Use of the Ocean Surface Wind Direction Signal in Microwave Radiance Assimilation

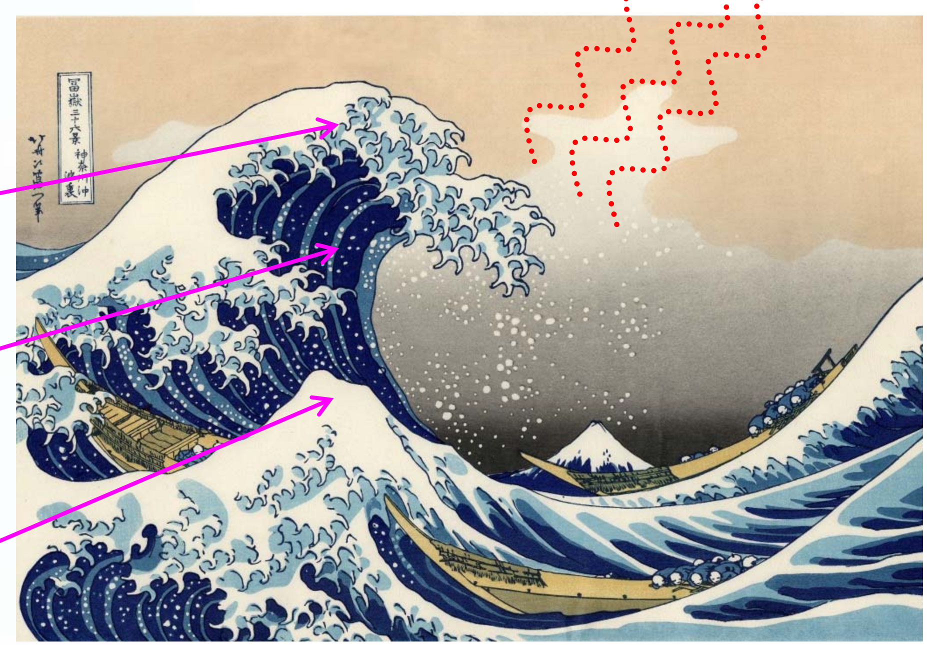
Masahiro Kazumori*
Japan Meteorological Agency

Stephen J. English
European Centre for Medium-Range Weather Forecasts

*This study was performed during the stay in ECMWF as a visiting scientist

Microwave Ocean Emissivity calculation in RTTOV

- **RTTOV-10** (Fast radiative transfer model) uses **FASTEM-5** 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 Downwelling 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.

Characteristics of oceanic microwave radiance

Measurements from Airborne Microwave Radiometer and Buoy

Ocean surface radiations have surface wind directional signals.

The azimuthal variation should be considered correctly in radiative transfer calculation for radiance assimilations.

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

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

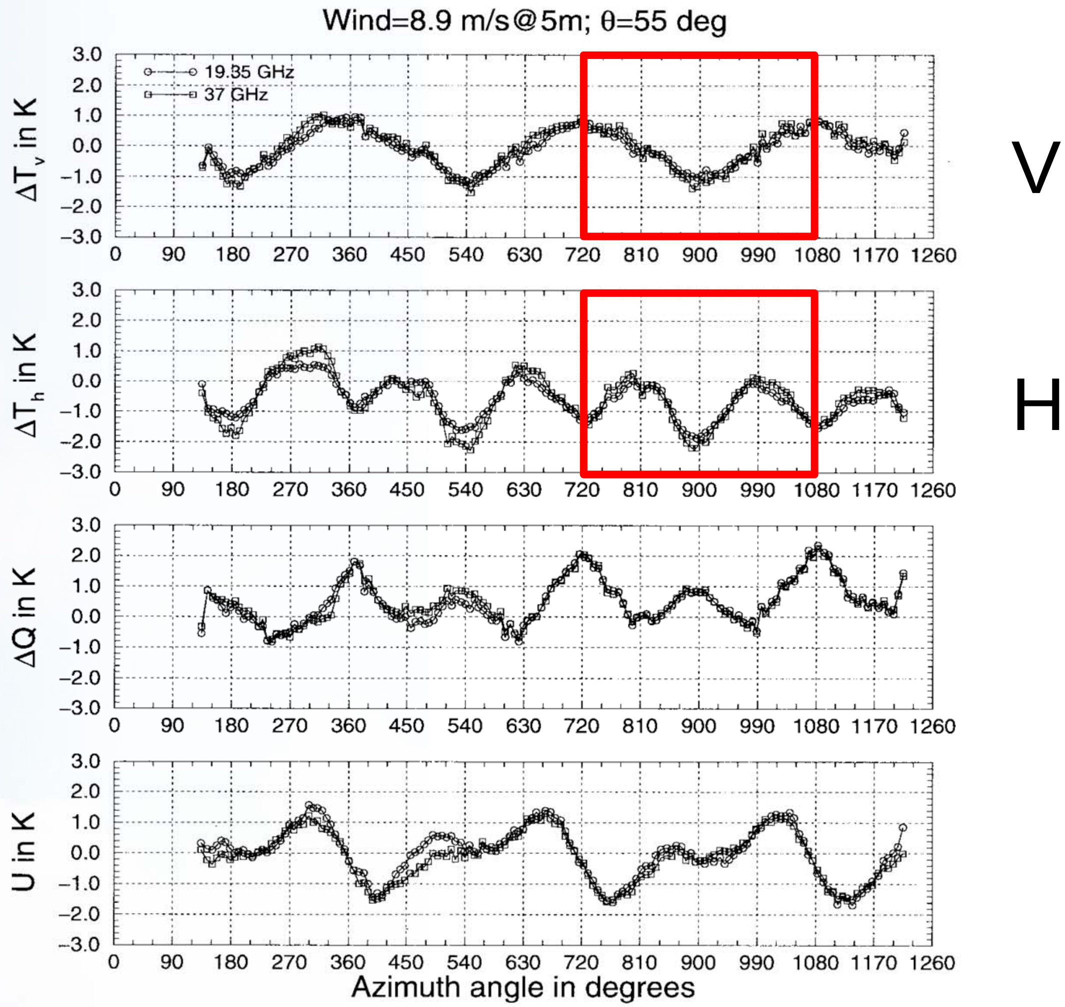
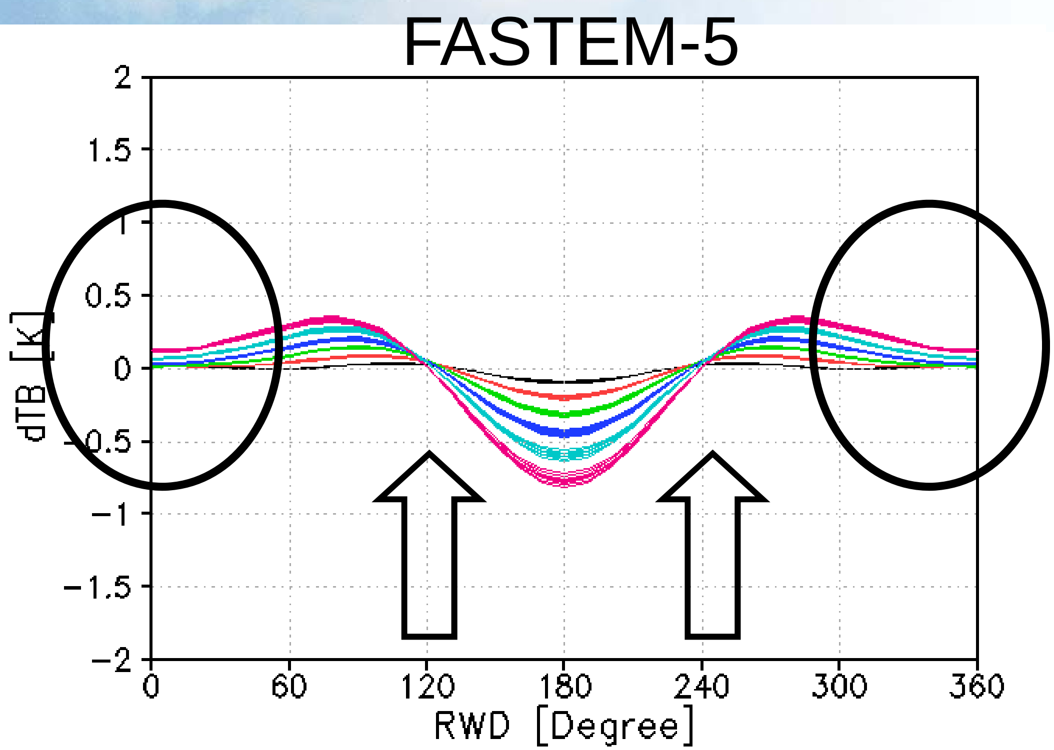
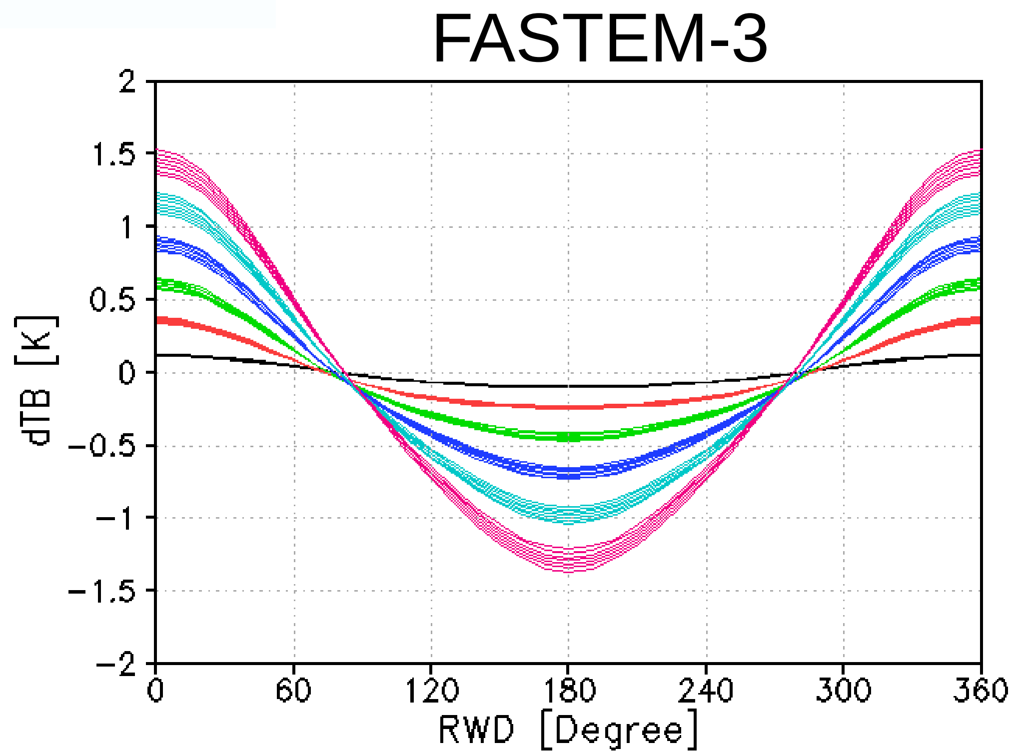


Fig. 2. Wind direction signals in polarimetric brightness temperatures of ocean surfaces acquired by JPL K- and Ka-band radiometers at 55° incidence angle. The data were acquired on 17 April, 1995, with NASA DC-8 flights over NDBC buoy 46005. The skies were mostly clear with some small scattered clouds. 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)

The Variations of Simulated Brightness Temperature 19 GHz V-pol.





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)

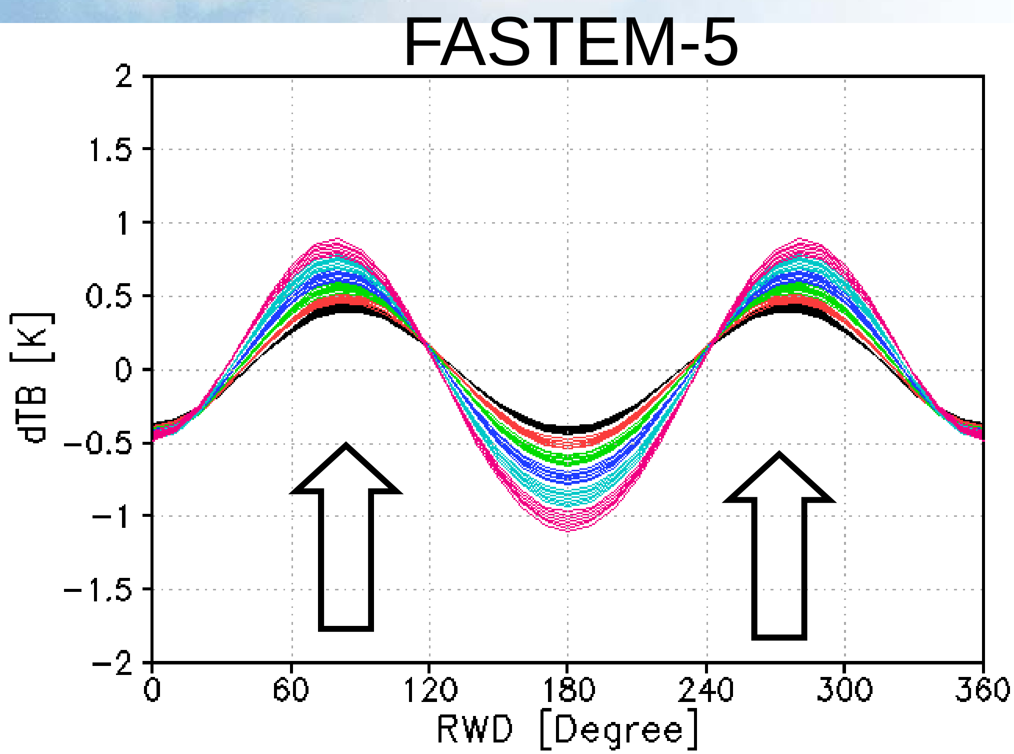
Differences:

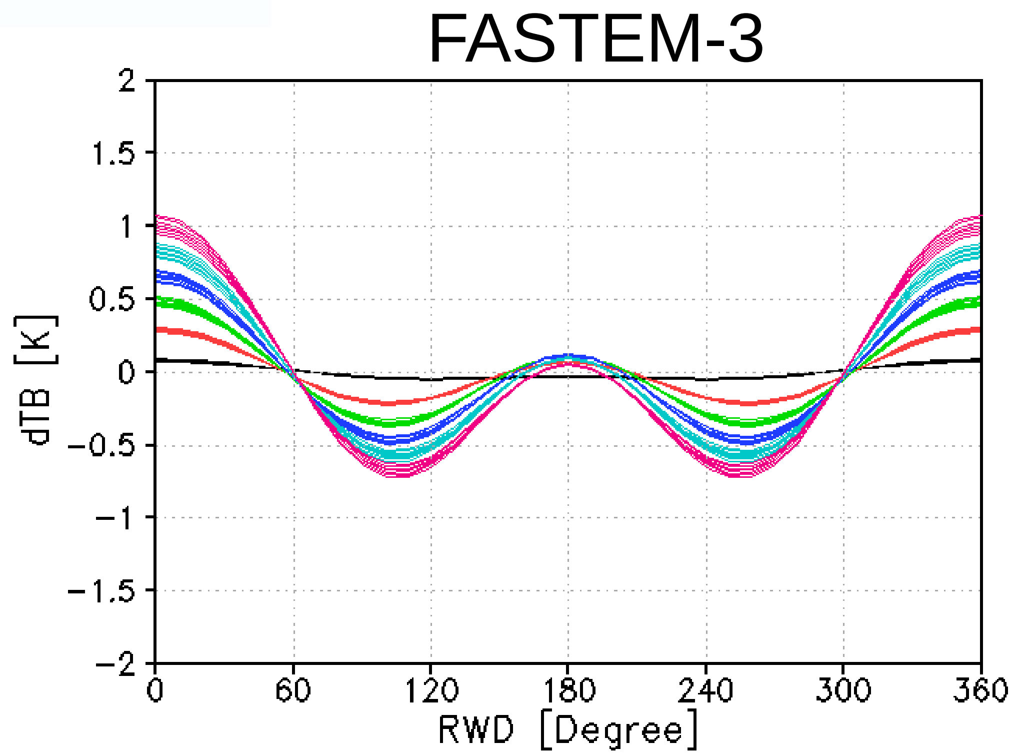
Behavior at RWD=0,360

Behavior at RWD=120,240

Magnitude of Amplitude

The Variations of Simulated Brightness Temperature 37 GHz H-pol.





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)

Differences:

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

Bugs in implementation of FASTEM3 RWD model into RTTOV?

Issues on FASTEM-5 and FASTEM-3 performance

- Many differences in RWD model function between FASTEM-5 and FASTEM-3
  - FASTEM-5
    - The phase of V-pol. RWD dependency is different from real observation (AMSR-E, SSMIS)
    - H-pol. Channel has strong RWD sensitivity in low wind speed.
  - FASTEM-3
    - Behavior of V-pol. channel looks fine, H-pol. channel's emissivity variation showed unphysical feature.
      Maybe a bug in implementation of RWD model into RTTOV.
- **RWD model in FASTEM-5 and FASTEM-3 are not consistent with real microwave imager's measurements. It is better to develop a new RWD model by ourselves.** New model should be more accurate and consistent with the real measurement.

Development of new Relative Wind Direction (RWD) model

- Strategy
  - New model should be based on real microwave measurement.
- Used Observations
  - Real measurements of wind vector and observed radiance data are necessary to construct the model.
    - Collocation BUOY or Scattrometer and Radiometer measurement
      - Available data is very limited in time and region
    - Simultaneous measurements of wind vector and radiance are available for a limited period.
      - The data obtained from **AMSR and Seawinds** on ADEOS-II satellite. The period is limited (7 months), but global data (various meteorological condition data) is available.
      - **Only clear condition data was used to separate cloud signal and surface wind signal.**
- Used ancillary data
  - Atmospheric profiles (T,Q) from ECMWF ERA-Interim for radiative transfer calculation (RTTOV)

Design of new RWD model

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

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

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

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

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

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

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

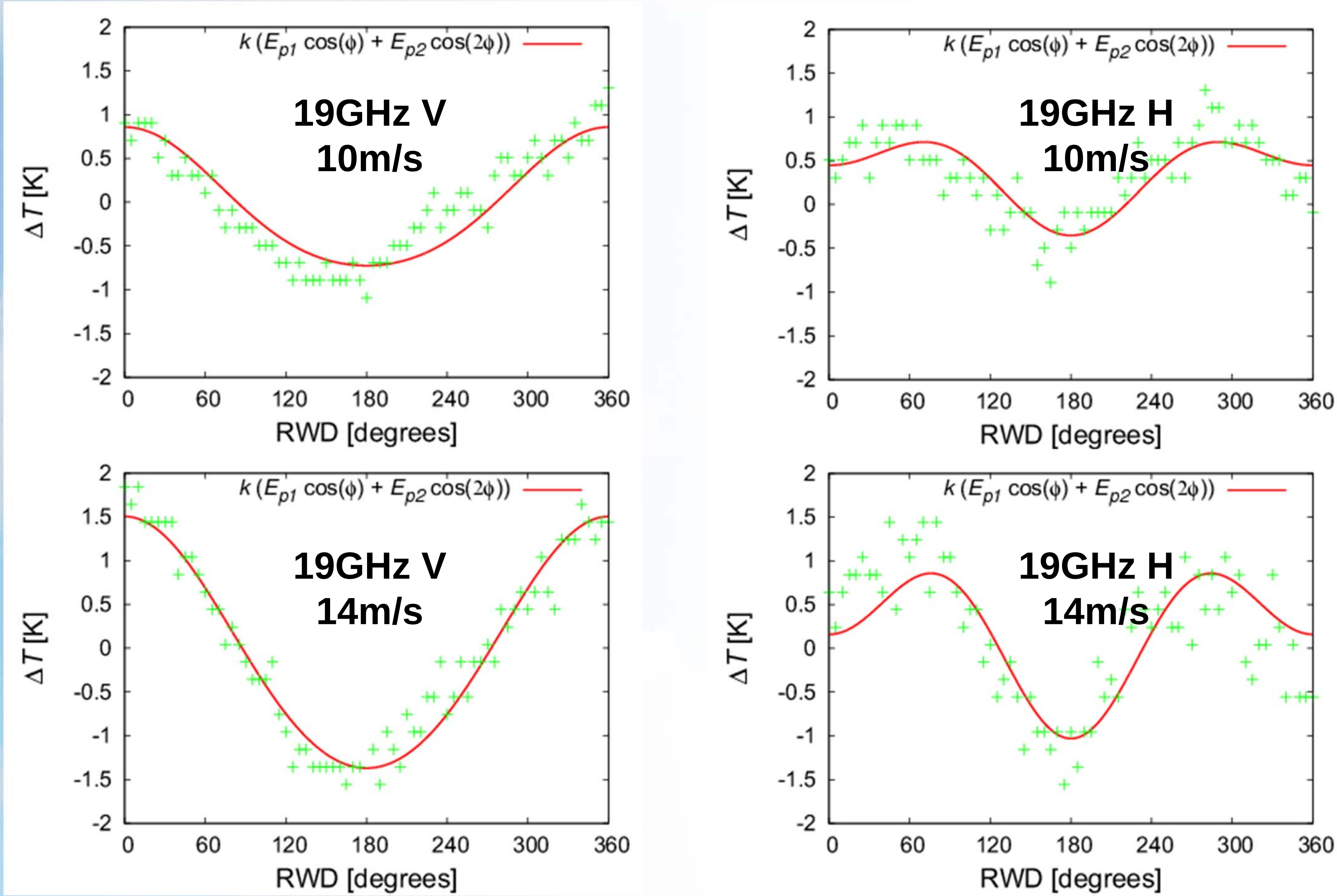
The coefficients (a,b,c,d, alpha) are derived for each channels.

x : wind speed

Dependency on incidence angle (Meissner 2012, Etkin 1991)

Determination of the coefficients

+ AMSR and Seawinds



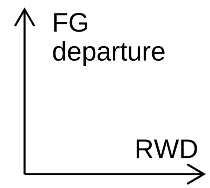
Impact study

Assimilation Experiment

- Purpose:
  - Investigation of the impact of the new RWD model. The new model changes simulated brightness temperature
    - AMSU-A, MHS, ATMS, SSMIS, TMI and AMSR-E
- Experiment Setting (ECMWF system)
  - **Control** : Cycle 38r2 T511 (approximately 30 km horizontal reso.)
  - **Test** : **Modified FASTEM with new RWD model**
    - <u>No change in QC</u>
- Experiment Period
  - June 20 – Oct 3, 2011 (AMSR-E, SSMIS, TMI are available)

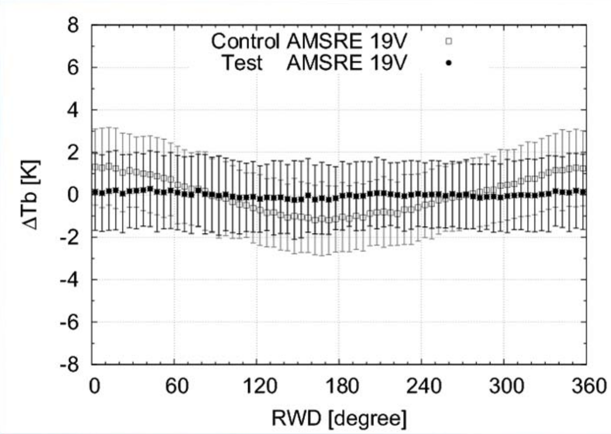
ECMWF

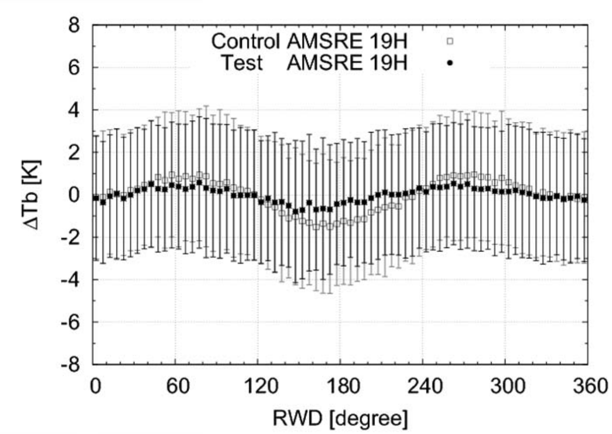
Impacts on FG departures of assimilated MW imager radiance



☐Control
●Test
SSW 12 m/s

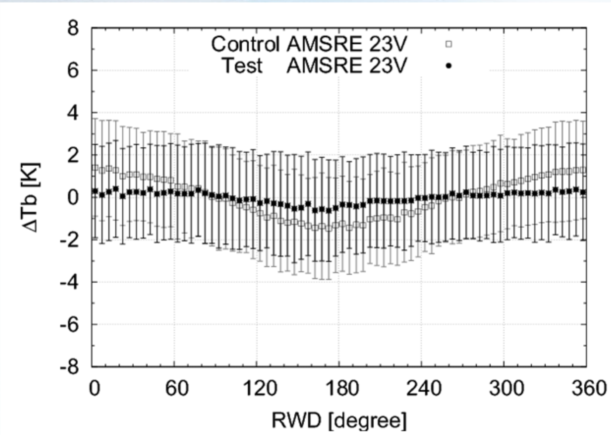
AMSRE
19V

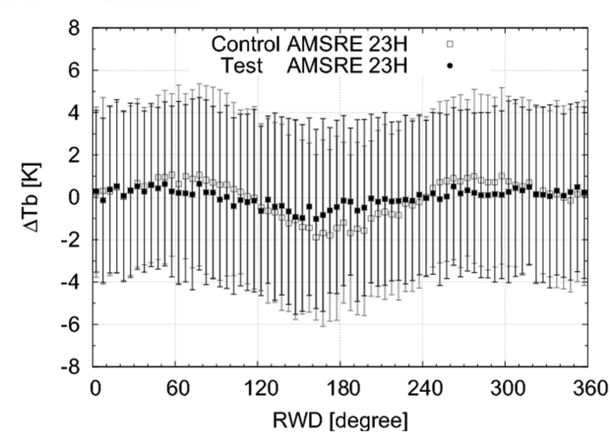




AMSRE
19H

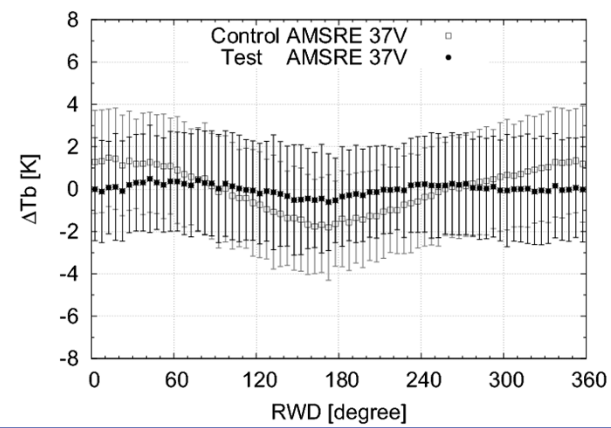
AMSRE
23V

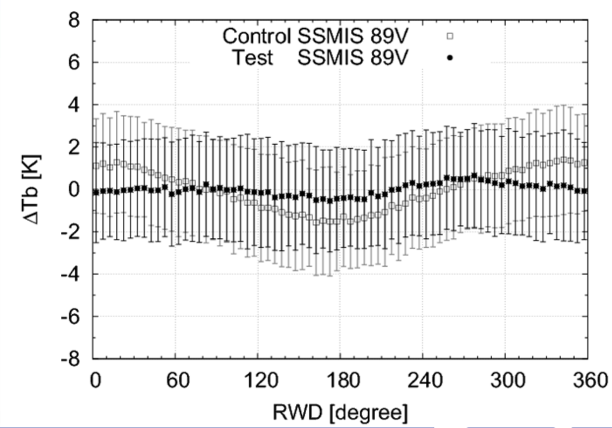




AMSRE
23H

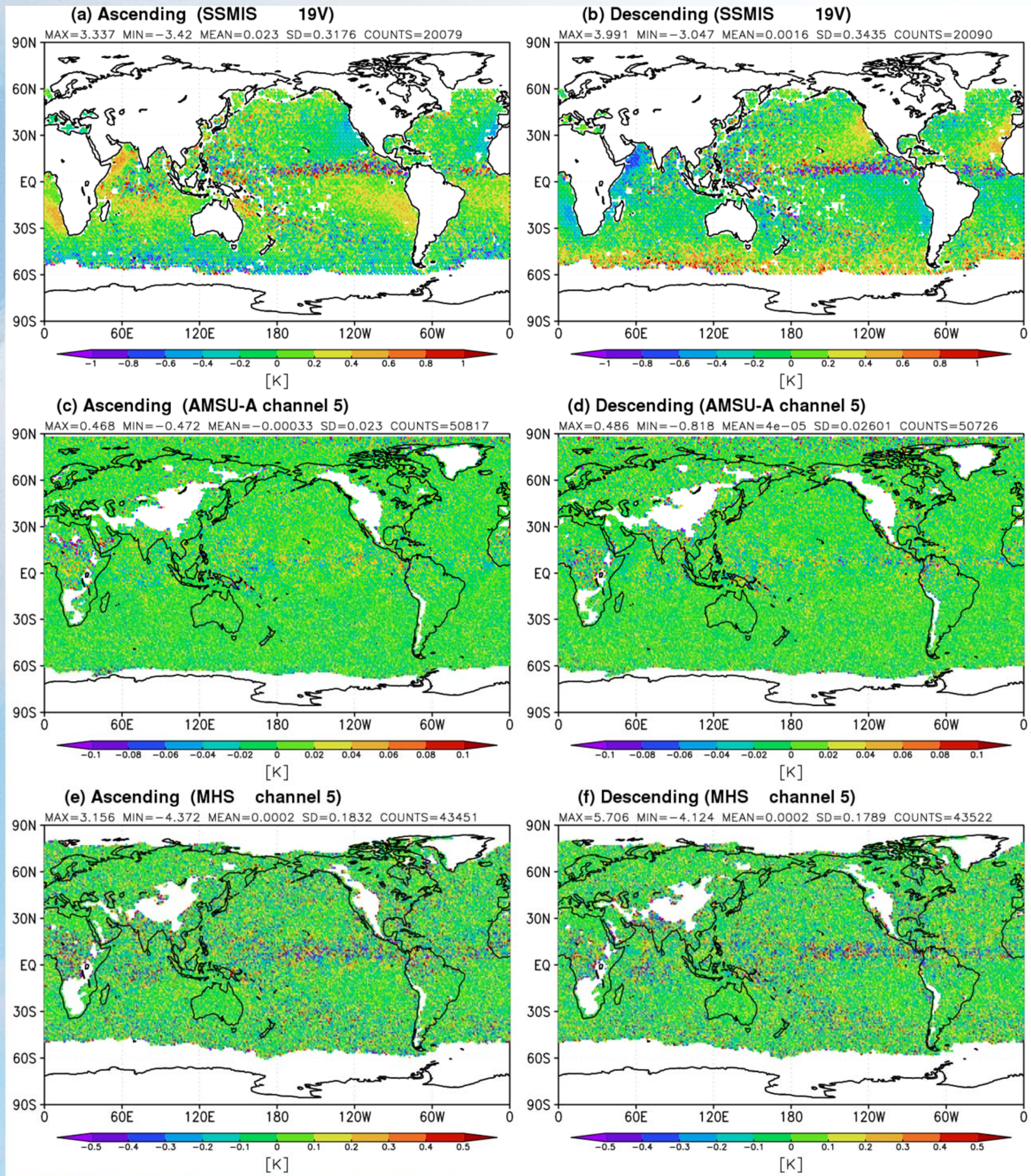
AMSRE
37V





SSMIS
89V

Differences of Mean FG departures (Test – Control)



SSMIS 19V Ascending

SSMIS 19V Descending

AMSU-A ch5 Ascending

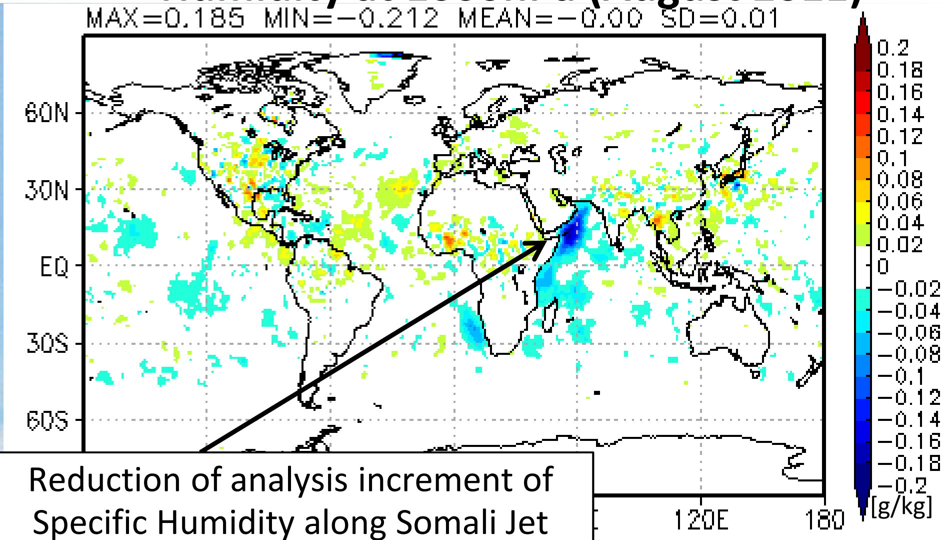
AMSU-A ch5 Descending

MHS ch5 Ascending

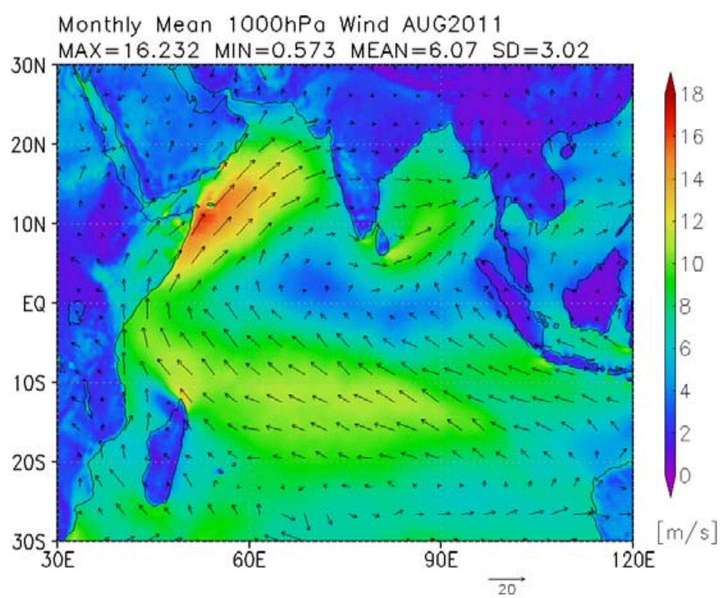
MHS ch5 Descending

Results of the impact study: Analysis Increment of Specific Humidity and Monthly Mean Surface Wind field

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

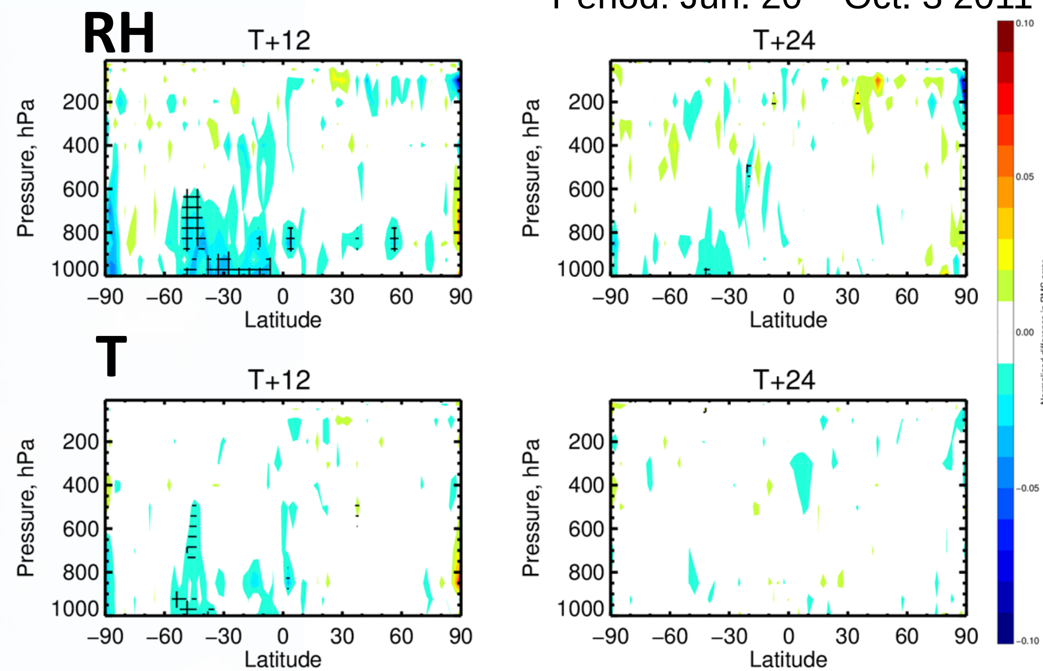


Reduction of analysis increment of Specific Humidity along Somali Jet



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

Period: Jun. 20 – Oct. 3 2011

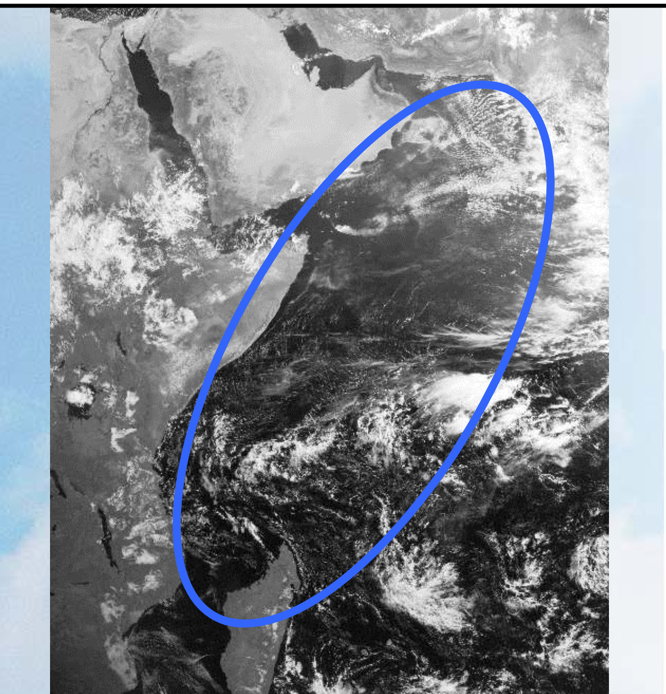


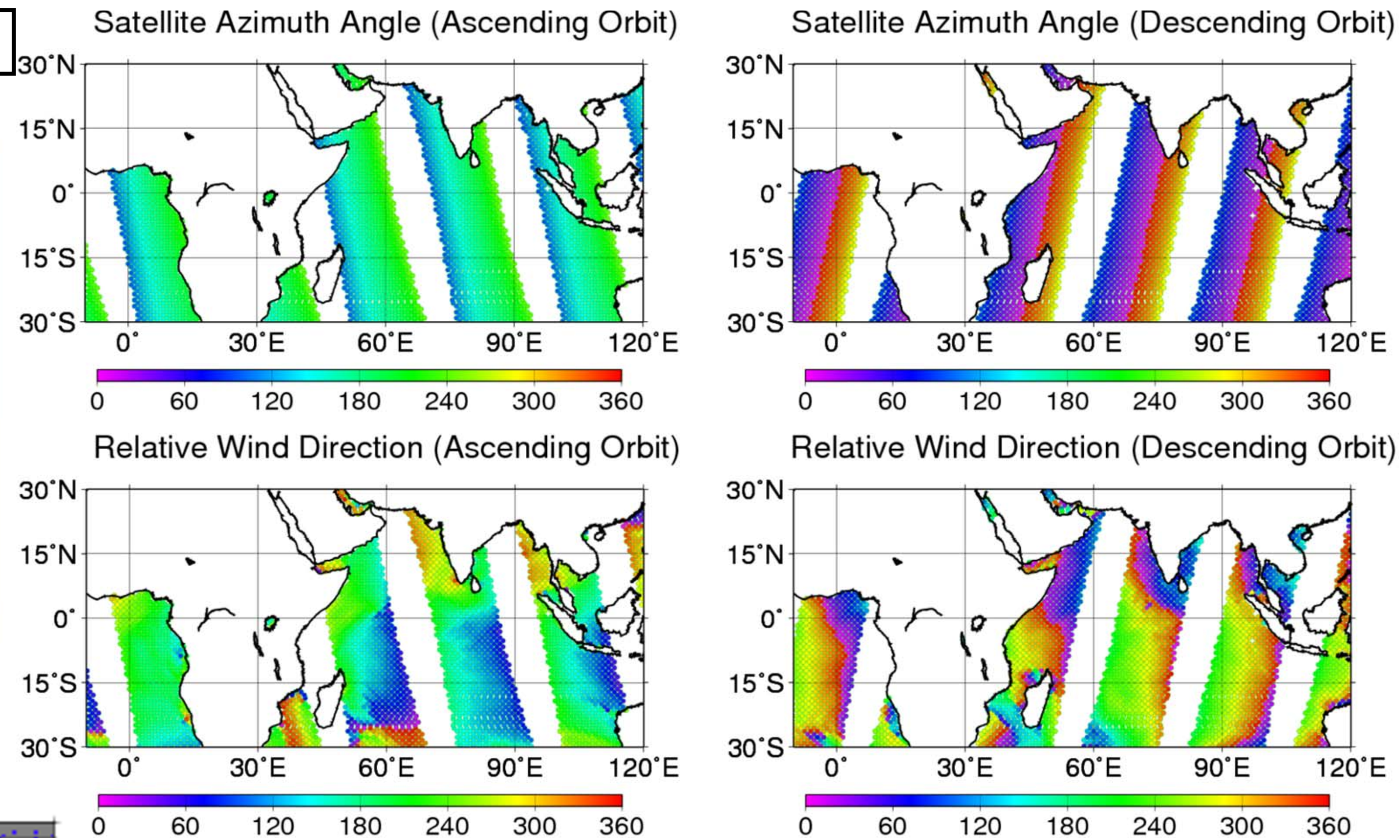
The use of surface wind directional signals of MW imager measurement reduced RH and T forecast errors significantly.

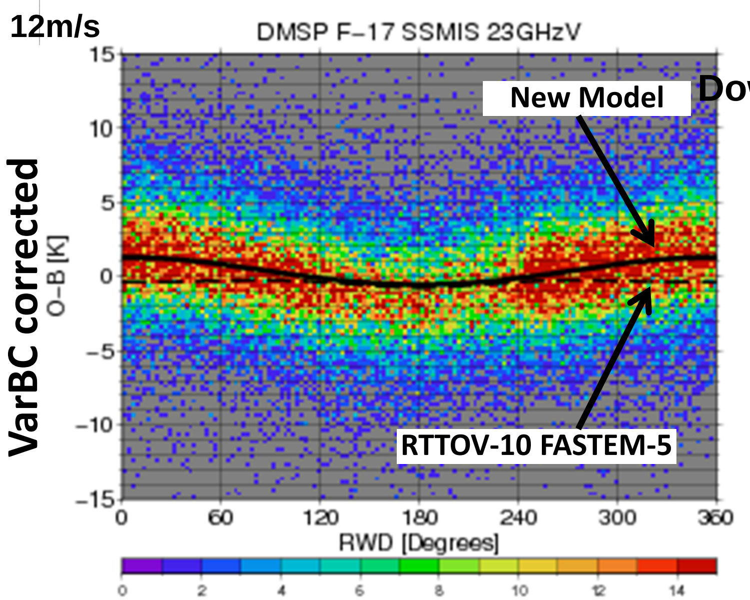
The introduction of the new RWD (relative wind direction) model into RTTOV Emissivity calculation is necessary.

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).

Summary

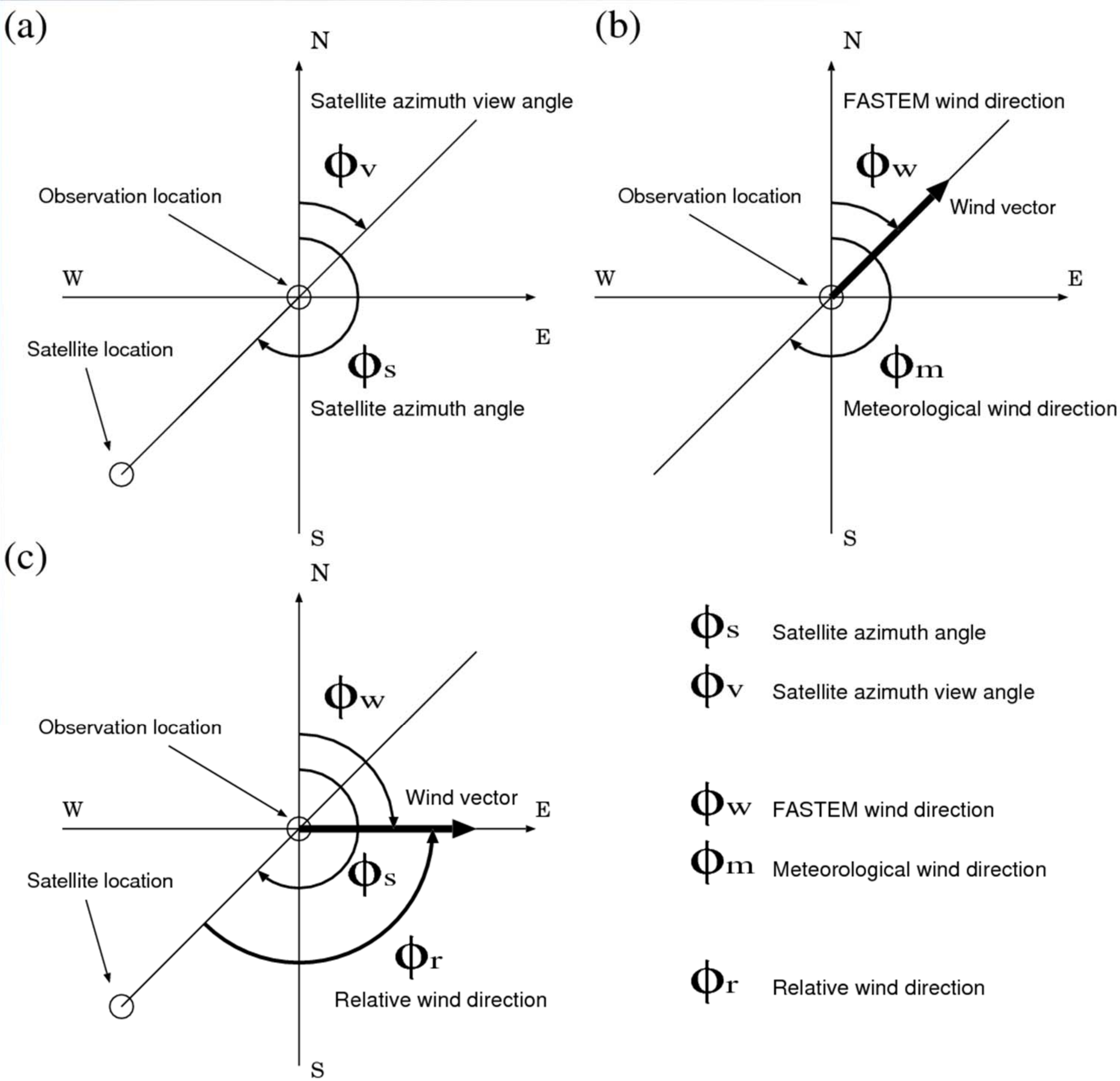
- Use of the new RWD model in FASTEM-5 reduced biases in FG departure of microwave imagers in strong wind condition
  - The RWD model has better performance than present FASTEM model
  - Results of the Impact study (Period: 20 June to 3 Oct. 2011)
    - Reductions of analysis increment of specific humidity 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.
- **Recommendation**
  - **Tb variation in terms of RWD should be taken into account correctly in the radiative transfer model (RTTOV).**
  - **Sensor azimuth information should be included in the original data by satellite data provider.**

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

Thank you for your attention.

Backup slides

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.