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SOFTWARE FOR VALIDATING PARAMETERS RETRIEVED FROM SATELLITE

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ABSTRACT

A PC-based interactive software has been developed and presented here for validating geophysical data retrieved from satellite mounted sensors operating in visible, infrared and microwave frequencies. The program, coded in Visual Basic, is user interactive and runs on Windows-98 or higher platforms. The system prepares the database on a pre-selected Microsoft platform to enhance processing efficiency. Sub-setting option is also provided to reduce the processing time. Data retrieved from Multi-channel Scanning Microwave Radiometer (MSMR) onboard the Indian satellites Occansat-1 during 1999-2001 were validated using this software as a case study. The program has several added advantages over the conventional method of validation that involves strenuous efforts to incorporate subroutines to meet every minute requirement. Satellite-sea truth relationships on various space-time window combinations are determined and exhibited in matrix form to visualize the nature of correlation. User has the option to visualize the satellite-sea truth relationship through graphical representations before selecting optimum relationship for prediction.

Introduction

Geophysical data products generated from satellite mounted sensors have 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 assured periodicity. Potential of satellite sensors in understanding processes occurring over the land is well documented. But the dynamics of both ocean and atmosphere make the entire process so complex that a certain level of uncertainty exists in the geophysical parameter retrieval algorithms. Therefore the data retrieved from the space mounted sensors need to be validated by making use of the

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synchronized ground observation. The retrieved coefficients in the algorithm are required to be fine-tuned with post launch validation in view of any bias and/or noise present in the data (Gohil *et al.*, 2000).

The interactive program developed and presented here has the capability to validate any satellite data measured by virtue of reflection or emission from the terrain (including ocean) or from the intervening atmosphere. The software was developed in Visual Basic to operate on a Windows 98 platform. The various phases through which the program operates are - data base preparation, input data selection, spatial and temporal range selection and corrected satellite data prediction from the best possible regression equation. 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. Potential of the software is demonstrated by validating the microwave sensor MSMR (Multi-channel Scanning Microwave Radiometer) onboard the Indian satellite Oceansat I, as a case study.

Multi-channel Scanning Microwave Radiometer (MSMR)

MSMR is a microwave sensor onboard the Indian satellite Oceansat 1 launched in May 1999. The satellite operates in a near circular, sun synchronous, near polar orbit. MSMR provides global microwave brightness temperature measurements at 6.6, 10.65, 18 and 21 GHz frequencies with dual polarizations. The operational parameters retrievable from MSMR measurements are sea surface temperature (SST), sea surface wind speed (WS) and columnar water vapor (WV). The data products consist of 24 hr data in three different grid sizes with 150, 75 and 50 km spatial resolution on the earth's surface. Details of sensor specifications are given elsewhere (IRS-P4 Hand Book, 1999; Muraleedharan, 2003).

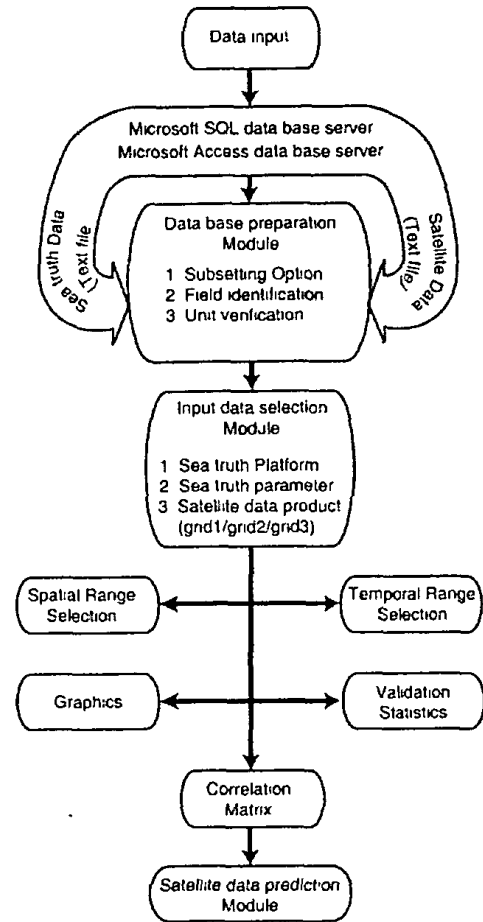


Fig. 1. An outline of the validation software

Data base preparation module

The satellite and sea truth data files are available in ASCII format to access as text files. This module transforms these text files into data bases for quick processing by using programs such as Microsoft Access, Microsoft SQL server etc. (Fig. 2). Online-help is provided at every stage. The user selects input file and the platform for generating respective data base tables. Options for viewing these data tables are also given. Column details of the text file are to be entered in the next window to generate the database under global mode (Fig. 3). Provision for area sub-setting is also provided for generating area specific or time specific data under regional mode. After the data base preparation the program enters into the validation phase.

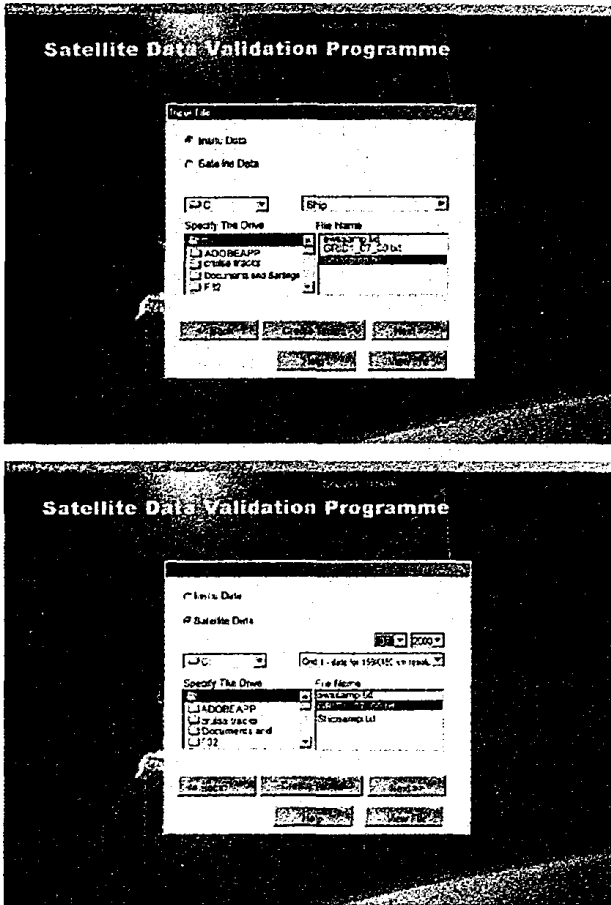


Fig. 2. Sea truth (top panel) and satellite (bottom panel) data import window for data base preparation.

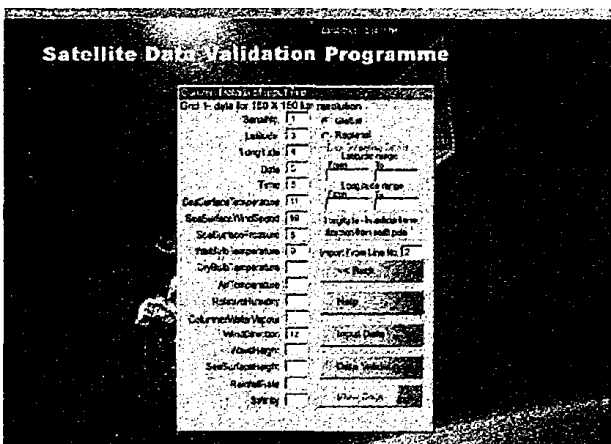


Fig. 3. Data base column details and data sub-setting window

Validation module

This module establishes relationship between satellite derived parameter and the corresponding in situ observation. It is extremely difficult to find a perfect match between a satellite and ground based observations due to the simple reason that one or both the platforms may be in motion. Satellite travels much faster than ships or drifting buoys and hence, several measurements are taken by the satellite while passing over a sea truth platform. Therefore several data match-ups are examined in various space-time window combinations to obtain reasonably closer and statistically significant relationship.

Spatial and temporal range selection

A large number of satellite measurements are, therefore, available in spatial and temporal scale for a single sea truth data point. The number varies with the dimension of spatial and temporal windows to be fixed around the sea truth point. Weighted average (see appendix) of satellite data falling within the selected spatial and temporal window denotes a synchronized match-up. Various spatial and temporal windows are selected to examine the nature of match-ups obtained. In case of MSMR validation exercise, upper limit of this selection was based on the following criteria. The drop in autocorrelation coefficient for SST was found to be marginal over a 24 hr time window while it deteriorates fast for WS even after 3 hr (Muraleedharan *et al.*, 2004). The spatial distribution of the standard deviation of each of the MSMR parameters with different windows fell within the pre-launch projected accuracy of 1.5° (Ali *et al.*, 2000). The present software, therefore, considers 2 and 320 minutes as the upper limits of the spatial and temporal windows respectively on either side of the sea truth point. A match-up table for various space-time window combinations are created for further analysis.

Scheme for removing spurious satellite data

The satellite-sea truth match up tables thus obtained have several spurious combinations as the

difference between satellite derived and the in-situ data turns out to be extremely large on various occasions. Presence of such data points make the entire relationship less significant and needs to be discarded. Hence a scheme was devised using this software to remove the spurious data combinations without disturbing the significance of relationship. The software has the provision to display data statistics of the selected combination such as the bias, root mean square deviation (RMSD), correlation coefficient etc.

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 Fig. 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 unrealistic. The correlation coefficient keeps decreasing as the discarded sea truth-MSMR gap widens.

Fig. 4b illustrates the relationship between percentage of data lost and the sea truth-MSMR difference discarded. 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 V 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 (WS) represents only those MSMR values which are close to the ground truth by 3°C (7 m/s) in default mode. User has the option of changing this cut off limit with appropriate reasoning.

Satellite data prediction module

Satellite match-ups within the user specified space-time window combination are subjected to statistical analysis to determine the best fit. This is performed by computing correlation coefficients (r) for various window combinations pertaining to each

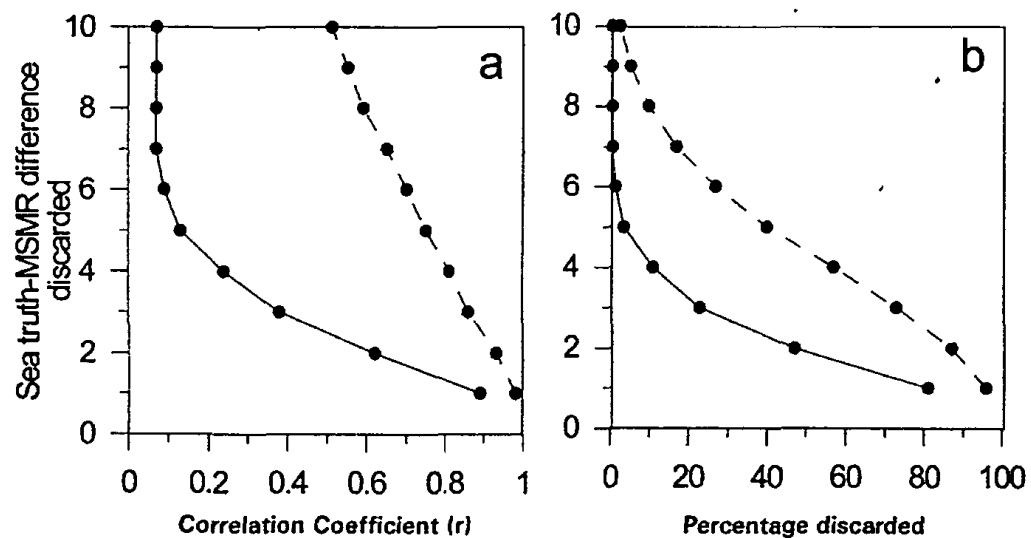


Fig. 4. Correlation coefficient between satellite and sea truth values when the scatter higher than various thresholds is discarded (a), percentage of the data lost when the scatter higher than various thresholds is discarded (b)

platform and to choose the best statistical relationship based on the coefficient of correlation obtained. At this stage user has the option to overrule the logical decision arrived at by the program by choosing another space-time window combination based on adequate reasoning. The selected combination is then saved and displayed with all statistical estimates in the next window under data prediction module. The exercise is repeated for other platforms measuring the same parameter and eventually for other geophysical parameters and satellite data products. Best relationship pertaining to a geophysical parameter is then chosen and the corresponding regression equation is used to predict the new set of corrected satellite data (after removing bias) and the same is saved in the user specified directory. The final corrected data is then subjected to scientific analysis and the results are explained on the basis of air-sea exchange processes.

Results and Discussion

Our program establishes the relationship between satellite and sea truth data for various spatial and temporal windows to understand the nature of its variability. Wentz *et al.* (2000) have discussed the effect of satellite-buoy spatial-temporal sampling mismatch while comparing SST from microwave radiometry with ocean buoys. Our program provides option for several space-time window combinations to study the relationship. Option is also given to examine the day and night variation of this relationship. The program displays the scatter plots of satellite-sea truth combinations as and when the user opts for it. The best relationship pertaining to a particular parameter is selected to predict a new set of satellite data. The predicted data was then analyzed to summaries results obtained from the case study.

The .software is capable of bringing out certain properties of the sea truth-satellite combinations that often remain unnoticed. The efficiency of various sea truth platforms that measure meteorological

parameters appears to be non-uniform. Drifting buoy (DB) seems to be an ideal platform for measuring sea surface temperature (SST) while both moored buoy (MB) and autonomous weather station (AWS) invariably exhibit certain level of bias in measuring wind speed (WS) (Fig. 5). One-degree latitude-longitude spatial window seems to be suitable for validating both SST and WS as the correlation peaks in this (spatial) window- However the correlation peaks in 120 minutes temporal window for SST and 15 minutes for WS (Fig. 6). In short, unlike WS, SST does not vary much with time. The night-time SST compares very well with satellite value when the wind speed is less than 10 m/s and maintains this correlation during day time only when wind speed is higher 10 m/s (Fig.7). Satellite measures the temperature of the thin surface layer (skin temperature) whereas the conventional sea truth platforms (MB) measure temperature represented by the upper 2-3 m layer (Wick *et al.*, 1992). During the day, the air temperature instantly modifies the skin temperature of the sea and that in turn modifies the satellite values. This variation is not necessarily picked up by a moored buoy. This contributes to the decrease in r for light wind conditions. Surface mixing is often associated with high wind speeds that ultimately destroy surface layer stratification enabling both the satellite and MB to pick up the same bulk temperature. So the correlation tends to increase. On the contrary, during the night, surface cooling induces mixing which results in deepening of surface mixed layer. Both satellite and MB measure this bulk temperature and the relationship tends to increase even when the wind speed is below 10 m.

In general, the wind speed measured from stationary platforms correlates very well with the satellite data. The correlation deteriorates when wind speed is measured from a moving platform like ship (Fig. 8). Wind speed measured during day time is better correlated with satellite values for ocean platforms (MB and Ship) while night time correlation is better for winds measured from land (AWS).

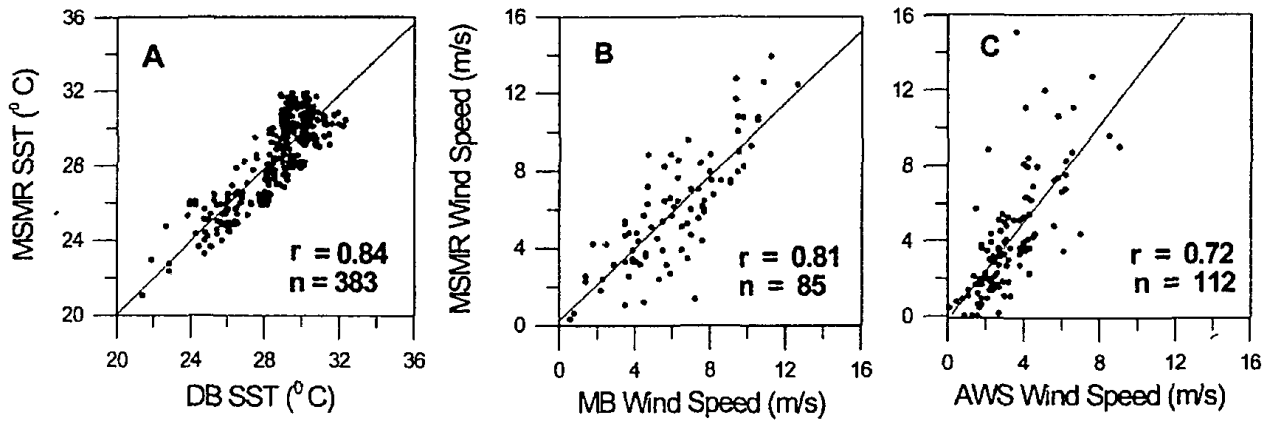


Fig. 5. Scatter plots of DB-SST (a), MB-WS (b) and AWS-WS (c) between sea-truth and Satellite.

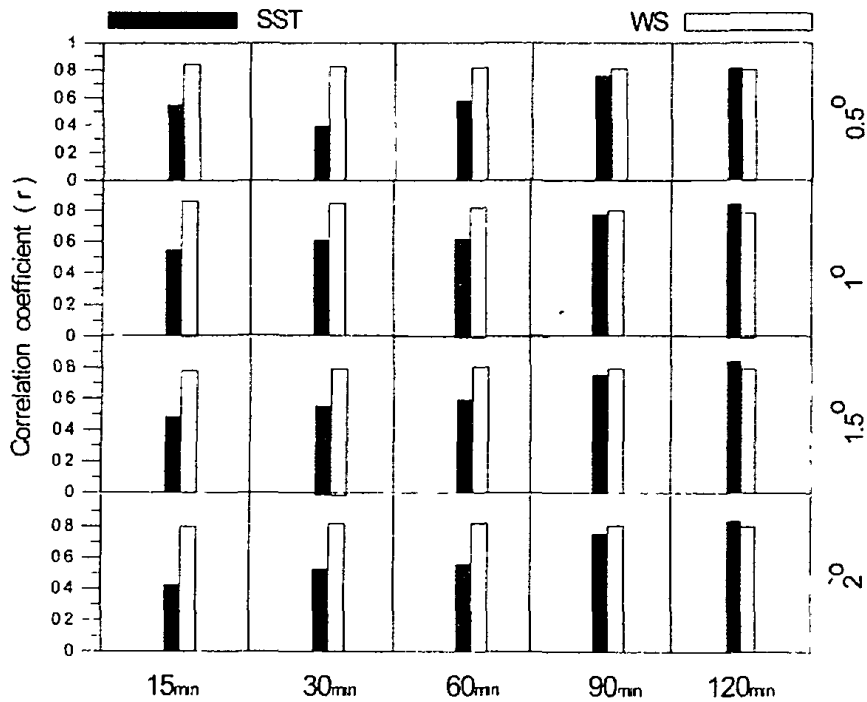


Fig. 6. Correlation coefficient between sea truth (DB-SST and MB-WS) and satellite (MSMR) at various spatial and temporal windows.

Our software has the capability to bring out such subtle properties of satellite-ground truth combinations successfully and with minimal effort from the user. Carefully selected modules have not only increased the efficiency of interaction but also enhanced the quality of validation.

Summary

PC-based software is presented for validating satellite derived parameters using data collected from various ground based instruments. The program, coded in Visual Basic, is user interactive

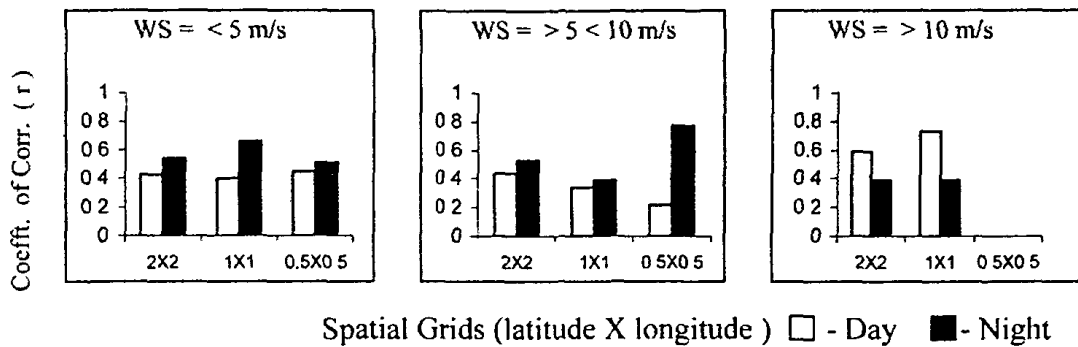


Fig. 7. Day and night correlation between satellite and sea truth based SST's for various wind conditions in different spatial grids.

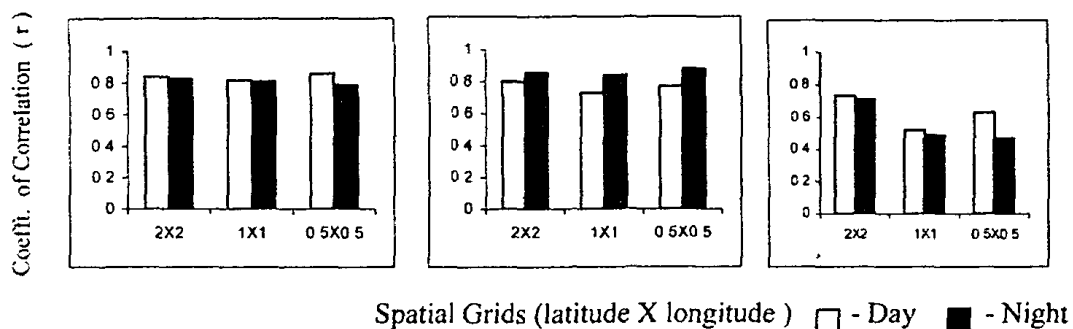


Fig. 8. Day and night correlation between satellite and sea truth wind speed measurements for various spatial grids [MB (left panel), AWS (middle panel) and Ship (right panel)].

and runs on Windows-98 or higher operating systems. The program has the option for choosing appropriate platforms such as Microsoft Access or Microsoft SQL server. Option for 'Help' is provided at every stage. MSMR data collected onboard IRS-P4 satellite was then taken as a case study to test the software. Data base preparation module imports both *in situ* and satellite data from ASCII format to the data base. Spatial and temporal sub-setting option is also provided to save processing time. Several space-time window combinations were provided to search for synchronized satellite-sea truth data points and to determine the best fit for each parameter and subsequently for various platforms. In this process spurious satellite data are filtered out to provide realistic relationship. Correlation coefficient of the collocated points falling at various space-time window combinations

for each parameter is displayed in matrix form for the user to pick the best fit pertaining to a particular parameter. Best statistical fit for parameters from various platforms are again displayed in the next window for the user to choose the best relationship to predict corrected satellite data and the same can be saved in the user specified directory. A graphical module is also incorporated to visualize the relationship in graphical form and save it in user specified format in user specified directory.

Corrected MSMR data was then subjected to scientific analysis to reconfirm the ability of the software to produce meaningful data products. Drifting Buoy is proved to be a better platform for validating satellite-SST values compared to MB or Ship-based measurements. Relationship between satellite and MB derived SST at various wind

conditions is unambiguously demonstrated over the eastern Arabian Sea and explained on the basis of ocean-atmosphere coupling processes. Wind speeds measured from stationary platforms are more efficient in comparing satellite values when compared to moving platforms. Similarly day time WS from ocean platforms is better correlated with satellite values. However, night time correlation is better for winds measured from land based platforms.

Appendix

The space window chosen for locating the synchronized satellite match ups is one degree on either side of the ground truth position (for example 1° latitude and 1° longitude grid). Similarly the time window chosen is 60 minutes on either side of the observation time. So we get several satellite values against one ground truth data point. Steps to determine the weighted average of all those satellite data, against the single ground truth, is as follows.

Let there be 'n' number of satellite match ups against an *in situ* SST observation. X_i and Y_i refer to latitude and longitude of the i^{th} (i varies from 1 to n) satellite match up, respectively. Similarly X_g and Y_g are latitude and longitude of the *in situ* observation.

Distance between *in situ* and satellite observation is obtained for various satellite match ups from the relation,

$$d_i^2 = (X_i - X_g)^2 + (Y_i - Y_g)^2$$

$$W_i = \frac{1}{d_i^2}$$

Now the weighted average of SST is obtained from the following relation

$$t_w = \frac{\sum (W_i * t_i)}{\sum W_i}$$

where t_w is the weighted average SST
 t_i is the satellite SST

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