SEASTAR: a new satellite mission to observe sub-mesoscale ocean surface currents & atmosphere/ocean coupling

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Context & Content

- New satellite mission concept – SEASTAR
  - Also known as Wavemill or Ocean Surface Current Mission (OSCM)
  - In preparation for submission to ESA Earth Explorer

- Content of this talk:
  - Science drivers & objectives of SEASTAR
  - Observation concept
  - ESA Earth Explorer call for missions
  - Science Readiness Levels: SEASTAR results and status
  - Summary & Outlook

Ubiquitous sub-mesoscale ocean variability

- Ocean is dominated by variability at the mesoscale (10-100km) and sub-mesoscale (1-10km)
- Observational evidence of the critical role for mixing of km-scale stirring by submesoscale eddies
- Seen in high-resolution IR SST and ocean colour images but little data on ocean dynamics at these scales
- Relevant to upper ocean dynamics & atmosphere/ocean coupling
- Generally not explicitly resolved by ocean and climate models

Sentinel-3 OLCI over Gibraltar Strait

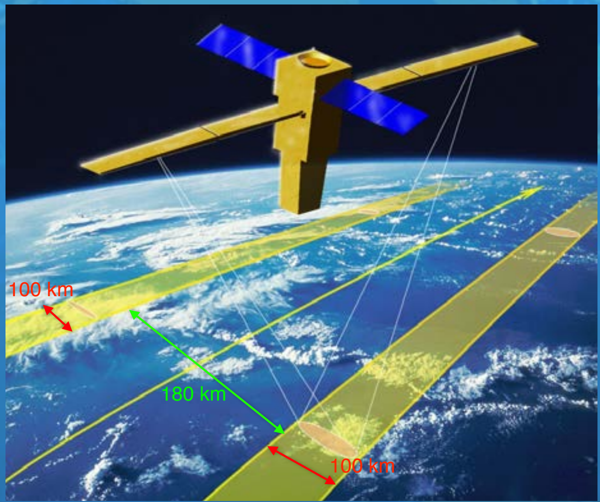
SEASTAR Scientific Objectives

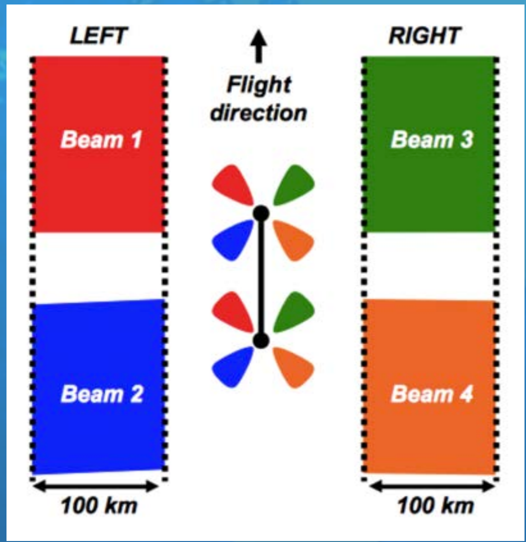
- To deliver new two-dimensional maps of total ocean surface current and wind vectors at 1km resolution to study sub-mesoscale ocean dynamics and air-sea interactions at small scales

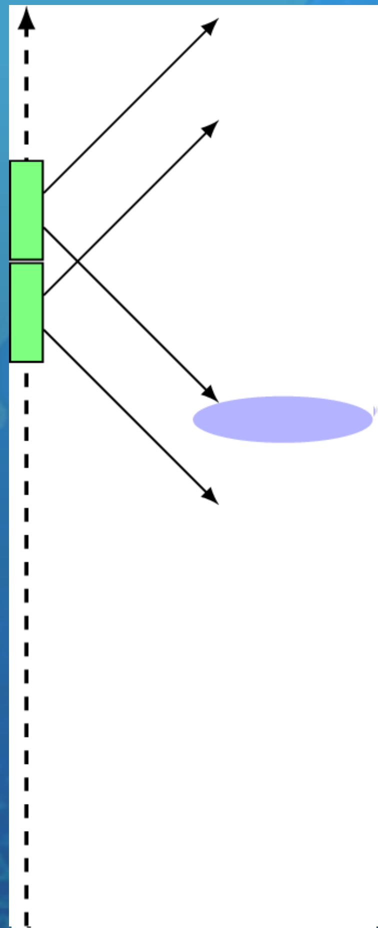
- To determine the spatial and temporal characteristics of the ocean submesoscale in the global coastal zone, the Arctic margins and ocean Sites of Special Scientific Interest.

- To contribute to validating high-resolution ocean and atmospheric models and support the development of better model parameterisations to represent the impact of the submesoscale on circulation models, air-sea interactions and vertical transports on basin to climate scales.

SEASTAR Observation & mission concept

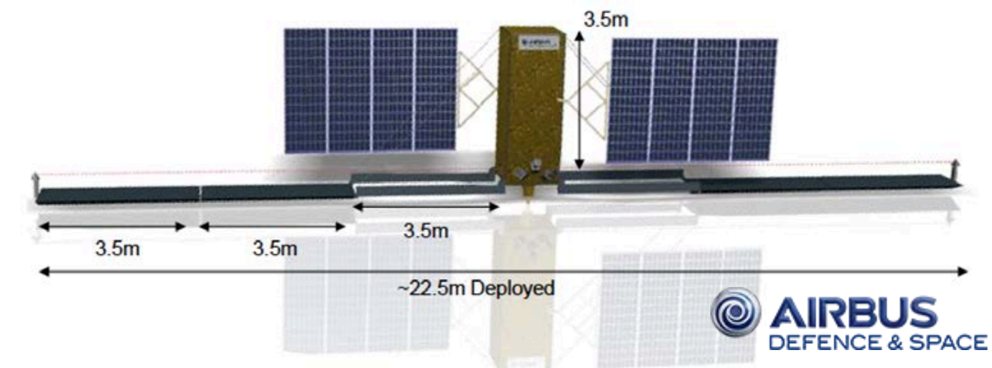






- Squinted Along-Track Interferometric SAR
  - Active microwave; Ku-band (2.2cm)
  - Single-pass along-track interferometry between two successive SAR images provides direct estimates of ocean surface motion
  - Each scene viewed from two azimuth angles to get motion vector

SEASTAR Payload overview

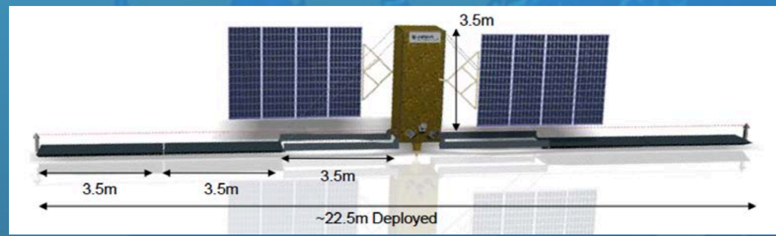


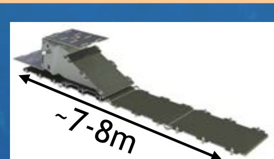
- Along-track Interferometric SAR
  - Monostatic master, bistatic slave
  - Physical baseline 15m, total length ~22.5m
  - VV and HH polarisation
  - Javelin configuration
  - Leaky waveguide antennas
  - 2 x 7m long antennas
  - Elevation beam shaping
- Architecturally simple
  - Centralised power source, realistic design, largely available and identified technologies
- Large mission
  - Earth Explorer Core class
- Challenging requirements on:
  - power (swath width)
  - data storage/downlink (duty cycle)
  - baseline & attitude knowledge (relative error)
  - stability (absolute error)
- All components TRL >= 4 except leaky waveguide
- ROM cost ~250MEuros + launch

ESA Earth Explorer call for missions

- Earth Explorer 9 (Nov 2015)
  - Scientific excellence & innovative technology
  - 120 M€ max for space segment
  - Vega dual-launch as baseline
  - TRL at least 4, reaching at least 5 by end of Phase-B1
  - launch no later than 2024
  - Scientific Readiness Level (SRL) at least 4
- Revised EE9 (Dec 2016)
  - Same as above except…
  - 150 M€ max for space segment
  - Scientific Readiness Level (SRL) between 4 & 6 (peer-review papers)

- CEOI support to downsize SEASTAR & increase SRL
  - Reduce volume, data, cost





  - But reduction of swath & duty cycle made mission unviable scientifically
  - Decision to wait for EE10…

Science Readiness Levels: SEASTAR status

Phase F	9	Science Impact Quantification
Phase E2	8	Validated and Matured Science
Phase E1	7	Demonstrated Science
Phase B, C, D	6	Consolidated Science and Products
Phase A	5	End-to-End Performance Simulations
Phase 0	4	Proof of Concept
(Pre –) Phase 0	3	Scientific and Observation Requirements
Pre – Phase 0	2	Consolidation of Scientific Ideas
Pre – Phase 0	1	Initial Scientific Idea

European Space Agency

SRL 5: "An end-to-end measurement performance simulator is developed, tested and validated using realistic and/or actual measurements";

"Retrieval algorithms are demonstrated.."

SRL 4: "… A model linking geophysical parameters and measurements is established…";

"Sensitivity of the measurements to the targeted geophysical parameter is demonstrated"

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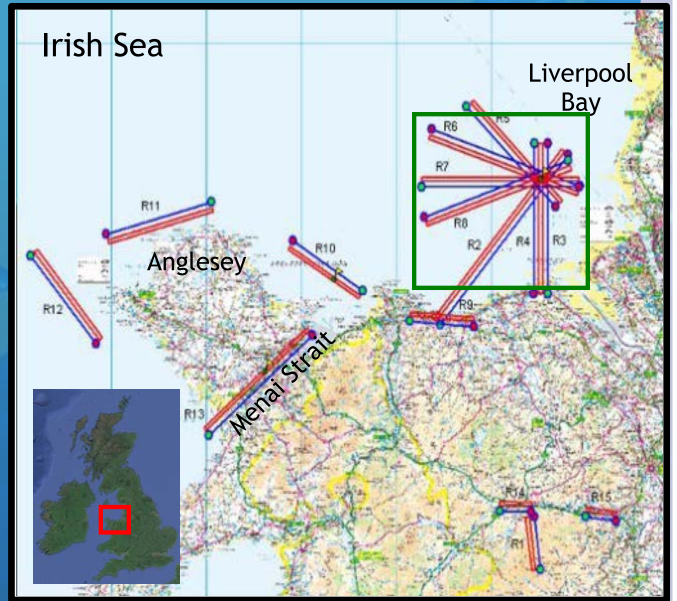
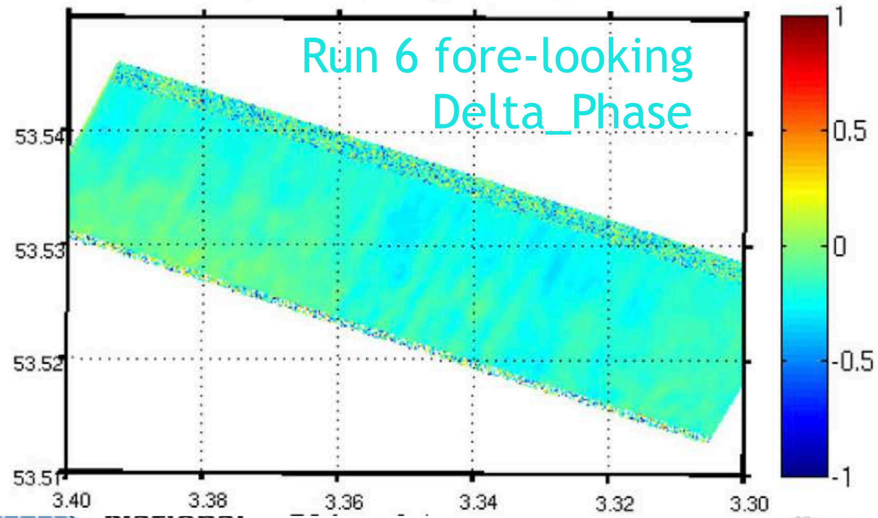
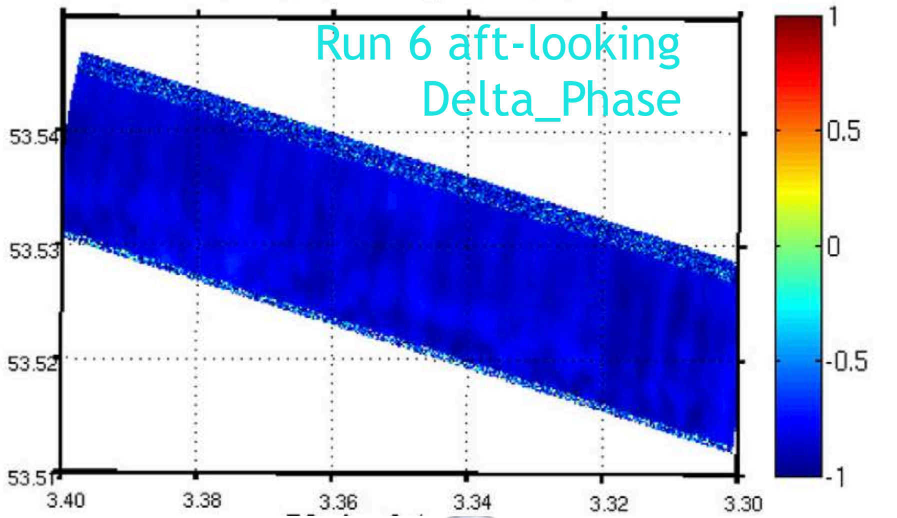
Airborne proof-of-concept

- Processing from single-look complex images to interferograms

Martin et al., JGR, 2016







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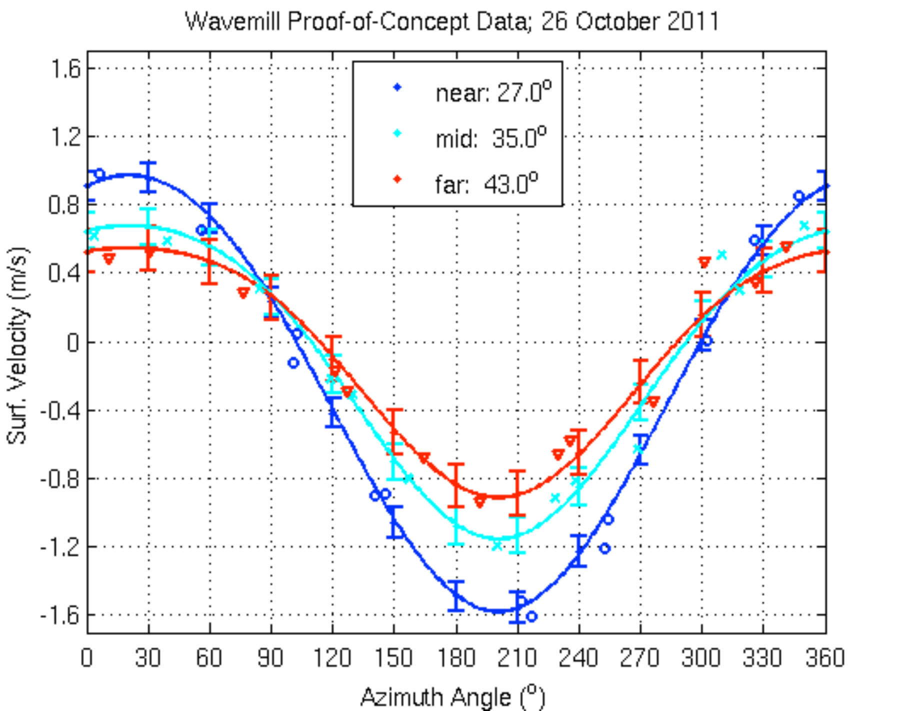
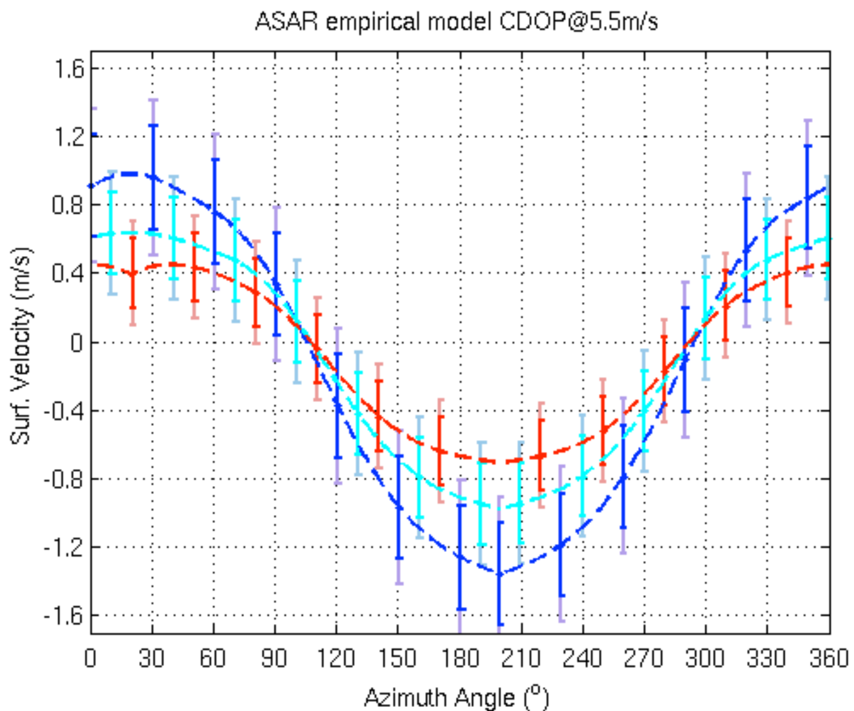
Geophysical retrieval: Sensitivity of SAR to wind waves

- Processing from interferograms to surface current vectors





[Martin et al., 2016, JGR-O] based on Wavemill airborne data

[Mouche et al., 2012] based on Envisat ASAR satellite data

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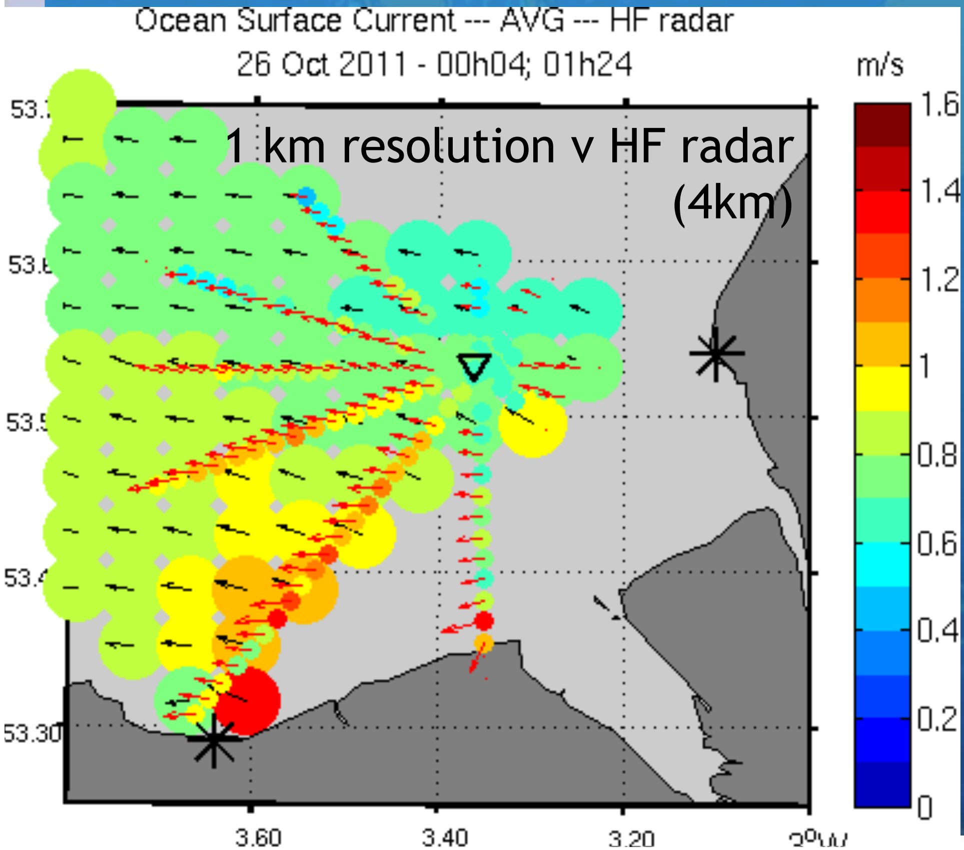
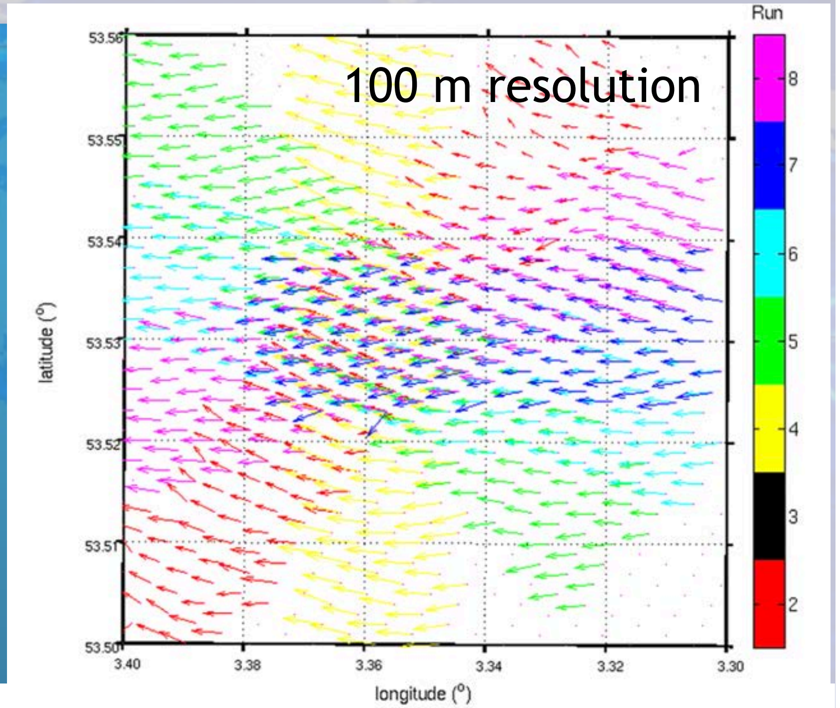
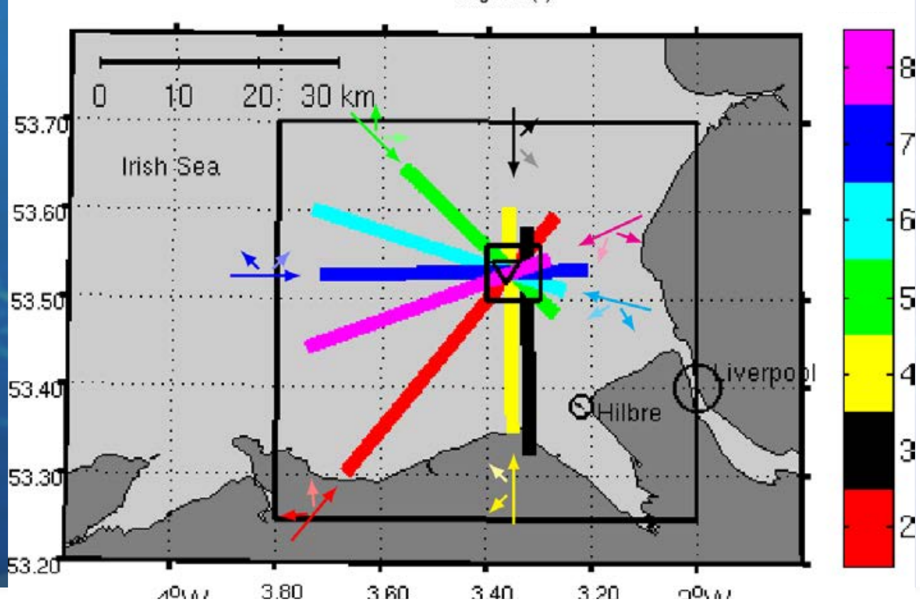
Performance against independent data

Martin & Gommenginger, RSE, 2017







Typical performance for current vectors @ 1.5 km resolution against HF radar:
Bias: less than 0.06 m/s; 10° Precision: better than 0.1 m/s; 7°

Geophysical inversion for joint current & wind retrieval

$$J_{pol}(\vec{u_{10}},\vec{c}) = \sum_{i=1,2}\left(\frac{\sigma^0_{meas,i} - KuMod(\vec{u_{10}}-\vec{c})}{\Delta\sigma^0}\right)^2 + \left(\frac{df_{meas,i} - KuDop(\vec{u_{10}}-\vec{c}) + 2.c_{//}.\sin\theta/\lambda_e)}{\Delta df}\right)^2$$

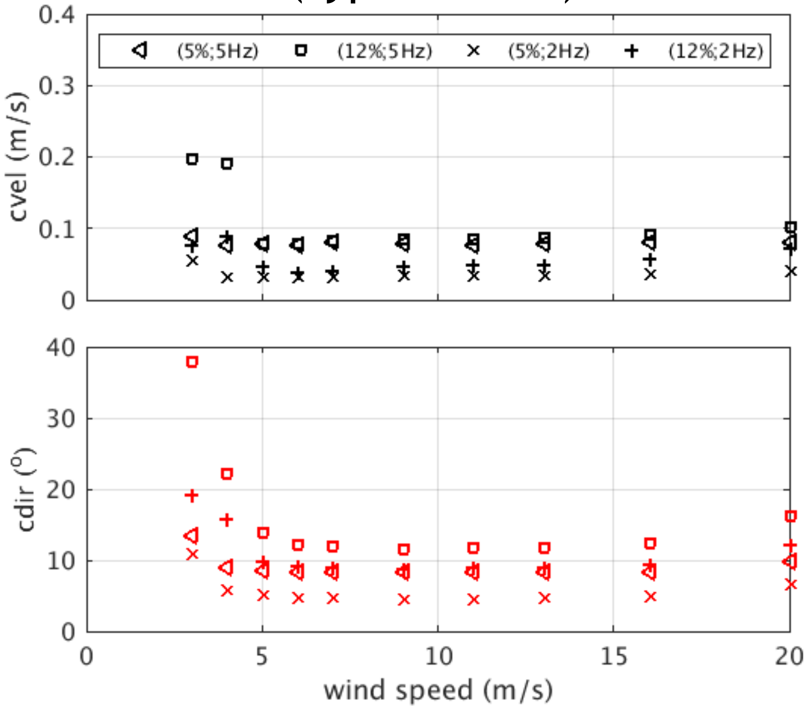
- Bayesian approach, minimization of the cost function
- Geophysical Model Functions (GMF):
  - NRCS KuMod from NSCAT
  - Doppler frequency KuDop from Envisat CDOP scaled for Ku-band

- Assumptions:
  - No impact of wind/wave/current interactions on NRCS and Doppler
  - Effect of breaking wave effects included in GMF

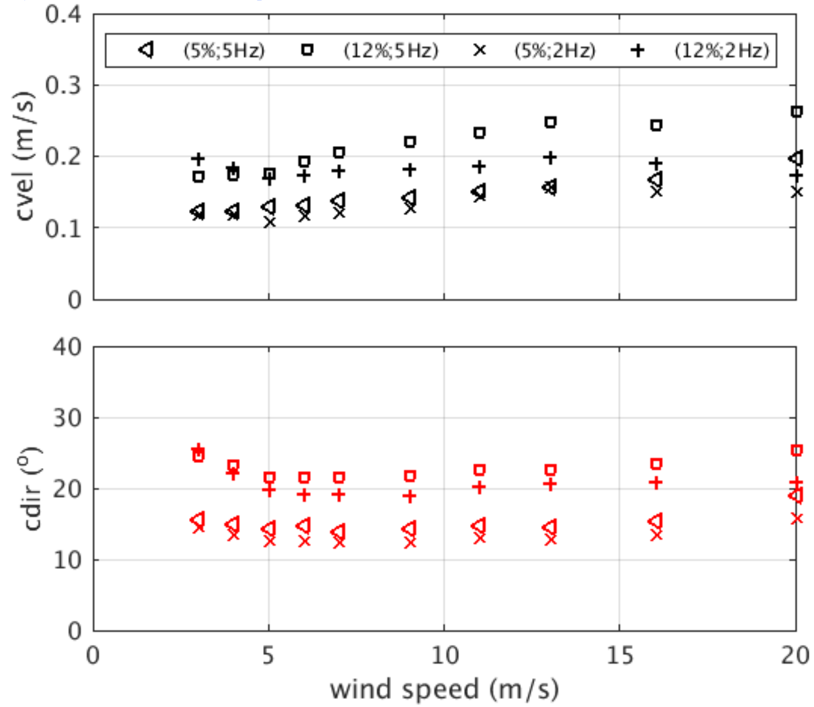
Martin et al., RSE, in prep

Retrieval performance: numerical results

RMS error on current speed & direction
(typical case)



RMS error on current speed & direction
(with wind parallel to look-directions)



- RMSE on current better than 0.1 m/s and 15 degrees
- Retrieval performance not strongly dependent on wind sp
- … BUT very sensitive to wind direction !

Not consistent with science objectives ! Now exploring benefits of three-look configuration

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Summary

- SEASTAR is an innovative mission concept that proposes to deliver maps of ocean surface current and wind vectors, simultaneously for the first time, at a resolution of 1km
  - The mission is highly relevant to present-day research about the role of the ocean sub-mesoscale
  - The concept was demonstrated with airborne data, revealing excellent data quality
  - Also led to major progress in quantifying the impact of wind waves on measurements
  - Current retrieval at a precision of 0.1 m/s, 7°
- SEASTAR is an Earth Explorer Core class
  - Unsuitable for EE9 (and revised EE9)
  - Hopefully suitable for EE10 (late 2017-early 2018?)

Outlook

- SEASTAR urgently needs more airborne campaigns
  - Results all obtained with 1 day of data in coastal and atypical current/wind/wave conditions
  - Need to assess performance in other conditions e.g. swell, wave breaking,…
  - Need to demonstrate the value of multiple polarisation
  - Test flight with ESA OSCAR system in late 2017? (unlikely)
- CEOI-supported activities to refine the geophysical inversion revealed performance issues of existing concept when the wind is aligned with the squinted line-of-sight
  - New three-look configuration under study
  - Concept continues to evolve thanks to ongoing partnership with Airbus D&S Ltd and Ifremer

Thank You

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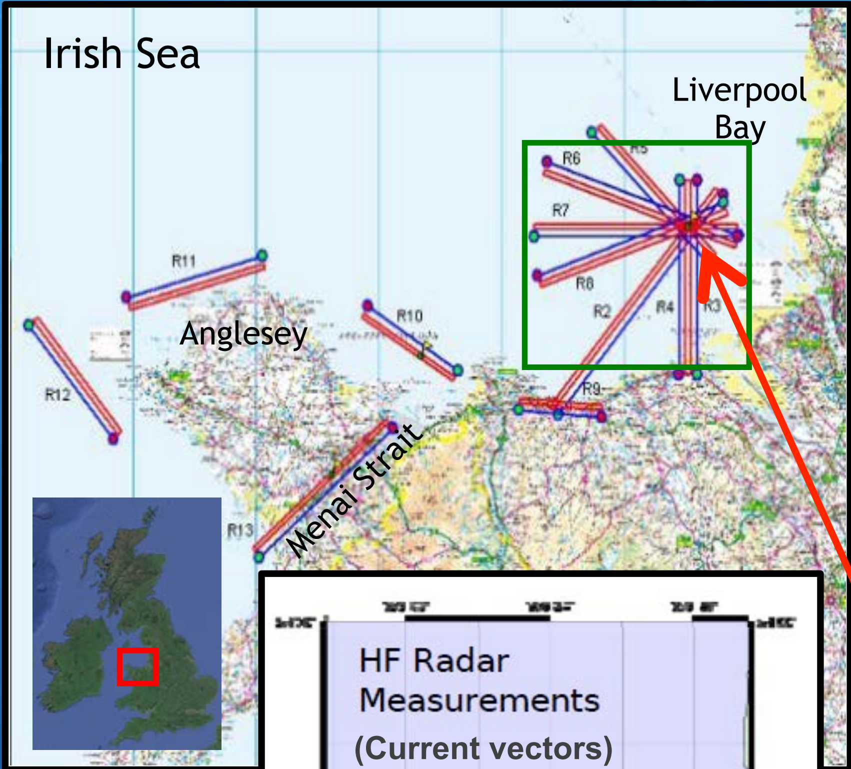
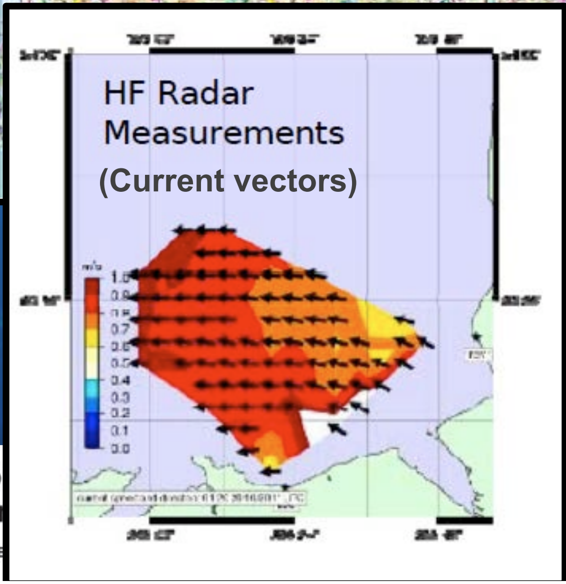
Additional slides

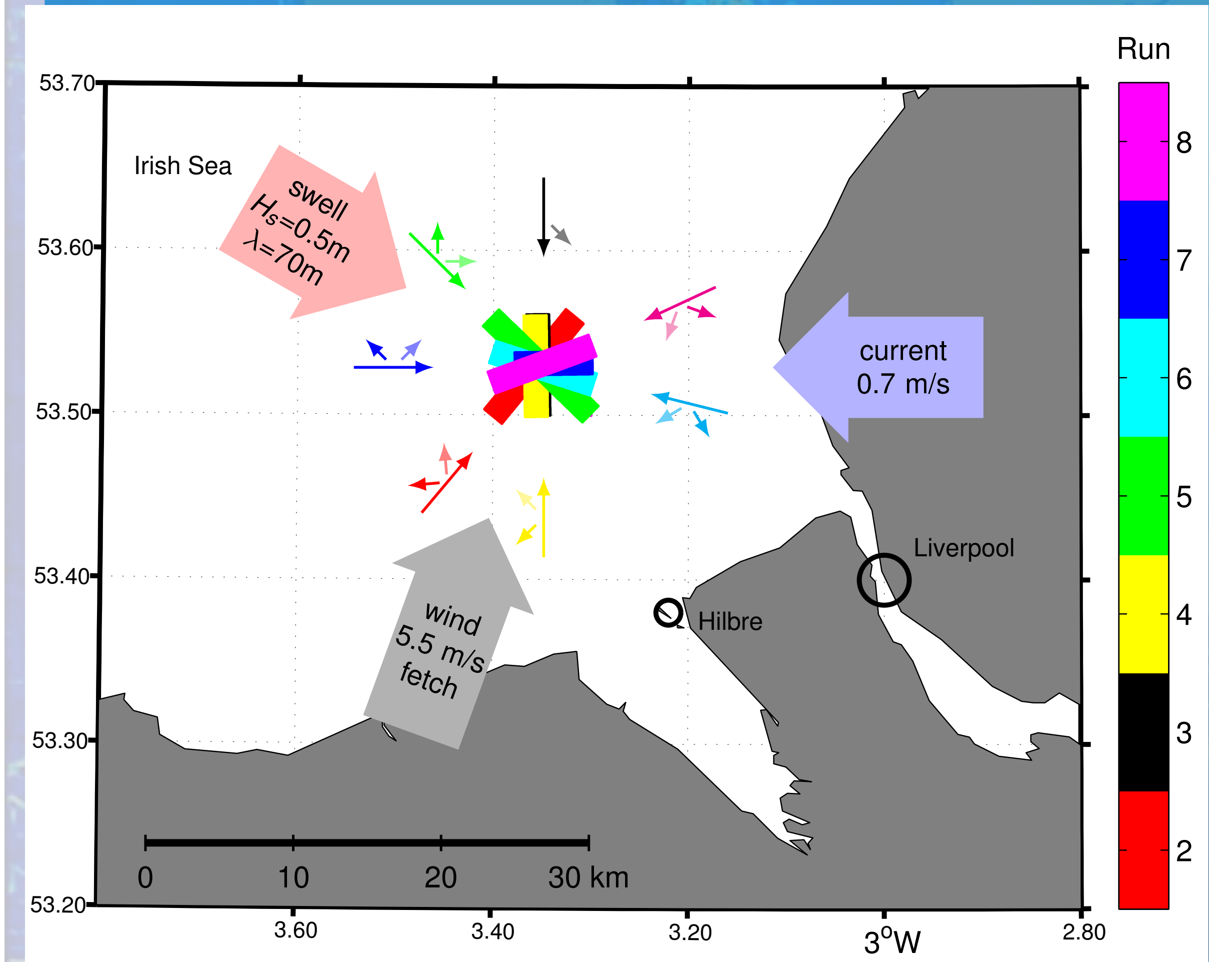
Wavemill airborne demonstration
Validation against ground-truth in Liverpool Bay

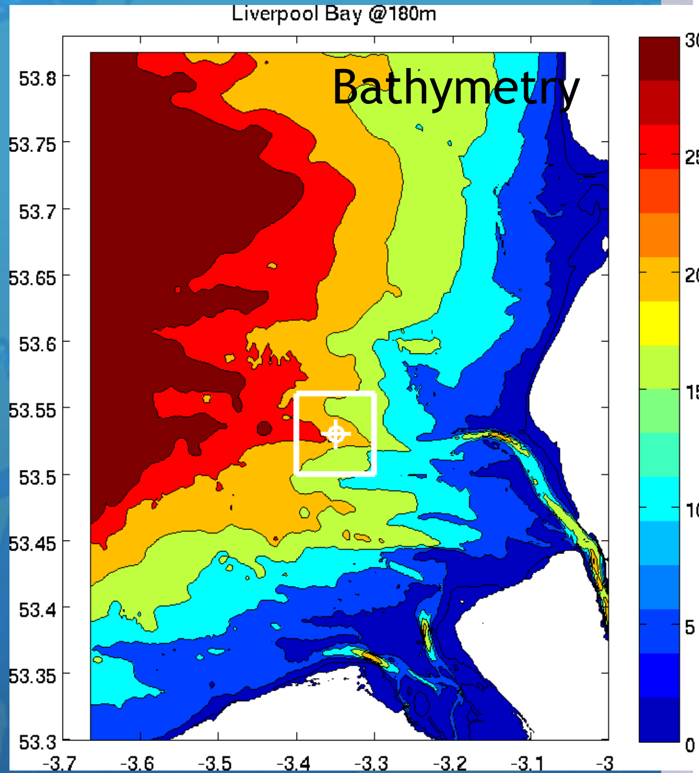




- ADCP (2-4m depth)
- Directional wave spectrum (shortest = 5 m)

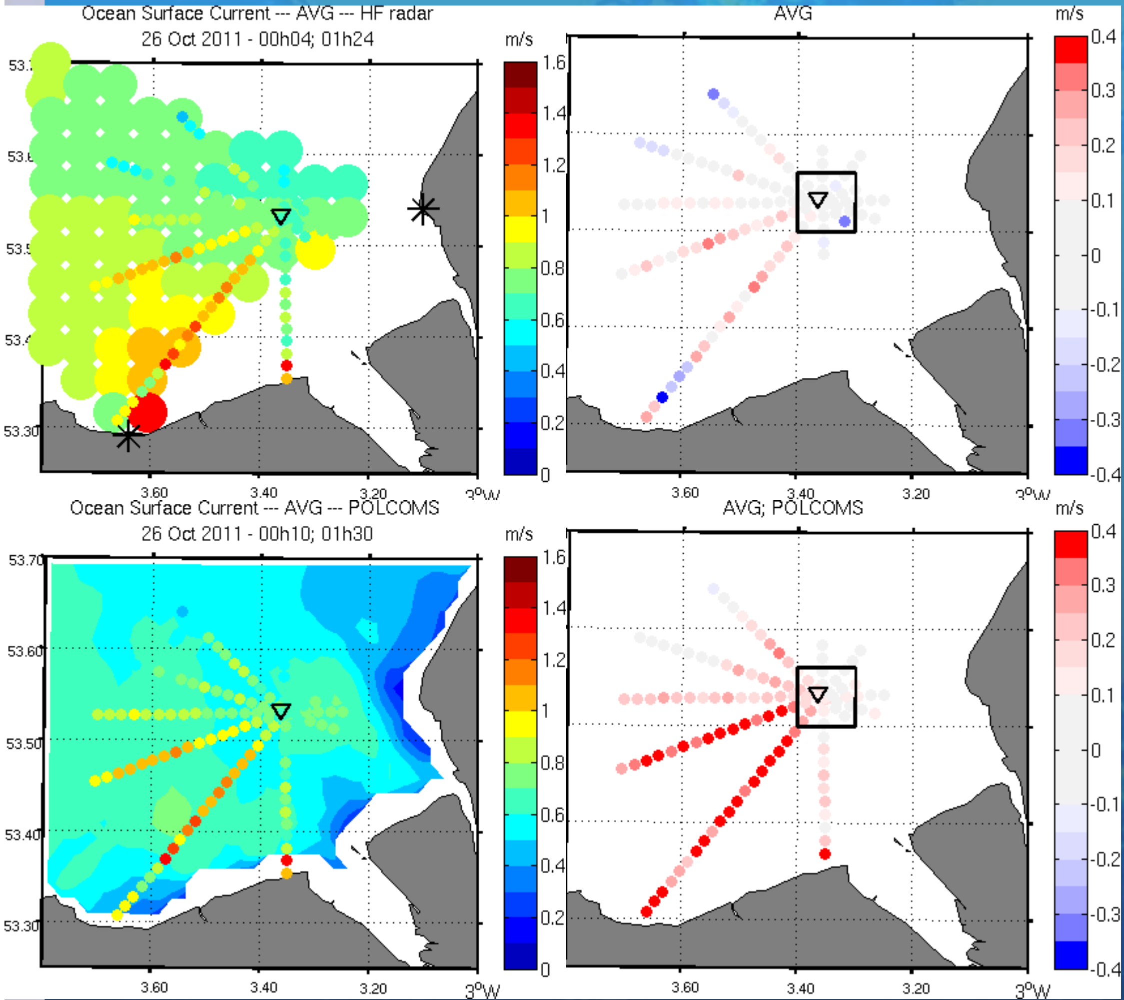
Geophysical conditions during the flight campaign

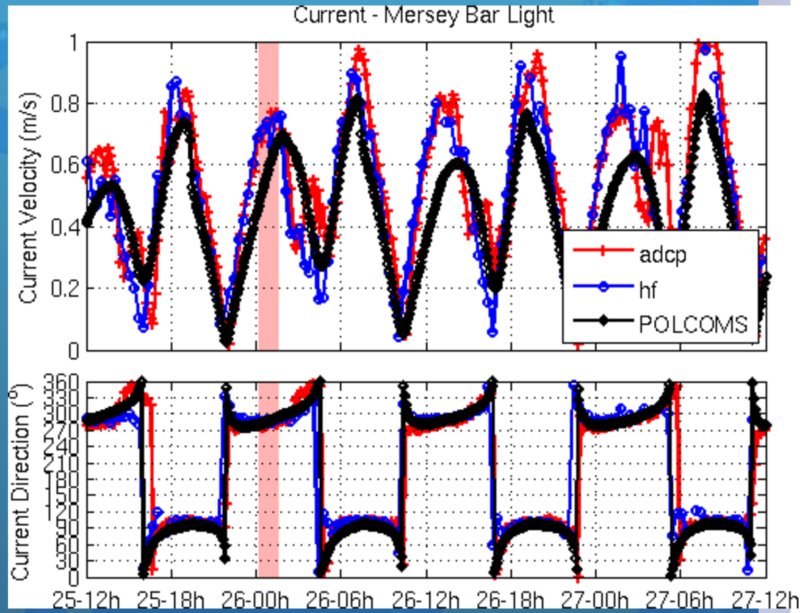




- Westward tidal current
- Light wind from SSW (fetch limited)
- Low energy NW swell
- Shallow water

HF radar & POLCOMS vs. Wavemill





POLCOMS:

- good temporal dynamic (but late ebbflow max)
- weak spatial dynamic at max ebbflow

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