MULTI-SATELLITE EARTH SCIENCE DATA RECORD FOR STUDYING GLOBAL VEGETATION TRENDS AND CHANGES

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Abstract—**One of the stated goals of NASA Making Earth Science Data Records for Use in Research Environments (MEaSUREs) program is the support of the Earth Science research community by providing reliable Earth Science Data Records (ESDR). These products are expected not only to be of high quality but should also combine data from multiple sources to form the long and coherent measurements required for studying climate change impact on the Earth system.**

To that end, this MEASUREs' project aims at generating a seamless and consistent sensor independent ESDR quality record of land surface vegetation index and phenology by fusing measurements from different satellite missions and sensors. We're using the AVHRR, MODIS, and VIIRS daily surface reflectance measurements, and the concept of homogeneous vegetation cluster model to design continuity algorithms that will be applied to these multi-sensor data sets. This effort will generate, characterize, and deliver 30+ years of consistent daily measurements of land surface vegetation index and annual phenology parameters at a climate modeling grid resolution (0.05^{o}, 5.6km). The consistency and accuracy of these products will be evaluated by comparison with in situ vegetation growing season observations over different biomes, latitudinal and elevational gradients. These ESDR products will be distributed through the USGS LP-DAAC. Key science and modeling community users, as well as the US National Phenology Network (US-NPN) will help with evaluating these ESDR products. Information about the project and the ESDR products status are available at http://measures.arizona.edu.

Keywords: Remote Sensing, Vegetation Index, Land Surface Phenology, AVHRR, MODIS, climate change.

I. INTRODUCTION

Vegetation indices (VI) from remote sensing are by far the most widely used remote sensing tools for studying vegetation and large-scale ecosystem processes [1]. In this context, knowledge of phenologic variability and the environmental conditions controlling their activity are further prerequisite to inter-annual studies and predictive modeling of land surface responses to climate change. Satellite phenology encompasses the analysis of the timing and rates of vegetation growth, senescence, and dormancy at seasonal and interannual time scales. Vegetation indices, which capture the aggregate functioning of a canopy, are the most robust and widely used measurement for extracting phenology information. Time series measures of MODIS enhanced vegetation index (EVI) have been shown highly correlated with flux tower photosynthesis in both tropical and temperate ecosystems at seasonal scales [2]. Changes in vegetation phenology depict an integrated response to change in environmental factors and provide valuable information to global change research.

Remote sensing of vegetation dynamics is based on the analysis of vegetation indices time series [3], because of their simplicity, stability, and inherent resistance to noise. Most vegetation index based studies are, however, limited to using one sensor, owing to the inter-sensor continuity challenge. Although, phenology is used for a variety of research and application topics, the central premise remains the study of vegetation dynamics, changes and trends in response to change in climate, natural conditions, or other factors. Consequently, the consistency and length of data records are key requirements. With satellite missions lasting only few years, long term studies of vegetation dynamics and phenology will have to combine multiple satellite data sources.

In the first phase of this project, our objectives were to design a set of continuity algorithms to enable the seamless conversion of data across the different sensors. The resulting sensor independent record of land surface vegetation will be used by our land surface Phenology algorithm to estimate the timing and rates of vegetation change at seasonal and interannual time scales. Herein, we're reporting on our progress with this first phase objectives.

II. DATA AND METHOD

Although, the project will eventually use data from the AVHRR, MODIS, and VIIRS [4] sensors, at this stage we're only working with the AVHRR and MODIS records (Table 1), since the VIIRS sensor is yet to fly. In order to facilitate the continuity work we plan to bridge the two records with data from SPOT-VEGETATION sensor for the period 1999 to 2002 in order to create the needed overlap between the two records.

We're using daily global 0.05^o resolution surface reflectance (AVH09C1) from 1981 to 1999 Advanced Very High Resolution Radiometer (AVHRR) Long Term Data Record (LTDR) [5] and daily Terra (starting March 2000) and Aqua (starting June 2002) MODerate Resolution Imaging Spectroradiometer (MODIS) surface reflectance (MOD09C1 and MYD09C1) [6]. Both records provide data in the red and near infrared (NIR) with different spectral characteristics (Figure 1), which is the primary cause of discontinuity in these records.

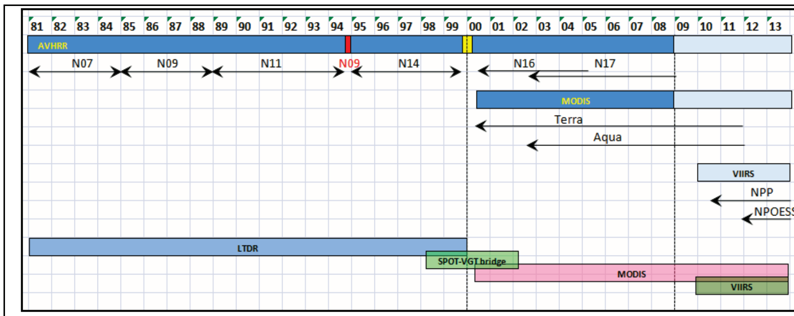

Table 1: Current and future sensors and data sources. This project will use data covering 30+ years.

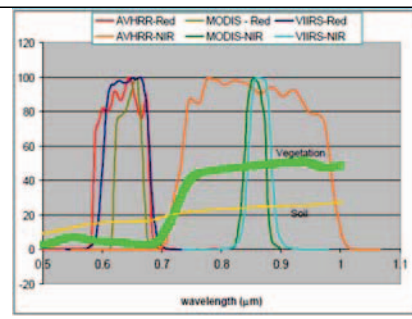

Figure 1: AVHRR, MODIS and VIIRS Red and NIR spectral bands.

Recent cross-sensor studies have shown the feasibility of NDVI and EVI translation across several sensor systems [7][8]. While NDVI requires only the Red and NIR channels, EVI extension, however, is limited to only sensors that carry a blue channel. To generate a backward compatible EVI data record that spans both AVHRR and MODIS we're implementing a 2-band adaptation of EVI, called EVI2 (Eq. 2), by eliminating the blue band, which does not provide additional biophysical information, and was primarily used to reduce noise and uncertainties associated with highly variable atmospheric aerosols [9].

$$EVI2 = 2.5\frac{\mathrm{N-R}}{N+2.4R+1} \quad (1)$$

To extend these measurements across AVHRR and MODIS sensor, we've developed a data fusion technique based on the homogeneous vegetation phenology clusters [10]. This method assumes that land surface vegetation behavior is the sum result of the controls exerted by factors related to climate, soil, elevation gradient, aspect, biological limitations and geographic location. The concept of vegetation phenology cluster is very similar to the biotic life-zones used to classify ecosystems, or the concept of climate classes [11]. In that regard, a homogeneous vegetation phenology cluster is also a biotic zone, with similar plant species, at around the same elevation, and governed by similar temperature, precipitation and radiation regimes. The first prototypes of the cluster map (Fig. 2) were constructed using elevation data (GTOPO30), mean annual temperature and precipitation [12], and the 2003 MODIS land cover map [13]. Future reprocessing will account for soil variability and other factors. Inter-sensor-continuity is then modeled separately in each of these homogeneous clusters.

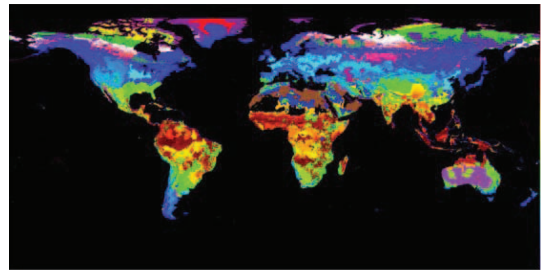

Figure 2: Homogeneous vegetation phenology clusters map. Each of the unit represents an area with similar vegetation dynamic and control factors.

We then compute a geometric mean regression (GMR) [14][15] model (Eq. 2) for linking the AVHRR LTDR with MODIS daily surface reflectance. The slope of this regression is defined as:

$$\beta = \text{sign}(S_{XY})\sqrt{\frac{S_{YY}}{S_{XX}}} \qquad (2)$$

Where: β = regression slope and S is the covariance.

The advantages of using a GMR, as opposed to using the more common ordinary least square linear regression, is that it assumes errors in both records. The regression model is then applied to the full record in each cluster enabling the conversion between the two records, and thus the creation of a sensor independent dataset.

III. RESULTS AND CONCLUSIONS

Our preliminary work indicates an overall high degree of agreement between the two records, owing to the VI ratioing capabilities. However, considerable differences (up to 30%) existed over the tropics and high latitude regions in the vegetation index signal. A large portion of this divergence resulted from poor data quality (aerosols, clouds, etc…). Using the data quality information, provided with both MODIS and AVHRR data records, we eliminated most poor quality data, and then applied the cluster based geometric models to the rest of the data.

For both indices (NDVI and EVI2), the average continuity regression slope varied between ~0.9 and ~1.4 with a coefficient of correlation (R^2) between 0.73 and 0.98 when converting from AVHRR to MODIS. The slopes over some clusters (rain forest and boreal forest regions) were very poor signifying the presence of excessive residual poor quality data. Because, the error sources are very complex in these remote sensing data records (due to atmosphere, geolocation, calibration, choice of algorithms, etc…), we estimated an overall noise related error as the deviation from the mean of homogeneous and adjacent pixels. The resulting error between the two records was reduced to about 5% globally, well within single sensor margin of error. These preliminary results suggest that reliable multi-sensor data for global long term trends and change analysis is possible, and that our hypothesis that a consistent sensor independent record is achievable using our cluster based continuity method. When completed, these ESDR records will be critical to understanding Earth System processes, to assessing change and long term trends, provide input and validation means to modeling efforts, and support policy decisions and operational services.

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