THE HOAPS-3 SATELLITE CLIMATOLOGY OF GLOBAL FRESHWATER FLUX

Stephan Bakan (1), Axel Andersson (2), Christian Klepp (2), Jörg Schulz (3)

(1) Max Planck Institute for Meteorology, Bundesstr. 53, D-20146 Hamburg(Germany), Email:stephan.bakan@zmaw.de
(2) Meteorological Institute, University of Hamburg, Bundesstr. 55, D-20146 Hamburg (Germany), Email: axel.andersson@zmaw.de; christian.klepp@zmaw.de
(3) German Weather Service (DWD), CM-SAF, Frankfurter Straße 135, 63067 Offenbach (Germany), Email: joerg.schulz@dwd.de

ABSTRACT

The paper presents an overview of the state and some application results of the HOAPS-3 satellite climatology of global freshwater flux.

The HOAPS data set utilizes SSM/I passive microwave data from polar orbiting satellites to retrieve several essential water cycle variables and the related evaporation, precipitation and the net freshwater flux over the global ice-free ocean for the interval 1988-2005. HOAPS shows all the known global climatological features and regional details. Average values and temporal development of precipitation and evaporation compare well with other established satellite data sets. Due to essentially constant precipitation and increasing evaporation, E-P increases with time, being about twice as large as the documented global continental runoff. The spatial trend distribution hints at an intensification of the Hadley circulation and of the general water cycle with time.

Comparison with widely used reanalysis fields exhibit remarkable similarities and differences in the temporal development of evaporation and precipitation and the resulting E-P balance over global oceans. The ERA globally averaged E-P products are not in balance with continental runoff and change systematically with time. On the other hand, as the globally averaged NCEP evaporation and precipitation both increase with time very similarly, this results in a nearly constant E-P in near balance with the global run-off. More detailed analysis will be necessary to understand the different results and issues involved.

1. INTRODUCTION

The proper knowledge of the global water cycle is crucial for the understanding and successful modelling of the global climate system. However, a reliable measurement of essential water cycle components with sufficient spatial and temporal coverage, especially over the global oceans, became only possible since the advent of satellite platforms with microwave detectors in space. This spectral range is well suited for the derivation of atmospheric parameters such as water vapor or liquid water as well as for the retrieval of relevant freshwater flux components at the ocean surface.

Especially since the availability of the Special Sensor Microwave Imager (SSM/I) on the satellites of the Defense Meteorological Satellites Program (DMSP) in the late 1980s, long-term global fields of water cycle related quantities have been derived and augmented by various additional data sources for special application purposes. Generally, these data sets provide either surface fluxes or precipitation estimates. An extensive overview of satellite derived air-sea flux data sets including detailed intercomparisons will be given in [1]. In addition, reference [2] provides a comprehensive introduction to the current state of the art precipitation algorithms and products and related validation and modelling aspects. In principle, the satellite retrieved data sets could be combined to estimate the global ocean freshwater flux. This would be a highly required but is also a difficult task, as different data sources have to be combined while there is no comprehensive in-situ validation data available [3].

The Hamburg Ocean Atmosphere Parameters and Fluxes from Satellite Data (HOAPS) is the first generally available compilation of both precipitation and evaporation from one consistently derived global satellite product [4]. Based on multi-satellite averages, inter-sensor calibration, and an efficient sea ice detection procedure, HOAPS provides a climatological data set of ocean latent heat flux and precipitation from satellite data with acceptable accuracy and frequent global coverage. With these data a climatological assessment of crucial water cycle processes over the global oceans has become possible.

The present paper contains a short overview of HOAPS features and a few application examples.

2. HOAPS

The HOAPS-3 climatology contains fields of precipitation, surface fluxes and related atmospheric parameters over the global ice-free ocean between 1987 and 2005. The climatology and the methodology to derive it from satellite data is described in detail by [4]. It utilizes passive microwave data from the SSM/I instrument, operating on the polar orbiting DMSP satellites, to retrieve basic variables. From these individual components of surface fluxes of heat, evaporation, and precipitation are derived. These data as well as the resulting net freshwater flux (E-P) fields are provided on a half degree grid through www.hoaps.org. Because a specific goal of the HOAPS effort was to generate a global ocean product for climatological studies from satellite based data, great care was put into inter-sensor-calibration from different satellites for a homogeneous and reliable spatial and temporal coverage. All HOAPS variables are derived from brightness temperature of the SSM/I radiometers. Only the additionally needed SST information is taken from the NODC/RSMAS Pathfinder SST data set which uses AVHRR data [5]. To avoid data contamination through sea ice in the individual pixels, a sea ice detection procedure based on the NASA Team algorithm has been applied [6].

HOAPS latent heat flux retrieval is based on the bulk aerodynamics COARE 2.6a algorithm described in [7] and [8]. This requires atmospheric specific humidity (implemented after [9]) and sea surface saturation specific humidity as well as near surface wind speed. The near surface wind speed and the precipitation in HOAPS are directly retrieved from the SSM/I measurements by a neural network approach.

A detailed uncertainty description for the satellite based HOAPS fluxes is difficult due to the lack of reliable and comprehensive in situ data. However, several studies demonstrated the good quality of the HOAPS evaporation and precipitation products on global scale (e.g. [10]). Although not fully closed with respect to the global river runoff, the HOAPS-3 global net freshwater flux estimate over the ocean lies within 10% of the individual E and P estimates. However, locally larger uncertainties may remain in regions with high variability or particular atmospheric conditions. For example, in regions of high aerosol load (e.g., originating from desert dust, biomass burning or volcanic eruptions such as Mt. Pinatubo in 1991) the accuracy of the SST data could be impaired as would be the evaporation retrieval and thus the net HOAPS surface freshwater flux product. Also for the precipitation in the ITCZ region large uncertainties among different data sets are found, with HOAPS showing higher absolute values and more variability than other data sets. On the other hand, a recent field study on the quality of high latitude precipitation indicates remarkable quality of HOAPS precipitation rates during snow fall events in comparison with e.g. the widely used GPCP data products [11].

3. APPLICATIONS

As Fig. 1 shows, the mean fields of HOAPS-3 (1988-2005) for precipitation, evaporation and freshwater flux contain all the well known climatological features. In particular, the well expressed ITCZ and the warm pool precipitation, the subtropical evaporation maxima, and the hydrological maxima over the warm Gulfstream and Kuroshio ocean currents catch the observer’s attention.

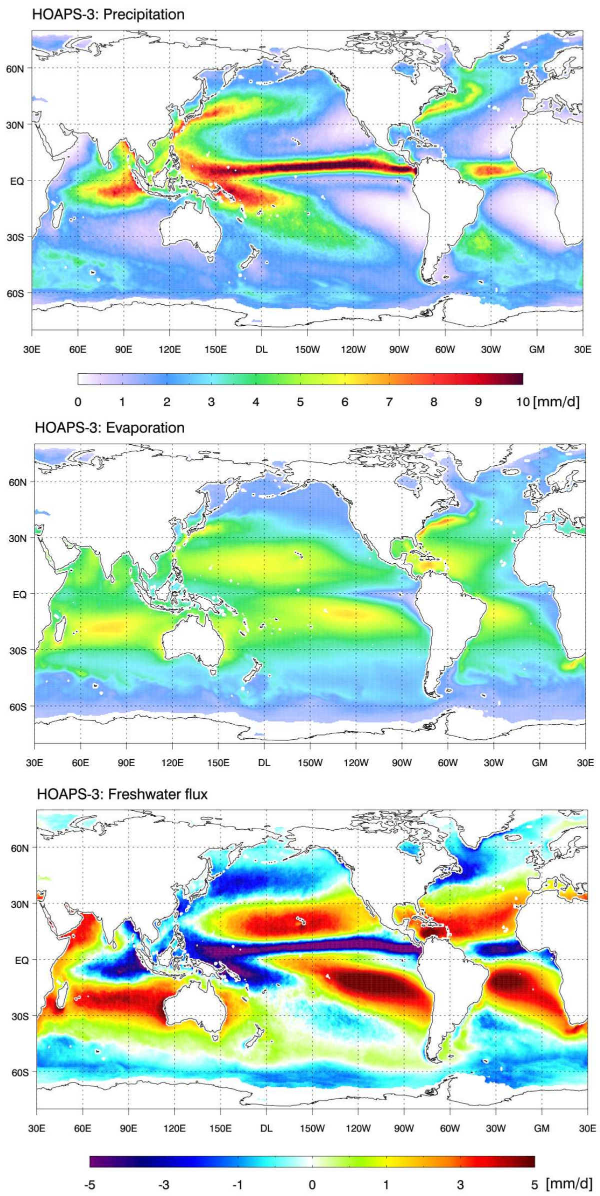

Figure 1. Climatological mean fields of HOAPS-3 precipitation (top), evaporation (mid) and freshwater flux (bottom) for the years 1988 to 2005.

On a global scale, the average evaporation in HOAPS-3 exceeds rain rate over the ocean systematically with almost negligible yearly cycle and small monthly variations.

Globally averaged precipitation over the ice free ocean is slightly increasing during the available 18 years of HOAPS, although this trend is not highly significant. Regionally, a substantial increase in the ITCZ and over the southern mid latitude oceans is somewhat compensated by reductions in the subtropics and no significant change over the northern oceans. In reference [12] the idea has been put forward, that due to the increase of the atmospheric water vapour mixing ratio by about 7% per degree increase of temperature (according to the Clausius-Clapeyron equation), various atmospheric water cycle components could be expected to increase on the global average by about 7% per degree increase of global average SST (according to the Clausius-Clapeyron equation). Although statistically not highly significant, this is almost exactly the value of the nominally calculated linear trend for the globally averaged HOAPS precipitation. The temporal development of HOAPS precipitation compares very well with other satellite climatologies as e.g. GPCP-V2 or CMAP, both of which have insignificant temporal trends at somewhat higher but less variable values. In comparison with reanalysis data we find, that both available NCEP reanalyses exhibit a substantial increase of over ocean precipitation after 1987. ERA40 data show an even stronger increase, which has been known for some time to be erroneous [13]. The recalculation in the ERA-interim project results now in similar but with time slightly decreasing average precipitation rates over the global ocean.

The globally averaged over ocean evaporation in HOAPS exhibits a substantial increase during the study period, which results mainly from the increase in wind speed and in sea-air difference of specific humidity in the subtropics. The related linear trend is substantially higher than would have been expected from the above mentioned Clausius-Clapeyron-criterion for yet unexplained reasons. Comparison with other satellite-derived evaporation products, among them e.g. the J-Ofuro V2 and the IFREMER V3 data sets, results in fairly similar values, variability and trend behavior. Especially noticeable is the very similar time behavior of the NOCS V2 data set, which is estimated from a completely different data set, namely the COARE ship measurements [14]. Only the recently published OAFlux V3, which is a blending of satellite and reanalysis data, exhibits a substantially smaller increase with time. Global evaporation in various reanalysis data sets show strongly different temporal behavior. While globally averaged ocean evaporation from both NCEP reanalyses increases with time at approximately the same rate as in HOAPS, both ERA reanalyses exhibit insignificant long-term trends.

Only a very few of the considered data sets provide also fields of the ocean freshwater flux and its time development. While this is readily available from reanalyses and model data, among the satellite based data sets to day only HOAPS provides this ocean surface water balance quantity. Fig. 2 shows the globally averaged monthly mean values of freshwater flux (evaporation – precipitation) between 1988 and 2005 together with the seasonal range of continental runoff from NCEP. The data reflect generally the expected average preponderance of evaporation over precipitation over the global oceans. Only the ERA40 data exhibit substantially negative freshwater fluxes due to the mentioned problems with the precipitation component. For a few months after the Pinatubo eruption in late 1991 also the HOAPS freshwater flux turns negative, which is mostly due to insufficiently corrected Pathfinder SST data during that time. Otherwise, all reanalysis products exhibit freshwater values in the early part of the comparison period that fit reasonably to the continental runoff distributed with the NCEP reanalysis data, but differ with time more and more. While the freshwater flux from both NCEP data sets remain fairly constant with time, ERA-interim increases at the same rate as HOAPS does. Both products seem to be substantially off the nominal continental runoff towards the end of the intercomparison period, although there is also some debate about the reliability of the runoff data.

For completeness, Fig. 2 contains also the time development of the freshwater flux in the ECHAM IPCC climate model run (mean of 3 ensemble members) for the 20th century (1988-2001). In this case non of the three quantities, average precipitation, evaporation and resulting freshwater flux over the global ocean, exhibits any obvious and significant trend during the 13 available model years.

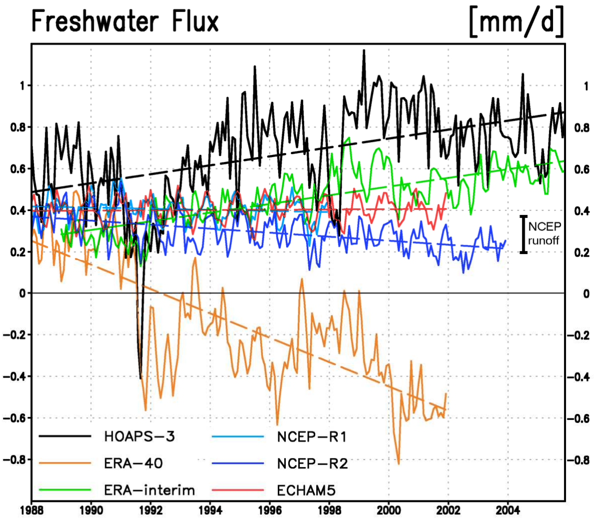

Figure 2. Monthly mean global average freshwater flux between 1988 and 2005 for several data products together with the seasonal range of NCEP continental runoff

4. CONCLUSIONS

HOAPS-3 is a well developed satellite climatology of water cycle components over the ice free global ocean, showing all the known global climatological features and regional details. Values and trends for precipitation and evaporation compare well with other established satellite data sets.

Precipitation remained essentially constant between 1988 and 2005, while evaporation increased by about 7% per decade, mostly due to wind and SST increase in the subtropical regions. E-P increases accordingly and is about two times larger than the documented global continental runoff. The spatial trend distribution hints at an intensification of the Hadley circulation and of the general water cycle with time.

Comparison with other widely used satellite and reanalysis fields exhibit remarkable similari-ties and differences in the temporal development of evaporation and precipitation and the resulting E-P balance over global oceans. ERA40 shows an implausible decrease of E-P, while it increases in ERAinterim similar to HOAPS. NCEP evaporation increases with time very similar to HOAPS, but as precipitation increases also considerably, E-P is nearly constant with time in near balance with the global run-off. Spatial pattern also turn out to be in parts substantially different among the various data sets. More detailed analysis will be necessary to understand the different results and issues involved.

HOAPS 3 is publicly available from www.hoaps.org. In near future, some of the core HOAPS products will be routinely derived and provided by the Eumetsat Climate Monitoring Satellite Application Facility (CM-SAF, www.cmsaf.eu) at the German Weather Service DWD.

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