Drift And Deformation From Satellite Images: Latest European Research (Status October 2015)

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Reference Systems?

Eulerian:

- velocity and deformation on a spatially fixed (geodetic) grid
- easy to compare to model simulations of sea ice dynamics
- deformation via divergence, shear, vorticity

Laplacian:

- following individual ice floes / ice structures
- reconstruction of path lines (corresponds to drift buoy tracks)
- deformation: as above + area changes of Lagrangian cells

Spatial Scales / Status of Operationalizing?

hemispherical => operational (Met. Norge, IFREMER)

- covering entire Arctic Ocean (/Antarctic) sea ice region
- use of coarse-resolution radiometers/scatterometers

hemispherical / regional patches => operational (DTU,DMI)

- covering only parts of the Arctic/Antarctic per time unit
- use of SAR wideswath modes (e. g. Sentinel-1a EW)

regional => operational (FMI)

- covering Baltic Sea
- use of SAR (Sentinel-1A EWS, Radarsat-2 SCW)

regional / local => experimental

- selected test sites (Baltic, Arctic, Antarctic)
- use of SAR images, different modes

Hemispherical drift fields: Sensors & Spatial / Temporal Resolution

Passive microwave radiometers: AMSR2 (37 & 89GHz H&V), SSM/IS (91 GHZ H&V) (archived: SSMI)

Scatterometers: ASCAT (archived: QuikSCAT, NSCAT)

OSI-SAF:	62.5 km	2 days
IFREMER:	62.5 km 31.25 km	3, 6, and 30 days 2, 3, 6 days

Data available from

(Met Norge) http://osisaf.met.no/p/ice/lr_ice_drift.html

(2007 – present, region: Arctic, (Antarctic) except melting period)

(IFREMER) http://cersat.ifremer.fr

(1992 – present; September – May, region: Arctic)

Regional drift fields -> operational: sensors & spatial / temporal resolution

SAR (Sentinel-1, Radarsat-2: wide coverage)

DTU/DMI: 10 km - ≥ 1 day (availability)

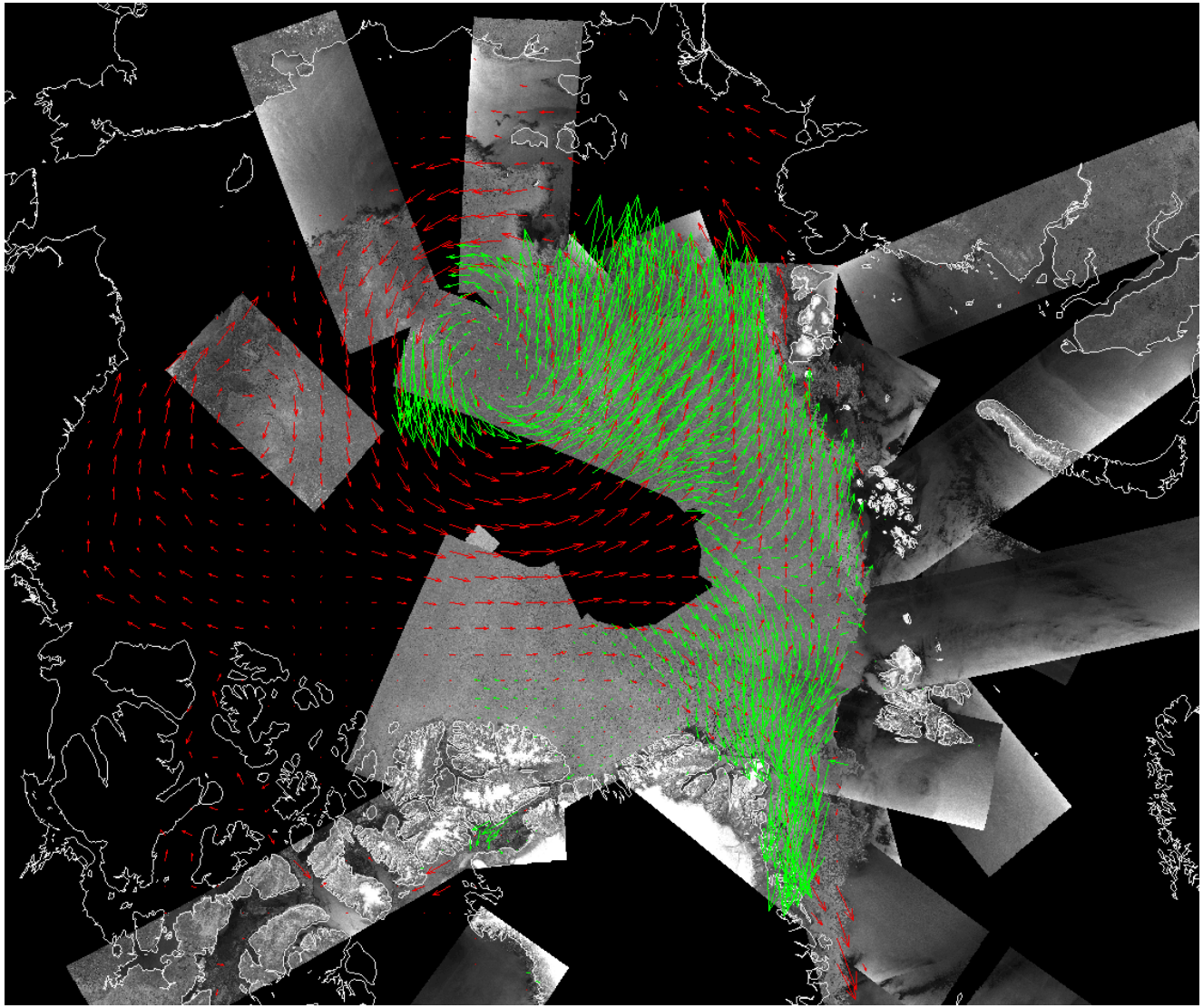
FMI: 800 m - ≥ 1 day (availabiliy)

Data available from:

(DTU/DMI) http://seaice.dk, http://marine.copernicus.eu
(2010-present, includes also ENVISAT ASAR
recent status: use of all S1-scenes, Arctic > 4000 per month
Antarctic > 600 per month)

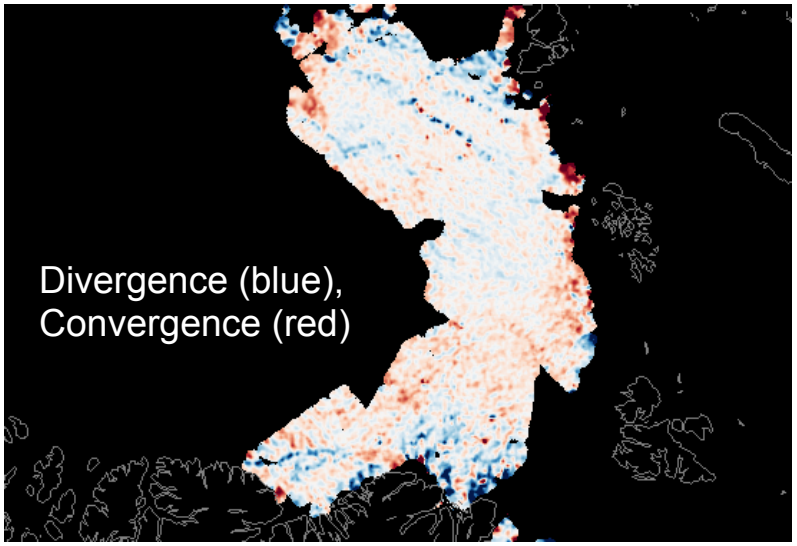
(FMI) http://marine.copernicus.eu
(2011-present, includes also ENVISAT ASAR,
region: Baltic Sea)

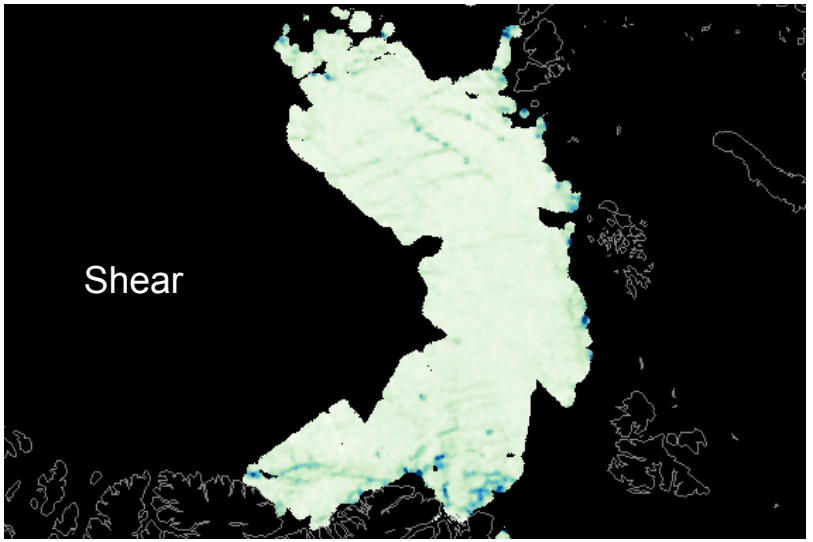
Hemispherical / Regional Patches

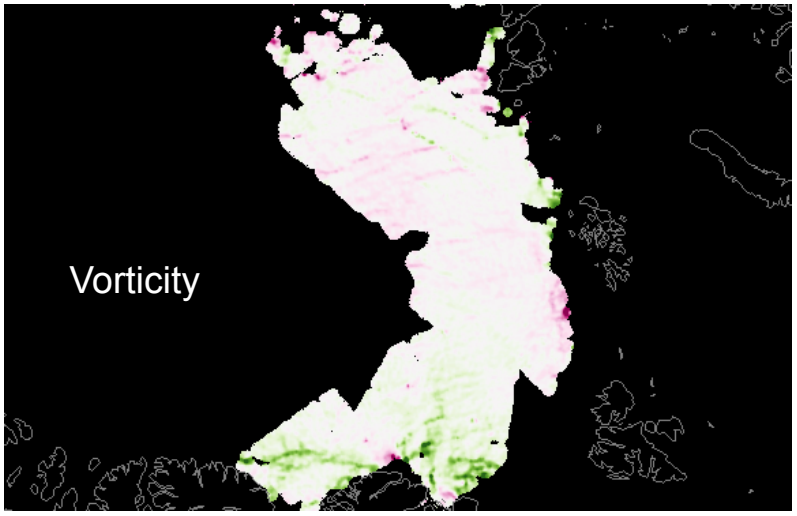


Arctic ice drift from Sentinel-1A, Oct 10 – 11 2015, www.seaice.dk

Divergence, Shear and Vorticity







- Operational products from DTU, www.seaice.dk, Sentinel-1 October 12-13, 2015
- Produced daily from the 10x10 kilometer Copernicus ice drift data

Regional / local drift fields -> experimental: sensors & spatial / temporal resolution

SAR imagery, recent missions
C-Band: Sentinel-1a, Radarsat-2,
X-Band: TSX/TandemX, Cosmo SkyMED
L-Band: ALOS-2 PALSAR

archived data: ERS-1, -2, Envisat ASAR, Radarsat, ALOS PalSAR

coverage:	100 – 400 km (few 10s km possible)
spatial resolution:	10-100 m
sp. res. drift fields:	about 5-15 times pixel size

Correlations

Maximum Cross-Correlation MCC

- IFREMER, DTU/DMI, FMI, (AWI)
- block (window) correlation in the spatial domain

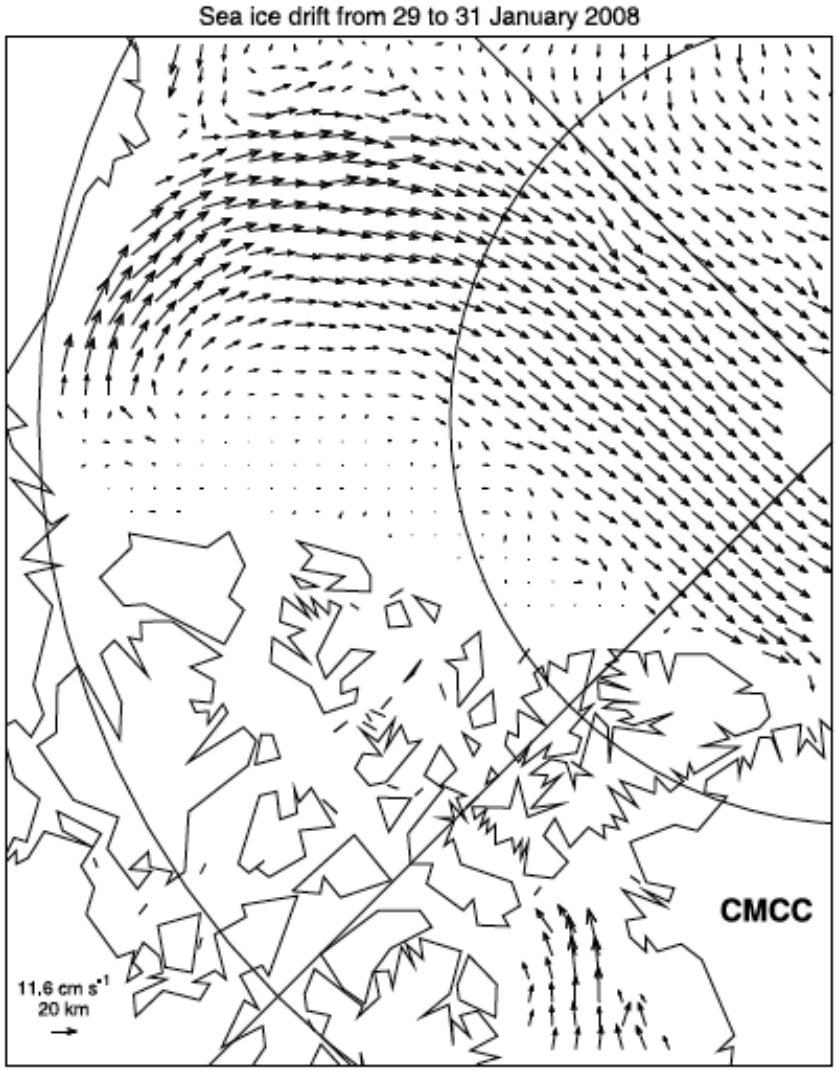
Continuous MCC

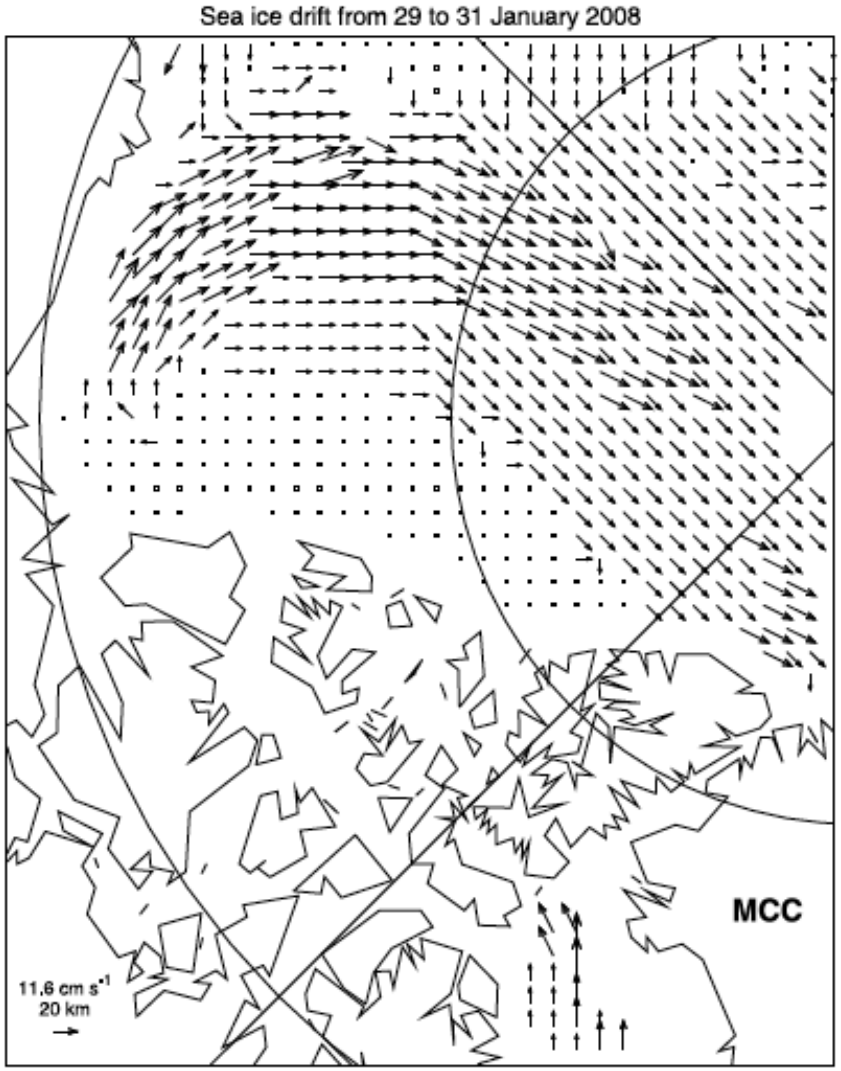
- OSISAF
- based on MCC, increase of lag resolution using pixel interpolation -> reduction of quantization noise

Phase correlation PC

- FMI, Chalmers, (AWI)
- block (window) correlation in the Fourier domain
- (insensitive to changes in intensity, all transform components are weighted equally)

MCC versus CMCC





Source: Lavergne et al., JGR, 2010

Methods Used?

Pattern matching

- two images needed
- block-wise area correlation (MCC, CMCC, PC)
- preferable for closed pack ice, negligible rotation

Feature tracking

- two images needed
- identification & tracking of stable structures (irregular grid)
- includes rotational motion
- preferable for marginal ice zone

Dopplershift analysis (UiT)

- only one image needed
- use of Sentinel-1 radial surface velocity product
- sub-second line-of-sight ice motion

Problems -> recent work on

- rotation of ice floes / ice floe clusters (correlation)
- discontinuities of the drift field (deformation)
- simultaneous evaluation of drift vector accuracy/reliability
- increase of computational speed
- scaling of drift and deformation

Specification of operational approach using SAR

FMI:

- *PC, 2 levels of spatial resolution with fixed window size*
  (second simpler approach: hardware-accelerated MCC)
- *pre-selection of areas to be correlated*
  (existence of structures/edges)
- *consideration of multiple drift vector candidates*
  (including lower phase correlation peaks and neighbouring vectors for final selection)
- *quality measure*
  (magnitude, distance, number of lower phase correlation peaks > 0.7 × absolute maximum)
- comparison of different frequency bands (X, C, L)
  (the optimal band depends on sea ice regime)

Specification of experimental approaches

Chalmers:

- *hybrid algorithm: phase correlation & feature tracking*
- *≥ 3 resolution levels*
  (simultaneous change of pixel & window size)
- *check for rotation at level of highest spatial resolution*
  (dominant rotation within window)
- *image segmentation for ice floe delimitation*
  (separation of amalgamated floes; feature tracking on ice floes, but not structures)
- *feature tracking: Least Average Residual Algorithm (LARA)*

Specification of experimental approaches

AWI:

- *phase correlation & subsequent NCC*
  (NCC for selection of “candidates” provided by PC)
- *resolution pyramid (pixel size) with cascade (window size)*
  (increases robustness of drift vector estimation)
- *quality measures*
  (> backmatching
  > confidence factor: effect of speckle
  image texture
  intensity outliers
  correlation)
- *comparison of HH- and HV-polarization (C-band)*
  (complementing one another, HV not necessarily better)

Specification of experimental approaches

NERSC:

- *feature tracking*
  (ORB = oriented FAST and Rotated BRIEF, open source)
- *FAST: keypoint detector*
  (identification of multi-scale features on different levels of spatial resolution with optimum candidate selection)
- *BRIEF: binary strings as feature point descriptor*
  (similarity of strings measured by Hamming distance)
- *comparison of HH- and HV-polarization*
  (HV significantly better)
- *ongoing: combine pattern matching & feature tracking*
  (collaboration with AWI)

Activity 2016/17 : ESA CCI Sea Ice Drift

- During next 2 years, the ESA CCI Sea Ice project will conduct a sea ice drift algorithm intercomparison.
- The target is a climate dataset, but R&D work on algorithms might benefit operational products.
- The project will build a test dataset which collocates image pairs (both SAR, PMR and SCATT) and buoy drift vectors. This dataset will be open and will be used to test existing algorithms.
- Dedicated work on uncertainties is also planned.
- Activity led by T. Lavergne (MET Norway), first results fall 2016.

Source Code Access

- FMI
  Open CL cross correlation=> http://joni.lehtiranta.net/

- NESRC
  ORB algorithm => http://opencv.org
  SAR processing=> https://github.com/nansencenter/nansat

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