Universität Hamburg
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MIN-Fakultät
Fachbereich Informatik
Arbeitsbereich SAV/BV (KOGS)

IP2: Image Processing in Remote Sensing
12. Image Processing II: Edge Detection and Motion Derivation

Summer Semester 2014

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Agenda

- Case Study 1: Edge Detection
  - Description of Edge Measures
  - Multispectral Imagery
  - Application to Remote Sensing Images
- Case Study 2: Motion Derivation
  - Derivation of Sea Surface Currents
  - Multimodal Images
  - Meso- to Small-Scale
  - Monitor and Understand Small-Scale Turbulent Features

Case 1: Outline

- Introduction
- Single-channel Images and Gradients
- Multi-channel Extension
- The Framework
- Results
- Conclusions and Outlook

Motivation

- Edge-detection is an important task, e.g.:
  - Scene segmentation
  - Object reconstruction
  - Basis for motion detection
- Well-defined for single channel images, fewer research for multi-spectral imagery
- Idea: Synergetic use of multi-spectral bands

Introduction

- Model of an image function
- Gradient operator for the single-channel case
- Possible multi-channel extensions
- Comparison and evaluation using a modular framework
  - Quantitative Evaluation
  - Application to Landsat 7 ETM+ data

Single-channel Images

- Continuous image

$$I : R \times R \to R$$

- Digital image

$$I : N \times N \to R_{discrete} \subset R$$

- Gradient (I is derivable)

$$\nabla I = \begin{pmatrix} I_x & I_y \end{pmatrix}^T \quad \text{with: } I_x = \frac{\partial I}{\partial x} \quad \text{and} \quad I_y = \frac{\partial I}{\partial y}$$

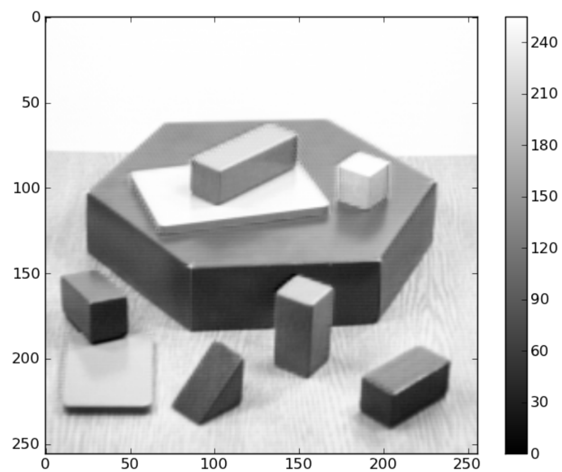
Note:

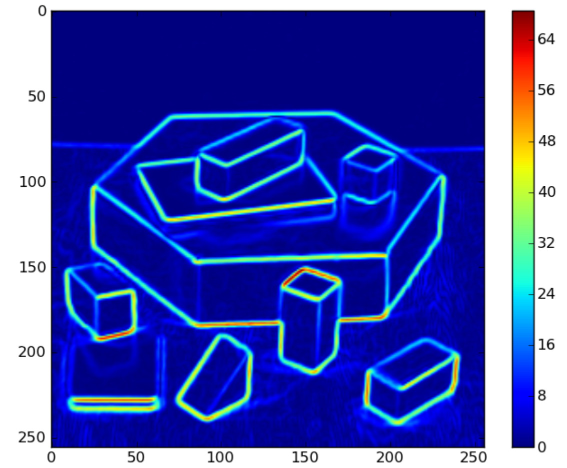
Gradients can be computed efficiently using convolution operations

Single-channel gradient

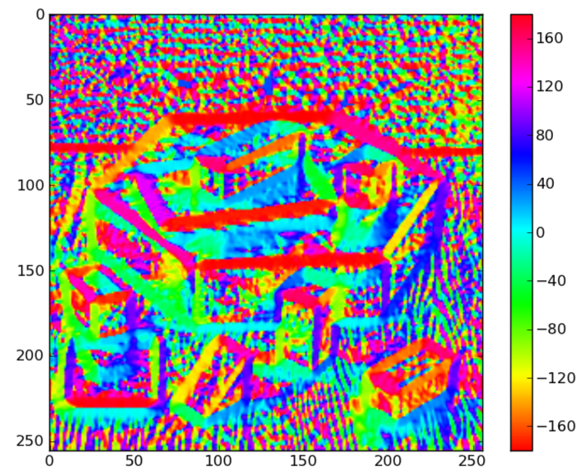
Representation by means of strength and direction

Image I





$\|\nabla I\|$



$\arctan(\nabla I)$

Multi-spectral Images

- Digital image

$$I : N \times N \to R^N_{discrete} \subset R^N$$

- Band wise gradient (Di Zenzo, 1986)

$$\nabla I = \begin{pmatrix} \nabla I_1 \\ \vdots \\ \nabla I_N \end{pmatrix} = \begin{pmatrix} I_{1_x} & I_{1_y} \\ \vdots & \vdots \\ I_{N_x} & I_{Ny} \end{pmatrix}$$

- where ∇I_i is the gradient of the i^{th} band

Integration of Band-wise Gradients

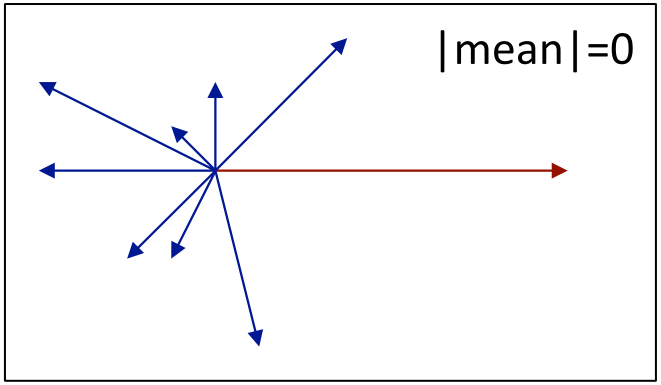
- Goal: Find a closed representation for the multi-spectral gradient!

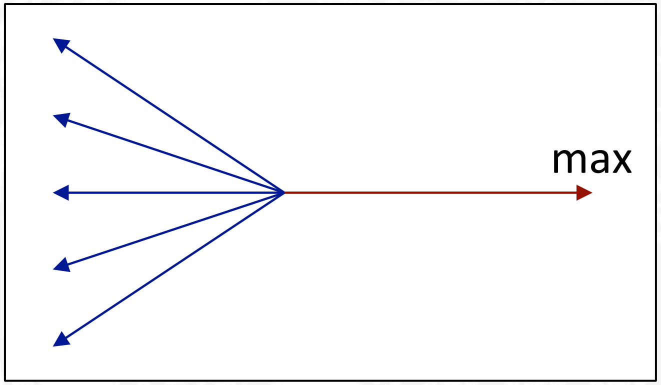
$$\nabla I = \begin{pmatrix} \nabla I_1 \\ \vdots \\ \nabla I_N \end{pmatrix} = \begin{pmatrix} I_{1_x} & I_{1_y} \\ \vdots & \vdots \\ I_{N_x} & I_{Ny} \end{pmatrix} = J \xrightarrow{?} \nabla I = \begin{pmatrix} I_x & I_y \end{pmatrix}^T$$

- Many heuristic, some mathematically motivated approaches

The Mean- and Max-Approach

- Select representing gradient vector by means of
  - Mean of all band-wise gradients
  - Vector of maximal strength
- Both approaches are heuristically motivated and will fail in some cases:





Multi-spectral approach

- Multi-spectral gradient as the solution of an Eigen-problem:

$$a_{11} = \sum_{c=1}^{N} \left(I_{c_x}\right)^2$$

$$\left(J^T \cdot J\right) = \begin{pmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{pmatrix} \quad \text{where} \quad a_{12} = a_{21} = \sum_{c=1}^{N} I_{c_x} I_{c_y}$$

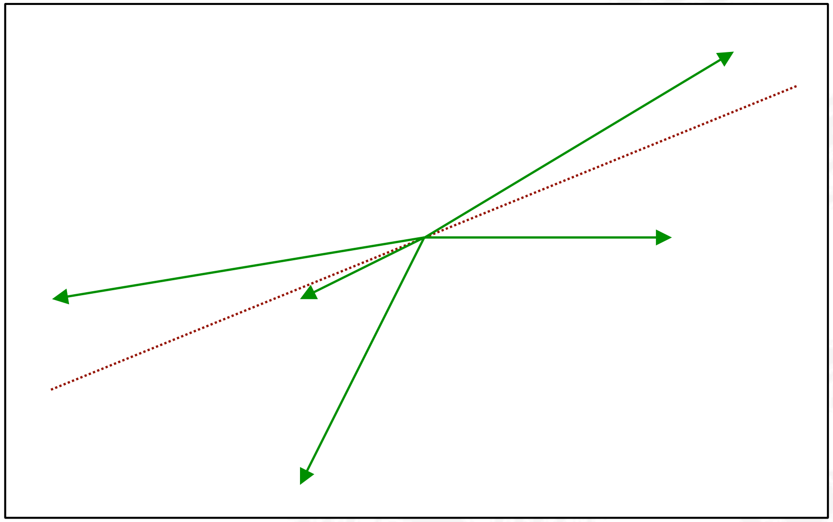
$$a_{22} = \sum_{c=1}^{N} \left(I_{c_y}\right)^2$$

- Analytical solution exists:

$$\lambda_{1,2} = \frac{1}{2}\left(\left(a_{11} + a_{22}\right) \pm \sqrt{\left(a_{11} - a_{22}\right)^2 + 4\left(a_{12}\right)^2}\right)$$

Geometrical interpretation

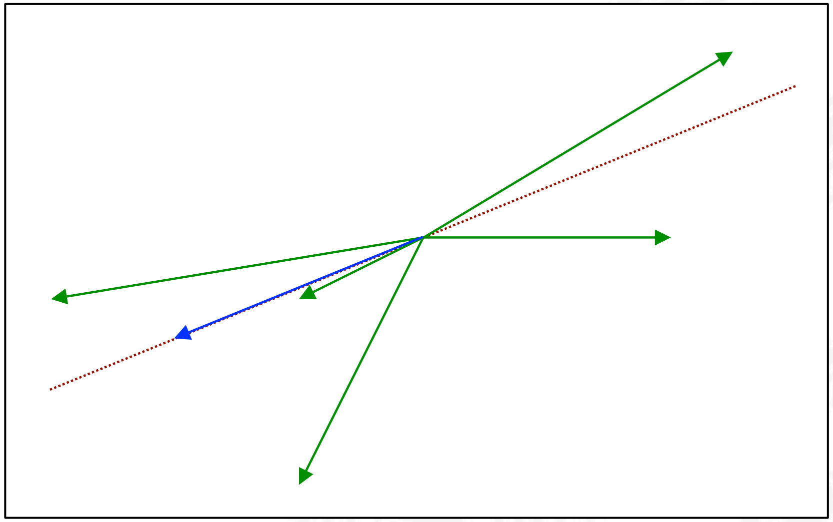
- The multi-spectral approach emphasizes anti-correlated band wise gradients



- Note: direction information is lost!

Geometrical interpretation

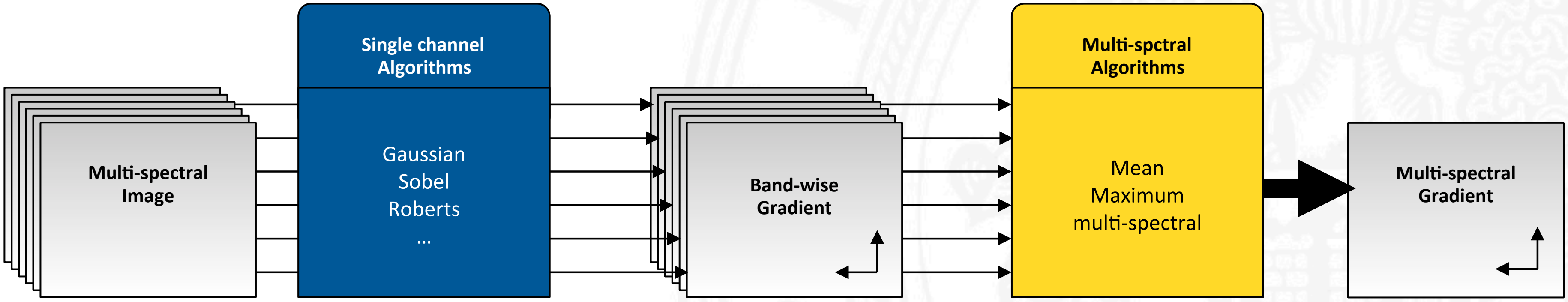
- The multi-spectral approach emphasizes anti-correlated band wise gradients



- Recover direction by voting algorithm!

The Developed Framework

- Flexible due to standardized Interfaces
- Interchangeable algorithms
- Interactively usable
- Realized using Python, NumPy, SciPy, MatplotLib and the VIGRA computer vision library



Quantitative Evaluation

- Artificial test image with defined ground truth
- Test the approaches w.r.t. noise stability
- Extract edgels as local gradient maxima
- Comparison against the ground truth using extended Vankatesh & Kitchen method
- Results:
  - Multi-spectral
  - Maximum
  - Mean approach

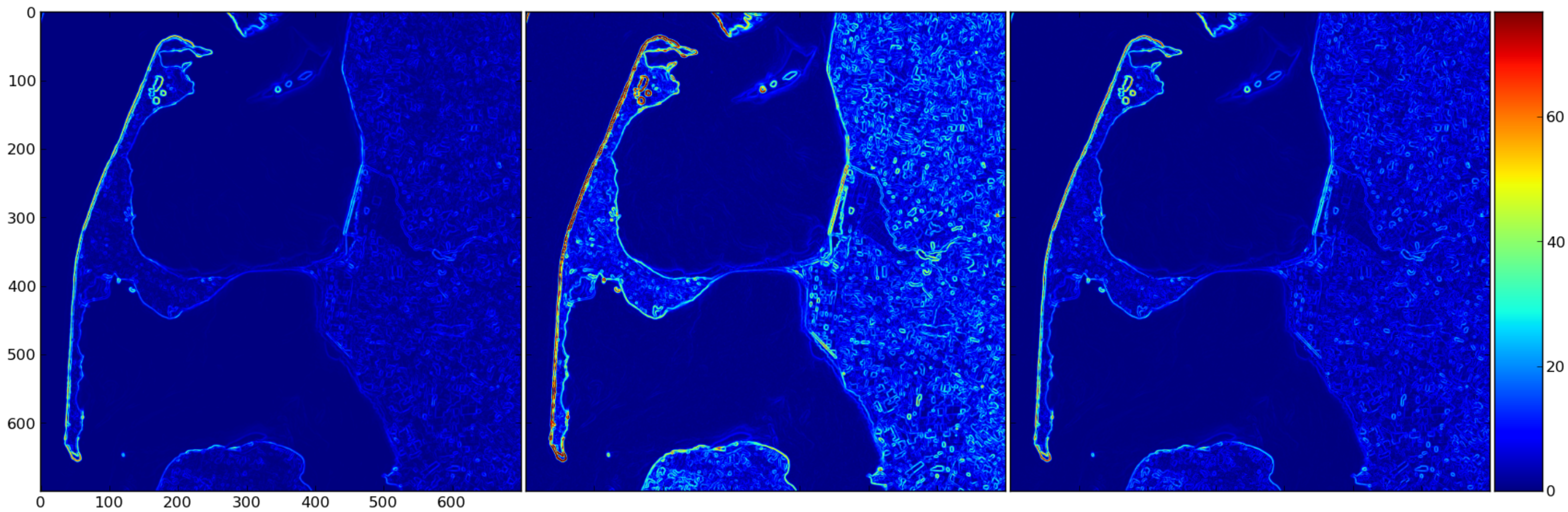
Landsat 7 ETM+ Data Used

- Images taken over North Germany
  - 2005/05/15 (60% cloud cover)
  - 2001/05/11 (10% cloud cover)
- 2 Images → 2 ROIs
  - First image: Island of Sylt
  - Second image: City of Hamburg
- All bands were used
  - Visible + NIR: 6, IR: 2(H+L), Panchromatic: 1
  - Subsampled to lowest resolution of 57m

First ROI: Island of Sylt (German Bight)

First ROI: Island of Sylt (German Bight)

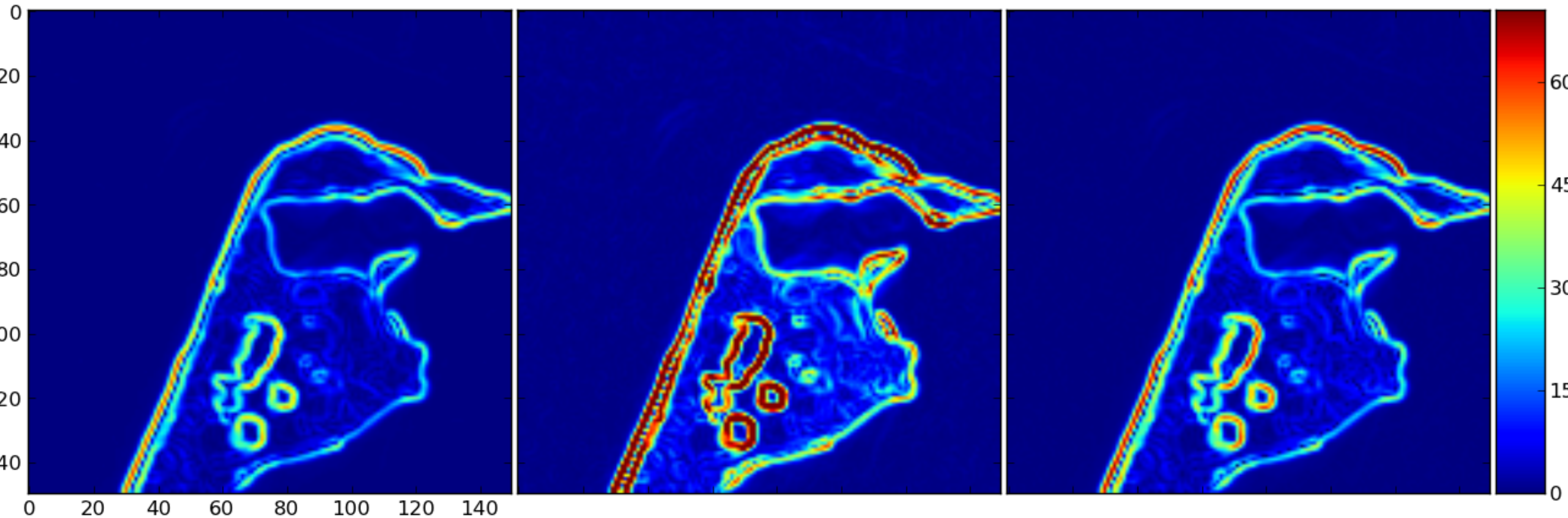
Gradient Magnitude



Mean- Maximum- multi-spectral approach

First ROI: Island of Sylt
Northern part

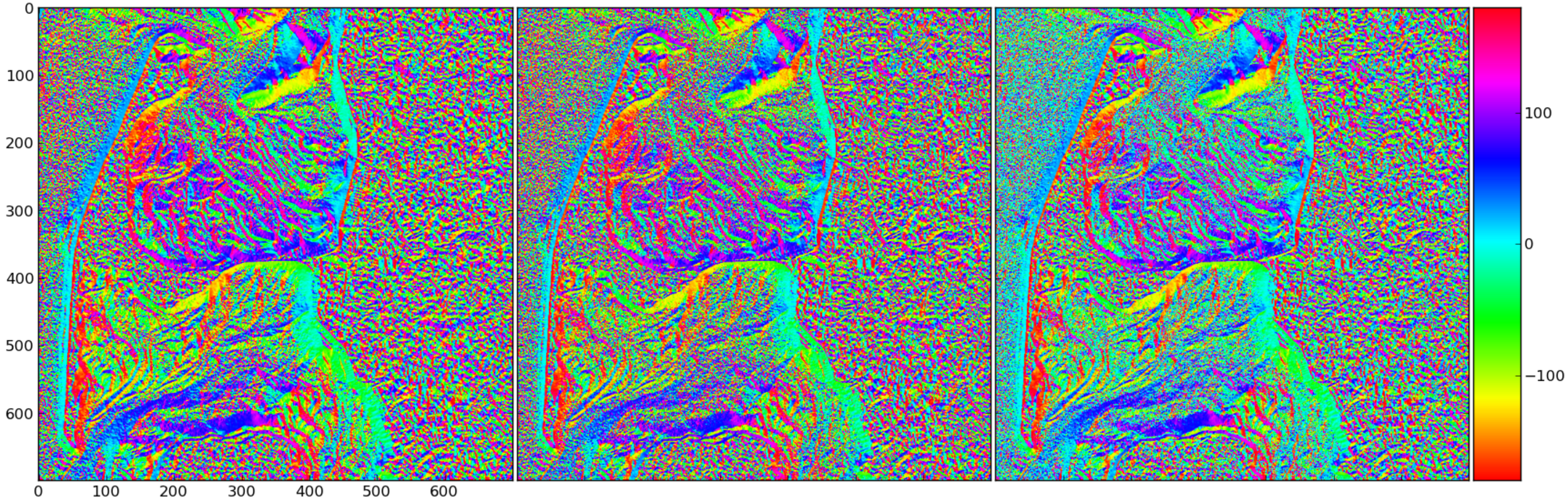
Gradient Magnitude



Mean- Maximum- multi-spectral approach

First ROI: Island of Sylt (German Bight)

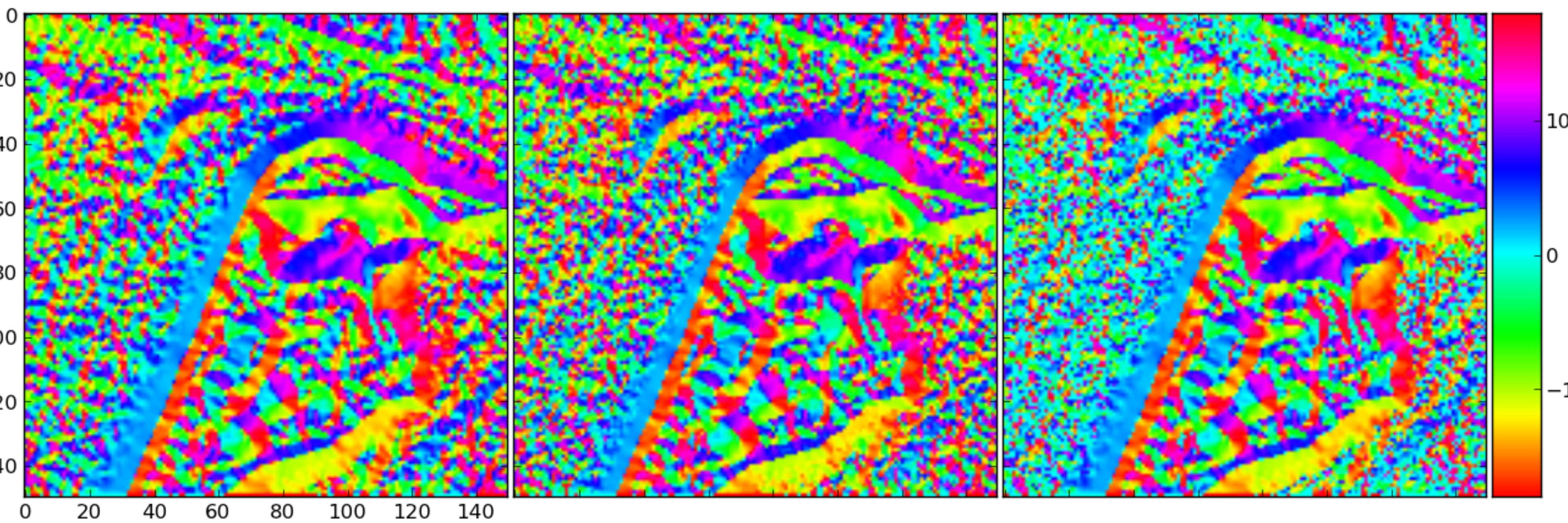
Gradient Angle



Mean- Maximum- multi-spectral approach

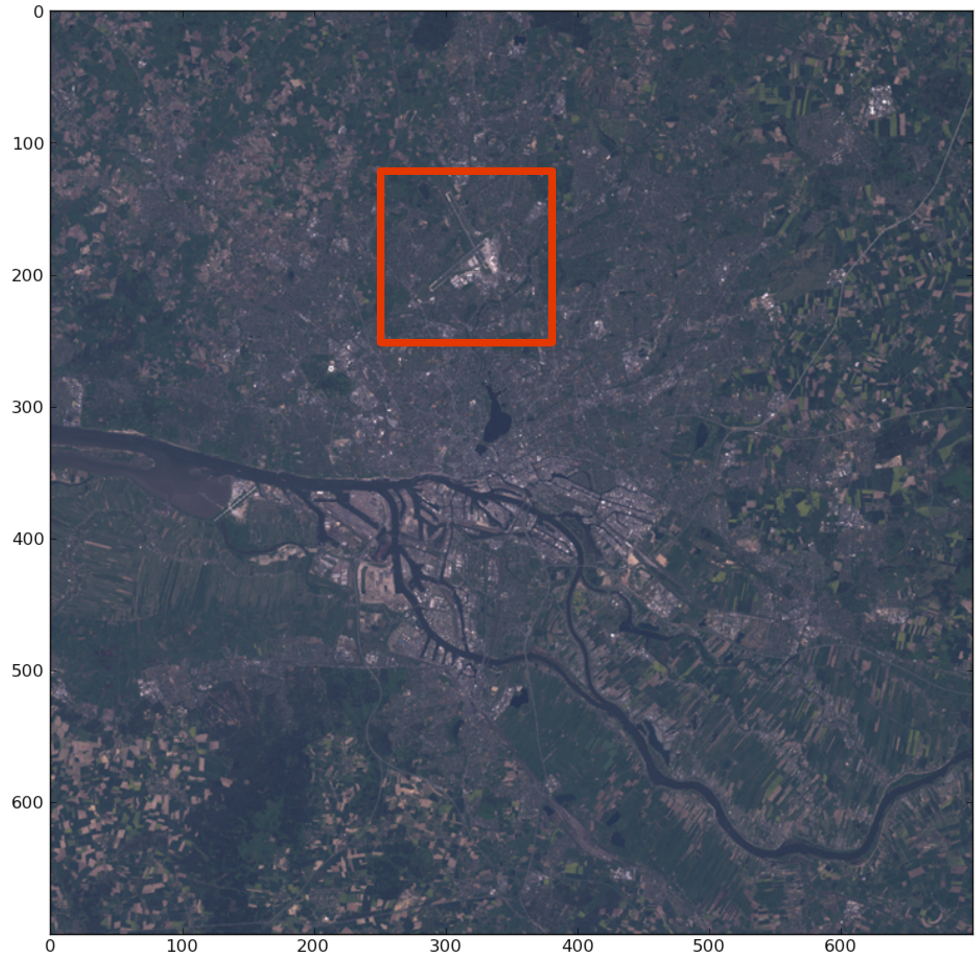
First ROI: Island of Sylt Northern part

Gradient Angle



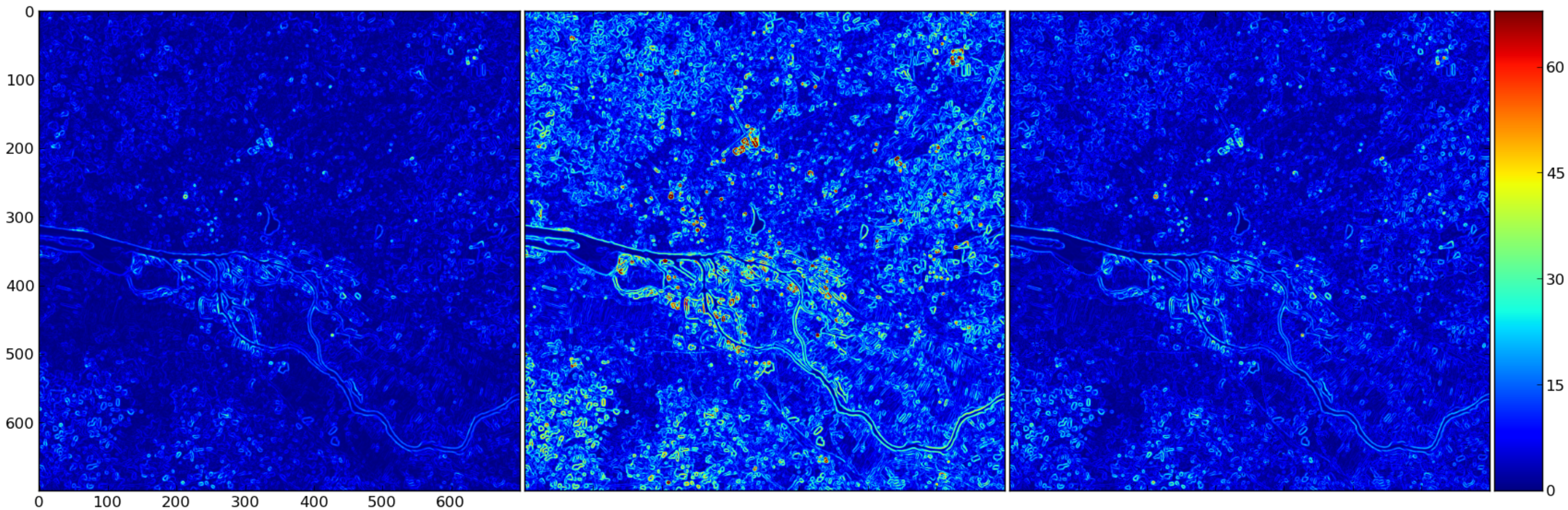
Mean- Maximum- multi-spectral approach

Second ROI: City of Hamburg (Northern Germany)



Second ROI: City of Hamburg (Northern Germany)

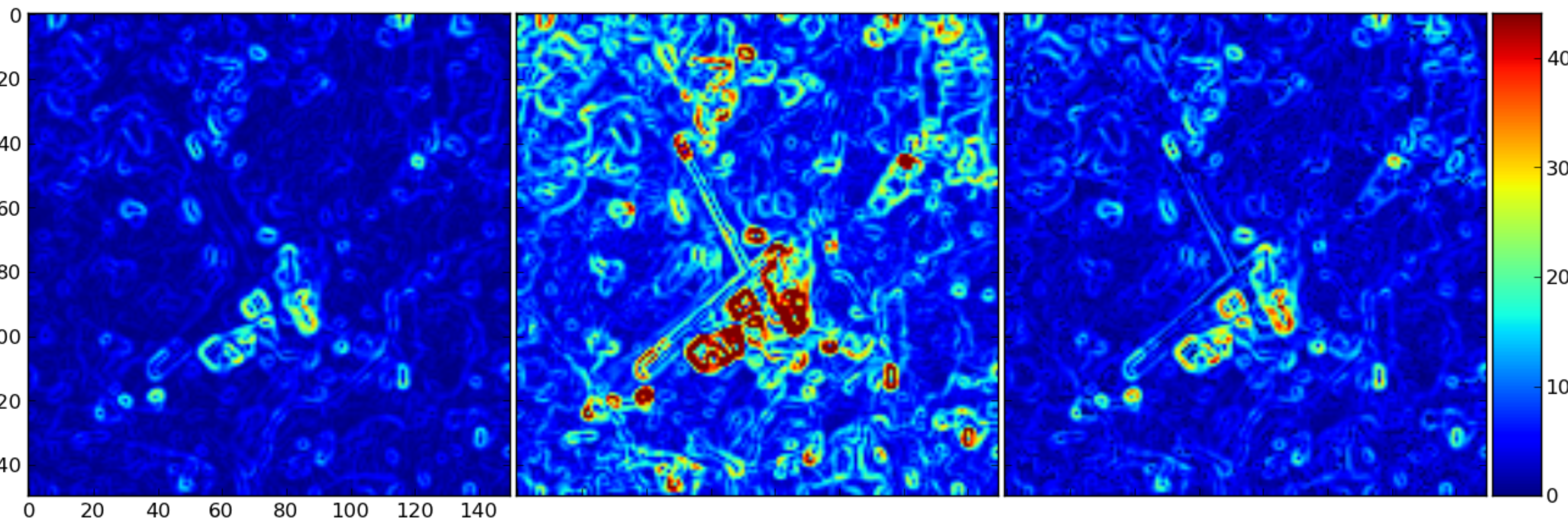
Gradient Magnitude



Mean- Maximum- multi-spectral approach

Second ROI: City of Hamburg Airport

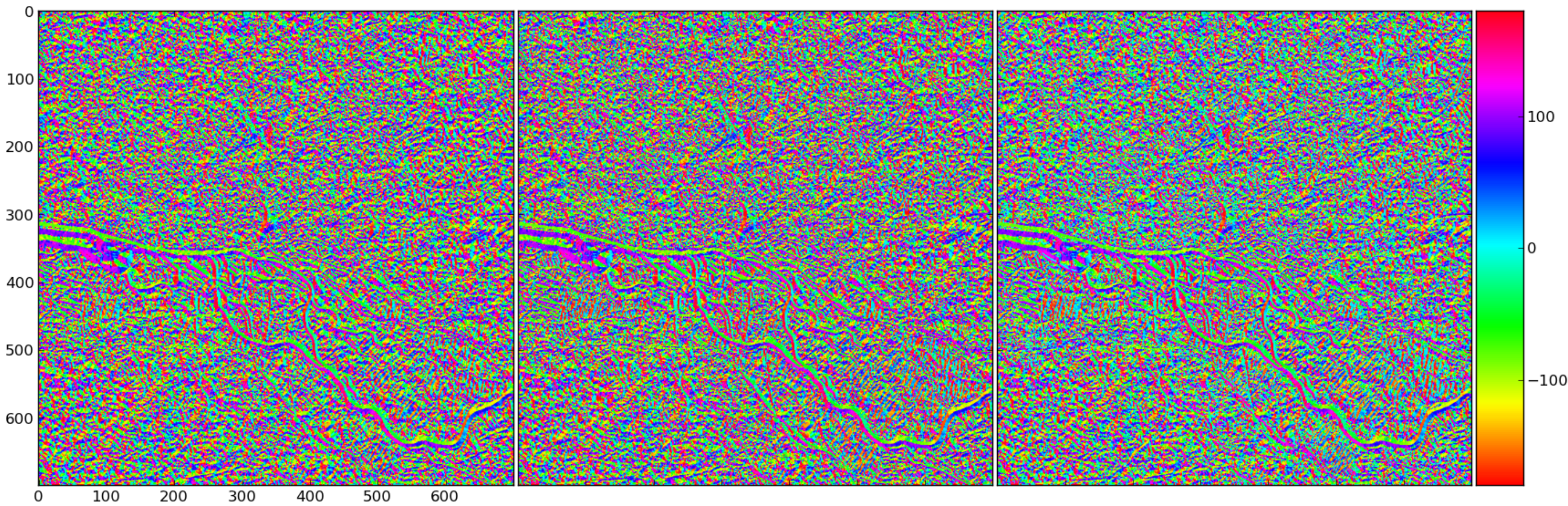
Gradient Magnitude



Mean- Maximum- multi-spectral approach

Second ROI: City of Hamburg (Northern Germany)

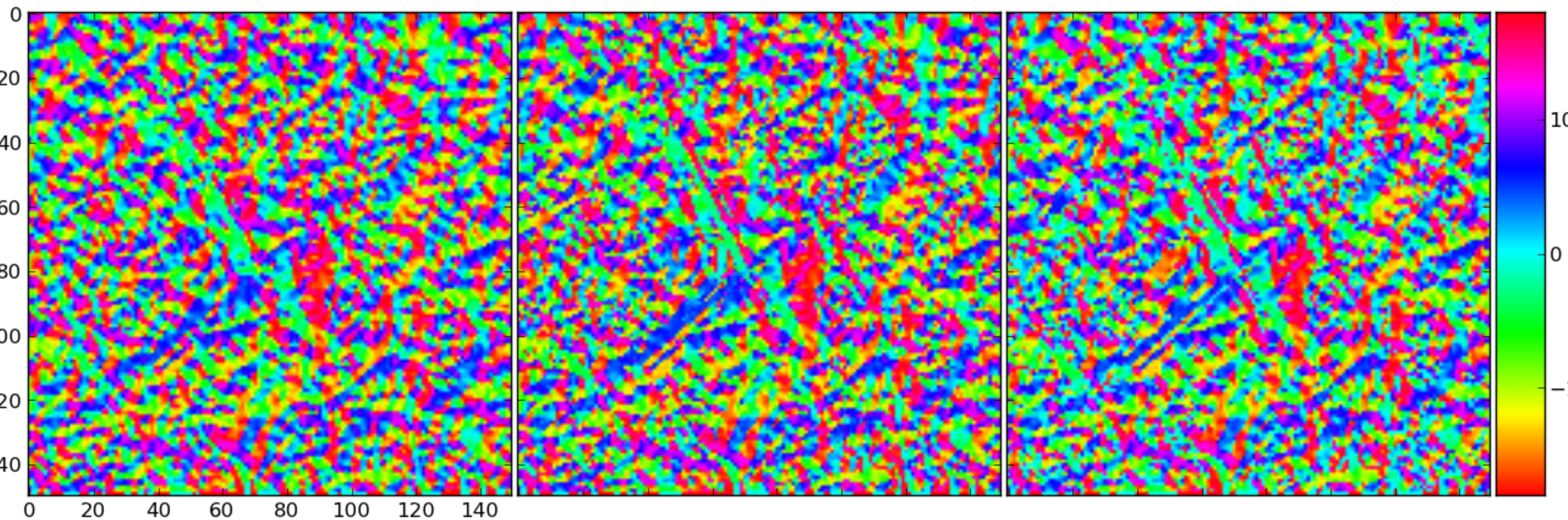
Gradient Angle



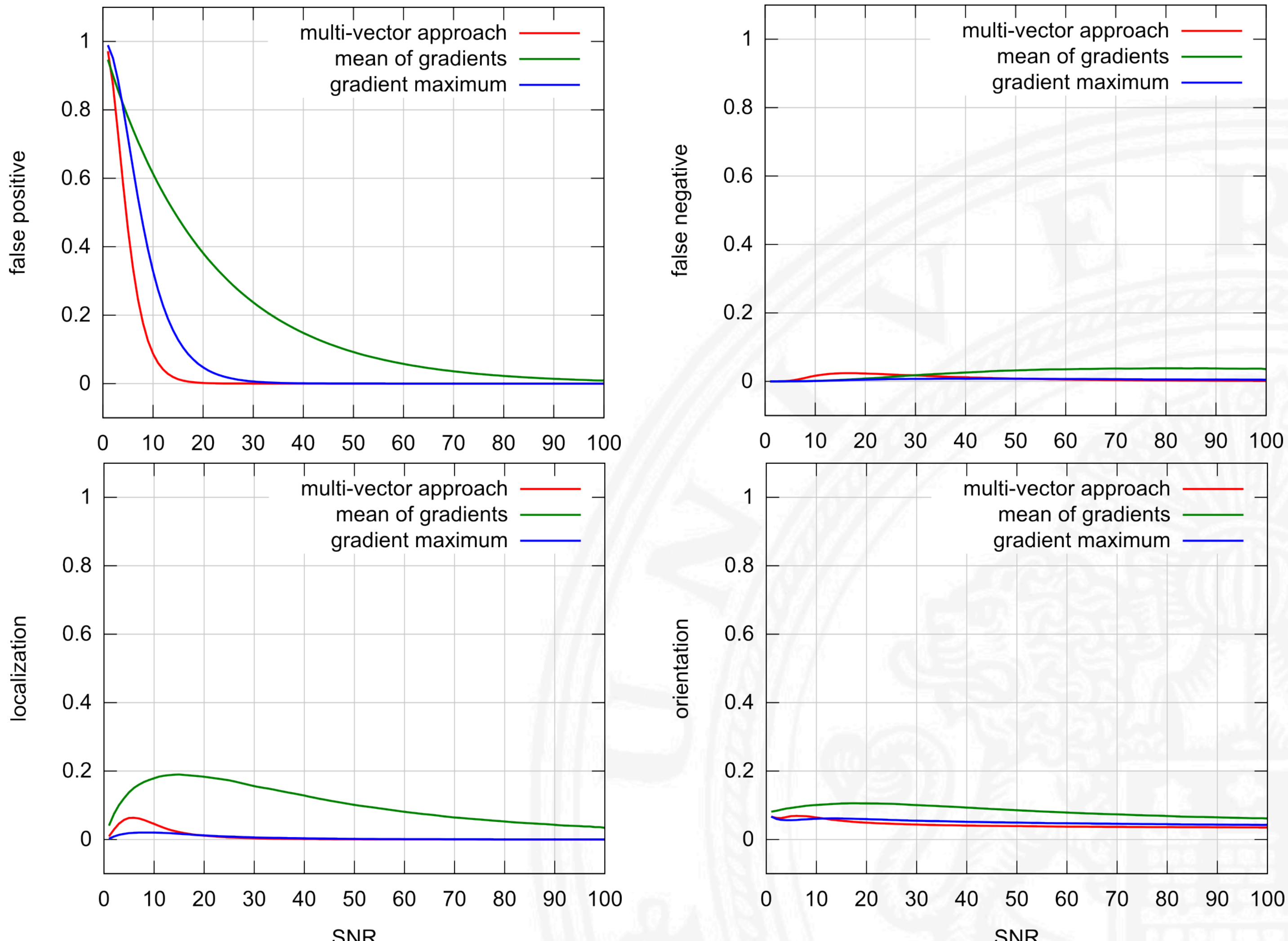
Mean- Maximum- multi-spectral approach

Second ROI: City of Hamburg Airport

Gradient Angle



Quantitative Evaluation



Conclusions

- Three different approaches for multi-spectral gradient estimation:
  - Mean: suffers from anti-correlated gradients
  - Max: overestimates, chance of error
  - Multi-spectral approach:
    performs best in quantitative evaluation
- Which one to use? Task dependent!
  - Max-approach for speed,
  - Multi-spectral approach for accuracy
- Selection of gradient estimate is essential for low-level image processing! All higher processing steps will profit, e.g.
  - Segmentation
  - Classification
- Our Framework makes it easy to test and compare different algorithms quantitatively and visually!

Second Case Study: Derivation of Sea Surface Currents

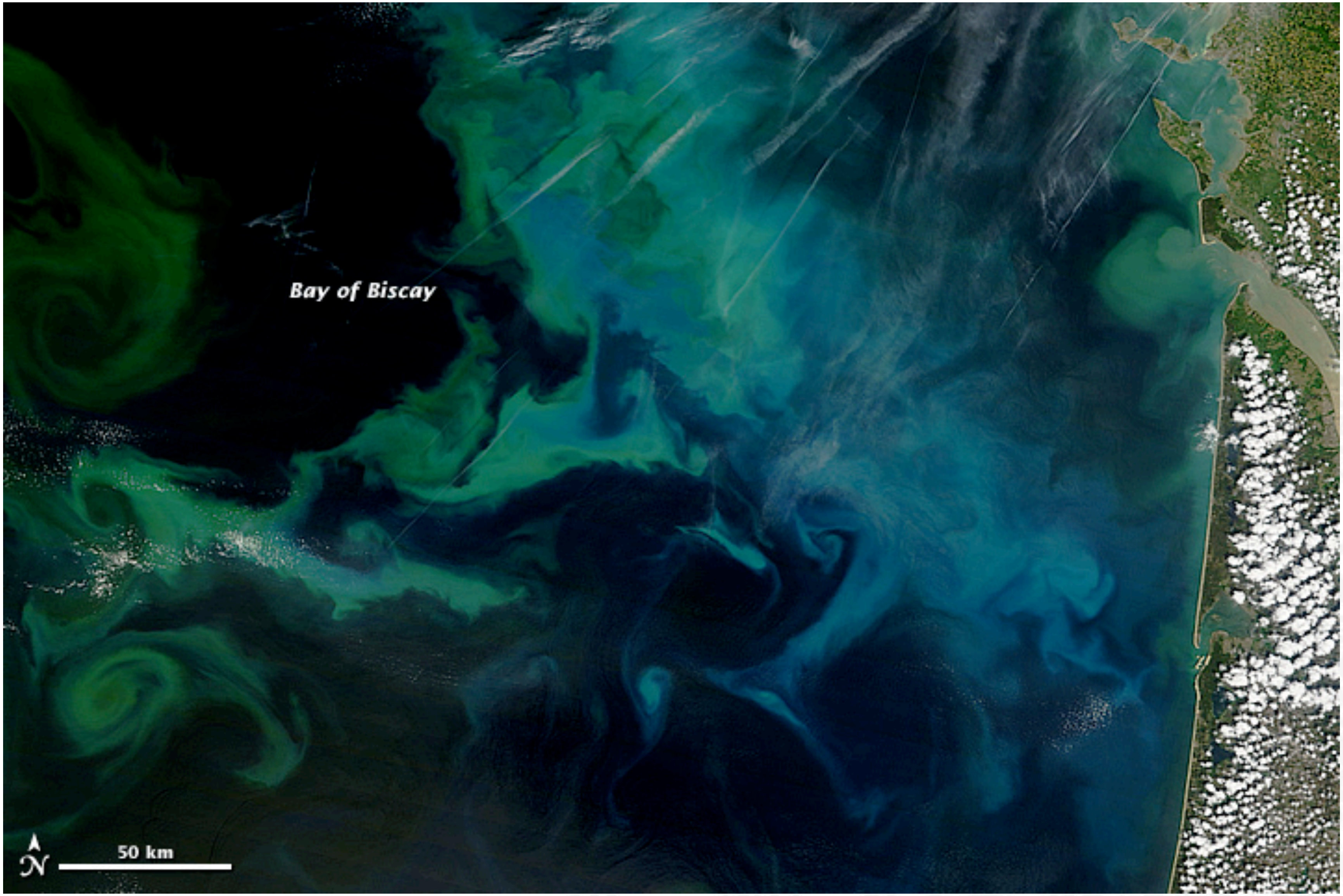
- Derivation of Sea Surface Currents
  - Synoptically based on series of satellite images
  - Aim: Monitor phenomena at the mesoscale (10 – 100 km)
- Requires: Visible, drifting objects at the sea surface
  - Biogenic sea surface films
  - Anthropogenic (man-made) sea surface films
- Use satellite images of different modalities to increase temporal sampling:
    - Synthetic Aperture Radar (SAR) and
    - Multi spectral Sensors
- Goal: Indirect Estimation of the (surface currents) by means of solving the correspondence problem between the imaged signatures

Interdisciplinary Motivation

- Synoptical measurements of the sea surface currents at mesoscale allow:
  - New insights and monitoring of mesoscale phenomena
  - Refinement of climatic/oceanographic models
  - More precise decision in case of a catastrophic events, like large oil spills

➢ Highly active research area!

- Advantages when using satellites images
  - Synoptical measurements with good spatial coverage
  - Comparably high spatial resolution



NASA Image of the Day: „Swirls in the Waters off France“ (4. Mai 2013)

Research History

1970

- From video/ image sequences to motion estimation
  - Pattern matching, feature based approaches

1980

  - Optical Flow (e.g. Lucas & Kanade, Horn & Schunck)
- Oceanographic applications

2000

  - Low-res. Current maps from infrared images (Emery et al.)
  - First tests at tracking sea surface films (Gade et al.)

2008

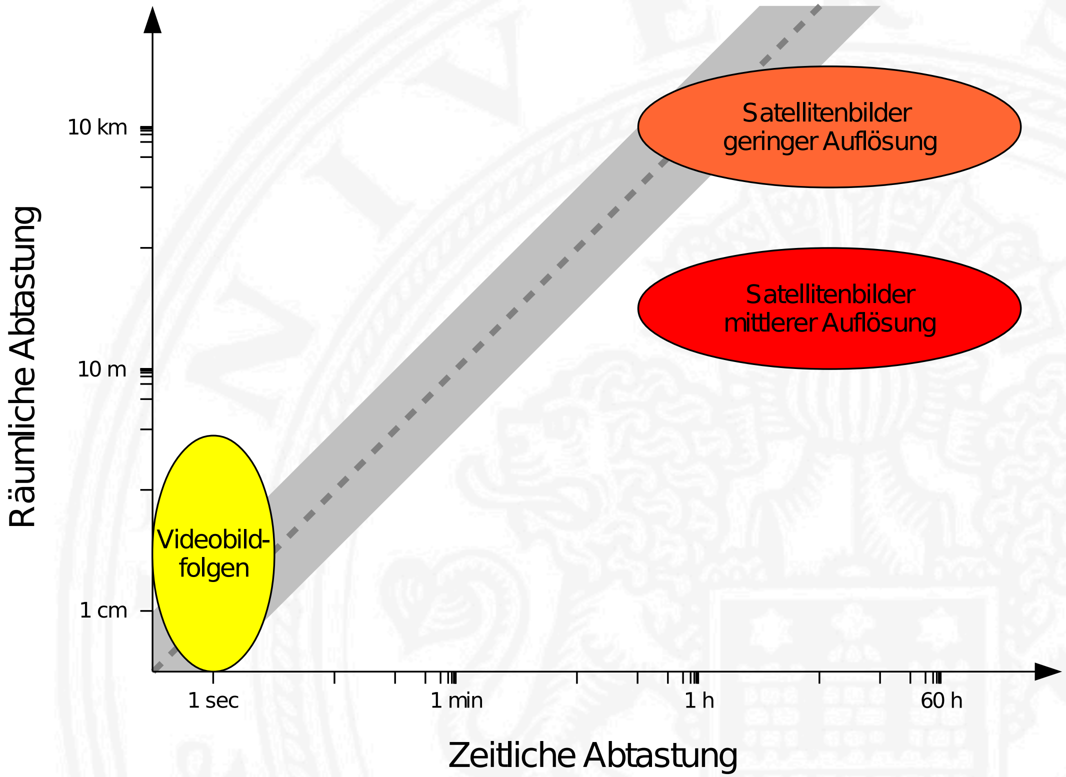
- Presentation today (Doctoral research B. Seppke)
  - Reliable Framework for current derivation
  - Presentation on numerous intl. conferences
  - Article at *International Journal of Remote Sensing* (Gade et al.)

2013

Challenges

In general: low availability of data, thus sparse temporal sampling

- Large spatio-temporal distanced
- Image pairs instead of image sequences



Challenges

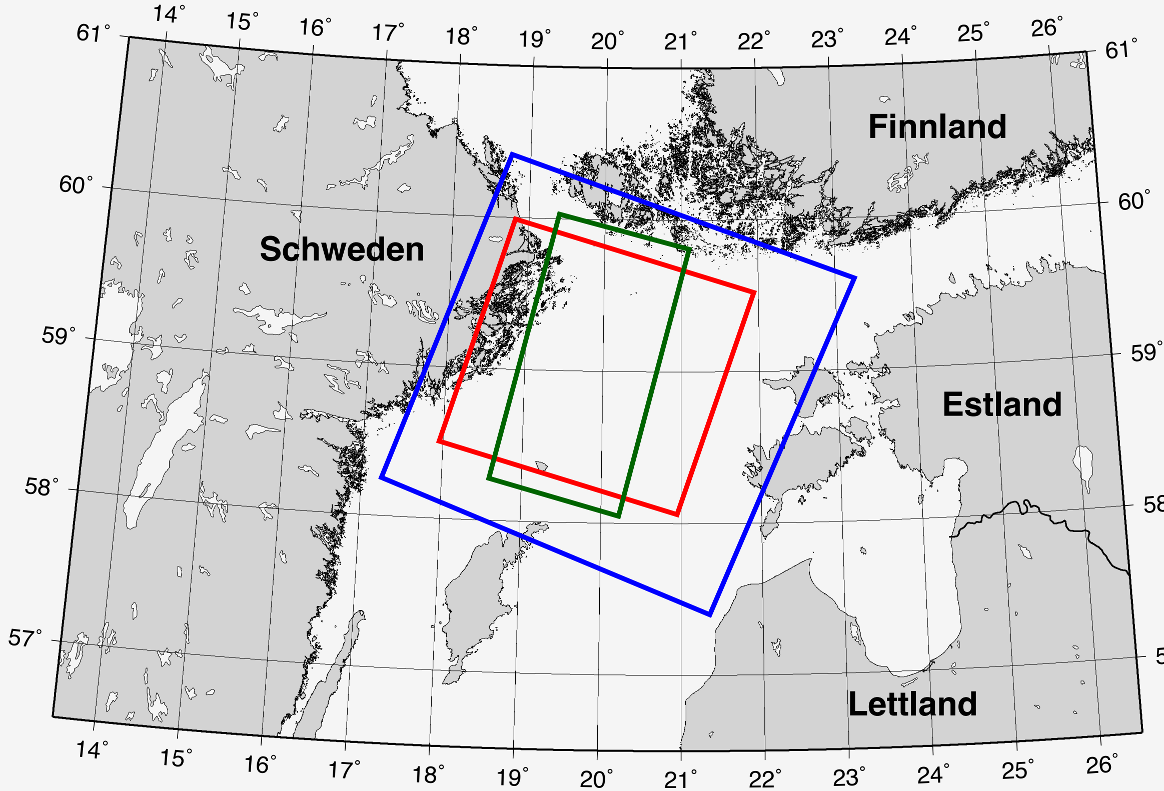
- In general: low availability of data, thus sparse temporal sampling
  - Large spatio-temporal distances
  - Image pairs instead of image sequences
- Specific to each approach
  - How to handle instable features?
  - Coverage of image parts
  - Smoothness constraints
- Evaluation and Interpretation
  - „Gold Standard“ (Model results) instead of „Ground Truth“
  - Knowledge modeling and automated (reasoning) Interpretation

Developed Process Chain

1. Preprocessing of the images
2. Solution of the correspondence problem
   – Feature based methods
   – Differential methods
   – To be solved generally:
     Handling of large spatio-temporal distances
3. Evaluation and Interpretation of the results

Northern Baltic Sea 15.07.1997

Time	Sensor	Resolution
08:57	Landsat TM	30.0 m
09:47	ERS-2 SAR	12.5 m
10:26	IRS-1C WiFS	188.0 m



TM: Thematic Mapper
WiFS: Wide Field of View Scanner

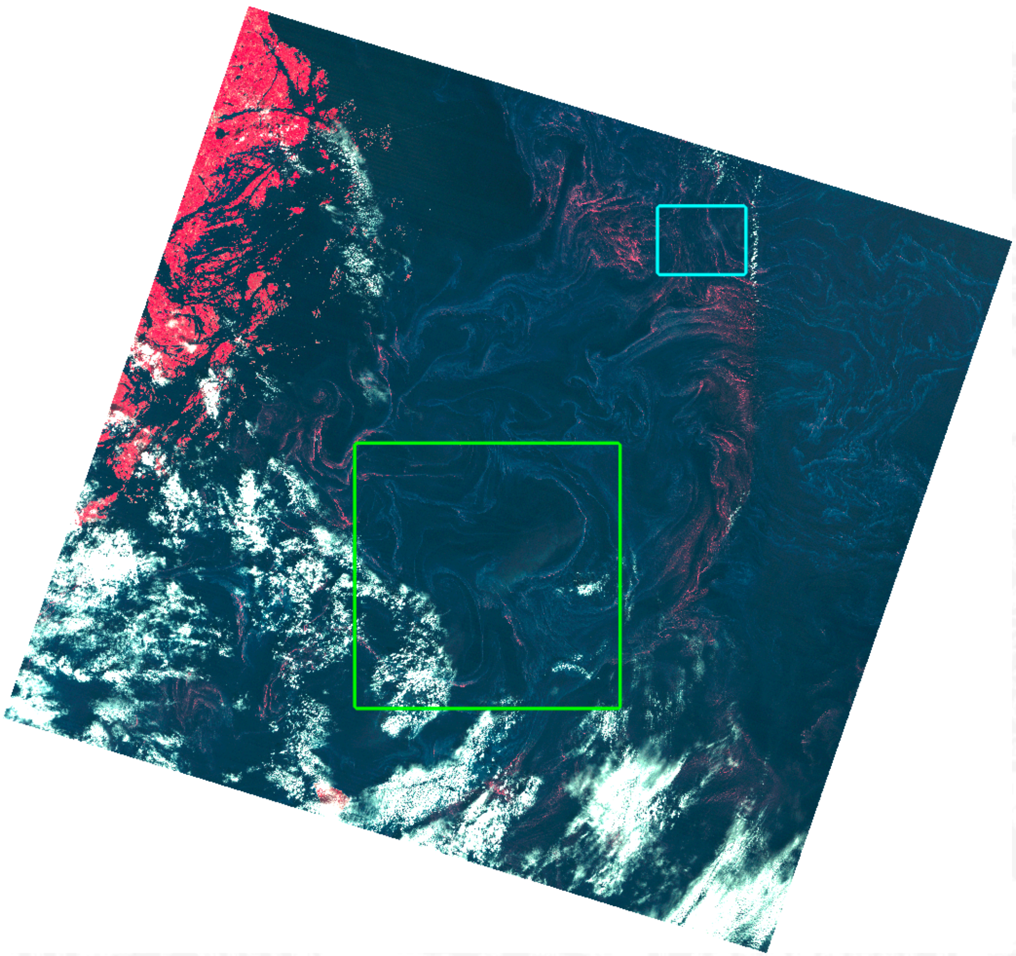
Northern Baltic Sea

Landsat TM

- Division into two „Regions of Interest“
  - North western (cyan)

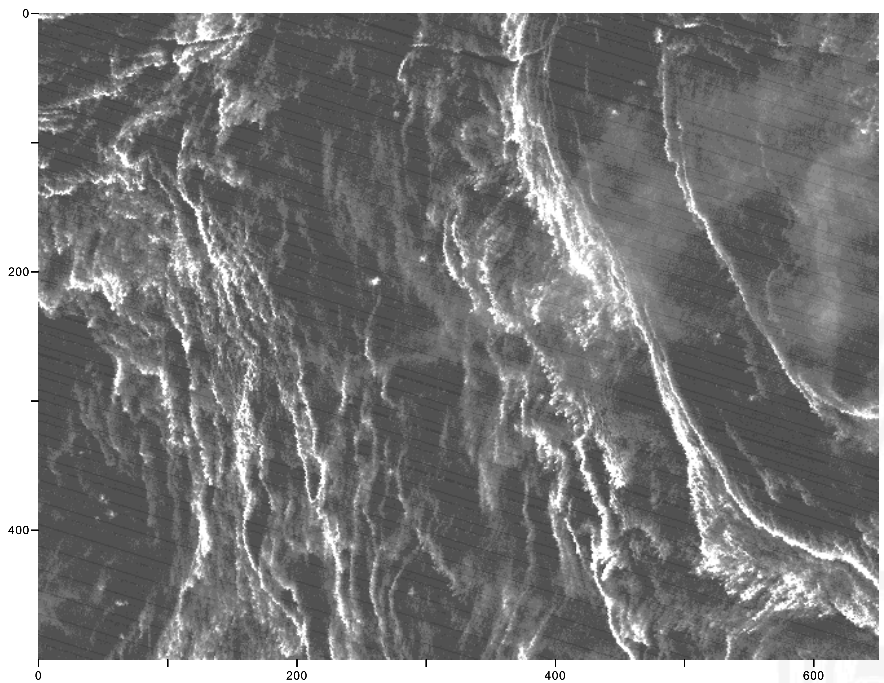
    TM & SAR Images may be used
  - Central (green)

    All Images may be used

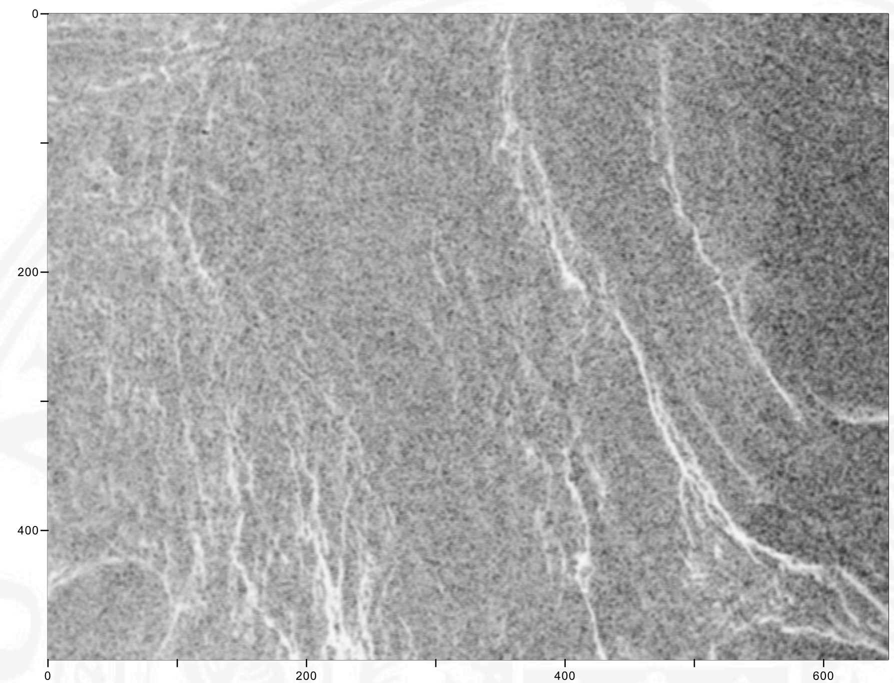


Northern Baltic Sea (NW ROI)
Images

Resolution: 30 m



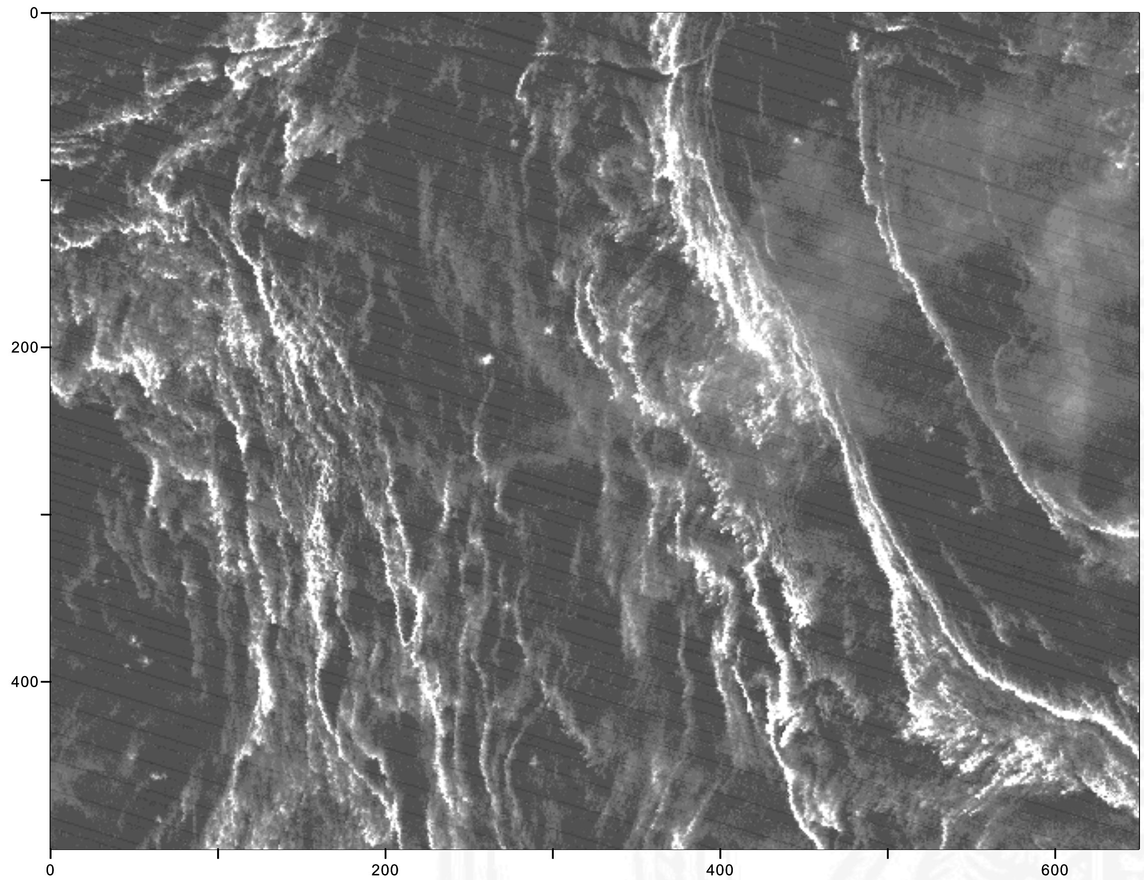
Landsat TM (Near Infrared)



ERS-2 SAR (inverted, filtered)

Northern Baltic Sea (NW ROI)
Images (flipping)

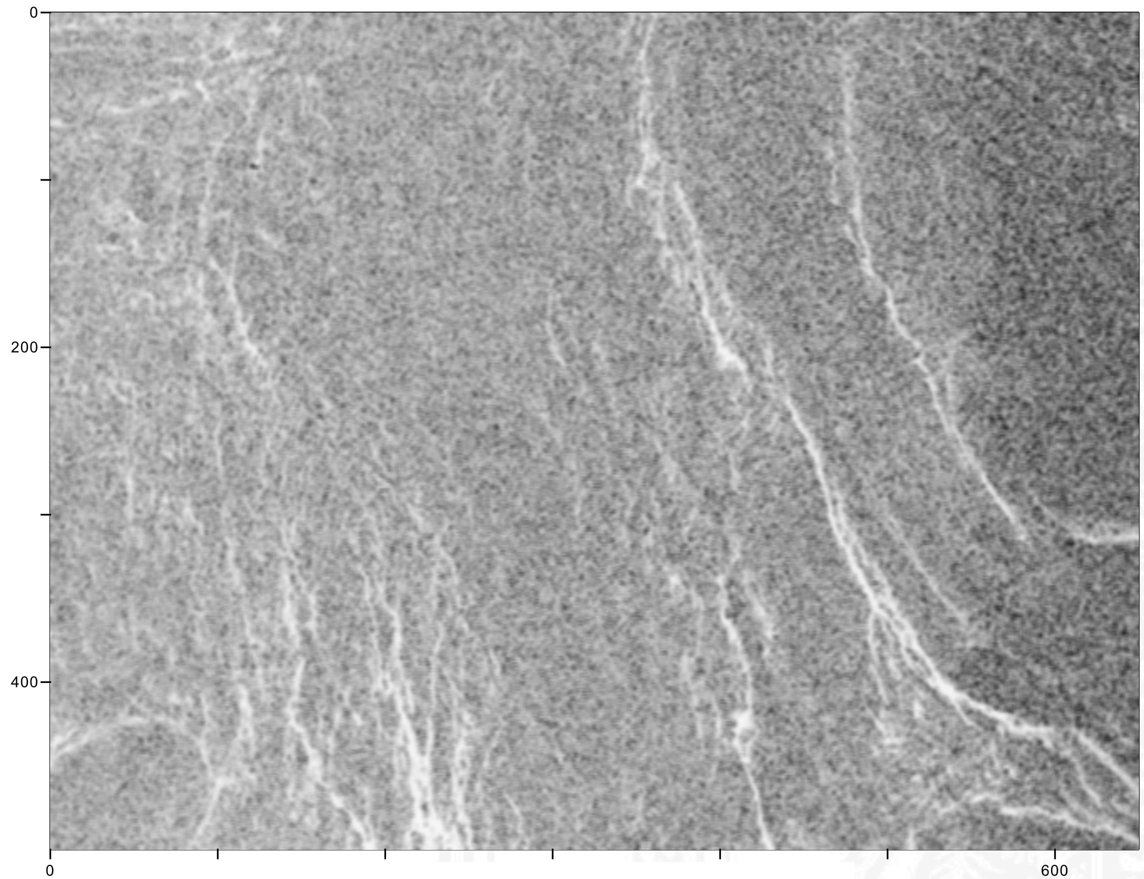
Resolution:
30 m



Landsat TM (Near Infrared)

Northern Baltic Sea (NW ROI)
Images (flipping)

Resolution:
30 m

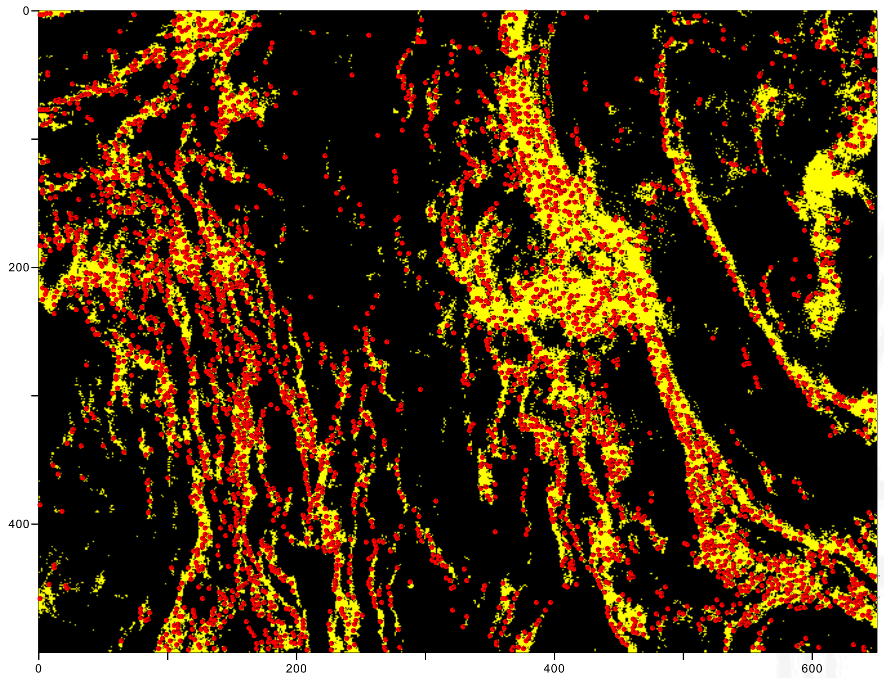


ERS-2 SAR (inverted, filtered)

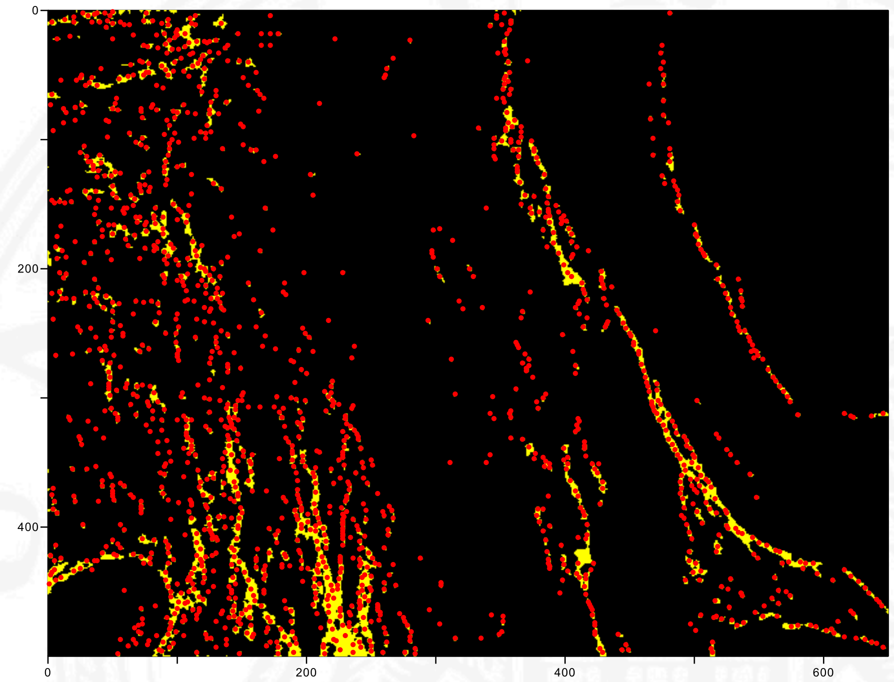
Northern Baltic Sea (NW ROI)
Feature detection

Features detected by the monotony operator (red) at pre-classified areas (yellow)

Resolution: 30 m



Landsat TM



ERS-2 SAR

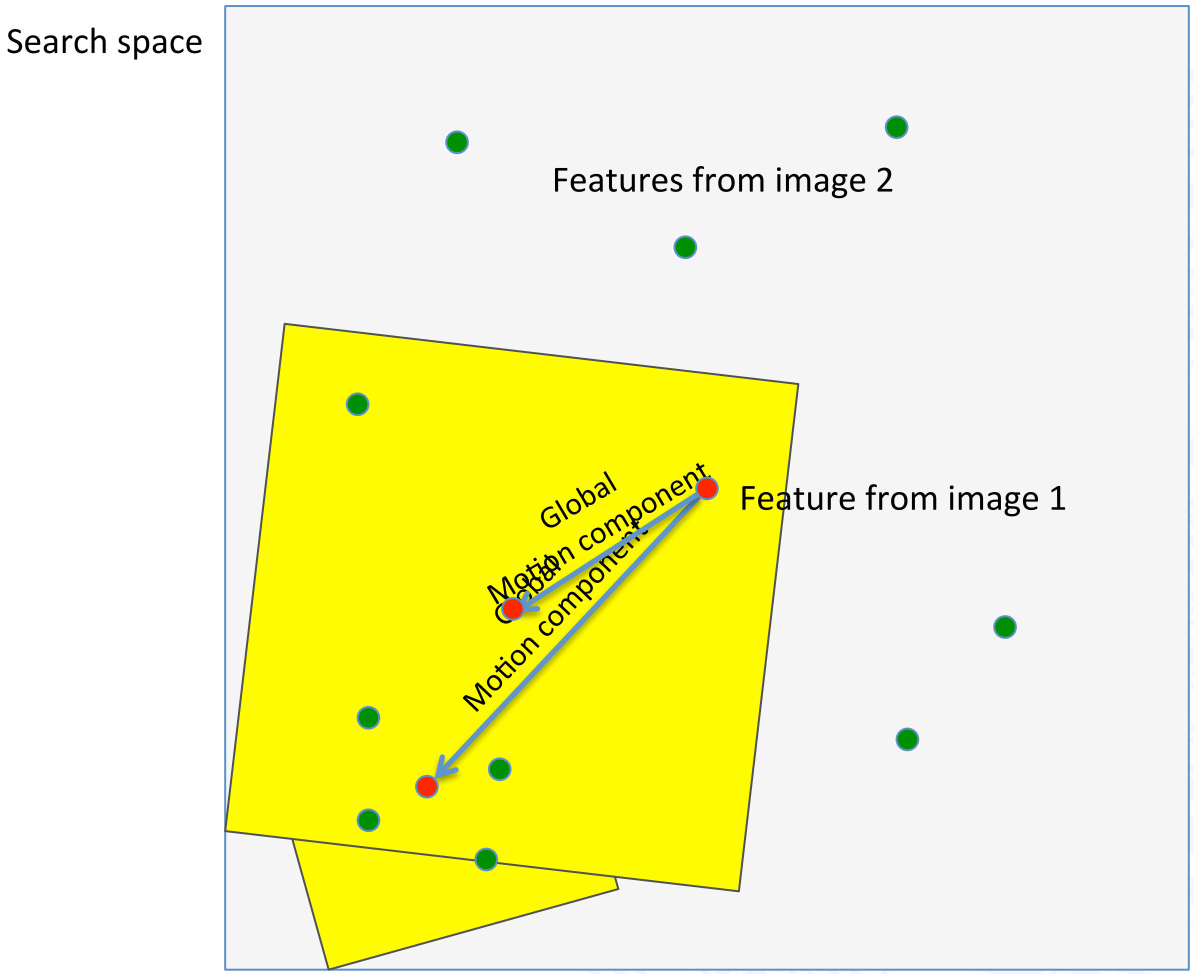
Feature based approaches

Low data availability

- Increasing search space:
  - (Squared) More time needed for computation
  - Increased danger of confusion
- Model assumption: The sea surface current may be decomposed!
  1. Derive the „global“ current component (following Y. Sun)
  2. Apply feature-based matching
  3. Back transformation of target coordinates
- **New**: dynamic adaption of the size of the search space

  → **Focused Search**

Example: Focused Search

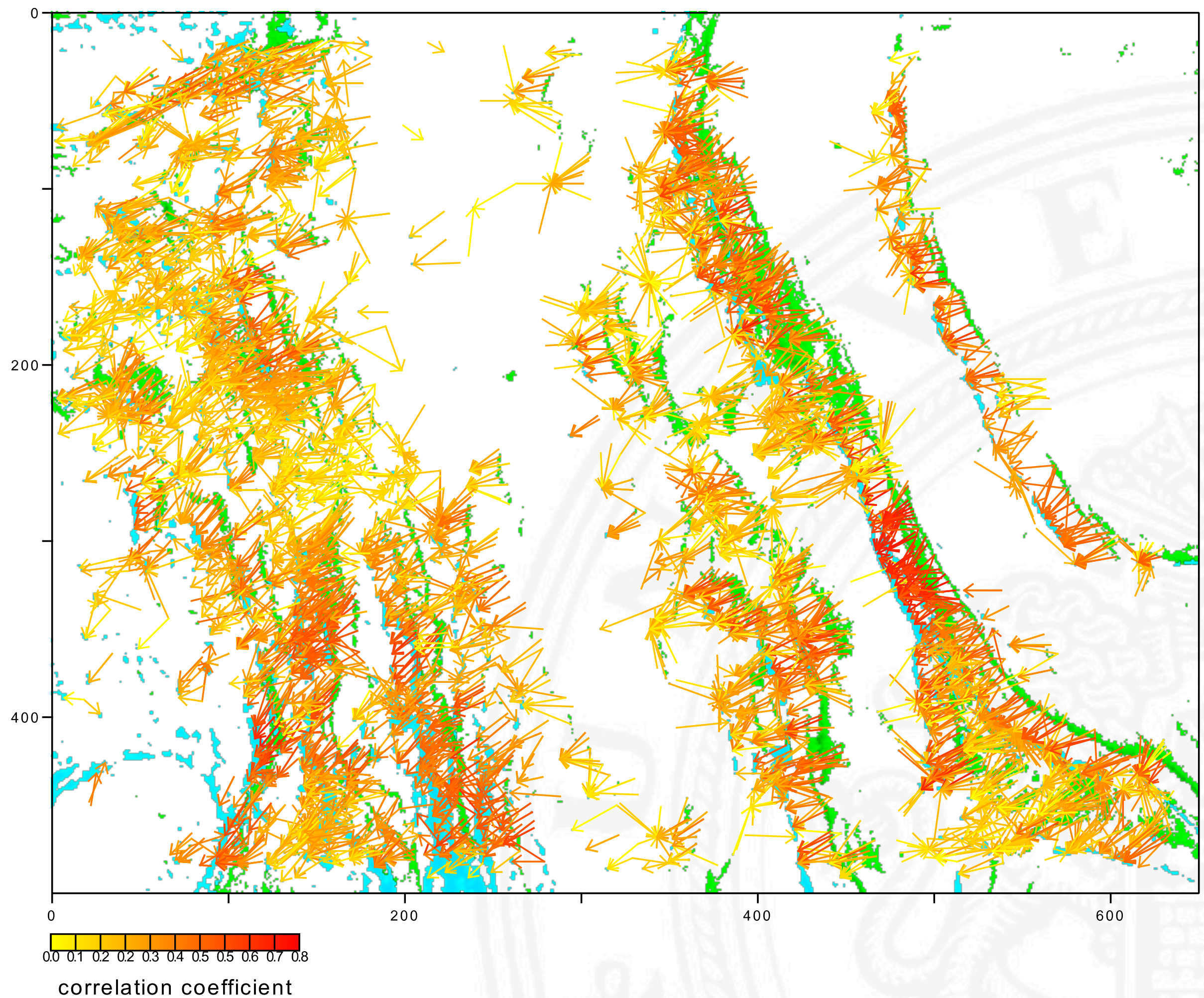


Northern Baltic Sea (NW ROI)

Standard Search

08:57 TM
→
09:47 SAR

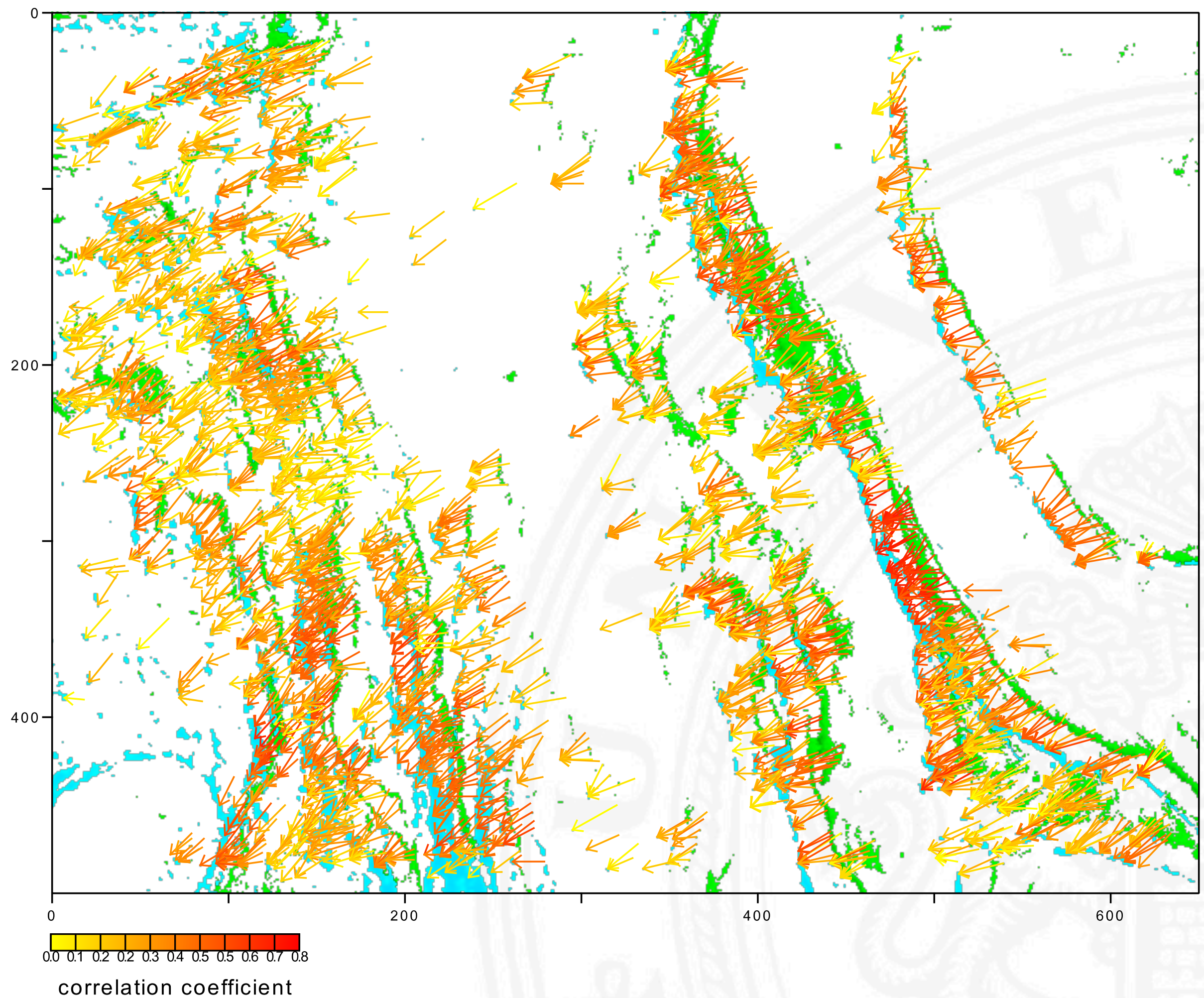
Resolution:
30 m



Northern Baltic Sea (NW ROI)
Focused Search

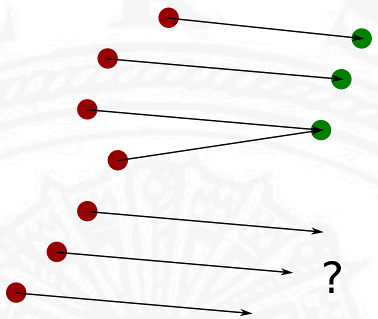
08:57 TM
→
09:47 SAR

Resolution:
30 m

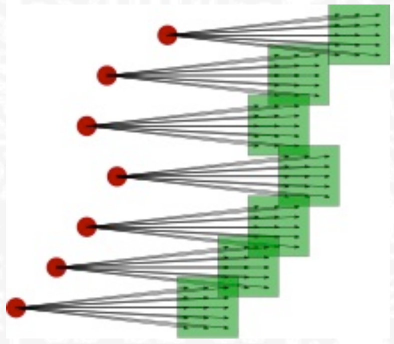


Feature Based Approaches
Handling instable features

- Multimodal image sequences → Instable features
  - Origin: Different kind of imaging
  - Cannot be solved by specialized detection operators!



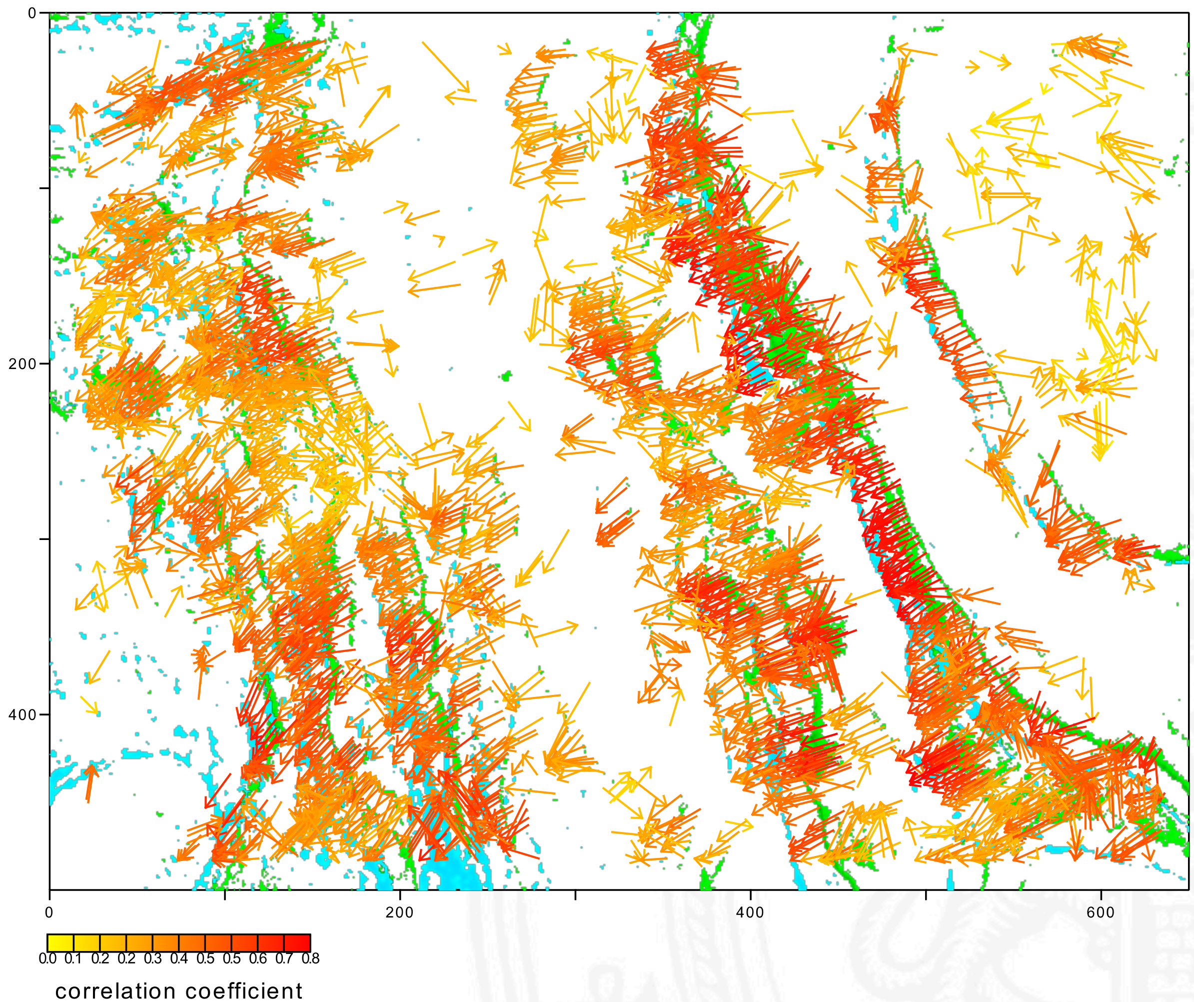
- Thus: Combine different approaches:
  - Complete Search: Fast normalized cross correlation (following J. P. Lewis)
  - Adapted assignment criterion: Smoothness instead of maximum likelihood!



Northern Baltic Sea (NW ROI) Complete Search

08:57 TM
→
09:47 SAR

Resolution: 30 m

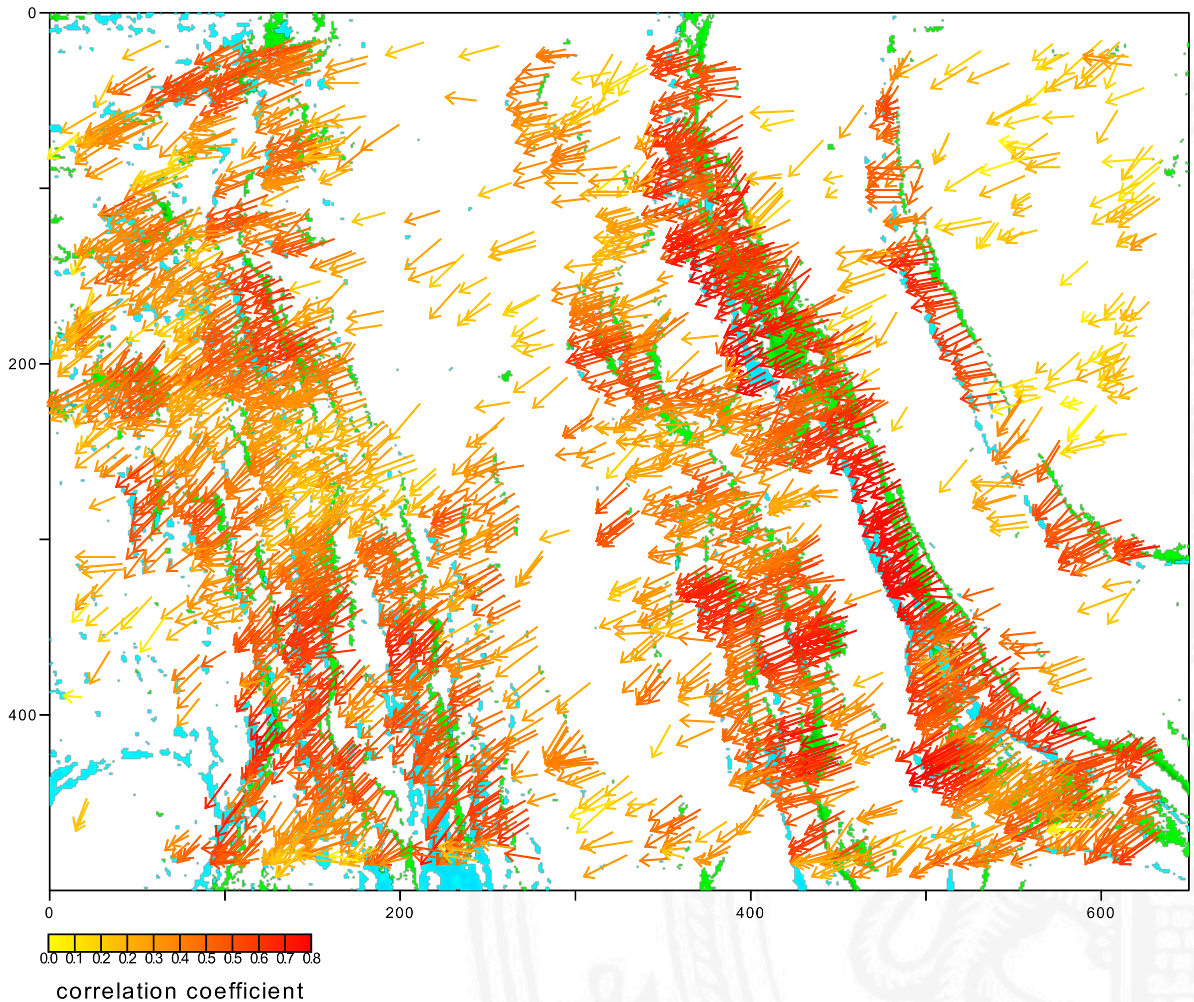


Northern Baltic Sea (NW ROI)

Focused complete search

08:57 TM
→
09:47 SAR

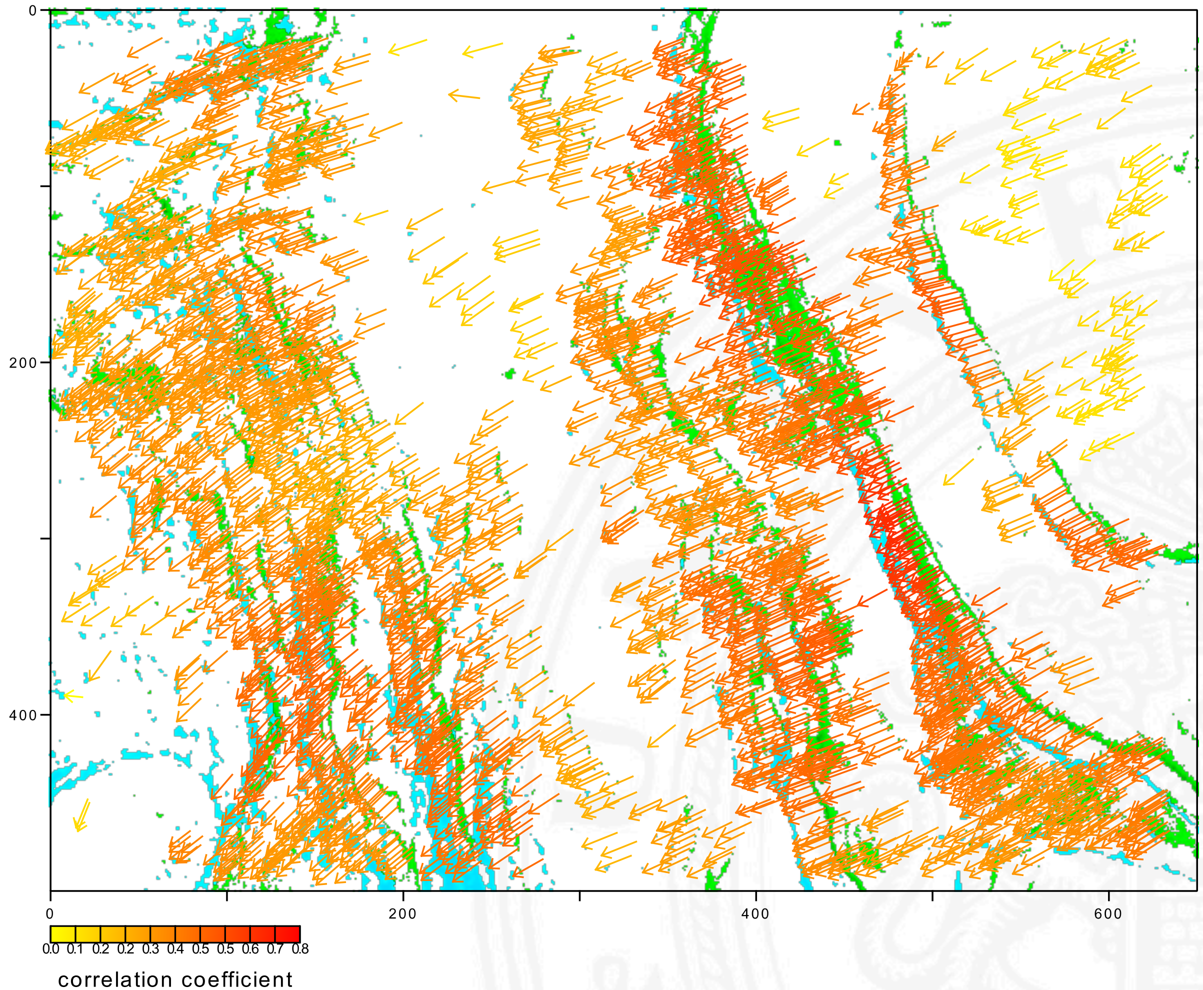
Resolution:
30 m



Northern Baltic Sea (NW ROI)
Focused complete search & Smooth assignment criterion

08:57 TM
→
09:47 SAR

Resolution:
30 m



Differential approaches

Low data availability

- Correspondence between image series‘ gradient and motion vanishes:
  - At large spatio-temporal distances and
  - At combined use of multimodal image data
- General solution: Image pyramids / Scale space
- **New:** Refined solution based on separability of the motion!
- General approach to the specific solution of Y. Sun:

  On each (pyramid) level:

  1. Estimate the global current component
  2. Derive the local component of the optical flow
  3. Back transformation of the target coordinates

Feature based approaches

Coverage (e.g. by clouds)

- Idea: Model the local operation of each algorithm by means of convolution operations:
  - Use the to estimate smoothing and gradients
  - But: Problems in covered image areas
- **New**: Approach independent solution!

  Replace the convolution operator by the normalized convolution operator (following Knutsson u. Westin):

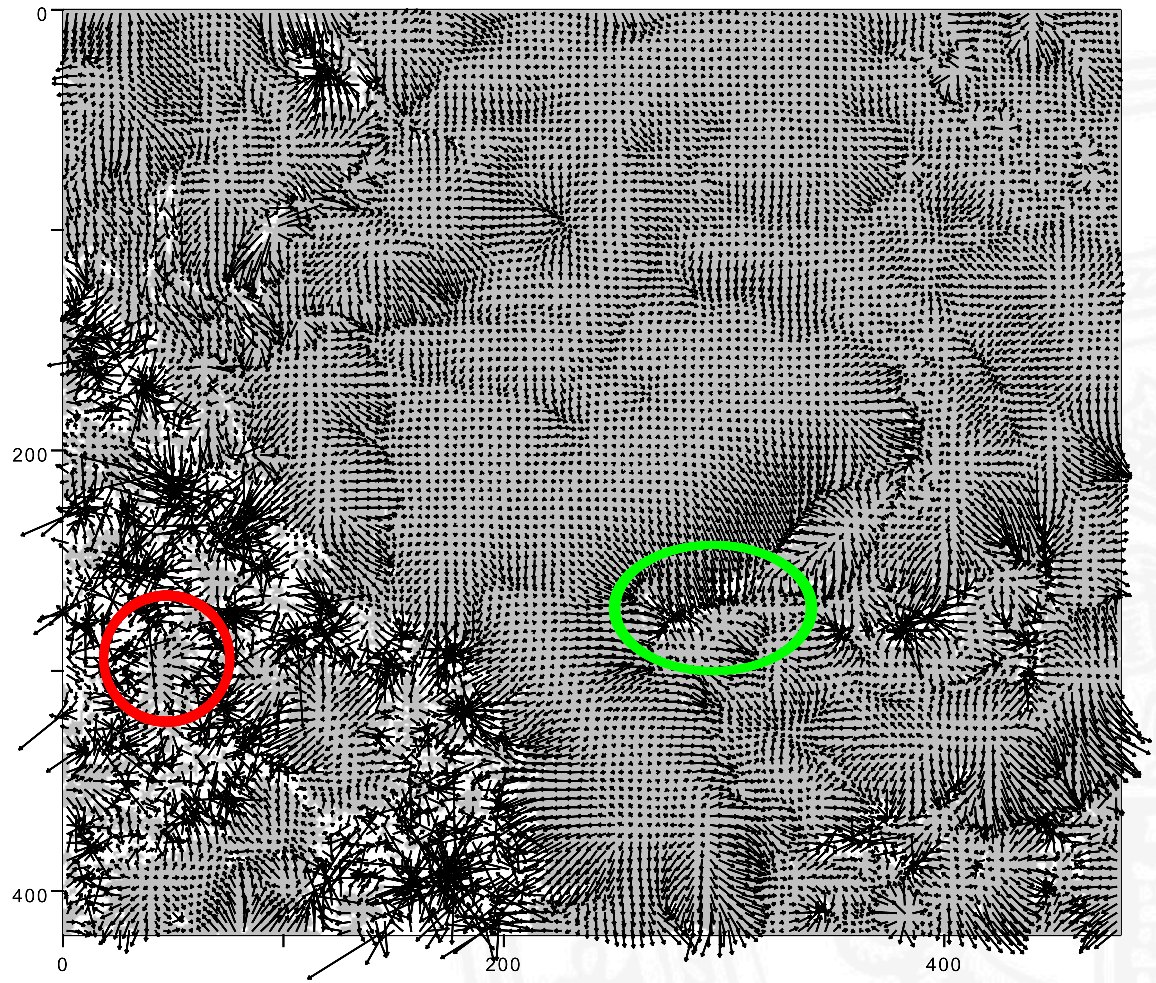
$$K *_M I = \frac{K * I}{K * M}$$

I: Image
K: Convolution kernel
M: Image mask

Optical Flow (Horn & Schunck)

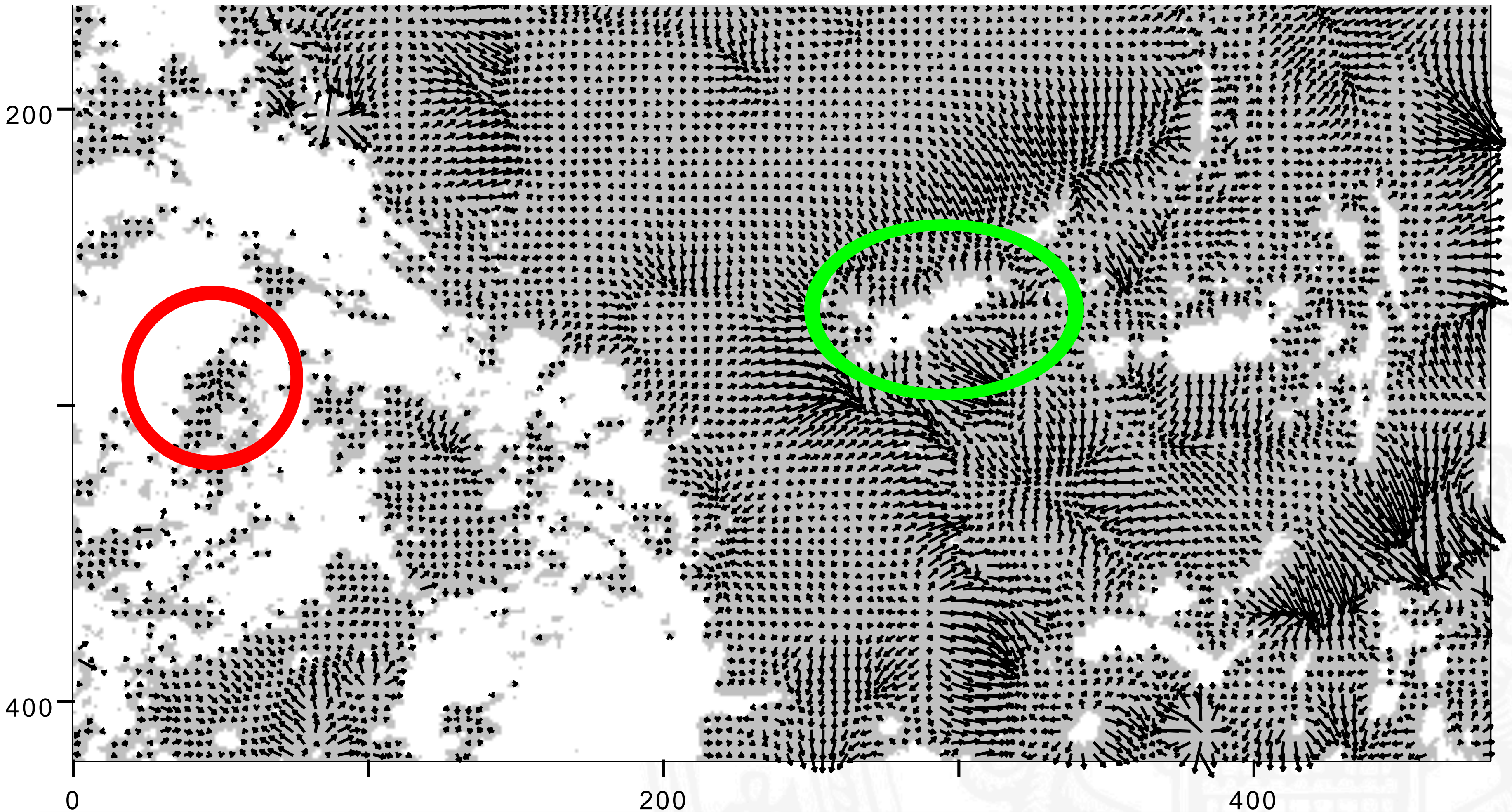
08:57 TM
→
10:26 WiFS

Resolution:
188 m

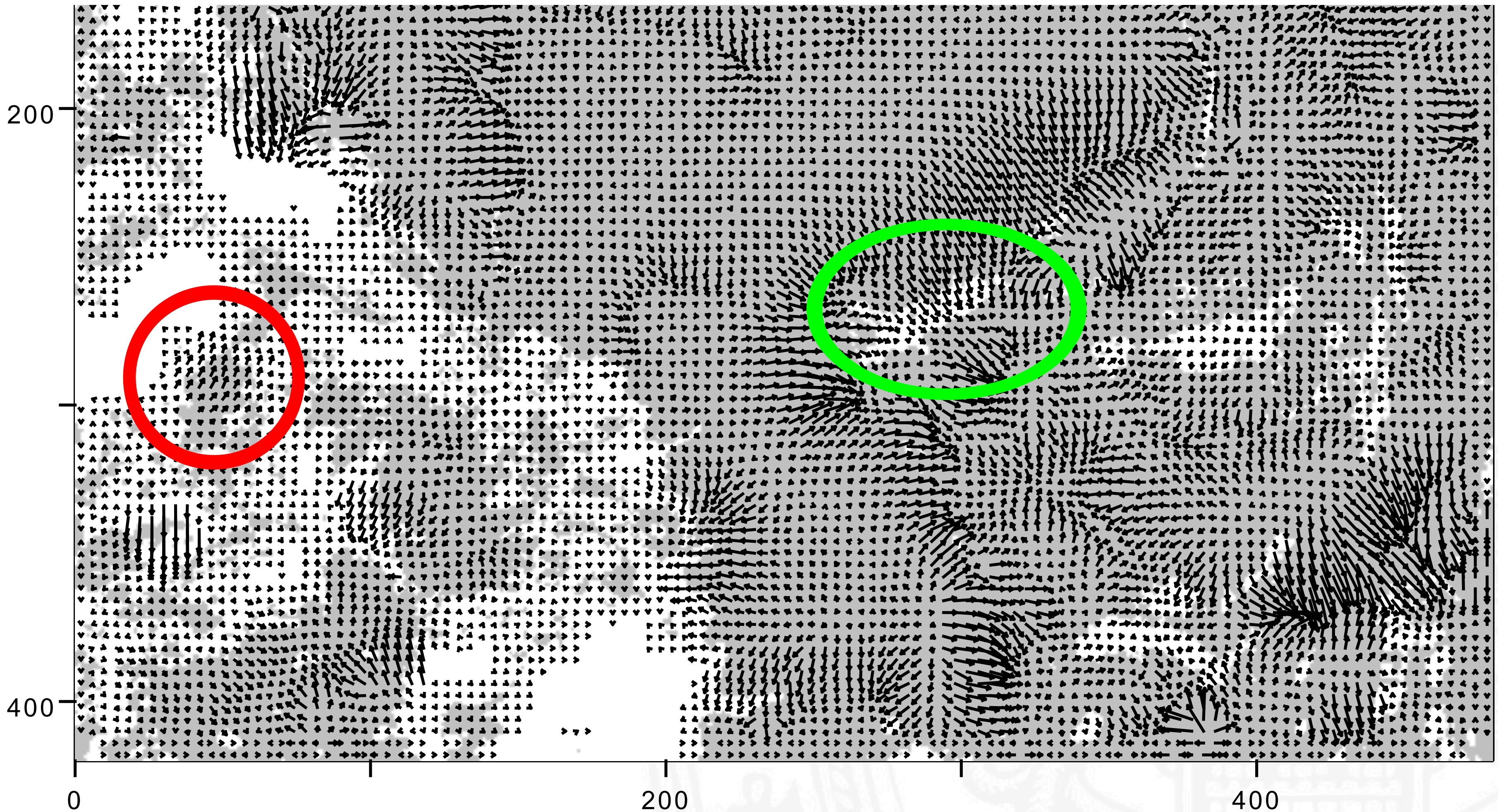


Optical Flow (Horn & Schunck)

Masked Optical Flow (Horn & Schunck)

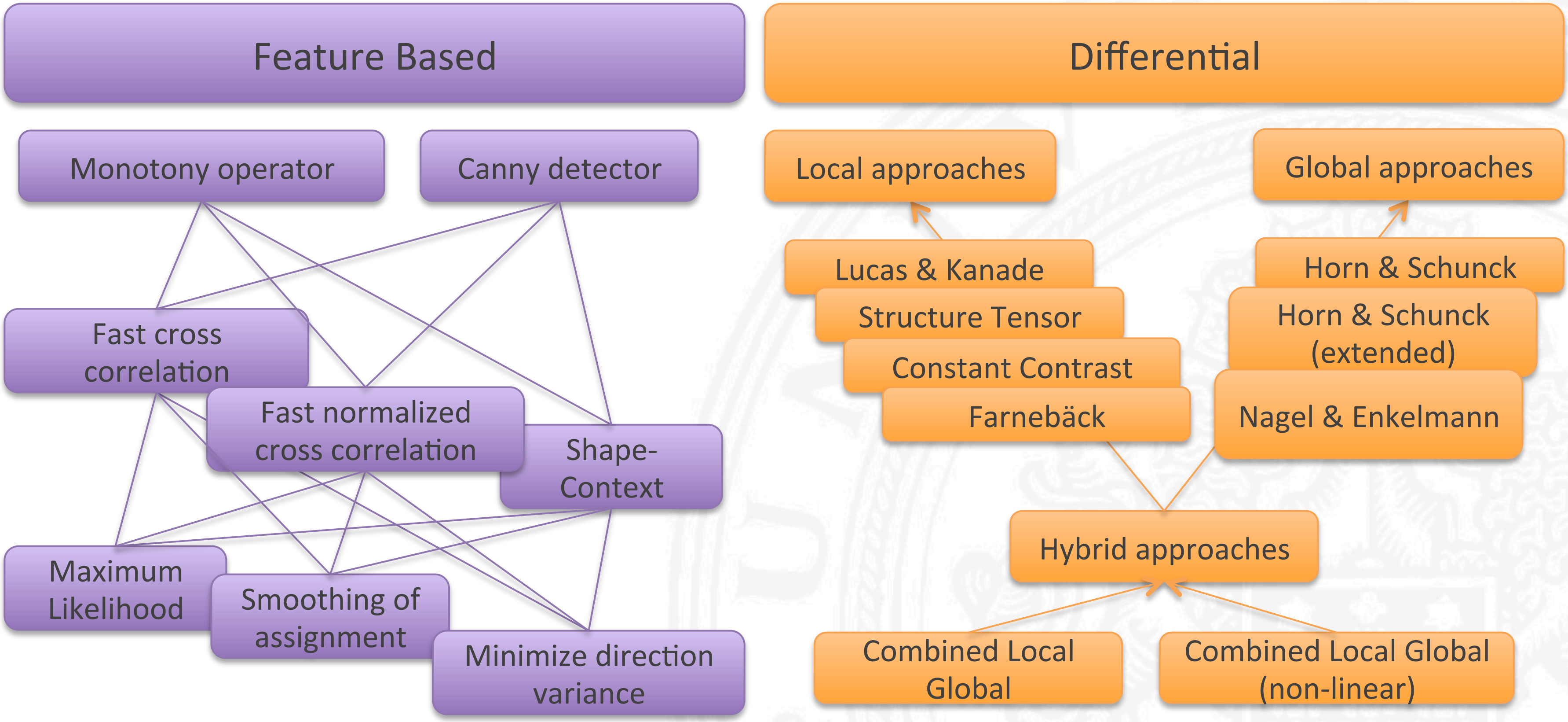


Normalized Optical Flow (Horn & Schunck)



One Generic Framework for a variety of motion derivation algorithms

Approved with many state-of-the-art algorithms:

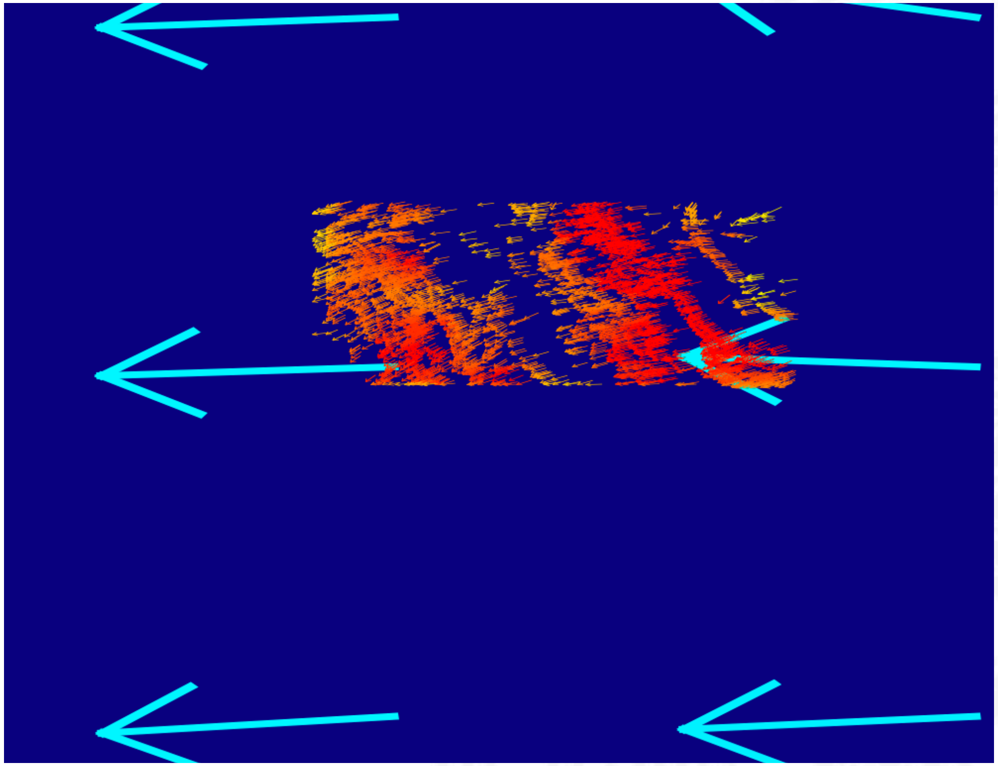


Evaluation and Interpretation

- Automatic Evaluation based on model results
  - Upper water layers vs. the very water surface
  - Modeled resolution very sparse compared with the resolution of the derived current fields
  - Valid comparison only at model scale!
- Interpretation of turbulent image signatures
- Automated knowledge based interpretation of the derived sea surface current fields

Automatic Evaluation
Comparison with Model results

Northern Baltic Sea (NW ROI)
Assignment by means of smoothness



Automatic Evaluation

Results for feature based approaches

- Influence of the focused search (Baltic Sea, NW ROI)

Expansion	fokussierte Suche	AAE (°)		AVE (cm/s)	
11×11	Nein	18.61	(23.36)	2.10	(0.08)
31×31		17.77	(17.28)	2.10	(0.08)
61×61		16.15	(6.98)	2.10	(0.08)
11×11	Ja	16.38	(4.39)	2.10	(0.08)
31×31		15.76	(5.04)	2.10	(0.08)
61×61		15.76	(5.07)	2.10	(0.07)

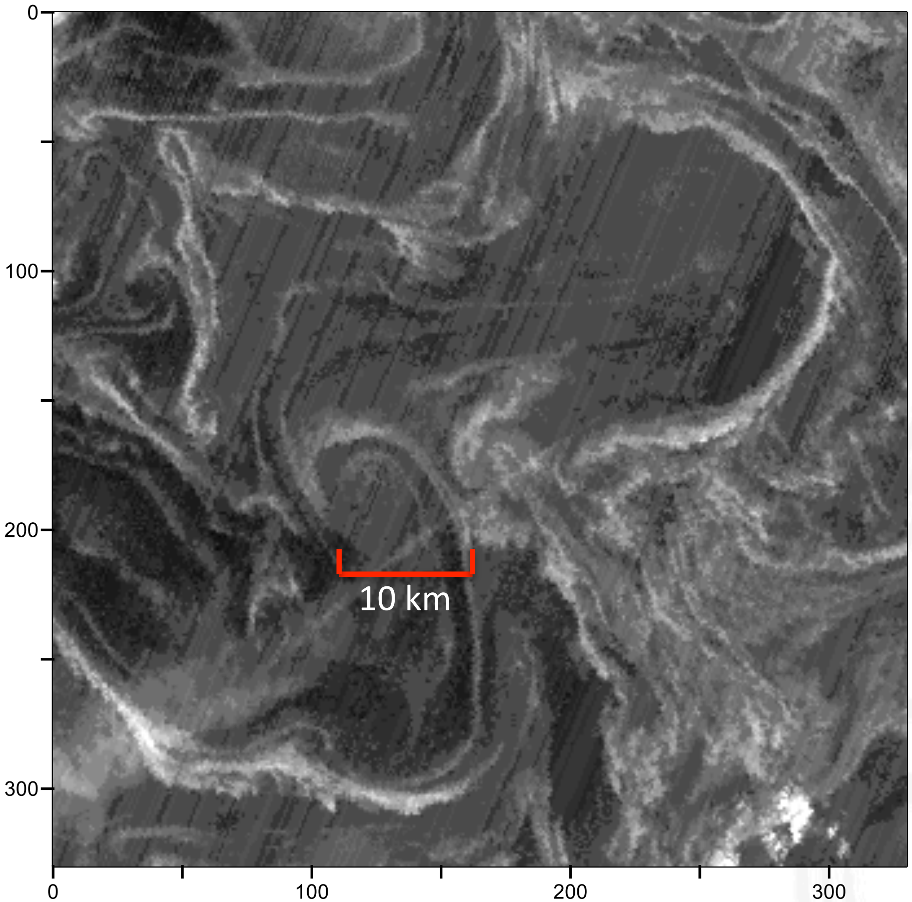
AAE: Average angulate error
AVE: Average velocity error
(): Standard deviation of errors

Evaluation and Interpretation
Interpreting turbulent image signatures

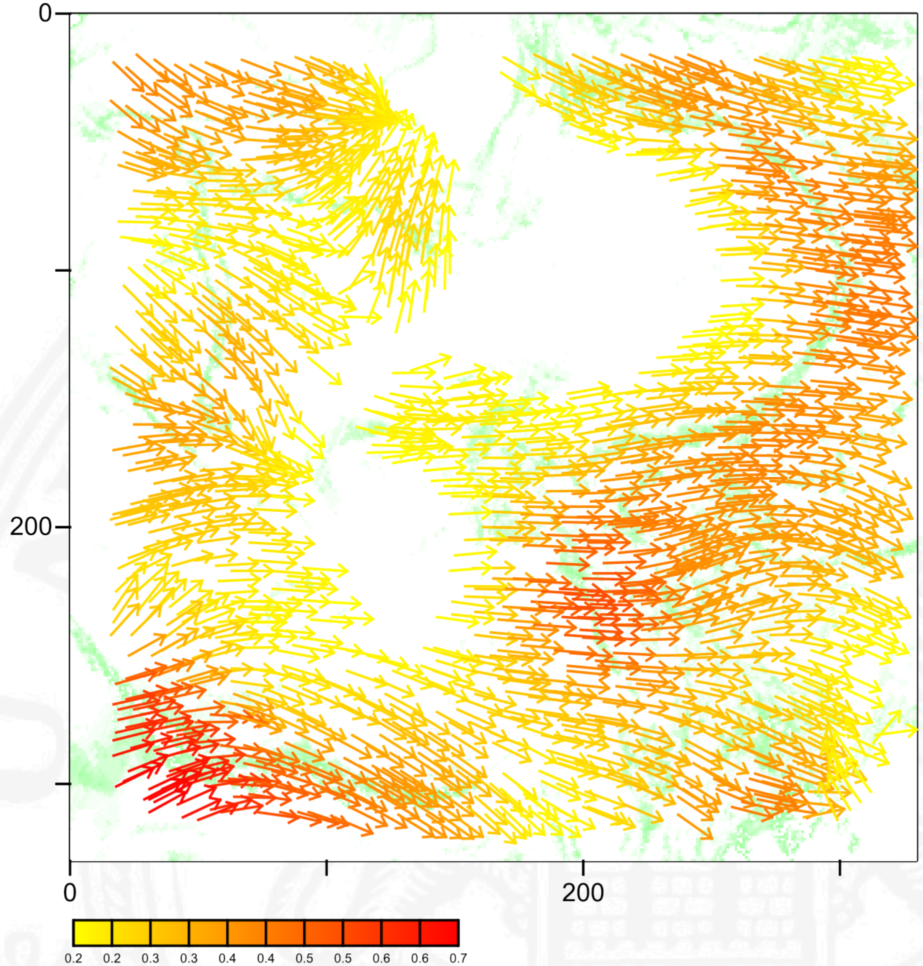
- Different kinds of visualization:
  - Vector wise display
  - Velocity- and direction map
  - Animation as particle system
- Extraction of the local current component
  - Already exists by means of focused search or
  - May be derived by model creation (registration)
  - Over emphasized display

Interpretation of turbulent image signatures

Derived current field (Baltic Sea)

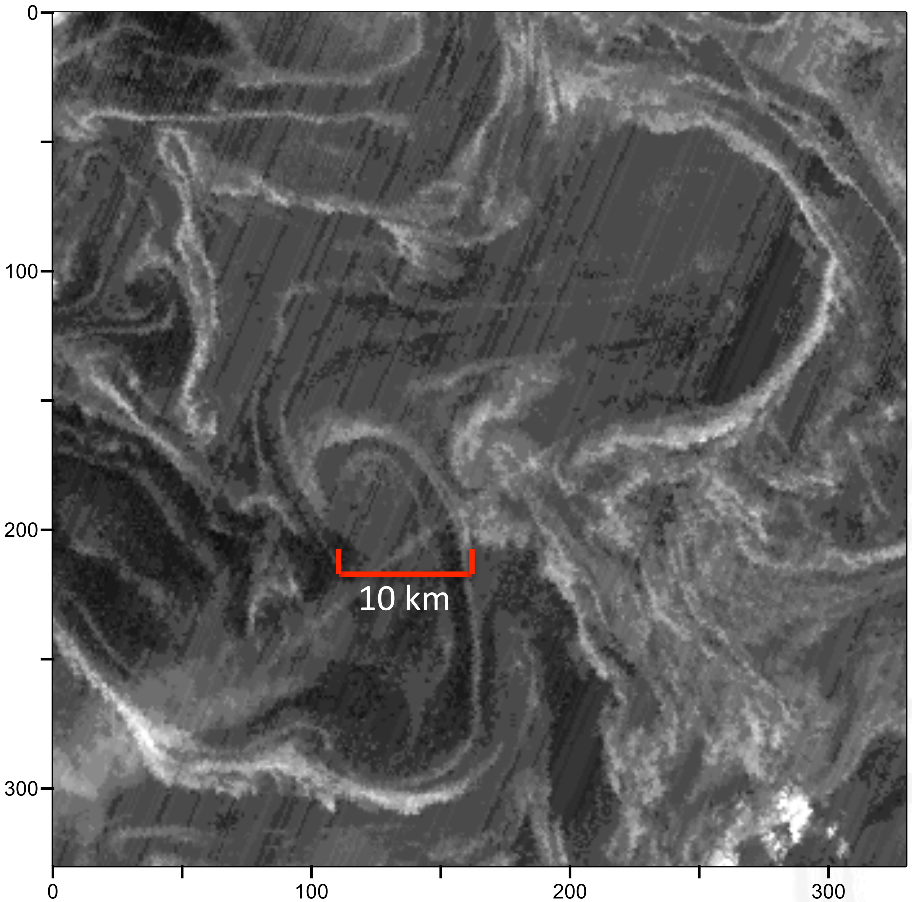


IRS-1C WiFS (Near Infrared)

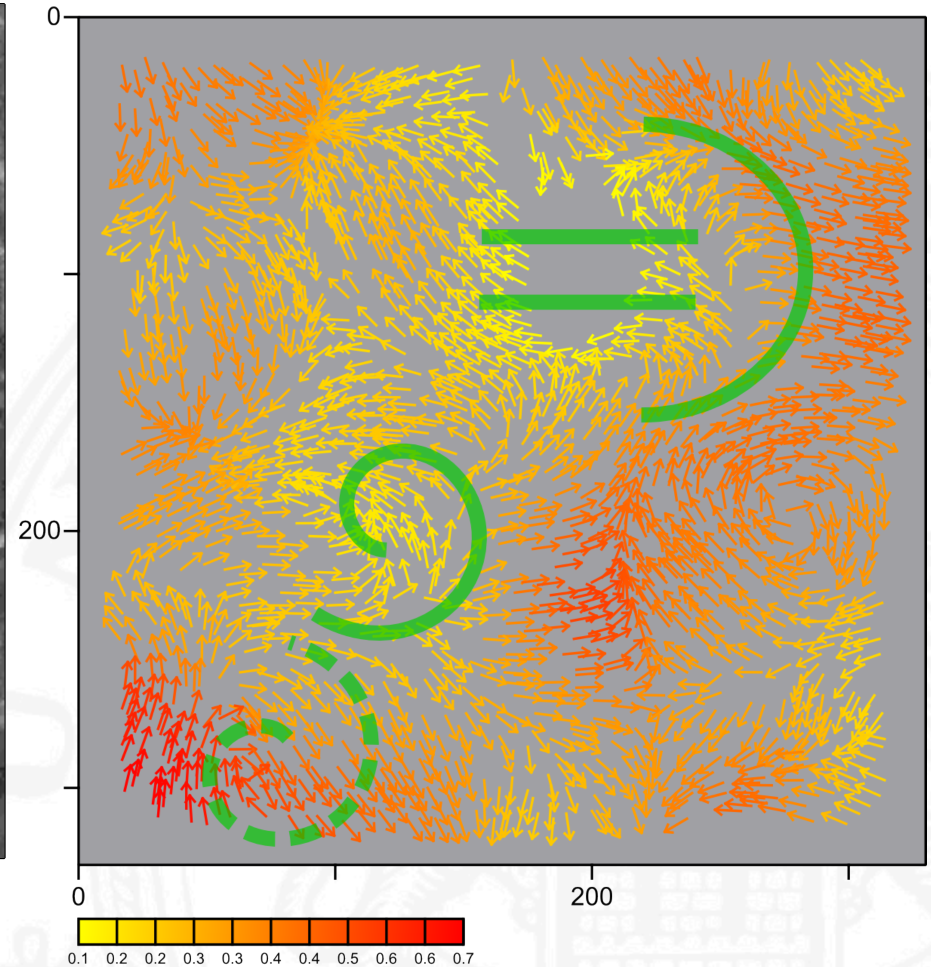


Interpretation of turbulent image signatures

Local current component (Baltic Sea)



IRS-1C WiFS (Near Infrared)



Conclusions

- Generic process chain forms the based for testing and analyzing different (well-known) approaches
  → Appropriate solutions for given sensor constellations
  → Anthropogenic and biogenic films may be used as tracer
- Often: Systematic deviation from model results of local agencies
- Developed Interpretation methods give explanations for turbulent mesoscale image signatures (like eddies, dipoles) for the first time using space borne images!
- Knowledge based framework will be discussed next week!