MODISoft Development and Sample Products

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Abstract

The Moderate Resolution Imaging Spectroradiometer (MODIS) sensor in TERRA and AQUA satellite was launched in December 18, 1999 and May 4, 2002 respectively. There are 36 spectral bands covering from 0.4 to 14 μm. MODIS data are the most comprehensive remote sensing data up to now, which can simultaneously retrieve information about ocean, land and atmosphere. But the current commercial remote sensing software cannot process these data correctly. In order to utilize the MODIS data efficiently, we have developed a software MODISoft® specified in automatically processing huge volume multitemporal MODIS data to produce standard product for terrestrial application. The original MODISoft® was developed starting in July 2002 and was published in December 2002. Now it has included four kernel modules: basic MODIS processing module, atmospheric product module, terrestrial product module and hazard monitoring module. The system has been operationally run in Chinese National Agency of Forest and other research institutes for different application. In our research team, the software was used to produce data for support research of landcover mapping, hazard monitoring and global climate change. In this paper, we describe the software and the wide range of products that are generated through its operation.

Key words: forests, remote sensing, snow, environmental protection

1 Introduction

The global environmental change was main issues facing to human today. Understanding of our living environment is more and more depended on global, integrated and quantitative description of our earth system. Different methods are used to gather data from different area and server for different applications. Of these various kinds of data, the satellite data are the most huge and important for terrestrial research. Especially, that NASA launched its Earth Science Enterprise in 1991 and then started to build its Earth Observing System (EOS) provided a comprehensive method to exploit the interaction of atmosphere, land and life for each other. As a part of EOS, two Moderate Resolution Imaging Spectroradiometer (MODIS) sensors were equipped in TERRA and AQUA satellite that were launched in December 18, 1999 and May 4, 2002 respectively. With 36 spectral bands covering from 0.4 to 14 μm, spatial resolution from 250m to 1km and temporal at most two days, MODIS data are the most comprehensive remote sensing data up to now, which can simultaneously retrieve information about ocean, land and atmosphere. But the current commercial remote sensing software cannot process these data correctly. In order to effectively utilize these data source, NASA established four scientist teams including land, atmosphere, ocean and calibration and designed 44 standard product data development scheme. Now several standard products can be downloaded from NASA data center. Although NASA took many efforts to establish the global satellite product algorithm, its MODIS standard products are still difficult for regional application because the design of global remote sensing algorithm is so challengeable. Its many products about terrestrial system are not consistent well with Chinese environment. It is still necessary to design software to produce data product for regional applications. In addition, MODIS data can extract more terrestrial parameters other than the 44 standard parameters, which also demand to develop a new software system. In order to utilize the MODIS data efficiently, we have developed a software MODISoft® specified to automatically process huge volume multitemporal MODIS data to produce standard product for terrestrial application. The original MODISoft was developed starting in July 2002 and was published in December 2002. Now it has included four kernel modules: basic MODIS processing module, atmospheric product module, terrestrial product module and hazard monitoring module. The system has been used operationally run in Chinese National Agency of Forest and other research institutes for different application. In our research team, the software was used to produce data for support of landcover mapping, hazard monitoring and global climate change as well as service data for several projects such as CIDA project “Combating global warming: enhancing China's capacity for carbon sequestration”, Chinese 973 project “Carbon cycle of Chinese terrestrial ecosystem and its driving mechanism” and “Asia environment monitoring” project. In this paper, we describe the software and the terrestrial products that are generated through its operation.

2 System overview

MODISoft® is a fully integrated, automatic and scalable software platform for processing of MODIS data. It currently comprises four modules: basic module, atmospheric module, land module and hazard monitoring module. It can produce standard product from MODIS 1B data, and also can georeference these data then composite generation. The system overview is shown in Figure 1. The MODISoft® is completely developed by C code and can be run independently without the support of any additional third party software. The C code programming makes the software processing speed more fast so that more suitable to handle huge MODIS data. The modularity design should allow for easy upgrades to support new sensors and add new functions to it. At the same time, the modularity also makes it easy to extend the module to establish special operational system.

A friendly graphical user interface (GUI) (Fig. 2.) has been designed to assist the operator in data input, display, product generation and output. At the same time, the console command also was provided to permit the user batch processing the data, which is especially useful for processing huge data that need run so long time. When generation of product, many accessory databases are required. This database was prepared in advance and provided with system. So the user need not know what accessories are needed when produce product. The MODISoft® can produce product and then georeference and composite.

The basic module includes MODIS 1B data input, preprocessing, georeference, display, image stretching, image display property adjust and output. To easily exchange data with other image processing platform, the output product are created as HDF, geotiff and flat raster binary image files. The HDF data are scaled to 8, 16 or 32 bits integer according to the data type and add the scale property. The Geotiff include float, color and grey type. The atmospheric module focuses on produce and composite atmospheric product from MODIS 1B data. The product data include cloud mask, aerosol distribution, precipitable vapor. The land module can produce product about land surface reflectance, land surface temperature, land emissivities, vegetation index (NDVI/ EVI), leaf area index and land cover classification. The hazard module use the MODIS 1B data to extract some hazard information, and it can be extended to independent operational monitoring system. Now the module can detect drough, fire, dust storm, snow event.

It is difficult to describe all products in the paper. We will only introduce the product relating to terrestrial system parameters.

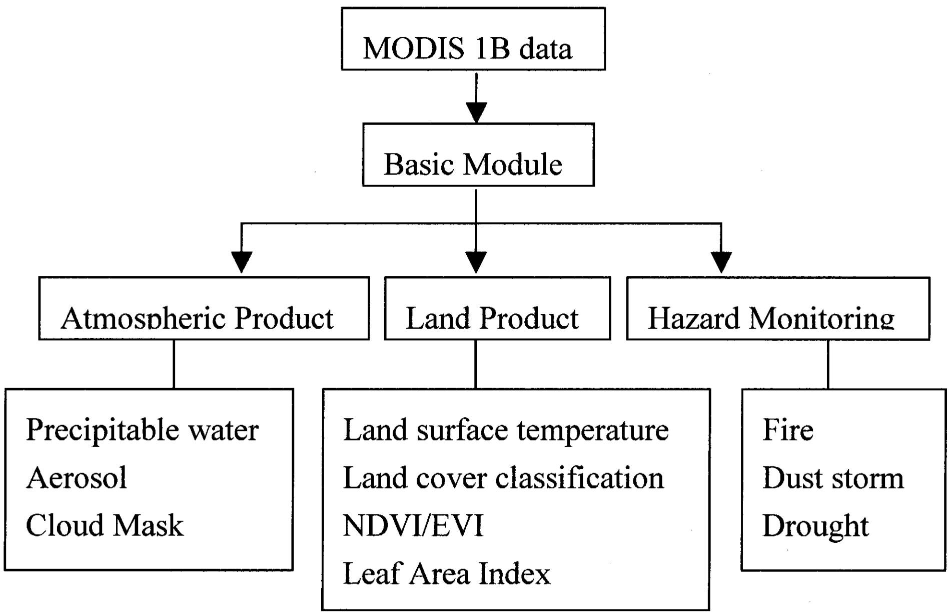

Fig. 1. Diagram of MODISoft

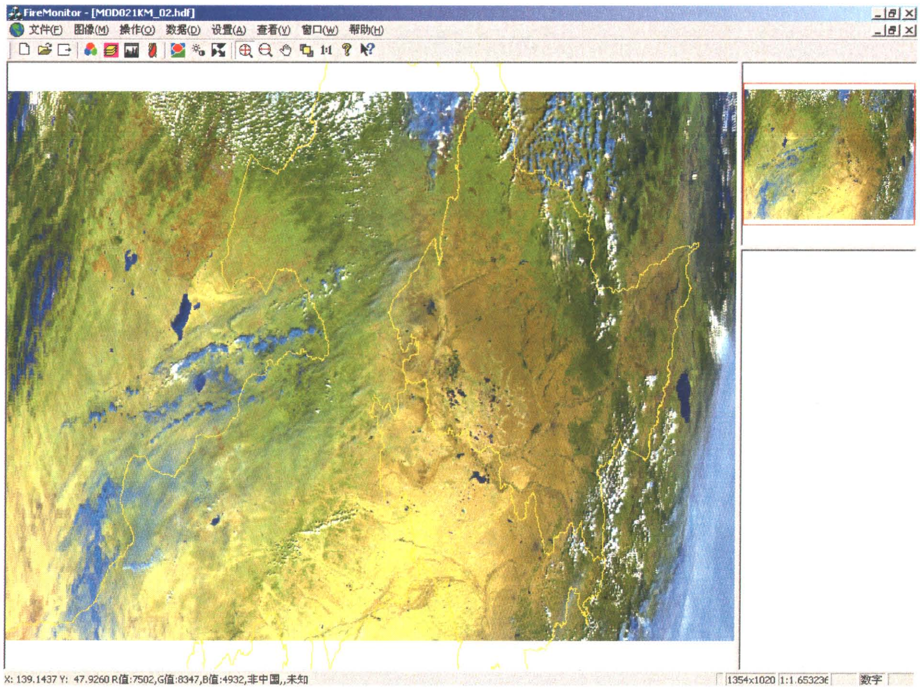

Fig. 2. MODISoft® Fire monitoring system interface

3 MODIS product

In MODIS standard product define several land product for MODIS, including land surface reflectance (MOD09), land surface temperature (LST, MOD11), land cover classification (LCC, MOD12), vegetation indices (VI, MOD13), thermal anomalies (MOD14) and burned scar (MOD40), leaf area index (LAI, MOD15), MODIS Surface Resistance and Evapotranspiration (ET, MOD16), Vegetation Production and Net Primary Production (NPP, MOD17), Surface Reflectance BRDF/Albedo Parameter (MOD43), Vegetation Cover Conversion & Vegetation Continuous Fields (MOD44). All these standard products can be downloaded from NASA web site freely except MOD16. However, because these product algorithms are designed for global scale, the product accuracy is not all appropriate for regional applications. We try to create product data in our MODISoft® from MODIS 1B data directly with the support of Chinese regional background information so as to be more consistent with Chinese environment. Up to now, the MOD09, MOD11, MOD12, MOD13, MOD14&MOD40, MOD15 can be produced from MODISoft®.

3.1 Land surface reflectance (MOD09)

The surface reflectance product is the input for product generation for several land products: Vegetation Indices (VIs), BRDF, snow/ice, and Fraction of Photosynthetically Active Radiation/ Leaf Area Index (FPAR/LAI), continuous field vegetation and vegetation conversion. It is, therefore, an important and essential product.

The MODIS Surface Reflectance Product is computed from the MODIS Level 1B land bands 1, 2, 3, 4, 5, 6, and 7 (centered at 648 nm, 858 nm, 470 nm, 555 nm, 1240 nm, 1640 nm, and 2130 nm, respectively) (Vermote et al., 1997). The product is an estimate of the surface spectral reflectance for each band as it would have been measured at ground level if there were no atmospheric scattering or absorption. The correction scheme includes corrections for the effect of atmospheric gases, aerosols, and thin cirrus clouds; it is applied to all noncloudy MOD 35 Level 1B pixels that pass the Level 1B quality control. The correction uses band 26 to detect cirrus cloud and remove its effect, water vapor from MOD 05, aerosol from MOD 04, and ozone from MOD 07 (Fig.3). If no these data in some regions, the accessory climatology can be used or else let it alone. Because the MODIS atmospheric product algorithm for aerosol can't work in bright surface, there is no aerosol in these regions. Therefore, current land surface reflectance is not corrected aerosol effect in bright region.

Before atmospheric correction After atmospheric correction

Fig. 3 Produce land surface reflect

3.2 Land surface temperature

Land surface temperature (LST) is a good indicator of both the energy balance at the Earth's surface and the greenhouse effect because it is one of the key parameters in the physics of the landsurface processes. It is required for a wide variety of climate, hydrological, ecological, and biogeochemical studies. This product will be used in generating other MODIS products and in a variety of EOS interdisciplinary studies.

The NASA LST product was used the generalized split-window LST algorithm to retrieve LST for MODIS pixels with emissivities in bands 31 and 32 estimated from land cover classification (Snyder et al., 1998). This method is rough because emissivities change with phenology and land cover classification deviation. In MODISoft®, the Becker and Li's (1990) split-window method was used to retrieve land surface temperature:

$$T_{b1} = [1.274 + [\frac{T4+T5}{2}(1+0.15616\varepsilon_{1b1} - 0.482\varepsilon_{2b1}) + \frac{T4-T5}{2}(6.26+3.98\varepsilon_{1b1} + 38.33\varepsilon_{2b1})]]$$ where

$\Delta\varepsilon = \varepsilon_4 - \varepsilon_5$, $\varepsilon = (\varepsilon_4 + \varepsilon_5)/2$.

and the emissivities of band 31 and band 32 determined from (Sobrino, 2001):

- $NDVI < 0.2$

$$\varepsilon = 0.980 - 0.042\rho_1$$
$$\Delta\varepsilon = -0.003 - 0.029\rho_2$$

- $0.2 \le NDVI \le 0.5$

$$\varepsilon_{31} = 0.968 + 0.021P_v$$
$$\varepsilon_{32} = 0.974 + 0.015P_v$$
$$\varepsilon = (\varepsilon_{31} + \varepsilon_{32})/2 = 0.971 + 0.018P_v$$
$$\Delta\varepsilon = (\varepsilon_{31} - \varepsilon_{32})/2 = -0.006(1 - P_v)$$
$$P_v = \frac{(NDVI - NDVI_{\min})^2}{(NDVI_{\max} - NDVI_{\min})^2} = \frac{(NDVI - 0.2)^2}{0.09}$$

- $NDVI < 0.2$

$$\varepsilon_{31} = \varepsilon_{32} = 0.985$$
$$\varepsilon = \varepsilon_{31} = \varepsilon_{32} = 0.985 + C_i$$
$$\Delta\varepsilon = 0$$

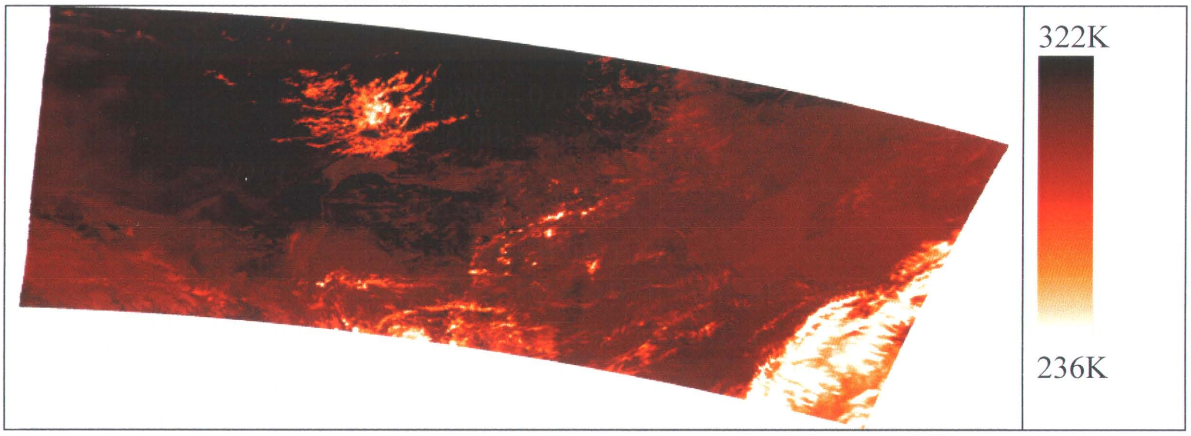

Fig. 4. Land surface temperature retrieval from MODIS top atmospheric radiance

3.3 Land cover classification

The land cover classification product is used for biophysical and biogeochemical parameterization of land cover for input to global- and regional-scale models of climate, hydrologic processes, and biogeochemical cycling. Examples of biogeophysical parameters keyed to land cover include leaf-area index, vegetation density, and FPAR. Other parameters are biomass permanence and energy-transfer characteristics of the land surface. The land cover parameter identifies 17 categories of land cover following the IGBP global vegetation database, which defines nine classes of natural vegetation, three classes of developed lands, two classes of mosaic lands, and three classes of nonvegetated lands (snow/ice, bare soil/rocks, water) and classified by artmap neural network (Friedl et al., 1999). There are many errors in the MODIS stand LCC product in China, especially in southern China where forests were mixed cropland. The MODISoft® designed the new algorithm using climate-based region division method (Liu et al., 2003) and at the same time using National Land Cover Database data as classification train data (Fig. 5).

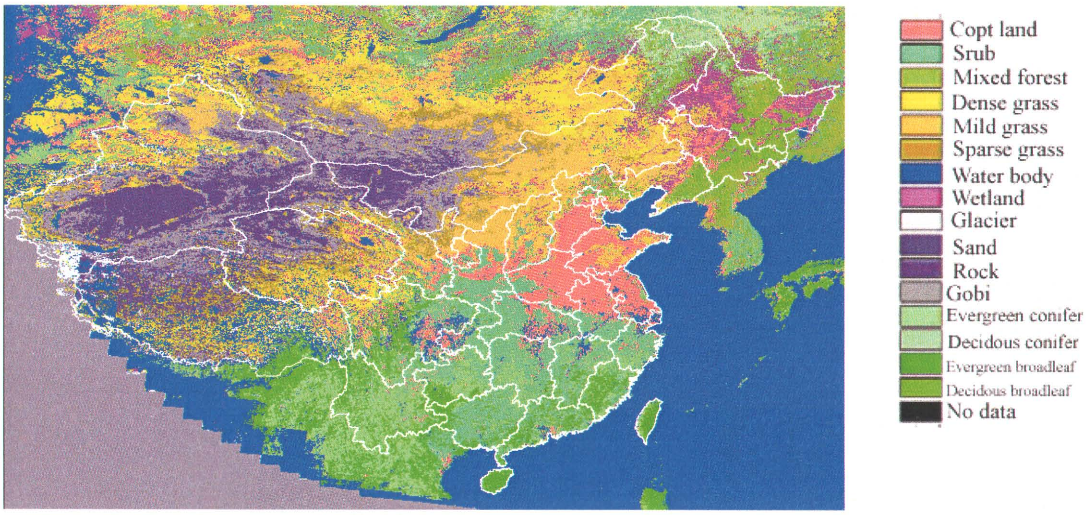

Fig.5. Chinese Land classification from MODIS data in 2002

3.4 Vegetation indices

The MODIS Vegetation-Index (VI) products will provide consistent spatial and temporal comparisons of global vegetation conditions that will be used to monitor the Earth's terrestrial photosynthetic vegetation activity in support of change detection and phonologic and biophysical interpretations. Gridded vegetation-index maps depicting spatial and temporal variations in vegetation activity are derived at 8-day, 16-day, and monthly intervals for precise seasonal and interannual monitoring of the Earth's vegetation. The MODIS VI products will improve upon currently available indices and will more accurately monitor and detect changes in the state and condition of the Earth's vegetative cover. The vegetation-index products are made globally robust with enhanced vegetation sensitivity and minimal variations associated with external influences (atmosphere, view and sun angles, clouds) and inherent, non-vegetation influences (canopy background, litter), in order to serve more effectively as a "precise" measure of spatial and temporal vegetation change.

Due to their simplicity, ease of application, and widespread familiarity, vegetation indices are widely used by the broader user community from global circulation climate modelers and EOS instrument teams and interdisciplinary projects in hydrology, ecology, and biogeochemistry to those making regional- and global-based applications involving natural-resource inventories, land-use planning, agricultural monitoring and forecasting, and drought forecasting. Some of the more common applications of the vegetation index concern:

- Global warming/climate
- Global biogeochemical and hydrologic modeling
- Agriculture; precision agriculture; crop stress, crop mapping
- Rangelands; water supply forecasting; grazing capacities; fuel supply
- Forestry, deforestation, and net primary production studies
- Pollution/health issues (Rift valley fever, mosquito producing rice fields)

• Desertification

• Anthropogenic-change detection and landscape disturbances.

Two vegetation-index (VI) products were designed in NASA VI standard product (Huete et al., 2002). One is the standard normalized difference vegetation index (NDVI), which is referred to as the "continuity index" to the existing NOAA-AVHRR-derived NDVI. The other is an enhanced vegetation index (EVI) with improved sensitivity in high biomass regions and improved vegetation monitoring through a decoupling of the canopy background signal and a reduction in atmosphere influences. The two VIs complement each other in global vegetation studies and improve upon the extraction of canopy biophysical parameters. The MODISoft® VI were produced by same methods but provided more flexible composite choice. The composite method can select by minimum red, blue or maximum NDVI. The composite period also can be select for any length. Fig. 6. is a NDVI composite map from all Beijing and Urumuqi MODIS receiver station data during August 2002. The operation is very simple that you only need tell the system where all MODIS 1B data located.

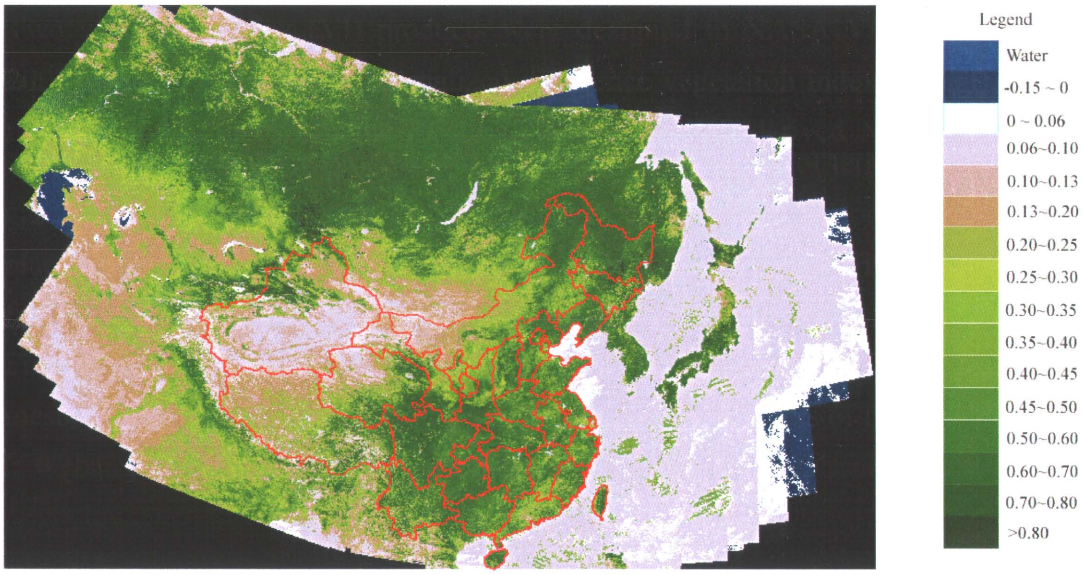

Fig. 6. NDVI composite data of XinJiang and Beijing MODIS receiver station in August 2002

3.5 Thermal anomalies & burned scar

Fire is an important process within a significant number of terrestrial biomes, and the release of gases and particulate matter during biomass burning is an important contributor to the chemical reactions and physical processes taking place in the atmosphere. Fire is a significant and continuous factor in the ecology of savannas, boreal forests, and tundra, and plays a central role in deforestation. Fire information will be used to drive regional emissions models, trace gas transport models, and mesoscale models of atmospheric chemistry. Important impacts of fires include:

● changes of physical state of vegetation and release of greenhouse gases;

- release of chemically reactive gases during biomass burning;
- release of soot and other particulate matter during fires;
- changes in the exchange of energy and water between land surfaces and the atmosphere; and changes in plant community development and soil nutrient, temperature, and moisture, and cloud development and reflectivity.

The MODIS Thermal Anomalies product includes fire occurrence (day/night), fire location, the logical criteria used for the fire selection, and an energy calculation for each fire (Kaufman et al., 1998). The NASA fire algorithm cannot discern some fires in boreal forest in winter. MODISoft® designed a new fire detection method and using the NLCC landcover data as background support. The burned scar detection method is improved from NASA threshold method. (Fig. 7.)

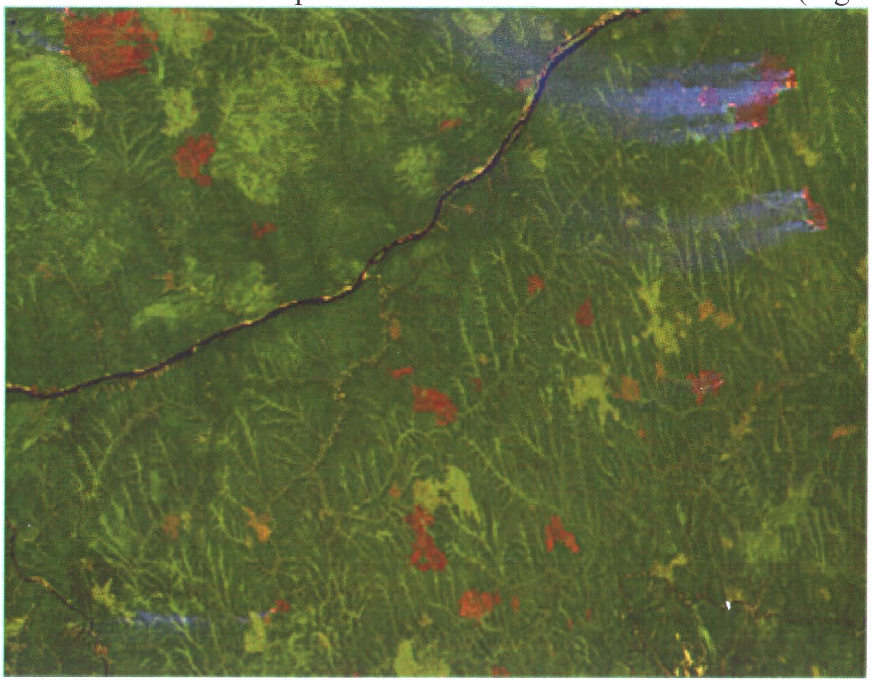

Fig. 7. Fire and fire scar

3.6 Leaf area index and photosynthetically active radiation (fPAR)

LAI and FPAR are biophysical variables that describe canopy structure and are related to functional process rates of energy and mass exchange. Both LAI and FPAR have been used extensively as satellite derived parameters for calculation of surface photosynthesis, evapotranspiration, and NPP. These products are essential in calculating terrestrial energy, carbon, water-cycle processes, and biogeochemistry of vegetation. The LAI product is an input to Biogeochemical models to produce conversion- efficiency coefficients, which are combined with the FPAR product to produce daily terrestrial photosynthesis and annual NPP.

Estimation of LAI from satellite data is challengeable. The simple method is establishment of regression relationship with vegetation index such as NDVI. But there are different relationships with NDVI in different landcover, it is restricted in local region. NASA product used a physically radiative transfer model to inverse the LAI and fPAR (Myneni et al., 2002), but its product are larger than measurement value in nearly all region. In MODISoft®, the BRDF-based method developed by Chen et al. (2004) was embedded. The land cover data used the NLCC land cover data (Fig. 8).

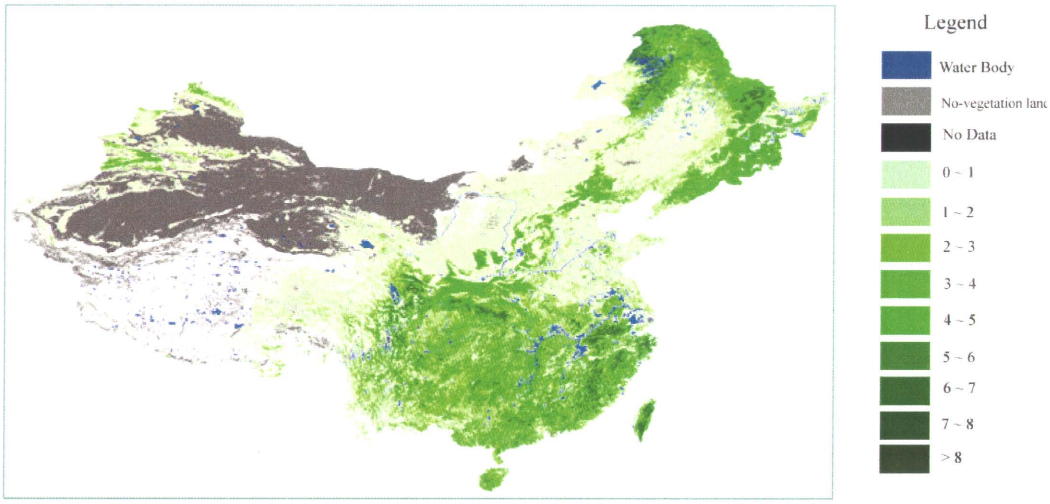

Fig. 8. Chinese LAI in June, 2002

4. Future work

At the present time, not many functions in MODISoft® are integrated into a friendly user GUI system. Some more urgent sub-systems are designed with more convenient for use and some module can only be used in our lab environment. In the next step, we will integrate all sub-system with same operational styles.

It is intended to continue implementing MODISoft upgrades as new and revised algorithms become available. At the same time, we are trying to design the new algorithm for MODIS data processing, such as LST and emissivities separation algorithm, land surface reflectance and aerosol separation algorithm. The new automatically operational monitoring application will extend, such as forest change monitoring system, dust storm monitoring system, aerosol air pollution system are under development.

Some algorithms designed for processing MODIS data can easily move to other satellite data. With its module-based program designed, MODISoft® will be developed for an automatic quantitative remote sensing data processing platform.

5. Conclusion

The MODISoft has been designed to automatically process huge MODIS data to generate application product. The modular design philosophy and C-based coding made it more scalable and efficient. The high degree of automation and flexibility in MODISoft® be adequate to meet the requirements (ranging from scientific to practical applications) of a wide variety of users including forest fire management agencies, crop forecasting and assessment agencies, crop insurance companies, forestry industries, and government environmental agencies.

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