# Remote sensing of snow cover relying on multispectral data

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Knowledge for Tomorrow





# 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

10°10'E 10°15'E 10°20'E 10°25'E 10°30'E 10°35'E 10°40'E 10°45'E 10°50'E 10°55'E 11°0'E 11°5'E 11°10'E



### 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.



#### Freeze and thaw processes affect the reflection.



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



#### Normalized Difference Snow Index (NDSI):

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

R <sub>vis</sub> :	Reflection in the visible part
R <sub>swir</sub> :	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

10°10'E 10°15'E 10°20'E 10°25'E 10°30'E 10°35'E 10°40'E 10°45'E 10°50'E 10°55'E 11°0'E 11°5'E 11°10'E



# **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.



# **Data Sources and Data Availability**



# 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 cloudremoval



Calculation of snow cover parameters

- Snow cover duration (SCD) - Early Season SCD - Late Season SCD (SCD<sub>ES</sub>) - Late Season SCD (SCD<sub>LS</sub>)  $SCD = \sum_{i=1}^{n} (s_i)$   $SCD_{ES} = Fd - SCD_{bFd}$   $SCD_{LS} = Fd + SCD_{aFd}$ n: number of observations (beginning on Sept. 1<sup>st</sup> of a year and ending on Aug. 31<sup>st</sup> of the following year)
  - s: cloud-free snow cover dataset

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

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



# **Global SnowPack – overview of all products**



# Global SnowPack Mean Snow Cover Duration 2000-2016





Mean Snow Cover Duration 2000-2016

0	91	182	273	365









# **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



2



-19.9 - -10

-9.9 - 10

10.1 - 20

< -40

-39,9 - -30

-29,9 - -20



# **Global SnowPack – World**

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



# **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**



#### AUG 28 2014

# **Global SnowPack available as WMS service**



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

• Contact:

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



# **MODIS tiles included in the Global SnowPack**

h6 v0	h7 v0	h8 v0	h9 v0	h10 v0	h11 v0	h12 v0	h13 v0	h14 v0	h15 v0	h16 v0	h17 v0	h18 v0	h19 v0	h20 v0	h21 v0	h22 v0	h23 v0	h24 v0	h25 v0	h26 v0	h27 v0	h28 v0	h29 v0	h30 v0	h31 v0	h32 v0
h6 v1	h7 v1	h8 v1	h9 v1	h10 v1	h11 v1	h12 v1	h13 v1	h14 v1	h15 v1	h16 v1	h17 v1	h18 v1	h19 v1	h20 v1	h21 v1	h22 v1	h23 v1	h24 v1	h25 v1	h26 v1	h27 v1	h28 v1	h29 v1	h30 v1	h31 v1	h32 v1
h6 v2	h7 v2	h8 v2	h9 v2	h10 v2	h11 v2	h12 v2	h13 v2	h14 v2	h15 v2	h16 v2	h17 v2	h18 v2	h19 v2	h20 v2	h21 v2	h22 v2	h23 v2	h24 v2	h25 v2	h26 v2	h27 v2	h28 v2	h29 v2	h30 v2	h31 v2	h32 v2
h6 v3	h7 v3	h8 v3	h9 v3	h10 v3	h11 v3	h12 v3	h13 v3	h14 v3	h15 v3	h16 v3	h17 v3	h18 v3	h19 v3	h20 v3	h21 v3	h22 v3	h23 v3	h24 v3	h25 v3	h26 v3	h27 v3	h28 v3	h29 v3	h30 v3	h31 v3	h32 v3
h6 v4	h7 v4	h8 v4	h9 v4	h10 v4	h11 v4	h12 v4	h13 v4	h14 v4	h15 v4	h16 v4	h17 v4	h18 v4	h19 v4	h20 v4	h21 v4	h22 v4	h23 v4	h24 v4	h25 v4	h26 v4	h27 v4	h28 v4	h29 v4	h30 v4	h31 v4	h32 v4
h6 v5	h7 v5	h8 v5	h9 v5	h10 v5	h11 v5	h12 v5	h13 v5	h14 v5	h15 v5	h16 v5	h17 v5	h18 v5	h19 v5	h20 v5	h21 v5	h22 v5	h23 v5	h24 v5	h25 v5	h26 v5	h27 v5	h28 v5	h29 v5	h30 v5	h31 v5	h32 v5
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h6 v7	h7 v7	h8 v7	h9 v7	h10 v7	h11 v7	h12 v7	h13 v7	h14 v7	h15 v7	h16 v7	117 vZ	h18 v7	h19 v7	h20 v7	h21 v7	h22 y7	h23 v7	h24 v7	h25 v7	h26 v7	h27 v7	h28v7	h29 v7	h30 v7	h31 v7	<sup>°</sup> h32 v7
h6 v8	h7 v8	h8 v8	h9 v8.	h10 v8	h11 v8	h12.v8	h13 v8	h14 v8	h15 v8	h16 v8	h47 v8	h18v8	h19 v8	h20 v8	h21 v8	h22 v8	h23 v8	h24 v8	h25 v8	h26 v8	h27 v8	h28 v8	h29 v8	h30 v8	h31 v8	h32 v8
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h6 v11	h7 v11	h8 v11	h9 v11	h10 v1 <u>1</u>	h11 v11	h12 v11	h13 v11	h14 v11	h15 v11	h16 v11	h17 v11	h18 v11	h19 v1	h20 v11	h21 v11	₩22 v11	h23 v11	h24 v11	h25 v11	h26 v11	h27 v11	h28 v11	h29 v11	h30 v11	h31 v14	h32 v11
h6 v12	h7 v12	h8 v12	h9 v12	h10 v12	? h11 v12	2 h12 v12	h13 v12	h14 v12	h15 v12	h16 v12	h17 v12	h18 v12	h19 v12	ĥ20 v12	h21 v12	h22 v12	h23 v12	h24 v12	h25 v12	h26 v12	h27 v12	h28 v12	h29 v12	h30 v12	h31 v12	h32 v12
h6 v13	h7 v13	h8 v13	h9 v13	h10 v13	6 h11 v13	3 h12 v13	h13 v13	h14 v13	h15 v13	h16 v13	h17 v13	h18 v13	h19 v13	h20 y13	h21,v13	h22 v13	h23 v13	h24 v13	h25 v13	h26 v13	h27 v13	h28 v13	h29 v13	h30 v13	h31 v13	h32 v13
h6 v14	h7 v14	h8 v14	h9 v14	h10 v14	h11 v14	h12 v14	h13 v14	h14 v14	h15 v14	h16 v14	h17 v14	h18 v14	h19 v14	h20 v14	h21 v14	h22 v14	h23 v14	h24 v14	h25 v14	h26 v14	h27 v14	h28 v14	h29 v14	h30 v14	h31 v14	h32 v14
h6 v15	h7 v15	h8 v15	h9 v15	h10 v15	5 h11 v15	5 h12 v15	h13 v15	h14 v15	h15 v15	h16 v15	h17 v15	h18 v15	h19 v15	h20 v15	h21 v15	h22 v15	h23 v15	h24 v15	h25 v15	h26 v15	h27 v15	h28 v15	h29 v15	h30 v15	h31 v15	h32 v15
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# **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**





# **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



# **Global SnowPack – Central Asia**

SCD<sub>ES</sub> development within major hydro catchments



# **Global SnowPack – Central Asia**

SCD<sub>LS</sub> development within major hydro catchments

