Monitoring Global Vegetation Using AVHRR

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Abstract — The availability of AVHRR time series for the past two decades has attracted many scientists to investigate inter-annual variability and trends in land surface conditions. To study inter-annual variability of land surface processes using these data, the change in radiances due to two varying factors -- sensor sensitivity and illumination conditions-- must be accounted for. This study analyzes the behavior of global AVHRR shortwave data over land, processed using updated post-launch calibration, for a 12-year period from April 1985-October 1997, and investigates their usefulness for the monitoring of global land surface processes. We focus on verifying the stability of post-launch calibrations for NOAA-11 and -14 by assuming correct calibration of NOAA-9 and by excluding the illumination effects, modeled with NOAA-9 data. The residual trends in data averaged over global, stable aggregates, such as deserts and rainforests, are then attributed to errors in calibration. These trends should be removed from the rest of the data to alleviate their misidentification as the real trends in the Earth’s climate system and to make statistical studies of anomalies more reliable. This study illustrates the potential of improving the available global AVHRR time series to infer more reliable conclusions from inter-annual variability studies. Spectral dependence of residual trends was examined. Preliminary assessments suggest that a desert calibration that has been widely used may not be sufficiently accurate for applications to vegetated areas. This paper is a synopsis of a larger paper submitted to Journal of Geophysical Research.

INTRODUCTION

Some aspects of sensor performance and satellite orbit characteristics require that data from the Advanced Very High Resolution Radiometer (AVHRR) onboard NOAA polar orbiting satellites, especially the shortwave channels, be used with great caution in climatological studies. The currently available 17-year long AVHRR time series have been assembled from observations made by several satellite sensors with slightly different radiometric characteristics. Sensor calibration, i.e. relating radiometer output to incoming radiation units, is the first crucial step in using instruments for remote sensing. AVHRR instruments are thoroughly calibrated before satellite launch but only the infrared channels are continuously calibrated in space. The problem is that the sensitivity of the shortwave channels changes in time in an unpredictable way, but there is no onboard calibration to monitor these changes. For quantitative use of measurements from these sensors, post-launch calibration as a function of time is mandatory. Moreover, although the NOAA polar orbiters are nominally sun-synchronous, the equator-crossing time of the afternoon satellites gradually shifts to a later hour during satellite life time. Therefore, AVHRR observations for any target on the Earth become later and later as the satellite ages, with an abrupt drop back to an earlier hour for a newly launched satellite. Fig. 1 summarizes these two characteristic features of multi-year AVHRR time series for the three NOAA afternoon satellites used in the current study. The main goal of this study is to draw attention of scientific community to some aspects of the global AVHRR time series that affect quantitative analysis of inter-annual variability of land surface variables, such as reflectances and vegetation indices. Our objectives include analysis of the behavior of global AVHRR shortwave data over land, processed using updated post-launch calibration, for a 12-year period from April 1985-October 1997, and investigation of their usefulness for the monitoring of vegetation cover on a global scale. We focus on verifying the stability of post-launch calibration

Fig. 1. Top: Equator crossing time and global mean solar zenith angle of NOAA afternoon observations. Bottom: NOAA/NESDIS reported calibration (in radiance/count) of channel 1 (solid) and 2 (dashed) (see [4,5]).
calibrations for NOAA-11 and -14 by assuming correct calibration of NOAA-9 and by correction for the illumination effects, which were modeled with NOAA-9 data. The residual trends in data averaged globally over stable regions, such as deserts and rainforests, are then attributed to errors in calibration. These trends should be removed from the rest of the data to alleviate their misidentification as real trends in the Earth's climate system and to make statistical studies of anomalies more reliable.

METHODOLOGY

Our two basic assumptions follow [1]: 1) the NOAA-9 calibration is correct and can be used as a standard reference for other satellites, and 2) certain global aggregates are stable in time. The justification for using the NOAA-9 calibration as a baseline is discussed in detail in [1]. In the current study, any residual trend in NOAA-9 data is attributed to the illumination effect. The second assumption - stability of global aggregates - is made for deserts and tropical rainforests, thus prohibiting "global desert greening" or "global tropical deforestation". However, local trends and oscillations, e.g. due to interannual variability in atmospheric aerosol amount and/or in surface characteristics, are allowed under such an assumption [1]. Note that the stability assumption, if made for global aggregates other than desert or rainforest, precludes analysis of trends for those global aggregates, such as that in [2], because, essentially, the second assumption implies that anomalies are mutually compensated on a global scale and no global change of surface characteristics is allowed for those aggregates.

The current procedure for data analysis consists of the following steps: 1) Parameterize a relationship between solar zenith angle trends and reflectances and NDVI anomalies for desert and rainforest classes based on the trends in the data from NOAA-9, assuming it is calibrated correctly, 2) Correct the full time series of the global desert and rainforest classes for solar zenith angle trends using relationships developed in step 1, 3) Recalculate the NOAA-9 monthly averages and the full time series of anomalies with sun angle-corrected data, 4) Analyze residual trends in NOAA-11 and -14, attributing them to calibration errors only, 5) Compare the residual trends for the desert and rainforest classes, 6) Apply the information from steps 4-5 to correct the time series for the other classes.

RESULTS

The third generation NOAA Global Vegetation Index (GVI) monthly mean visible and near-IR reflectances and NDVI [3], based on calibration from [4,5], were aggregated into six classes with a clustering procedure based on the NDVI annual (snow season included) mean and standard deviation as the clustering variables. Further, we extracted the end members of the distribution that can be considered stable (deserts and rainforests). Despite the crudeness of the classification, the major classes were correctly delineated. The polar deserts (above 60°N) were excluded from our analysis because the visible reflectance values were restricted to be 5%-50% in the GVI monthly dataset.

For further analysis, we followed [1] and removed the annual cycle using the NOAA-9 period as a standard reference, assuming that NOAA-9 was calibrated correctly. The anomalies of the reflectances and NDVI for each class were calculated as departures from the NOAA-9 average annual cycle. The data for the period with Pinatubo aerosol contamination (July 1991-December 1992) and for the time with substantial change in viewing geometry (October 1993-September 1994) were omitted from further analysis.

Fig. 2 shows the desert and rainforest NDVI anomalies after step 3 of the procedure. At this stage, the anomalies for the NOAA-9 period show no trend, which is expected after solar zenith angle correction. Assuming the NOAA-9 calibration is correct, then if NOAA-11 and -14 were also correct, there would be no visual trends or discontinuities in the anomalies for those satellites. However, small discontinuities for both NOAA-11 and -14 and well pronounced trends for NOAA-14 are easily traced in Fig. 2.

CONCLUSIONS

We analyzed the behavior of a 12-year sample of AVHRR time series of reflectances and NDVI calculated from NOAA/NESDIS calibration formulae. A method for verification of the stability in calibration for NOAA-11 and -14 relies on two basic assumptions: that the NOAA-9 calibration is correct and that the desert and rainforest global aggregates are stable in time. The residual trends in anomalies are
attributed to uncounted for drifts in channels responsivities. The NOAA-11 slopes for NDVI are close to 0. The slopes for NOAA-14 are all consistent, producing strong increasing trends. The differences between the intercepts and slopes for the desert and rainforest classes suggest a potential spectral dependence. For example, it is clear from Fig. 2 that the desert correction for NDVI will not remove the "green" bias in the rainforest data observed in 1995.

To detect residual calibration errors, we first had to remove solar illumination effect, which we did by fitting a relationship between the anomalies and a transform of solar zenith angle, using only data from the NOAA-9 period. A drawback of this approach stems from the fact that NOAA-9 was launched later in the day than both NOAA-11 and -14, so that the NOAA-9 solar zenith angle domain is narrower, and extrapolation errors may lead to uncertainties in the corrections for NOAA-11 and -14. The errors at the low solar zenith angle, however, should be negligible, owing to the shape of the directional functions below 30°. On the other hand, the data for high solar zenith angles (>65°) have differences in the viewing geometry biases and thus are less compatible with the rest of the data. Thus, the anomalies from October 1993 through September 1994 are not recommended for the GVI time series analysis. The lack of data for NOAA-11, due to the Pinatubo event and the extreme sun-satellite geometry in the late 1993-1994 period, result in very few points for determining the NOAA-11 slopes. Despite the above limitations, our results agree well with those in [1] and by the remote sensing group in Meteo France in Lannion.

The NOAA-14 NOAANEISDIS calibrations for both reflectances were found to be in error in the beginning of NOAA-14 period (early 1995). The predicted slopes, however, were sufficiently steep to reduce the errors to almost 0 in the middle of 1996 for the near-IR and in second half of 1997 for the visible. Thus, at the time of the current study (end of 1997), the visible calibration is supposed to produce reasonable satellite products, such as aerosol.

Summarizing, this study illustrates the potential of improving the available global AVHRR time series so that more reliable conclusions can be inferred from inter-annual variability studies. Detection of trends, however, will remain ambiguous because of potential residual errors at each step of the proposed method, such as the uncertainties of the solar zenith angle dependence removal and statistical uncertainties of the consequent trend analysis. Therefore, the approach of the current method, as well as that of the ISCCP calibration, invokes some constraints on the use of these time series, specifically concerning trend analysis on a global scale, but not excluding detection of regional inter-annual variability.

The current scientific potential of vegetation studies with the NOAA AVHRR data can be prioritized as follows: 1) climatological annual cycle (phenology) studies - high potential, 2) interannual (year-to-year for the same month) studies moderate to high potential, 3) intramonthly (within same month) studies - low to moderate potential, 4) long-term (decadal) trend studies - low potential.

The above order of scientific potential is directly related to the ratio of the sought signal to the inherent noise level in the data. Note that the increase in the potential of intra-monthly and inter-annual studies corresponds to the accuracy of atmospheric and surface corrections applied to the calibrated data. Cloud detection remains a crucial factor for these studies, however.

In view of the uncertainties in calibration and illumination corrections, the results obtained in [2], indicating an increase in the vegetation greenness for the high latitudes of the Northern Hemisphere, have to be verified using long-term independent datasets. The ISCCP reflectance products based on the measurements from several geostationary satellites would be a candidate for some cross-validation of the inferences derived in [2]. More thorough processing of daily AVHRR data, e.g. stratified by sun-satellite geometry and/or corrected for the atmospheric and surface bi-directional effects, could also shed some light on this very important aspect of the global warming phenomenon. The stability of post-launch calibration will remain crucial, however, and it should be tackled by all available methods.

One of the conclusions of the Workshop on Strategies for Calibration and Validation of Global Change Measurements was that "the calibration uncertainty is still much larger than any climate change signal apparent in the data record". The potential of using the available AVHRR time series, however, has been proven to be reasonably high in many studies for exploring vegetation phenology and the response of ecosystems to various weather and climate phenomena.

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