Development of an algorithm for estimation of specific humidity using TMI data

Shinsuke Iwasaki
Masahisa Kubota

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Bulk method

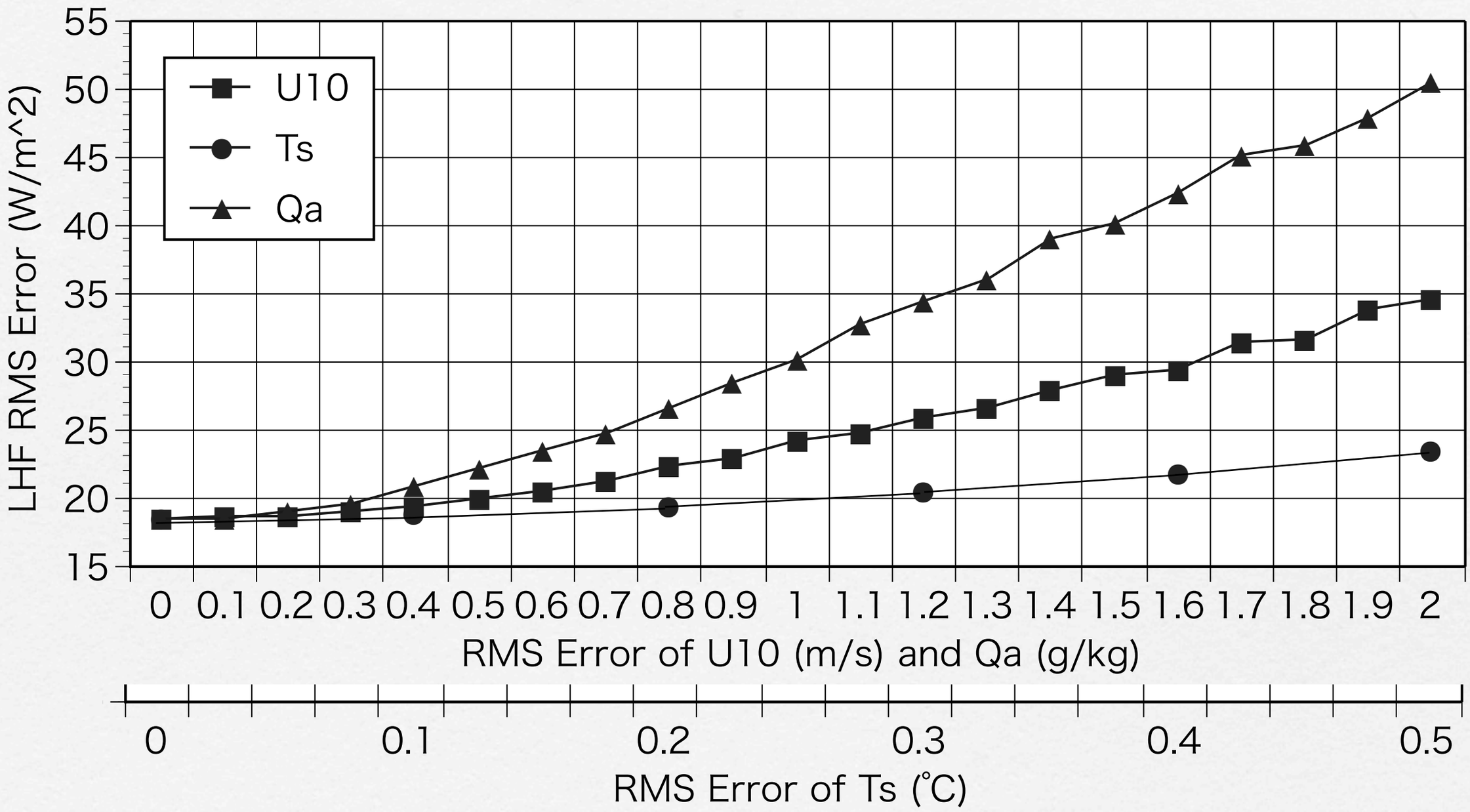
$$LHF = \rho a * Lv * Ce * U * (Qs - Qa)$$

LHF : Latent heat flux (W/m**2)
ρa : Density of air (kg/m**3)
Lv : Latent heat of vaporization (J/kg)
U : Wind Speed (m/s)
Qa : Near surface air specific humidity (g/kg)
Qs : Saturated specific humidity (g/kg)

The RMS errors of the daily mean for satellite data..

U : 1-1.5 (m/s)	SST : 0.3-0.5 (°C)	Qa : 1-2 (g/kg)
Tomita et al.(2009)	Iwasaki et al.(2008)	Kubota and Hihara (2008)

RMS error of the LHF as a function of the RMS error of several meteorological values.



The RMS error of the Qa largely contributes to that of the LHF.

Reference: Iwasaki et al.(2010)

Qa retrieval algorithms at the previous studies

SSM/I

Liu (1986)
Integrated Water Vapour

Schulz et al. (1993)
Low-Level Water Vapour

Shlussel et al. (1995)
Brightness temperature (BT)

Bentamy et al. (2003)
Brightness temperature (BT)

AMSR-E

Zong et al.(2007)
Meteorological Values

Kubota and Hihara (2008)
Brightness Temperature (BT)

TMI

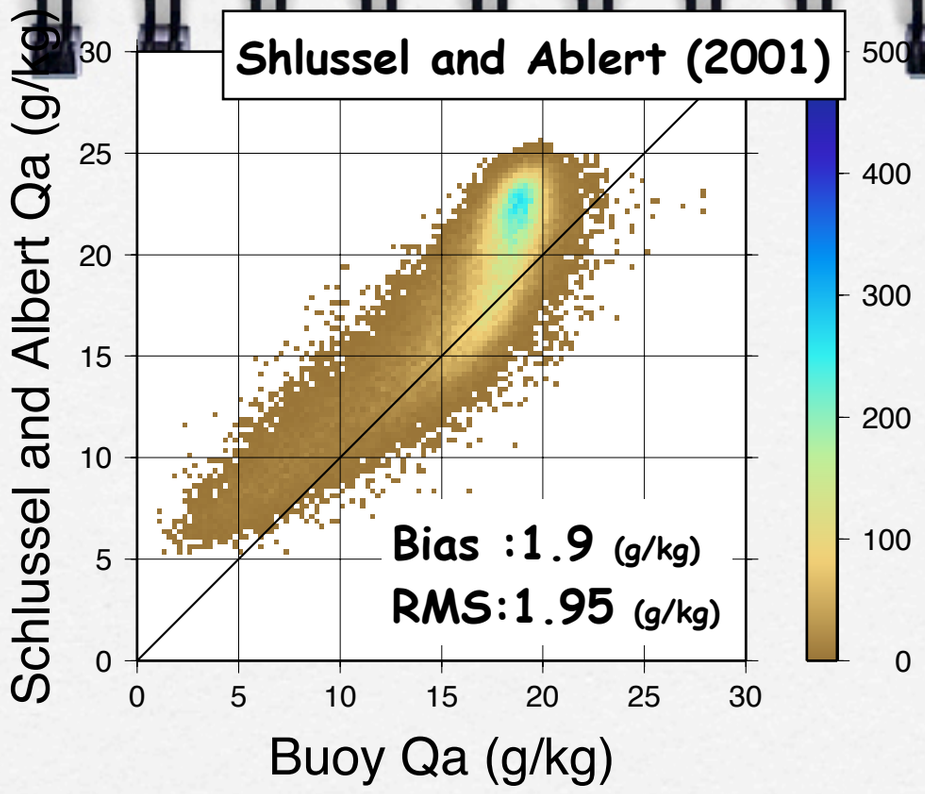
Schlussel and Albert (2001)
Brightness Temperature (BT)

SSM/I,AMSU-A

Jackson et al. (2006)
Brightness temperature (BT)

Jackson et al. (2009)
Brightness temperature (BT), SST

- Defense Meteorological Satellite Program (DMSP)/Special Sensor Microwave/Imager (SSMI)
- Advanced Microwave Scanning Radiometer for EOS (AMSR-E)
- Tropical Rainfall Measuring Mission (TRMM)/Microwave Imager (TMI)



Microwave observations from TMI are observed at 9 channel. But they used only 6 channel (10H/V,19H/V, 21V,and 37H) for Qa retrieval.
On the other hand, for the Qa retrieval from the AMSR-E, Kubota and Hihara (2008) revealed that accuracy of Qa retrieval is good by using all channel.
Therefore, there is possibility that the Qa retrieval algorithm from TMI can be improved by using all channel.

Frequency (GHz) observed for several microwave radiometer

sensor	6	10	18	22	36	89
AMSR-E	6.925H/V	10.65H/V	18.7H/V	23.8H/V	36.5H/V	89.0H/V
TMI		10.65H/V	19.35H/V	21.3V	37.0H/V	85.5H/V

V and H means vertically and horizontally polarized radiation, respectively

The objective in this study

Produce the Qa retrieval from the TMI

Data

TRMM/MI (TMI)

Tropical Rainfall Measuring Mission Microwave Imager

- Brightness Temperature (Level 1B)

Frequency (GHz) observed for several microwave radiometer

sensor	6	10	18	22	36	89
SSM/I			19.35H/V	22.235V	37.0H/V	85.5H/V
AMSR-E	6.925H/V	10.65H/V	18.7H/V	23.8H/V	36.5H/V	89.0H/V
TMI		10.65H/V	19.35H/V	21.3V	37.0H/V	85.5H/V

V and H means vertically and horizontally polarized radiation, respectively

Training data set to derive the Qa regression formula

ICOADS release 2.5

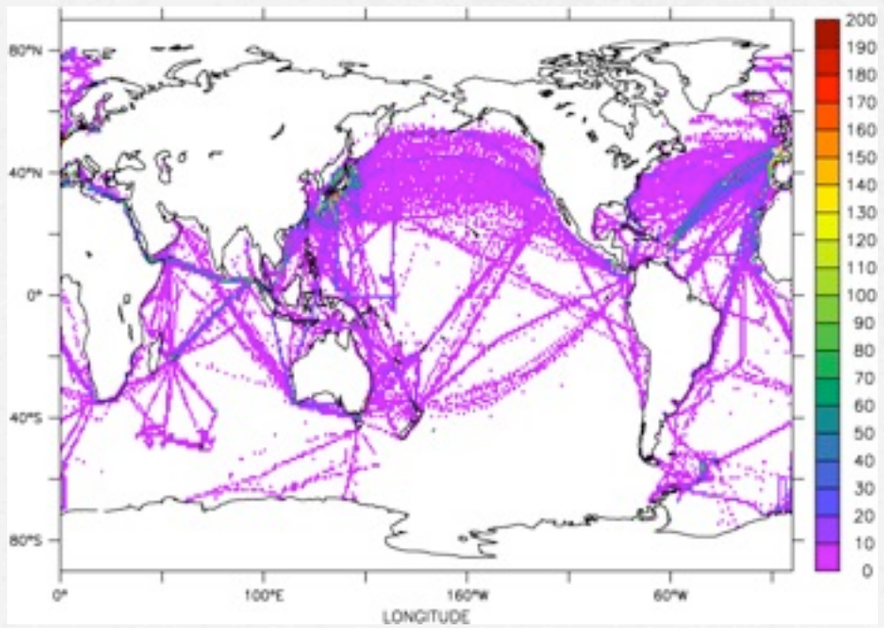
(International Comprehensive Ocean-Atmosphere Data Set)

- **Meteorological parameter 1662/10-2009/08**

The ICOADS data are constructed by a combination of observations from voluntary observing ships (VOS), buoys, and other observations from Ocean Data Acquisition Systems.

Buoy data are not used here because buoy data are used for validation of the Qa derived from TMI.

Time period: 2003-2006



Distribution of observation number (year: 2005)

Adjust Qa data to 10 meter

flow chart

ICOADS

We used only data including meteorological parameter (Wind Speed, Sea Surface Temperature, Air Temperature, Humidity, and Instrument Height).

COARE3.0 (Fairall et al.,2003)

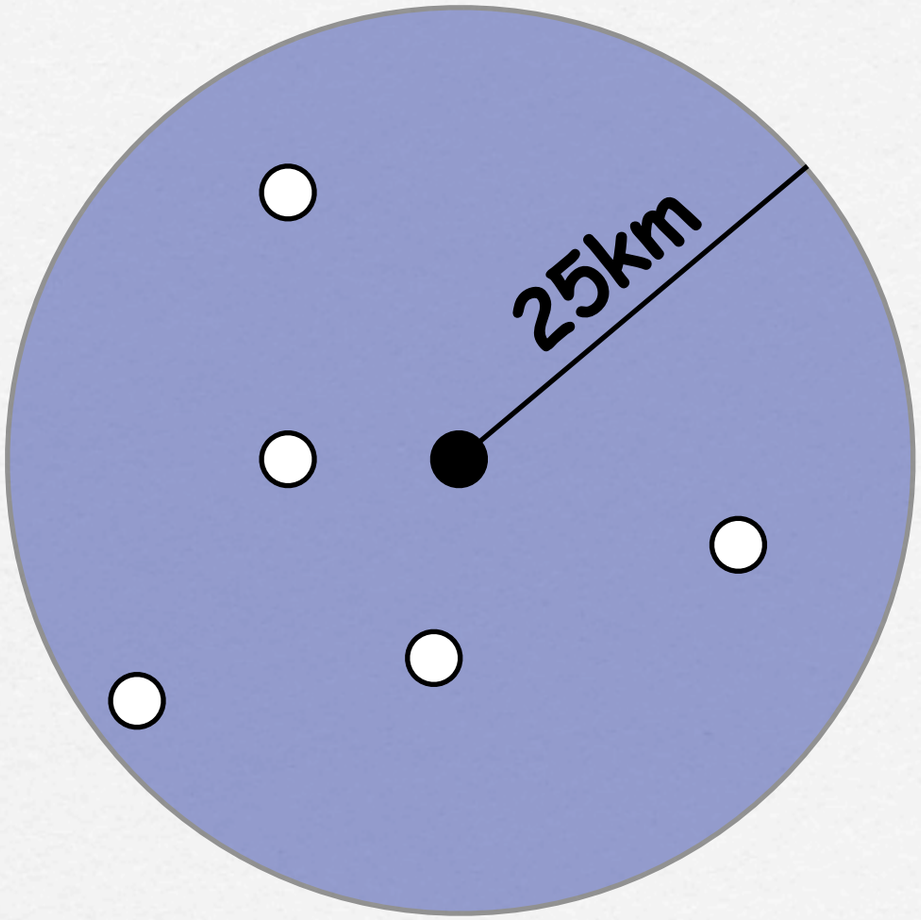
The Coupled Ocean-Atmosphere Response Experiment (COARE) version 3.0 bulk flux model (Fairall et al.,2003) was used to adjust the Qa data to standard height (10m) because Qa observation heights of ICOADS are various.

Qa_10m

We removed the values outside of inner fence which are the upper quartile plus 1.5×IQR (inter-quartile range) and the lower quartile minus 1.5×IQR (Wilks, 2006)

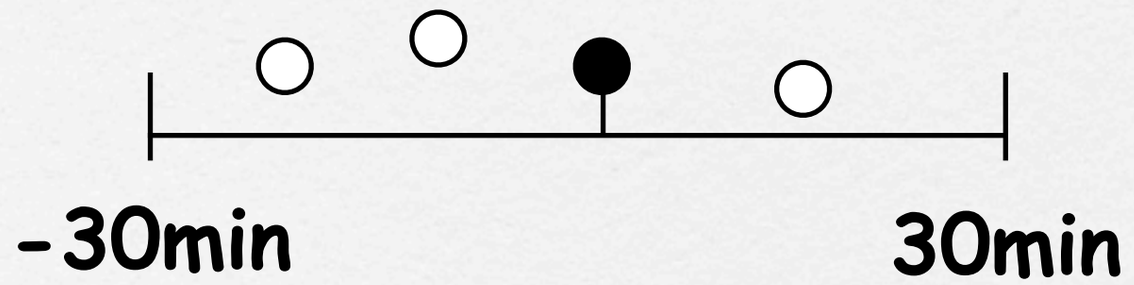
We used Qa for 0-28.3 (g/kg)

Match up the TMI observations and ICOADS data.



Spatial

●: ICOADS
○: TMI



TIME

TMI observations were matched to ICOADS data using a criterion of 30 min and 25 km.

Quality Control (QC) for match up data (Qa)

match up data

↓

Rain Flag

$(Tb_{37V} - Tb_{37H}) < 20K$ or $Tb_{19H} > 190K$

Tb : Brightness Temperature (K)

Subscript : The frequency (GHz) of TMI

Schlussel and Albert (2001)

↓

We removed the data if the standard deviation of matching TMI data is larger than 10K, in order to improve the quality of the training data sets.

↓

Training data

Regression equation

The regression equation has a following form.

$$Qa^{9CH} = -108.2082 + 0.2973\ Tb_{10V} - 0.2074\ Tb_{10H} + 0.6971\ Tb_{19V} - 0.2351\ Tb_{19H} + 0.0871\ Tb_{21V} - 0.9880\ Tb_{37V} + 0.4246\ Tb_{37H} + 0.6854\ Tb_{85V} - 0.3031\ Tb_{85H}, \quad (1)$$

Qa^{9CH}: Regressed Qa (g/kg)
Tb: The Brightness Temperature (K)
Subscripts: The frequency (GHz)

The RMS of fit: 1.73 (g/kg)

Matched number :6757

There are some frequencies having negative effects for the estimation of Qa.

Schulz et al.(1993)

(Mean Square Error)

Reference : Jackson et al.(2006)

Therefore, we tried the selection of the frequency using the following forward selection method (Wilks, 2006).
The forward selection method is an iterative process.

$$MSE = \frac{\sum_{i=1}^{N_0} (y_i - \hat{y}_i)^2}{N_0 - K - 1}$$

y_i : Observed Qa (ICOADS)　　N_0 : Number of observations

$\hat{y}_i$: Regressed Qa　　K : Number of predictor channels

The method begins with a single variable regression and tests each channel to identify the channel with the lowest MSE.
Subsequent channels are added one at a time, while previous channels are saved in the regression.
To prevent over-fitting the regression, a stopping rule was applied to terminate the channel selection process.
If the change in MSE became less than 0.2 at the all channels when selecting the next channel, then the regression was considered to be complete.

Regression equation

$$Qa^{9CH} = -108.2082 + 0.2973\ Tb_{10V} - 0.2074\ Tb_{10H} + 0.6971\ Tb_{19V} - 0.2351\ Tb_{19H} + 0.0871\ Tb_{21V} - 0.9880\ Tb_{37V} + 0.4246\ Tb_{37H} + 0.6854\ Tb_{85V} - 0.3031\ Tb_{85H}, \quad (1)$$

The RMS of the fit : 1.73 (g/kg)

Based on the result of the forward selection method, the following regression formula was obtained.

$$Qa^{7CH} = -111.3940 + 1.0791\ Tb_{19V} - 0.4780\ Tb_{19H} + 0.1132\ Tb_{21V} - 1.1169\ Tb_{37V} + 0.4916\ Tb_{37H} + 0.7015\ Tb_{85V} - 0.3077\ Tb_{85H}, \quad (2)$$

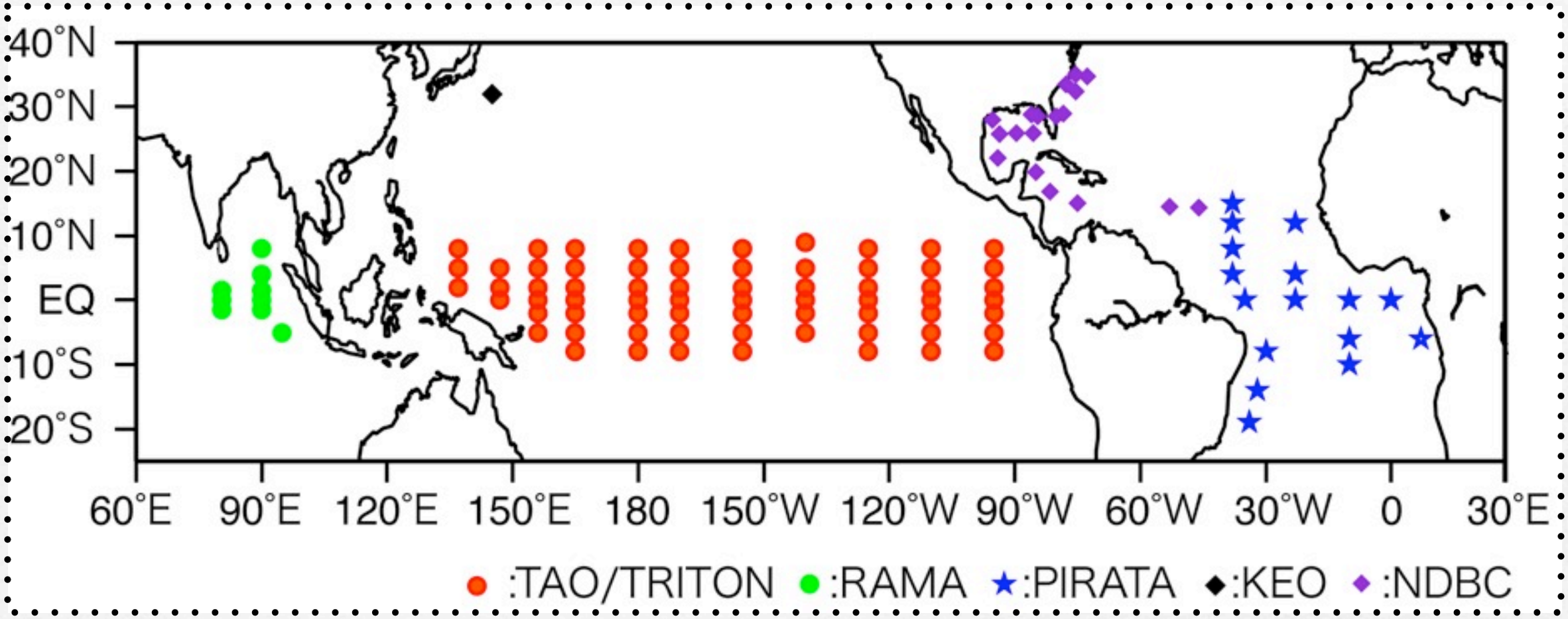
Qa^{7CH}: Regressed Qa (g/kg)
Tb: The Brightness Temperature (K)
Subscripts: The frequency (GHz)

The RMS of the fit : 1.74 (g/kg)

Matched number :6757

Locations of the buoy

Time Period : 2003-2006



Qa observations from buoys were adjusted to 10m using COARE3.0 model.

- Tropical Atmosphere Ocean/Triangle Trans-Ocean Buoy Network (TAO/TRITON)
- Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA)
- Pilot Research Moored Array in the Tropical Atlantic (PIRATA)
- Kuroshio Extension Observatory (KEO)
- National Data Buoy Center (NDBC)

Qa products used for evaluation.

We used following other three products addition to present two products.

Procuts	Algorithm	Sensor
Schlussel and Albert	Schlussel and Albert (2001)	TMI
J-OFURO2	Schlussel et al.(1995)	SSM/I
AMSR-E	Kubota and Hihara (2008)	AMSR-E

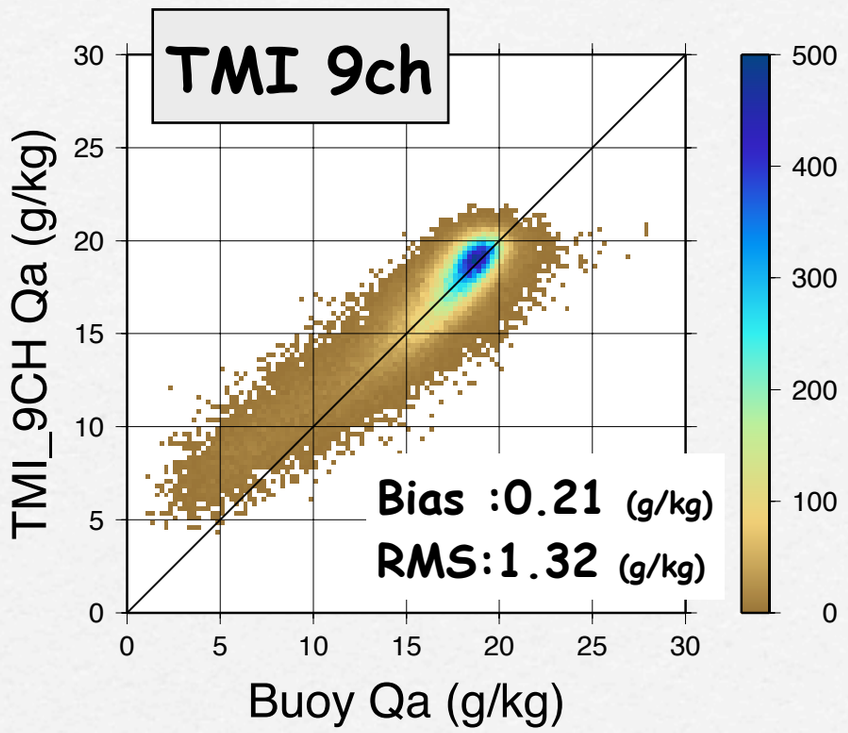
$$Qa^{S\&A(2001)} = -20.44 + 0.07330\,Tb_{10V} - 0.1529\,Tb_{10H} + 0.3547\,Tb_{19V} + 0.3339\,Tb_{19H} - 0.09973\,Tb_{21V} - 0.2432\,Tb_{37H} - 0.3795\,\theta$$

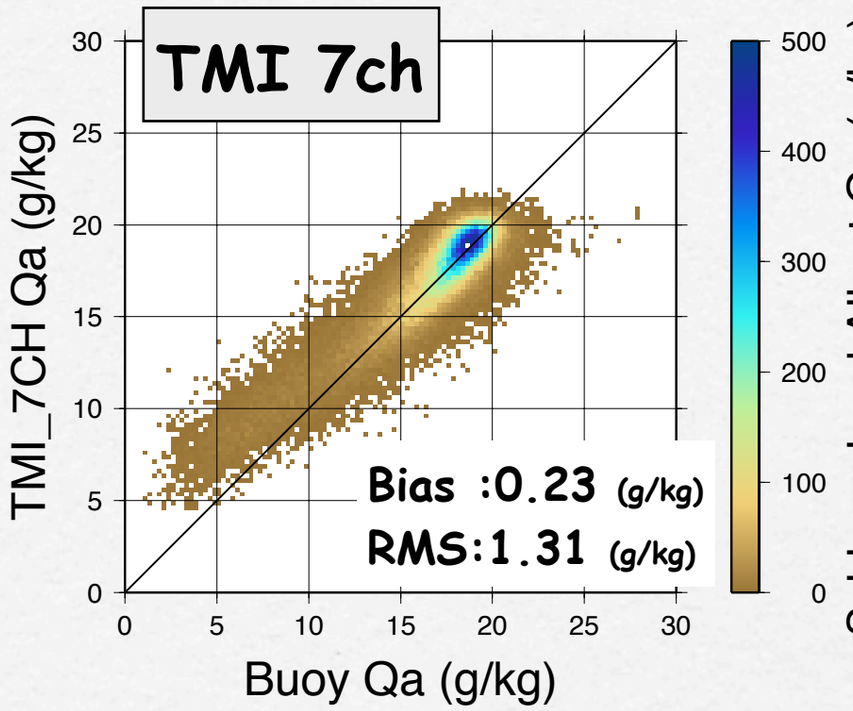
$$Qa^{Schlussel(1995)} = -80.23 + 0.6295\,Tb_{19V} - 0.1655\,Tb_{19H} + 0.1495\,Tb_{22V} - 0.1553\,Tb_{37V} + 0.06695\,Tb_{37H}$$

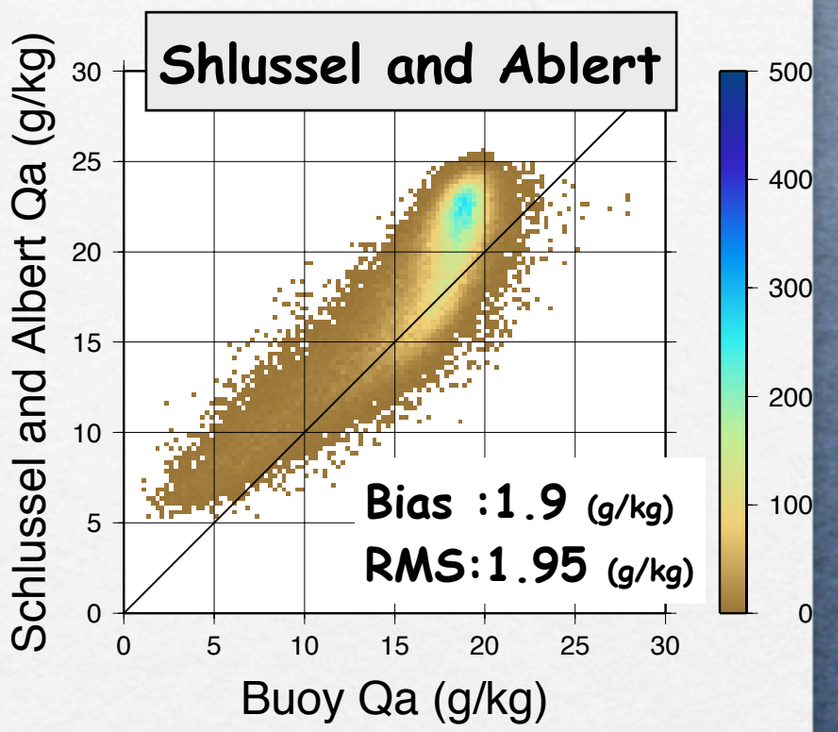
$$Qa^{K\&H(2008)} = -92.7752 + 0.0920\,Tb_{6V} - 0.0674\,Tb_{6H}\ 0.1988\,Tb_{10V} - 0.1810\,Tb_{10H} - 0.2595\,Tb_{18V} + 0.3103\,Tb_{18H} + 1.4513\,Tb_{22V} - 0.6801\,Tb_{22H} - 0.9083\,Tb_{36V} + 0.3162\,Tb_{36H} + 0.1730\,Tb_{89V} - 0.0675\,Tb_{89H}$$

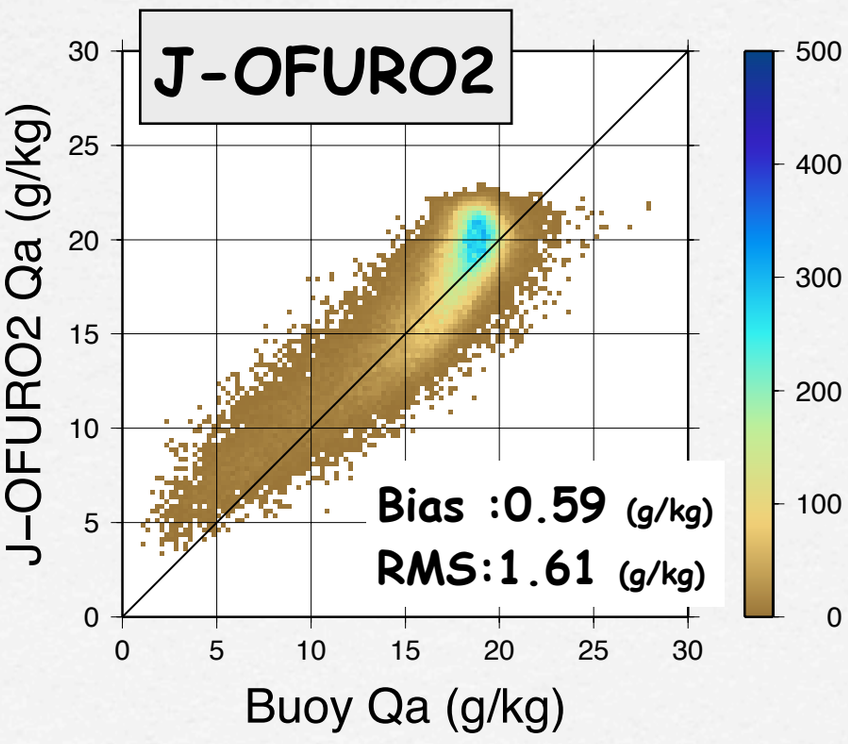
Temporal resolution: Daily
Spatial resolution : 1°
Time Period : 2003-2006

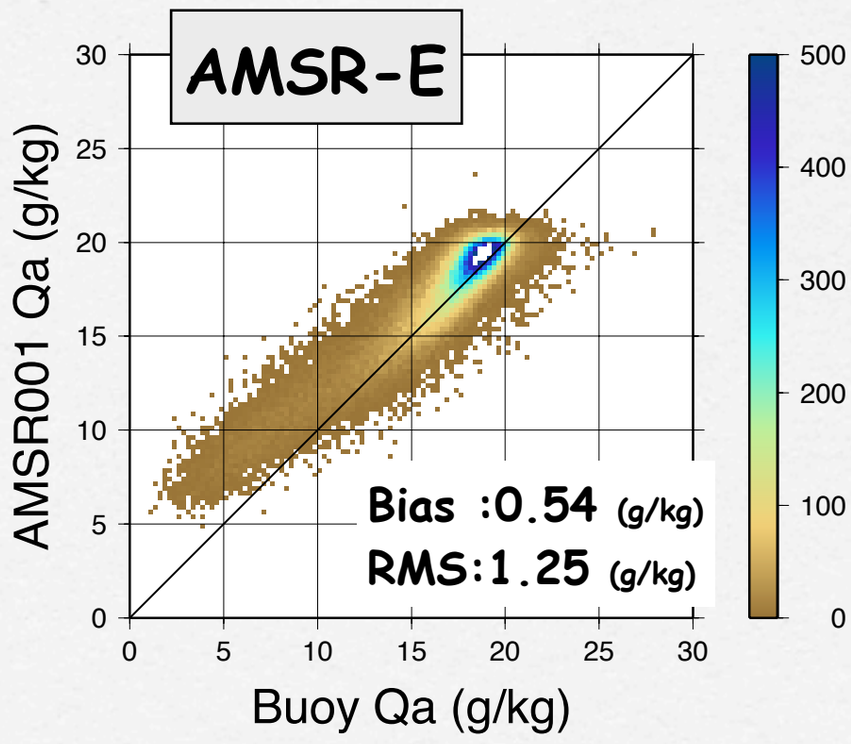
Comparison between Qa products and buoy Qa





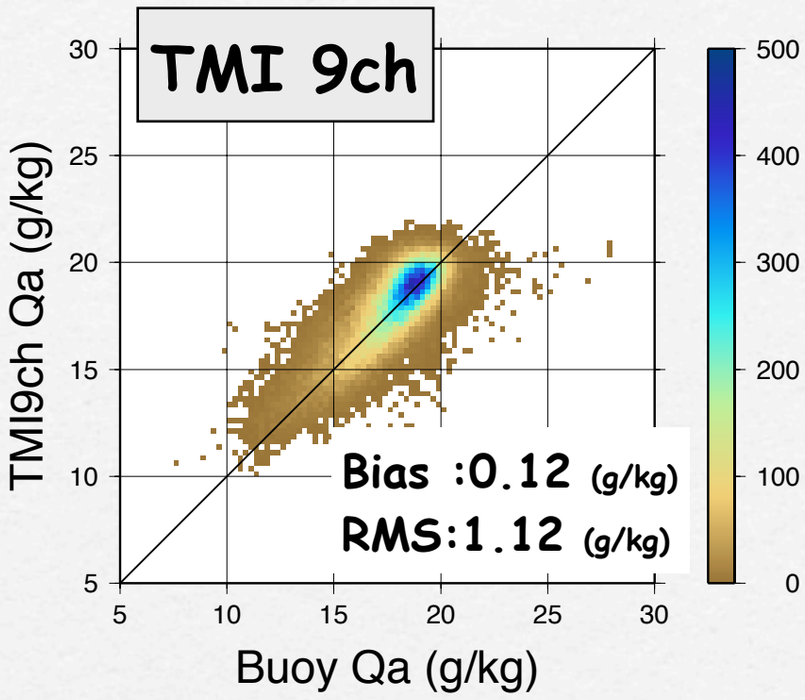


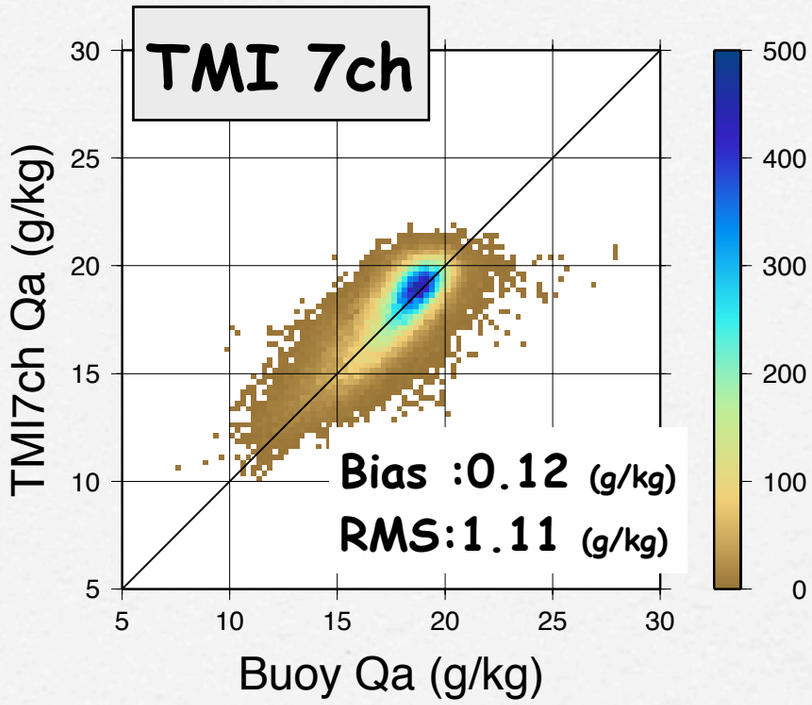


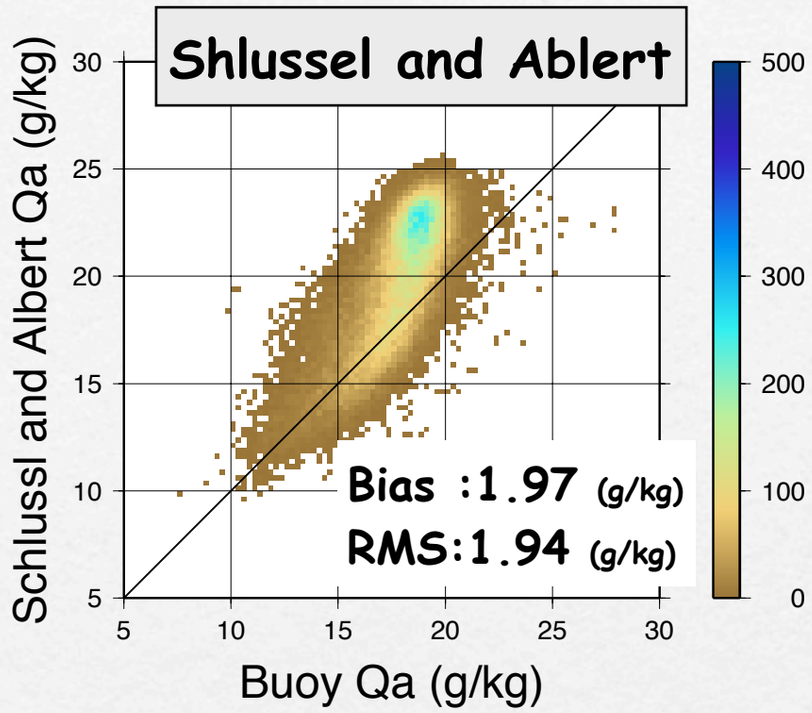


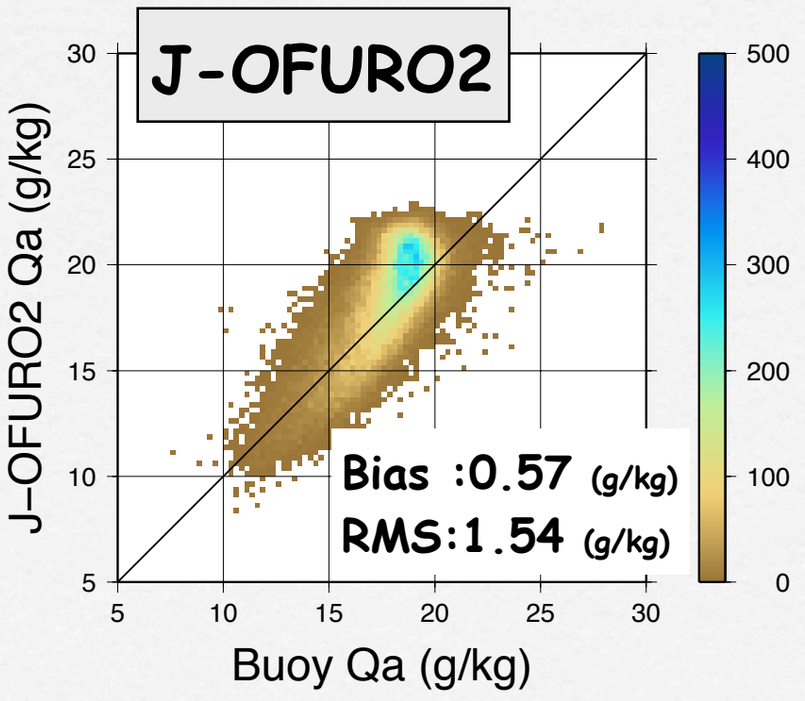
Data num.65780

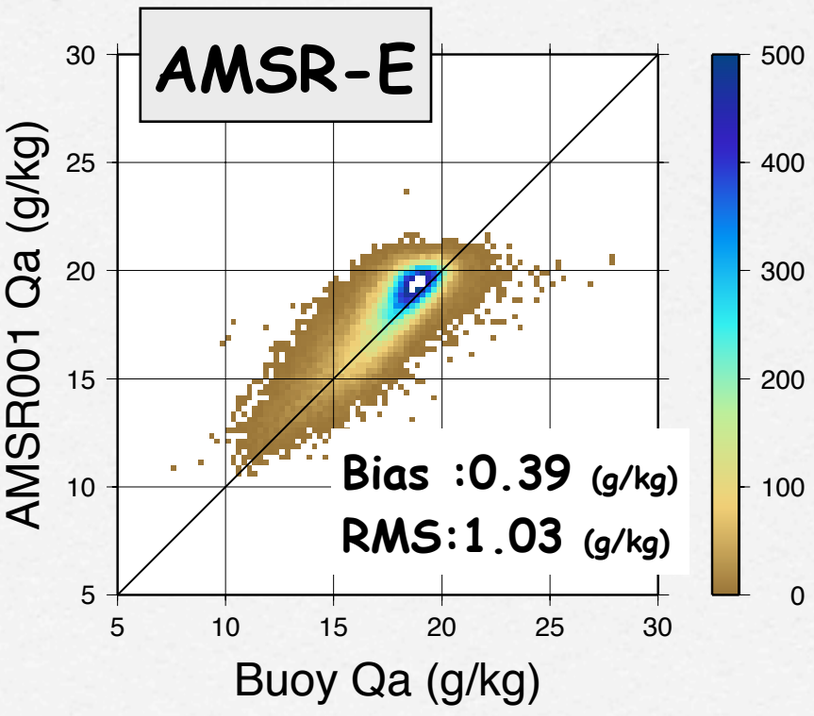
Comparison between Qa products and buoy Qa (TAO, RAMA, PIRATA)





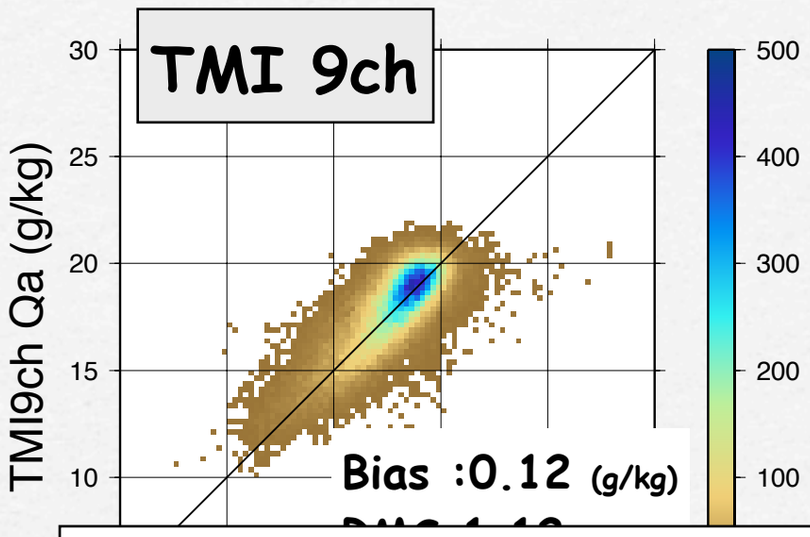


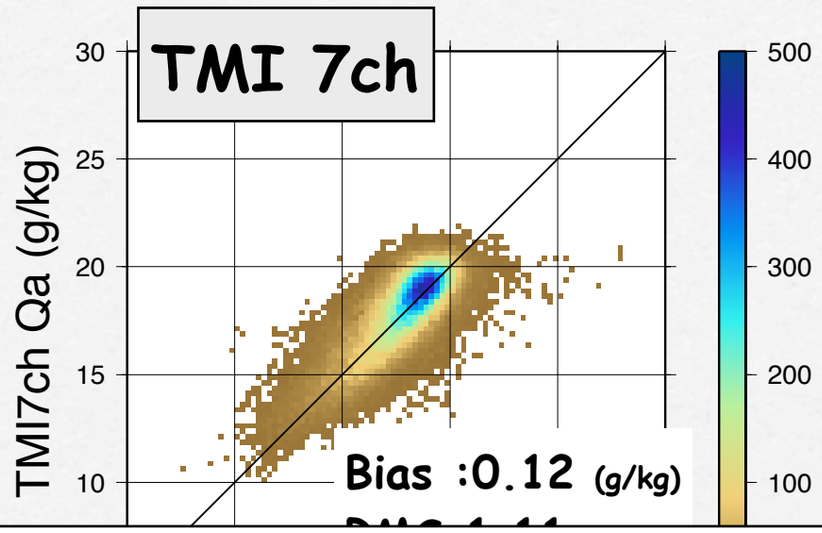


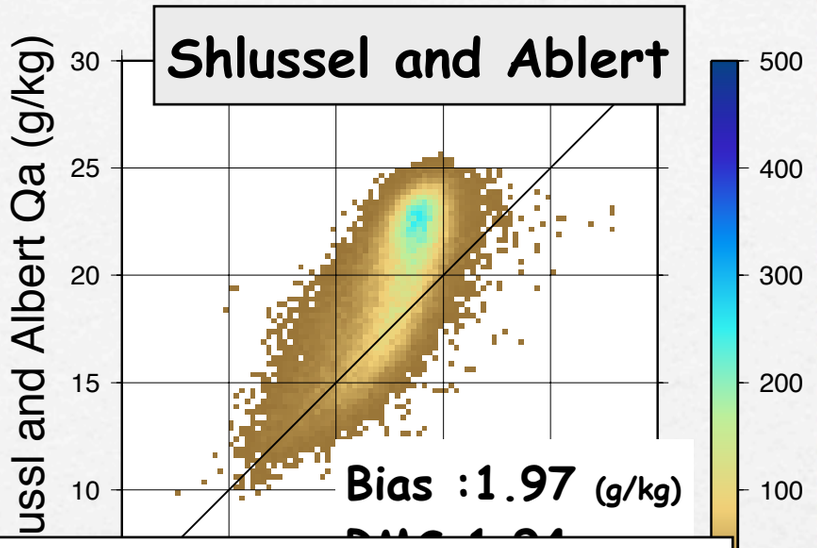


Data num.51869

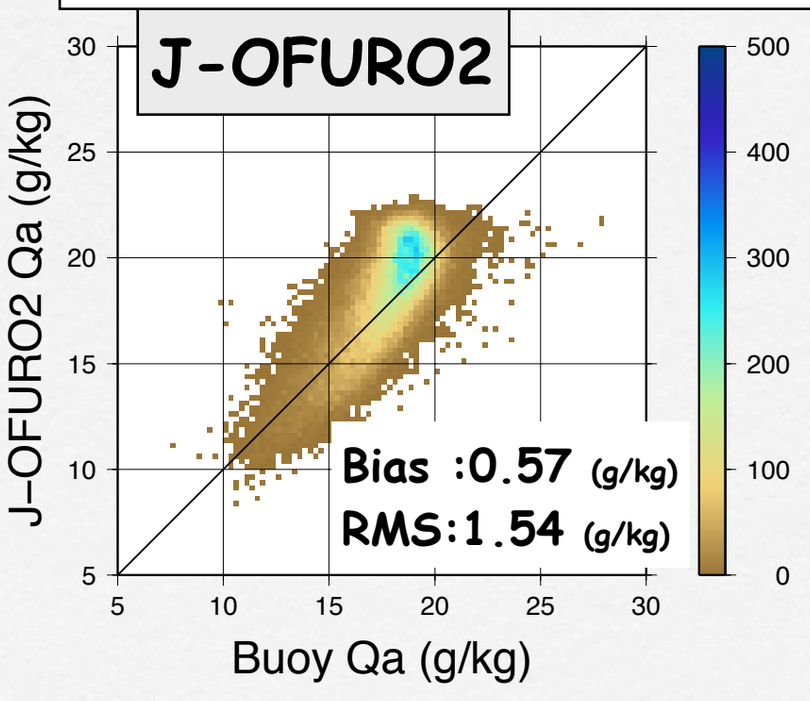
Comparison between Qa products and buoy Qa (TAO, RAMA, PIRATA)

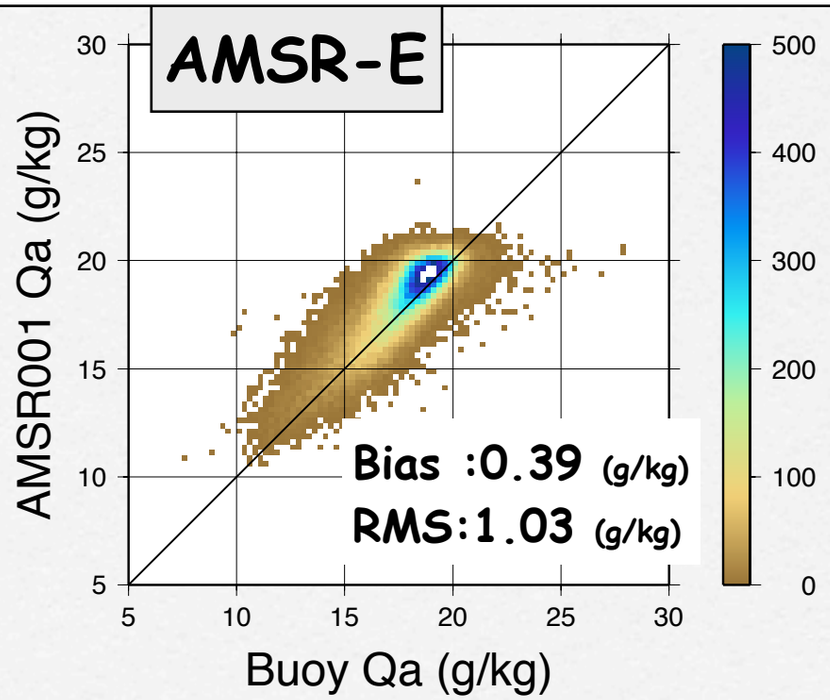






Here, J-OFURO2 and Schlussel and Albert are not used the 85 GHz polarized radiation for the retrieval Qa.
Therefore, it is considered that this is a cause of overestimation for large values.

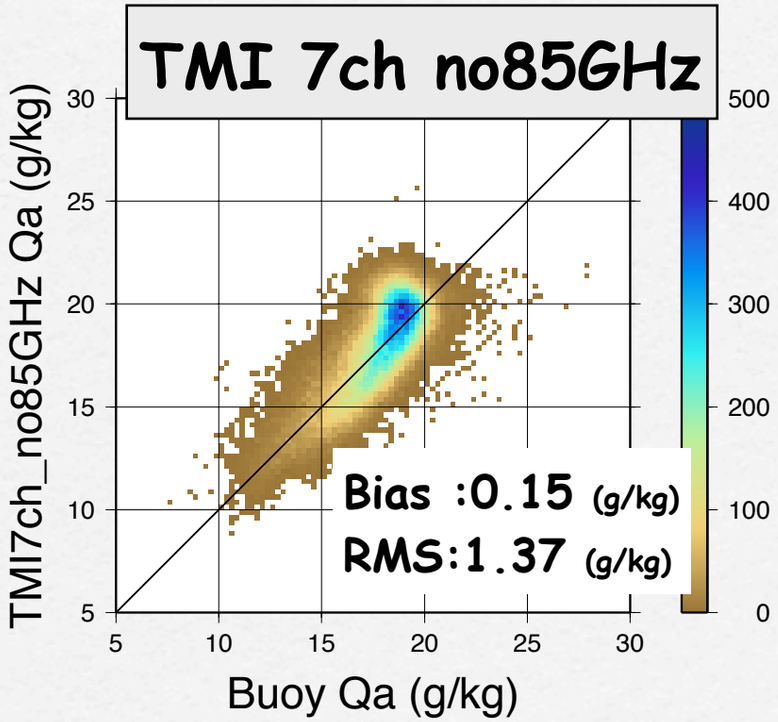


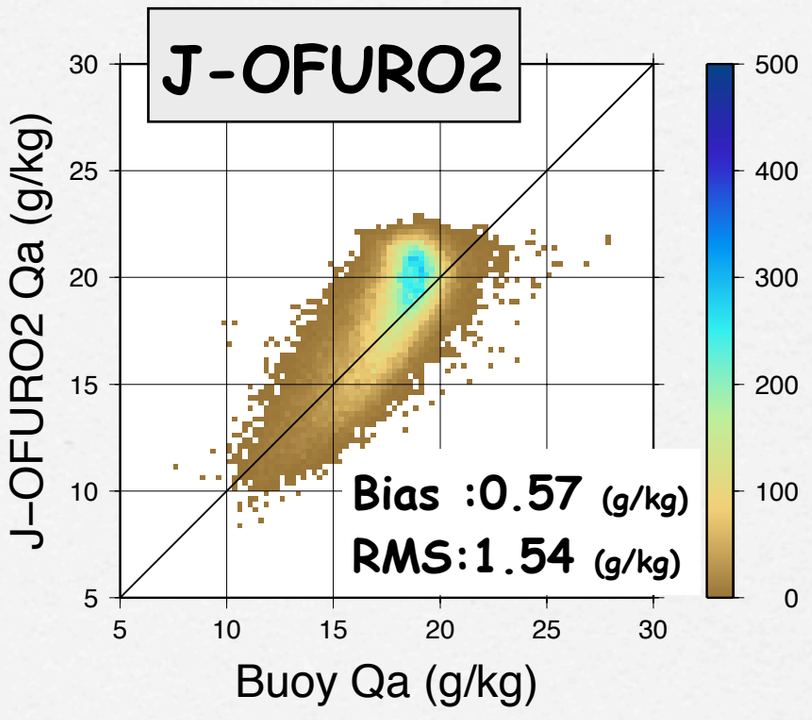


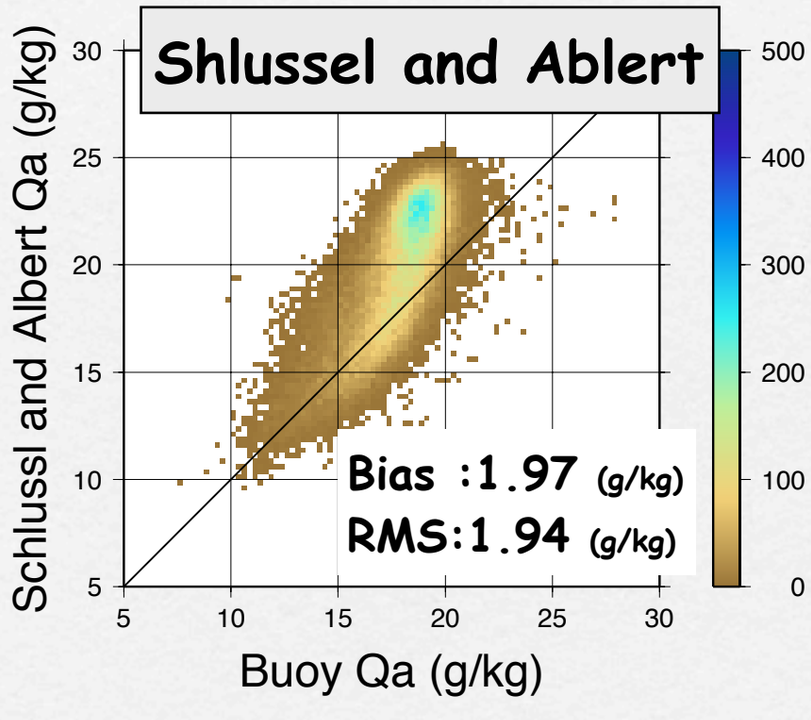
Data num.51869

Comparison between Qa products and buoy Qa (TAO, RAMA, PIRATA)

$$Qa^{7CH\_no85GHz} = -75.2929 + 0.5065\,Tb_{10V} - 0.3428\,Tb_{10H} + 0.7017\,Tb_{19V} - 0.1700\,Tb_{19H} + 0.0817\,Tb_{21V} - 0.5545\,Tb_{37V} + 0.1086\,Tb_{37H}$$





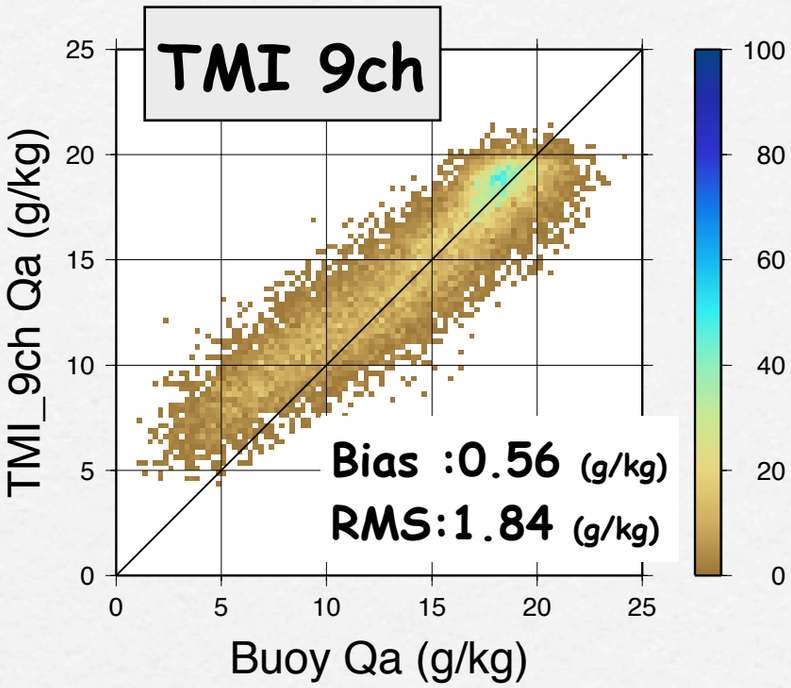


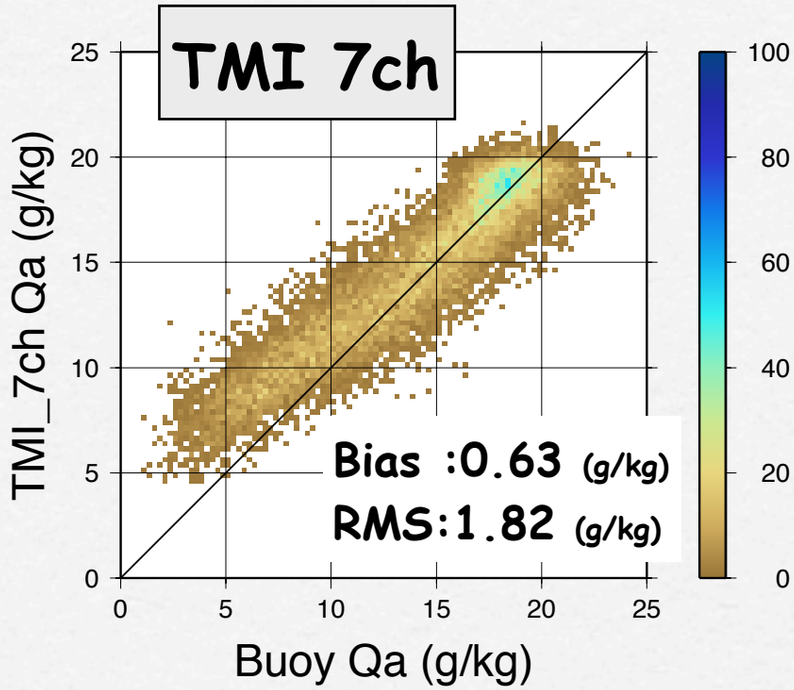
TMI 7ch no85GHz : Qa derived from the all brightness temperature of TMI except for 85 GHz.

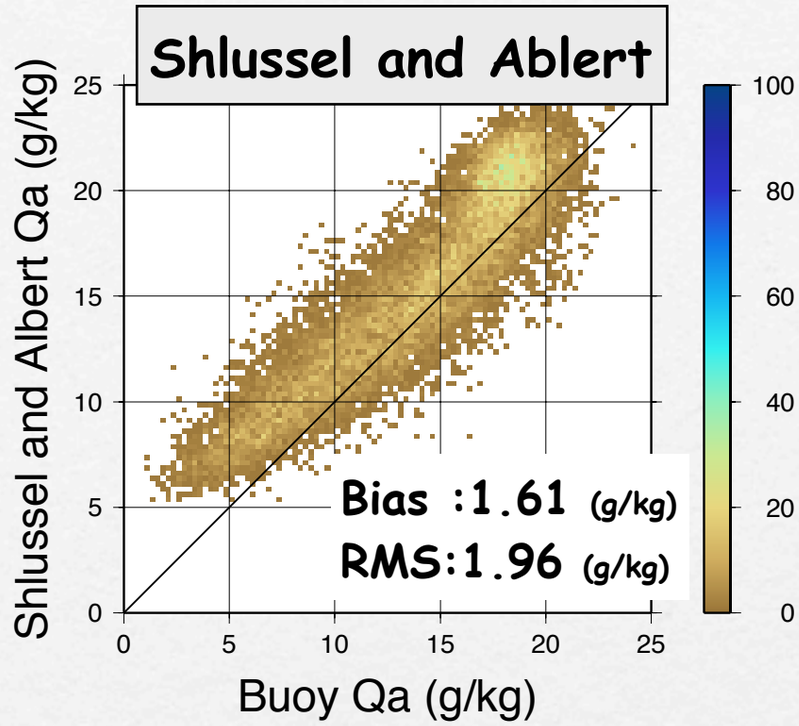
This feature is similar to these products.

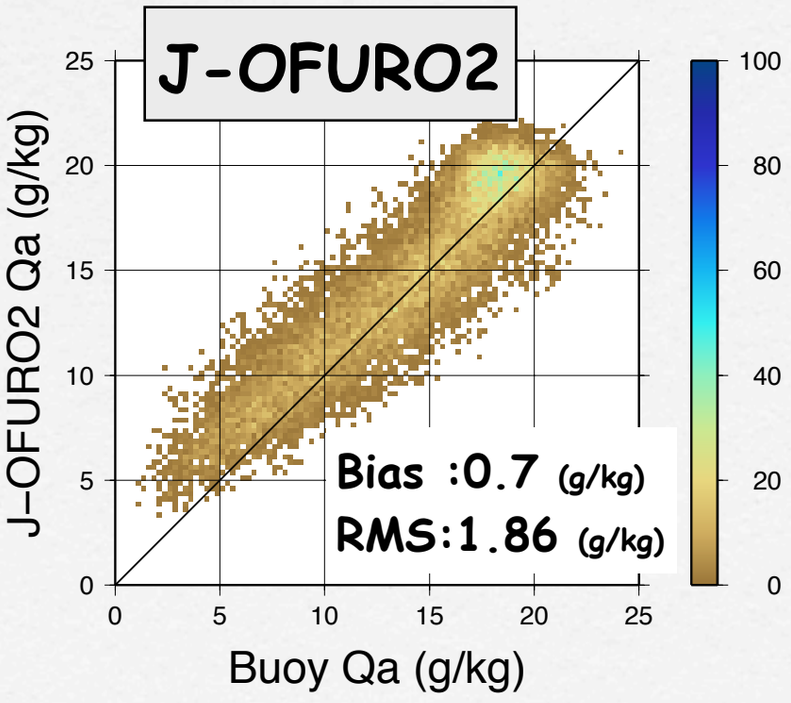
This result suggests that the brightness temperature of 85 GHz polarized radiation is very important for the accurate estimation of satellite-derived Qa.

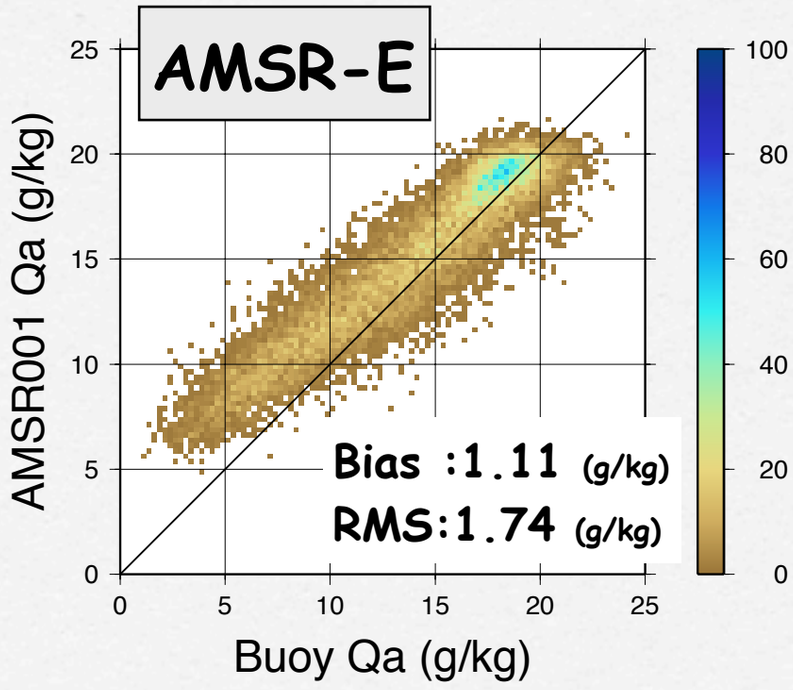
Comparison between Qa products and buoy Qa (KEO, NDBC)











Data num.13911

Summary and Conclusion

We developed an algorithm to determine the Qa from the TMI brightness temperature data by assuming the in situ data of ICOADS for the year 2003-2006 to be true values. We validated the products obtained by the present regression formulae, by using moored buoys.

From the comparison results of tropical region buoy, we found the bias of our products is considerably small, i.e. 0.12 g/kg, compared with other products. J-OFURO2 and Schlussel and Albert (2001) overestimate for large value. Although the RMS errors are not as small as that for Kubota and Hihara (2008), the present products are considerably small compared with J-OFURO2 and Schlussel and Albert's Qa.

In the mid-latitude, the all products overestimate for small values. The difference of RMS between the data products is small.

Summary and Conclusion

J-OFURO2 and Schlussel and Albert are not used the 85 GHz polarized radiation that was a cause of overestimation for large values.

The brightness temperature of 85 GHz polarized radiation has been used for Qa retrieval from SSMI in previous studies because the 85 GHz polarized radiation was considered not to significant information about the boundary layer from results of radiative-transfer calculations (Schulz et al., 1993).

However, the present results show that the brightness temperature of 85 GHz polarized radiation is very important for improvement of overestimation for large values. We think that this information is important for Qa retrieval from the brightness temperature observed by SSMI.

Summary and Conclusion

At present, we can use Qa data sets from three microwave radiometer (SSMI, AMSR-E and TMI). Therefore the data sets can be made that the sampling error become small by combining these data sets.

Future work in satellite-derived Qa retrievals should make multi-sensor Qa products for more accurate satellite-derived LHF retrievals.

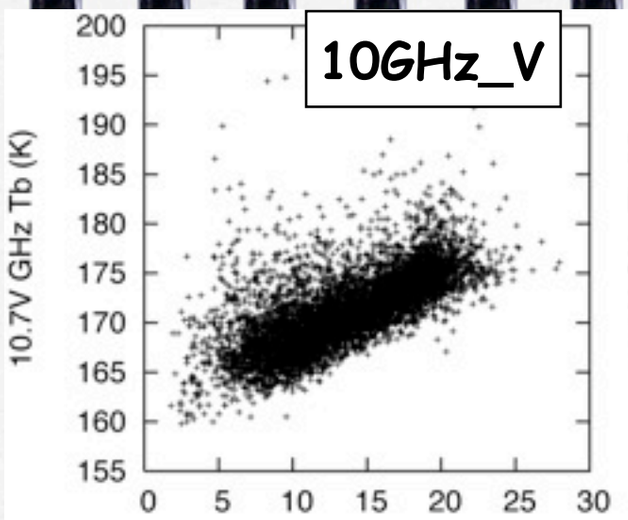
Thank you very much for kind attention !!

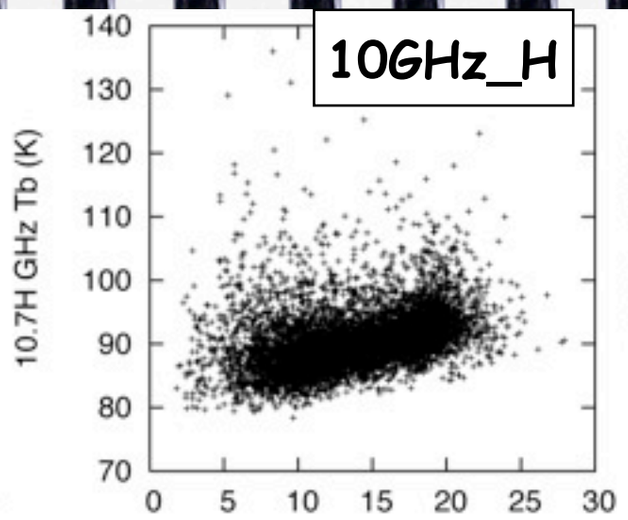
Frequency (GHz) used for retrieval Qa with three products.

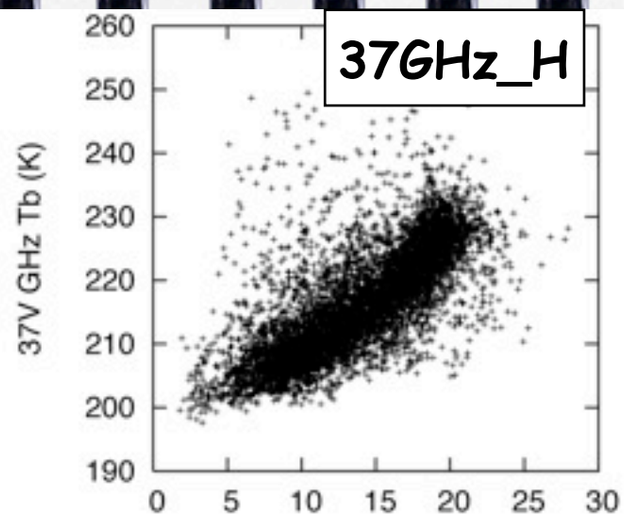
	6	10	19	22	37	85
Schlussel et al.(1995)			19.35V/H	22.235V	37.0V/H	(85.5V/H)
Schlussel and Albert (2001)		10.65V/H	19.35V/H	21.3V	37.0V (37.0H)	(85.5V/H)
Kubota and Hihara (2008)	6.925V/H	10.65V/H	18.7V/H	23.8V/H	36.5V/H	89.0V/H

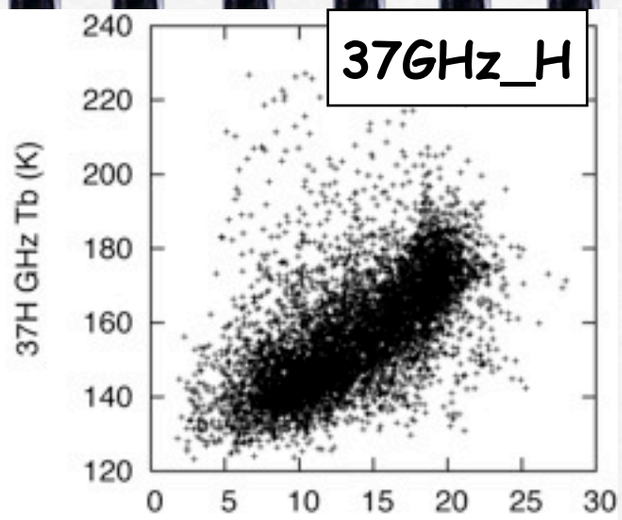
The values in parentheses are the frequency (GHz) not used for the retrieval Qa in spite of observes with each sensor.

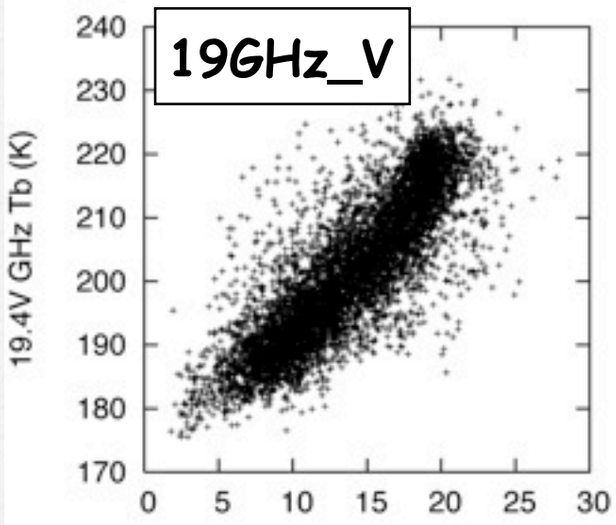
V and H means vertically and horizontally polarized radiation, respectively.

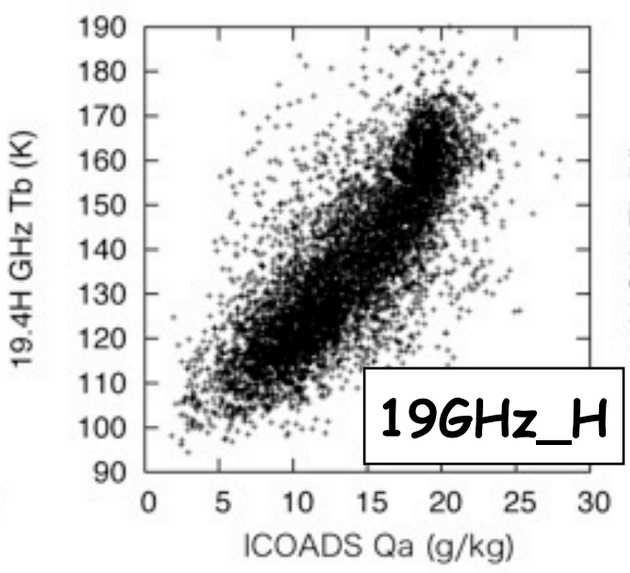


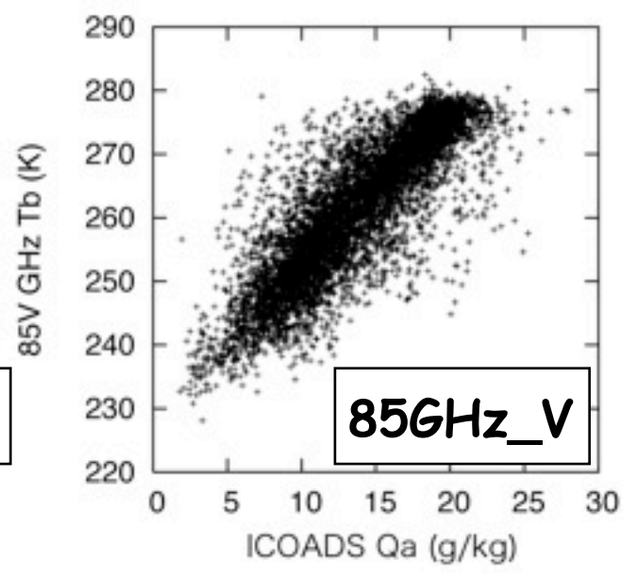


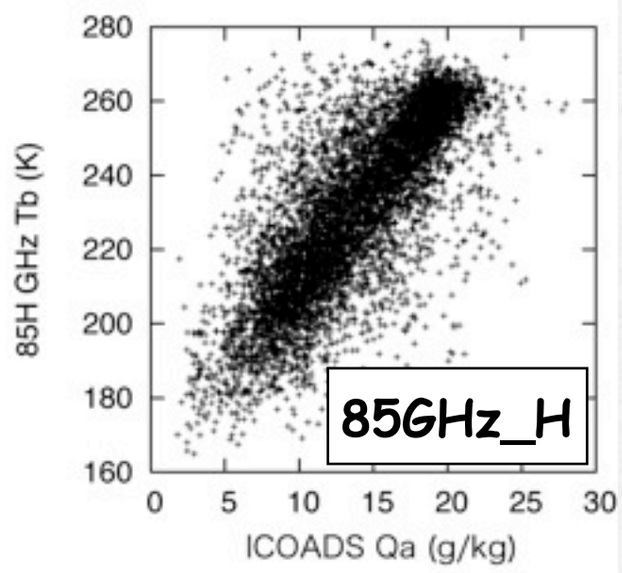


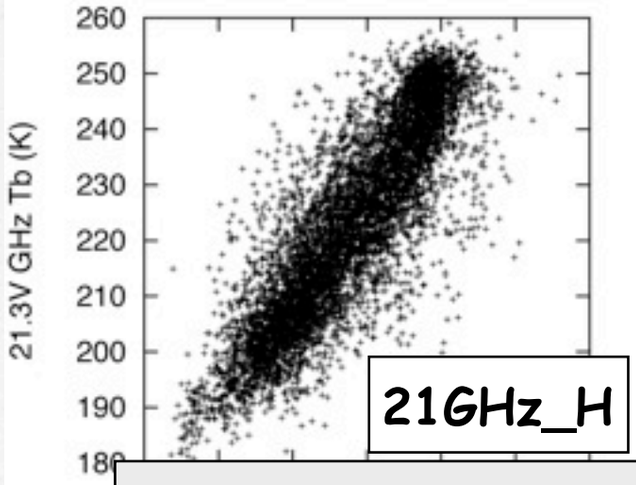












$Qa^{S\&A(2001)} = Tb_{10V/H}, Tb_{19V/H}, Tb_{21V}, Tb_{37H}$

$Qa^{Schlussel(1995)} = Tb_{19V/H}, Tb_{22V}\ Tb_{37V/H}$

Scatter results between ICOADS Qa and Tb observed by TMI (2003-2006)