WP 3660: Continental Scale Investigation

Risk Assessment Modeling of Coal Fires
Using Artificial Neural Networks and GIS

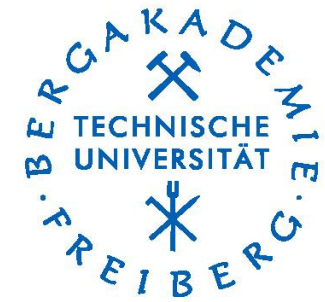**C. Drebenstedt[1], A. Knobloch[1,3], O. Gusat[1], C. Fischer[2], A. Barth[3]**
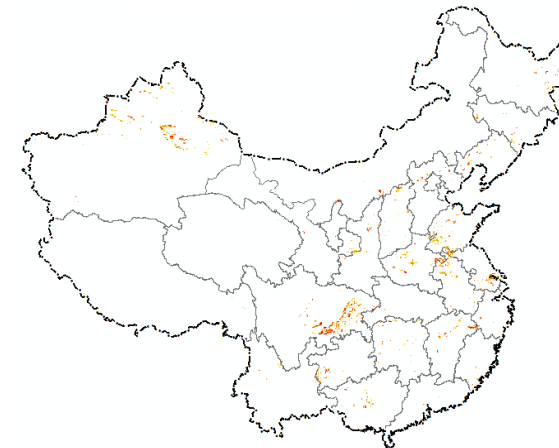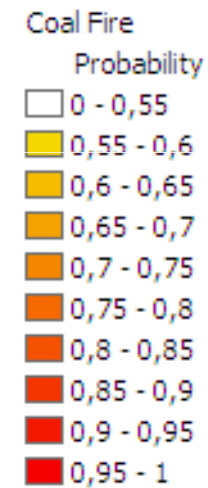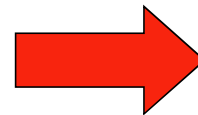
1   TU Bergakademie Freiberg, Institute for Mining and Special Civil Engineering, Freiberg, Germany
2   German Aerospace Center (DLR), German Remote Sensing Data Center (DFD-LA), Wessling, Germany
3   Beak Consultants GmbH, Freiberg, Germany

■ **<u>Motivation for Predictive Modeling / Mapping</u>**

Which coal fields are burning ?
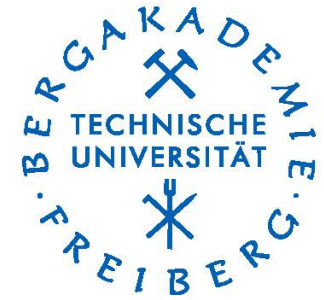**What parameters influence natural coal fires?**

Coal Fire
Probability
☐ 0 - 0,55
☐ 0,55 - 0,6
☐ 0,6 - 0,65
☐ 0,65 - 0,7
☐ 0,7 - 0,75
☐ 0,75 - 0,8
☐ 0,8 - 0,85
☐ 0,85 - 0,9
☐ 0,9 - 0,95
☐ 0,95 - 1

→ **Country-Wide Prediction of Probability of Occurrence of Natural Coal Field Fires**

- **<u>Agenda</u>**

■ Traditional Approach
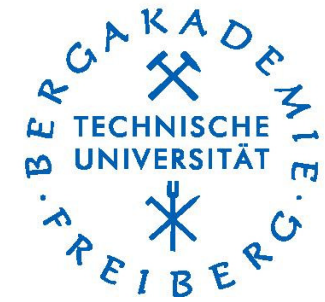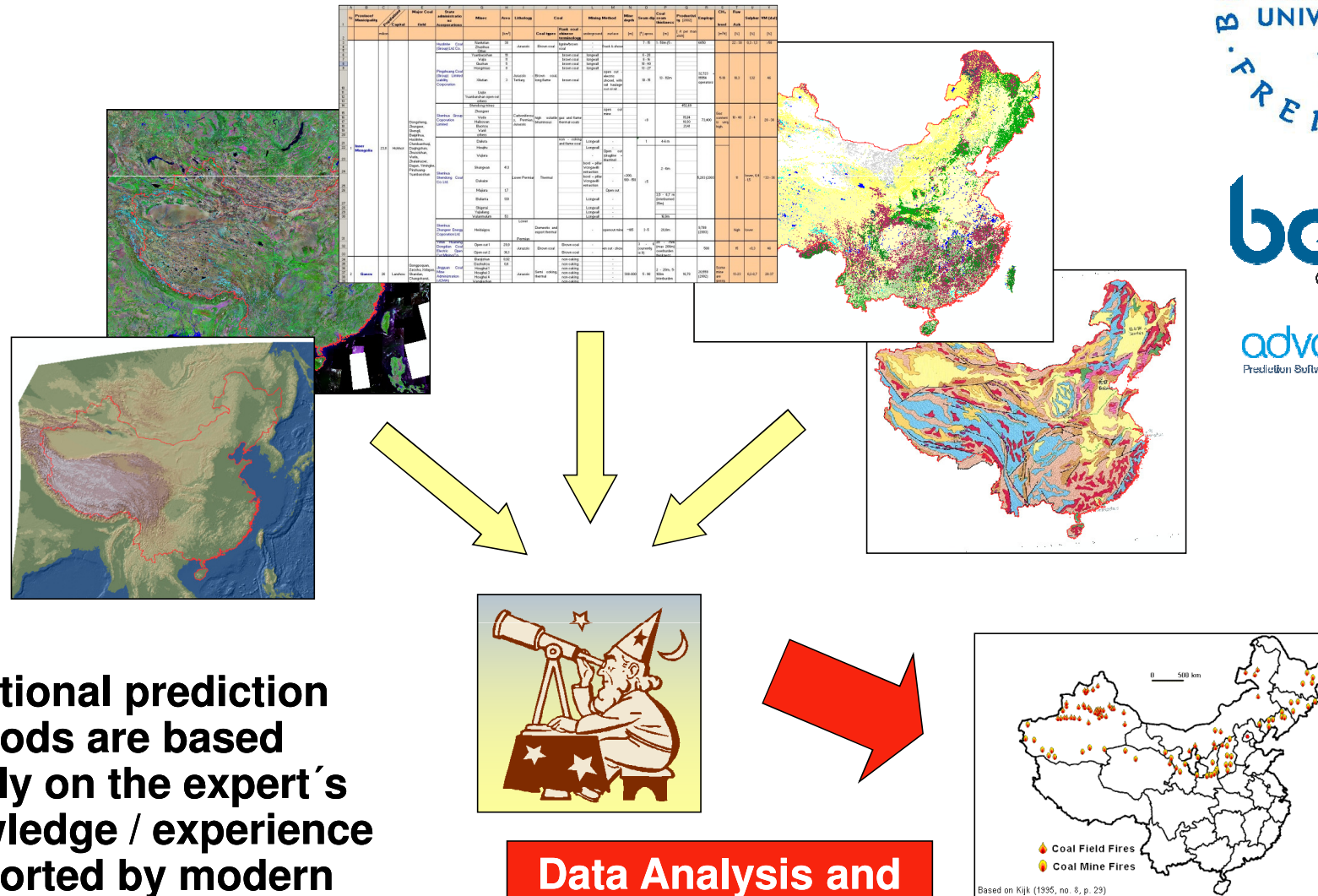
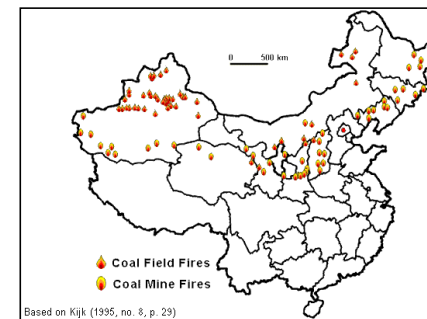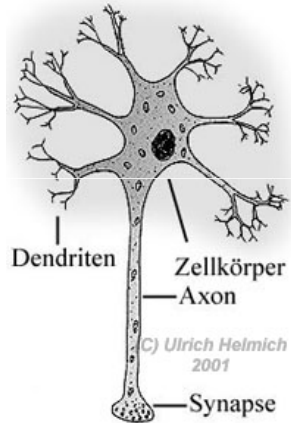**Traditional prediction methods are based mainly on the expert´s knowledge / experience supported by modern information technology**

Data Analysis and Interpretation

■ **Modern Approach Using Artificial Intelligence**

Pre-Processing

Validation

The artificial neuronal network "replaces" the experts empirical data analysis
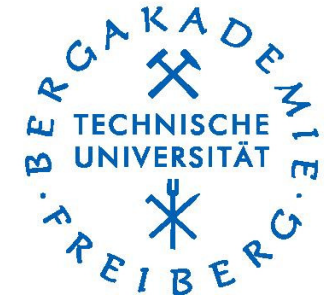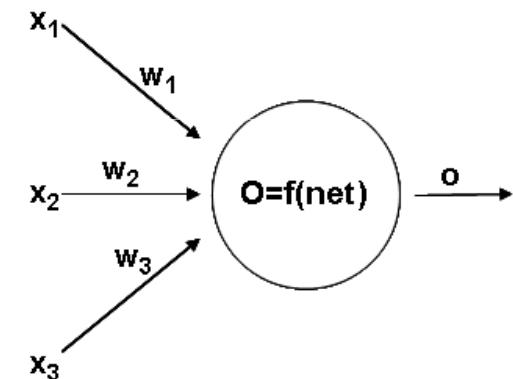
▪ Definition: Artificial Neural Networks

Model: Neuron Cell

- Functionality as a biological neural system
- Consists of artificial neuron cells
- Simulation of biological processes of neurons by use of suitable mathematical operations
- In most cases layer-like configuration of the neurons

Dendriten Zellkörper —Axon (C) Ulrich Helmich 2001 —Synapse

The Neuron Cell as a Processor

- Connection between the neurons by **weights w**
  - Enforce or reduce the level of the input information
  - Are directed, can be trained
- Input signals
  - Re-computed to a single input information: the **propagation function**
- Output signals
  - **Activation function** computes the output status of a neuron (often used: Sigmoid function)

x_1 w_1 x_2 w_2 $O=f(net)$ o w_3 x_3

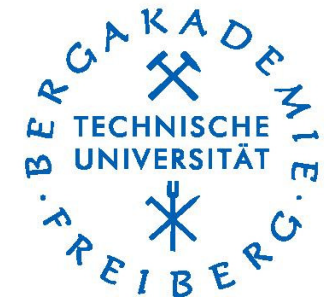## ▪ **Principles of Artificial Neural Networks**

Network Topology: MLP (Multi Layer Perceptron)

- Set-up of neurons in layers
- Direction and degree of connections
- Amount of hidden layers and neurons

Input Layer

Hidden Layer

w_{ij}

Output Layer

Σ

Activation Function: Sigmoid

$s(x) = 1/1+e^{-x}$
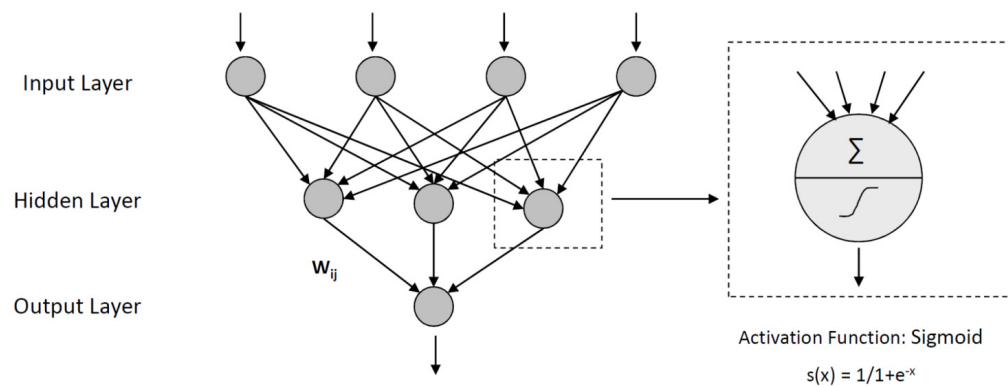
Learning Algorithm: Back-Propagation

- Repeated input of training data
- Modification of weights w
- Reduces error between expected and actual output of the network

- **<u>Advantages / Disadvantages of Artificial Neural Networks</u>**

Advantages

- learnable: learning from examples
- generalisation: able to solve similar problems that have not been trained yet
- universal: prediction, classification, pattern recognition
- able to analyse complex, non-linear relations
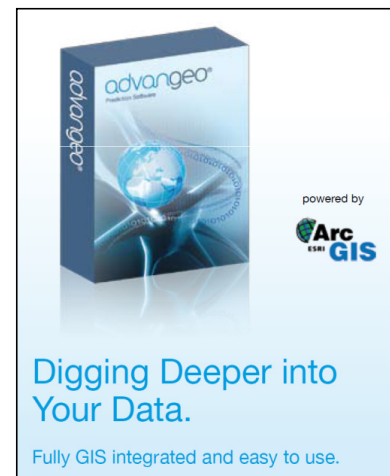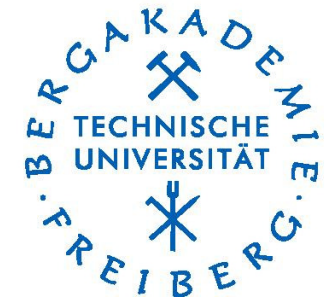- fault-tolerant against noisy data (e.g. face recognition)

Disadvantages

- choice of topology and training algorithm not easy
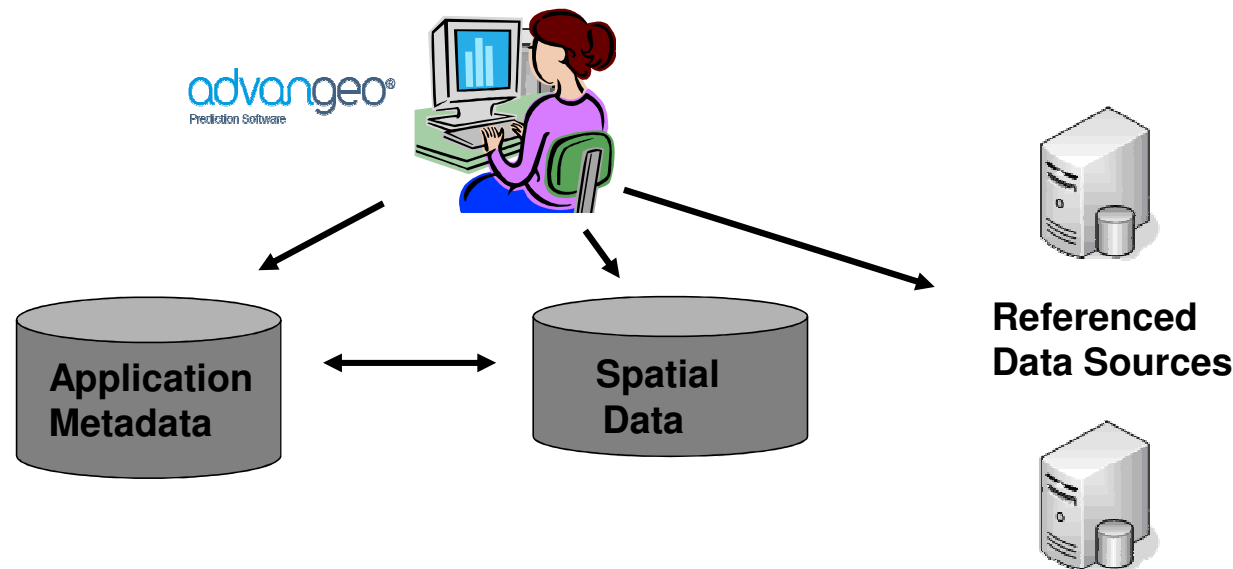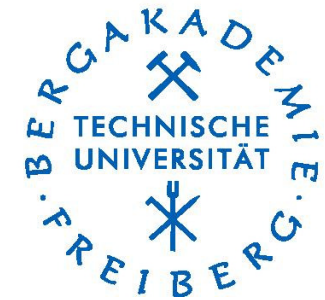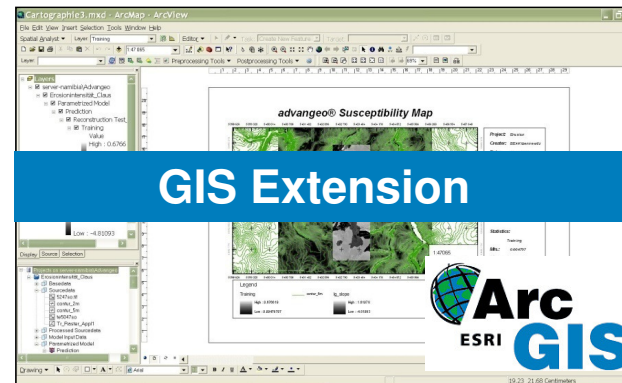- black box system: limits of the networks are unclear (e.g. whether non-relevant data will be analysed and used)
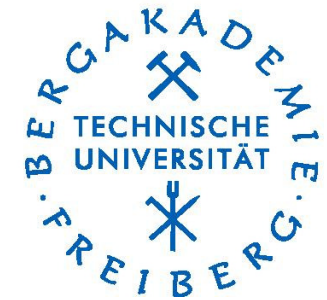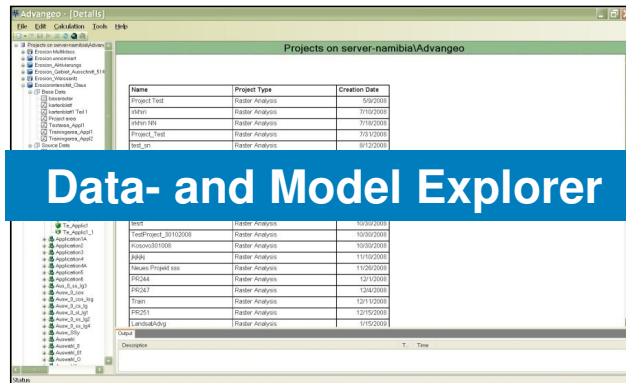
▪ **Software: advangeo®**

- Easy Access to Methods of Artificial Intelligence for Spatial Prediction
- Documentation of Working Steps
- Capture and Management of Metadata for Geodata
- Tools for Data Pre-Processing, Post-Processing and Cartographic Presentation
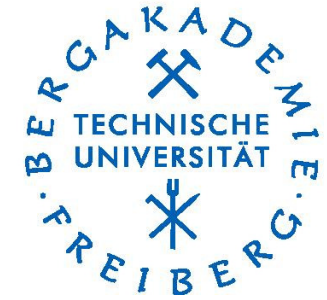- Integration into Standard ESRI ArcGIS-Software

advangeo®
Prediction Software

advangeo®
Prediction Software

powered by
Arc GIS
ESRI

Digging Deeper into Your Data.
Fully GIS integrated and easy to use.

▪ Software Components

Data- and Model Explorer

GIS Extension

Application Metadata

Spatial Data

Referenced Data Sources

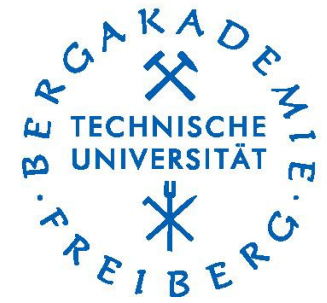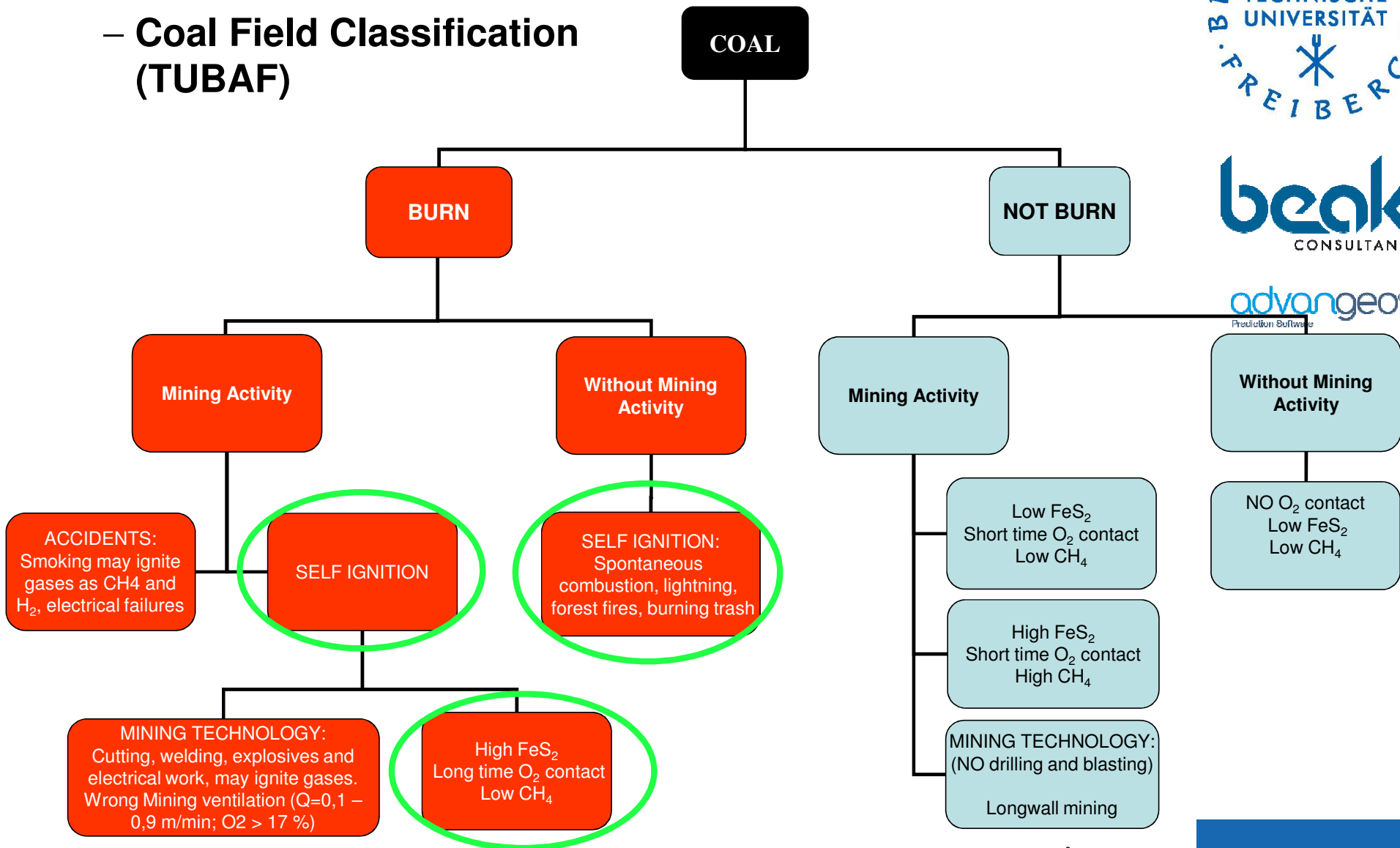- **<u>Case Study: Coal Fire Probability Mapping in China</u>**

Work Flow / Methodology

1. **Task description**

2. **Definition of working area borders**

3. **Collection of primary source data**

4. **Statistical pre-processing**

   (unit transformation, data recoding, reduction of dimensions…)

6. **Processing of model input data**

7. **Modelling of training and application scenarios**

8. **Statistical post-processing**

   (appraisal of repeatability, robustness…)

9. **Presentation of prediction results**

- **Work Flow: Parameter Knowledge**

  – **Coal Field Classification (TUBAF)**

COAL

BURN

NOT BURN

Mining Activity

Without Mining Activity

Mining Activity

Without Mining Activity

ACCIDENTS:
Smoking may ignite gases as CH4 and H_2, electrical failures

SELF IGNITION

SELF IGNITION:
Spontaneous combustion, lightning, forest fires, burning trash

Low FeS_2
Short time O_2 contact
Low CH_4

NO O_2 contact
Low FeS_2
Low CH_4

High FeS_2
Short time O_2 contact
High CH_4

MINING TECHNOLOGY:
Cutting, welding, explosives and electrical work, may ignite gases. Wrong Mining ventilation (Q=0,1 – 0,9 m/min; O2 > 17 %)

High FeS_2
Long time O_2 contact
Low CH_4

MINING TECHNOLOGY:
(NO drilling and blasting)

Longwall mining

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▪ **Work Flow: Definition of Working Area Borders**

• **Compilation of Base Data:**

– **Base Raster (Model Area)**
  → Raster Resolution: 1 km (4676 x 3775 Pixel)
– **Training Area**
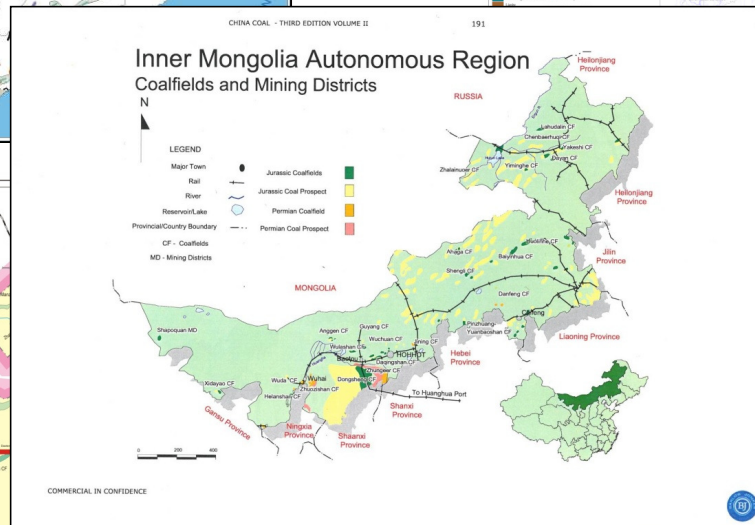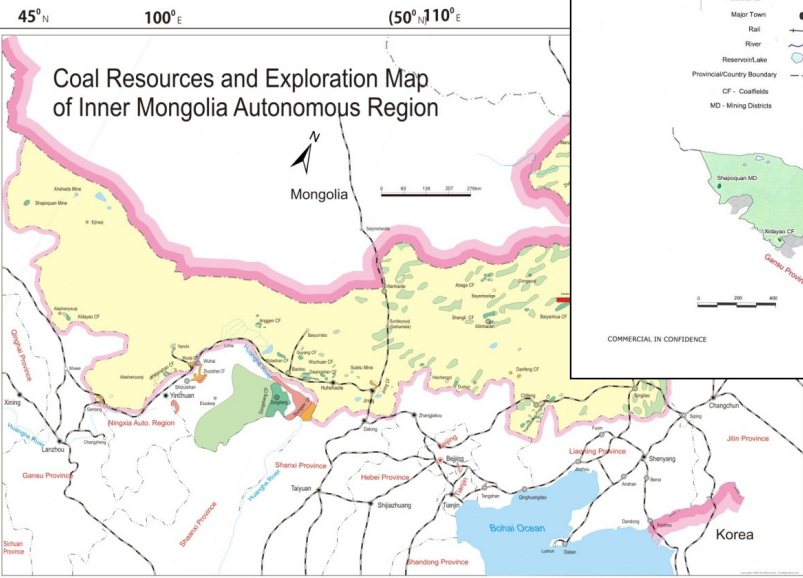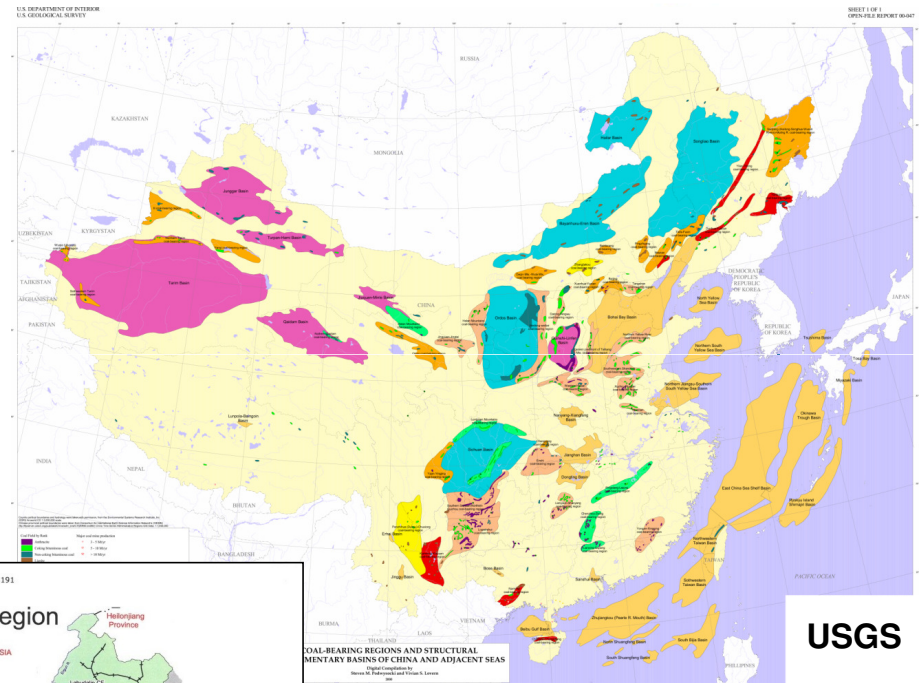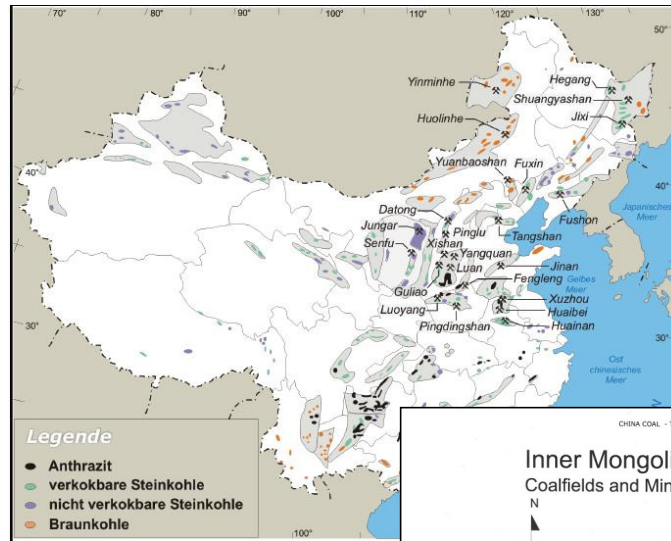– **Application Area**

3775 km

4676 km
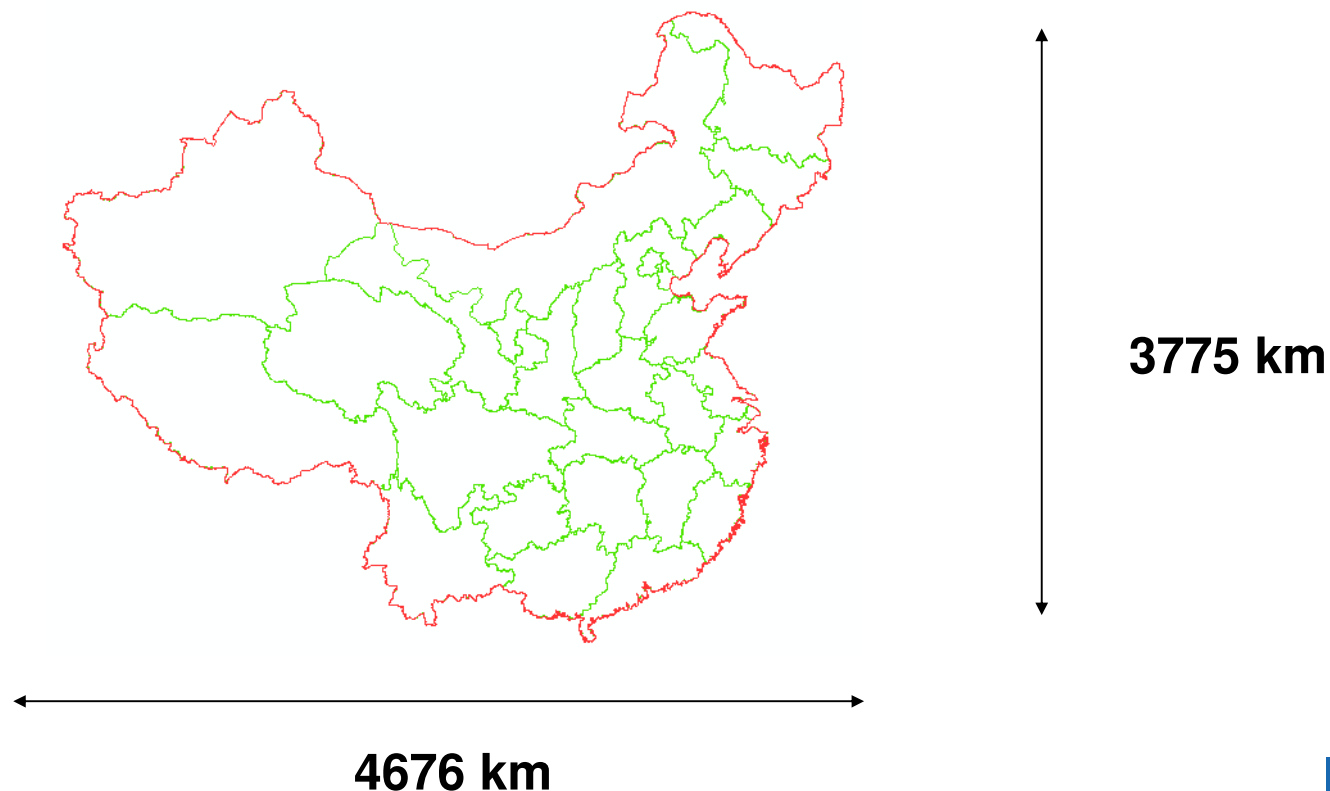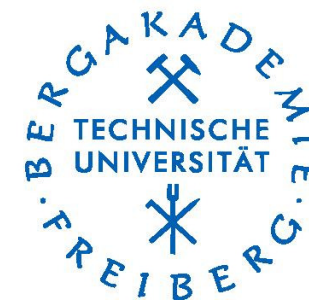
- **Work Flow: Collection of Primary Source Data**

  – **Topography, Hydrography**
  – **Digital Elevation Model**
  – **Landcover, Vegetation Index**
  – **Climate Data (Precipitation, Temperature)**
  – **Population Data**
  – **Satellite Imagery (LANDSAT, MODIS)**
  – **Resource Data**
  – **Coal Field Locations**
  – **Coal Mine Locations**
  – **Geological Map**
  – **Burning Areas / Not Burning Areas**

  – **Knowledge of Significant Influencing Parameter:**
    • **Coal Field Classification**
    • **Parameter List**
    • **Coal Mine Data Sheet**
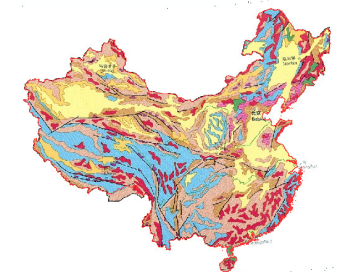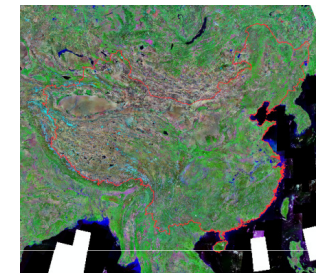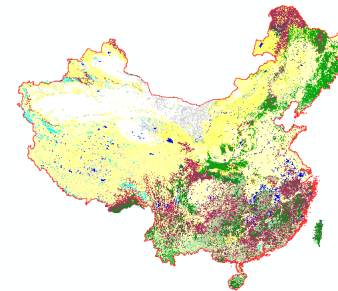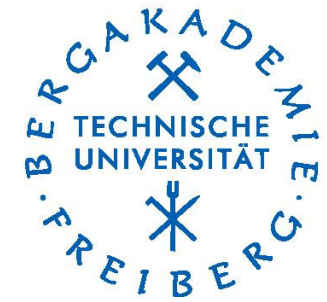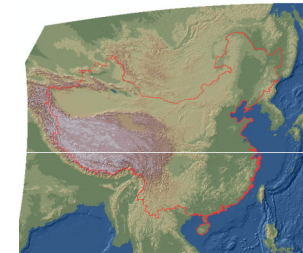
▪ Source Data: Coal Fields of China

BGR

USGS

Barlow Jonker

Barlow Jonker

AAA Minerals
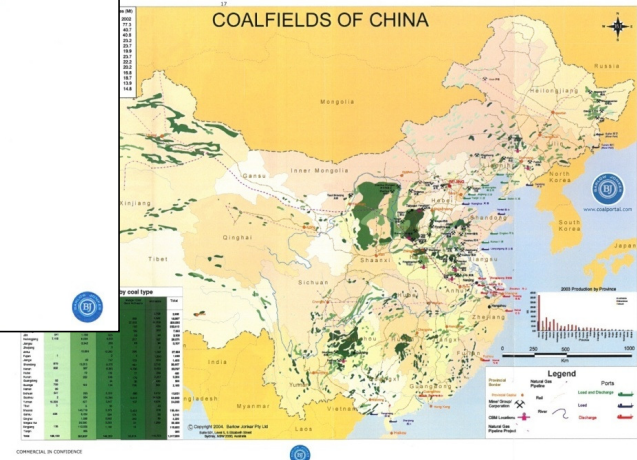
▪ Source Data: Coal Mine Data Sheets (TUBAF)

- **Work Flow: Processing of Source Data**

  – **Scanning / Georeferencing of Coal Field Maps**
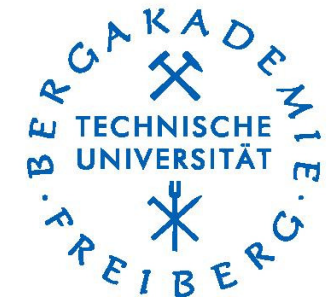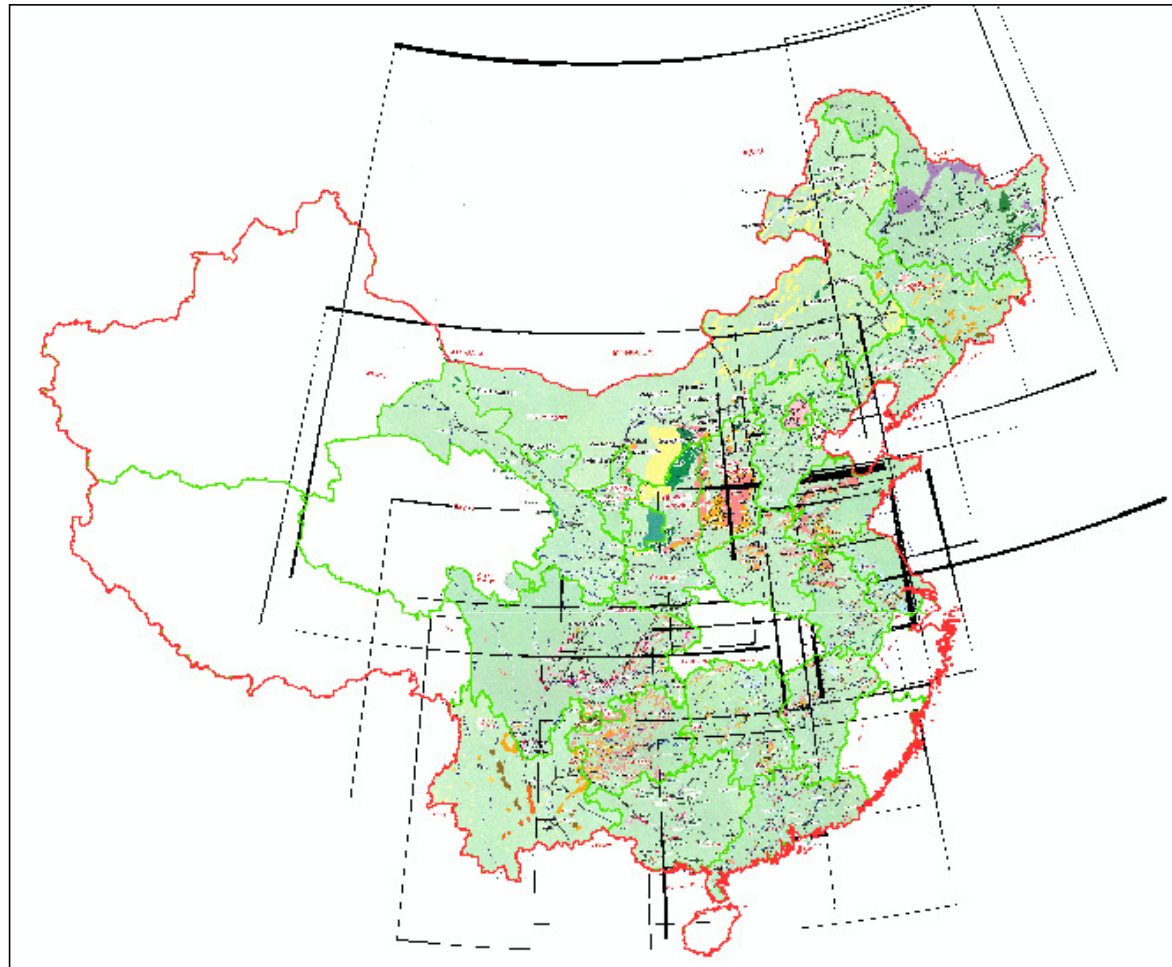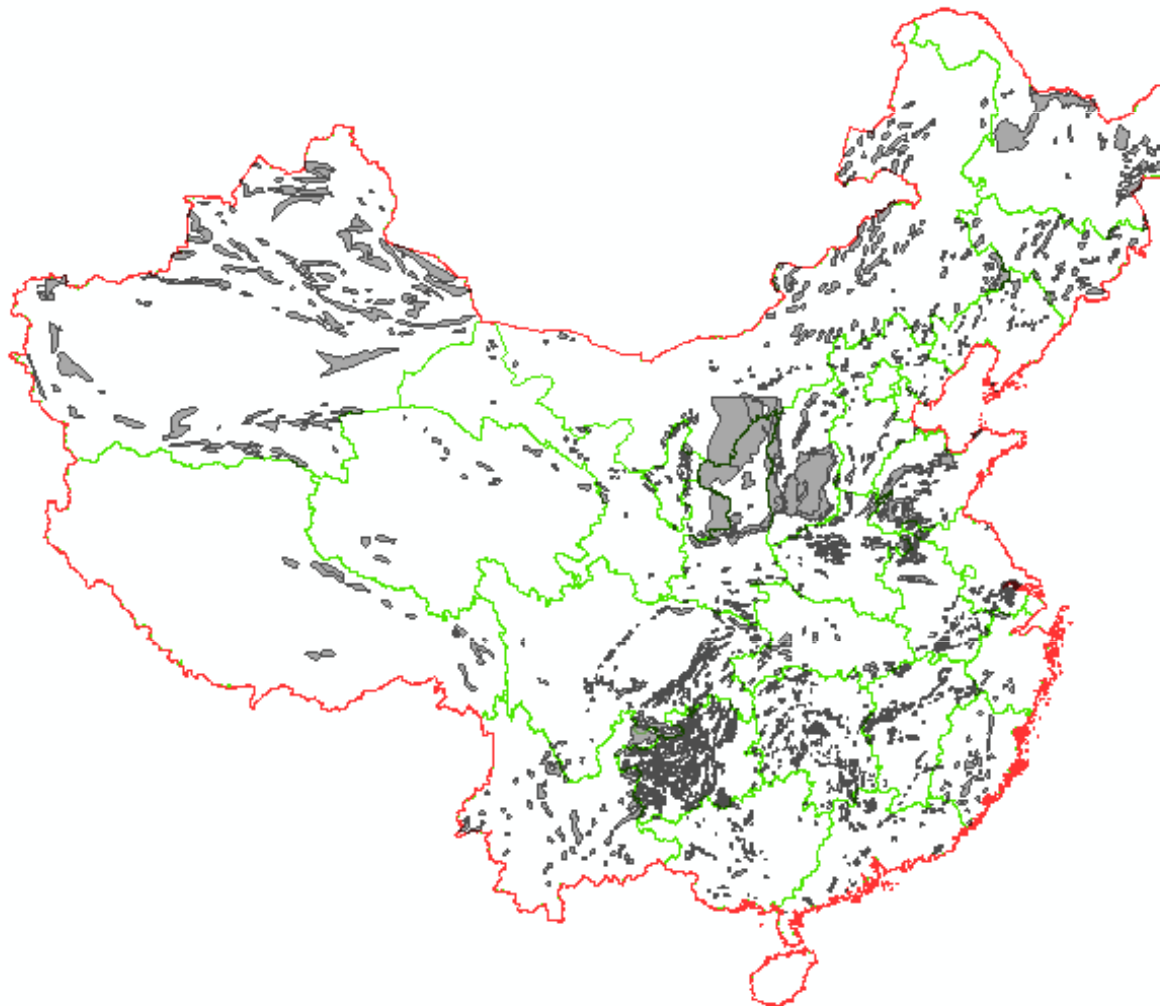

Barlow Jonker

- **<u>Work Flow: Processing of Source Data</u>**

  – **Digitalization of Coal Fields**

2092 object digitized
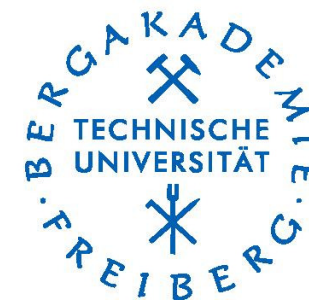
- **<u>Work Flow: Processing of Source Data</u>**

  – **Classification of Coal Fields**

  ➢ **Attributes (country-wide):**
  - **Province**
  - **Stratigraphy / Age**
  - **Coal Rank**
  - **Raw Ash**
  - **Sulphur**
  - **Volatile Matter**

  ➢ **Attributes (only partly):**
  - **Name**
  - **Coal Seam Thickness**
  - **Coal Seam Dip**
  - **CH$_4$ level**
  - **Mining Activity**
  - **Mining Method**
  - **Mine Depth**
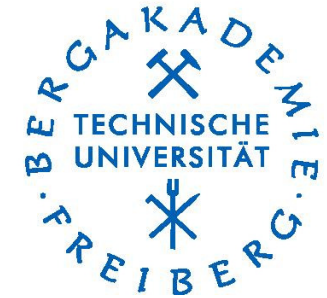
- **Work Flow: Statistical Pre-Processing of Model Input Data**

  – **Model Input Data Raster:**

    - **Location of Coal Fields**
    - **Rank of Coal**
    - **Stratigraphic Age of Coal**
    - **Sulphur Content of Coal**
    - **Ash Content of Coal**
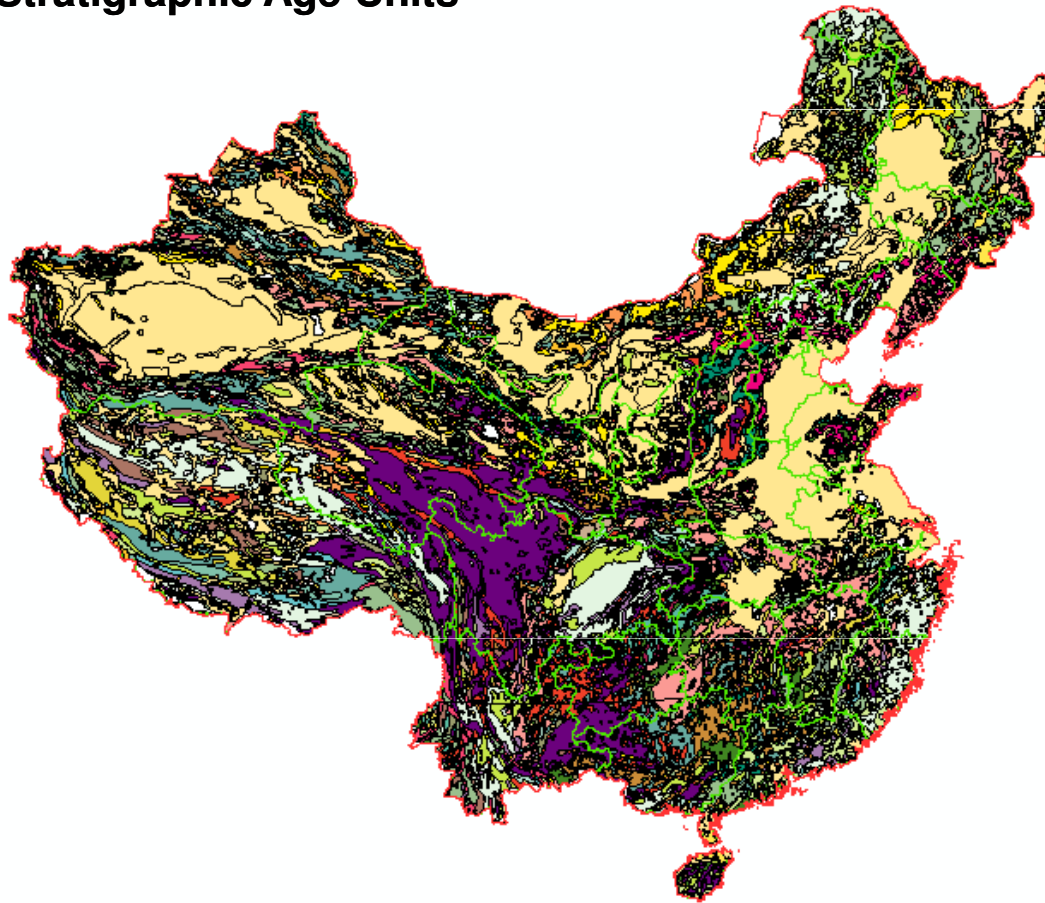   - **Volatile Matter of Coal**

    - **Elevation**
    - **Gradient / Slope**
    - **Euclidian Distance to Hydrographic Features**
    - **Mean Annual Temperature**
    - **Total Annual Rainfall**
    - **Population**
    - **Landcover / Vegetation Classes**
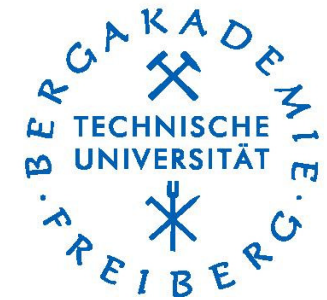   - **Stratigraphic Main Units from Geological Map**
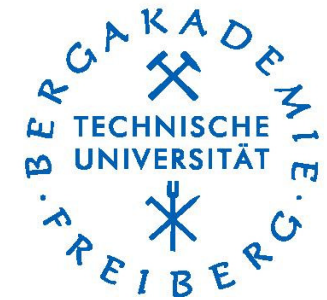
Model Input Data: Geological Map of China (USGS)

Stratigraphic Age Units
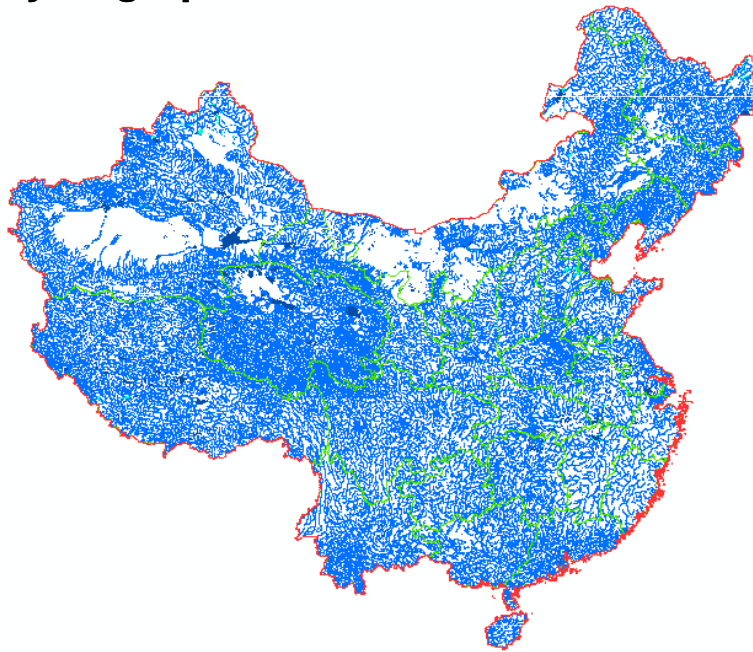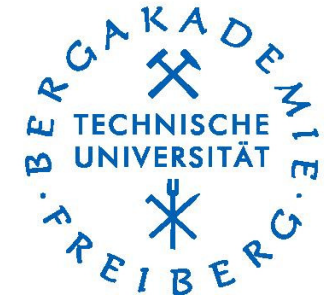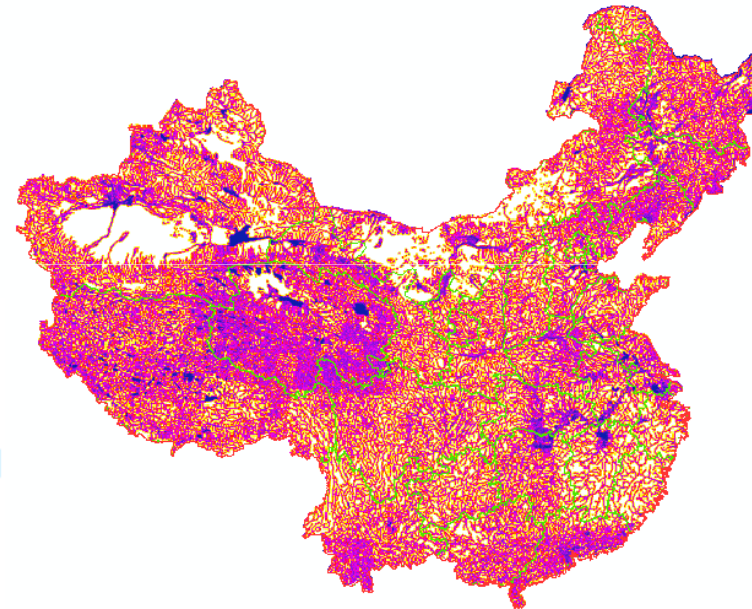
■ Model Input Data: Hydrography (USGS)

Hydrographic Features

Euclidian Distance to Hydrographic Features, Maximum: 5km

Distance [m]
High : 5000
Low : 0

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- **Model Input Data: DEM (USGS)**

Elevation

Elevation [m]
High : 8713
Low : -59

Slope / Gradient
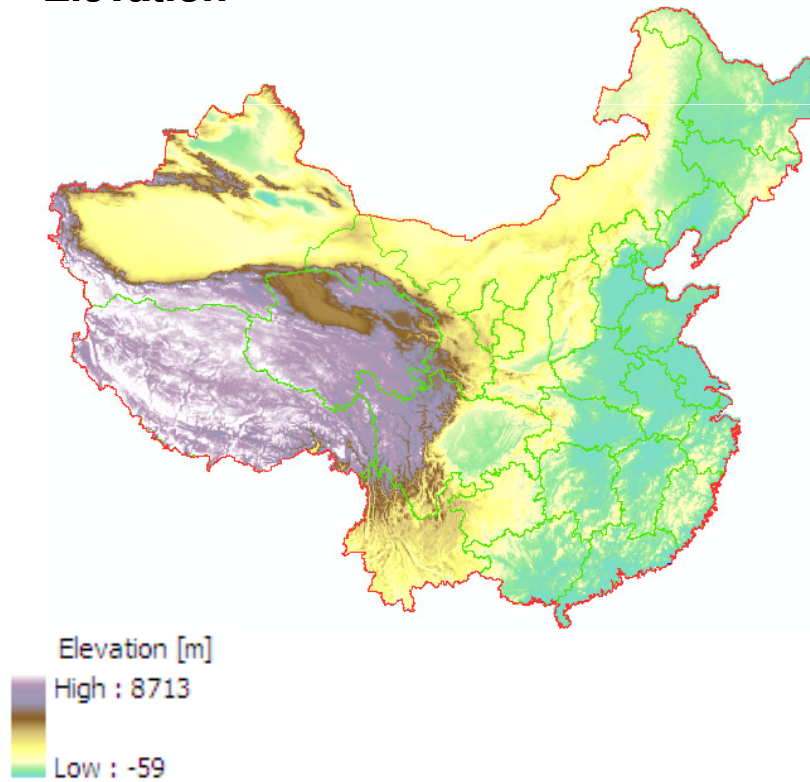
Slope / Gradient [°]
High : 52,1778
Low : 0
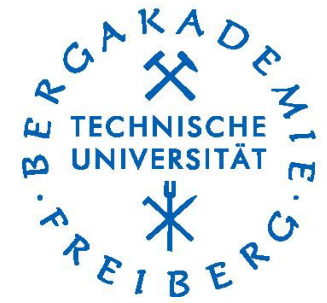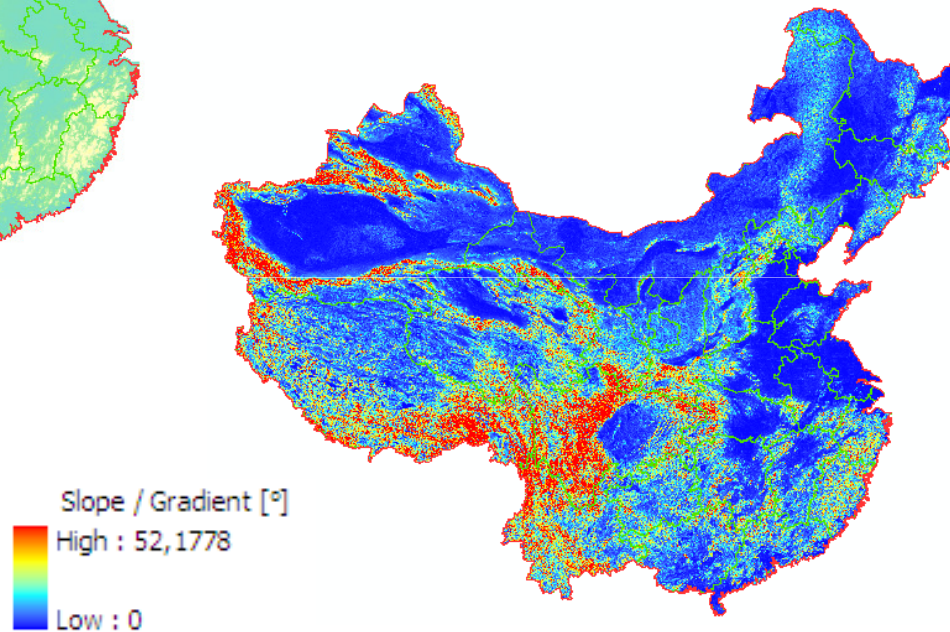
■ Model Input Data: Landcover / Vegetation Index (GLCF)

Vegetation Classes
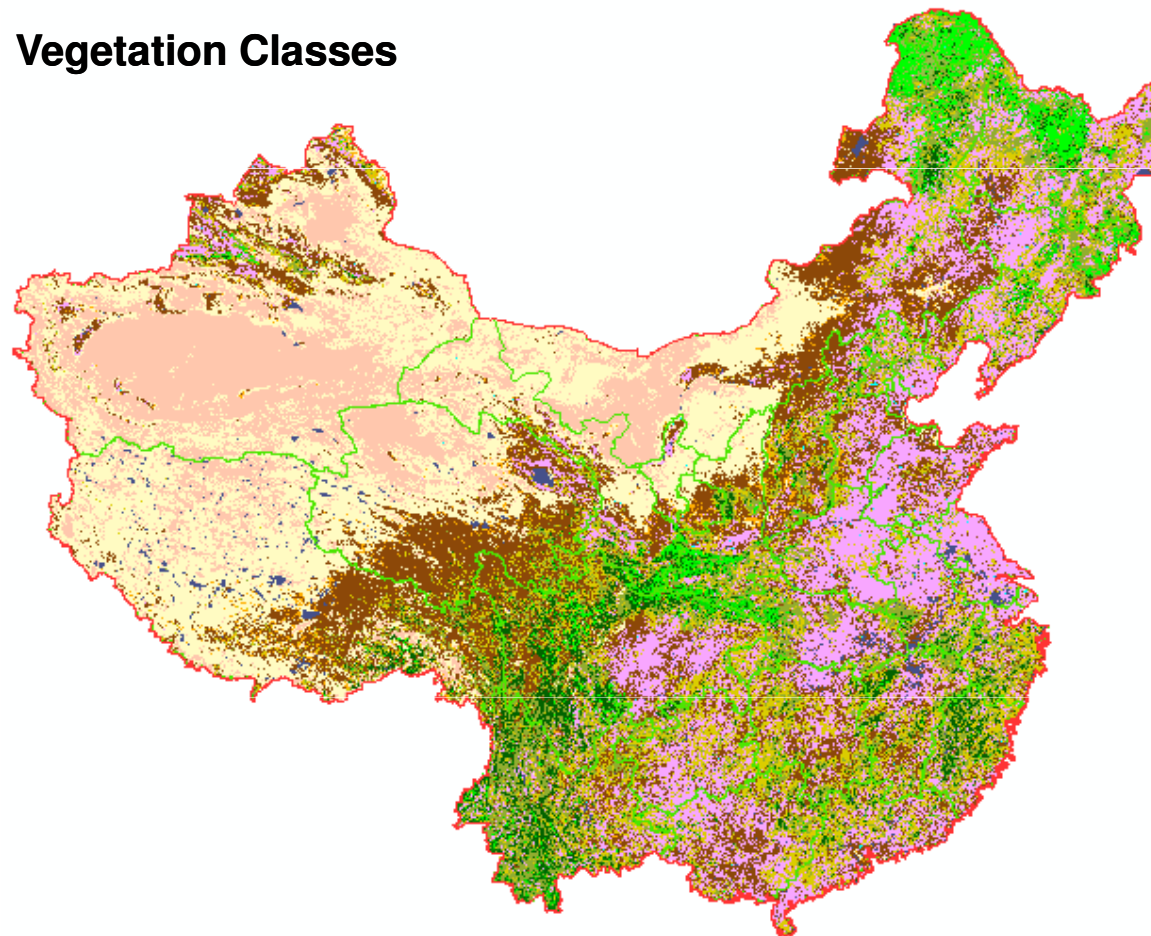
Landcover
- Water
- Evergreen Needleleaf Forest
- Evergreen Broadleaf Forest
- Deciduous Needleleaf Forest
- Deciduous Broadleaf Forest
- Mixed Forest
- Woodland
- Wooded Grassland
- Closed Shrubland
- Open Shrubland
- Grassland
- Cropland
- Bare Ground
- Data Unavailable
- Urban and Built

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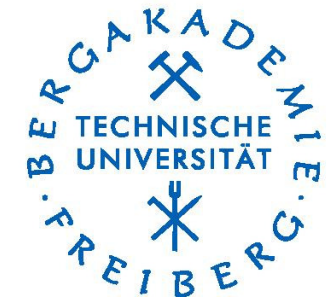
- **<u>Model Input Data: Mean Annual Temperature (WORLDCLIM)</u>**

Temperature

Temperature [°K]
High : 250
Low : -223
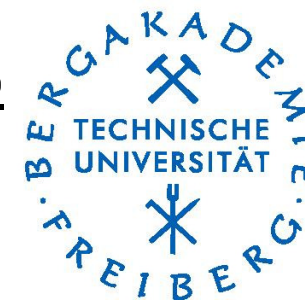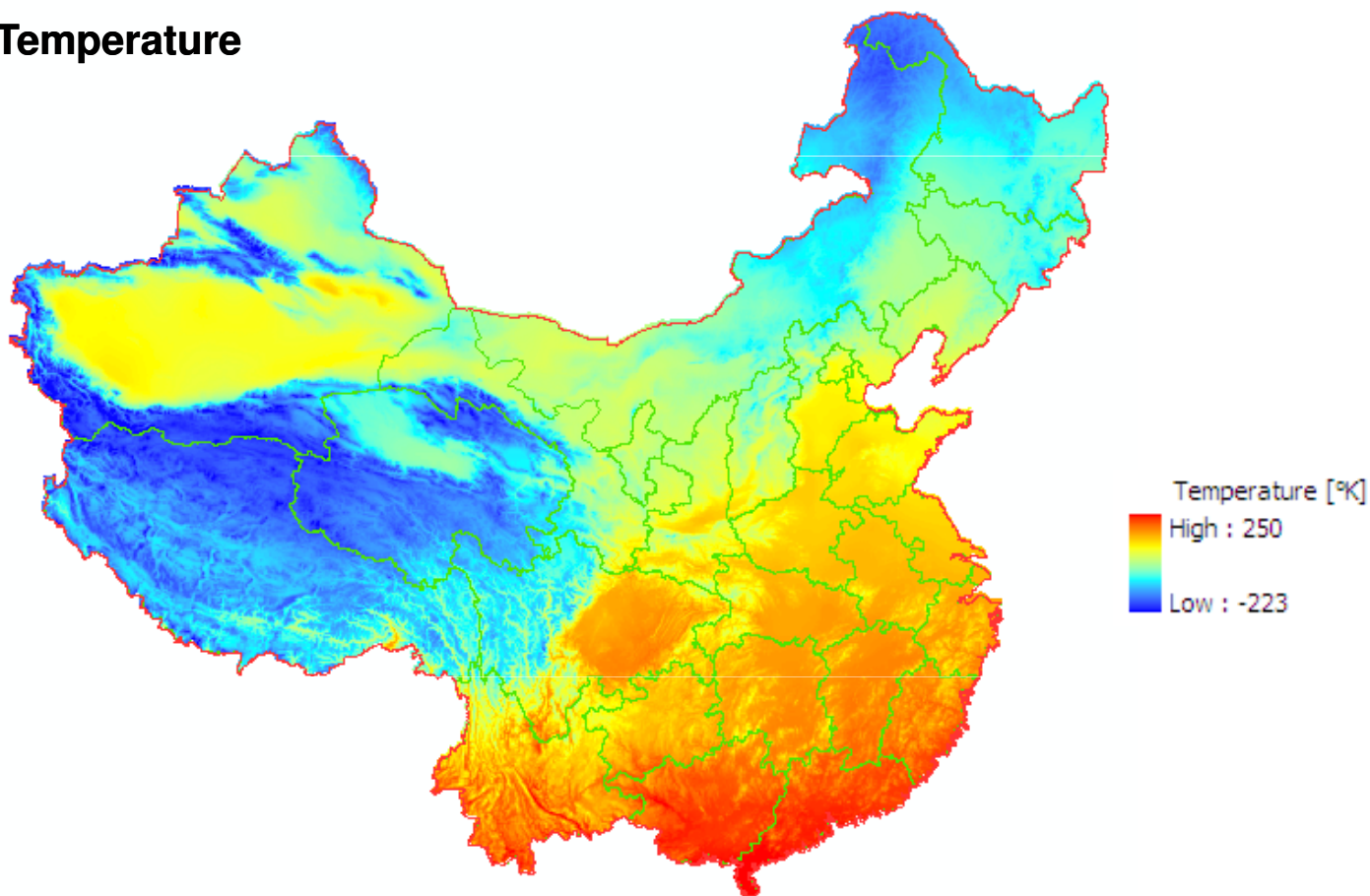
- **Model Input Data: Total Annual Rainfall (WORLDCLIM)**

Rainfall

Rainfall [mm]
High : 2723
Low : 12
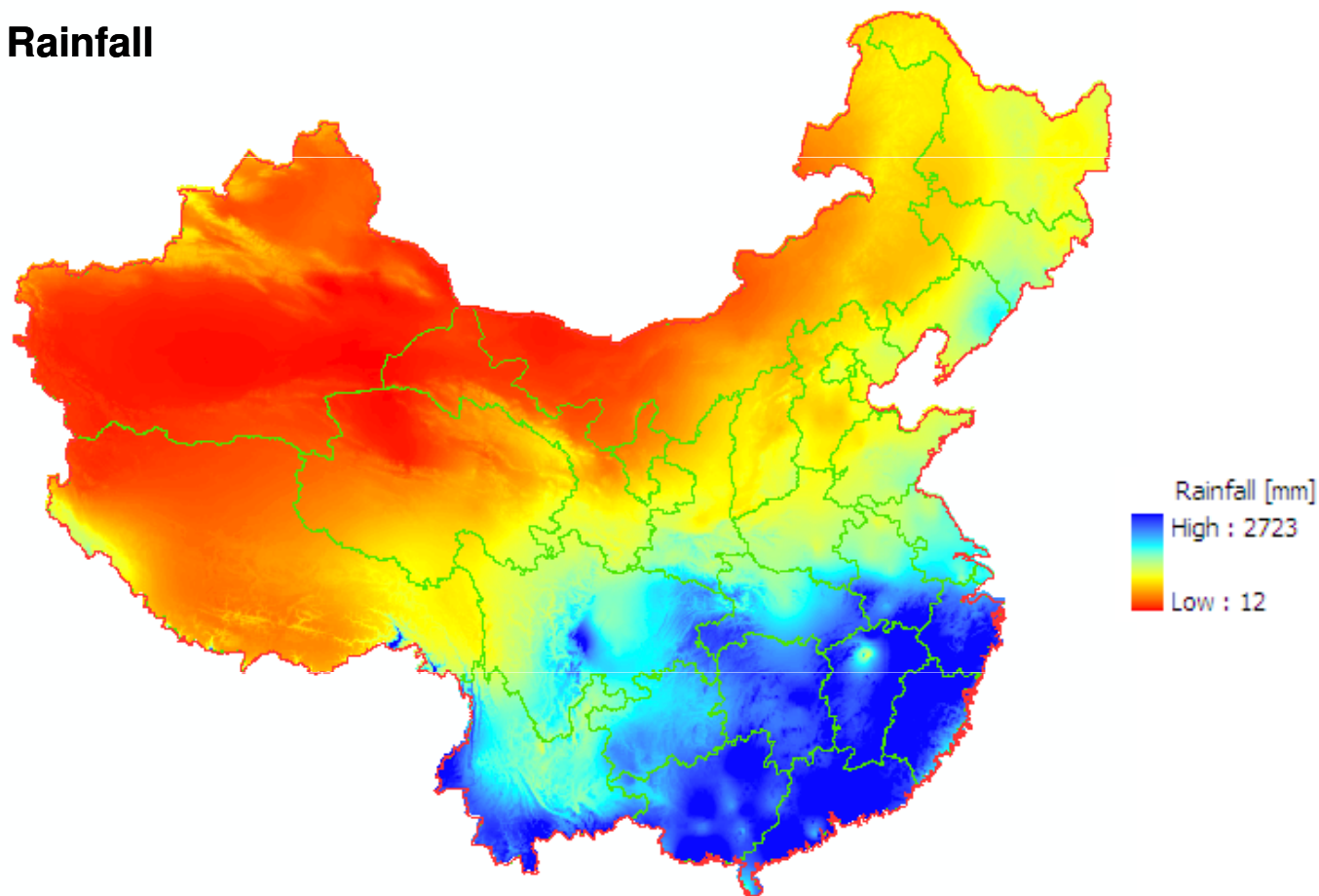
▪ **<u>Model Input Data: Population (USGS)</u>**

Population

Population [/km²]
High : 130745
Low : 0
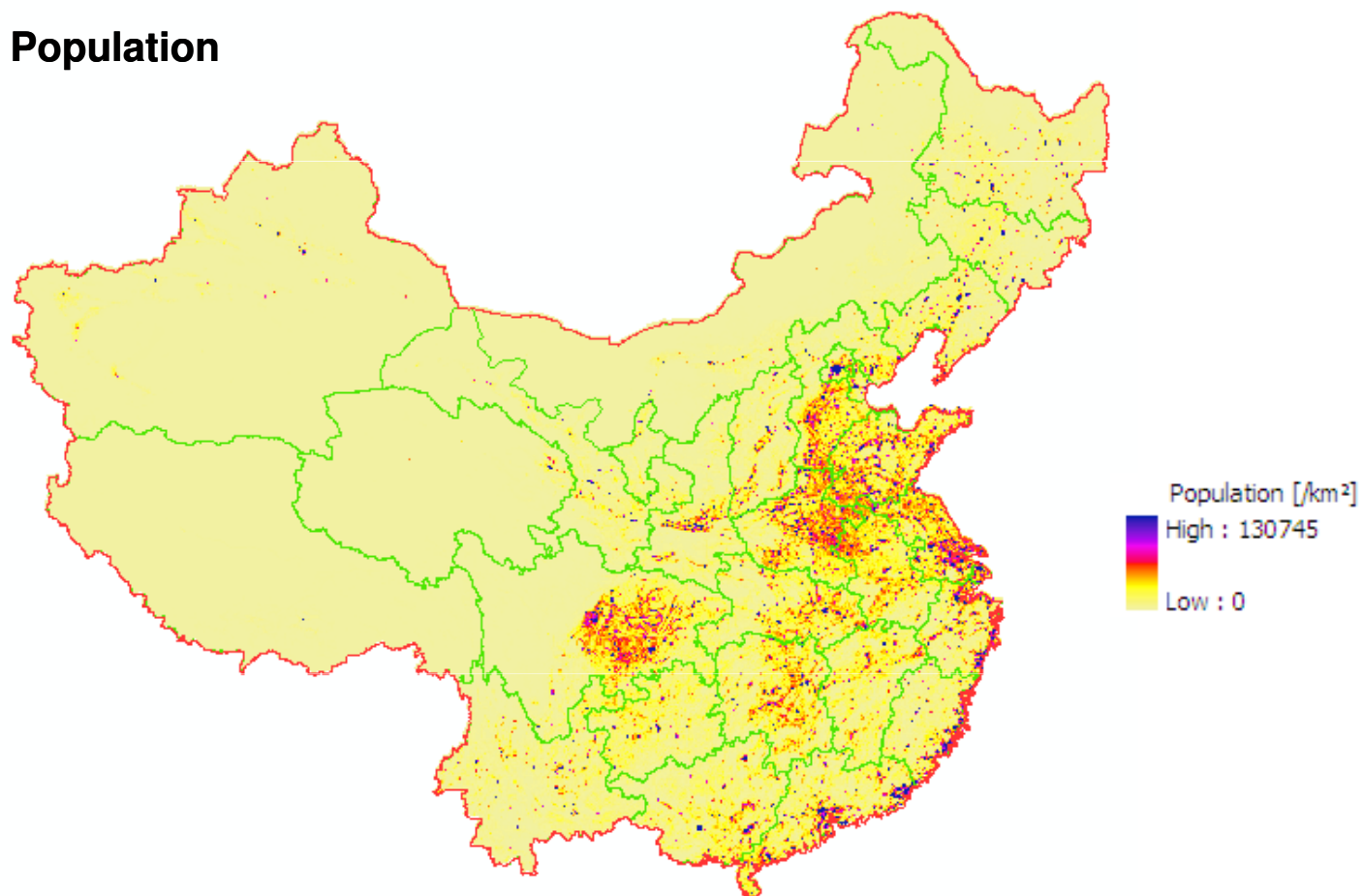
▪ **<u>Work Flow: Modeling of Training Scenarios</u>**

– **Training Data:**

➢ **Data about known locations of coal field and coal mine fires from field observations**
➢ **Knowledge of areas with tendency to spontaneous combustion**

Coalfield Fire Distribution in Xinjiang
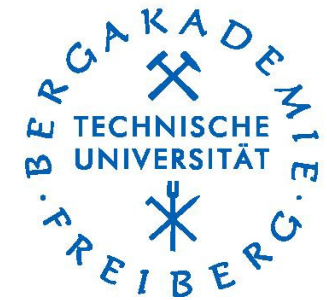
- **Work Flow: Modeling of Training Scenarios**

  – **Training Data:**
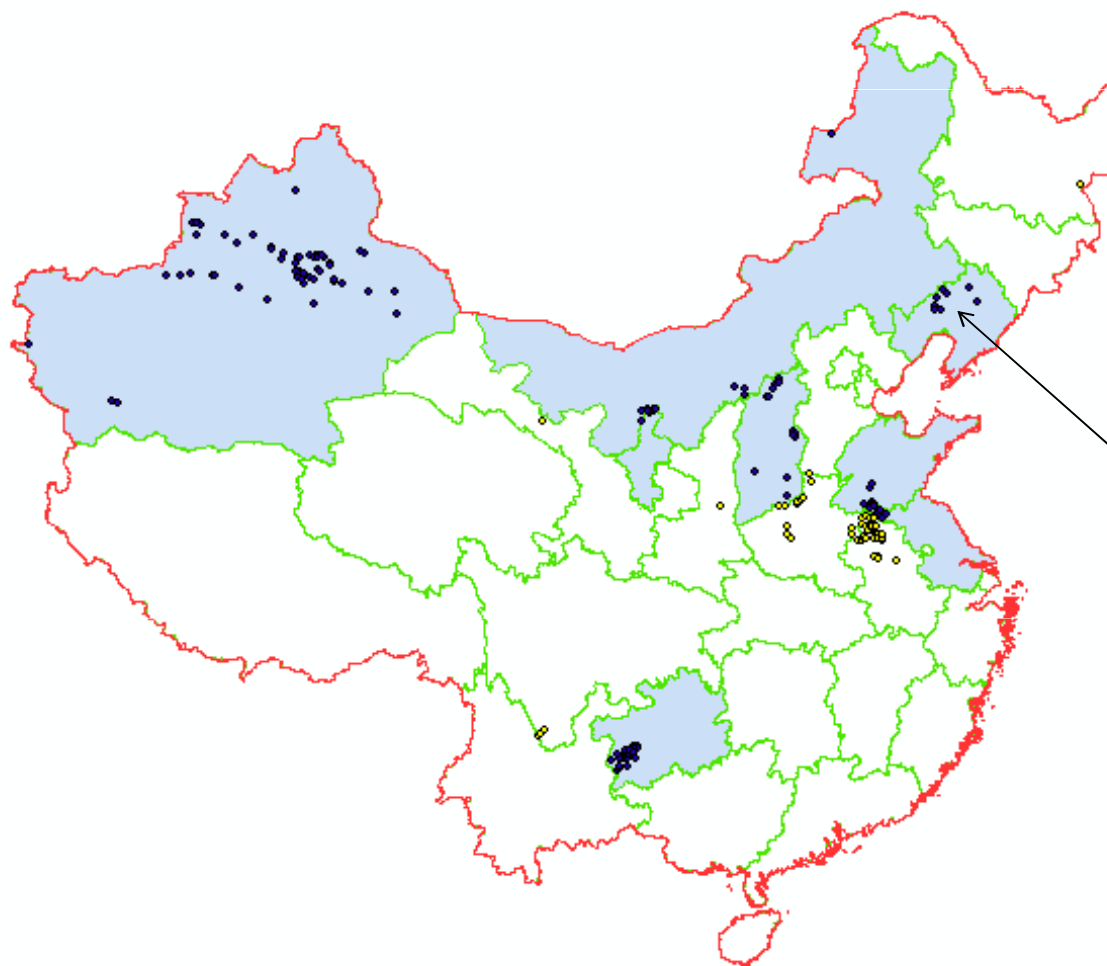
Training Points
132 Locations in
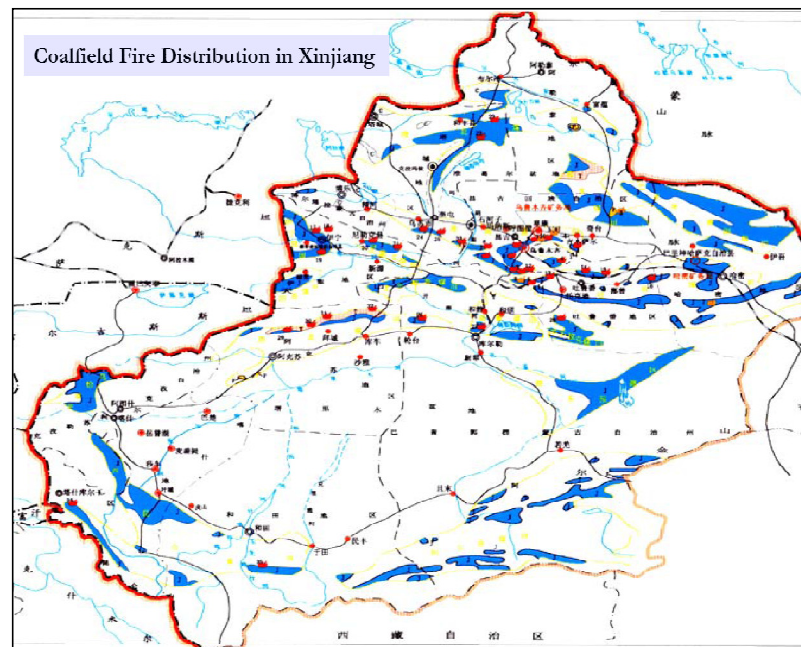8 Selected Provinces

■ **Results**

– **China Map: Coal Field Classification –
Coal Rank**

Legend

☐ Administrative Boundary

Coalfields (Rank)

🟨 Lignite / Brown Coal and Sub-bituminous Coal

🟧 Flame and Gas Coal

🟥 Fat, Coking and Lean Coal

🟪 Meagre Coal / Semi Anthracite

🟦 Anthracite

▪ **<u>Results</u>**

– **China Map: Coal Field Classification –
Stratigraphic Age**

Legend

☐ Administrative Boundary

Coalfields (Age)
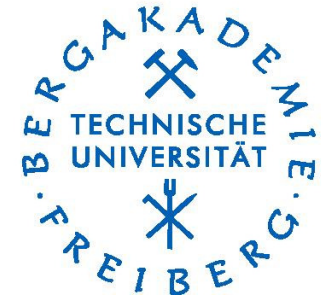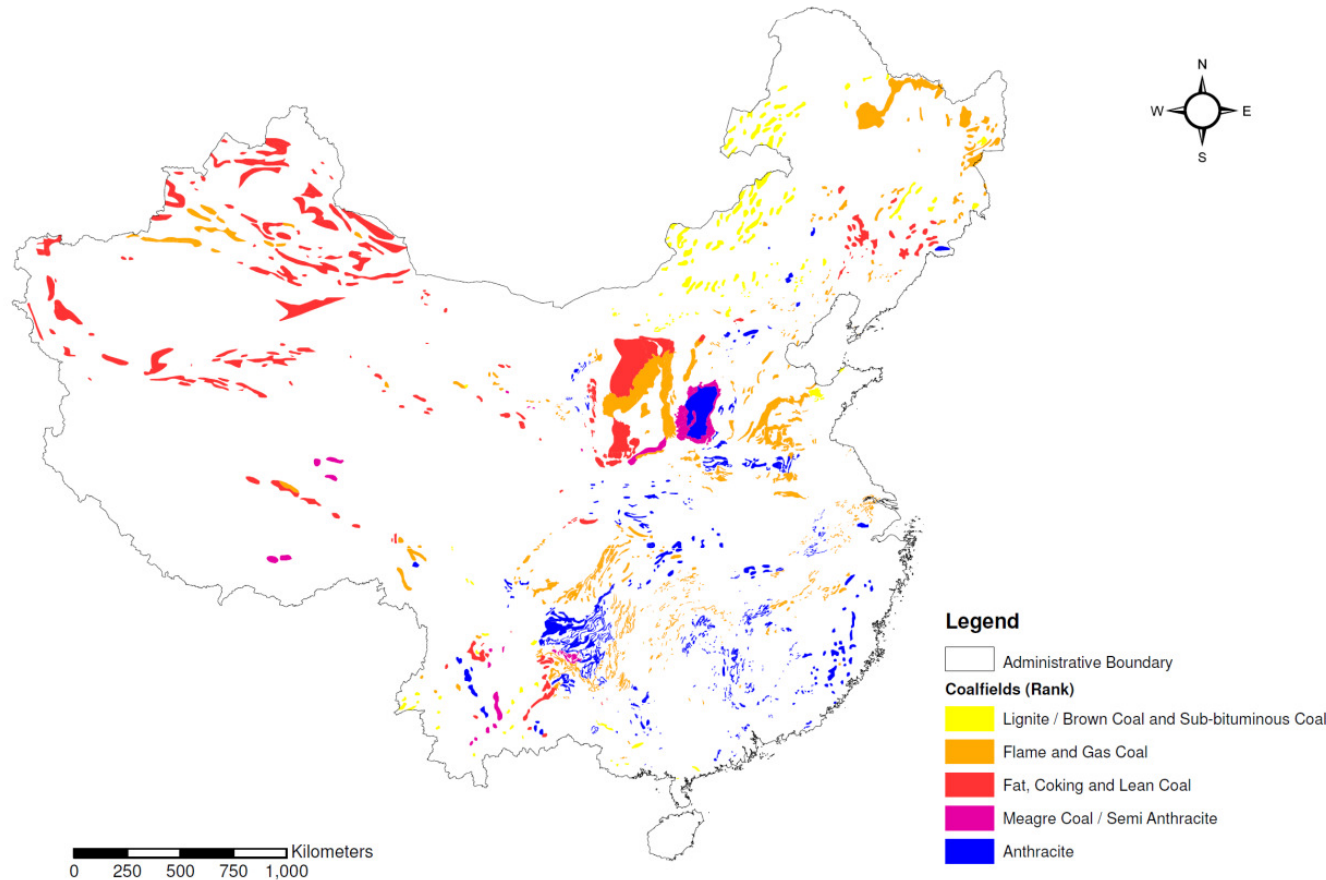
- Tertiary Coalfield
- Tertiary Coal Prospect
- Jurassic Coalfield
- Jurassic Coal Prospect
- Triassic Coalfield
- Triassic Coal Prospect
- Permian Coalfield
- Permian Coal Prospect
- Carboniferous Coalfield
- Carboniferous Coal Prospect
- Cambrian Coalfield
- Cambrian Coal Prospect
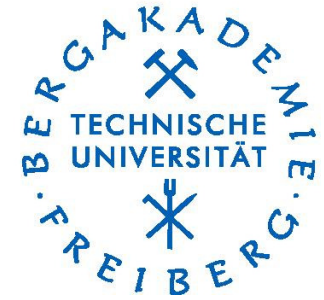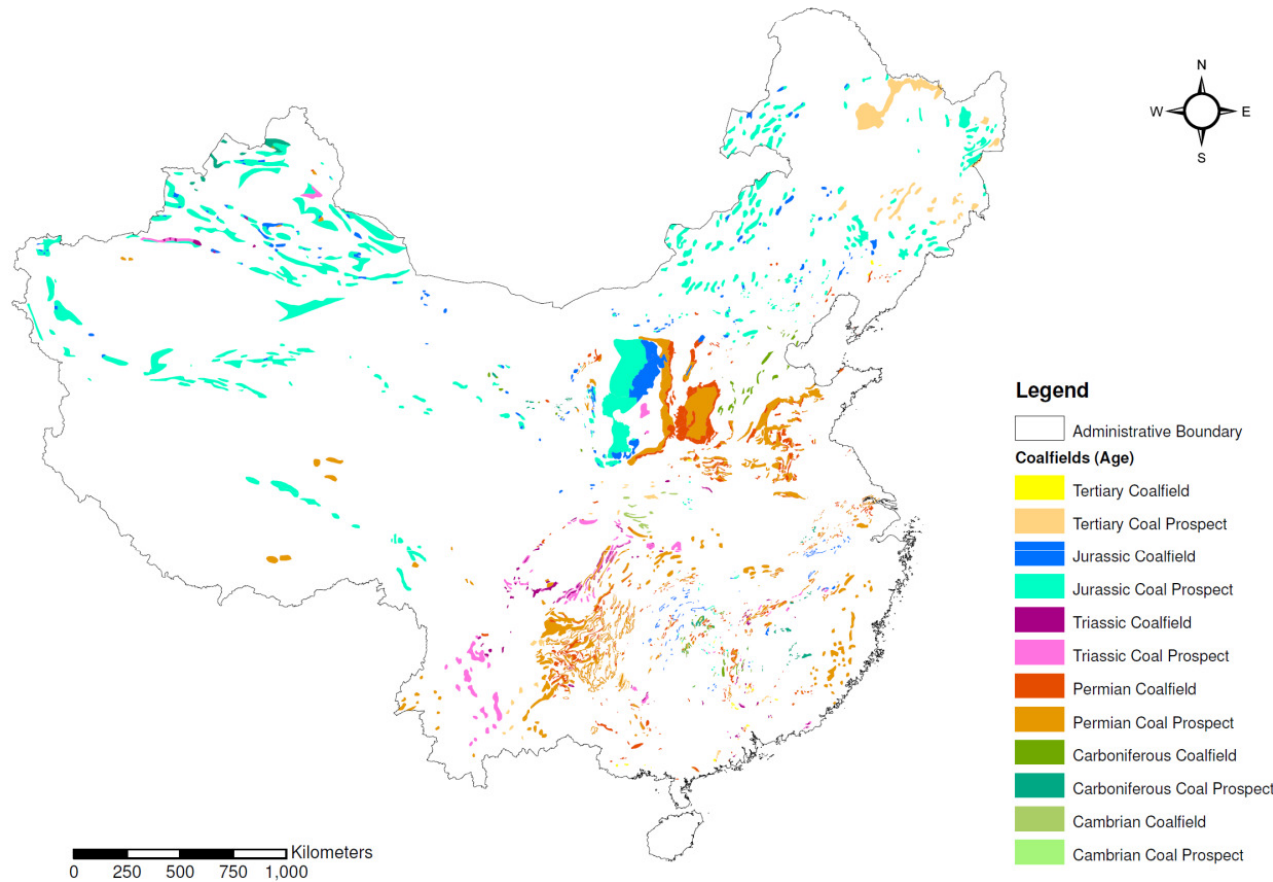
- **Preliminary Results**

  – **China Map: Coal Fire Probability**

Coal Fire
Probability

- ☐ 0 - 0,55
- ☐ 0,55 - 0,6
- ☐ 0,6 - 0,65
- ☐ 0,65 - 0,7
- ☐ 0,7 - 0,75
- ☐ 0,75 - 0,8
- ☐ 0,8 - 0,85
- ☐ 0,85 - 0,9
- ☐ 0,9 - 0,95
- ☐ 0,95 - 1
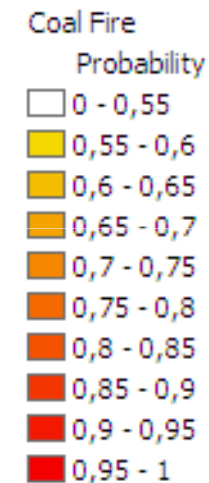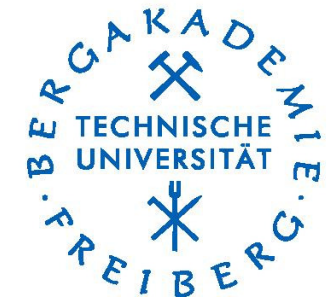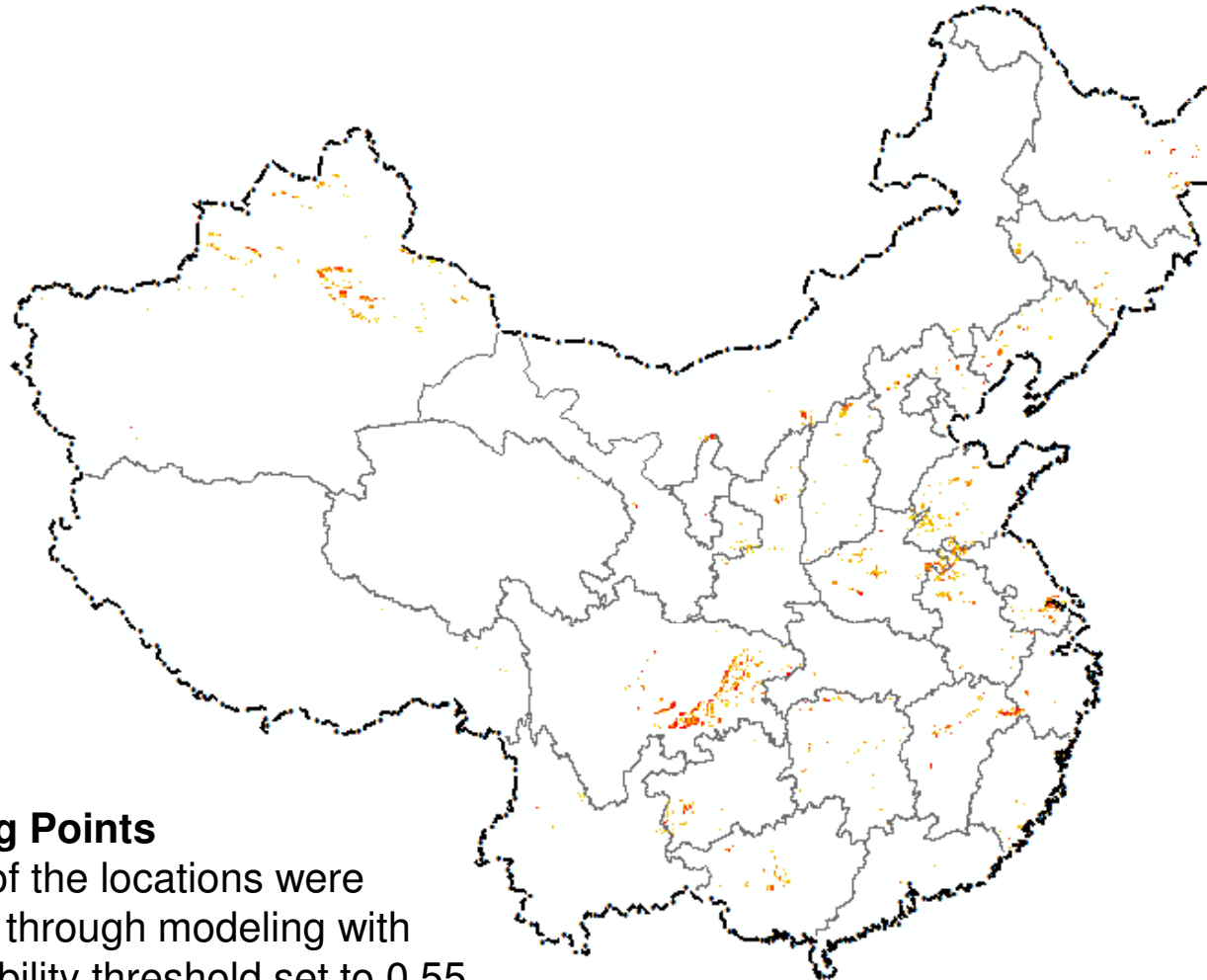
Training Points
96% of the locations were found through modeling with probability threshold set to 0,55

Preliminary Results

– **Detail Map: Northern Xinjiang Province**
  Coal Fire Probability

- **<u>Problems / Data Required</u>**

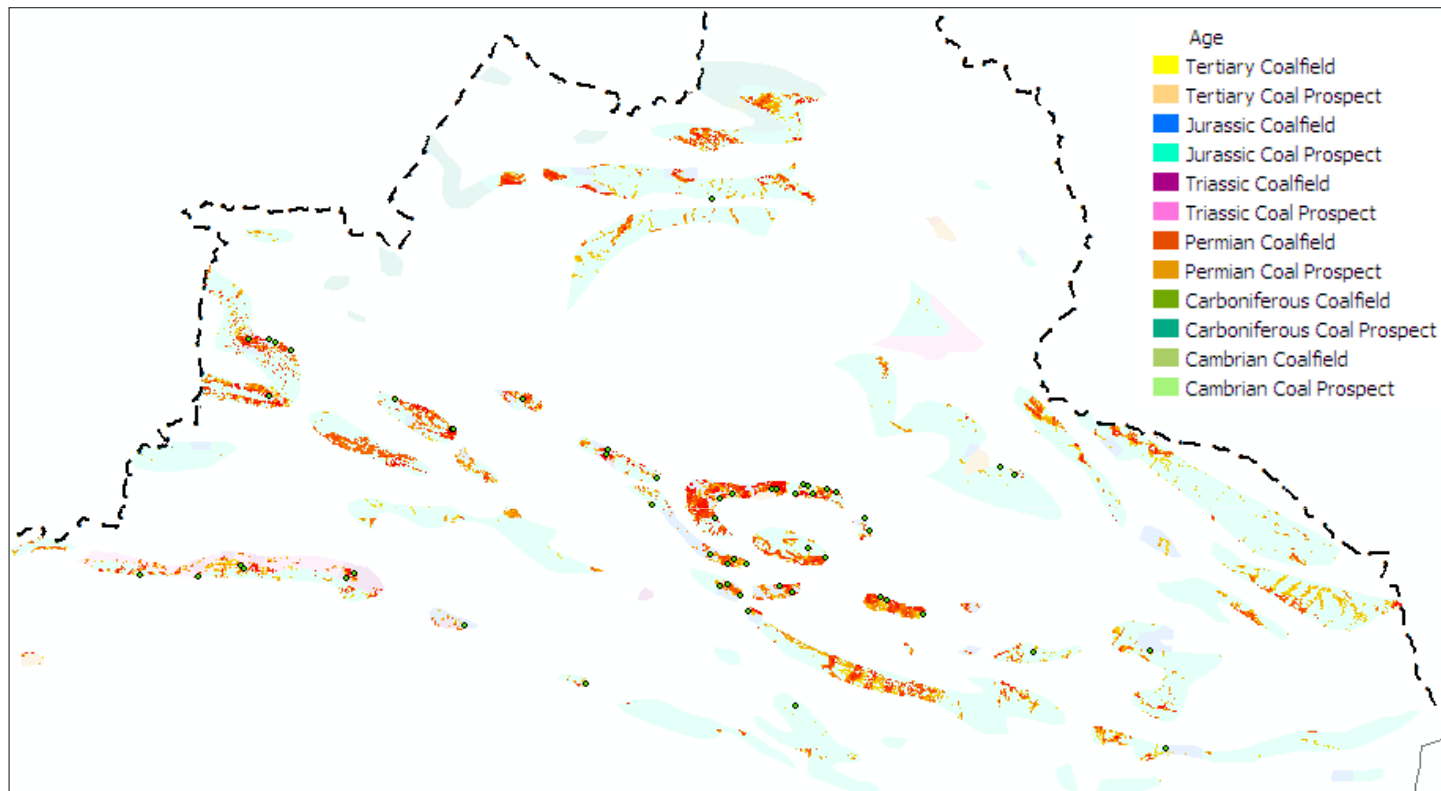 - **Data from different data sources not matching, especially coal fields and geological maps**
  - **Training data not accurate and detailed enough**
  - **Required country-wide vector data:**
    - ➤ **Coal fields / mines**
    - ➤ **Rock lithology**
    - ➤ **Coal fires**
    - ➤ **Tectonic elements**
  - **Processing of country-wide soil moisture / vegetation coverage raster data from MODIS**
  - **Import of geophysical data from CHAMP**
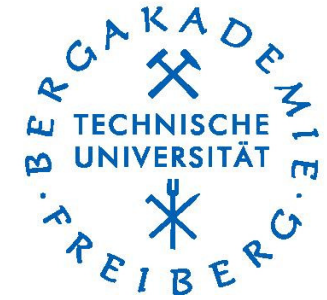
▪ **Conclusion / Outlook**

– **Sensitivity analysis in order to analyze influence of each used parameter (layer) and in order to exclude non-significant information layers**
– **ANN with MLP approach using advangeo® successfully applied**
– **More detailed, proven training data (known coal fire locations) required from e.g. coal fire cadastre**