ESA - MOST Dragon 2 Programme

中国科技部-欧洲空间局合作“龙计划”二期

2011 DRAGON 2 SYMPOSIUM

“龙计划”二期2011年学术研讨会

Modeling Coal Fire related Radiative Energy Release by using TIR Satellite Data and Geo-Spatial Risk Assessment Strategies at a Regional Scale

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presentation

- background and structure

- temperature measurements
- modeling approach
- remote sensing
- risk assessment
- case studies in northern China

- summary & conclusions

- environmental problems
  - **gas emissions (CO_2, CH_4)**
  - **land subsidence and cracks**
  - **threat to human health**
  - **regional landscape degradation**

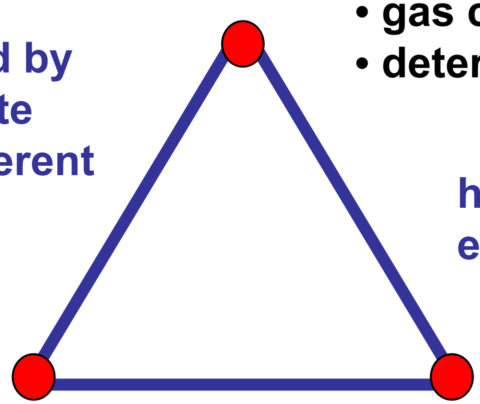
- economic facts in China
  - **70% of primary energy production is based on coal**
  - **estimated (!) loss of coal: up to 20 Mio. t / year**

- international aspects
  - **perspective for emission trade within CDM**

baseline estimations

amount of emitted exhaust gases
- ventilation or flux measurements
- gas component measurements
- determination of fire categories

exhaust gases emitted by complete or incomplete combustion or by different fire categories



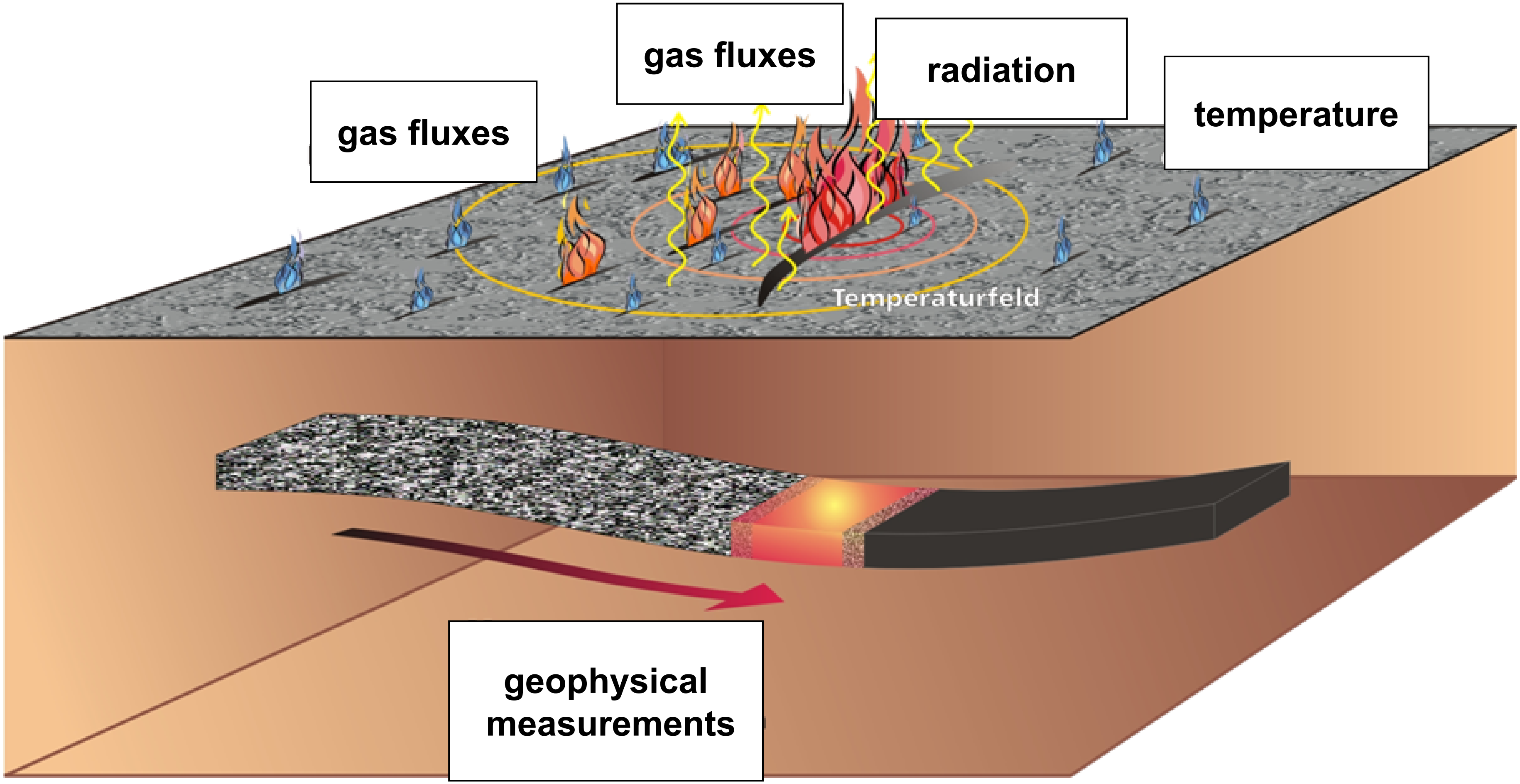
heat transport via exhaust gas flux

amount of burnt coal
- geological basis data
- mining data
- data about the coal fire
- repeated remote sensing
- repeated ground surveys
- passive seismics

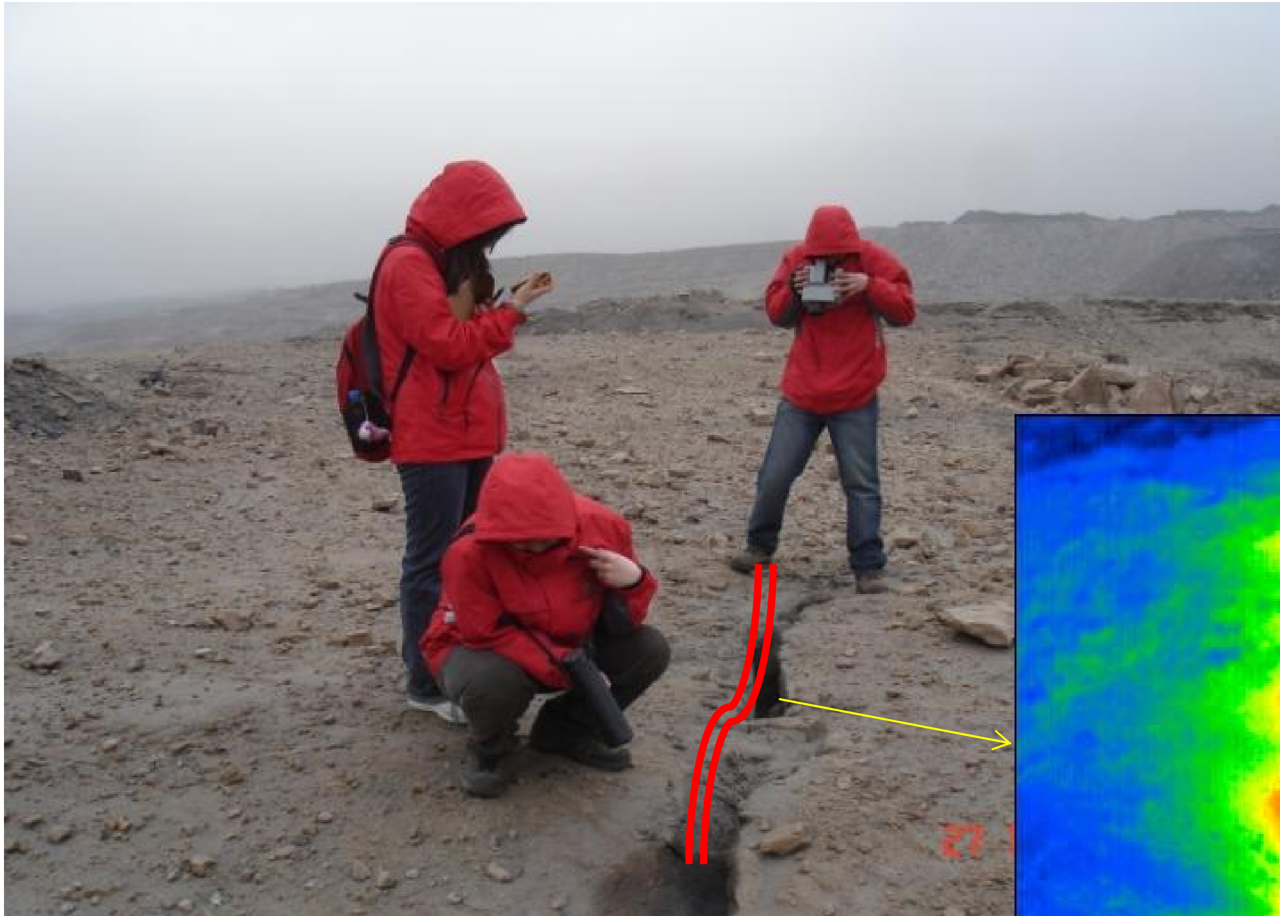
- calorific values of coal
- relation of emitted energy (surface) vs. total energy produced (power)
- radiated energy
- energy emitted by conduction/ conversion
- energy emitted through mass (gas) transport

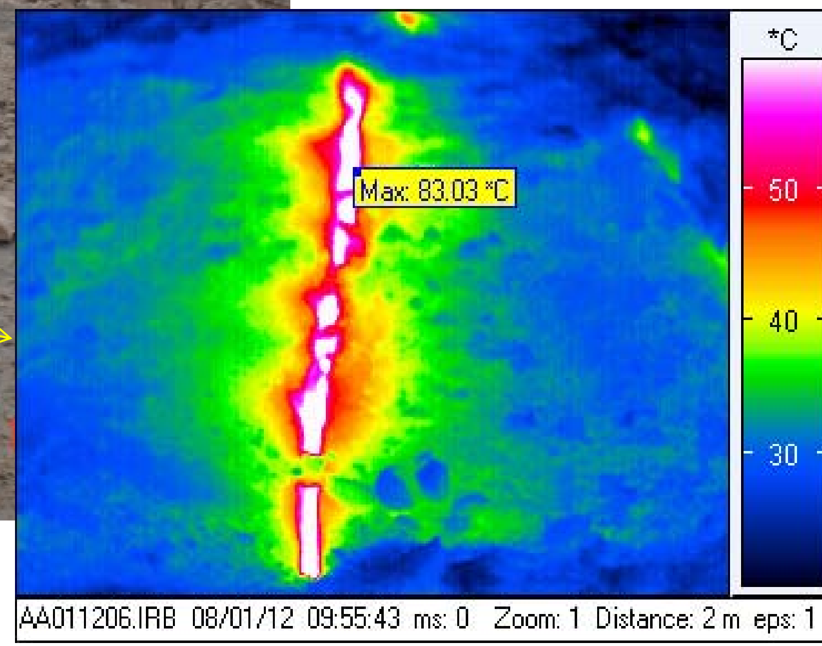
amount of energy release
- thermal remote sensing
- (airborne or satellite based)
- temperature measurements
- calorimetric measurements

baseline estimation & modeling approaches



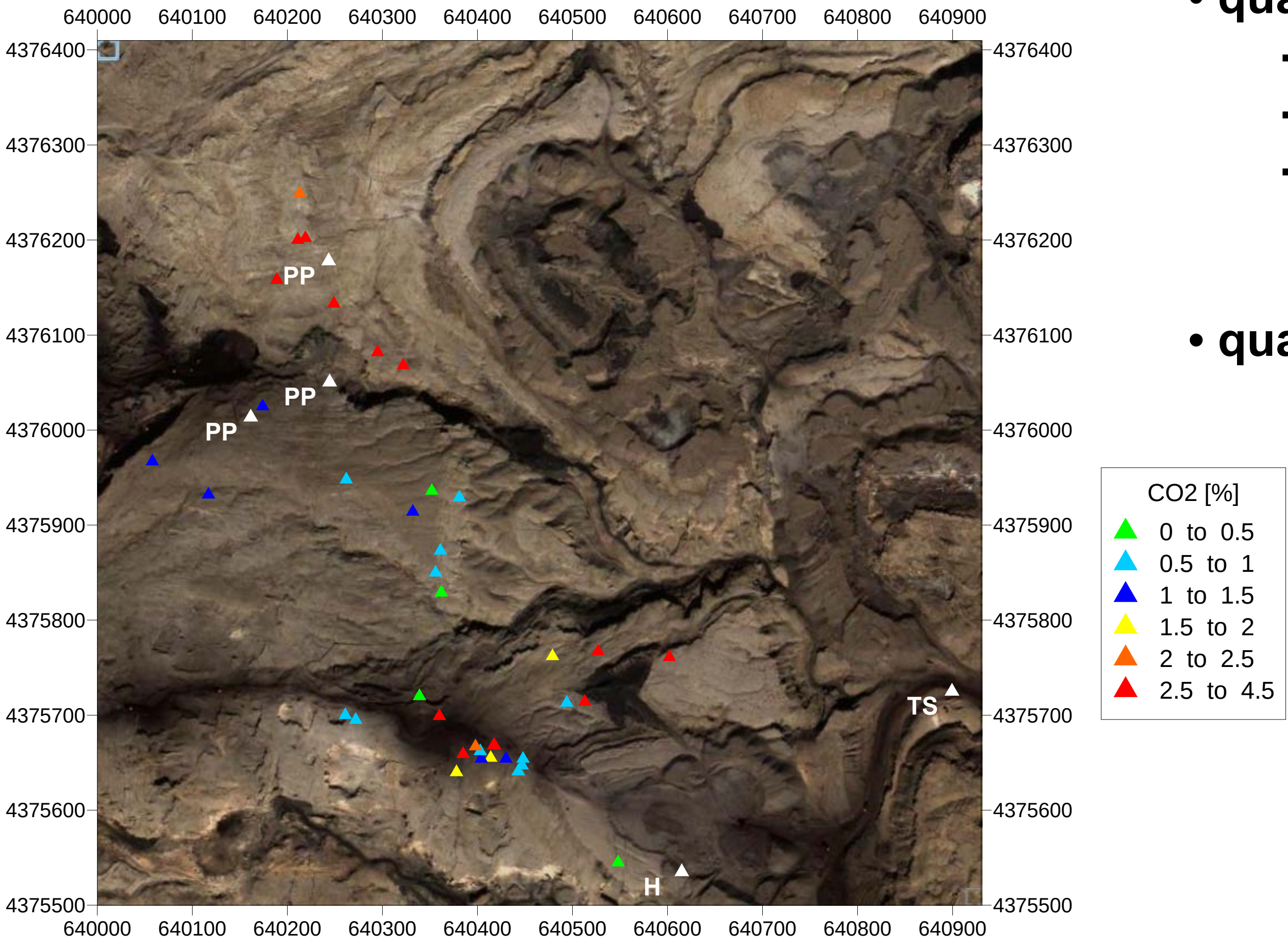
geophysical measurements





fracture measurements and thermal observations

gas measurements

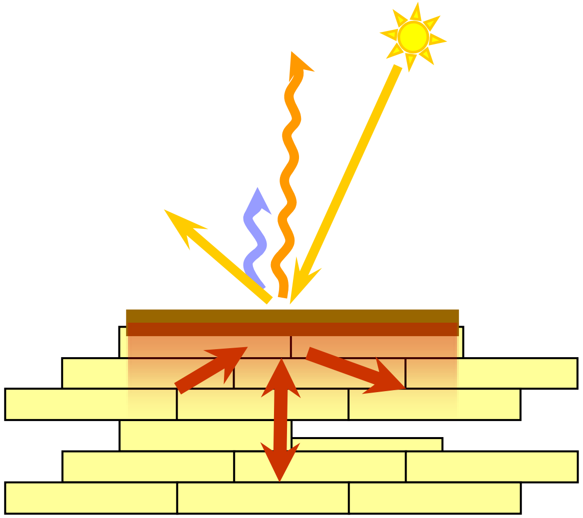


- qualitative composition
  - combustion processes
  - spatial extension
  - calibration of dynamic models
- quantification of emissions
  - Kyoto (CDM) ?
  - dynamics of coal fires (propagation)
  - process understanding e.g. influence of weather conditions)

surface energy balance scheme

- processes
  - input: solar irradiation, coal fire
  - loss: long wave emission, sensible + latent flux
  - imbalances lead to heating/cooling

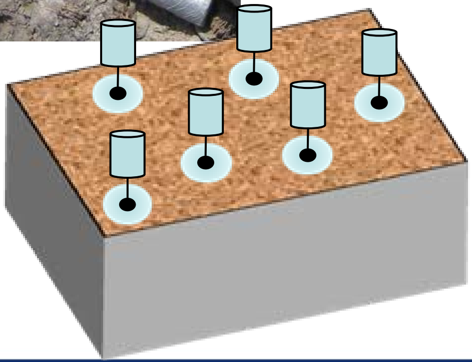
$$E_{net} + E_{sensible} + E_{latent} + E_{ground} = 0$$

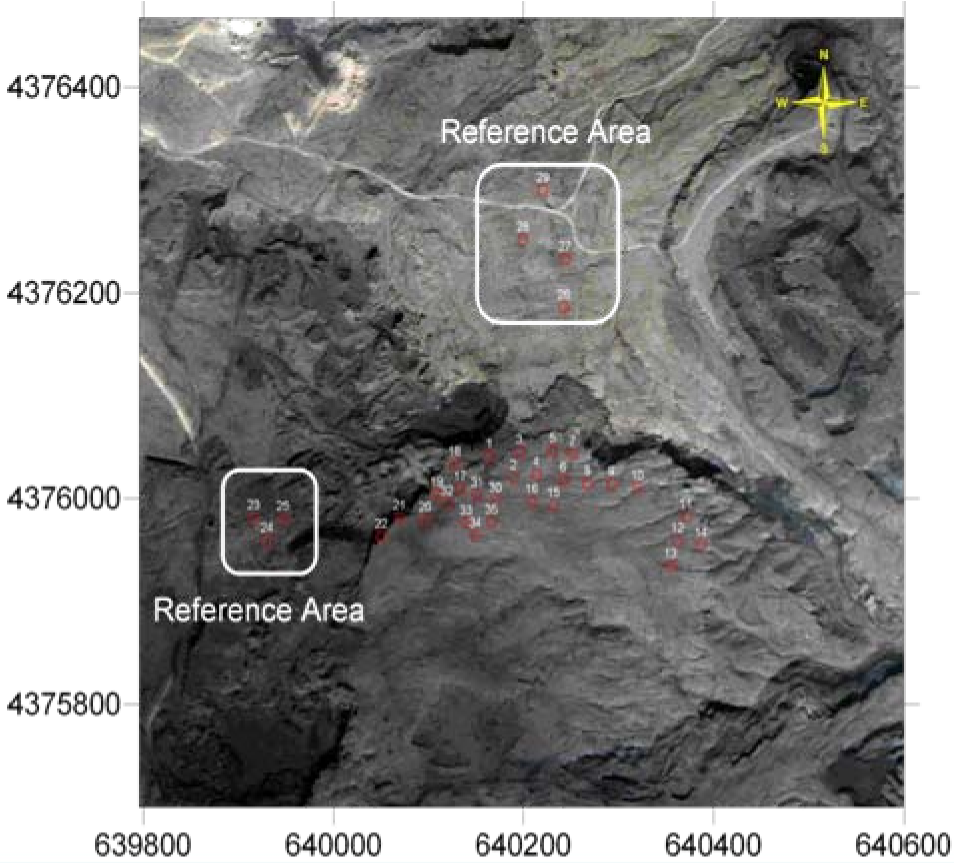


- limitations
  - remote sensing measures radiative part only
  - no lateral transport
    → simplifications have to be made

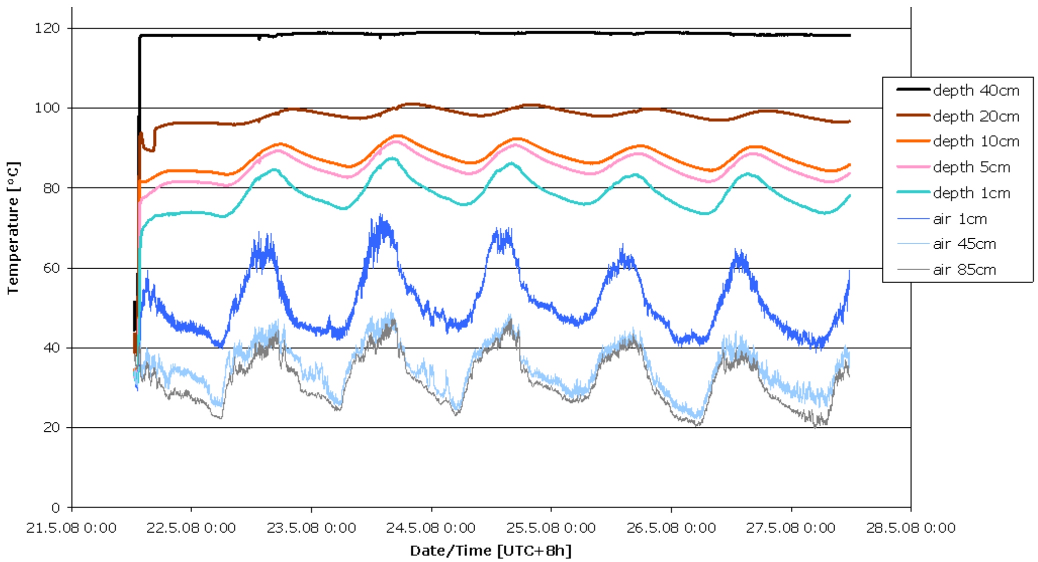
temperature measurements

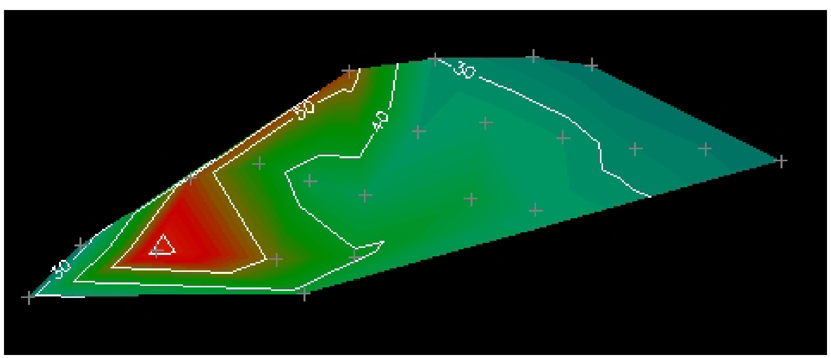
spatial temperature distribution/variation
- **long-term, wide area, dense grid**
- **single sensor loggers used**





temperature measurements



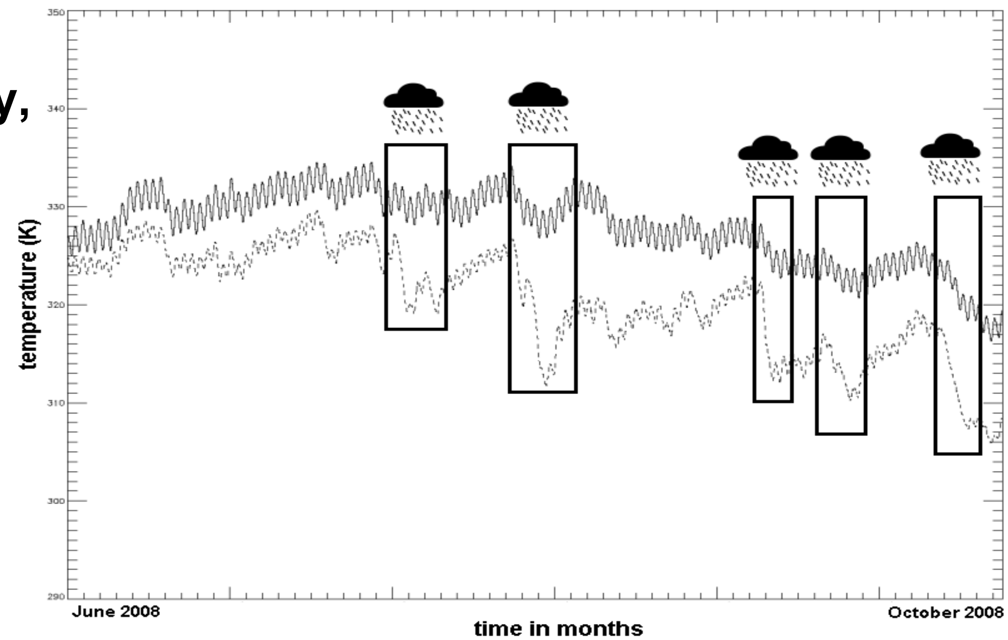


- temp. profiles
  - link surface - subsurface T
  - lag, damping,
  - climate influence
- spatial temp. distribution
  - ground truth for RS
  - climate influence, surface variability
- additional data needed
  - climate (air temp, wind speed, etc.)

temperature measurements

- results

  - examine influences of topography, climate, subsurface heat source, observation time, etc.
  - significant precipitation effect

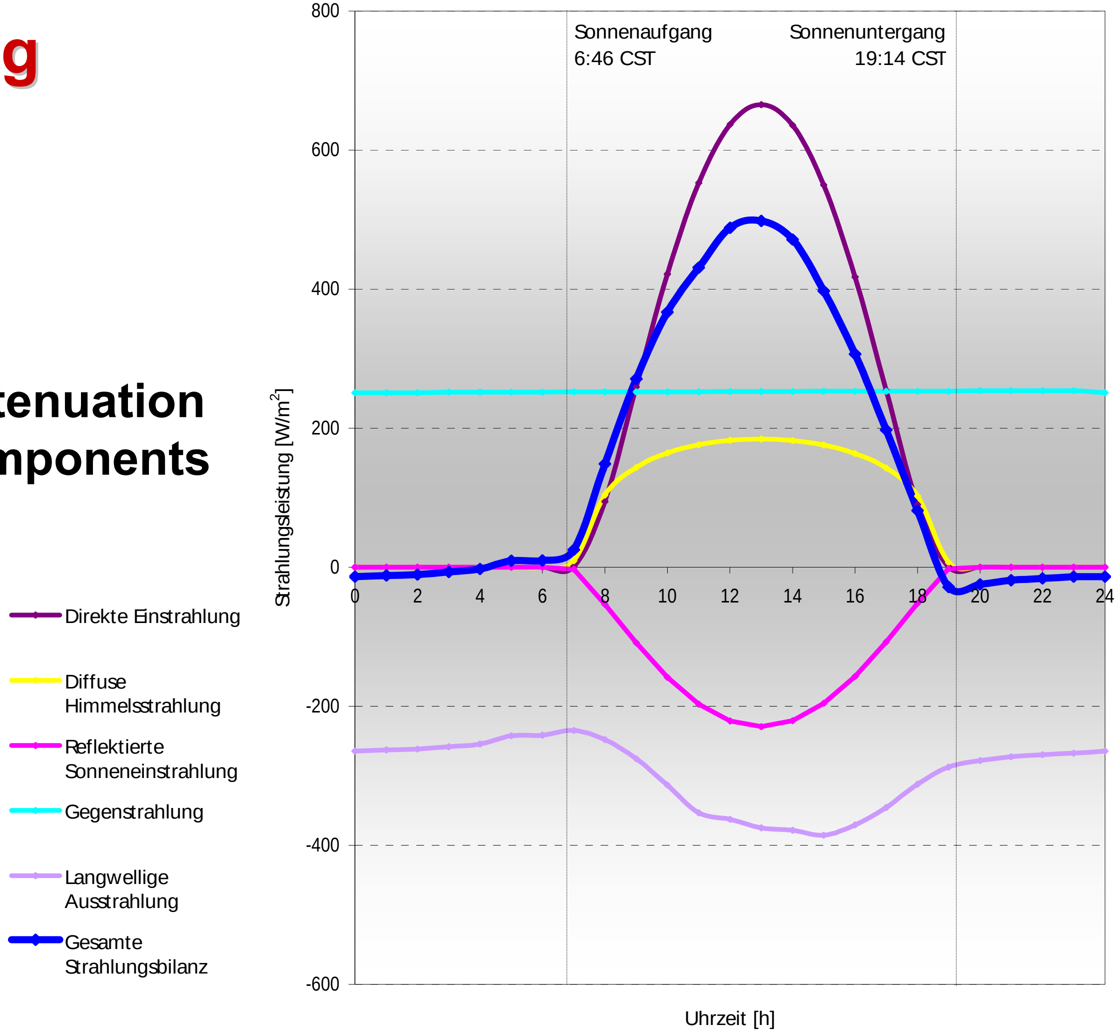


- limitations & assumptions

  - bare soil, no heat convection
  - ideal atmosphere, no clouds, arid
  - no latent or lateral heat flux

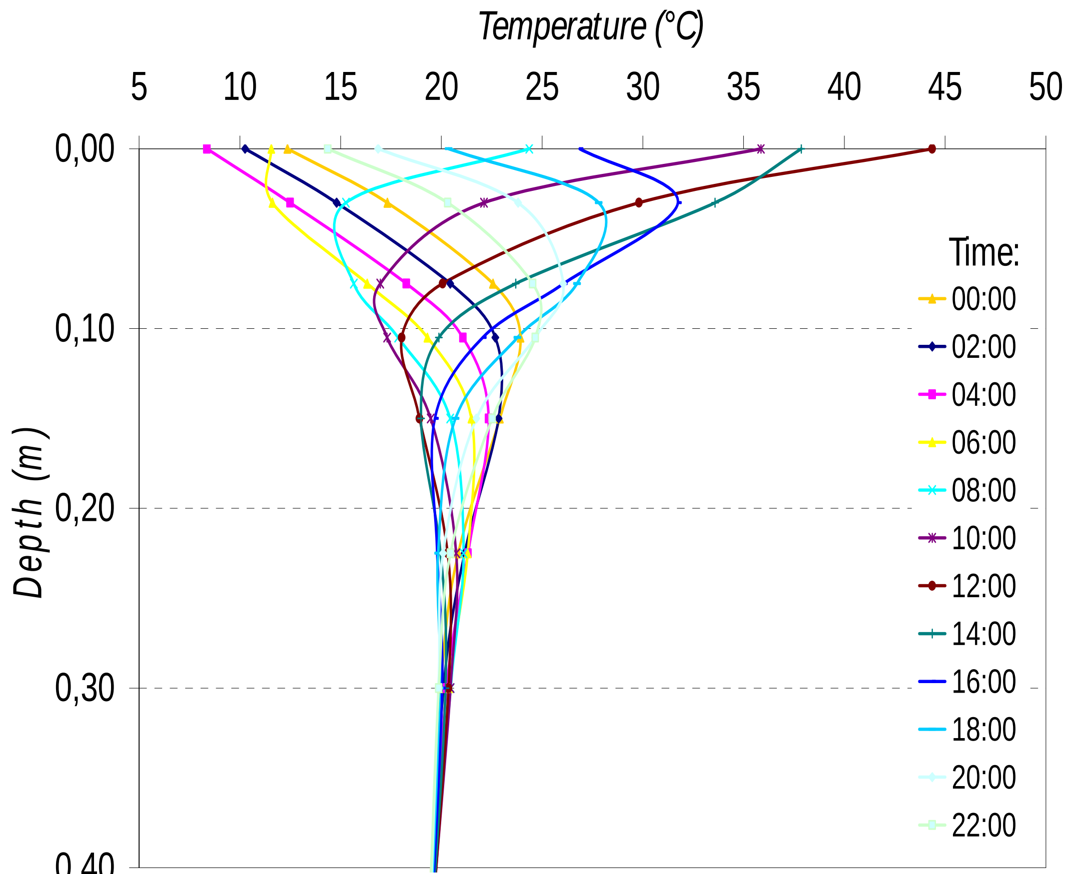
energy balance modeling

- **solar irradiation**
  - interaction atmosphere, attenuation
  - modelling of individual components



energy balance modeling

- **energy conversion at surface**
  - calculation of energy balance terms
  - surface temperature estimation
- **subsurface temperature dissemination**
  - temperature buffer day/night
  - heating by underground fire



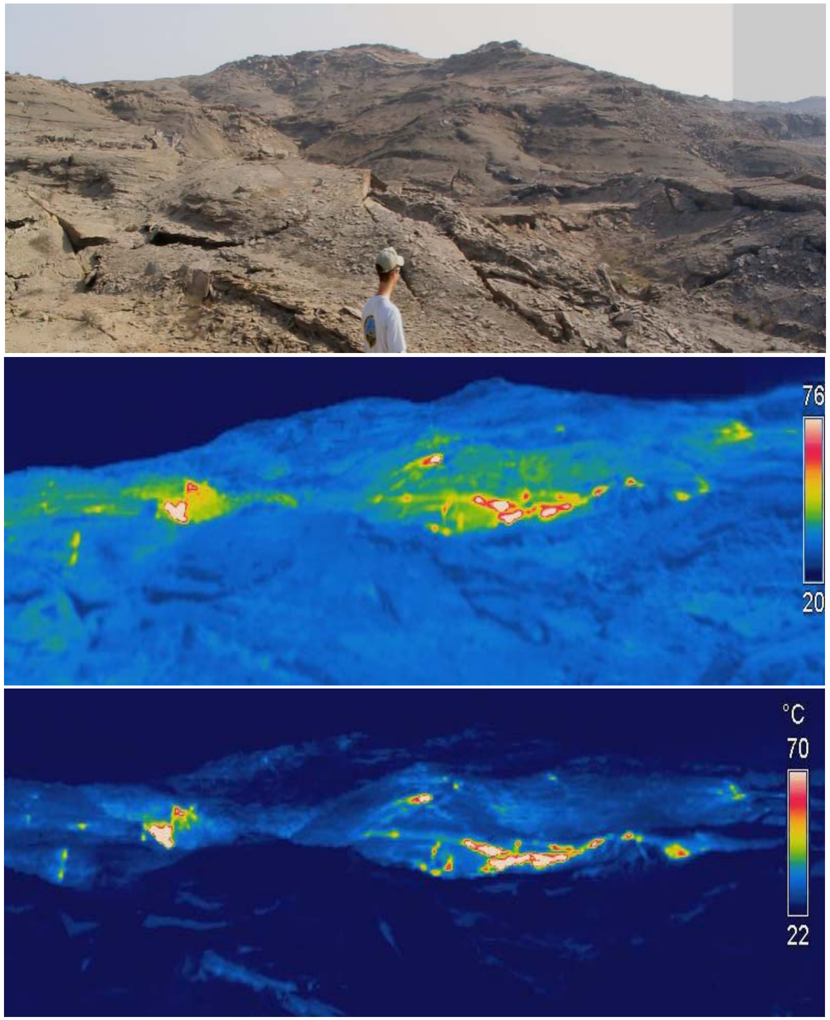
benefits

- model surface temp. for arbitrary times or periods
  - fire influenced → fire pixel radiance
  - ambient conditions → background radiance

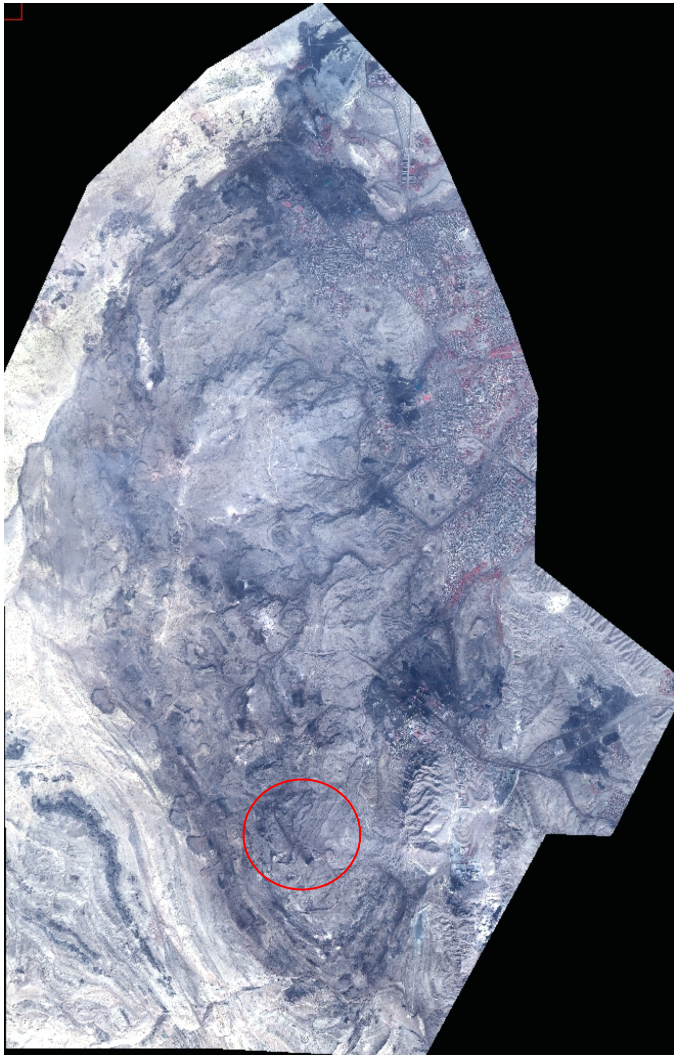
- validatation
  - simulated CFRE as reference → satellite overpass
  - summation of CFRE → contribute to CDM methodology

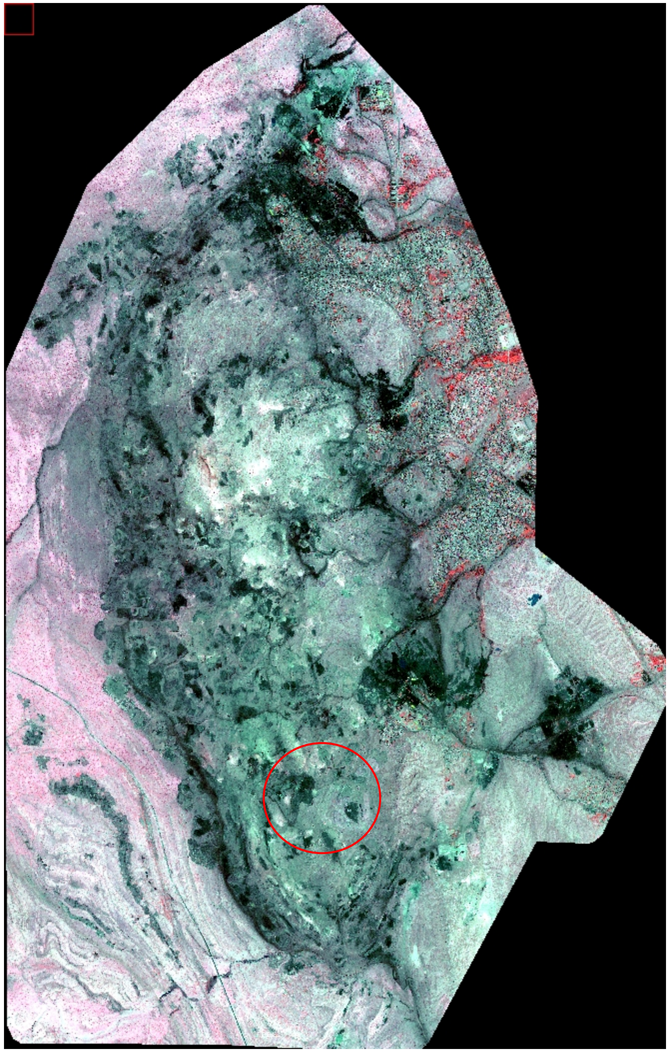
- enhance stability
  - reduce false alarms using simulated background radiances

- bridging the gap surface - subsurface temperature



- fire temperatures varying strongly
- most fires are subsurface – crack system at topographic surface
- mostly surface temperatures below 600 K
- fire dynamic unknown
- energy release is based on
  - radiated energy
  - emitted energy by conduction and conversion
  - transported by emitted gases
- validated models still under development
- satellite based analysis:
  - night time data sets are needed





Wuda – changes 2006 - 2007

left:
QB 09/2006

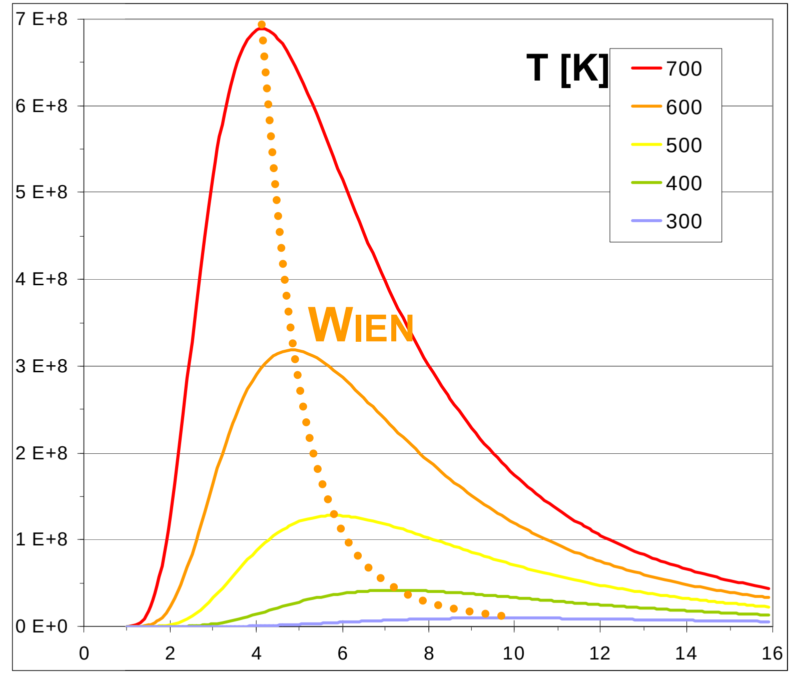
right:
QB 07/2007

Thermal Infrared TIR

- **TIR signal**
  - Planck's Law: radiation ~ object T
  - maximum radiance of coal fire in TIR
  - no solar reflections, but solar heating
  - RS: long wavelength → low energy → coarse pixels

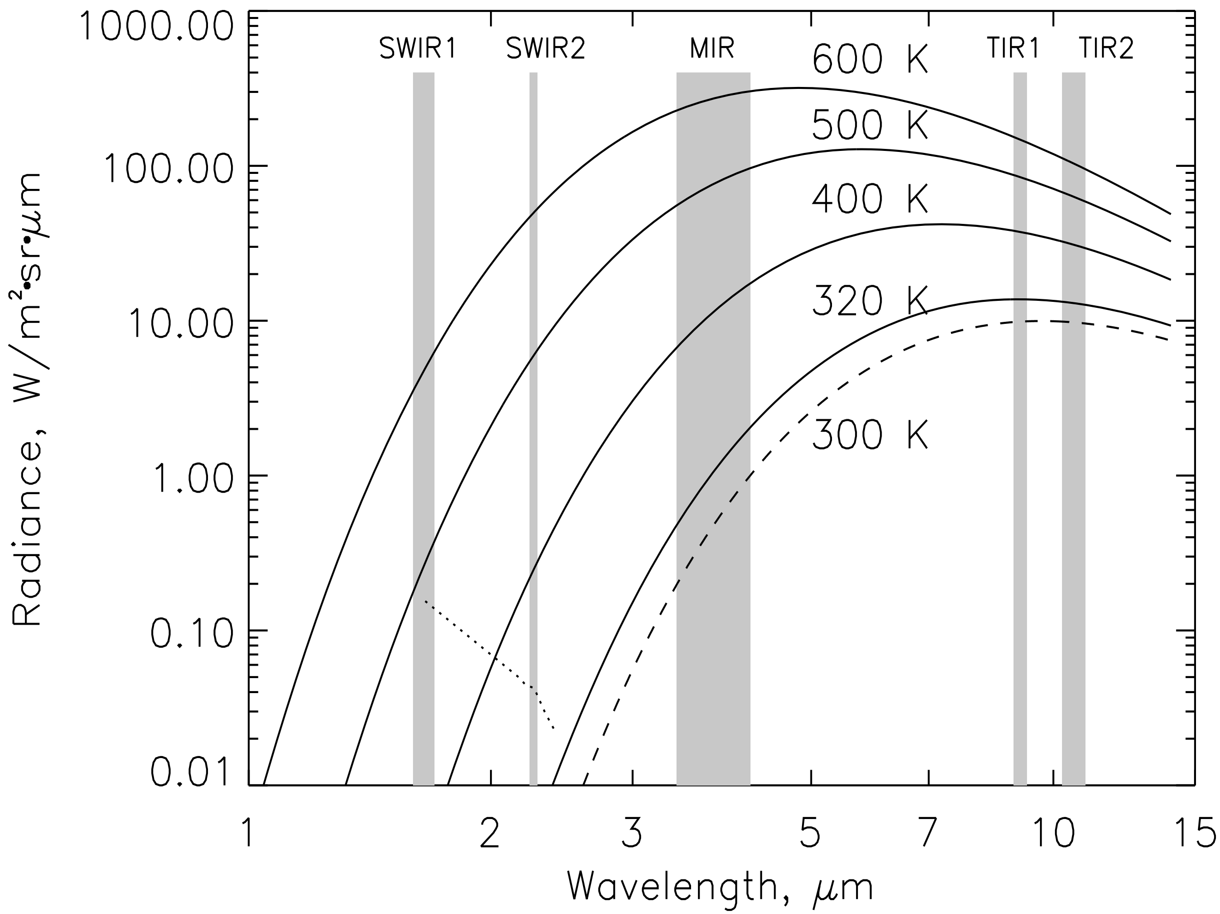
- **sensors and platforms**
  - spaceborne: ASTER, LANDSAT, CBERS, HJ-1B
  - airborne: tbd.

L [$Wm^{-2}\mu m^{-1}sr^{-1}$]



[µm]

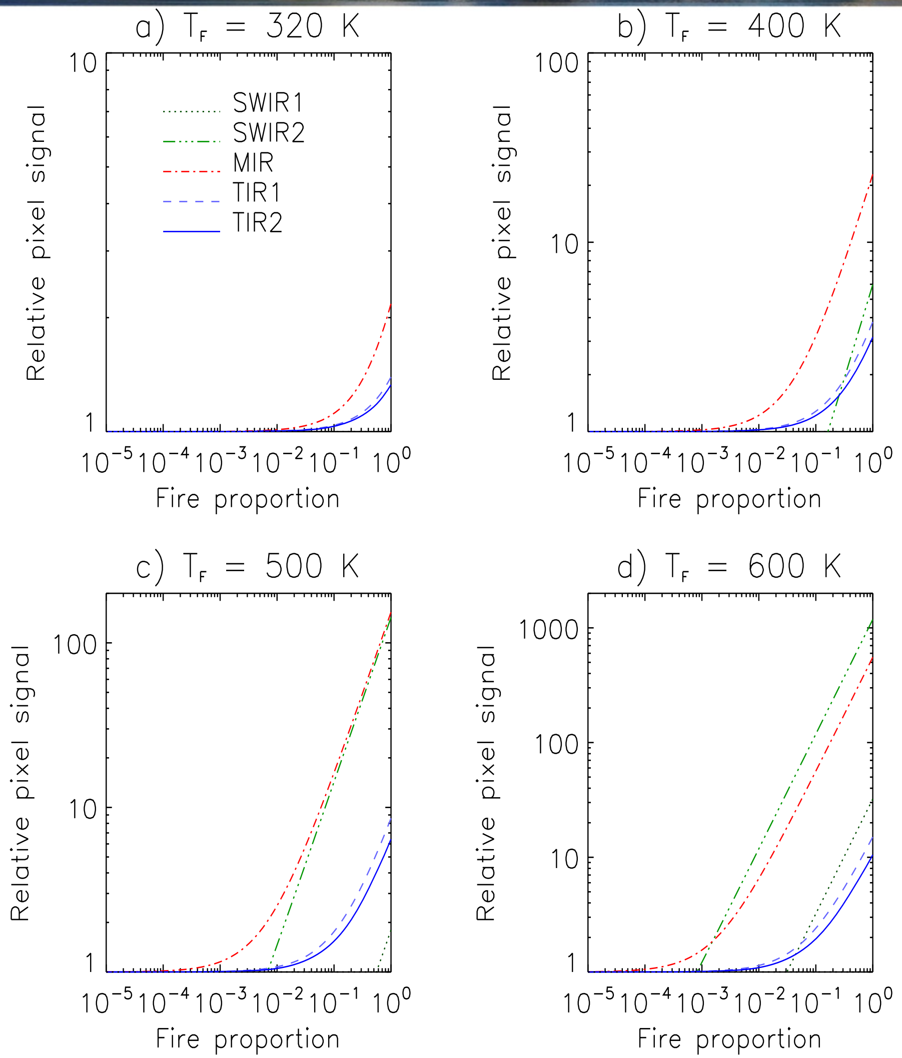
coal fire radiances



blackbody radiances as a function of wavelength and temperature.

dotted line: minimal detectable signal of ASTER SWIR channels

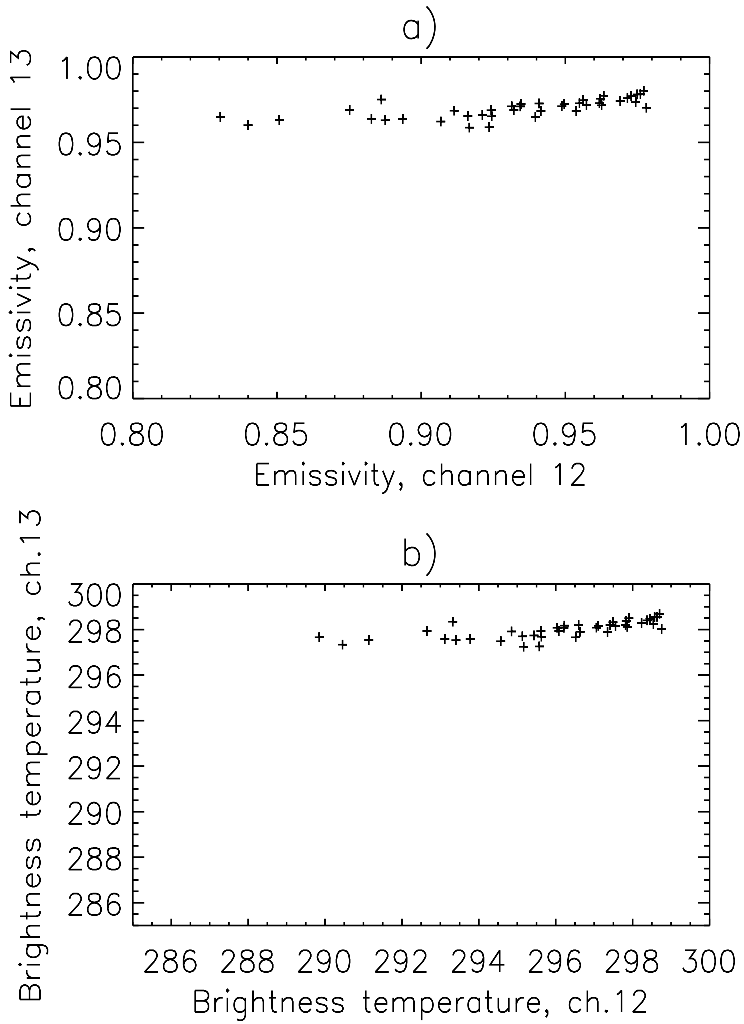
dashed line: background radiance @ 300 K



relative signal of a fire pixel as a function of the fire temperature and the fire pixel size.

assumption: in the SWIR spectral range the night time background temperature radiance is less than the minimal detectable signal

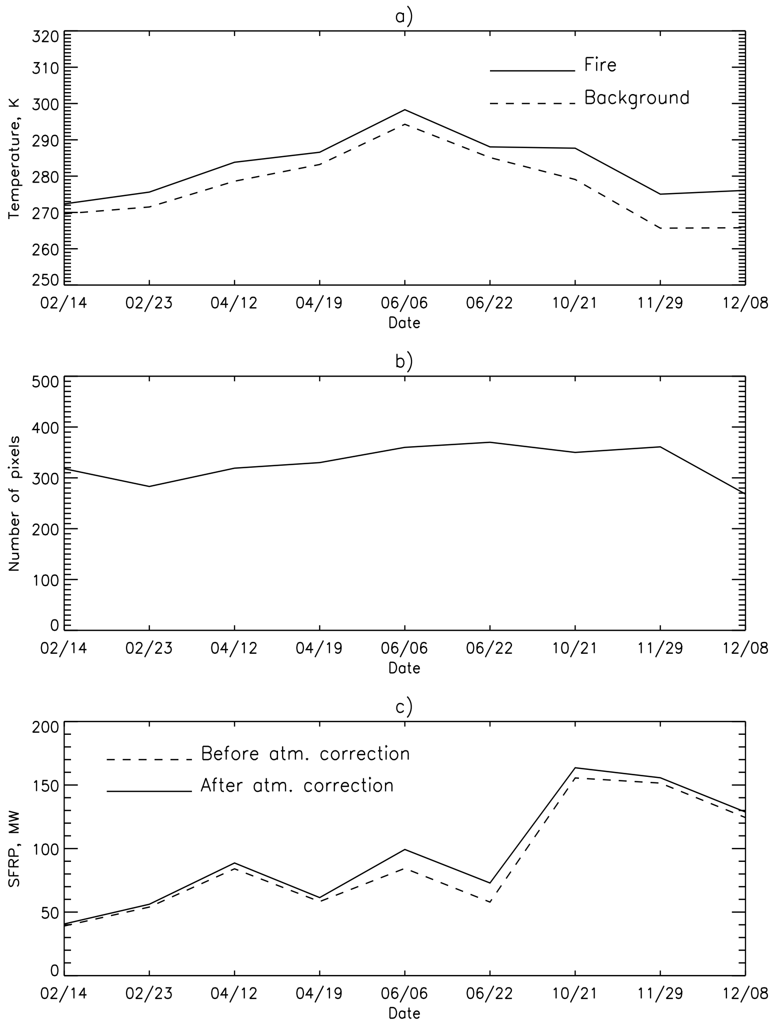
- **to detect fires with comparable low temperatures reprocessing is a crucial step**
- **influences caused by climate conditions have to take into account**
- **temperature measurements and estimation of the surface energy alance is of key importance**



emissivity - surface fire radiative power

emissivity for quartz sand, example from the ASTER spectral library

- **large variations in channel 12 due to strong absorption bands of quartz, comparable small variations in channel 13**
- **calculated brightness temperature show the corresponding changes**
- **recommendation to define proper emissivity correction factors**



improvement of pre-processing

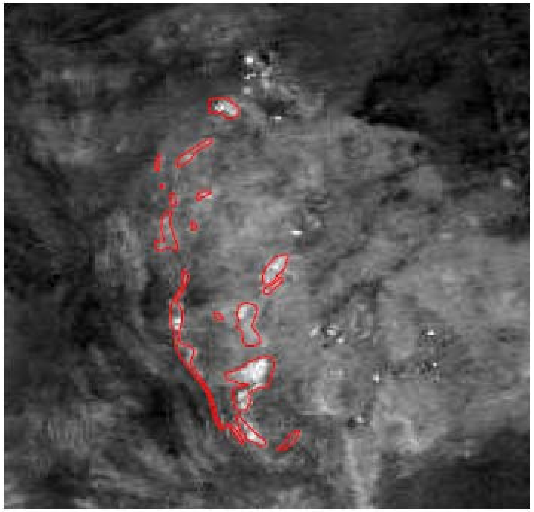
water vapor column (WVC) obtained from the MODIS MOD07 product, simultaneously recorded with the ASTER night time data (9 scenes for 2007)

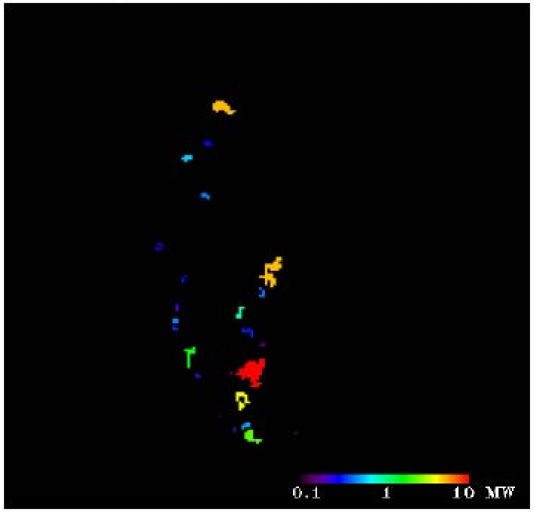
- **mean brightness temperature increases for the second half year**
- **number of detected pixel is comparable stable**
- **surface fire radiative power (SFRP) increase as well – due to an increase of the pixel - background temperature difference**

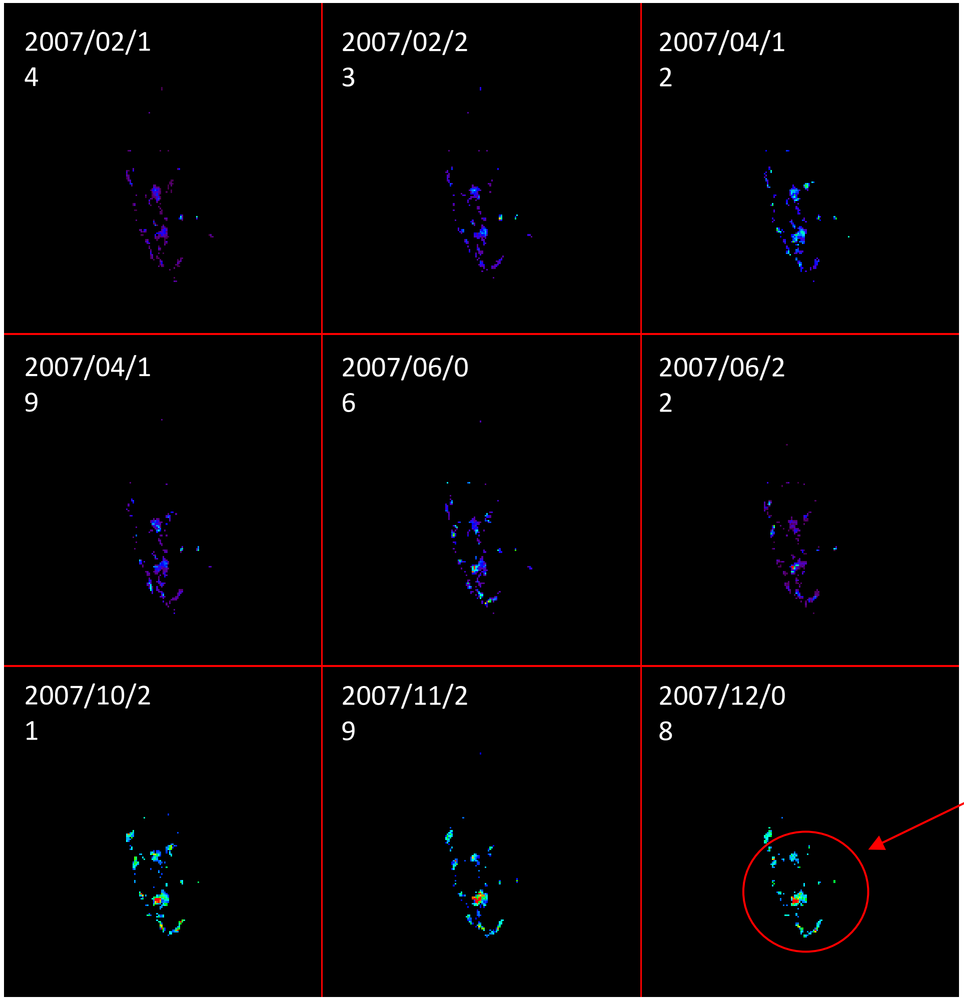
quantification

- **value conversion**
  raw DN to calibrated physical value
- **anomaly detection**
  separate fire and background pixels
- **clustering**
  join neighbouring fire pixels to fire cluster
- **CFRE quantification**
  use correlation between registered radiance L and fire radiative energy

$$CFRE = a + b \cdot (L_{fire} - L_{bg}) + c \cdot (L_{fire} - L_{bg})^2$$





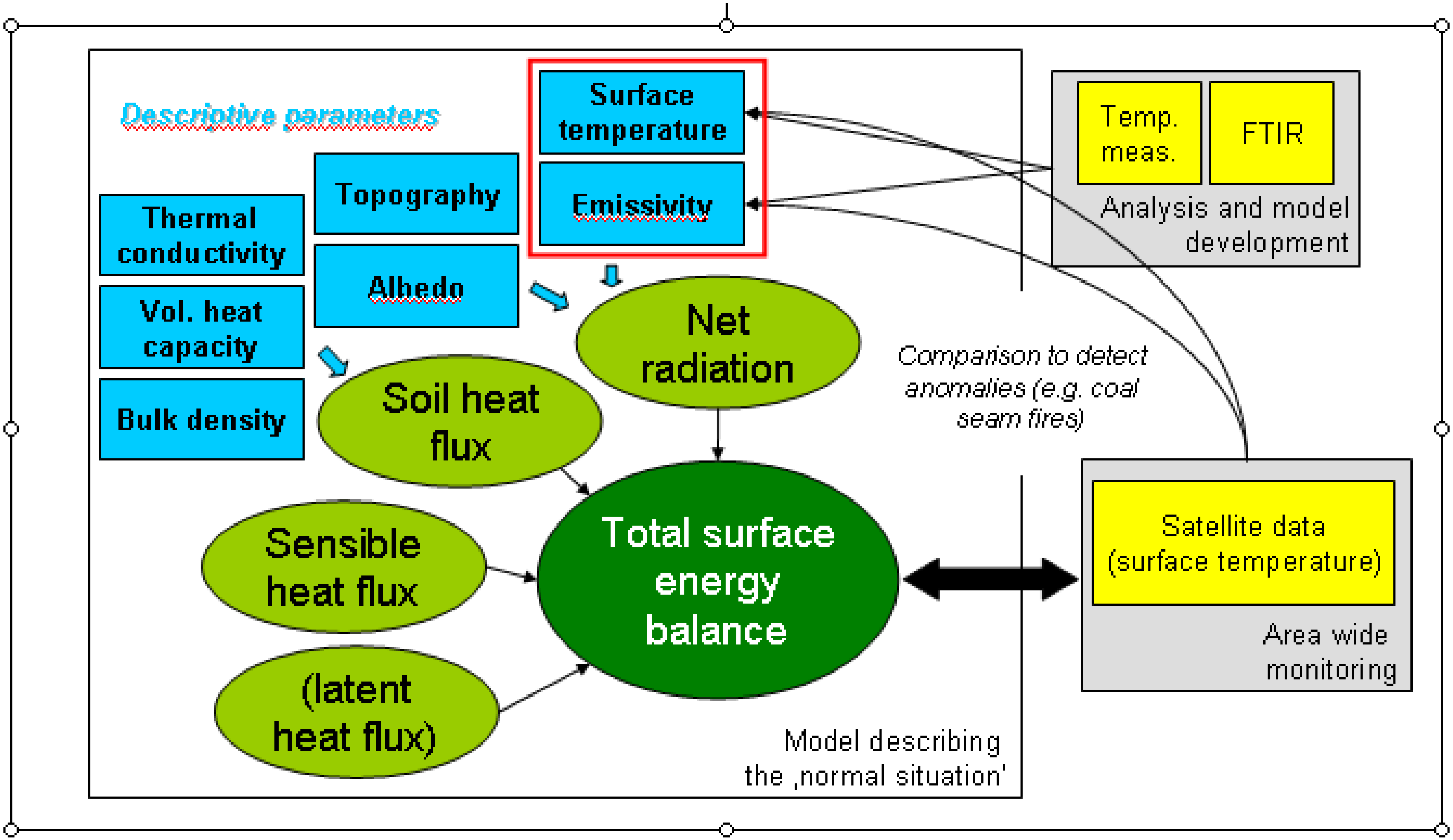


surface fire radiative power (SFRP)

SFRP distribution for Wuda in 2007.

SFRP increases from 02/2007 to 12/2007

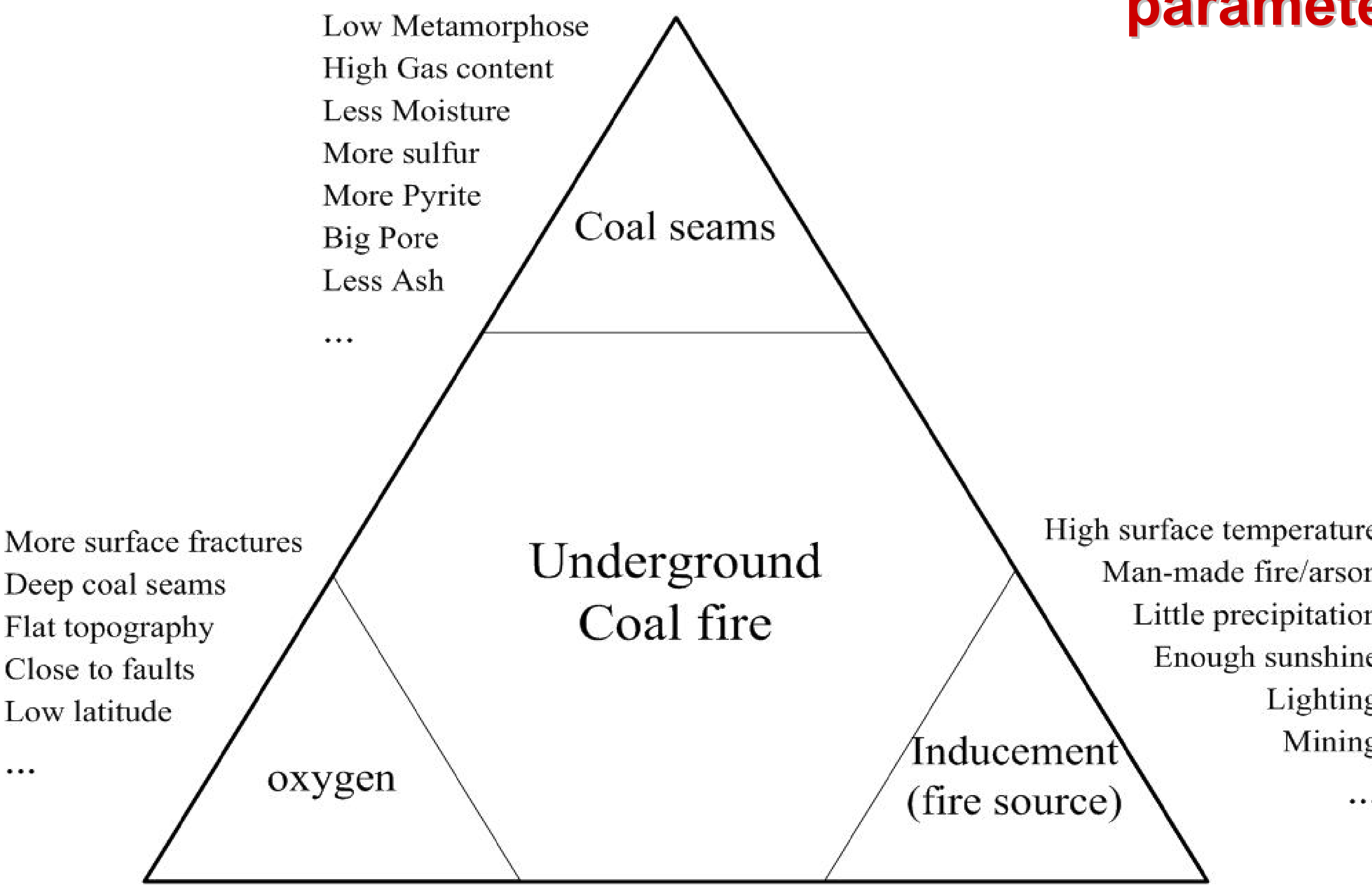
red pixels correspondents to a SFRP of 1 MW/pixel


Descriptive parameters
Surface temperature
Emissivity
Topography
Albedo
Thermal conductivity
Vol. heat capacity
Bulk density
Net radiation
Soil heat flux
Sensible heat flux
(latent heat flux)
Total surface energy balance
Model describing the ‚normal situation'
Temp. meas.
FTIR
Analysis and model development
Comparison to detect anomalies (e.g. coal seam fires)
Satellite data (surface temperature)
Area wide monitoring

risk asessment

- risk assessment of the underground coal fire
  - areas prone to the probability of combustion
  - focus on a regional scale, basis for a state-wide estimations
- significance of the research
  - micro-level: direction for campaign & extinguishing
  - support government to reasonable allocate resources, improve fire fighting strategy
  - input parameters of a monitoring system
  - to some extent, investigations can be used for a warning system

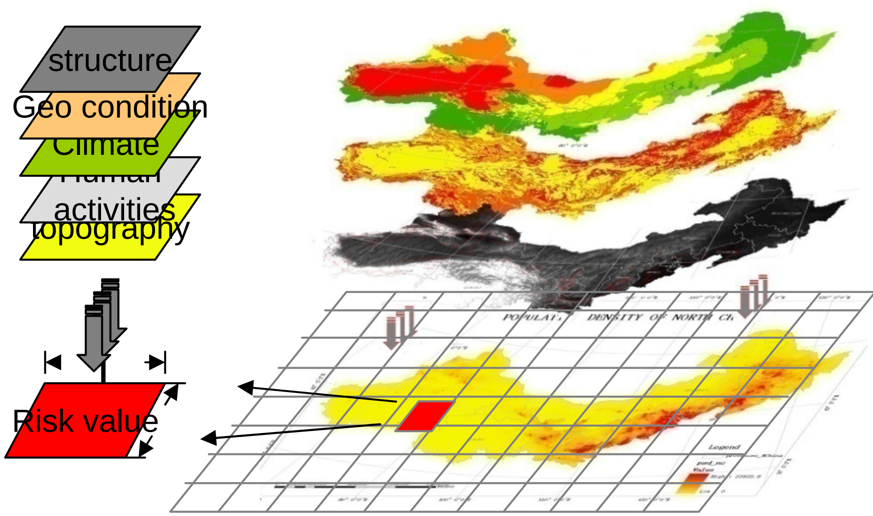
parameters

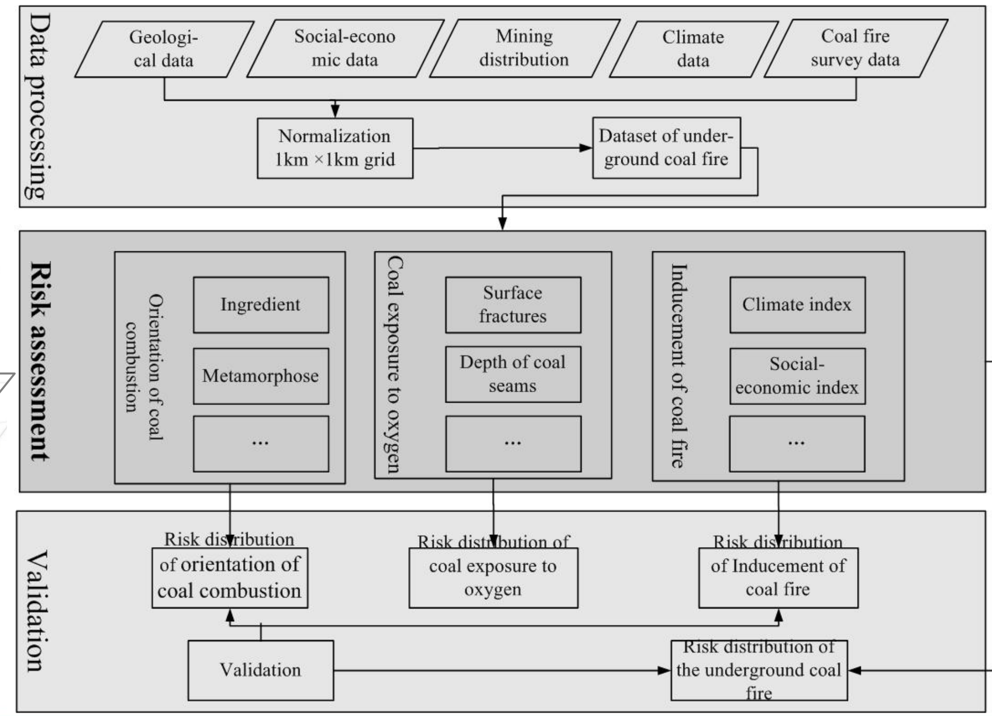

Low Metamorphose
High Gas content
Less Moisture
More sulfur
More Pyrite
Big Pore
Less Ash
…
Coal seams
Underground
Coal fire
More surface fractures
Deep coal seams
Flat topography
Close to faults
Low latitude
…
oxygen
High surface temperature
Man-made fire/arson
Little precipitation
Enough sunshine
Lighting
Mining
…
Inducement
(fire source)

methodology

composed of: data processing, evaluation model and verification part

- **basic hypothesis: the influence of each index on coal fire is equal**
- **method of spatial overlay is applied for the sum of the all index values, based on a 1km×1km grid**





index system

Factor [a]	Index	Theory of index choosing
spontaneous combustion （content & structure）	Gas content	The coal gas reduces the amount of oxygen, and restrains the development of combustion.
	Ingredient	more mineral coal, easy to burn, while more dull coal, difficult to catch fire.
	Porosity	The larger the Porosity is, more oxygen can seep into the interior of coal,
	Brittleness	If the coal is more brittle, the coal easily to burn.
	Moisture content	The moisture content in porosity of coal make it fragile, even inhibit combustion when the moisture is large enough, while if the moisture evaporate, probably to lead to combustion.
	Ash content	Inorganic minerals, big amount of the ash content suppress coal spontaneous combustion.
	Sulfur/Pyrite	Heat released from the pyrite oxidation in low-temperature will intensify the coal combustion,
	Geological age	the distribution of coal fire in north concentration in Jurassic and Permian coalfield.
	Metamorphic grade	Coal with high metamorphic grade, contains less oxygen-enriched group, difficult to oxidize under low temperature.
	Thickness/Angle	The thickness of coal seam influences the transfer of heat,

Coal oxygen contact factors （geology condition）		Depth	Along the increasing of the depth, the content of oxygen will gradually decrease and below certain depth, the burning process may be restrained
		Location/latitude	Latitude in different regions lead to different solar angles and the uneven distributed heat absorbed is in different region influence oxygen supply.
		Fault	Fault boost the connecting of coal seam and oxygen, and faults will slow speed of mining,
		Anticline	Heat is easily accumulated in anticline, larger probability to cause fire.
		Slope/Aspect	Topography affect the distribution of the surface heat
		Surface fracture	Surface fracture provides visa for the underground coal seams fully contact with oxygen,
Inducement factors	Weather condition	Temperature	High surface temperature in summer provides favorable conditions for the combustion.
		Precipitation	Less rainfall but strong evaporation is good to combustion.
		Wind force	Wind speed and direction will affect heat accumulation.
	Human activities	Population density	The urban area with large resident requires lot of energy supply.
		Mine distribution	Region with poor management, human's heating absorbed for survival in winter some mines especially smaller ones, is in all probability to become an important inducement of coal fire.

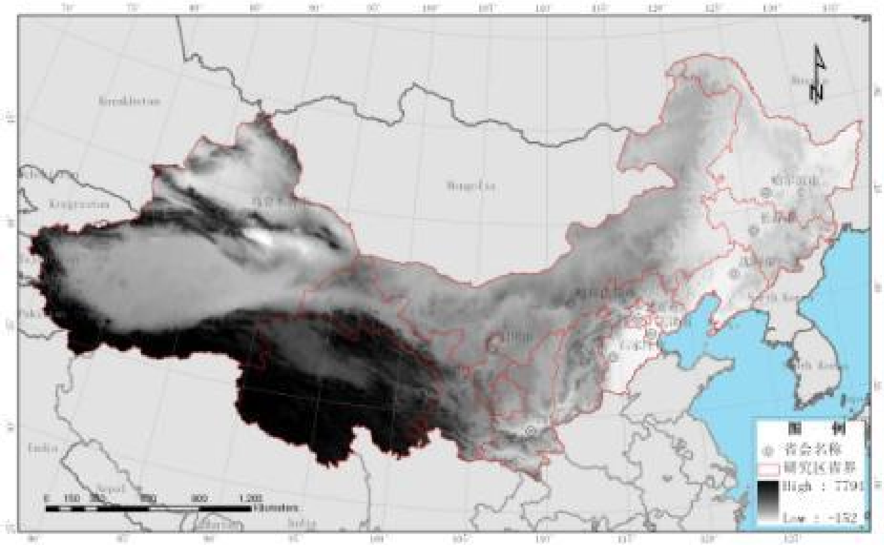
used information

Data name	type	Description	Source
Ash content	Statistical data	0-44.395%	Institute of Geography, CAS
volatilization	Statistical data	0-52.604%	Institute of Geography, CAS
Sulfur/Pyrite	Statistical data	0-23.73%	Institute of Geography, CAS
Heat	Statistical data	0-36.465J/kg	Institute of Geography, CAS
Geological age	Shape file	Jurassic/cretaceous/tertiary / Permian-carboniferous Triassic Permian/carboniferous other	China petroleum BBS nets
Faults	Shape file	-	Institute of Geography, CAS
DEM	Raster	-152-7794	Institute of Geography, CAS
Temperature	Recording data	734stations	http://cdc.cma.gov.cn/
Precipitation	Recording data	734stations	http://cdc.cma.gov.cn/
Mine distribution	Shape file	Large , minimum, small	Institute of Geography, CAS
Population density	Shape file	0-23822.8	Institute of Geography, CAS

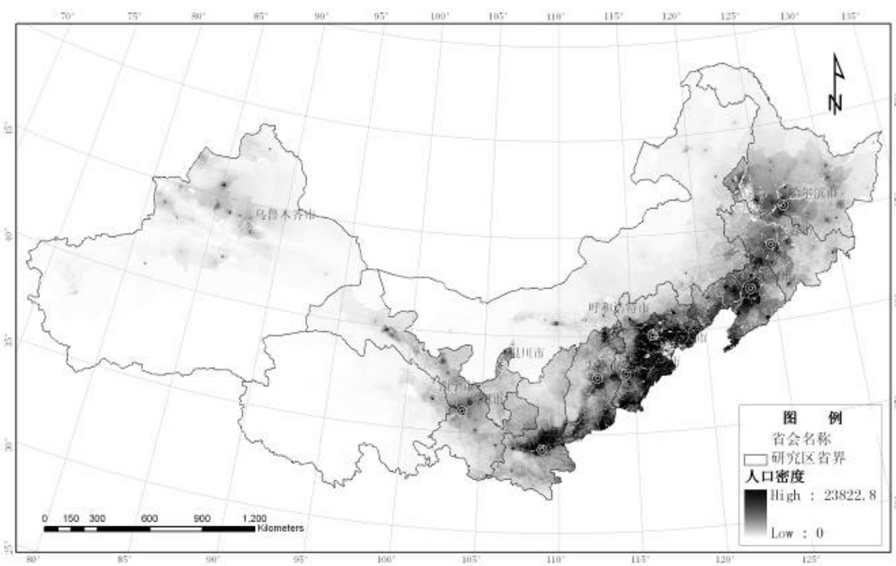
northern China

11 provinces in north China are selected as the research area, from the Pamir plateau in the west to Changbai Mountain in the east, the area take up more than 50% of the whole country land.

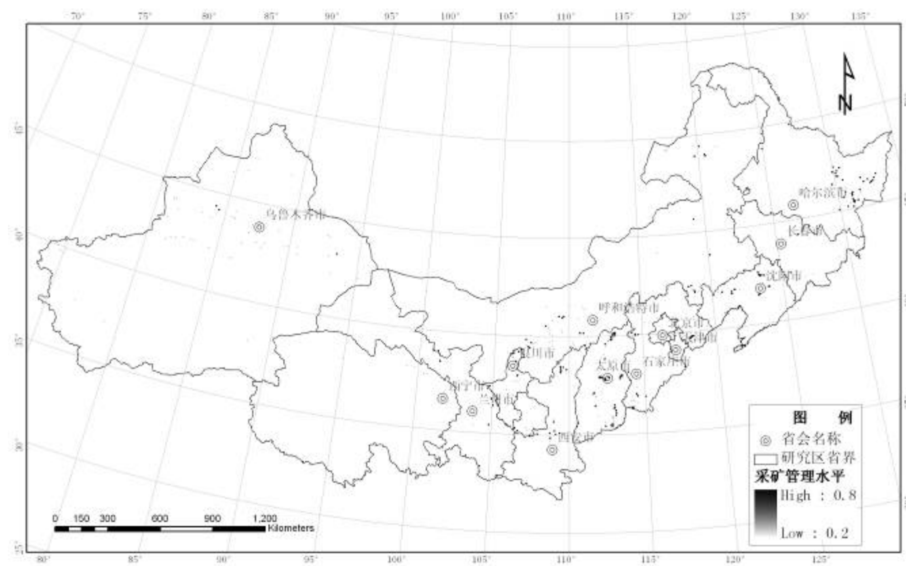
- climate condition
- geology and ecological situation
- society and economical situation



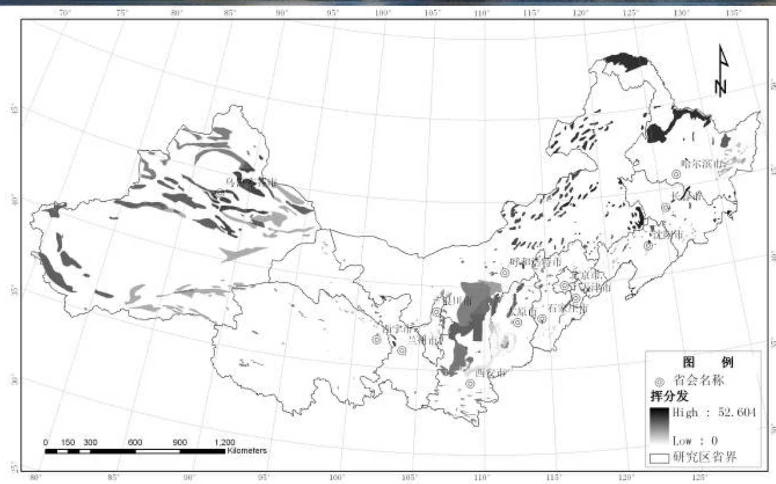
- **Note on data quality**
  - **missing data in some areas, averaged values have been calculated**
  - **data on mining have been calculated based on different buffer areas (large - 5km, medium - 3km, small - 1km)**



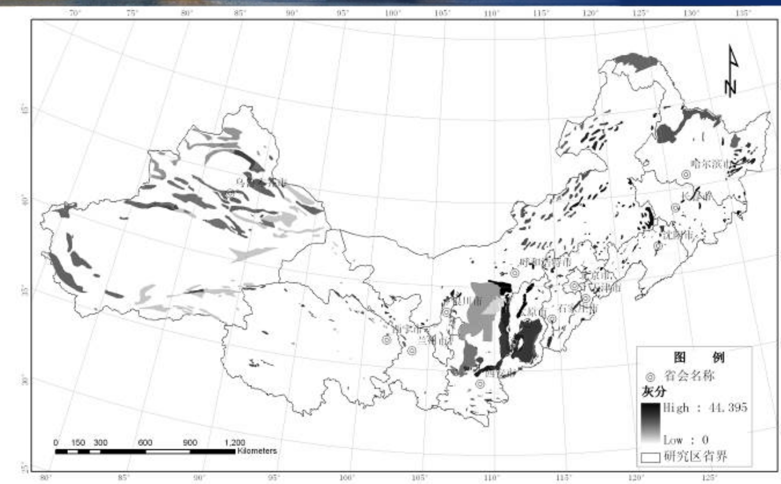
Population density



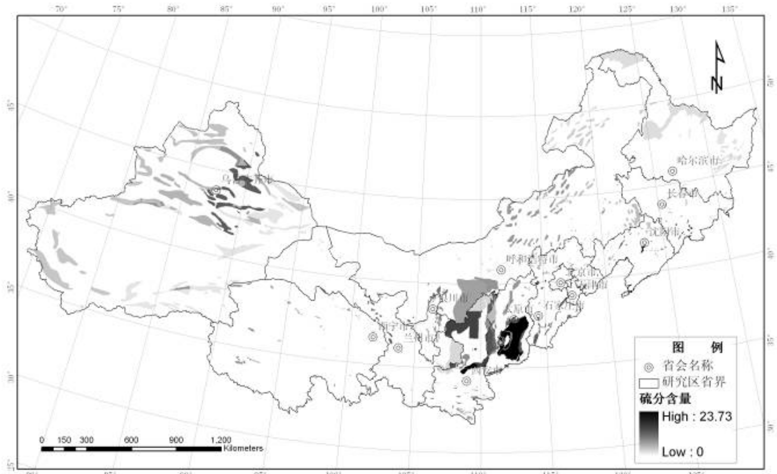
Mining distribution



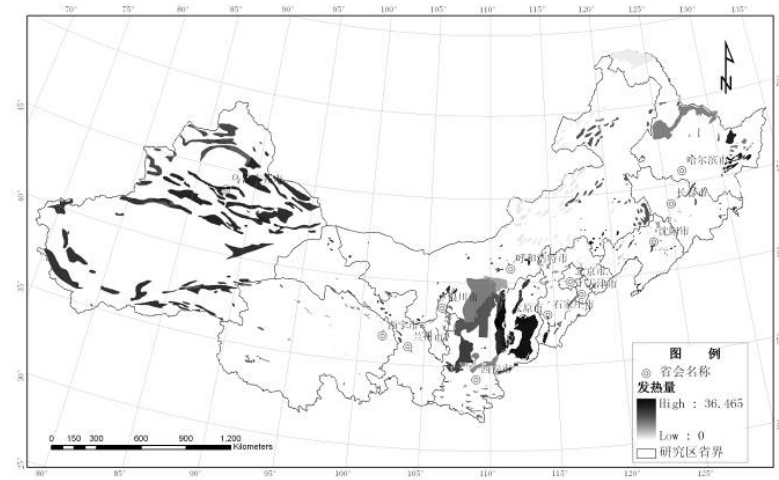
volatilization



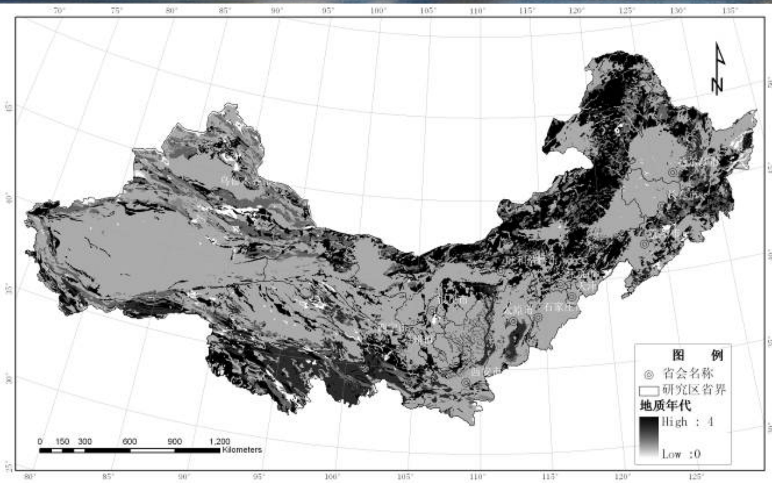
Ash content



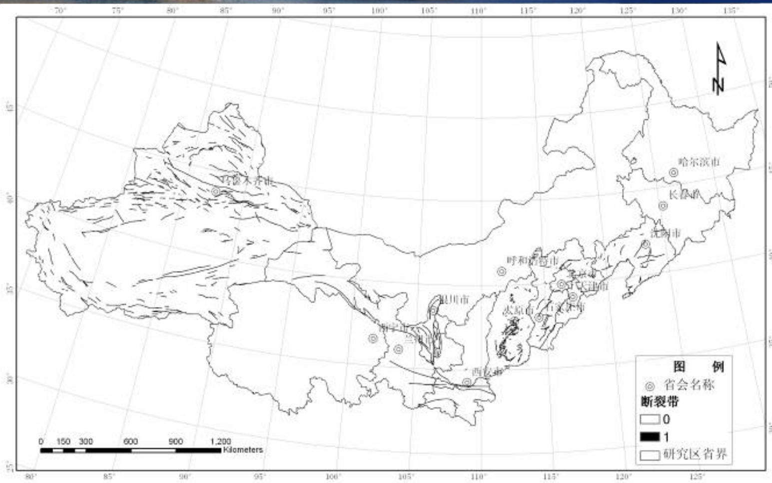
Sulfur/Pyrite



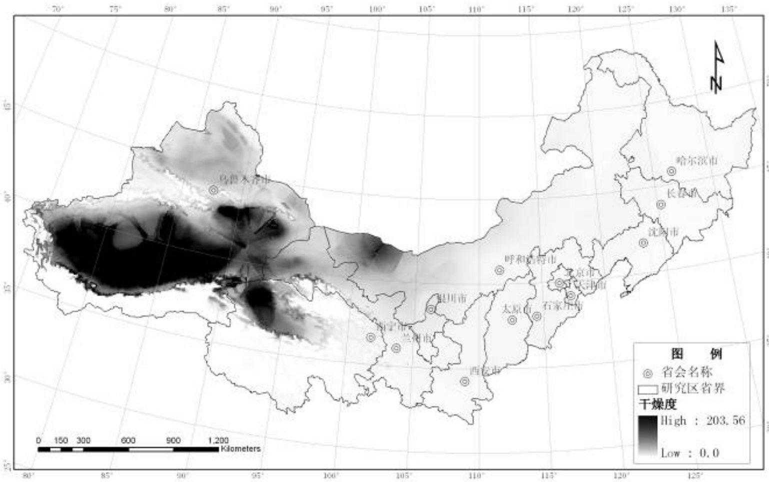
Temperatures



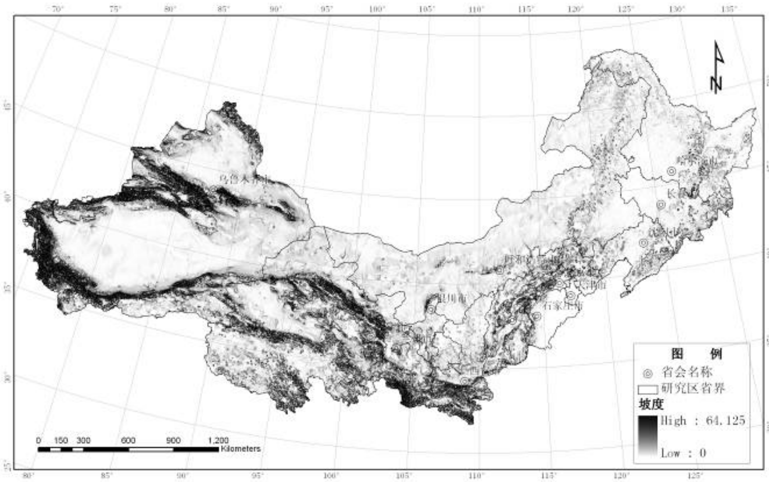
Geological age



Faults



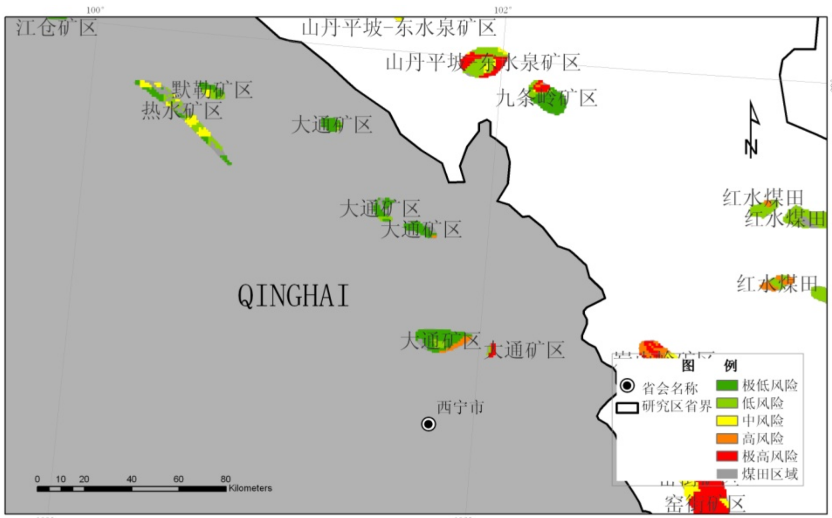
Aridity index



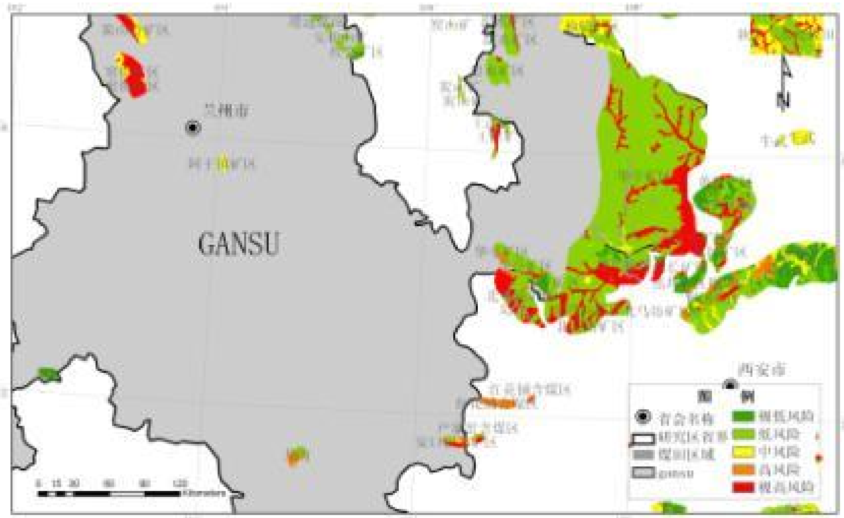
Slope

Verification in north China:

- Qinghai-Datong coalfield, extreme high risk on different sites, low risk for the majority of coal fields
- Gansu-Yaojie, Huating coalfield are covered by extreme high risk area



Gansu-Datong coalfield

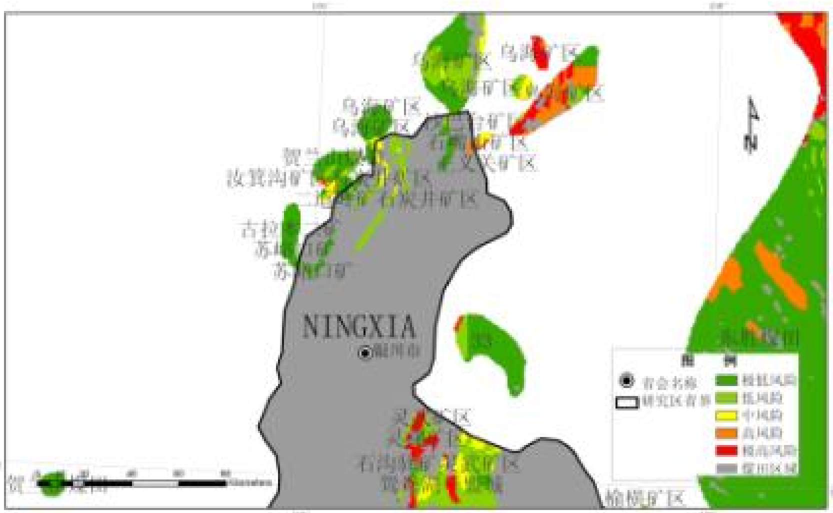


Gansu-Huating coalfield

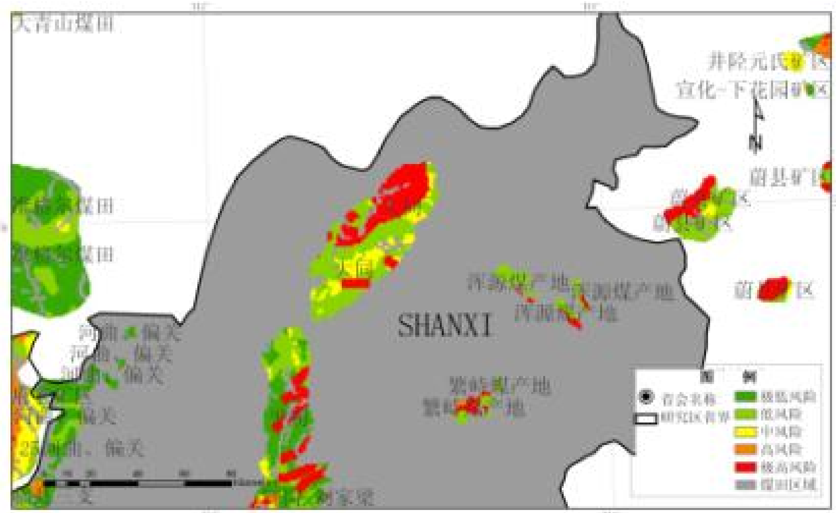
Ningxia-Rujigou coalfield is part of an extreme high risk area

Shanxi-Datong coalfield, high risk area

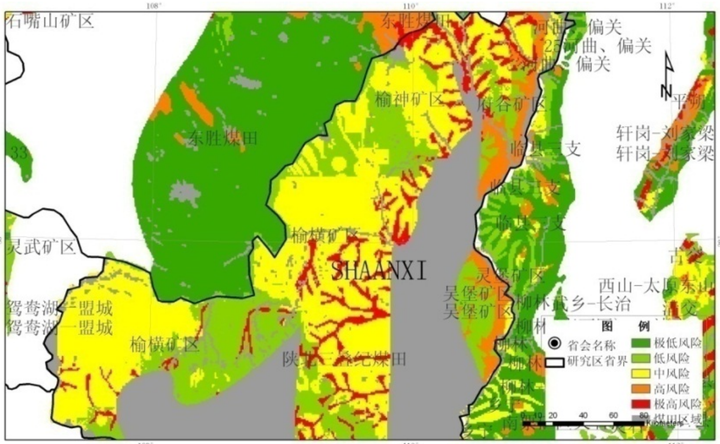
Shaanxi-Shanbei, Hunaglin coalfield extreme high risk areas are the majority



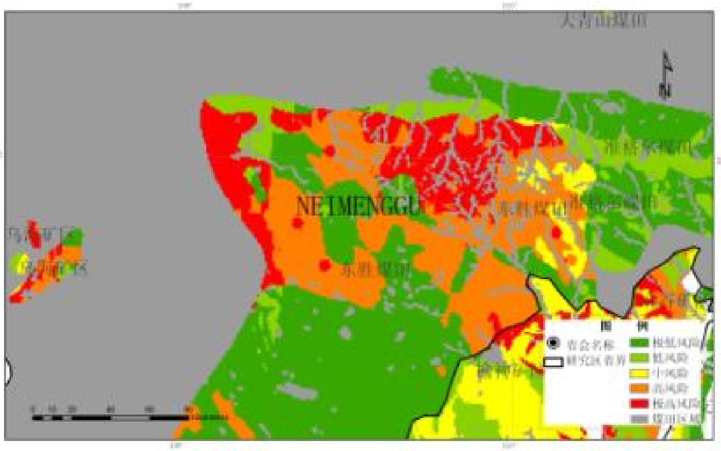
Ningxia-Rujigou coalfield



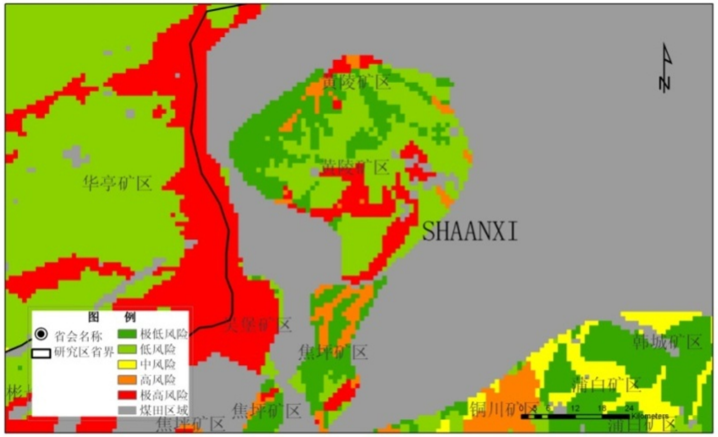
Shanxi-Datong coalfield



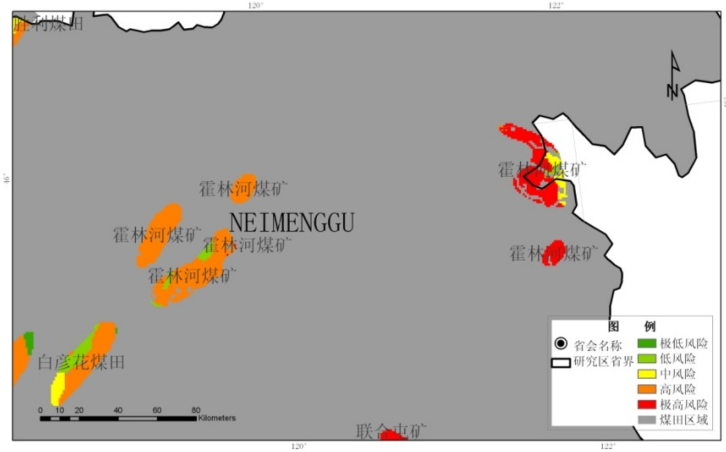
Shaanxi-Shanbei coalfield



Inner Mogolia-Dongsheng coalfield

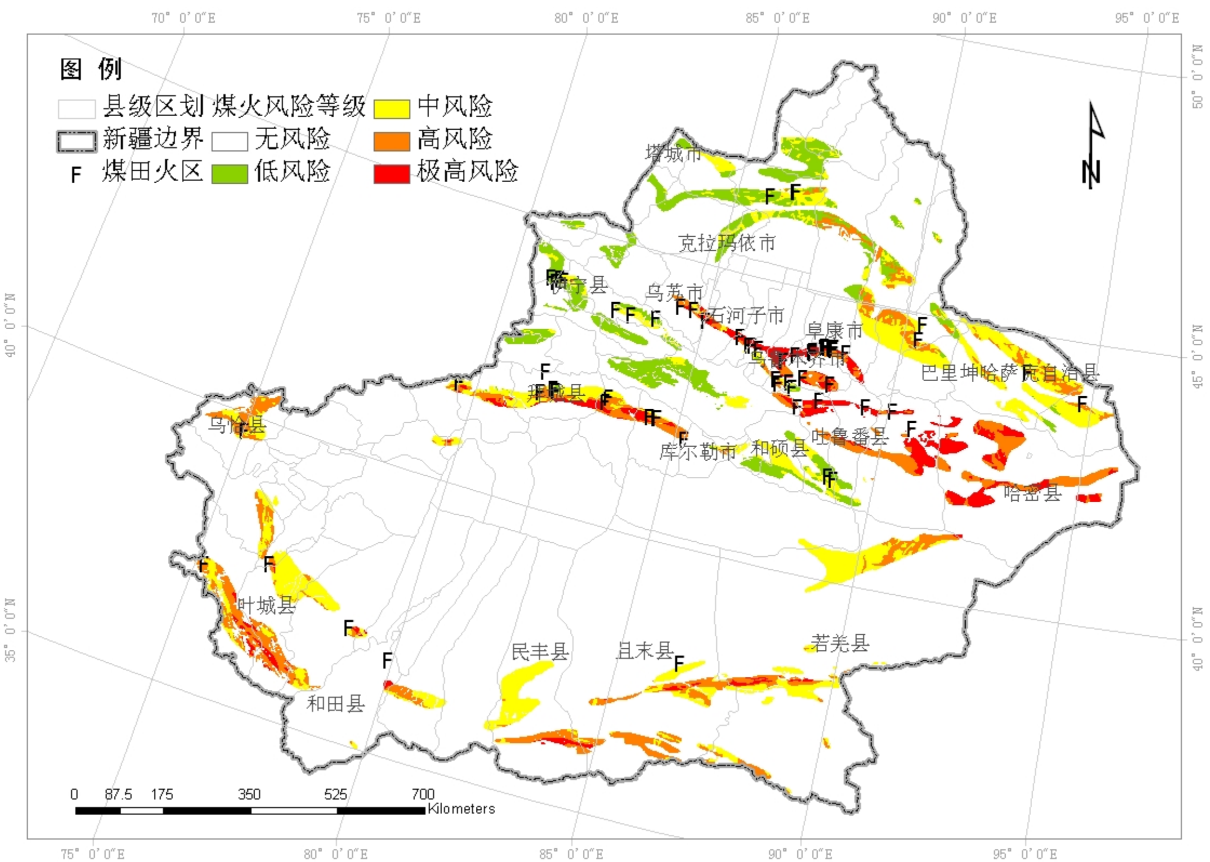


Shaanxi-Huangling coalfield



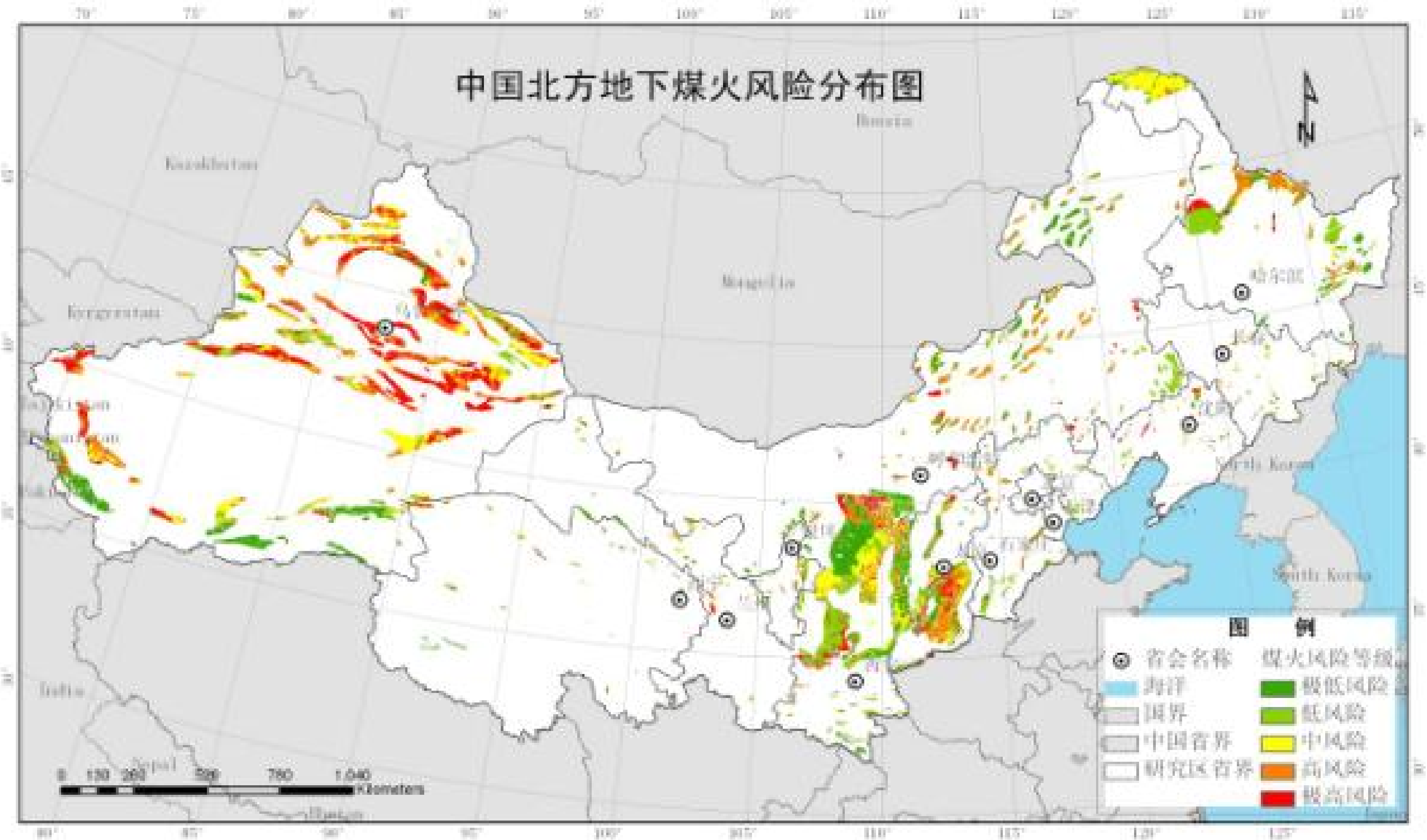
Inner Mogolia-Huolinhe coalfield

Xinjiang



Fire zones located in high coal fire risk areas can sum up to 81.53% of the total number of fire zones

coal fire risk distribution in northern China



summary & conclusion

- the high-resolution TIR2 channels of the ASTER and (potentially) of the IRMSS sensors are recommended for coal fire monitoring since they provide a high sensitivity of ~1 MW/pixel to coal fires in the entire typical coal fire surface temperature range of 300 to 600 K
- using multi-temporal information allow a significant improvement of coal fire monitoring. The developed algorithm to estimate the surface heat balance has to be further tested and its parameters optimized for specific coal fire areas
- the developed risk assessment methodology and the ranking procedure of coal fields in different provinces, where coal fires have ever been indicate produces reliable results.

➢ We gratefully acknowledge the support from Mr. Cai Zhongyong from the Xinjang Fire Fighting Bureau and from the DRAGON2 program

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Thank you for your attention !!