Global Snow Cover Mapping Using a Multi-Temporal Multi-Sensor Approach

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July 23, 2015

Snow cover monitoring

- Important component of the climate system (water storage, energy balance)
- Sensitive indicator of climate change
- Long time series desired

NASA/Goddard Space Flight Center Scientific Visualization Studio

Snow monitoring using optical satellite imagery

- E.g. AVHRR
- Reflectance sensitive to the presence of snow, even a thin layer
- Limited by cloud coverage
- Long periods of the year with no data due to lack of daylight

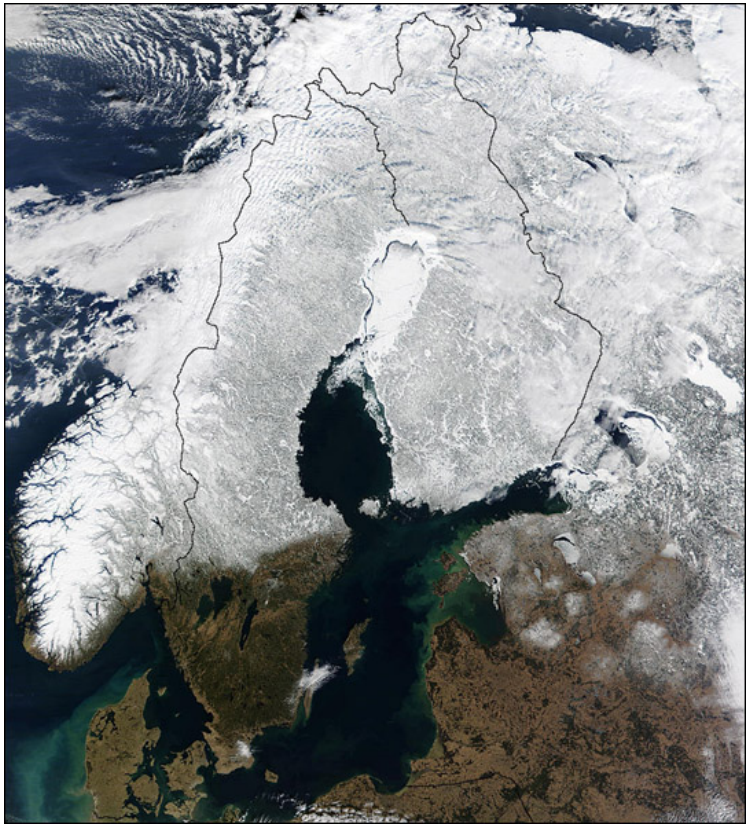


Image courtesy Jacques Descloitres, MODIS Land Rapid Response Team at NASA GSFC

Snow monitoring using PMR

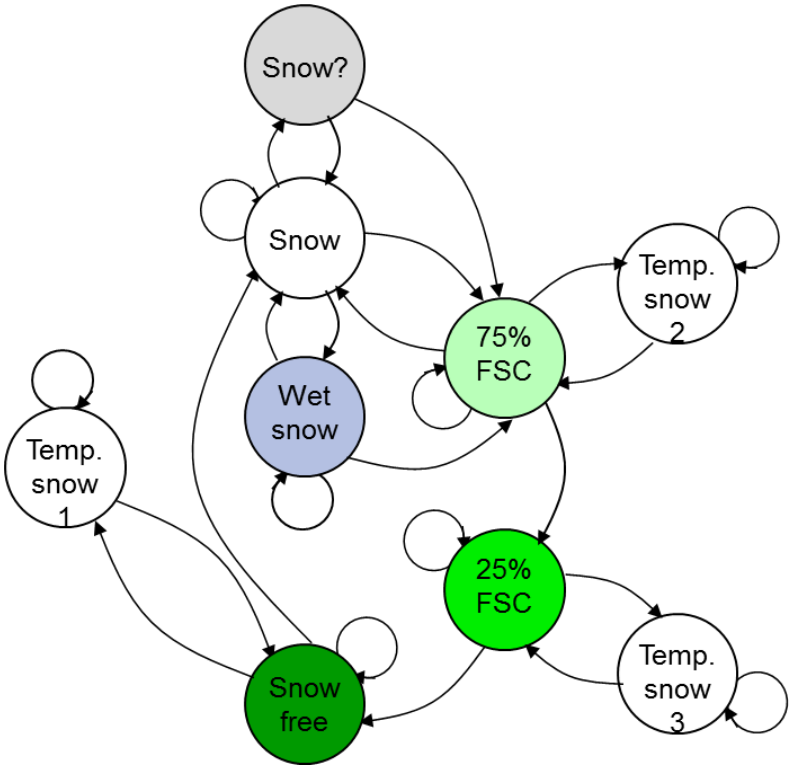
- E.g. SSM/I
- Observations also in cloudy weather and during dark period
- Observations limited to dry snow
- Insensitive to thin layers of snow

Image from NASA JPL Physical Oceanography DAAC (http://podaac.jpl.nasa.gov)

Input data

- Daily global snow cover maps based on optical satellite imagery from NOAA AVHRR GAC prepared by Norwegian Meteorological institute.
- Daily global snow cover maps based on PMR data from SSM/I.
- Both datasets express snow probabilities, and cover at least a year.

The hidden Markov model

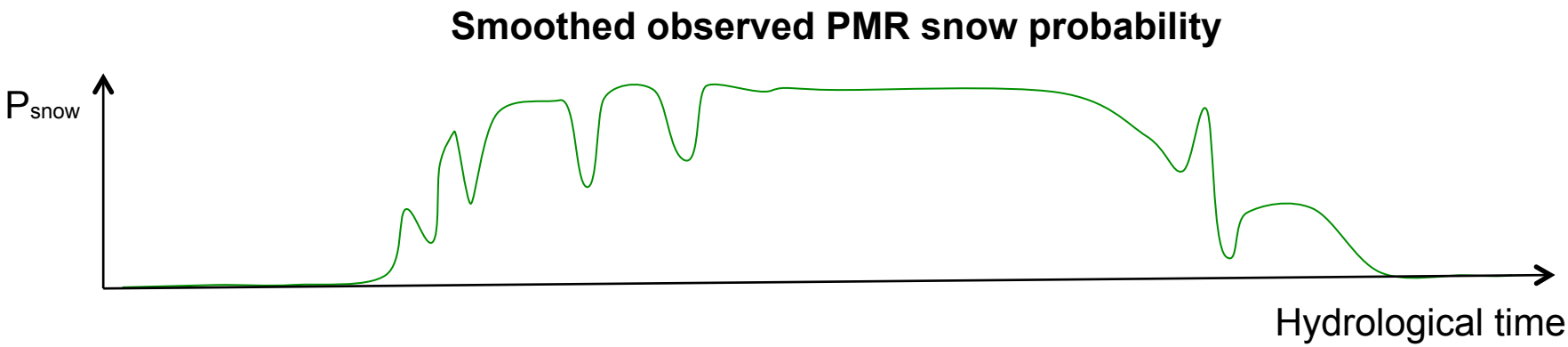


- Markov chain with unknown (hidden) states.
- States produces observable signatures with given probabilities.
- Use as input signatures estimated **snow probabilities** from optical and PMR data.
- Only some transitions between states are allowed, with defined probabilities.

The Viterbi algorithm

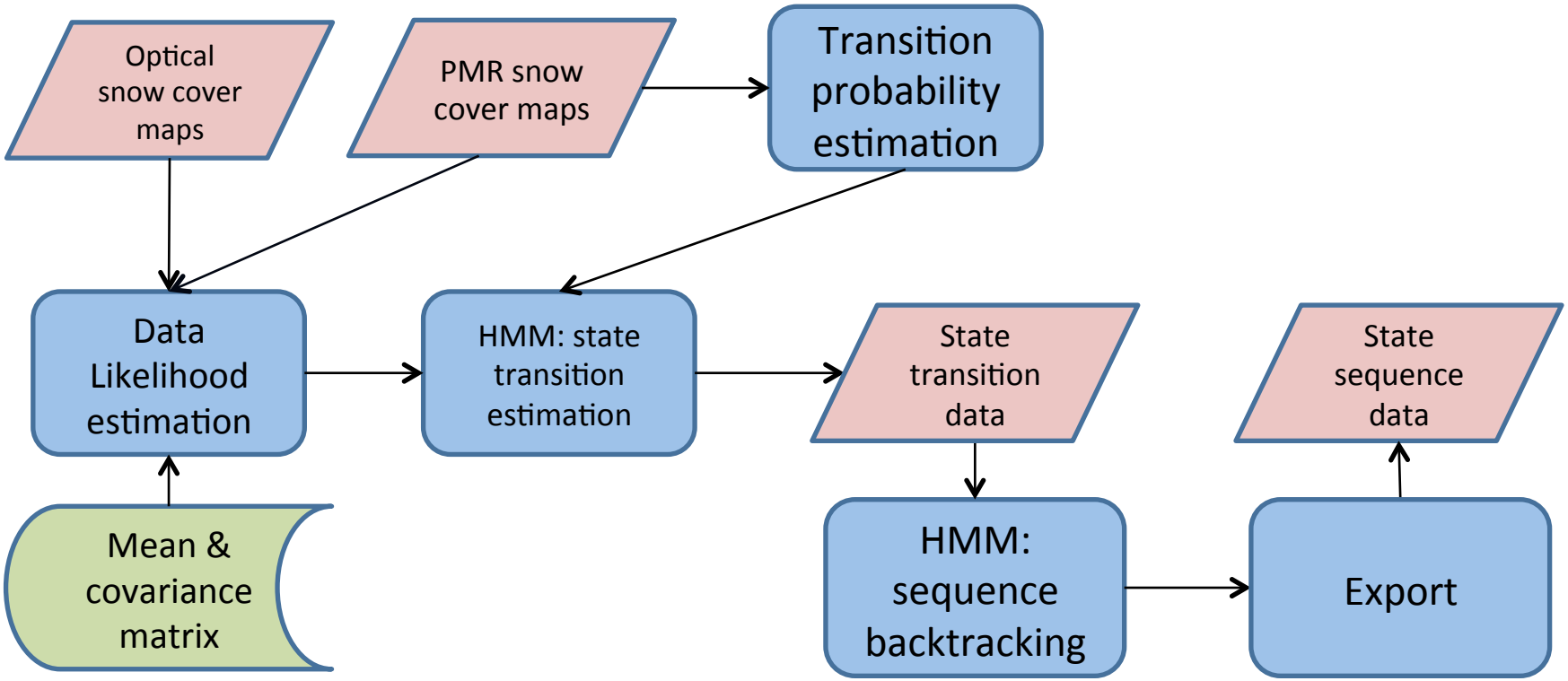
- Given a hidden Markov model and a series of observations, finds the most likely **sequence** of states
- Initialization
  - Find the starting probability of each state
- Recursion
  - Iterate through entire time series
  - For each step, find cumulative likelihood of each state
  - For each possible ***current*** state, find the most probable ***previous*** state
- Termination
  - At the final step in the series, determine the most probable state
- Sequence backtracking
  - Iterate backwards through the time series selecting the most likely sequence of states

Prior snow probability

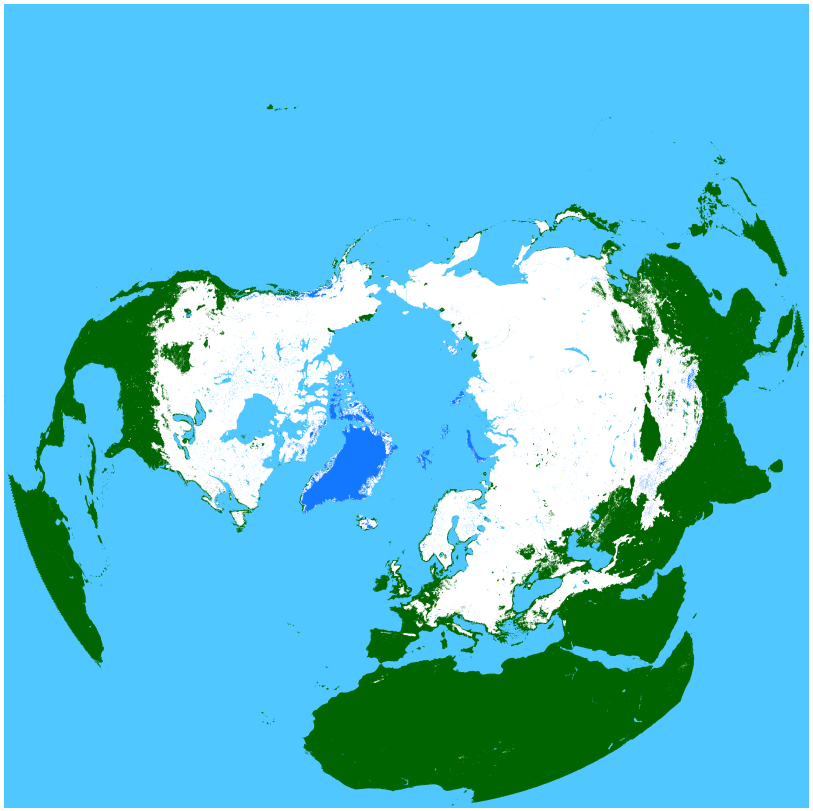


- Per pixel daily snow probability from smoothed PMR snow probabilities
- Used to estimate transition probabilities and initial probabilities
- Observation probabilities assumed Gaussian

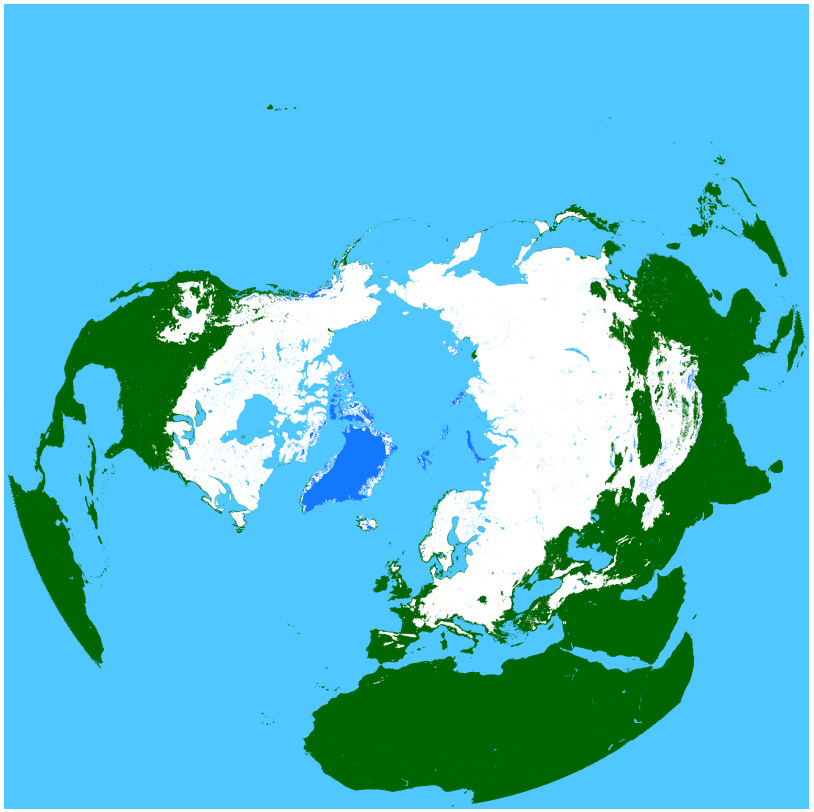
Processing chain



Daily snow cover maps

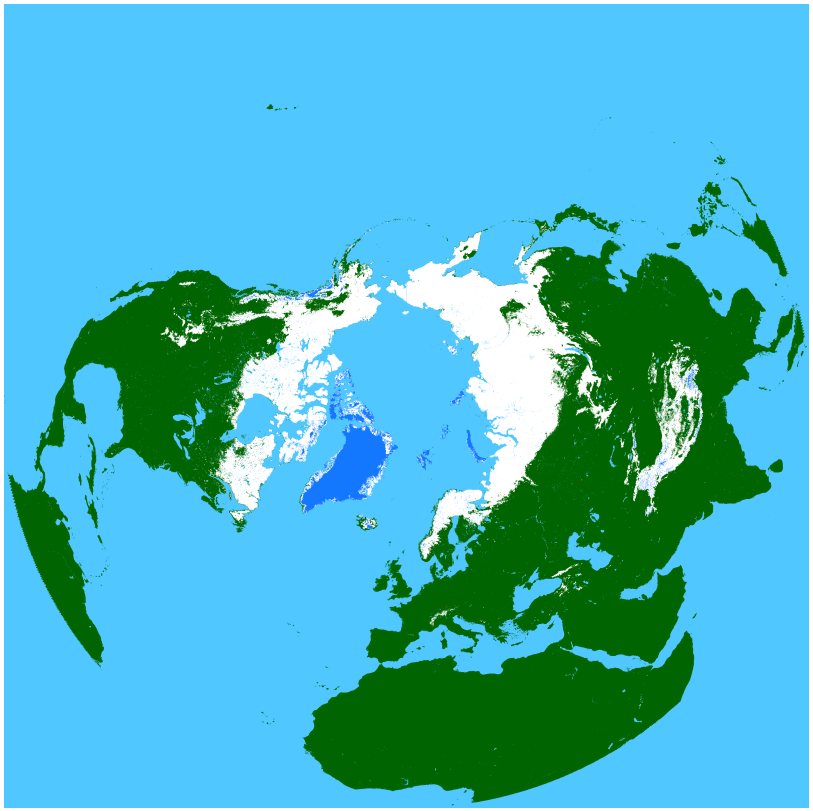


February 1, 2005

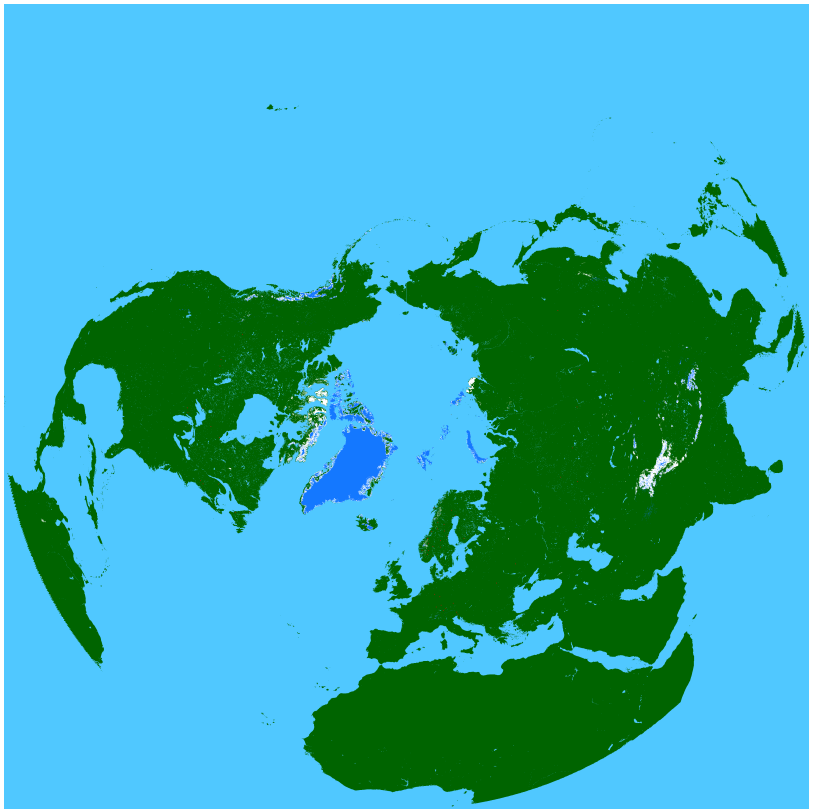


March 1, 2005

Daily snow cover maps

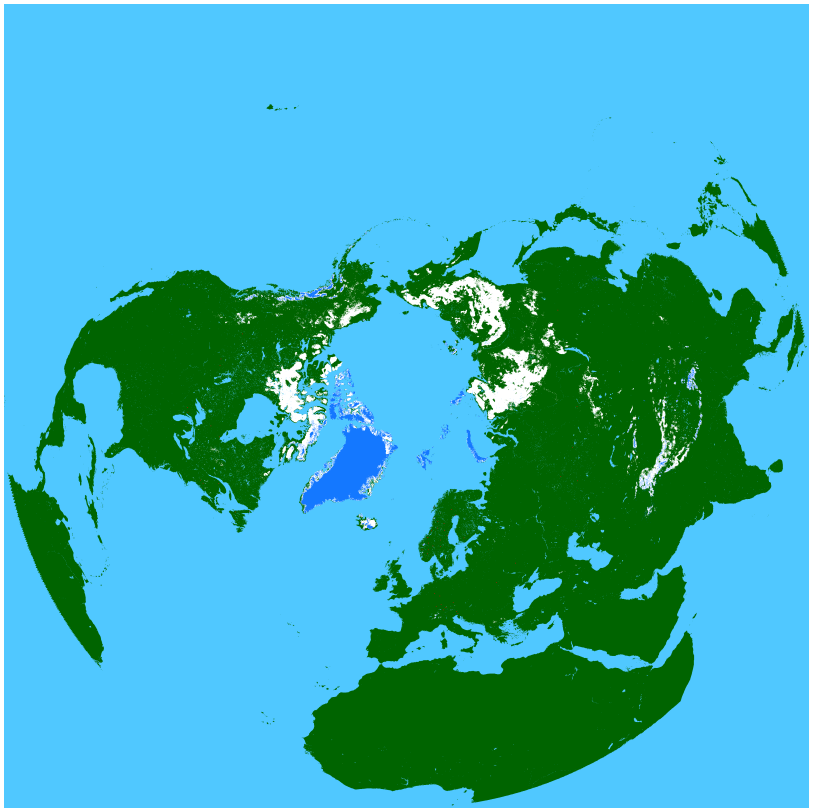


May 1, 2005

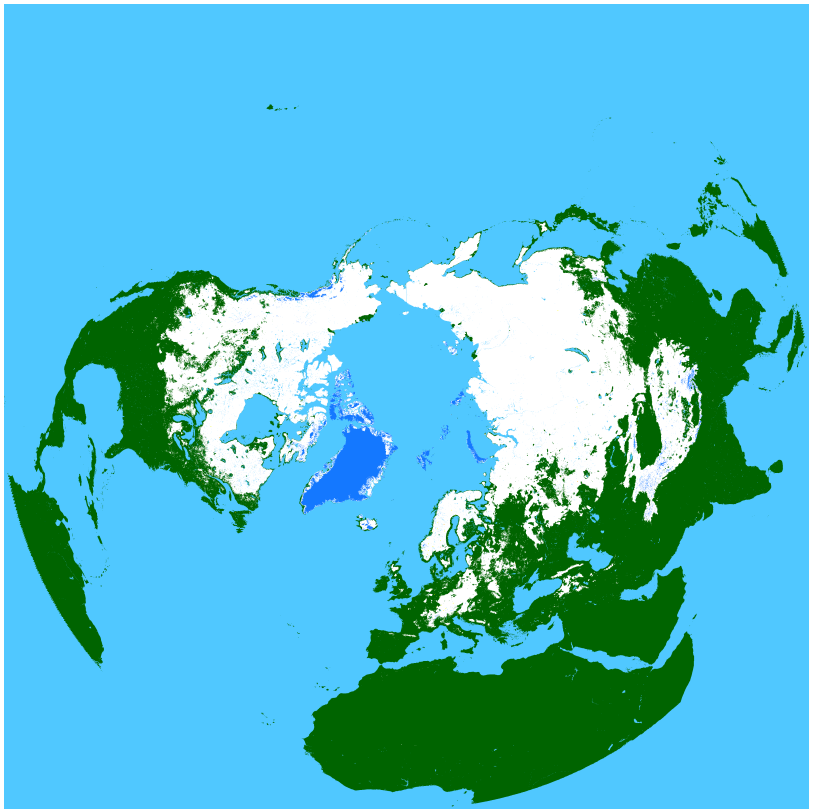


July 1, 2005

Daily snow cover maps



October 1, 2005



December 1, 2005

Validation results

Using GHCN-D in situ data

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
True	0.82	0.90	0.94	0.88	0.93	0.99	1.00	1.00	1.00	0.98	0.78	0.76
False	0.18	0.10	0.06	0.12	0.07	0.01	0.00	0.00	0.00	0.02	0.22	0.24
Total pixels	1298	1318	1385	1008	1254	1437	1488	1488	1427	1225	702	1170

Category	Total Accuracy
All pixels from multi-sensor product	92.4%
Only pixels with optical product available	96.5%
Only pixels with optical product unavailable	89.5%
Only pixels with clouds	91.7%
Only pixels with no optical satellite data	83.6%

Conclusions

- Daily global snow cover products based on both optical and PMR data
- Based on a hidden Markov state model and Viterbi algorithm to find most likely sequence of snow states.
- Full coverage in space and time
- Overall 92.4% accuracy
- Planning a 30 year time series (15 years so far)
- www.cryoclim.net