Assimilation of microwave imagers (GCOM-W1/AMSR2, GPM/GMI)

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ECMWF Annual Seminar 2014
Use of Satellite Observations in Numerical Weather Prediction, 8-12 September 2014

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  An improved ocean surface emissivity model
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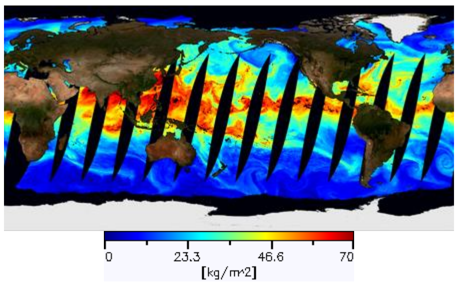
- Microwave imager radiance assimilation in regional model (**GMI** in JMA)
- Summary and future prospect

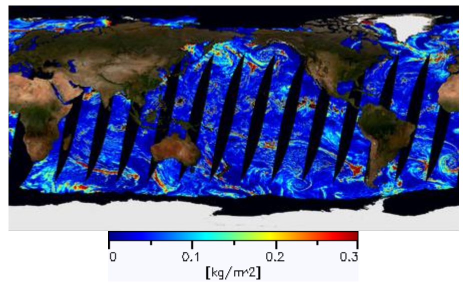
Microwave imager observation

Level 2 products from GCOM-W1/AMSR2

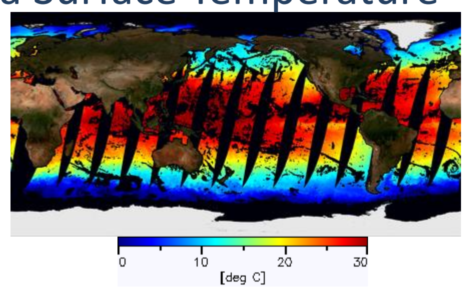
Integrated water vapor



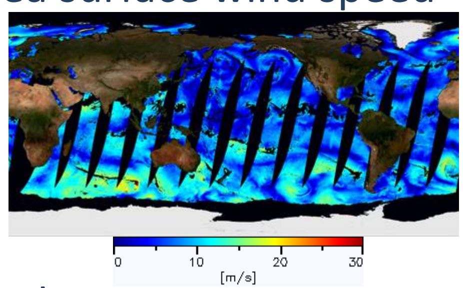
Integrated cloud liquid water



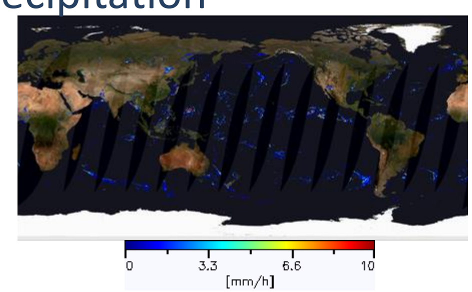
Sea Surface Temperature



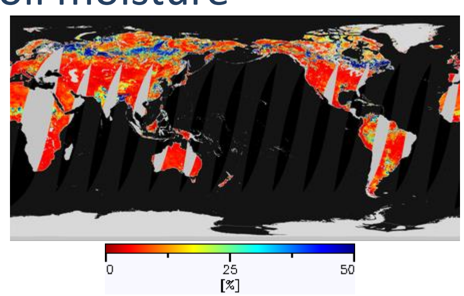
Sea surface wind speed



Precipitation



Soil moisture



http://kuroshio.eorc.jaxa.jp/JASMES/index.html

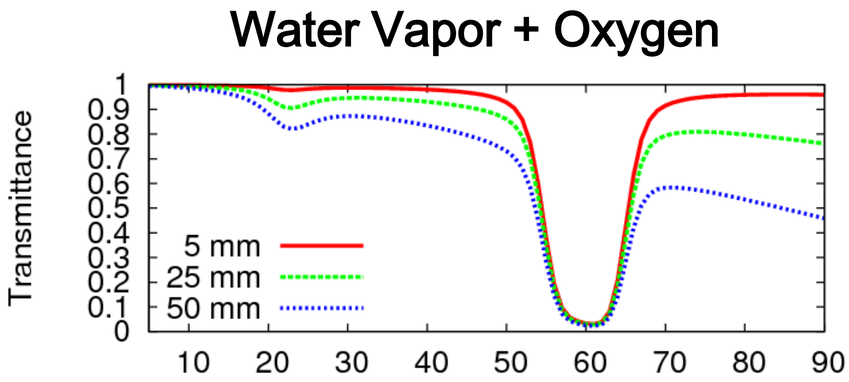
Microwave imager observations contain information on various geophysical parameters

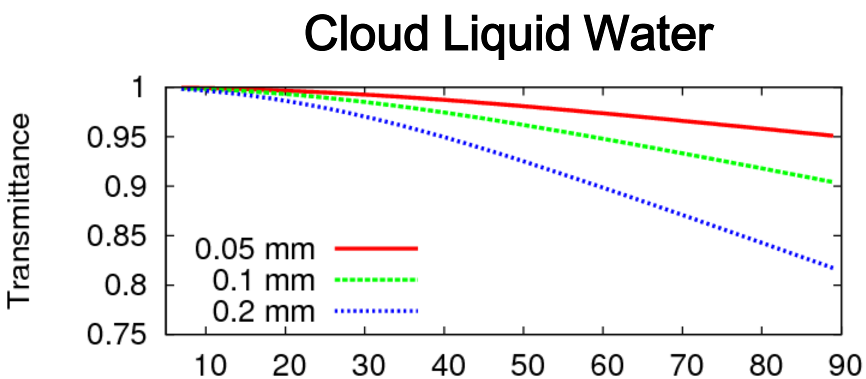
e.g.

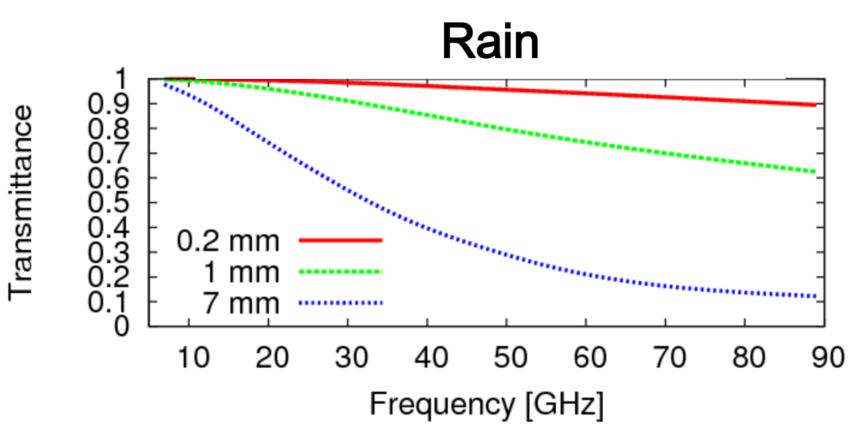
- Total column water vapor
- Total column liquid water
- Sea surface temperature
- Sea surface wind
- Precipitation
- Soil moisture
- Sea ice
- Snow depth

Characteristics of Microwave imager observation

Transmittance in MW spectral range







The absorption features are due to water vapor and oxygen. Resonant absorption occurs 22GHz (Water Vapor) and 50 to 70GHz (Oxygen).

Cloud liquid water droplets produce relatively small absorption and it increases monotonically with frequency.

For weak precipitation condition (< 1mm), and low frequency channels (< 25 GHz), rain droplet scattering effect can be negligible.

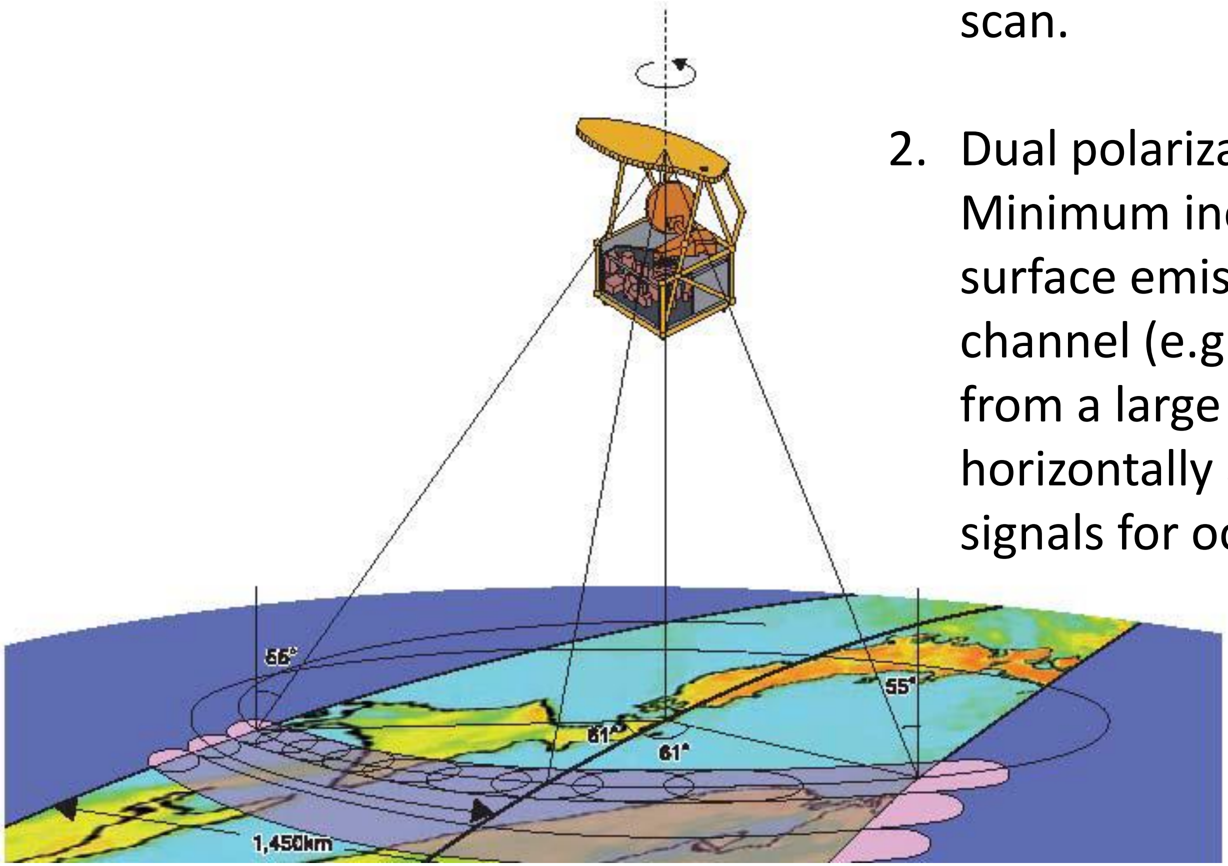
Large effect of incidence angle dependence for surface reflectivity (i.e. down-welling radiance) should be taken into account in radiative transfer calculation

Surface emissivity range in microwave from 0.2 to 1.0.

Conical scanning microwave imager

1. Fixed incidence angle (e.g. 55 degree) allow uniform observation during the scan.

2. Dual polarization measurement (V and H). Minimum incidence angle dependence in surface emissivity for vertically polarized channel (e.g. surface wind speed retrieval from a large differential between horizontally and vertically polarized signals for ocean case)



GCOM-W/AMSR2 scanning geometry

In microwave observations, low surface emissivity and dual polarization measurements can provide information on water vapor, cloud, rain, and surface wind over oceans.

Assimilation of microwave imager observation

- **Oceanic** microwave radiance data contain information on various geophysical parameters: **water vapor**, **atmospheric hydrometeors** and **ocean surface condition** (sea surface temperature, surface wind speed, salinity)

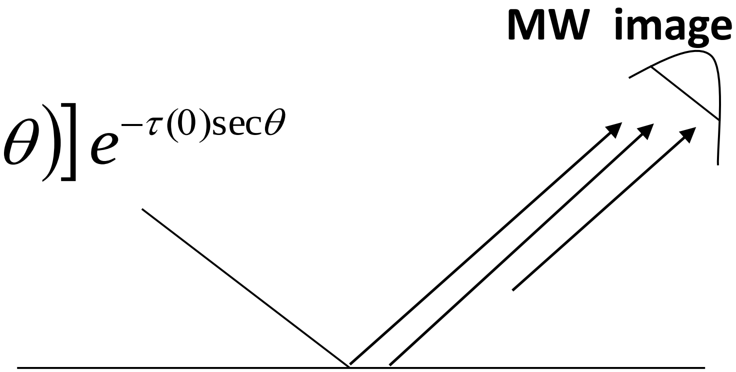
- Microwave imager observation are assimilated as brightness temperatures by means of **radiative transfer calculation**

- The sensitivity needs to be included in the radiative transfer calculations in order to make consistent changes in initial states for NWP.

Microwave radiative transfer

For microwave spectral range, Rayleigh-Jeans approximation can be applied for oceanic and clear sky condition

$$T_b(\nu,\theta) = T_u(\nu,\theta) + \left[\varepsilon_s\, T_s + \left(1-\varepsilon_s\right) T_d\left(\nu,\theta\right)\right] e^{-\tau(0)\sec\theta}$$



The observed brightness temperature T_b can be expressed by the upwelling T_u and reflected down-welling atmospheric radiation $\left(1-\varepsilon_s\right) T_d\left(\nu,\theta\right) e^{-\tau(0)\sec\theta}$ and the surface emitted radiation $\varepsilon_s\, T_s e^{-\tau(0)\sec\theta}$.

Possible error sources:

1. Cosmic microwave background T_c=2.7K
   Generally small compared to the atmospheric contribution
2. T_{RFI}: Radio Frequency Interference
   From ground and geostationary satellite. Related to human activity
3. T_{sun}: Reflection of sun light into the instrument
   Seasonal change
4. Errors in atmospheric profiles from NWP model output

Surface emissivity effects (ocean case)

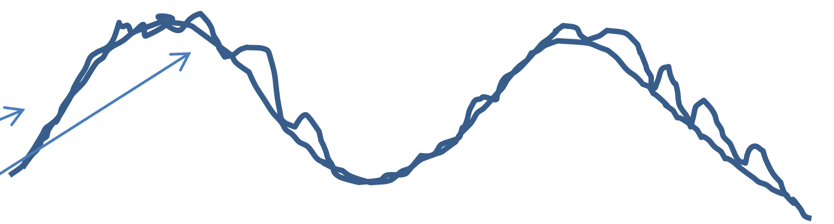
The emissivity is determined by **sea surface temperature**, **salinity**, **foam and surface roughness**. An accurate microwave ocean emissivity model is necessary to assimilate surface sensitive microwave radiances over the ocean

Two-scale models of the ocean surface (Wu and Fung (1972) and Wentz (1975)) were suggested. The theoretical models require an integration over the ocean wave spectrum to calculate the microwave ocean emissivity. This requires huge computational costs. Parameterizations are necessary for fast calculation in operational data assimilation.

Two scale modeling

1. Surface waves with wave length that are long compared to the radiation wave length (a collection of tilted facets, each acting as an independent secular surface), Large-scale wave
2. The diffraction of microwave by surface waves that are small compared to the radiation wave length , Small-scale wave
3. Sea foam (fractional coverage and emissivity)

Conceptual wind-roughened ocean wave image in two scale modeling



These effects are parameterized as functions of incidence angle, wind speed, sea surface temperature, and frequency.

Effects of salinity are negligible except L band channels

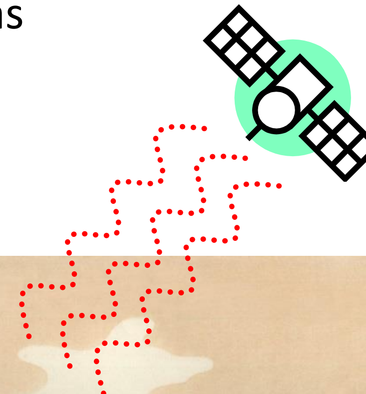
History of FASTEM

FASTEM is a FAST microwave Emissivity Model used for satellite radiance assimilation. FASTEM is used in RTTOV and CRTM for ocean surface emissivity calculation

- **FASTEM-1** (English and Hewison, 1998)
  - Based on a geometric optics model simulation
- **FASTEM-2** (Deblonde and English 2001)
  - An updated version of FASTEM-1 and released in RTTOV-7
- **FASTEM-3** (Liu and Weng 2003)
  - An azimuth variation model function was introduced and released in RTTOV-8
- **FASTEM-4** (Liu et al., 2011)
  - Updated permittivity calculation, a new parameterizations of the roughness effect, foam parameterization and a new azimuthal model function, released in RTTOV-10
- **FASTEM-5**
  - Modified the large scale roughness and foam parameterization
- **FASTEM-6**
  - Improved azimuth variation model function (Kazumori and English 2014)

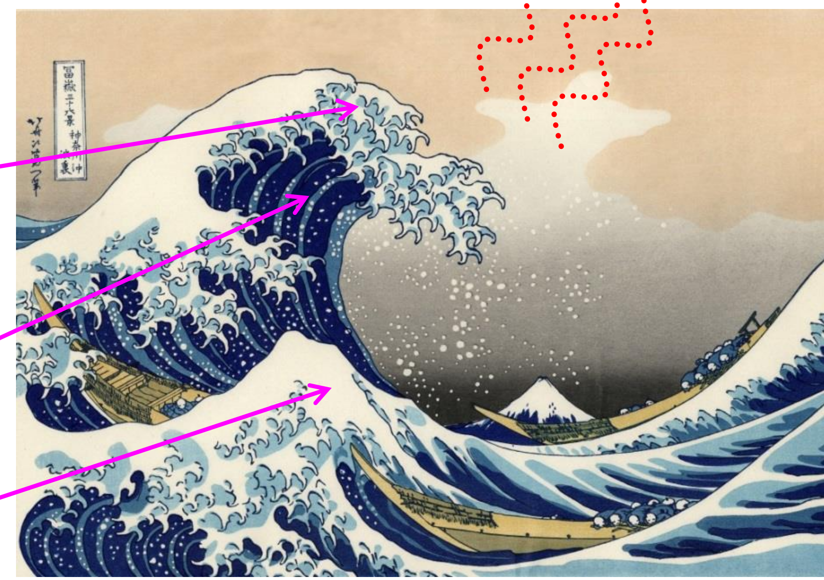
Microwave Ocean Emissivity calculation in RTTOV

A fast radiative transfer model (RTTOV-10) is used for the brightness temperature calculation in the data assimilation. RTTOV-10 uses **FASTEM** (fast emissivity model) as the microwave ocean emissivity calculation module



- Specular Ocean surface emissivity (calm ocean)

  Largest part of ocean emissivity calculated by Fresnel formula, depend on frequency, incidence angle, SST, salinity and dielectric constant of sea water.



- Small scale correction

  Radiation from small scale waves (capillary wave),

  Isotropic wind-induced emissivity

- Large scale adjustment

  Radiation from large scale waves (gravity wave, swell) caused by wind

- Correction by foam and whitecap

  Correction on down-welling atmospheric radiation

- Azimuthal variation correction (**R**elative **W**ind **D**irection effect)

  Dependence on surface wind direction relative to the sensor azimuthal look

Not used operationally!

Sensor azimuth angle is not stored in SSMIS, TMI real time data.

Components of ocean emissivity

$$\varepsilon = \varepsilon_0(\theta, T_s, S) + \Delta\varepsilon_{\mathrm{iso}}(\theta, W_s, F) + \Delta\varepsilon_{\mathrm{dir}}(W_s, \phi_R)$$

$$\varepsilon_0(\theta, T_s, S)$$

The first term: Specular sea surface emissivity, This is dominant term of the ocean emissivity and depends on incidence angle, sea surface temperature, and salinity. The value can be theoretically calculated. (Fresnel formula)

$$\Delta\varepsilon_{\mathrm{iso}}(\theta, W_s, F) = (1-F)\Delta\varepsilon_{\mathrm{W}}(\theta, W_s) + F\Delta\varepsilon_{\mathrm{F}}(\theta, W_s)$$

The second term: Wave-induced isotropic emissivity. This term depends on sea surface wind speed, and fractional coverage of foam ***F***

This term contains the large scale and small scale wave contribution. The effects are parameterized with wind speed and incidence angle, and foam emissivity.

$$\Delta\varepsilon_{\mathrm{dir}}(W_s, \phi_R)$$

The third term: Wind directional dependent part of the emissivity. Asymmetric distribution of foam and small scale wave contribute this variation. The value can be parameterized with wind speed and relative wind direction.

Characteristics of oceanic microwave radiance

Measurements from Airborne Microwave Radiometer and Buoy

Ocean surface microwave radiations have surface wind directional signals.

The azimuthal variation should be considered correctly in radiative transfer calculation for geophysical parameter retrievals (TPW, SST etc.) and radiance assimilations.

Microwave radiances (brightness temperature) are assimilated for Numerical Prediction Model. However, the directional information are not used because of a lack of sensor azimuth angle information in real time data and insufficient modeling.

The variation of Tv and Th in terms of relative wind direction is expressed by harmonic cosine function.

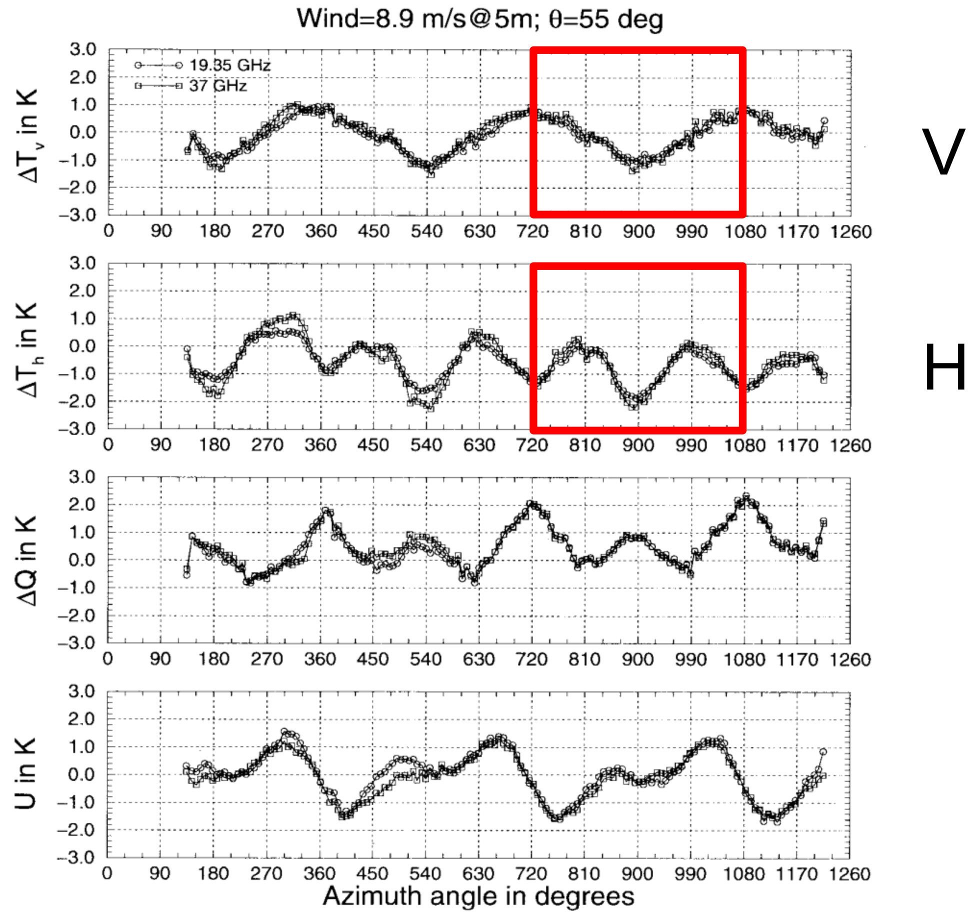
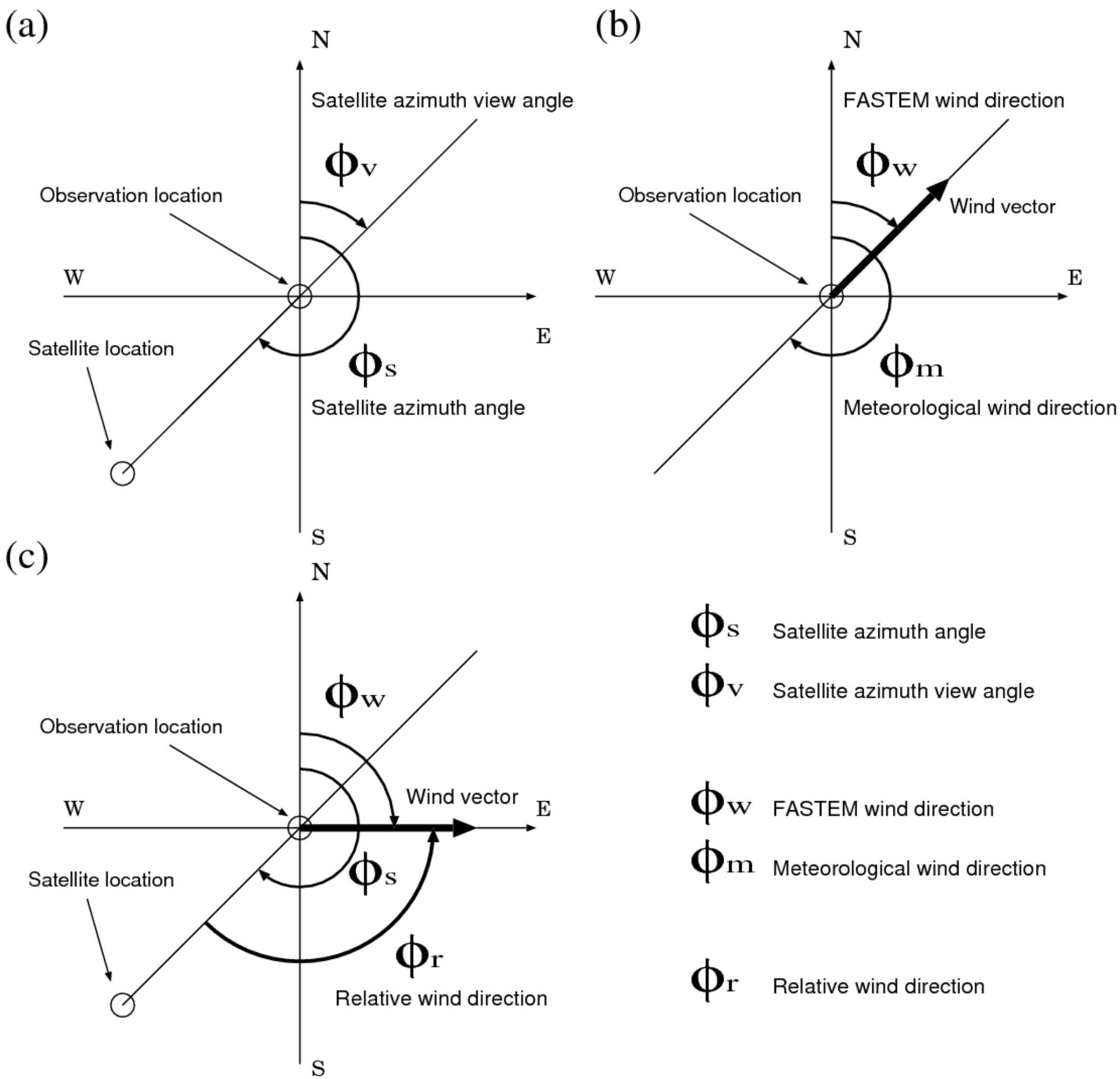


Fig. 2. Wind direction signals in polarimetric brightness temperatures of ocean surfaces acquired by JPL K- and Ka-band radiometers at 55° incidence angle. The data were acquired on 17 April, 1995, with NASA DC-8 flights over NDBC buoy 46 005. The skies were mostly clear with some small scattered clouds. The buoy wind speed is 8.9 m·s^{-1} at 5 m elevation, which corresponds to 9.6 m·s^{-1} at 10 m elevation and 10.1 m·s^{-1} at 19.5 m elevation based on the correction of a boundary layer model [12]. For ease of comparison, T_v, T_h, and Q at 19.35 GHz have been offset by 187.5, 119.3, and 68.2 Kelvin, respectively, while those at 37 GHz have been offset by 203.9, 136.8, and 67.1 Kelvin.

Yueh, S. H., & Wilson, W. J. (1999)

Definitions of angles



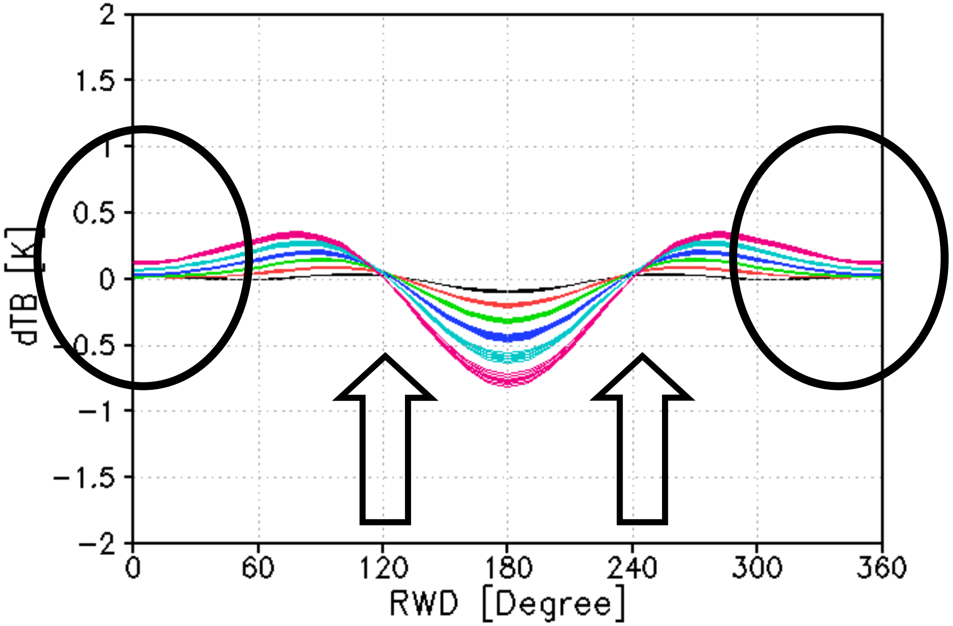
(a): Satellite azimuth view angle and Satellite azimuth angle.

(b): FASTEM wind direction and Meteorological wind direction.

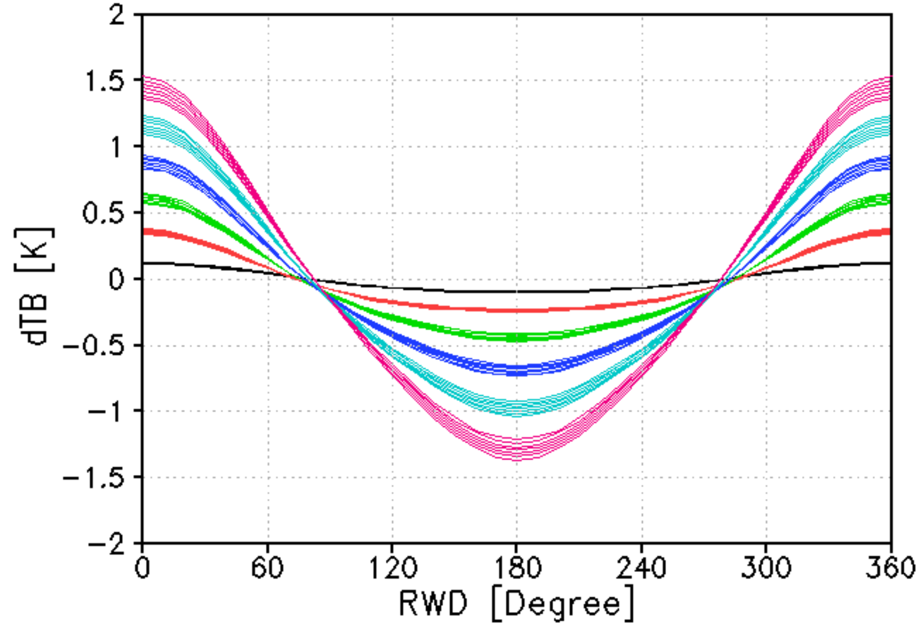
(c): Relative wind direction (westerly wind case). Wind vector is drawn in thick black arrow.

The Variations of Simulated Brightness Temperature 19 GHz V-pol. from FASTEM-5 and 3

FASTEM-5 RWD model function



FASTEM-3 RWD model function



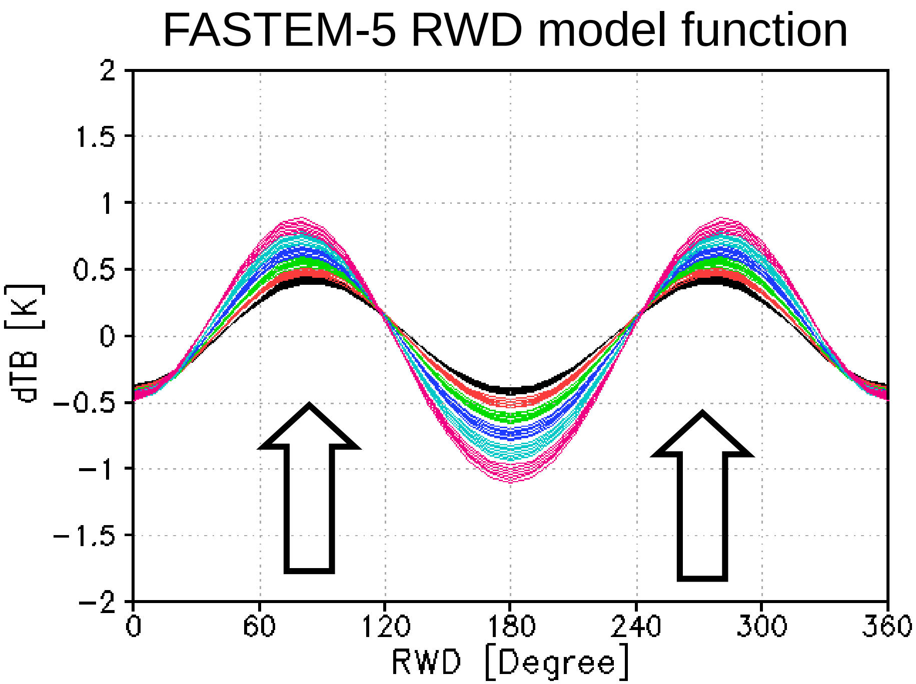
RTM: RTTOV-10.2, **Instrument:** AMSR-E
Input profile: US standard atmosphere (T,Q)
Wind Speed
Black: 3m/s Red: 6 m/s Green: 9 m/s Blue: 12 m/s
Light Blue: 15 m/s Pink: 18m/s
SST range: From 0 to 30 Celsius

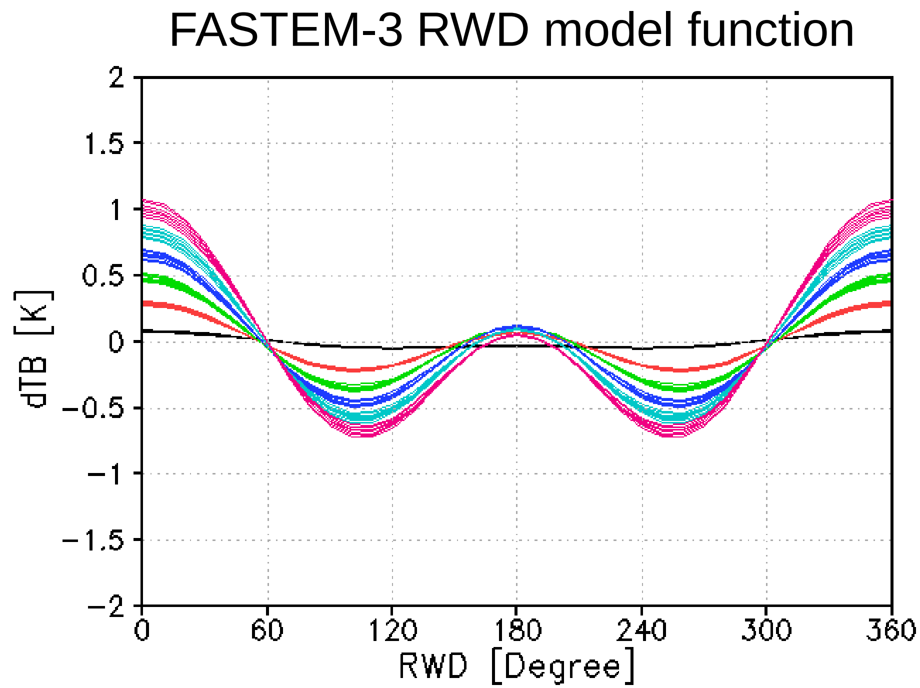
dTB= TBsim – Ave(TBsim)

Unrealistic features
Behavior at RWD=0,360
Behavior at RWD=120,240
Magnitude of Amplitude

RWD:
Relative Wind Direction is wind direction relative to sensor azimuth angle

The Variations of Simulated Brightness Temperature 37 GHz H-pol. from FASTEM-5 and 3





RTM: RTTOV-10.2, **Instrument:** AMSR-E
Input profile: US standard atmosphere (T,Q)
Wind Speed
Black: 3m/s Red: 6 m/s Green: 9 m/s Blue: 12 m/s
Light Blue: 15 m/s Pink: 18m/s
SST range: From 0 to 30 Celsius

dTB= TBsim – Ave(TBsim)

Unrealistic features

FASTEM5's Large sensitivity w.r.t RWD in low wind speed

Bugs in implementation of FASTEM3 RWD model into RTTOV?

RWD:
Relative Wind Direction is wind direction relative to sensor azimuth angle

Design of new RWD model

Emissivity variation with regard to RWD is modeled with a series of harmonic functions. This is normal approach adapted by many literatures.

$$E_i = E_{i0} + E_{i1}\cdot\cos(\varphi) + E_{i2}\cdot\cos(2\varphi) + \cdots$$

$$\boxed{\Delta E_i = E_i - E_{i0} = E_{i1}\cdot\cos(\varphi) + E_{i2}\cdot\cos(2\varphi) + \cdots \quad i = v \text{ or } h}$$

$$E_{i1} = E_{v1} = a_{v1}\left[\exp\left(-\alpha_v x^2\right) - 1\right]\left(b_{v1}x + c_{v1}x^2 + d_{v1}x^3\right)$$

$$E_{i2} = E_{v2} = a_{v2}\,x$$

$$E_{i1} = E_{h1} = a_{h1}\,x$$

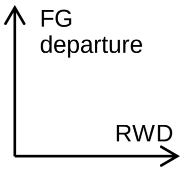
$$E_{i2} = E_{h2} = a_{h2}\left[\exp\left(-\alpha_h x^2\right) - 1\right]\left(b_{h2}x + c_{h2}x^2 + d_{h2}x^3\right)$$

The coefficients (a,b,c,d, alpha) are derived for each channels. They were determined based on simultaneous measurements of radiance and surface wind speed by ADEOS-II (AMSR and SeaWinds)

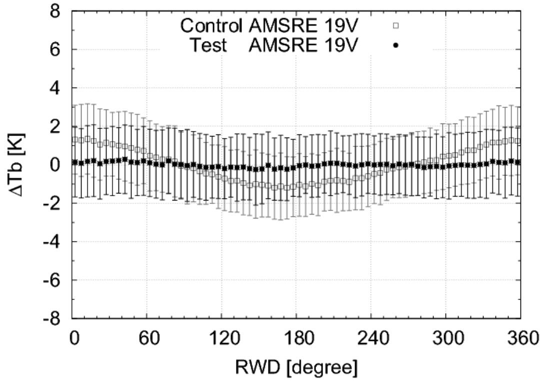
x : wind speed

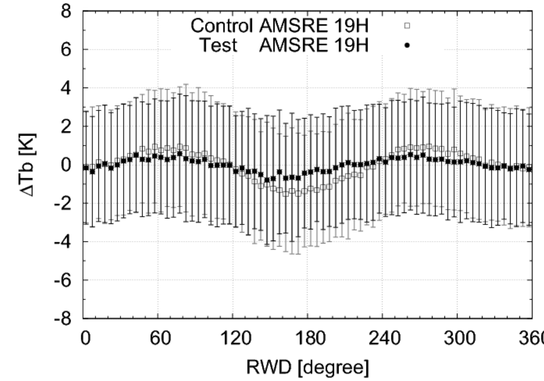
Dependency on incidence angle (Meissner 2012, Etkin 1991)

Comparison of FG departures of assimilated MW imager radiance (Obs. – Sim.)



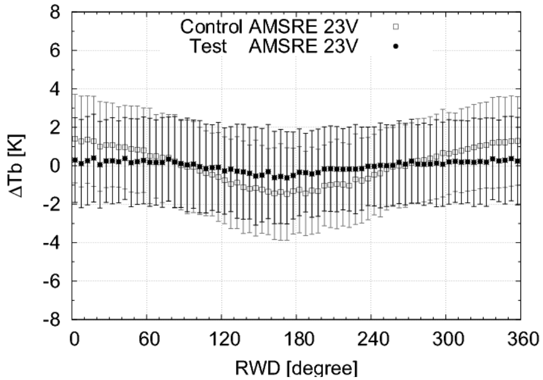
AMSRE
19V

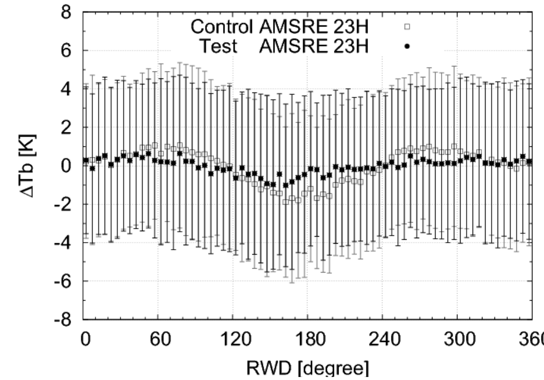




AMSRE
19H

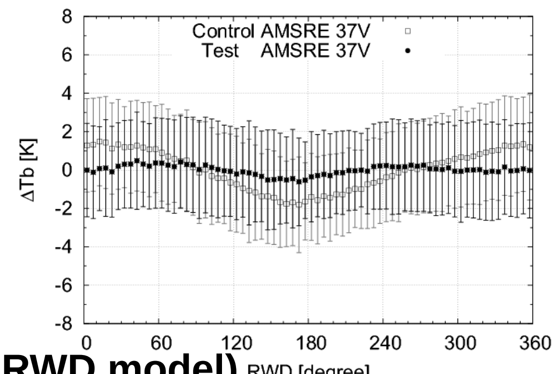
AMSRE
23V

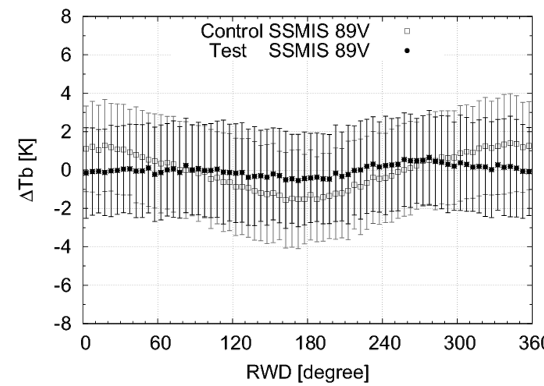




AMSRE
23H

AMSRE
37V



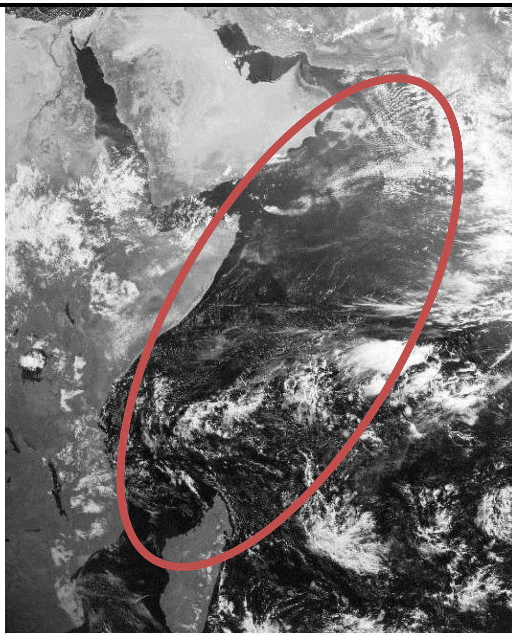


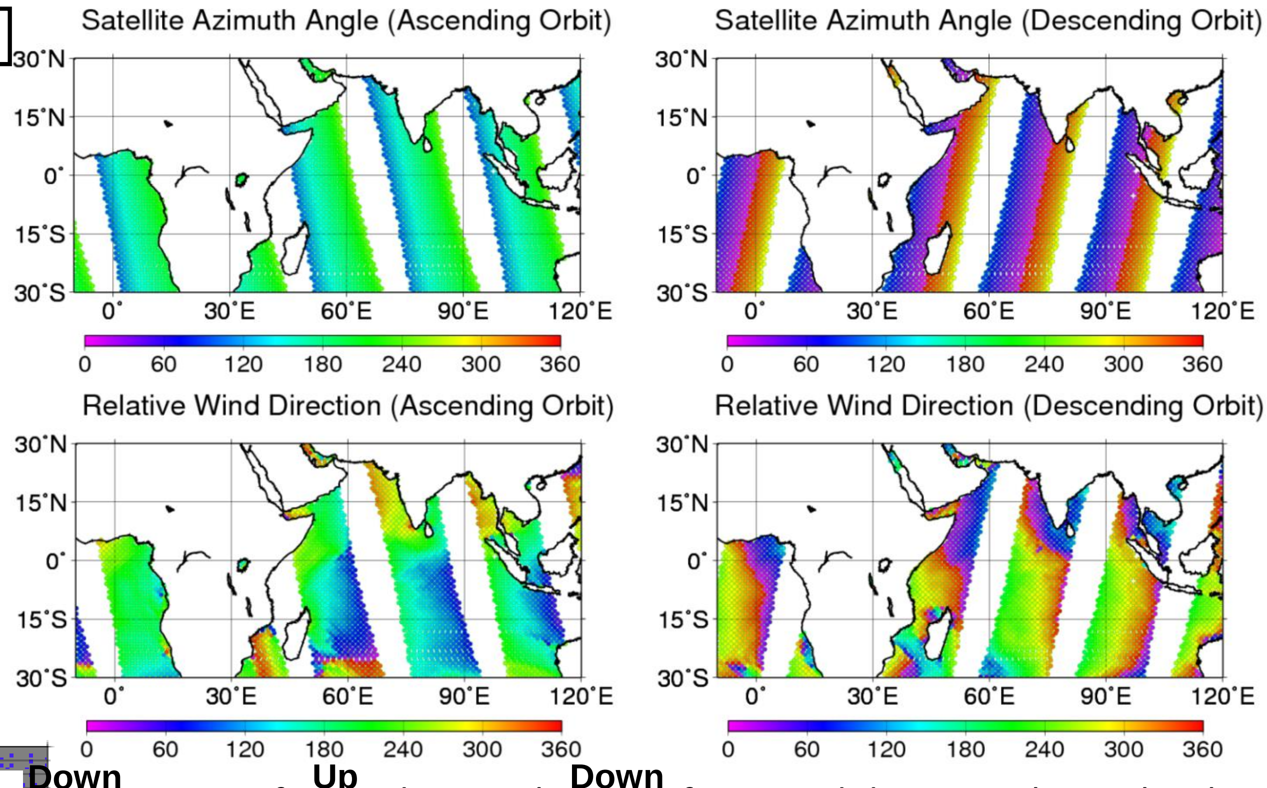
SSMISS
89V

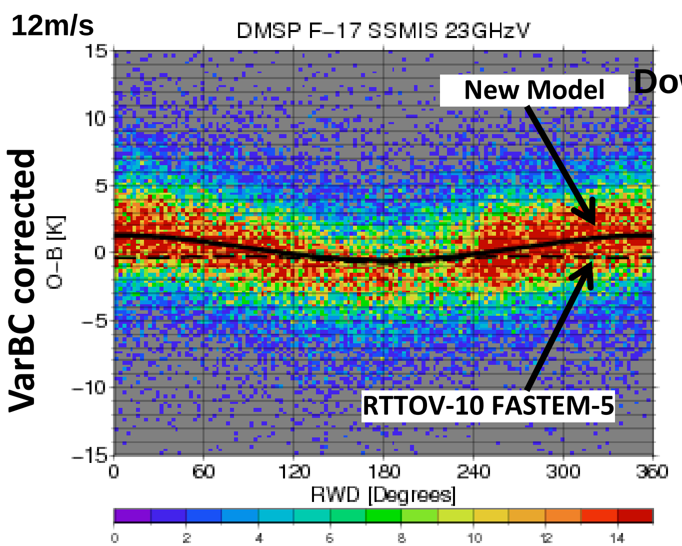
□Control (wo RWD model)
●Test (w RWD model)
SSW 12 m/s case

Somali Jet: Strong southwesterly wind (>12m/s) in Arabian Sea

Meteosat Image 06UTC 1 July 2013







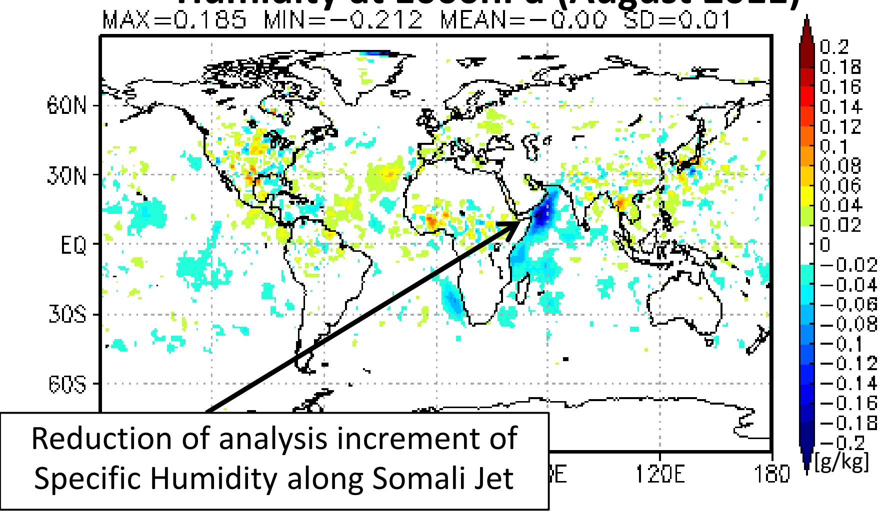
Ocean surface radiations have surface wind directional signals. The variation of T_v and T_h in terms of **R**elative **W**ind **D**irection (**RWD**) is expressed by harmonic cosine function. The RWD variation should be considered correctly in radiative transfer calculation for the radiance assimilation.

However, the directional information are not used because of a lack of sensor azimuth angle information.

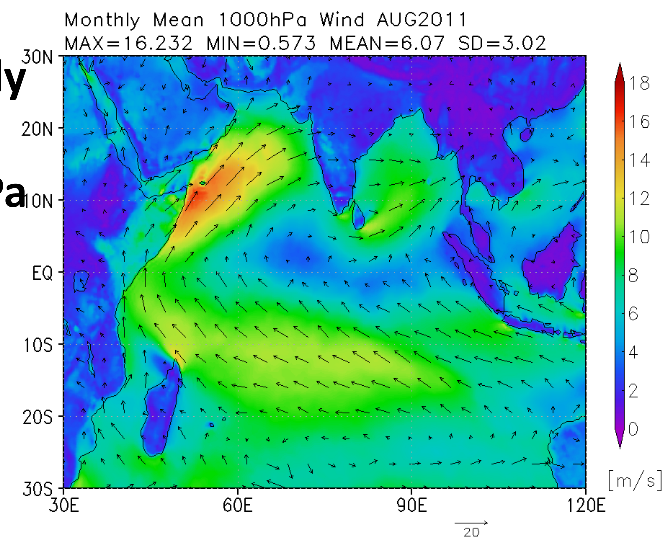
A new emissivity model (RWD model) was developed based on simultaneous measurements of radiance and wind vector from ADEOS-II (AMSR & Seawinds).

The impact of RWD model function Analysis Increment of Specific Humidity and RMS error of RH and T forecast

RMS difference Analysis Increment of Specific Humidity at 1000hPa (August 2011)

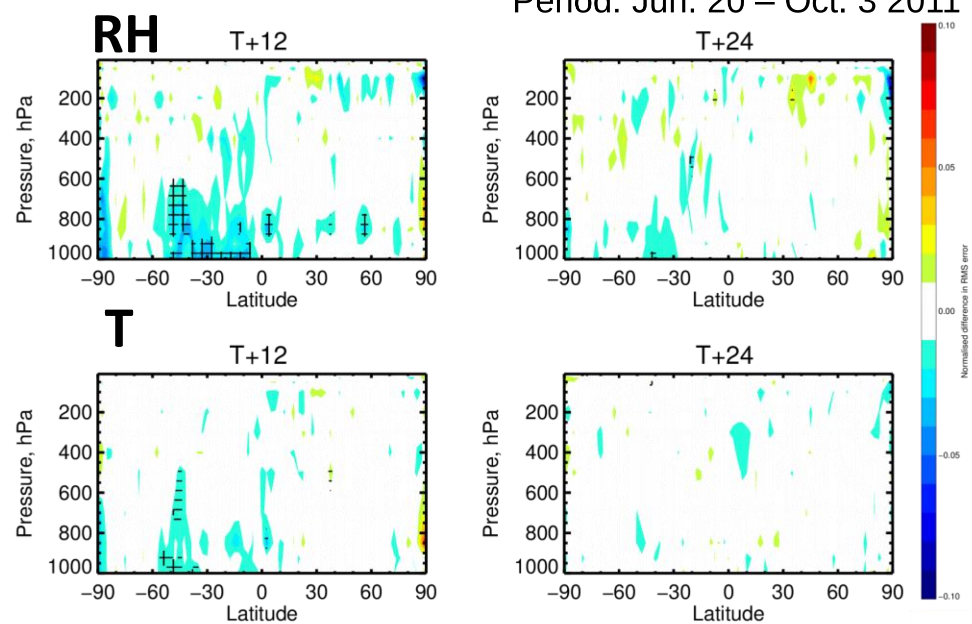


Monthly Mean 1000hPa wind speed



Normalized difference in RMS error of forecasts (against own analysis)

Period: Jun. 20 – Oct. 3 2011



The use of surface wind directional signals with RWD model reduced RH and T forecast errors significantly.

Improved ocean emissivity model

- Use of the new RWD model in FASTEM-5 reduced biases in FG departure of microwave imagers in strong wind condition
  - The RWD model has better performance than present FASTEM RWD model
  - Results of the Impact study (Period: 20 June to 3 Oct. 2011)
    - Reductions of analysis increment of specific humidity were found in high wind speed and low wind direction variability areas (Arabian sea in boreal summer).
    - In short range forecasts, reductions of RMS errors of RH and T fields in lower troposphere were significant.

  - Inclusion of the azimuth variation improves the analysis and forecast accuracy in ECMWF system. The new RWD modes will be introduced in ECMWF IFS as a part of RTTOV-11 (**FASTEM-6)**.

Reference: Use of the Ocean Surface Wind Direction Signal in Microwave Radiance Assimilation (in press, QJRMS)

New microwave imagers

- **GCOM-W1/AMSR2**
  - Data available from JAXA since July 2012
- **GPM/GMI**
  - Data available from NASA since March 2014
- DMSP/SSMIS, F16,17,18,19
- FY3/MWRI
- TRMM/TMI
- Coriolis/WindSat

GCOM-W1 “SHIZUKU” by JAXA

GPM –core by NASA and JAXA

AMSR series

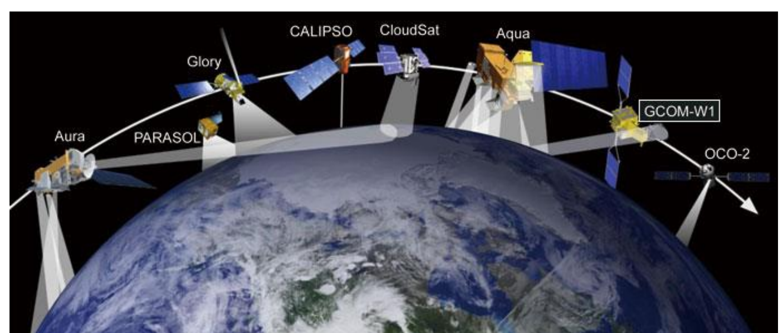
- **A**dvanced **M**icrowave **S**canning **R**adiometer (**AMSR**)

GCOM-W1/AMSR2
May, 2012 -

Aqua (US)/AMSR-E
May, 2002 - Oct, 2011

ADEOS-II/AMSR
Dec, 2002 - Oct, 2003

GCOM-W1 joined the international Afternoon Constellation (A-train)



Microwave Imager channels

GCOM-W1/AMSR2
May, 2012 -

Main reflector size (1.6m→2.0m)

Improved horizontal resolution

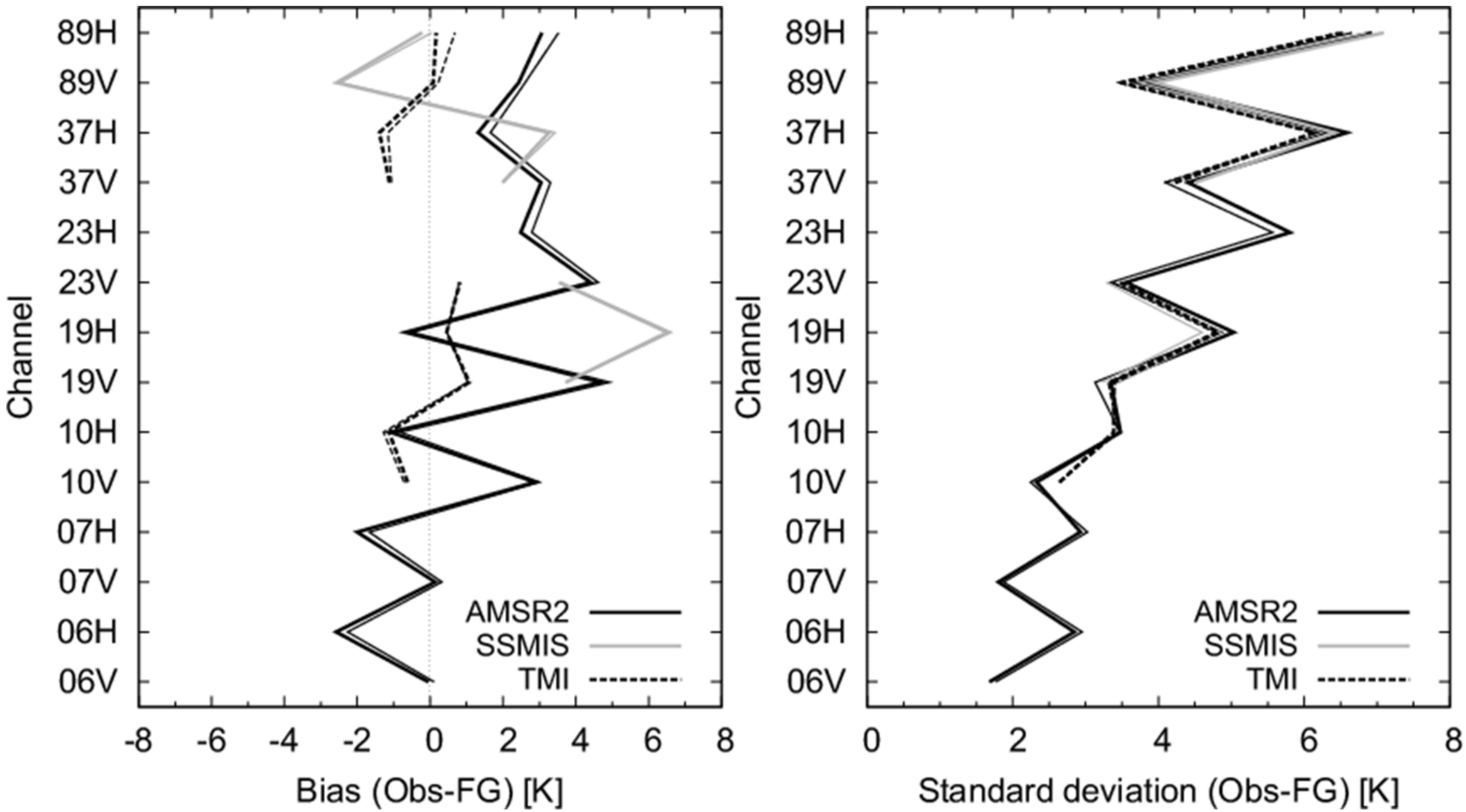
Addition of 7.3GHz channels to mitigate RFI

Band	Notation	Polarization	Sensor (channel number and frequency [GHz])							
			AMSR2		AMSR-E		TMI		SSMIS	
			Ch	Frequency	Ch	Frequency	Ch	Frequency	Ch	Frequency
C	6GHz	V	1	6.925	1	6.925				
		H	2	6.925	2	6.925				
	7GHz	V	3	7.3						
		H	4	7.3						
X	10GHz	V	5	10.65	3	10.65	1	10.65		
		H	6	10.65	4	10.65	2	10.65		
Ku	19GHz	V	7	18.7	5	18.7	3	19.35	13	19.35
		H	8	18.7	6	18.7	4	19.35	12	19.35
K	23GHz	V	9	23.8	7	23.8	5	21.3	14	22.235
		H	10	23.8	8	23.8				
Ka	37GHz	V	11	36.5	9	36.5	6	37	16	37
		H	12	36.5	10	36.5	7	37	15	37
W	89GHz	V	13	89.0A	11	89.0A	8	85.5	17	91.655
		H	14	89.0A	12	89.0A	9	85.5	18	91.655
		V	15	89.0B	13	89.0B				
		H	16	89.0B	14	89.0B				

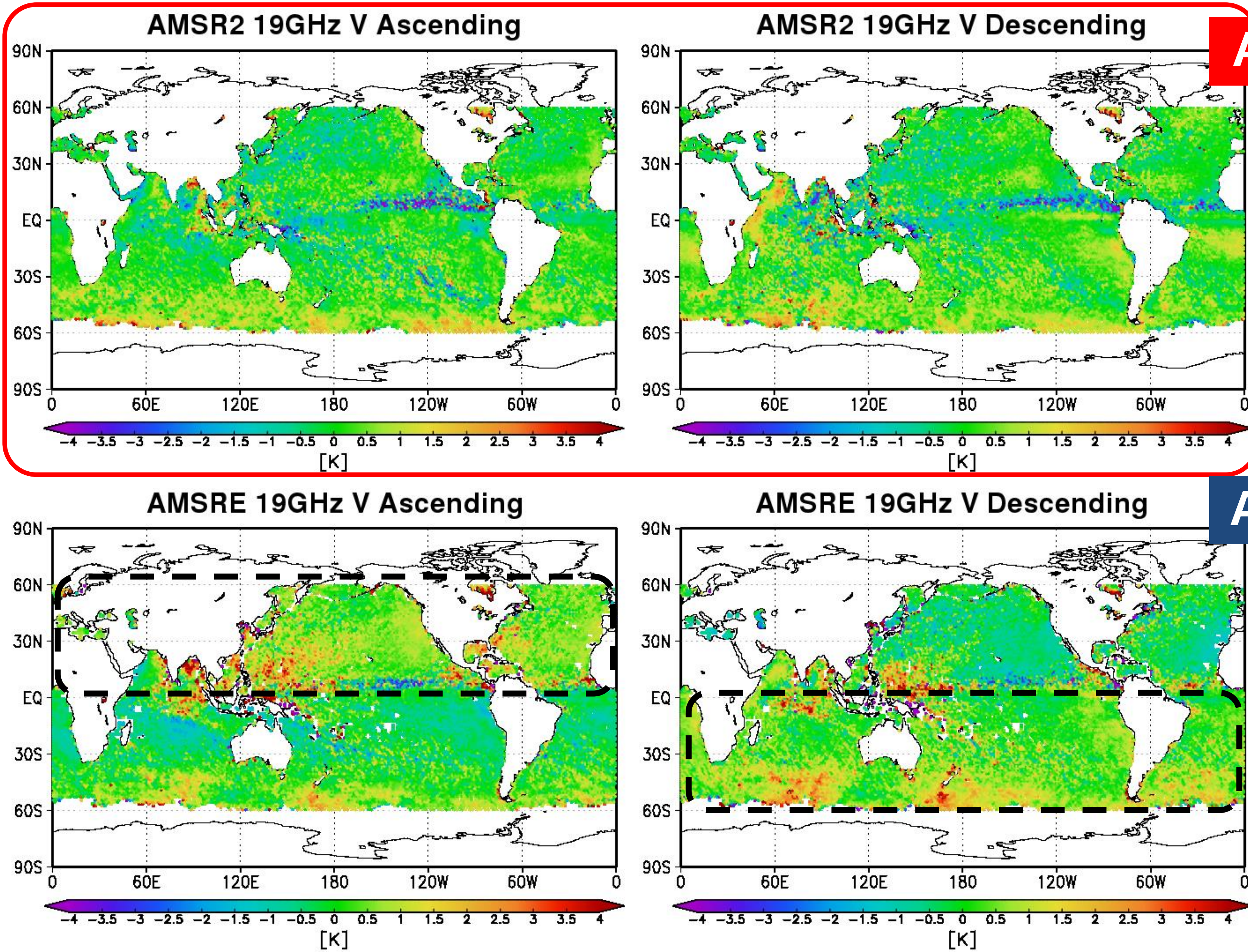
Better calibration (improved hot load stability)

FG departure comparison in IFS
(WO bias correction, not normalized)

1-20 Jan. 2013 (thick line)
1-20 Jul. 2013 (thin line)



Mean FG departures (Oceanic Data) 19GHzV, 3month average in IFS



AMSR2

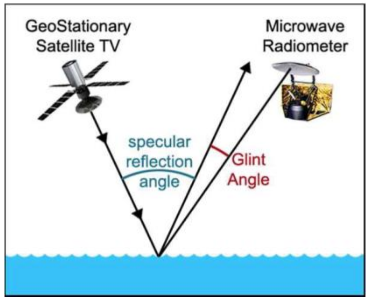
JJA
2013

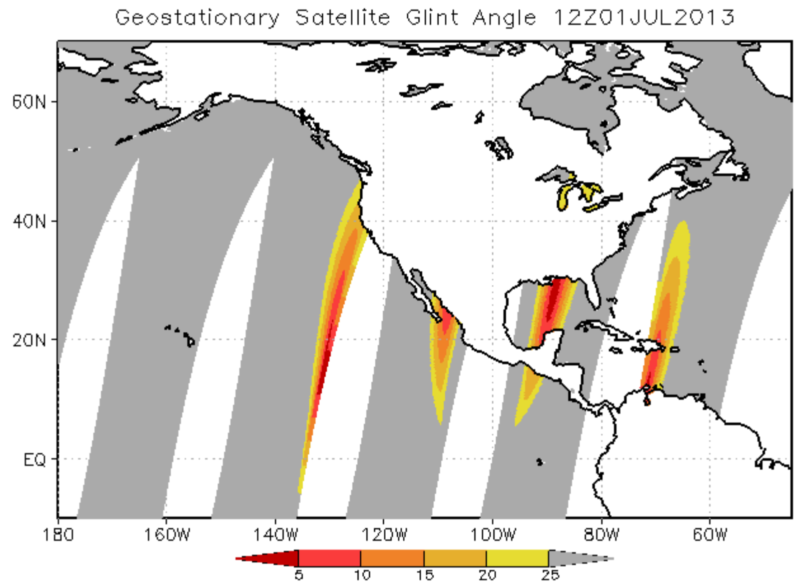
AMSRE

JJA
2011

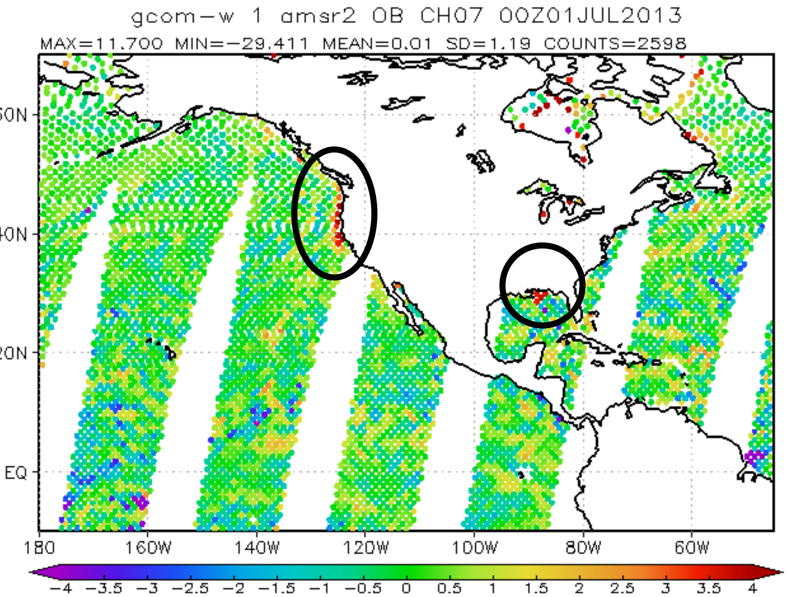
Radio Frequency Interference (RFI) in 19GHz channel

- The source of RFI contamination in descending AMSR2 18.7 GHz vertically and horizontally polarized channels is broadcasting activities from DirecTV satellite 10 in geosynchronous orbit at 102.8 West Longitude.
- RFI is identified in the U.S. coast and the intensity is affected by glint angle, geographic location, and surface roughness.





Normalized FG departure



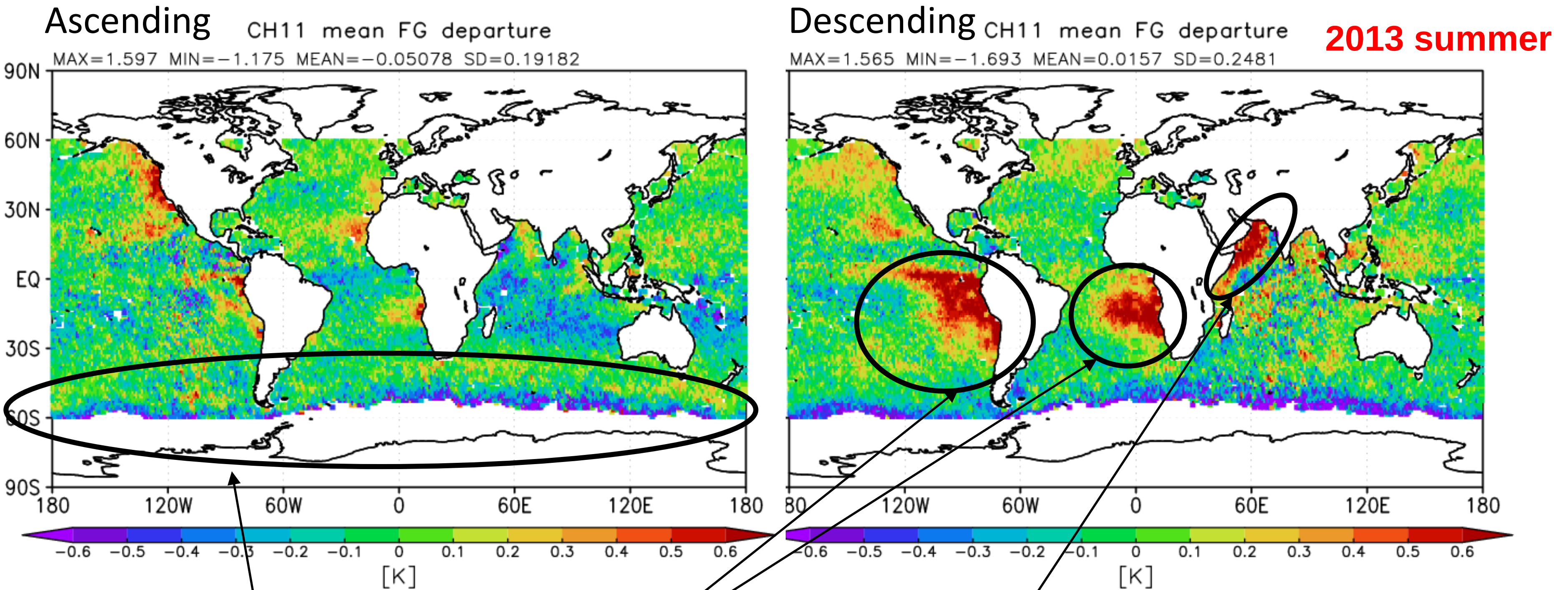
Results of AMSR2 data quality assessment

- Generally, AMSR2 data quality outperforms AMSR-E, and performs well compared to SSMIS and TMI data
  - Less sensor related biases and no orbit-dependent bias in AMSR2.

- Evidence for RFI contamination in 18.7GHz descending orbits for AMSR2 and AMSR-E. (RFI Source : US Geostationary Satellite)

Use of AMSR2 data for ECMWF model (CY40R1) evaluation

Normalized mean FG-departures, AMSR2 37V

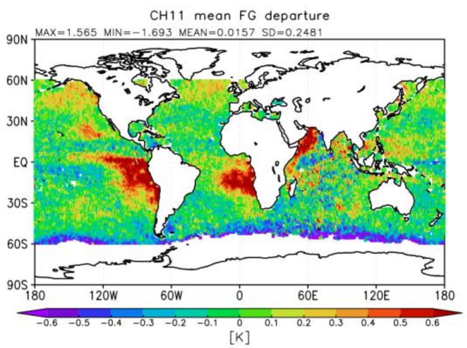
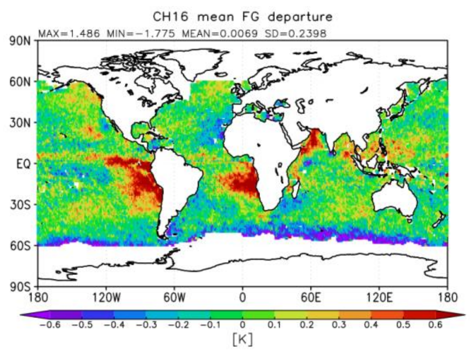
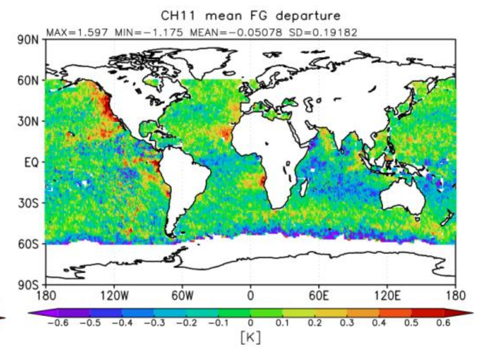
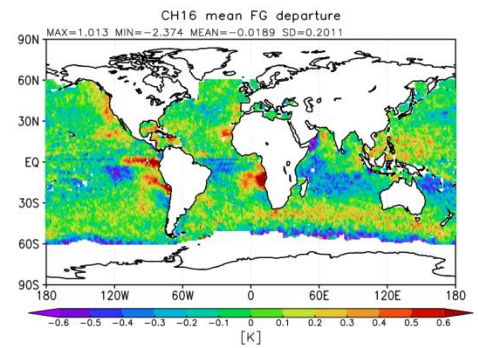


1. Biases depending on Relative Wind Direction (RTM origin)
2. Biases from diurnal variation of cloud liquid water (Stratocumulus area) in West coast of continents (Forecast Model origin)
3. Positive biases in Winter Hemisphere in cold sector (Forecast Model and RTM origin) Type I cold sector bias
4. Negative biases in frontal area in cold sector (Forecast Model origin) Type II cold sector bias

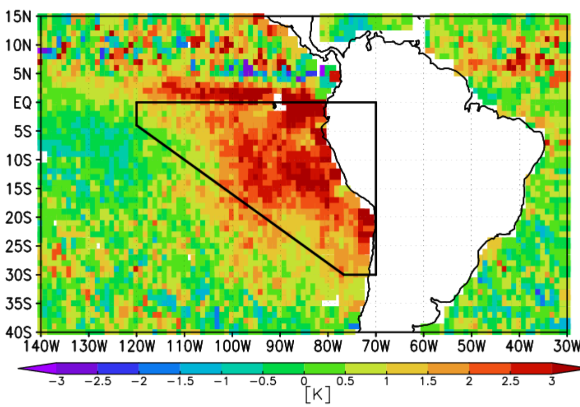
Diurnal bias of the forecast model in stratocumulus areas

Normalized mean FG-departures, AMSR2 37V

Summer

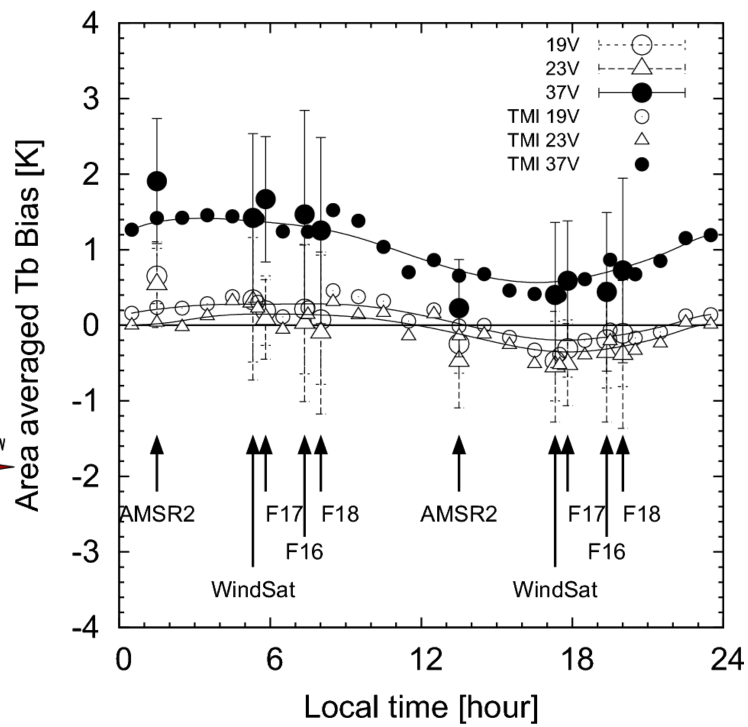
01:30	05:49	13:30	17:49
			

Focused area



37V FG departure (not normalized)

(a) 15 Jul. - 15 Oct. 2013



Positive FG departure biases exist in stratocumulus areas.

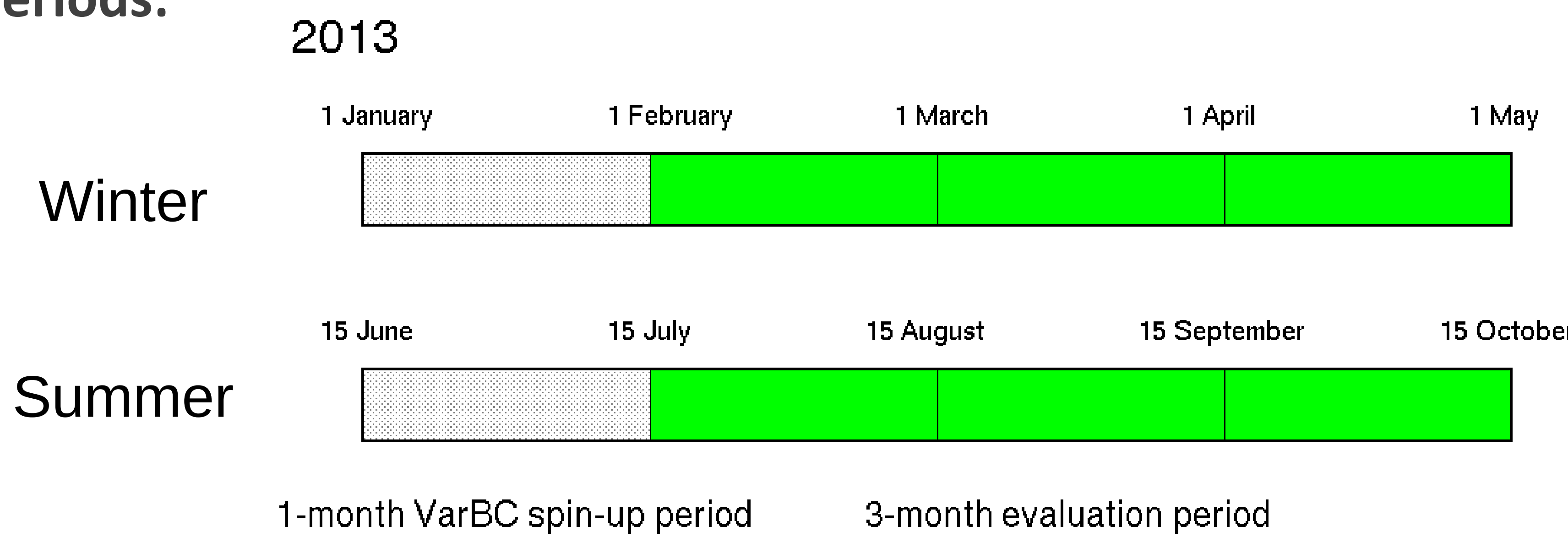
The biases show diurnal variation.

Assimilation experiments with AMSR2

- **Experiments:**
  - **Baseline:** ECMWF (CY40R1 T511L137) minus all MW imager data
  - **AMSR2**: Baseline + AMSR2
  - **SSMIS**: Baseline + SSMIS F17
  - **TMI**: Baseline + TMI

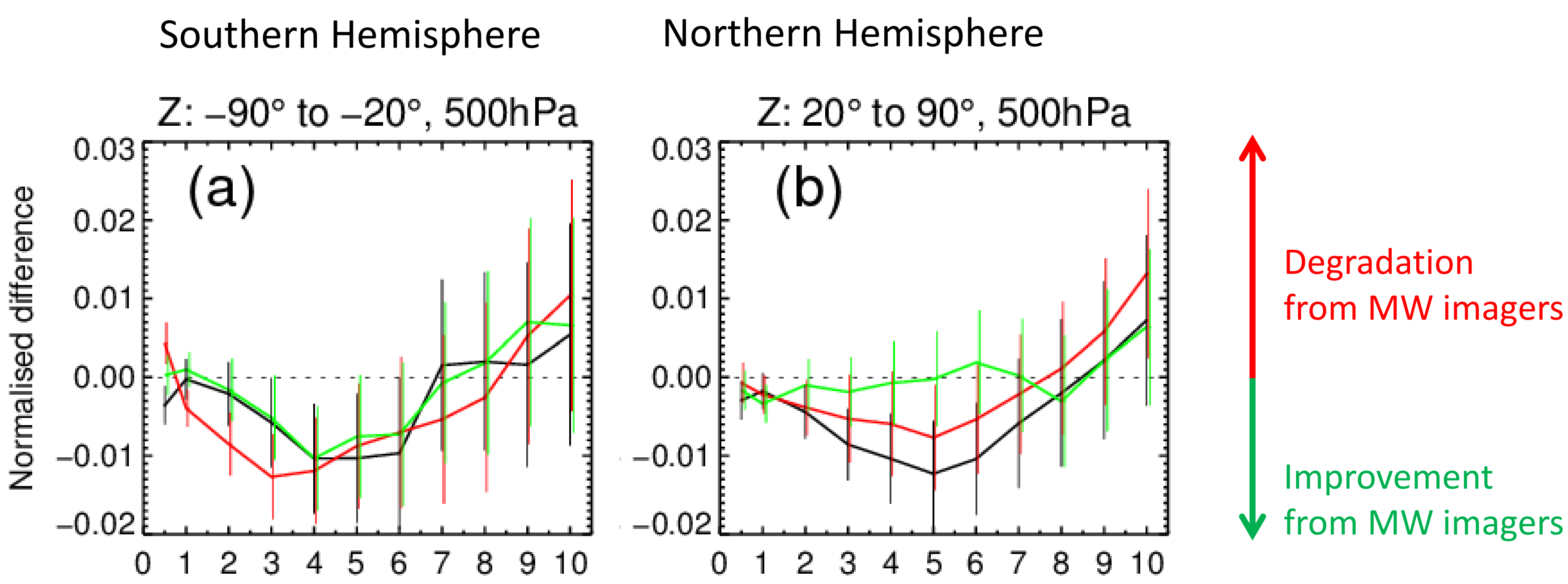
SSMIS humidity sounding channels are used in all experiments.

- **Periods:**



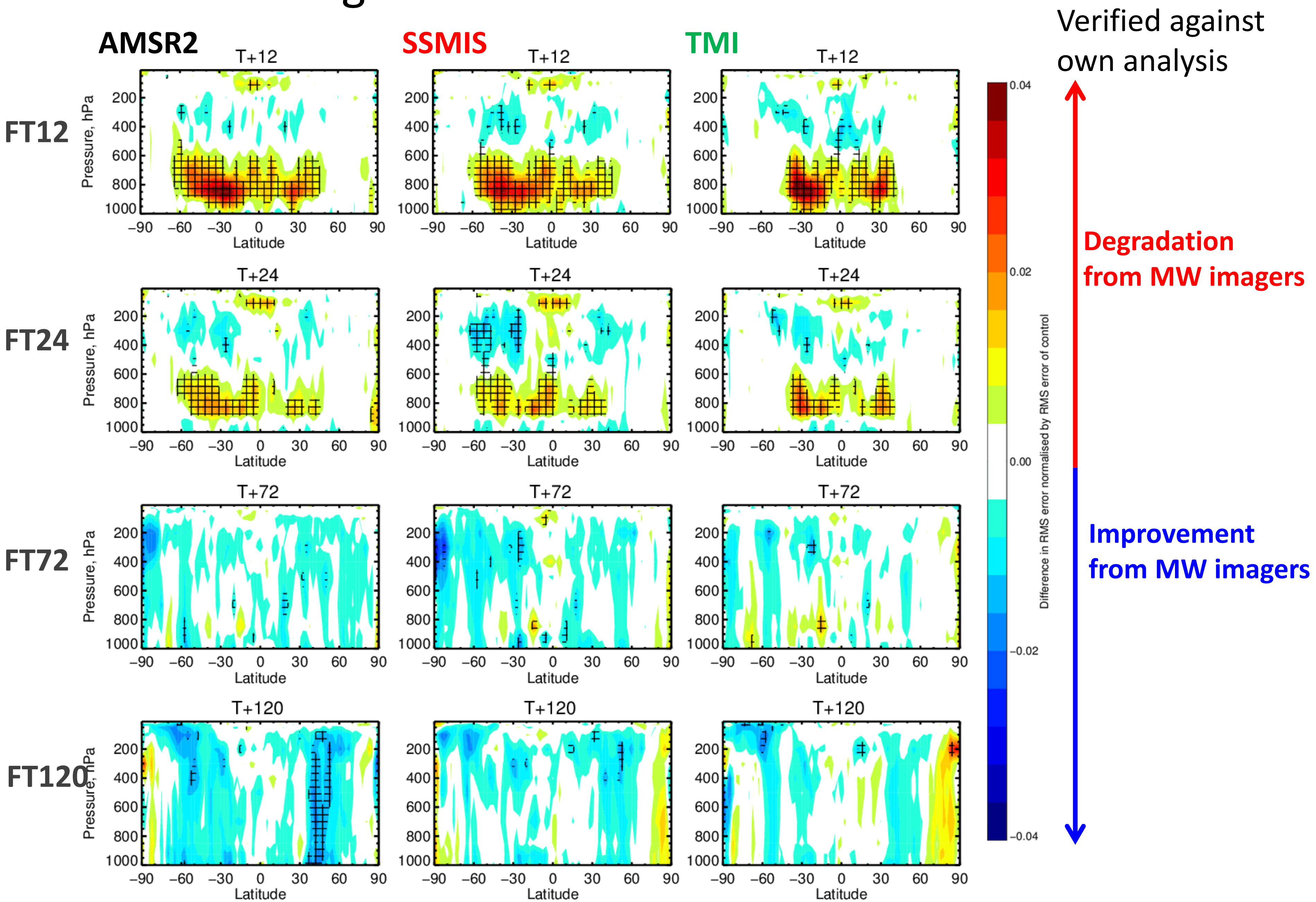
Impacts on forecast

Normalized difference in the RMSE of the 500 hPa geopotential,
Both seasons combined (6 months)



AMSR2 – Baseline
SSMIS – Baseline
TMI - Baseline

Change in error in Vector Wind forecast



Summary on AMSR2 data

- AMSR2 data have been evaluated in the ECMWF system.

  Generally good data quality, comparable to other MW imagers.

- AMSR2 data have been assimilated in the ECMWF system, with positive impact on medium-range forecasts.

- AMSR2 data offers great potential for enhanced model evaluation.

GPM/GMI

Global **P**recipitation **M**easurement

Joint Mission of JAXA and NASA

Launch: 27 February 2014

GPM core satellite

GMI: **G**PM **M**icrowave **I**mager

DPR: **D**ual **P**recipitation **R**adar

Key features of GMI for NWP

Wide data coverage (High altitude area)

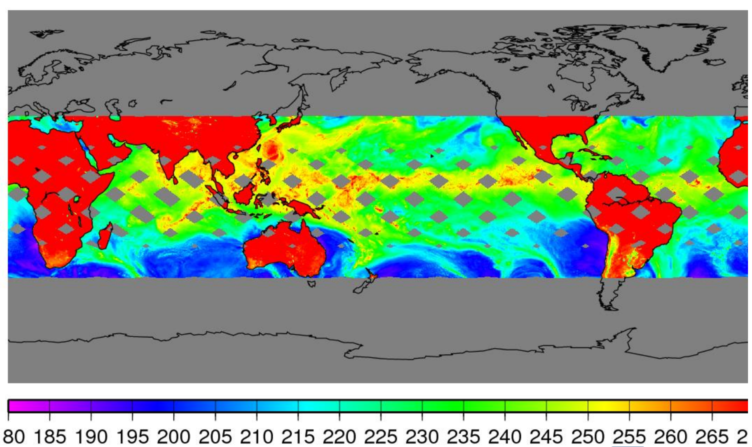
Non Sun-synchronous orbit

New observation channels, 166GHz, 183GHz for solid precipitation measurements

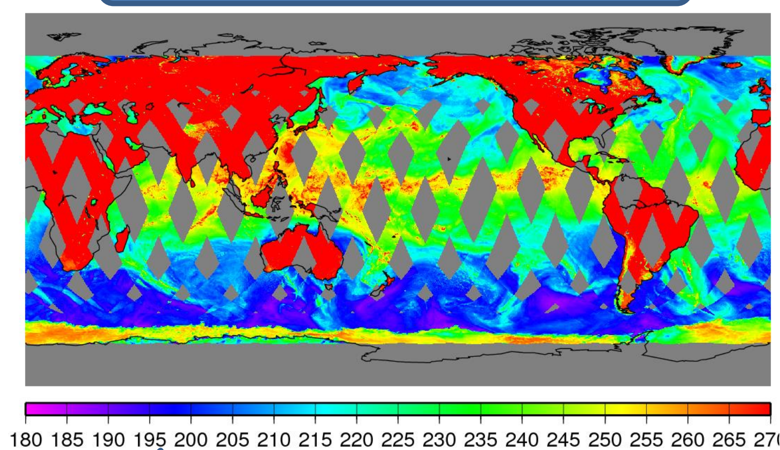
TMI	GMI
10.65V	10.65V
10.65H	10.65H
19.35V	**18.7V**
19.35H	**18.7H**
21.3V	**23.8V**
37V	**36.64V**
37H	**36.64H**
85.5V	**89V**
85.5H	**89H**
	166V
	166H
	183+3V
	183+7V

Center frequency [GHz]

TRMM/TMI 1 day coverage

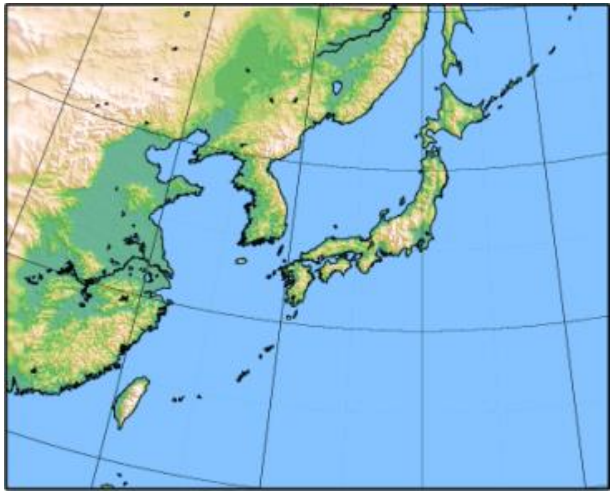


GPM/GMI 1 day coverage



Assimilation of GMI radiances in JMA Meso-scale NWP system

Main target of JMA Meso-scale NWP system is accurate precipitation forecasts for Japan and its surrounding areas.



- **JMA Meso-scale NWP system**
  - **DA system:**
    Non-hydrostatic model based 4D-Var (Honda *et al*. 2005)
  - **Forecast model:**
    Non-hydrostatic model, JMA-NHM (Saito *et al*. 2006)
  - **Model Resolution:**
    Outer 5km, Inner 15km
  - **Three hourly assimilation cycle:**
    8 times per day, three hour assimilation window
  - **Used data:**
    satellite radiance and rain, rain rate and wind from ground-based radar, TCWV from GNSS, AMV, and conventional data
  - **RTM for satellite radiance assimilation:**
    RTTOV-10
- **Added new data**

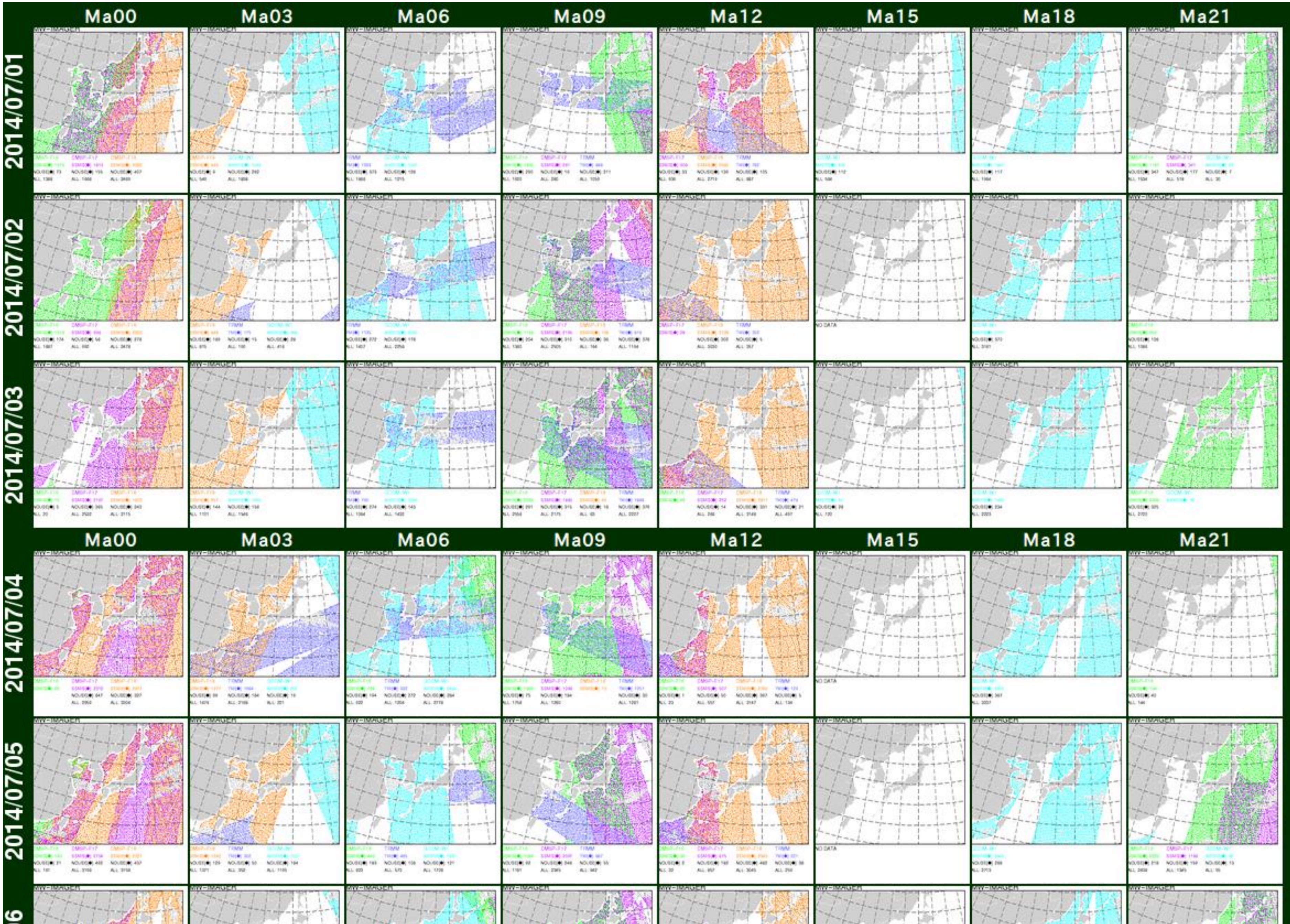
GMI: Global Precipitation Measurement (GPM) Microwave Imager

- Channel**:** 18V, 21V, 37V, 85V
- Retrieved Rain Rate

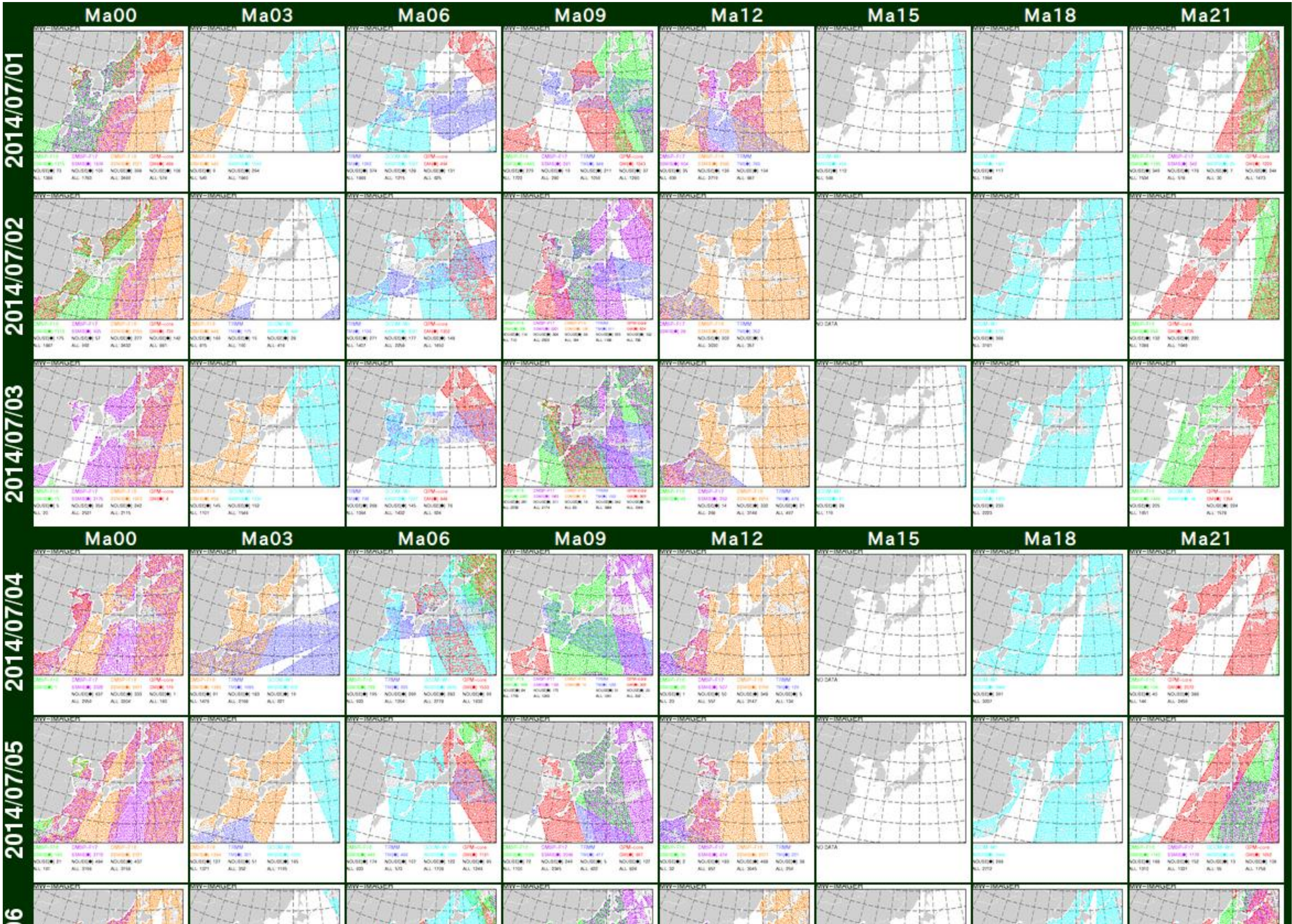
GMI Tb data are obtained from JAXA in real time

Distribution of used microwave imager data in JMA Meso-scale analysis:

AMSR2, SSMIS F16, SSMIS F17, SSMIS F18, TMI, GMI

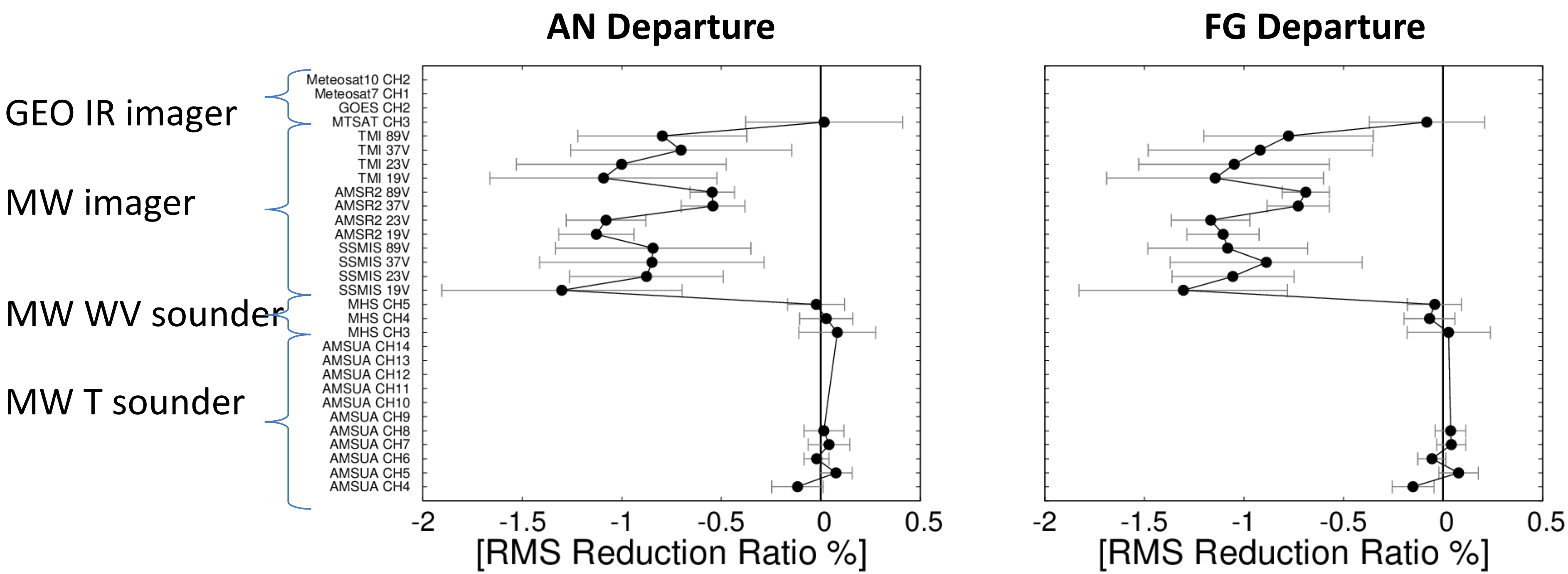


Distribution of used microwave imager data in JMA Meso-scale analysis:
AMSR2, SSMIS F16, SSMIS F17, SSMIS F18, TMI, GMI



RMS reduction ratio of AN departure and FG departure

Area: JMA Mesoscale Model Domain



Addition of GMI improves the fits in other microwave imager data and AMSU-A channel 4.

This suggest improvements of humidity and temperature field in the lower troposphere.

A case study: Heavy precipitation event in Japan

Assimilation experiment:

Control run: same as JMA operational configuration (wo GMI data)

Test run: Control + GPM satellite data (GMI brightness temperature, retrieved rain rate)

Period:

Data assimilation: 1 – 11 July, 2014

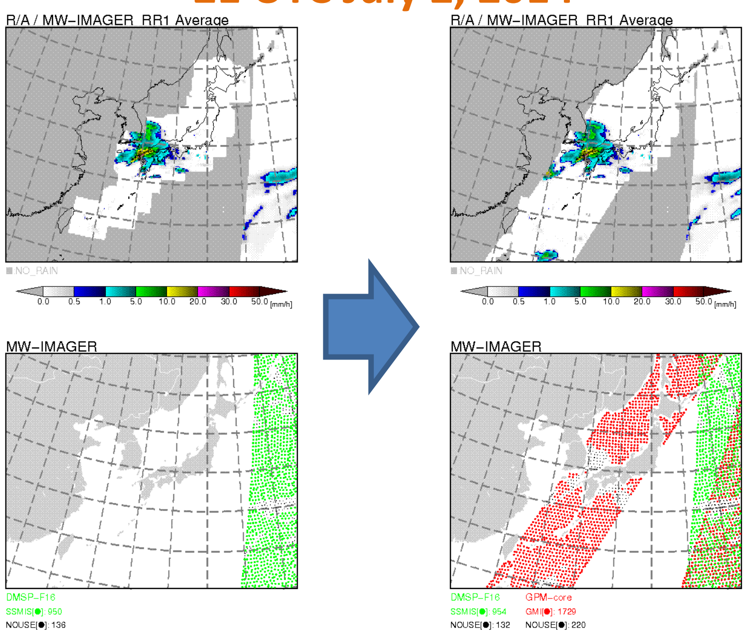
Forecast: 39 hour forecasts every 3 hour

21 UTC July 2, 2014

Rain Rate from ground-based radar and microwave imagers

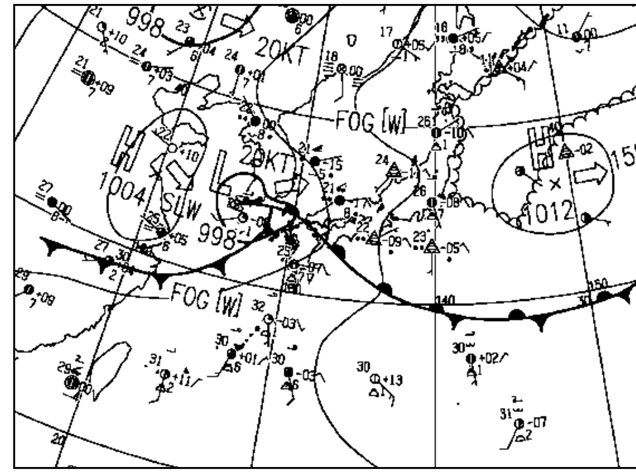
GMI brightness temperature

SSMIS brightness temperature

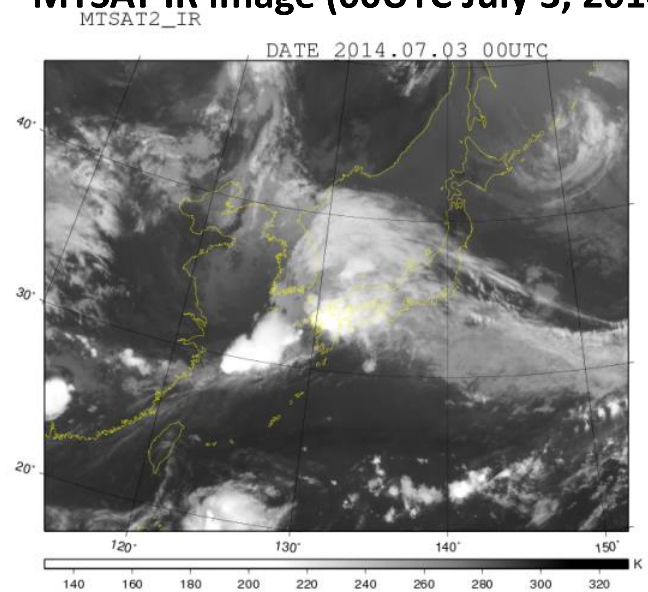


Heavy rain in Nagasaki prefecture in the western Island of Japan

Surface weather chart (00UTC July 3, 2014)

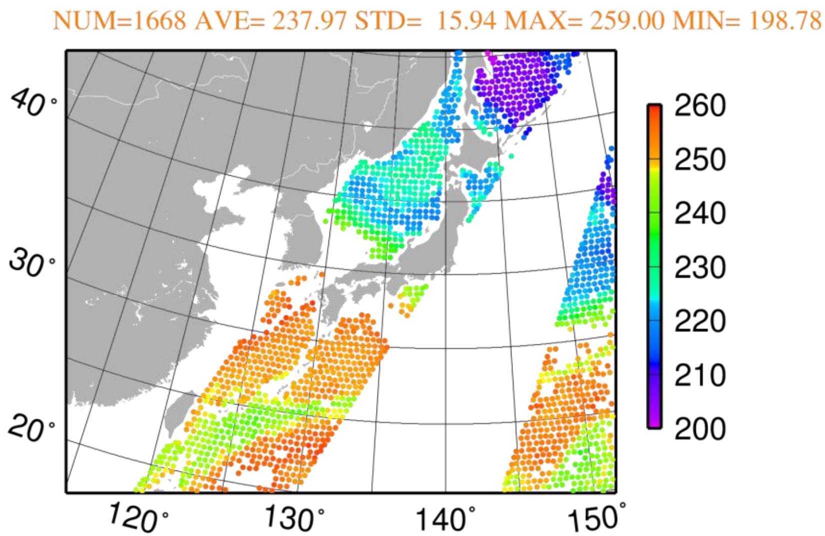


MTSAT IR image (00UTC July 3, 2014)

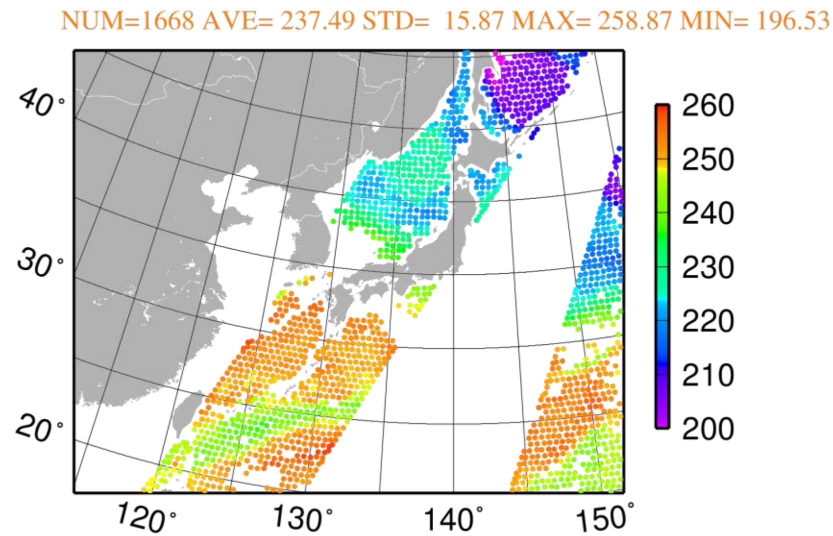


GMI data coverage

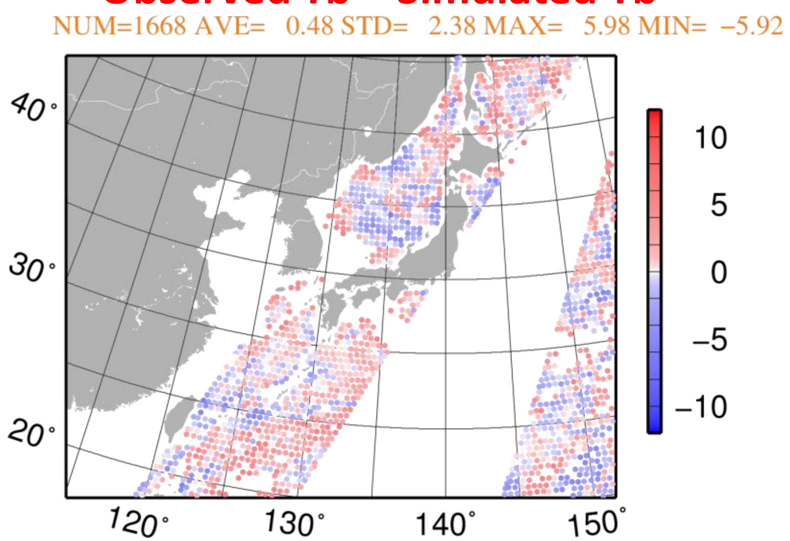
GMI observed Tb (21GHzV) w BC



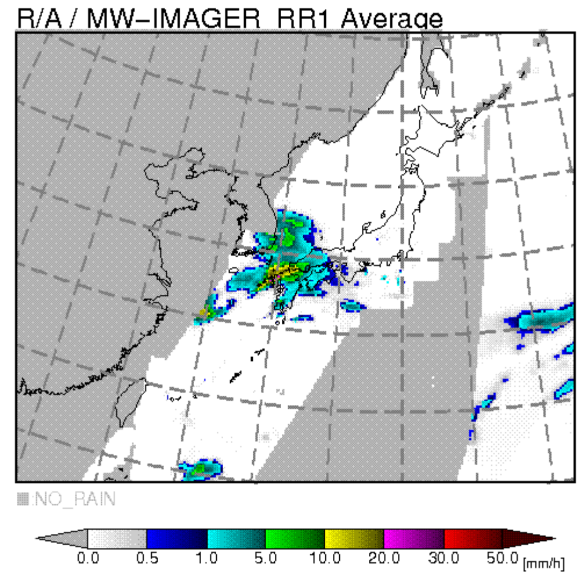
GMI simulated Tb (21GHzV)



Observed Tb – Simulated Tb



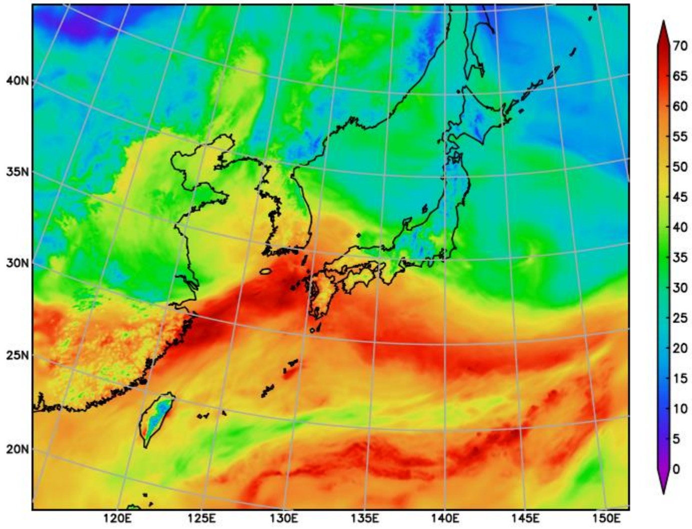
Retrieved Rain Rate



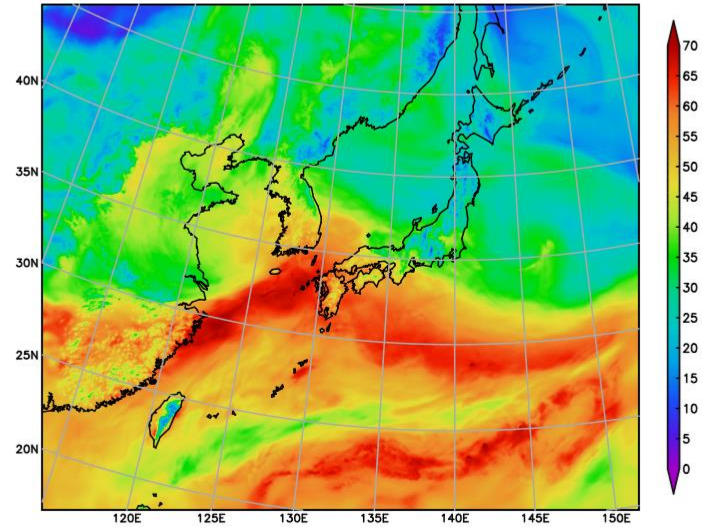
Added new data

Impacts on analyzed TCWV field

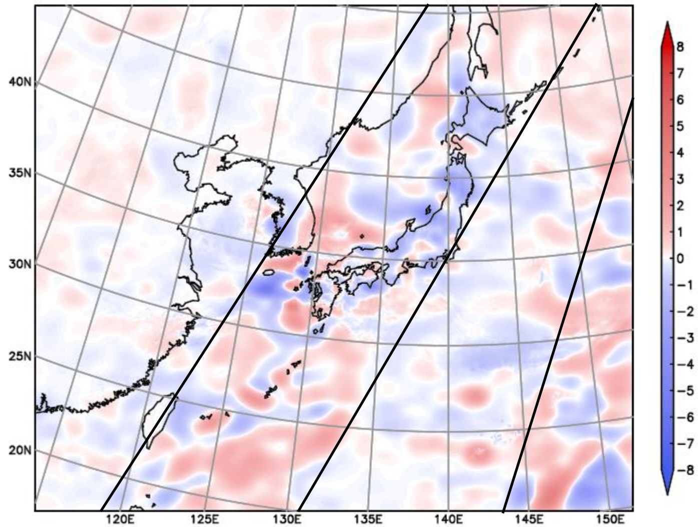
TCWV (analysis) （w GMI）



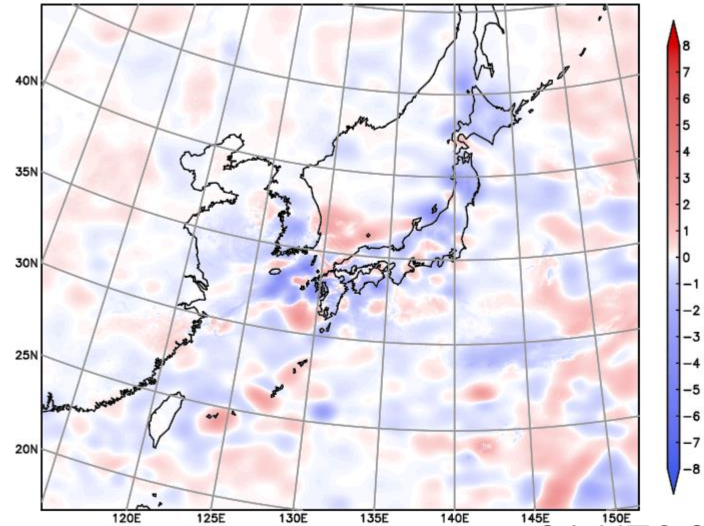
TCWV (analysis) （wo GMI）



Analysis increment（w GMI）



Analysis increment（wo GMI）

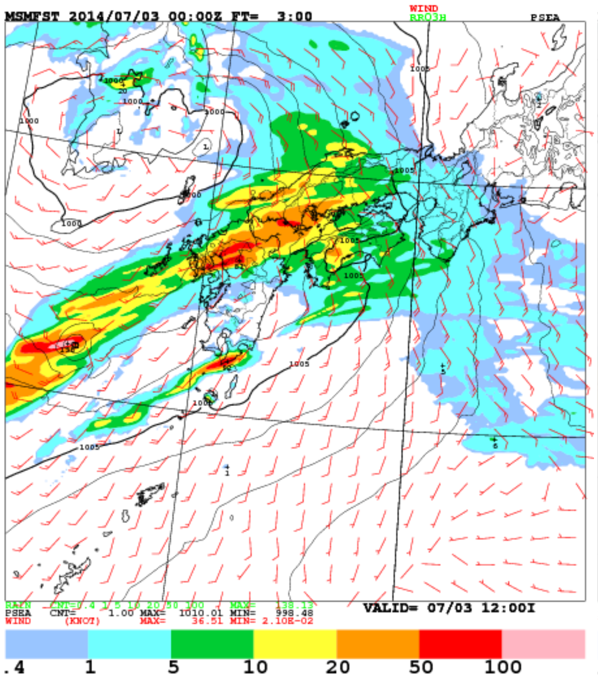


21 UTC 2 July 2014

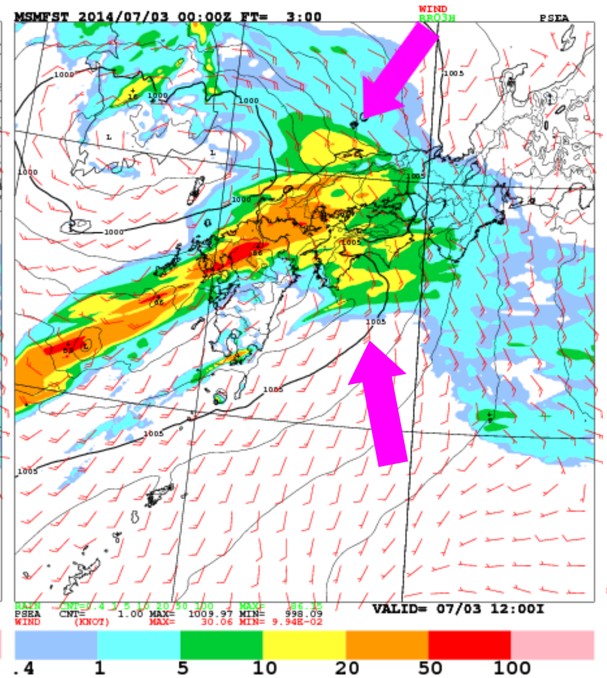
Comparison of precipitation forecast

Three hour accumulated rainfall forecast for 03 UTC July 3, 2014
Three hour forecast from initial time (00UTC July 3, 2014)

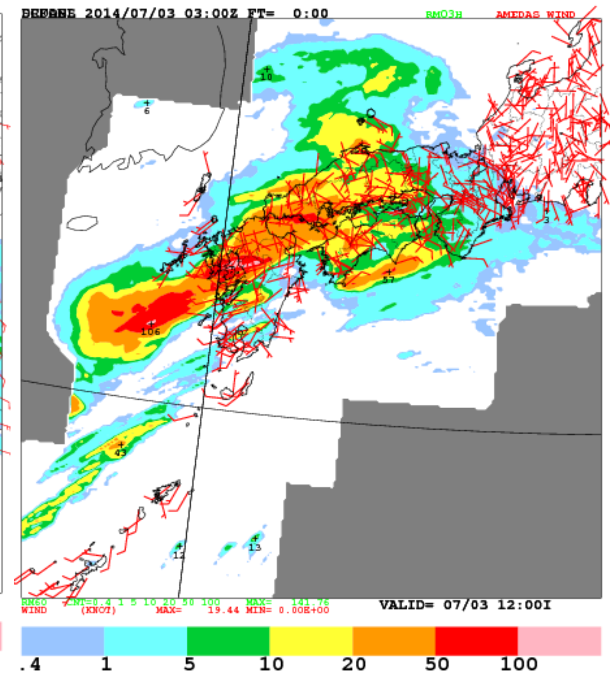
Control (WO GMI)



Test (W GMI)



Radar Observation



There is no big change in heavy precipitation forecast in the northern part of Kyusyu Island. The forecasts have already had high accuracy for the heavy precipitation event.

However, the assimilation GMI data brought improvements in the short range precipitation forecasts for adjacent areas of the heavy precipitation

Summary and future prospect

- Microwave imager observation provide information on various geophysical parameters. They are **essential data for initialization of NWP models**. The data can be utilized for NWP model evaluation.

- Accuracy of microwave radiative transfer model is a key element for the data assimilation.
  - Recently, **improved microwave ocean emissivity model** was developed (**RWD model function**) and named as **FASTEM-6**.
- New microwave imager data are available and their utilization are in progress.
  - **AMSR2** data assimilation in ECMWF global model
  - **GMI** data assimilation in JMA Meso-scale model

- Assimilation of **low frequency channels** (6 and 10 GHz) are not yet fully explored. The atmospheric signal and surface signal can be obtained under rainy situation.

Thank you for your attention.