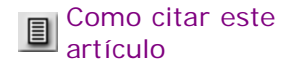




Gayana (Concepción)
ISSN 0717-6538 *versión on-line*

Gayana (Concepc.) v.68 n.2 supl.TIIProc Concepción 2004



Gayana 68(2): 411-419, 2004

AN INTERACTIVE SOFTWARE PACKAGE FOR VALIDATING SATELLITE DATA

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ABSTRACT

Earth observation satellite launched in the last three decades have made vital contributions to the understanding of the planet. The earth system consisting of land, oceans and atmosphere is linked together by a number of complicated processes. Potential of microwave sensors in studying the boundary layer dynamics of the ocean-atmosphere system is well documented. Technology has revolutionized the application of such sensors and several missions are planned to take off in near future for meeting specific objectives. Launching of such sensors need to be followed by an extensive validation campaign for providing accurate and reliable information to the users.

A PC-based interactive system has been developed and presented here for validating satellite mounted microwave sensors. The program, coded in Visual Basic, is user interactive and runs on Windows-98 platform. The system prepares the data base on a selected platform according to the global/regional nature of the satellite data. Preset space-time windows are selected to study the nature of satellite-sea truth relationship. The program design a scheme to discard spurious satellite data by keeping the relationship and its significance intact. The best relationship obtained is used to predict the new set of correct satellite data for application purpose. The program has, therefore, several added advantages over the conventional method of validation which involves strenuous efforts to incorporate subroutines to meet every minute requirements.

Geophysical data retrieved from the sensor 'Multi-channel Scanning Microwave Radiometer (MSMR) onboard the Indian satellite IRS-P4 (Oceansat I)' has been validated on this system by making use of various sea truth platforms. Drifting buoy SST's appear to be highly correlated ($r = 0.75$) with the satellite data. Very good correlation ($r = 0.80$) is

obtained for wind speed measured from both Moored buoy and Autonomous Weather Station. Night time SSTs are found to be closer to the satellite values for wind speed less than 10 m/s and day time SSTs are better correlated for wind speed greater than 10 m/s. Wind speed from stationary platforms are better correlated with the satellite values when compared with moving platform like ship. Wind speed measured from ocean platforms (Moored buoy and Ship) during day time appears to be closer to the satellite measurement but the night time wind gives better correlation when measured from the island-based weather station.

Key words: Validation, microwave sensor, autocorrelation, sea surface temperature, wind speed, columnar water vapor

INTRODUCTION

Geophysical data products measured from space has tremendous advantages over the conventional data collection methods. Synoptic coverage of space mounted sensors make it possible to reach out remote areas including those hostile to human approach that too with asking periodicity. Technology has developed to such an extent to provide acceptable accuracy in measuring several oceanographic as well as meteorological parameters from such altitudes. But the dynamics of both ocean and atmosphere make the entire process so complex that a certain level of uncertainty do exists in the geophysical parameter retrieval algorithms. Therefore the data retrieved from the space mounted sensors needs to be validated by making use of the synchronized ground observation. In this exercise the coefficients in the algorithms are fine tuned using the collocated data set to produce more accurate data products. Hence validation is an important component of any satellite mission.

India has launched her first operational oceanographic satellite [IRS-P4 \(oceansat I\) in May 1999](#). It carried two sensors namely Ocean Colour Monitor (OCM) and Multi-channel Scanning Microwave Radiometer (MSMR). OCM operates on the visible part of the spectrum and has the potential to monitor the coastal fishery resources while the later being a microwave radiometer, senses both atmosphere and ocean to produce valuable data that are useful to study the air sea interaction and monsoon. Objective of the mission was to address the above two important processes which has remarkable influence on the welfare of the nation. Several such national and international missions are planned to take off in the coming decade to address processes occurring over the earth system consisting of land, oceans and atmosphere.

An interactive software package is developed and presented here for validating parameters retrieved from MSMR onboard Oceansat I. Software has the capability to validate any satellite data retrieved from microwave sensors provided the naming convention of the input satellite data file need to be reorganized to accommodate information of the grid size, month and year to provide instant access to the data base. The software was developed in Visual Basic to operate on a Windows 98 platform. The program passes through various phases while accepting options from the user. The various phases through which the program operates are - data base preparation, input data selection, spatial and temporal range selection and satellite data prediction. An outline of the PC version of the validation software with various modules is given in [Fig. 1](#). This interactive PC-based package is easier and faster in executing various options to reach the final results when compared with the conventional method of validation.

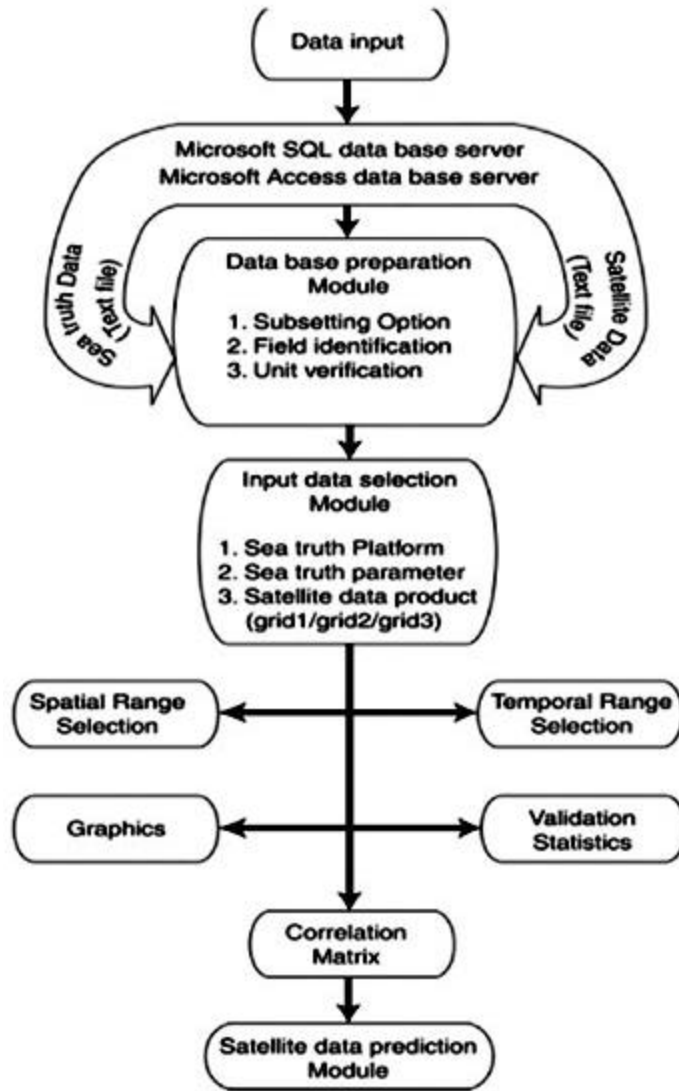


Figure1: Out line of various modules.

1.2. Basic Concepts

Remote sensing satellites are known to be launched at an altitude of approximately 800 km to revolve around the Earth in a inclined north-south orbit (polar orbit). This viewing geometry will felicitate data collection over the Earth surface in two modes namely ascending (northward path) and descending (southward path) modes. Satellite mounted sensor while moving in near polar orbit, collects data by scanning across the track. The width of the track is called its swath. This swath may lie directly below the passing satellite or away from its nadir depending upon its viewing geometry. Radiation emitted from the terrain is recorded at the satellite height in digital numbers and are often called radiance values received from corresponding ground elements. Such ground elements are called pixels or brightness temperature depending upon the context in which they are referred. Several such ground elements in both along the track and across the track direction constitute a scene. The geometrical area covered by each ground element is called the scene resolution. Since the scene resolution is constant, there is always a fixed number of cross track pixels called scan line. Several such scan lines constitute a satellite image.

1.3. Multi-channel Scanning Microwave Radiometer (MSMR)

MSMR is a passive microwave sensor onboard the Indian satellite IRS-P4 (Oceansat I) launched in May 1999. The primary objective of this mission is to provide systematic and repetitive acquisition of data of the earth's surface, under nearly constant illumination conditions. The satellite operates in a near circular, sun synchronous, near polar orbit with a nominal inclination of 98.28 degrees, at a mean altitude of 720 km. The mean equatorial crossing time at the descending node is 12:00 noon MAS MENOS 10 minutes. Details of this mission are described elsewhere ([IRS-P4 data user's hand book, 1999](#)).

MSMR provides global microwave brightness temperature measurements at 6.6, 10.65, 18 and 21 GHz frequencies with dual polarizations. The brightness temperature data product consists of 24 hr data and is generated on three different grid sizes with 150, 75 and 50 km spatial resolution. Grid 1 (150 km), Grid 2 (75 km) and Grid 3 (50 km) correspond to data acquired at 6.6, 10.65, 18 and 21 GHz frequency respectively. The 150 km grid is the nearest in size to the spatial resolution of the 6.6 GHz channel. All other frequencies are, therefore, used to generate data in this grid. Hence this grid will contain the brightness temperature data for all channels (ie. 6.6 GHz V/H, 10.65 GHz V/H, 18 GHz V/H and 21 GHz V/H). The 75 km grid is closer in size to the spatial resolution of the 10.65 GHz channels. Except 6.6 GHz, all other frequencies are, therefore, used to generate data in this grid. Hence this grid will contain the brightness temperature data for 10.65 GHz V/H, 18 GHz V/H and 21 GHz V/H channels. The 50 km grid is nearest in size to the spatial resolution of the 18 and 21 GHz channels. Except 6.6 & 10.65 GHz, all other frequencies are, therefore, used to generate data in this grid. Hence this grid will contain the brightness temperature data for the 18 GHz V/H and 21 GHz V/H channels only. These radiation data products are then transformed to the geophysical data product through radiation transfer models. The operational parameters retrievable from MSMR measurements are sea surface temperature (SST), sea surface wind speed (WS) and columnar water vapor (WV).

2. Data base preparation

The satellite and sea truth data files are initially generated in ascii format to access as text file. Reading this voluminous data files for one to one comparison is time consuming unless the fields are transformed into data base by making use of programs such as Microsoft Access, SQL server etc. The present software converts the text file to data base to expedite the processing speed by choosing any one of this data base servers. If the data set is exceptionally large (exceed 3 GB storing space) then the user should opt for SQL server for data base management as it is meant for handling very large data products. Availability of licensed version of SQL server is the natural prerequisite for selecting this option. Microsoft access is a better alternative as it is readily available with any system operating on windows 98 or similar platform. Area sub-setting option is also provided in this module for minimizing the task of reading unnecessary records while concentrating on area specific or time specific data. User need to identify the column of the respective fields of geophysical data derived from both satellite and sea truth platforms. Option for viewing files is also given for gathering the above information. Program creates its own data base having files with same naming convention in sub directories created under this module.

3. Input data selection module

On completion of the data base, one need to choose the sea truth platform and parameter for comparing with various satellite data products (grid1, grid2 and grid3) [[Fig. 2](#)]. SST, true WS, WV, air temperature (AT), wet bulb temperature (WBT) and sea level pressure

(SLP) are the parameters of importance when platform 'ship' is chosen. SST, WS, relative humidity (RH), AT and SLP are measured by moored buoy deployed at several places over the tropical Indian Ocean. SST and WS are the parameters retrievable from drifting buoys. Island based autonomous weather station (AWS) is designed to record all surface meteorological parameters at a regular interval of time. User can opt these data one by one to compare with the satellite data. Upon completion of one parameter the software provides 'back' button to come to the previous module to select a different option.

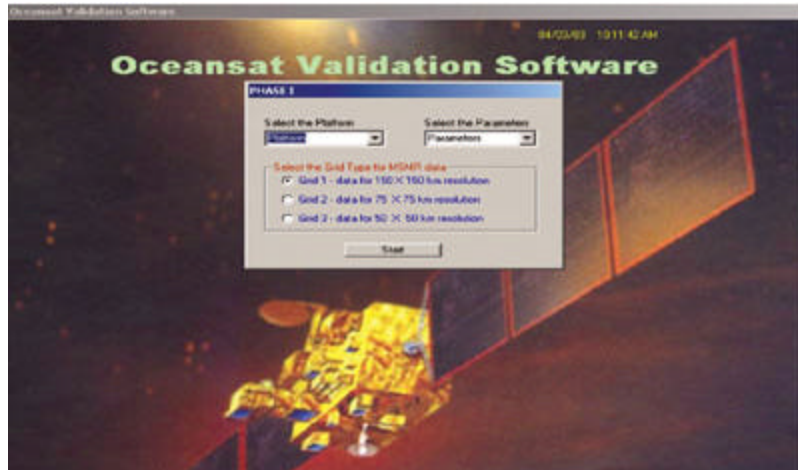


Figure 2: Satellite-seatruth data specification window

4. Spatial and temporal range selection

It is extremely difficult to find a perfect match between a satellite and ground based observations due to the simple reason that both the platforms are in constant motion. Several measurements are made from satellite while passing over a sea truth platform. So a number of observations from space are available in spatial and temporal scale to surround the sea truth data point. The number varies with the extent of spatial and temporal windows to be fixed around the sea truth point. Weighted average of this group of satellite data falling on this spatial and temporal grid denotes the synchronized match-up. The nature of relationship between satellite and sea truth seems to vary with the change in spatial and temporal grid size.

This variation also depends upon the kind of sea truth parameter under investigation. Autocorrelation analysis indicate that the temporal variation of sea surface temperature is much less when compared with the sea surface wind speed ([Muraleedharan, 2003](#)). However the spatial variation restricts to the foot print size of the respective sensor with frequencies suitable to retrieve various parameters. To be on the safe side, the present software considers 2 degrees and 120 minutes as the upper limit of the spatial and temporal windows respectively on either side of the sea truth point. Hence this serves as the default option. Spatial module has the options for lower grid sizes such as 1.50, 1.00 and 0.50. Similarly temporal module provide options for 90, 60, 30 and 15 minutes windows. The module has the provision for saving (if opted) the match up tables for various spatial and temporal window combinations ([Fig.3](#)).



Figure 3. System window for defining path to save intermediate data files.

4.1. Scheme for removing spurious satellite data

The satellite-sea truth match up obtained has several spurious combinations as the difference turns out to be extremely large at various occasions. Presence of such data set makes the entire relationship unrealistic and needs to be discarded. Hence a scheme was devised using this software to remove the spurious data combinations while performing the final statistical computations ([Muraleedharan et al., 2003](#)).

The collocated data sets of both SST and WS were subjected to this scheme of analysis. The correlation coefficients were calculated for each set of SST/WS data. The correlation improves for both cases when the scatter is reduced. An X-Y plot between correlation coefficient (r) and the sea truth-MSMR difference discarded is shown in figure 4A. The value of r is highest for SST/WS when the sea truth-MSMR difference is brought to a minimum of 1 or 1m/s but the number of data units discarded reaches 90%, which is definitely unscientific. The correlation coefficient keeps decreasing as the discarded sea truth-MSMR gap widens. The number of data points discarded is, therefore, directly proportional to the correlation coefficient. It is interesting to note the nature of relationships for sea surface temperature and sea surface wind speed. In both cases there is inverse relationship between sea truth-MSMR difference discarded and the correlation coefficient. But the relationship is exponential for SST and linear for wind speed. This implies that r does not vary drastically for wind speed when the sea truth-MSMR difference increases. The correlation coefficient for SST appears more or less constant beyond a certain value of sea truth-MSMR difference (say 6 C).

[Figure 4B](#) illustrates the relationship between percentage of data discarded and the sea truth-MSMR difference. The patterns are more or less the same as in the previous case. SST curve remains exponential while the WS is closer to a linear relationship. Three degree cut off limit in SST data yields a correlation coefficient of 0.40 ([Fig. 4A](#)) allowing a data loss of 20% ([Fig. 4B](#)). The relationship is quite statistically significant with this value

of r when it represents 80% ($n > 1000$) of the samples. The corresponding cut off limit for WS is 7 m/s to sustain a statistically significant correlation coefficient of 0.60 (Fig.4A). Here the sea truth-MSMR difference higher than 7 m/s accounted for about 20% of the total sample. In short, in the present validation exercise, the collocated data set for SST represents only those MSMR values which are close to the ground truth by ± 3 C. The remaining values higher than this cut off limit are discarded. Similarly the cut off limit for wind speed is ± 7 m/s.

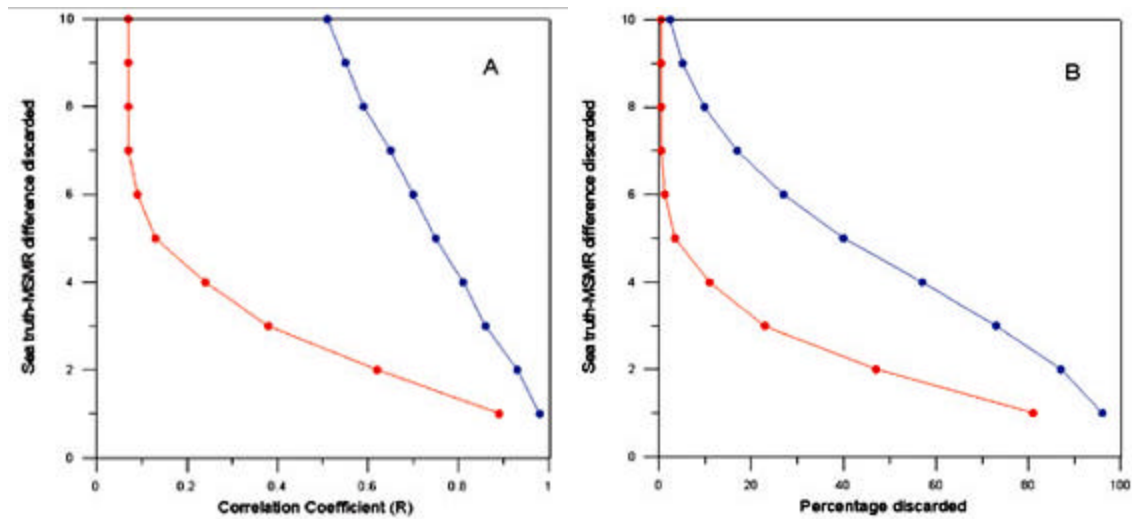
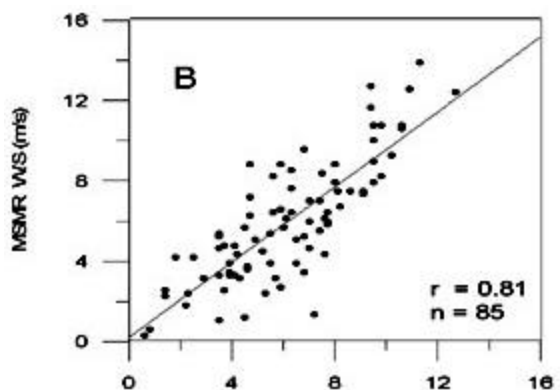


Figure4: Coefficient of correlation (r) between satellite and sea truth values when the scatter higher than various thresholds is discarded. Percentage of the data lost when the scatter higher than various thresholds is discarded.

5. Satellite data prediction module

Collocated data match-ups are then subjected to statistical analysis to compute the bias, Root Mean Square Deviation (RMSD), Coefficient of correlation (r) etc. Variation of RMSD was very marginal for SST data even after the removal of bias whereas the variation was significant for WS once the bias is removed. Option is also available for choosing day time and night time (or both) data match-up separately while performing the operation under this module. Drifting buoy SSTs ($r = 0.75$) and moored buoy wind speeds ($r = 0.80$) were having high correlation with the satellite measurements (Fig. 5).



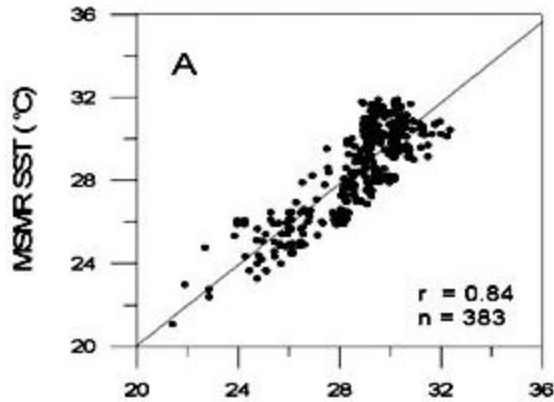


Figure 5: A scatter plot of (A) MSMR SST vs Drifting buoy SST (B) MSMR WS vs Moored Buoy WS.

The importance of day and night discrepancies in the validation of both SST and WS are illustrated in Fig. 6 & 7. Night time SSTs are found to be closer to the satellite values for wind speed less than 10 m/s and the opposite is true for wind speed greater than 10 m/s (Fig. 6). Wind speed from stationary platforms like Autonomous Weather Station and Moored Buoy are better correlated with the satellite values when compared with moving platform like ship (Fig. 7). Night time wind speeds are better correlated with satellite data than its day time counterpart for land based platforms (AWS) but the day time winds are closer to satellite data for ocean platforms like Ship and Moored buoy (Fig. 7). The software can pick up such vital clues leading to the understanding of ocean-atmosphere coupling mechanism and its affects on the radiation transfer models.

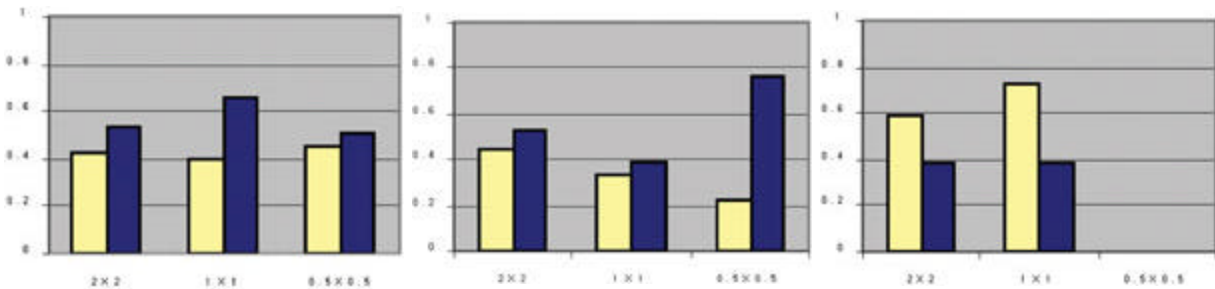


Figure 6: Day and night correlation (r) between drifting buoy SST and MSMR SST at various spatial windows (1 hour temporal window) for different wind conditions.

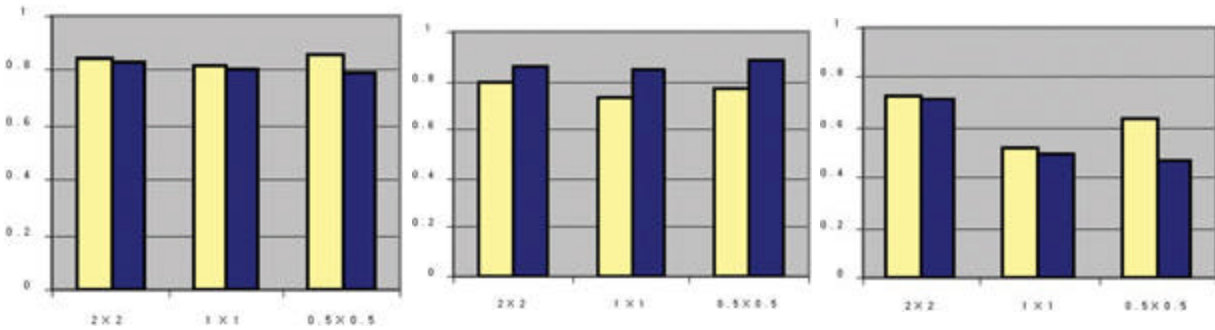


Figure 7: Day and night correlation of MB (left), AWS (middle) and Ship (right).

After identifying the best regression fit for a given parameter, the program proceed further to predict the new set of satellite values by making use of the relationship. The new set of satellite data is used to compare with other satellite/model data products. In [Fig. 8](#) the monthly mean MSMR SST maps of June 2000 are compared with both Levitus climatology (June) and [Reynolds reanalysis data \(June 2000\) \[1994\]](#). Major thermal features of the tropical Indian Ocean were depicted in all the three maps during the onset month of the south-west monsoon season. Comparison of MSMR derived monthly mean wind speed data of July 2000 with other satellite data products such as SSM/I [Special Sensor Microwave Imager onboard DMSP (Defense Meteorological Satellite Program) satellite] wind climatology of July and QuikSCAT monthly wind field during July 2000 yielded encouraging results ([Fig. 9](#)). All the three maps depict the wind pattern of a typical monsoon month.

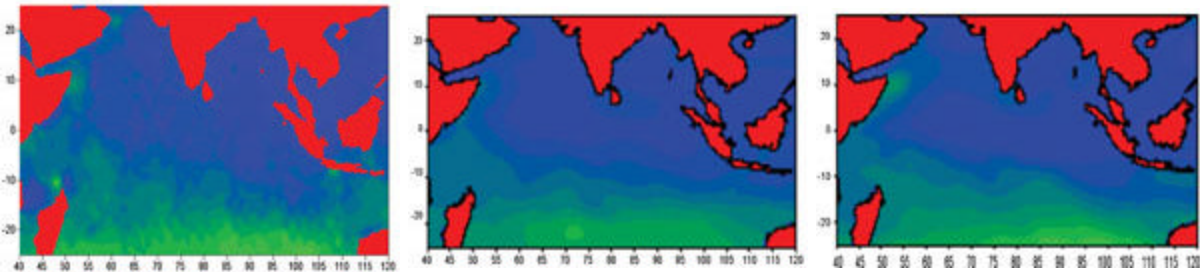


Figure 8: Monthly mean SST maps of MSMR (June 2000) [left], Levitus climatology (June) [middle] and Reynolds reanalysis data (June 2000) [right].

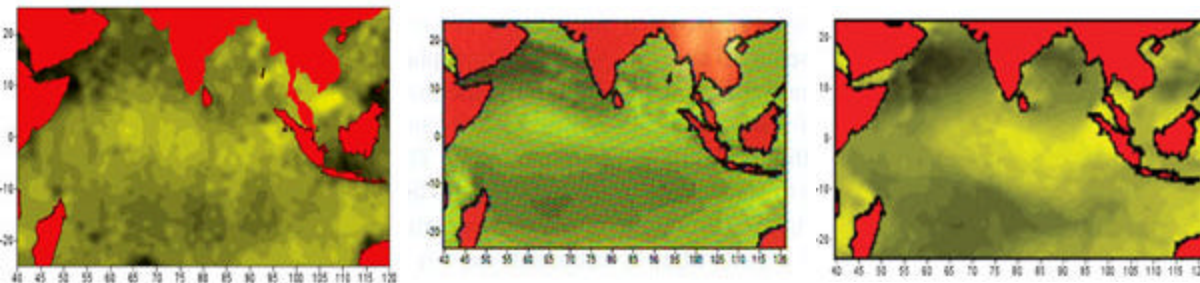


Figure 9: Monthly mean wind speed maps of MSMR (July 2000) [left], SSMI wind climatology of July [middle] and QuikSCAT monthly wind field during July 2000 [right].

DISCUSSION

An interactive software package has been developed and presented for validating the passive microwave sensor MSMR onboard the Indian satellite IRS-P4 (Oceansat I). The satellite was launched in May 1999. The microwave radiometer is designed to measure brightness temperature in four dual polarization channels such as 6.6, 10.65, 18 and 21 GHz. The operational products that are retrievable from these channels are sea surface temperature, wind speed and columnar water vapor. First two channels are sensitive to SST and WS respectively while the third and fourth channels are meant for retrieving columnar water vapor. The retrieved geophysical products are available in three grid sizes (spatial resolutions) viz; grid 1 (150 x 150 km), grid 2 (75 x 75 km) and grid 3 (50 x 50 km). Sea truth platforms such as ships of opportunity, drifting buoys, moored buoys and island weather station were employed for validating the satellite product. The validation period stretched from June 1999 to the end of 2001.

The program performs the validation exercise in user interactive mode. User defined text files (sea truth and satellite data files) are transformed into a data base for increasing the performance efficiency. User defined data base management platform is selected to accommodate the volume of data available. This can be either an independent SQL server or a more accessible Microsoft access. Provision is also provided in this software to subset the global data to suite the commonly available Microsoft access platform. Input data fields are to be identified under this module with appropriate units for preparing the data base tables. The program displays the available parameters upon opting the platform in the subsequent module. User need to specify the type of satellite data to be validated. All geophysical parameters could be retrieved under the wider foot print of 150 km by making use of grid1 data product. 75 km (grid 2) is the minimum spatial resolution required for retrieving wind speed. Water vapor retrieval is possible in all the three grids as it needs only a spatial coverage of 50 km. The program checks the satellite product one by one to see its closeness to the sea truth value. Read-me files are provided at every stage to guide the user for smooth interaction.

The relationship between satellite and sea truth data has to be established for various spatial and temporal windows to understand the nature of variability. [Wentz et al., \(2000\)](#) has discussed the effect of satellite-buoy spatial-temporal sampling mismatch in the observed higher RMSD while comparing SST from microwave radiometry with ocean buoys. The program provides option for several space-time window combinations to try out the relationships. The option is crucial for validating those parameters which vary drastically with space and time. Experimental data output for various window combinations are selectively stored under specified sub directories if required. Collocated data points obtained in such window combinations often shows poor relationship due to the presence of spurious satellite data. These spurious data combinations are removed by following certain scheme to improve the coefficient of correlation by safeguarding the significance of the statistical relationship. The processed data match-ups are then subjected to the statistical computations to bring out a new relationship to predict a new set of corrected satellite data. Option is also available for looking at day and night variation of this relationship. This would enable one to understand the significance of such changes in view of noticeable environmental perturbations. This is essential for any validation exercise as the satellite often retrieves the skin temperature and is quite sensitive to the diurnal changes occurring over the atmospheric boundary layer.

The software is capable of bringing out certain properties of the sea truth-satellite combinations which is often left unnoticed. The efficiency of various sea truth platforms in measuring surface meteorological parameters appears to be non uniform when compared with satellite values due to several reasons. Drifting buoy seems to be an ideal platform

for SST while both MB and AWS (island) invariably exhibit certain level of bias in measuring WS but retains relatively high correlation. Moreover the night time SST compares very well with satellite value when the wind speed varies from 0 to 10 m/s and maintains this correlation during day time only when there is higher wind speed (> 10 m/s). Satellite measures the temperature of the thin surface layer as it contribute more to the emissivity whereas the conventional sea truth platforms measure SST represented by the surface 2 m layer (Wick *et al.*, 1992). Diurnal variation of air temperature will instantly modify the temperature of the surface layer immediately in contact with the atmosphere which will in turn modify the emissivity and the satellite values. This variation is not necessarily picked up by the conventional sea truth platforms. This would contribute to the apparent difference in *r* for light wind conditions. Surface mixing is often associated with high wind speed which ultimately destroy surface layer stratification enabling the satellite to pick up the bulk temperature.

In general, the wind speed measured from stationary platforms correlates very well with the satellite data and deteriorates when taken from moving platform like ship. Another interesting aspect of this day-night discrepancy, picked up by the program, is apparent on the selection of platform. Wind speed measured during day time are better correlated with satellite values for ocean platforms (MB & Ship) but night time correlation is better for wind speed measured from land (AWS). No satisfactory explanation is available for this day-night ambiguity at this point of time. The land contamination of the radiation received at the satellite due to the presence of a small piece of land in the fairly big field of view of the microwave sensor cannot be ruled out completely and its ability in modifying the radiation to affect the day-night discrepancy is worth studying.

ACKNOWLEDGMENTS:

We thank the Director, National Institute of Oceanography for providing facilities to carryout this work. We are also indebted to the Director, Space Application Center, Ahmedabad for providing the financial support for undertaking this experiment. Sincerely acknowledge the efforts of Mr. Shoby Thomas, Project Trainee for writing the program code in Visual Basic.

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