Generating a Long-term Land Data Record from the AVHRR and MODIS Instruments

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Abstract—**The goal of NASA's Land Long Term Data Record (LTDR) project is to produce a consistent long term data set from the AVHRR and MODIS instruments for land climate studies. The project will create daily surface reflectance and normalized difference vegetation index (NDVI) products at a resolution of 0.05°, which is identical to the Climate Modeling Grid (CMG) used for MODIS products from EOS Terra and Aqua. Higher order products such as burned area, land surface temperature, albedo, bidirectional reflectance distribution function (BRDF) correction, leaf area index (LAI), and fraction of photosynthetically active radiation absorbed by vegetation (fPAR), will be created. The LTDR project will reprocess Global Area Coverage (GAC) data from AVHRR sensors onboard NOAA satellites by applying the preprocessing improvements identified in the AVHRR Pathfinder II project and atmospheric and BRDF corrections used in MODIS processing. The preprocessing improvements include radiometric in-flight vicarious calibration for the visible and near infrared channels and inverse navigation to relate an Earth location to each sensor instantaneous field of view (IFOV). Atmospheric corrections for Rayleigh scattering, ozone, and water vapor are undertaken, with aerosol correction being implemented. The LTDR also produces a surface reflectance product for channel 3 (3.75 µm).**

Quality assessment (QA) is an integral part of the LTDR production system, which is monitoring temporal trends in the AVHRR products using time-series approaches developed for MODIS land product quality assessment. The land surface reflectance products have been evaluated at AERONET sites. The AVHRR data record from LTDR is also being compared to products from the PAL (Pathfinder AVHRR Land) and GIMMS (Global Inventory Modeling and Mapping Studies) systems to assess the relative merits of this reprocessing vis-à-vis these existing data products. The LTDR products and associated information can be found at http://ltdr.nascom.nasa.gov/ltdr/ltdr.html.

Keywords-component; remote sensing, AVHRR, MODIS, climate studies

I. INTRODUCTION

The goal of the Land Long Term Data Record (LTDR) project is to produce a consistent long term data set from the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS) instruments for use in global change and climate studies. The LTDR is funded as part of the NASA Earth Science Research, Education, and Applications Solutions Network (REASoN). The project is creating daily surface reflectance and vegetation index products using a geographic projection at a resolution of 0.05°, identical to that used by the MODIS Climate Modeling Grid (CMG) products. The LTDR is prototyping the development and production of a climate quality data record (CDR).

The AVHRR on the NOAA polar orbiting satellites senses a red (0.58–0.68 µm, channel 1), a near-infrared (0.725–1.10 µm, channel 2), a mid-infrared (3.55–3.93 µm, channel 3) and two thermal (10.5–11.3 µm & 11.5–12.5 µm, channels 4 & 5) spectral channels (the AVHRR/2 configuration). Starting with the AVHRR/3 on NOAA-16, launched in 2000, the sensor operation alternated between bands centered on 1.6 µm (channel 3a) during the day and on 3.75 µm (channel 3b) at night, disrupting continuity, but the historical configuration returned in May 2003 when NOAA-16 again operated channel 3b continuously. The red and near-infrared channels on the AVHRR are spectrally broad, which makes them highly

sensitive to atmospheric conditions. The spatial resolution at nadir is approximately 1 km (~0.01°), but due to mission resource limitations these data are aggregated onboard the spacecraft by averaging 4 out of 5 pixels in every 4th scan to create a Global Area Coverage (GAC) data set. The thermal infrared channels are calibrated in-flight using an onboard black body, but the reflective channels are only calibrated preflight.

The MODIS instrument has 36 very narrow channels (±20 nm in the visible to ±100 nm in the longwave infrared) optimized to sense terrestrial, cryospheric, oceanic and atmospheric properties. The MODIS spatial resolution varies from 250 m at nadir for the 0.67 μm and 0.87 μm bands to 500 m in the visible–middle infrared land bands, and to 1 km for longwave infrared bands. MODIS is flown on the Terra and Aqua spacecrafts with nadir local overpass times of 10:30 AM and 1:30 PM respectively, providing nearly full daily coverage of the Earth. Terra records start in March, 2000, while Aqua records start in June 2002. The MODIS instrument is equipped with a state of the art calibration system with a high quality blackbody, solar diffuser, solar diffuser stability monitor and spectral and radiometric calibration assembly that provides better than 2% accuracy in the visible to shortwave and 0.7% in the longwave [1]. MODIS has a sub-pixel geolocation accuracy of ~50 m (1 σ) [2].

II. DATA PROCESSING AND PRODUCT GENERATION

LTDR is processing the AVHRR GAC time-series that begins in June 1981. A Version 1 (or Beta) data set was generated in 2006. This data set was generated by applying the preprocessing improvements identified in the AVHRR Pathfinder II project [3], including vicarious radiometric calibration and inverse navigation to geolocate each sensor's instantaneous field of view. Cloud screening was applied using the CLAVR algorithm [4].

Calibration is a critical issue when building a multi-decade time-series that spans several sensors [5]. We have demonstrated a 1% calibration accuracy with the AVHRR data despite the lack of an onboard calibrator for the visible/near-infrared bands. The technique of Vermote & Kaufmann [6] uses ocean observations to track the degradation of channel 1 and observations of clouds to follow the evolution of the channel 1/channel 2 ratio. The large magnitude of these trends (e.g. ~25% degradation in channel 1 during NOAA-9's lifetime) clearly indicate that any long term assessments must account for this sensor degradation. This vicarious calibration technique was evaluated [7] by using MODIS observations over a stable desert site, where the independently derived sets of AVHRR calibration coefficients were consistent to within less than 1% (Figure 1).

Atmospheric corrections currently applied include Rayleigh scattering, ozone, water vapor, while aerosol corrections [8] are currently being implemented. Ancillary data for the Rayleigh scattering and water vapor corrections are obtained from the NOAA Center for Environmental Prediction (NCEP) [9], while column ozone measurements are obtained from the Total Ozone Mapping Spectrometer (TOMS) [10]. For the mid-infrared channel 3b (3.75 μm) LTDR is generating both surface

reflectance and brightness temperature products [11], although the surface reflectance product should be considered experimental.

Daily surface reflectance and the normalized difference vegetation index (NDVI) products are packaged in HDF-EOS format and are available for ordering through our website. Individual data layers, e.g. the surface reflectance for each channel, are packaged in separate Scientific Data Sets (SDS). A data format guide is available to help users understand the file-naming convention, SDS packaging, scaling from integer to physical units, and importantly the Quality Assessment (QA) bits. The QA bits are stored in a 2-byte integer that describe, for each pixel, whether the individual channel values are valid, if a pixel is cloudy, is over water, land, dense vegetation or desert, was sensed with high solar zenith angle, etc. As with the MODIS land products, it is critical that users evaluate the QA bits prior to using a given pixel in any scientific analyses [12].
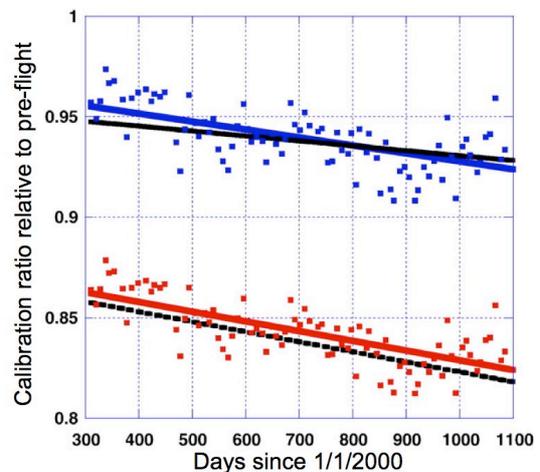

Figure 1: Comparison of the desert calibration trends for AVHRR band 1 (black solid line) and band 2 (black interrupted line), with trends obtained using the ocean and clouds method for AVHRR band 1 (blue line and squares) and band 2 (red line and squares).

III. QUALITY ASSESSMENT AND PRODUCT EVALUATION

Quality assessment (QA) is an integral part of the LTDR production system, using an approach based on that used by the MODIS Land Science Team [12]. QA is critical since the correct interpretation of scientific information from global, long-term series of remote sensing products requires the ability to discriminate between product artifacts and changes in the Earth processes being monitored [12]. LTDR personnel undertake routine QA of all products, develop and maintain the associated QA tools, web sites, and procedures, disseminate QA results and information within the LTDR project, and ensure that the QA results are available to the public.

A time-series of summary statistics derived from all the products at several AERONET sites and for 9 "golden tiles" is maintained and monitored by the QA team in order to identify anomalous product behavior. Golden tiles (10°x10° each)

cover areas that are expected to be representative of the variability of the majority of the MODIS Land products. Time-series statistics for an AERONET site are evaluated over a 50 km x 50 km spatial subset. Statistics collected at these locations include mean, standard deviation, minimum and maximum for clear land and high quality pixels. Product time-series analyses are important because they capture algorithm sensitivity to surface (e.g. vegetation phenology), atmospheric (e.g. aerosol loading) and remote sensing (e.g. sun-surface-sensor geometry) conditions that change temporally, and because they reveal changes in the instrument characteristics and calibration.

The QA of the LTDR Version 1 data set revealed problems that were addressed in the Version 2 products now in production. The problems included errors in calibration, geolocation, water vapor correction, cloud screening and QA bit consistency. Figure 2 shows a time-series of surface reflectance and NDVI values at a vegetated site for 1981–2000, which illustrates trends and spurious features from incomplete correction for calibration degradation, orbital drift, satellite changes, etc. We anticipate that the Version 2 time-series will correct these artifacts, thus providing a prototype climate data record (CDR).
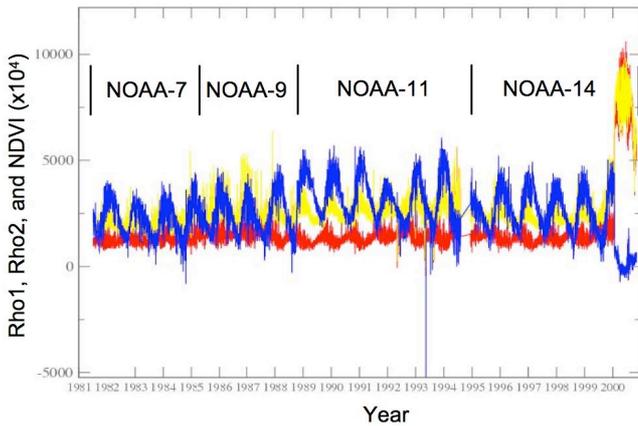

Figure 2: Time-series of surface reflectance (rho) for channel 1 (red), channel 2 (yellow), and NDVI (blue) for 1981-2000. Note the data gap in 1994 and the problems in 2000 due to the late overpass of NOAA-14.

We have compared Version 2 LTDR data for 1999 with Pathfinder AVHRR Land (PAL) daily products [13] over 48 sites distributed across the globe. Atmospheric data from AERONET [14] sunphotometers at each site were used as input to the 6S radiative transfer model [15], [16] to atmospherically correct the top of the atmosphere AVHRR data to determine surface reflectance values for channels 1 and 2. Figure 3 shows that the LTDR data for channel 2 follow the one-to-one line very closely for surface reflectance values up to ~0.5. Similar LTDR results are obtained for channel 1, although the PAL data are closer to the 1-to-1 line. The LTDR data are clearly more accurate than the PAL values, and we anticipate obtaining agreement for higher surface reflectance values with an improved water vapor correction. For NDVI values we find the RMS error about the one-to-one line to be

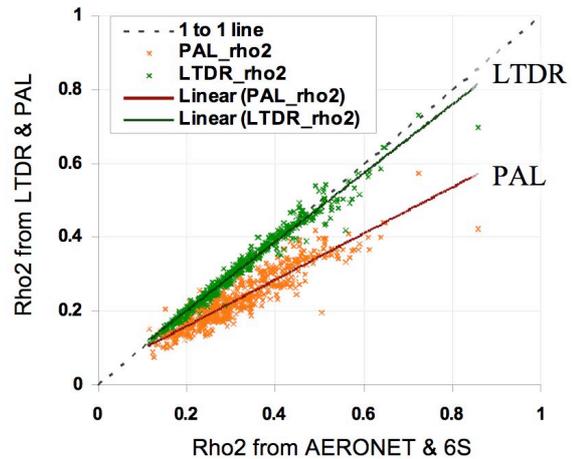more than two times lower for the LTDR data than for the PAL values.

Figure 3: Comparison of LTDR and PAL data for channel 2 at 48 AERONET sites in 1999. The x-axis shows the surface reflectance values (rho2) determined from the 6S code supplied with atmospheric parameters from an AERONET sunphotometer, while the y-axis shows the surface reflectances retrieved from the AVHRR data using LTDR and PAL algorithms.

IV. HIGHER ORDER DATA PRODUCTS

The LTDR project will generate higher order products, including burned area, land surface temperature (LST), albedo, bidirectional reflectance distribution function (BRDF), leaf area index (LAI), and fraction of photosynthetically active radiation absorbed by vegetation (fPAR).

As an example, we applied the MODIS anisotropy and albedo algorithm [17], [18] to the AVHRR data every 8 days, using the last 16 days of clear sky data to retrieve a temporal history of the surface anisotropy and its variability for 1999. Initial results indicate that the AVHRR retrievals compare favorably with MODIS retrievals (Figures 4 and 5) for 2000.
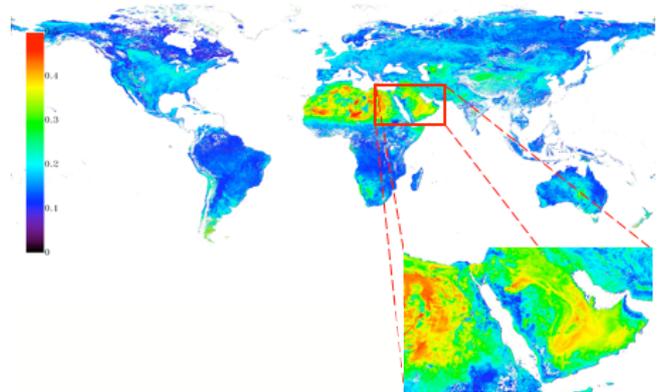

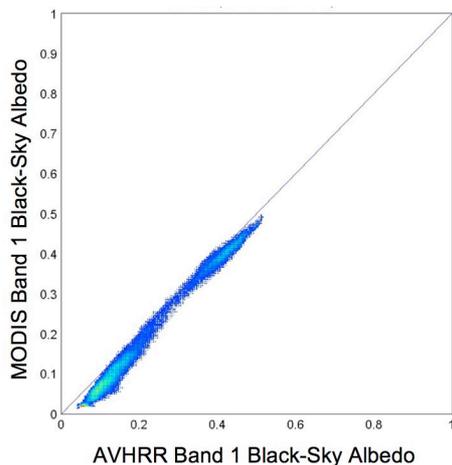**Figure 4:** AVHRR broadband black-sky albedo for July 1999.

Figure 5: MODIS (7/2000) vs. AVHRR (7/1999) black-sky albedos in the red band (channel 1). A perfect 1-to-1 correspondence between the two sensors is not expected due to the different dates and spectral response functions along with the lack of aerosol corrections for the AVHRR data.

V.   COMMUNITY OUTREACH

An important element of the LTDR project is community outreach and feedback. Most recently, we held a half-day workshop in January 2007 to update the remote sensing community on our progress and to solicit comments and feedback from the more than 100 scientists who attended. We presented overviews of the algorithms, quality assessment efforts, product formats, and plans for surface temperature and burned area products, along with LTDR product evaluations and intercomparisons with PAL and Global Inventory Monitoring and Modeling System (GIMMS) data. International AVHRR data producers and users were also represented by M. Leroy (POSTEL/France), A. Trishchenko (CCRS/Canada) and P. Frost (CSIR/South Africa).

VI.   FUTURE PLANS

Following the MODIS refinement and reprocessing strategy [19], we are planning for additional versions of the LTDR data products. Aerosol corrections will be implemented and a complete reprocessing will result in a Version 3 release planned for the summer of 2007. These data will provide the basis for BRDF/albedo, surface temperature, and burned area products. We will also process a year of NOAA-16 data beginning in May 2003 to cross-calibrate with the MODIS products. We anticipate that the implementation, testing, and evaluation of the higher order products and the cross-calibration efforts will lead to further refinement of the surface reflectance algorithms, so we are planning for a release of Version 4 products in early 2008.

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