Estimation of the surface heat budget over the South China Sea

FENG Bao-Xina, LIU Hai-Longb, LIN Peng-Feib and WANG Qia

acollege of physical and environmental oceanography, ocean University of china, Qingdao, china; bstate Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LAsG), institute of Atmospheric physics, chinese Academy of sciences, Beijing, china

ABSTRACT

In situ data are employed to evaluate five gridded surface heat flux datasets over the South China Sea. The surface heat budgets for these gridded datasets are computed. The authors find that the gridded datasets tend to underestimate both the solar radiation and sensible heat flux in general, while the latent heat fluxes are close to the observations, except for that of NOC unadjusted version 2 (NOC2), which overestimates both the latent and sensible heat flux. The underestimation of solar radiation also indicates that the gridded datasets might underestimate the surface heat budget. The net surface heat flux of the five gridded datasets is always positive. However, the net surface heat flux of COADS, NOC1, NOC2, and OAFlux, in the range 48–56 W m−2, is around twofold more than that of NOC1a (22 W m−2). The budget for NOC2 is smaller than that of NOC1 and OAFlux, by approximately 49 W m−2, because of the large release of latent heat flux. Based on the comparison, the authors believe that the net surface heat flux over the South China Sea should be higher than 56 W m−2, which is significantly larger (around 10%–20%) than previous estimations.

1. Introduction

The South China Sea (SCS) is the largest marginal sea in the northwestern Pacific. It connects with the East China Sea through the shallow Taiwan Strait and with the Pacific Ocean through the deep Luzon Strait in the northeastern part, and also with the Sulu and Java seas through the shallow Mindoro and Karimata straits in the south, respectively. Since the SCS is located in the tropics, south of the Tropic of Cancer, it receives heat from the atmosphere on average over the basin, and is balanced by the ocean heat transport through the straits (Qu, Du, and Sasaki 2006). Owing to insufficient observational data to estimate the heat transport through the straits, the surface heat budgets become an important proxy of the heat transports. Recently, Qu, Song, and Yamagata (2009) estimated the area-averaged net surface heat flux (Qnet, hereafter) over the SCS by using both OAFlux (Yu and Weller 2007) and COADS (Oberhuber 1988) data. The value from OAFlux (49 W m−2) was twice as high as that from COADS (23 W m−2). Zeng et al. (2009) used seven satellite-derived latent heat flux products to compare with moored buoy data and concluded that all of the products did not compare well to the in situ data. All of these studies suggest that there are large uncertainties in the estimation of the surface heat budget in this region (Zeng et al. 2009), meaning further investigation is needed.

In the last 20 years, much effort has been made to produce global gridded surface heat flux datasets, and these datasets are extensively used in climate studies. They can usually be grouped into three categories: satellite-based datasets (Schulz et al. 1997; Kubota et al. 2002; Chou et al. 2003), atmosphere datasets (Kalnay et al. 1996; Gibson and Harper 1997; Uppala et al. 2005), and reconstructed datasets (Ji, Leetmaa, and Derber 1995; Behringer and Xue 2004; Carton and Giese 2008) come from operational system assimilated observations. Since surface flux data from atmospheric reanalysis may contain large biases on regional scales, the second of the above-listed data-set types is seldom used

CONTACT LIU Hai-Long lh@lasg.iap.ac.cn
© 2016 The Author(s). Published by Taylor & Francis
This is an Open Access article distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/4.0/), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.
The five gridded surface heat flux datasets have differences in their data sources and temporal resolutions, but the spatial resolutions are the same. They cover different periods of time. NOC1a is only a climatology, but the other four are monthly datasets. The five surface flux datasets also use different formulas to calculate the surface turbulent fluxes.

2.2. In situ data

The in situ datasets used in this paper are listed in Table 2. We use the turbulent fluxes (both latent and sensible fluxes) from the air–sea flux tower at Yongxing Island (YX) in 2008, and the turbulent fluxes computed by atmospheric and oceanic data collected by the research vessels ‘ShiYan 3’ (SY3) and ‘KeXue 1’ (KX1) during the intensive observation period of SCSMEX in 1998. The algorithm used to calculate the turbulent heat flux for YX is COARE.
Table 2. Details of the in situ surface heat flux datasets.

| Name                  | Data source                      | Spatial resolution | Temporal resolution and period   | Variables       | Reference               |
|-----------------------|----------------------------------|--------------------|----------------------------------|-----------------|-------------------------|
| Rexue 1 (KX1)         | Research vessel during SCSMEX    | (6°15'N, 110°E)    | 1998.5.5–1998.5.25, 1998.6.5–1998.6.20 | Latent, Sensible| Qu, Hu, and Li (2000)   |
| Shiyan 3 (SY3)        | Research vessel during SCSMEX    | (20°24'N, 116°54'E)| 1998.5.5–1998.5.25, 1998.6.5–1998.6.20 | Latent, Sensible| Qu, Hu, and Li (2000)   |
| Yongxing island (YX)  | Marine observation tower         | (16°50'N, 112°20'E)| 2008.4.25–2008.10.7               | Latent, Sensible| Sun, Chen, and Yan (2010)| Website*               |
| Tropical Atmosphere Ocean (TAO1) | TAO buoys                   | (13°N, 114°E)     | 1998.5.1–1998.11.30               | Shortwave       | Website*               |
| Tropical Atmosphere Ocean (TAO2) | TAO buoys                   | (15°N, 115°E)     | 1999.9.1–1999.10.31               | Shortwave       | Website*               |
| Tropical Atmosphere Ocean (TAO3) | TAO buoys                   | (18°N, 116°E)     | 1997.11.1–1998.2.28; 1998.5.1–1998.6.30 | Shortwave       | Website*               |

Note: The abbreviations in parentheses in the first column are the names used in this paper.
*http://www.pmel.noaa.gov/tao/proj_over/scsmex/scsmex_deliv.html.

3.0 (Fairall et al. 2003), while that for both SY3 and KX1 is the bulk air–sea flux formula in terms of wind speed and stratification of the atmosphere (Kondo 1975). We also use shortwave radiation data from three Tropical Atmosphere Ocean (TAO) buoys employed during SCSMEX. The buoys were located at (13°N, 114°E), (15°N, 115°E) and (18°N, 116°E), and are referred to as TAO 1, TAO 2, and TAO 3, respectively. We regard these turbulent and shortwave radiation fluxes as the in situ datasets. The locations of these datasets are shown in Figure 1.

3. Results

Since the gridded datasets are all monthly means, we also use the monthly mean values of in situ data to carry out the comparison. Figure 2 is a scatter plot between the in situ and gridded data for the shortwave radiation, and the latent and sensible heat fluxes (we define the ocean gaining heat from the atmosphere as positive, and vice versa as negative). The whole period–averaged values of the in situ data are listed in Table 3. The different marks stand for different gridded datasets. The points below (above) the diagonal mean the gridded data are smaller (larger) than the in situ data. Because the latent and sensible heat fluxes are negative, the points below (above) the diagonal mean the absolute values of the gridded data are larger (smaller) than the in situ data.

In general, the gridded shortwave radiation fluxes are slightly smaller than the in situ observations. There are more points below the diagonal (Figure 2(a)). The ensemble mean for the in situ data is 227 W m⁻², while it is only 216 W m⁻² for the gridded data (Table 3). However, it is clear that there are more marks for NOC2 located above the diagonal. The mean value for NOC2, 224 W m⁻², is close to the in situ data, and COADS and NOC1 are a little smaller—better than NOC1a and OAFlux.

The latent heat flux is another dominant component of the Qnet. It is apparent that the points are almost evenly distributed around the diagonal (Figure 2(b)), meaning the gridded data are close to the in situ observations. The ensemble mean for the in situ and gridded data is −98 W m⁻² and −100 W m⁻², respectively (Table 3). However, the latent fluxes for NOC2 deviate the most from the in situ data, which is consistent with the finding of Zeng et al. (2009) that ICOADS possesses moderate systematic errors with respect to in situ data. The mean value is −120 W m⁻² (Table 3)—about 20 W m⁻² larger than the ensemble mean and the observational data, meaning there is much more latent heat flux released from the ocean in NOC2. However, the mean value of NOC1, approximately −94 W m⁻², is close to the in situ observations.

The absolute value of sensible heat flux (<10 W m⁻²) is much smaller than that of the shortwave radiation and latent heat fluxes. Figure 2(c) shows that almost all the gridded datasets are above the diagonal, except for NOC2, meaning the gridded data tend to underestimate the release of sensible heat and NOC2 tends to overestimate it. The mean values in Table 3 also confirm the results: −8 W m⁻² for the in situ data and −5 W m⁻² for all of the gridded data, except −9 W m⁻² for NOC2.

Based on the above comparison, the gridded datasets generally tend to underestimate both the solar radiation and the sensible heat flux, while the latent heat fluxes are close to the observations. NOC2, which is different from the other datasets, overestimates the turbulent heat fluxes—both the latent and sensible heat fluxes. We compute the sum of shortwave radiation and latent heat flux at YX (Table 3). Because these two terms dominate the surface heat budget, this value can explain most of the heat budget. We can see that the values for both NOC1a (121 W m⁻²) and NOC2 (105 W m⁻²) are remarkably lower than the observation (152 W m⁻²) and the other three datasets. The former (NOC1a) is due to the underestimated shortwave radiation, and the latter (NOC2) to the overestimated latent heat. Among the other three datasets, the sum for OAFlux is also about 10–15 W m⁻² larger than the
The $Q_{\text{net}}$ is generally calculated through four components: the shortwave radiation, longwave radiation, latent heat flux, and sensible heat flux. The period is from 1984 to 1993 for the five gridded datasets. The averaged domain is $1.5^\circ-22.5^\circ \text{N, } 106.5^\circ-121.5^\circ \text{E}$, shown in Figure 1. The $Q_{\text{net}}$ of other two datasets, COADS and NOC1. That is, the heat budget for COADS and NOC1 may be more reasonable than the other datasets.

We next compute the period-averaged surface heat budget over the SCS for the five gridded datasets (Table 3). The scatter diagrams of (a) shortwave radiation, (b) latent heat flux, and (c) sensible heat flux, between the in situ ($x$-axis) and gridded ($y$-axis) datasets. Notes: COADS, NOC1, NOC1a, NOC2, and OAFlux are shown as red crosses, green points, brown triangles, blue diamonds, and purple squares, respectively. Units: W m$^{-2}$.

**Table 3.** The period-average values of the in situ datasets and the five gridded datasets at the observational stations.

|                     | Observation | COADS | NOC1 | NOC1a | NOC2 | OAFlux | Ensemble mean |
|---------------------|-------------|-------|------|-------|------|--------|---------------|
| **Shortwave radiation** |             |       |      |       |      |        |               |
| TA01                | 218±85      | 224   | 227  | 206   | 243  | 208    |               |
| TA02                | 220±55      | 210   | 197  | 196   | 200  | 201    |               |
| TA03                | 223±17      | 191   | 208  | 179   | 207  | 200    |               |
| YX                  | 245±15      | 250   | 244  | 230   | 246  | 238    |               |
| Mean                | 227         | 219   | 219  | 203   | 224  | 212    | 216           |
| **Latent heat flux** |             |       |      |       |      |        |               |
| KX1                 | −110±52     | −97   | −120 | −113  | −134 | −91    |               |
| YX                  | −93±27      | −91   | −92  | −109  | −141 | −96    |               |
| SY3                 | −91±32      | −78   | −69  | −91   | −86  | −84    |               |
| Mean                | −98         | −89   | −94  | −104  | −120 | −90    | −100          |
| **Sensible heat flux** |             |       |      |       |      |        |               |
| KX1                 | −10±5       | −5    | −8   | −6    | −10  | −4     |               |
| YX                  | −6±3        | −2    | −2   | −3    | −11  | −1     |               |
| SY3                 | −8±2        | −4    | −5   | −4    | −5   | −4     |               |
| Mean                | −8          | −4    | −5   | −4    | −9   | −3     | −5            |
| **Shortwave radiation + Latent heat flux** |               |       |      |       |      |        |               |
| YX                  | 152         | 159   | 152  | 121   | 105  | 142    |               |

Note: Units: W m$^{-2}$. 

Figure 2. Scatter diagrams of (a) shortwave radiation, (b) latent heat flux, and (c) sensible heat flux, between the in situ ($x$-axis) and gridded ($y$-axis) datasets.


the range of 45–60 W m$^{-2}$, is around twofold that of NOC1a and more than fourfold that of the constrained COADS. This can be explained by NOC1a having smaller shortwave

Table 4. The surface heat flux budget for the five gridded datasets in the SCS for the period 1984–1993. The averaged domain is shown in Figure 1.

| Variable | COADS | NOC1 | NOC1a | NOC2 | OAFlux |
|----------|-------|------|-------|------|--------|
| SW       | 214±36| 210±37| 200±31| 214±32| 207±30 |
| LH       | −115±24| −106±31| −125±25| −117±24| −100±23 |
| SH       | −8±4 | −5±2 | −6±2 | −7±3 | −7±5 |
| LW       | −43±4 | −43±4 | −47±4 | −41±4 | −47±12 |
| NET      | 48±63 | 56±56 | 22±30 | 49±56 | 53±52 |

Note: Units: W m$^{-2}$.

*The value in brackets is from the constrained COADS data-set.

Figure 3. The annual mean (a–e) shortwave radiation and (f–j) latent heat flux for the five gridded datasets during 1984–1993.

Figure 4. The annual mean net surface heat flux for the five gridded datasets over the domain shown in Figure 1. Notes: The constrained COADS, NOC1, NOC1a, NOC2, and OAFlux are shown as red dashed, green solid, brown dash-dot, blue dashed, and purple solid lines, respectively. The unconstrained net surface heat flux data for COADS (black solid line), which is calculated from the sum of the shortwave radiation, longwave radiation, latent heat, and sensible heat flux, are also shown. Units: W m$^{-2}$.

the five gridded datasets is always positive; that is, the SCS receives heat from the atmosphere. However, the $Q_{\text{net}}$ of the non-constrained COADS, NOC1, NOC2, and OAFlux, in
radiation but larger latent heat flux. As mentioned above, the shortwave radiation for COADS, NOC1, and OAFlux are underestimated according to the comparison with the in situ data. Therefore, the $Q_{\text{net}}$ over the SCS should be higher than 56 W m$^{-2}$, which is significantly larger (around 10%–20%) than previous estimations (e.g. Qu, Song, and Yamagata 2009).

Figure 3 shows the annual mean pattern of the shortwave radiation and latent heat flux for the five gridded datasets. The average period is the same as that in Table 4, i.e. from 1984 to 1993. We can see that the patterns of the five gridded datasets are all similar. The large incident solar radiation and the latent heat flux releases occur between 5°N and 20°N, north of the region favorable for convection. Clearly, the solar radiation for NOC1a and OAFlux is smaller than for the other three datasets (Figures 3(c) and (e)), and the latent heat fluxes for NOC1a and NOC2 are larger than the other three datasets (Figures 3(h) and (i)). The differences among the datasets are mostly homogeneous.

It is also apparent that the $Q_{\text{net}}$ possesses a clear decreasing trend (Figure 4). The $Q_{\text{net}}$ values of NOC1, NOC2, and OAFlux are all near 50–60 W m$^{-2}$ for the period from 1984 to 1993—around twofold more than the value for NOC1a (approximately 20 W m$^{-2}$). The NOC1 and OAFlux data are mostly larger than the NOC2 data during this period. This also explains why the period-mean values of NOC1 and OAFlux are larger than those of NOC2. The NOC1 and NOC2 values decrease to approximately 30 W m$^{-2}$ around 1998–2001, and then increase to around 50 W m$^{-2}$ and 40 W m$^{-2}$, respectively. The OAFlux decrease is much slower than that of NOC1 and NOC2; it decreases to approximately 40 W m$^{-2}$ around 2003 and remains there until the end of the record.

4. Summary and discussion

This study employs in situ observations to evaluate five gridded surface heat flux datasets over the SCS. The surface heat budgets for these gridded datasets are computed. It is found that the gridded datasets generally tend to underestimate both the solar radiation and sensible heat flux, while the latent heat fluxes are close to observations, except for NOC2, which overestimates both the latent and sensible heat flux. The underestimation of the solar radiation indicates that the gridded datasets might also underestimate the surface heat budget. Based on the better performance regarding shortwave radiation, latent heat flux, and the sum of these two heat fluxes (Table 3), we speculate that NOC1 is the relatively better gridded data-set among the five, although it underestimates the sensible heat flux and $Q_{\text{net}}$.

There are also possible errors in the observational datasets. For instance, the observation tower is only 360 m away from the island. It could overestimate the ocean turbulent heat flux loss, because the shallow coastal water around the island may be much warmer than the SST far away from land. However, based on our results (Table 3), three of the five datasets possess a larger latent heat release than that of YongXing Island. It is therefore hard to say, based on the observation data, whether or not it is overestimated in the present study. More observations of the surface fluxes are required.

The $Q_{\text{net}}$ of the five gridded datasets is always positive. However, the $Q_{\text{net}}$ of COADS, NOC1, NOC2, and OAFlux, ranging from 48 to 56 W m$^{-2}$, is around twice that of NOC1a (22 W m$^{-2}$). The imbalance for NOC2 is smaller than that for NOC1 and OAFlux, at about 49 W m$^{-2}$, because of the large release of latent heat flux. Based on the comparison, we believe that the $Q_{\text{net}}$ over the SCS should be higher than 56 W m$^{-2}$, which is significantly larger (roughly 10%–20%) than previous estimations (e.g. Qu, Song, and Yamagata 2009).

It is also found that the $Q_{\text{net}}$ possesses a clear decreasing trend. The decreasing trend in the $Q_{\text{net}}$ is caused by the decreasing trend in the latent heat flux, not the shortwave radiation (not shown). We also calculate the surface heat budget for NOC1, NOC2, and OAFlux during the period 1994–2005 (not shown). The shortwave and longwave radiation of the three datasets are almost similar to that in Table 4. However, the latent heat flux becomes much larger and the $Q_{\text{net}}$ decreases to 42, 33, and 45 W m$^{-2}$ for NOC1, NOC2, and OAFlux, respectively. This is consistent with the decreasing trend shown in Figure 4, and the $Q_{\text{net}}$ of NOC1 and OAFlux is still larger than that of NOC2. The decreasing trend is also closely related to the Pacific Decadal Oscillation index. Song et al. (2014) found that the upper layer heat content possesses an increasing trend during our study period. That may indicate that the increasing surface temperature will increase the temperature differences between the atmosphere and ocean, and ultimately increase the release of turbulent heat flux and decrease the $Q_{\text{net}}$. However, this may be not as simple as what we have explained, and so further analysis is required.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the National Key Basic Research Program of China [grant number 2013CB956204]; the National Natural Science Foundation of China [grant number 41576025], [grant number 41275084], [grant number 41075059]; and the Strategic Priority Research Program entitled ‘Western Pacific Ocean System: Structure, Dynamics and Consequences’ of the Chinese Academy of Sciences [grant number XDA11010304].
References

Behringer, D., and Y. Xue. 2004. “Evaluation of the Global Ocean Data Assimilation System at NCEP: The Pacific Ocean.” Preprints, Eighth Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land Surface, Seattle, Washington, American Meteorological Society, Vol. 2.

Berry, D. L., and E. C. Kent. 2009. “A New Air–Sea Interaction Gridded Dataset from ICOADS with Uncertainty Estimates.” Bulletin of the American Meteorological Society 90 (5): 645–656.

Carton, J. A., and B. S. Giese. 2008. “A Reanalysis of Ocean Climate Using Simple Ocean Data Assimilation (SODA).” Monthly Weather Review 136 (8): 2999–3017.

Chou, S. H., E. Nelkin, J. Ardizzone, R. M. Atlas, and C. L. Shie. 2003. “Surface Turbulent Heat and Momentum Fluxes over Global Oceans Based on the Goddard Satellite Retrievals, Version 2 (GSSSTF2).” Journal of Climate 16 (20): 3256–3273.

Da Silva, A., C. Young, and S. Levitus. 1994. “Algorithms and Procedure. Vol. 1, Atlas of Surface Marine Data 1994.” Washington: NOAA Atlas NESDIS 6: 83.

Fairall, C. W., E. F. Bradley, J. E. Hare, A. A. Grachev, and J. B. Edson. 2003. “Bulk Parameterization of Air–Sea Fluxes: Updates and Verification for the COARE Algorithm.” Journal of Climate 16 (4): 571–591.

Gibson, M. M., and R. D. Harper. 1997. “Calculation of Impinging-jet Heat Transfer with the Low-Reynolds-Number Q-ζ Turbulence Model.” International Journal of Heat and Fluid Flow 18 (1): 80–87.

Grist, J., and S. Josey. 2003. “Inverse Analysis Adjustment of the SOC Air–Sea Flux Climatology Using Ocean Heat Transport Constraints.” Journal of Climate 16 (20): 3274–3295.

Ji, M., A. Leetmaa, and J. Derber. 1995. “An Ocean Analysis System for Seasonal to Interannual Climate Studies.” Monthly Weather Review 123 (2): 460–481.

Josey, S., E. Kent, and P. Taylor. 1998. The Southampton Oceanography Center (SOC) Ocean-atmosphere Heat, Momentum and Freshwater Flux Atlas. Southampton: Southampton Oceanography Centre.

Josey, S., E. Kent, and P. Taylor. 1999. “New Insights into the Ocean Heat Budget Closure Problem from Analysis of the SOC Air–Sea Flux Climatology.” Journal of Climate 12 (9): 2856–2880.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, et al. 1996. “The NCEP/NCAR 40-Year Reanalysis Project.” Bulletin of the American Meteorological Society 77 (3): 437–471.

Kondo, J. 1975. “Air–Sea Bulk Transfer Coefficients in Diabatic Conditions.” Boundary-Layer Meteorology 9 (1): 91–112.

Kubota, M., N. Iwaseka, S. Kizu, M. Konda, and K. Kutsuwada. 2002. “Japanese Ocean Flux Data Sets with Use of Remote Sensing Observations (J-OFURO).” Journal of Oceanography 58 (1): 213–225.

Large, W. G., and S. G. Yeager. 2008. “The Global Climatology of an Interannually Varying Air–Sea Flux Data Set.” Climate Dynamics 33 (2–3): 341–364.

Oberhuber, J. M. 1988. An Atlas Based on COADS Data Set: The Budgets of Heat Buoyancy and Turbulent Kinetic Energy at the Surface of the Global Ocean. Hamburg: Max-Planck-Institut fur Meteorologie.

Qu, S., F. Hu, and Y. Li. 2000. “Some Characteristics of Air–Sea Exchange for the South China Sea Summer Monsoon in the Period of SCSMEX98.” Climatic and Environmental Research 5 (4): 434–446.

Qu, T., Y. Du, and H. Sasaki. 2006. “South China Sea Throughflow: A Heat and Freshwater Conveyor.” Geophysical Research Letters 33: L23617. doi:10.1029/2006GL028350.

Qu, T., Y. Song, and T. Yamagata. 2009. “An Introduction to the South China Sea Throughflow: Its Dynamics, Variability, and Application for Climate.” Dynamics of Atmospheres and Oceans 47 (1): 3–14.

Schulz, J., J. Meywerk, S. Ewald, and P. Schlüssel. 1997. “Evaluation of Satellite-derived Latent Heat Fluxes.” Journal of Climate 10 (11): 2782–2795.

Song, W., J. Lan, Q. Liu, D. Sui, L. Zeng, and D. Wang. 2014. “Decadal Variability of Heat Content in the South China Sea Inferred from Observation Data and an Ocean Data Assimilation Product.” Ocean Science 10 (1): 135–139.

Sun, Q., J. Chen, and J. Yan. 2010. “The Variation Characteristics of Air Sea Fluxes over Xisha Area before and after the Onset of the South China Sea Monsoon in 2008.” Acta Oceanologica Sinica 32 (4): 12–23.

Uppala, S. M., and P. W. Källberg, A. J. Simmons, U. Andrae, V. D. C. Bechtold, M. Fiorino, J. K. Gibson, et al. 2005. “The ERA-40 Re-analysis.” Quarterly Journal of the Royal Meteorological Society 131 (612): 2961–3012.

Yu, L., and R. A. Weller. 2007. “Objectively Analyzed Air–Sea Heat Fluxes for the Global Ice-free Oceans (1981–2005).” Bulletin of the American Meteorological Society 88 (4): 527–539.

Yu, L., X. Jin, and R. Weller. 2008. Mutidecade Global Flux Datasets from the Objectively Analyzed Air–Sea Fluxes (OAFlux) Project: Latent and Sensible Heat Fluxes, Ocean Evaporation, and Related Surface Meteorological Variables. Tech. Rep. OA-2008-01, Woods Hole: Woods Hole Oceanographic Institution, 64 pp.

Zeng, L., P. Shi, W. T. Liu, and D. Wang. 2009. “Evaluation of a Satellite-derived Latent Heat Flux Product in the South China Sea: A Comparison with Moored Buoy Data and Various Products.” Atmospheric Research 94 (1): 91–105.

Zhang, Y., W. B. Rossow, A. A. Lacis, V. Oinas, and M. I. Mishchenko. 2004. “Calculation of Radiative Fluxes from the Surface to Top of Atmosphere Based on ISCCP and Other Global Data Sets: Refinements of the Radiative Transfer Model and the Input Data.” Journal of Geophysical Research 109: D19105. doi:10.1029/2003JD004457.