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

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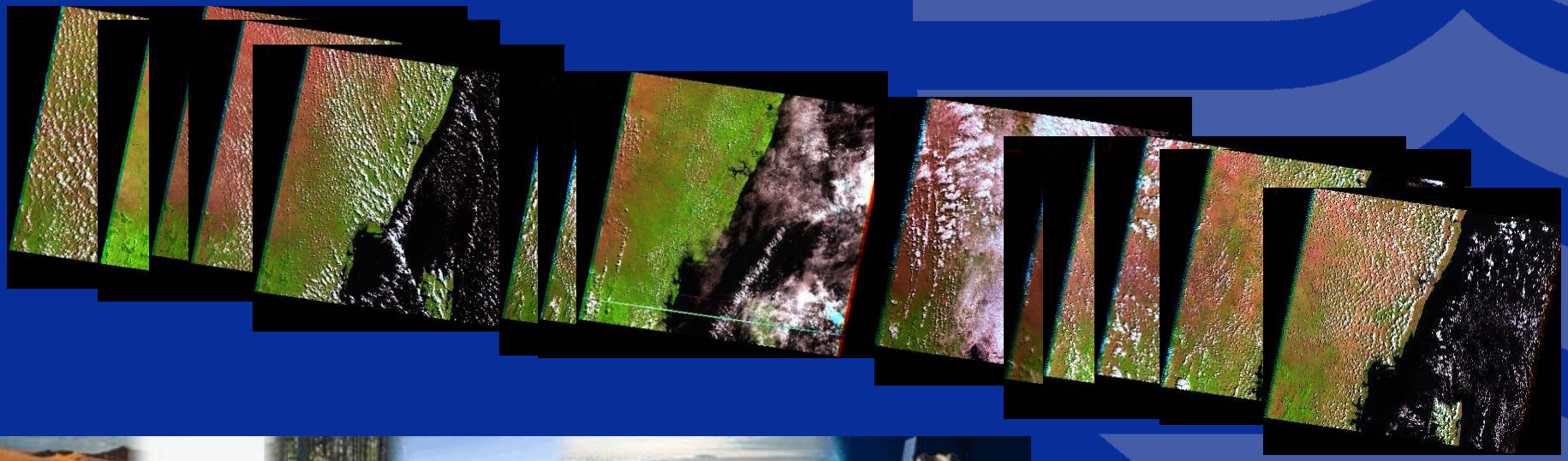
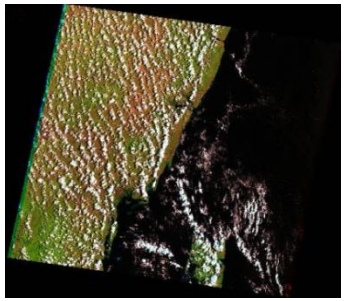


Goals

- 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

Landsat TM images (166/63)



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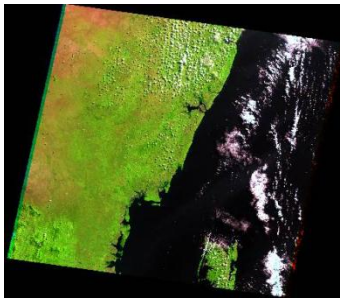

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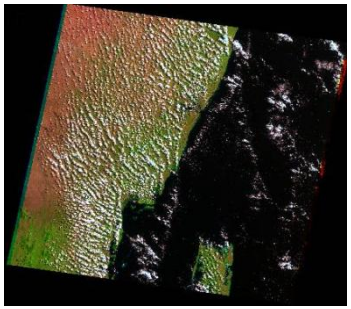

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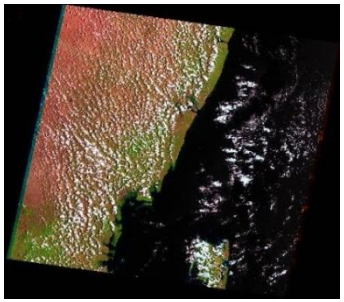

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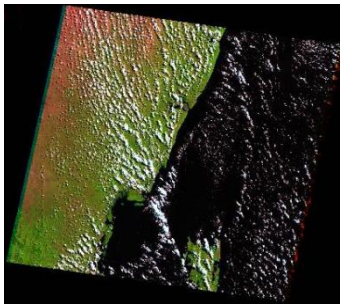

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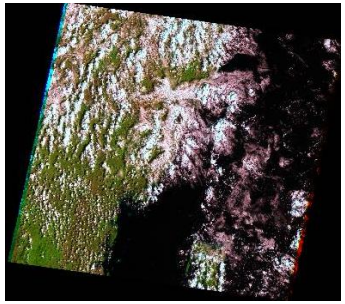

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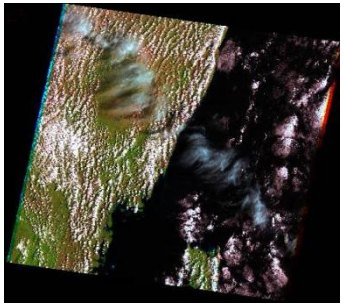

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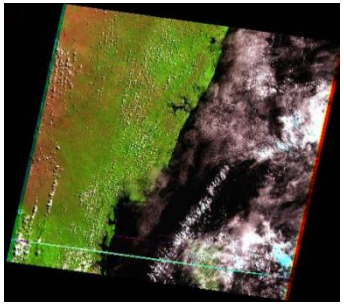

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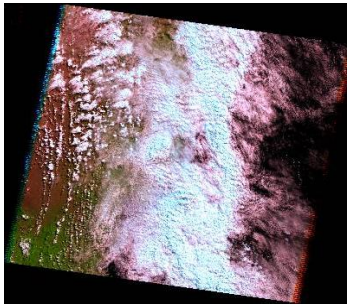

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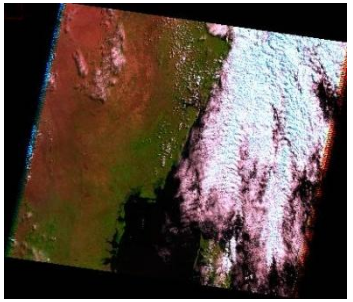

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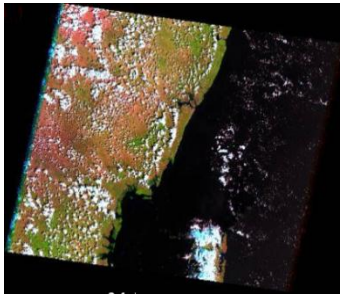

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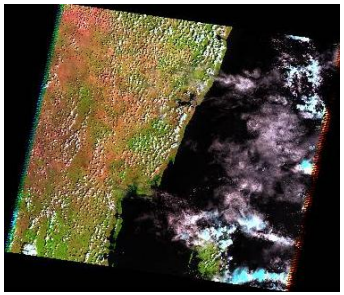

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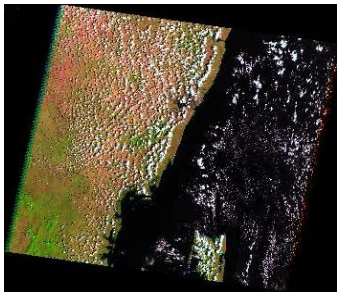

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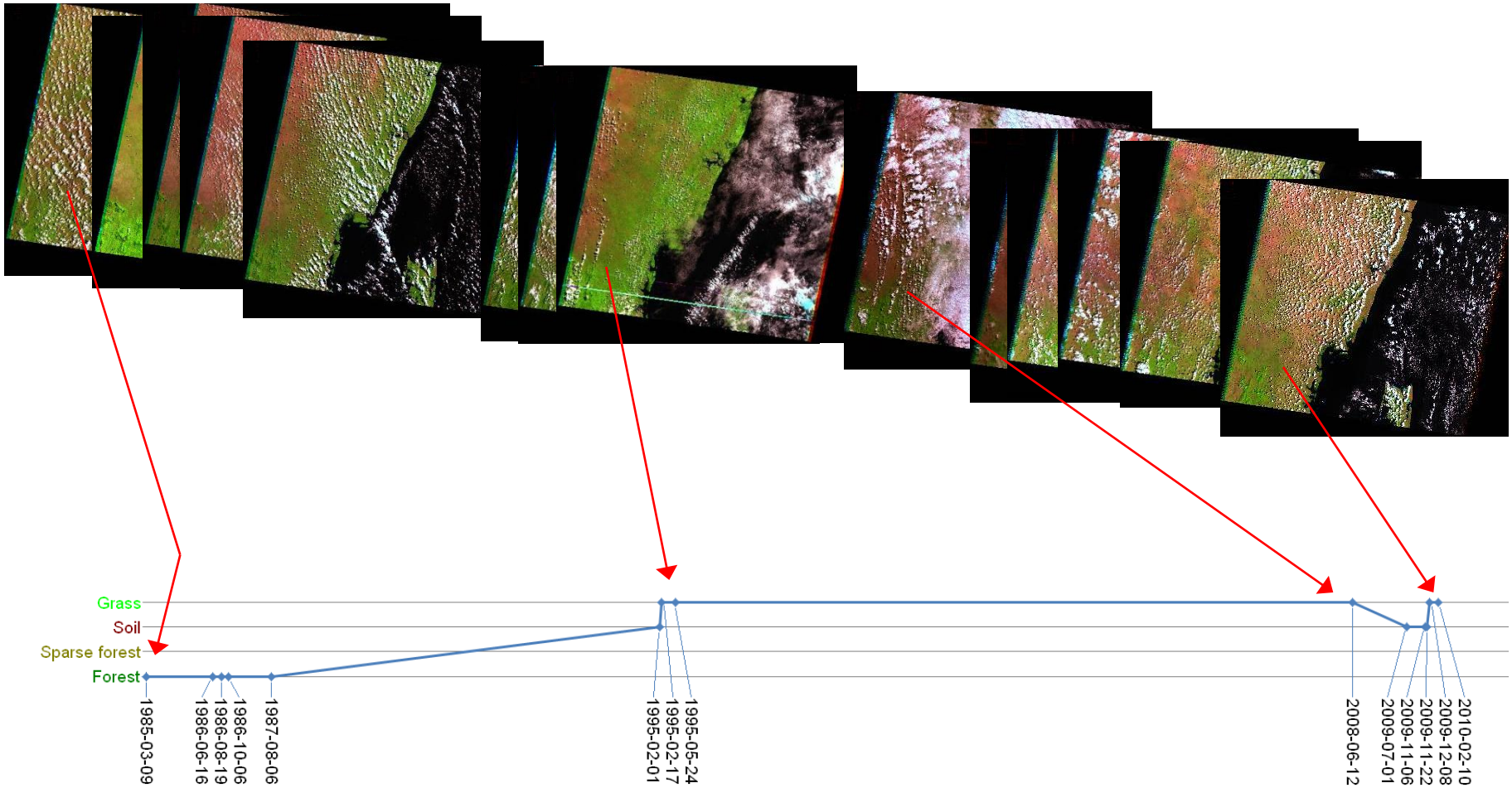
Time series analysis



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

Background

- NR and Norut have created **automatic processing chains** at Kongsberg Satellite Services (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

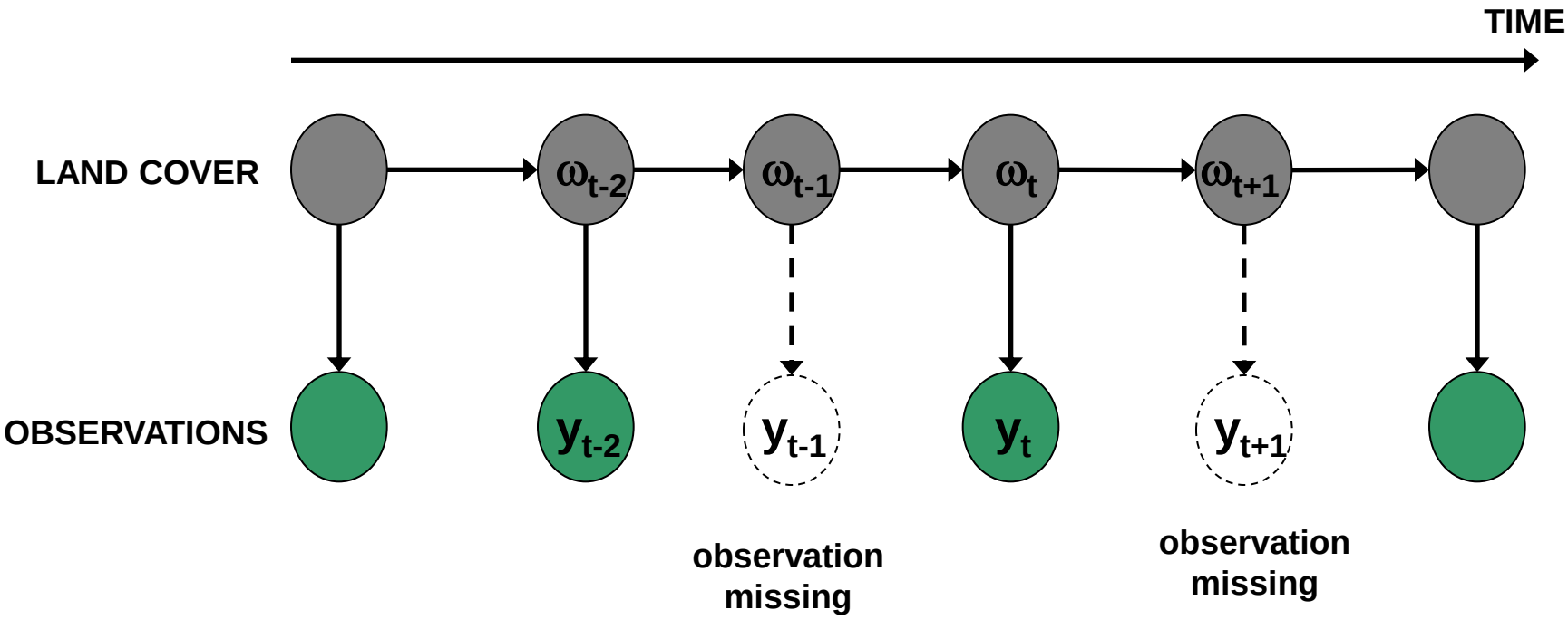
- **Naive:** simply create forest cover maps from two years, and compare
  - Errors in both maps are added. ***Not a good idea!***
- **Better:** model what is going on by using all available images from the two years (and between)
  - Time series analysis
  - Hidden Markov model
  - Viterbi algorithm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

Temporal forest cover sequence

- **Demonstrate:** a concept for temporal forest cover analysis
- **Products:**
  - 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

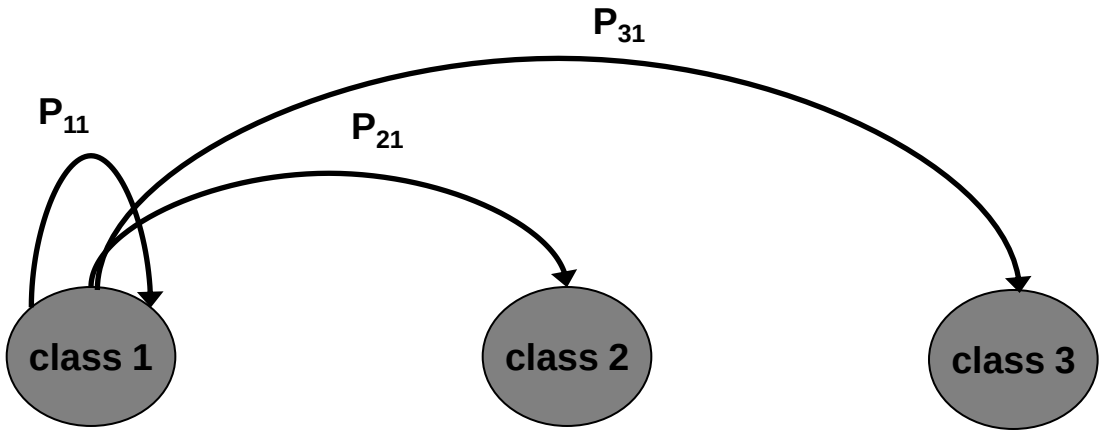
- Hidden Markov model



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

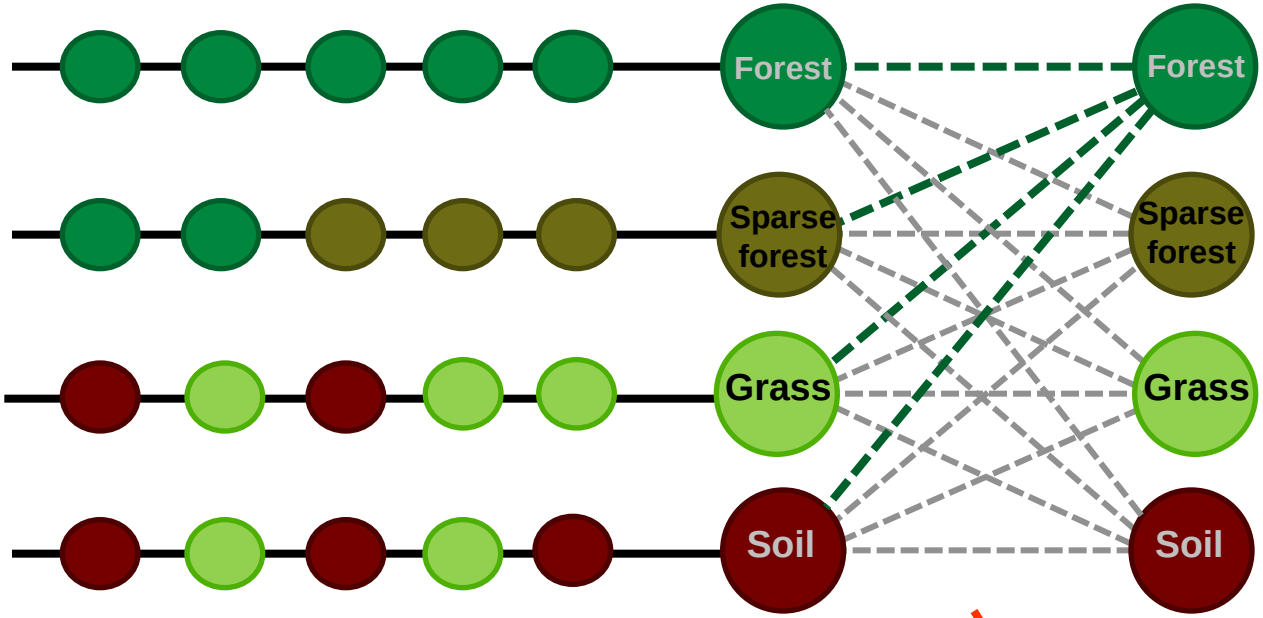
Temporal forest cover sequence

- Model each pixel using a class transition probability



- $P_{jk} = P(class\ j|class\ k)$ 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*

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

Possible states at time *t*

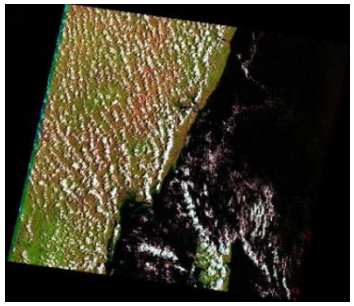
The probability of jumping from state c to state k (this is dependent on the time interval)

Possible states at time *t*+1

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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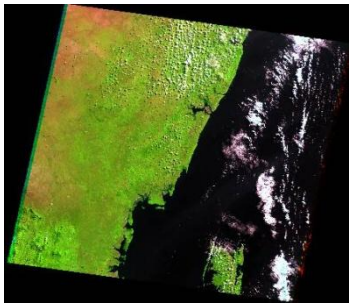
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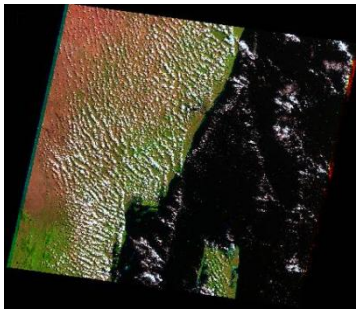
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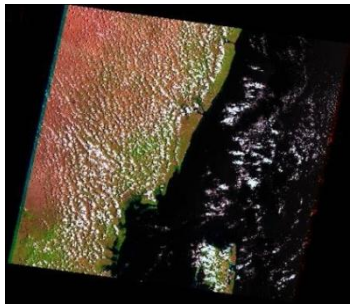
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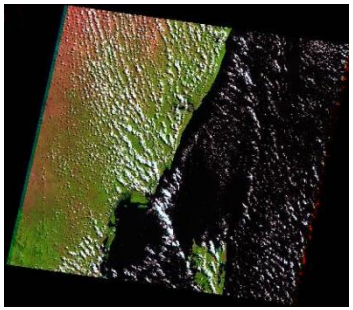
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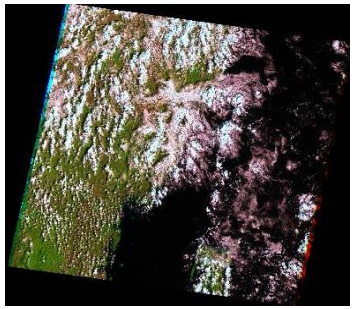
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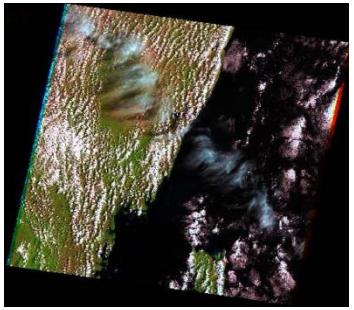
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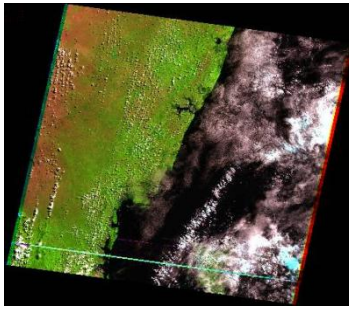
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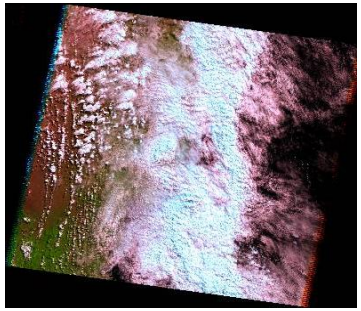
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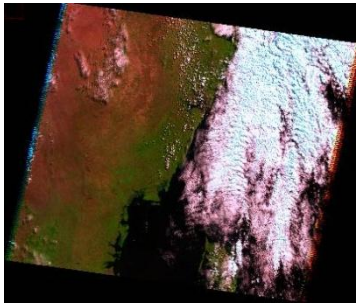
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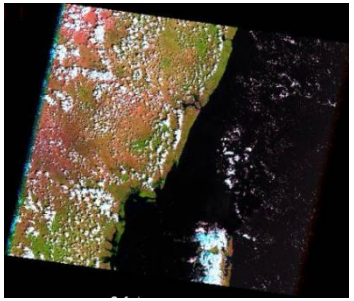
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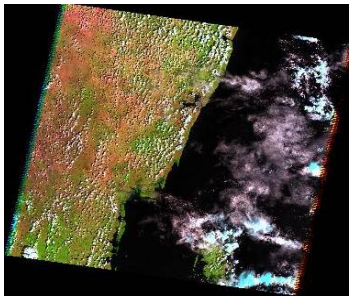
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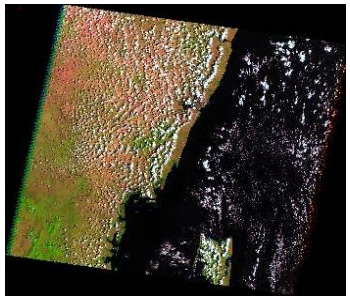
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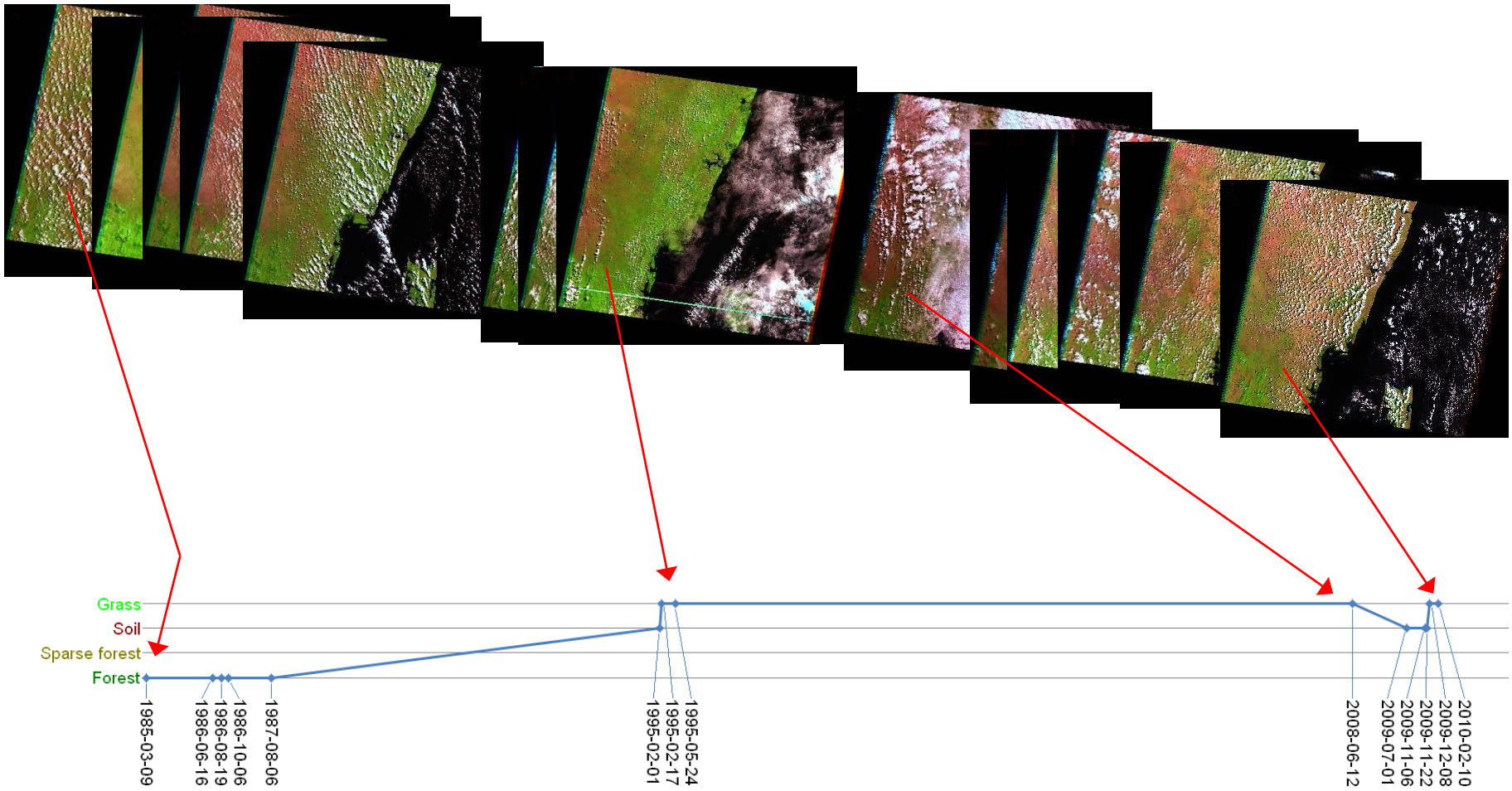
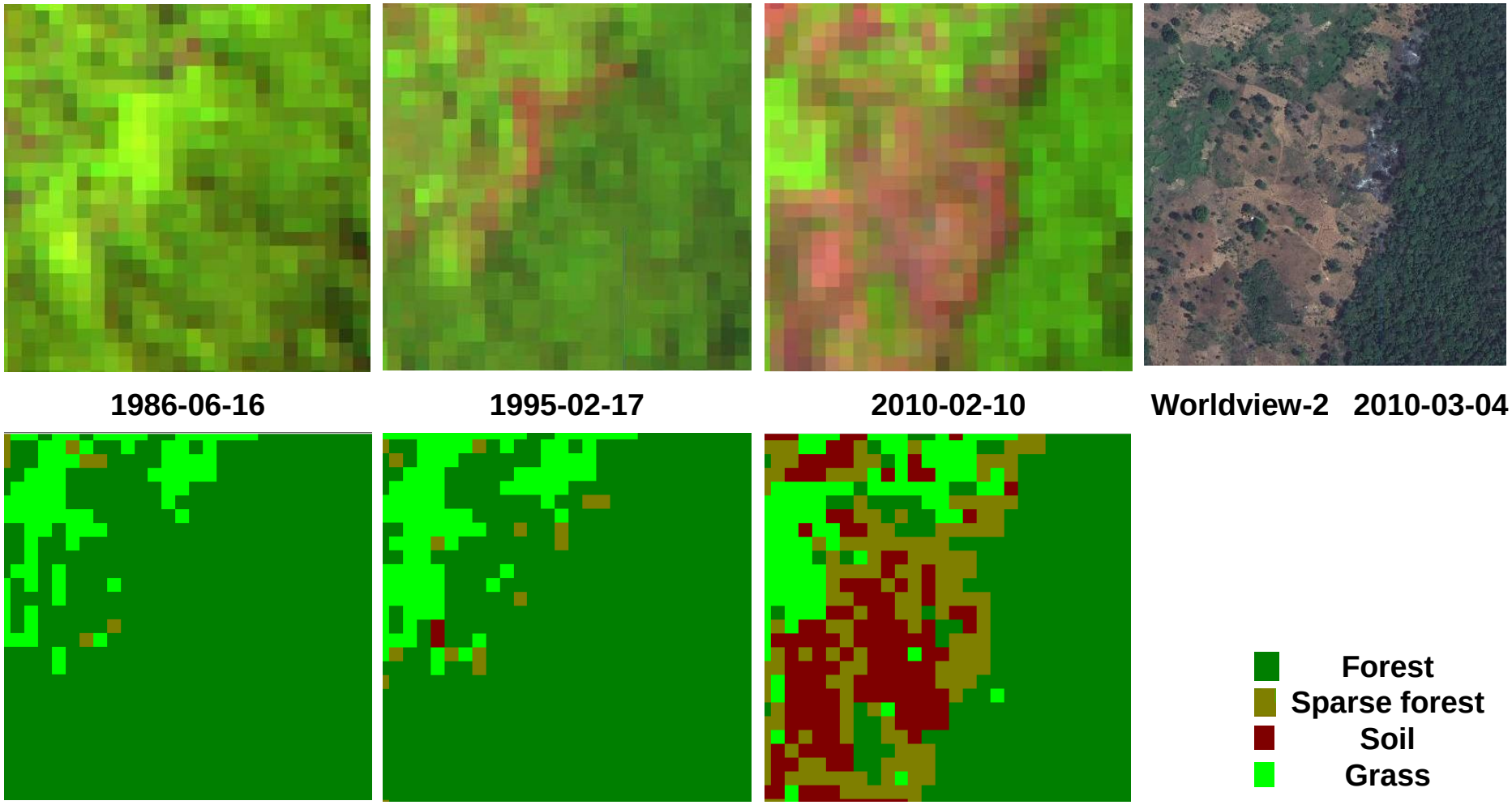
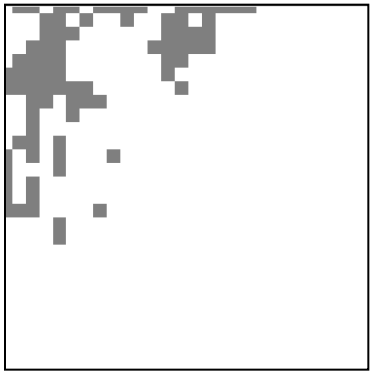
Landsat TM image stack (166/63)



Results - Forest cover maps



Results - Forest cover change



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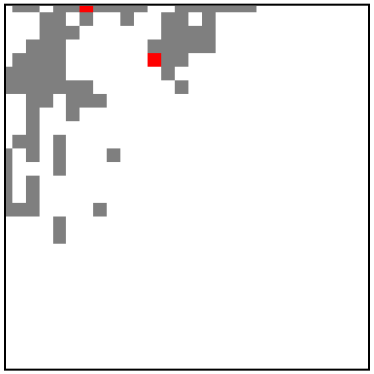

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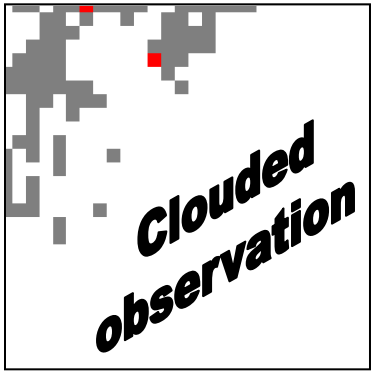

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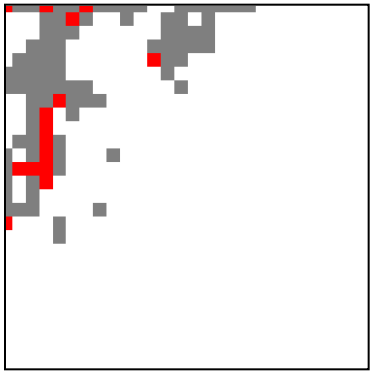

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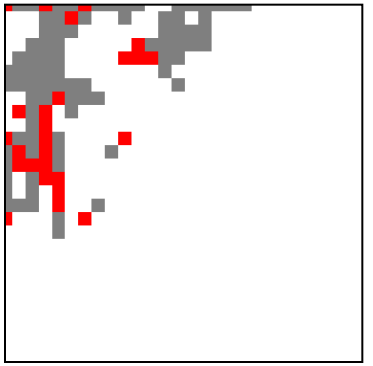

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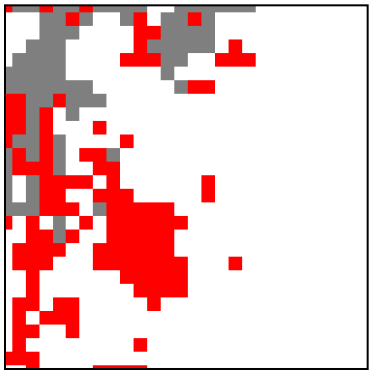

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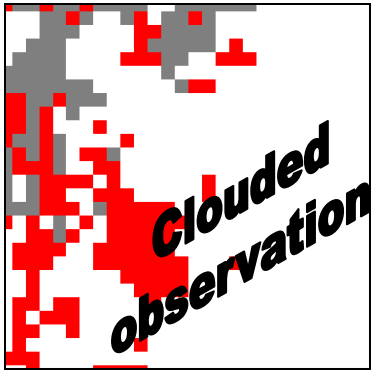

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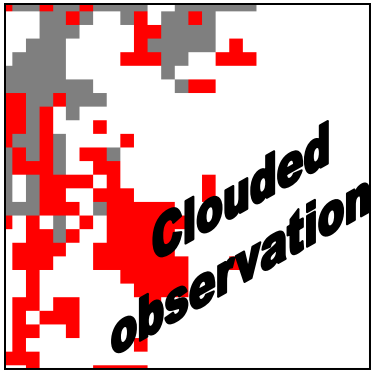

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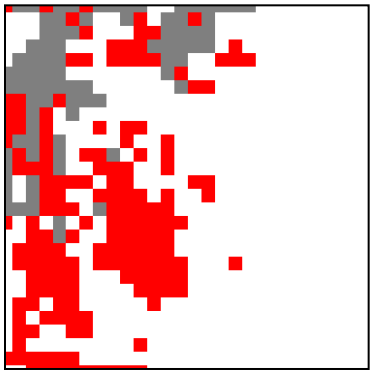

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Conclusions

- 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

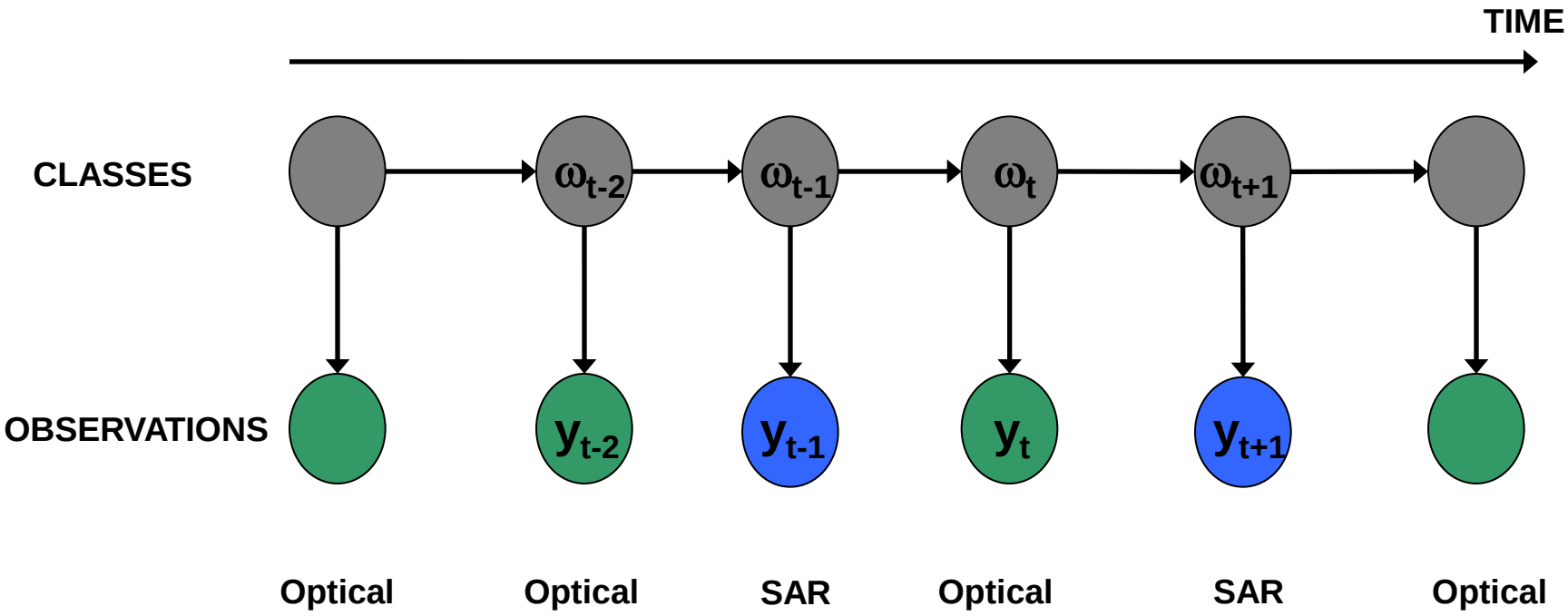
- Multitemporal observations from other sensors (e.g., radar) may naturally be modeled in the hidden Markov model
  - Only the sensor data distributions are needed, e.g.

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

- Different physical properties of the land cover may be used in a multi-sensor framework to enhance the performance.
- The multi-sensor images need to be geocoded to the same grid

Temporal forest cover sequence

- Multi-sensor Hidden Markov model



Acknowledgements

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

References

- **Salberg, A.-B., 2011. Land Cover Classification of Cloud-Contaminated Multitemporal High-Resolution Images. *IEEE Transactions on Geoscience and Remote Sensing* 49 (1), pp. 377-387.**
- **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.**