Precise SAR Doppler calibration and application for sea ice drift estimation

Jeong-Won Park, Morten Hansen, Anton Korosov
Nansen Environmental and Remote Sensing Center, Bergen, Norway (jeong-won.park@nersc.no)

Abstract

- The proposed calibration scheme effectively removes errors come from attitude anomaly and antenna mispointing which are generic for all SAR sensors. The resulting calibrated Doppler signal of the entire ENVISAT ASAR ScanSAR data for one repeat cycle (35 days) showed largely reduced uncertainty (RMSE: 9.8 Hz and 11.3 Hz for HH and VV polarisation, respectively, without land reference) and well balanced inter-swath measurements.
- Sea ice drift in the Fram Strait was derived using both the pattern matching and the Doppler estimation. Intercomparision of the time averaged velocities showed overall high consistency (RMSE: 0.15 m/s).

Doppler Calibration

Elimination of non-geophysical terms from the raw Doppler shift, \( f_{dc} \).

\[ f_{phys} = f_{dc} - f_{geom} - f_{em} \]

- \( f_{geom} \): geometric Doppler related to the relative motion between SAR antenna and the rotating Earth surface
- \( f_{em} \): electronic mispointing originated by beam center misalignment and failure of antenna transmit/receive module
- \( f_{phys} \): geophysical Doppler that induced by the true motion of the target object

Geometric Doppler \( (f_{geom}) \)

1. Initial prediction is made by solving the range-Doppler equations with auxiliary information (precise orbit state vectors and attitude anomalies)
2. Antenna misalignments with respect to satellite body axes are estimated in terms of yaw and pitch angles from the slope and offset of the mean Doppler centroid anomaly of land coverage (Fig. 1a).
3. The revised prediction corrected for the antenna misalignments (Fig. 1b) is used to estimate the residual drift associated with satellite hour angles (Fig. 1c).
4. The best-fitting curve is subtracted from the revised prediction to get the result which contains the electronic mispointing only (Fig. 1d).

Electronic mispointing \( (f_{em}) \)

1. Topography induced look angle shifts (Fig. 2) are corrected using DEM and the two-way travel distances of radar pulses. In practice, this can be done during solving the range-Doppler equations in the step 1 of geometric Doppler calculation.
2. A look-up table (Fig. 3) is generated by taking average of Doppler centroid anomalies for each look angle bins in Fig. 1d.

Sea Ice Drift Estimation

We applied the developed Doppler calibration algorithm for image strips over north-east Greenland Sea where the sea ice motion is relatively fast. Conventional pattern matching-derived mean ice velocity was used for intercomparison.

- Performance evaluation
  - The measured velocities are in reasonable range, and the contrast between landfast ice and the others is clear (Fig. 4).
  - The Doppler estimation covers almost all area in the image, while the pattern matching covers only 63\% of sea ice.

Fig. 5. Examples of normalized radar backscatter (gray scale), sea ice edge (black line) and Doppler derived instantaneous velocity (colored, m/s) for four dates: 1, 10, 16 and 29 January 2010. White color shows areas where the pattern matching algorithm performed well.

Comparison of time averaged velocity fields

- Good agreement in overall patterns and velocities. The sharp boundaries between non-moving fast ice and drifting ice are clearly seen in both results.
- The Doppler-derived velocity map covers almost every pixels in the given source data, while the pattern matching-derived velocity map has successive observation only over the area with distinct features.

Fig. 6. Comparison of time averaged (35 days) velocity fields from (b) SAR Doppler derived instantaneous velocity and (c) pattern matching based mean velocity. The ice-water boundary is recognizable in both (a) the backscattering power and (b) the Doppler derived instantaneous velocity.

From the quantitative comparison between the two velocity fields,
- The instantaneous velocity was 15% faster than the mean velocity, however, this changes from scene to scene as the actual short-term motion of sea ice is highly heterogeneous.
- The intercept of -0.01 m/s and the RMSE of 0.15 m/s indicate that the two measurements are comparable, without significant differences.

Summary and Conclusions

- A data-driven Doppler calibration scheme was developed and applied to retrieve sea ice drift velocity. The method effectively corrects the Doppler contributions from both geometry and electronic mispointing.
- The Doppler estimation can retrieve ice velocity over marginal ice zone where the pattern matching fails. The pattern matching covers only 63\% of sea ice on average.
- The time averaged velocity fields from the Doppler shift and pattern matching are comparable, thus the Doppler estimato can be used for extending the coverage of ice drift map.

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