EastFireWatch : A remote sensing based fire weather monitoring platform for eastern USA

Swarvanu Dasgupta, John J. Qu, Xianjun Hao, Sanjeeb Bhoi, Patrick Coronado

Abstract—**Although wildfires east of the Mississippi are less frequent and less intense, the proximity of a huge population closer to fire-prone areas, a vast expanse of wildland-urban interface and the importance of prescribed burns makes fire-weather monitoring a necessity in this region. Real time monitoring and wide area coverage across the landscape are important properties that make a remote sensing based monitoring platform desirable. Direct broadcast or real time transmission of satellite data to the ground from MODIS abroad the Terra and Aqua satellites allows opportunities for real time fire weather monitoring of the eastern US. The Direct Readout Lab (DRL) station at NASA Goddard Space Flight Center (GSFC), Greenbelt, Maryland has the technological and infrastructural capability of acquiring this freely transmitted data with coverage across the entire eastern United States. Four satellite revisits two each of Terra and Aqua provides opportunities for observing the diurnal variations in fire weather. At George Mason University in collaboration with NASA's DRL at GSFC we are developing a comprehensive real time fire weather monitoring portal for the eastern USA. The portal which we call EastFireWatch would provide near real-time products for monitoring pre-fire, during fire and post-fire conditions. The real time products range from traditional products such as true color images, vegetation indices, and active fire to indigenous products such as fuel moisture content, fire danger indices, fire scar indices. In this paper we describe the motivation for EastFireWatch, the scientific products it provides along with the algorithms used, their scientific basis, their limitations, and possible errors due to factors such as aerosols, clouds and any directional effect. We illustrate the system architecture and the technology used in this system. Future developments in terms of empowering the portal with sophisticated tools that would allow better visualizations, online fire simulations are also discussed.**

I. Introduction – Motivation for EastFireWatch

WILDFIRE conditions in the Eastern United States is vastly different from its western counterpart in terms of the topography, climate, ecosystems and most importantly the human dimensions. Wildfires east of the Mississippi are less frequent, less intense and relatively smaller primarily due to the more humid and wetter conditions. A much higher precipitation in the east keeps forest fuels less drier and vegetation much greener that the west. Fig 1a depicts the average precipitation in conterminous USA. It clearly depicts the much wetter conditions in east. This however does not imply that forest fires are rare in the Eastern States. In fact every year thousands of forest fires are reported in the eastern landscapes. Fig 2 illustrates the no of fires, acres burnt and the average fire size in Georgia over 10 years in Georgia alone (Georgia Forestry Commission Annual Report, 2003). Moreover because of the substantial human dimensions at stake, the management of these fires becomes inherently complicated and dangerous. Fig 1b shows the skewed population distribution on opposite banks of the Mississippi. A larger population closer to forests creates a vast expanse of what is termed as the wildland-urban interface. The wildland-urban interface is defined as the line, area, or zone where structures and other human development meet or intermingle with undeveloped wildland or vegetative fuels (Society of American Foresters, July 1990). Matt and Sampson, 2003 used the Landscan 2000 global population dataset to create a wildland-urban interface map for the entire United States. Fig 1c is taken from their study and clearly exhibits the larger proportion of wildland-urban interface in the east. A larger wildland fire interface directly correlates with the increase in anthropogenic causes of fires starting from campfires, to debris burning in the backyard or even playful children. Fig 2 shows the proportional causes of fires in Georgia. Fires in the wildland urban interface can be extremely dangerous to residential or industrial communities on this sensitive interface, both in terms of life and property. A Georgia Forestry commission published video clip (http://www.eventstreams.com/gfc/010/) rightly points out "a 5 acre fire in the wrong place on the wrong day could destroy your home just as surely as a 1000 acre fire can". In this perspective prescribed fires induced by forest management authorities become an extremely useful tool in reducing a fuel buildup, which may later become a source of more drastic fires. Apart from this fire management issue prescribed fires have been recognized for other beneficial effects. Fire is an effective tool in eliminating undesirable hardwood species that compete for soil nutrients and water. Moreover fire releases nutrients that are bound in leaf litter and woody debris on the forest floor (http://www.bugwood.org/gfcbook/wandpf.html). Thus fires can revitalize the landscape and make way for healthier vegetation. Inherently associated with forest fires is

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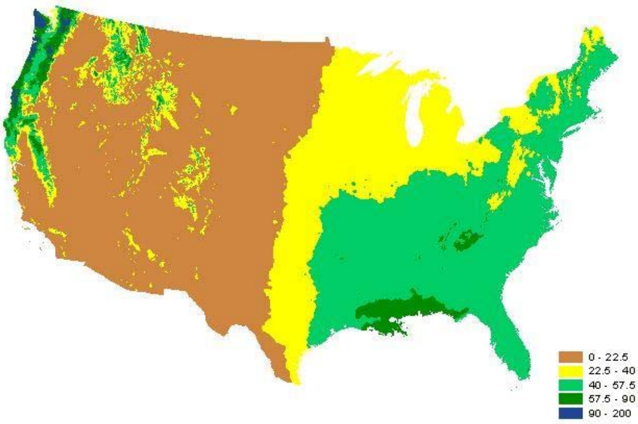
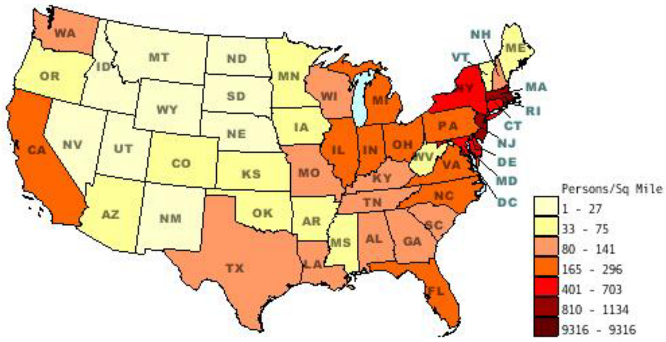
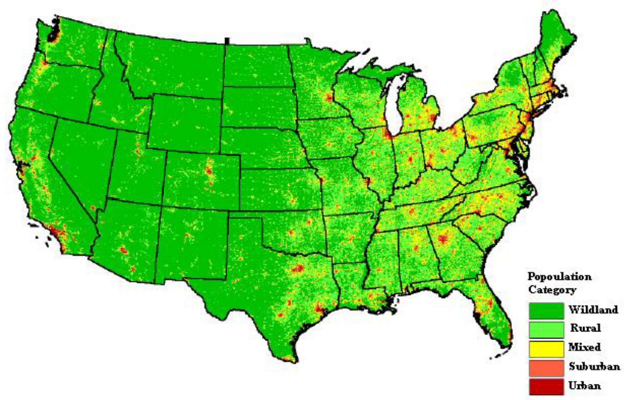


(a)



(b)



(c)

Fig 1. (a) Average Annual Rainfall (in inches) across USA (b). Population Distribution across USA (Source: US Census, 2000) (c) Categorizing population to show the larger proportion of wildland-urban interface in eastern USA (Source:Matt and Sampson, 2003). Categorization used is given in the table below

POPULATION CATEGORY	PEOPLE PER SQUARE MILE
Wildland	<4
Rural	8 – 40
Mixed or Wildland Urban Interface	40 – 400
Suburban	400 - 1600
Urban	>1600

the issue of smoke or air quality. Apart from the poor visibility and dangerous driving conditions it causes, smoke has been known to be detrimental to human health ranging from simple ailments such as burning eyes, runny nose to more serious problems such as bronchitis, heart and lung diseases and even premature deaths (Southern Center For Wildland Interface and Research, http://www.interfacesouth.org/). Again the human dimensions in the east make air quality due to smoke a major cause for concern. Forests are vital resources from the economics point of view as well. For example 66% of Georgia's area is forest land and forestry is a mammoth 25.4 billion dollar industry in this state, generating above 70,000 jobs directly and another 169,366 jobs indirectly (Georgia Forest Facts, Georgia Forestry Commssion). In short even though the eastern fires are smaller and less intense, their vulnerability in terms of human life, property, health and economics remains extremely high. All this calls for focused look on forest fires from the eastern USA perspective.

The USDA Forest Service operates a network of weather stations to monitor fire conditions and manage fires. These stations measure several variables relevant to fire weather such as temperature, humidity, wind, fuel moisture and compute various meteorological fire danger indices which are then spatially interpolated over the landscape. These indices are aimed at reinforcing the fire management efforts and orienting local policies and decisions. While remote sensing can not replace the role of these weather stations, it certainly can support and reinforce the ground based observations to a large extent. Remote sensing offers a cost effective way for circumventing the spatial interpolation problem, with other obvious advantages of spatial and regular temporal coverage. Remote sensing techniques have demonstrated the capability of detecting hotspots or fires. Remote sensing has also been proved to be useful in measuring vegetation status, stress and moisture content; variables that are critical in estimating fire susceptibility or fire behavior. In this respect, the potential of the MODIS sensor (Moderate Resolution Spectrometer) aboard the NASA Terra and Aqua satellites needs to be harnessed. Together the Terra and the Aqua platforms can provide four satellite revisits during a day over a landscape, two of which are during the daytime. The availability of Direct Broadcast facilities for MODIS makes it even more suitable for the real-time fire weather monitoring of the eastern states. Direct Broadcast (DB) is the real-time transmission of satellite data to the ground. As the Earth is being observed by satellite instruments the data is formatted and transmitted to any user below in real-time (http://directreadout.gsfc.nasa.gov/). Users who have compatible ground receiving equipment and are in direct line of sight to the satellite may receive or directly readout these transmissions. EastFireWatch, the topic of this paper is built on this concept and is an online system aimed at providing remote sensing based support to forest fire community. The idea of remote sensing support to wildfire community is not new. There have already been efforts in this direction. The MODIS Rapid Response program, the Wildland Fire Assessment System (WFAS) operated by National

Fiscal Year	No. of Fires	Acres Burned	Average Size
1994	10,269	36,726	3.57
1995	5,913	18,977	3.21
1996	10,668	40,053	3.75
1997	7,224	22,997	3.18
1998	6,579	36,660	5.57
1999	11,004	47,370	4.30
2000	11,688	71,595	6.13
2001	8,392	41,574	4.95
2002	10,369	45,332	4.37
2003	4,288	11,890	2.77
Ten Year Average	8,639	37,317	3.93

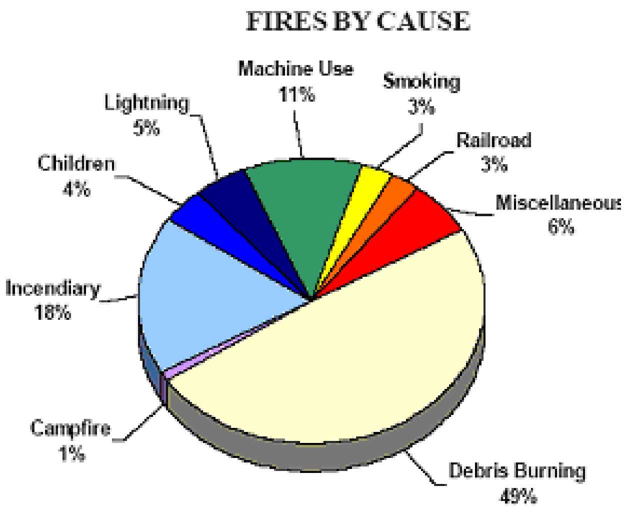


Fig 2. Top: No of fires, Total acres burnt and average fire size in Georgia (Source: Annual Report 2003, Georgia Forestry Commission); Bottom: Fire causes as percentage

Interagency Fire Center (NIFC, Boise, ID) and the Oklahama fire danger Mesonet are three such excellent systems that have demonstrated the immense possibilities for remote sensing to contribute in the area of wildland fires. Today the MODIS Rapid response program generates four primary real time science products (Active fire, surface reflectance, vegetation indices and surface temperature) apart from the imagery that is freely available online. The WFAS also generates an experimental remote sensing based Fire Potential Index over conterminous United States. The Oklahama Mesonet also uses Relative Greenness measures to estimate vegetation dryness. However a comprehensive effort in looking at all aspects of fires starting from pre fire risk conditions, to fire detection, to assessing the damage and recovery after a fire ,using remote sensing to its full potential has not been fully realized.

At George Mason University in close collaboration with NASA's Direct Readout Lab at GSFC we are developing a comprehensive real time fire weather monitoring portal for the eastern USA. The Direct Readout Lab (DRL) station at NASA Goddard Space Flight Center (GSFC), Greenbelt, Maryland has the technological capability of acquiring this freely transmitted data with coverage across the entire eastern United States. The portal which we call EastFireWatch would provide near real-time products for monitoring pre-fire, during fire and post-fire conditions. The real time products would range from traditional products such as true color images, vegetation indices, and active fire to indigenous products such as fuel moisture content, fire danger indices, fire scar indices, and fuel load. Remote sensing based air quality monitoring support would also be provided by combining data from MODIS and other sensors such as MOPITT (Measurements of Pollution in the Troposphere) which can measure carbon monoxide and methane. The potential advantages of this portal would be its comprehensiveness in providing an entire gamut of images and products for monitoring eastern USA fire weather, and the availability of these products and images in real time. The portal would also be equipped with fire management tools for simulating fires on eastern landscapes, and modeling air quality effects of fires. This would be done by integrating FARSITE fire behavior tool and BlueSky into the system. BlueSky is a product developed by the USDA Forest Service that links computer models of fuel consumption and emissions, fire, weather, and smoke dispersion into one system for predicting the cumulative impacts of smoke from wildfires, prescribed or agricultural fires (http://bluesky.cfr.washington.edu/bluesky/). We believe such images, products and tools would be greatly useful not only in managing wildfires but also in planning prescribed fires. Our knowledge engineered outputs would provide useful, timely and geographically specific information to federal, state and local fire managers and other users. EastFireWatch would use continuous satellite measurements to: (1) generate near real time fire related products,; (2) deliver the data products appropriately tuned to specific users; (3) post fire related information to interested public; and (4) provide support to Regional, State and local decision makers. In the next section of this extended abstract we briefly describe the data and image products to be available on the EastFirewatch portal.

II. Current Data Products

A. True color images

True color images are built using MODIS band 1 (250m), band 4 (500m) and band 3 (500m). Standard atmospheric corrections are performed for generating the true color image.

B. Vegetation Indices

We are currently using the MODIS Rapid Response version of the Vegetation Index algorithm which can be used to generate Vegetation indices for a single swath. Vegetation indices include the Normalized Difference Index and the Enhanced Vegetation Index. The algorithms are simple and are applied on a corrected reflectance product. The corrected reflectance product is generated by a simple atmospheric correction using MODIS visible and near-infrared bands (bands 1 to 7) ( ). Corrections for molecular (Rayleigh) scattering and gaseous absorption (water vapor, ozone) are also made using climatological values for gas contents. Thus no real time input or ancillary data is necessary. However no aerosol correction is made. Since the reflectance product is not corrected for aerosols the Rapid Response version of the products may be of poorer quality in presence of aerosols compared to the official MOD13 16 day composite vegetation indices product. Moreover the Rapid response version of NDVI/EVI currently performs no correction for directional effect and can be generated for a single swath as opposed to MOD13 16 day composite product.

C. *Live fuel moisture Content*

Burgan's algorithm for live vegetation moisture estimation is based on current observation and historical records of NDVI, and it is easy to be implemented for operational use. Currently it is used in Wildland Fire Assessment System (WFAS). With Burgan's approach, live vegetation moisture (MC) is computed as follows:

MCpix= RG/100*(MCmax_pix-MCmin_pix)+MCmin_pix

where, RG is relative greenness index, and

RG=(VIobs_pix-VImin_pix)/(VImax_pix-VImin_pix)*100

For a given pixel, MCmax_pix and MCmin_pix are maximum and minimum potential live vegetation moisture contents, respectively, and they are determined with fuel model empirically. VIobs_pix is the observed NDVI, and VImax_pix (VImin_pix) is the maximum (minimum) NDVI value observed historically. NDVI is the most popular vegetation index. Nevertheless, it has some disadvantages, such as atmospheric influence, scaling problem, saturation problem, and high sensitivity to canopy background variations. EVI was developed to improve vegetation signal sensitivity in high biomass regions and to reduce the influences of canopy background signals and atmosphere. We will evaluate using EVI for real-time live fuel moisture retrieval. We are also investigating other techniques using shortwave IR (infrared bands) for fuel moisture measurements.

D. *Active Fires*

The Active Fire Detection Product alternatively called the Thermal anomaly product is generated using the algorithm used by the MODIS Rapid Response program. The algorithm uses brightness temperatures derived from the MODIS 4 and 11 micrometer channels (Giglio et al 2003). The fire detection strategy is based on absolute detection of the fire, if the fire is strong enough i.e radiating at a brightness temperature of 360K. Temperatures less than that could be natural to the surface, for eg in deserts. To filter out naturally hot surfaces and detect weaker fires, the algorithm uses a contextual test. This latter test identifies pixels with values elevated above a background thermal emission obtained from the surrounding pixels. This method accounts for variability of the surface temperature and reflection by sunlight. The contextual approach was a significant improvement in the original algorithm and results in less false detection than traditional threshold-based algorithms. The algorithm is also sensitive to small fires, which makes it even more suited to wildfire applications.

E. *Fire Danger Indices*

We are currently evaluating a normalized difference index using MODIS bands 7 and 2 for fire danger estimation. Band 7 in SWIR, being a water absorption band is sensitive to fuel moisture content. Band 2 in NIR is not very sensitive to fuel moisture. The following index may be useful for fire danger rates

FDI= -(Band2-Band7)/(Band2+Band7)

We are also investigating a fire susceptibility index (FSI). The proposed index is based on the concept of heat energy of pre-ignition and thus allows a physical meaning to be associated to the index values (Dasgupta et al 2004).

F. *Carbon Monoxide*

Biomass burning is an important source of global CO concentration which, when influenced by the atmospheric circulation system, can affect areas lying far from the actual source of the fire. CO concentration is computer for the eastern Unites States using CO data from MOPITT (Measurements of Pollution in the Troposphere) measurements.

III. Summary of the Extended Abstract

This extended abstract describes the motivation for EastFireWatch and the possible role it can play in wildland fire management in Eastern USA. It describes the products and images to be available on the portal. Our presentation at the conference would cover the aforementioned and other science products and tools we are working on to enhance the fire monitoring capabilities. We will discuss the system architecture from an Information Technology point of view, and the present the current status of EastFirewatch.

IV. References

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