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ACCURACY OF SATELLITE DERIVED LATENT HEAT FLUX

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1 Introduction

Surface heat fluxes play a critical role in the global climate system. In particular, latent heat flux can be considered to be one of the most important component because latent heat flux is larger than other components in several time scale (Tomita and Kubota, 2000) and can carry heat energy from ocean to atmosphere with large spatial scale. However, it is very difficult to estimate global latent heat flux because of limited *in situ* observation. Recently, we can use various global and high resolution data because of technological development of remote sensing, numerical simulation and *in situ* observation.

As a result, there are several global surface heat flux data sets derived from satellite data at present. J-OFURO (Japanese Ocean Flux Data Sets with Use of Remote Sensing Observations) data (Kubota et al., 2002a) contains surface heat flux data such as shortwave radiation, logwave radiation, latent heat flux and sensible heat flux. Also, HOAPS (Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite) and GSSTF (Goddard Satellite based Surface Turbulent Fluxes) are similar data sets made in Germany and U.S.A, respectively. In addition, there are reanalysis data sets including surface heat flux data, such as NRA (NCEP/NCAR Reanalysis, Kalney et al., 1996) and ERA (ECMWF Reanalysis). These data sets may provide very important information for research on air-sea interaction. Accuracy of surface heat flux data, however, has not been discussed enough. For example, Kubota et al. (2002b) compared each latent heat flux product and mentioned that there are large differences between each latent heat flux data. In this study, we evaluate accuracy of several global latent heat flux data sets using several buoy data as in situ data and we compare each result. Data sets and methods used in this study are described in section 2. Results of comparison are shown in section 3. Summary and discussions are given in section 4.

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2 Data sets and Methods

We used several global latent heat flux data sets. J-OFURO, HOAPS and GSSTF are mainly derived from satellite data. In order to estimate latent heat flux using satellite data, we generally use a bulk method shown as Eq.(1).

$$LHF = \rho LCeW(Qs - Qa) \qquad (1)$$

ρ is density of air, L is latent heat of walter, Ce is bulk coefficient, W is wind speed at 10m, Qs is saturate specific humidity of sea surface temperature (SST) and Qa is air specific humidity at surface. In order to estimate L, W, Qs and Qa, we use satellite data. L and Qs can estimate using global SST data. W and Qa are derived form DMSP/SSMI data. There are various methods to estimate W and Qa. Each product use different data (or a method) and a bulk coefficient as summarized in Table 1.

Table 1: Differences in satellite latent heat flux data sets. RS(1994) means Reynolds and Smith (1994).

Data Sets	**Bulk**	**W**
J-OFURO	Kondo (1975)	Wentz (1997)
GSSTF2	Chou (1993)	Wentz (1997)
HOAPS	Smith (1988)	Schlussel and Luthadit (1991)
Data Sets	**SST**	**Qa**
J-OFURO	RS(1994)	Schlussel et al. (1995)
GSSTF2	NRA	Chou et al.(1995,97)
HOAPS	RS(1994)	Schlussel et al.(1996)

We also used re-analysis latent heat flux data sets of NRA and ERA15. Details of global latent heat flux data sets used in this study are summarized in Table 2.

In order to evaluate accuracy of these data sets, we used several buoy data as in situ data. TAO/TRITON (Tropical Atmosphere Ocean / Triangle Trans-Ocean buoy Network) buoy data and JMA buoy data are used in this study. We calculated buoy latent heat flux using bulk method proposed by Kondo (1975). This method is the same method adopted in J-OFURO. This is not fair for comparison because each satellite latent heat flux data set uses different bulk method. However, in this study we ignored difference of bulk method. The discussion of results for the comparison using other bulk methods will be given in feature.

Table 2: Summary of global latent heat flux data sets

Data Sets	Hor. Res.	Temp. Res.	Temp. Coverage
J-OFURO	1.0deg	3 days	1992 - 2000
GSSTF2	1.0 deg	daily	1987.7-2000
HOAPS	0.5 deg	daily	1987.7-1997
NRA	gaussian	daily	1992-2000
ERA15	1.125 deg	daily	1992-1994.2

Each latent heat flux data set has different temporal and spatial resolution (see table 2). Therefore, we convert temporal and spatial resolution to 3days mean and $1^{\circ} * 1^{\circ}$ grid using a liner or spline interpolation method to simplify inter-comparison. In order to adapt 3days mean and $1^{\circ} * 1^{\circ}$ grid data to buoy location, we calculate much-up data using data on four girds around buoy. The time period of the comparison is from 1992 to 1993 (2 years) for inter-comparison. For other comparison, we used data from 1992 to 2000 (9 years).

3 Results

3.1 Global latent heat flux data sets and TAO/TRITON buoy inter-comparison

In order to evaluate accuracy of each global latent heat flux data set, we compare the buoy latent heat flux with each global latent heat flux data set. We show scatter plots of the comparison of buoy latent heat flux with (a) J-OFURO, (b) GSSTF2, (c) HOAPS, (d) NRA and (e) ERA15. The statistics of a bias, a root-mean-square error (rms), a rms removed bias (rmsr) and a correlation coefficient between buoy and global latent heat flux data sets are calculated. Each statistic is given in Table 3. J-OFURO and GSSTF2 latent heat flux are very similar and characterized by large overestimation when buoy latent heat flux shows a large value ($\geq$150 Wm^{-2}). And also, we found that J-OFURO and GSSTF2 latent heat flux underestimate when buoy latent heat flux shows a small value ($\leq$ 150 Wm^{-2}). Overall HOAPS latent heat flux underestimate and a bias is largest in this comparison. J-OFURO and re-analysis data sets have small bias ($\leq \pm 7$ Wm^{-2}). GSSTF2 and ERA15 show small rms value (35 - 38 Wm^{-2}). In general, satellite latent heat flux shows high correlation ($\geq$ 0.7) in the tropical Pacific region. On the other hand, re-analysis latent heat flux shows relatively low correlation (0.5 - 0.6) there.

Table 3: Statisitics between TAO/TRITON buoy and each global latent heat flux data sets. Units in W/m^2, except correlation.

Data Sets	Bias	RMS	RMSR	Corr.
J-OFURO	6.22	42.76	42.31	0.74
GSSTF2	12.34	37.65	35.58	0.74
HOAPS	46.20	56.23	32.03	0.71
NRA	6.97	43.02	42.45	0.51
ERA15	-6.19	35.84	35.31	0.63

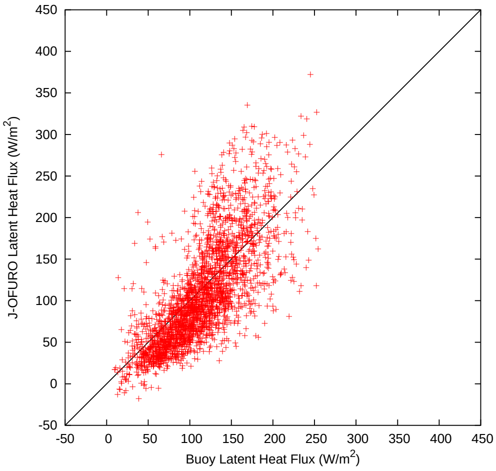

Fig.1 Comparison of latent heat flux between J-OFURO and TAO/TRITON buoys .

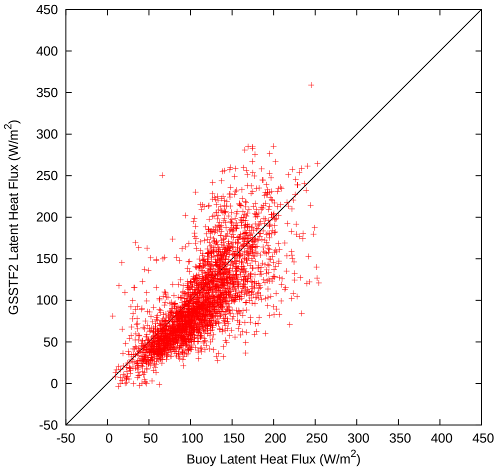

Fig.2 Same as Fig.1, except for GSSTF2.

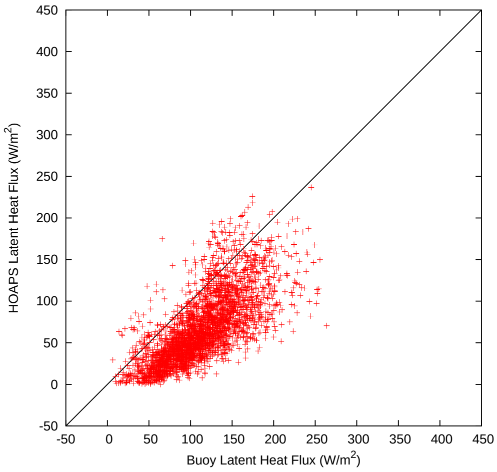

Fig.3 Same as Fig.1, except for HOAPS

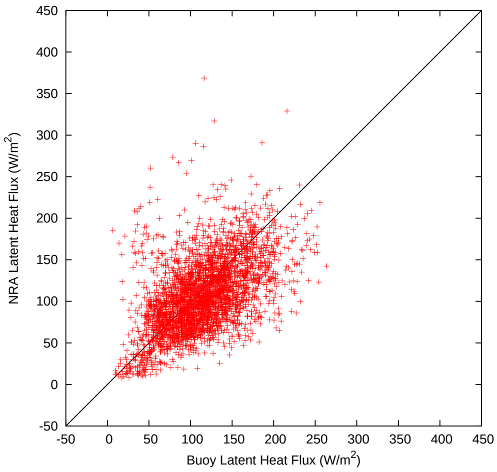

Fig.4 Same as Fig.1, except for NRA.

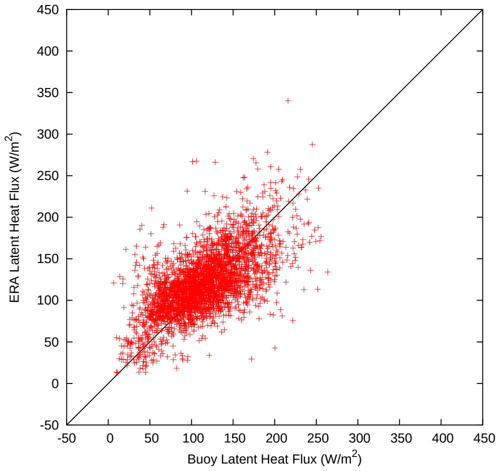

Fig.5 Same as Fig.1, except for ERA15.

Results of comparison showed that satellite latent heat flux data sets are lager than buoy latent heat flux when buoy latent heat flux shows large value. In order to show what component data has a large effect on this overestimation, we constructed following fake data sets using J-OFURO and buoy component data. The fake data set made by a following way. Buoy data are used for one component, while J-OFURO data are used for other components (see Table 3). For example, the fake 1 is that using buoy data for only W and SST(L and Qs) and Qa are same data as J-OFURO. We compared buoy latent heat flux with each fake data set.

Table 4: The fake data sets of J-OFURO.

Data Sets	W	SST	Qa
Fake 1	buoy	J-OFURO	J-OFURO
Fake 2	J-OFURO	buoy	J-OFURO
Fake 3	J-OFURO	J-OFURO	buoy

Results of comparison show that the fake 3 considerably agreed with buoy latent heat flux. That is, this result shows that cause of most error of J-OFURO latent heat flux is accuracy of Qa. If we use Qa observed by buoys for estimating latent heat flux (i.e. fake 3), the statistics (a bias, a rms, a rmsr, correlation) are remarkably improved, -4.22, 24.6 Wm^{-2}, 24.25 Wm^{-2}, 0.87, respectively.

3.2 Global latent heat flux data sets and JMA buoy inter-comparison

Figs.6-10 are same as Figs.1-5 except for JMA buoy latent heat flux. The statistics between buoy and each global latent heat flux data set are shown in Table 5. The re-analysis data sets (i.e. NRA and ERA15) are extremely accurate compared with satellite latent heat flux data sets. Overall bias, rmsr, correlation for satellite latent heat flux are 40 - 45 $\mathrm{Wm^{-2}Wm^{-2}}$, 83 - 93 $\mathrm{Wm^{-2}}$ and 0.75 - 0.85, respectively. On the other hand, statistics for re-analysis latent heat flux are 4 - 6 $\mathrm{Wm^{-2}}$, 49-56 $\mathrm{Wm^{-2}}$, 0.9, respectively. Three satellite latent heat flux data sets have same character in this comparison. In contrast to comparison with TAO/TRITON buoy, satellite latent heat flux underestimate when buoy latent heat flux shows large value ($\geq$150 $\mathrm{Wm^{-2}}$). We examined what component data has large effect on satellite latent heat flux using the same method mentioned in section 3.1. Results show that the error of satellite latent heat flux is mainly due to the accuracy of satellite Qa. However, even if we use Qa observed by buoys for estimating latent heat flux (i.e. fake 3), there are large differences between buoy and fake 3 latent heat flux when buoy latent heat flux shows large value. That is, this is due to error of other components (SST or W). We concluded this error is due to W because if we use Qa and W observed by buoys for estimating latent heat flux , we found most accurate latent heat flux.

Table 5: Statisitics between JMA buoy and each global latent heat flux data sets. Units in $\mathrm{Wm^{-2}}$, except correlation.

Data Sets	Bias	RMS	RMSR	Corr.
J-OFURO	44.69	92.88	81.39	0.75
GSSTF2	40.80	82.95	72.19	0.84
HOAPS	49.82	92.02	77.33	0.81
NRA	-6.23	49.02	48.62	0.93
ERA15	4.27	55.83	55.67	0.92

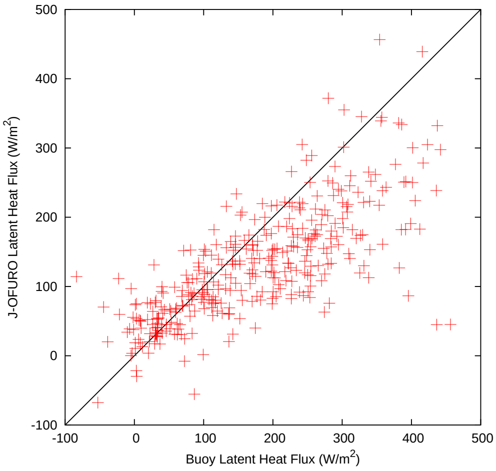

Fig.6 Comparison of latent heat flux between J-OFURO and JMA buoys .

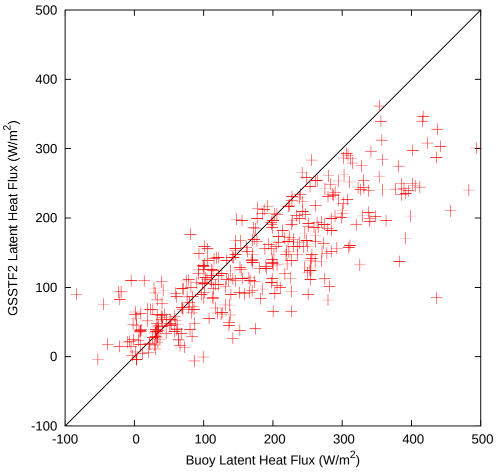

Fig.7 Same as Fig.6, except for GSSTF2.

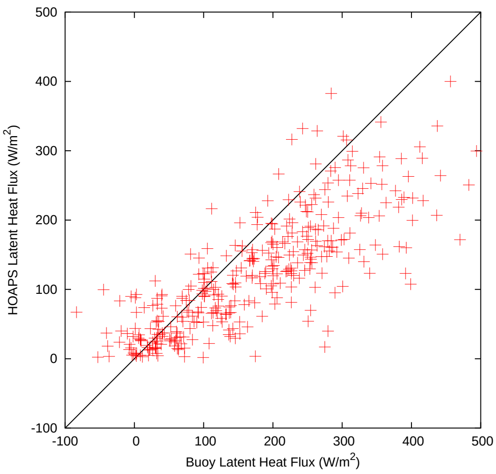

Fig.8 Same as Fig.6, except for HOAPS

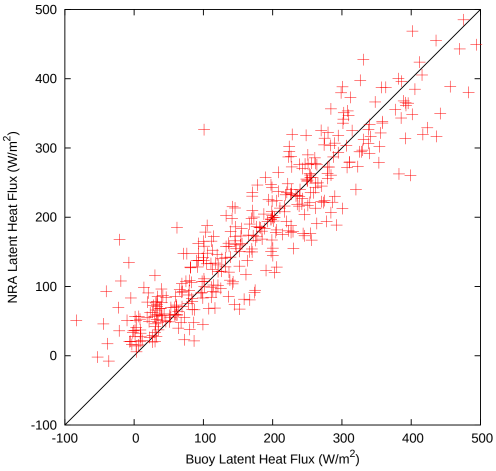

Fig.9 Same as Fig.6, except for NRA.

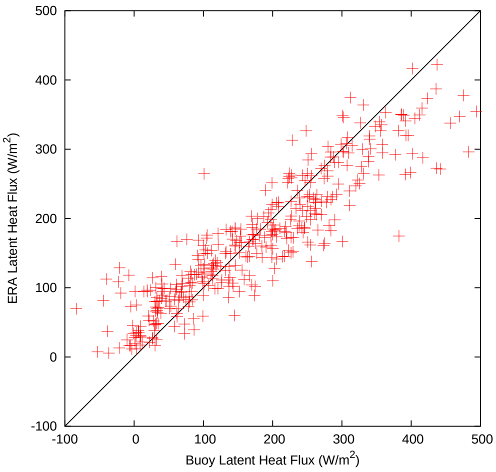

Fig.10 Same as Fig.6, except for ERA15.

4 Summary

We compared global latent heat flux data sets with buoy latent heat flux. We used two kinds of global latent heat flux data set. One is that produced by satellite data (J-OFURO, GSSTF2 and HOAPS). Another is re-analysis data set based on an output from AGCM (NRA and ERA15). Also we used two kinds of buoys data sets as in situ data. One is that located in Pacific tropical region (TAO/TRITON) and another is that located around Japan (JMA).

We found that satellite latent heat flux shows high correlation ($\geq$ 0.7), on the other hand, re-analysis latent heat flux shows relatively low correlation (0.5 - 0.6) in the tropical Pacific region. On the other hand, overall statistics show that differences of accuracy between satellite and re-analysis latent heat flux are small in the tropical Pacific region. However, there were large differences around Japan. The re-analysis latent heat flux data sets are more accurate compared with each satellite product.

We found J-OFURO and GSSTF2 latent heat flux data set have same character. In the Pacific tropical region, J-OFURO and GSSTF2 latent heat flux overestimate when buoy latent heat flux shows a large value ($\geq$ 150 Wm^{-2}). On the other hand, satellite latent heat flux underestimate when buoy latent heat flux shows large value around the Japan. These are mainly due to accuracy of satellite Qa. Also, the effect of error of W on accuracy of satellite latent heat flux is large around Japan. Therefore, improvement of algorithm of Qa are extremely needed to estimate accurate satellite latent heat flux. Also, accurate W data is important around Japan.

In this study, we used bulk method of Kondo (1975) to calculate in situ latent heat flux. This method are used to estimate J-OFURO latent heat flux. Therefore, results of inter-comparison in this study are not fair because other satellite latent heat flux data sets are using other bulk method. Therefore, we should discuss about an error of each bulk method in the near future.

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