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Time-series analysis of satellite images for forest cover change monitoring in tanzania

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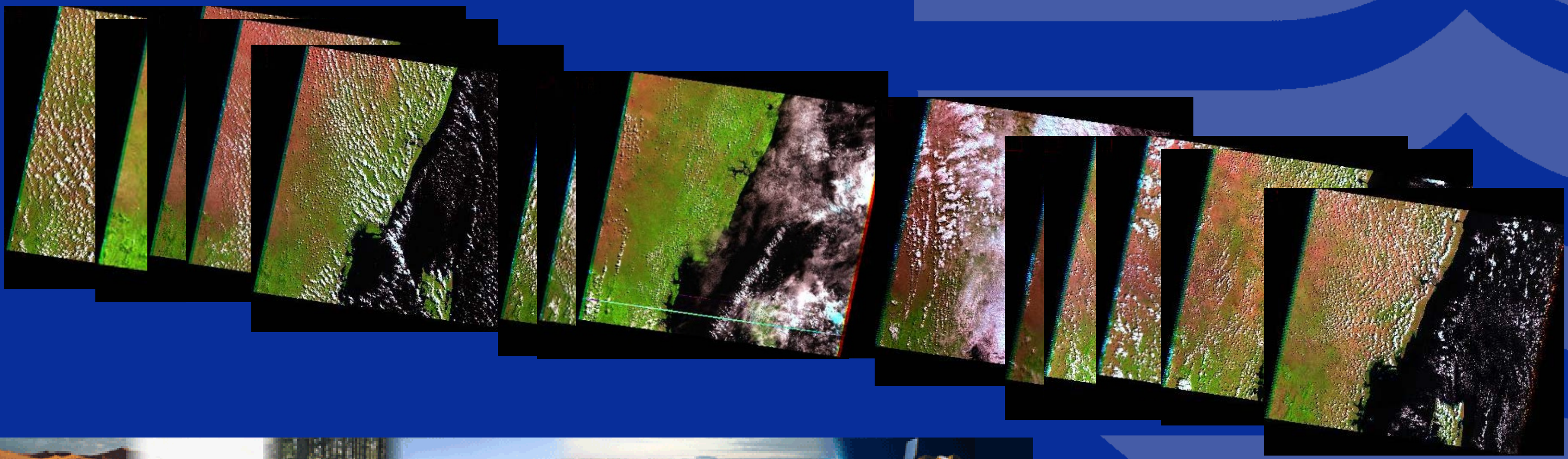
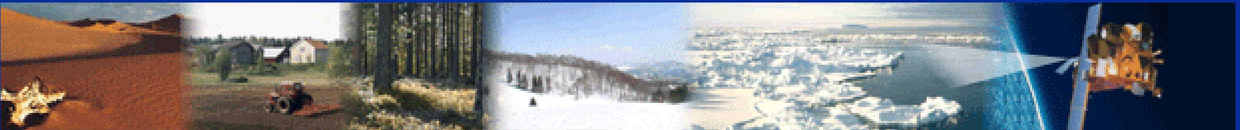
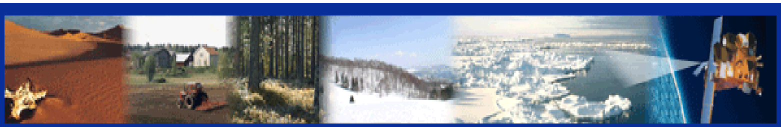




Goals

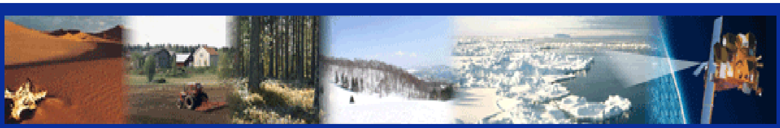
- Map forest cover
- Map forest change:
  - Degradation
  - Deforestation
  - Regrowth
- Record historic changes in forest cover

NR will develop methods and processing chains for these purposes



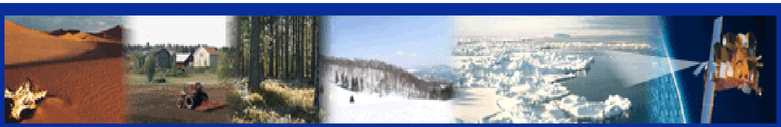
Challenges

- Data volume: Tanzania is covered by 48 Lansat scenes. Both Landsat-5 and Landsat-7 have 16 days repeat cycle.
- Overcome problems with cloud cover in optical images (and missing data in Landsat-7)
- Atmospheric disturbances
- Sparse forests and open woodland
- Natural variability



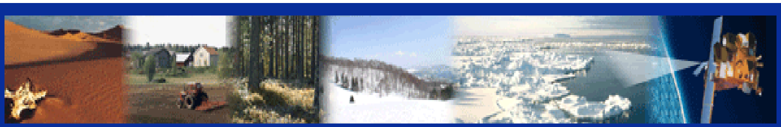
Solutions (1)

- Data volume: Tanzania is covered by 48 Lansat scenes. Both Landsat-5 and Landsat-7 have 16 days repeat cycle.
  - Solution: Automatic processing chains
- Overcome problems with cloud cover in optical images (and missing data in Landsat-7)
  - Solution: Use all available acquisitions of the same path/row in a time series analysis which allows missing observations
  - Solution: Use SAR images in addition to optical images



Solutions (2)

- Atmospheric disturbances
  - Solution: atmospheric correction
- Sparse forests and open woodland
  - Solution: Model pixels as mixtures of, say, 1-3 landcover types
  - Solution: Time series analysis to monitor gradual changes
- Natural variability
  - Solution: Time series analysis to discriminate natural variability from changes

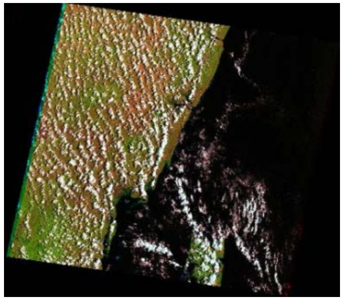


Preprocessing

- Automatic processing chain
- Provide optical satellite images that can be used in subsequent time series analysis for the mapping of forest area and forest area change
- Provide optical satellite images (Landsat) with ground cover reflectance values
- Develop automatic processing chains

NR will develop methods and processing chains for these purposes

Landsat TM images (166/63)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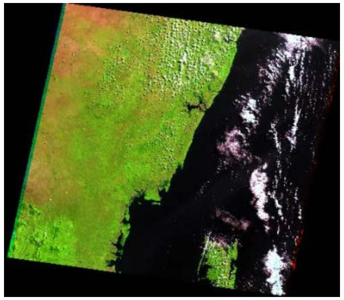
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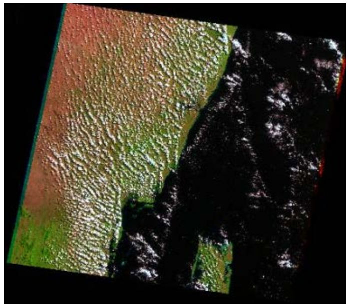
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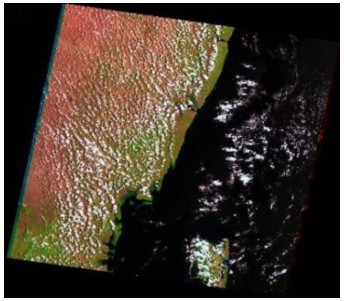
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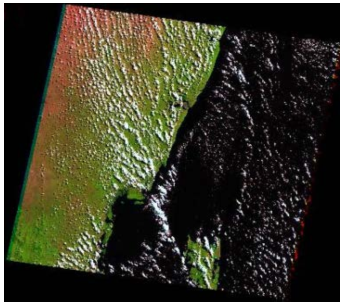
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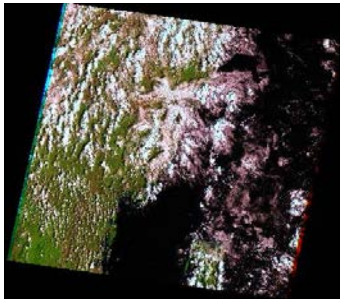
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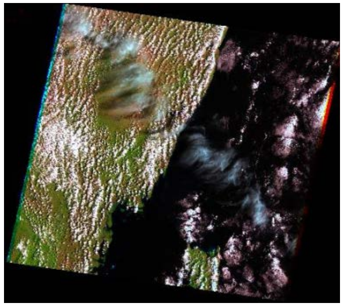
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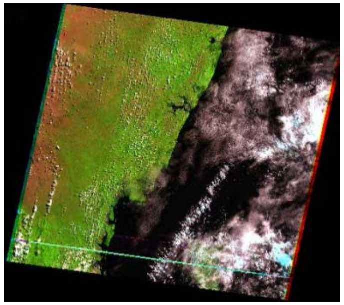
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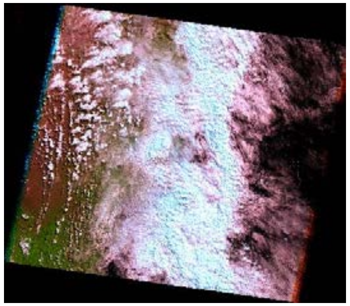
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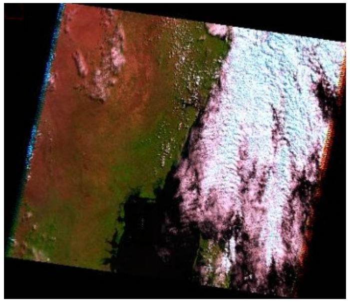
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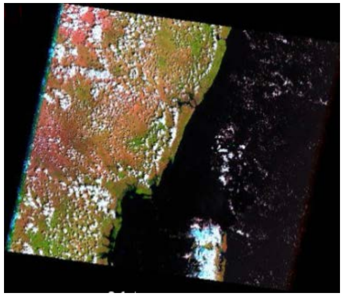
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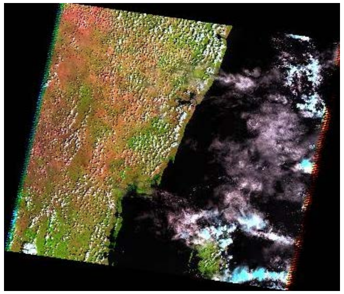
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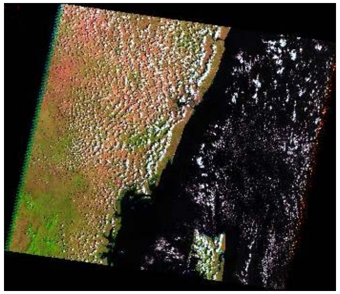
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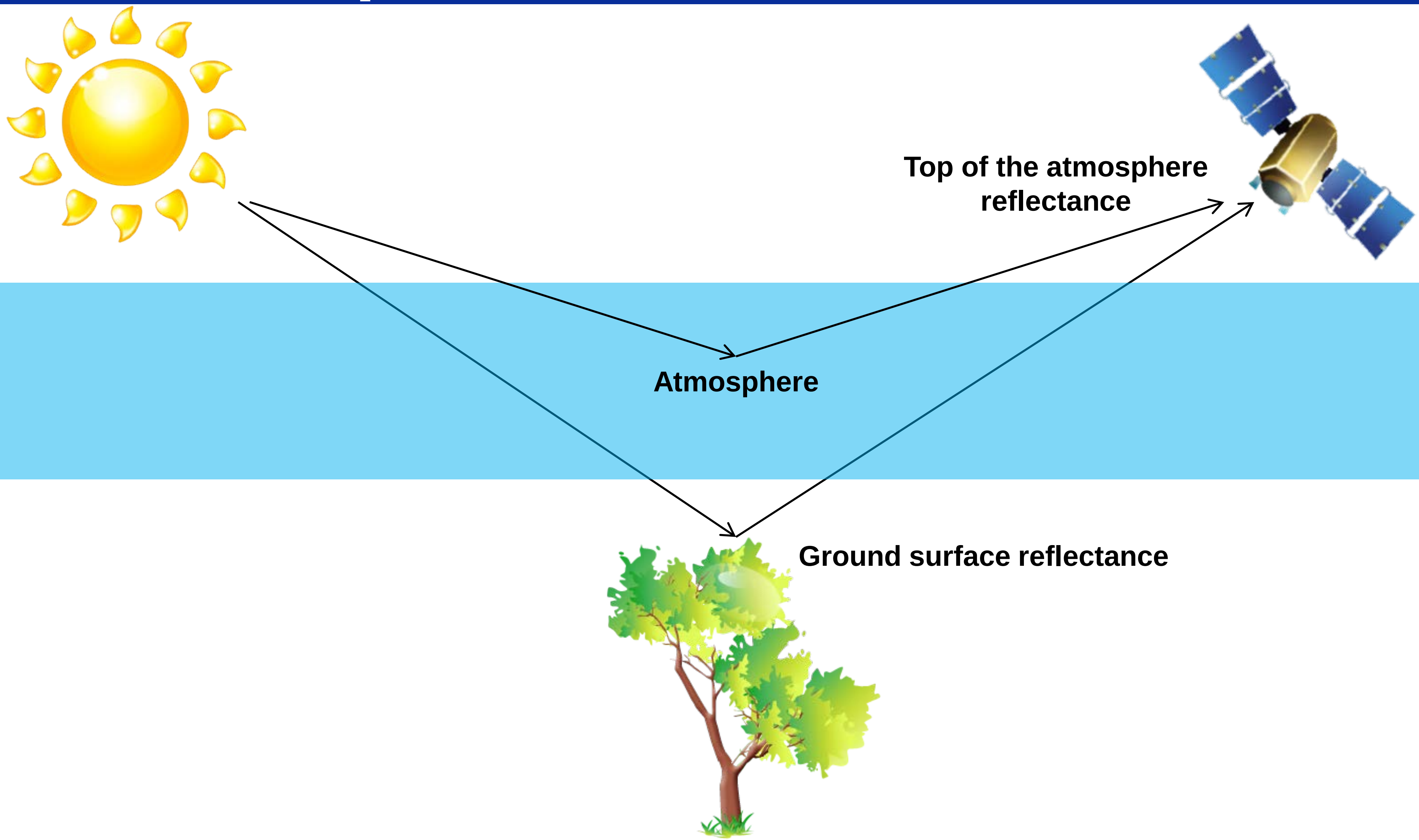
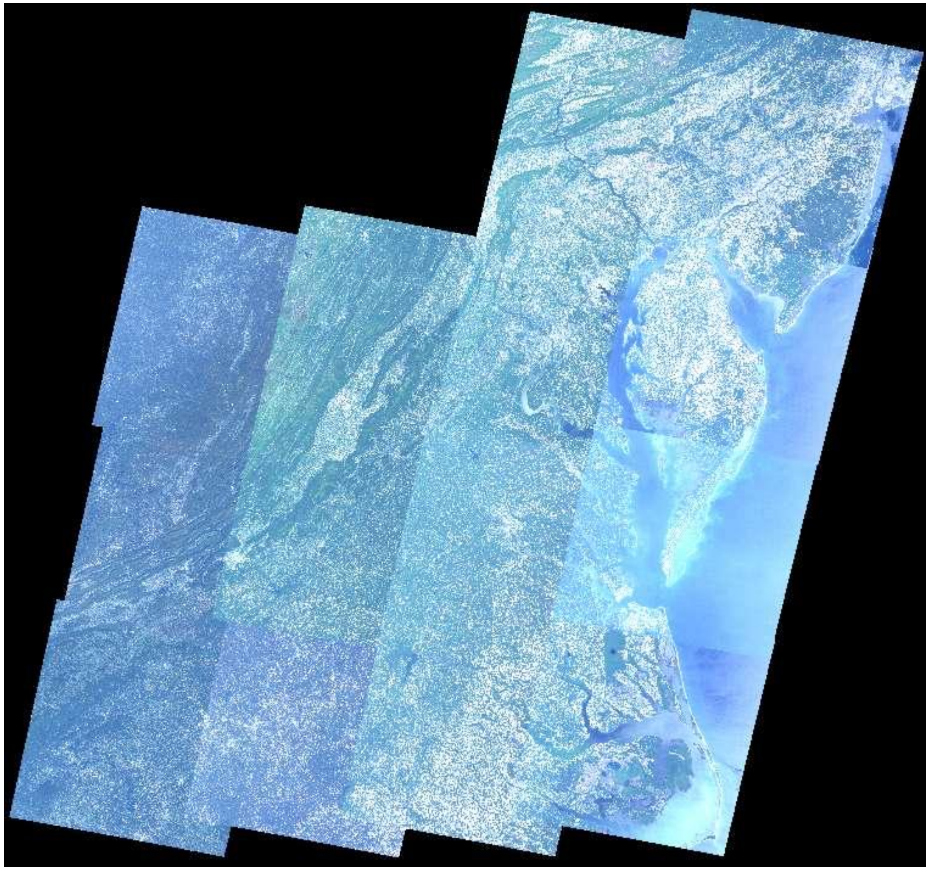
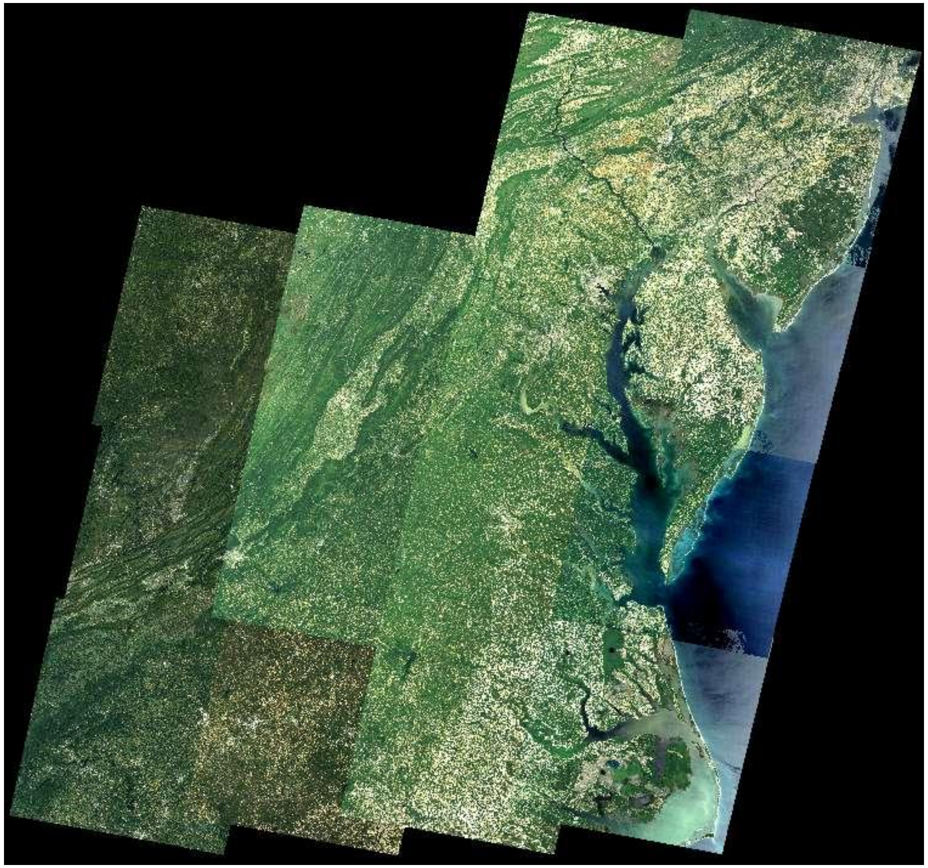
Atmospheric disturbance



Atmospheric correction with LEDAPS preprocessing tools



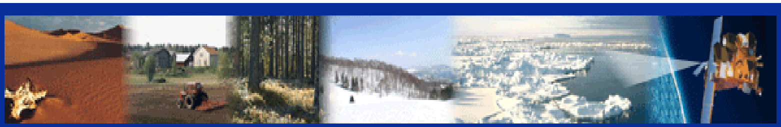
Top of the atmosphere reflectance



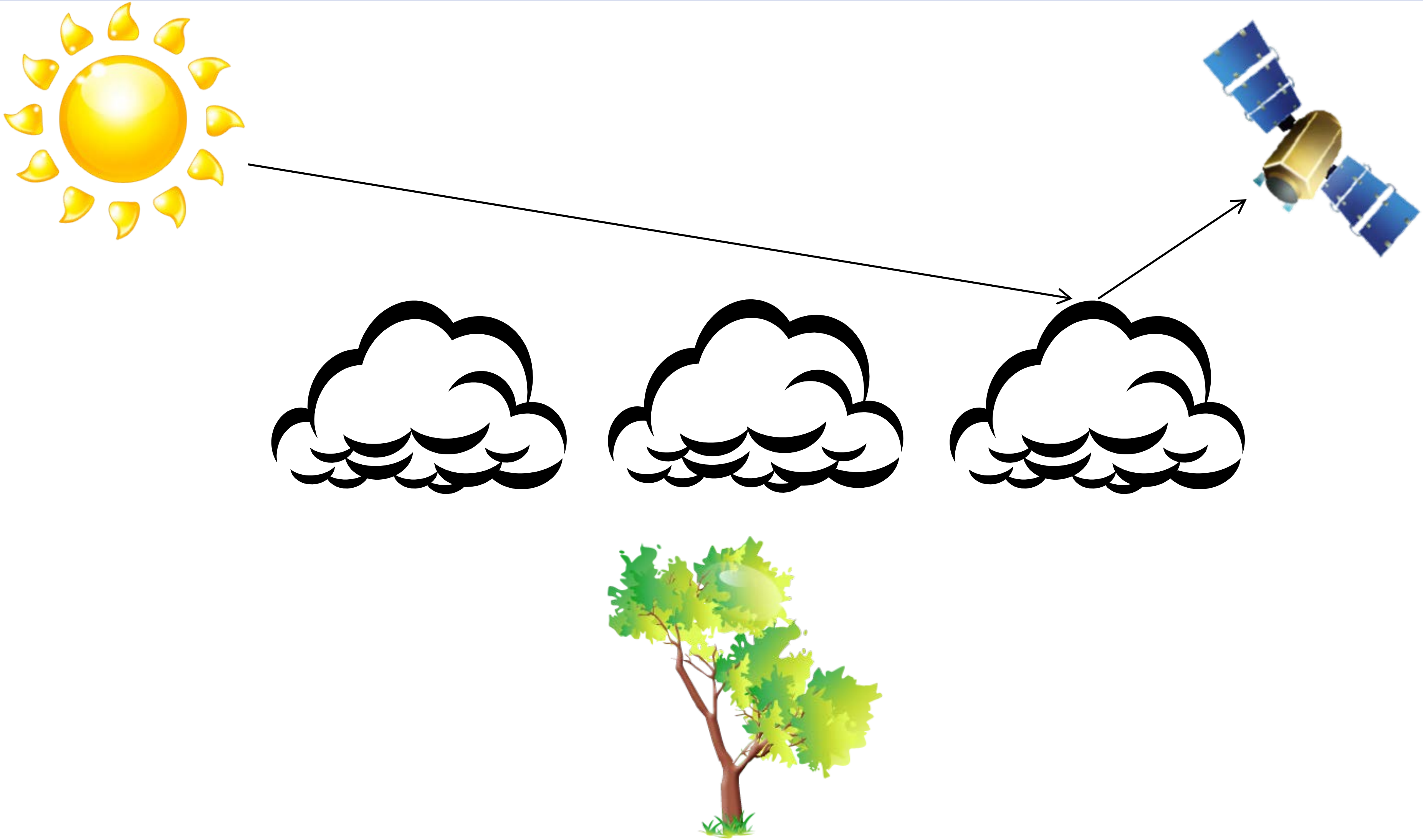
Surface reflectance

Atmospheric correction

- The LEDAPS preprocessing is a good starting point, but has some shortcomings:
  - Requires presence of dark green forest
  - Requires less than 30% cloud cover

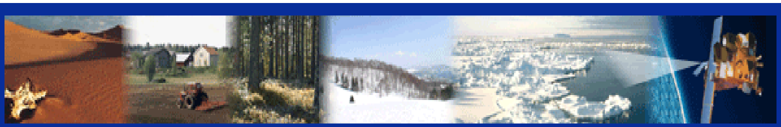


Cloud cover

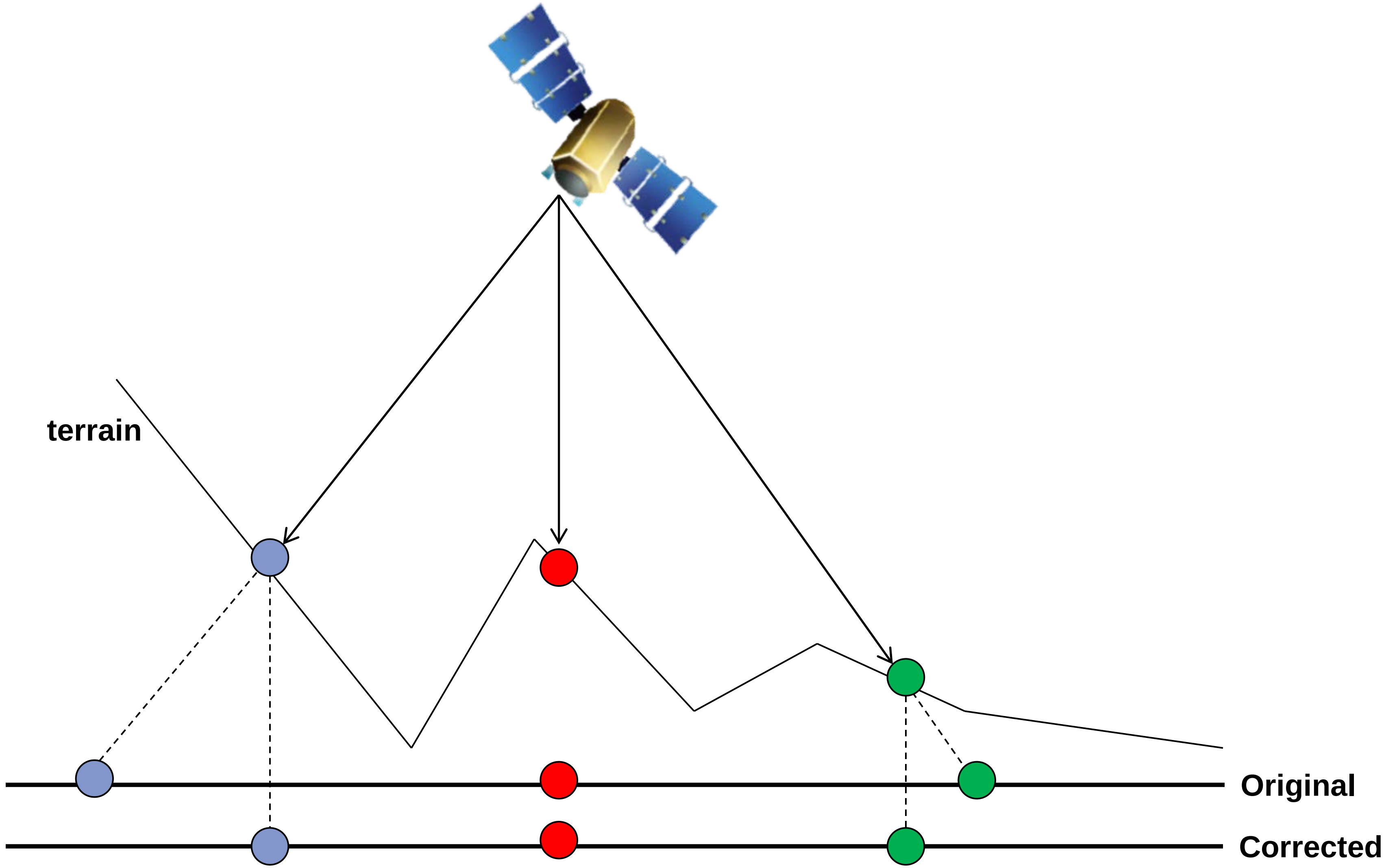


Cloud cover

- Develop and test methods for **cloud** and **cloud shadow**
  - Detection
  - Masking
- No mosaicing!
  - We need to keep the dates of observations
  - We need all observations
- Radar images can penetrate cloud cover, however, these images are more difficult to interpret
  - Multisensor optical + radar time series

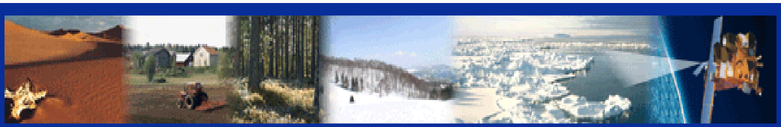


Terrain height correction

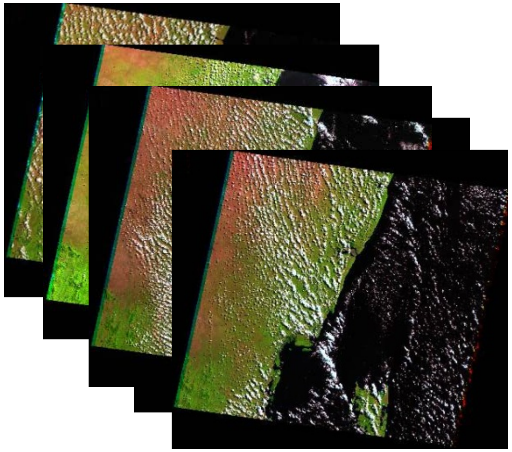


Terrain height correction

- Requires a good digital elevation model
- Important for multi-sensor
  - Landsat + SAR
  - Landsat + Sentinel-2
- Is Landsat L1T sufficiently accurate?
- Not an issue if only Landsat is used



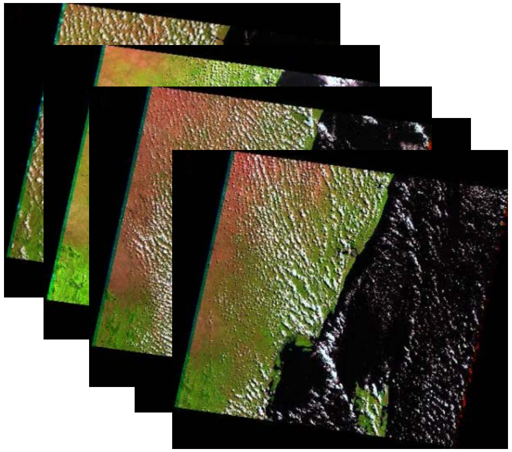
Automatic pre-processing chain



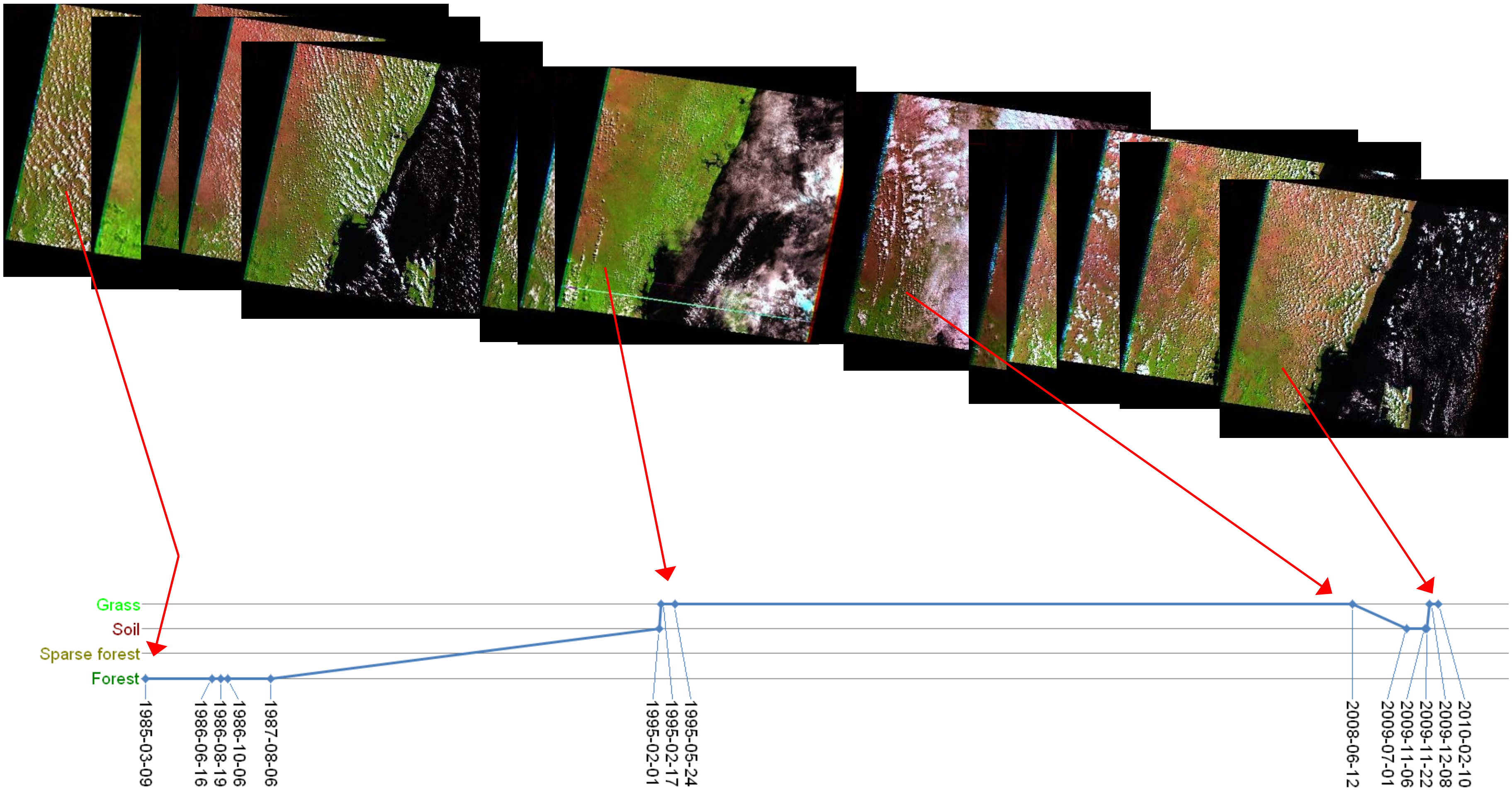
Original images

Atmospheric correction → **Cloud and shadow masking** → **Terrain height correction**

Corrected images, ready for forest mapping and forest change detection



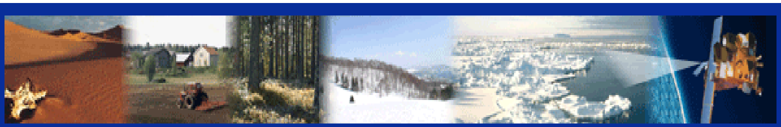
Time series analysis



Timeline for one pixel = most likely sequence of land cover classes.

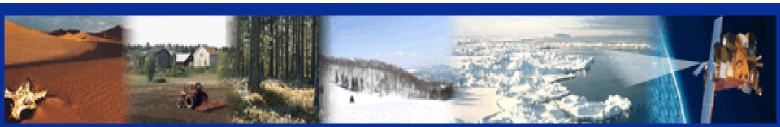
Background

- NR and Norut have created **automatic processing chains** at KSAT:
  - Optical images
  - Radar images
  - Multisensor optical + radar images
- Previous projects:
  - **Time series** better than individual images
  - **Multisensor** better than optical or radar alone



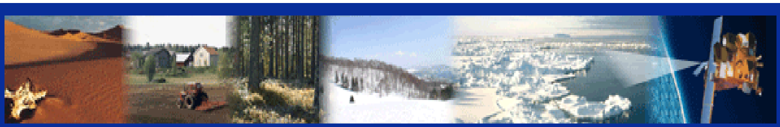
Change detection

- **Naive:** simply create forest cover maps from two years, and compare
  - Errors in both maps are added. ***Not a good idea!***
- **Better:** model what is going on by using all available images from the two years (and between)
  - Time series analysis
  - Hidden Markov model
  - Viterbi algorithm
- **Then:** get forest cover map as a ***by-product*** of **time series analysis**



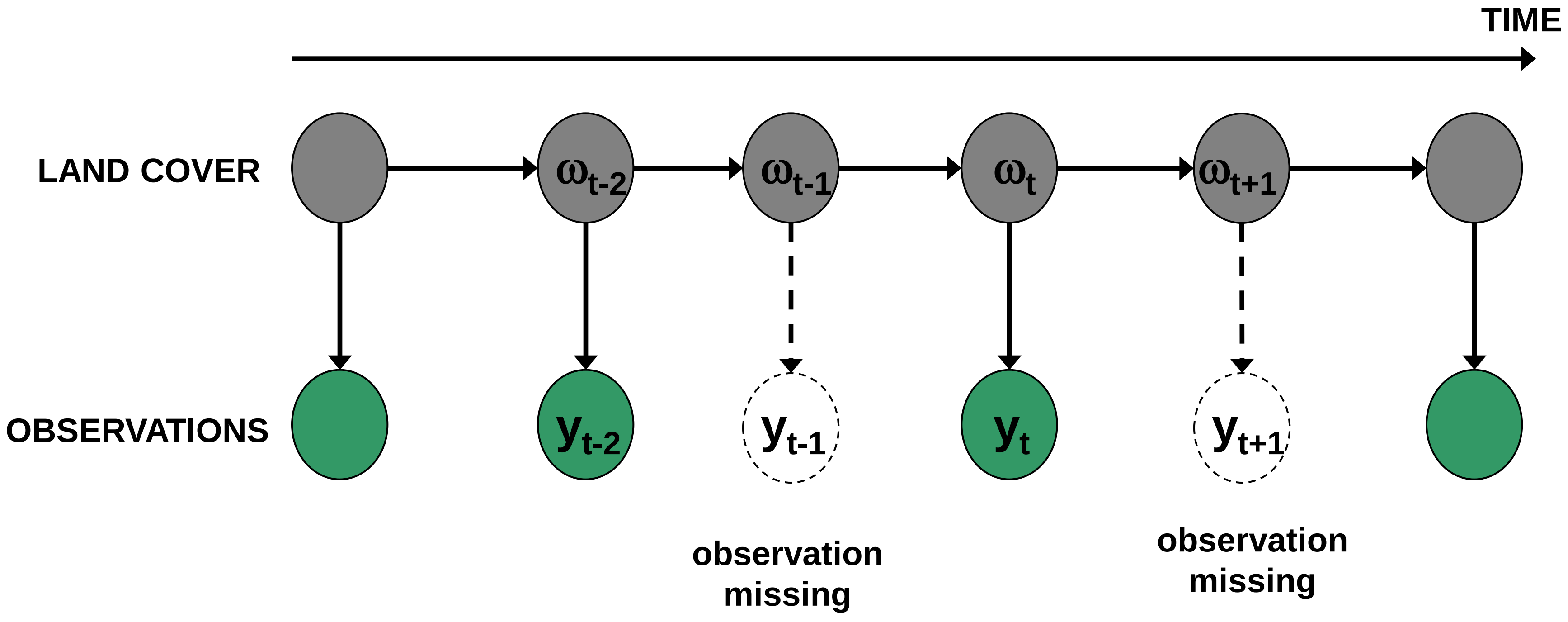
Temporal forest cover sequence

- **<u>Demonstrate:</u>** a concept for temporal forest cover analysis
- **<u>Products:</u>**
  - Spatial forest/land cover at any time instant.
  - Forest/land cover change detection map at any time instant
    - no propagation of classification errors from one time instant to the next.
  - Cloud free image estimate at any time instant.

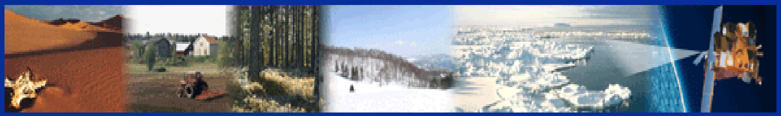


Temporal forest cover sequence

- Hidden Markov model

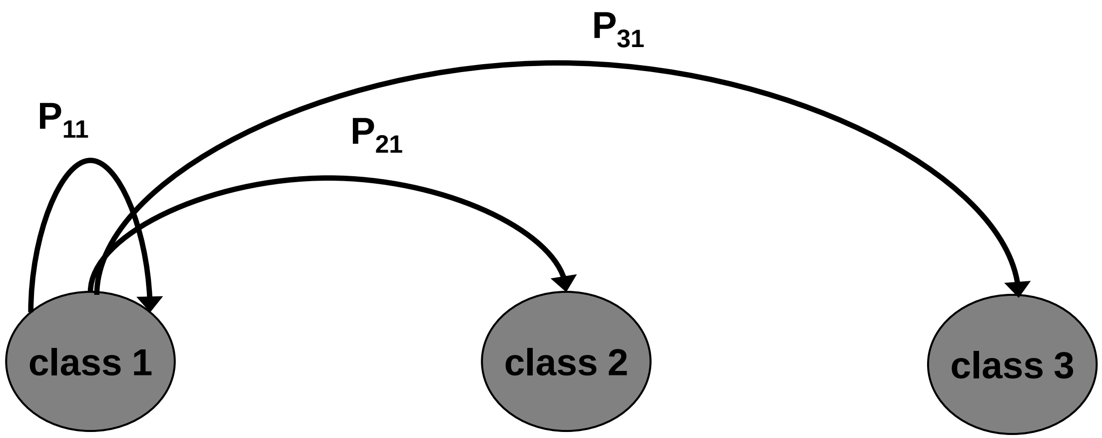


Land cover classes (or states):
forest, sparse forest, soil and *grass.*

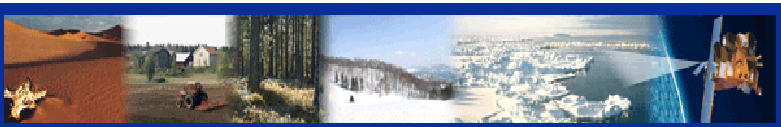


Temporal forest cover sequence

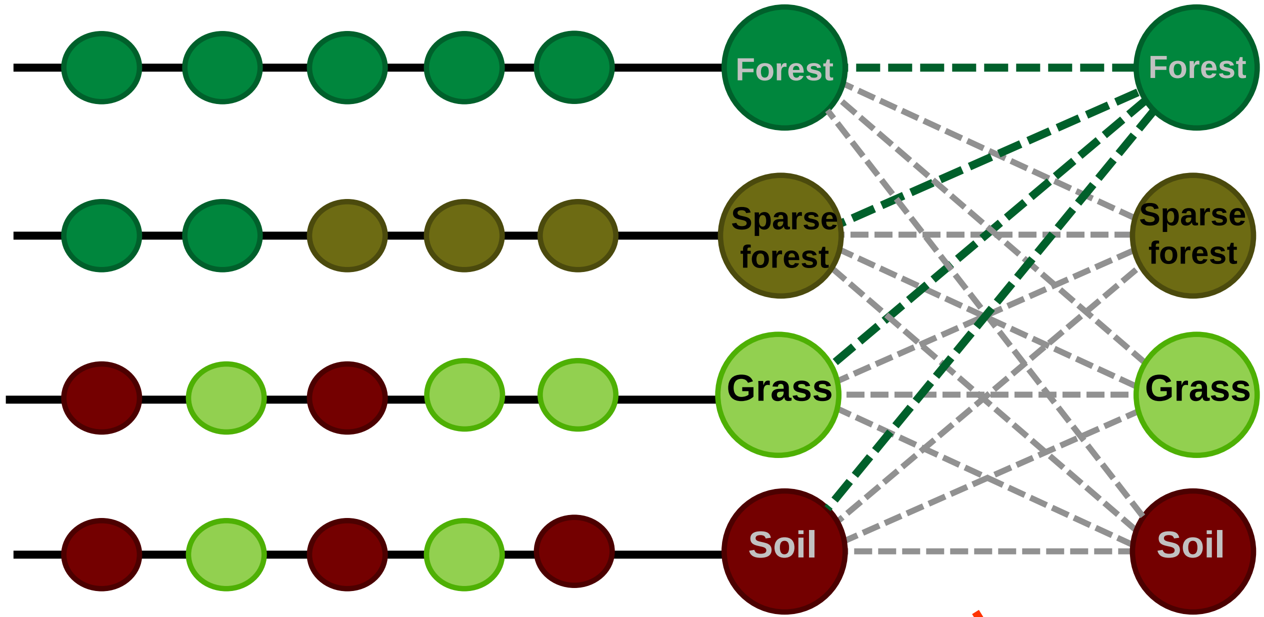
- Model each pixel using a class transition probability



- P_{jk} = $P(\mathit{class}\ j|\mathit{class}\ k)$ is the probability that a pixel containing class *k* is containing class *j* in the next time instant.



One step in the Viterbi algorithm



Most probable sequence of previous states for each state at time *t*

Possible states at time *t*

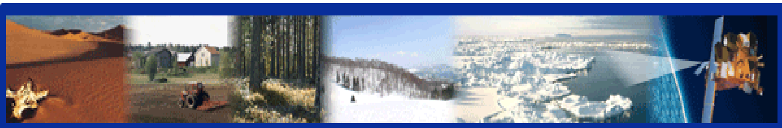
Possible states at time *t*+1

The best sequence ending at state c, given the observations $x_1, \ldots, x_t$

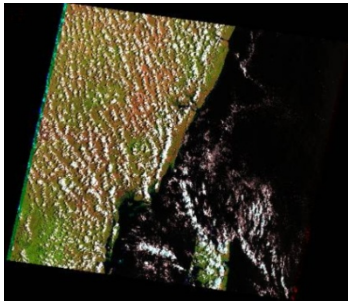
The probability of jumping from state c to state k (this is dependent on the time interval)

The probability of observing the actual observation, given that the state is k

$$\Pr[bestsequence(t+1,k)] = \max_{c=1,..,K}\{\Pr[bestsequence(t,c)]\,P(\omega_{t+1}=k|\omega_t=c)P(\boldsymbol{x}_{t+1}|\omega_{t+1}=k)\}$$



Landsat TM image stack (166/63)



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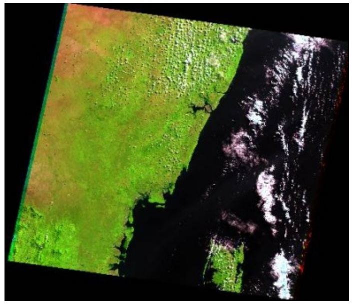

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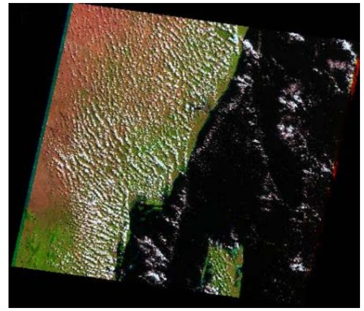

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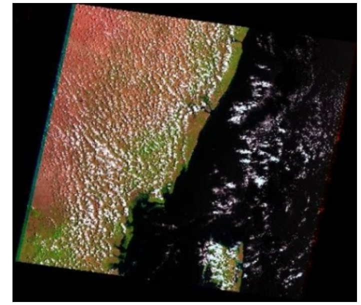

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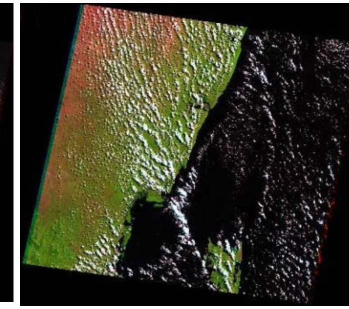

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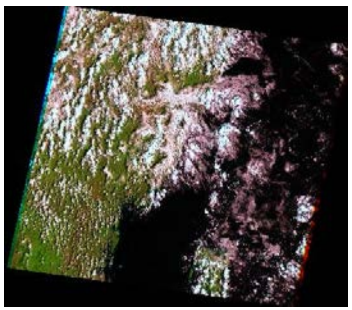

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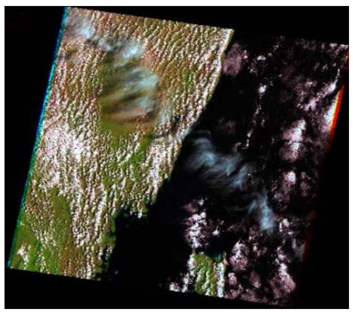

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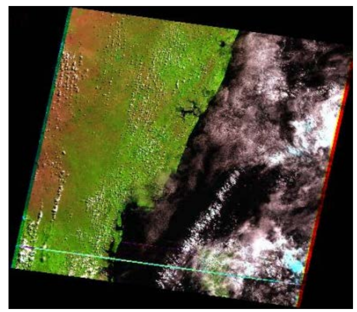

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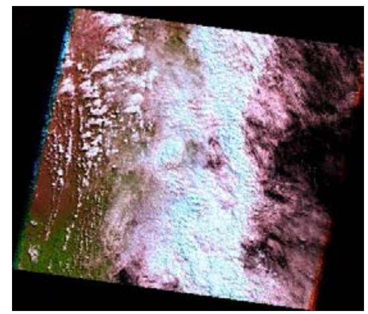

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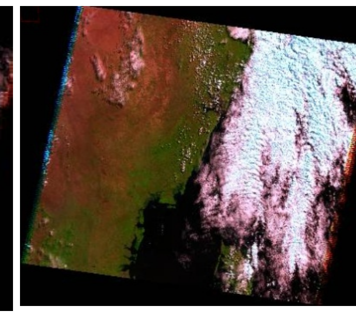

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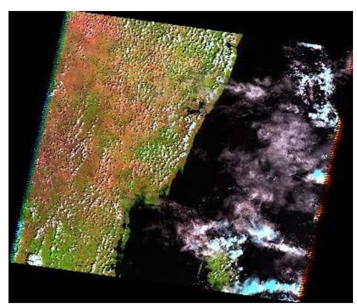

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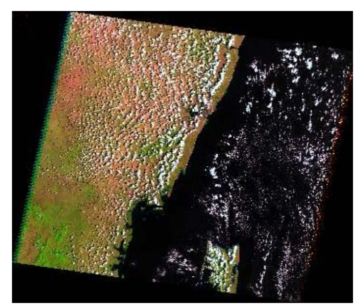

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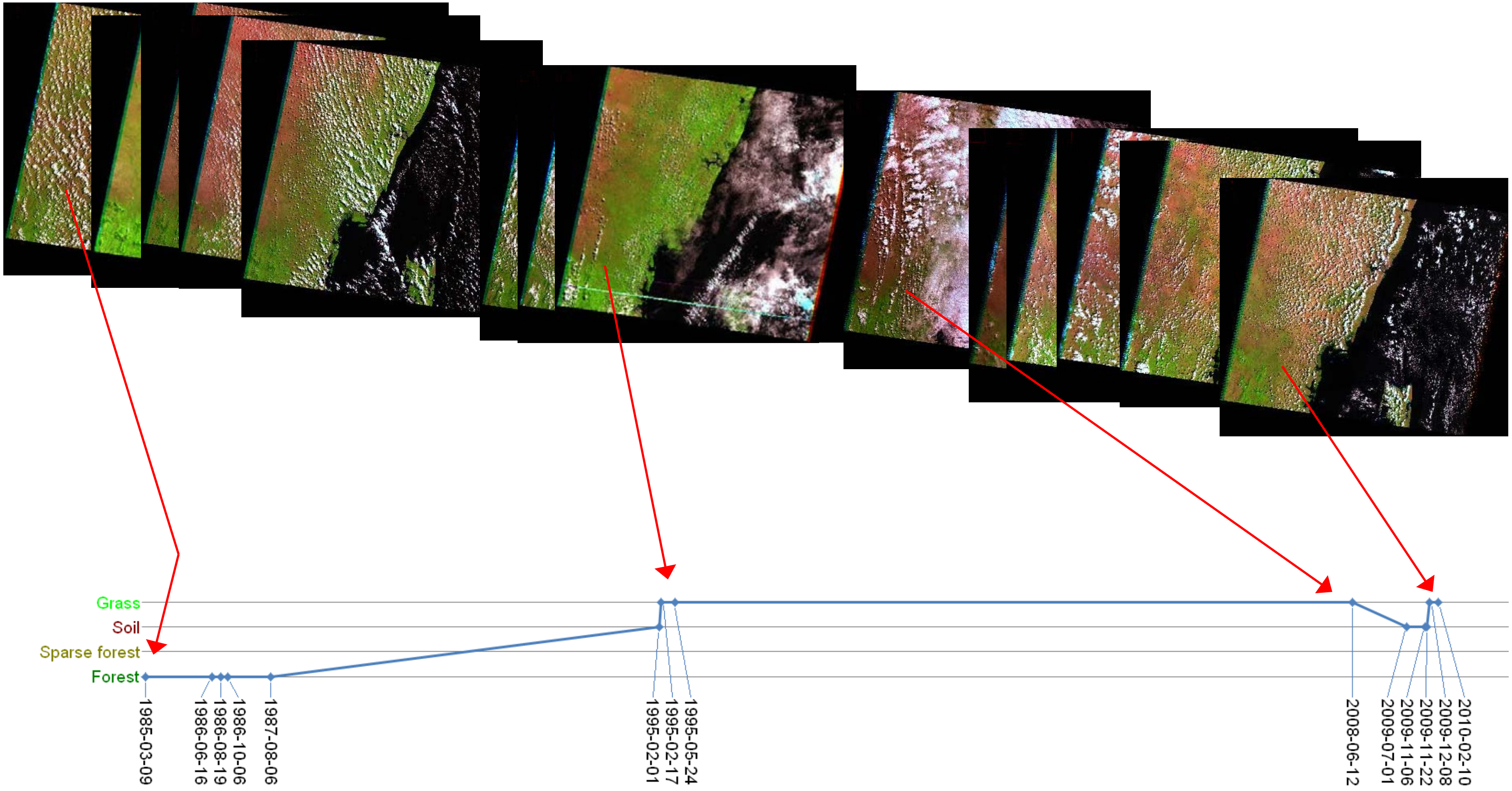
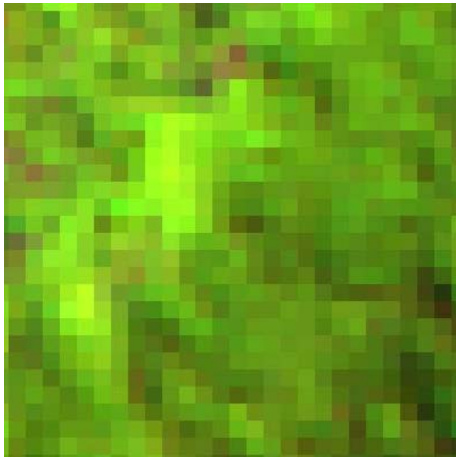
Landsat TM image stack (166/63)



Results - Forest cover maps



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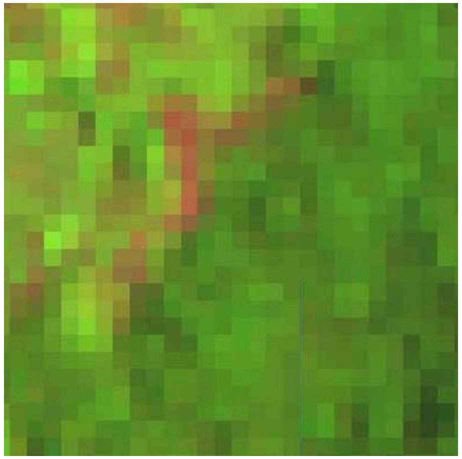

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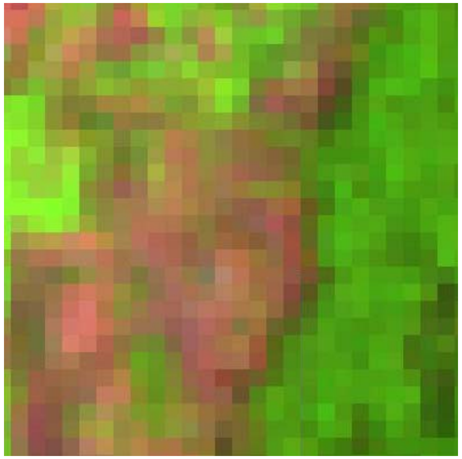

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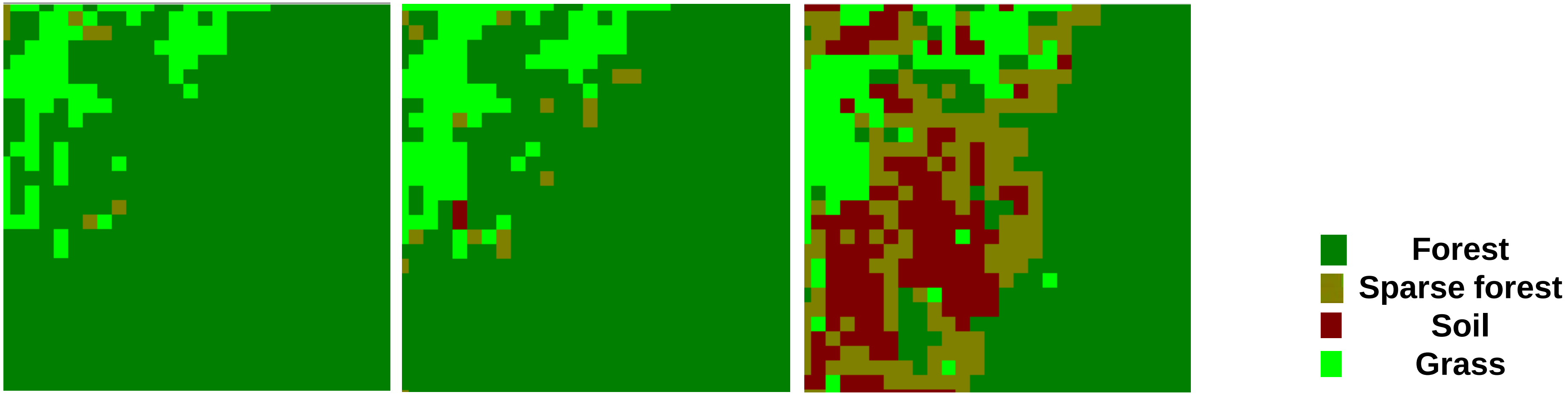
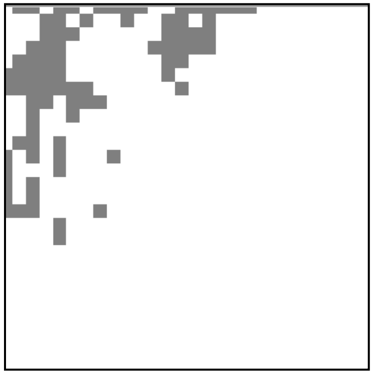
Worldview-2 2010-03-04



Results - Forest cover change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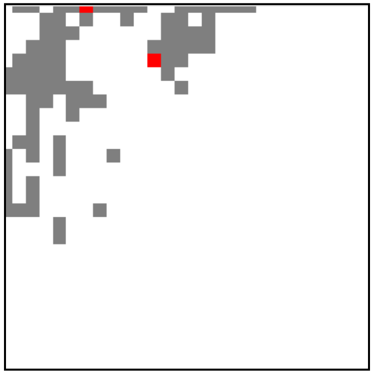
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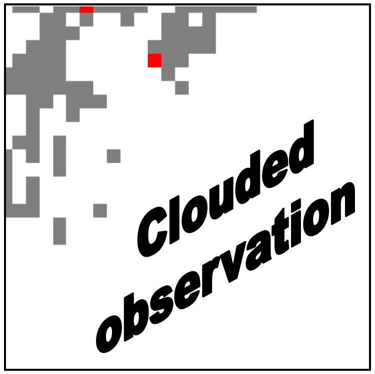

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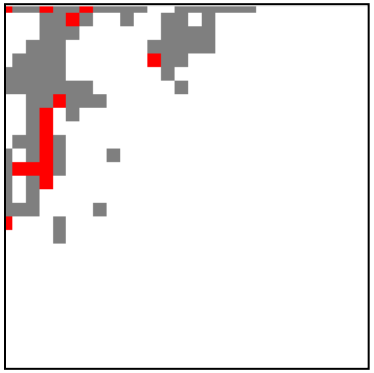
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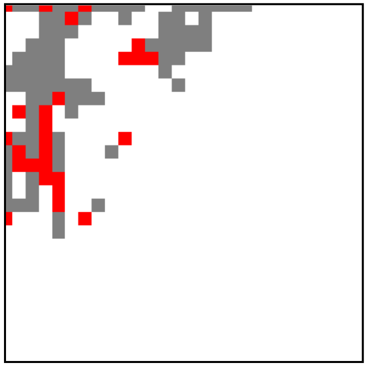
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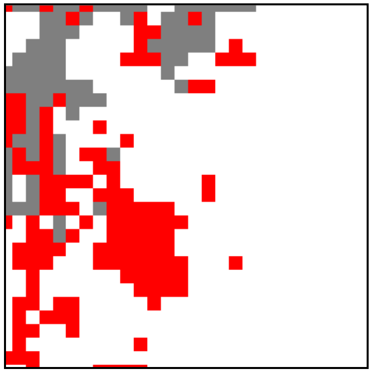
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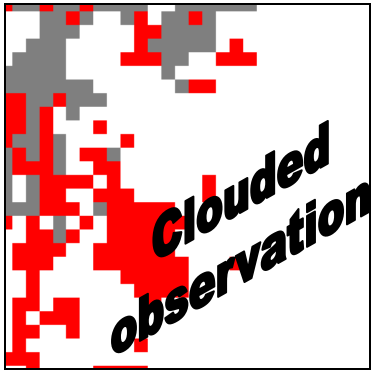

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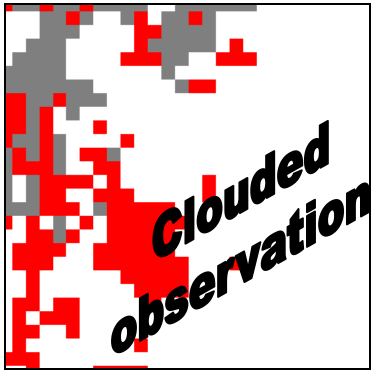

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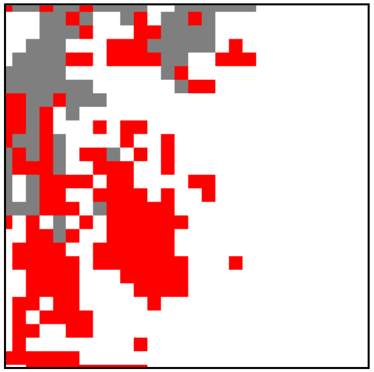
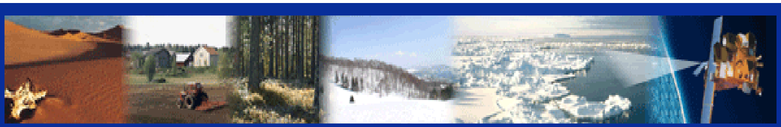

2010-02-10


WV2 2010-03-25

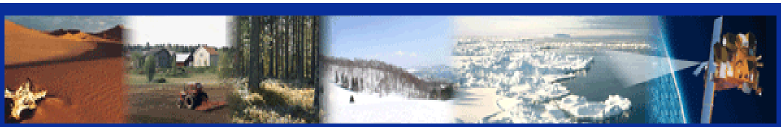
Conclusions

- Time series analysis of each pixel based on a hidden Markov model
- Finds the most likely sequence of land cover classes
- Change detection based on classified sequence
  - Does not propagate errors since the whole sequence is classified simultaneously.
  - Regularized by the transition probabilities.
- Handles cloud contaminated images
  - Cloud free land cover generated by allowing missing observations for each pixel



Future work

- A lot of work remains before this may be applied on national coverage mapping:
  - Better cloud and cloud shadow detection
  - Better atmospheric correction
  - Fine-tune transition probabilities
  - Appropriate land cover classes
  - Calibration and verification with field data
  - Integrate into automatic processing chain
- This will be done in the present project



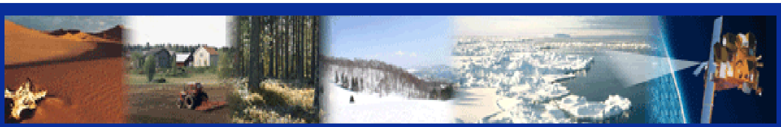
Multsensor possibilities

- Multitemporal observations from other sensors (e.g., radar) may naturally be modeled in the hiddem Markov model
  - Only the sensor data distributions are needed, e.g.

$$p_{SAR}\left(\mathbf{y}_t \mid \text{class } k\right)$$

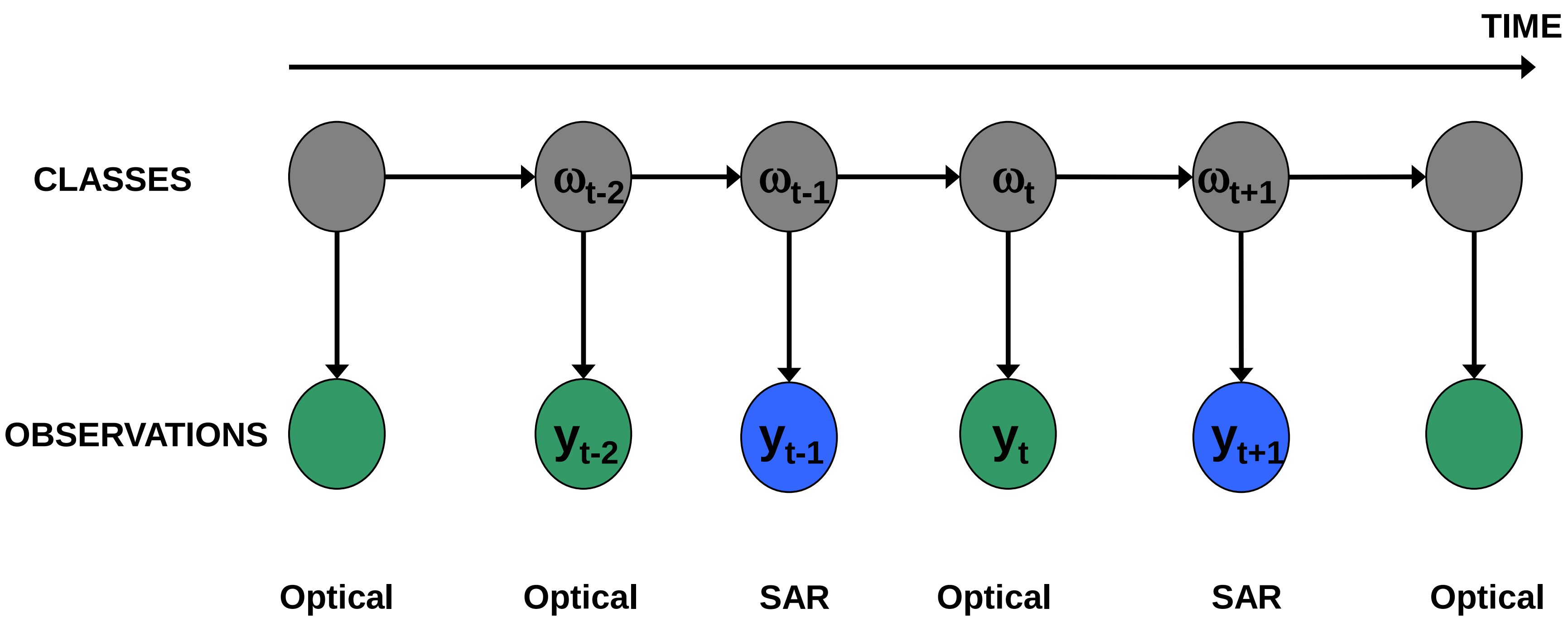
- Different physical properties of the land cover may be used in a multisensor framework to enhance the performance.

- The multisensor images need to be geocoded to the same grid



Temporal forest cover sequence

- Multisensor Hidden Markov model



Acknowledgements

► The experiment presented here was supported by a research grant from the Norwegian Space Centre.

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- **Salberg, A.-B., Trier, Ø. D., 2011. Temporal analysis of forest cover using hidden Markov models. 2011 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 24-29 July, Vancouver, Canada.**