Remote sensing of snow cover relying on multispectral data

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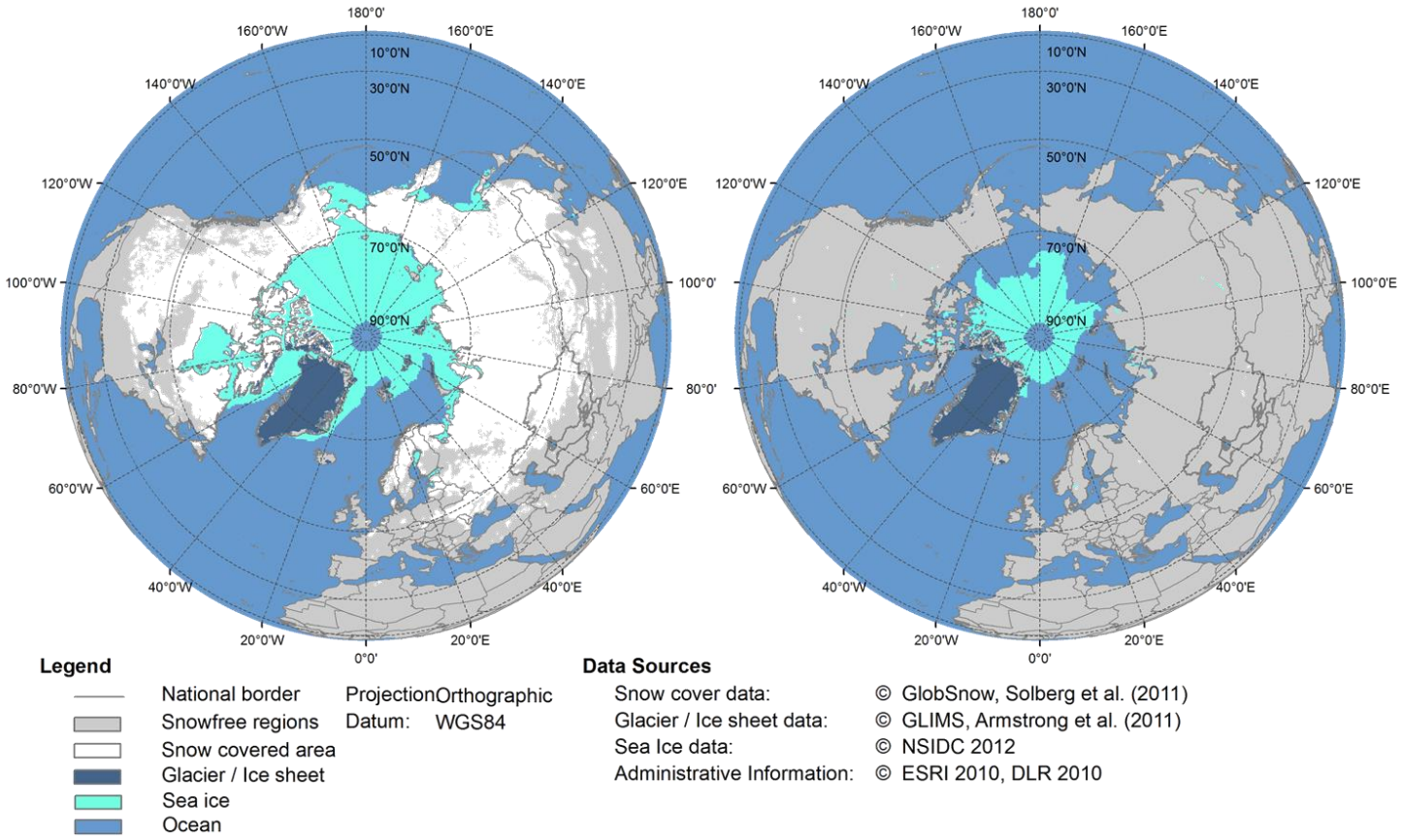
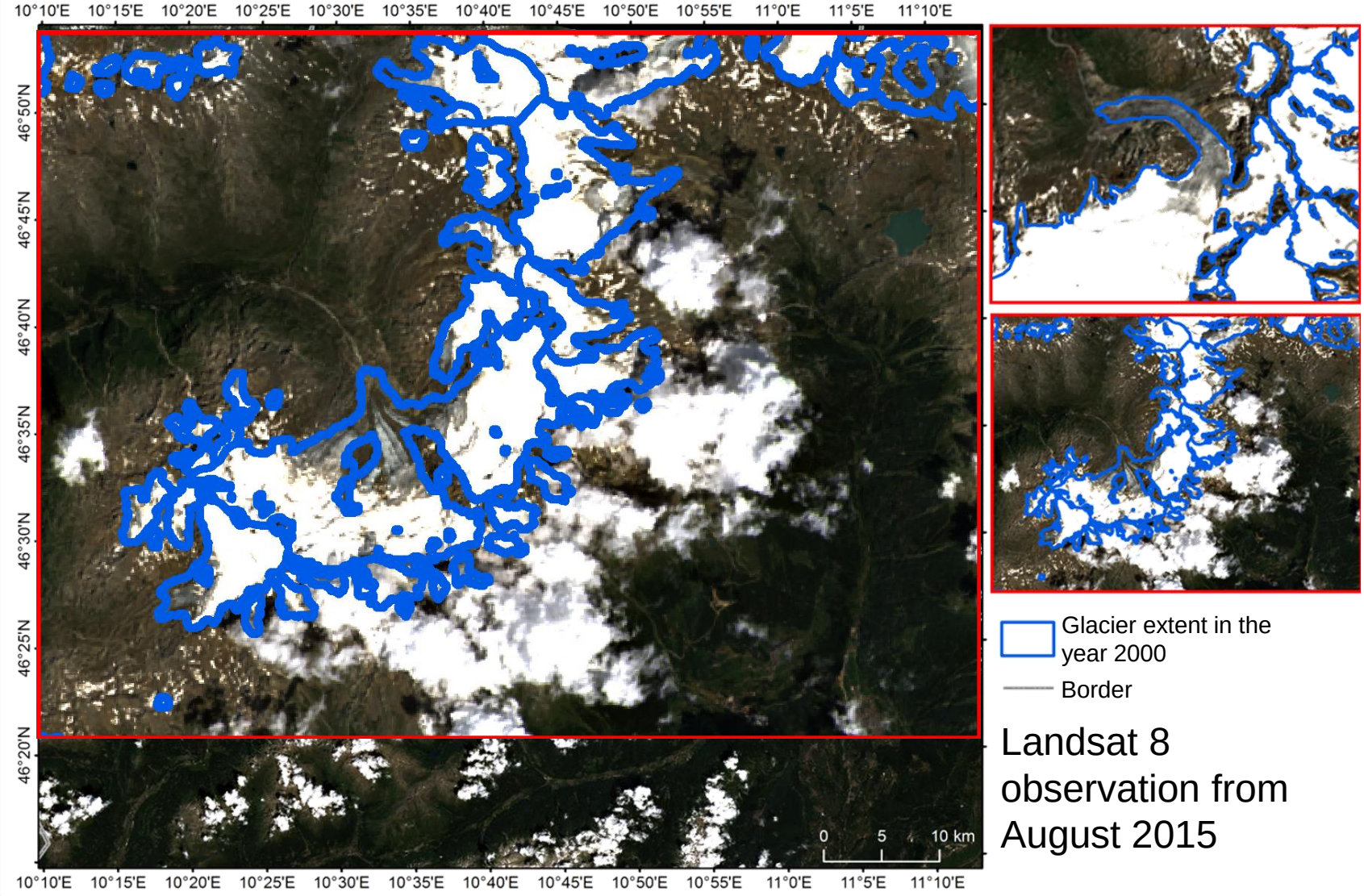
Some background

- Snow covers up to 50% of the Northern Hemisphere
- Snow influences the global radiation budget
- Hydrology, Vegetation, Energy, Tourism, Natural disasters



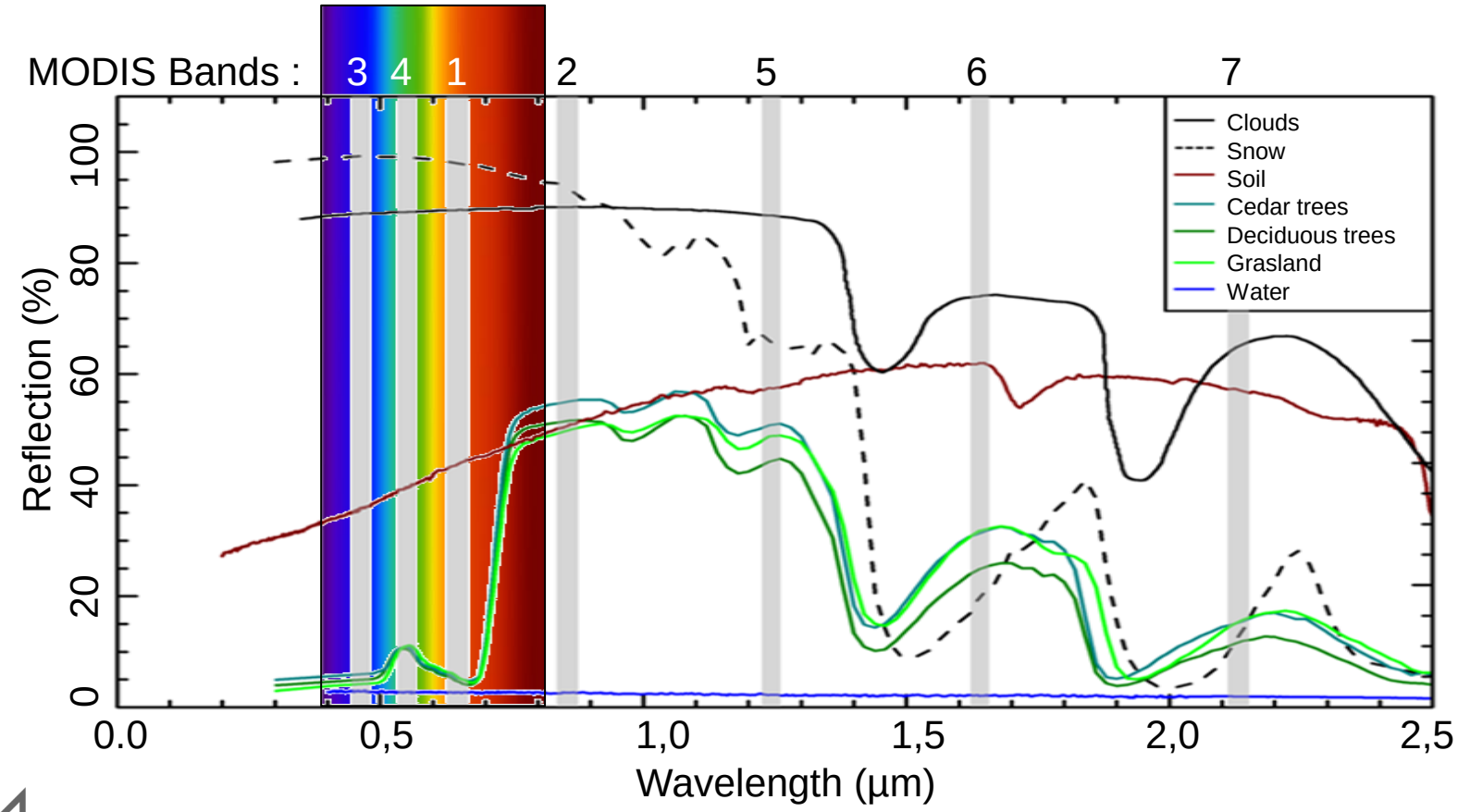
Snow as seen from space



Methods

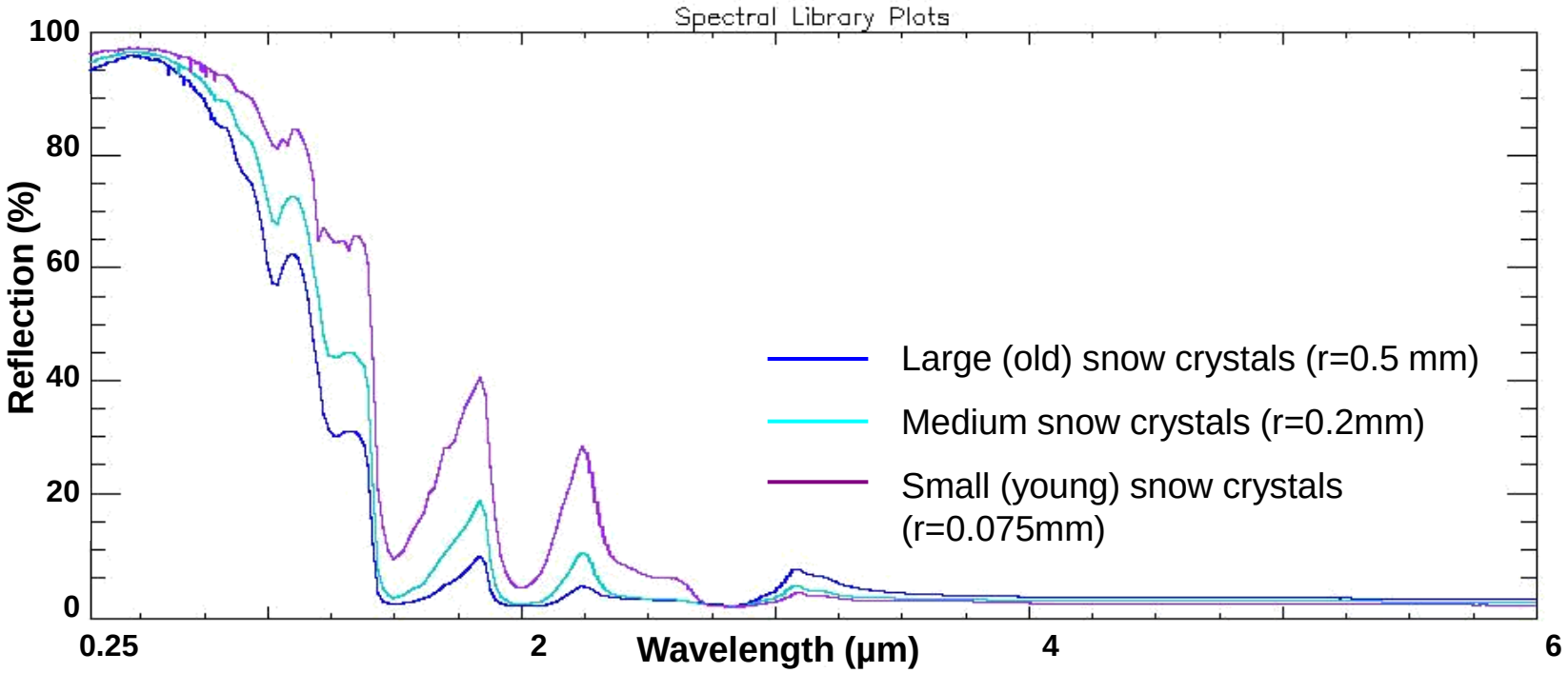
Spectral characteristics of snow

- High reflection in the visible part
- Very low reflection in the short wave infrared
- Freeze and thaw processes affect the reflection.



Methods

Freeze and thaw processes affect the reflection.



Spectral signature of different snow types (source: *ENVI 4.8 spectral library; Choudhury & Chang, 1979*)

Methods

Normalized Difference Snow Index (NDSI):

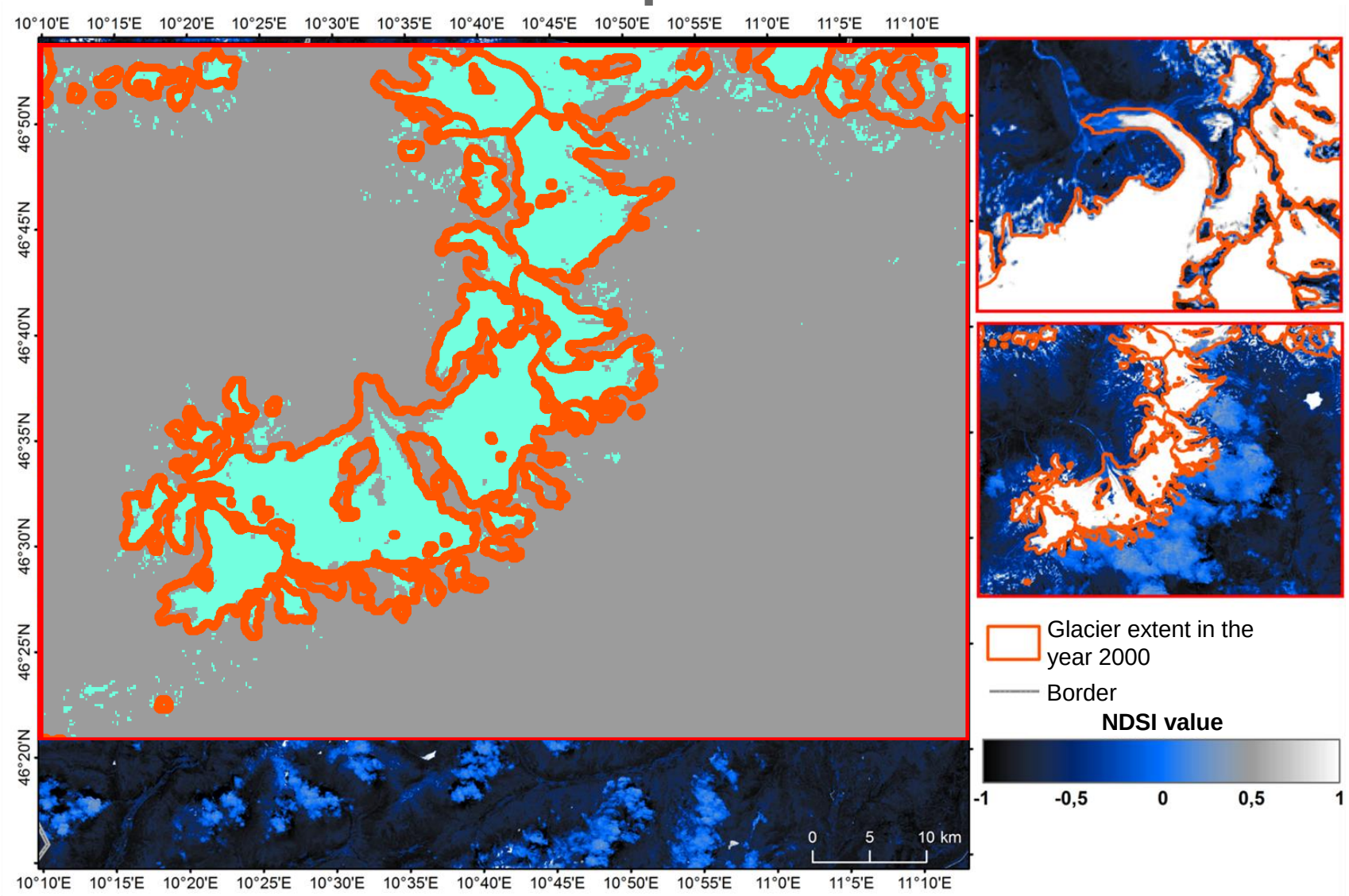
$$NDSI = \frac{R_{vis} - R_{SWIR}}{R_{vis} + R_{SWIR}}$$

R_{vis}: Reflection in the visible part
R_{SWIR}: Reflection in shortwave infrared

NDSI > 0.4 is a good indicator for the presence of snow

As the reflection of water is very low in the visible, but even lower in the short wave infrared, the NDSI of water surfaces can be similar to the one of snow. Therefore, a simple reflectance test for the visible part needs to be included to prevent confusion.
In forested areas, the threshold has to be adjusted according to the vegetation fraction

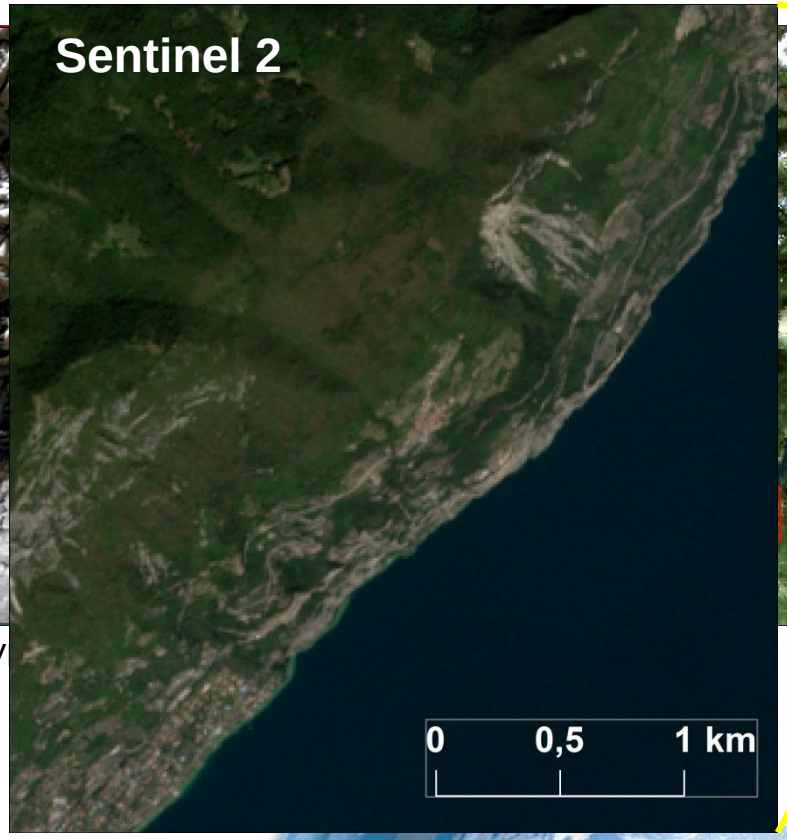
Snow as seen from space

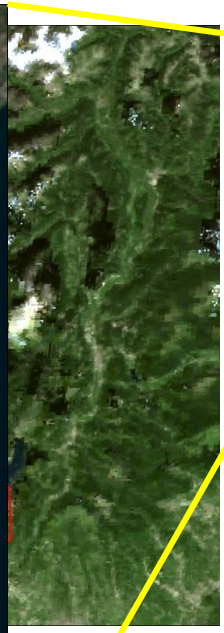


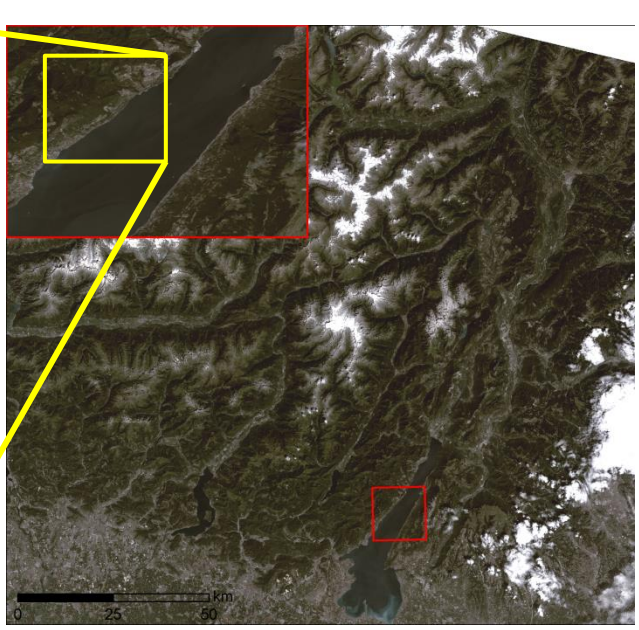
Data Sources

Different sensors and their resolutions in a quick overview: Even though a higher spatial resolution would be desired, the increased processing effort and the lack of daily data make it unfeasible to rely on Landsat (or Sentinel 2). Therefore, MODIS (and Sentinel 3 in the future) is the ideal choice.

AV

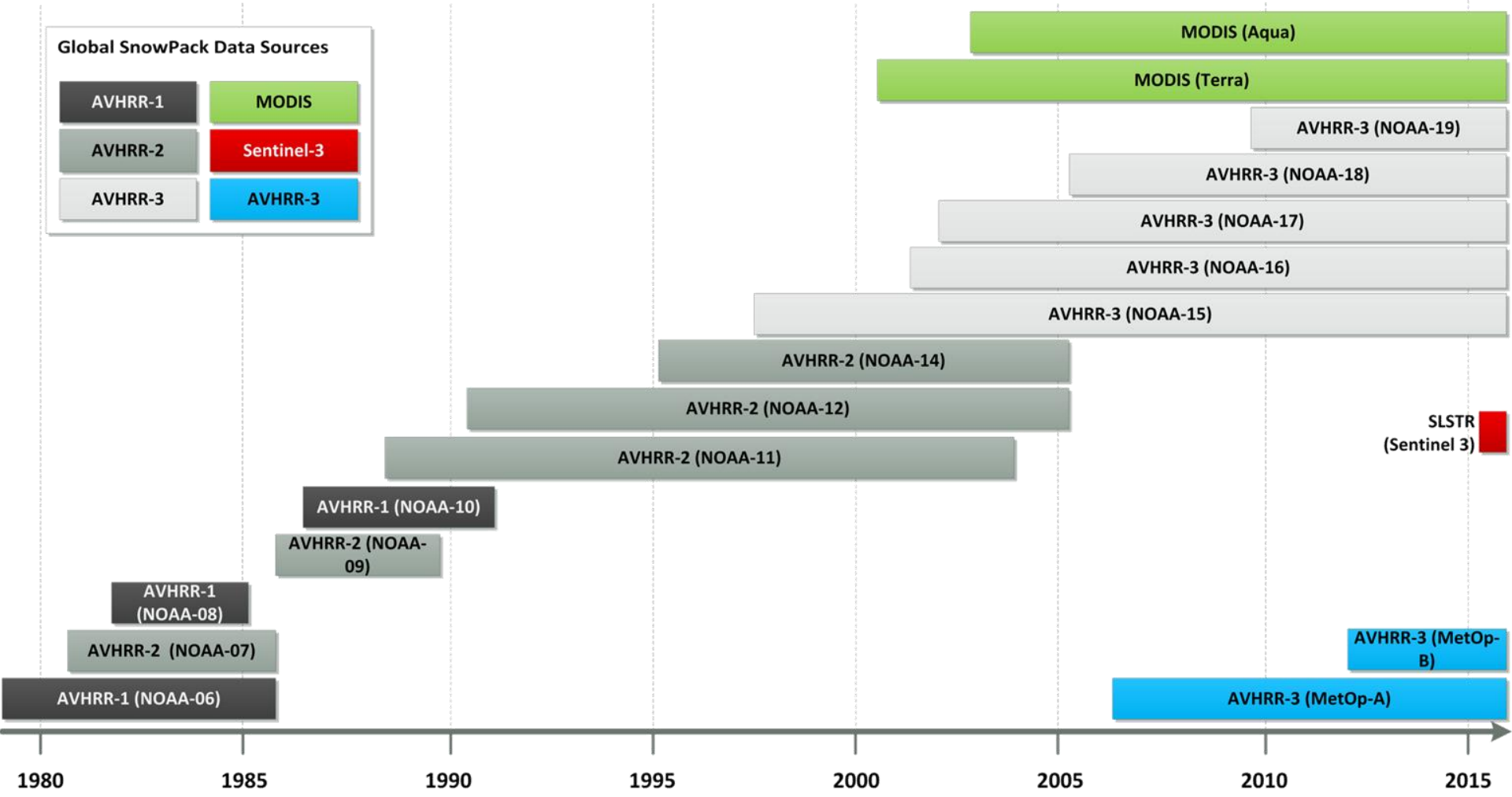






Landsat 8

Data Sources and Data Availability



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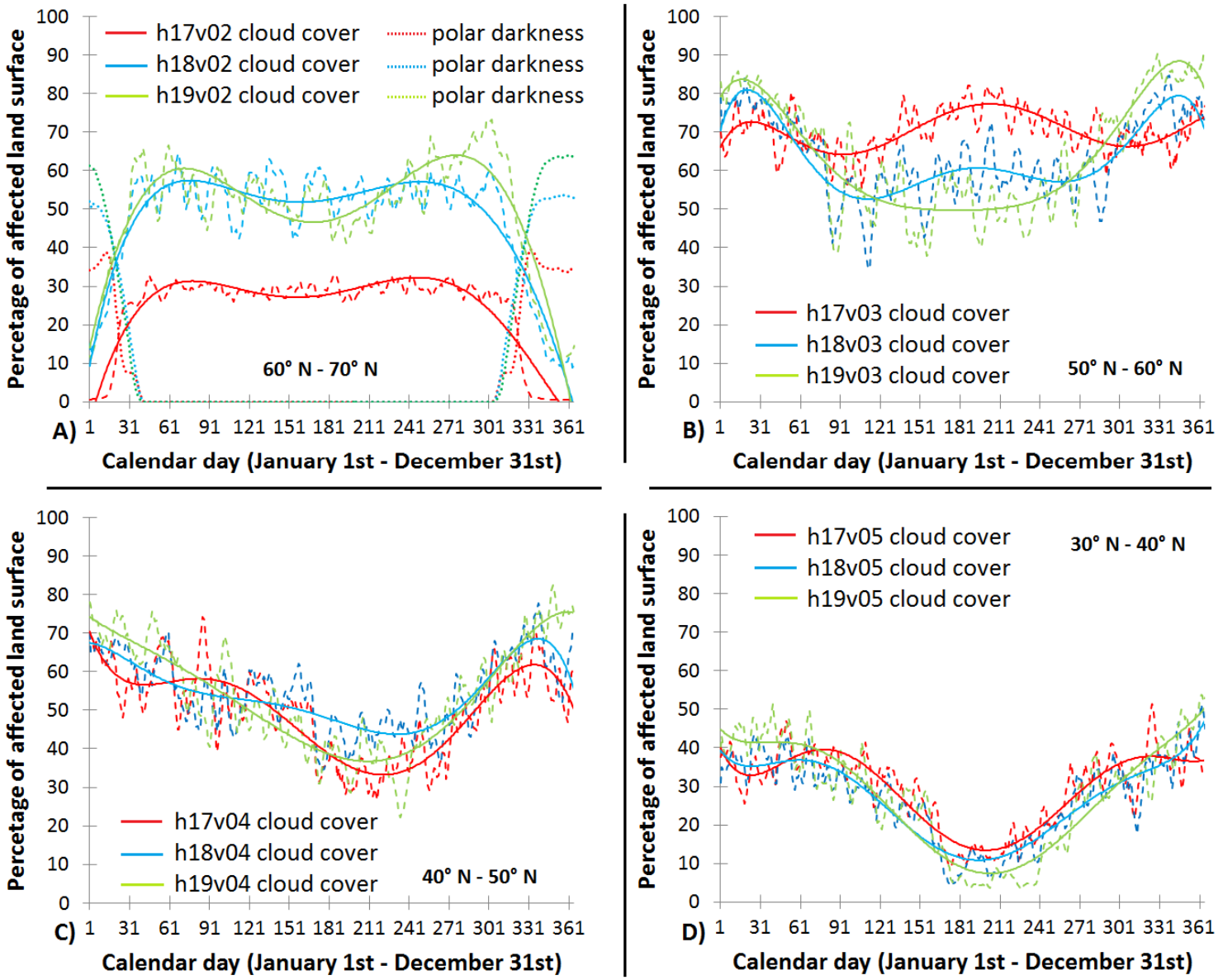
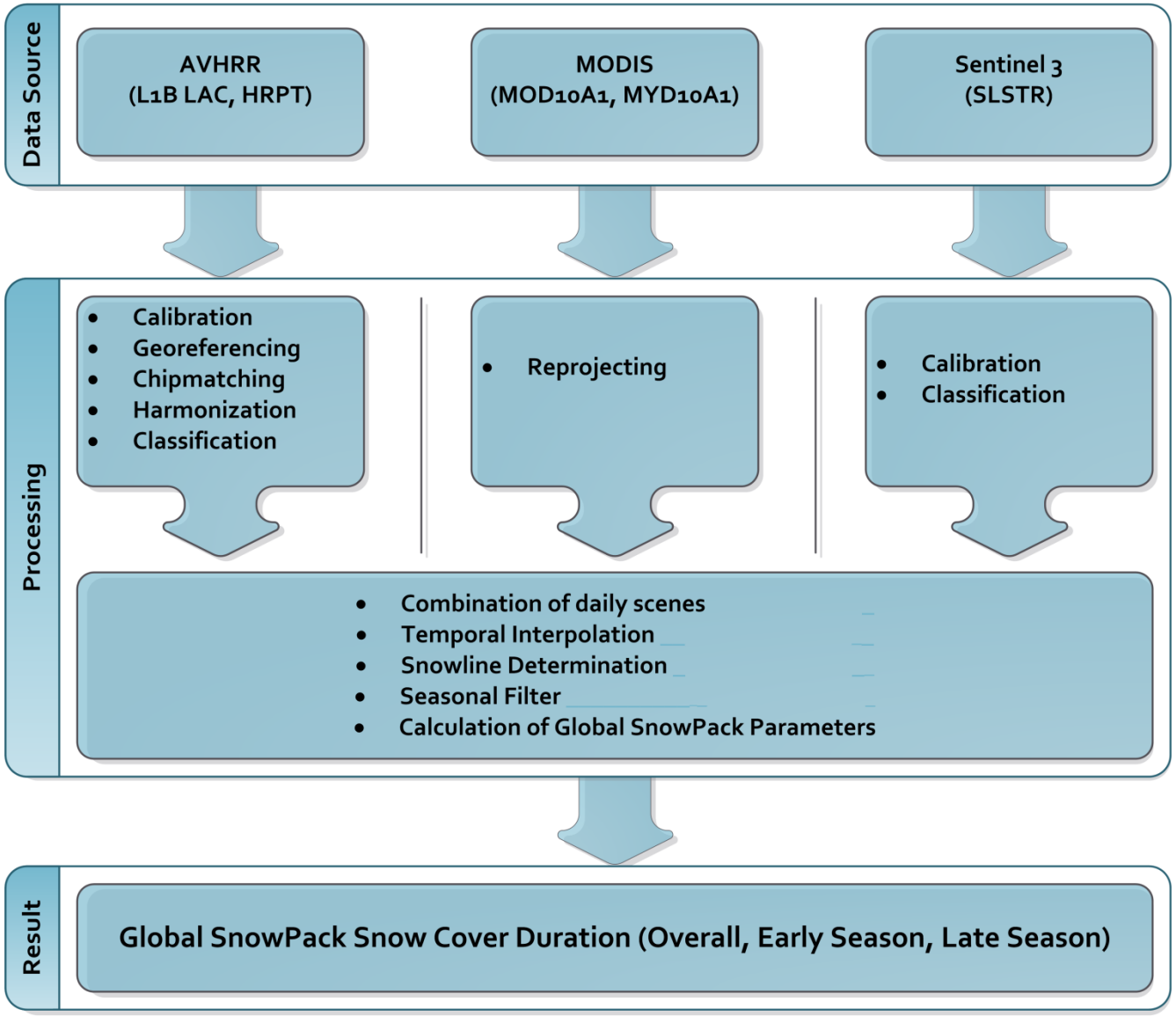
Challenge for optical data: Cloud coverage

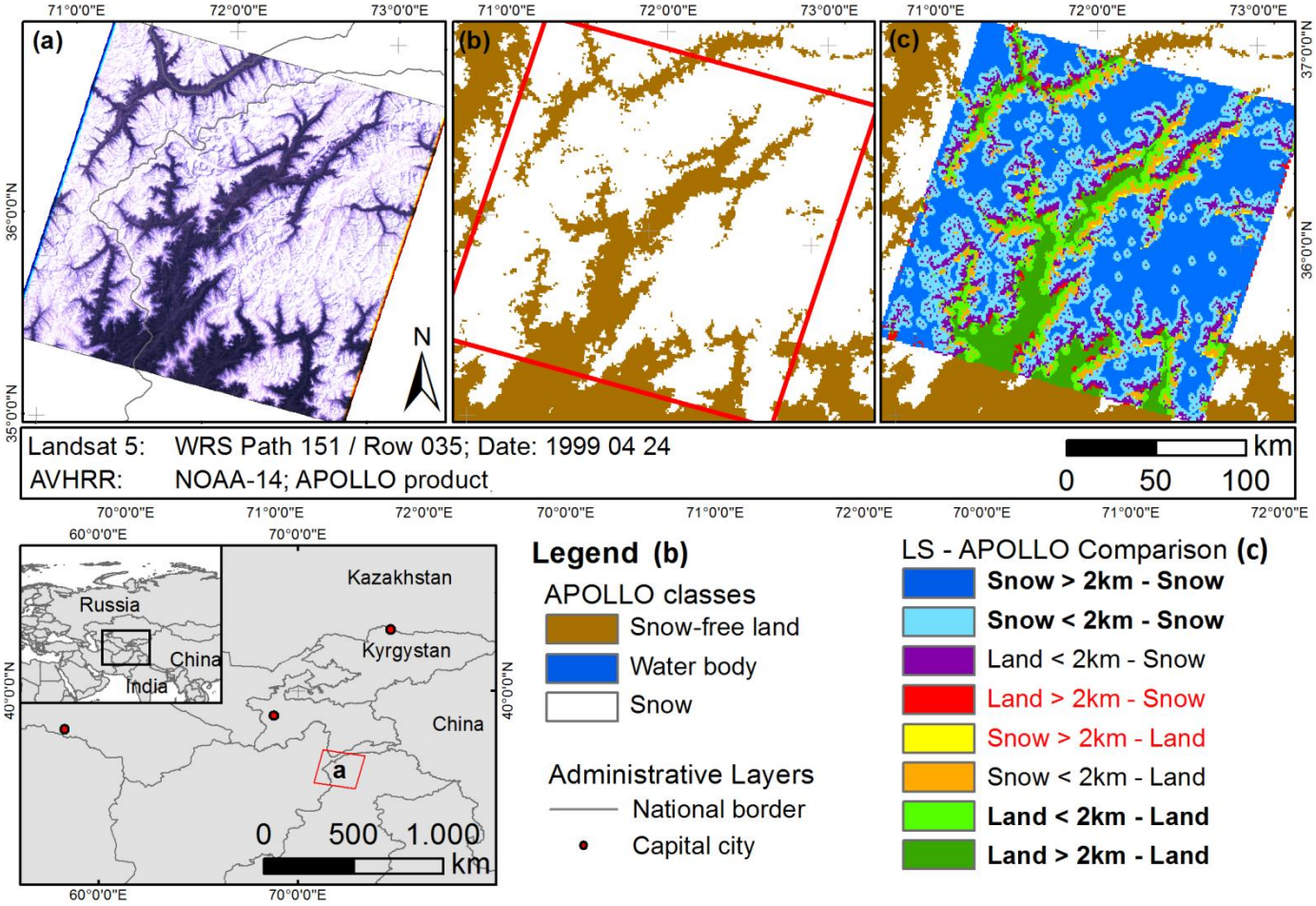


Processing Workflow



Methods – accuracy assessment

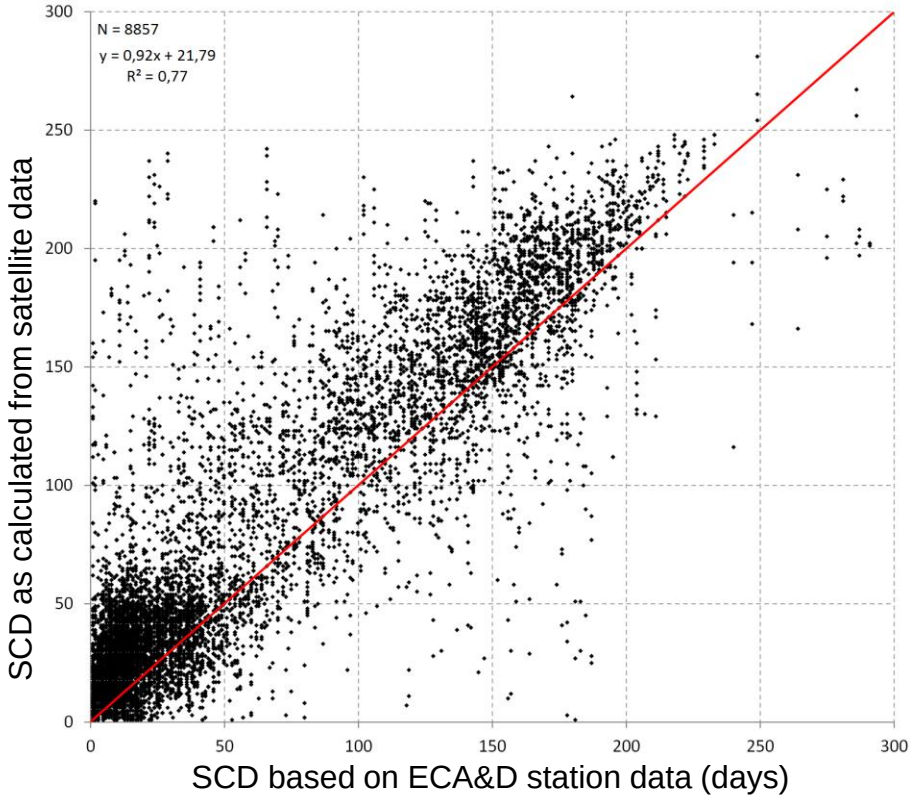
Validation of AVHRR snow cover for Central Asia: Landsat image on the left, AVHRR snow cover product in the middle, comparison between both products on the right

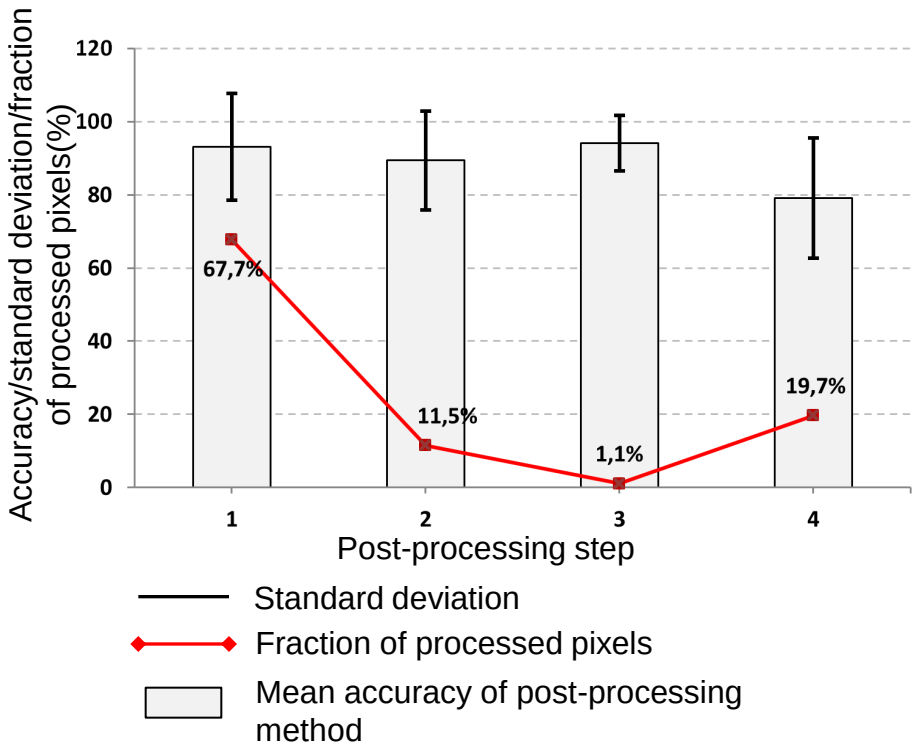


Methods – accuracy assessment

Accuracy assessment of post-processing steps relying on 2 methods:

- Comparison with station data (not available everywhere)
- Simulation of cloud cover in cloud-free scenes and subsequent cloud-removal





Methods

Calculation of snow cover parameters

- Snow cover duration (SCD)

$$SCD = \sum_{i=1}^{n} (s_i)$$

- Early Season SCD (SCD_{ES})

$$SCD_{ES} = Fd - SCD_{bFd}$$

- Late Season SCD (SCD_{LS})

$$SCD_{LS} = Fd + SCD_{aFd}$$

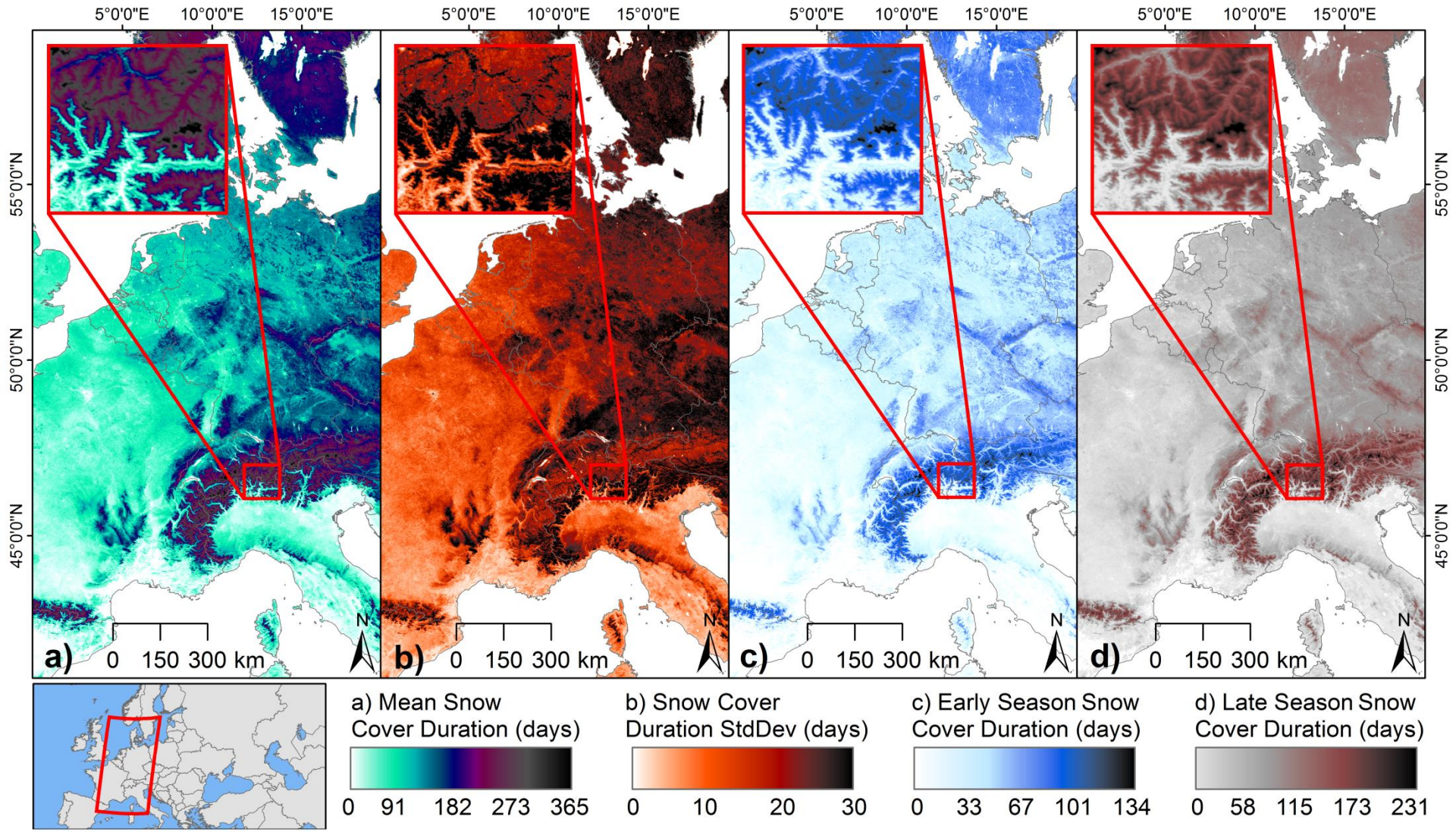
n: number of observations (beginning on Sept. 1st of a year and ending on Aug. 31st of the following year)

s: cloud-free snow cover dataset

Fd: Date of maximum snow cover extent (Jan. 15th for Central Asia)

bFd/aFd: SCD before (bFd) and after (aFd) the date of maximum snow cover extent

Global SnowPack – overview of all products



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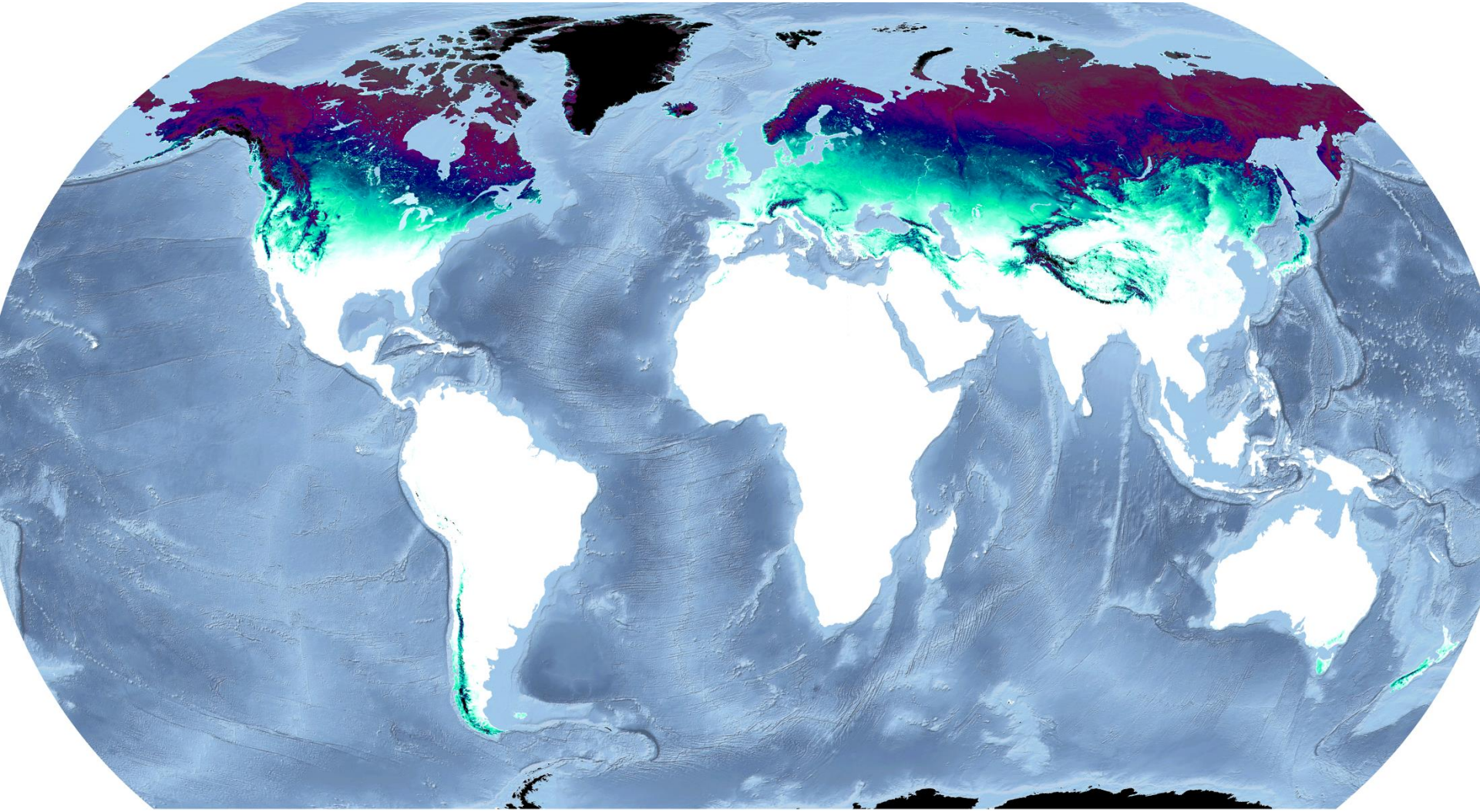
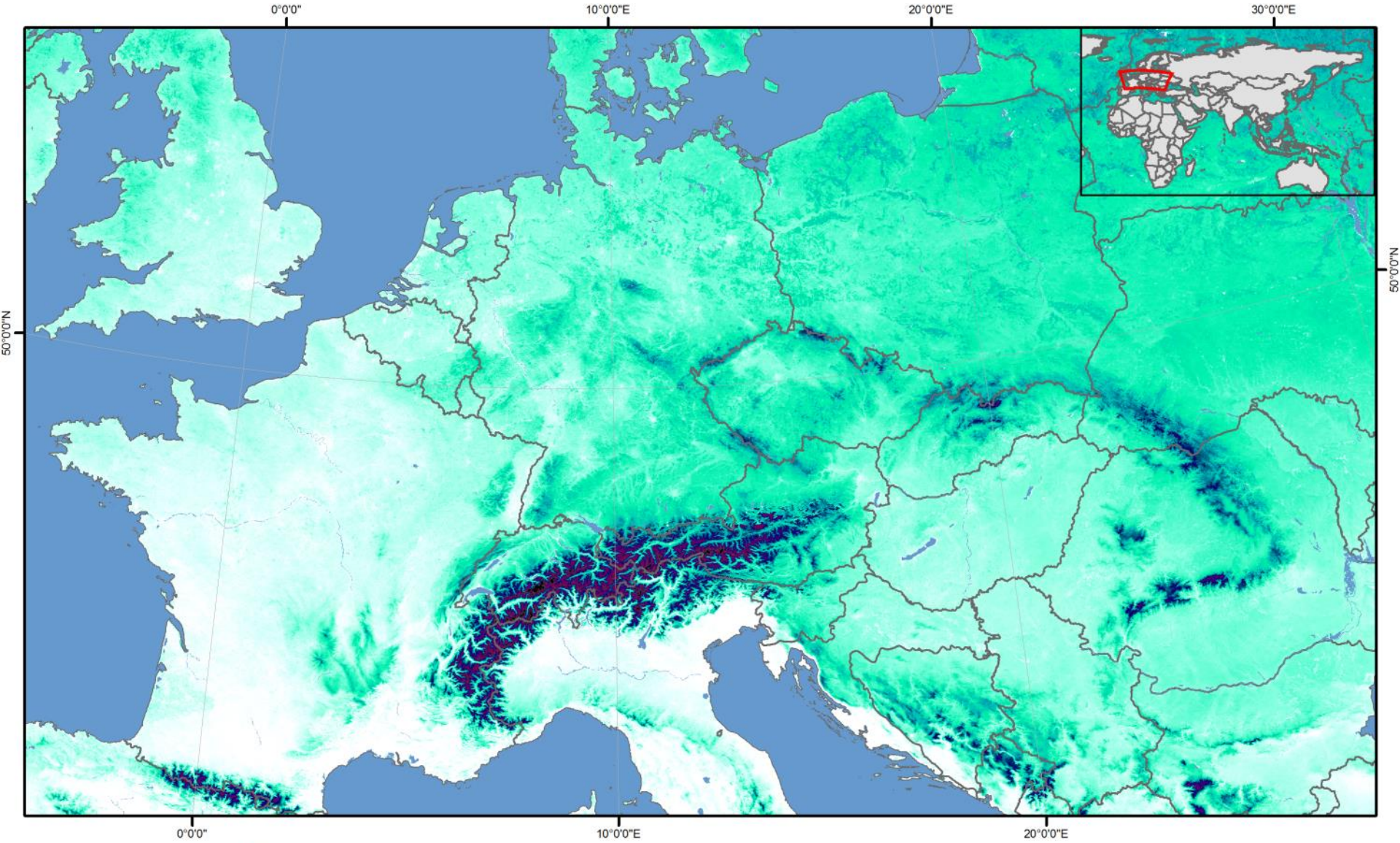
Global SnowPack

Mean Snow Cover Duration 2000-2016



Global SnowPack

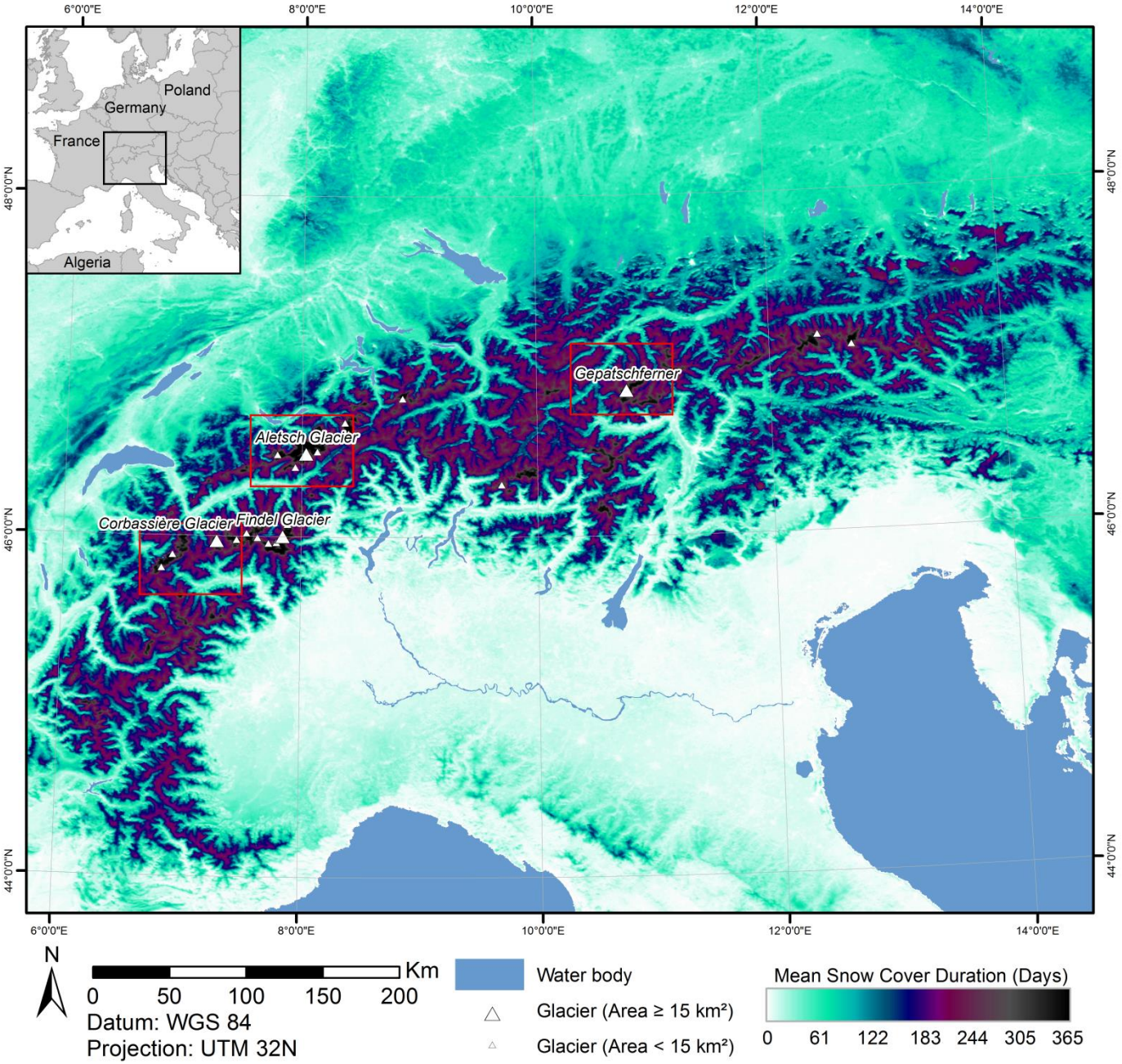


Km
0 200 400
Projection:
Gauss Kruger PD 83 Zone 3

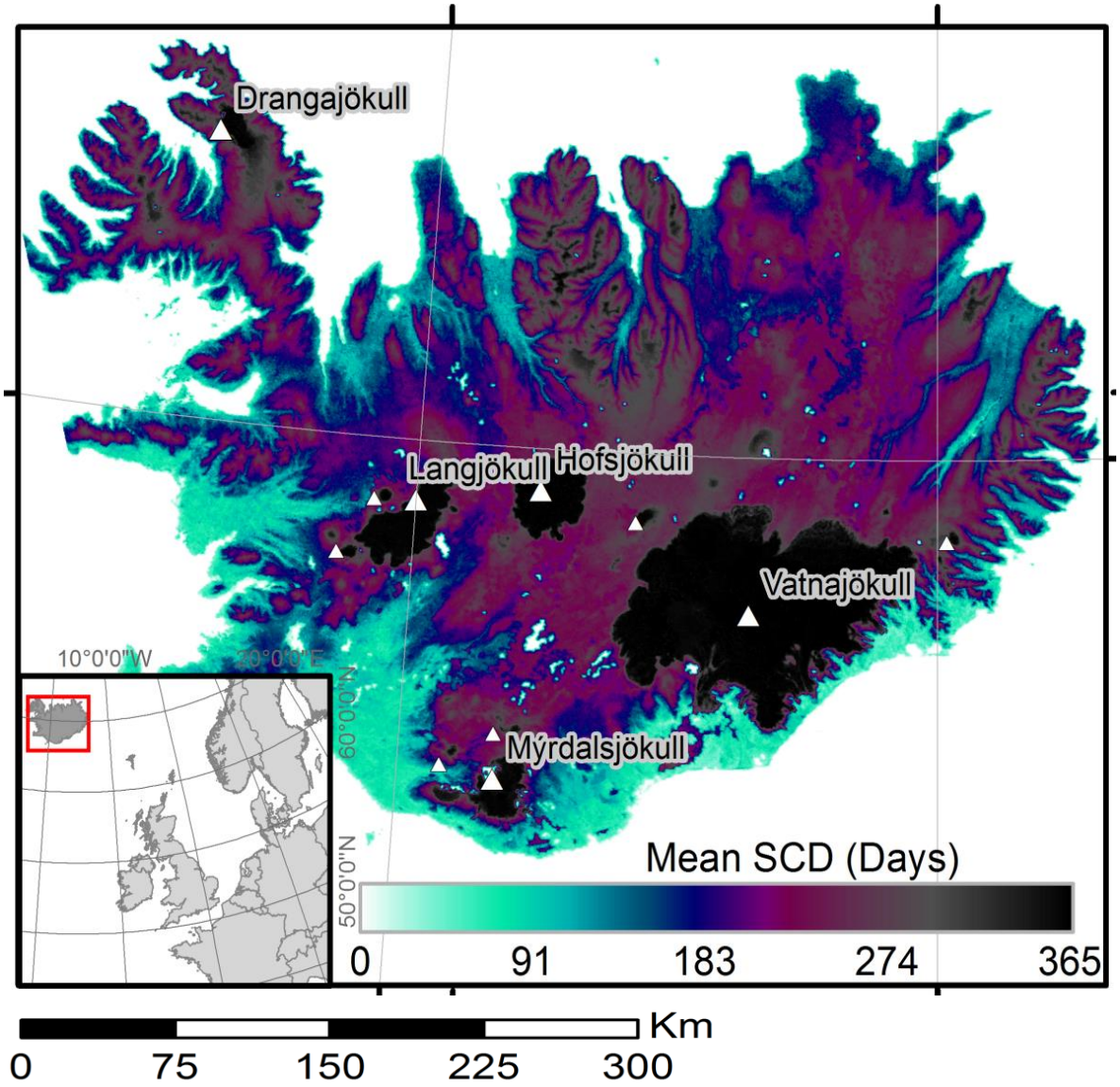
Mean Snow Cover Duration (Days)
0 61 122 183 244 305 365

National Border

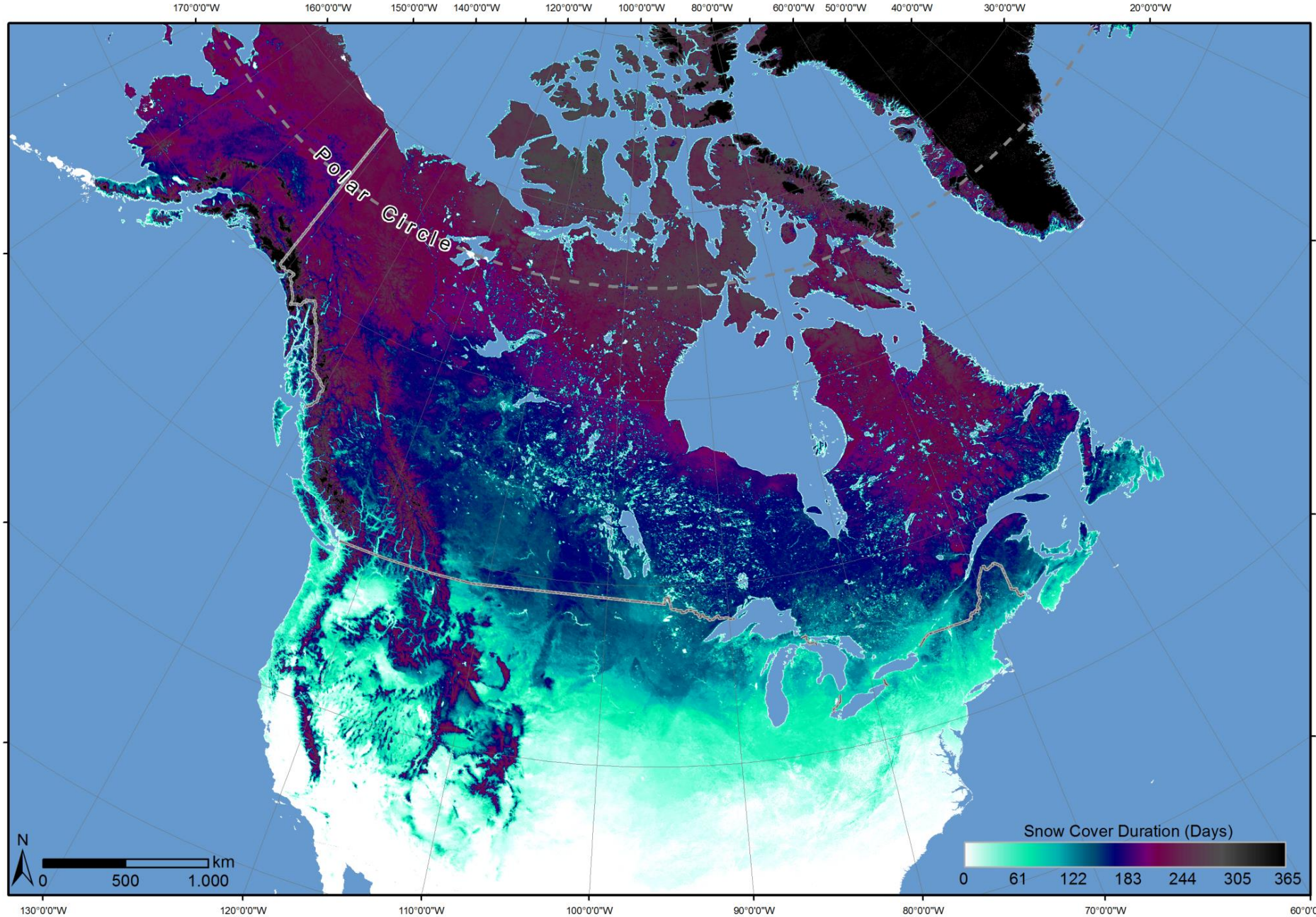
Global SnowPack



Global SnowPack



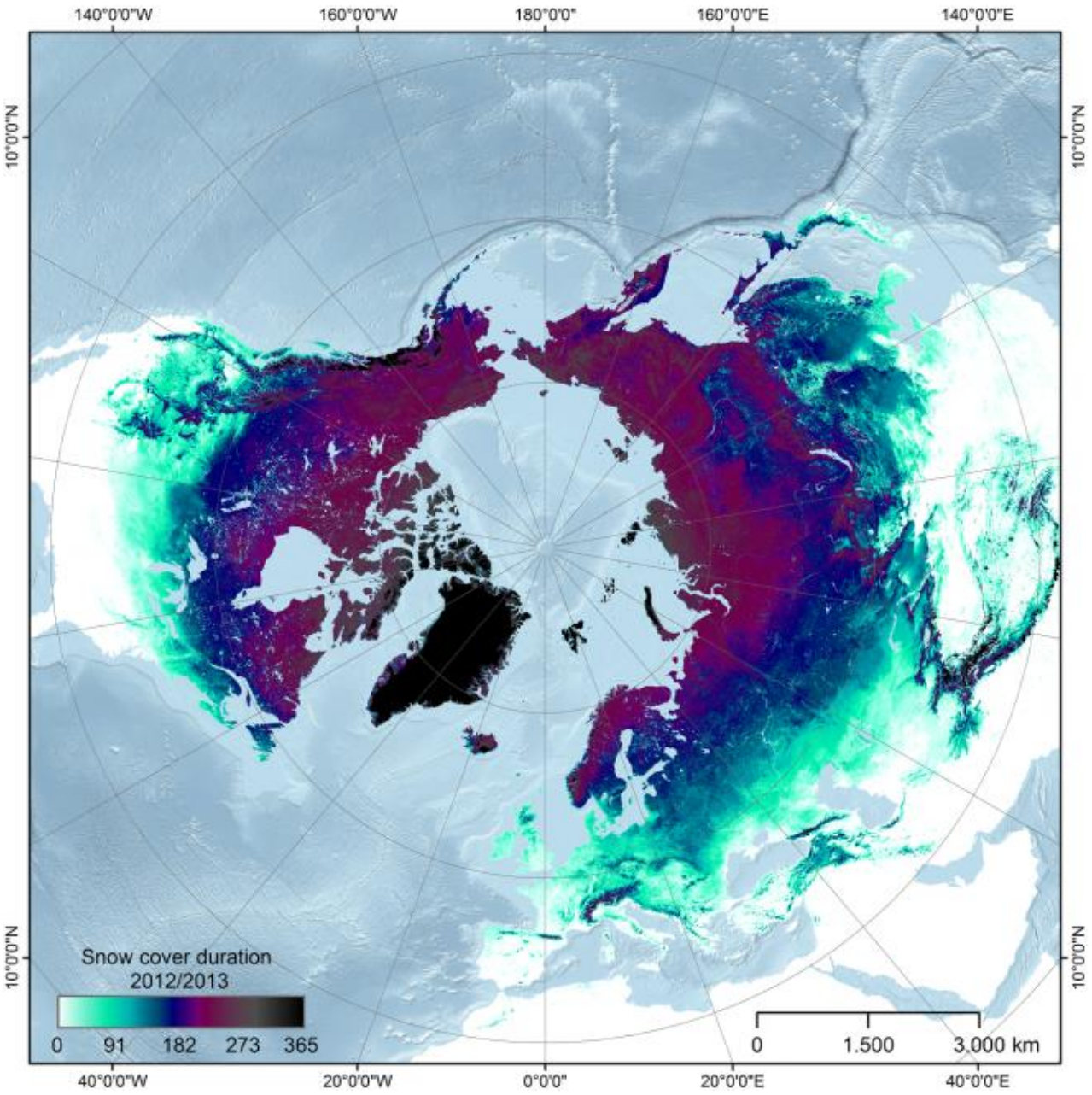
Global SnowPack



Global SnowPack

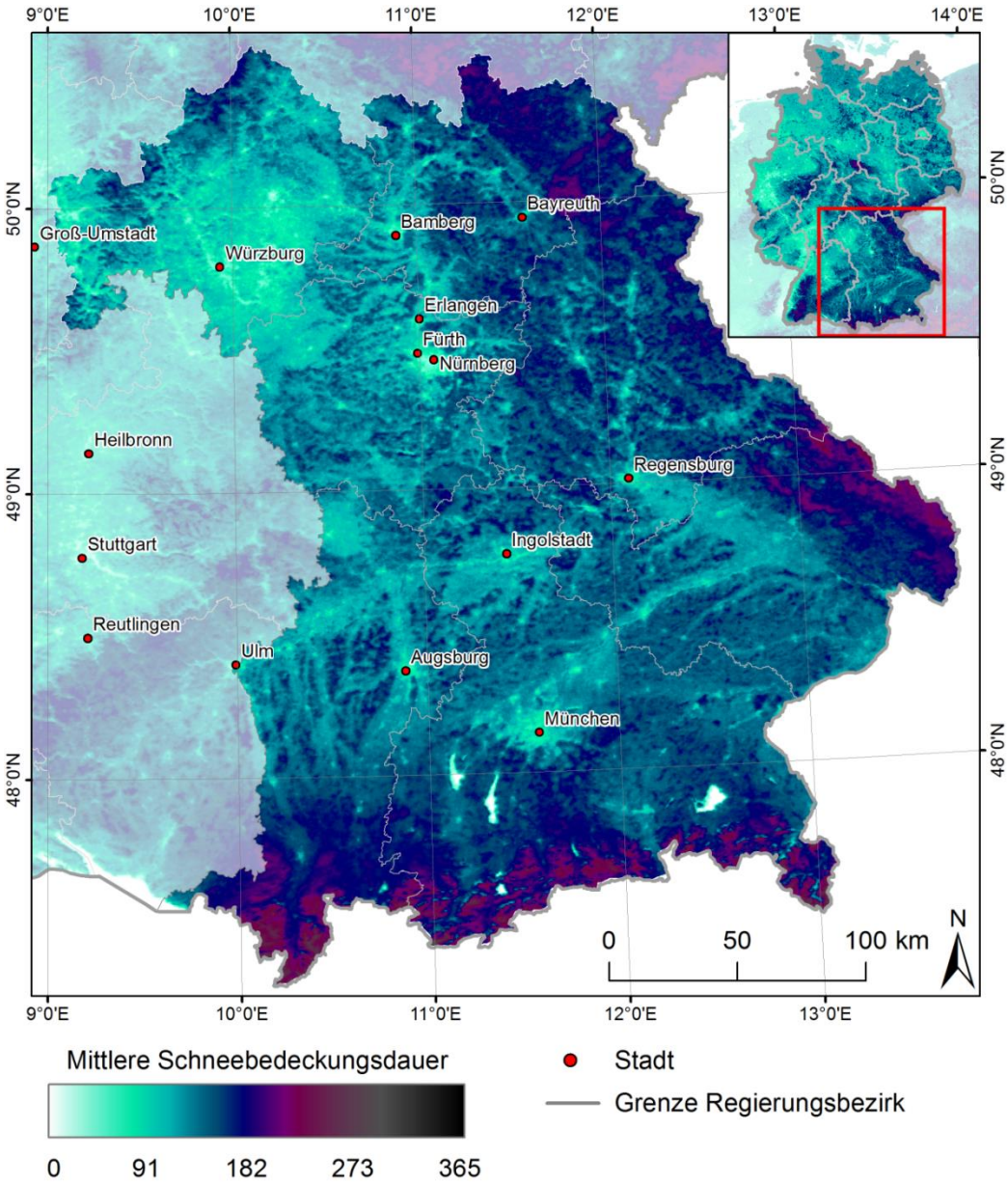
Attributes:

- 500m spatial resolution
- Daily snow cover information
- Products: Snow cover duration, Early Season SCD, Late Season SCD, Standard Deviation on a global scale
- Consistent since 2000
- Processing of AVHRR time series under development (1km spatial resolution, daily data since ~ 1985)
- Sentinel 3 data will replace MODIS in the near future

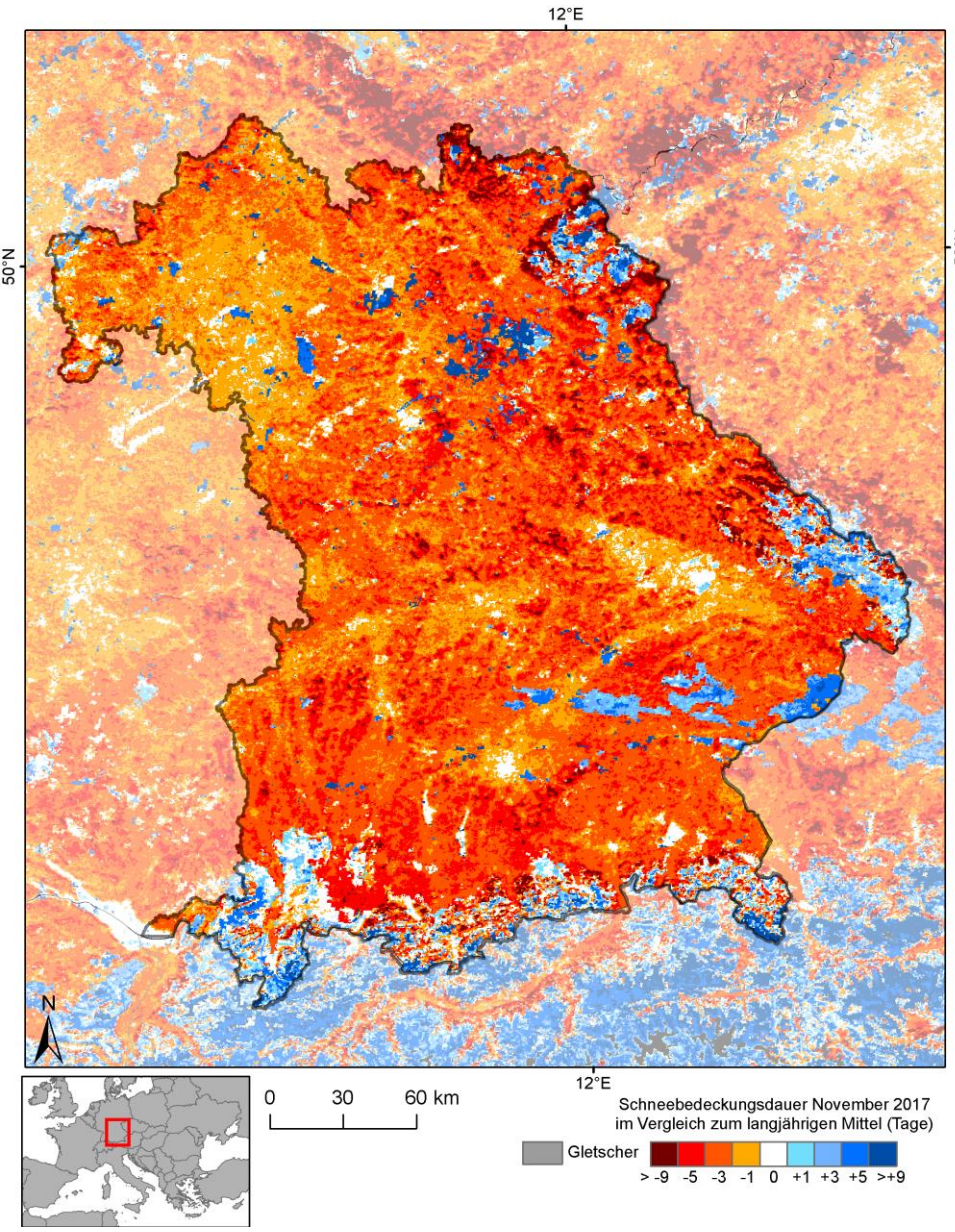


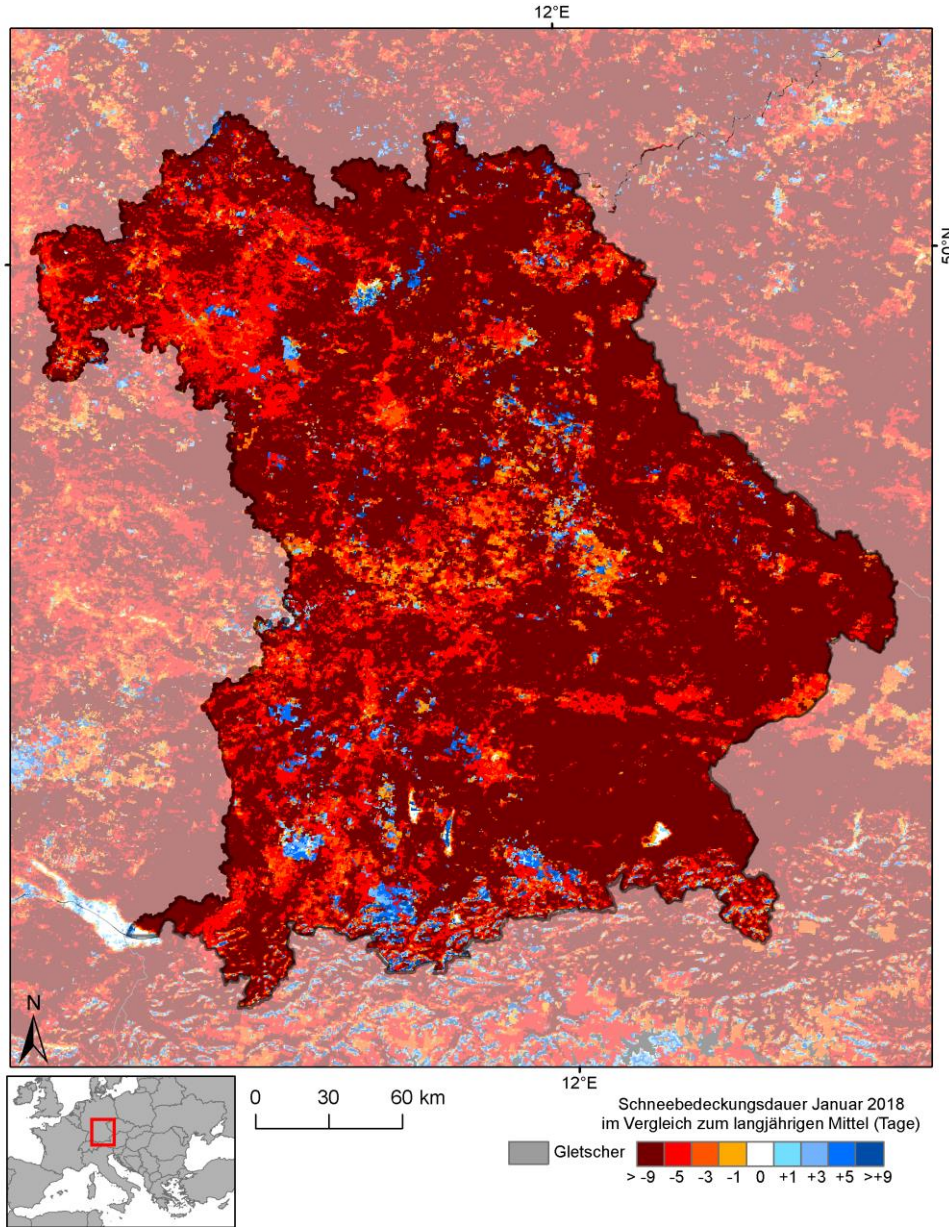
Global SnowPack – Germany, Bavaria

- Mean Snow cover duration in Bavaria is characterized by the effect of mountainous areas.
- Very low SCD in the Middle Main Valley and around the big cities
- Alpine regions as well as the Bavarian Forest, Fichtelgebirge, and Oberpfälzer Forest feature higher SCD



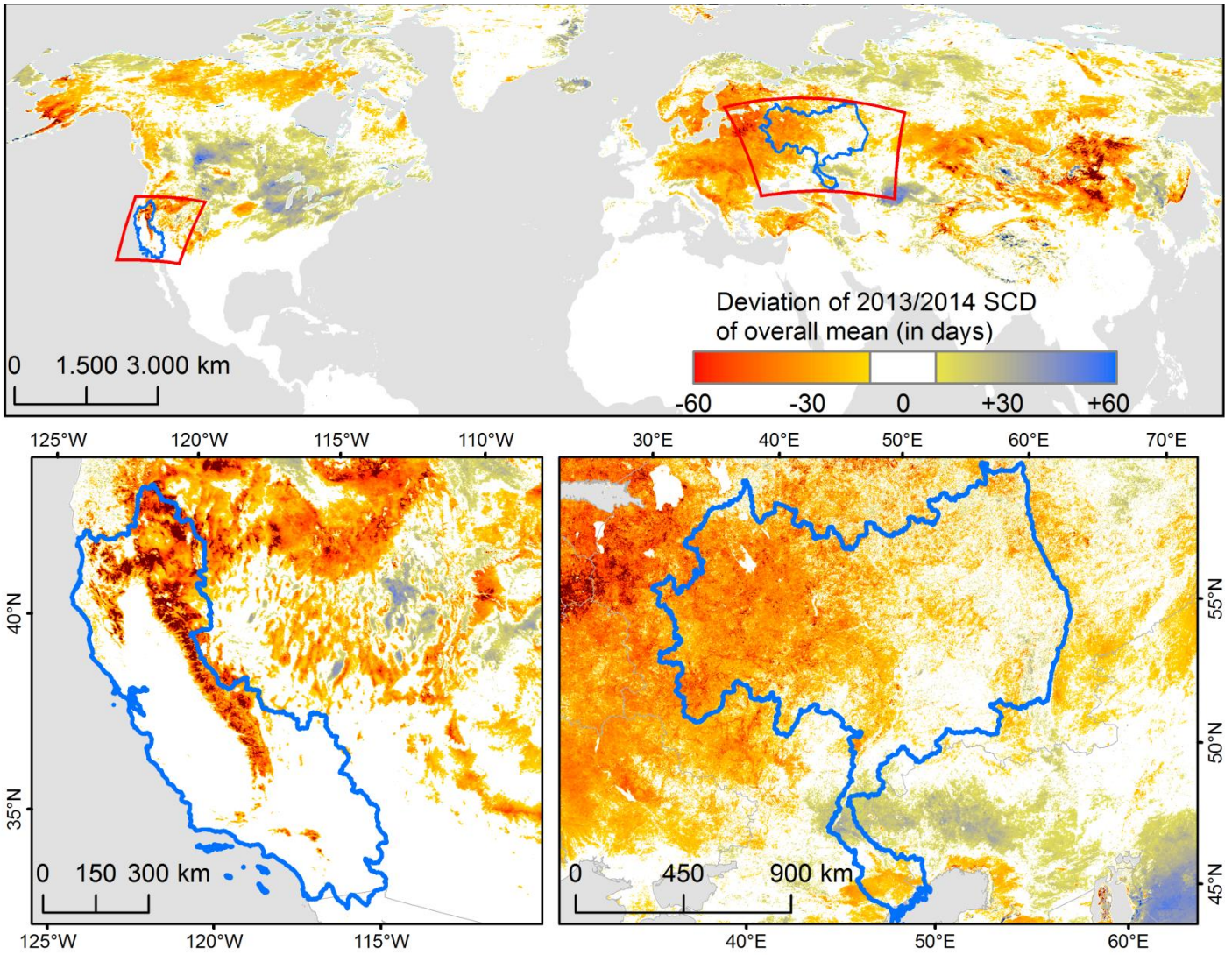
Difference of Snow cover durations November 2017 and January 2018 to the mean conditions





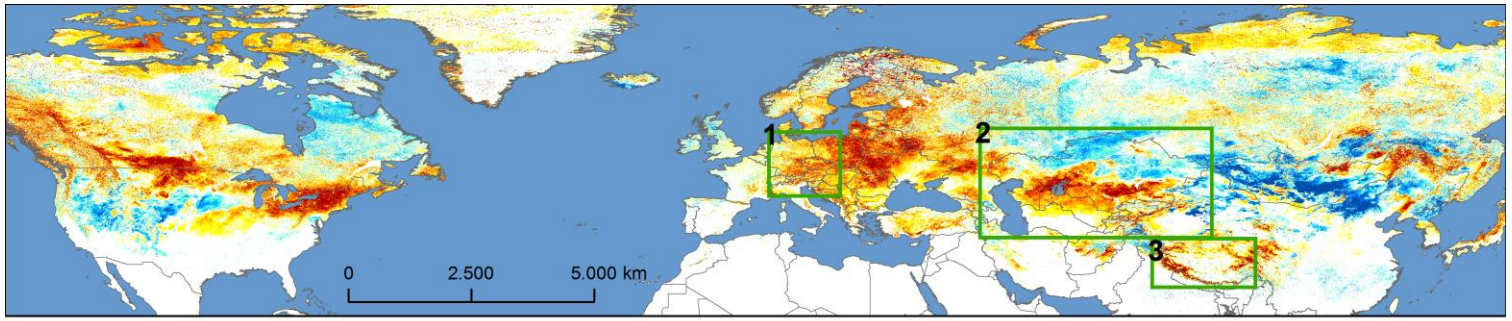
Global SnowPack – World

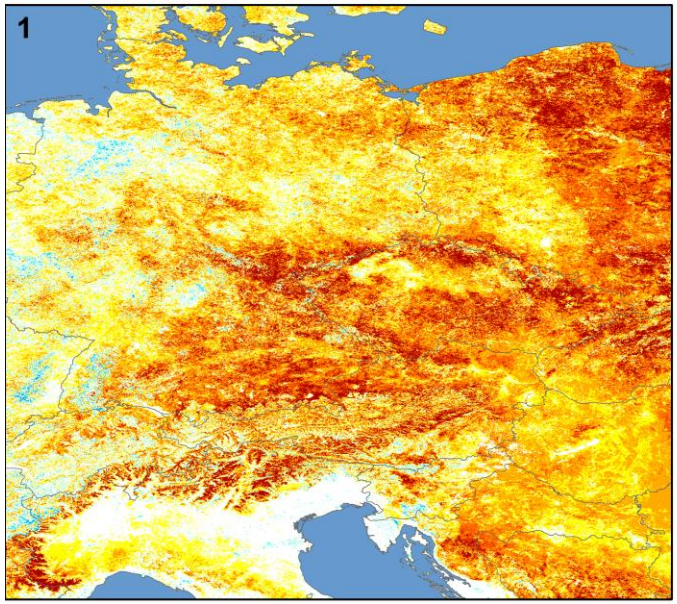
- Difference between SCD 2013/2014 and mean SCD 2000-2013
- Two basins have been selected for a detailed view:
- Volga basin features an overall lower SCD
- California basin also shows very low SCD for the Sierra Nevada – the main source of fresh water in the whole region

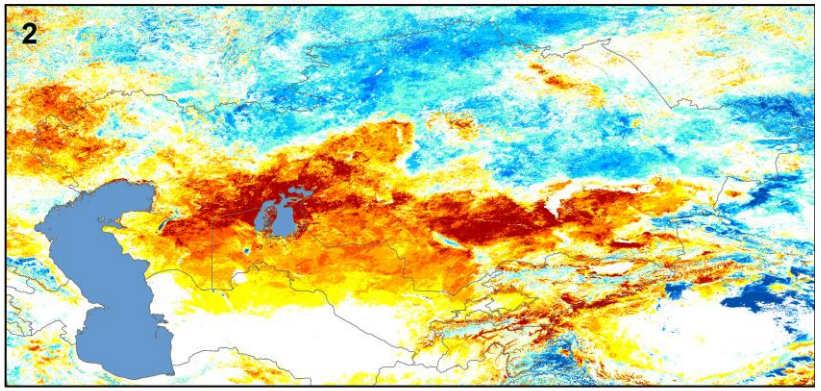


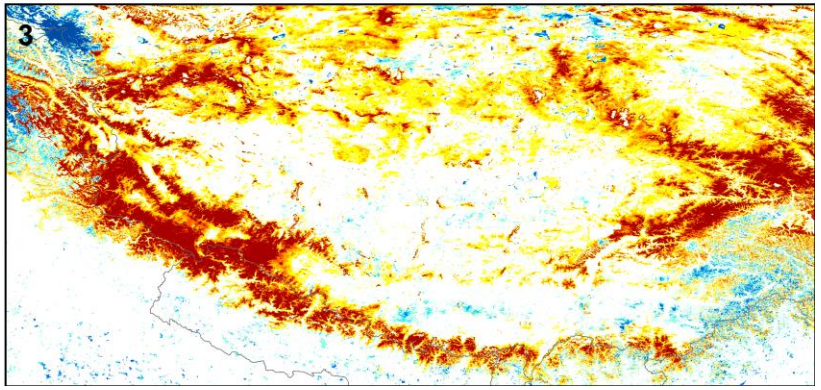
Global SnowPack – World

- Difference between SCD 2015/2016 and mean SCD 2000-2015
- Very low SCD in parts of Europe, Central Asia, Tibet Plateau/ Himalaya.
- High SCD in Central USA, Mongolia, Central Siberia, Northern Central Asia







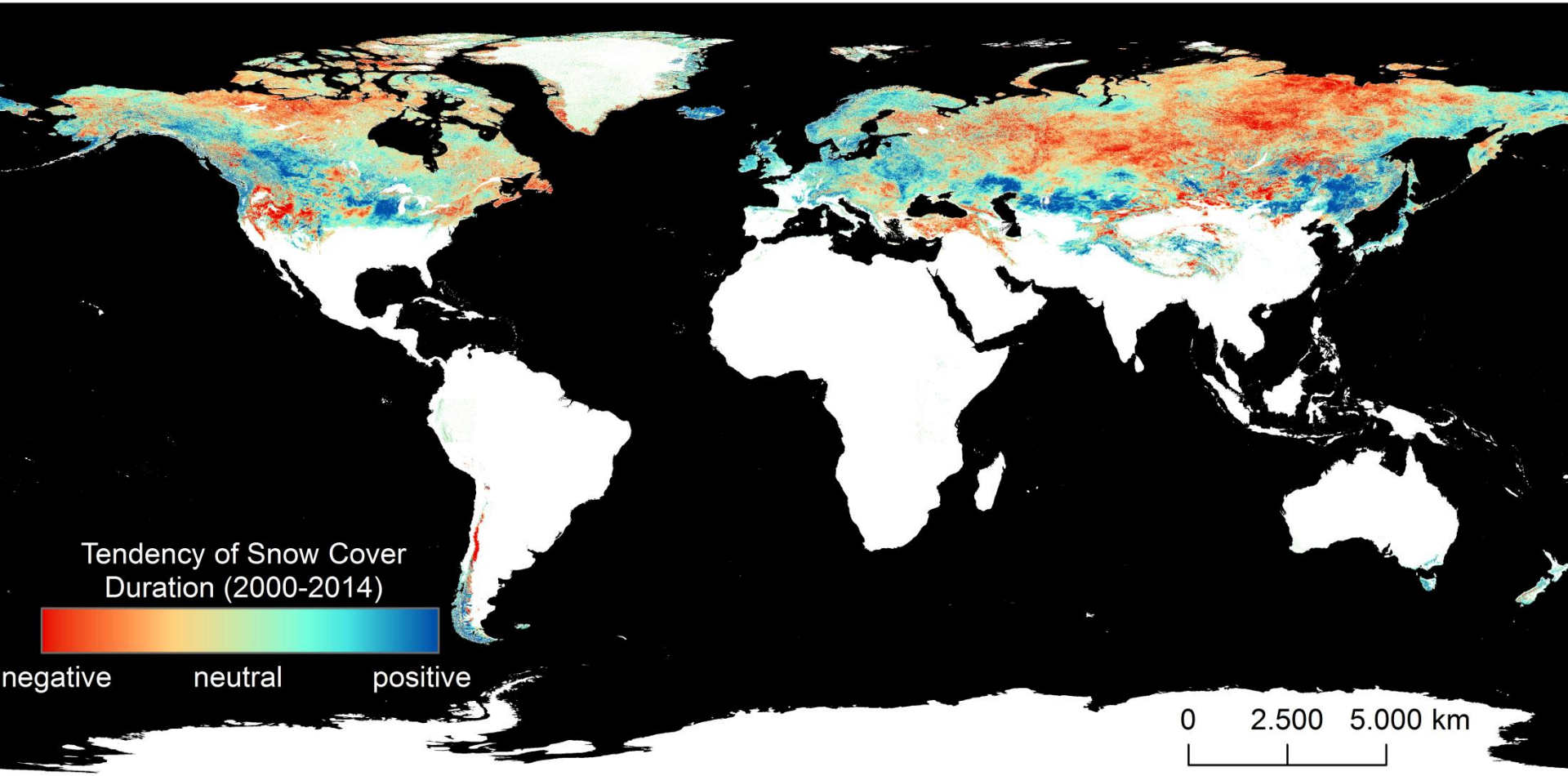


Snow cover duration 2015/2016 compared to mean (days)

< -40	-19,9 - -10	20,1 - 30
-39,9 - -30	-9,9 - 10	30,1 - 40
-29,9 - -20	10,1 - 20	> 40,1

Global SnowPack – World

Tendency of global SCD between 2000/2001 and 20014/2015



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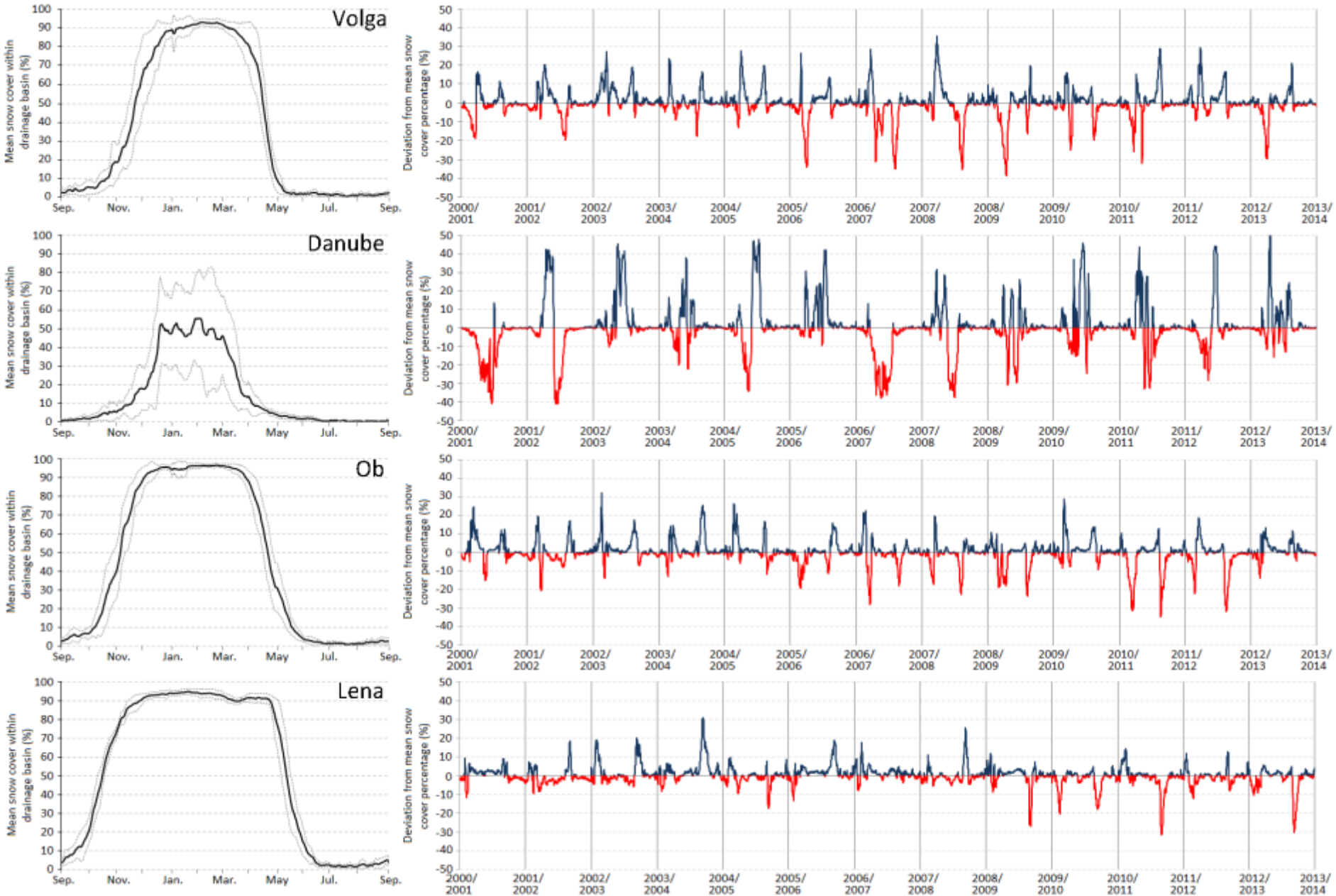
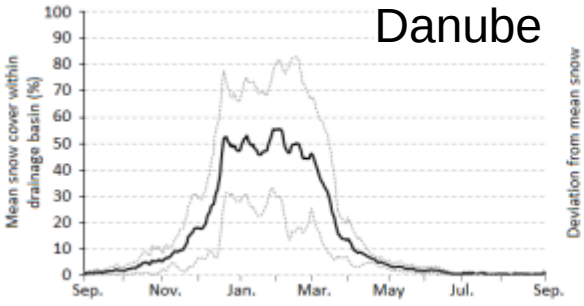
Global SnowPack – Hydrology

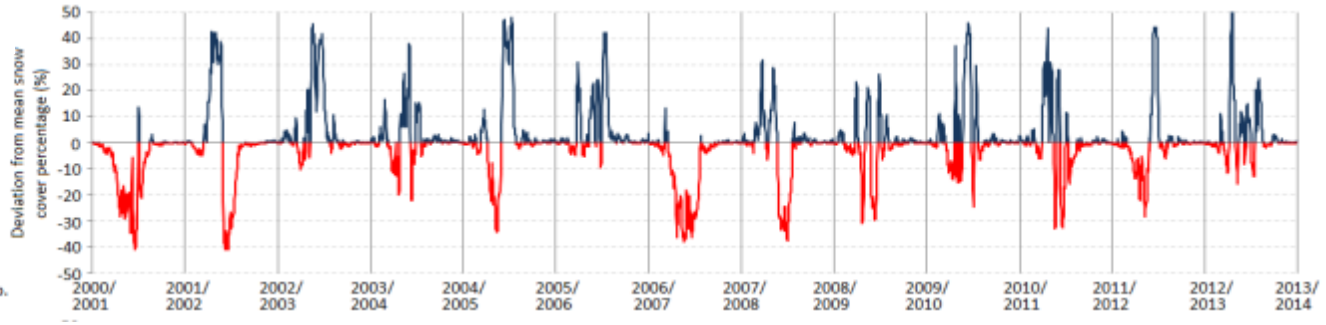


Global SnowPack – Hydrology

Observation of daily snow cover can help analyzing and predicting possible events within river catchments.

- Many rivers worldwide (more than 50% within Northern Hemisphere) are dominated by snowmelt runoff
- Abrupt changes in snow cover percentages within a river basin can lead to flood events.
- Analyzing the long term development within each catchment can help identifying possible trends in snow cover characteristics and therefore, future runoff regimes





Global SnowPack – Temporal development

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Global SnowPack available as WMS service

GLOBAL SNOWPACK

- Statistical products are available from the WMS of EOC Geoservice:
- https://geoservice.dlr.de/web/

- Contact: Global-SnowPack@dlr.de
  Andreas.Dietz@dlr.de

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Methods

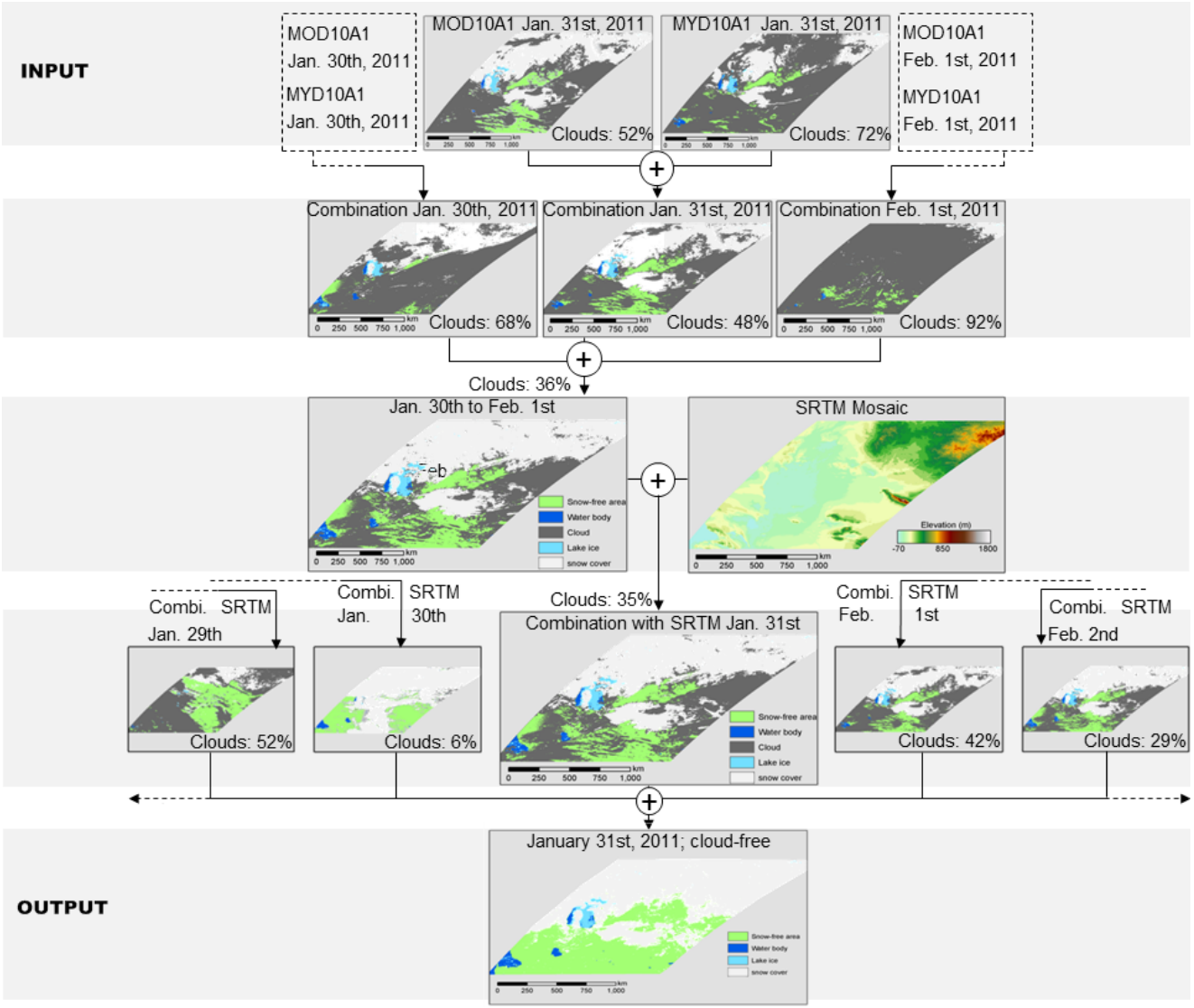
Post-Processing of satellite data time series to be able to estimate the snow cover status below clouds (example for MODIS):

Step 1: Daily mosaic

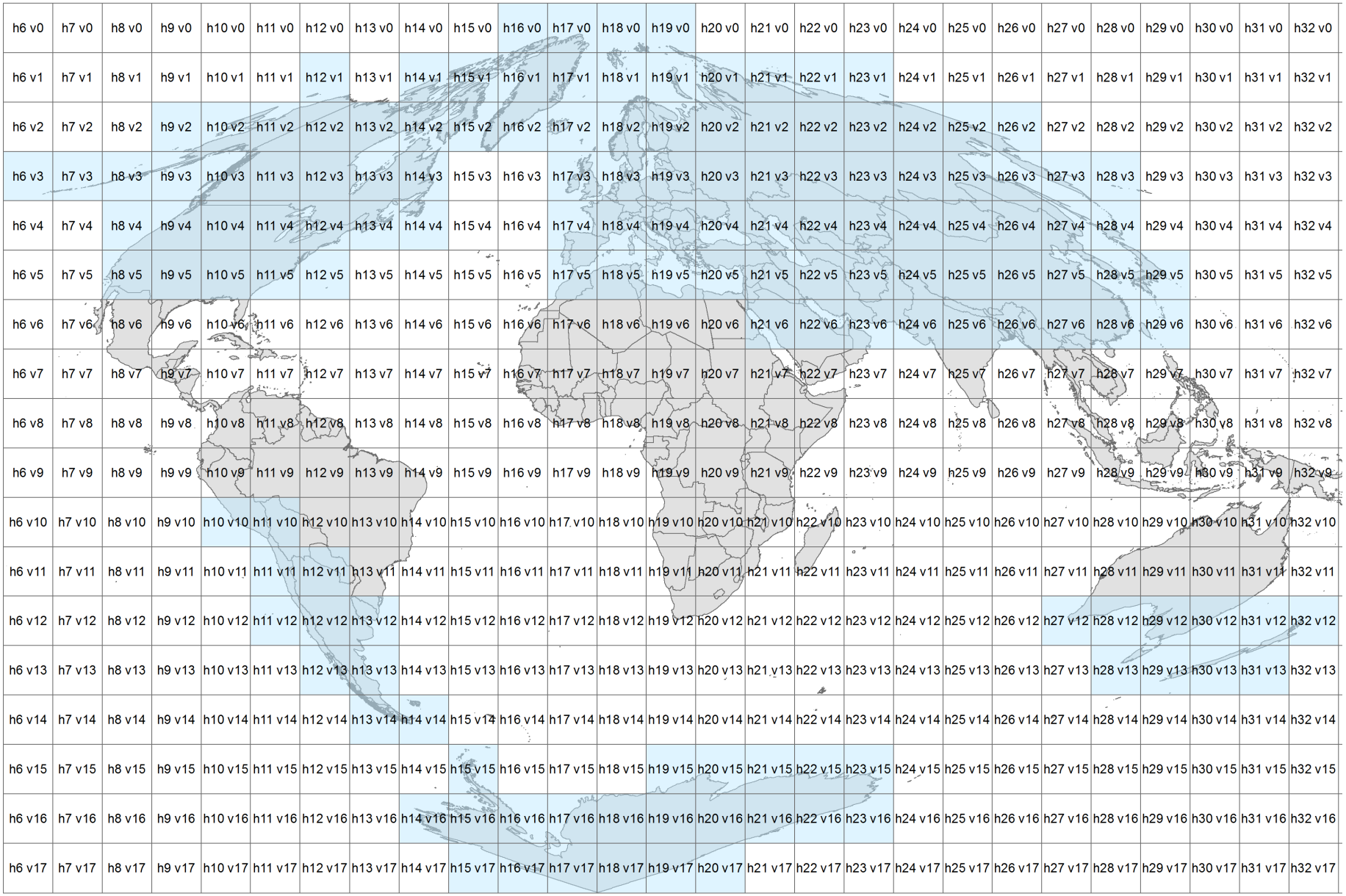
Step 2: Combination of several days

Step 3: Regional snowline detection using a DEM

Step 4: Seasonal filter



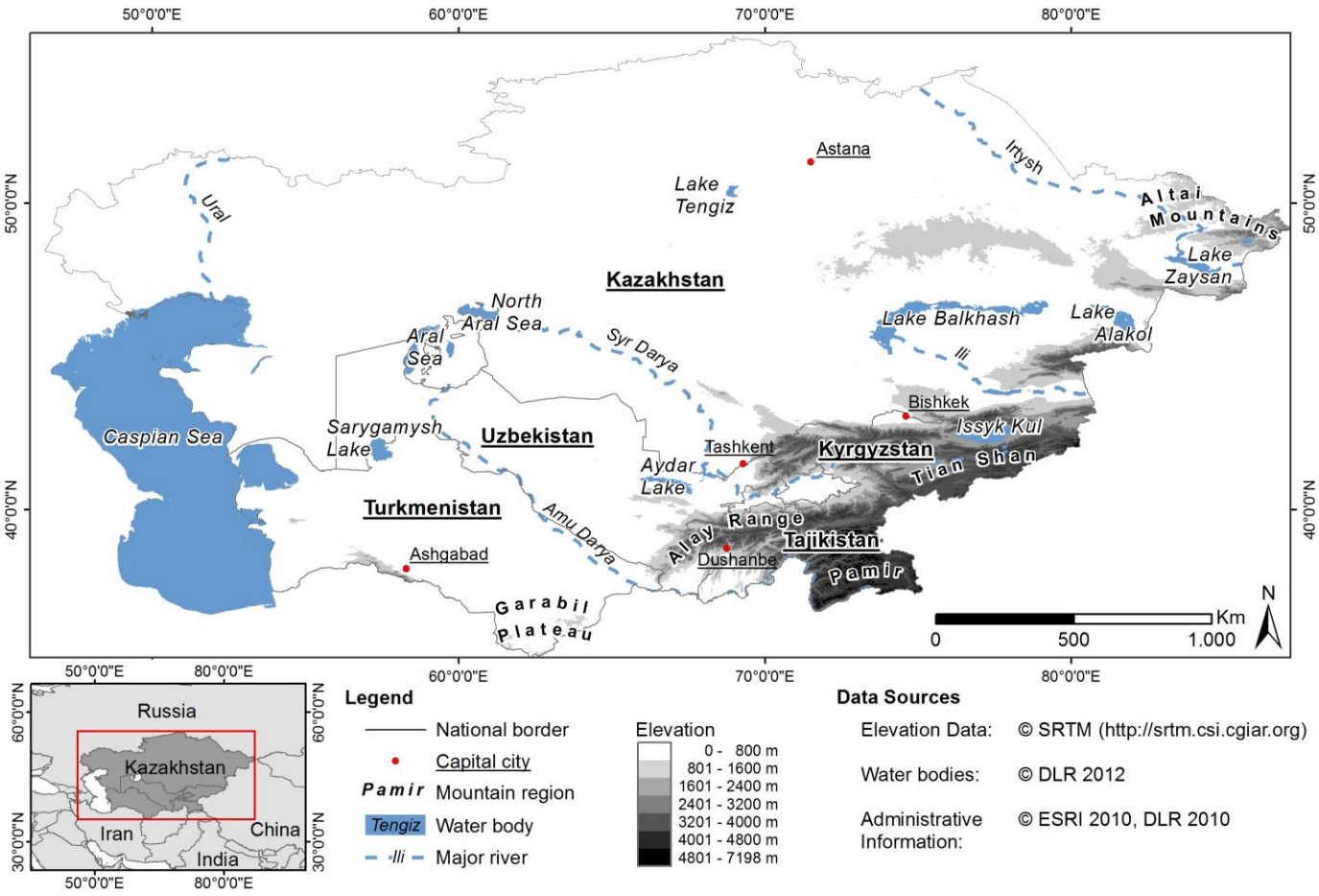
MODIS tiles included in the Global SnowPack



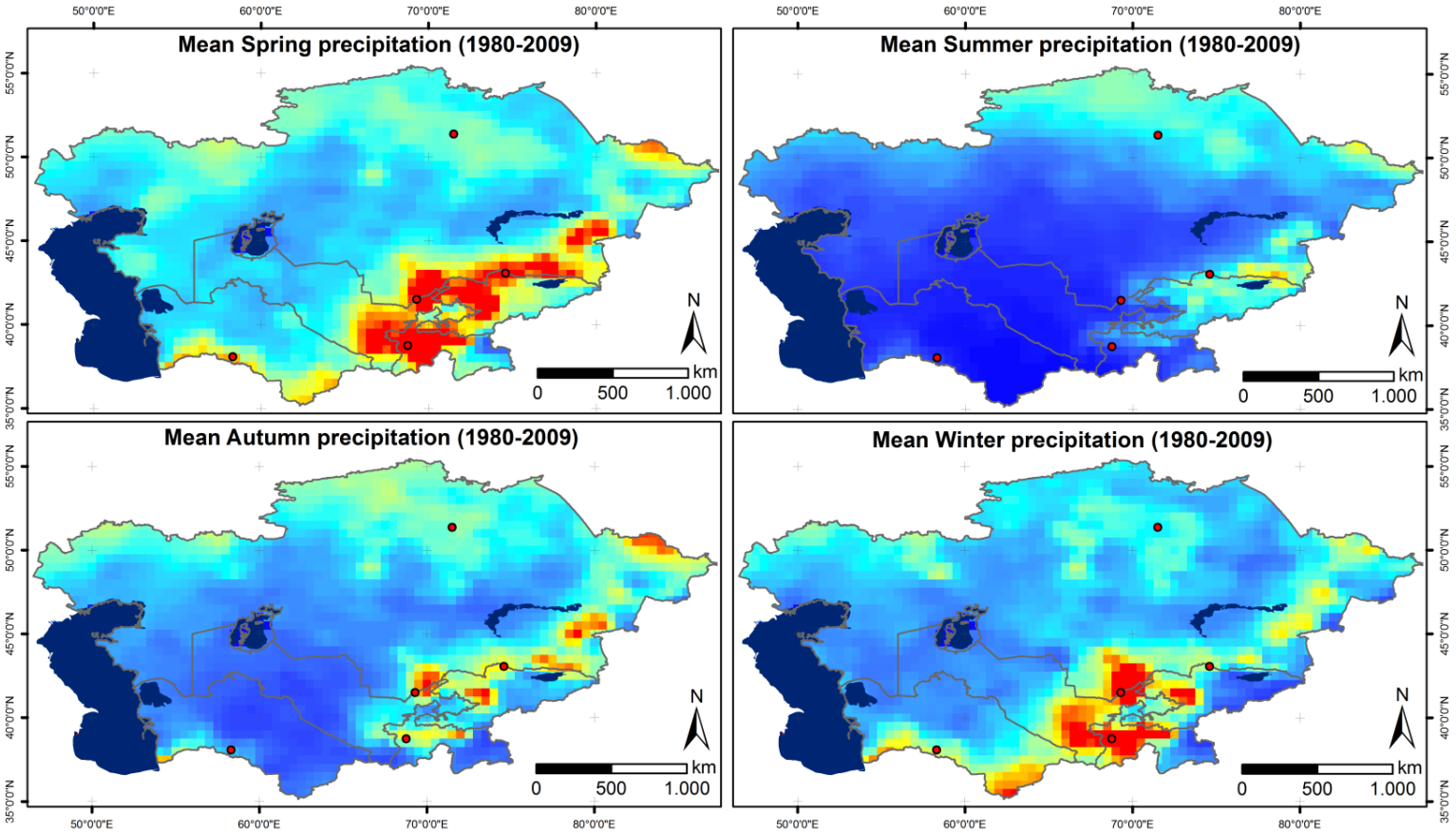
Global SnowPack – Central Asia

Central Asia – general aspects

- Continental climate
- Arid summer, precipitation only during winter and spring
- Aral Sea Disaster
- Irrigation along Amu Darya and Syr Darya
- Political conflicts between countries
- Population growth and increasing demand for water
- Snow cover is the main source for water



Global SnowPack – Central Asia



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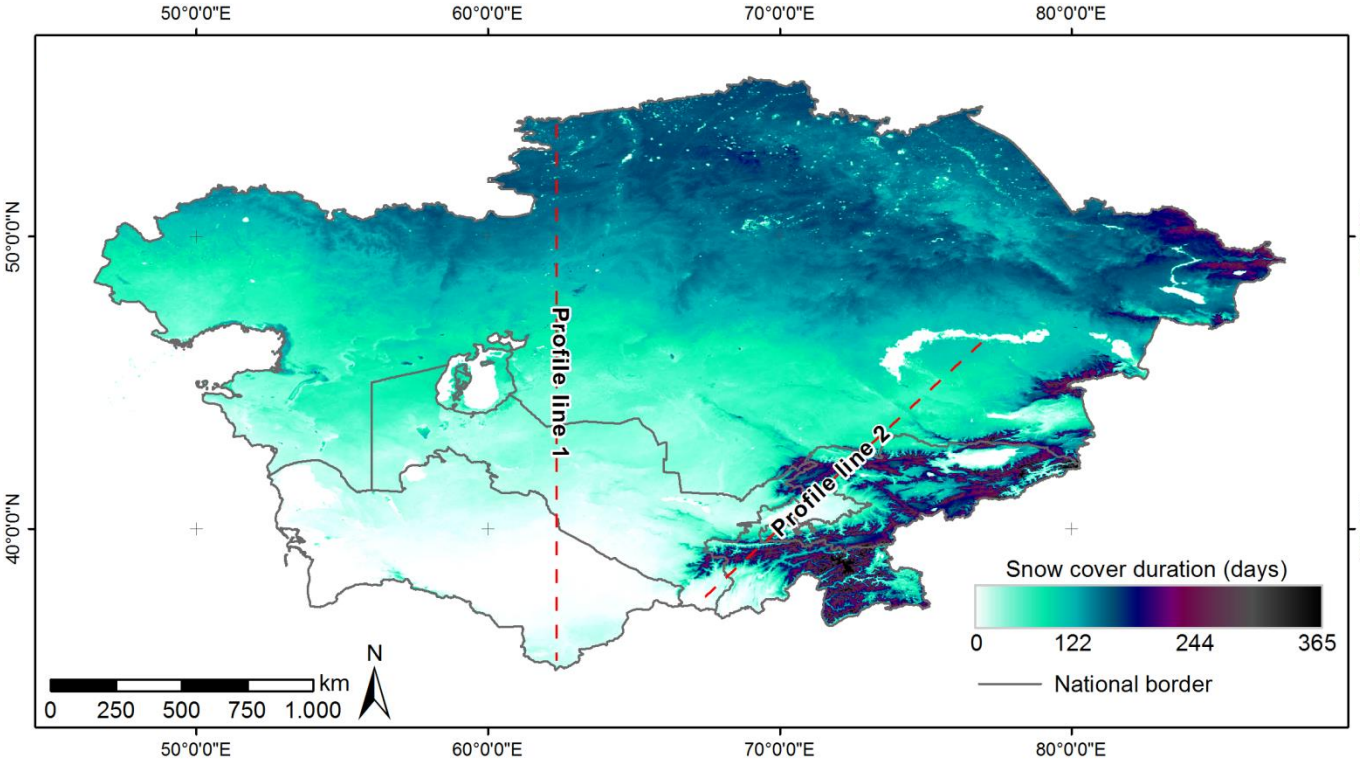
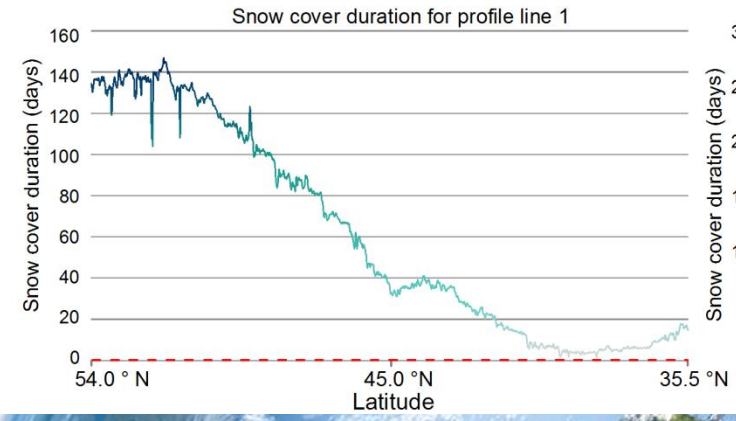
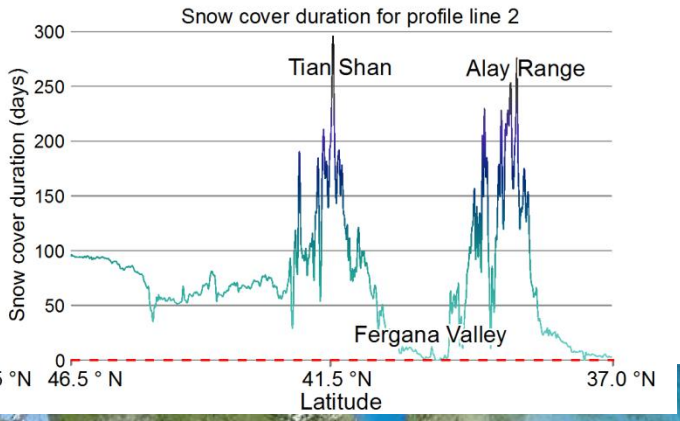
Global SnowPack – Central Asia

- SCD increases by ~ 5 days per degree latitude. In mountain regions, SCD increases by ~ 4 days per 100 m elevation
- The Fergana Valley is shielded by Tian Shan and Alay Range and receives very little snow cover



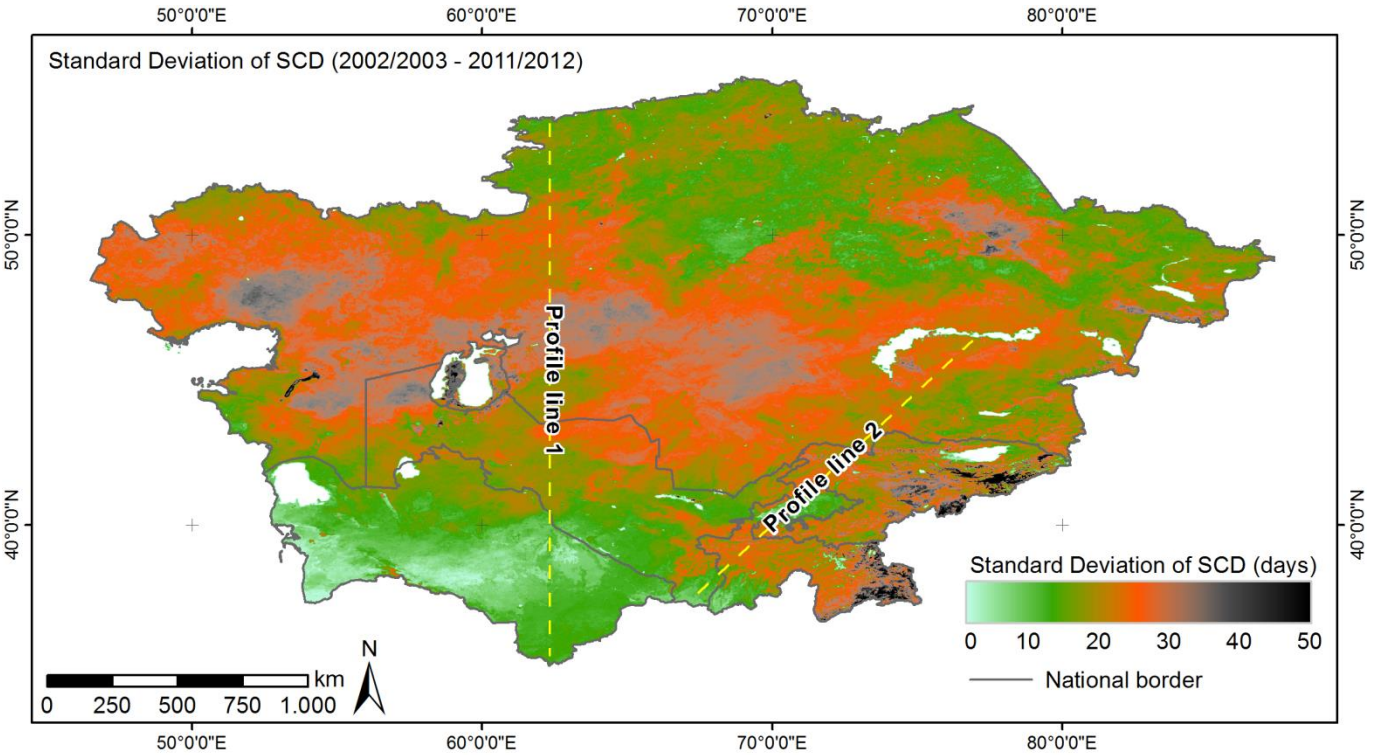


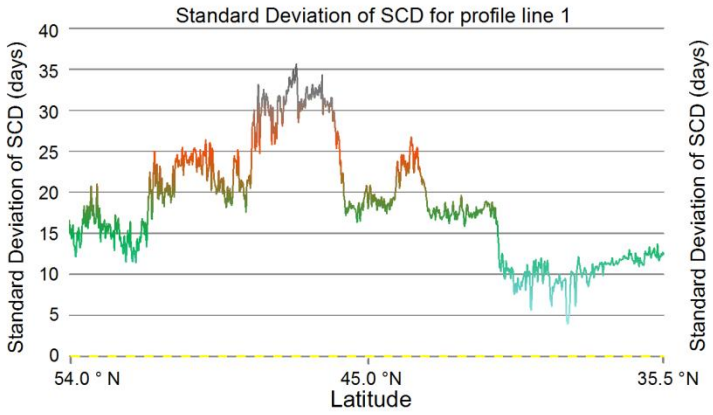


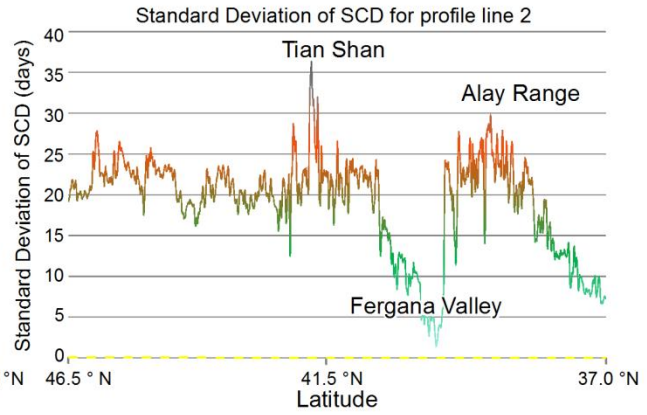
Global SnowPack – Central Asia

Variability of SCD

- Variability is high within the mountain regions and central Kazakhstan as well as close to the Caspian Sea
- The desert is Turkmenistan has low standard deviation of SCD because there is generally low SCD
- Snow cover in Northern Kazakhstan is very stable



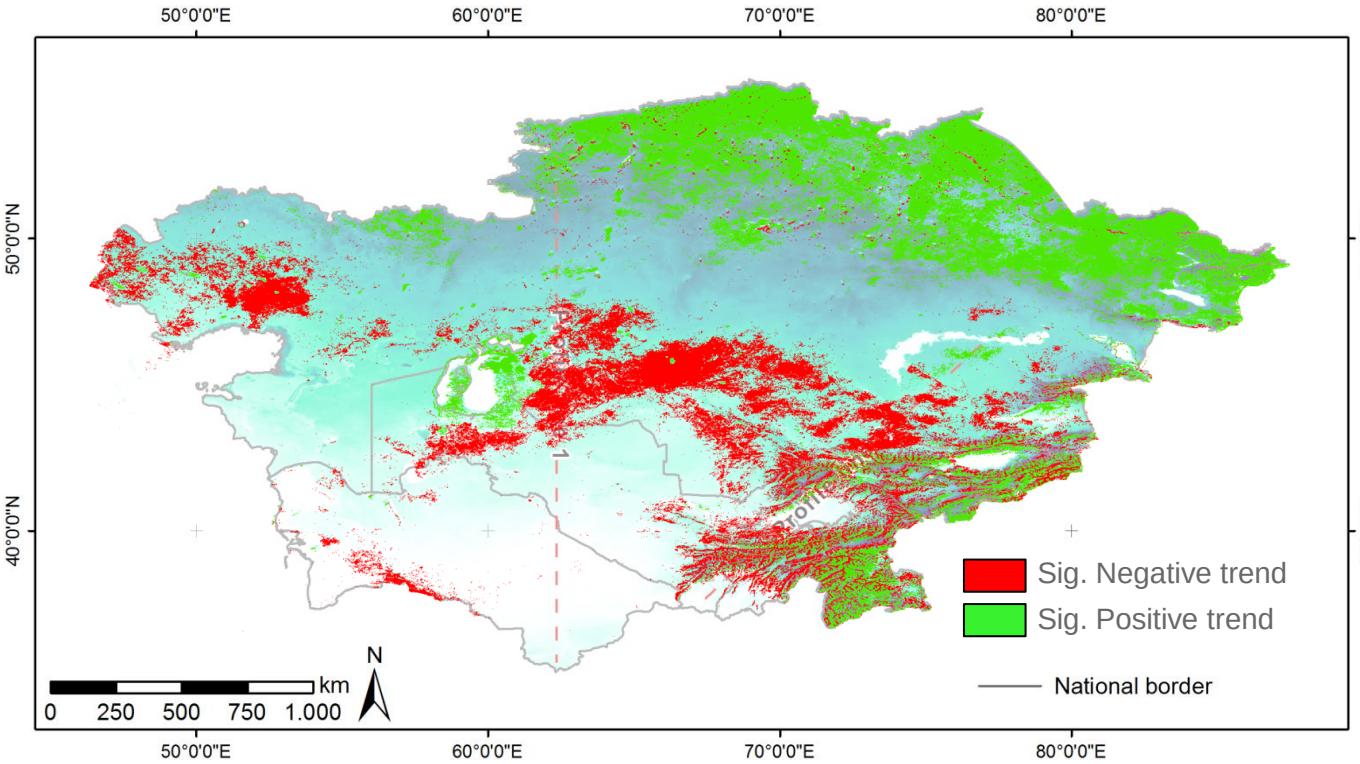


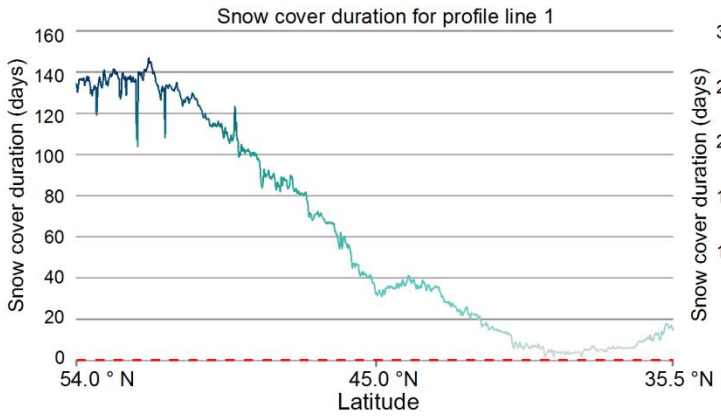


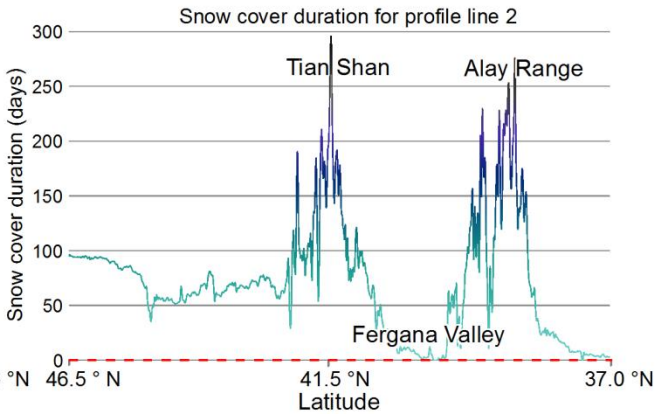
Global SnowPack – Central Asia

Trend of SCD

- Trend of SCD is negative for Central and West Kazakhstan as well as some mountain regions.
- Positive SCD trends can be found in Northern and Eastern Kazakhstan as well as some mountain tops
- The time series is too short to detect *significant* trends for most parts.



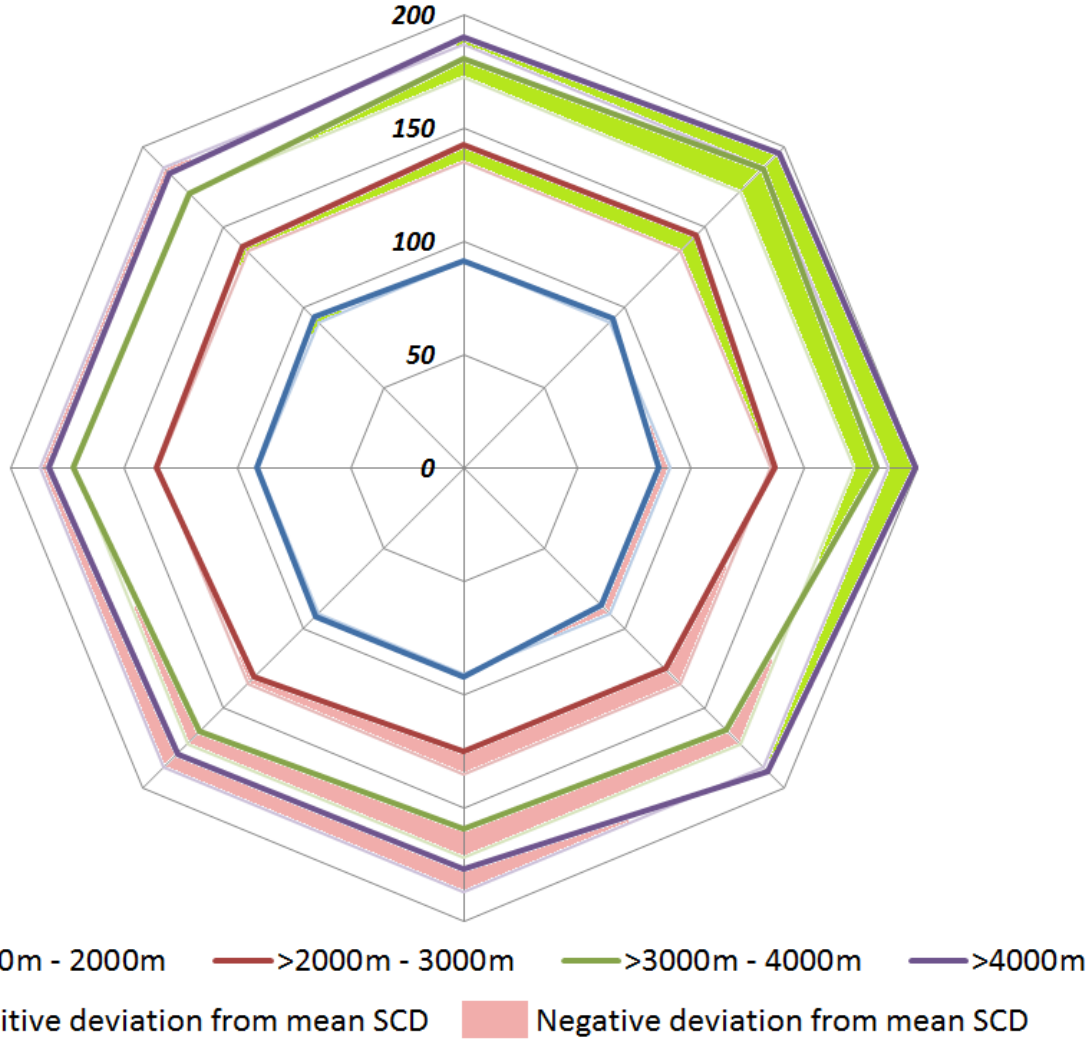




Global SnowPack – Central Asia

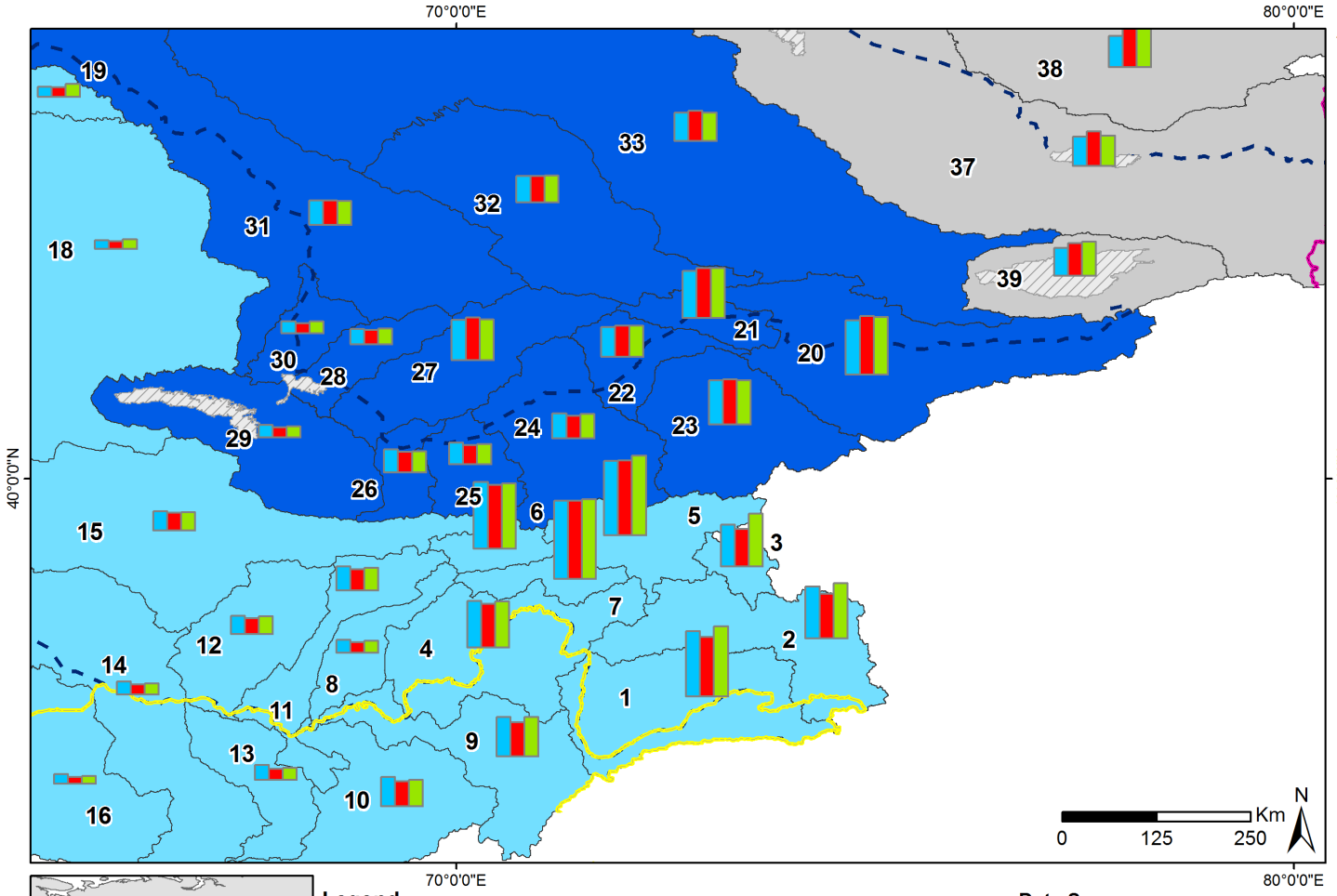
Dependency of altitude and SCD

- Mean SCD on Northern and Eastern slopes is generally higher than on Southern and Western slopes
- The effect is bigger in higher elevation zones
- SCD increased by roughly 4 days per 100 m elevation in mountains lower than 1500 m. Above this altitude, SCD can increase up to 10 days per 100 m elevation.



Global SnowPack – Central Asia

SCD development within major hydro catchments



Legend

Water body
Major river
Border to Afghanistan
Border to China

Catchments
Amu Darya
Syr Darya
Lake Balkhash

Mean SCD per sub-catchment (days)
Max: 215
Min: 0
1986-1993
1994-2002
2003-2011

Data Sources

Catchment Data: © FAO 2010
Water bodies: © DLR 2012

Amu Darya Subcatchments

1. Wakhan Rod
2. Bartang / Sarezskoe Lake
3. Lake Karakul
4. Panji
5. Kyzyl - Suu / Surhob
6. Surhob
7. Oblhingou
8. Vakshs
9. Kokcha Rod
10. Surkhab Rod
11. Kafirnigan
12. Surkham Darya
13. Samangan Rob
14. Balkhab
15. Zeravshan
16. Shirin Tagab
18. Kyzylkum Desert
19. Aral Sea

Syr Darya Subcatchments

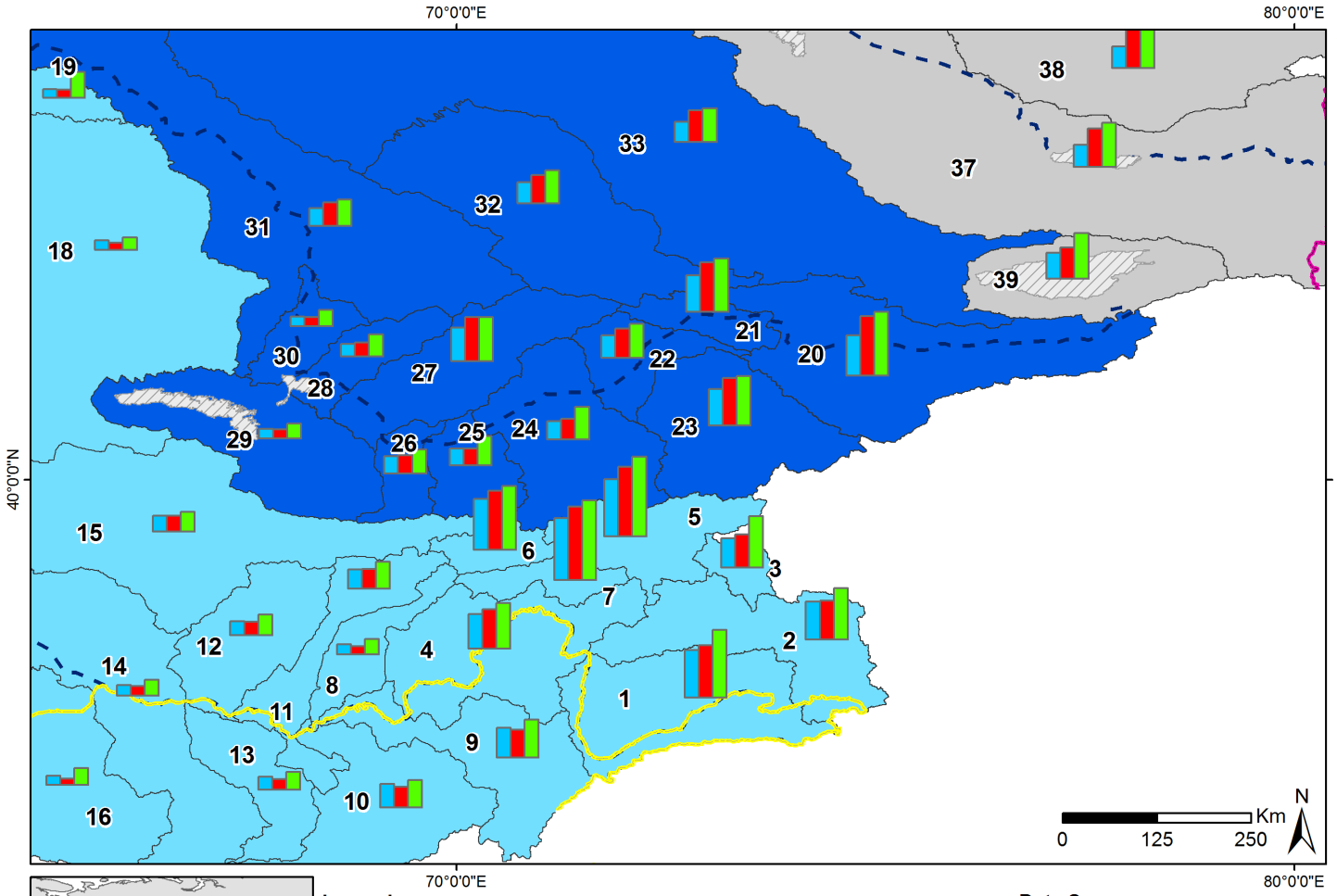
20. Naryn 1
21. Toktogul Reservoir
22. Naryn 2
23. Karadare
24. Syr Darya 1
25. Kayrakkum Reservoir
26. Syr Darya 2
27. Catkol
28. Sardara Reservoir
29. Lake Chordare
30. Syrdarija
31. Syr Darya
32. Talas / Assa
33. Chu

Lake Balkhash Subcatchments

37. Ili
38. Lake Balkhash
39. Issyk Kul

Global SnowPack – Central Asia

SCD_{ES} development within major hydro catchments



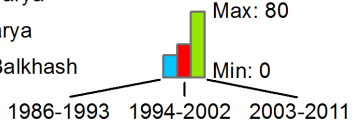
Legend

- Water body
- Major river
- Border to Afghanistan
- Border to China

Catchments

- Amu Darya
- Syr Darya
- Lake Balkhash

Mean SCD_{ES} per sub-catchment (days)



Data Sources

Catchment Data: © FAO 2010

Water bodies: © DLR 2012

Amu Darya Subcatchments

1. Wakhan Rod
2. Bartang / Sarezskoe Lake
3. Lake Karakul
4. Panji
5. Kyzyl - Suu / Surhob
6. Surhob
7. Oblhingou
8. Vakshs
9. Kokcha Rod
10. Surkhab Rod
11. Kafirnigan
12. Surkham Darya
13. Samangan Rob
14. Balkhab
15. Zeravshan
16. Shirin Tagab
18. Kyzylkum Desert
19. Aral Sea

Syr Darya Subcatchments

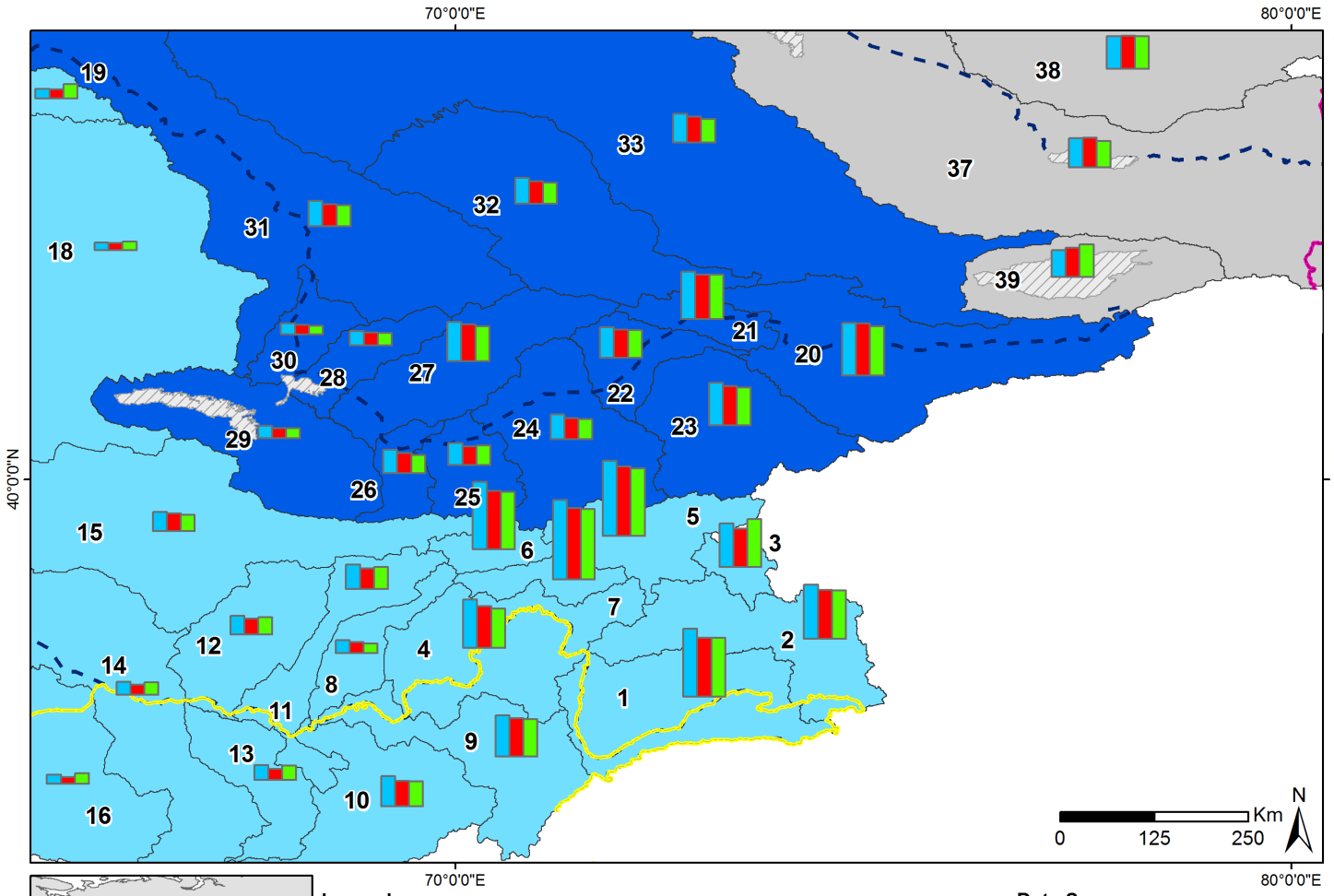
20. Naryn 1
21. Toktogul Reservoir
22. Naryn 2
23. Karadare
24. Syr Darya 1
25. Kayrakkum Reservoir
26. Syr Darya 2
27. Catkol
28. Sardara Reservoir
29. Lake Chordare
30. Syrdarija
31. Syr Darya
32. Talas / Assa
33. Chu

Lake Balkhash Subcatchments

37. Ili
38. Lake Balkhash
39. Issyk Kul

Global SnowPack – Central Asia

SCD_{LS} development within major hydro catchments



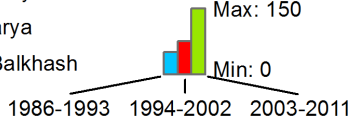
Legend

- Water body
- Major river
- Border to Afghanistan
- Border to China

Catchments

- Amu Darya
- Syr Darya
- Lake Balkhash

Mean SCD_{LS} per sub-catchment (days)



Data Sources

Catchment Data: © FAO 2010

Water bodies: © DLR 2012

Amu Darya Subcatchments

1. Wakhan Rod
2. Bartang / Sarezskoe Lake
3. Lake Karakul
4. Panji
5. Kyzyl - Suu / Surhob
6. Surhob
7. Oblhingou
8. Vakshs
9. Kokcha Rod
10. Surkhab Rod
11. Kafirnigan
12. Surkham Darya
13. Samangan Rob
14. Balkhab
15. Zeravshan
16. Shirin Tagab
18. Kyzylkum Desert
19. Aral Sea

Syr Darya Subcatchments

20. Naryn 1
21. Toktogul Reservoir
22. Naryn 2
23. Karadare
24. Syr Darya 1
25. Kayrakkum Reservoir
26. Syr Darya 2
27. Catkol
28. Sardara Reservoir
29. Lake Chordare
30. Syrdarija
31. Syr Darya
32. Talas / Assa
33. Chu

Lake Balkhash Subcatchments

37. Ili
38. Lake Balkhash
39. Issyk Kul