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Md Zahidur Rahman

CUNY La Guardia Community College

Leonid Roytman

CUNY City College

Felix Kogan

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Removing long-term errors from the AVHRR-based brightness temperature (BT)

Mohammed Z. Rahman¹, Leonid Roytman², and Felix Kogan³

^{1,2}Department of Electrical Engineering, The City College of the City University of New York
138 street & convent Avenue, New York, NY-10031

³National Oceanic and Atmospheric Administration (NOAA) Silver Spring, MD 20910

ABSTRACT

Empirical distribution functions were applied for removing long-term errors from BT data derived from AVHRR sensor on NOAA environmental satellites. This paper investigates BT stability in the NOAA/NESDIS Global Vegetation Index (GVI) data set during 1982-2003. This period includes five NOAA satellites. Degradation of BT over time for each satellite was estimated for geographical location in China. The method of matching empirical distribution function (EDF) improves the time relative stability of BT data for all satellites, especially NOAA-9, -11 and -14.

Keywords: BT data, Stability of BT, GVI, EDF, NOAA satellites

1. INTRODUCTION

For almost two decades, The Advanced Very High Resolution Radiometer (AVHRR) on NOAA polar orbiting satellites have observed radiances, which were collected, sampled, and stored for the entire world. These data were intensively used by global community for studies and monitoring land surface, atmosphere and recently for analysis of climate and environmental changes [3] [4]. These goals were seriously challenged by performance of NOAA satellites, which orbit degraded over time, and by deterioration of AVHRR sensor. As the result long-term time series of the Brightness Temperature (BT) calculated from the thermal infrared channel (CH4) experienced some trend. The Method of Matching empirical distribution functions were applied for improving stability of BT data for AVHRR observations. The purpose of this paper is to test stability of BT, corrected CH4 value for all over china region.

1.1 Land Targets

The land targets of 28⁰ N to 43⁰ N in latitude and 75⁰ E to 123⁰ E in longitudes were selected from China (Figure 1).



Figure 1. Geographical Map of China with the area study (boardered).

We attempted to select relatively small uniform areas using common knowledge of geography, climate, ecosystem, and human activities. The main cover types are desert, forest, and grassland. The information collected by the ground truth survey is useful for the classification of NOAA AVHRR weekly-composited BT data.

2. DATA AND PROCESSING

The Ch4 were obtained from the NOAA/NESDIS Global Vegetation Index (GVI) data set [5]. The GVI is produced by sampling and mapping the 4 km AVHRR- derived radiance to a 16 km map daily. The daily maps are composited over a seven-day period by saving the channel and BT values for that day that has the largest BT value during the seven days for each map cell. We used weekly Ch4 data from 1982-2003, which were collected from five satellites NOAA -7, -9, -11, -14 and -16. Multi-temporal NOAA -7, -9, -11, -14 and -16 dataset from the NOAA Satellite Archive (SA) were used for this study. The calibration of AVHRR CH4 (10.3-11.3 μm) utilizes a set of time varying calibration coefficients to correct for sensor degradation, as there is no on-board calibration for these channels. The seven-day composited CH4 values were corrected for using the matching of empirical distribution functions and BT was calculated. High frequency (from week to week) fluctuations in the corrected weekly BT time series were smoothed with a statistical filter.

NOAA-NASA AVHRR pathfinder program, which has been entrusted with the task of the reprocessing and rehabilitation of the AVHRR records for the period 1981-1990 (which has been termed the pathfinder period) for the purpose of the production of long- term records for climate studies, set up the AVHRR Pathfinder Calibration Working group in March 1991 to assess the degradation of channels 1 and 2 on the NOAA-7, -9, -11, and -14 spacecraft (referred to as the afternoon satellites since they cross the equator traveling north-wards in the afternoon) and to make recommendations for implementing appropriate corrections for the observed degradation .The report of this working group has now been published [10].

3. METHODOLOGY

There is no physical method used for stability of BT. We used statistical analysis for the correction of BT in 1988, 1992, 1993, 1994, and 2000. The matching of empirical distribution function (EDF) is a statistical technique which is applied to improve the stability of BT time series. EDF is a non-decreasing function of BT value and its maximum value is unity (Figure 2).

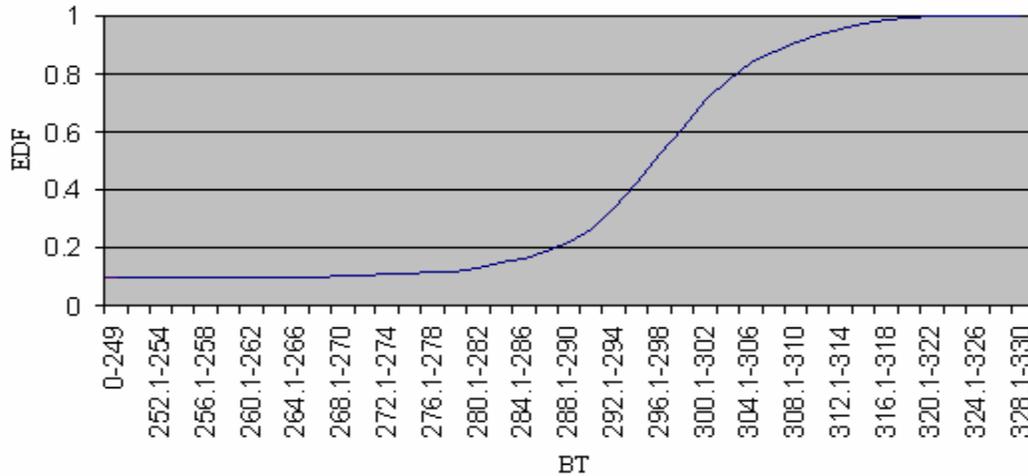


Figure 2. Empirical distribution functions of BT data

We assume that data from NOAA-7(1982, 1983), NOAA-9 (1985, 1986), NOAA-11(1989, 1990), NOAA-14(1996, 1997), and NOAA-16 (2001, 2002) are the best suited for analysis because of their equator crossing time between 1330 and 1500. As this period of the day is the best time (hottest temperature) for satellite observation, we consider data for these years as standard. Then the BT values of other years (1988, 1992, 1993, 1994, and 2000) are adjusted so that their distributions are the same as that of the standard.

To find the normalized value corresponding to the unnormalized value, the following is the procedure:

- i) For the BT value in unnormalized EDF year, find the EDF value from the EDF of unnormalized year
- ii) Then find the point on the standard year's EDF with the same EDF value.
- iii) Finally, use the EDF of the standard year to find the normalized BT value. Since the data are actually discrete, we will need to interpolate within the EDF of the standard year to find the new value of BT.

4. RESULTS AND DISCUSSION

We have produce BT time series of five NOAA satellites are illustrated in Figure 3 which shows BT data for 1988 (NOAA-9), 1992, 1993, 1994 (NOAA-11), and 1995, (week #1-8), 2000 (NOAA-14) are not enough stable compare to other years because of satellite orbital drift, Mt Pinatubo, and sensor degradation. Therefore, we need to correct the BT data for affected years.

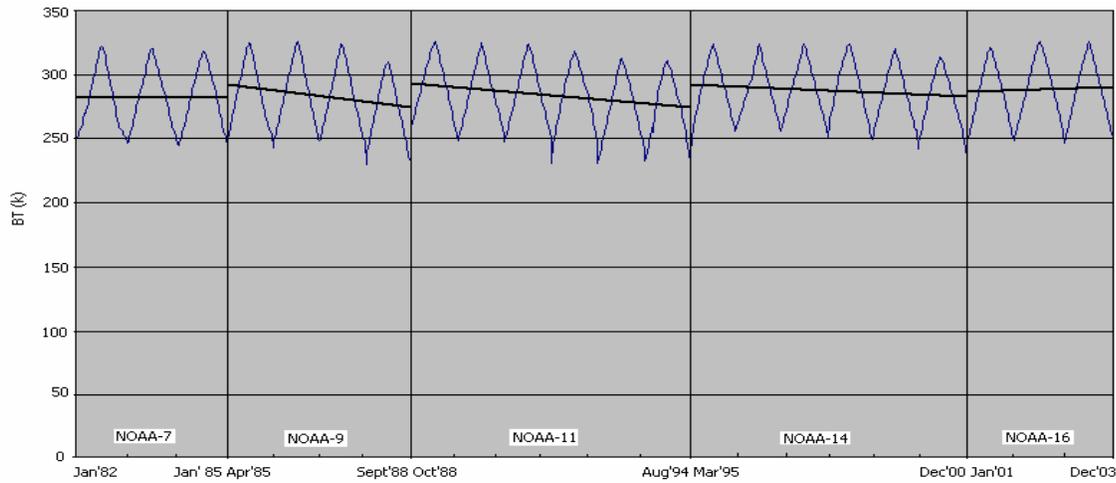


Figure 3 BT time series

For this correction, we apply the method of matching empirical distribution functions for affected years. We normalize data by the method of matching of EDF's compared with standard according section 3. Figure 4 depicts how the procedure is applied in actual practice to generate normalization BT values. The figure depicts idealized EDF's for the standard year and 1988 year. In the figure the EDF's are continuous, but in practice they are discrete, being specified only at integer values of BT.

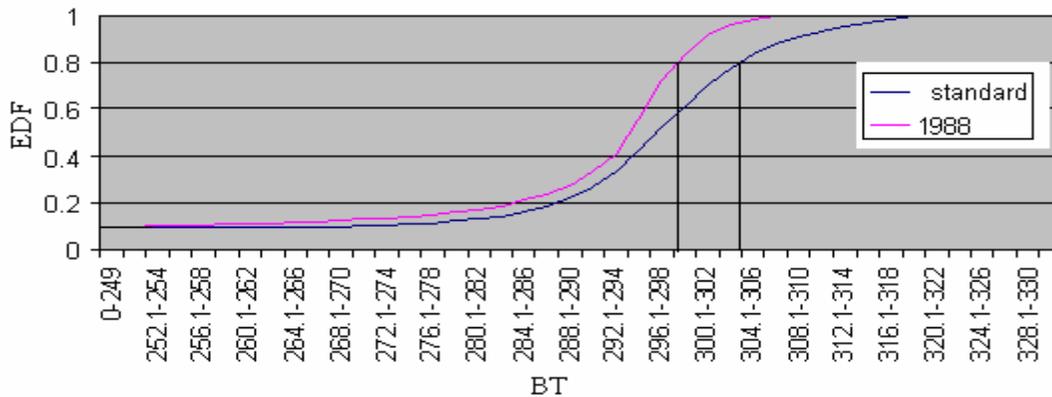


Figure 4 Illustration of procedure to generate normalization BT data

For example, for the BT value 300 in year 1988 find the EDF value from the EDF of year 1988. In the illustration it is EDF_{88} is 0.8. Then find the point on the standard year's EDF with the same EDF value. Therefore, EDF value can also be expressed as $EDF_{standard}$ is 0.8. Finally, use the EDF of the standard year to find the normalized count value 306. Since the data are actually discrete, we will need to interpolate within the EDF of the standard year to find the value of 306, which must then be rounded to the nearest integer. We do interpolate with in the EDF of the standard year to find the normalized count value. After interpolated, we found the normalized BT value 300 in year 1988 is 306. Therefore, 1988 new 300 = $300_{1988} + (306_{standard} - 300_{1988}) = 306$

Using this technique, EDF's produce to normalize or correct data for the years 1988, 1992, 1993, 1994, and 2000 compared with standard which are illustrated in following Figures.

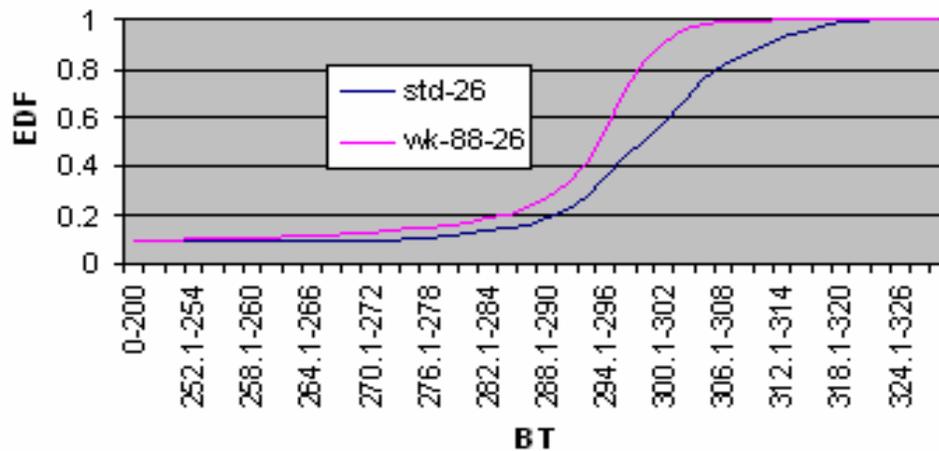


Figure 5 (a). Empirical distribution functions for unnormalized BT data of 1988 (26th week) compared with standard

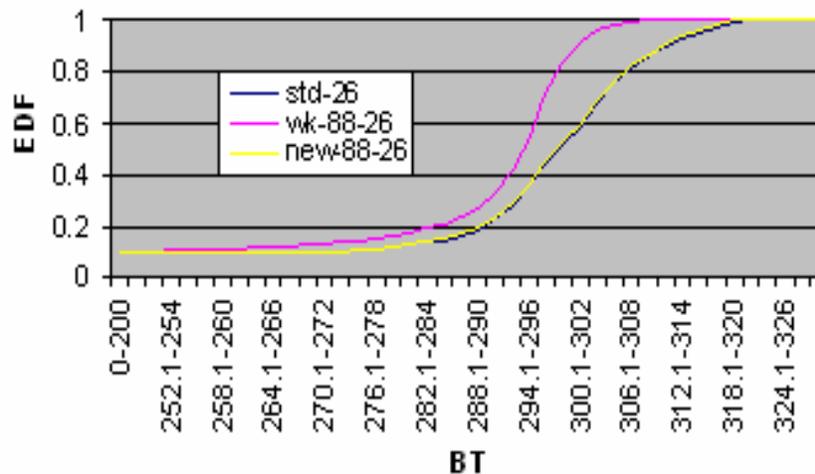


Figure 5 (b) Empirical distribution functions for normalized BT data of 1988 (26th week) compared with standard

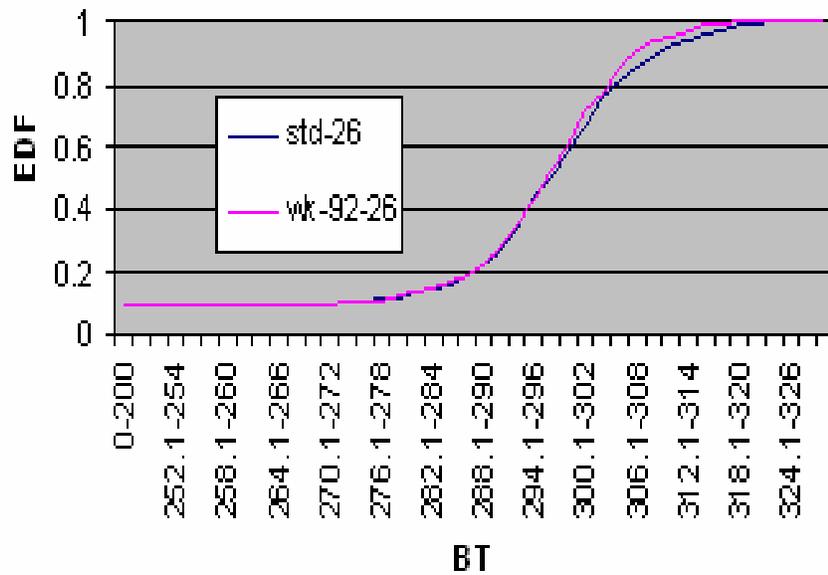


Figure 6(a). Empirical distribution functions for unnormalized BT data of 1992 (26th week) compared with standard

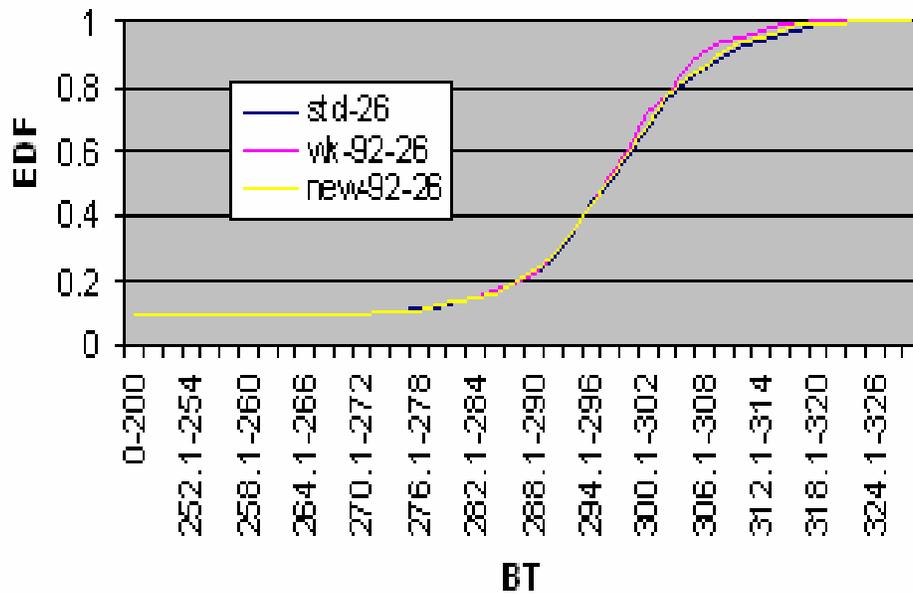


Figure 6(b). Empirical distribution functions for normalized BT data of 1992 (26th week) compared with standard

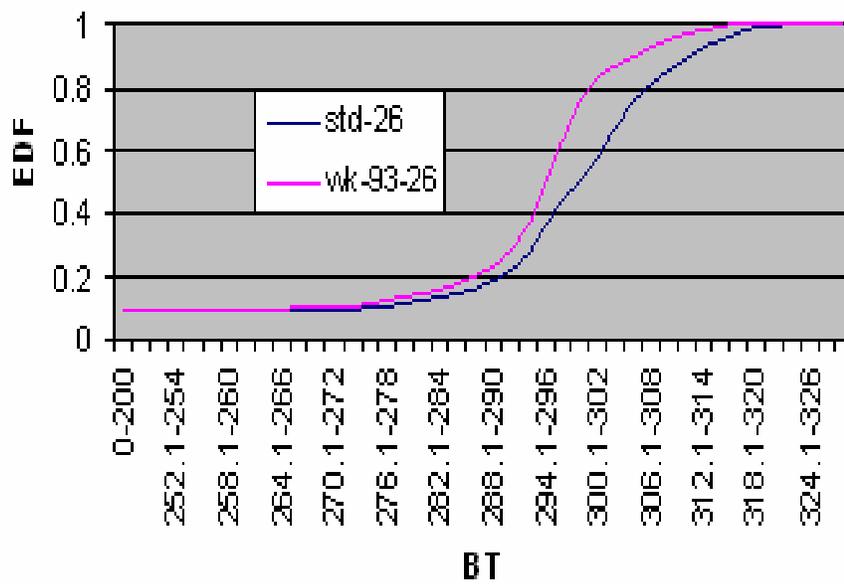


Figure 7(a). Empirical distribution functions for unnormalized BT data of 1993 (26th week) compared with standard

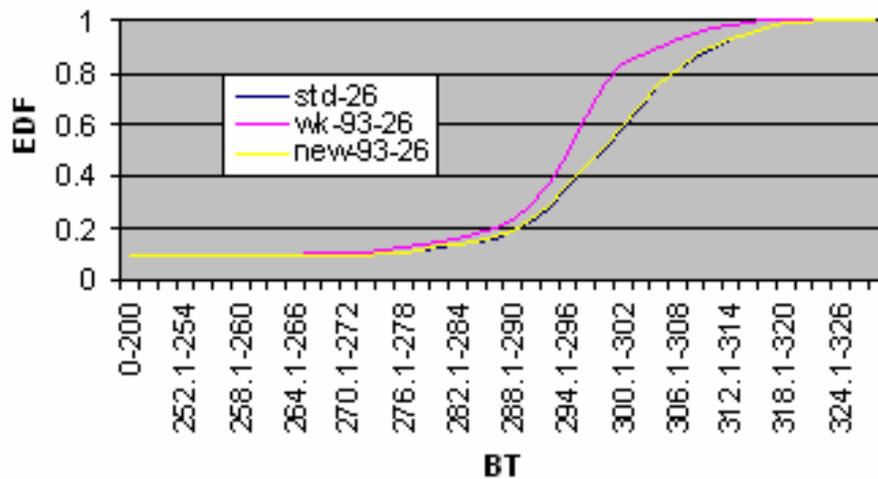


Figure 7 (b). Empirical distribution functions for normalized BT data of 1993 (26th week) compared with standard

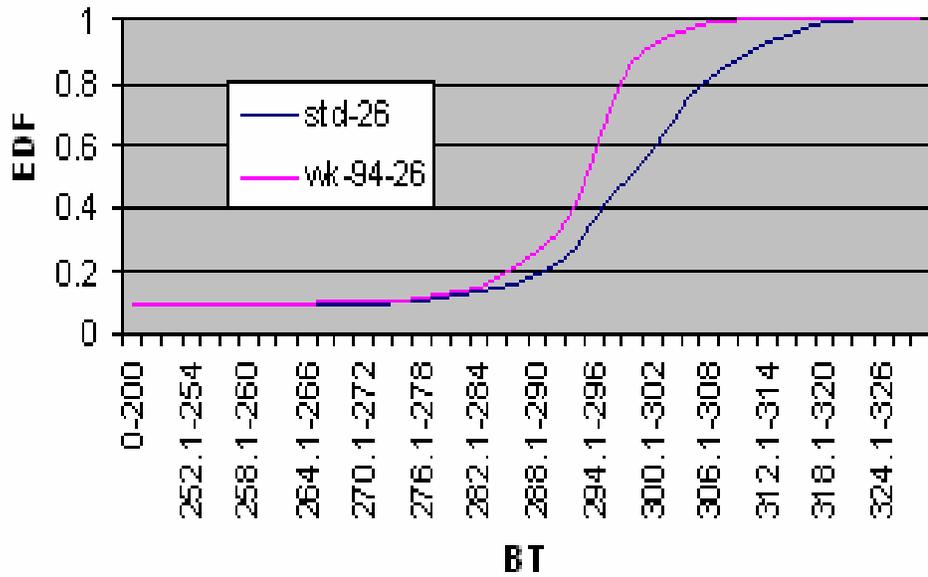


Figure 8(a). Empirical distribution functions for unnormalized BT data of 1994 (26th week) compared with standard

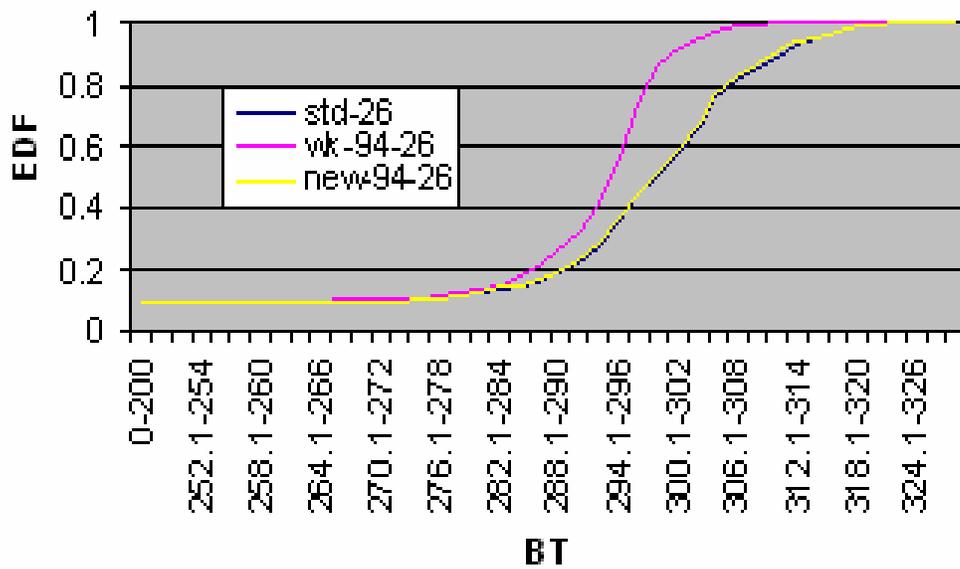


Figure 8(b). Empirical distribution functions for normalized BT data of 1994 (26th week) compared with standard

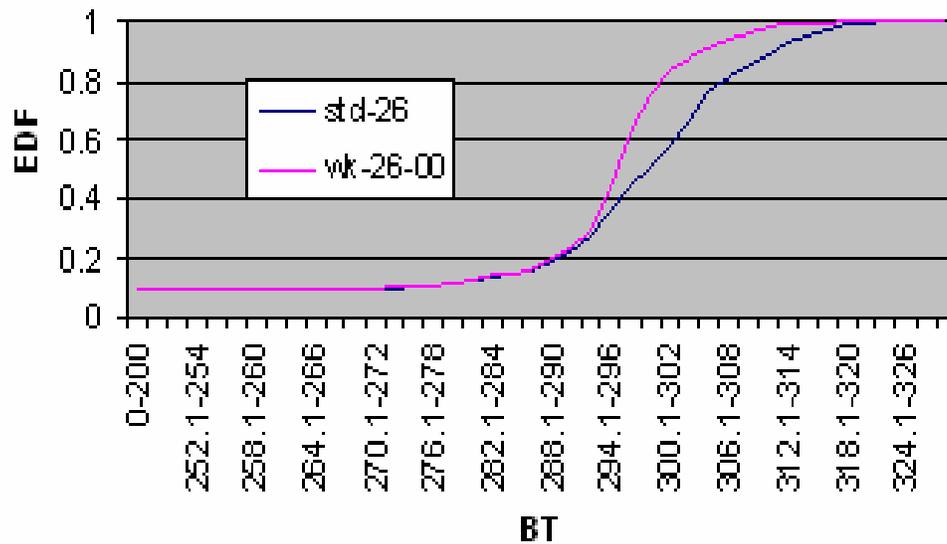


Figure 9 (a). Empirical distribution functions for unnormalized BT data of 2000 (26th week) compared with standard

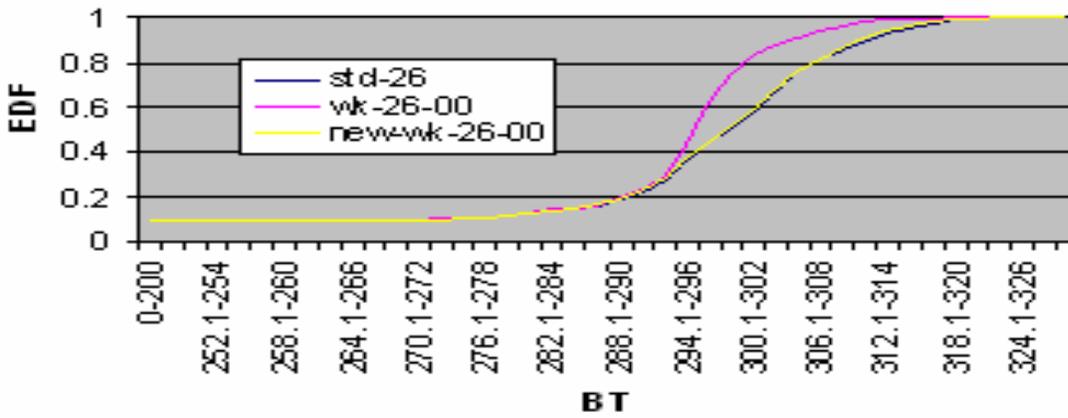


Figure 9 (b) Empirical distribution functions for normalized BT data of 2000 (26th week) compared with standard

Figure 5-9 (part a) shows the EDF's of unnormalize data for the years 1988, 1992, 1993, 1994, and 2000 as well as the EDF of the standard. The abscissa labeled "BT" value and ordinate labeled "EDF" (0 to 1). Figure 5-9 (part b) shows the EDF's of the normalize data for each of those years and indicates that the normalization was successful in making the EDF's of the two years nearly identical. This implies that the relationships between the EDF's remained essentially the same between two years. Those relationships, in fact, depend only on the relative function between two years. As long as the relative functions remain in the same, the normalization data remain effective. Using normalized value, we produce new BT time series as shown in Figure 10 which shows improve the BT data (pink line) of the year of 1988, 1992, 1993, 1994, and 2000.

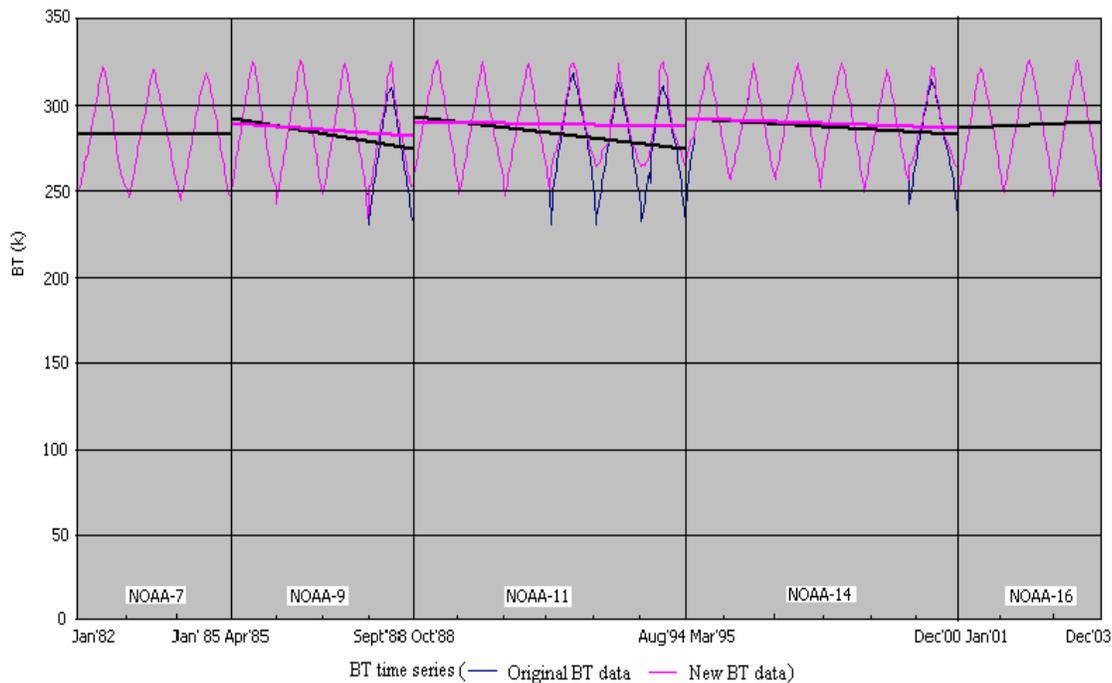


Figure 10. Corrected BT time series

BT trends for china and jumps between the satellites are illustrated in Figure 3 and 10 and the errors are estimated in Table 4.1 Figure 3 shows some BT trends for each satellite except NOAA-16 and jump from one satellite to the next one. Considering old BT trend (Table 4.1), for china, NOAA-9, -11, and -14 have negative trend and NOAA-7, -16 have positive or no trend. Therefore, NOAA-7, and -16 shows clear tendency to BT increase during its three years in operation. However, important is trend rate. Analysis shows that high rate of BT change for NOAA-9,-11, and -14 by reduction of BT in 1988, 1992-1994, and 2000 due to elevated amount of stratospheric aerosol from Mt Pinatubo and considerable degradation of satellite orbit.

Regarding BT jump from one satellite to the next in Table 4.1 (B), general tendency is a reduction of BT between beginning of NOAA-9 and the end of NOAA-7, between beginning of NOAA-16 and the end of NOAA-14. An increase

in BT is observed only during satellite change from NOAA-9 to NOAA-11, NOAA-11 to NOAA-14, and NOAA-14 to NOAA-16 due to already mentioned sharp stratospheric aerosols increase and orbit drift of satellite.

After correction of BT, we also estimate errors in Table 4.1 for new BT. Figure 10 shows improve the BT trends for each satellite and jump from one satellite to the next one. But there remain other potential sources of error in BT such as an incomplete drift correction, inaccurate BT calculation, and influence from Mt. Pinatubo. The EDF method is designed to reduce errors due to orbit drift, the dominant uncertainty in temperature variation during the satellite life time [11]. However, it may be difficult to accurately and completely remove this effect and thus orbit remains as an error source, though at a reduced level. Another large uncertainty lies in BT calibration and Mt Pinatubo which includes all errors such as incomplete atmospheric corrections, surface corrections, sensor degradation and volcanic eruptions.

Table 4.1 : Estimation of Errors in (A) BT trend at the End of a Satellite Life and (B) Jumps between the Satellites (% to the beginning level)

| Ecosystem | | A | | | B | | | |
|-------------|--------|-----|------|------|-------|--------|---------|---------|
| | | N-9 | N-11 | N-14 | N-7/9 | N-9/11 | N-11/14 | N-14/16 |
| Whole China | Old BT | -6 | -6.5 | -3 | 3.3 | 7 | 6.5 | 5.1 |
| | New BT | -2 | -1 | -1.7 | 2 | 3 | 1.7 | 0 |

5. CONCLUSIONS

Empirical distribution function improves the time related stability of NDVI for all satellites, especially NOAA-9, -11, and -14 environmental satellites. This is strong evidence that normalization by EDF matching is an effective method for improving stability of long-term BT time series. For climate and global change studies, BT time series are not stable enough. Following BT data distortion due to external forcing (stratospheric aerosols and satellite orbit degradation), BT data for 1988 (NOAA-9) and 1993, 1994 (NOAA-11), and 2000 (NOAA-14) will likely distort mean values and other statistics and should be tested comprehensively before they are used for monitoring the environment.

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