Forest Fire Detection Techniques Using Satellite Data

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OUTLINE

1. Forest Fire Present Situation

2. Fire Detection using Satellite Images

3.Typical Application

1. Forest Fire Present Situation

Forest Fire in abroad

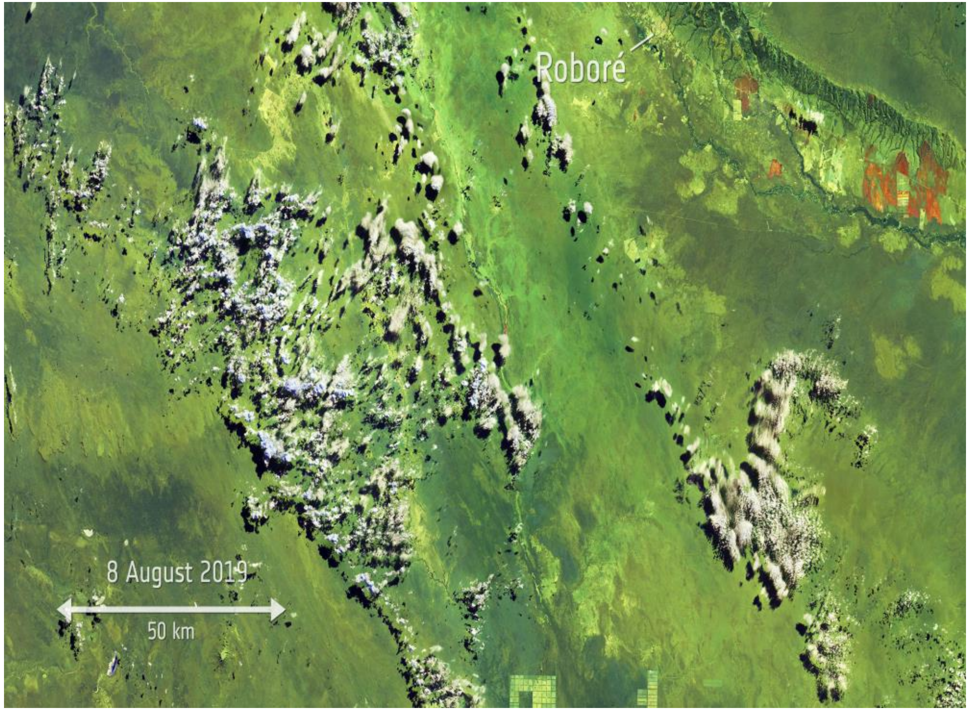
More than 9250 km² had been burned in August, 2019 in Amazon. There were 9507 times forest fire in one week (Aug. 22, 2019).

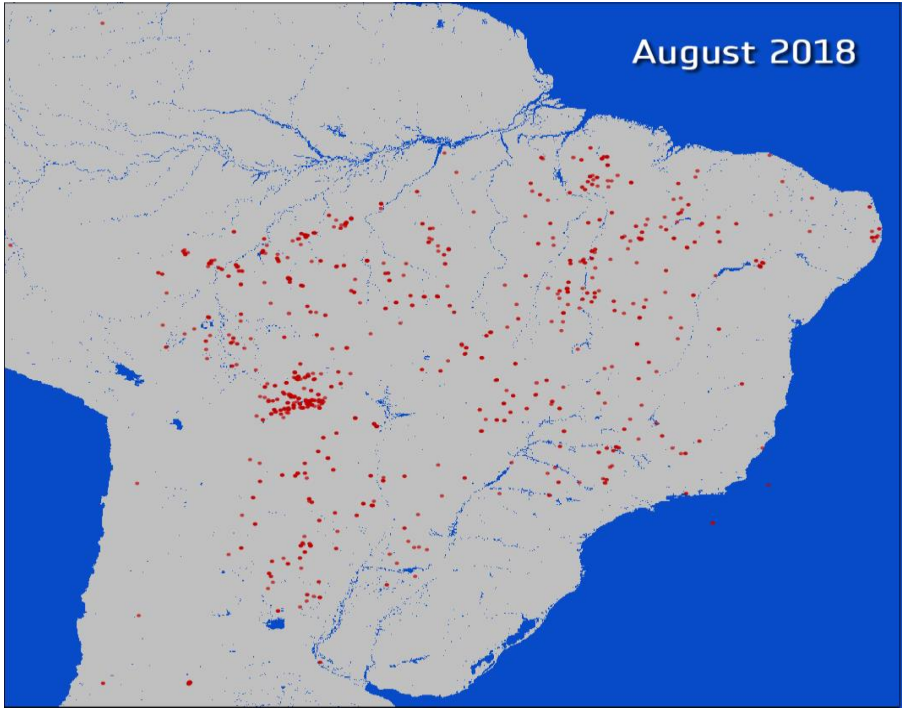
August 13, 2019 **(from NASA)**

BRASIL **Sep. 15, 2019**

1. Forest Fire Present Situation

➢ Forest Fire in abroad





BRASIL， August, 2019 **(from ESA)**

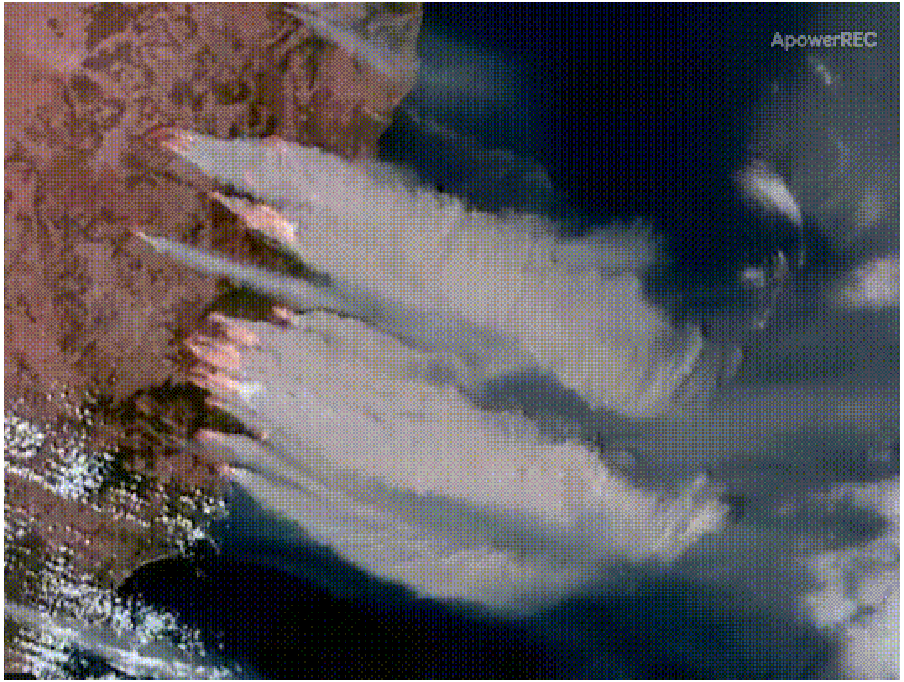
1. Forest Fire Present Situation

➢ Forest Fire in abroad

Australia， 2019.11.11

1. Forest Fire Present Situation

➢ Forest Fire in abroad



Australia，2019.11.11

1. Forest Fire Present Situation

➢ Forest Fire in abroad

Australia，2019.11.11

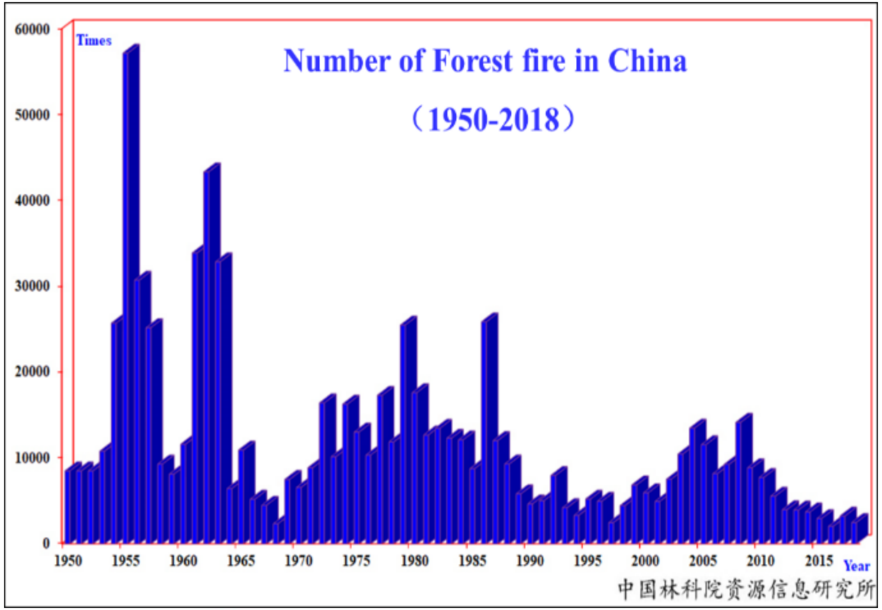
1. Forest Fire Present Situation

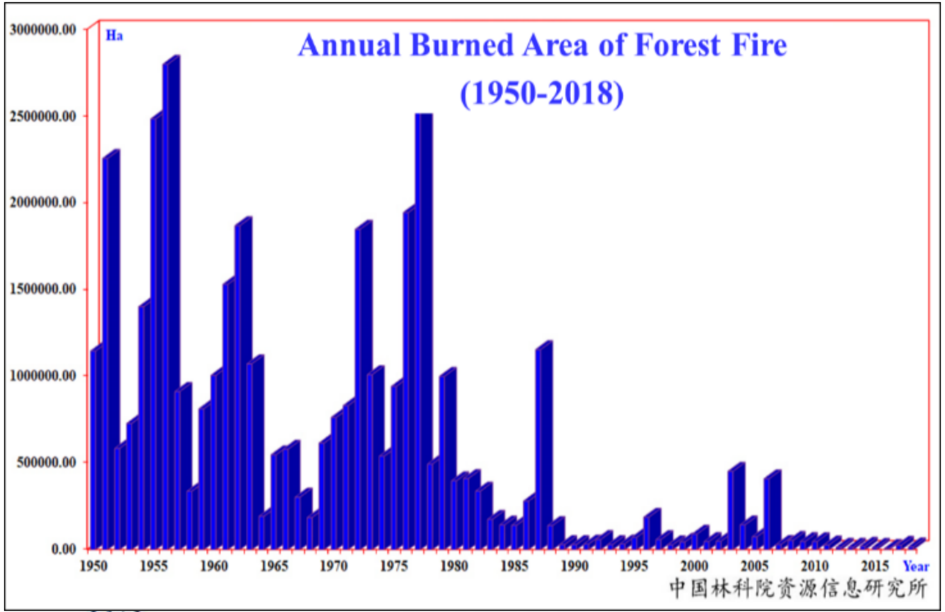
➢ Forest fire in China

1. Forest Fire Present Situation

➢Forest fire in China

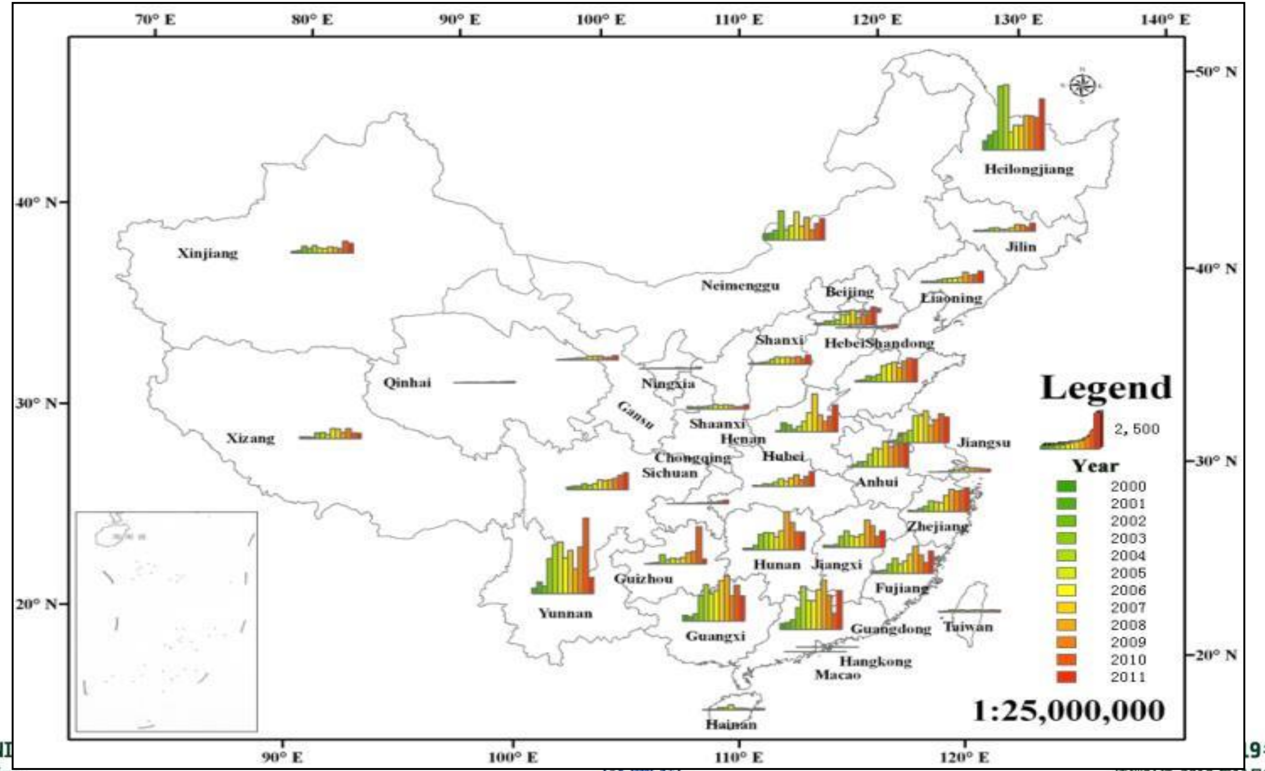
The annual average of forest fires is about 12,000 times and the damaged forest area is over 550,000 hm^2 in China from year 1950 to 2018.





1. Forest Fire Present Situation

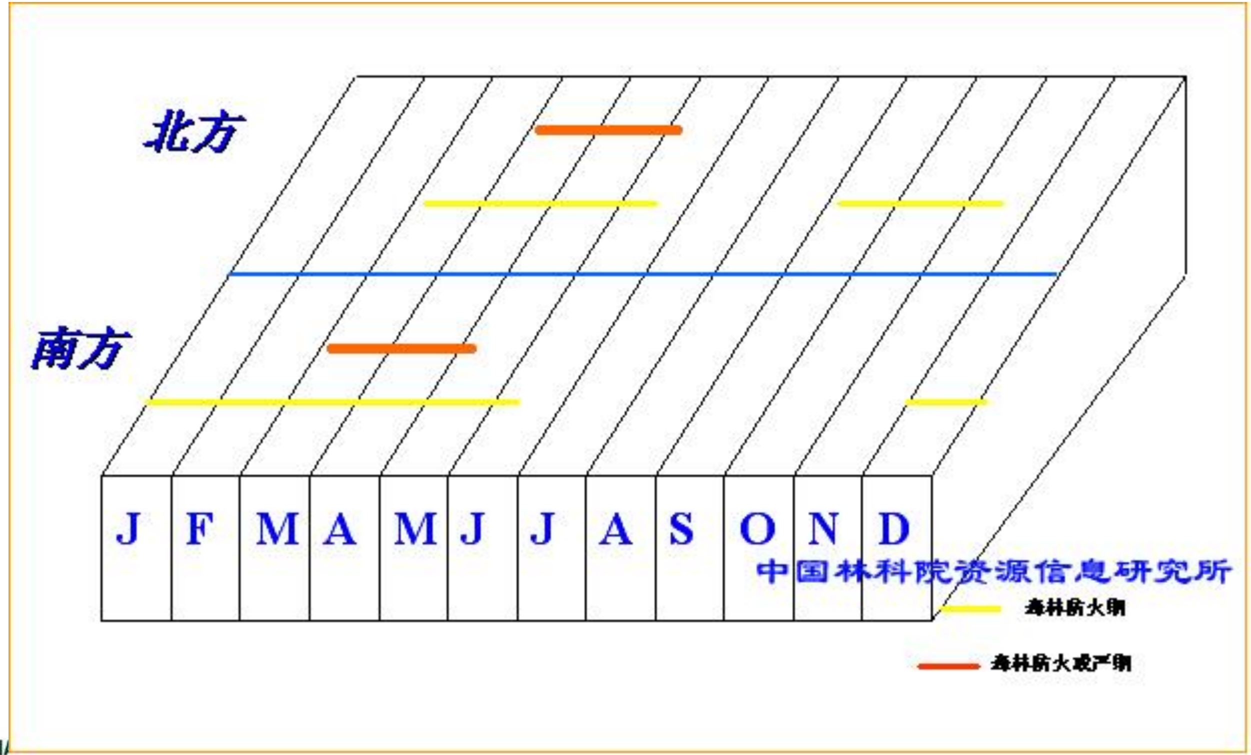
➢Forest fire in China



➢Forest fire season of China

North

South



1. Forest Fire Present Situation

➢ Regulations of Chinese forest fire prevention

Type	1988.1.16	2009.1.1
火警 (Fire alarm)	The damaged forest area is less than 1hm^2 or ignition in other forest land	/
一般森林火灾 (General forest fire)	The damaged forest area is between 1hm^2 and 100hm^2	The damaged forest area is less than 1hm^2 or ignition in other forest land; or died person is between 1 and 3 ; or hurt person is between 1 and 10
较大森林火灾 (Large forest fire)	/	The damaged forest area is between 1hm^2 and 100hm^2; or died person is between 3 and 10 ; or hurt person is between 10 and 50
重大森林火灾 (Serious forest fire)	The damaged forest area is between 100hm^2 and 1000hm^2	The damaged forest area is between 100hm^2 and 1000hm^2; or died person is between 10 and 30 ; or hurt person is between 50 and 100
特别重大森林火灾 (Extra serious forest fire)	The damaged forest area is larger than 1000hm^2	The damaged forest area is larger than 1000hm^2; or more than 30 person died; or more than 100 person hurt

我国的森林防火条例

森林火灾是林地上失控的火，它是自由蔓延、超过一定面积、造成一定损失的林火。

类型	1988年1月16日颁布	2009年1月1日起执行
火警 (Fire alarm)	受害森林面积不足1公顷或者其他林地起火的	/
一般森林火灾 (General forest fire)	受害森林面积在1公顷以上不足100公顷的	受害森林面积在1公顷以下或者其他林地起火的，或者死亡1人以上3人以下的，或者重伤1人以上10人以下的
较大森林火灾 (Large forest fire)	/	受害森林面积在1公顷以上100公顷以下的，或者死亡3人以上10人以下的，或者重伤10人以上50人以下的
重大森林火灾 (Serious forest fire)	受害森林面积在100公顷以上不足1000公顷的	受害森林面积在100公顷以上1000公顷以下的，或者死亡10人以上30人以下的，或者重伤50人以上100人以下的
特别重大森林火灾 (Extra serious forest fire)	受害森林面积在1000公顷以上的	受害森林面积在1000公顷以上的，或者死亡30人以上的，或者重伤100人以上的

1. Forest Fire Present Situation

➢ Fire Classification

- Forest Fire
- Grassland fire
- Prescribed burning (Fire in Silviculture)
- Agricultural fire (prescribed residues burning, crop residue burning, etc.)

➢ The Four Steps of Forest Fire-fighting

- **Prevention**

Previous works of cleanliness of the forest: tracing firewalls, preparation of firefighting strategies…

- **Warning**

Fire Risk Indexes Maps: **fuel and vegetation parameters monitoring (TIR)**, meteorological conditions, human factor …

- **Crisis**

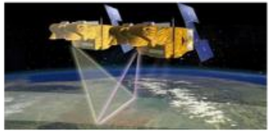
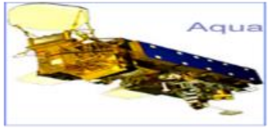
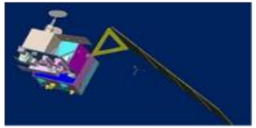
Fire detection and monitoring (SWIR/MIR/TIR); fire propagation simulator.

- **Post-crisis**

Mid and long-term damage assessment and vegetation evolution.

2. Fire Detection

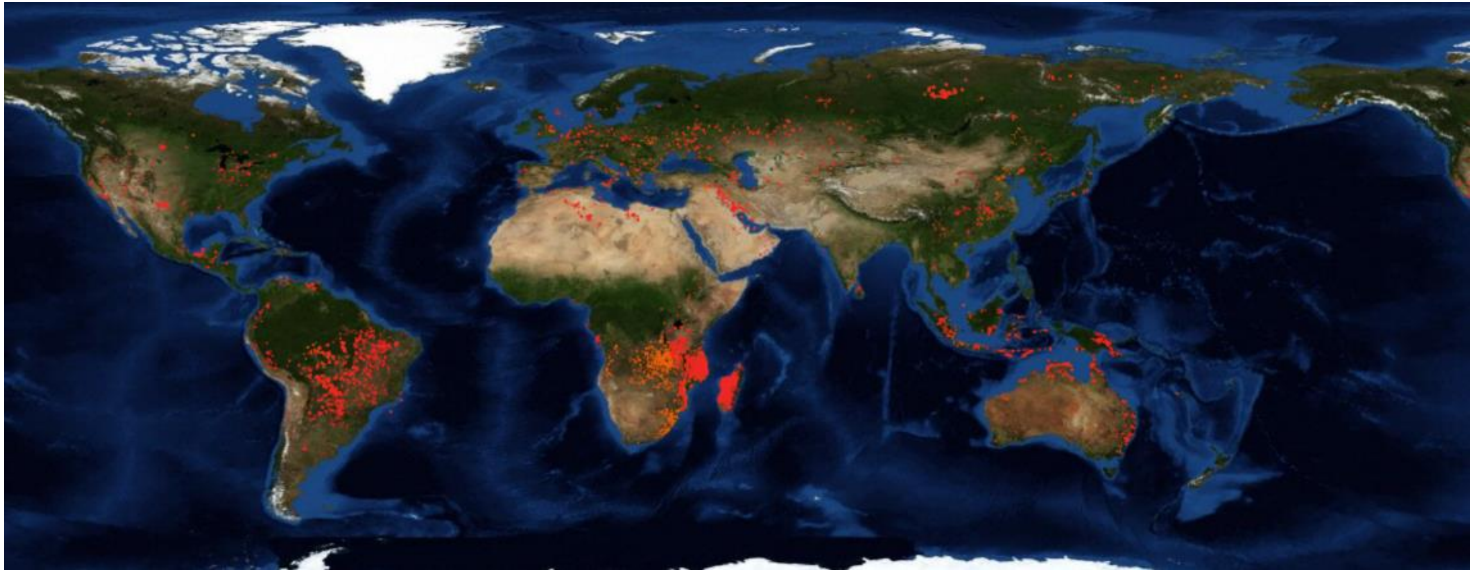
➢ Fire Monitoring System

Satellite	NOAA/AVHRR 	Terra/Aqua MODIS 	FY 	Space
Airplane		UAV		Air
Fire Watch		Video image		Near Ground
Watch man				Ground

2. Fire Detection

➢Active Fire Monitoring using Satellite Images

Satellite remote sensing has been a unique technique to monitor global active fire.



（https://firms.modaps.eosdis.nasa.gov/map，August 25,2019）

2. Fire Detection

➢ Principle of hotspots identification

● **Plnack's Law**

$$M_\lambda = \pi L_\lambda = \frac{\pi 2hc^2 \lambda^{-5}}{\exp\left(\frac{hc}{k\lambda T}\right) - 1}$$

$$M_\lambda = \frac{\pi k_1 \lambda^{-5}}{\exp\left(\frac{k_2}{\lambda T}\right) - 1}$$

c = 3.0 × 10^8 m/s
k = 1.38 × 10^{-23} J.K^{-1}
h = 6.62 × 10^{-34} J.s

k_1 = 3.74 × 10^{-16} W.m^2
k_2 = 1.44 × 10^{-2} m.K

Principle of Hotspots Identification

● Stefan-Boltzman's Law

$$M = \int_0^\infty M_\lambda \, d\lambda = \frac{2\pi^4 k^4 T^4}{15 c^2 h^3} = \sigma T^4$$

$\sigma = 5.67 \times 10^{-8}$ W.m^{-2}.K^{-4}

The total emittance from a black body, including all wavelengths, is directly proportional to the fourth power of its temperature.

This temperature is call "Brightness Temperature, BT", and it is what we directly obtain from the satellite signal.

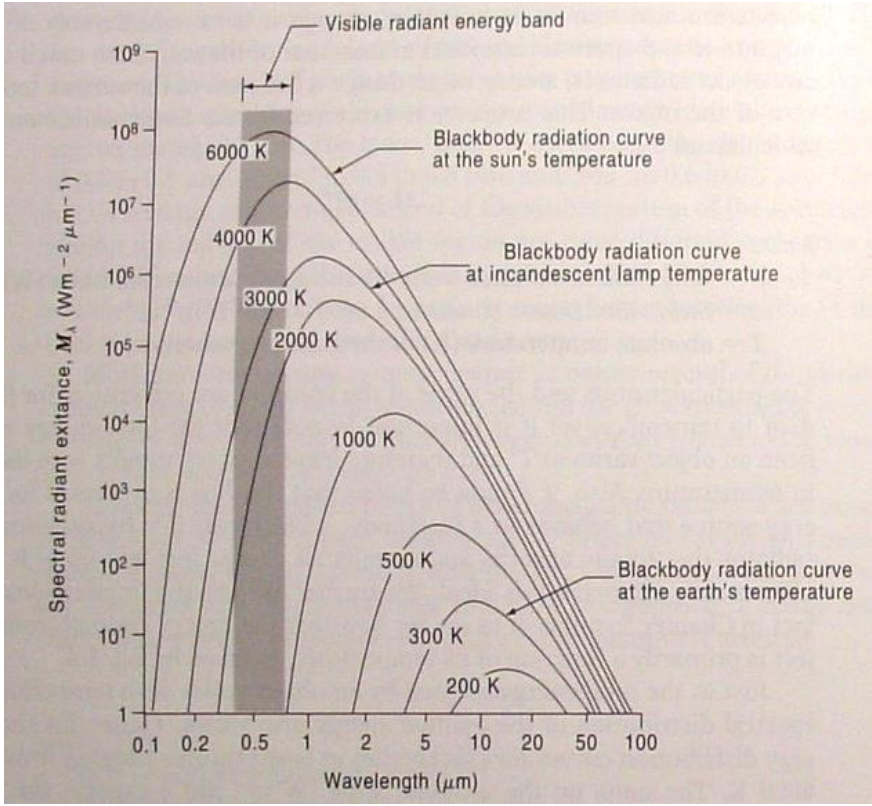
● Wien's Law

$$\lambda_{max} = p_1/T \qquad M_{\lambda max} = p_2.T^5$$

$p_1 = 2.898 \times 10^{-3}$ m.K, $p_2 = 1.2862 \times 10^{-5}$

The maximum **spectral emittance** is proportional to the **fifth** power of the **temperature**, and it corresponds to a peak wavelength, λ_{max}, which is **inversely proportional** to the **temperature.**

➤ Principle of Hotspots Identification



The λ_{MAX} Displacement from the Law of Wien.

Examples of Wien's Law

T (sun) = 6000K
λ_{max}= k/T = 2898/6000 = 0.483μm

T (earth) = 300K
λ_{max}= k/T = 2898/300 = 9.66μm

The GREY (REAL) Bodies

Emissivity

The real bodies are not black bodies, BB's. Its emittance is always lower that that of the black bodies. So we need to introduce a factor call "emissivity", ε , being ε < 1, to obtain its emittance. Then, they are called "grey bodies".

$$M_{GB} = \varepsilon.\sigma.T^4_{GB};\ \ \varepsilon < 1$$

We can imagine a BB with the same emittance that the GB

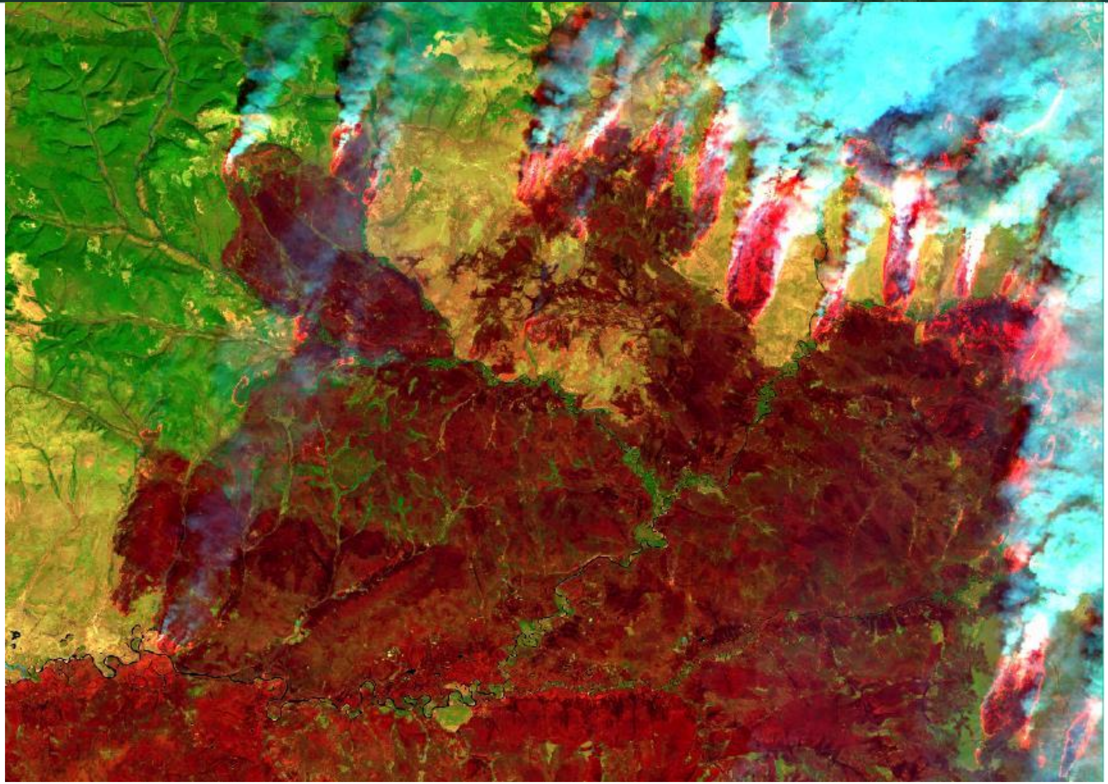
$$M_{BB} = M_{GB} = \sigma \,.\, T^4_{BB}$$

To have the same emittance that the grey body, this BB has to be at a temperature T_{BB}

$$T_{BB} = \varepsilon^{1/4}.T_{GB}$$

Combustion status

- Smoking
- Flaming
- Smouldering
- Burned area



S2B, 2018.5.9

2. Fire Detection

➢ Purpose

- Detect burning in the vast forest areas
- Map large fires to support suppression
- Monitor all phases of a fire in the key regions

2. Fire Detection

➢ Satellite Data

Low Spatial Resolution Optical Data

- NOAA-AVHRR (1100m)
- MODIS (1000m)
- ENVISAT-AATSR（1100m）
- Himawari-8/9（500/2000m）
- VIIRS (375/750m)
- Sentinel-3 SLSTR（1000m）
- FY Series (1100/1000m)

Mid-high Spatial Resolution optical Data

- TM/ETM$^+$/Landsat 8 OLI (30m)
- SPOT (10/20m)
- Sentinel-2（10/20/60m）
- HJ-1B IRS (30/150/300m)
- GF-4（50/400m）

Comparison of the Sentinel-3 SLSTR, AATSR and ATSR-1/2 instruments

	Capability	SLSTR	AATSR & ATSR-1 & 2
Swath	Nadir view	>1400 km	500 km
Dual view	>740 km	500 km	
Global coverage revisit times	1 satellite (dual view)	1.9 days (mean)	3 days at mid-latitudes
2 satellites (dual view)	0.9 day (mean)	–	
1 satellite (nadir view)	1 day (mean)	3 days at mid-latitudes	
2 satellites (nadir view)	0.5 day (mean)	–	
Spatial sampling interval at SSP (km)		0.5 km VIS-SWIR 1 km IR-Fire	1 km
Spectral channel Centre, λ (μm)	VIS SWIR MWIR/TIR Fire1/2	0.555; 0.659; 0.865 1.375; 1.610; 2.25 3.74; 10.85; 12 3.74; 10.85	0.555; 0.659; 0.865[a] 1.610 3.74; 10.85; 12
Radiometric resolution	VIS (A = 0.5%) SWIR (A = 0.5%)	SNR >20 SNR >20	SNR >20 SNR >20
	MWIR (T = 270K) TIR (T = 270K) Fire-1 (<500K) Fire-2 (<400K)	NEΔT < 80mK NEΔT < 50mK NEΔT < 1K NEΔT < 0.5K	NEΔT < 80mK NEΔT < 50mK
Radiometric accuracy	VIS–SWIR (A = 2–100%)	<2% (BOL) <5% (EOL)	<5%
	MWIR–TIR (265–310K) Fire (<500K)	<0.2K (0.1K goal) <3K	<0.2K
Design lifetime [b]		7.5 years	ATSR-1 & 2: 3 years AATSR: 5 years

A, albedo; BOL, beginning of life; EOL, end of life; SSP, subsatellite point; NEΔT, Noise-Equivalent Temperature Difference.
a These channels were present for the AATSR and ATSR-2, but not the ATSR-1.
b Some instruments remain in operation for much longer than their 'design lifetimes'. Launched in 2002, Envisat's AATSR, for example, was designed for 5 years, but continued to operate for almost 10 years until 2012. Similarly, ERS-1 has provided an uninterrupted series of ATSR-type data and data products since its launch in 1991.

The Sentinel-2 Mission

Band number	Central wavelength (nm)	Bandwidth (nm)	Spatial resolution (m)	*Lref* ($W.m^{-2}$ sr-1 μm^{-1})	SNR @ *Lref*
1	443	20	60	129	129
2	490	65	10	128	154
3	560	35	10	128	168
4	665	30	10	108	142
5	705	15	20	74.5	117
6	740	15	20	68	89
7	783	20	20	67	105
8	842	115	10	103	174
8b	865	20	20	52.5	72
9	945	20	60	9	114
10	1380	30	60	6	50
11	1610	90	20	4	100
12	2190	180	20	1.5	100

GF-4 Satellite

Have been launched in Xichang Satellite Launch Center on December 29, 2015. It’s Geostationary orbit satellite. The fixed point location is 105.6° E.

To explore the forest fire monitoring method of GF-4 PMI images.

Sensor	Spectrum band No.	Spectral range (μm)	Spatial resolution (m)	Breadth (km)	Revisit time	Application for fire
Visible light near infrared (PMS)	1	0.45~0.90	50	500	20s	
	2	0.45~0.52				Smoke
	3	0.52~0.59				
	4	0.63~0.69				Burned area mapping
	5	0.77~0.89				
Medium wave infrared (IRS)	6	3.50~4.10	400	400		Fire identification

Detection Methods

- **Image Processing**

  (Image enhanced, RGB composition, PCA, etc.)

- **Classification**

  (Supervised, Decision Tree, SVM, Random Forest Classification, etc.)

- **Threshold Value**

  (Fixed threshold, Variable Threshold, Context threshold, etc.)

- **Vegetation Index**

  (NDVI, Ratio Vegetation, etc.)

- **Artificial Intelligence**

  (Neural Network , Expert System, Deep learning, etc.)

Example

Algorithms based on threshold: These algorithms look for a minimum threshold of the **MIR** and **TIR** values and a minimum difference between **MIR** and **TIR** values. The **MIR** and **TIR** values are its brightness temperatures.

The general condition of this kind of algorithms is:

$$T_{MIR} > T_{MIR,\ threshold}$$

$$T_{TIR} > T_{TIR,\ threshold}$$

$$T_{MIR} - T_{TIR} > T_{MT,\ threshold}$$

Sometimes an additional condition is included:

$$\alpha_{NIR} < \alpha_{threshold}$$

Due to the fact that the burnt soil has a very low **NIR** reflectance.

Detection Methods

- **Example**

ALGORITHMS BASED ON CONTEXTUAL ANALYSIS: These algorithms analyzes the **MIR** and **TIR** values on the analyzed pixel plus the pixels around it, and they check if the mean value and standard deviation of these values overcome some conditions. Then the core of this analysis is the variability of the pixels around the possible fire. The general condition of this kind of algorithms is:

$$\sigma_{MIR} > \sigma_{MIR,threshold}$$

$$\sigma(T_{MIR} - T_{TIR}) > \sigma_{MT,threshold}$$

Being σ the standard deviation.

Sometimes an additional condition is also included:

$$\alpha_{NIR} < \alpha_{threshold}$$

Due to the fact that the burnt soil has a very low **NIR** reflectance.

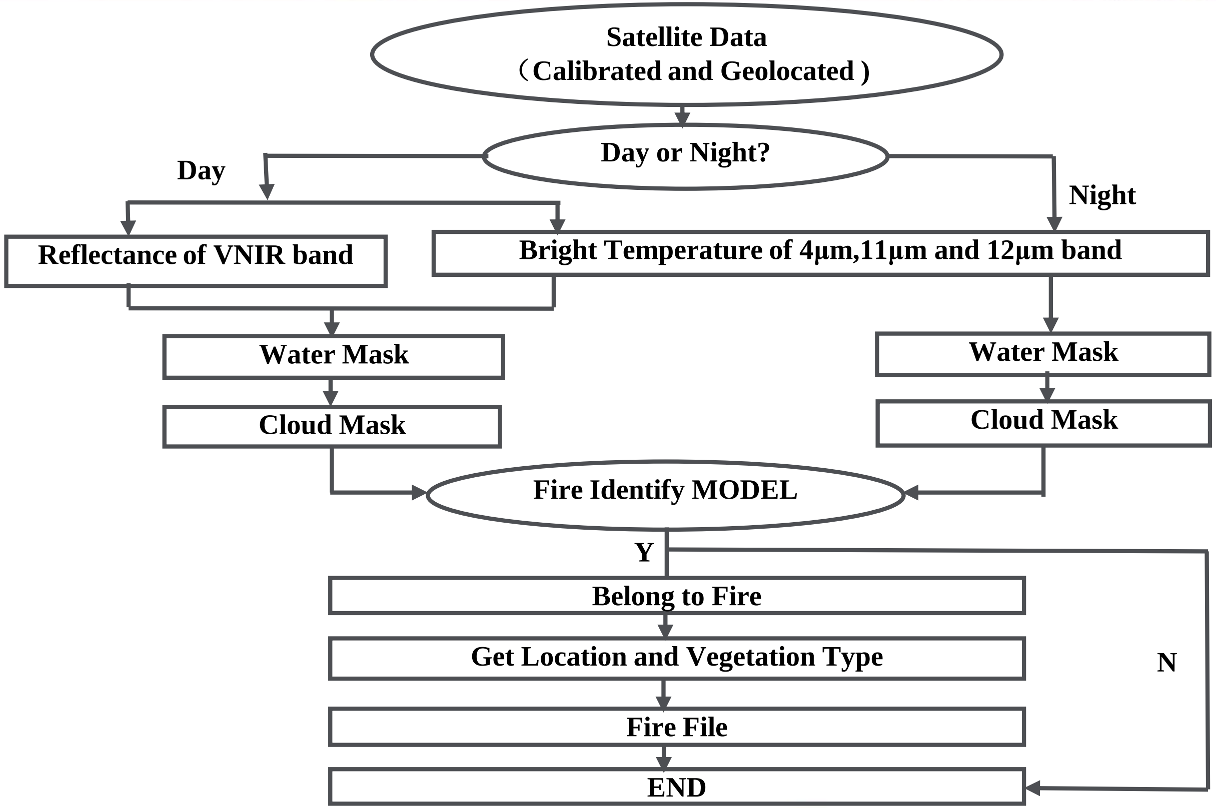
➢ Detection Methods

- **Example**

Table 2. Five fire detection algorithms tested over the Canadian boreal forest. Note that all statistics (av, ad, md, sd) refer to background pixels; all temperature values are expressed in degrees Kelvin (K); all thresholds given here refer to daytime data.

Algorithm / Description	CCRS	ESA	IGBP	GIGLIO	MODIS
Algorithm category and geographic applicability	fixed thresholds, regional (Canada)	fixed thresholds, global/regional	contextual, global	contextual, global	contextual, global
Potential fire detection			$T_3>311$ AND $T_{34}>8$	$T_3>310$ AND $T_{34}>6$	$T_3\geq315$ AND $T_{34}\geq5$
Background window size			3x3 to 15x15	5x5 to 21x21	3x3 to 21x21
Min. number of pixels			Max{25% of pixels tested , 3}	Max{25% of pixels tested , 6}	Max{25% of pixels tested , 3}
Background selection			$T_3\leq311$ OR $T_{34}\leq8$	$T_3\leq318$ OR $T_{34}\leq12$	$T_3\leq320$ OR $T_{34}<20$
Actual fire detection with T_3 and/or T_4	$T_3>315$	$T_3>320$	Define: ξ_3= av(T_3)+2*sd(T_3)+3 ξ_{34}= Max{8, av(T_{34})+2*sd(T_{34})} Then, Confirm potential fires as real if: $T_3>\xi_3$ AND $T_{34}>\xi_{34}$	Define: ξ_4= av(T_4) + ad(T_4) - 3 ξ_{34}= av(T_{34})+Max{2.5*ad(T_{34}),4} Then, Confirm potential fires as real if: $T_4>\xi_4$ AND $T_{34}>\xi_{34}$	Define: ξ_3=Min[320,av(T_3)+4*Max{sd(T_3),2}] ξ_{34}=Min[20,md(T_{34})+4*Max{sd(T_{34}),2}] Then, Confirm potential fires as real if: $T_3>360$ OR [$T_3>\xi_3$ AND $T_{34}>\xi_{34}$]
Filter hot surfaces	$T_{34}\geq14$	$T_{34}>15$	Incorporated into fire detection	Incorporated into fire detection	Incorporated into fire detection
Filter clouds	$T_4\geq260$	$T_4>245$	$R_1+R_2\leq1.2$ AND $T_5\geq265$ AND ($R_1+R_2\leq0.8$ OR $T_5\geq285$)	*IGBP criteria applied here (no external cloud mask).*	*IGBP criteria applied here (no external cloud mask).*
Filter reflective surfaces	$R_2\leq0.22$	$R_1<0.25$	$R_2<0.20$	$R_2<0.25$	
Filter sun glint		$\lvert R_1-R_2\rvert>0.01$			$R_1\leq0.3$ OR $R_2\leq0.3$ OR reflected sun angle $\geq 40°$
Other detection criteria	$T_{34}\geq19$ OR $T_{45}<4.1$				
Post processing (*not applied in this investigation*)	• Elimination of non-forest and isolated pixels	• Quicklook inspection, • Max annual NDVI > 0			

➤Basic flowchart of Fire detection



➢Basic steps of Fire detection

Step 1: Pre-processing

(Radiometric Correction, Geometric Correction, etc.)

Step 2: Physical value calculation

(Reflectance, Bright Temperature, Vegetation Index, etc.)

Step 3: Characteristic Analysis (Sample)

Step 4: Constructing Model

Step 5: Validation Results

Step 6: Mapping Results

Physical Value Calculation

- **Reflectance Calculation**

Radiance(L_λ)=scales*DN −offset

TOA_Ref = Radiance *1.0/cos (D2R *θ_s)

Where: DN is the digital data

TOA_Ref is the Top-of-Atmosphere (TOA) reflectance

θ_s is solar zenith angle

D2R is degree to radian; the value is 0.0174533.

- **Vegetation Index (VI)**

NDVI = (ρ_{nir}-ρ_{red})/(ρ_{nir}+ρ_{red})

Physical Value Calculation

Radiance Calculation

Radiance(L_λ)=scales*DN −offset

Bright Temperature Calculation

$$BT_\lambda = \frac{C_2}{\lambda * \ln(1.0 + \frac{C_1}{L_\lambda * \lambda^5})}$$

Where: BT_λ is the bright temperature of central wavelength;

λ is the central wavelength;(unit: μm);

L_λ is the radiance of Wavelength ; (unit: W micron^4 / m^2 sr)

C1, C2 are constants;

Here, C1 = 1.19107E+8 (unit: W micron^4 / m^2 sr)

C2 = 1.43883E+4 (unit: micron K）

Physical Value Calculation

- **Bright Temperature Correction**

$$T_\lambda = BT_\lambda * Ta_\lambda + Tc_\lambda$$

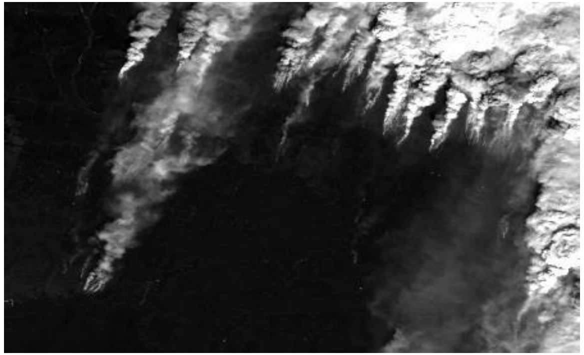
Where:

T_λ is the λ Wavelength's bright temperature after correction;

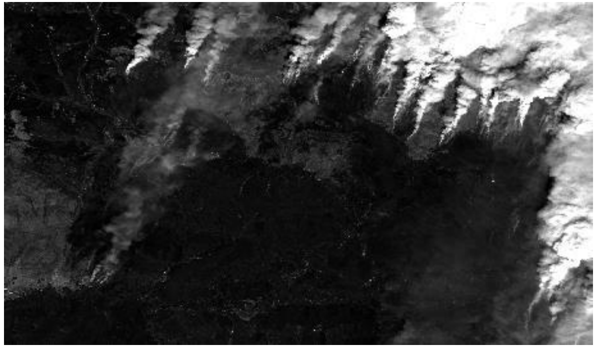
BT_λ Is the λ Wavelength's bright temperature before correction;

Ta_λ is the λ Wavelength's bright temperature correction scale;

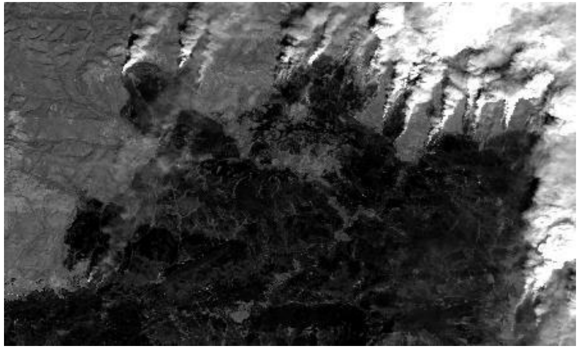
➤ Characteristics Analysis



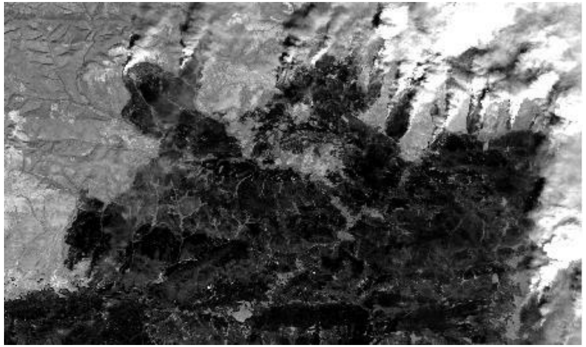
Blue(0.442μm)



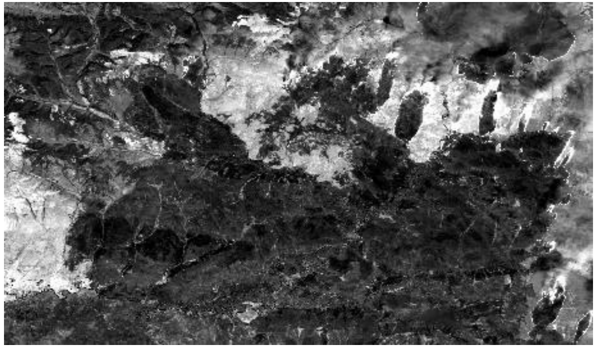
Red(0.665μm)



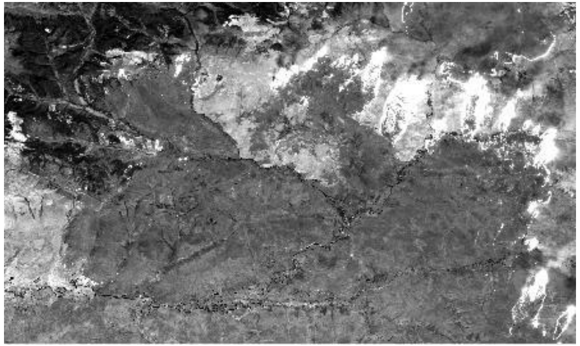
Red edge(0.739μm)



NIR(0.864μm)



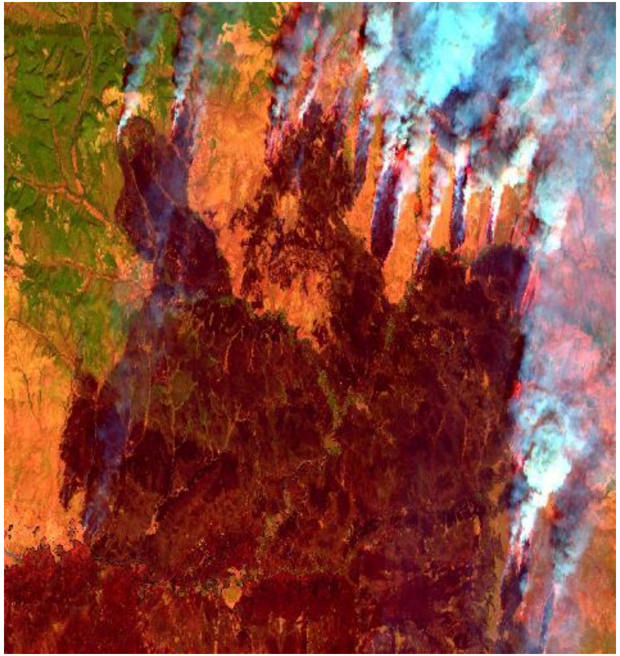
SWIR(1.610μm)



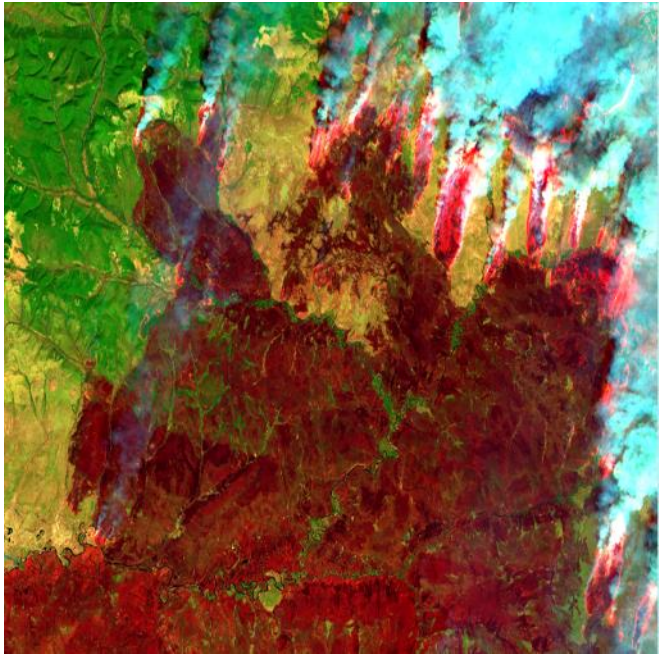
SWIR(2.186μm)

Characteristics Analysis

RGB(0.665, 0.559, and 0.442μm)



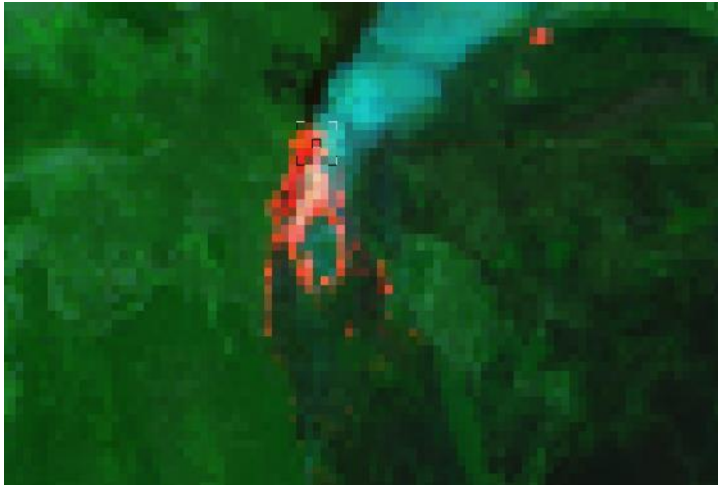
RGB(1.610, 0.864, and 0.665μm)



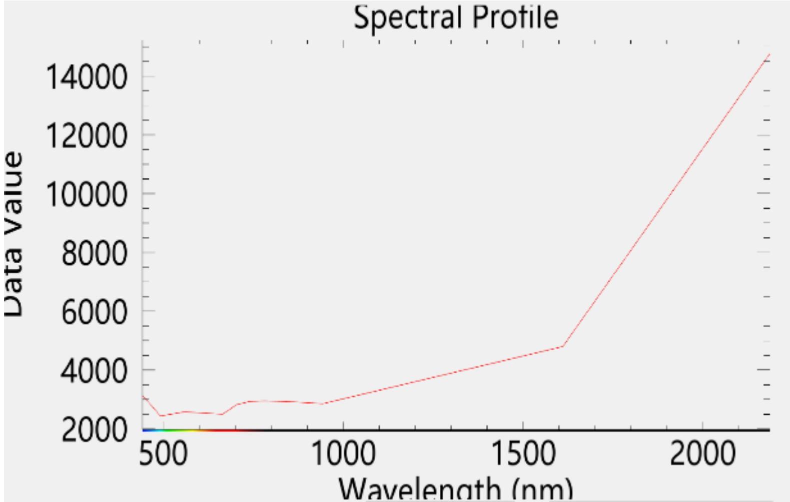
RGB(2.186, 0.864, and 0.665μm)

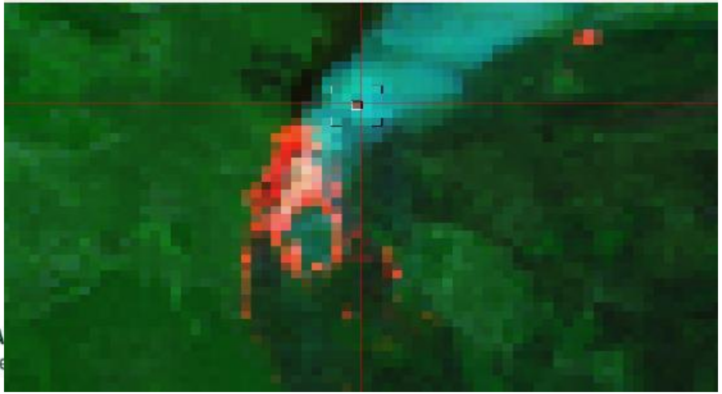
Characteristics Analysis

S2B

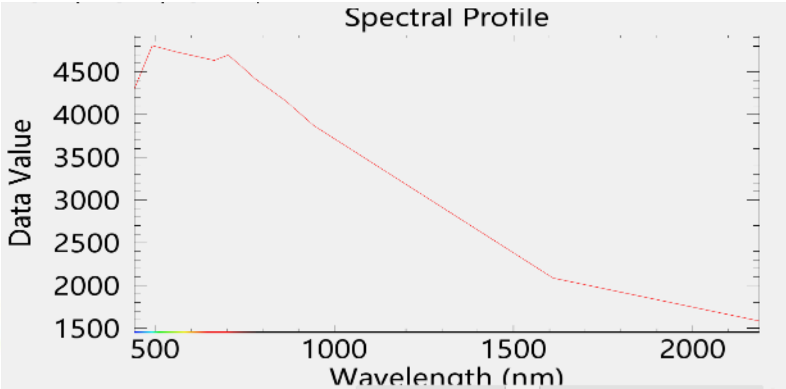


Fire



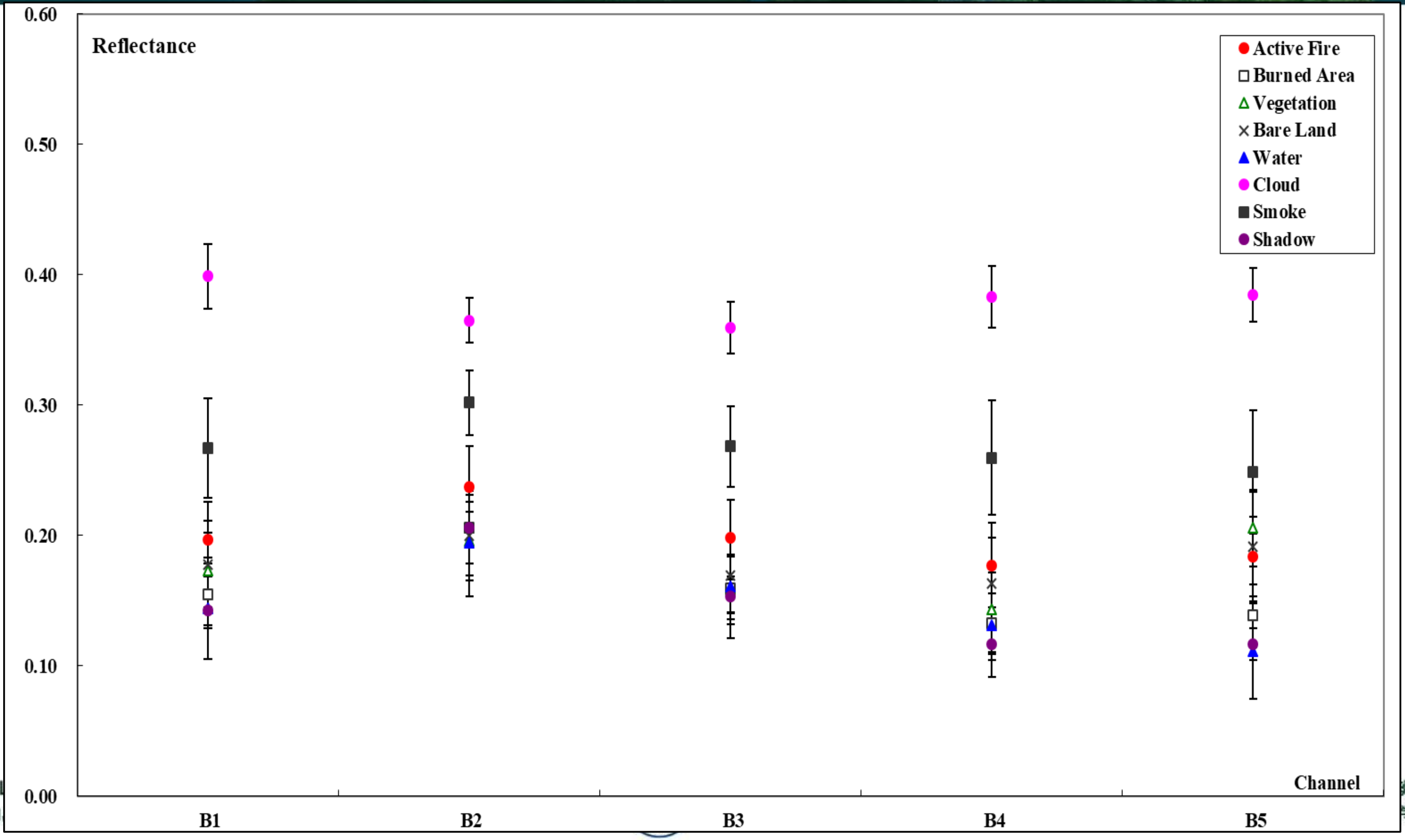


Smoke



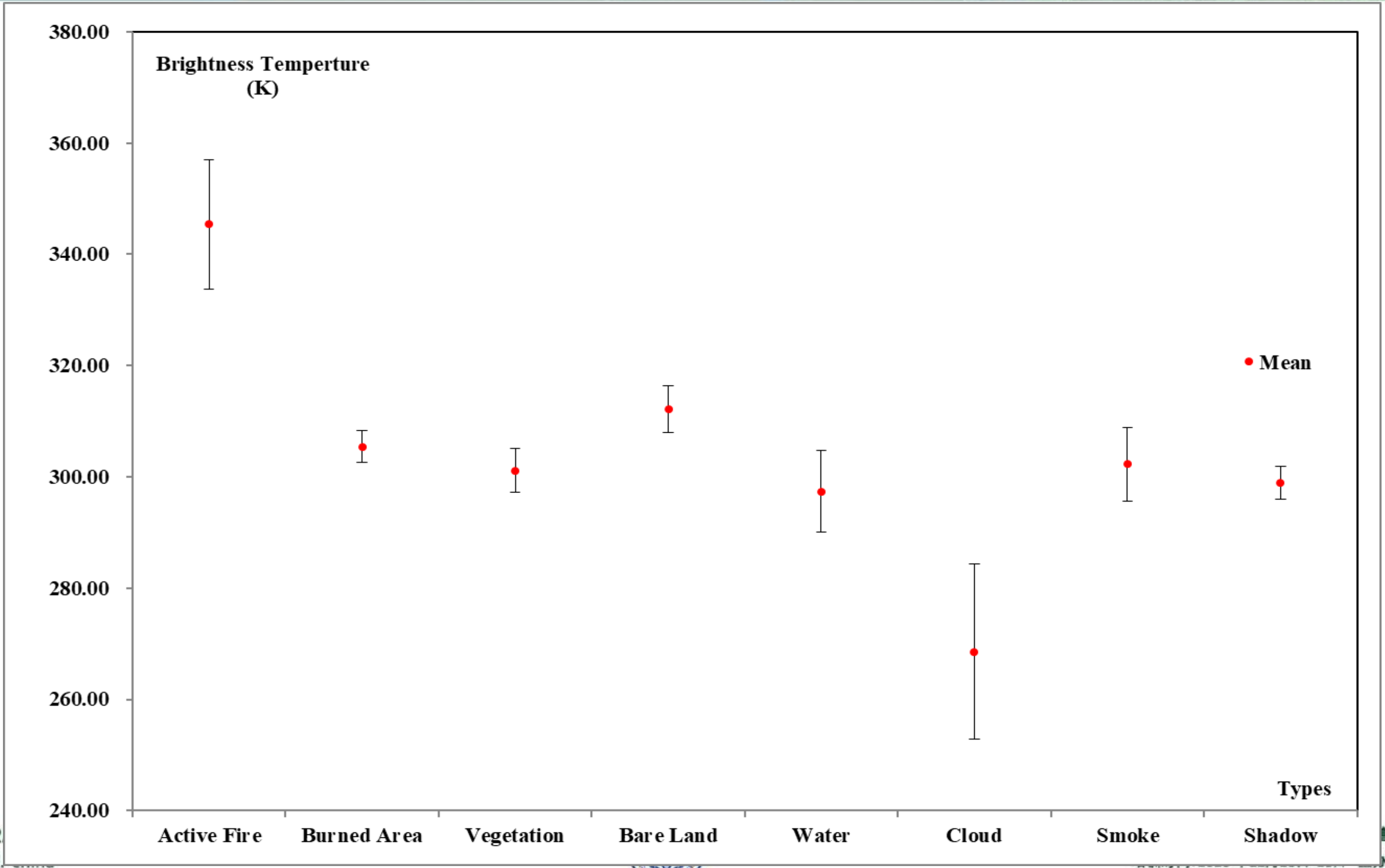
Characteristics Analysis

GF-4 PMI



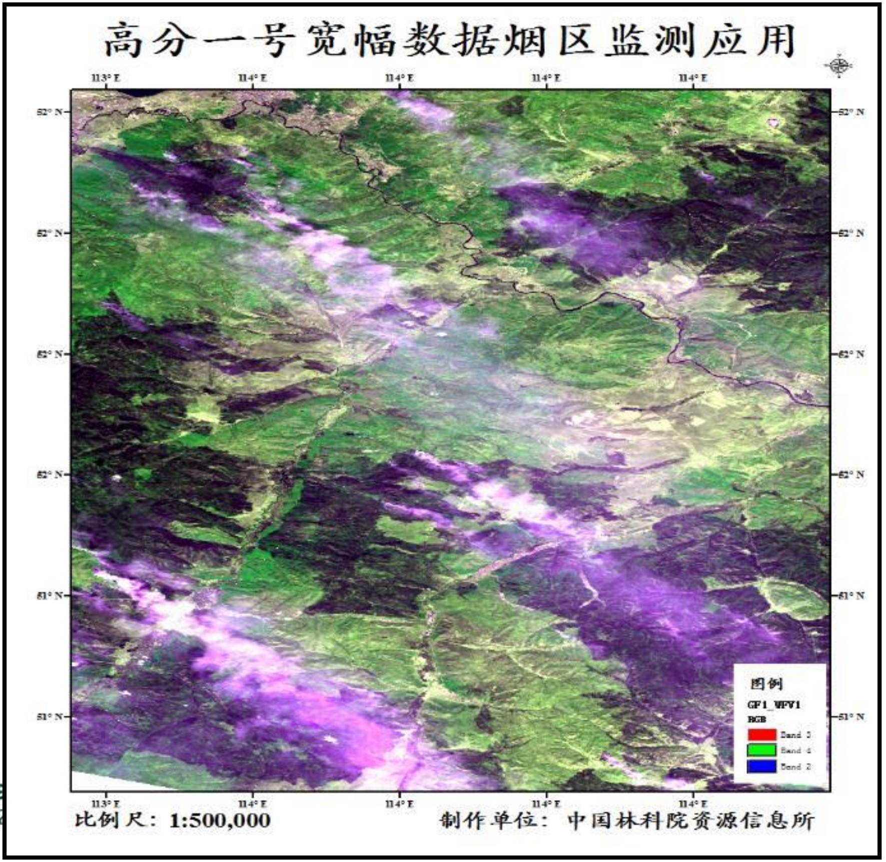
➢ Characteristics Analysis

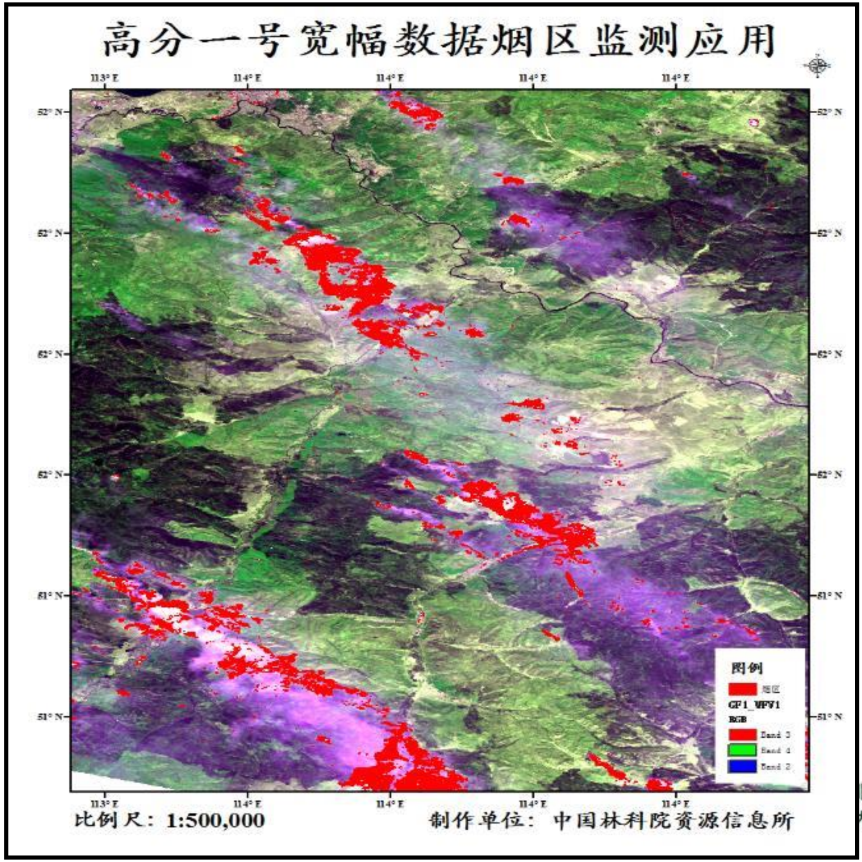
GF-4 PMI



3. Typical Application

➢ **Smoke identification**



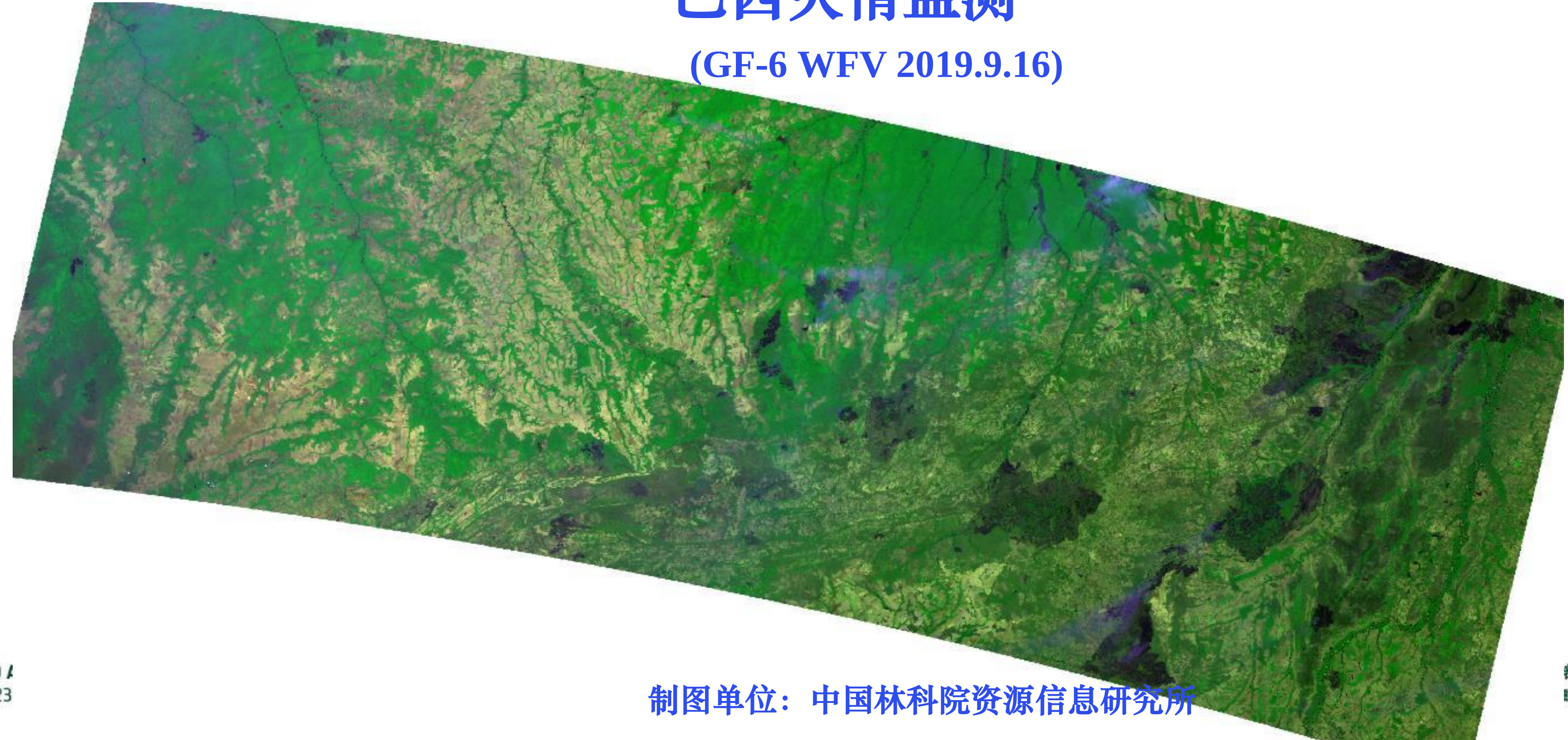


3. Typical Application

Smoke identification

巴西火情监测

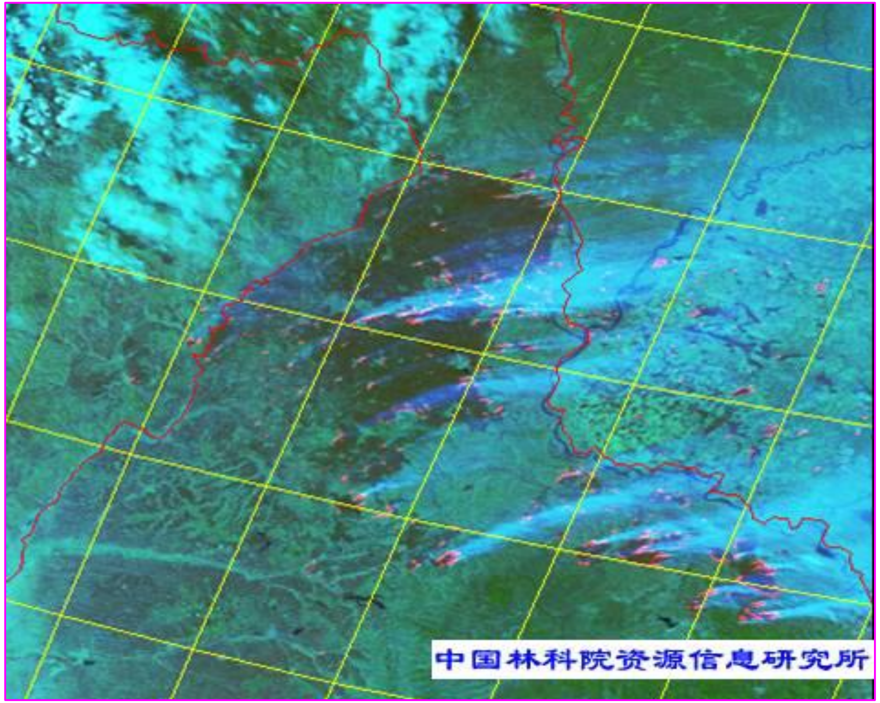
(GF-6 WFV 2019.9.16)

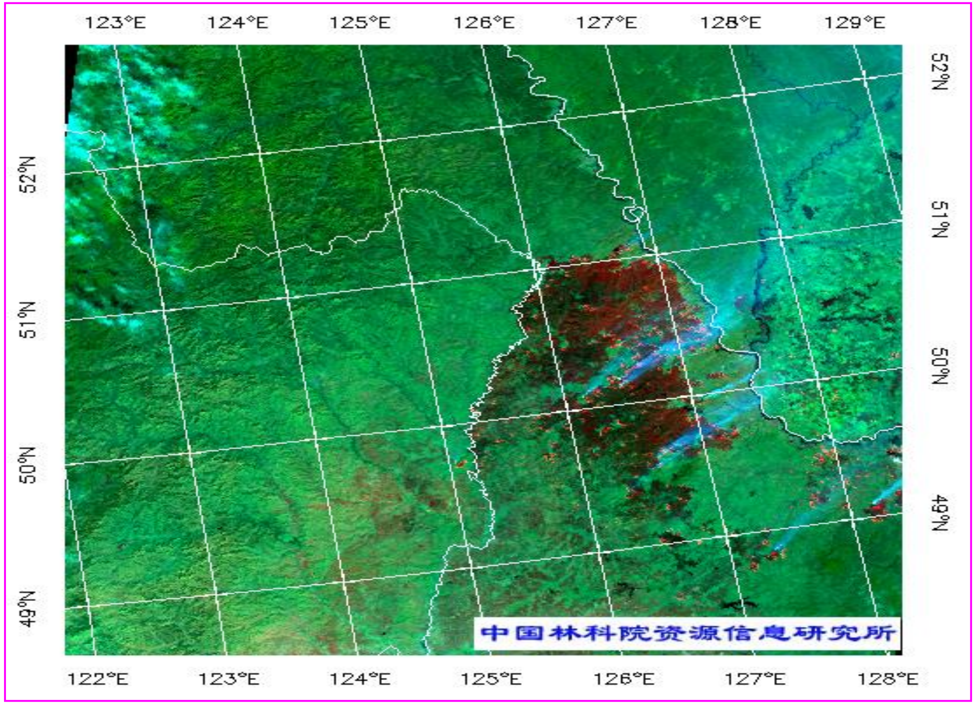


制图单位：中国林科院资源信息研究所

3. Typical Application

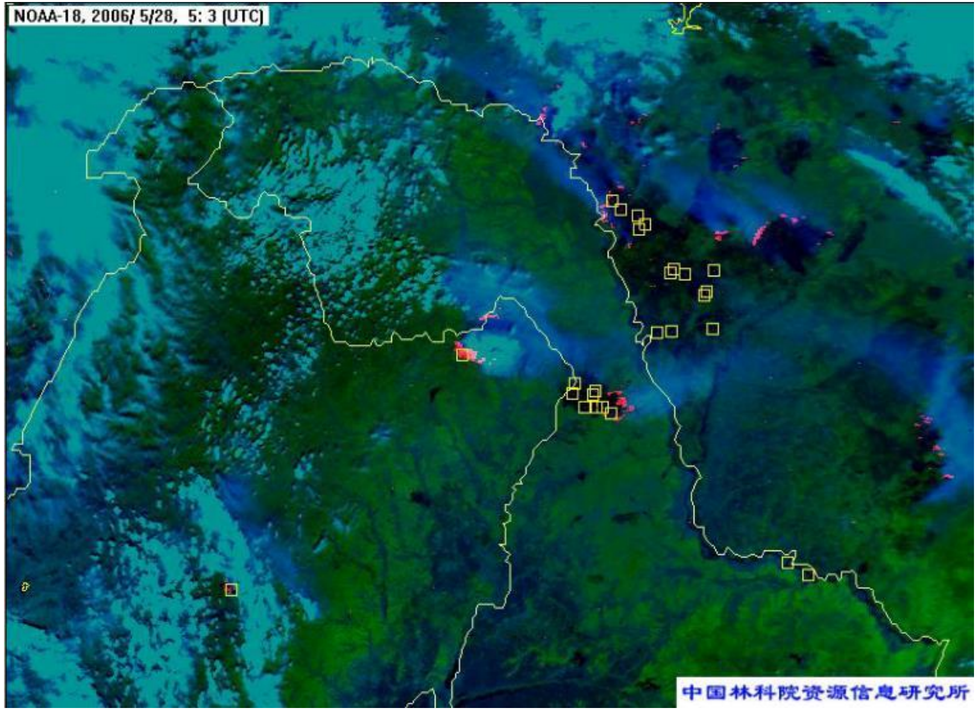
➢ **Fire identification**

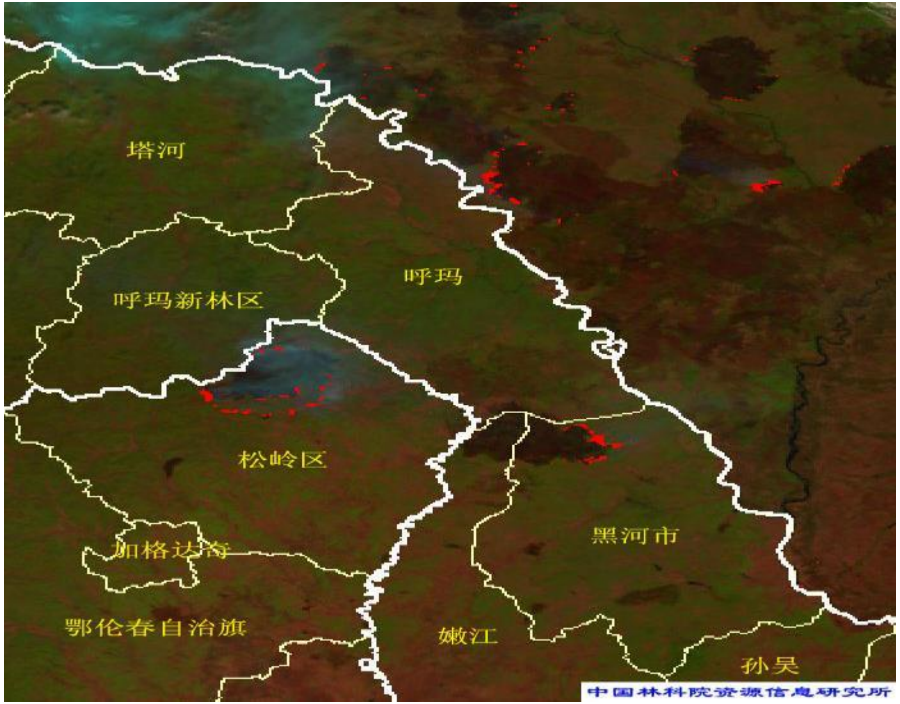




NOAA-16 **Fire Image, Hei Longjiang Province, 10/17/2004** **AATSR**

➢ Fire identification

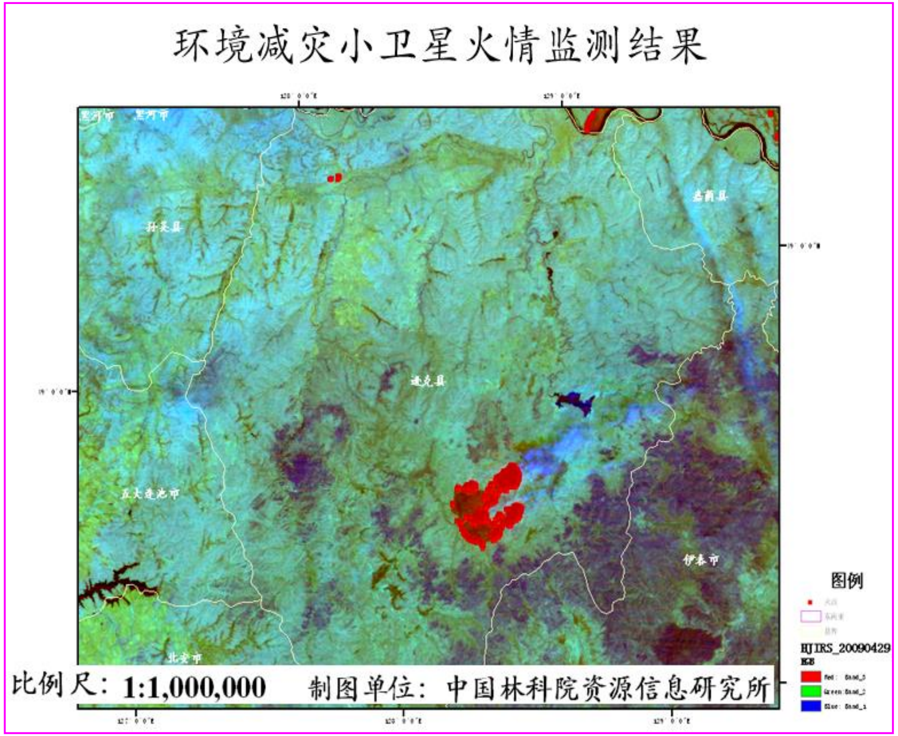




NOAA-18 Fire Image, Inner Mongolia and Hei Longjiang, May 28, 2006 Terra/MODIS

3. Typical Application

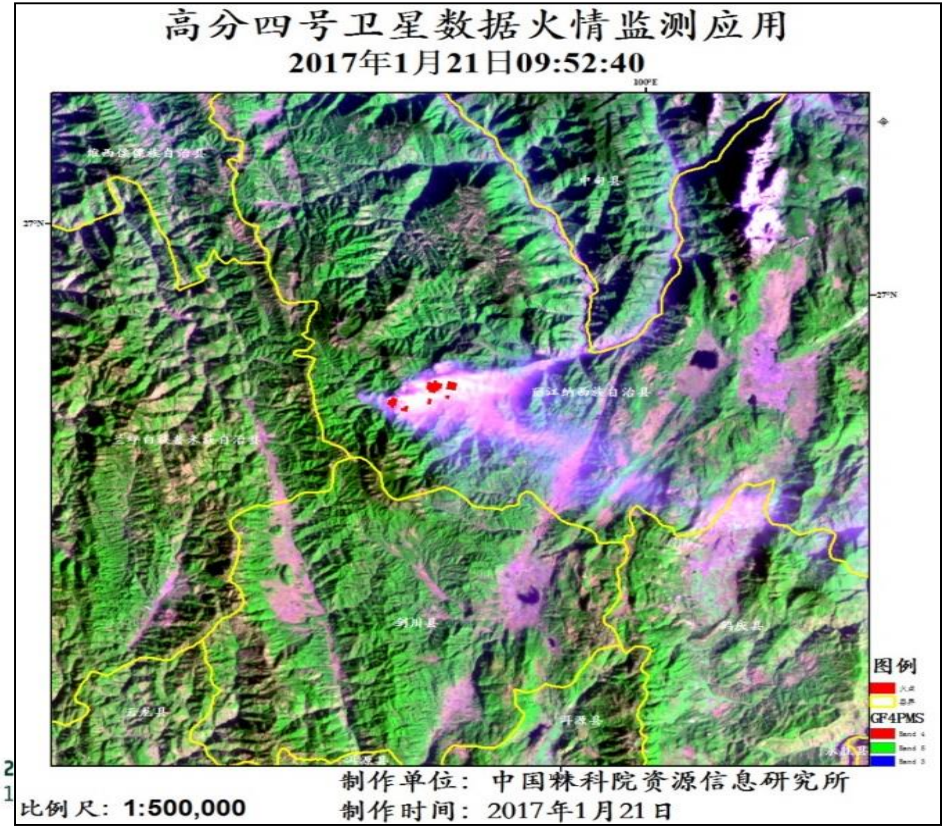
➢ Fire identification

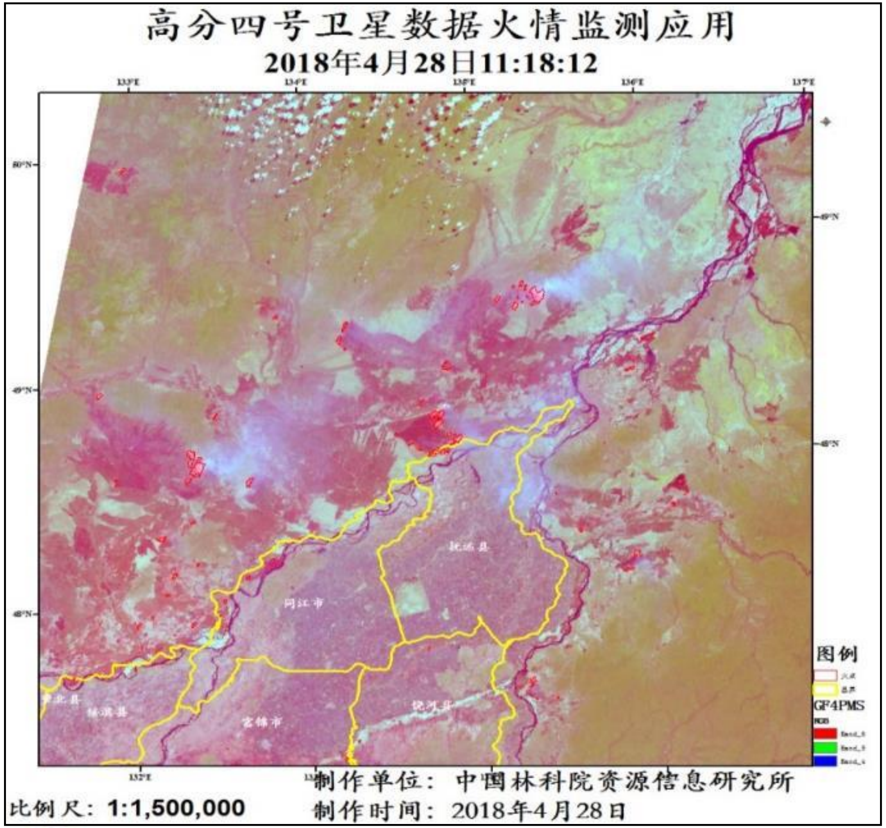


Fire Image, Hei Longjiang Province, 4/29/2009

3. Typical Application

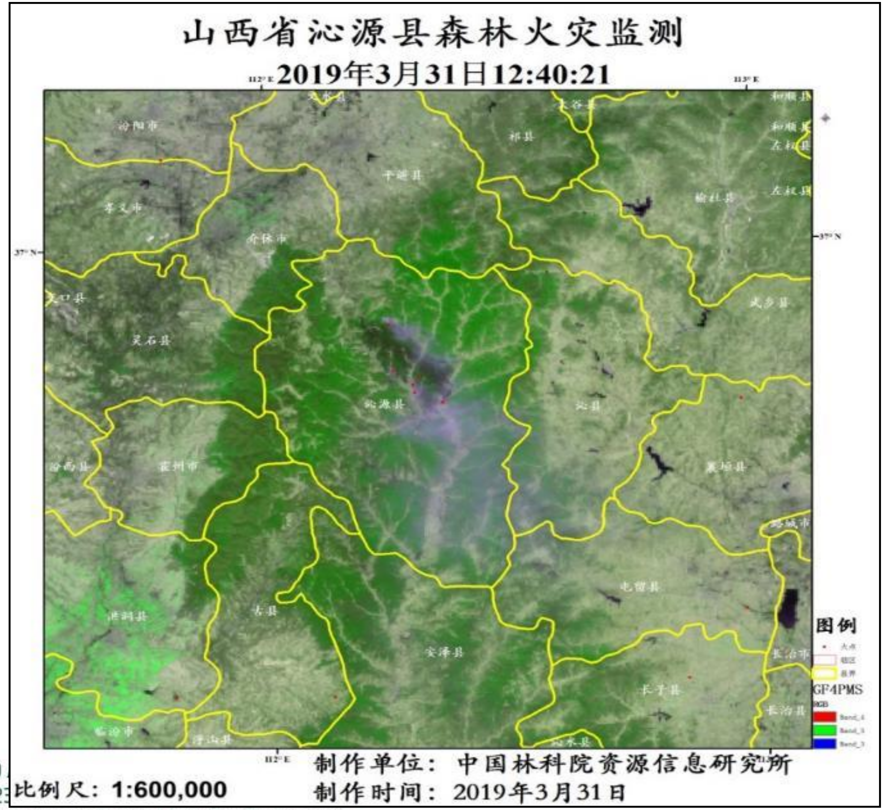
➢ Fire identification

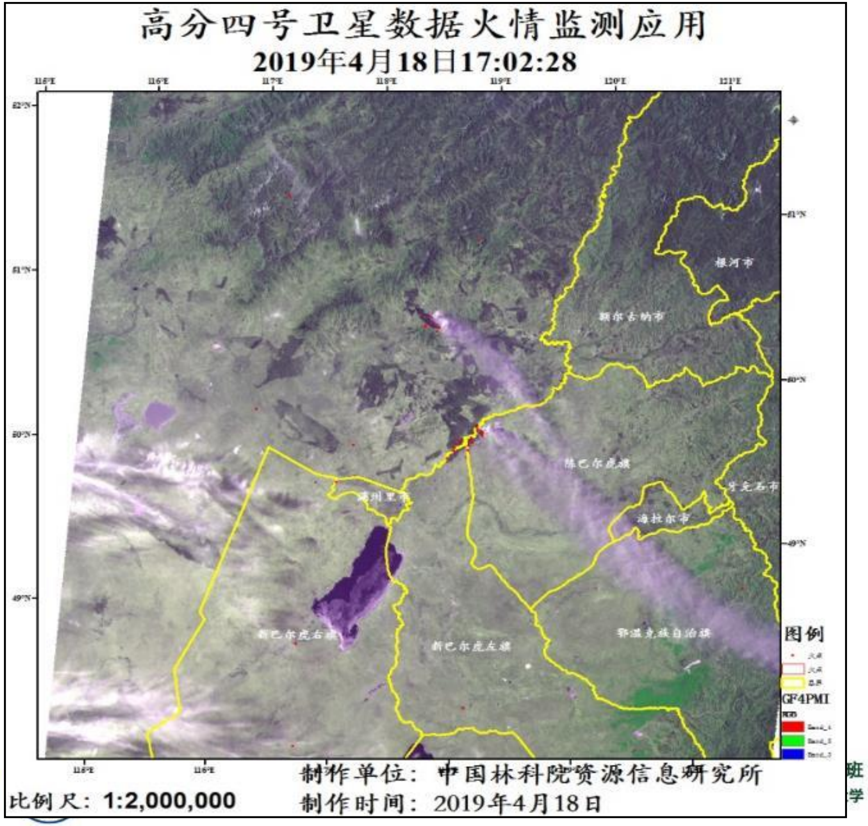




3. Typical Application

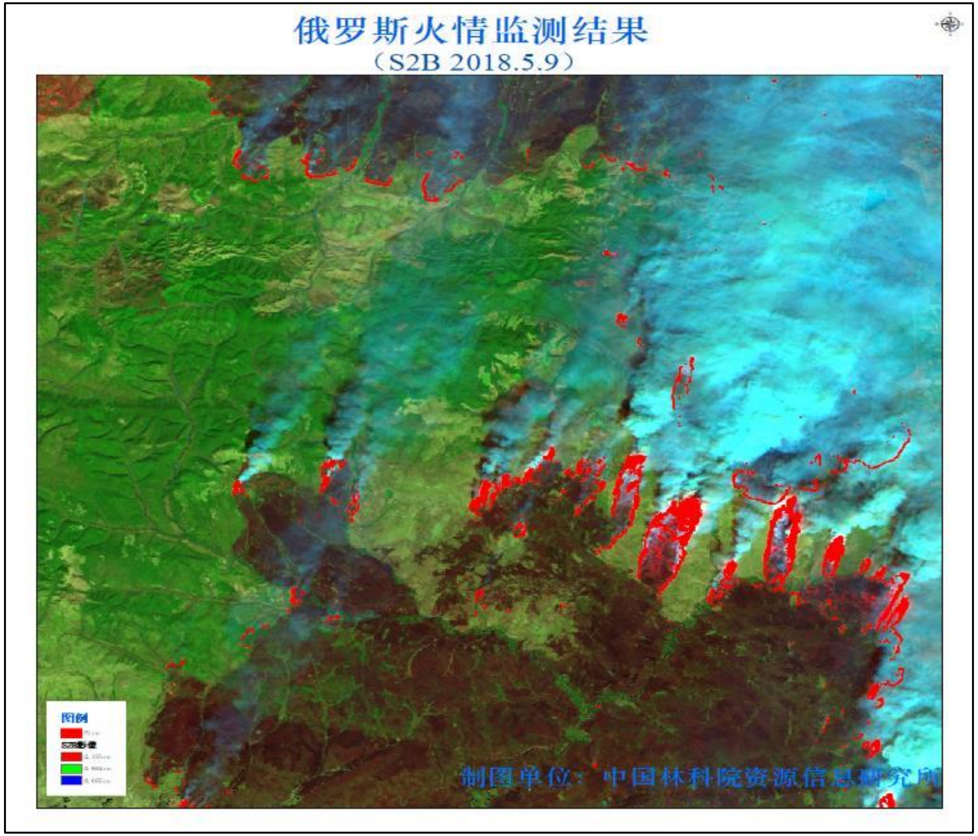
➢ Fire identification

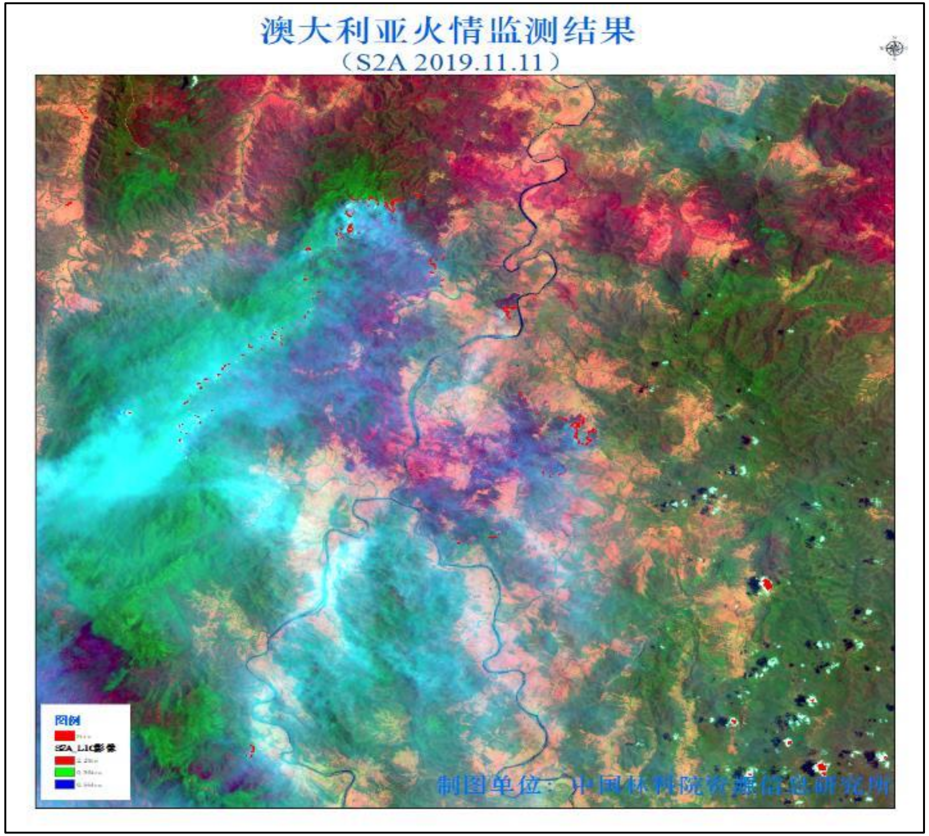




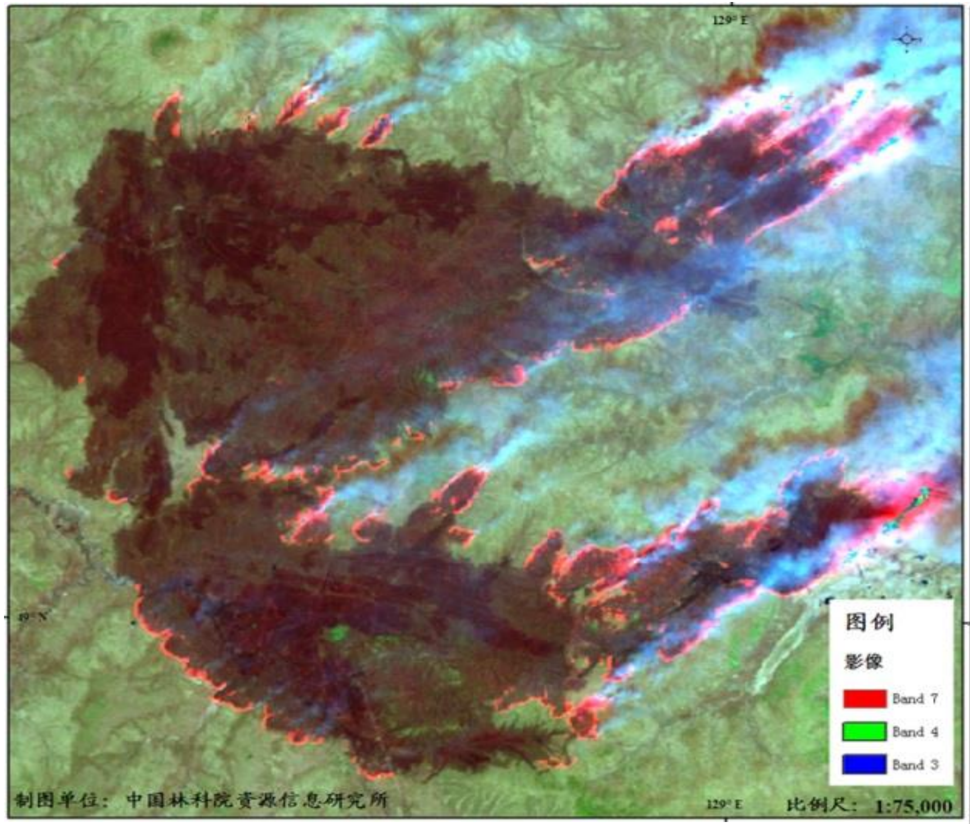
3. Typical Application

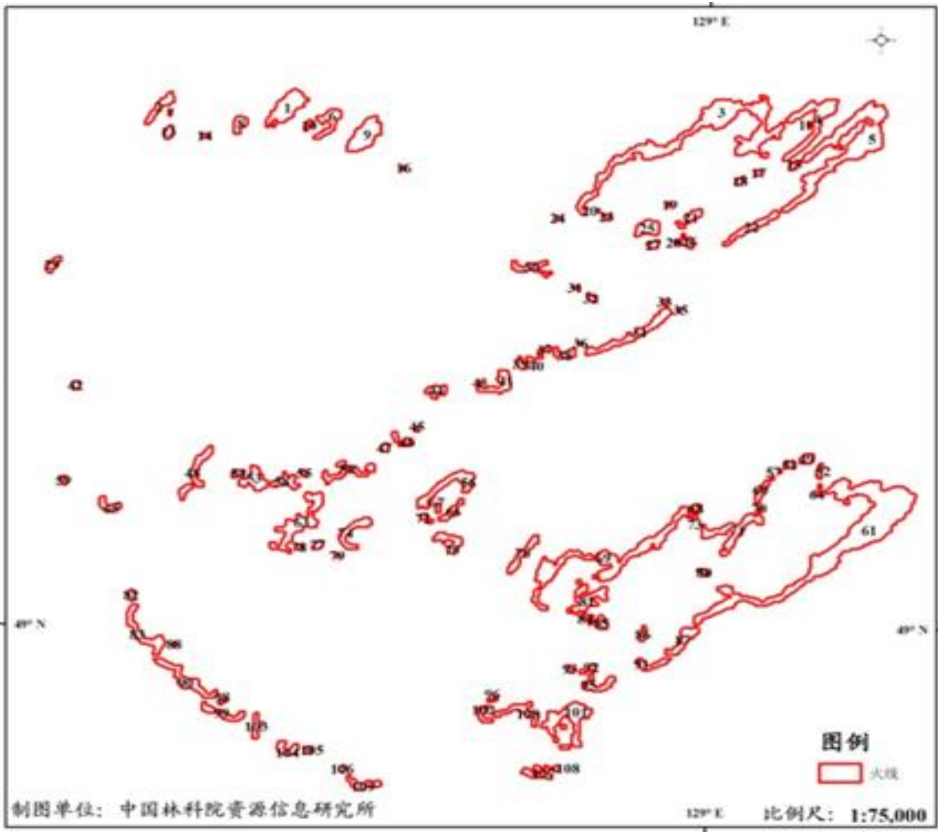
➢ Fire identification





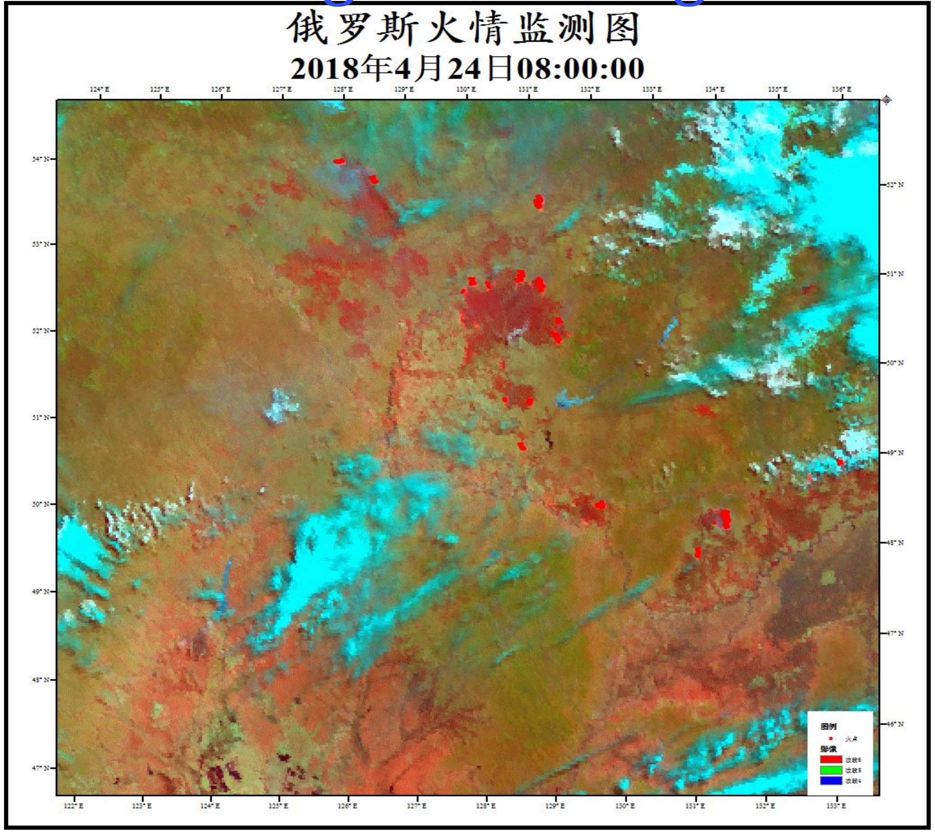
➢ Fireline extraction

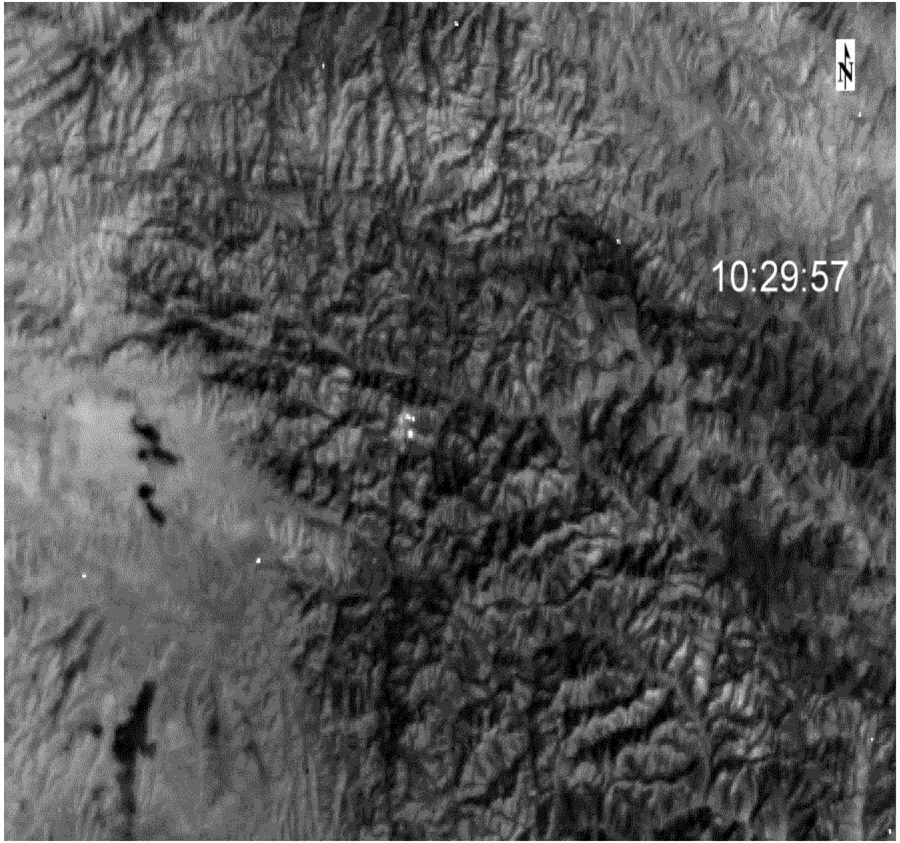




3. Typical Application

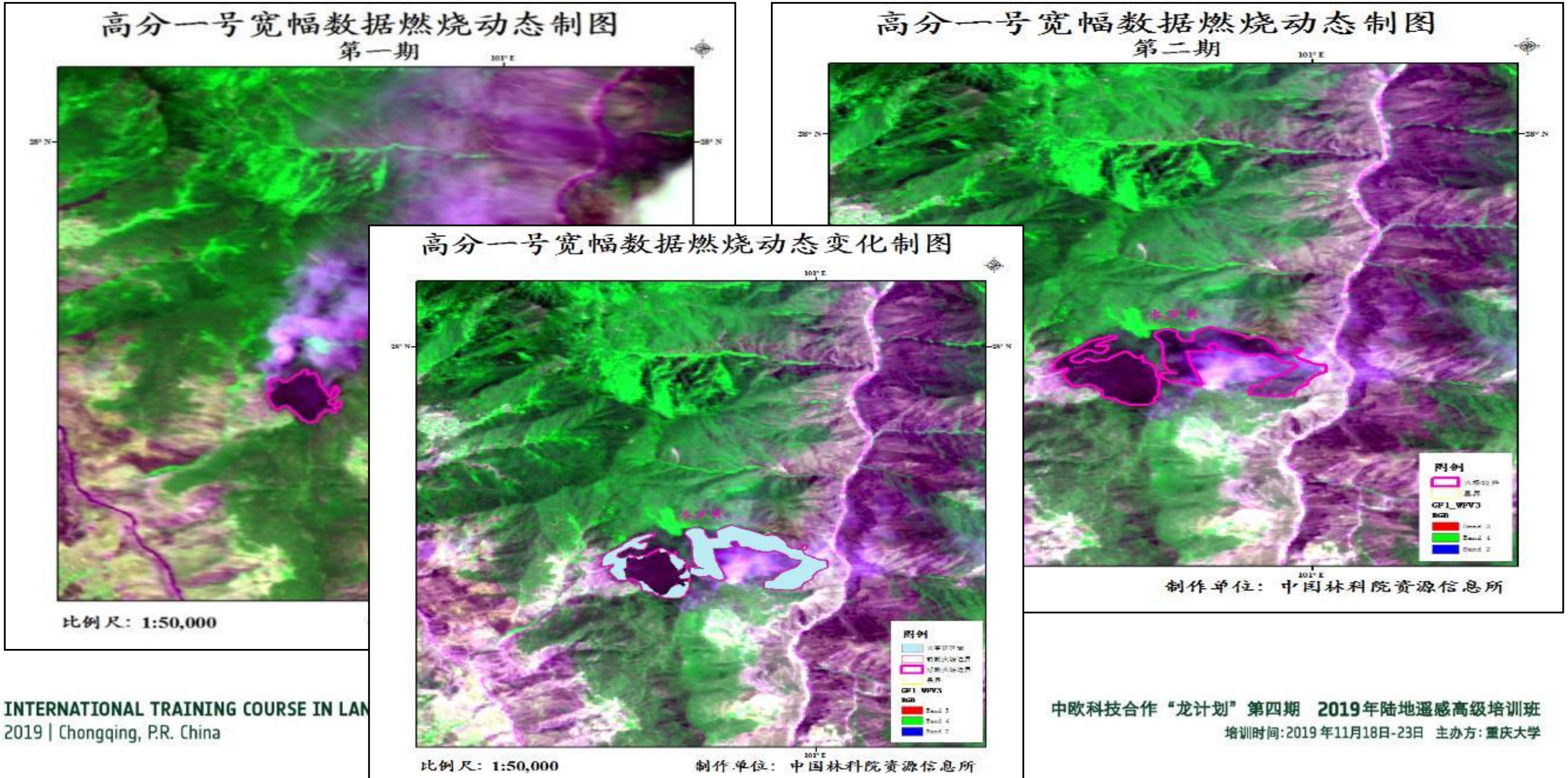
➢ Fire change monitoring





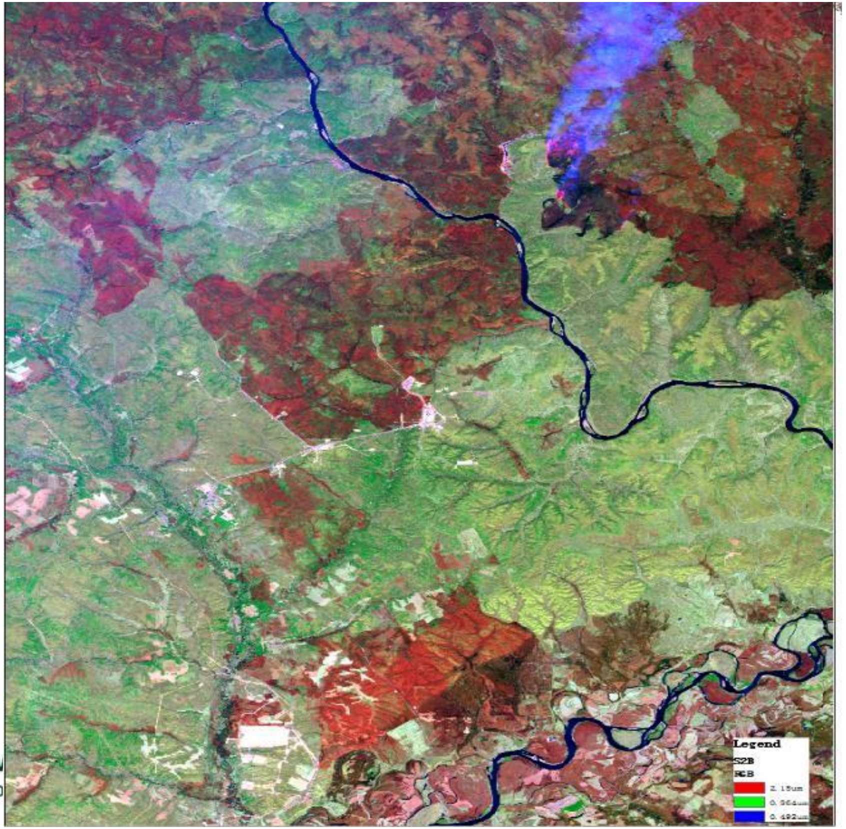
3. Typical Application

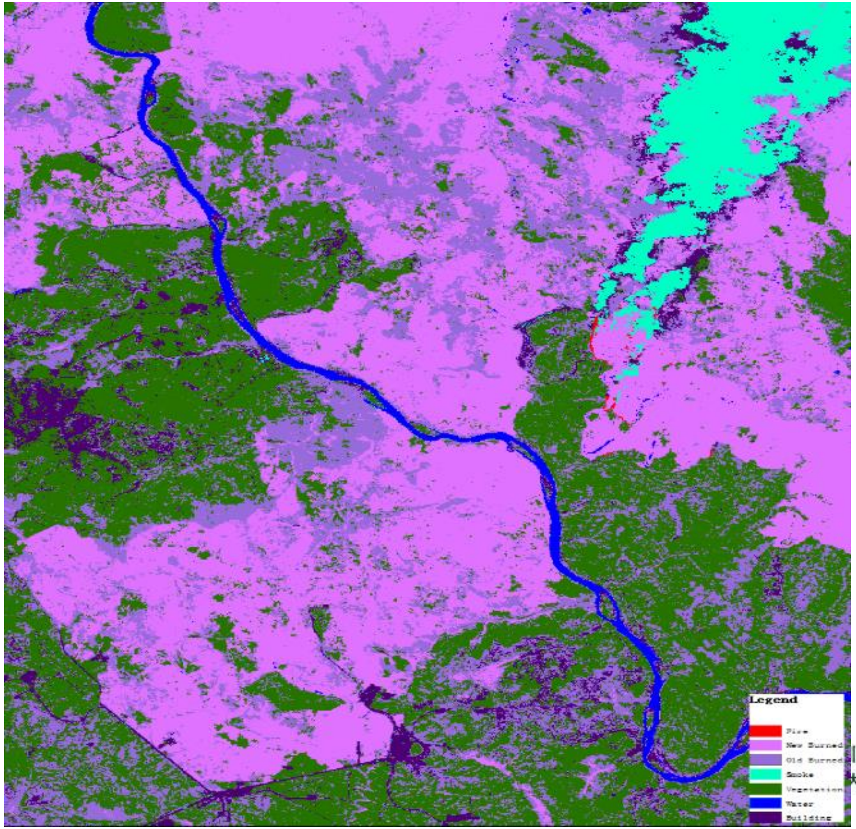
➢ Fire change monitoring



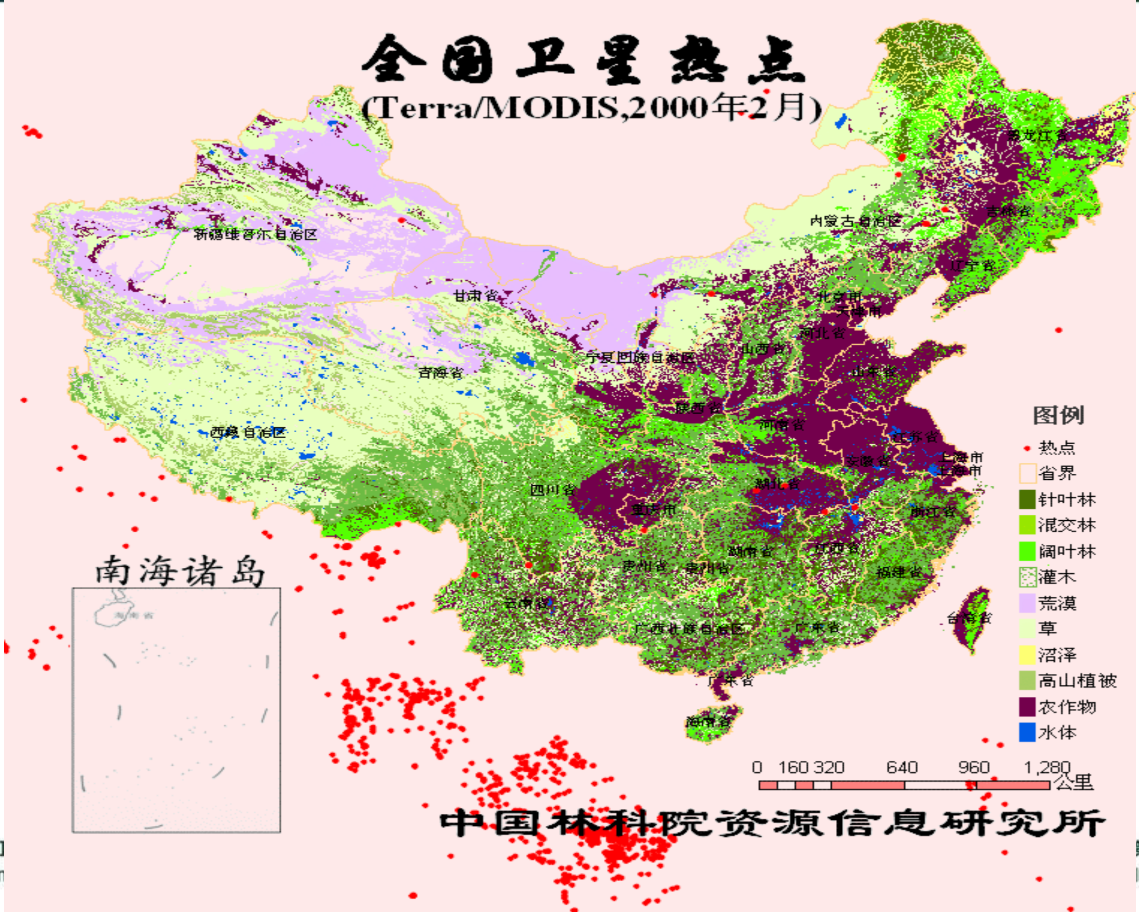
3. Typical Application

➤ Fire status monitoring

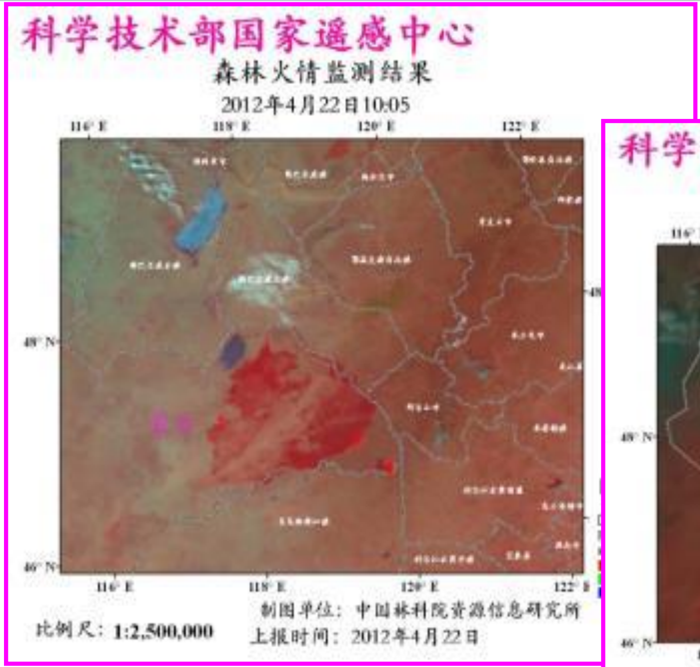


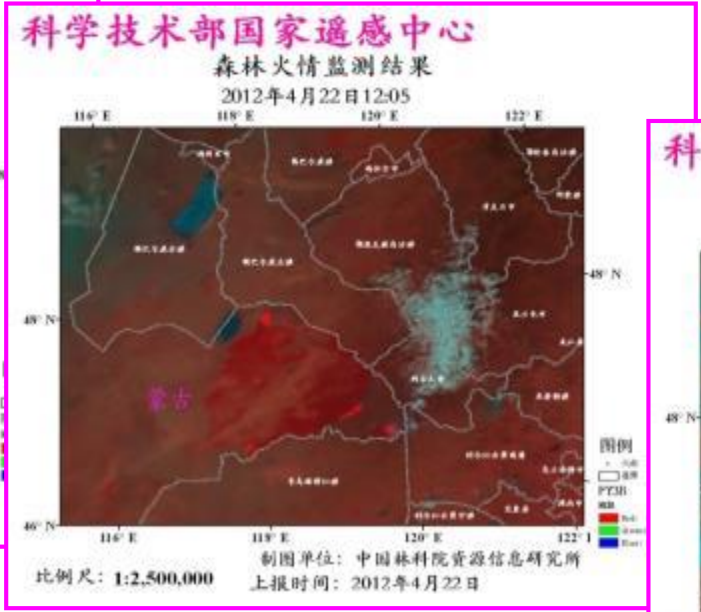


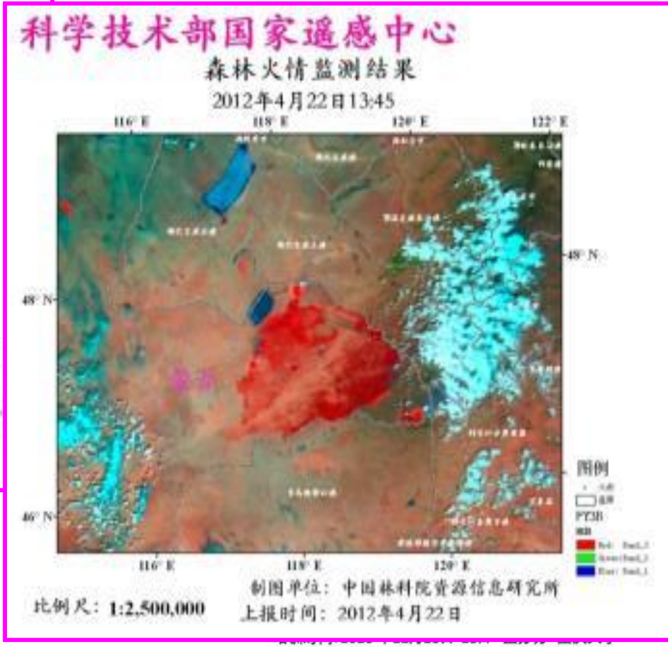
3. Typical Application



3. Typical Application







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5. Wilfrid Schroeder, and Louis Giglio. NASA VIIRS land science investigator processing system (SIPS) Visible Infrared Imaging Radiometer Suite (VIIRS) 375 m & 750 m active fire products, Product User's Guide Version 1.4. July, 2018.

https://scihub.copernicus.eu/ (Sentinel-1/2/3/5p)

Thanks !