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Assessment of various global freshwater flux products for the global ice-free oceans

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ABSTRACT

In this study, we compare sea surface freshwater flux products over the global ocean for the period of 1988–2005, taking into consideration the average field, global water budget, and interannual variability and trends. The analysis considers satellite-based products (Japanese Ocean Flux Datasets with Use of Remote Sensing Observations [J-OFURO2], Hamburg Ocean–atmosphere Parameters from Satellite Data 3 [HOAPS3], Remote Sensing Systems [RSS], Global Precipitation Climatology Project [GPCP2], and Climate Prediction Center Merged Analysis of Precipitation [CMAP]); reanalysis (Japanese 25-year reanalysis [JRA25], National Centers for Environmental Prediction [NCEP]/National Center for Atmospheric Research reanalysis [NRA1], NCEP/Department of Energy reanalysis [NRA2], Climate Forecast System Reanalysis [CFSR]); and a hybrid product (Objectively Analyzed Air–Sea fluxes [OAFlux]). Recommendations are made for the developers of future freshwater flux products; these recommendations also aim to guide users to select products most suitable for their applications.

For the global average field, evaporation and precipitation products of reanalysis are larger than satellite products in the tropical and subtropical regions. The large evaporation data values obtained by reanalysis are attributed to the low air specific humidity values and the differences between the bulk algorithms for the tropical and subtropical regions. Moreover, for the global water budget and the inter-annual variability and trends, the reanalysis precipitation product is largely dependent on its evaporation product. If we use reanalysis precipitation and satellite evaporation data, we obtain a negative value for the global ocean water budget. This study demonstrates the difficulty of using different evaporation and precipitation products to analyze the global hydrologic cycle.

1. Introduction

The components of the global hydrologic cycle include air–sea and air–land exchanges, movement of water vapor in the atmosphere, and river runoff. This cycle has been closely related to extreme weather events, such as torrential rain, flood, and drought, during recent years. In particular, the air–sea water exchanges occur at much larger scales than the other components of the global hydrologic cycle (Oki & Kanae, 2006). For example, Mehta, DeCandis, and Mehta (2005) investigated the average annual water cycle. They found that 75–85% of the total global evaporation and approximately 70% of the total global precipitation occur over the ocean in each season. Therefore, accurate evaluation of the air–sea water budget is critical for understanding the global hydrologic cycle. Water transport between the ocean and the atmosphere involves evaporation and precipitation at the sea surface, and the budget of these data is called the freshwater flux.

Freshwater flux can be calculated using the following relation:

$$\mathrm{FWF} = \mathrm{E} - \mathrm{P}, \tag{1}$$

where FWF represents freshwater flux (mm/day); E, evaporation; and P, precipitation. Moreover, evaporation can be determined using the following relation:

$$\mathrm{E} = \mathrm{LHF}/L_v, \tag{2}$$

where L_v is the latent heat of vaporization (J/kg) and LHF is the latent heat flux (W/m^2). We can easily estimate latent heat flux by using the following bulk method:

$$\mathrm{LHF} = \rho_a L_v C_e U (Q_s - Q_a), \tag{3}$$

where ρ_a is the density of air (kg/m^3); C_e, the bulk exchange coefficient for moisture; and U, the wind speed at a height of 10 m above the ocean surface relative to the ocean surface current speed (m/s). Q_s and Q_a are the saturated and near-surface air specific humidity (g/kg), respectively. Q_s is a function of sea surface temperature (SST).

At present, several global datasets for evaporation or latent heat flux and for precipitation have been compiled on the basis of satellite observations, reanalysis data, and in situ data (e.g., Adler et al., 2003; Kubota & Tomita, 2007). Therefore, we can evaluate the global freshwater flux using these datasets. However, the values of evaporation or

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precipitation differ depending on the products because the estimation methods and satellite sensors vary for each product (e.g., Kubota, Kano, Muramatsu, & Tomita, 2003; Quartly, Kyte, Srokosz, & Tsimplis, 2007). A number of papers focus on individual parameters such as latent heat flux or precipitation (e.g., Beranger, Barnier, Gulev, & Crepon, 2006; Quartly et al., 2007; Smith, Hughes, & Bourassa, 2011). Smith et al. (2011) compared nine global latent heat flux products. Moreover, Bourras (2006) investigated the reason for differences between buoy- and satellite-derived latent heat fluxes. These papers demonstrate that differences or errors in the latent heat flux were largely dependent on those of air specific humidity. Yin, Gruber, and Arkin (2004) compared two satellite-based precipitation products (Global Precipitation Climatology Project [GPCP2] and Climate Prediction Center [CPC] Merged Analysis of Precipitation [CMAP]). Moreover, Quartly et al. (2007) carried out an inter-comparison using GPCP2 and three reanalysis precipitation products (National Center for Environmental Prediction [NCEP1/2] and European Centre for Medium-Range Weather Forecasts [ECMWF]). These papers show that the precipitation data differ greatly in regions with high precipitation, such as the Inter Tropical Convergence Zone (ITCZ) and the South Pacific Convergence Zone (SPCZ).

Few comparison studies focus on global freshwater flux itself. Andersson et al. (2011) assessed the quality of four surface freshwater flux products. Additionally, the humidity and wind speed input parameters for determining evaporation are examined to identify the reasons behind the differences between the products. Schlosser and Houser (2007) also assessed the global water cycle's mean value and variability using various satellite-based datasets. They indicated that the globally averaged annual precipitation and evaporation estimates are out of balance by 5%, which exceeds the uncertainty in global mean annual precipitation. They also pointed out that the variation in global precipitation and evaporation shows monthly and interannual consistency, and mainly depends on the ocean evaporation data. Moreover, they evaluated the freshwater flux trend from 1988 to1999 and suggest that global ocean evaporation increases by ~1%/year. They also showed that ocean evaporation trends are driven by trends in the specific humidity of air and wind speed, and the largest year-on-year changes are coincident with transitions in the Defense Meteorological Satellite Program (DMSP)/Special Sensor Microwave/Imager (SSMI) fleet.

Both Mehta et al. (2005) and Schlosser and Houser (2007) did not use reanalysis products in their studies. Meanwhile, Andersson et al. (2011) only used four surface freshwater flux products in their studies. With the development of new algorithms for estimating meteorological parameters from satellite observations by using multi-satellite data, the accuracy of recent satellite-based data has improved. Because many kinds of global freshwater flux data products are now available for various studies, it is important to clarify the characteristics of each freshwater flux dataset and parameters related to freshwater flux as well as the differences between the datasets. In this study, we perform an inter-comparison of a number of global ocean surface freshwater flux products using satellite-based as well as reanalysis products. We compare sea surface freshwater flux products for the global ocean from the following points of view: average fields, global water budget, and global inter-annual variability and trends. Moreover, we investigate the relative significance of each meteorological parameter with respect to the differences in freshwater flux products and trends. A number of comparison papers focus only on the difference between a particular meteorological parameter from different datasets in order to investigate the cause for the differences between the evaporation products (e.g., Andersson et al., 2011; Smith et al., 2011). However, their analyses could not quantify the differences in the evaporation products due to each meteorological parameter. Therefore, we investigated the variability of evaporation as a function of each meteorological parameter. The purpose of this paper is to clarify the characteristics for a number of freshwater flux products and related meteorological parameters.

In the next section, we briefly describe the used data. Results for the global average fields and global water budget are presented in Sections 3 and 4, respectively. In Section 5, the inter-annual variability and trends are discussed, and finally, the summary and conclusions are presented in Sections 6 and 7, respectively.

2. Data

We used 10 different monthly global datasets covering the period 1988–2005. Basic descriptions of the global data products are presented in Table 1. Japanese Ocean Flux Data Sets with Use of Remote Sensing Observation 2 (J-OFURO2), Hamburg Ocean–atmosphere Parameters from Satellite Data 3 (HOAPS3), Remote Sensing Systems (RSS), GPCP2, and CMAP are based on satellite data. Japanese Re-analysis 25 (JRA25), NRA1, NRA2, and Climate Forecast System Reanalysis (CFSR) are reanalysis data. Objective Analyzed Air–Sea Fluxes (OAFlux) is obtained from a combination of satellite-based, reanalysis, and in situ data. Some of these abovementioned data products provide latent heat flux data rather than evaporation data. Therefore, all evaporation data except those from the HOAPS3 and RSS products were estimated using the latent heat flux data and merged satellite and in situ Global Daily Sea Surface Temperature (MGDSST) (Kurihara, Sakurai, & Kuragano, 2006). To unify the spatial resolution of all datasets, we converted GPCP2, CMAP, and reanalysis data (except CFSR) from a 2.5° original grid size to a 1° grid by a linear interpolation method. HOAPS3, RSS, and CFSR, which have spatial resolutions of less than 1°, were simply averaged to a 1° grid.

2.1. J-OFURO2

J-OFURO2 is provided by Tokai University, Japan (Kubota & Tomita, 2007). To reduce the sampling error of the daily mean value, wind speed is constructed from a combination of various microwave radiometers, i.e., DMSP/SSMI F08, F10, F11, F13, F14, F15, Aqua/Advanced Microwave Scanning Radiometer for NASA's Earth Observing System (Aqua/AMSR-E), Tropical Rainfall Measurement Mission (TRMM)/TRMM Microwave Imager (TMI), and microwave scatterometers (ERS/AMI and QuikSCAT/SeaWinds). For SST, J-OFURO2 uses the new merged multi-satellite and in situ product MGDSST (Kurihara et al., 2006) provided by the Japan Meteorological Agency (JMA). MGDSST is constructed by merging the in situ and satellite data from AMSR-E and the advanced very-high-resolution radiometer (AVHRR), which has multiple infrared (IR) channels and has been operational onboard the National Oceanic and Atmospheric Administration (NOAA) satellites. For air specific humidity, J-OFURO2 uses the retrieving algorithm of Schlüssel, Schanz, and Englisch (1995) from DMSP/SSMI brightness temperatures. Finally, a bulk algorithm of version 3.0 of the Coupled Ocean–atmosphere Response Experiment (COARE 3.0; Fairall, Bradley, Hare, Grachev, & Edson, 2003) is used to estimate the latent heat flux.

Recently, Tomita et al. (2010) evaluated five satellite-based latent heat flux products using the in situ latent heat flux derived from the Kuroshio Extension Observatory (KEO) buoy. As a result, they found that the J-OFURO2 latent heat flux provided the best statistics.

2.2. HOAPS3

HOAPS3 comprises three types of datasets, HOAPS-G, HOAPS-C, and HOAPS-S (Andersson et al., 2010). HOAPS-G comprises 0.5° monthly mean data and is used in this study. The HOAPS-C dataset comprises 1° and twice-daily globally gridded products. HOAPS-S comprises all retrieved physical parameters in the original SSMI scan resolution for every individual satellite.

The wind speed algorithm uses a neural network to derive wind speed at a height of 10 m above the sea surface from SSMI brightness temperatures. SSTs are determined using data from Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS) Oceans Pathfinder Version 5.0 SST (Casey, 2004; Kilpatrick, Podestá, & Evans, 2001). The air