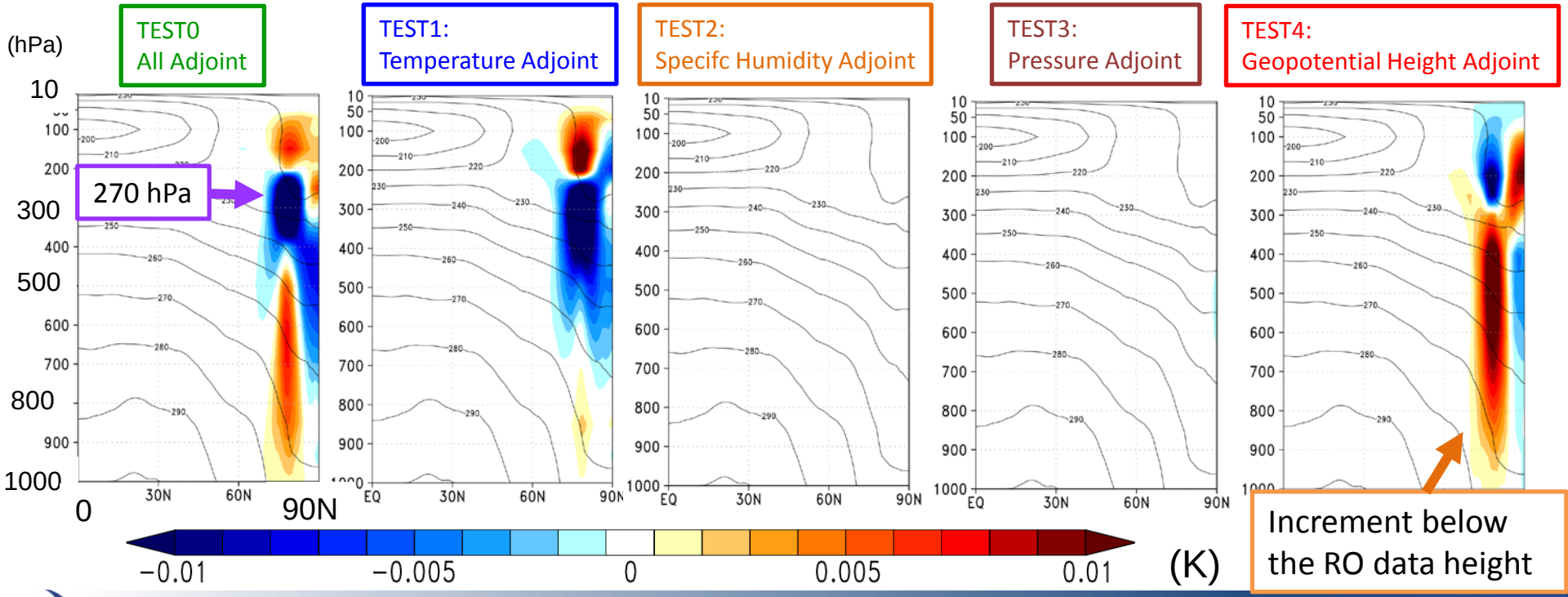
Single observation tests at the Arctic region

Latitude=78.36°, Longitude=61.55°, Altitude=9.682 km (270 hPa)

O-B>0, Analysis: 2018/07/13 18UTC

TEST0: adjoint of all elements
TEST1: Temperature Adjoint, TEST2: Specific Humidity Adjoint
TEST3: Pressure Adjoint, TEST4: Geopotential Height Adjoint

Increment of temperature (0 – 90N)

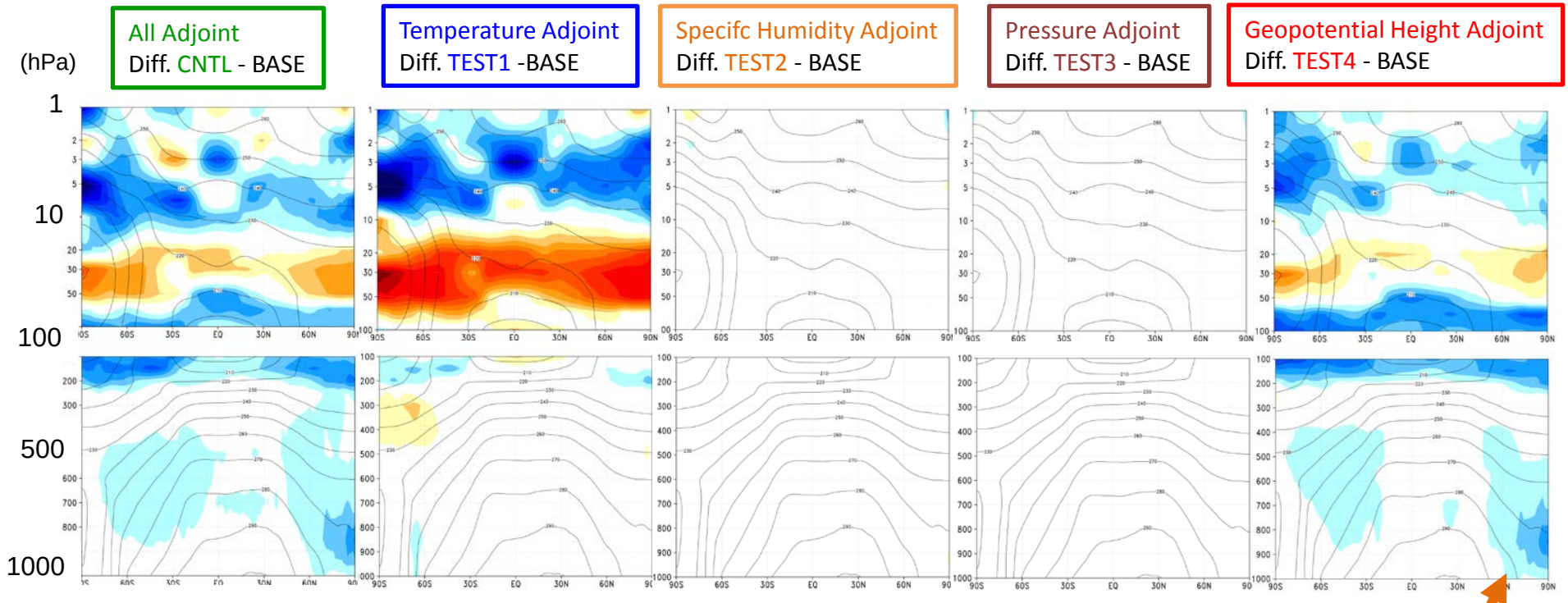


Difference of temperature in the cycle analysis

- Use of adjoint of temperature and geopotential height have mainly impact on analysis fields.
- Analyzed temperature around 100 hPa is decreased by using the geopotential height adjoint.
- Decrease of temperature in the troposphere is mainly brought from the use of geopotential height adjoint.

TEST1: Temperature Adjoint, TEST2: Specific Humidity Adjoint
TEST3: Pressure Adjoint, TEST4: Geopotential Height Adjoint
CNTL: JMA's Operational Global NWP system (adjoint of all elements)
BASE: RO data denial

Period: Aug. 2018



Impacts on Temperature Forecast Fields

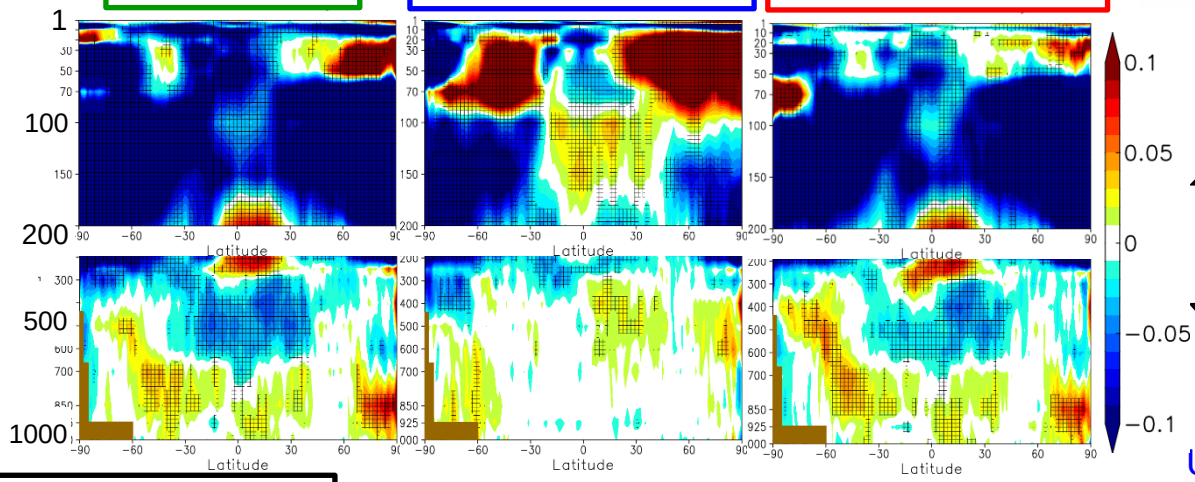
24-hour forecast (reference ECMWF ERA5)

Changes of RMSE

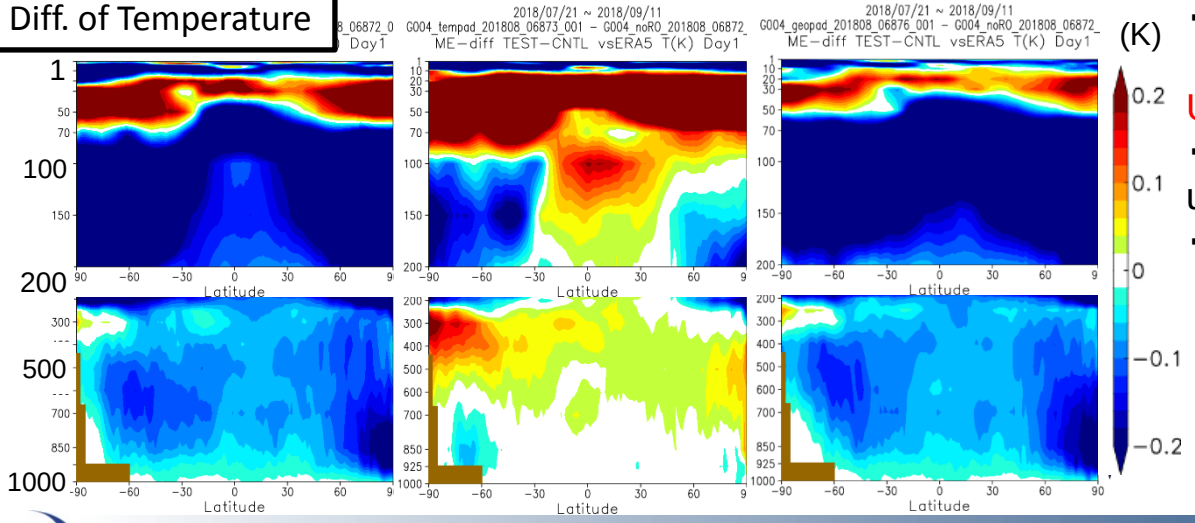
All Adjoint (CNTL – BASE)

Temperature Adjoint (TEST1 –BASE)

Geopotential Height adjoint (TEST4 – BASE)



Diff. of Temperature



TEST1: Temperature Adjoint
TEST4: Geopotential Height Adjoint
CNTL: JMA's Operational Global NWP system (adjoint of all elements)
BASE: RO data denial
Period: 2018/07/21 - 2018/09/11

Worse

Better

Using only temperature adjoint

- no large impact in the lower troposphere

Using only geopotential height adjoint

- positive impact in the stratosphere and upper troposphere
- negative impact in the lower troposphere

→ Similar tendency to denial experiment

Impact in the lower troposphere mainly come form the use of geopotential height adjoint.

Summary（1/2）

- The effect of RO data assimilation was investigated in JMA's Global NWP system.

  Negative impact in the lower troposhere

- RO data denial experiments were conducted.
  - RO data have significant positive impact on temperature of analysis and forecast fields in the upper troposphere and stratosphere.
  - The assimilation of RO data decreased analyzed temperature in the lower troposphere and brought negative impacts on forecasted temperature fields, especially for Arctic region.

- Single observation tests were conducted.
  - The assimilation of RO data raised analysis increments of temperature not only near the RO data height but also below the height such as 850 hPa in JMA's NWP system.

Summary（2/2）

- The experiment using only the adjoint of each element
  - The use of adjoint of temperature and geopotential height have large impact in the assimilation of bending angels.
  - The use of geopotential height adjoint have significant positive impact on temperature forecast field in the stratosphere and upper troposphere. On the other hand, it has negative impact in the troposphere.
    - It changes analyzed temperature in lower troposphere when the single RO data is assimilated at stratosphere.

- Path forward
  - It is necessary to investigate the geopotential height adjoint in the JMA's NWP system in detail.


Thank you for your attention
Tak for din opmærksomhed