# *The Derivation of Current Fields from Multi-Sensor Satellite Data*

Challenges, approaches and validations for the current derivation from multi-sensor imagery

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DER FORSCHUNG | DER LEHRE | DER BILDUNG

# *Outline*

- Introduction
- Solving the correspondence problem
- Application to satellite images
- Conclusions and future work

# *Outline*

- Introduction
  - The task
  - Constraints, challenges and problems
  - Motivation
- Solving the correspondence problem
- Application to satellite images
- Conclusions and future work

# *The Task*

- Brief description
  Derive / compute the sea surface currents from at least two satellite images
- Basic Assumption
  There are some „scene objects“ in the images, whose motion is caused only by the local sea surface current, e.g.:
    - Algae- or other surface films
    - Ice floe

# *Image Constraints*

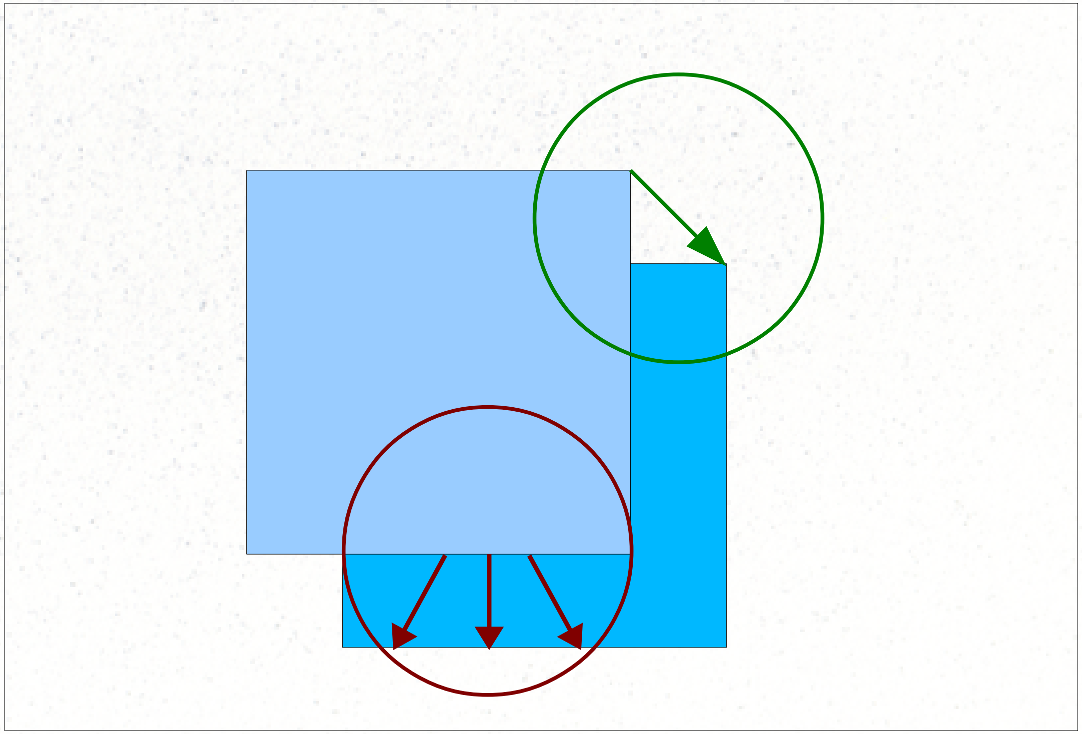
- The spectral domains of the images can be quite different, e.g.:
  - infrared
  - multispectral or even hyperspectral
  - microwave (active / passive)
- Additionally, the spatial domain of the images is never equal
- Hard to find images with big spatial overlap and small temporal distance

# *Some Challenges*

- Different types of sensors:
  - Specific noise
  - Different properties are imaged
- Atmospheric  interference and distortion
- Low sampled time axis:
  - Mainly just two images
  - Big temporal distances
- The aperture problem

# *The Aperture Problem*

- Even if an object was sampled “optimally” at both images, it may be impossible to calculate a displacement vector only based on local information.



# *Optical Flow vs. "Real Motion"*

Show movies...

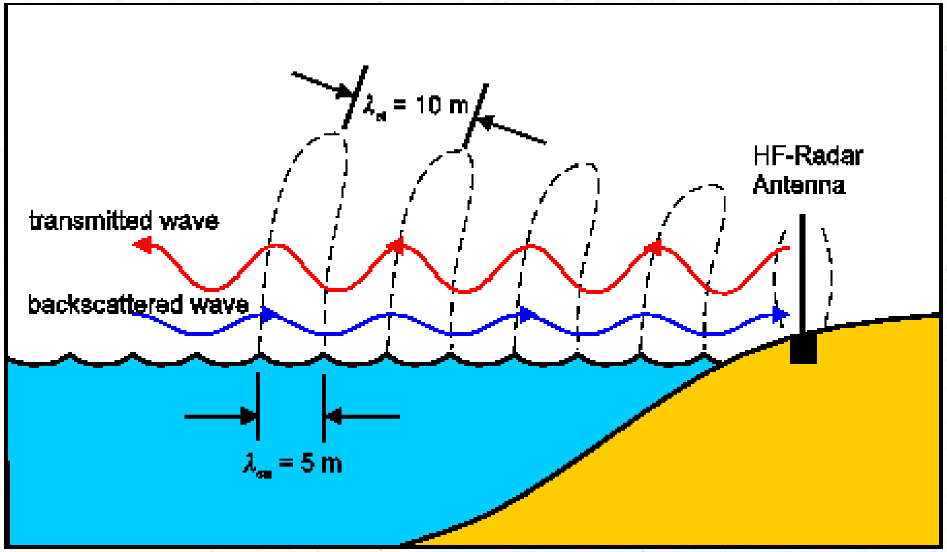
# *Motivation*

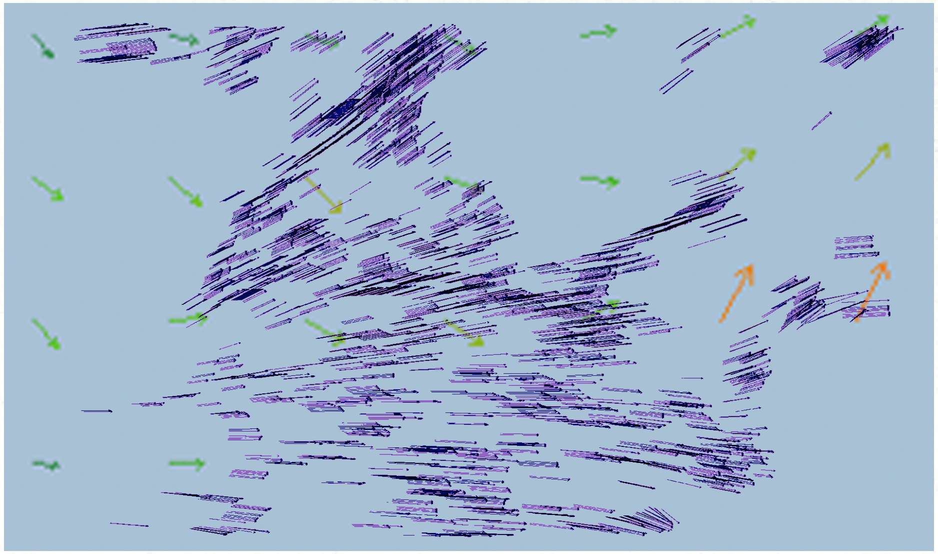
- Currently, there is research interest for high-resolution surface current **measurements**, e.g.:
  - Validate or refine climate or oceanographic *models*
  - Improve accuracy of the measurement of ice drift or biological development e.g. of algae blooms
  - ➔ General enhancement of predictions
- Further advantages:
  - Satellite images are relatively cheap compared to other methods
  - Allow the highest resolution current fields
  - Greatest possible amount of **measurements** overall

# *Other Methods of Current Derivation*

- Buoys or other in-situ measurements
- Climate or oceanographic models
- SAR-Techniques
  - Along-Track Interferometry
  - Doppler-Centroid Analysis
- HF-Radar arrays

# HF-Radar


$\lambda_{el} = 10$ m
HF-Radar
Antenna
transmitted wave
backscattered wave
$\lambda_{ow} = 5$ m



# *Table of Contents*

# *The Feature Based Approach*

1. Step: Find the features
   - There are many possible operators like e.g. the Monotony and Moravec operator [MORAVEC 1977]
   - Wavelet based approaches [LIU ZHAO HSU 2006]
   - Model based approaches like Snakes [OETJENS 1997], [WENDKER 1997]
2. Step: Calculate the similarity between the features
   - General pattern matching problem, Solution via (normalised) cross-correlation, shape context algorithm or other metrics
3. Step: Determination of correspondences
   - Maximum likelihood decider
   - Smooth vector-field decider
   - ➡ Relaxation [KITCHEN ROSENFELD 1979], [BARNARD THOMPSON 1981]

# *The Gradient Based Approach*

- Basic assumption [HORN SCHUNK 1981]:
  - Flat surfaces (Intensity of objects does not change at movement)
- Let I(x,y,t) be the intensity of a pixel (x,y) at time t
  - $\frac{dI}{dt}=0$ , and using the chain rule: $\frac{\partial I}{\partial x}\cdot\frac{dx}{dt}+\frac{\partial I}{\partial y}\cdot\frac{dy}{dt}+\frac{\partial I}{\partial t}=0$
  - Substitution of $u=\frac{dx}{dt}, \quad v=\frac{dy}{dt}$ results in a linear system of equations:

    $$I_x\cdot u+I_y\cdot v+I_t=0$$

    where $I_x$, $I_y$ and $I_t$ are the partial derivatives of the intensity function.
  - Problem: One equation for two unknowns u and v!

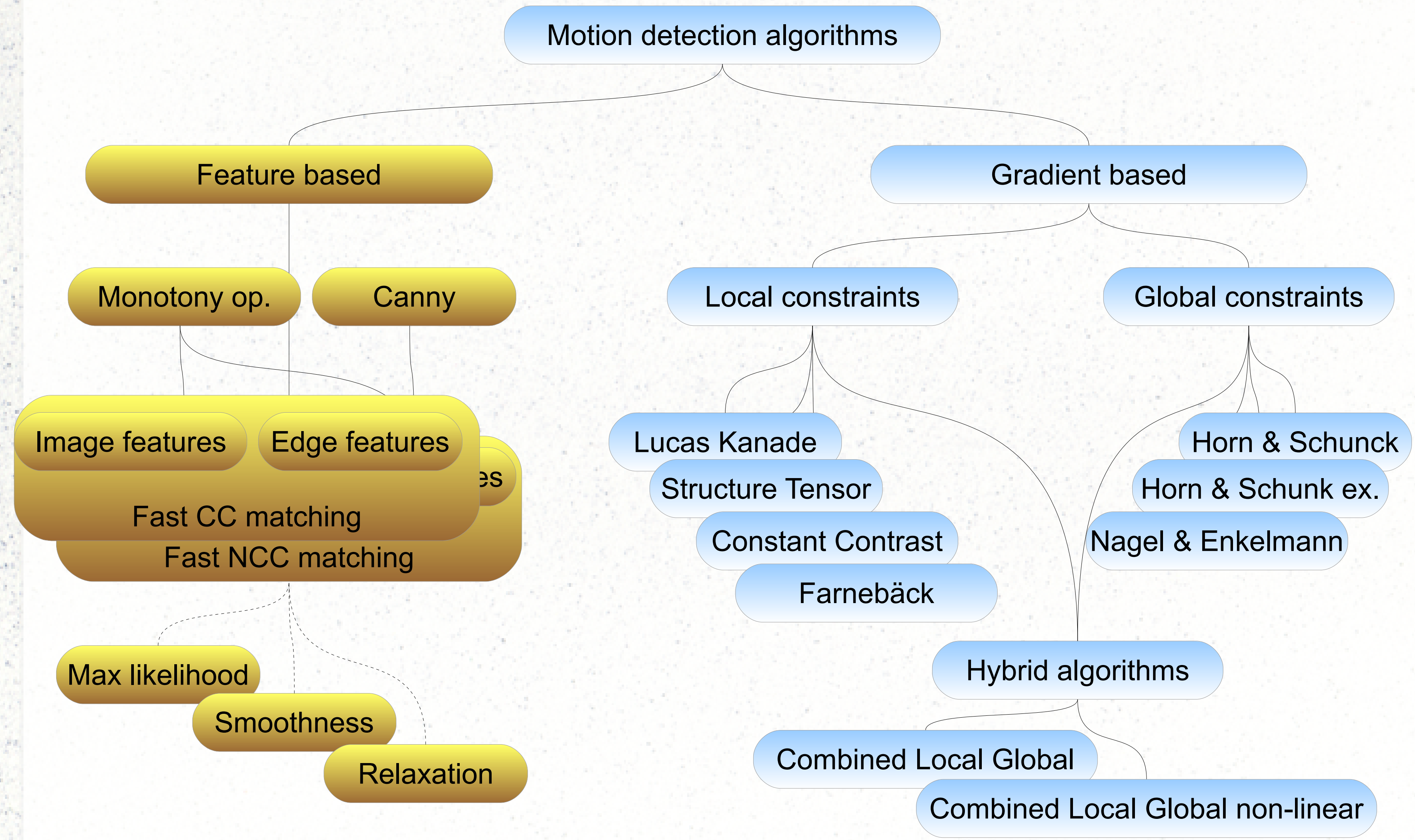
# Constraints for Gradient Based Methods

- Global constraints
  - Example: Horn & Schunk: Smoothness of movement
  - Minimization of the quadratic gradient magnitude of the flow velocity:

$$\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y}\right)^2 \text{ and } \left(\frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2$$

- Local constraints
  - Assume local equality of the motion
  - Example: Lucas Kanade method: $\begin{bmatrix} \sum_\sigma (I_x)^2 & \sum_\sigma I_x \cdot I_y \\ \sum_\sigma I_y \cdot I_x & \sum_\sigma (I_y)^2 \end{bmatrix} \cdot \begin{bmatrix} u \\ v \end{bmatrix} = -\begin{bmatrix} \sum_\sigma I_x \\ \sum_\sigma I_y \end{bmatrix} \cdot I_t$
- Hybrid approaches
  - Combining local and global constraints
  - Example: Bruhn et. al

# Detail of Analysed Algorithms



# Problems of Each Approach

- Gradient based
  - Calculation for the whole image
  - No explicit quality index for the vectors
  - Poor quality if constraints are violated, e.g. flexible objects, change of illumination or at big spatio-temporal distances
  - Do not have to select and adjust special feature detectors
  - No final determination of correspondences needed
- Feature based
  - Calculation only for the features of interest
  - The quality of each vector is explicitly given
  - Less problems at changes in illumination, big spatio-temporal distances and a time axis containing just two images
  - Difficult selection of feature detectors depending on task
  - Difficult final determination of correspondences

# *Improvements*

- Accuracy of gradient based approaches
  - Extended original Horn & Schunck algorithm
  - Moved from Lucas Kanade algorithm to Structure Tensor approach
  - Embedded state-of-the art algorithms
    - Hybrid Models / non-linear approaches
- Speed of the feature matching
- Split motion detection
  - A global motion / non-global motion part
  - Hierarchically

# *The Fast Normalized Cross-Correlation* *[LEWIS 1995]*

- Given the mask-image t and the image to correlate with f, the normalized cross-correlation can be described by:

$$\gamma(u,v)=\frac{\sum_{x,y}(f(x,y)-\bar{f}_{u,v})(t(x-u,y-v)-\bar{t})}{\sqrt{\sum_{x,y}(f(x,y)-\bar{f}_{u,v})^2\cdot\sum_{x,y}(t(x-u,y-v)-\bar{t})^2}}$$

- Improve speed by using the Fast Fourier Transform (FFT)

$$FT^{-1}(FT(f')\cdot conj(FT(t')))$$

- Re-use the constant right part of the nominator

$$\sqrt{\sum_{x,y}(t(x-u,y-v)-\bar{t})^2}$$

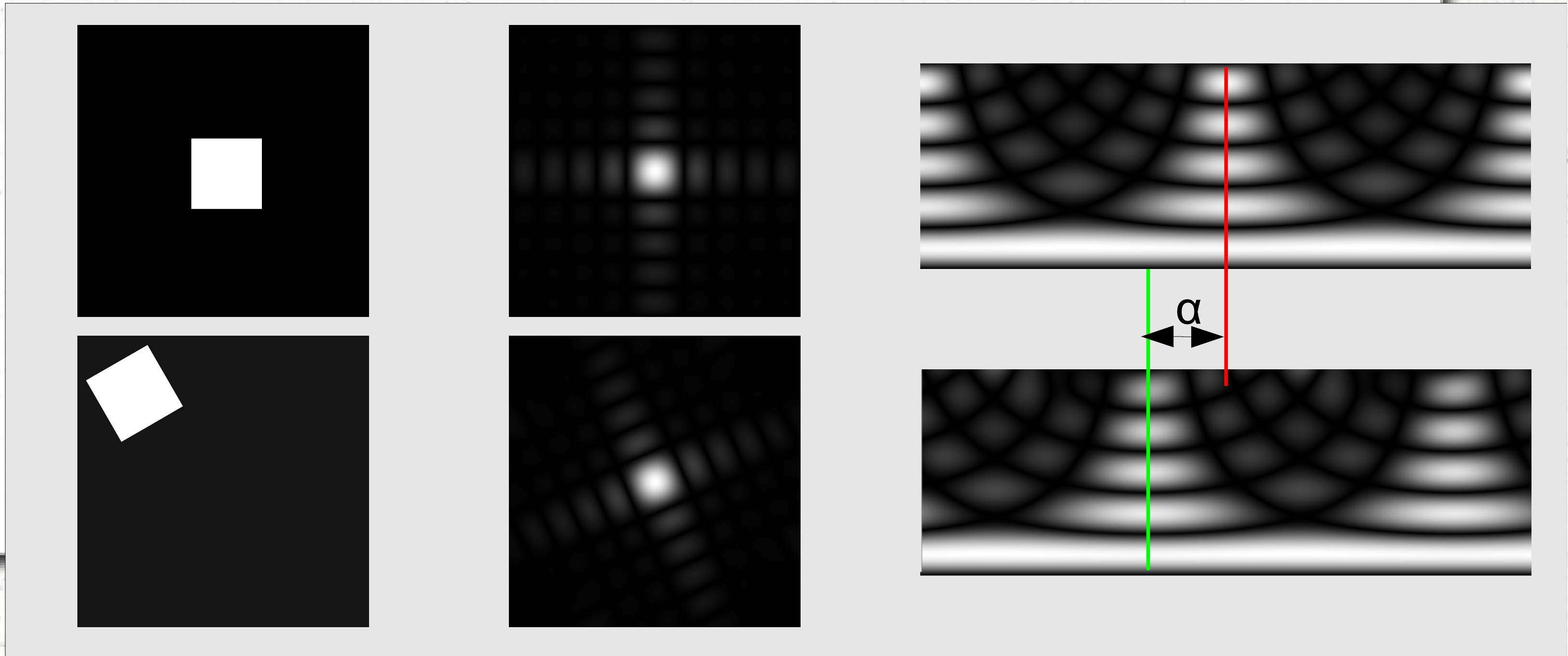
- Improve speed by calculating sum-tables for the non-constant right part of the nominator

$$\sqrt{n\cdot\sum_{x,y}f(x,y)^2-\left(\sum_{x,y}f(x,y)\right)^2}$$

Sum of squares Squared sum

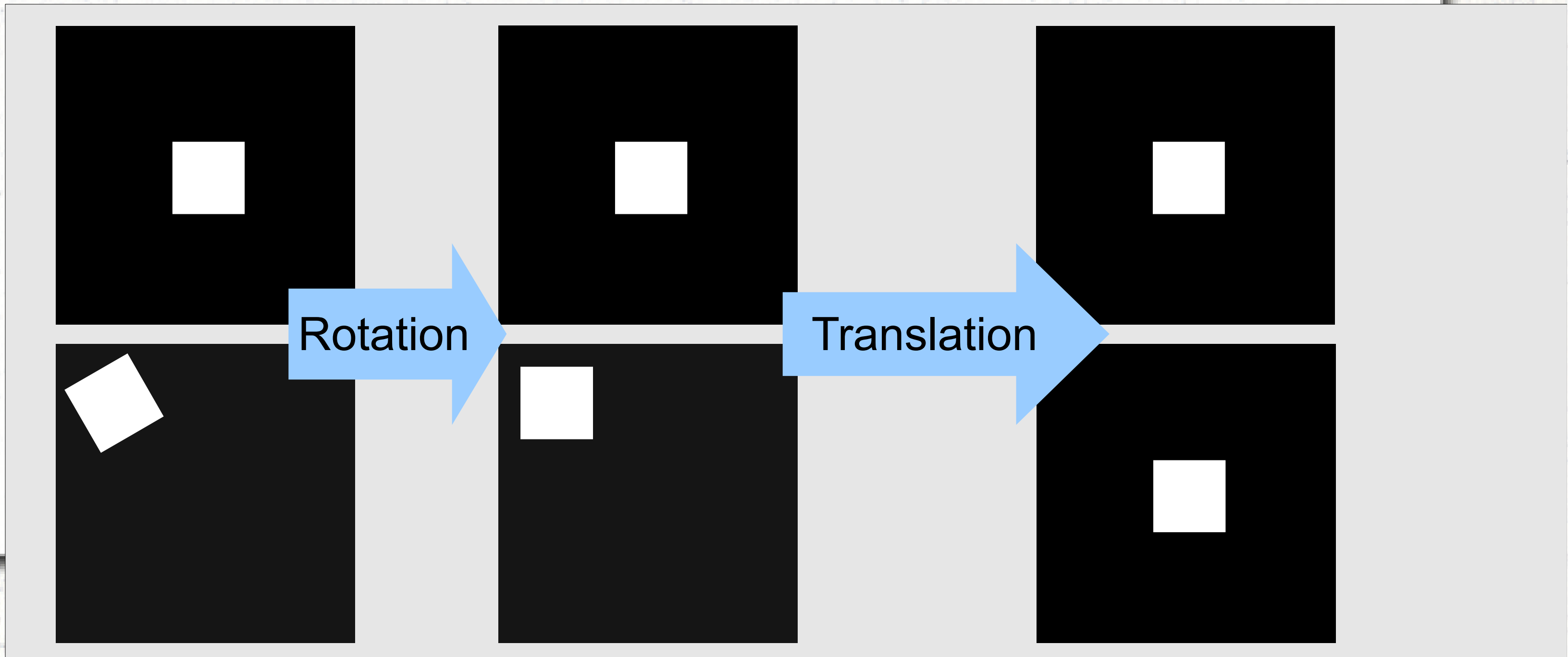
# Global Motion Estimation: Rotation

- Assumption: The motion can be split into two parts:
  - A global rotation and translation and
  - A non-global part, that describes the individual motion
- Calculation
  - Determine the rotation between the images by means of FFT



# *Global Motion Estimation: Translation*

- Calculation
  - Determine the rotation between the images at the Fourier Space (in polar coordinates)
  - Correct the rotation of the second image
  - Perform a (unnormalized) cross correlation using FFT

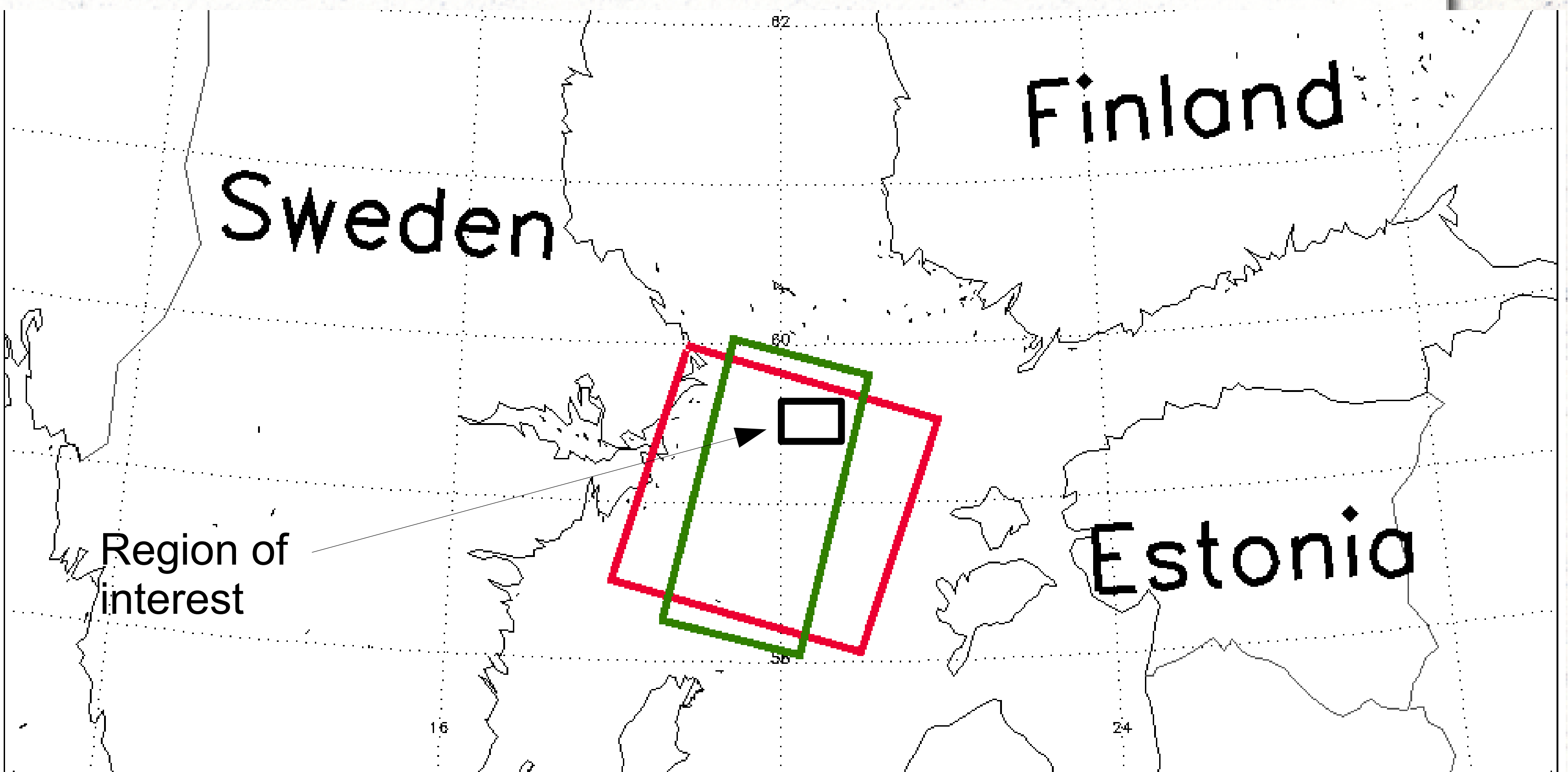


# *Outline*

- Introduction
- Solving the correspondence problem
- Application to satellite images
  - Multi-Sensor application (Landsat TM & SAR)
  - Single-Sensor application
    - SeaWiFS images
    - SAR images
- Conclusions and future work

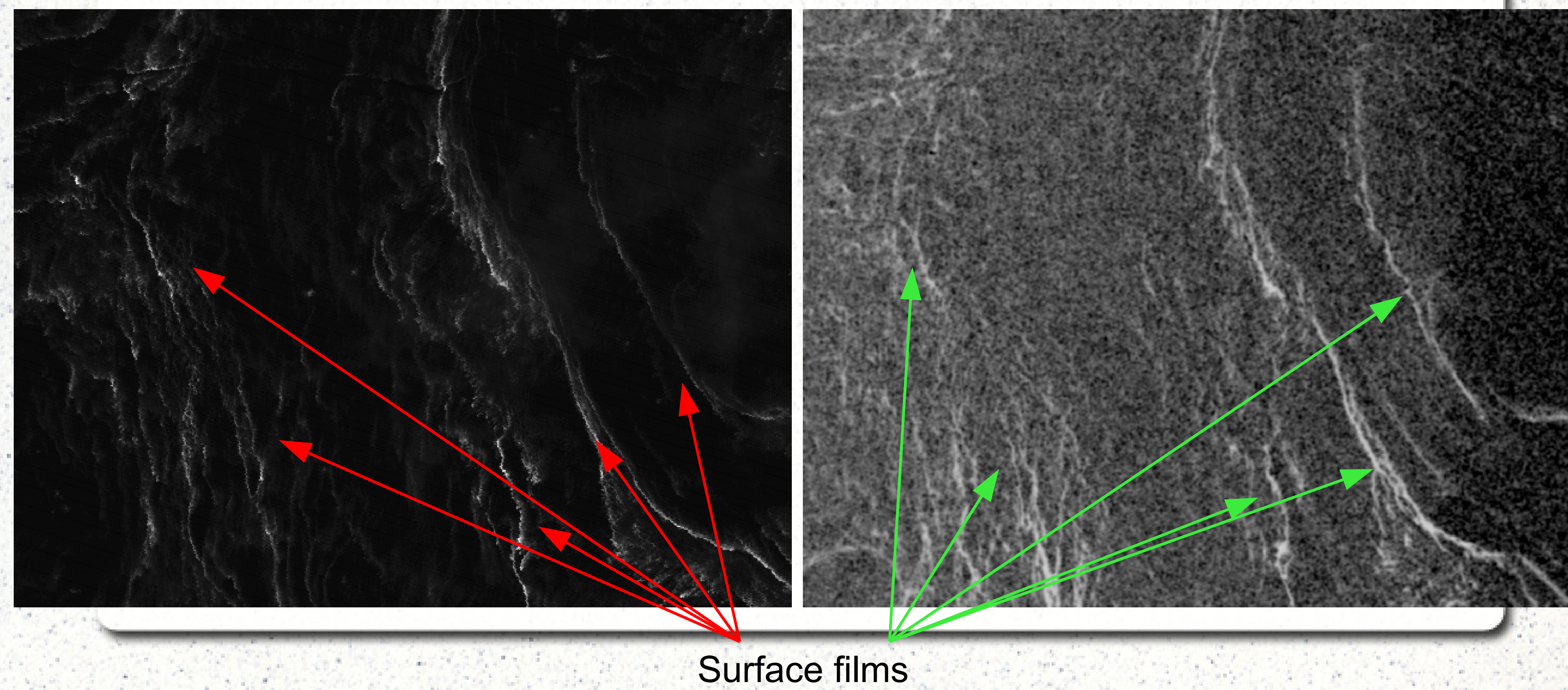
# *Multi-Sensor Data: Overview*

- Image 1
  - Landsat TM
  - 15.07.1997
  - 08:57 UTC
- Image 2
  - ERS-2 SAR
  - 15.07.1997
  - 09:47 UTC



# Multi-Sensor Data: The Images

- ROI of Landsat TM
  - 15.07.1998
  - 08:57 UTC
- Inverted ROI of ERS-2 SAR
  - 15.07.1998
  - 09:47 UTC

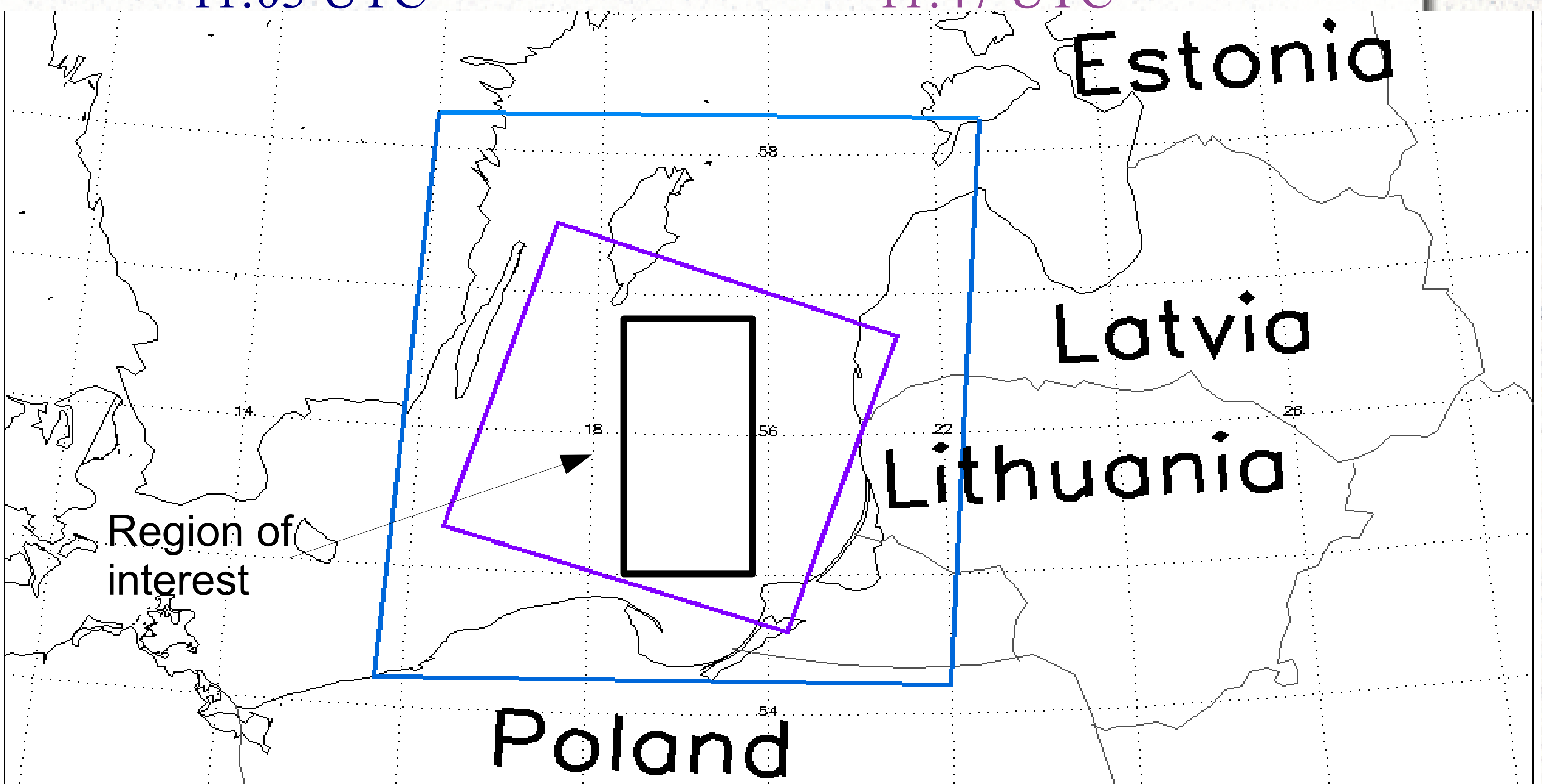


# *Multi-Sensor Data: Motion Derivation*

Entering interactive demonstration...

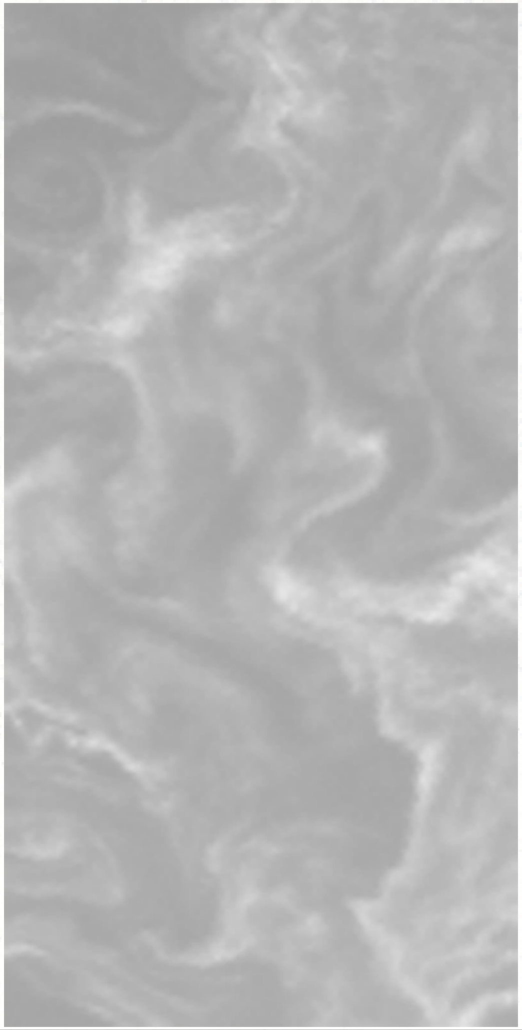
# *Single-Sensor WiFS: Overview*

- Image 1
  - SeaStar SeaWiFS
  - 1.08.1999
  - 11:03 UTC
- Image 2
  - SeaStar SeaWiFS
  - 2.08.1999
  - 11:47 UTC

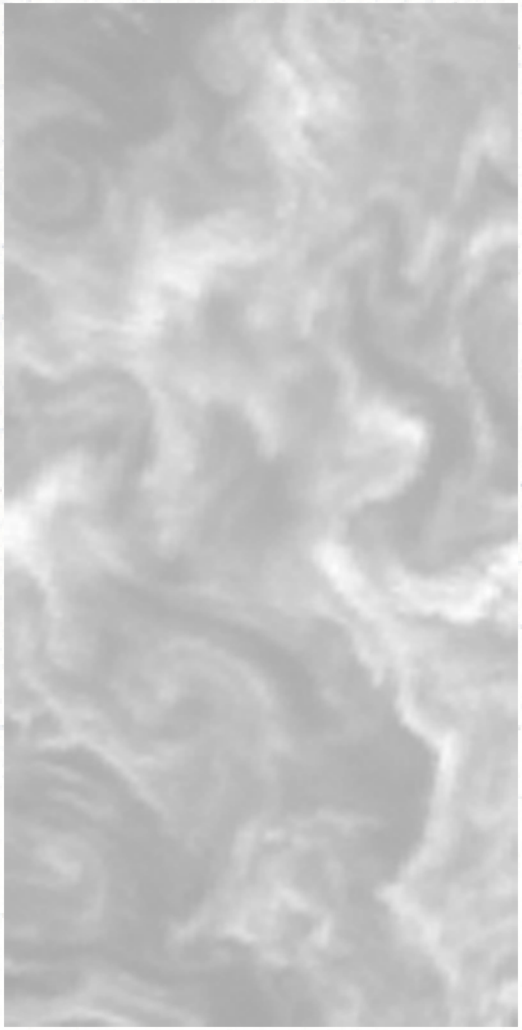


# Single-Sensor WiFS: The Images

- ROI of image 1
  01.08.1999 / 11:03 UTC



- ROI of image 2
  02.08.1999 / 11:47 UTC

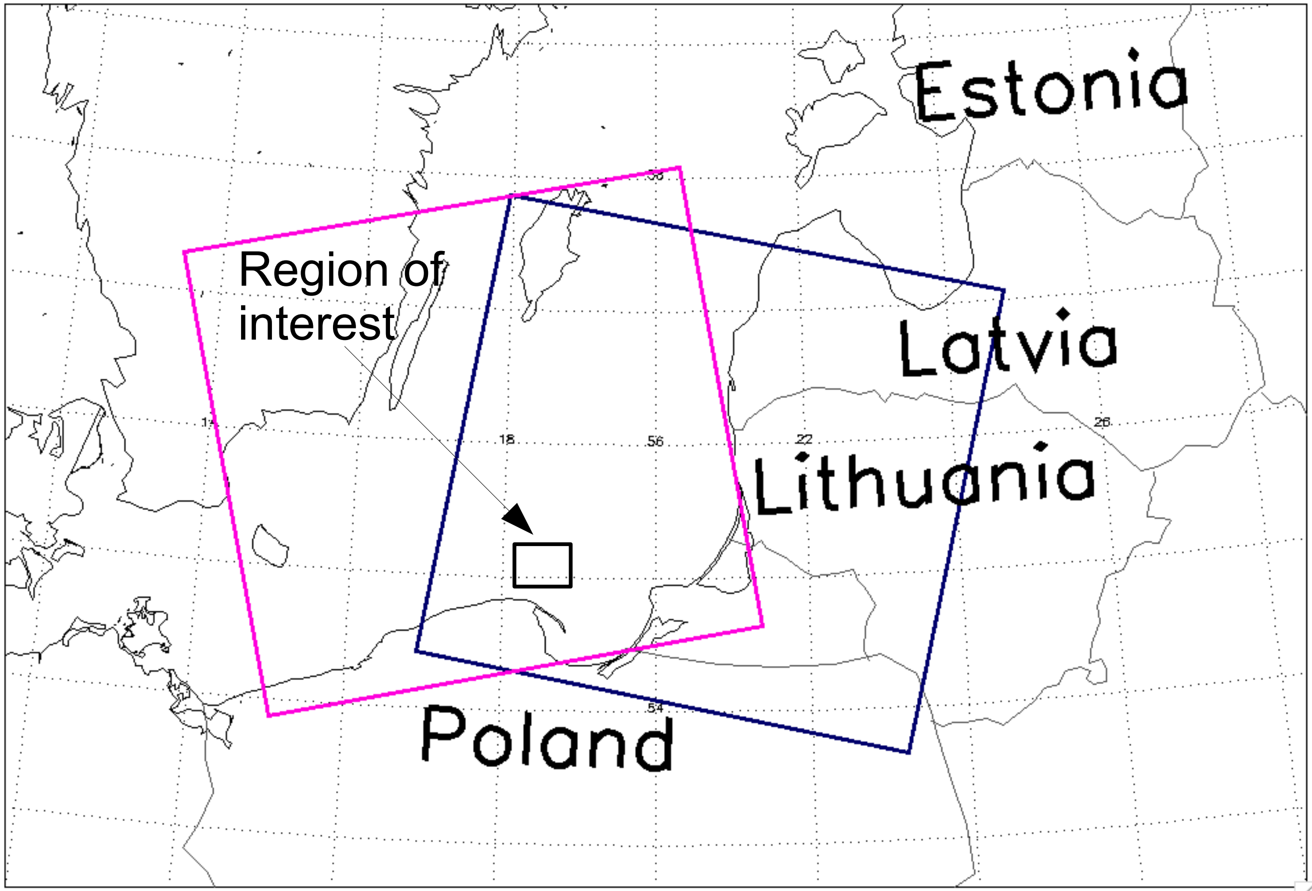


# *Single-Sensor WiFS: Motion Derivation*

Entering interactive demonstration...

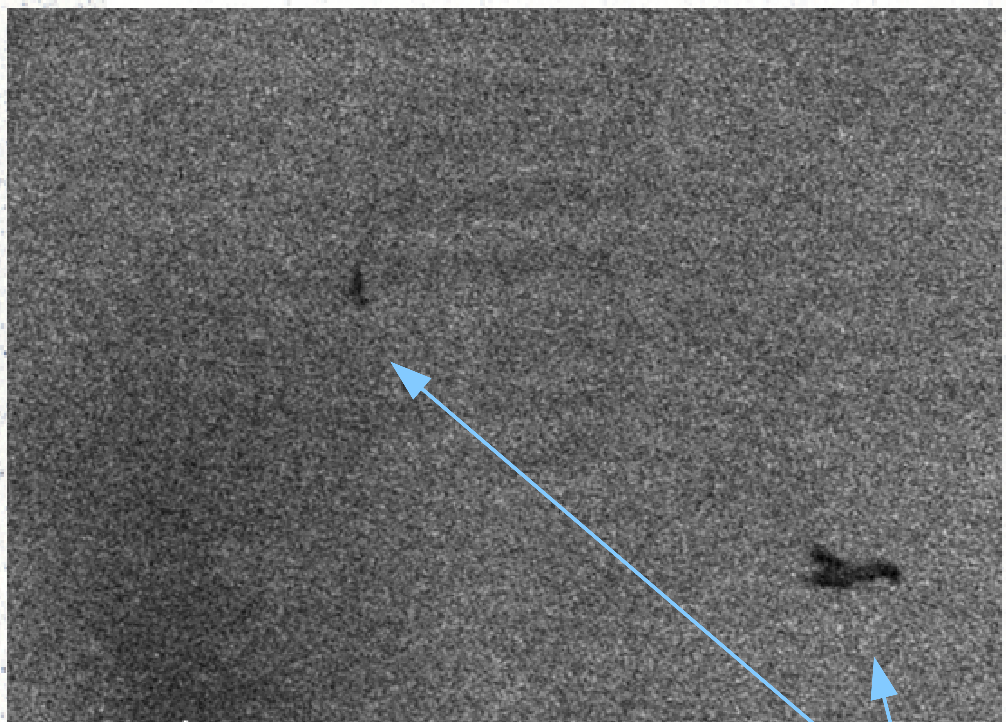
# *Single-Sensor SAR: Overview*

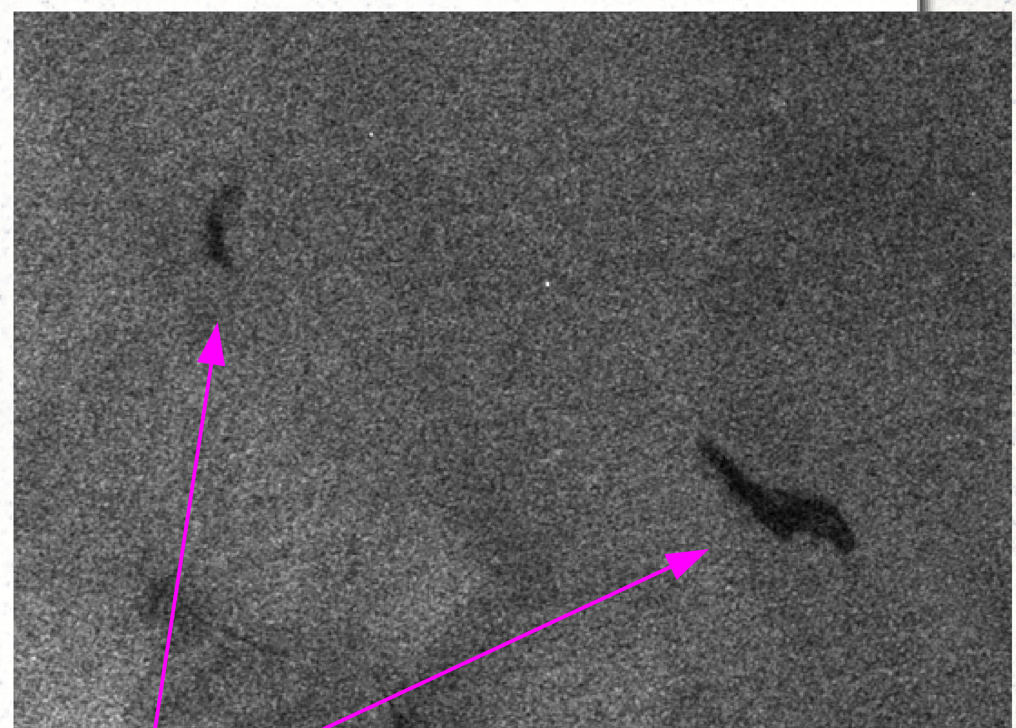
- Image 1
  - ENVISAT ASAR
  - 15.05.2005
  - 09:00 UTC
- Image 2
  - ENVISAT ASAR
  - 15.05.2005
  - 20:25 UTC



# *Single-Sensor SAR: The Images*

- ROI of Image 1
  - 15.05.2005 / 09:00 UTC
- ROI of Image 2
  - 15.05.2005 / 20:25 UTC





Oil spills

# *Single-Sensor SAR: Motion Derivation*

Entering interactive demonstration...

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# *Conclusions I*

- In many cases, we get promising results!
- Different sensors
  - Spectral sensors
  - SAR
- Different kinds of tracked objects
  - Algae films
  - Oil spills
- The results refine the model currents on a mesoscale

# *Conclusions II*

- Algorithmic improvements lead to speed or accuracy improvements (or both)
- If applicable, gradient based approaches result in high resolution current fields
- However, in some cases we currently have to “fall back” to fast normalized cross-correlation
- Hard to get satellite images that:
  - show “objects of interest” and
  - have a spatiotemporal overlap.
- Ground-truth or gold-standard?

# *Future work I*

- Improve current low-level image processing
  - Make algorithms more robust
  - Self detection of failures
  - Implement and test other algorithms
- Use the spectral information of multi-spectral images
  - Move from single band image ↔ single band image processing to multi-band processing
  - Use multi-spectral information for feature detection
  - Multi-sensor multi-sensor fusion
- Further development of GRAIPE

# *Future work II*

- Use more high-level knowledge
  - Improve the results (e.g. filtering unreliable currents)
  - Perform reasoning on images and currents
  - Explicit representation of different domains
- Where could high-level knowledge support us?
  - Automatic learning of feature detectors
  - Designing optimized gradient based algorithms for sea surface currents
  - Interpretation of the calculated currents
- Extend to different areas

# *End of presentation*

Thank you for your attention!

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