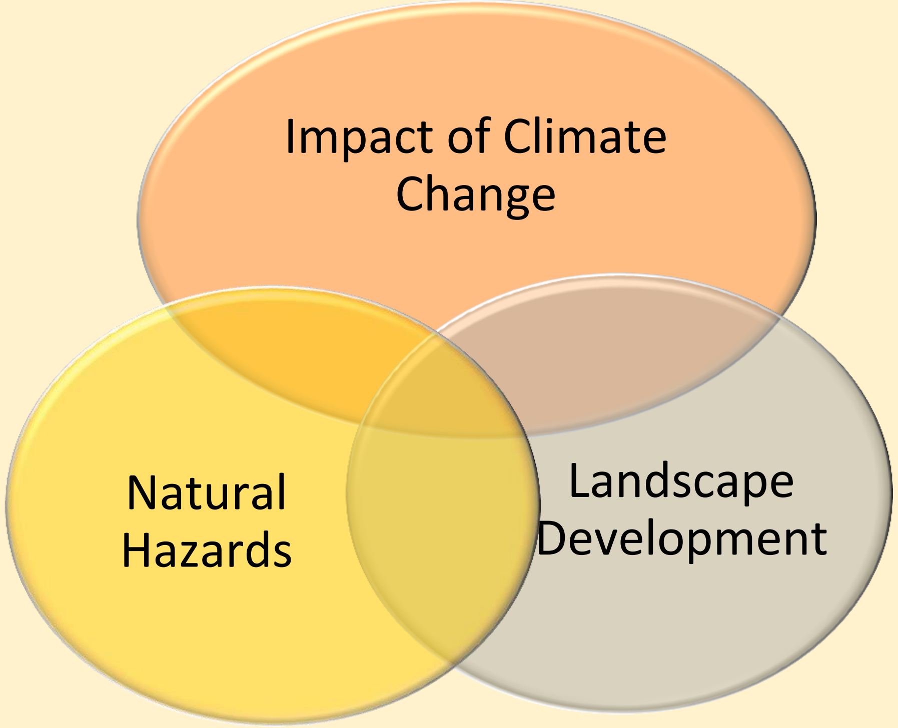
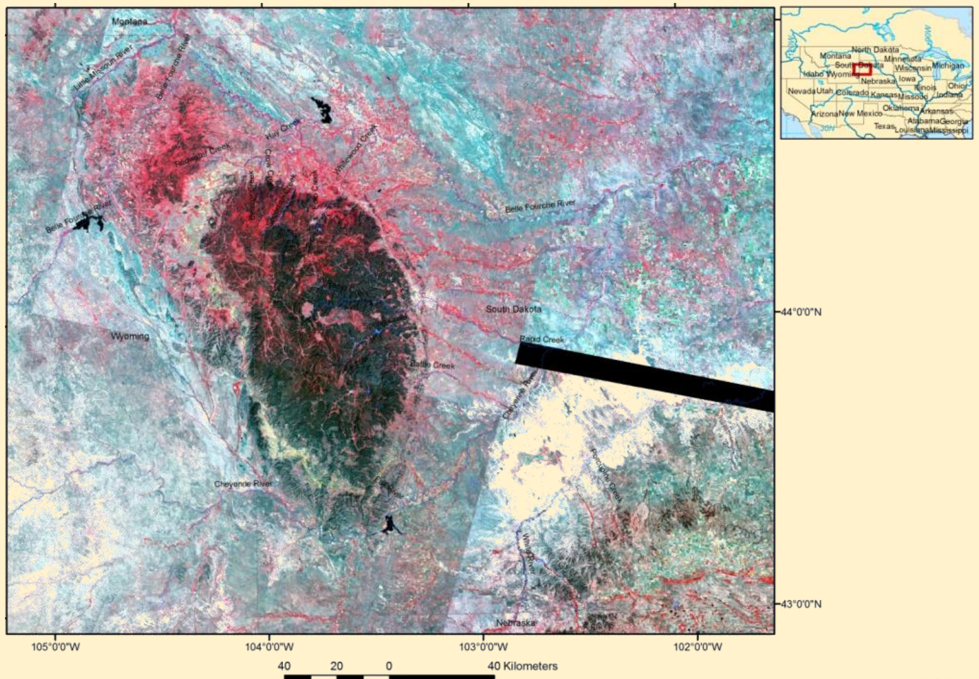
United Nations - Austria Symposium on Integrated Space
Technology Applications for Climate Change
Graz, Austria, 12-14 September 2016

Impact of Climate Change on Natural Hazard Intensity and on Landscape Development in the Black Hills and Adjacent Areas, South Dakota, Montana and Wyoming, USA, using Remote Sensing and GIS-Methods





Mosaic_RGB321

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Digital Image Processing of Satellite Data

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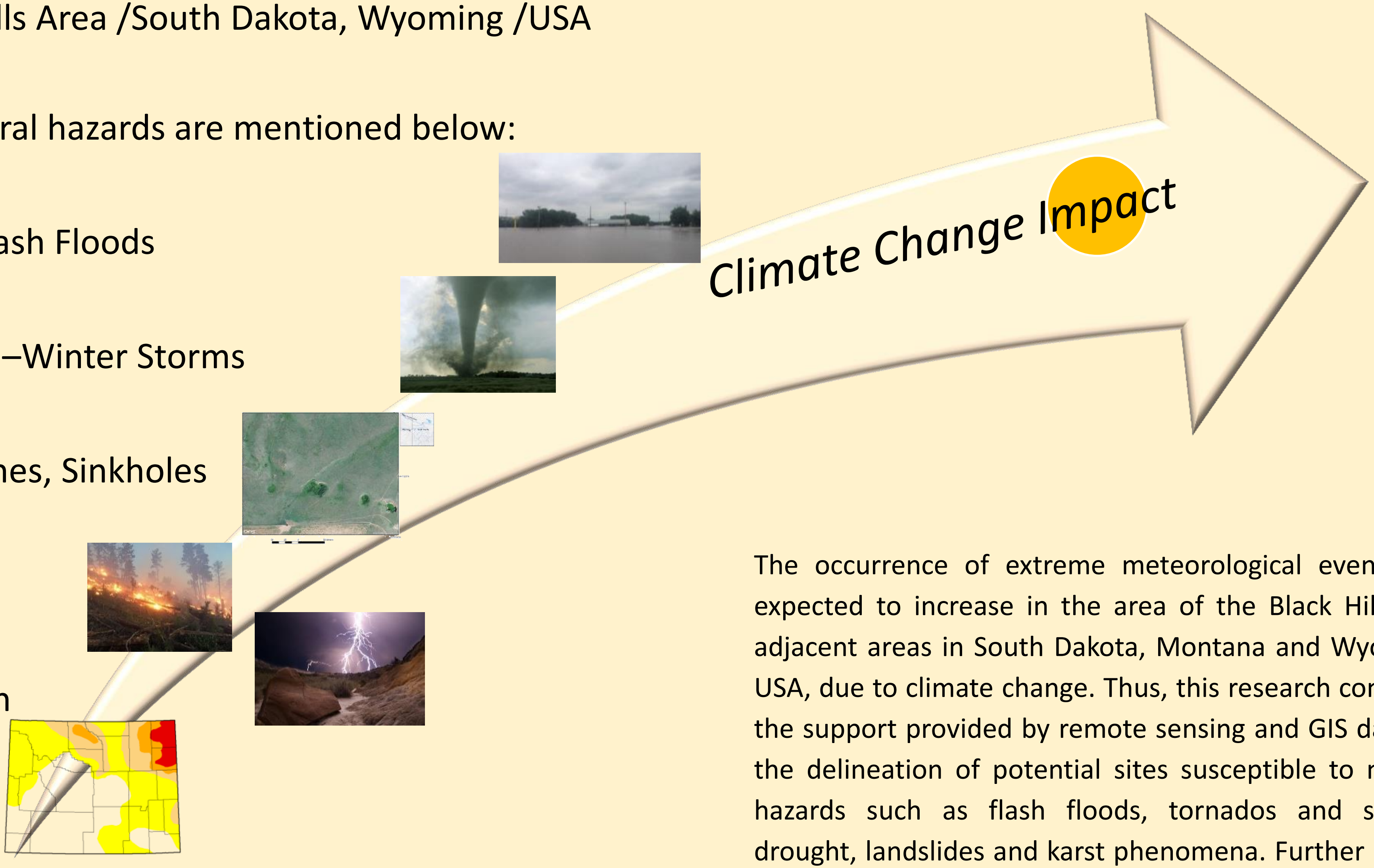
1. INTRODUCTION

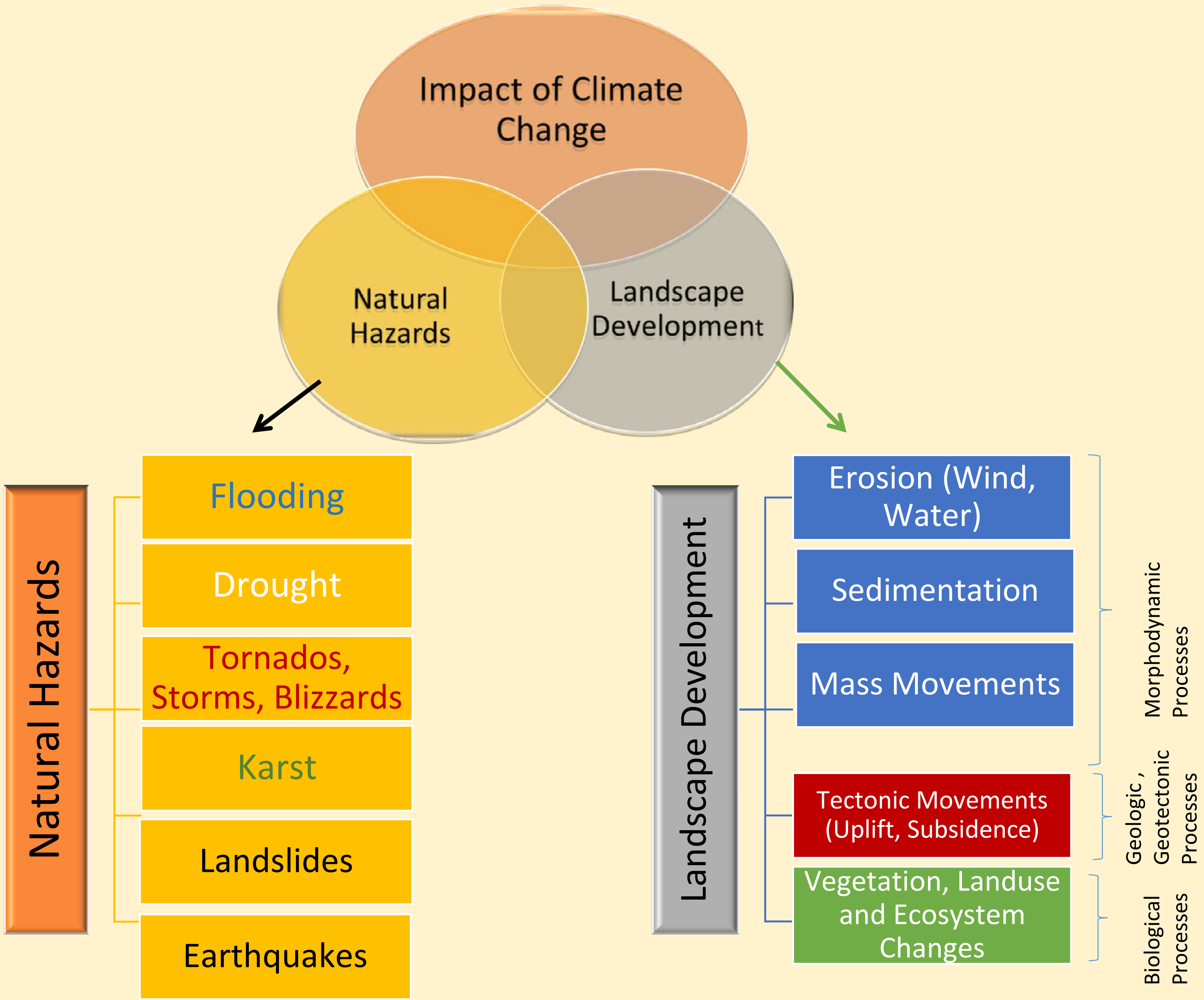
Remote Sensing and GIS Contribution to the Detection of Areas Susceptible to Natural Hazards in the Black Hills Area /South Dakota, Wyoming /USA

The main natural hazards are mentioned below:

- Floods / Flash Floods
- Tornadoes –Winter Storms
- Karst, Dolines, Sinkholes
- Wildfires
- Soil Erosion
- Drought
- Earthquakes



The occurrence of extreme meteorological events are expected to increase in the area of the Black Hills and adjacent areas in South Dakota, Montana and Wyoming, USA, due to climate change. Thus, this research considers the support provided by remote sensing and GIS data for the delineation of potential sites susceptible to natural hazards such as flash floods, tornados and storms, drought, landslides and karst phenomena. Further on the impact of climate change on landscape development is a focus of the research.

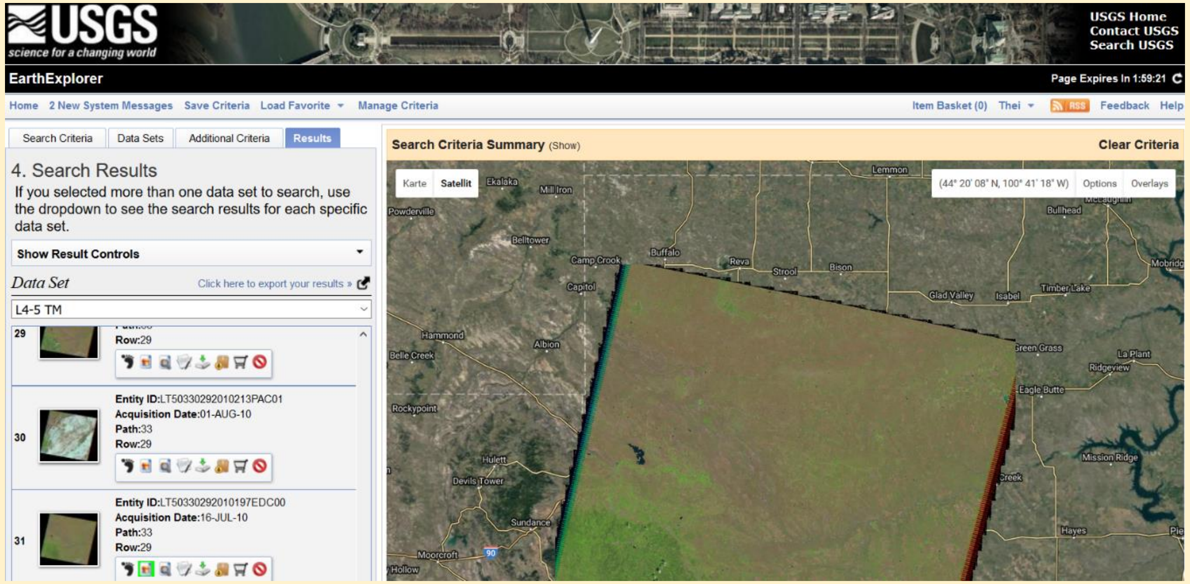


Impact of Climate Change
Natural Hazards
Landscape Development
Natural Hazards
Flooding
Drought
Tornados, Storms, Blizzards
Karst
Landslides
Earthquakes
Landscape Development
Erosion (Wind, Water)
Sedimentation
Mass Movements
Tectonic Movements (Uplift, Subsidence)
Vegetation, Landuse and Ecosystem Changes
Morphodynamic Processes
Geologic, Geotectonic Processes
Biological Processes

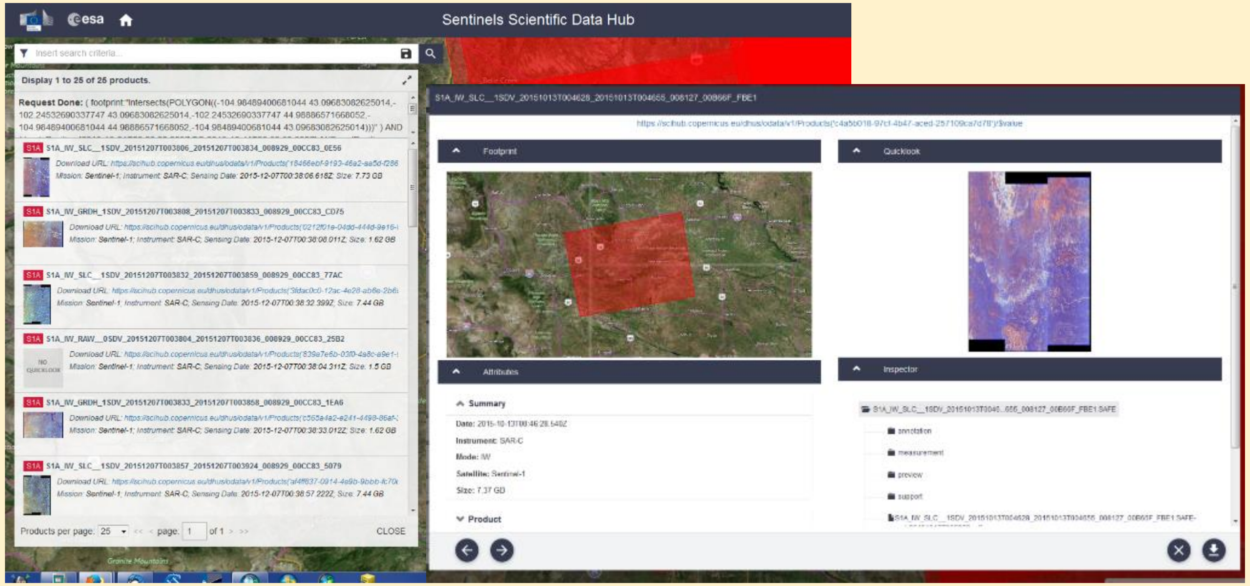
2. MATERIALS AND METHODS

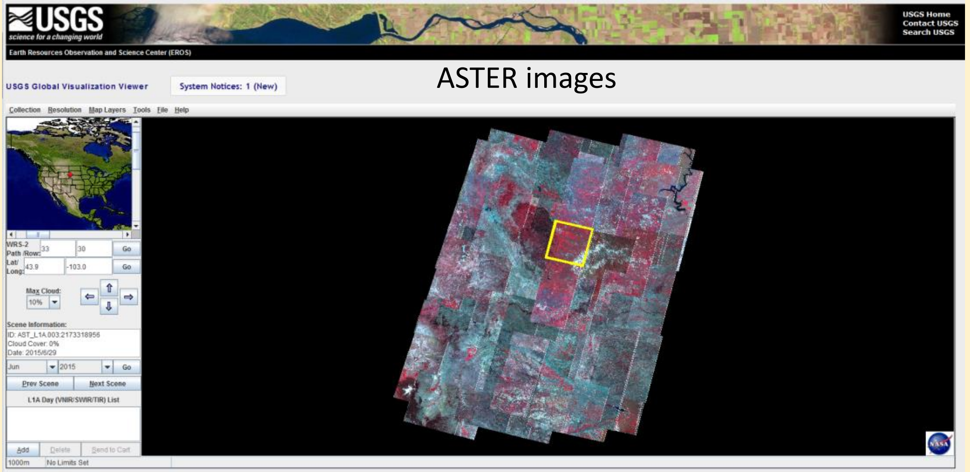
Open Source Satellite Images (Landsat, ASTER, Sentinel) and Digital Elevation Data (DEM) Data (SRTM, ASTER)

Free satellite data and open-source software are provided by many institutions, such as NASA, NOAA,ESA, USGS, universities.,etc. These data are used in the scope of this study.

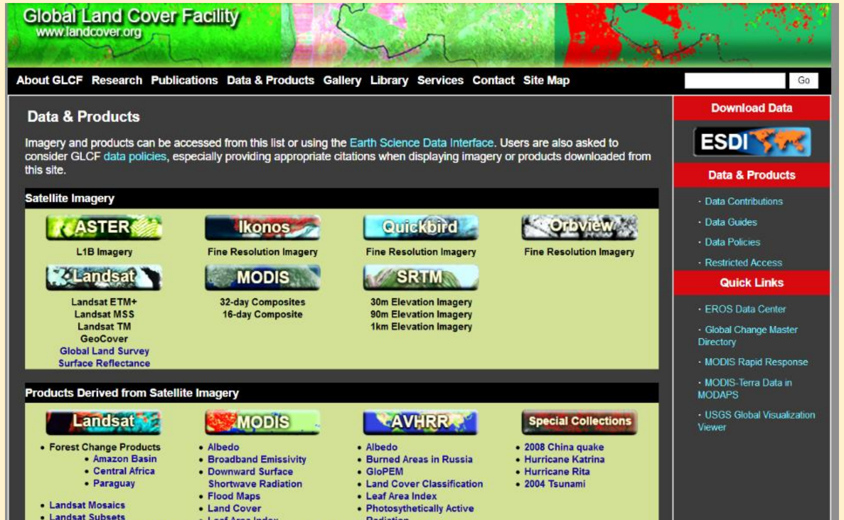


http://earthexplorer.usgs.gov/





ASTER images



Remote Sensing and GIS Tools for the Monitoring of Impact of Climate Change

Workflow

Digital Image Processing of ASTER, Sentinel and LANDSAT-Data

- RGB
- NDWI-Wasser-Index for soil moisture detection
- NDVI-Vegetationsindex for vegetation anomaly detection
- Principal Component, Classifications
- Filter techniques (Morphologic Convolution)

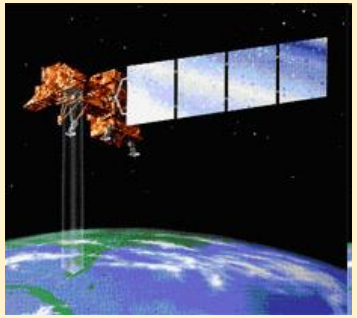
GIS integrated Evaluation of Satellite Data

- Change detection of the soil moisture and surface water bodies
- Change detection of the photosynthetic activity
- Change detection of the snow cover
- Weighted Overlay

Integration and Combination of Geodata

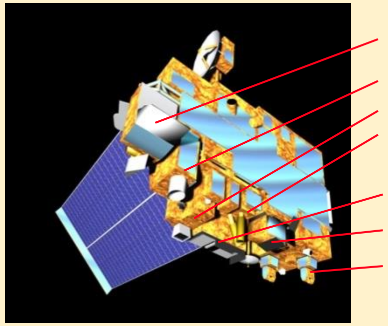
- Integration of geophysic, geologic, geomorphologic and pedologic data
- Digital Elevation Data (DEM)
- Vegetation, land use, infrastructure

Satellite Data used for the Environmental Monitoring in the Black Hills Area



LANDSAT series

Spatial resolution:15 – 30 m



MODIS

ASTER (TIR)

ASTER (SWIR)

ASTER (VNIR)

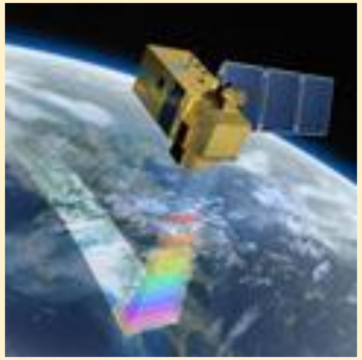
MISR

MOPITT

CERES

Advanced SpaceborneThermal Emission & Reflection Radiometer - ASTER

Spatial resolution:15 – 30 - 90 m

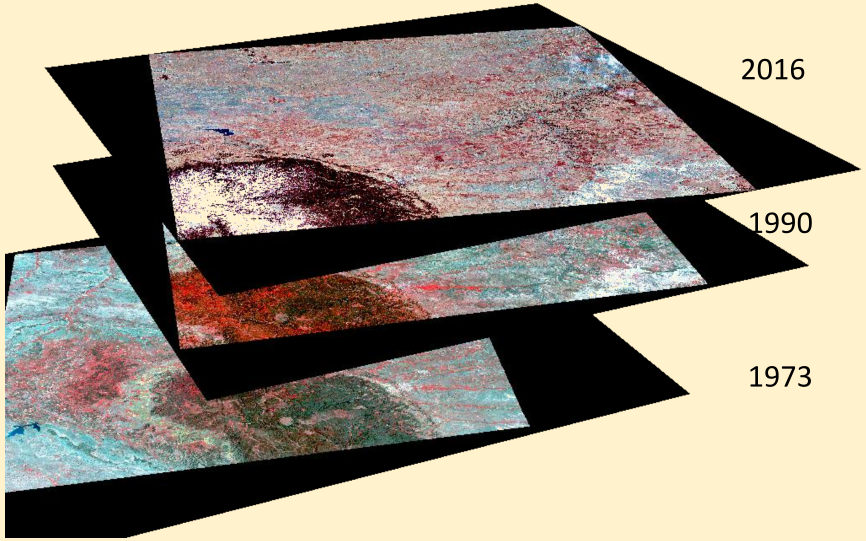


Sentinel-1 and 2

Spatial resolution: 10-20 m

The free access to these data

Time Series of Satellite Data for the Change Documentation

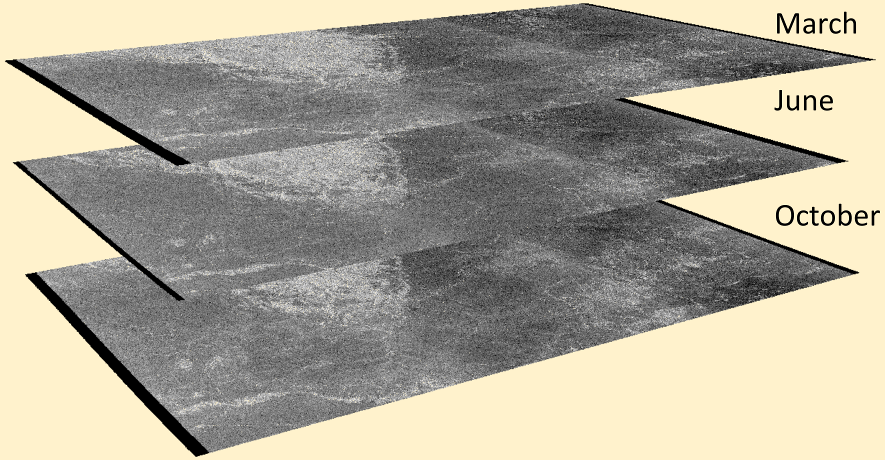


2016

1990

1973

Landsat satellite images available since 1972 allow the ling-term monitoring. However, cloud cover is the main hindrance for a continuously monitoring.



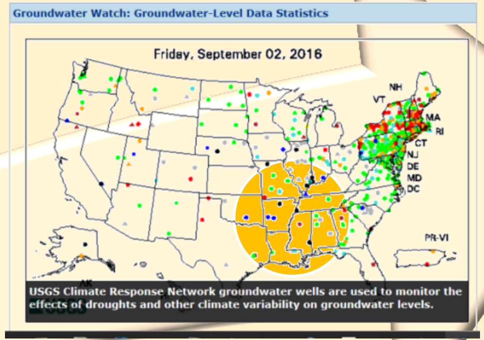
March

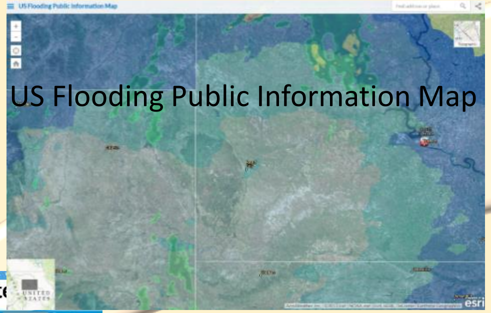
June

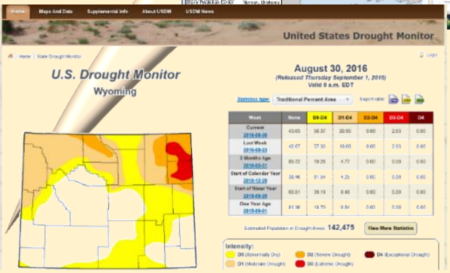
October

Sentinel-1 radar images allow the **seasonal,** weather-independent monitoring of the area. This is of great importance for the surface water and soil moisture monitoring.

Examples of Interactive Web-Services and Satellite Images providing Data for the Documentation and Monitoring of Climate Change







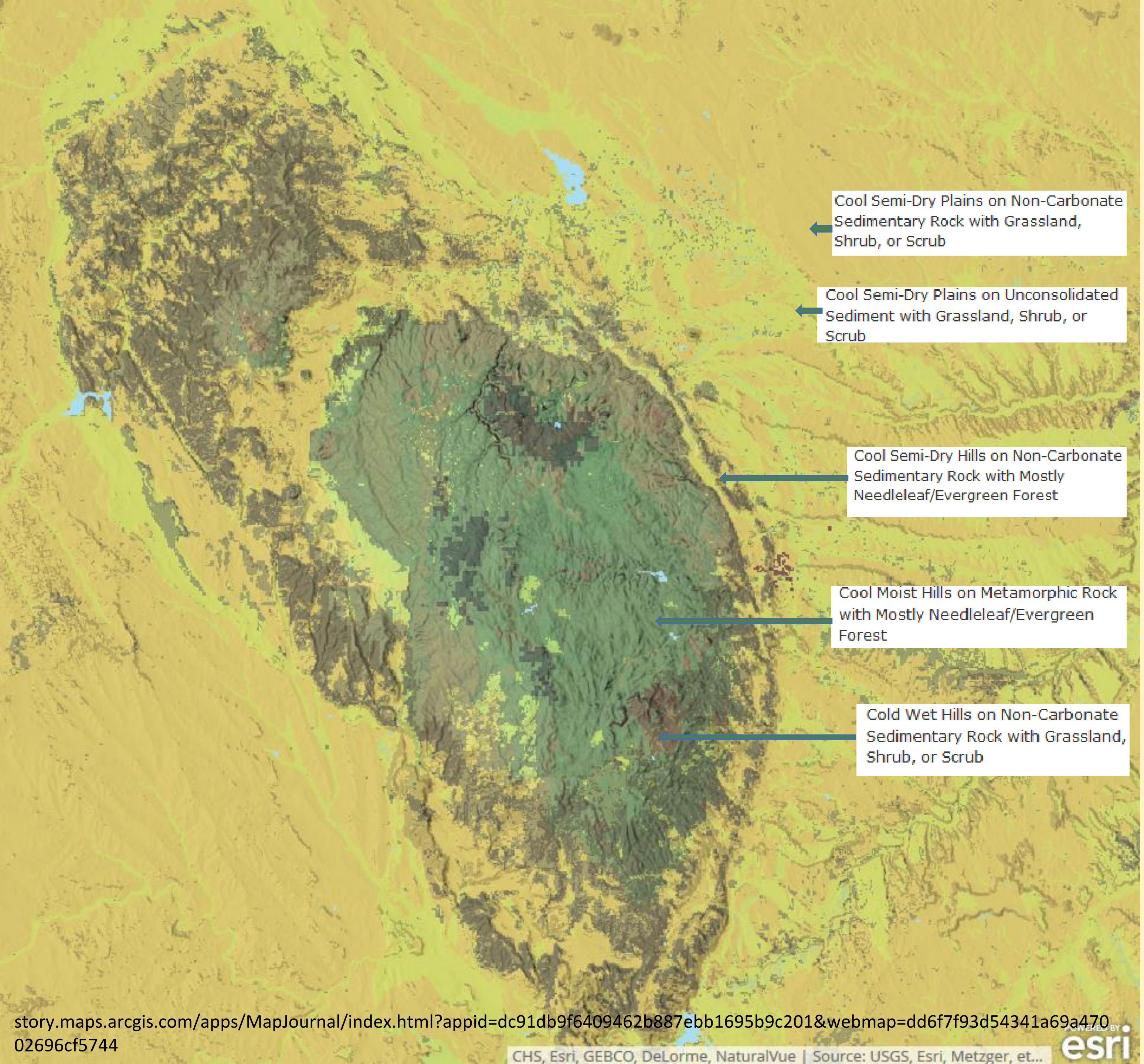
Numerous Web-services and interactive maps provide environmental data allowing the documentation of the impact of climate change.

Varying Impacts of Climate Change due to different, specific local Conditions

A challenge is to distinguish changes of the earth surface driven by natural forces from changes induced by global warming and population growth.

Questions:

Landuse Vegetation / Ecosystems	• How will the landuse development (increasing built-up areas, intensified agriculture and water resource management) influence the local micro-climate? • How will be the development of the vegetation growth and composition and the ecosystems considering the increasing days with higher temperatures?
Geohazards	• How will the increasing extreme weather events as storms with high precipitations influence the intensity of geohazards, such as flash floods, landslides, soil erosion or karst phenomena in the Black Hills area?
Geodynamic Processes	• Are the geodynamic processes in this area more related to climatic conditions or are there other influences such as tectonic uplift of the Black Hills intensifying soil erosion, sedimentation and landslide processes?



story.maps.arcgis.com/apps/MapJournal/index.html?appid=dc91db9f6409462b887ebb1695b9c201&webmap=dd6f7f93d54341a69a470 02696cf5744

Ecosystems

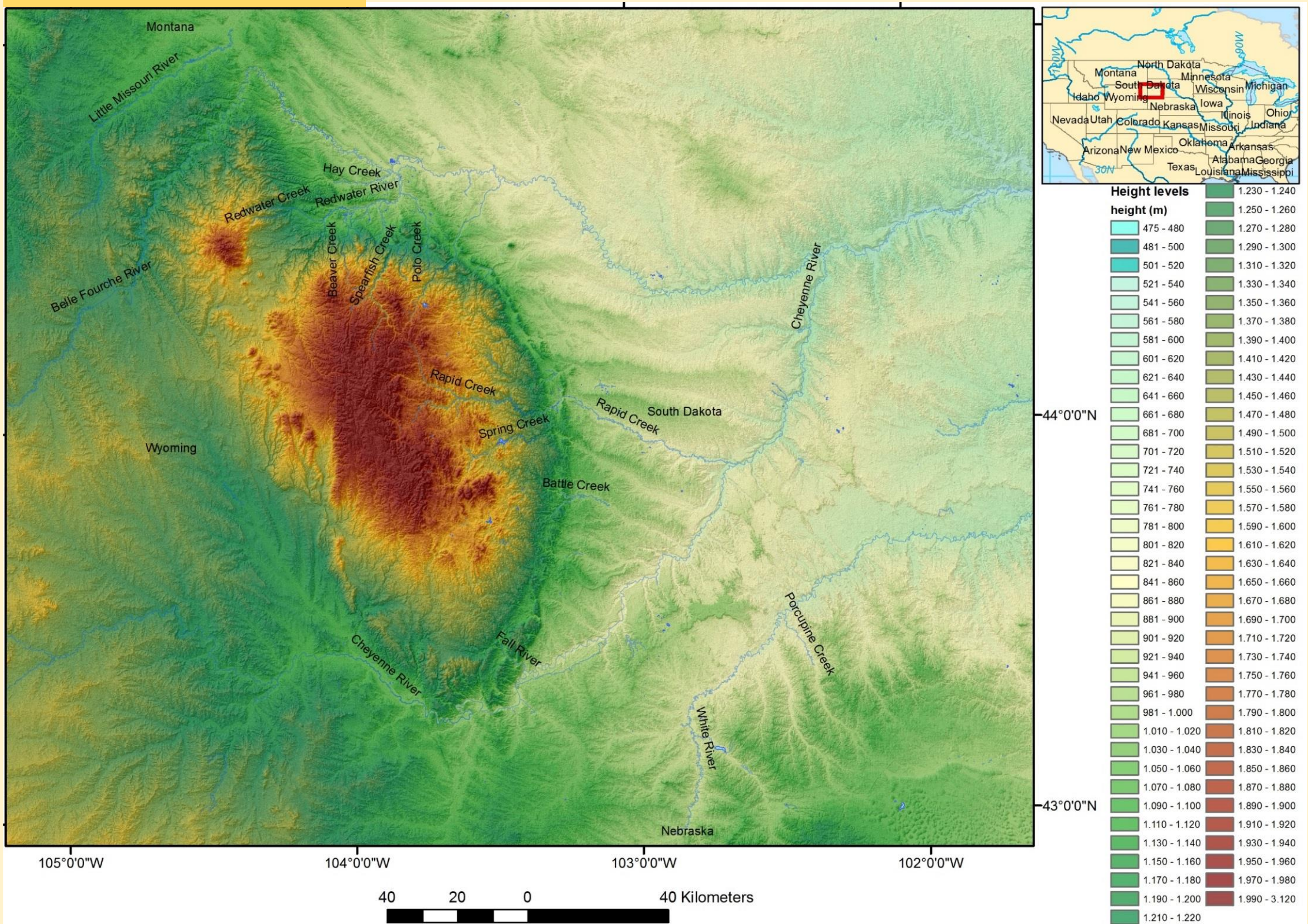
Ecological land units according to AAG, USGS, ESRI

Most of the higher altitudes are heavily forested with ponderosa pine, which is the primary product of an active timber industry. White spruce, quaking aspen, paper birch, and other native trees and shrubs are found in cooler, wetter areas.
Numerous deciduous species such as cottonwood, ash, elm, oak, and willow are common along streams in the lower altitudes (Driscoll et al.,2002).

A New Map of Global Ecological Land Units — An Ecophysiographic Stratification Approach
A Special Publication of the Association of American Geographers

http://www.aag.org/galleries/default-file/AAG_Global_Ecosyst_bklt300.pdf

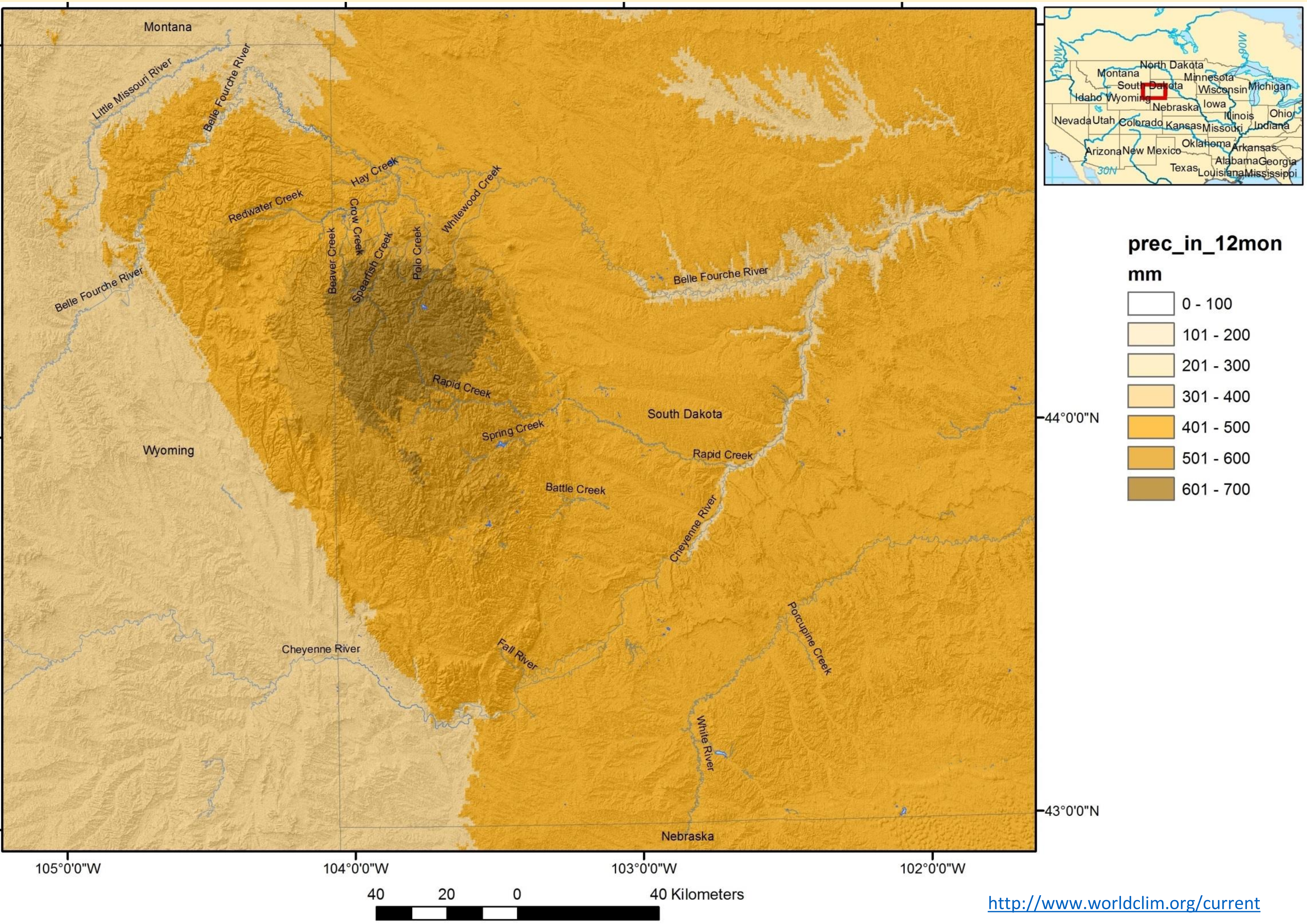
3. GEOGRAPHIC SETTING



Height Level Map based on ASTER GDEM Data

The Black Hills in western South Dakota and eastern Wyoming rise above the surrounding Great Plains. Its eastern side rises from the prairie (650 – 900 m height level) to a height from up to 2100 m in the western part of the Black Hills.

The 290-km-long Black Hills uplift extends from the South Dakota-Nebraska border to southeast Montana. The general shape of the Black Hills is elliptical with a NNW-SSE-oriented axis.



http://www.worldclim.org/current

Yearly Precipitations

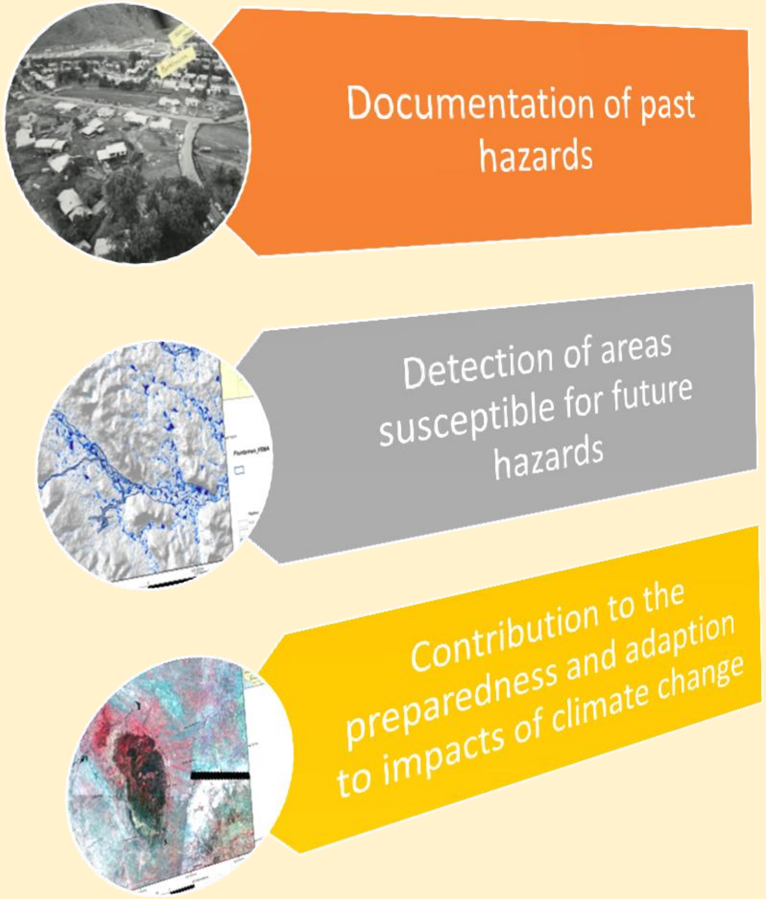
(~1950-2000)

Climate change will have an influence on the the damage intensity of natural hazards in the Black Hills area such as flash flood occurrence, on soil erosion, on droughts and fire susceptibility. Thus, the continuously analysis of meterologic data is of great importance for the monitoring of natural hazards in this area.

The semi-arid climate conditions in the study area are characterized by cold winters and warm to hot summers. This combination of hot summers and limited precipitation in a semi- arid geography places South Dakota in a potential position of suffering a drought in any given year.
About one-third of average annual precipitation typically occurs during May and June. November to February are consistently the driest months.

4. REMOTE SENSING AND GIS EVALUATION RESULTS FOR THE DETECTION AND MONITORING OF AREAS PRONE TO NATURAL HAZARDS

using the Examples of Flash Floods and Karst Phenomena



Recent sediments due to flash flood deposits in lowland areas

Deriving morphometric properties of a terrain from Digital Elevation Modell (DEM) data such as

the lowest local height level or

the lowest slope gradient and

the minmum curvature

help to detect flat flow accumulation zones: areas with the highest surface water input and recent, unconsolidated sediments

(Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms.)

Morphometric Analysis based on Digital Elevation Data- DEM) for the Detection of Areas susceptible to Flash Floods

Morphometric Maps (Examples)

Height level maps help to search for topographic depressions covered of almost recently formed sediments. When extracting the lowest height levels of an area, it becomes visible where the areas with higher surface water input and higher ground-water tables can be expected.

Slope gradient maps help to detect those areas with basin and depression topography.

Minimum Curvature maps contribute to the detection of the flattest areas.

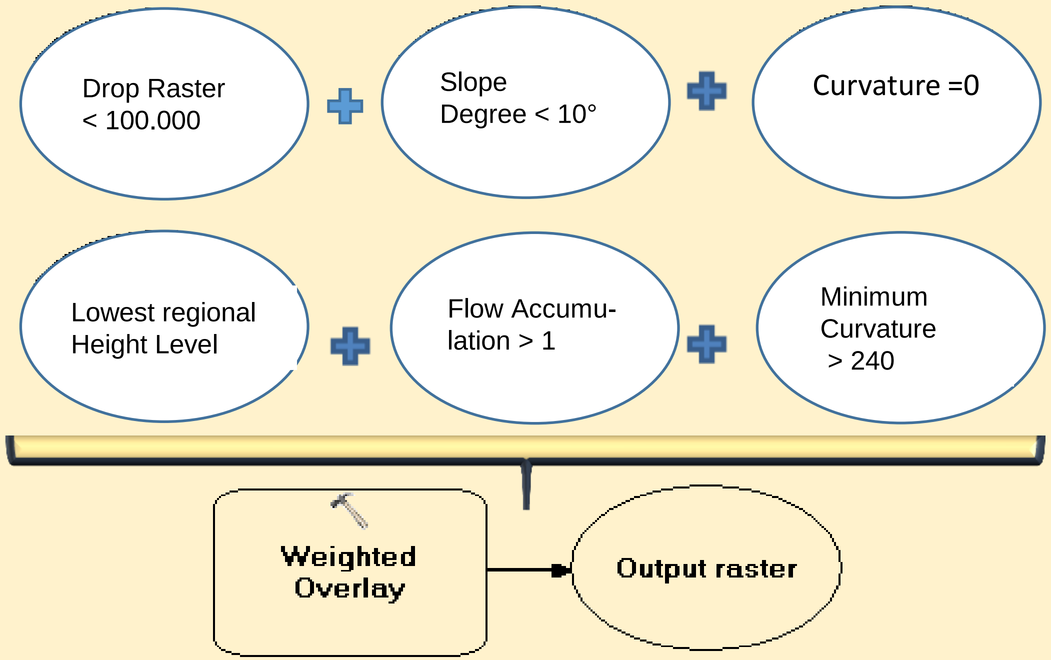
Flow Accumulation maps help to identify higher accumulation of surface water flow.

Drop raster calculations provide information of relatively highest water flow input.

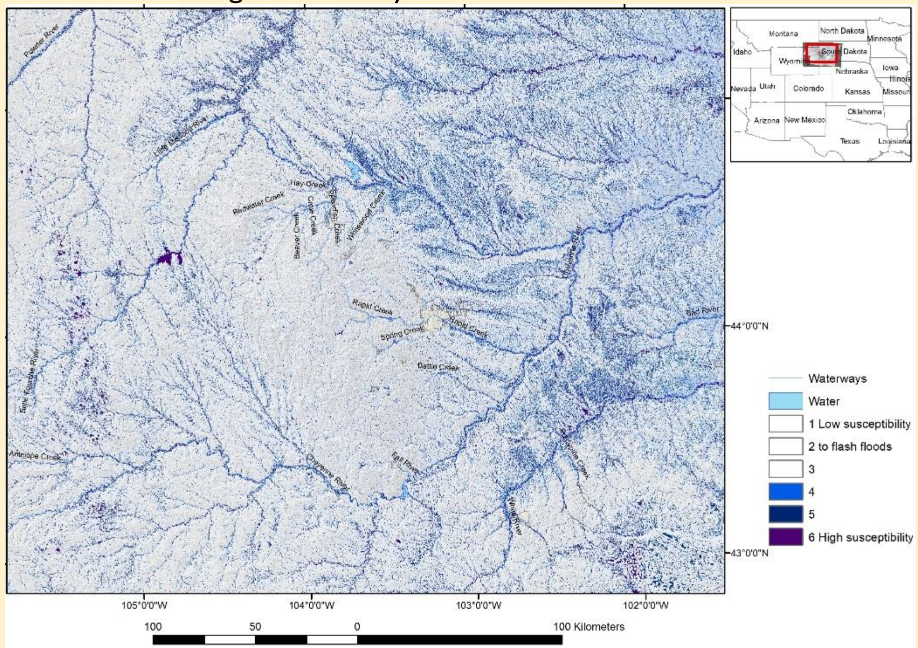
Of course, many further factors and data play an important role, that (if available) should be included into the data base. By combining some of the causal or preparatory factors influencing flooding intensity in a georeferenced GIS environment those areas can be detected where causal factors occur aggregated and superimpose each other.

4.1. Floods

Aggregation of causal, morphometric factors influencing flooding susceptibility using the weighted overlay-tool in ArcGIS



Result of the weighted overlay calculation



The resulting maps are divided into **susceptibility classes**. The susceptibility to flooding is classified by values from 0 to 6, whereby **the value 6** is standing for the **highest, assumed susceptibility due to the aggregation of causal / preparatory factors**.

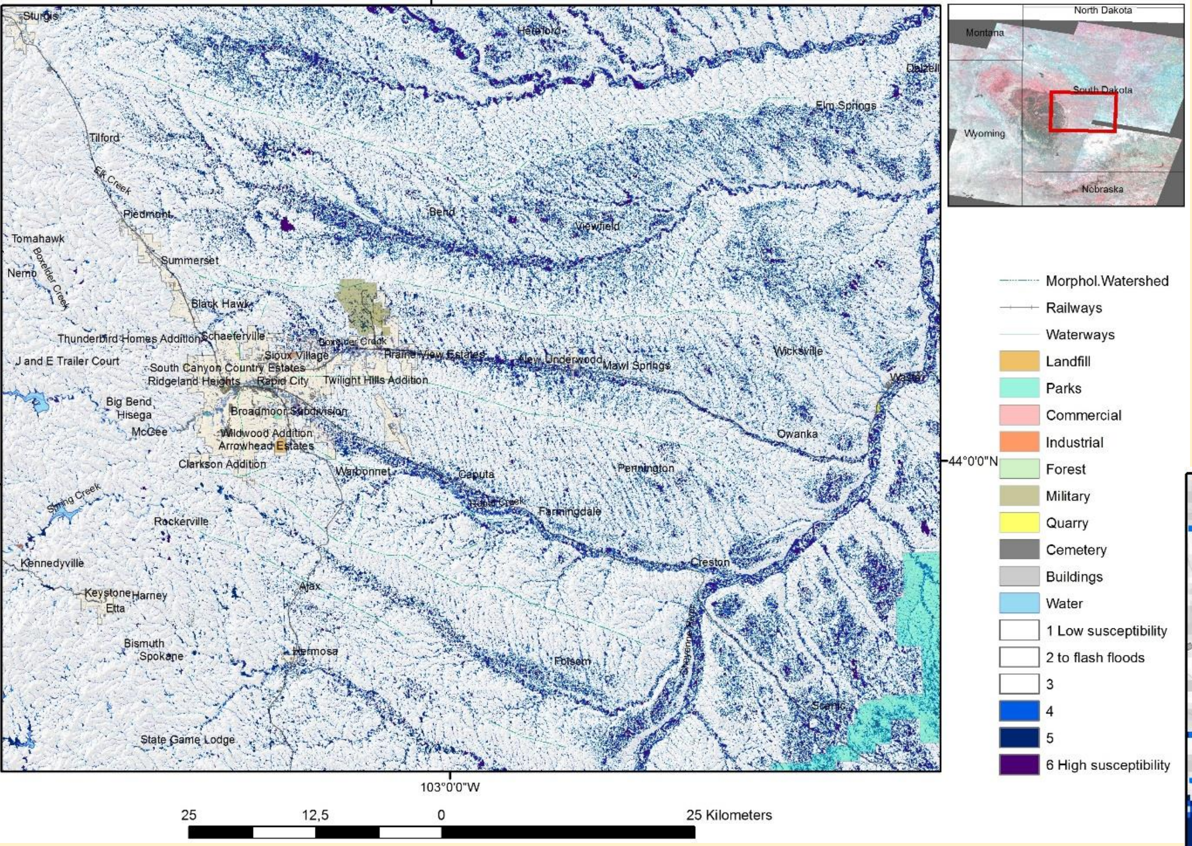
Workflow of the Weighted Overlay of Causal / Preparatory Factors influencing the Flooding Susceptibility

The weighted overlay approach in a GIS can be used for the detection and identification of endangered lowland areas susceptible to flooding. *Due to the aggregation of the below mentioned, morphologic factors these areas are more susceptible to flooding than the environment in case of flash floods.*

Based on ASTER Digital Elevation (DEM) data the following morphometric factors are extracted and then aggregated in the weighted overlay tool of ArcGIS:

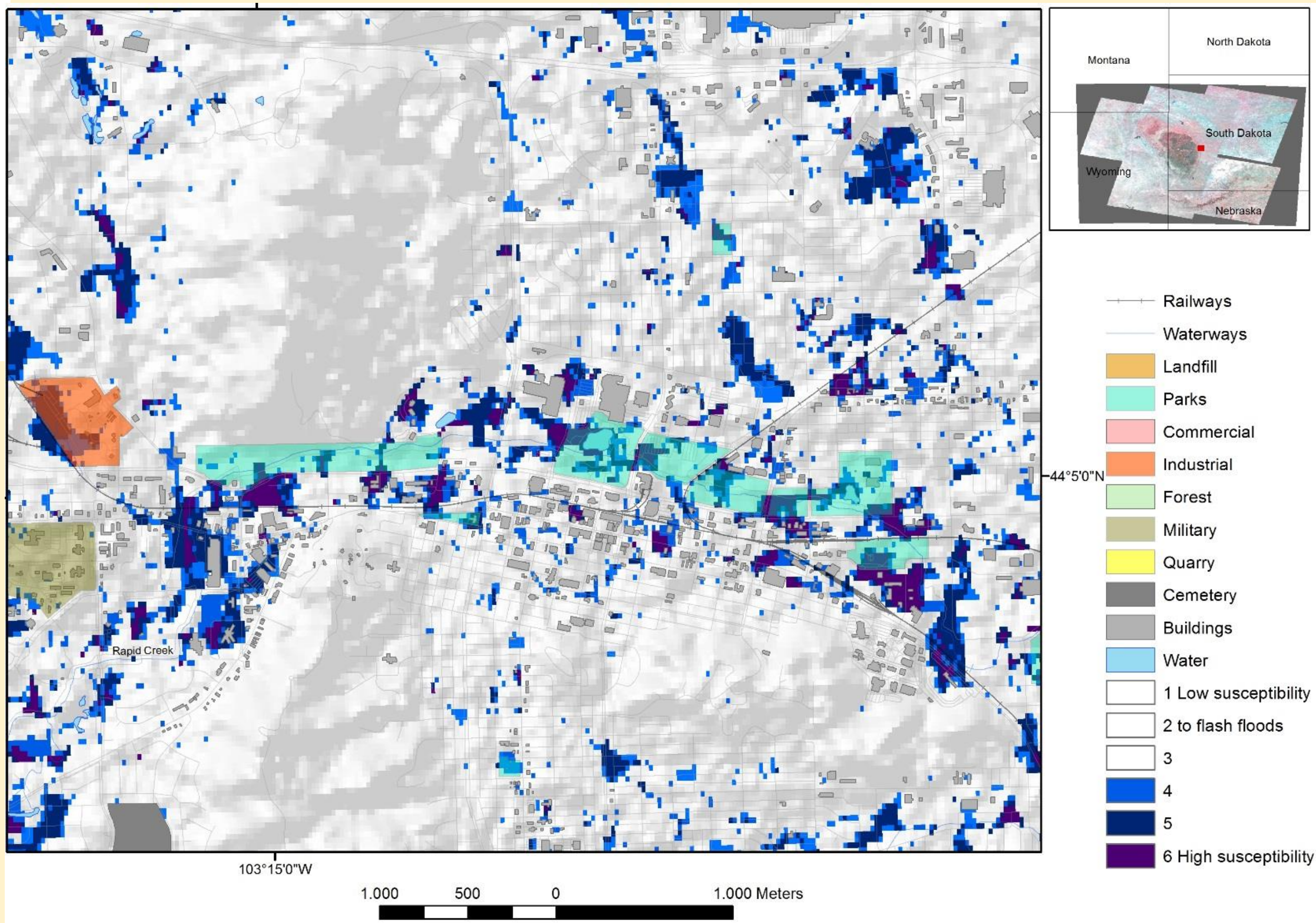
- Lowest, local height levels
- flat terrain, calculating terrain curvature (curvature values= 0 , calculated in ArcMap, minimum curvature > 250 , calculated in ENVI)
- slope gradients < 10°
- drop raster < 100.000 and
- high flow accumulation values

Susceptibility to Flash Floods due to the morphometric Disposition in and around Rapid City

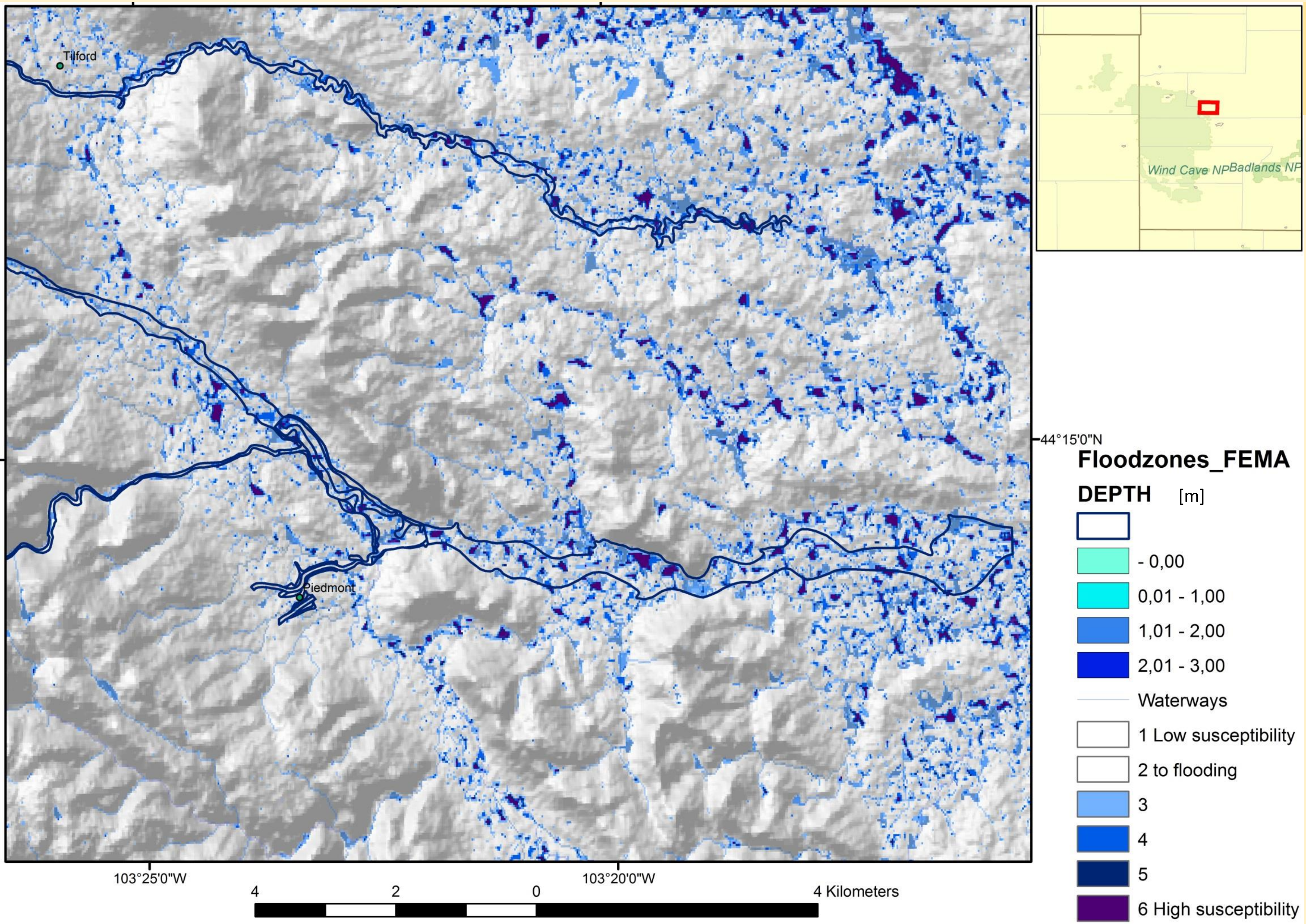


Susceptibility maps are elaborated for the detection of areas that are assumed to be more affected by flooding hazards due to the aggregation of causal / morphometric factors influencing the disposition to flooding. Maps were created providing an overview of areas that are more susceptible to flooding due to local morphologic site conditions following a standardized work flow.

Whenever the before mentioned causal factors occur aggregated in an area, the susceptibility to flooding events such as flash floods is rising. The local lowest and flattest areas are prone more to flooding than the environment.



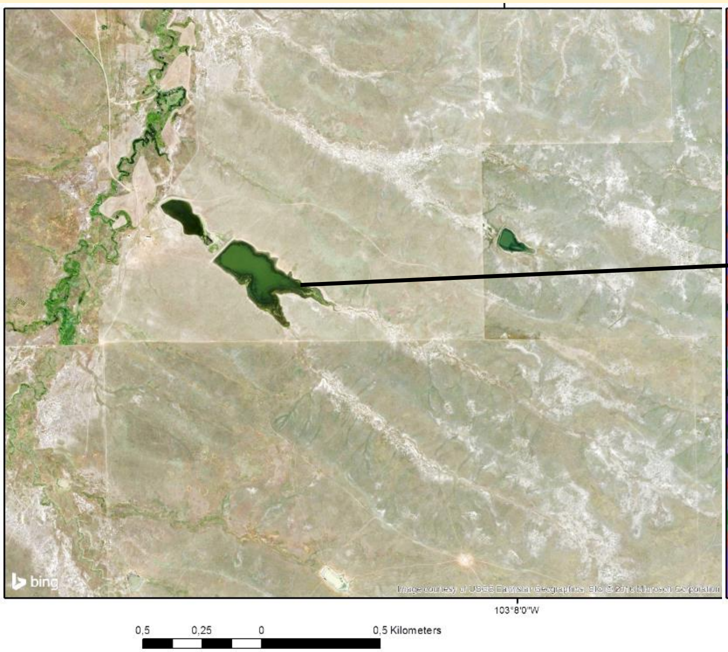
Comparison of the weighted overlay results with mapped flood zones by FEMA

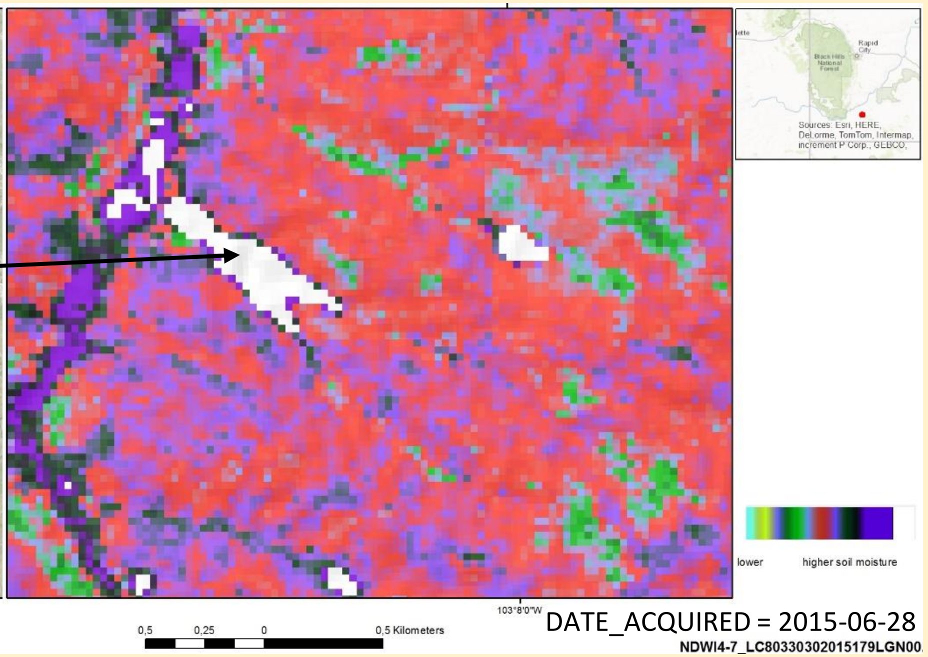


The results of the weighted overlay were compared with the flood data of Federal Emergency Management Agency - FEMA (delivered as shapefiles) revealing a clear coincidence of areas with the highest susceptibility to flooding and flooded areas in the past (100 years flood events).

Of course, many factors play a role when dealing with flash floods such as the precipitation intensity, the size of catchment areas, morphologic watersheds, lithologic conditions, vegetation cover or land use. The results of the weighted overlay using morphometric parameters help to delineate those areas with a morphometric disposition to be flooded.

Long-term Evaluation of NDWI-Water Index image products based on Landsat, Sentinel 1 and 2-images for the Detection of Climate Change





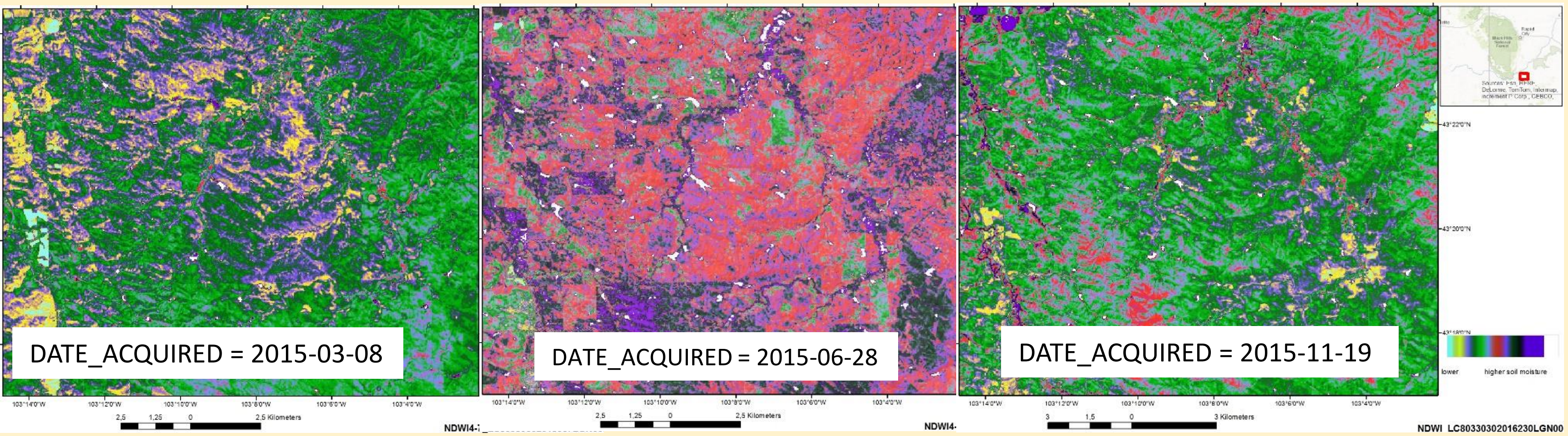
BingMap-scene of water reservoirs in South-Dakota

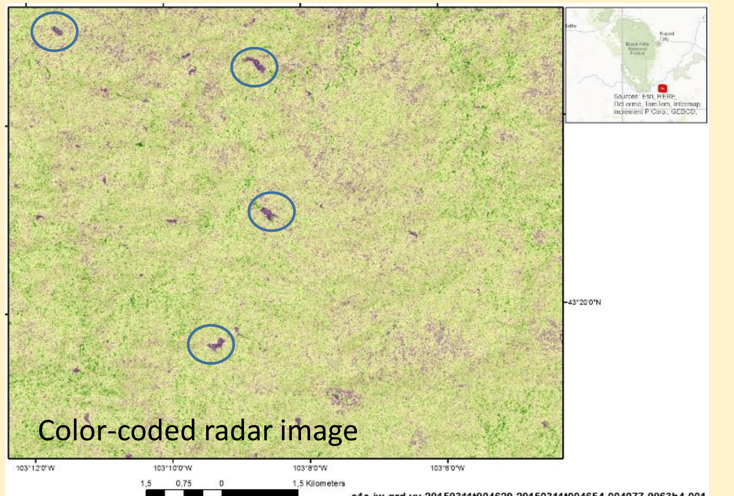
Landsat 8-NDWI-scene (30 m spatial resolution)

Normalized Difference Water Index (NDWI) for Soil Moisture Monitoring

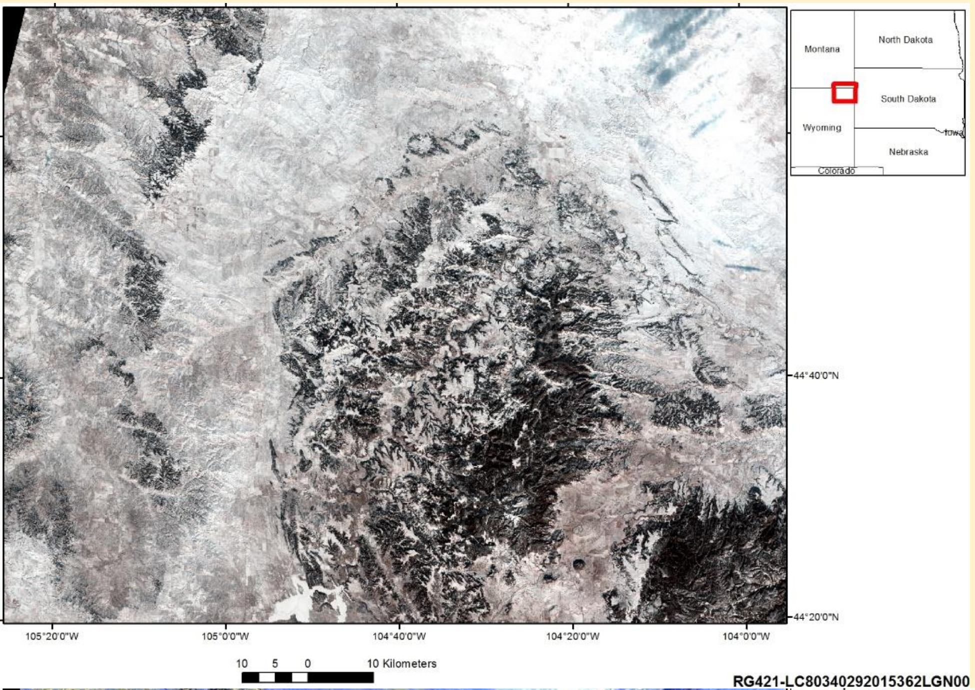
On the NDWI-image water surfaces, areas with higher groundwater tables or higher soil moisture contents, vegetation with relatively high water content, appear in dark-blue-violet, surface water bodies in white

Seasonal and local differences in the surface-near soil moisture content become visible on the Landsat 8-NDWI-scenes in the south of the Black Hills. Local precipitation patterns, topographic and geologic influence and the vegetation cover / agriculture are further factors that modify the soil moisture.
The long-term monitoring of the shape and varying size of surface water bodies might help to detect trends related to climate change. Here, Sentinel-1 radar images will play an important part





Long-term Snow Cover Monitoring in the Black Hills Area



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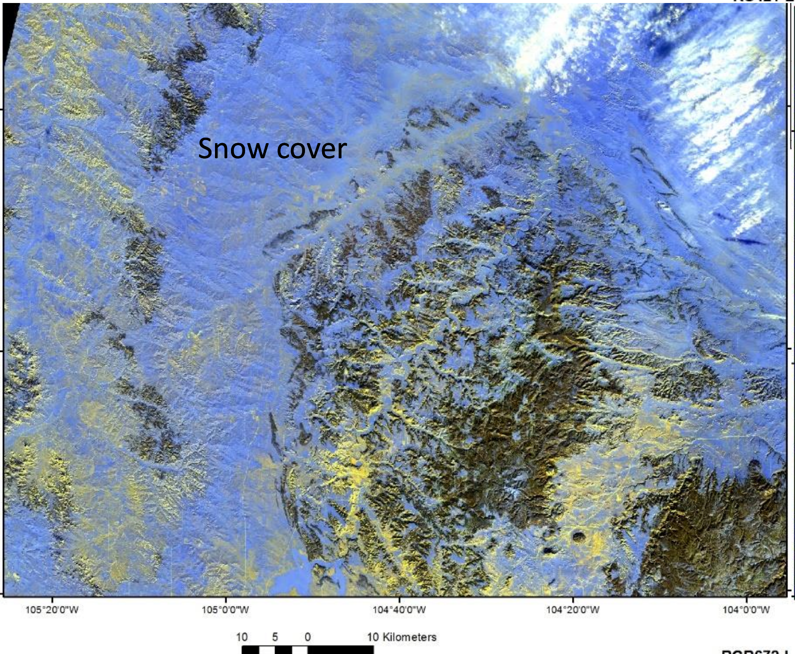
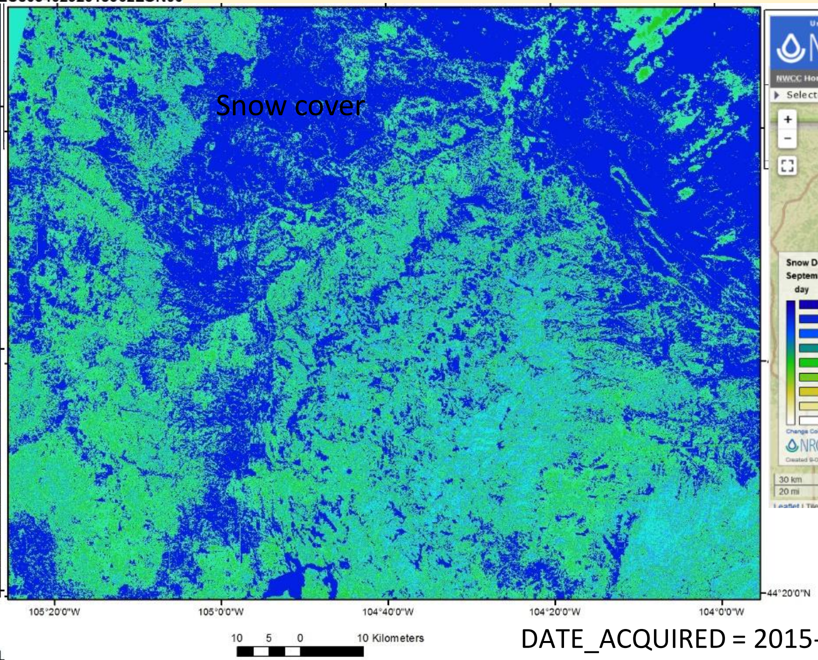
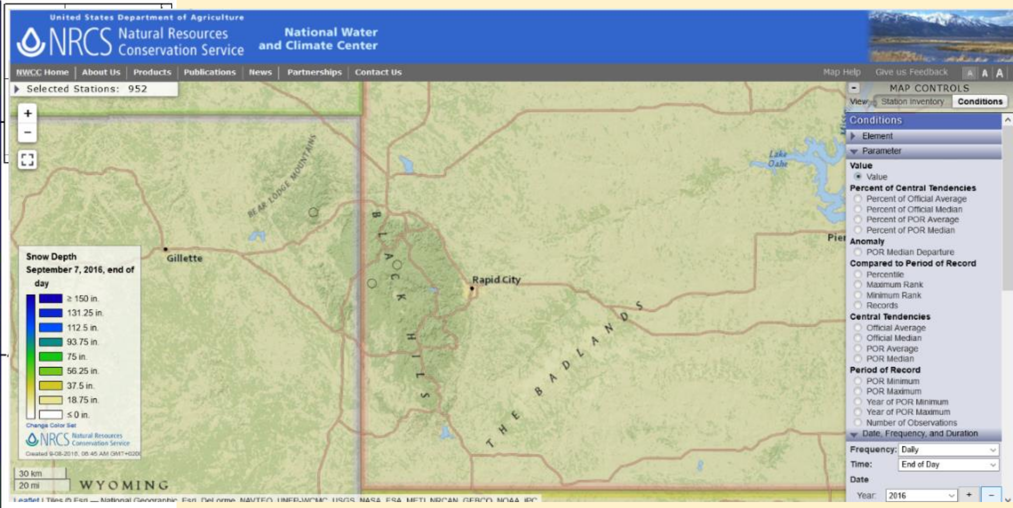
Evaluation of time series of satellite images support the documentation of snow covers, their distribution and size as well as their duration. In combination with meteorological data long-term trends might become visible.



RGB672-L

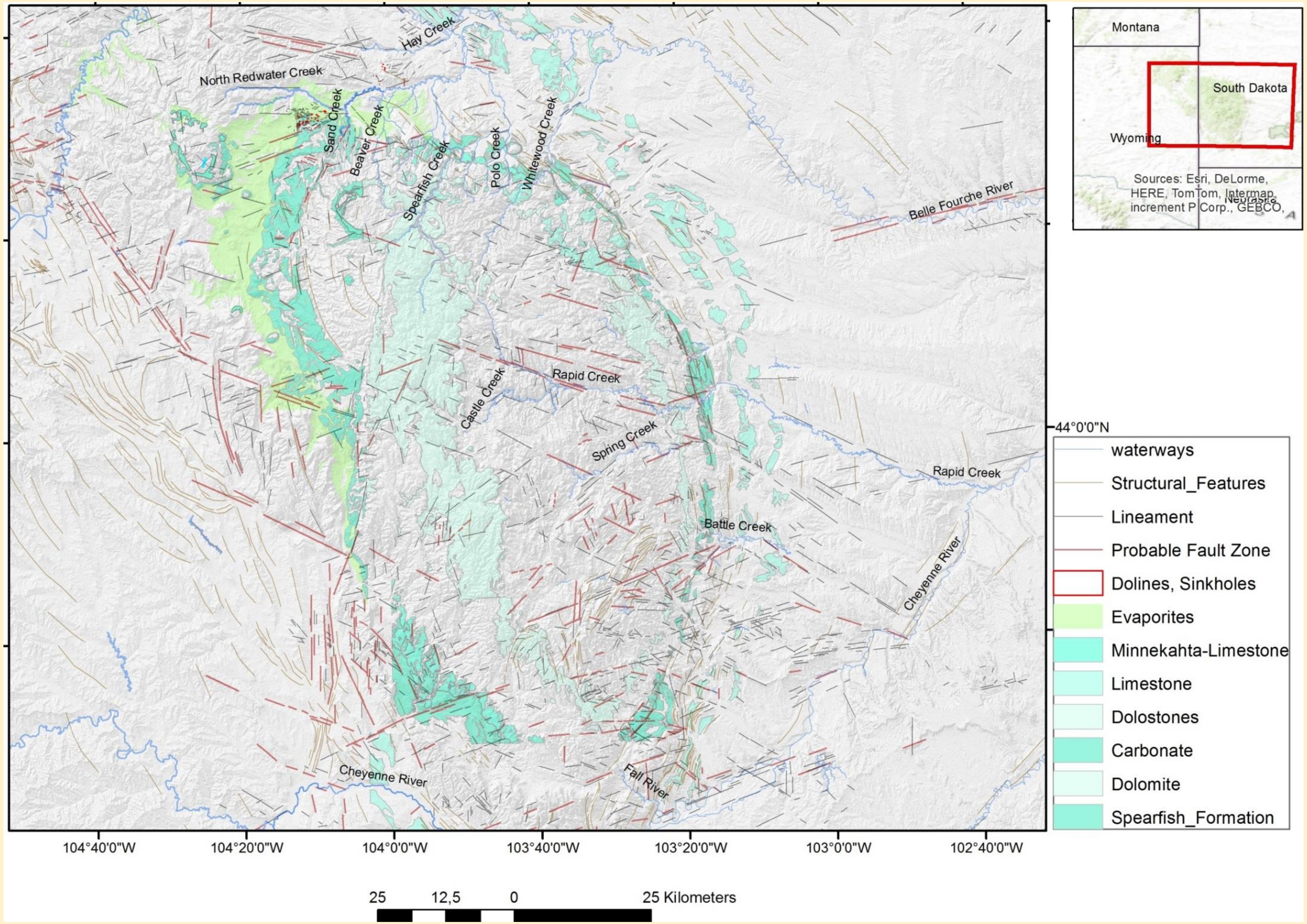




http://www.wcc.nrcs.usda.gov/webmap

DATE_ACQUIRED = 2015-12-28

4.2. Karst Phenomena

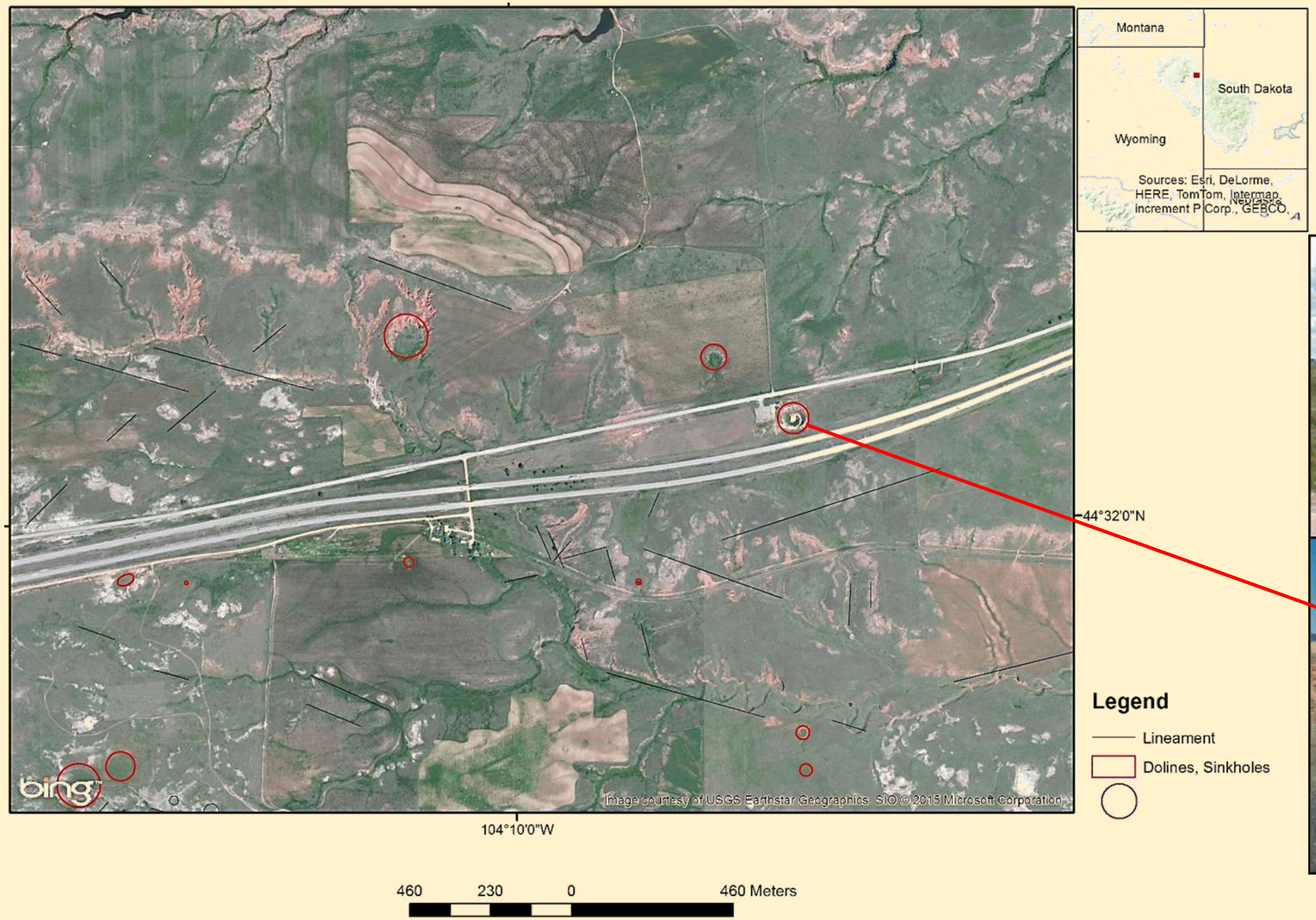


Class caves, sinking streams, and other karst features are found in limestones, gypsum and dolomites. Dissolution of gypsum and anhydrite in four stratigraphic units in the Black Hills, South Dakota and Wyoming, has resulted in development of sinkholes. Subsidence has caused damage to houses and water and sewage retention sites. Evaporite karst has developed extensively in the anhydrite and gypsum in the Minnelusa, Spearfish, and Gypsum Spring Formations (Epstein and Putnam,2005).

The water table and the amount of water availability influence the karst development which will be affected, thus, by climate change.

Rock Units prone to Karstification – shapefiles provided by USGS

Dolines in the Northern Black Hills

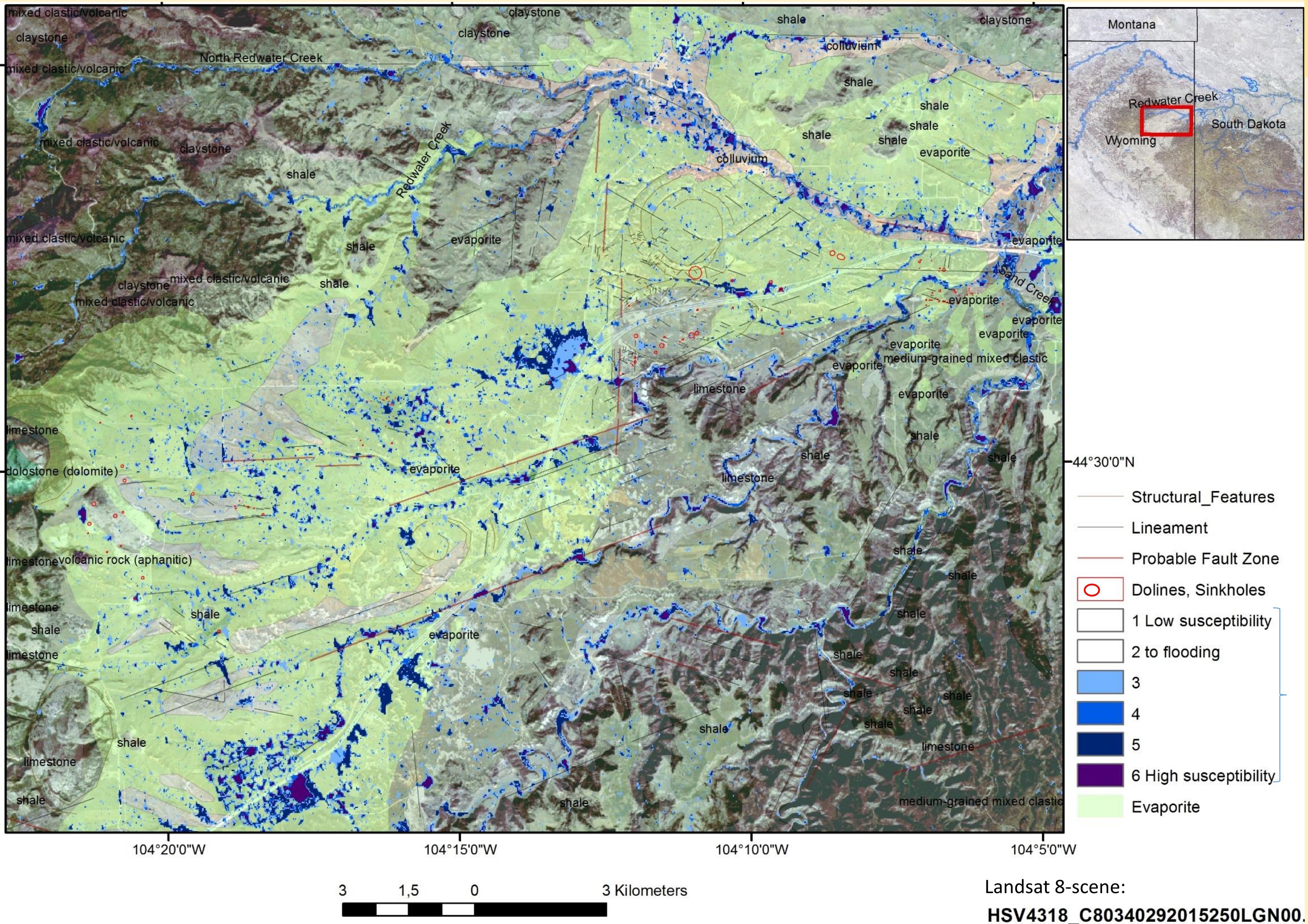


Two sinkholes located 5.6 km (3.5 mi) west of Beulah, Wyoming, and immediately north of Interstate 90. (A) Sinkhole with a laterforming smaller internal sinkhole at arrow. (B} The “Vore Buffalo Jump” is an 18-m (60 ft)-foot deep sinkhole.

Jack B. Epstein, Daniel H. Doctor : EVAPORITE KARST IN THE BLACK HILLS, SOUTH DAKOTA AND WYOMING, AND THE OIL PLAY IN THE WILLISTON BASIN, NORTH DAKOTA AND MONTANA. 13TH SINKHOLE CONFERENCE NCKRI SYMPOSIUM 2, 2013

Fault and Fracture Zones influencing the linear Arrangement of Dolines in the Northern Black Hills

How will climate change affect karst processes?



Weighted overlay of morphometric factors influencing the amount of surface water input.

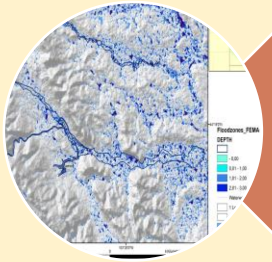
Landsat 8-scene:
HSV4318_C80340292015250LGN00.

Some of the factors influencing the development of karst phenomena:

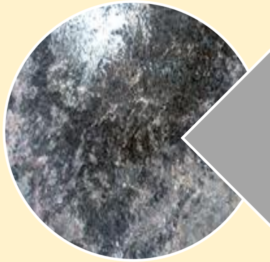
- Lithologic properties: evaporites, limestones, dolomites
- Structural pattern: fracture and fault zones, anticlines, synclines, etc.
- Surface water input: dissolution processes are likely to be more intense in areas with relatively higher surface water input after rain fall what can be derived from the terrain morphology

5. Conclusions

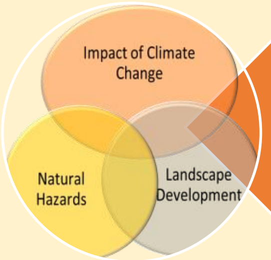
The evaluations of satellite imageries such as Landsat, Sentinel, ASTER, digital topographic data and of open-source geodata contribute to the acquisition of the specific tectonic, geologic, geomorphologic / topographic settings influencing the disposition to natural hazards such as the morphologic disposition to flash floods, or karst phenomena. Thus, these data improve the preparedness for the upcoming environmental changes.



Whatever might be the source of extreme flooding events, the lowest and flattest areas and river beds will be prone first. Therefore maps are elaborated showing areas susceptible to flooding due to their morphometric disposition. A flooding hazard map, that predicts the probable locations of possible future inundation is required which takes into consideration as well the potential morphodynamic consequences such as erosion, debris and mud deposits. The weighted overlay of those specific morphometric factors in ArcGIS might be one step toward this objective.



Long-term evaluations of different satellite data contribute to the detection of trends such as related to the development of the size and shape of water bodies, soil moisture or snow cover. The long-term evaluation of availabe satellite imageries combined with additional geodata will contribute to a better understandig of the complex interactions of the different factors and their varying influences.



The impact of climate change on the landscape development in the Black Hills area, especially on the vegetation composition and the ecosystems, and on the morphodynamic development, requires detailed field investigations additionaly to the remote sensing and GIS research. However, the GIS integrated evaluation of satellite data will perform an essential part of the monitoring the impact of climate change.

Thank you for your attention

Barbara Theilen-Willige: Natural Hazard Assessment and Monitoring in the Black Hills and Adjacent Areas, South Dakota and Wyoming, USA, Using Remote Sensing and GIS-Methods
Journal of Geography, Environment and Earth Science International, 6(1): 1-24, 2016; Article no.JGEESI.24388, ISSN: 2454-7352, DOI : 10.9734/JGEESI/2016/24388
http://sciencedomain.org/download/MTQzOTRAQHBm