WP1000- Review of ATI SAR Surface Current Velocity retrieval

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

WP1000 Overview

- in-depth literature review of past experimental and theoretical modelling studies relating to ATI SAR interferometry for retrieval of ocean currents
  - Only ATI SAR for currents; not SAR, not wind/waves
- Work performed Jan-April 2013
- D1: ATI SAR Surface Current Report
  - Final version issued Oct 2013

WP1000 Objectives

- Review of ATI SAR Surface Current Velocity retrieval
- identify key geophysical phenomena affecting ATI surface current retrieval, review theoretical models & their capability to reproduce experimental results
- document past experimental results in terms of
  - environmental conditions
  - ground-truth used for validation
  - basic parameters of the radar systems
- elaborate the implications for a spaceborne Wavemill mission and Wavemill scientific product requirements

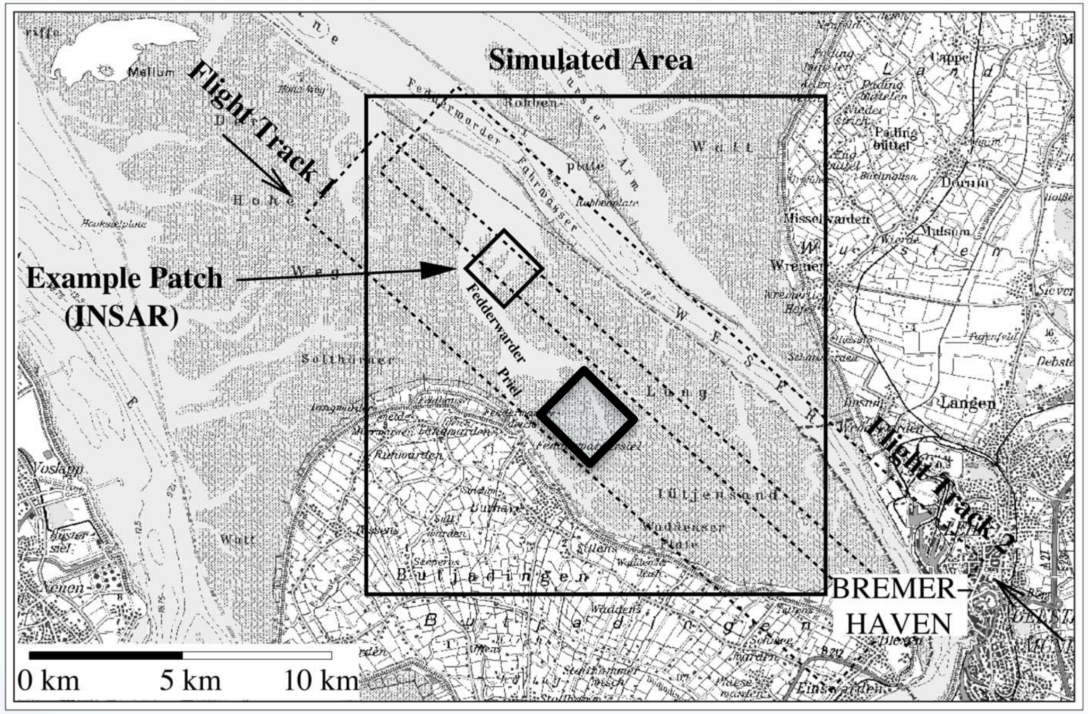
Section 3. Key publications

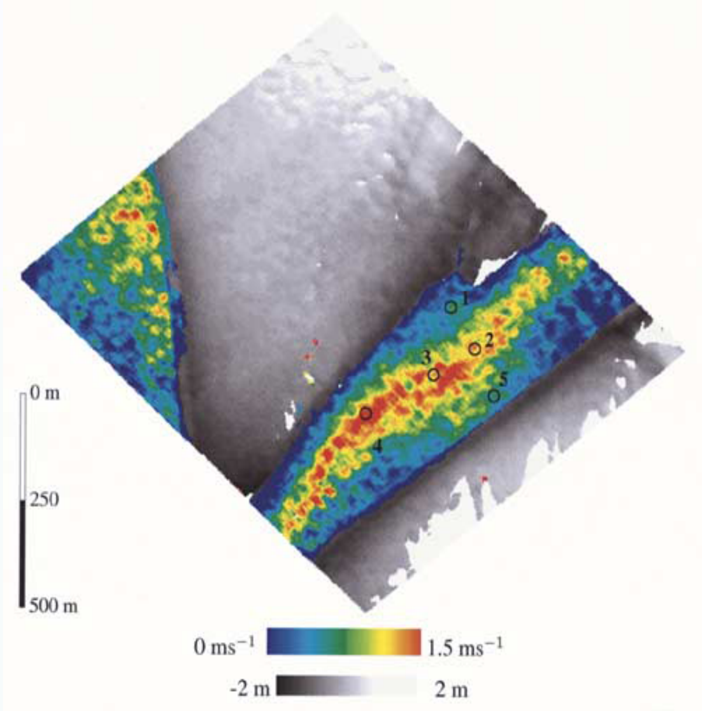
- Goldstein & Zebker, 1987: Interferometric Radar Measurement of Ocean Surface Currents
- Graber, Thompson & Carande (1996): Ocean surface features and currents measured with SAR interferometry and HF radar
- Romeiser & Thompson, 2000: Numerical study on the ATI radar imaging mechanism of oceanic surface currents
- Frasier & Camps, 2001: Dual-beam interferometry for ocean surface current vector mapping
- KoRIOLiS, 2002: Study on Concepts for Radar Interferometry from satellites for Ocean (and Land) Applications
- The BNSC NEWTON study, 2002: Along Track SAR Interferometry for Ocean Currents and Swell
- Siegmund et al., 2004: First demonstration of surface currents imaged by hybrid along- and cross-track interferometric SAR
- Romeiser et al., 2005: Current measurements by SAR along-track interferometry from a space shuttle
- Toporkov et al., 2005: Sea surface velocity vector retrieval using dual-beam interferometry: First demonstration
- Sletten, 2006: An analysis of gradient-induced distortion in ATI-SAR imagery of surface currents
- Romeiser et al., 2010a: First Analysis of TerraSAR-X Along-Track InSAR-Derived Current Fields
- Kumagae et al., 2011: Sea Surface Current Measurement with Ku-Band SAR Along-Track Interferometry
- Toporkov et al., 2011: Surface Velocity Profiles in a Vessel's Turbulent Wake Observed by a Dual-Beam Along-Track Interferometric SAR
- Hansen et al., 2012: Simulation of radar backscatter and Doppler shifts of wave-current interaction in the presence of strong tidal current

Annex A: Summary table (extract)

Reference	Radar system & geometry	Spatial Resolution	What & where	Environmental conditions & retrieval accuracy	Validation data sources	Errors, mitigation strategies & modelling
Junek *et al.* (2003)	Alt: 600 m, V: 100 m/s I: 69-86 deg Squint: 20 deg	Swath ~ 7km 16.7 (XT) m	Charlotte Harbour, Florida, USA	Biogenic surfactant slicks (i.e. wind < 5 m/s)		First airborne trials of prototype above Different backscatter intensity in forward and aft looks, attributed to directionality of surface wave spectrum (Bragg)
Anderson *et al.* (2003a)	Airborne, L & C-band JPL AIRSAR Alt: 8.6km, V: 216m/s B_{AT}: 19m (L) B_{AT}: 1.9m (C) I: 23-73 deg	10(AT) x 6(XT) m	Currents and waves Hawaii (close to north tip of Big Island), USA	Current: 0.25m/s (tide) Wind: strong wind shear (orographic effects) Waves: swell present	None	Un-calibrated amplitude and phase Strong phase gradients due to poor aircraft attitude control Modelling: ATI phase modelled with composite model by Romeiser & Thompson (2000) with input from OCCAM & HOME tidal currents coupled with WAM 3rd generation wave model (wave-current interactions) and ECMWF winds
			Kuroshio, SW Japan	Current: Kuroshio jet and eddy (1m/s)	None	
Siegmund *et al.* (2004)	Airborne, X-band Hybrid AT/XT (squinted) HH pol Alt: 3.2km, V~80m/s B_{AT}: 0.034m B_{XT}: 1.56m I: 45 deg	0.5(AT) x 0.5(XT) m Accuracy: 0.2m/s	Land elevation and currents Estuary mouth of Weser river, Wadden Sea, German Bight	Shallow inter-tidal zone; tidal range: 3.6m Current: + 30 minutes from low tide; Max current: 0.7-0.9m/s Wind: 8-10m/s	Hydrodynamic model (TRIM-2D) Coastal weather station	Model to quantify ambiguity between elevation and velocity retrieval in hybrid Interferometric phase Mis-registration in azimuth due to XT baseline leads to bias in phase because of squint. Remove wind drift (3% Wind speed) and Bragg waves phase velocity (~0.2m/s) estimated with Romeiser & Thompson (2000) Resolves elevation from currents with two anti-parallel flights 10min apart.

Siegmund et al., 2004





- Airborne X-band, HH, Squinted, Inc = 45 deg
- First hybrid Interferometric SAR to measure elevation and currents
- Reports biases in velocity due to azimuth mis-registration of squinted system

Synthesis: InSAR systems

- Mainly airborne, some XTI on Space Shuttle (SRTM) and ATI on LEO satellite (TerraSAR-X).
- Radar frequency evolved from low frequency L-band in early ATI systems to high frequency (X and Ku-band)
  - Modelling predicts better performance at high frequencies
- Except for Siegmund et al., 2004, chosen polarisation is VV for improved SNR at far ranges in the swath
- Airborne systems use generally large incidence angles
  - *20-70 deg (Goldstein & Zebker, 1987; Anderson et al., 2003a)*
  - *60 deg (Kumagae et al., 2011)*
  - *70 deg (Toporkov et al., 2005)*

Synthesis: InSAR systems

- TerraSAR-X: limited azimuth sampling rate (PRF) and short effective ATI baseline => increased phase noise and ghost echoes of nearby land by aliasing (Romeiser et al., 2010a)
- SRTM: sensitivity of the phase to height of surrounding land severely hinders current retrieval in rivers (Romeiser et al., 2007).
- Squinted SAR systems to measure both current components in a single pass
  - but there are inherent errors for systems where hybrid baseline is achieved with squinted beams.
    - *Bias in retrieved velocity linked to mis-registration in azimuth of moving surfaces in the fore and aft look of squinted systems*
    - *Gradient-induced distortion of ATI surface velocity maps caused by the displacement in azimuth of moving targets typical of SAR imaging*

Synthesis: Experiments & validation

- Vast array of oceanographic settings
  - mostly in areas with strong tidal regime (max current > 1 m/s)
  - Experiment sites mainly close to land
    - *limits of the aircraft range? availability of validation data e.g. HF radar data within 45km from land?*
- Means of validation of the ATI currents were, on the whole, disappointing.
  - Often comparisons with models, without information on forcing and validity.
  - Three notable exceptions:
    - *Graber et al., 1996 (HF radar, weather buoys, directional wave buoys, current-meters and coincident ship campaigns)*
    - *Goldstein et al., 1989; Kumagae et al., 2011: validation against near-surface drifters*
- Wind & waves info?
  - typically from a weather station in the vicinity
  - Only Perkovic et al., 2004 tries to derive wind from ATI scenes to interpret ATI currents.
  - Information about wave conditions is generally inexistent

Synthesis: Errors & mitigation strategies

- ATTITUDE AND NAVIGATION ERRORS
  - critical need for accurate platform attitude and navigation data during processing to avoid fluctuations and biases in the phase and resulting velocity fields.
    - *Even after correcting these effects, low frequency fluctuations can remain and contribute 0.1-0.2 m/s bias in velocity.*
    - *Most studies mitigate these residual errors by calibrating the interferograms over land, setting retrieved velocity over land to zero.*
  - Toporkov et al., 2011, explore the use of ships as targets of known velocity to calibrate the ATI phase in open ocean where land is not imaged
    - *But smearing of the ships in the SAR images (due to SAR imaging of moving targets) introduce estimated uncertainty in the ship velocity of the order of 0.2 m/s, which makes this approach of limited use in its present form.*

Synthesis: Errors & mitigation strategies

- LONG SWELL WAVES
  - Typically, if swell waves are not visible in the high-resolution ATI images, no swell correction is applied
  - Otherwise, the effect of long swell waves is mitigated by degrading the spatial resolution of the current maps to grid scale greater than the swell wavelength
    - *averaging, smoothing and filtering down to 100 x 100 metres or coarser*
    - *If fine spatial resolution needs to be retained (e.g. Toporkov et al., 2005), there is no reported strategy to mitigate the effect of swell on ATI currents.*
- WIND
  - contribution to surface motion by wind drift is also recognised, and is typically estimated as 3 to 5 % of the wind speed at 10 metres in the direction of the wind
    - *legitimate constituent of the surface current one wants to measure*
    - *this contribution by wind to surface displacement is separate from, and in addition to, the unwanted surface motion related to the phase velocity of the wind-generated Bragg scatterers*

Synthesis: Theoretical modelling and model performance

- Unwanted contributions to ATI signals by ocean surface wind and waves are the most important cause of errors in ATI retrieved currents
  - Surface wave contribution is usually quantified and removed using a theoretical scattering model
  - Several models available
    - *Thompson et al., 1989;1991*
    - *Romeiser & Thompson, 2000*
    - *DopRIM (e.g. Hansen et al., 2012)*
    - *Much to learn from the SAR Doppler centroid & SAR wind literature*

Conclusions

- Extensive review of ATI SAR literature
  - Provided useful pointers to potential issues
    - *Azimuth ambiguity; squint mis-registration; sensitivity to attitude,...*
    - *Problems with validating ocean surface currents*
    - *Unwanted wind & waves effects*
    - *Available models to correct wave effects*
  - What we missed and learned since ?
    - *Lessons learned from SAR Doppler centroid and SAR wind retrieval experience*