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The Global Energy Balance Archive (GEBA): A Database for the Worldwide Measured Surface Energy Fluxes

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Abstract. The Global Energy Balance Archive (GEBA) is a database for the worldwide measured energy fluxes at the Earth's surface. GEBA is maintained at ETH Zurich (Switzerland) and has been founded in the 1980s by Prof. Atsumu Ohmura. It has continuously been updated and currently contains around 2500 stations with 500‘000 monthly mean entries of various surface energy balance components. Many of the records extend over several decades. The most widely measured quantity available in GEBA is the solar radiation incident at the Earth's surface ("global radiation"). The data sources include, in addition to the World Radiation Data Centre (WRDC) in St. Petersburg, data reports from National Weather Services, data from different research networks (BSRN, ARM, SURFRAD), data published in peer-reviewed publications and data obtained through personal communications. Different quality checks are applied to check for gross errors in the dataset. GEBA is used in various research applications, such as for the quantification of the global energy balance and its spatiotemporal variation, or for the estimation of long-term trends in the surface fluxes, which enabled the detection of multi-decadal variations in surface solar radiation, known as "global dimming" and "brightening". GEBA is further extensively used for the evaluation of climate models and satellite-derived surface flux products. On a more applied level, GEBA provides the basis for engineering applications in the context of solar power generation, water management, agricultural production and tourism. GEBA is publicly accessible over the internet via www.geba.ethz.ch.

INTRODUCTION

Knowledge on the spatio-temporal distribution of the energy balance components at the Earth's surface is essential for the understanding of the genesis and evolution of Earth's climate. Such knowledge is also required for a various practical applications in the sectors of agriculture, water management, tourism and renewable energies. The monitoring of some of the energy balance components, particularly solar radiation incident at the Earth surface, started in the early 20th century at a small number of sites. More widespread measurements of the surface energy balance components were initiated in the International Geophysical Year (IGY, 1957/1958). Many of these historic measurements have been compiled in the Global Energy Balance Archive (GEBA) at ETH Zurich, which is described in this paper.

HISTORY OF GEBA

In the mid-1980s, Professor Atsumu Ohmura at ETH Zurich started to collect observational data from worldwide measured surface energy balance components. In 1986, this endeavor became a project of the World Climate Program – Water. The first version of the GEBA database was implemented in 1988, following the design of a relational database[1]. Since the retirement of Prof. Ohmura in 2007, the first-author of this paper ensures the continuation of the GEBA database at ETH Zurich.

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CONTENT AND DATA SOURCES OF GEBA

GEBA compiles monthly data from various energy fluxes observed at the Earth's surface, namely global radiation (i.e., total downward shortwave radiation), diffuse and direct shortwave radiation, surface albedo and reflected shortwave radiation, longwave downward and upward radiation, radiation balance (surface net radiation), sensible and latent heat flux, subsurface heat flux, and latent heat of melt. Over the years, surface energy flux data have been compiled from various sources as listed in the following:

- Data from WRDC St. Petersburg
- Periodicals/Journal publications
- Various data reports
- Unpublished data and personal communications
- National weather services (e.g., Meteoswiss)
- Monthly data from BSRN, SURFRAD, ARM, NOAA

GEBA contains currently 2500 worldwide distributed stations as shown in Figure 1, with about 500'000 monthly mean values. It is accessible through the website www.geba.ethz.ch (Figure 2). By far the largest amount of data in GEBA refers to the downward shortwave radiation. Error estimates of these data and quality checks applied are described in Gilgen et al. (1998)[2]. The longest record in GEBA comes from Stockholm and contains downward shortwave radiation observations back to 1922 (Figure 3).

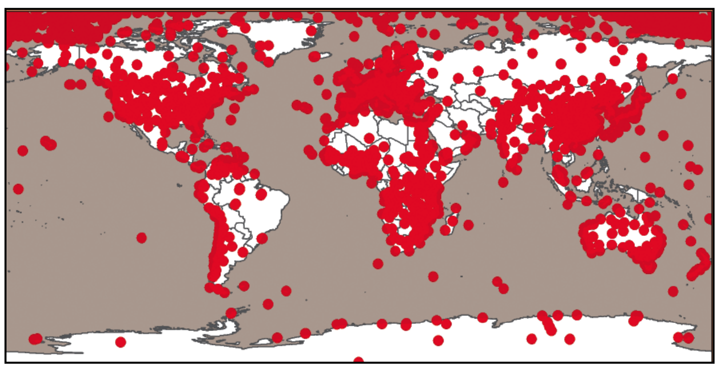

FIGURE 1 Worldwide observation sites in GEBA

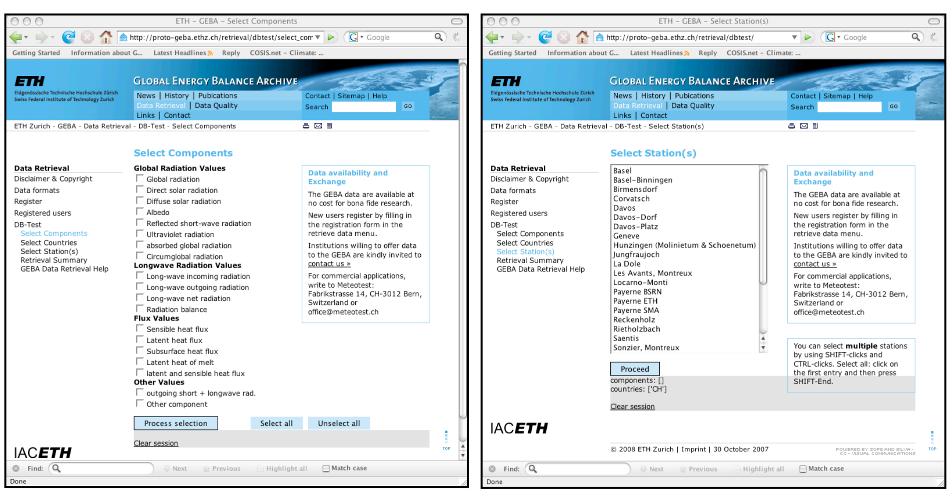

FIGURE 2 Extract from the GEBA web interface at www.geba.ethz.ch

RESEARCH DONE WITH GEBA

GEBA data have been applied in various studies as exemplarily highlighted below:

Estimation of the global energy balance
A major aim of GEBA since its initiation in the 1980s was the reevaluation of the global energy balance[1]. A first estimation based on GEBA was performed by Ohmura and Lang (1993)[3]. Wild et al. (1998)[4] used a combination of GEBA data and respective biases of a climate model to infer the magnitude of the global mean energy balance components. For the fifth IPCC assessment report (AR5) they updated their estimates based on a comprehensive set of state of the art models from CMIP5 and their biases with respect to GEBA[5]. In addition they estimated the energy balance separately for land and ocean mean conditions[6]. All these GEBA-based evaluations advocate a lower surface downward shortwave and higher downward longwave radiation compared to previous estimations.

Solar absorption in the atmosphere
In the early days of GEBA, it was debated whether estimates of shortwave atmospheric absorption may be too low due to an underestimated absorption in clouds, a phenomenon known as “anomalous cloud absorption”. GEBA was of key importance to show that the underestimated absorption is due to underestimation in the cloud-free atmosphere rather than in clouds[7-9]. The shortwave fluxes in GEBA have also been combined with surface albedo estimates and collocated top of atmosphere (TOA) irradiances measured from satellites during the ERBE and CERES projects to provide improved estimates of atmospheric shortwave absorption as a residual[4, 5, 9, 10]. Combining surface and TOA measurements from GEBA and CERES, respectively, the atmospheric shortwave absorption over Europe has been estimated by Hakuba et al. (2014)[10] at 23% of the TOA insolation. The 23% were shown to be largely invariant with respect to latitude and season[10, 11], and in line with recent global estimates[5, 6]. To estimate potential uncertainties induced by the scale mismatch between the gridded TOA satellite data and the surface point observations the representativeness of the GEBA sites for their larger scale surroundings has been thoroughly assessed[12, 13].

Detection of decadal changes in the downward shortwave radiation
GEBA has played a key role in the discovery that downward shortwave radiation at the Earth’s surface is not stable over time, but undergoes substantial multidecadal variations (see Figure 3 as an illustrative example). Based on European GEBA sites, Ohmura and Lang (1989)[14] identified a decline in downward shortwave radiation from the 1950s to the 1980s, later popularly known as “global dimming". Follow-up studies found similar tendencies at GEBA sites around the world[2, 15, 16]. When updating the GEBA records into the 2000s, Wild et al. (2005)[17] noted a trend reversal and widespread recovery from previous dimming, which they coined “brightening”. Norris and Wild (2007, 2009)[18, 19] used the GEBA data and a satellite-derived regression method to estimate the effects of changes in cloud cover on dimming and brightening. A recent update of the trends in homogeneous European GEBA records is reported in Sanchez-Lorenzo et al. (2016)[20].

Validation of surface energy fluxes simulated by climate models
A first evaluation of the global surface radiation fields simulated by a climate model with direct surface observations is documented in Wild et al. (1995)[8], which revealed an overestimated downward shortwave and underestimated downward longwave radiation in climate models. Numerous follow-up studies emerged thereafter as reviewed in Wild (2008)[21], which underline the importance of GEBA as a primary reference dataset for radiative flux evaluation in climate models. A GEBA-based evaluation of the radiation fields of the latest generation of climate models (CMIP5) used in the 5th IPCC assessment report (AR5) is found in Wild et al. (2013, 2015)[5, 6].

Validation of surface radiative fluxes inferred from satellites and reanalyses.
GEBA data have also extensively served as ground truth for surface radiative fluxes derived from satellites and reanalyses. The earliest attempts were made by Whitlock et al. (1995)[22], Rossow and Zhang (1995)[23], and Li et al. (1995)[24] for satellite products, and Wild et al. (1998)[25] for reanalyses. GEBA continues to play a major role in the assessment of satellite-derived and reanalysis surface fluxes, including tests of their stability[26].

Applied studies
On a more applied level, GEBA provides the data base for the assessment of the worldwide availability of solar resources for solar power production[27], or for the assessment of the worldwide distribution of diffuse and direct shortwave radiation of relevance for biosphere growth and agricultural production[28, 29].

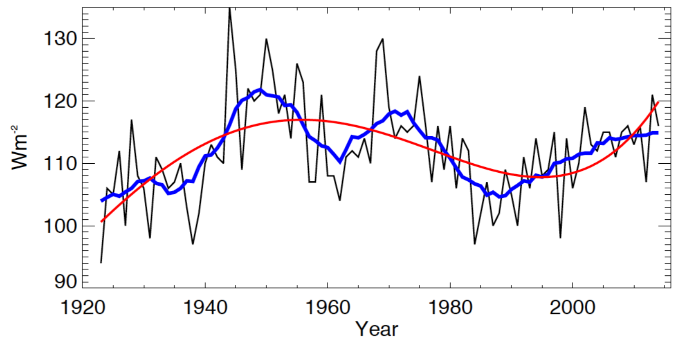

FIGURE 3. The longest record available in GEBA: Downward solar radiation measured in Stockholm since 1922. Five year moving average in blue, 4^{th} order regression model in red. Units Wm^{-2}.

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