DATA FUSION FOR ENVIRONMENTAL ASSESSMENT: INTEGRATING MODIS IMAGERY AND NEXRAD WEATHER RADAR

R. P. Watson [ab], L. A. Scuderi [a], K. K. Benedict[b], T. R. Kuntz[a]

[a] CREATE – Center for Rapid Environmental Assessment and Terrain Evaluation, University of New Mexico, Albuquerque, NM USA – (rwatson, tree, tera) @unm.edu
[b] Earth Data Analysis Center, University of New Mexico, Albuquerque, NM USA – (kbene) @edac.unm.edu

ABSTRACT:

This paper discusses the fusion of terrestrial NEXRAD weather radar with MODIS hyperspectral imagery. Issues of data fusion relating to the differing character of terrestrial weather radar and hyperspectral satellite imagery are evaluated and discussed. The integration of these disparate data types provides challenges particularly in the geometric registration of the radial pattern of weather radar to the gridded imagery data of MODIS. Weather radar data are systematically collected over virtually all of the Continental United States and provide spatially continuous and calibrated rainfall estimates at a nominal spatial resolution of 4 km. Several MODIS Level 4 products (MOD 13 - Gridded Vegetation Indices [NDVI & EVI]; MOD 15 - Leaf Area Index [LAI] and Fraction of Photosynthetically Active Radiation [FPAR]; MOD 17 Net Photosynthesis [PSN] and Net Primary Production [NPP]) provide global validated sources of vegetation conditions at 1 km resolution. The short-term response of vegetation to varying local weather conditions is difficult to assess due to the spatially discontinuous nature of precipitation. Understanding the vegetation response to local weather events is particularly important in arid and semi-arid regions such as the American Southwest that are susceptible to periodic droughts characterized by a high spatial variability in precipitation. The high temporal frequency of these data (hourly to daily for NEXRAD, and one to eight days for MODIS) allow the analysis of short-term local vegetation response and ecosystem change to be undertaken at a finer temporal scale than has previously been possible.

1. INTRODUCTION

1.1 Background

This paper discusses research on the relationship between two modes of environmental remote sensing; terrestrial NEXRAD weather radar and the Terra and Aqua based MODIS hyperspectral imagery for the purposes of monitoring the short-term response of grasslands to localized rainfall. The short-term response of vegetation to varying local weather conditions is difficult to assess due to the spatially discontinuous nature of precipitation. Understanding the vegetation response to local weather events is particularly important in arid and semi-arid regions such as the American Southwest that are susceptible to periodic droughts characterized by a high spatial variability in precipitation.

The high temporal frequency of these data (hourly to daily for NEXRAD, and one to eight days for MODIS) allow the analysis of short-term local vegetation response and ecosystem change to be undertaken at a finer temporal scale than has previously been possible. The realization of this potential however requires the integration of these fundamentally different data sources.

1.2 Project Area

The study area covers a portion of the semi-arid eastern plains of New Mexico, USA (Figure 1). This region consists primarily of low relief grasslands with average elevations across the study area ranging from approximately 1500 to 2500 meters. The major agricultural/economic activity of this area includes dairy farming and beef cattle production and is part of the region known as "*Cattle Feeding Country*" where more than 7 million fed cattle are marketed annually, representing fully 30 percent of the fed cattle production in the United States. These rangelands are a vital national resource where monitoring is critical to efficient, and sustainable use.
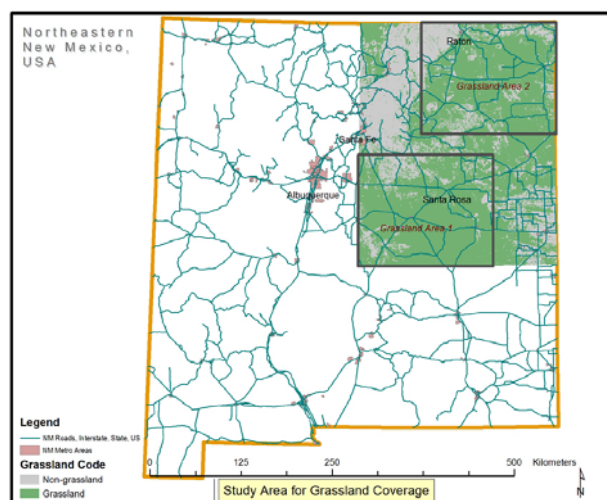

Figure 1: Project Area

Annual moisture availability is dominated by summer monsoonal flow into the region from the Gulf of Mexico. Additional cold season frontal precipitation is typically associated with low-pressure disturbances that track eastward across the state producing moderate precipitation totals during the winter and early spring. Maximal precipitation occurs in

July with an average monthly precipitation of 75mm. Peak temperatures occur between June and August and as such contribute to the rapid evaporation of available soil moisture in the root zone.

These factors create grassland conditions that are highly responsive to local rainfall by virtue or little or no available soil moisture during the principal summer growth period. Sensitivity to local rainfall is further exacerbated by drought conditions that began in late 1999 and continue to the present. This extended period of subnormal precipitation has strongly influenced both near and subsurface moisture availability and has had a significant impact on grassland ecosystems, grassland productivity and economic use.

2. DATA AND METHODS

2.1 Data

The data used in this study were acquired from publicly available sources and processed using standard software and algorithms. MODIS data were acquired from the Land Processes Distributed Active Archive Center (LPDAAC) through the Earth Observing System Data Gateway (EOS). Precipitation data were acquired the National Centers for Environmental Prediction of the US Weather Service.

2.1.1 MODIS Data. The vegetation data were derived from the MODIS Terra products, specifically the MOD15A2 Leaf Area Index/FPAR 8-day L4 Global 1km SIN Grid. MOD15A2 provides Leaf Area Index (LAI) and Fraction of Photosynthetically Active Radiation (FPAR) absorbed by vegetation with a spatial resolution of 1 km and is updated once each 8-day period throughout the calendar year (Knyazikhin, et al, 1999; Myneni, et al, 2003; MCST, 2003). The MODIS FPAR product (MOD15A2) was selected because it provides information on the structural property of the plant canopy. A plant productivity product was selected as more likely to indicate vegetation response to precipitation in the sparse grassland environment of Northeastern New Mexico.

Fourteen files of 8-day composite FPAR data were downloaded from the LPDAAC for the period of study of June 01, 2002 through September 15, 2002. The native hdf data files were converted into ERDAS Imagine version 8.6 img files and reprojected to UTM zone 13, using the NAD 27 datum. Eight-day differences were calculated between the available data sets to capture the change in FPAR over time. These difference images were used in ArcGIS to compare changes in FPAR values to areas of local precipitation derived from the NEXRAD data (Figure 2).

2.1.2 NEXRAD Data. Weather radar data are systematically collected over virtually all of the Continental United States and provide spatially continuous and calibrated rainfall estimates at a nominal spatial resolution of 4 km.

2.1.3 Processing of NEXRAD Stage IV data. The conversion of NEXRAD Stage IV data to a format suitable for use in an image processing and GIS requires several steps. The native format for NEXRAD data is NWP HRAP GRIB (National Centers for Environmental Prediction) which must converted from the radial GRIB format be integrated into raster based systems. The acquisition and conversion process involved 5 steps:

1. Data Acquisition
2. Data Conversion
3. Georeferencing
4. Conversion to Raster Format
5. Data Export

2.1.3.1 Data Acquisition. NEXRAD Stage IV data are available for 1-, 6-, and 24-hour total precipitation summaries for a continental US grid. These data are mosaiced from local, 4 km polar-stereographic grids for each of the 12 regional River Forecast Centers (RFCs) in the continental US. These data are derived from the Stage III precipitation products generated by the RFCs. Each grid point in the Stage IV product provides accumulated precipitation measured in mm for the specified span of time. The nominal ground spacing is approximately 4 km nationally, but varies with actual NEXRAD coverage and distance from the radar installation. For New Mexico the nominal ground spacing is approximately 4.8 km. The data for this analysis were obtained via FTP from the online 6-month archive of data files ftp://ftpprd.ncep.noaa.gov/pub/gcp/precip/mpe.arch/stage4/.

2.1.3.2 Data Conversion. The downloaded files are provided as compressed HRAP GRIB files. The compressed GRIB files were uncompressed and converted from binary to ascii text format using wgrib (http://wesley.wwb.noaa.gov/wgrib.html). The ASCII text format generated by wgrib encodes the number of columns and rows in the grid in the first line of the file and stores the values for each row in sequence as a single column of values. This output was then used to generate the desired output format through an automated process.

2.1.3.3 Georeferencing. After conversion, the ASCII precipitation values were merged with their corresponding geographic coordinates to generate a point dataset from which a raster representation could be generated. To facilitate automated processing, a reference ASCII file containing UTM (Zone 13, NAD27) coordinate pairs for each GRIB grid point was generated for each point. The order of the coordinate pairs in the reference file exactly matched the order of the precipitation values in the ASCII output of wgrib.

A custom Perl script was used to merge the UTM coordinates pairs with the precipitation values, to subset the data to the defined area of interest, and generate a GRASS GIS (http://grass.itc.it/) sites file. A GRASS sites file consists of an ASCII encoded point GIS coverage.

2.1.3.4 Conversion to Raster Format. The GRASS s.surf.idw command was used with a 1 as the specified number of points for the inverse-distance-weighting algorithm, resulting in a nearest neighbor conversion of the points in the sites file into a 1 km raster.

2.1.3.5 Data Export. To maximize portability, the GRASS raster file was exported as an ASCII ArcGRID using the r.out.arc GRASS command. The resultant ASCII file could then be imported into ArcGIS for analysis of the precipitation and any resultant vegetation response. This entire conversion and reformatting process was automated using a Perl script that performed all of the conversion, import, and export processes on the HRAP NEXRAD GRIB files.

2.2 Methods

After conversion to gridded raster data the NEXRAD precipitation data was imported into ArcGIS ver. 8.3 for analysis. For analysis purposes, total precipitation was grouped into eight classes (Table 1). A comparison of NEXRAD

precipitation and FPAR values was undertaken to identify the importance of local precipitation to changes in vegetation.

Total Precipitation Class	Range (mm)	
	Min	Max
1	0	10
2	10.01	20
3	20.01	30
4	30.01	40
5	40.01	50
6	50.01	60
7	60.01	70
8	70.01	>70

Table 1. Total Precipitation Classes

To assess differences in vegetation response, a sample region was selected for analysis in Northeastern New Mexico. The selected sample corresponds to Grassland Area 2 shown in Figure 1. This area constitutes a sample of almost 32,000 1 km pixels in an area that is predominantly grassland. A difference image for two FPAR 8-day composites (June 10th-16th and June 17th-24th) was calculated to identify those areas where there was an identifiable vegetation response (Table 2).
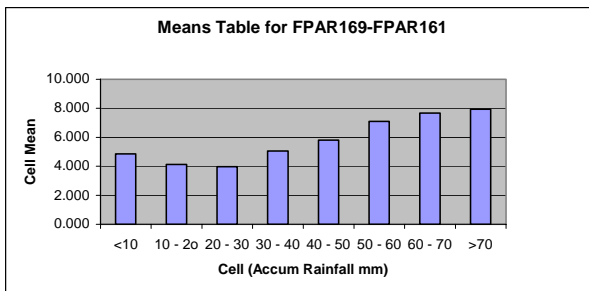

Table 2: Change in FPAR means by precipitation class.

To further assess the extent of the vegetation change, a ratio image of the early June image divided by the late June image was calculated. The resultant image and values show the location and percentage of change in the FPAR values (Table 3).
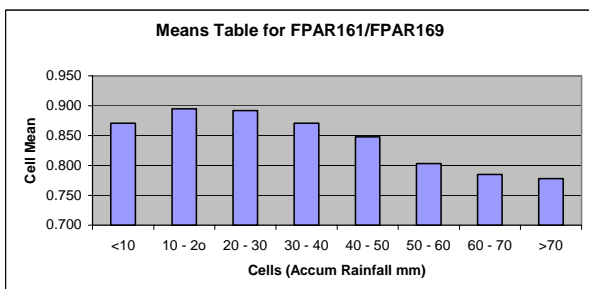

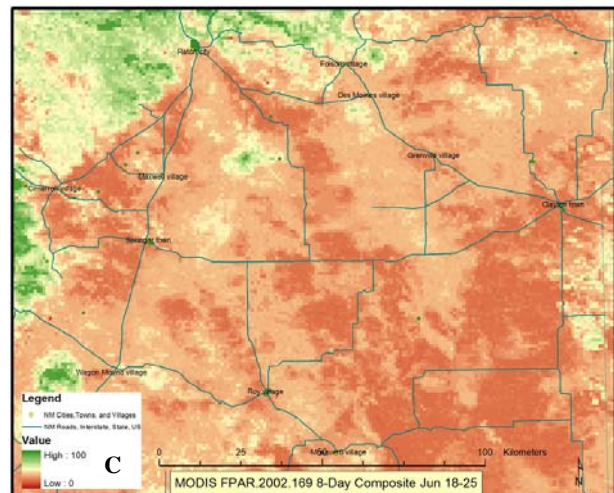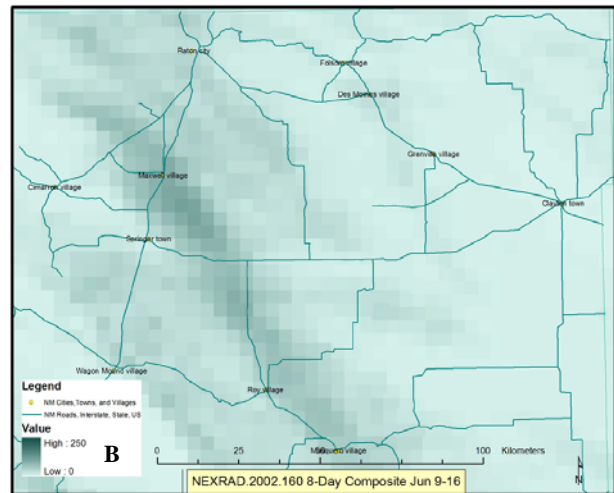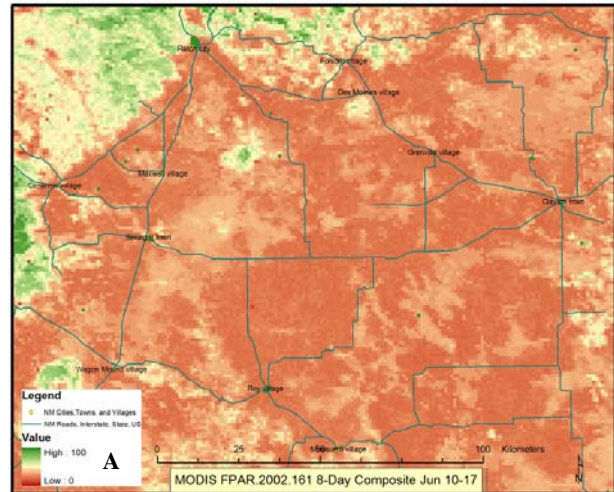Table 3: Percentage Change in FPAR means by precipitation class.

Figure 2: FPAR Images During (A) and After (C) the Precipitation (B)

3. RESULTS AND CONCLUSIONS

The images show a generalized change that occurs over the entire area of interest that is interpreted to be the result of seasonal vegetation greenup. An ANOVA of the NEXRAD and FPAR difference values reveals that there is some change in FPAR values regardless of precipitation, representing a base

level of greenup. The extent and significance of the change varies with the presence of precipitation. An examination of the difference image comparing total precipitation to FPAR change shows that there is a fairly constant greenup in areas having little or no precipitation (i.e. <40 mm) and a greater difference in those areas receiving more than 40 mm (Table 2). An examination of the ratio images and values shows approximately 11% change for those areas receiving less than 40 mm of rain with a dramatic change from approximately 13% change for those areas receiving 30-40 mm to as much as 22% change for those receiving more than 70 mm of total precipitation over the 8-day study period (Table 3).

This study shows that the 8-day composite FPAR data can be used to show even relatively modest changes in vegetation in the semi-arid grasslands of Northeastern New Mexico. As such, near real-time MODIS FPAR data can make a valuable contribution to the integrated and active management of the grassland environment. By providing timely information on vegetation response to localized rainfall, decisions on irrigation and grazing allocation can be tailored to meet grazing needs while minimizing impacts and maximizing sustainability.

Future work will focus on the lag time from precipitation events to the occurrence of the vegetative green-up. Analysis of the relationship of FPAR values to grassland health will also be investigated as this is an important factor in semi-arid environments and areas highly dependent on local precipitation events. This and future work can provide a basis for streamlining both FPAR and NEXRAD data for managers of grasslands and livestock and can provide valuable input into a system for real time management of the grassland resource.

4. REFERENCES

Y. Knyazikhin, J. Glassy, J. L. Privette, Y. Tian, A. Lotsch, Y. Zhang, Y. Wang, J. T. Morisette, P.Votava, R.B. Myneni, R. R. Nemani, S. W. Running, MODIS Leaf Area Index (LAI) and Fraction of Photosynthetically Active Radiation Absorbed by Vegetation (FPAR) Product (MOD15) Algorithm Theoretical Basis Document, http://eospso.gsfc.nasa.gov/atbd/modistables.html, 1999.

Myneni, R., Knyazikhin, Y., Glassy, J., Votava, P., Shabanov, N., 2003, "User's Guide FPAR, LAI (ESDT: MOD15A2) 8-day Composite NASA MODIS Land Algorithm," Terra MODIS Land Team, http://cybele.bu.edu/modismisr/products/modis/userguide.pdf (accessed 2 Feb 2004).

Members of the MODIS Characterization Support Team (MCST), 2003, "MODIS Level 1B Product User's Guide", Document #PUB-01U-0202-REV B, NASA/Goddard Space Flight Center, Greenbelt, MD, 2003.