J-OFURO3
Official Document

J-OFURO3
Data Set Detailed Document

Hiroyuki Tomita (ISEE, Nagoya University)

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Document author: Hiroyuki Tomita（cooperated with J-OFURO member）
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1. Introduction

Japanese Ocean Flux Data Sets with Use of Remote Sensing Observations (J-OFURO) is a research project investigating the flux between the ocean and atmosphere in the Earth system. J-OFURO uses observation data from multi satellites to develop and provide data sets on surface heat, momentum, and freshwater fluxes over the global ocean, with the exception of sea ice areas.

The first-generation data set was released in 2000, and a second-generation data set, J-OFURO2, expanded to global oceans, was released in 2008 with substantial improvements. A third-generation J-OFURO3 has recently been developed with even more improvements, which began providing a surface flux data set in 2016.

This document provides basic information to users for their research, along with more detailed information on the development of the data set.

Chapter 2 briefly summarizes the data set, including the list of variables provided, the spatial and temporal resolutions, the time period of available data, data sources, file names, download details, and citation methods. Referencing these information may be sufficient for end users who want to use the data as soon as possible. Chapter 3 elaborates further on data set construction. It provides details on how the J-OFURO3 data set was constructed from source data observed by satellites and the changes that have taken place between J-OFURO2 and J-OFURO3.

Chapter 4 provides figures for the climatological monthly mean of surface flux depicted by J-OFURO3 data set . Lists of figures, tables, and acronyms used in this document are provided in the end of the document.

2. Overview of the J-OFURO3 Data Set

J-OFURO3 is a satellite-based data set of surface flux between the atmosphere and the ocean, as well as physical parameters related to the flux. This is the third generation data set for J-OFURO, which contains many improvements from previous versions. J-OFURO3 is characterized by the use of multi-satellite data for the estimation of various parameters, providing a data set on the surface flux in almost all oceans except for sea ice areas. It also includes relevant physical parameters, including sea surface temperature, surface wind speed, and surface air specific humidity, as daily mean values in 0.25° grids.

Table 1.1 summarizes a comparison of major features of the current data set against previous data sets. Further information is detailed in later sections. Latest news on the project and data set, and information on how to obtain the data, are available on the J-OFURO website (https://j-ofuro.scc.u-tokai.ac.jp).

Table 1.1: Features across all versions of the J-OFURO data set

	J-OFURO1	J-OFURO2	J-OFURO3
Time period	1992–1993	1988–2008	1988–2013 (1996–2013 for now)
Temporal average	monthly mean	daily mean	daily mean
Spatial grid size	1.0 degree	1.0 degree *1	0.25 degree
SST	Reynolds SST	MGDSST	Ensemble median product
QA	Schlüssel et al. 1995 single SSMI	Schlüssel et al. 1995 multiple SSMIs	New algorithm SSMIs, SSMISs, AMSR-E, TMI, AMSR2
WND	SSMI	SSMIs, AMSR-E, TMI ERS1/2, QuikSCAT,	SSMIs, SSMISs, AMSR-E, TMI, WindSat, AMSR2, ERS1/2, QuikSCAT, ASCAT-A/B, OSCAT
WND Vector	ERS1/2	ERS-1/2, QuikSCAT	same as WND
LHF, SHF	available	available	available
NHF	available, but limited area	available	available
FWF	not available	not available	available
Reference paper	Kubota et al. 2002	Tomita et al. 2010	Tomita et al. (in preparation)

*1: High-resolution version provides 0.25 degree grid data for 2002-2008

Variables

Table 2 summarizes the variables treated in J-OFURO3. Data for the major variables are accessible by the public, but some are not publicly available for now. Variable names listed here are also used as the names of publicly available files, discussed later, and as variable names defined in netCDF. Table 2 also shows the data source and method of estimation for each variable. See chapter 3 for further details.

Table 1.2: List of variables in J-OFURO3

Variable name	Description	Unit	Data source and estimation method	Public status
LHF	latent heat flux	W/m^2	COARE 3.0	o
SHF	sensible heat flux	W/m^2	COARE 3.0	o
SWR	net short wave radiation flux	W/m^2	CERES and ISCCP with CSF	o
LWR	net long wave radiation flux	W/m^2	ULWR + DLWR	o
NHF	net heat flux	W/m^2	SWR + LWR + LHF + SHF	o
ULWR	upward long wave flux	W/m^2	calculated from SST	–
DLWR	downward long wave flux	W/m^2	CERES and ISCCP with CSF	–
TAUX	zonal component of momentum flux	N/m^2	COARE 3.0	o
TAUY	meridional component of momentum flux	N/m^2	COARE 3.0	o
FWF	freshwater Flux	mm/day	EVAP – RAIN	–
EVAP	evaporation	mm/day	calculated from SST and LHF	–
RAIN	precipitation	mm/day	GSMaP (+ GPCP)	–
SST	sea surface temperature	deg. C	ensemble median based on multiple global sea surface temperature products (see Tables 3.1 and 3.2)	o
WND	surface scalar wind speed (at 10m height)	m/s	multiple microwave radiometers and scatterometers (see Tables 3.3 and 3.4)	o
UWND	zonal component of surface wind vectors (at 10m height)	m/s	multiple microwave radiometers and scatterometers (see Tables 3.3 and 3.4)	o
VWND	meridional component of surface wind vectors (at 10m height)	m/s	multiple microwave radiometers and scatterometers (see Tables 3.3 and 3.4)	o
QA	surface air specific humidity (at 10m height)	g/kg	New algorithm, multiple satellite microwave radiometers (see Tables 3.5 and 3.6)	o
QS	saturated surface specific humidity	g/kg	calculated from SST	o
DQ	humidity difference	g/kg	QS minus QA	o
TA10	air temperature (at 10m height)	deg. C	air temperature at 2m height, TA2M in NCEP/DOE Reanalysis (NCEP2)	o
DT	temperature difference	deg. C	SST minus TA10	o

Data set resolution and availability

J-OFURO3 provides a numerical data set for the variables listed in Table 2 over the global oceans except sea ice areas. The data set is provided in 0.25° grids, with three temporal resolutions: daily mean, monthly mean, and climatological monthly mean* values.

Development of the J-OFURO3 data set is planned for the years between 1988 (when observations by microwave radiometers began) and 2013. Of this period, data from 1996 to 2013 have been developed already and released in advance. Data for the remaining periods will be provided as soon as the data processing and flux calculations are completed, and data over the entire time period is planned to be made available in the JFY2017.

*Currently, climatological monthly mean values are calculated using data from 2002 to 2013 and are publicly available only for surface heat flux components.

Data site, file names, format, and versions

All publicly available data can be downloaded from the official J-OFURO website (https://j-ofuro.scc.u-tokai.ac.jp).

Data files provided by J-OFURO3 are grouped by variable name *(VAR),* temporal resolution *(TR)*, spatial resolution code *(SR),* data set version code *(VER),* and year *(YYYY).* Data files are named under the following rules.

File name rule

J-OFURO3_*VAR*_*VER*_*TR*_*SR*_*YYYY*.nc

VAR: variable name

VER: version code

TR: temporal resolution code (DAILY / MONTHLY / CLM)

SR: spatial resolution code (LR: low resolution/ HR: high resolution)

YYYY: four-digit year (e.g. 2013), *none if *TR* is CLM

The data file format is a self-descriptive netCDF. The file extension is '.nc'.

The data set may be updated at irregular intervals for reasons such as bug fixes. Every file released will have a version code *(VER)* attached, describing the version of the data provided. The data download site will always have the latest version of the data available, and older versions will not be available unless there is a specific reason. The latest data set at the time of writing is V1.0.

Data set citation

If you are using the J-OFURO3 data set for your research and presenting its results, we would like for you to cite the use of J-OFURO3 data set with URL (https://j-ofuro.scc.u-tokai.ac.jp) and a sentence similar to the example below. In case the findings are published in a peer-reviewed journal, we ask that you write to the following email address and notify us of the news. Publication details we receive will be listed on the J-OFURO website.

This work uses the J-OFURO3 data set for analysis of xxx.

Contact email address for publications:

JOFURO3@google.com

Inquiries and contact information

If you are using or considering using the J-OFURO3 data set, contact us at the following email address for any questions regarding the data. Please let us know if you find any problems or issues over the use of the data set, or have comments you would like to share with us. Information and opinions we receive will be utilized for future versions of the data set.

Contact email address:

JOFURO3@google.com

3. Details of the J-OFURO3 Data Set

This chapter provides the details pertaining to the J-OFURO3 data set. Calculation methods of surface fluxes, estimation methods of variables, and data sources are described.

Data flow overview

Figure 3.1 shows the overall data flow for the construction of the J-OFURO3 data set. In summary, J-OFURO3 obtains satellite data required for calculation of the surface turbulent heat flux, including sea surface temperature (SST), surface wind speed (WND), surface wind vector (U/VWND), and surface air specific humidity (QA). It then processes each variable and calculates daily mean values in the form of 0.25° gridded data. The gridded data for these variables are then used to calculate surface turbulent heat fluxes (LHF, SHF) and surface momentum fluxes (TAU, TAUX/Y). Atmospheric reanalysis data is used for parameters that are difficult for satellites to observe, and as the initial values in estimation algorithms for some of the variables.

For the calculation of surface net heat flux (NHF), J-OFURO uses the surface turbulent heat flux data, calculated in advance, and the satellite radiation flux product processed by external projects such as ISCCP and CERES. Of the surface turbulent heat flux, latent heat flux (LHF) is used to estimate evaporation (EVAP), which is combined with the precipitation (RAIN) product from satellite data to calculate the freshwater flux (FWF).

After processing the daily mean values, monthly mean values are calculated from the daily mean, and monthly data sets are constructed. Climatological monthly mean data[*1] are calculated from the monthly mean data. See the following sections for further details on data processing and calculation methods.

[*1] Currently, climatological monthly mean values are calculated using data from 2002 to 2013 and are publicly available only for surface heat flux components.

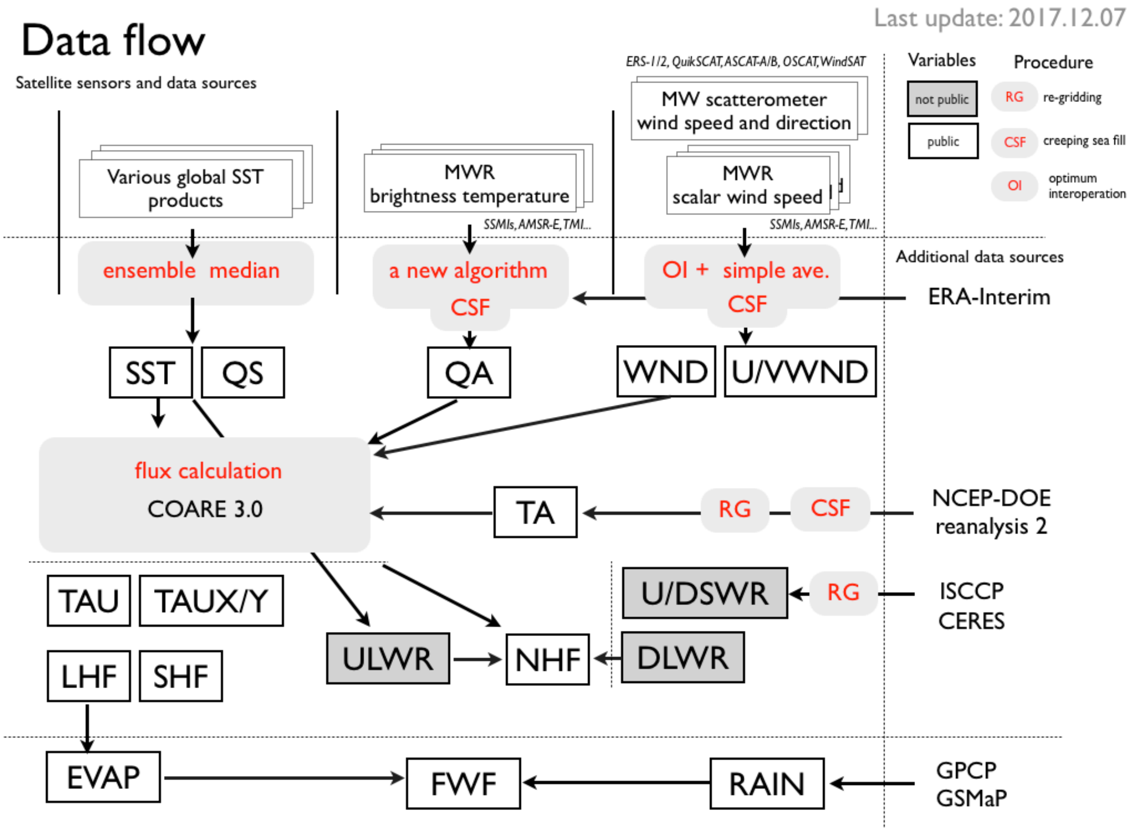

Figure 3.1. J-OFURO3 data flow.

Calculating surface turbulent heat flux

There are no changes to the calculation method of surface turbulent heat flux (LHF, SHF) from J-OFURO2 to J-OFURO3, and both use the bulk flux algorithm of COARE3.0 (Fairall et al., 2003). All input data use the daily mean value. Calculations are configured to skip corrections on the estimation of skin temperature provided by COARE3.0.

For calculations of surface turbulent momentum fluxes (TAU, TAUX/Y), a different method to that of heat flux was used for J-OFURO1 and 2. However, J-OFURO3 uses COARE3.0 to calculate surface turbulent momentum fluxes as well as turbulent heat fluxes.

Sea surface temperature: SST (°C)

Sea surface temperature (SST) is the most basic oceanic parameter, and has been observed in long-term period. It is essential for estimating surface heat flux, and is a fundamental variable determining surface turbulent heat fluxes (LHF, SHF). It is also used to estimate the upward long wave radiation flux (ULWR) from the surface. Today, various SST products based on satellite observations are available.

J-OFURO3 collects global SST products of various types offered by a wide range of institutions, and provides an ensemble median SST (EMSST) of the SST products along with related information (see Figure 3.2). Surface fluxes of J-OFURO3 are calculated based on the ensemble median SST. Table 3.1 shows the global SST products (source products) used for ensemble median SST calculations in J-OFURO3.

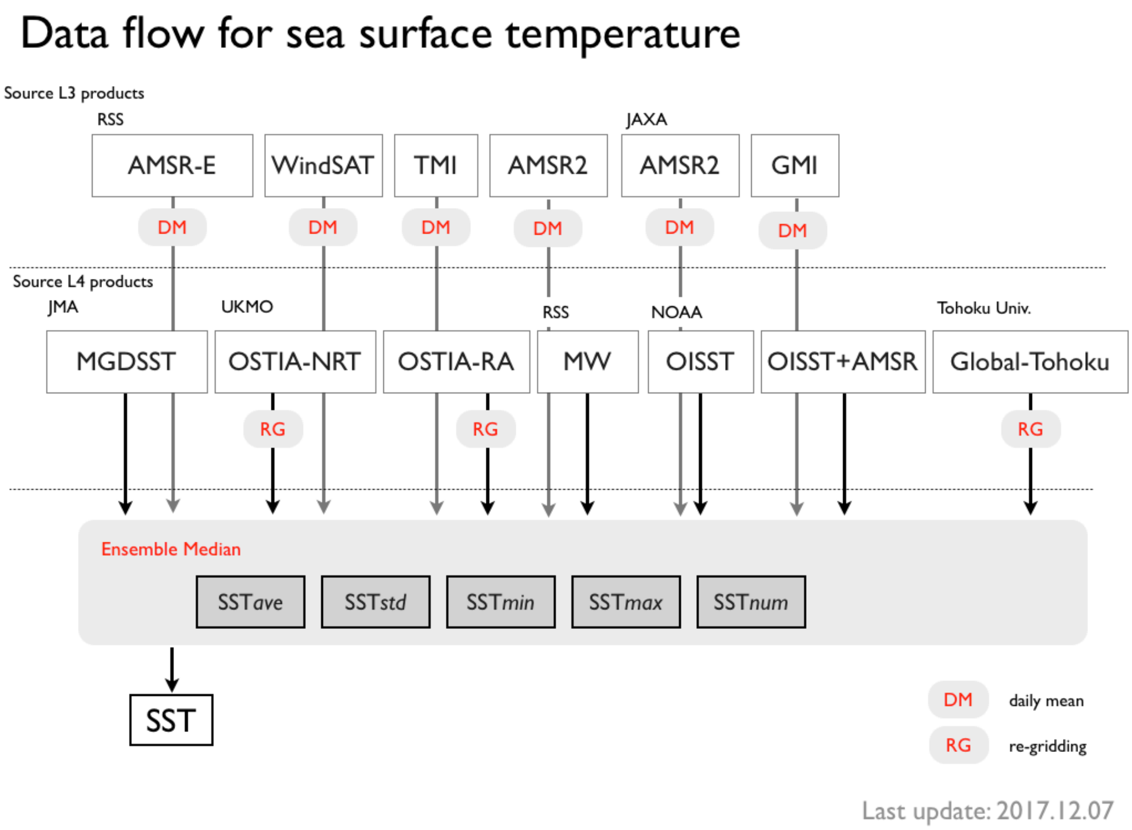

Fig. 3.2: J-OFURO3 sea surface temperature data flow

Table 3.1: List of source products for ensemble median SST in J-OFURO3

ID	Product name	Provider	Original spatial grid size (deg.)	Level	SST type	Data period	Version	Used in V1.0
1	MGDSST	JMA (NEAR-GOOS)	0.25	L4	depth	-2015	-	o
2	OSTIA-NRT	UKMO	0.05	L4	foundation	2006.04.01-current	V1	o
3	AMSR-E	RSS	0.25	L3	sub-skin	-2011.10.04	V7	o
4	MW	RSS	0.25	L4	foundation	2002-current	V4	o
5	OISST	NOAA	0.25	L4	depth	-current	-	o
6	OISST + AMSR	NOAA	0.25	L4	depth	—2011.10.04	-	o
7	WindSAT	RSS	0.25	L3	sub-skin	2002-current	V7.0.1	o
8	TMI	RSS	0.25	L3	sub-skin	1997-2014	V7.1	o
9	Global_Tohoku_SST	TOHOKU UNIV.	0.1	L4	foundation	2003-2014	V7.0.3	o
10	AMSR2	JAXA	0.25	L3	sub-skin	2012.07-current	V2.1	o
11	AMSR2	RSS	0.25	L3	sub-skin	2012.07-current	V7.2	o
12	GMI	JAXA	0.25	L3	sub-skin	2014-current	V1.0	-
13	OSTIA-RA	UKMO	0.05	L4	foundation	-2007	-	o

The current J-OFURO3 ensemble median SST product (V1.0) uses data from 12 kinds of source product. While there are various source products, they are gridded satellite-base data that was constructed from data observed by satellites sensors with thermal infrared radiometers and microwave radiometers. Products are categorized into gridded products with data from a single satellite (L3), and products generated by merging data from several satellites and other observation data (L4). Most products have 0.25° spatial grid system, but OSTIA and the SST product by Tohoku University provide data have finer grid system with 0.05° and 0.1°, respectively. Upon calculating the ensemble median for J-OFURO3, these high-resolution products were first averaged into 0.25° grids and then used with other source products. L3 products provide daily data separated into ascending and descending satellite paths, thus they were averaged into a daily mean value and then used to calculate the EM.

SST types of source products (see in Table 3.1) require some explanation. SSTs are categorized into several specific types depending on the depth of observation. This is due to systematic differences in SST values depending on observation depths when there is a strong water temperature stratification near the surface layer. The source product for J-OFURO3 ensemble median SST is categorized into foundation, sub-skin, and depth. 'Foundation' targets the deepest depth, which is unaffected by the strong stratification. 'Sub-skin' SST is involves a the very shallow depth measurable by microwave radiometers, which ranges from 1 mm to a few µm, and is heavily influenced by the strong water temperature stratification. 'Depth' is the water temperature at several meters depth and in between foundation and sub-skin depths, typically observed by in-situ moored buoys, and which is affected by stratification.

Data for sea ice areas should also be noted. SST values in sea ice areas vary by source product. In L3 products based on microwave radiometers, values for sea ice areas are treated as missing. Of the L4 products, MGDSST, OSTIA-NRT, OISST, and OISST+AMSR take sea ice concentration into account, and provide sea surface temperature values even for grids where sea ice exists. However, in cases where the sea ice concentration is 1 (i.e. the entire grid space is covered by sea ice), the grid is assumed to be at -1.8 °C. Of these L4 products, OISST, OISST+AMSR, and OSTIA-NRT also provide sea ice concentration data. The L4 product MW, provided by RSS, and the product by Tohoku University treat values in sea ice areas as missing.

Table 3.2 shows the source products used in J-OFURO3 for each year between 1988 and 2013, which includes periods planned for data construction. The ensemble median SST is calculated using only the three kinds of data from L4 products for the period during which microwave radiometers were not commonly available (1988-1996). Observations by TRMM/TMI began later; therefore, 4-5 products are used for the years among 1997-2001, and 8-10 products are used from 2002 onwards.

Table 3.2: Availability of source products for J-OFURO3 ensemble median SST

L4 product (blue) / L3 product (green)

ID	Product name	Type	Provider	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	ID
1	MGDSST	Multi-L4	JMA	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	1 MGDSST
2	OSTIA-NRT	Multi-L4	UKMO																			o	o	o	o	o	o	o	o	2 OSTIA-NRT
3	AMSR-E	MW	RSS															–	o	o	o	o	o	o	o	o	–			3 AMSR-E
4	MW	L4	RSS											o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	4 MW
5	OI SST (AVHRR)	Multi-L4	NOAA	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	5 OI SST (AVHRR)
6	OI SST (AVHRR, AMSR-E)	Multi-L4	NOAA															–	o	o	o	o	o	o	o	o	–			6 OI SST (AVHRR, AMSR-E)
7	WSAT	MW	RSS																–	o	o	o	o	o	o	o	o	o	o	7 WSAT
8	TMI	MW	RSS										–	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	8 TMI
9	Global Tohoku Univ. SST	L4	TOHOKU UNIV.																o	o	o	o	o	o	o	o	o	o	o	9 Global Tohoku Univ. SST
10	AMSR2	L3	JAXA																									–	o	10 AMSR2
11	AMSR2	L3	RSS																									–	o	11 AMSR2
12	GMI	L3	JAXA																											12 GMI
13	OSTIA-RA	Multi-L4	UKMO	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o							13 OSTIA-RA
	Number of Member			3	3	3	3	3	3	3	3	3	4	5	5	5	5	7	9	9	9	10	10	9	9	9	9	9	9	

Calculations for surface flux in J-OFURO2 used a single SST product, MGDSST, which was developed by the Japan Meteorological Agency using an integrated analysis of data from AVHRR and AMSR-E by OI. This is because it showed a better agreement with in situ buoy data, but MGDSST data was also flawed in that it did not capture high- frequency SST variations well due to influences of smoothing (Iwasaki et al. 2008). J-OFURO3 EMSST, however, can more appropriately capture high-frequency variations in SST.

Surface wind speed: WND, U/VWND [m/s]

Surface wind speed variables in J-OFURO3 include scalar wind speed (WND) and its zonal and meridional components (U/VWND). These data are constructed using satellite microwave radiometer and scatterometer data, providing data as daily mean values in grids of latitudinal and longitudinal 0.25° intervals at 10 m above sea level. Surface wind speed data in J-OFURO3 are used to calculate surface turbulent heat fluxes (LHF and SHF) and surface momentum fluxes (TAU, TAUX, and TAUY), and to estimate evaporation (EVAP).

Tables 3.3 and 3.4 show the microwave radiometers and microwave scatterometers used to construct surface wind speed and their data availability, respectively. In total, 18 satellite sensor data are used. Due to differences in satellite observation periods, the number of satellites used vary from year to year. Relatively few satellites (1-4) were used between 1988 and 1998, but 6-9 satellite sensors were used from 1999 onwards.

Table 3.3: List of satellites sensors of microwave radiometers (MWR) and microwave scatterometers (SCAT) used to construct the surface wind speed data sets in J-OFURO3

Sensor	Type	Provider	Level	Data period	Version
SSMI F08	MWR	RSS	L3	1988.01–1991.12	V7
SSMI F10	MWR	RSS	L3	1990.12–1997.11	V7
SSMI F11	MWR	RSS	L3	1991.12–2000.05	V7
SSMI F13	MWR	RSS	L3	1995.05–2009.11	V7
SSMI F14	MWR	RSS	L3	1997.05–2008.08	V7
SSMI F15	MWR	RSS	L3	1999.12–2006.08	V7
SSMIS F16	MWR	RSS	L3	2003.10–2013.12	V7
SSMIS F17	MWR	RSS	L3	2006.12–2013.12	V7
TMI	MWR	RSS	L3	1997.12–2013.12	V7.1
WindSAT	MWR	RSS	L3	2003.02–2013.12	V7.0.1
AMSR-E	MWR	RSS	L3	2002.06–2011.10	V7
AMSR2	MWR	RSS	L3	2012.07–2013.12	V7.2
ERS-1/AMI	SCAT	CERSAT/IFREMER	L2B	1991.08–1996.06	–
ERS-2/AMI	SCAT	CERSAT/IFREMER	L2B	1996.03–2001.01	–
QuikSCAT	SCAT	PO.DAAC NASA/JPL	L2B	1999.10–2009.11	V3
ASCAT-A	SCAT	PO.DAAC NASA/JPL	L2	2007.03–2013.12	Operational/NRT
ASCAT-B	SCAT	PO.DAAC NASA/JPL	L2	2012.10–2013.12	Operational/NRT
OSCAT	SCAT	PO.DAAC NASA/JPL	L2B	2010.01–2013.12	V2

Table 3.4: Data availability of microwave radiometers and microwave scatterometers used for the surface wind speed data set in J-OFURO3

Satellite sensor	Provider	Version	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	
SSMI F08	RSS	V7	o	o	o	–																							SSMI F08
SSMI F10	RSS	V7			–	o	o	o	o	o	o	–																	SSMI F10
SSMI F13	RSS	V7								–	o	o	o	o	o	o	o	o	o	o	o	o	o	–					SSMI F13
SSMI F14	RSS	V7										–	o	o	o	o	o	o	o	o	o	o	–						SSMI F14
SSMI F15	RSS	V7												–	o	o	o	o	o	o	o								SSMI F15
SSMIS F16	RSS	V7																–	o	o	o	o	o	o	o	o	o	o	SSMIS F16
SSMIS F17	RSS	V7																			–	o	o	o	o	o	o	o	SSMIS F17
TMI	RSS	V7.1										–	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	TMI
WindSAT	RSS	V7.0.1																–	o	o	o	o	o	o	o	o	o	o	WindSAT
AMSR-E	RSS	V7															–	o	o	o	o	o	o	o	o	–			AMSR-E
AMSR2	RSS	V7.2																									–	o	AMSR2
ERS-1/AMI	CERSAT	–				–	o	o	o	o	–																		ERS-1/AMI
ERS-2/AMI	CERSAT	–									–	o	o	o	o	–													ERS-2/AMI
QuikSCAT	PODAAC	V3												–	o	o	o	o	o	o	o	o	o	–					QuikSCAT
ASCAT-A	PODAAC	NRT																				–	o	o	o	o	o	o	ASCAT-A
ASCAT-B	PODAAC	NRT																									–	o	ASCAT-B
OSCAT	PODAAC	V2																							–	o	o	o	OSCAT
	Number of satellite		1	1	1	2	2	2	2	2	4	4	4	6	6	6	6	8	8	8	9	9	9	7	7	7	8	8	

Figure 3.3 shows the process for the construction of the surface wind speed data set. The major source of satellite data is the L3 data (gridded data) from microwave radiometers, provided by RSS. For the microwave scatterometer observation, J-OFURO3 also acquires L2 (instantaneous) data from PO.DAAC and converts them to gridded data in our data process.

Scalar wind speed is determined by averaging the gridded values (WND_{Sat}) obtained from all satellites to calculate the multi-satellite scalar surface wind speed (WND_{Multi}). Missing grids in coastal areas are then extrapolated using the creep sea fill (CSF) method (Kara et al. 2007) to obtain the final scalar surface wind speed (WND).

Surface wind speed vectors (U/VWND) are processed by the following steps. First, gridded data for the zonal component ($UWND_{Sat}$) and the meridional component ($VWND_{Sat}$) of the surface wind speed are calculated from satellites capable of observing the wind direction (i.e. equipped with microwave scatterometers and WindSAT). These components are then averaged to obtain $U/VWND_{Multi}$ based on several micro-scatterometers and WindSAT. Few satellites observe $U/VWND_{Multi}$ and its values are often missing compared to those of WND. These missing values are interpolated by two-dimensional optimum interpolation (OI). The process is followed by a calculation of daily mean wind direction (DIR), and its results are combined with the aforementioned scalar wind speed (WND) to obtain gridded data for the final surface wind vectors (U/VWND).

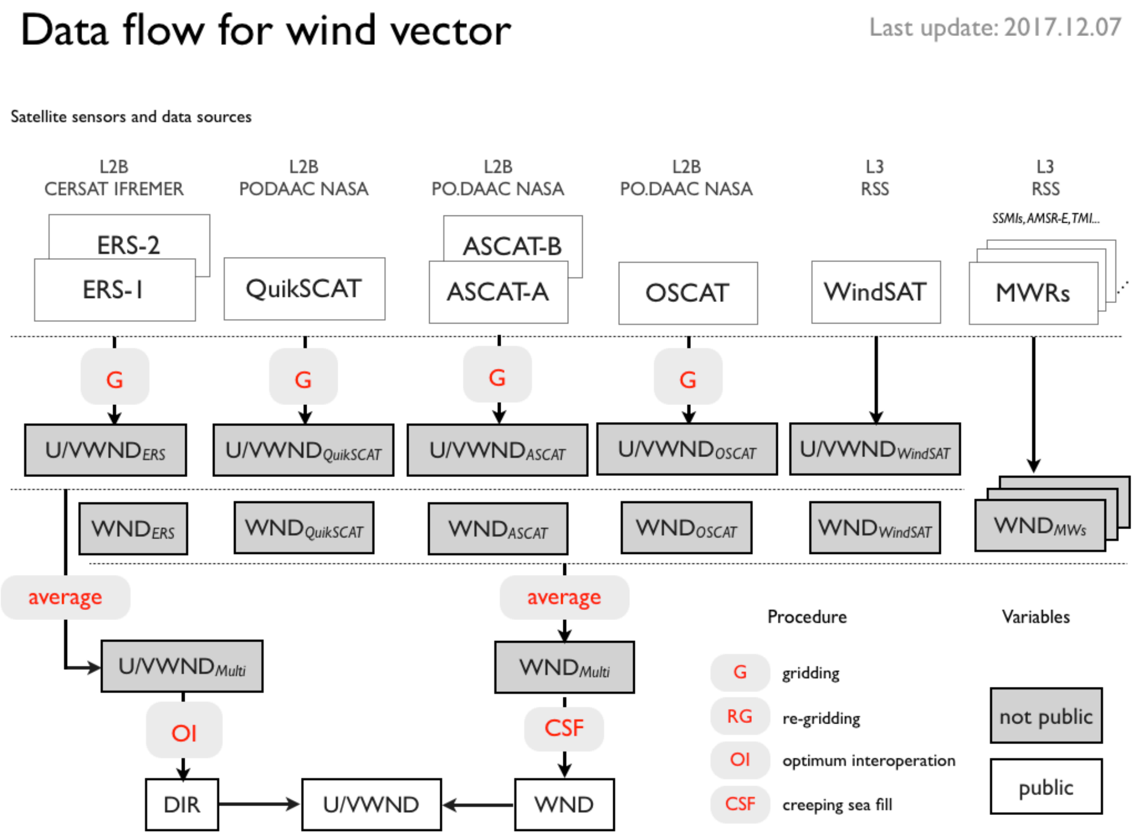

Fig. 3.3 J-OFURO3 surface wind speed data flow

Surface air specific humidity: QA (g/kg)

J-OFURO3 provides surface air specific humidity (QA) data as daily mean values at 0.25° spatial grid intervals based on estimates at 10 m above sea level from multi-satellite microwave radiometer data. Surface air specific humidity data in J-OFURO3 is largely related to the calculation of turbulent latent heat flux (LHF) and evaporation (EVAP).

J-OFURO3 uses a new algorithm that estimates surface air specific humidity from observations on brightness temperature by microwave radiometers (Tomita et al. 2017, submitted to GRL). Past J-OFURO versions (J-OFURO1 and 2) used an algorithm for the single, SSMI microwave radiometer proposed by Schlussel et al. (1995). However, the new algorithm employed by J-OFURO3 was developed for the multiple microwave radiometers: SSMIS, TMI, AMSR-E, and AMSR2 microwave radiometers, in addition to SSMI. The new algorithm is also characterized by its consideration of vertical water vapor profile data (water vapor scale height, Kanemaru and Masunaga 2013), which was previously overlooked in analyses of the relationship between brightness temperature and sea surface specific humidity. As a result, estimation of surface air specific humidity became possible across the global oceans with higher accuracy. For further details on the algorithm, see Tomita et al. 2017.

Figure 3.4 shows the data flow for the estimation of surface air specific humidity. The algorithm estimates air specific humidity at 10 m above sea level from instantaneous values (L1 data) of brightness temperature data across multiple channels observed by satellite microwave radiometers. At this point in time, the algorithm refers to separately prepared water vapor scale height (HV) data as an index for the vertical profile of water vapor. HV data is calculated from the gridded data of columnar water vapor (WV), obtained from multiple microwave radiometer observations (daily mean, 0.25° intervals), and the gridded data for air specific humidity at 2 m above sea level (QA2m), obtained from the ERA interim data set (daily mean, 0.75° interval). Instantaneous values of surface air specific humidity obtained by the algorithm are converted to daily mean values in 0.25° spatial grids for each satellite sensor, then averaged to obtain the grid value QA_{Multi} of multi-satellite surface air specific humidity. At this step, daily values of sea ice concentration provided by NOAA OISST are used to mask the values for sea ice areas. This process is required because the current algorithm cannot estimate surface air specific humidity over sea ice areas. Surface air specific humidity values show a systematic difference between satellite sensors (global average maximum of 1 g/kg). One reason is an insufficient calibration of brightness temperature data among several satellite sensors. Therefore, surface air specific humidity values from satellite sensors are adjusted to obtain multi-satellite grid values. J-OFURO3 runs a process that minimizes systematic differences between sensor estimates by using the surface air specific humidity provided by

SSMI F13, chosen as the baseline after comparison with in situ observations. For further details, see ‘Correction of Surface Air Specific Humidity Product from Microwave Radiometers’ (Tomita, 2017). Grids with values missing in coastal areas are extrapolated using the creep sea fill (CSF) method (Kara et al., 2007) to obtain finalized surface air specific humidity grid values (QA).

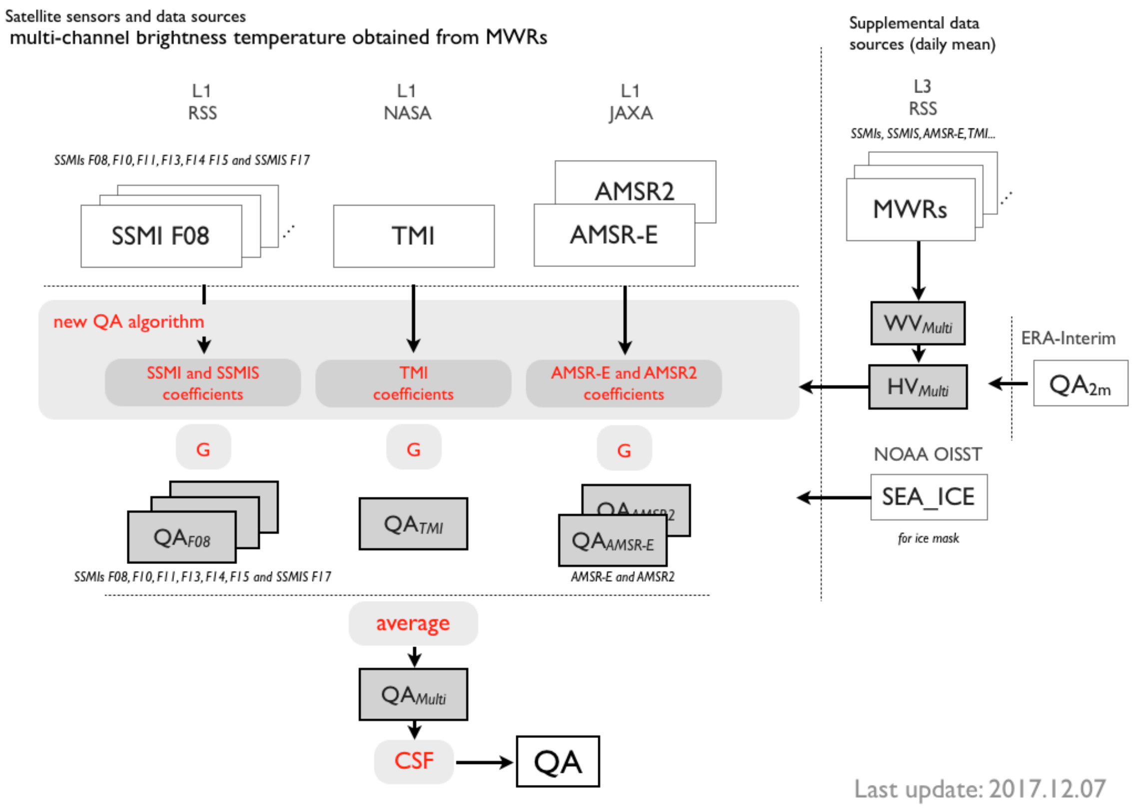

Fig. 3.4: J-OFURO3 surface air specific humidity data flow

Tables 3.5 and 3.6 show brightness temperature data from microwave radiometers used to construct the data set of surface air specific humidity. The brightness temperature data sets from ten types of satellite sensors are used. J-OFURO3 uses brightness temperature data from FCDR version 7 provided by RSS for SSMI and SSMIS series data. Brightness temperature data provided by NASA GES DISC (1B11) version 7 is used for TMI. L1B data provided by JAXA in versions 3 and 2.1 are used for AMSR-E and AMSR2, respectively.

As shown in Table 3.6, the number of satellites used by year varies depending on the observation period of the satellites. Data from 1-2 satellites were used between 1988 and 1996, 3-4 satellites were used between 1997 and 2001, and 5-6 were used between 2002~2008. The number of satellites has decreased again to 3-4 satellites since 2009.

Table 3.5: Brightness temperature data from microwave radiometers (MWR) used for the J-OFURO3 surface air specific humidity data set

Satellite sensor	Data provider	Product name	Level	Data period used in J-OFURO3	Version
SSMI F08	RSS	FCDR	L1	1988.01−1991.12	V7
SSMI F10	RSS	FCDR	L1	1990.12−1997.11	V7
SSMI F11	RSS	FCDR	L1	1991.12−2000.05	V7
SSMI F13	RSS	FCDR	L1	1995.05−2009.11	V7
SSMI F14	RSS	FCDR	L1	1997.05−2008.08	V7
SSMI F15	RSS	FCDR	L1	1999.12−2006.08 *1	V7
SSMIS F17	RSS	FCDR	L1	2007.01−2013.12 *2	V7
TMI	NASA	1B11	L1B	1997.12−2013.12	7
AMSR−E	JAXA	−	L1B	2002.06−2011.10	V3
AMSR2	JAXA	−	L1B	2012.07−2013.12	V2.1

*1: For SSMI F15, RSS reported that the quality of brightness temperature data at 22 GHz has declined since August 14, 2006, due to an impact from a beacon correcting the radar. Therefore, data from SSMI F15 after August 14, 2006 were not used in J-OFURO3 (http://www.remss.com/node/3871, Hilburn and Wentz, 2008).

*2: J-OFURO3 does not use the brightness temperature data from SSMIS F17 during December 2006 since it was not provided by RSS.

Table 3.6: Data availability of microwave radiometers used for the J-OFURO3 surface air specific humidity data set

Satellite sensor	Provider	Version	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	
SSMI F08	RSS	V7	o	o	o	−																							SSMI F08
SSMI F10	RSS	V7			−	o	o	o	o	o	o	−																	SSMI F10
SSMI F13	RSS	V7								−	o	o	o	o	o	o	o	o	o	o	o	o	o	−					SSMI F13
SSMI F14	RSS	V7										−	o	o	o	o	o	o	o	o	o	o	−						SSMI F14
SSMI F15	RSS	V7												−	o	o	o	o	o	o	−								SSMI F15
SSMIS F17	RSS	V7																				o	o	o	o	o	o	o	SSMIS F17
TMI	NASA	V7										−	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	o	TMI
AMSR−E	JAXA	V3															−	o	o	o	o	o	o	o	o	−			AMSR−E
AMSR2	JAXA	V2.1																									−	o	AMSR2
	Number of satellite		1	1	2	2	1	1	1	2	2	4	3	4	4	4	5	5	5	5	5	5	5	4	3	3	3	3	

Other variables: surface air temperature, TA10 (°C)

J-OFURO3 uses atmospheric reanalysis data for surface air temperature data. Selection of the atmospheric reanalysis data is provisional, and the current version of J-OFURO3 (V1.0) uses data from NCEP-DOE Reanalysis 2, but the plan is to use data based on JRA-55 in the future. This section will discuss the NCEP-DOE Reanalysis 2 data processing. Daily mean values are calculated using temperatures at 2 m above sea level obtained from NOAA/OAR/ESRL PSD at 6 hour intervals on a Gaussian grid. Interpolated data for 0.25° grids in J-OFURO3 is conducted by two-dimensional linear interpolation. Terrestrial and ocean grids are distinguished using a land-sea mask data provided by NCEP-DOE Reanalysis 2, and data over land are excluded from the interpolation process. Data for coastal areas are then interpolated by CSF. The 0.25° grid daily mean temperature data at 2 m above sea level (TA2m) are then used to calculate the surface turbulent heat flux. Publicly available surface air temperature data in J-OFURO3 is the temperature at 10 m above sea level (TA10), obtained during the calculation of surface turbulent heat flux.

Surface turbulent heat flux: LHF, SHF (W/m^2)

Surface turbulent heat fluxes consist of the latent heat flux (LHF) and the sensible heat flux (SHF). Both values are calculated by a bulk method using sea surface temperature (SST), scalar surface wind speed (WND), surface air specific humidity (QA), and surface air temperature (TA2m) as input data. For details on the bulk calculation method, see "Calculation Method for Surface Turbulent Heat Flux".

Positive value of latent/sensible heat fluxes means heat transport from the ocean to the atmosphere. In most cases these fluxes shows positive values over the ocean, however, negative values also exist in the data set.

Surface turbulent momentum flux: TAU, TAUX, and TAUY (N/m^2)

The surface turbulent momentum flux is calculated by a bulk method using wind stresses (TAU) from the scalar surface wind speed. For details on the bulk calculation method, see "Calculation Method for Surface Turbulent Heat Flux". Zonal (TAUX) and meridional (TAUY) components of wind stress on the sea surface are obtained after calculation of TAU by separating it into two components using wind direction data.

Radiation flux: LWR, SWR (W/m^2)

Radiation fluxes consist of the long wave radiation flux (LWR) and the short wave radiation flux (SWR), both of which have an upward and downward components (U/DLWR, U/DSWR). The upward long wave radiation flux is calculated from sea surface temperature data (SST). Data sets from ISCCP (Rossow and Schiffer 1991) and CERES are used for the downward long wave radiation flux and the short wave radiation flux. Spatial grid size of each data set is 2.5° and 1.0° grid, so it was interpolated into a 0.25° grid. In this process, data over land or ocean are distinguished using SST data and data over land area are not used in the process. Grids for coastal areas are then interpolated by CSF.

Surface net heat flux: NHF (W/m^2)

As shown in equation [1], the surface net heat flux is calculated as the sum of the surface heat fluxes, which includes the latent heat flux (LHF) and the sensible heat flux (SHF), the long wave radiation flux (LWR), and the short-wave heat flux (SWR). The upward heat transport (from the ocean to the atmosphere) is positive in all heat flux data.

$$NHF = LHF + SHF + LWR + SWR \qquad [1]$$

Freshwater flux: FWF (mm/day)

As shown in equation [2], the surface freshwater flux is the difference between evaporation (EVAP) from the ocean and precipitation above the ocean (RAIN). This variable was not provided prior to J-OFURO2.

$$FWF = EVAP - RAIN \qquad [2]$$

EVAP has units of mm/day and is calculated by multiplying the evaporation flux E (mm/s), which is calculated from LHF and surface sea temperature (SST) using equation [3], by 60×60×24 for unit conversion.

$$E = LHF / (\rho Le) \quad [3]$$

where Le is the latent heat in water evaporation, which equals $(2.501 - 0.00237 \times SST) \times 10^6$.

At the time of writing, J-OFURO provisionally uses GPCP (Adler et al. 2003) for precipitation data (RAIN), but another version using data obtained from the GSMaP project by JAXA is being planned for public release.

4. Climatological Monthly Mean Fields

Figures 4.1-4.5 show the distribution of the climatological monthly mean of surface heat fluxes obtained from the monthly mean values using data between 2002 and 2013 in J-OFURO3 V1.0.

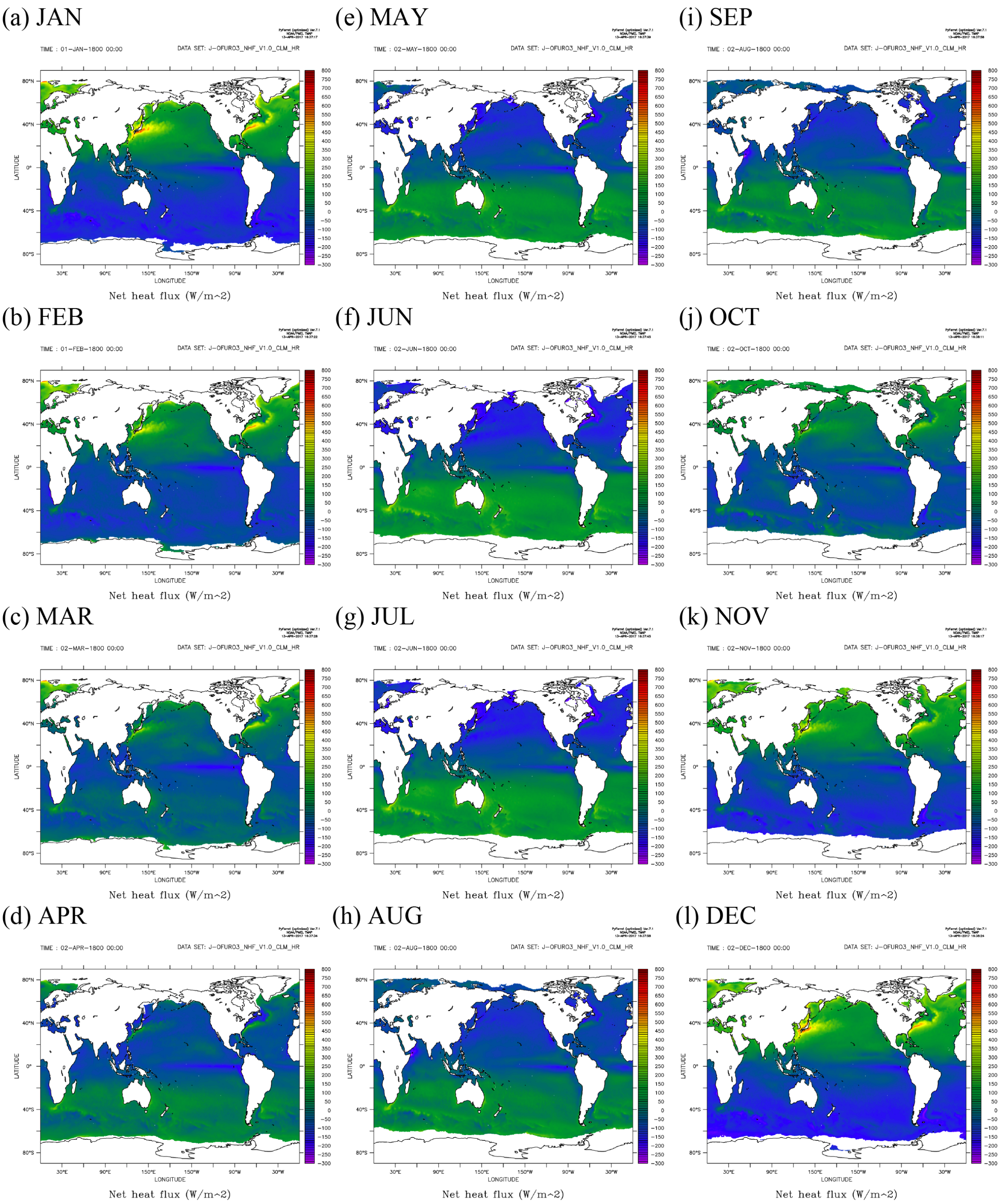

Figure 4.1 Climatological monthly mean fields of surface net heat flux. Positive values mean heat release from the ocean to the atmosphere.

Units in W/m^2

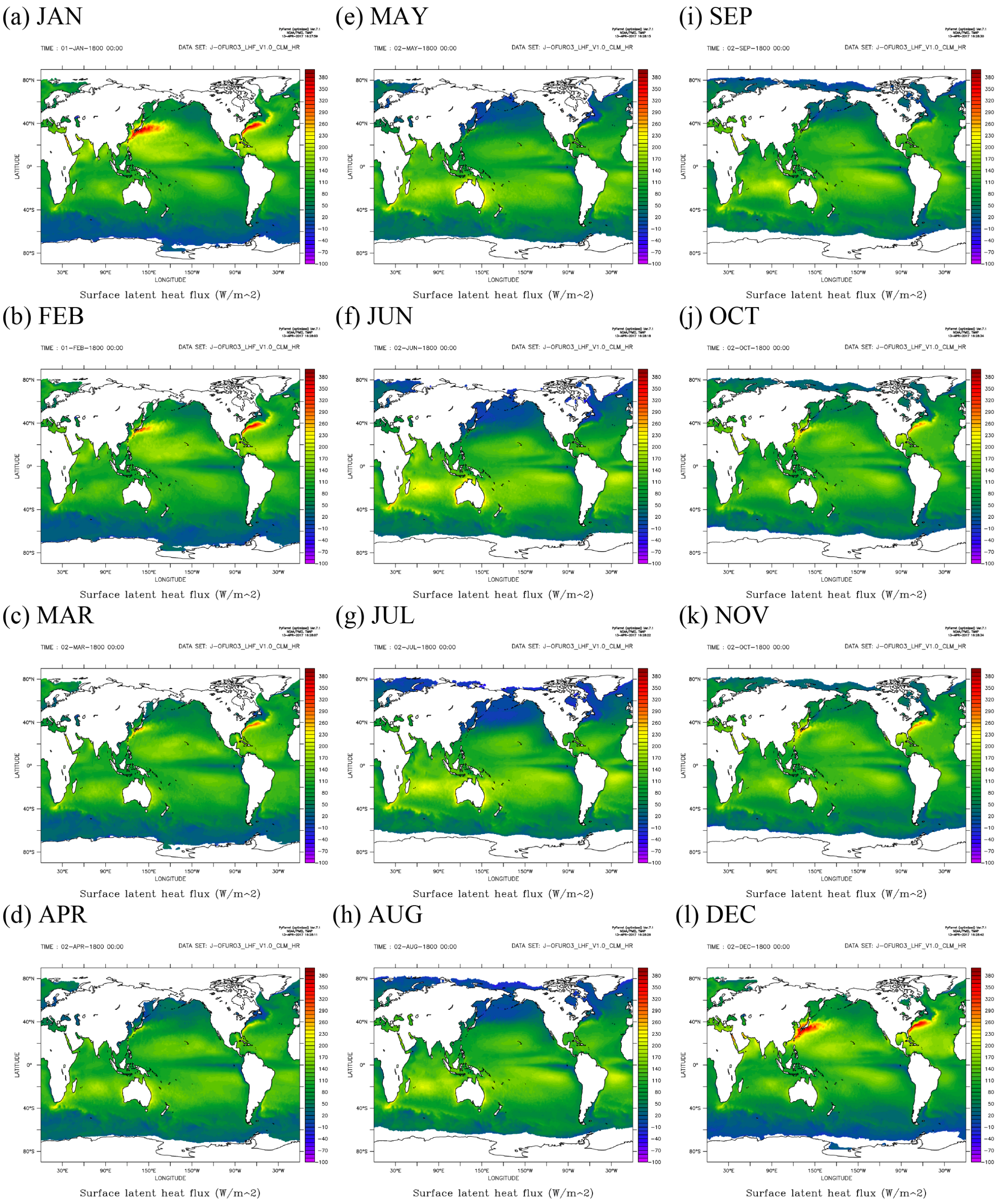

Figure 4.2 Same as Fig.4.1 except for latent heat flux

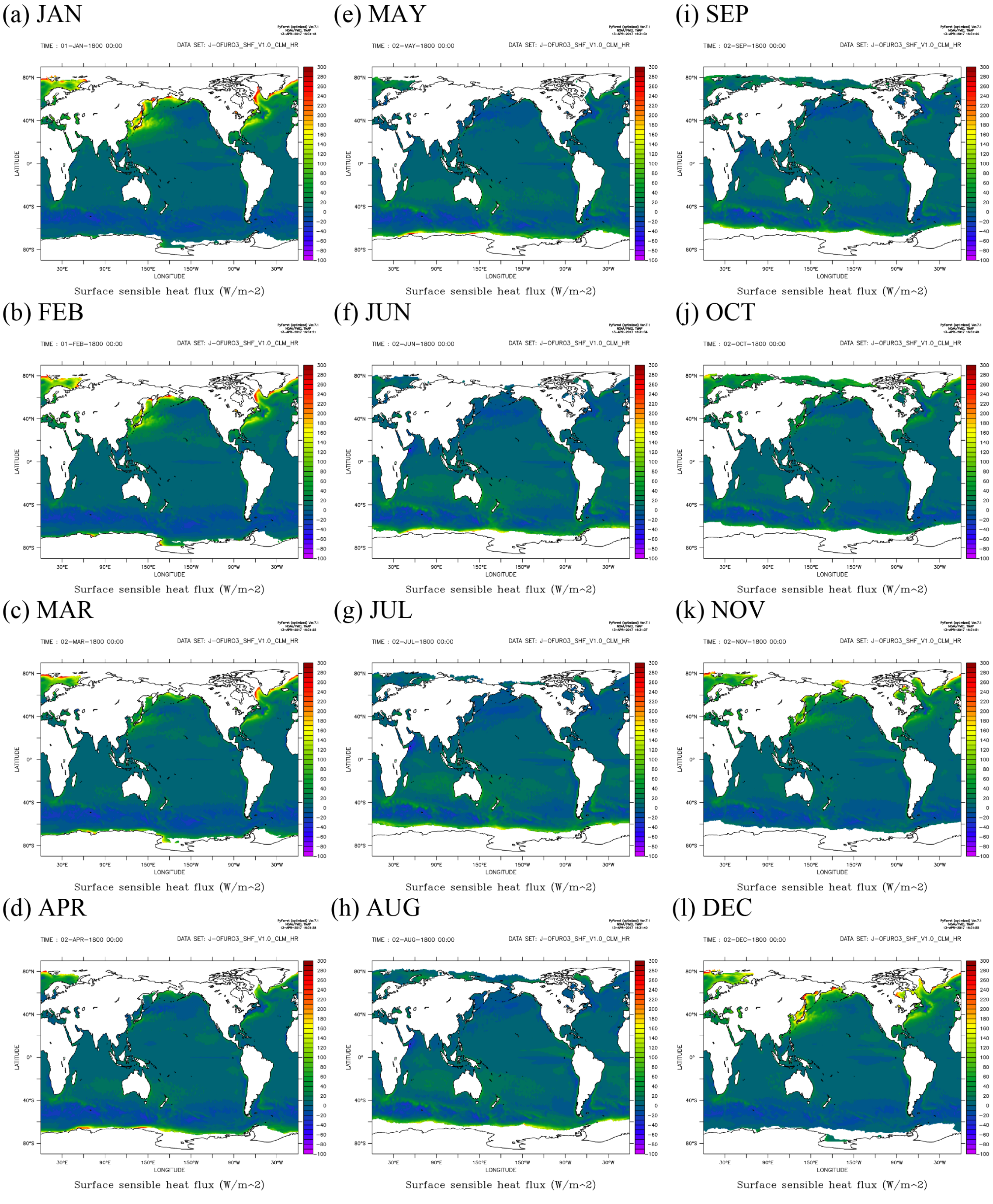

Figure 4.3 Same as Fig.4.1 except for sensible heat flux

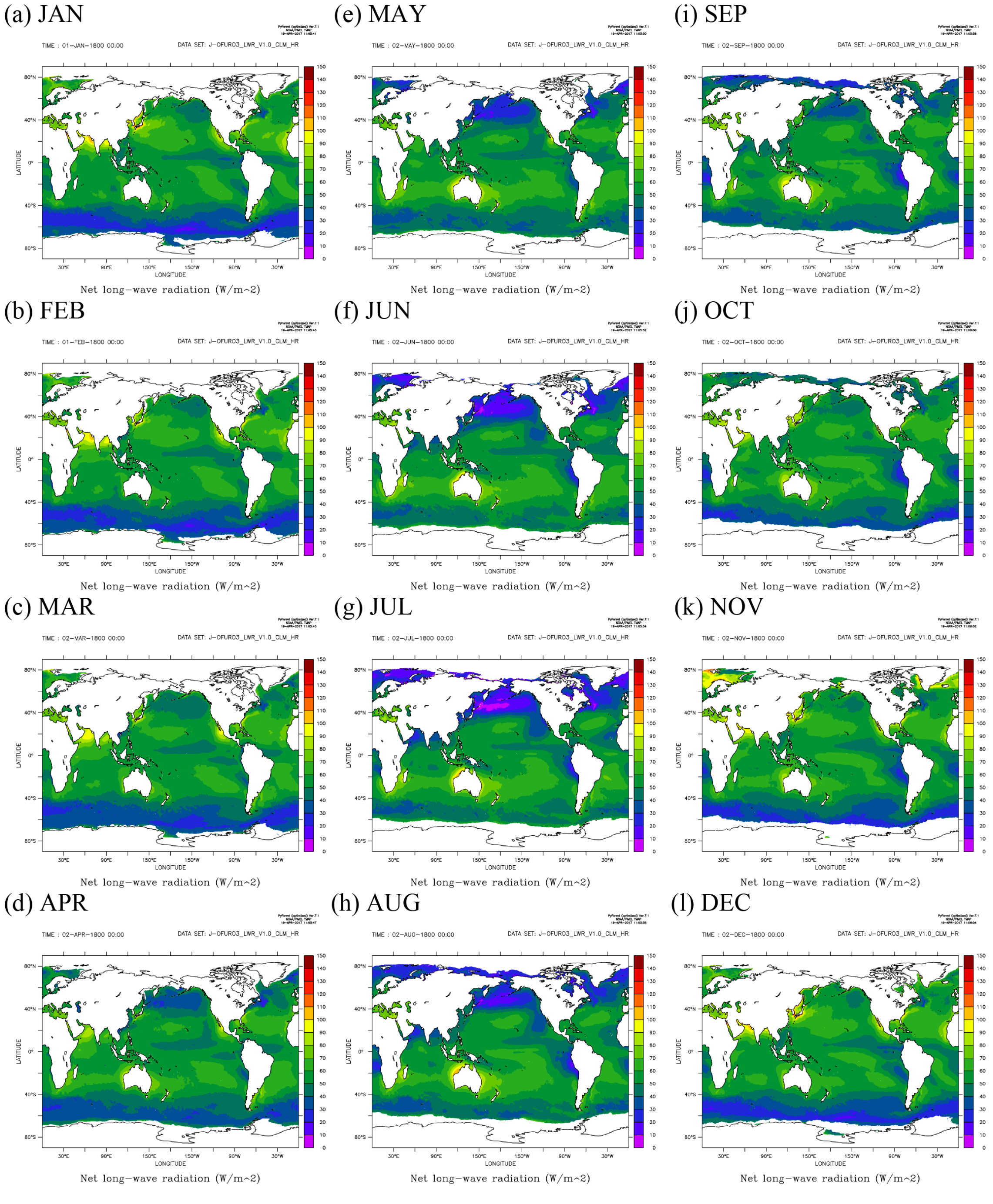

Figure 4.4 Same as Fig.4.1 except for net longwave radiation flux

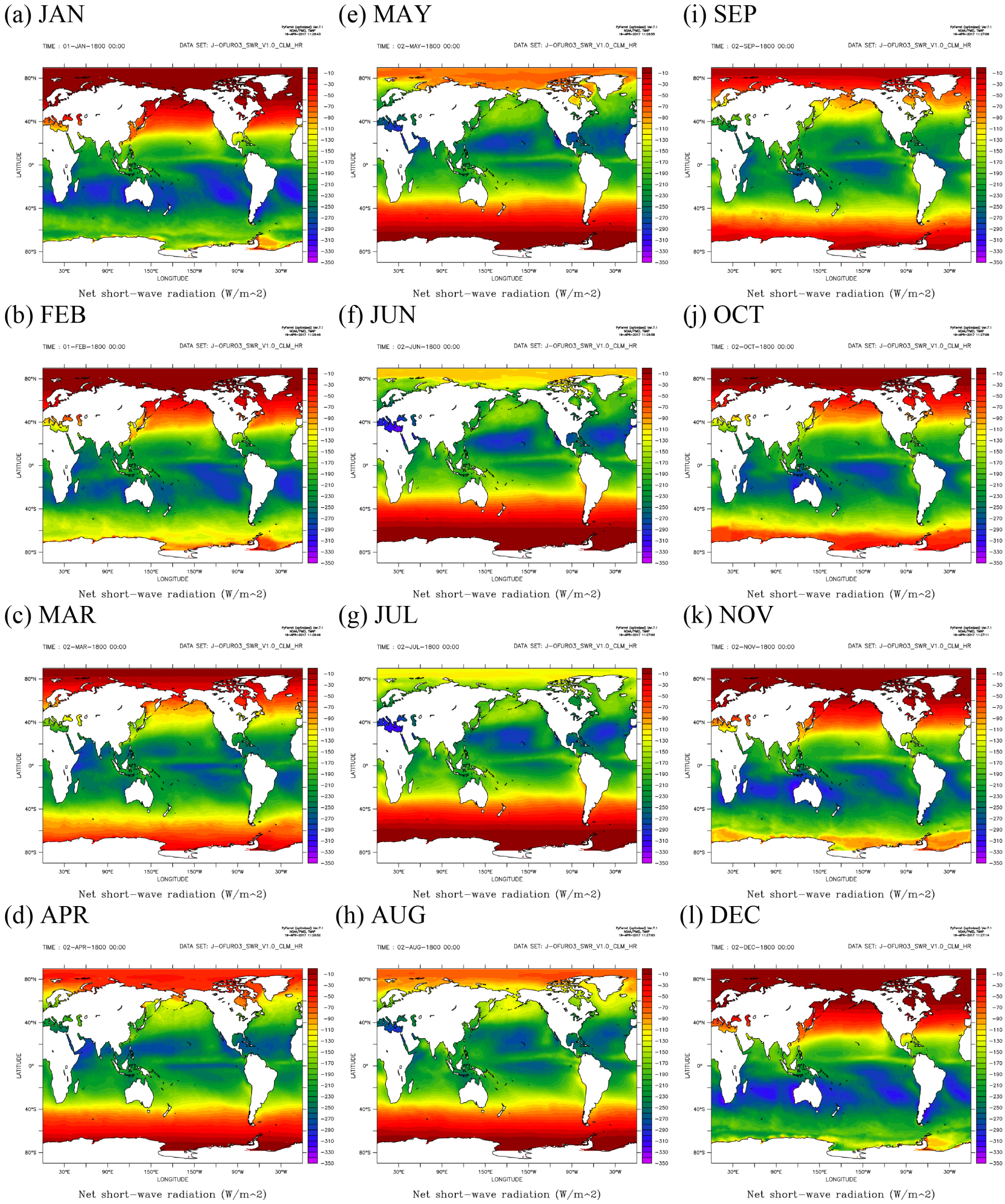

Figure 4.5 Same as Fig.4.1 except for net shortwave radiation flux

Acknowledgments

The research project J-OFURO used results and information from other research projects and data sets for the development, construction, and validation of J-OFURO3. Particularly, the satellite-derive air-sea flux data set J-OFURO3 was developed using data from satellites launched and operated by NASA, JAXA, and ESA. We appreciate to these institutes for Earth observation. Part of the J-OFURO research was supported by some research funds (e.g, KAKENHI). We list those here with our gratefulness.

Table. External data and program code used in J-OFURO3

Program code to calculate turbulent heat flux	COARE 3.0 Dr. Christopher W. Fairall (NOAA)
Brightness temperature data from DMSP/SSMI and SSMIS series	Remote Sensing Systems
Brightness temperature data from Aqua/AMSR-E and GCOM-W/AMSR2	JAXA EORC
Brightness temperature data from TRMM/TMI	NASA
Gridded data for columnar water vapor from satellite microwave radiometers	Remote Sensing Systems
Gridded data for surface wind speed from satellite microwave radiometers	Remote Sensing Systems
Surface wind vector data from QuikSCAT/SeaWinds	PO.DAAC NASA/JPL
Surface wind vector data from ASCAT	PO.DAAC NASA/JPL
Surface wind vector data from OSCAT	PO.DAAC NASA/JPL
Satellite-derived global precipitation data set	JAXA Global Satellite Mapping of Precipitation （GSMaP） Project
Satellite-derived global precipitation data set	NASA/GSFC Global Precipitation Climatology Project (GPCP)
Global sea surface temperature data set	Japan Meteorological Agency, Merged satellite and in situ data Global Daily Sea Surface Temperatures (MGDSST)
Global sea surface temperature data set	UKMO Operational Sea Surface Temperature and Sea Ice Analysis (OSTIA)
Global sea surface temperature data set	Tohoku University
Sea surface temperature data from satellite microwave radiometers	Remote Sensing Systems
Sea surface temperature data from GCOM-W/AMSR2	JAXA EORC
Sea surface temperature data from GPM/GMI	JAXA EORC
Satellite-derived surface radiation data set	NASA Clouds and the Earth's Radiant Energy System (CERES)
Satellite-derived surface radiation data set	International Satellite Cloud Climatology Project

Table. Foundation support

Foundation	Title	PI	Period (JFY)
KAKENHI	A study for understanding of variability of satellite-derived freshwater flux and surface salinity	Hiroyuki Tomita	2014-2017
JAXA GCOM RA	Construction of validation system for AMSR2 ocean products	Hiroyuki Tomita	2014-2016
Institute of Oceanic Research and Development/Tokai University	Construction and analysis of long-term global turbulent flux product	Kunio Kutsuwada	2016
Institute for Space-Earth Environmental Research /Nagoya University	Construction of global ocean surface wind vector data set using multi satellite observation data	Shin'ichiro Kako	2016–2017

References

Adler, R. F., G. J. Huffman, A. Chang, R. Ferraro, P. P. Xie, J. Janowiak, B. Rudolf, U. Schneider, S. Curtis, D. Bolvin, A. Gruber, J. Susskind, P. Arkin and E. Nelkin (2003), The version-2 global precipitation climatology project (GPCP) monthly precipitation analysis (1979-present), *J. Hydrometeorol.* 4(6): doi: 10.1175/1525-7541(2003)004<1147:tvgpcp>2.0.co;2.

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. *J. Climate* **16**(4), 571-591.

Hilburn, K. A. and F. J. Wentz (2008), Mitigating the impact of RADCAL beacon contamination on F15SSM/I ocean retrievals, *Geophys. Res. Lett.* **35**(18): Artn L18806, doi 10.1029/2008gl034914.

Iwasaki, S., M. Kubota and H. Tomita (2008), Inter-comparison and evaluation of global sea surface temperature products, *Int. J. Remote. Sens.* **29**(21), 6263-6280.

Kanemaru, K. and H. Masunaga (2013), A satellite study of the relationship between sea surface temperature and column water vapor over tropical and subtropical oceans, *J. Climate* **26**(12): 10.1175/jcli-d-12-00307.1.

Kara, a. B., A. J. Wallcraft and H. E. Hurlburt (2007), A correction for land contamination of atmospheric variables near land-sea boundaries, *J. Phys. Oceanogr.* **37**(4), 803-818.

Kubota, M., N. Iwasaka, S. Kizu, M. Konda and K. Kutsuwada (2002), Japanese Ocean Flux Data Sets With Use of Remote Sensing Observations (J-OFURO), J. Oceanogr., 58(1), 213–225.

Rossow, W. B. and R. A. Schiffer (1991), ISCCP cloud data products, Bull. Amer. Meteorol. Soc. 72(1), doi: 10.1175/1520-0477(1991)072<0002:icdp>2.0.co;2.

Schlussel, P., L. Schanz and G. Englisch (1995), Retrieval of latent-heat flux and longwave irradiance at the sea-surface from SSM/I and AVHRR measurements, *Adv Space Res*, **16**(10), 107-116.

Tomita (2017), Correction of J-OFURO3 air specific humidity product form microwave radiometers, J-OFURO3 official document, J-OFURO3-

DOC-005, V1.0J, 7pp (in Japanese).

Tomita, H., M. Kubota, M. F. Cronin, S. Iwasaki, M. Konda, and H. Ichikawa (2010), An assessment of surface heat fluxes from J-OFURO2 at the KEO and JKEO sites, J. Geophys. Res –Oceans, 115(C3), doi:10.1029/2009jc005545.

Tomita et al. (2017), Improved satellite estimation of near-surface humidity using vertical water vapor profile information, (submitted)

List for figures and tables

Figures:

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Acronym list

AMSR2	Advanced Microwave Scanning Radiometer 2
AMSR-E	Advanced Microwave Scanning Radiometer –Earth observing system
ASCAT	Advanced Scatterometer
COARE	Coupled Ocean Atmosphere Response Experiment
CERES	Clouds and the Earth's Radiant Energy System
CERSAT	Centre ERS d'Archivage et de Traitement
CSF	Creep Sea Fill
DOE	Department of Energy
EMSST	Ensemble median SST
ERA-Interim	ECMWF Reanalysis Interim
ERS1/2	ESA Remote-Sensing Satellite 1/2
ESA	European Space Agency
ESRL	Earth System Research Laboratory
GMI	GPM Microwave Imager
GOOS	Global Ocean Observing System
GPCP	Global Precipitation Climatology Project
GPM	Global Precipitation Measurement
GSMaP	Global Satellite Mapping of Precipitation
IFREMER	French Research Institute for Exploitation of the Sea
ISCCP	International Satellite Cloud Climatology Project
JAXA	Japan Aerospace Exploration Agency
JMA	Japan Meteorological Agency
J-OFURO	Japanese Ocean Flux Data Sets with Use of Remote Sensing Observations
JPL	Jet Propulsion Laboratory
MGDSST	Merged satellite and in situ data Global Daily Sea Surface Temperatures
MW	Microwave
MWR	Microwave Radiometer
NASA	National Aeronautics and Space Administration
NCEP	National Centers for Environmental Prediction
NEAR-GOOS	North-East Asian Regional GOOS
NOAA	National Oceanic and Atmospheric Administration
NRT	Near Real Time
OAR	Oceanic and Atmospheric Research
OI	Optimum Interpolation
OISST	Optimum Interpolation Sea Surface Temperature
OSCAT	Oceansat-2 Scatterometer
OSTIA	Operational Sea Surface Temperature and Sea Ice Analysis
PO.DAAC	Physical Oceanography Distributed Active Archive Center
PSD	Physical Science Division
RA	Re-Analysis
RG	Re-gridding
RSS	Remote Sensing Systems
SCAT	Microwave Scatterometer
SST	Sea Surface Temperature
SSMI	Special Sensor Microwave Imager
SSMIS	Special Sensor Microwave Imager/Sounder
TMI	TRMM Microwave Imager
TRMM	Tropical Rainfall Measurement Mission
UKMO	Unite Kingdom Meteorological Office

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