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# North Atlantic Ocean heat budget and its variability over the last 130 years from VOS observations

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Voluntary Observing Ship (VOS) observations by merchant ships provide the longest in time coverage of the World Ocean by in-situ meteorological measurements going back to the mid 19th century. However, being collected primarily along the major shipping routes, VOS observations have poor sampling density, especially for the period prior 1940s. We consider the potential of Voluntary Observing Ship (VOS) observations available form the ICOADS for estimating ocean surface heat budget at different time scales. In order to minimize sampling impact on the means and variability patterns derived from VOS-based surface turbulent fluxes, we propose a concept suggesting integration of the turbulent heat fluxes in the coordinates of steering parameters (vertical surface temperature and humidity gradients on one hand and wind speed on the other). For these variables theoretical probability distributions are assumed to be Weibull distribution for the wind speed and Modified Fisher-Tippet distribution for surface temperature and humidity gradients. This approach allows for the switch from flux integration over the geography domain to the integration in the parameter space and, thus, obtaining less biased and more robust large-scale estimates. Turbulent fluxes were derived using COARE-3 algorithm. Analysis was performed for the North Atlantic latitudinal band from 25 N to 60 N, for which also estimates of the meridional heat transport are available from the ocean cross-sections. Over the last 35 years turbulent fluxes within the region analysed increase by about 6 W/m2 with the major growth during the 1990s and early 2000s. For short wave radiative fluxes sampling uncertainties were minimized by (i) applying new advanced parameterization for short wave radiation accounting for cloud types, (ii) "rotating" local observation time "around the clock" to avoid biases associated with astronomical factors, and (iii) using probability density functions for the cloud cover occurrence distributions to minimize sampling uncertainties in cloud cover. Decreasing incoming short wave radiation during the same time (over the last 35 years) about 1 W/m2 implies upward change of the ocean surface heat loss by about 7-8 W/m2. These estimates as well as characteristics of interannual variability are further compared to the similar estimates derived from different reanalyzes and satellite data for the last decades and with meridional transports in the ocean from the North Atlantic oceanic cross-sections at 25N and 60N. Further we applied the concept to longer time series going back to 1900s. We derived surface air-sea turbulent fluxes using the same methodology for turbulent fluxes and radiative fluxes. Considering only anomalies of the derived turbulent fluxes and radiative fluxes (short wave and long wave radiation), we derived annual estimates of the North Atlantic heat budget for the period from 1900 onwards. Long-term interdecadal variability of surface turbulent fluxes is of an order of magnitude stronger compared to the radiative fluxes (10-20 W/m2 vs 0.5-2 W/m2), thus implying the dominant role of turbulent fluxes on forming long-term changes of the ocean heat budget. Further interdecadal variability of surface heat budget is discussed in the context of the North Atlantic multidecadal variations.