Daily SST Fields Produced by Blending Infrared and Microwave Radiometer Estimates

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ABSTRACT

Measurement of Sea Surface Temperature (SST) using satellite based sensors have matured during the last decade. The infrared measurements, using the AVHRR sensor, flown onboard the NOAA satellites, have been used for the generation of high resolution operational products on daily basis, since 1982. However, the intrinsic problem of the infrared radiation prevents the retrieval of SST in the presence of clouds. This causes heavy loss of SST data over the north Indian Ocean especially during the summer monsoon (June - September). The recent advances in the microwave remote sensing of SST provide an alternative for the retrieval of SSTs in the presence of clouds. The microwaves, though they can measure the SSTs in the presence of clouds, their spatial resolution is poorer than that of infrared measurements. Near land boundaries the retrievals of the SSTs using microwaves are inferior due to the contamination from the emissions from land. In this study we take the advantage of the SST retrievals from infrared (NOAA/AVHRR) and microwave (TRMM/TMI) sensors and produce a new SST filed. An objective analysis scheme is used to combine the SSTs retrieved using AVHRR (9 km daily ascending and descending passes) and TMI (25 km ascending and descending passes) sensors to produce a daily field at a spatial resolution of 18 km. The new SST fields when compared with in situ measurements (drifting buoy SSTs) showed improvement (Root Mean Square Error of 0.659 °C). The corresponding root mean square error of the SSTs derived from AVHRR and TMI were 0.642 °C, and 0.783 °C respectively.

Keywords : SST, Infrared measurements, Microwave measurements, Objective analysis

INTRODUCTION

The Sea Surface Temperature (SST) is an important parameter for the studies on air-sea interaction and climate change. Through remote sensing it is possible to obtain higher resolution SST data at global scales. Currently, two types of remote sensing techniques are used for the retrieval of SSTs, the infrared and the microwave. The SSTs derived using the infrared sensor named Advanced Very High Resolution Radiometer (AVHRR) are available routinely at near real time since 1982. However, the SSTs from AVHRR are not available when there are clouds in the filed of view of the sensor. The accuracy of the measurement also is affected due to the atmospheric dust and aerosol.

On the other hand the microwave sensors can provide reasonable SSTs even in the presence of clouds in the filed of view. Ocean areas with persistent cloud coverage can now be viewed on a daily basis by using a sensor named TRMM Microwave Imager (TMI). The TMI has a channel at 10.7 GHz which can be used for the measurement of SST with reasonable accuracy. The advantage of microwave retrievals is that they are not affected by aerosol and atmospheric water vapour. However, the microwave retrievals are sensitive to the sea-surface roughness, while the infrared retrievals are not. Another disadvantage of the microwave estimate is that they have a poor spatial resolution. Also, near the land boundaries the accuracy of SST estimated using the microwaves degrades considerably due to the contamination from the emissions from land. The swath width of TMI sensor is only ~750 km and hence it takes 3 days to get complete coverage. In the case of AVHRR sensor the swath width is ~2700 km which ensures a daily coverage. This shows that the retrieval of SST using infrared and microwave have their own advantages and drawbacks.

In this study we explore the possibilities to take the advantages of one data set to coverup the disadvantage of other. Two complementary datasets are used to generate a new SST filed which will have the spatial and temporal resolutions of infrared derived SSTs even during the period of cloud cover. The next section describes the method used for combing the two SST fields. The third section compares the satellite derived SST fields with the in situ SSTs. Finally, the result are summarized in the last section.

MATERIALS AND METHODS
Satellite data
The Pathfinder SST data set (ascending and descending passes) derived from the AVHRR sensor flown onboard the NOAA-14 satellite for the period 1998-1999 are used as the infrared measurements. The equatorial crossing time of NOAA-14 for the ascending node is at 1330 hrs local solar time and 0130 hrs for the descending node. The daily fields of Pathfinder SST (PFSST) obtained from the Jet Propulsion Laboratory (JPL) Physical Oceanography Distributed Active Archive Center (PODAAC) has a spatial resolution of 9 km. A variant of non-linear SST algorithm suggested by Walton[1] and Walton et al.[2] is used to derive the Pathfinder SST.

The SST derived from TMI sensor available from the website http://www.ssmi.com is used as microwave derived SSTs. These SST fields have a nominal spatial resolution of 0.25 degree in latitude and longitude. The TRMM satellite which carries the TMI sensor travels west to east in a semi-equatorial orbit. This produces data collected at changing local times for any given earth location between 40°S and 40°N. The satellite takes 3 days for the full coverage of a particular region. In this study we use the daily pass data of TMI for the period 1998-1999. The AMSR Ocean Algorithm[3] was used for the retrieval of SST's using the TMI radiometer.

In situ Data
To evaluate the error associated with the satellite estimates, data from drifting buoys are used as in situ measurements. The drifting buoy data is available from the whole Indian Ocean region bounded by the latitudes 30°S to 30°N and longitudes 30°E to 100°E for the years 1998 and 1999. The SST data obtained from the drifting buoys are thoroughly quality checked using the method suggested by Hanson and Pouline[4]. These checks include the checks for consistency between the successive observations, range check for SST, checks for transmission errors etc. Fig 1 shows the locations at which the SST measurements are available from the drifting buoys in the Indian Ocean region.
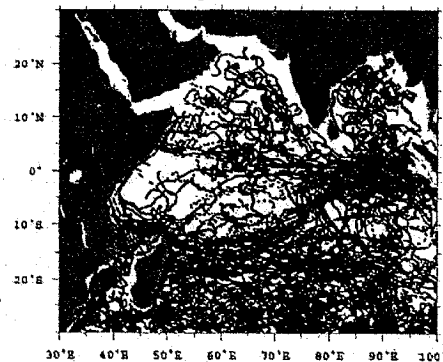

Figure. 1

Objective analysis
In order to blend the two types of SST fields we have first created the daily composite of infrared and microwave SSTs using the data from ascending and descending passes. In the case of overlapping area we choose higher SST value because the AVHRR estimate shows a lower value when the field of view is fully or partially contaminated by the undetected clouds.

In the second step the Gaussian interpolation is carried out following the method suggested by Kessler and McCreary[5]. This method is similar to that adopted by Levitus[6] for the analysis of hydrographic data over the world oceans.

The Gaussian interpolation maps the irregularly spaced SSTs $T_n^{'}$ to a regular grid (x_0, y_0) of spatial resolution 18 km). The value of the SST, T^{*} at each grid point is estimated as

$$T''(x_0, y_0) = \frac{\sum_{n=1}^{N_P} T_n^{'} W_n}{\sum_{n=1}^{N_P} W_n}$$

where N_P is the total number of irregular points within the "influence region" of a particular grid point and W_n is Gaussian weight function.

The Gaussian weight function W_n is determined by the relation

$$W(x_n, y_n) = \exp\{-[(\frac{x_n - x_0}{X})^2 + (\frac{y_n - y_0}{Y})^2]\}$$

X and Y in the denominator on the right hand side indicate the mapping scales in longitude and latitude respectively. Because the weight function W_n has non zero value everywhere, in theory every observation should be part of the summation for each grid point. Since this would involve tremendous amount of computation and in most of the cases the weight function is vanishingly small, the summation were truncated at the point where the weight function equaled e^{-8}. The area where $W_n > e^{-8}$ defines the influence region of a data point for the set of values of N_P. Visualising the two-dimensional grid with the data points scattered irregularly through it, the mapping operation appears as an ellipsoid moving from grid point to grid point, averaging the data points that fall within the ellipsoid. Each data point falls within the summation for several grid points, weighted according to distance. In region of very sparce sampling, a single data point may be the only information for one or several grid points. When no

data point falls within the ellipsoid that grid point will be left blank.

SST fields

The infrared estimate of SST from AVHRR for 1st January 1998 is shown in Figure 2a. The daily fields was created using the ascending (day time) and the descending (night) pass data. Though this data set has a spatial resolution of 9 km it has several data gaps mainly due to the presence of clouds. A perfect overlap between two adjacent passes are possible for this data set due to the higher swath width of the AVHRR. The TMI SST composite of the same day is shown in Figure 2b. In this case the data gaps seen are due to the low swath width. The blended SST filed is shown in Figure 2c. Obviously, the data coverage of the blended SST field is far better than the individual infrared or microwave estimates.
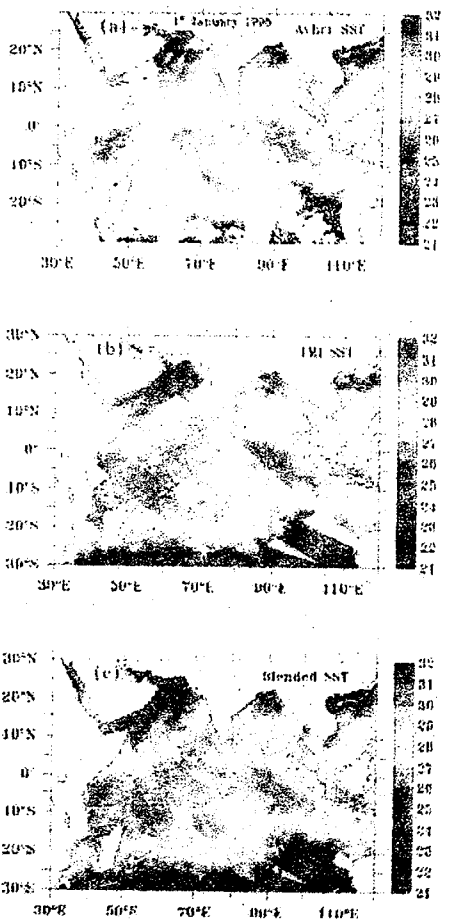
The infrared estimation is questionable and difficult during the monsoon period due to the presence of clouds. Figure 3a shows the AVHRR SST on a typical monsoon day (20th July 1998). In this case more than 83% of data is lost due to the presence of

clouds virtually making the AVHRR sensor unusable during monsoon season. Figure 3b shows the SST estimates for the same day using the TMI. The data gaps due to the cloud cover are comparatively less in the TMI SST (Figure 3b).

Figure 3c shows the SST field derived by blending the SST fields shown in figures 3a and b. The blended data fills the gaps when SSTs are available from either data sets. The blended SST has a spatial resolution of 18 km compared to the 9 km resolution of AVHRR field and 0.25 degree resolution of TMI fields. The features in the SST fields are consistent
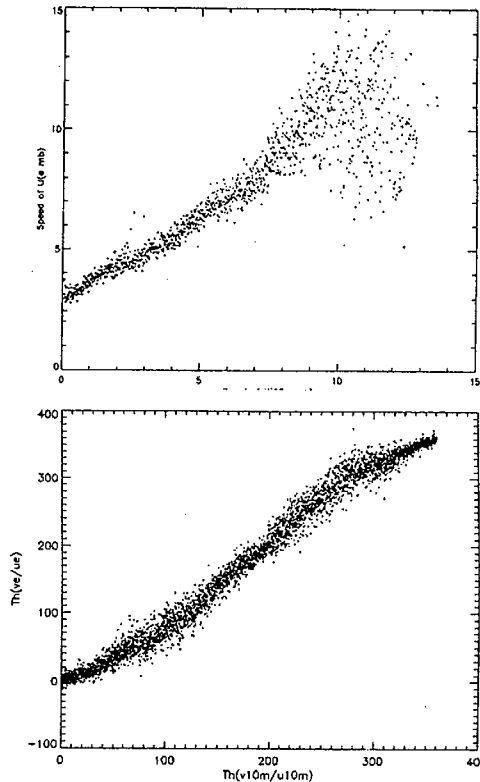

Fig. 3. Relation between the equivalent velocity for moisture transport and the 10   -m wind velocity, from ECMWF data.

indicating that the blending and objective analysis scheme has not introduced any unwanted trends in the blended fields.

Validation of SST fields

To ascertain the accuracy of SST estimates from infrared measurements (AVHRR) and microwave measurements (TMI) we have also compared them with the in situ measurements. The comparisons are done only when the satellite and in situ observations coincided within acceptable limits in space and time (10 kms and 12 hrs). The summary of the error statistics is given in given in Table.1. The bias shows

that the AVHRR SST is always cooler than the in situ SSTs (0.144 °C) while the TMI SST is warmer than the in situ SST (0.265 °C). The new blended SST appears to have improved on this trend and it shows a bias of only -0.055 °C. In conclusion, the blended SST has not only filled the gaps in the infrared and microwave estimates, it has also improved on the error statistics.

SUMMARY
An objective analysis technique is used to produce a daily SST field by blending the AVHRR and microwave SST estimates. This technique exploits the positive aspects of infrared and microwave measurements of SST to create a superior daily SST product. The evaluation of the SST fields showed that the blended SST has considerable improvements in the error statistics. The blended SST has a spatial resolution of 18 km which is higher than the microwave estimated (TMI) SST which has a resolution of 0.25 degree in latitude and longitude.

ACKNOWLEDGEMENTS

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