ANALYSIS OF MARINE AIR TEMPERATURE MEASUREMENTS OBTAINED FROM BRAZILIAN BUOYS TRACKED BY POLAR ORBITING SATELLITES

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ABSTRACT

Environmental data collected from drifting oceanographic buoys tracked by satellite are making an important contribution to both the overall oceanographic data base, and through their use, to a better understanding of air/sea interaction processes. Air temperature data, when combined with water temperature data, allows the scientist to calculate sensible heat fluxes across the ocean's interface. Drifting buoys, including those developed by Brazil, have the ability to transmit a nearly continuous time series of these data, from any place on the Earth for periods of weeks to months. Because a satellite in polar orbit (e.g., NOAA-N) is normally above a buoy's regional horizon for several minutes during each overflight, the buoy's transmissions, made at one minute intervals, will produce a small data set for each overpass. These small sized data samples are used to determine a mean air temperature for each of the 6-15 overflights per 24-hour day. Because the air temperature sensors are of necessity located close to the sea surface on small buoys, waves or ocean spray may frequently wet this sensor during stormy conditions. A wet sensor provides temperatures that are indicative of a wet bulb thermometer, not a dry bulb thermometer. The result is that some of the individual measurements from each overflight may be wet (contaminated), and thereby provide lower than expected temperatures. It is important to eliminate or minimize the effect of these "wet" air temperature readings on the good (dry) temperature data, before these data are used in later analyses. A careful analysis of the air temperature data collected from a drifting buoy launched during the IV Brazilian Antarctic Expedition, shows that a statistical approach may be used to minimize this problem from the air temperature data. The statistical method developed and used to largely eliminate these comtaminated air temperature measurements is explained and the resulting improvement in the quality of air temperature measurements is estimated.

RESUMO

Dados ambientais coletados por boias oceanográficas de deriva observadas via satélite, tem dado uma importante contribuição para a integração de uma maior base de dados oceanográficos e, através de seu uso, um melhor entendimento dos processos de interação ar/mar. Dados de temperatura do ar quando combinados com dados de temperatura da água, permitem aos cientistas calcular os fluxos de calor sensível através da interface do oceano. Boias de deriva, incluindo aquelas desenvolvidas no Brasil, tem capacidade para transmitir uma série de tempo desses dados aproximadamente continua, em qualquer região da terra, por períodos de semanas até meses. Devido o satélite em órbita polar (e.g., NOAA-N) estar normalmente sobre o horizonte dentro do qual está localizada a boia, por vários minutos, durante cada sobrevôo, a transmissão da boia, feita em intervalos de um minuto, produzirá um pequeno grupo de dados a cada passagem. Essa pequena amostragem de dados será usada para determinar a temperatura média do ar para cada 6-15 sobrevoos por dia. Devido os sensores de temperatura do ar estarem necessariamente localizados próximos a superfície do mar, sobre pequenas boias, ondas ou "spray" do oceano podem frequentemente umedecer este sensor durante condições de tempestade. Um sensor úmido fornece medidas de temperatura que são indicativas de um termômetro de bulbo úmido, e não termômetro de bulbo seco. O resultado é que algumas das medidas individuais de cada sobrevôo podem ser umida (contaminados), e por causa disso fornecer temperaturas mais baixas do que o esperado. É importante eliminar ou minimizar o efeito dessas leituras de temperatura do ar "úmido" sobre os dados bons de temperatura (seco), antes que os dados sejam usados em análises posteriores. Uma análise cuidadosa de dados de temperatura do ar recolhidos de uma boia de deriva lançada na IV Expedição Antártica Brasileira, mostra que uma aproximação estatística pode ser usada para eliminar grande parte desses problemas de dados de temperatura do ar. É explicado um método estatístico desenvolvido e utilizado para eliminar grande parte dessas medidas de temperatura do ar contaminado, assim como também é estimado a melhoria resultante na qualidade das medidas de temperatura do ar.

1. INTRODUCTION

Measurements of air and sea surface temperatures play an important role in studies of air-sea exchange processes. This research is basic to our ability to understand changes in climate, on a regional to global scale. The ability to understand as well as predict climate changes is based in large part on our ability to acquire these important data.

The historical method used ships to acquire these marine air and water temperatures. The ever greater cost of ship operations, combined with the vastness of the world's oceans, has unfortunately continued to result in very irregular spatial coverage of these data. With continual improvements in modern technology, instrumented buoys have been developed and in use by various countries during the past 1-2 decades. The early buoys, however, possessed a number of limitations such as unproven reliability of automatic equipment, limited autonamy due to the power supplies,etc.

The most promising type of instrumented buoy to date incorporates a transmitter (or data collection platform-DCP) within the buoy, capable of transmitting environmental data to satellites passing over the buoy, in their polar orbits (System ARGOS). More than 300 such buoys were successfully used in 1979-1980 by the First GARP Global Experiment in a comprehensive study of the Southern Ocean (Keeley and Taylor, 1981). By using these satellite-tracked buoys, countries such as Brazil can obtain the needed data coverage in remote or inacessible regions of the world ocean. Moreover, these modern buoys offer the advantages of low initial and operating costs, are sturdy floating platforms, carry dependable environmental sensors, and possess an operational autonamy of up to 1-2 years.

Among the first environmental sensors to be included in the Brazilian (INPE's) buoy were those used for measuring air and ocean temperature (Stevenson and Barbosa, 1986). Thermistors were used as the temperature sensing elements for both types of sensors.

The buoy's biconic form provides a low profile for reduced wind drag (Figure 1). This is necessary if the buoy is to closely follow the surrounding water motion (current). While the low profile poses no problems for the water temperature sensors, the proximity of the air temperature sensor to the sea surface may cause the sensor to become wet from breaking waves or wind driven spray.

When wet, the air temperature sensor provides temperature readings different from those observations obtained when the same sensor is dry. The dry sensor data must therefore be separated from the wetted sensor data, if the use of these observations is not to cause serious errors in the determination of parameters such as heat flux. The objective of this report to present a statistical method for the detection and separation of the good (dry sensor) from the bad (wetted sensor) data.

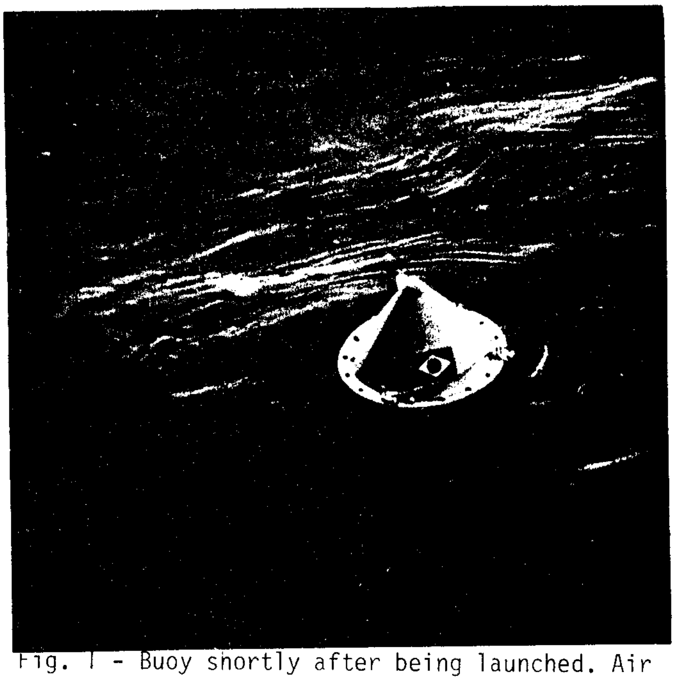

Fig. 1 - Buoy shortly after being launched. Air temperature sensor located inside small housing atop buoy.

2. DATA

Air temperature time series measurements were obtained from INPE's buoy Vilma during an experiment made in the Strait of Bransfield, Antarctica during March 1986. The air temperature data were available in the form of 8 bit words (0-255), covering a thermal range of approximately -30C to 10C with a discrete thermal resolution of 0.09C per count.

As noted in the Introduction, the DCP within the buoy transmitted data at nominal 60 second intervals. When one of the operational NOAA satellites passed over the buoy's geographic horizon, these transmissions were received and recorded. The duration of each overflight varied from 1 to 16 minutes with an average period of 11 minutes. In this report these small data sets (N=1-16 obs.) are referred to as high frequency (HF) data. Due to the high latitude of the experiment (63S) and the use of two operational NOAA satellite, about 20 HF data sets were received in a 24 hour day. Because these satellites do not pass over the same point on the earth at the same time each day, the time interval between successive data sets is irregular. Rough weather with high waves further increases the time interval, because the transmitting buoy may be frequently hidden behind these waves. During our experiment, the time interval varied from 1 minute to 3.4 hours; the average interval between reception of successive data was 63 minutes.

Because the individual measurements are transmitted at one minute intervals, the HF data can be averaged to obtain a single, more stable value for each overflight. The presence of one or more inaccurate (wetted sensor) measurements within any of the HF data, however, will adversely affect the quality of any subsequently derived values.

2. METHODOLOGY

Before discussing the details of the methodology, it is necessary to note that a wet bulb air temperature measurement will always be less than or equal to the corresponding dry bulb temperature. This result is due to the evaporation of a small quantity of water from the wet bulb, which removes thermal energy from the surface of the bulb. For a more detailed physical explanation see Haltiner and Martin (1957).

For our case the situation is more complicated because it is the dry temperature sensor that occasionally becomes wet. Also, the sea water that wets the sensor may be cooler or warmer than the actual (dry) air temperature. Warm water wetting the sensor will initially increase the temperature reading from the sensor; the opposite will occur if the water temperature is cooler than the actual air temperature. The effect of evaporation of water from the sensor, however, is to always cool the sensor through evaporation of the water on the surface of the sensor. During the Austral summer, the air temperature is often, but not always, warmer then the sea surface temperature. Since the situation of relatively warmer water wetting a cold air temperature sensor may be resolved by comparing such readings with the actual sea surface temperature, this report will concentrate on the problem associated with cooler sea water wetting a relatively warmer air temperature sensor.

The method used to detect those air temperature measurements most likely contaminated by the wetting of the sensor is similar to that developed by NOAA (Brower et al., 1976). Their problem was to detect thermal infrared temperature pixels contaminated by the presence of clouds in the field of view of a satellite sensor, where the cloud top temperatures are usually cooler than the ocean's surface. Because the contaminated temperature data are somewhat cooler than the uncontaminated temperature measurements, the method compares a statistically acceptable standard deviation (σ) for the data without contaminated measurements, with each experimental data set. A mean temperature based on a combination of the observations lying on the warm side of the data set mean is determined.

The first step, in detecting air temperature data contaminated by the sensor being wet at the time of measurement, was to determine a standard deviation for the high frequency data that was representative of "good" (dry sensor) measurements. The best approach was to use buoy data collected before the buoy's launch and to compare these observations to those obtained after the buoy was launched into the ocean. Because the buoy was turned on several days prior to its launch for a final test of its electronic circuitry and sensors, these data were available for this analysis.

A computer program was first written to determine the mean value ($\overline{\mathrm{cnt}}(i)$) and standard deviation ($\sigma(i)$) for each high frequency data set, followed by a histogram plot of each data set. A typical histogram for "dry" sensor HF data is seen in Figure 2. It is important to note that the distribution is approximately Gaussian. The standard deviations from all data sets were in turn used to determine a mean ($\overline{\sigma}_i$) and standard deviation of the standards deviations ($\sigma(\sigma_i)$). These final statistical values were considered to represent the variability of all data from the dry sensor prior to buoy launch.

Because the contaminated air temperature data are somewhat cooler than the (dry) temperature measurements, we determine a set of mean air temperatures based on combinations of air temperatures greater than the mean temperature of the original data, that may include some erroneous observations. The mean and standard deviation of this set of means is determined and used to determine a one sided (cool) confidence limit, whereby those original data cooler than the cutoff limit are excluded from the data set. The resulting modified data set will present a warmer and smaller variance than the original data set. In order for the method to function effectively, a standard deviation must be originally calculated from good (dry) data sets so that individual data sets can be successively tested against the statistical characteristics of the good data set.

Following Brower et al. (op.cit), the algorithm used to determine the set of mean values based on combinations of individual temperatures warmer then the original data set mean is

$$\overline{P}(i)=\frac{(P_3^2-P_1^2)\cdot\ln(f_1/f_2)+(P_1^2-P_2^2)\cdot\ln(f_1/f_3)}{2(P_1-P_2)\cdot\ln(f_1/f_3)-2(P_1-P_3)\cdot\ln(f_1/f_2)} \qquad (1)$$

where P(i) are the individual measurements and f(i) are the frequencies corresponding to the values of P(i).

The several computed mean values are then used to approximate a warm sided mean value:

$$\overline{P}=\frac{1}{N}\sum_{i=1}^{N}\overline{P}(i) \qquad (2)$$

Once $\overline{P}$ is obtained, the (bad) wetted sensor measurements (cnt(i)) can be identified by the statistical inequality:

$$\mathrm{CNT}(i)\leq\overline{P}-t_{0,05}\sqrt{S^2/N} \qquad (3)$$

To process the air temperature time series data, another computer program was written that incorporated the above algorithms and necessary decision making steps.

3. RESULTS

The overall standard deviation ($\overline{\sigma}$=1.00) and the deviation of the standard deviations ($\sigma(\sigma_i)$=0.31) were determined from the prelaunch data series, and used to determine the 90% probability distribution of these data ($0.38 \leq cnt(i) \leq 1.62$). A small threshold value imposes more rigid conditions on which measurements will be acceptable, while the larger limit allows the acceptance of experimental observations that may represent actual changes in air temperature during the several minute sampling period. For this study, $\bar{P}=1.62$ was used.

The effect of this screening process on two individual HF data sets is seen in Figs.3-4. In Figure 3 the histogram shows the data set to be quase Gaussian, with the standard deviation within the accepted limit. From this we conclude that there are no wetted sensor measurements present in this data set. Visual inspection of Figure 4, however, shows the data distribution to be bimodal; those observations to the left of the mean value are considered to have been collected when the sensor was wet. The improvement in this data set, after having been subjected to the statistical method described herein, is seen in Figure 5. After the bad data are removed from the data set, the resulting histogram is approximately Gaussian.

The untreated air temperature time series is illustrated in Figure 6. The dotted envelope ± 1 std. dev.) about the solid curve in this figure includes the effect of the wetted sensor data. The mean of the std. dev. for the untreated data series is ± 6.145 with a deviation of ± 3.024. The improvement gained from removal of the contaminated air temperature observations is

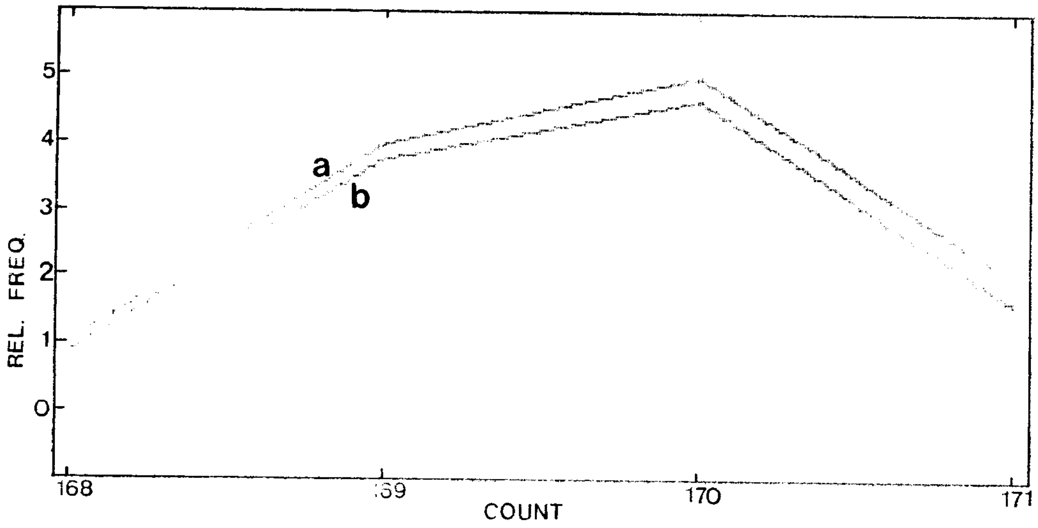

Fig. 2 - Typical histogram from the pre-launch data set.

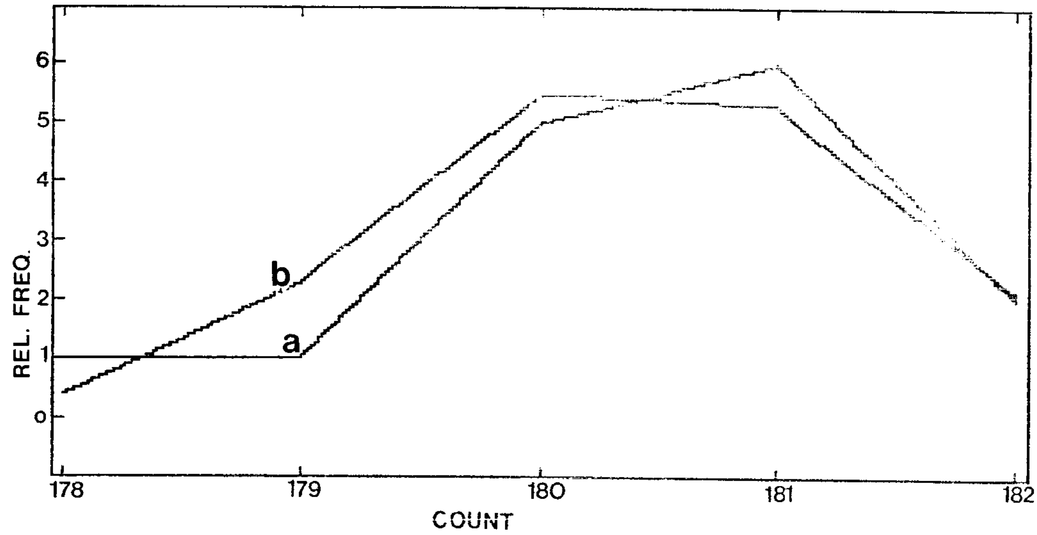

Fig. 3 - Frequency histogram of HF data set (a) for dry sensor, with equivalent Gaussian curve (b).

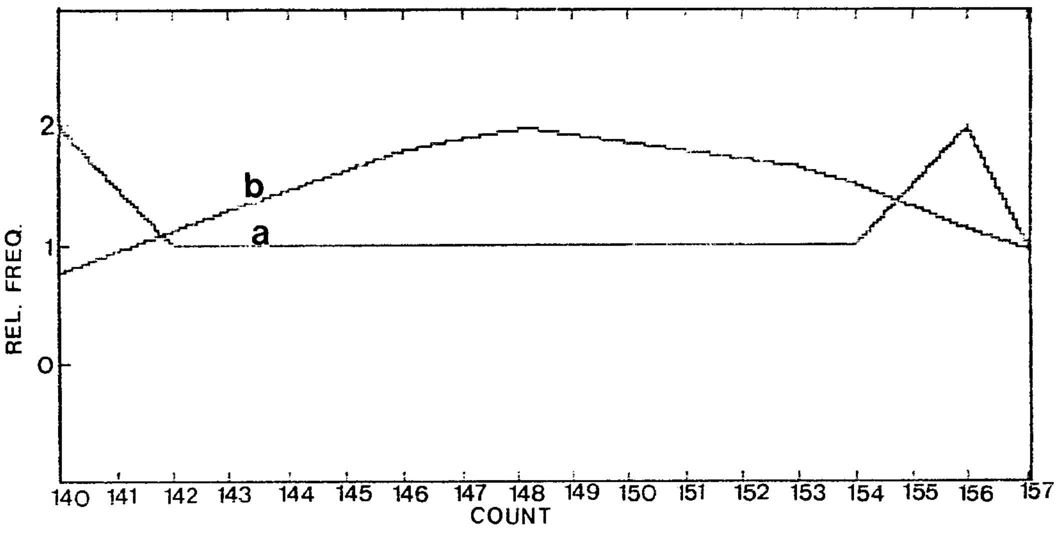

Fig. 4 - Frequency histogram of HF data set for partially wetted sensor (a), with equivalent Gaussian curve (b).

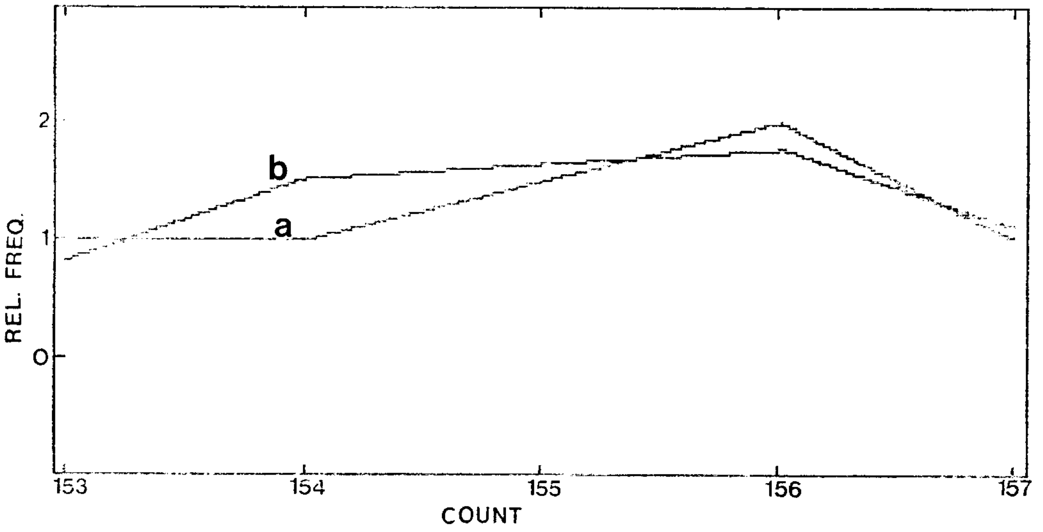

Fig. 5 - Frequency histogram of HF data set after statistical treatment (a), with equivalent Gaussian curve (b).

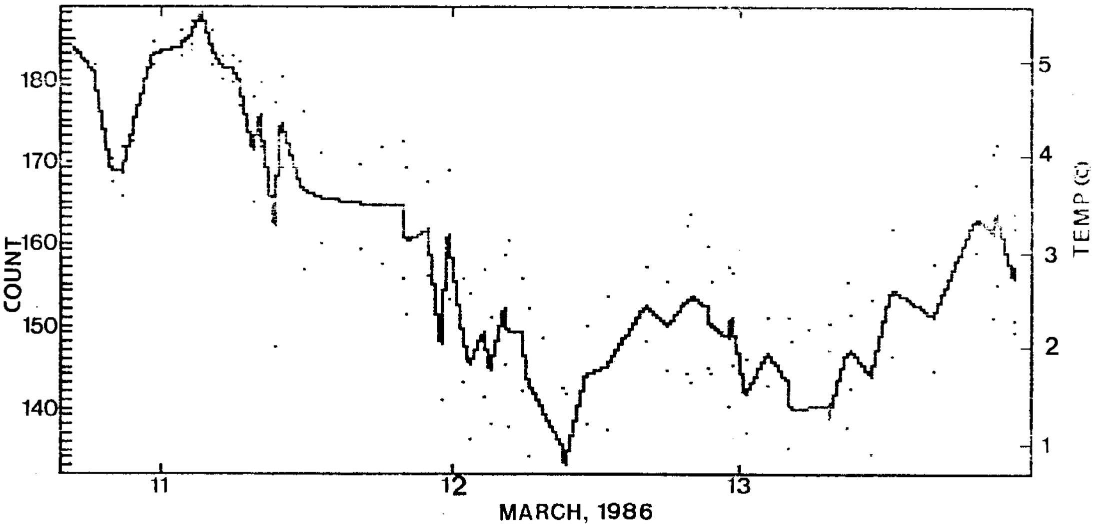

Fig. 6 - Air temperature time series for Buoy Vilma (solid curve); ± 1 std. dev. shown by dotted envelope.

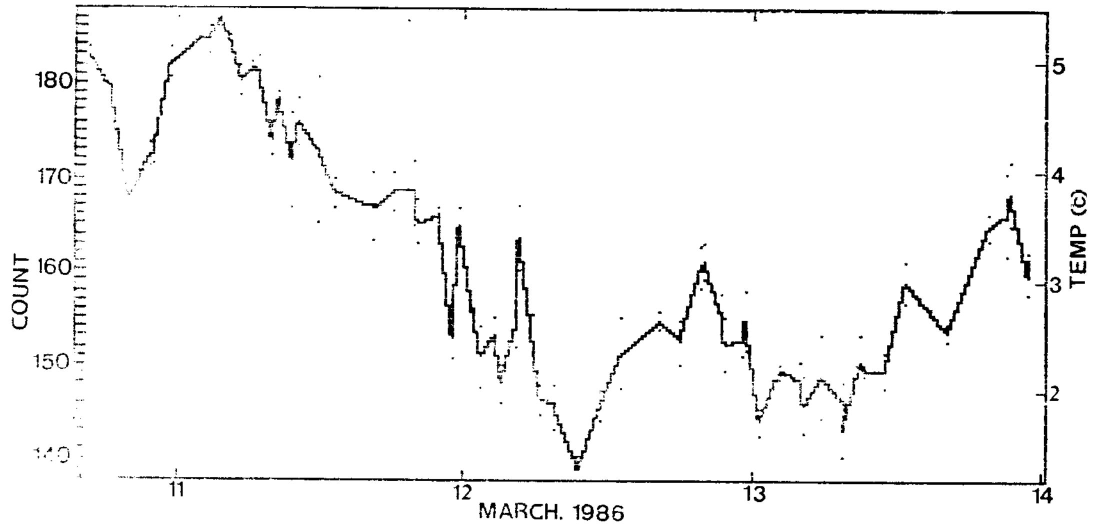

Fig. 7 - Air temperature time series for Buoy Vilma (solid curve) after treatment with statistical method.

seen in Figure 7. The variation in the HF data is smaller, with the curve slightly displaced to warmer temperatures. The variance in the data set is reduced, as seen from the proximity of the dotted envelope to the solid curve. The mean std. dev. for the treated series is ± 2.069, with a deviation of ± 1.257. The improvement in the time series is perhaps best indicated by the fact that there was a reduction in standard deviation and its deviation of 66.3% and 58.4%, respectively after treatment with the method proposed in this study.

4. CONCLUSIONS

The following conclusions may be drawn from this study:

1. Air temperature data from INPE's buoys probably contain errors due wetting of this sensor by breaking waves or from wind driven spray during stormy conditions. This problem is evidenced from histograms for pre and post launch data sets.
2. Based on considerations of how a wet bulb thermometer functions, our wetted sensor should provide erroneous temperature readings that are usually cooler than the equivalent dry sensor.
3. By adapting a statistical method, previously developed for the correction of satellite infrared data, it appears possible to detect those air temperature data most likely to be contaminated and to remove them from the time series.
4. Application of this method to the air temperature time series reduced the standard deviation and its deviation in data set data by 66.3% and 58.4% respectively, over the untreated time series. To our knowledge, this is the first published literature dealing with the treatment of such sensor data.

5. REFERENCES

BROWER, R.L.; GOHRBAND, H.S.; PICHEL, W.G.; SIGNORE, T.L.; WALTON, C.C. Satellite derived sea-surface temperatures from NOAA spacecraft. Wash., D.C. NOAA Tech. Mem. NESS 78. 1976. 74p.

KEELEY, J.R.; TAYLOR, J.D. Data products from the First GARP Global Experiment. Mar. Environ. Serv., Mar. Sci. and Inform. Dir., Dept. Fisher. and Oceans. Manuscript Rep. Ser. Nº 57. Ottawa, Ontario. 1981. 181 p.

STEVENSON, M.R.; BARBOSA, M.N. Brazil tests oceanographic buoy (System ARGOS) in Antarctica. ARGOS Newsletter, Nº 25, April 1986. p. 10-11.