AN EVALUATION OF BULK FORMULAE FOR ESTIMATING RADIATION BUDGET COMPONENTS OVER THE WESTERN MEDITERRANEAN SEA

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Abstract

Direct measurements of longwave radiation flux, incident solar radiation and meteorological parameters at sea were carried out in the Western Mediterranean Sea during different seasons in the years 1989-1997. The data collected were used to perform validation tests on the most widely used radiative empirical equations. Some results are reported.

Key-words: Western Mediterranean, Heat budget

Precise evaluation of the radiation budget at the sea surface is essential for world climate research as well as for the improvement of the marine circulation models. In spite of its importance, there is no network of radiation measurements over the oceans. Several radiative transfer models have been developed to compute this flux , but the data required as input are generally lacking over the ocean. Satellite measurements are attractive, but the most difficult problem is the validation of the techniques to extract the geophysical data from the remote sensing signals. Routine ship meteorological observations are the only overwater data available having a fairly good spatial and temporal resolution. As a consequence, in order to estimate this term of the air-sea energy balance, modelers and climatologists have favoured an empirical approach using only surface weather observations: air temperature, humidity, barometric pressure, water temperature and visual cloud cover. Many formulae of this type have been proposed and employed during the years but only few tests have been done to assess their applicability over the whole ocean and the results obtained are often contradictory. Thus, there is now no single universally accepted bulk scheme. The principal reason of the observed discrepancies between predictions and measurements and between the predictions obtained by different formulae is that the empirical equations as well as their numerical coefficients are determined by fitting some parameters which are highly variable both in space and in time. Therefore the data set used to achieve the fit becomes crucial. Many formula have been obtained from data sets collected over the land. When marine observations have been used, the data were too few and limited to allow a generalisation. As a consequence, the results of the validation tests of the different bulk formulae may be highly variable depending on the resemblance between the data set used to derive the formula and the data set employed in the comparison. Since the use of an incorrect bulk formula can produce considerable mistakes in the output of climatic and dynamic models and can even lead to inverting the estimated direction of the net heat flux, a careful examination of these expressions is necessary. The tests are especially required over the Mediterranean Sea, where air-sea energy exchanges play a fundamental role in the dynamics and climatology of the region. Additionally, the validation of empirical equations for the Mediterranean Sea must be performed *ad hoc* the atmospheric and marine features of this semiclosed basin being different from those of the open oceans.

Direct measurements of solar radiation, atmospheric radiation, sea surface temperature and meteorological parameters were carried out on board of the R/V *Minerva* and R/V *Urania* of the Italian National Research Council (Consiglio Nazionale delle Ricerche) during 13 cruises in the Western Mediterranean Sea in the years 1989-1997.

The period and the working area of each cruise are listed in Table 1, while a detailed description of the instrumental setup and of the methodology used to elaborate the data is given in Schiano *et al.* (1).

Table 1 : Period and working area of the 13 cruises.

1	Sept. 28 to Oct. 7, 1989	North Tyrrhenian Sea
2	Feb. 17-22, 1990	North Tyrrhenian Sea
3	Nov. 10-19, 1990	Ligurian Sea
4	April 20 to May 5, 1991	Ligurian Sea
5	Oct. 24 to Nov 8, 1991	South Tyrrhenian Sea
6	April 21 to May 5, 1992	South Tyrrhenian Sea
7	August 12-30,1992	Balearic Sea
8	Feb. 27 to march 15, 1993	South Tyrrhenian Sea
9	Nov. 4-22, 1993	Sicilian Channel
10	May 17-29, 1994	Sicilian Channel
11	Oct. 10-20, 1994	Sicilian Channel
12	July 4-30, 1995	Western Mediterranean Sea and Sicilian Channel
13	Jan 10-30, 1997	Sicilian Channel

These measurements have supplied the more large experimental radiation data set over this basin.

Part of this data set was used to carry out a first comparison between experimental measurements and the predictions obtained by the most widely used radiative bulk formulae.

Eight formulae for estimating the net longwave flux at sea were checked using the data collected from 1989 to 1992. This earlier test shows that the measured flux is systematically underestimated by about 30 Wm^{-2} (2). The bias was ascribed to the bad parameterization of the water vapour effect. and an alternative empirical formula was derived from these data.

The data from 1989 to 1994 were used to check the empirical formula proposed by Reed (3) for estimating the solar radiation at sea (4). The results reveal that the computed solar radiation is overestimated under clear sky conditions and underestimated for cloudy sky. The disagreement of clear sky predictions was ascribed to a regional misevaluation of both aerosols and water vapour attenuation that could be corrected by a simple adjustment of the numerical coefficients. The inadequacy of the cloud cover index was indicated to explain the discrepancy of the estimates under cloudy sky.

The enlargement of the data set allows a better analysis of the parametrizations for both the radiative terms. In particular, since the longwave radiation flux formulae require hourly values as input, the data set used to perform this analysis changes from 1335 to 2779 points, while the one employed for the test on the solar radiation formula, in which only mean daily values are included, changes from 88 to 126 observations.

The data increase is not sufficient to significantly improve the results given by Schiano (4), but the new data strengthen the main conclusions of that work. Figure 1 shows the measured daily values of solar radiation compared with the predictions obtained by Reed's formula (3) and by the same formula computed using the adjusted coefficients. The agreement between computed and measured solar radiationis is good using the formula in both original and revised configuration.

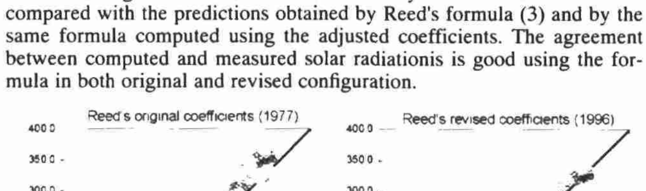

Figure 1 : Reed's predictions *versus* measurements. Original and revised formula.

More than 90% of the differences between predictions and measurements are within 10% of the measured value. The agreement is noteworthy, taking into account the coarseness of the formula and the experimental errors, that, due to the difficulties in making this type of measurements on board, cannot be completely left out. The new comparison demonstrates that the correction of the numerical coefficients for the water vapour attenuation is necessary for improving the predictions under clear sky, though, in order to select the numerical coefficients, the threshold value of water vapour density should be better definite. The disagreement between predictions and measurements under cloudy sky confirms that the cloud cover index is too much coarse to represent the cloud effects on the solar radiation transmission. The differences between measured and computed solar radiation under cloudy sky show a light dependence on the water vapour density, but the data are still too few for this analysis.

The nine formulae used for computing the longwave radiation flux are given in Table 2.

The validation of the formula by Bignami *et al.* (2) is achieved by using only the data obtained during the last six cruises (Figure 2).

Examining the whole data set, the new comparison confirms that the early seven tested empirical equations underestimate the longwave net flux, while the formula by Bignami *et al.* (2), *ad hoc* developed for the