



# Wavemill: a new mission for highresolution mapping of Total Ocean Current Vectors

Christine Gommenginger<sup>1</sup>, Adrien Martin<sup>1</sup>, Meric Srokosz<sup>1</sup>  
Jose Marquez<sup>3,4</sup>, Sam Doody<sup>4</sup>, Victor Navarro<sup>3</sup>

<sup>1</sup>National Oceanography Centre (UK) <sup>2</sup>Ifremer (France) <sup>3</sup>Starlab (Spain/UK)

<sup>4</sup>Airbus Defence & Space (UK) <sup>5</sup>SatOC (UK)



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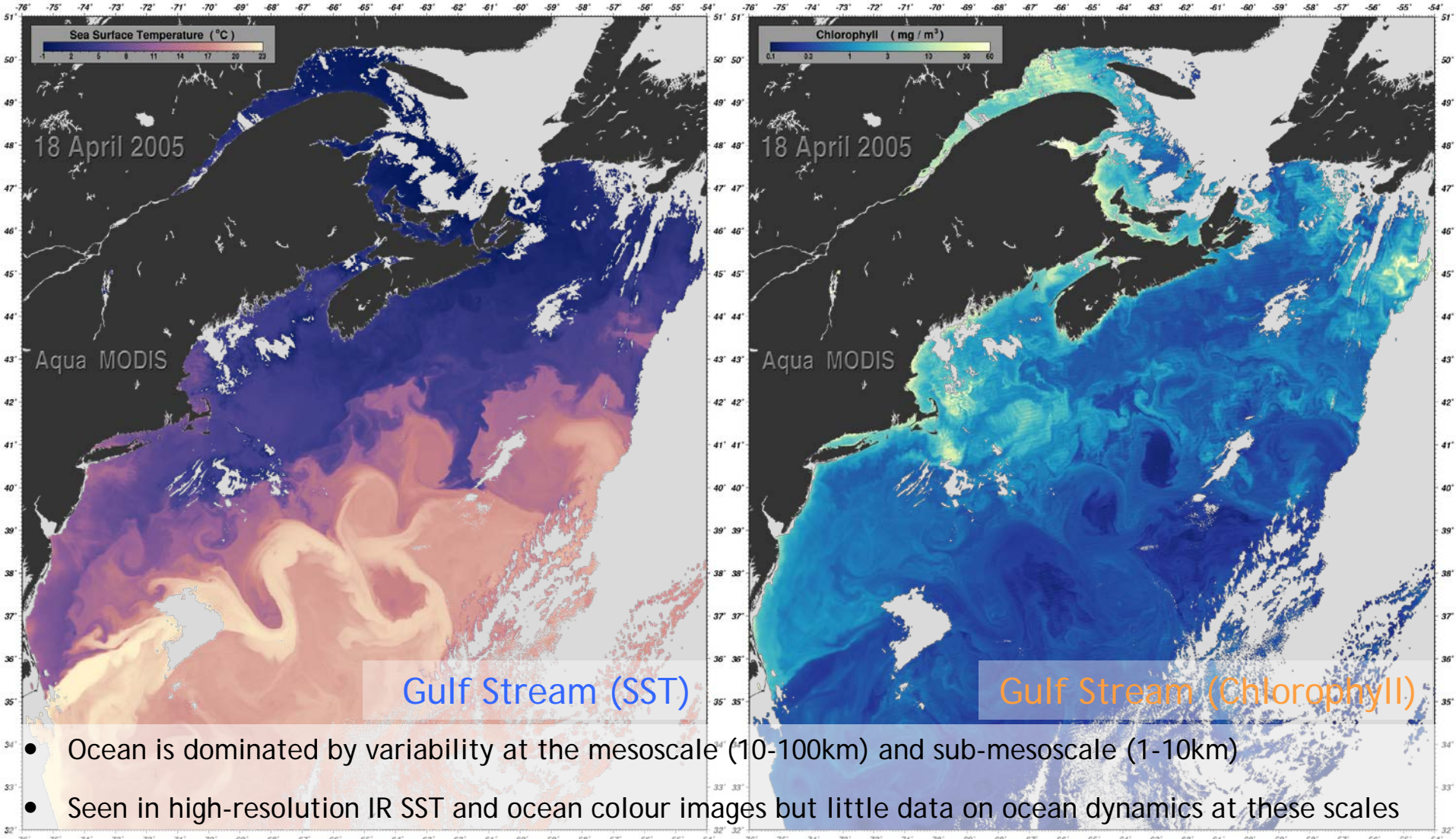
# Context & content

- Wavemill (also known as Ocean Surface Current mission) is a new satellite mission concept under study
  - High-resolution ocean surface currents, surface winds & waves
  - Possible candidate for ESA Earth Explorer 9 call for missions expected in 2015
- Content of this talk:
  - Science drivers for a Wavemill mission
  - Instrument concept
  - Airborne demonstration, geophysical inversion and validation
  - Science, instrument and mission trade-offs
  - Interferometric phase error and calibration strategy
  - Summary & Outlook



# Ubiquitous small scale ocean variability

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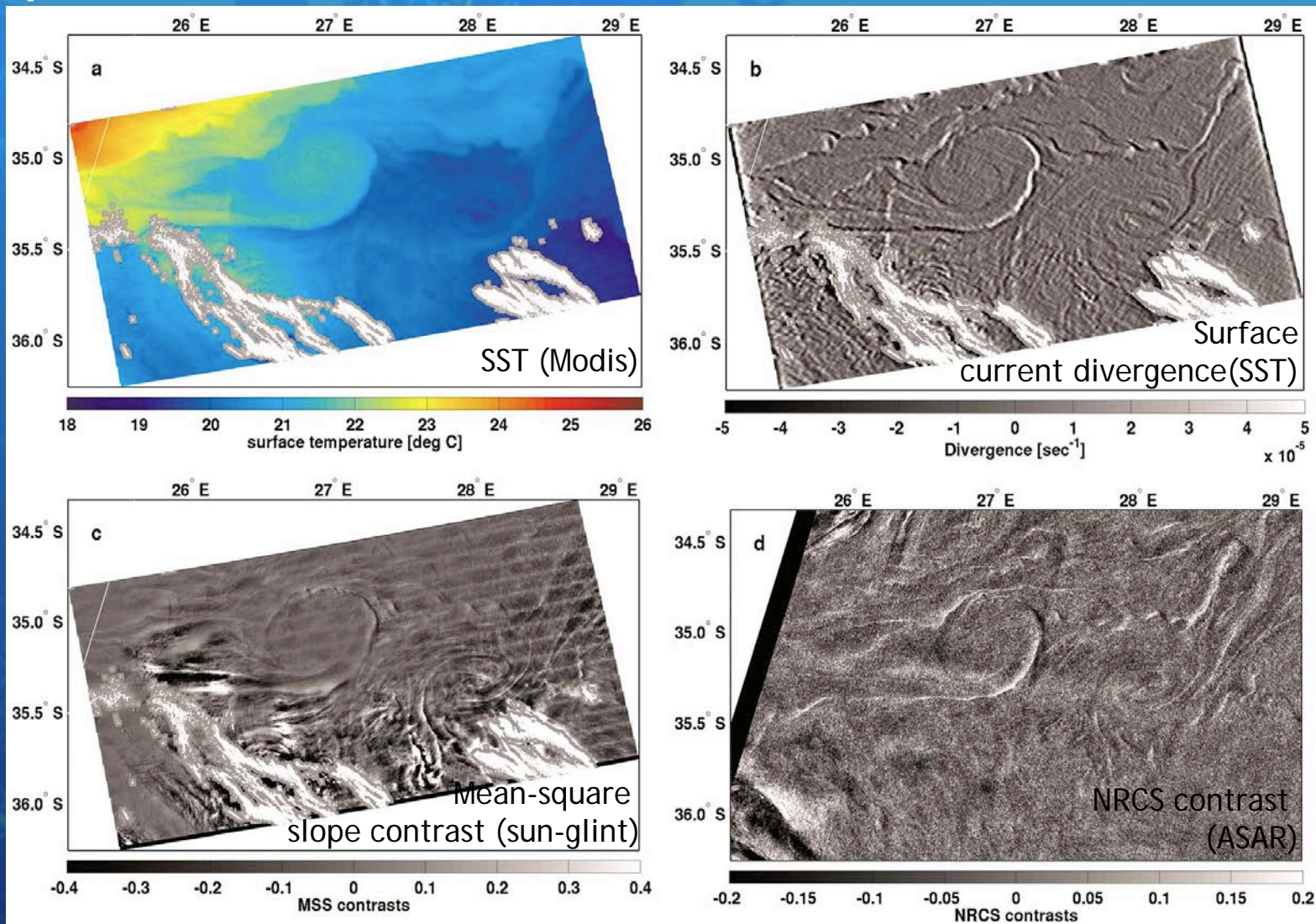
Gulf Stream (SST)

Gulf Stream (Chlorophyll)

- Ocean is dominated by variability at the mesoscale (10-100km) and sub-mesoscale (1-10km)
- 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

Source: <http://oceancolor.gsfc.nasa.gov>

# Imprint of small scales on the surface



Source: Kudryavtsev et al., 2012



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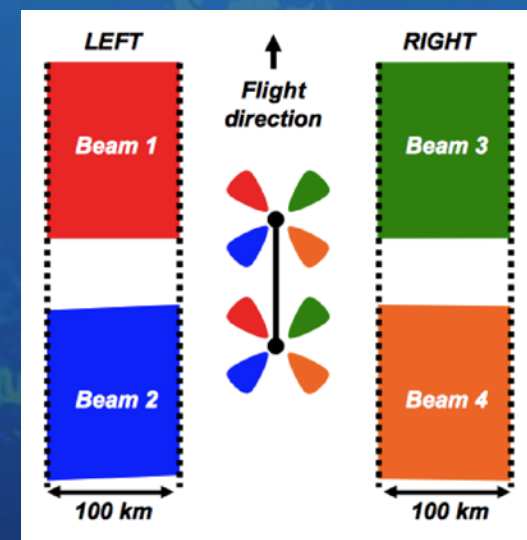
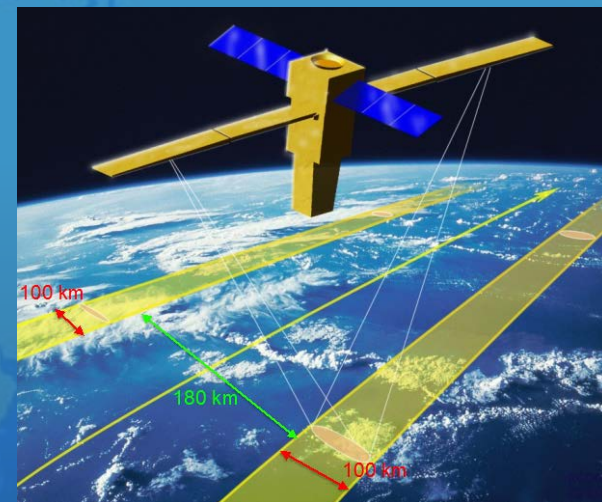
# Impact on ocean circulation, vertical transports and biology

- 50% of the vertical transport of ocean biogeochemical properties takes place at scales  $< 100\text{km}$  (Lapeyre and Klein, 2006)
- Fronts and filaments in vicinity of eddies induce large ageostrophic circulation and vertical velocities
  - $w \sim 10\text{m/day}$  compared to  $0.5\text{ m/day}$  for Ekman pumping
- Eddy-induced upwelling is amplified by eddy/wind interactions
- Resolving the sub-mesoscale in ocean models reduces SST biases and has significant impact on climatic scales (100yrs) on large scale ocean circulation, meridional heat transport, mixed layer depth, etc..



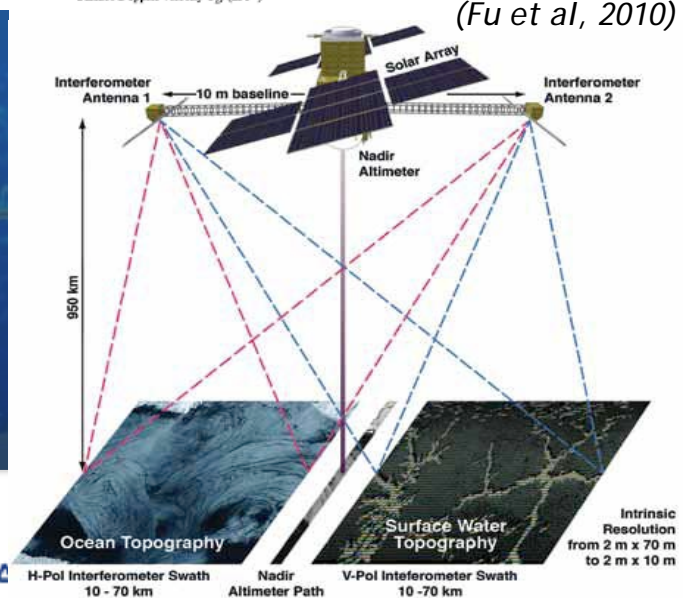
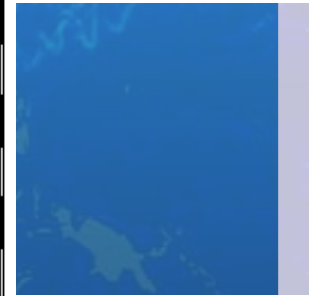
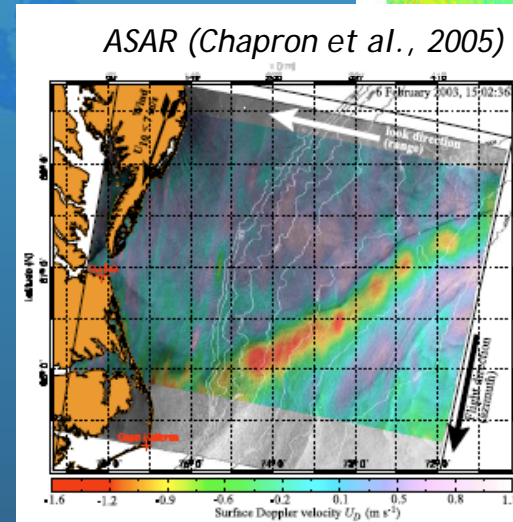
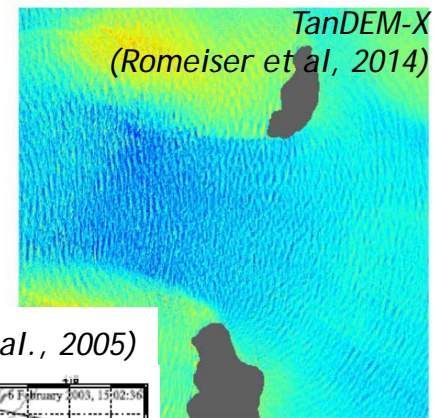
# The Wavemill concept

- Interferometric Synthetic Aperture Radar
  - Active microwave; Ku-band (2.2cm)
  - Single-pass along-track interferometry between two SAR images provides direct estimates of ocean surface motion
  - Each scene viewed from two azimuth angles to get motion direction
- What's new with Wavemill ?
  - Measures total ocean surface current vectors
    - Includes ageostrophic currents (unlike altimetry)
    - Measure current direction in a single-pass
  - 1km spatial resolution; 0.05 m/s accuracy
  - Wide swath
    - 2 x 100 km or 1 x 200km swath (TBD)
  - High-resolution wind vectors (1 km) and directional wave spectra (swell)
    - Coincident wind/wave/current data for the first time
  - Measurements right up to the coast
- Instrument & mission configurations currently under study (two competing ESA OSCM studies ongoing)
- Exploring SAR Interferometer calibration solutions (CEOI)
- ESA Earth Explorer 9 mission proposal in prep. led by NOC and Ifremer

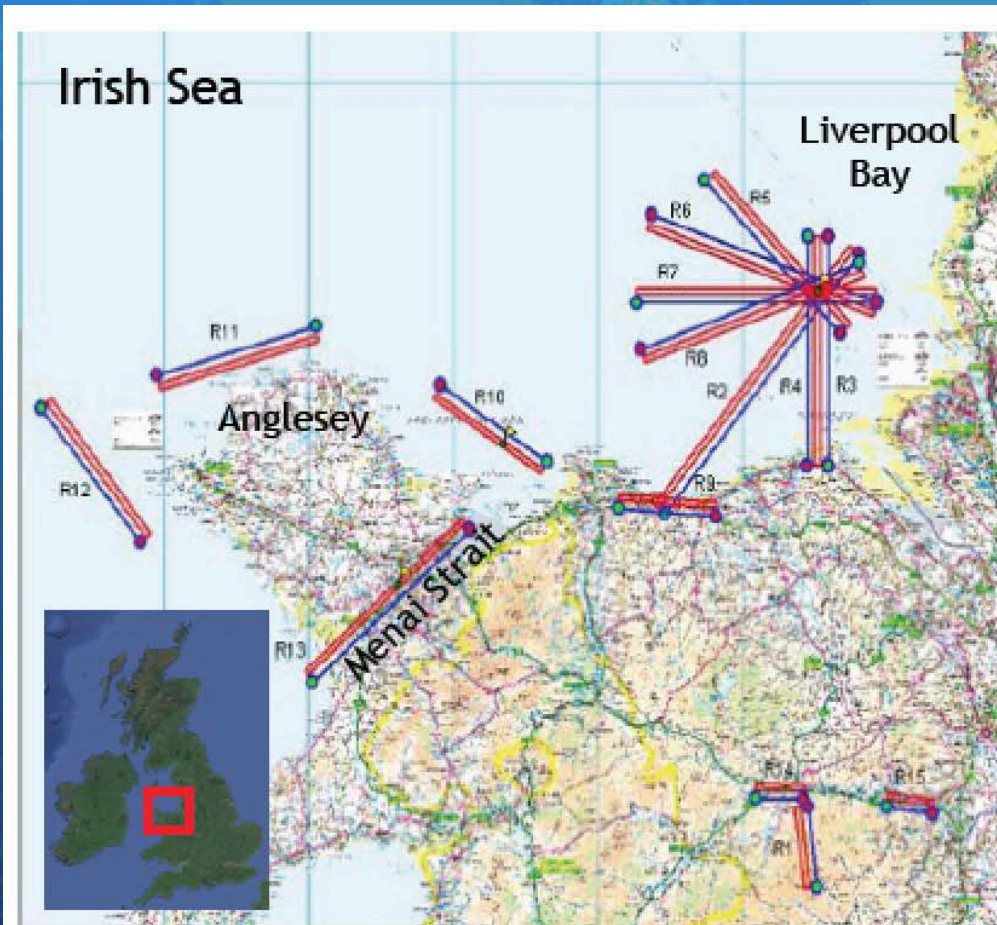


# Heritage and complementarity with other missions

- TerraSAR-X and TanDEM-X
  - Opportunistic demonstration of current retrieval with spaceborne ATI since 2010
- Envisat ASAR and Sentinel-1
  - SAR Doppler Centroid anomaly (Chapron et al., 2005)
- Sentinel-3
  - Synergy with SST and ocean colour and high-resolution SAR altimetry (SSH, wave height, wind)
- Surface Water & Ocean Topography mission (SWOT)
  - Wide-swath ocean altimetry & geostrophic currents
    - To resolve ocean mesoscale variability at 10-25 km
    - SSH at 1km resolution over 2 x 100km swaths
  - Launch expected 2020
  - Strong scientific complementarity between high-resolution SSH from SWOT and high-resolution total currents from Wavemill



# Wavemill airborne demonstration (Oct 2011)



- October 26th, 2011
- Javelin Configuration



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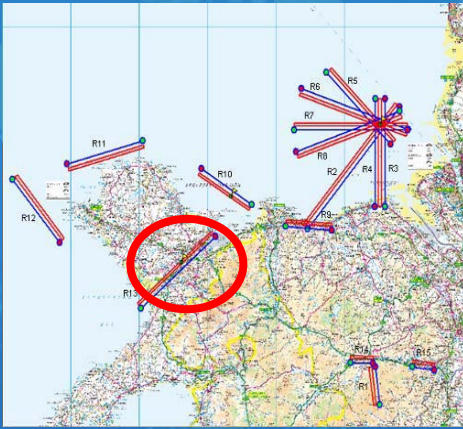


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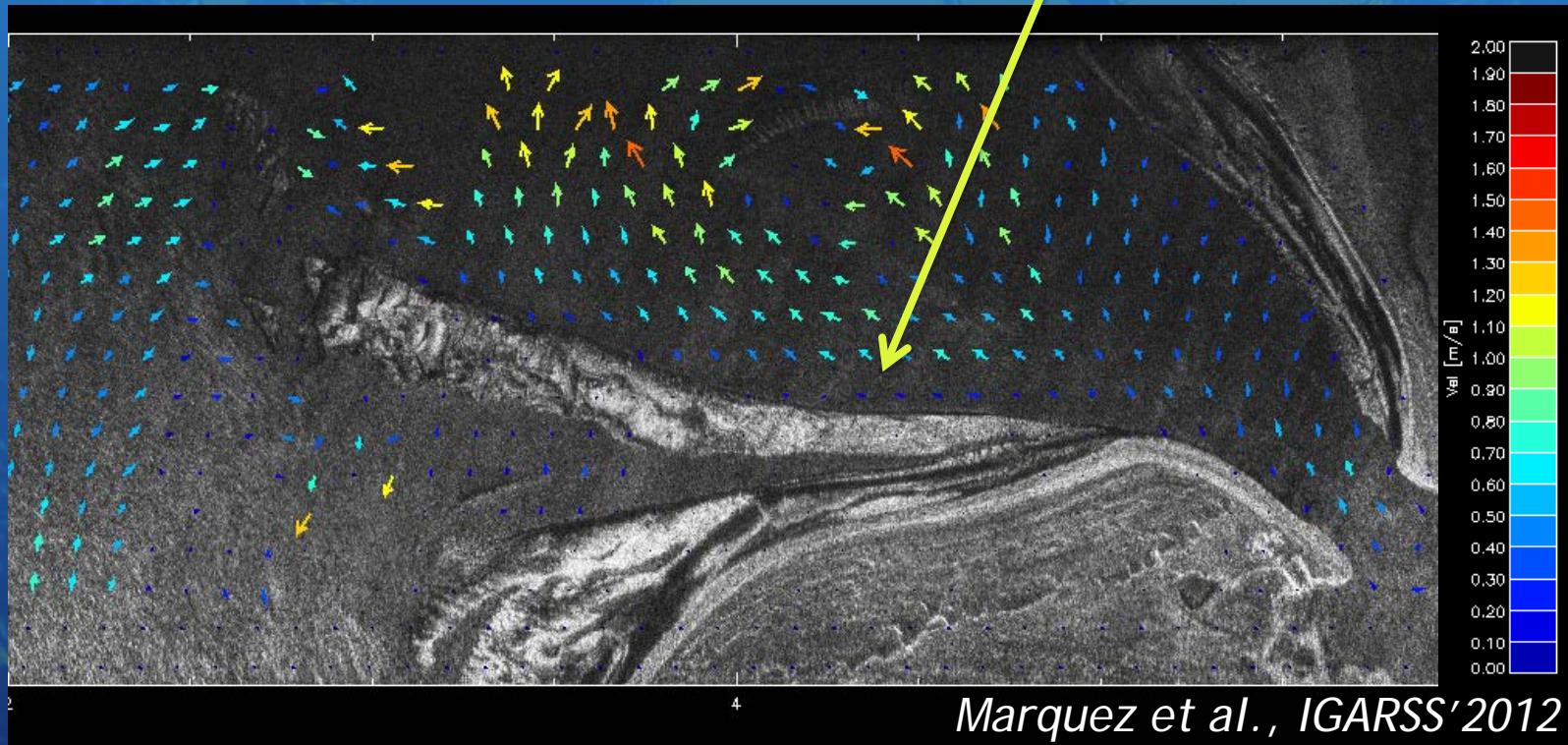
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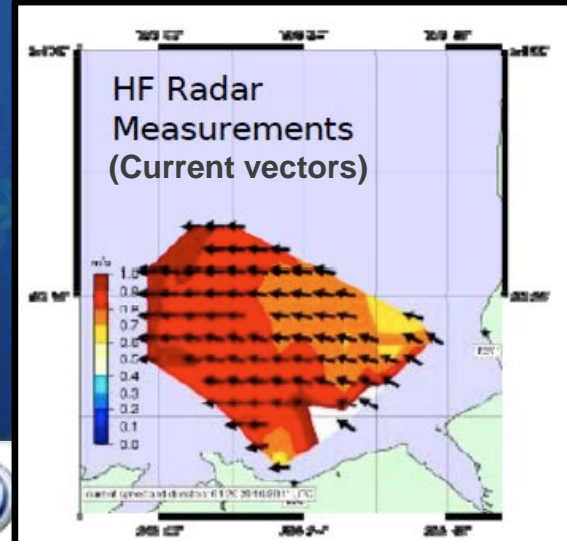
# Flight over Menai Strait <sup>9</sup>



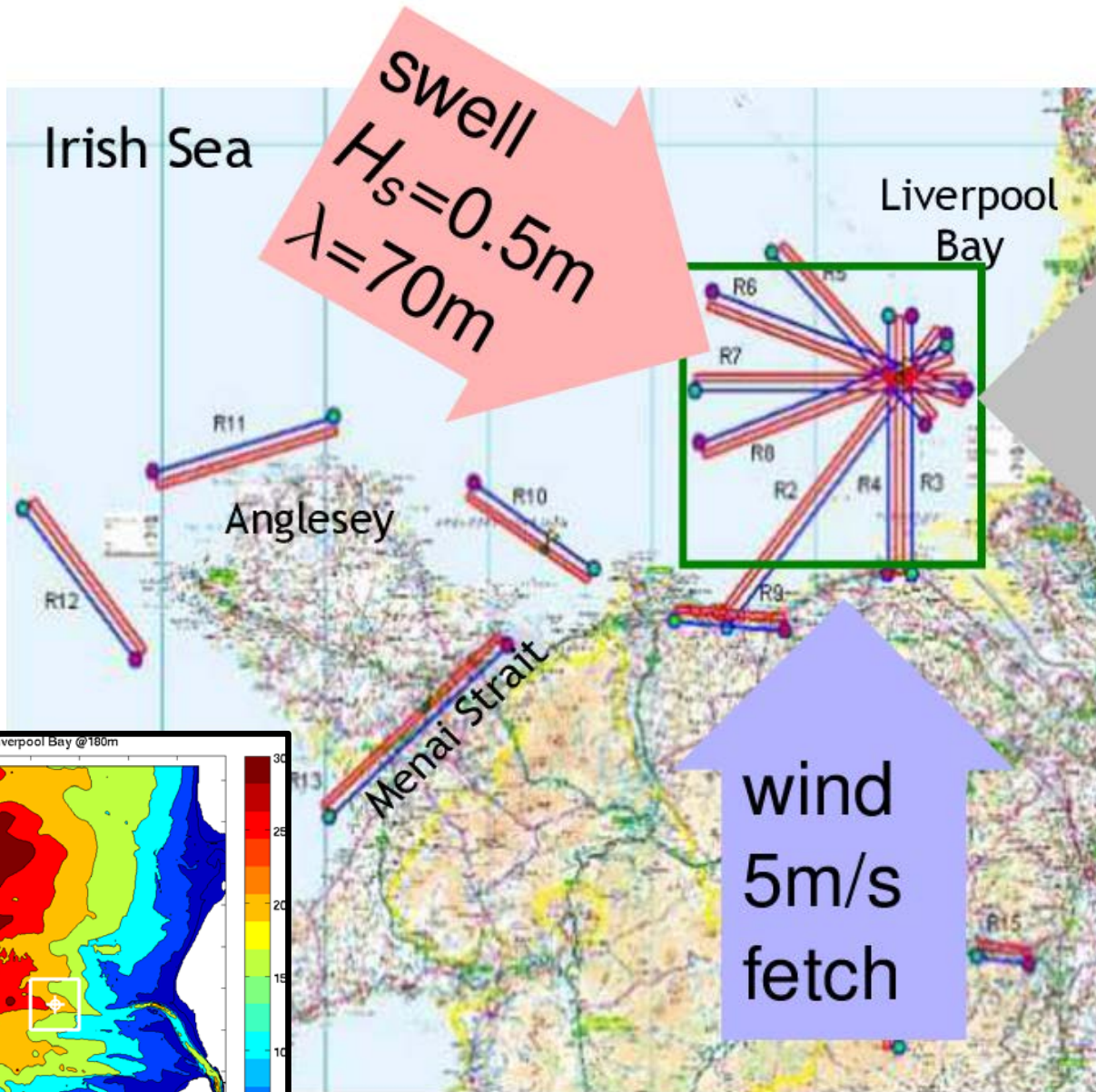
Current vector measurements  
right up to the coast



# Validation against ground-truth in Liverpool Bay

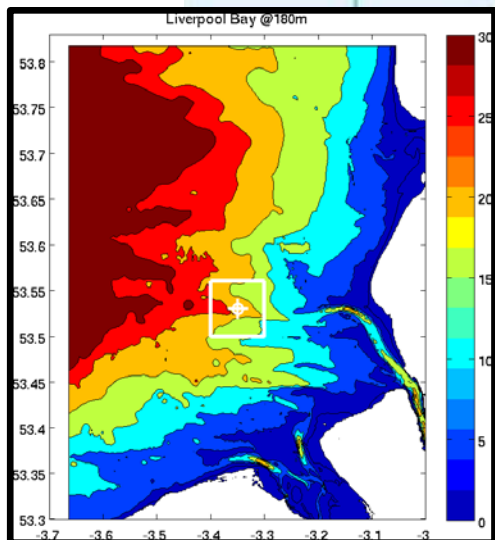


+ hourly winds from UK Met Office atmospheric model (1.5 km resolution)



current  
 $0.7\text{m/s}$

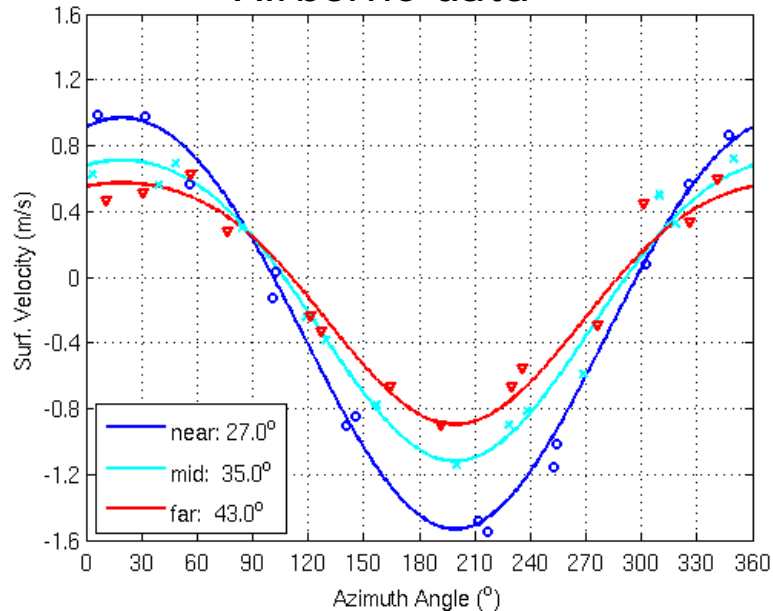
- Westward tidal current
- Light wind from the south
  - short fetch
- Low energy swell from NW
- Shallow waters



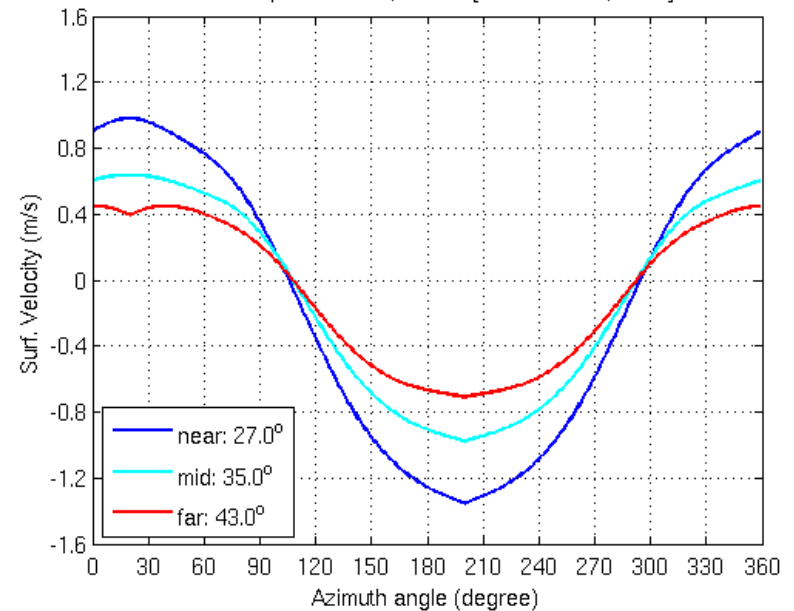
# Geophysical retrieval: currents, wind and waves

## Wave artefact velocity

Airborne data



ASAR empirical model; CDOP [Mouche et al., 2012]



# Science, instrument and mission tradeoffs

- Complex relations between spatial resolution, antenna length, power, swath width, noise level, coverage, re-visit time, data volumes, ...
  - Large, power-hungry, data-intensive instrument
  - Special care needed for calibration of interferometric phase
    - Error in interferometric phase = error in retrieved current
- Geophysical inversion: work in progress
  - What is the optimal choice of incidence angles ?
  - Is there a scientific justification for multiple polarisation ?



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# Interferometric phase error



- Interferometric phase error = retrieved current error
- Dominated by platform attitude (pitch) errors
  - Sentinel-1 attitude knowledge (StarTracker):  $70\mu\text{rad} \Rightarrow 50 \text{ cm/s}$
  - Astrix<sup>®</sup> 200 Inertial Measurement Unit:  $4\mu\text{rad} \Rightarrow 3 \text{ cm/s}$
- Need for very accurate baseline knowledge
  - Present technology permit:  $0.01\text{mm} \Rightarrow 0.5 \text{ cm/s}$



# Calibration strategy (Starlab)



- Combination of ATI and Doppler Centroid radial velocity estimates
  - => derive platform attitude value
- Combination of Fore and Aft looking antennas
  - => derive along track baseline deformation
- Combination of Left and Right antennas
  - => derive combination of attitude and baseline deformation
- Need land calibration to correct the IMU drift





# Summary and Outlook

- Wavemill could deliver new high-resolution observations of current and wind vectors at 1km resolution, supported by swell data
  - Relevant to research on air-sea interactions, ocean/atmosphere coupling, upper ocean dynamics, vertical transports, large scale ocean circulation, with implications for long-term climate forecasting
- Trade-off analyses are underway to assess how science needs can be addressed given various instrument options and mission constraints
- Calibration techniques are underway and feed the mission concept (single versus dual swath)



# Summary and Outlook

- Concept was successfully demonstrated with airborne campaign
  - Excellent data quality and good progress in quantifying contributions to measured motion by wind and waves
- Need more airborne flights to test
  - Various geophysics conditions
  - Instrument features not yet tested (polarisation, ATI vs. DCA)
- Need access to an aircraft!



# Summary and Outlook

- Proposal in prep. for ESA Earth Explorer 9 mission call
  - But extended delay and ongoing uncertainties about exact timing of the ESA call and the available budget

## Thank You

For more information, contact: Christine Gommenginger

[cg1@noc.ac.uk](mailto:cg1@noc.ac.uk)

National Oceanography Centre

Southampton, UK



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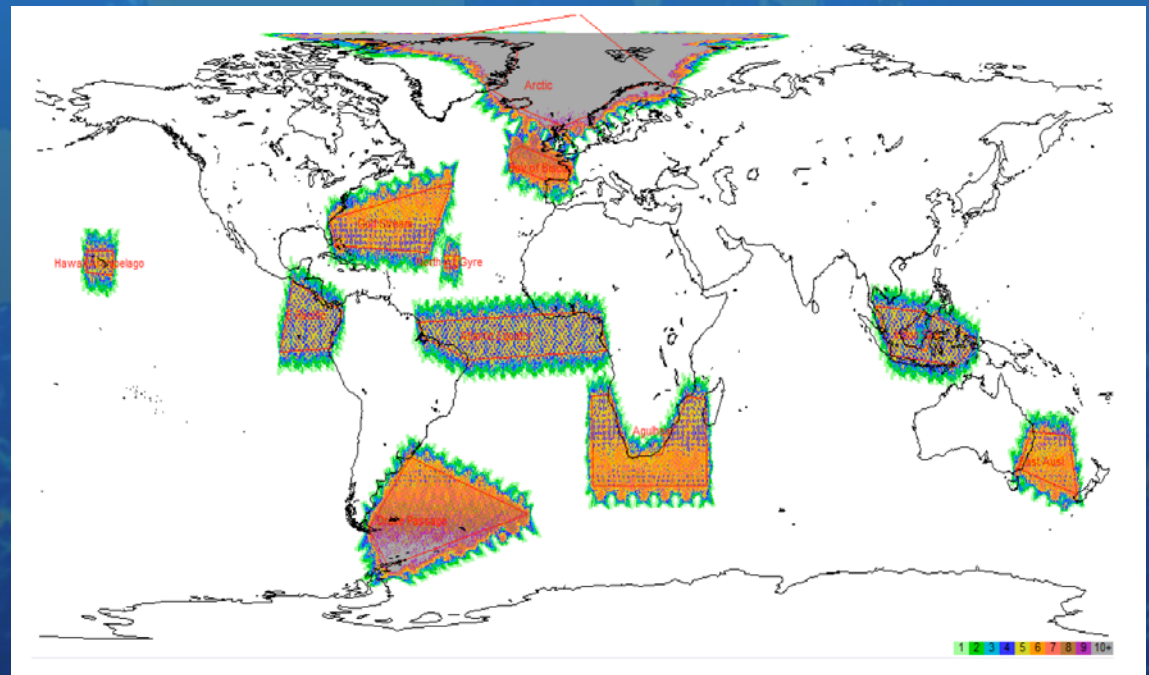


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# Example areas of scientific interest to identify sampling needs and orbit options

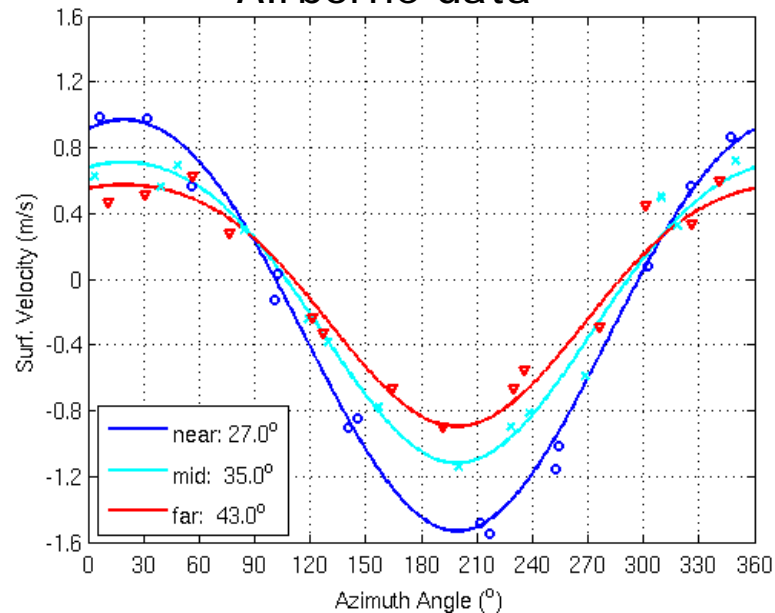
- Example regions (not fixed!) for sub-mesoscale monitoring could include:
  - Highly-variable areas (W. boundary currents), quiet areas (subtropical gyres), well-monitored areas (Agulhas, NW Europe, long-term mooring sites)
  - Other ?
- Sampling needs:
  - fast-revisit (< 3 days) to view/follow small ocean features
  - Global coverage within 1 month
- Orbit choices
  - See talk by Ben Dobke



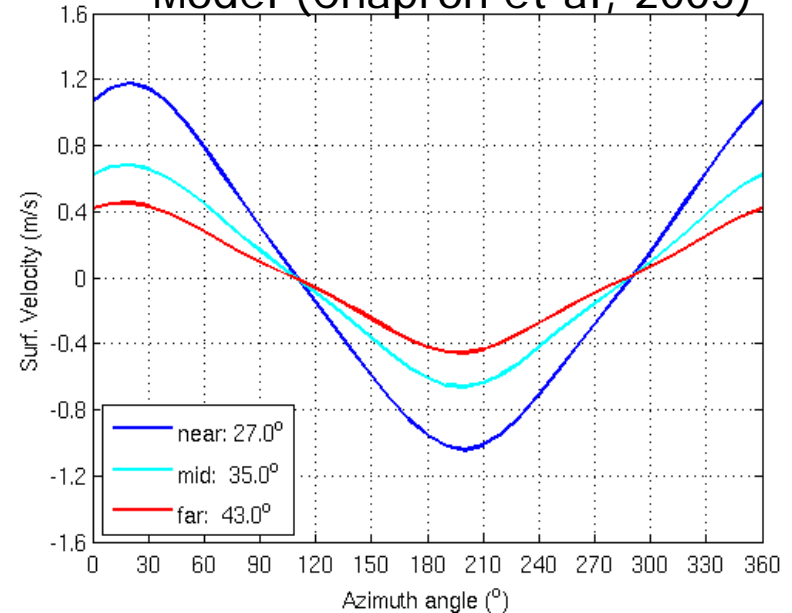
# Geophysical retrieval: currents, wind and waves

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Model (Chapron et al, 2005)



# Interferometric phase error

- Baseline errors
  - $0.01\text{mm} \Rightarrow 0.5 \text{ cm/s}$
- Attitude errors (pitch)
  - StarTracker (S1)  $70\mu\text{rad} \Rightarrow < 50 \text{ cm/s}$
  - Astrix<sup>®</sup> 200 Inertial Measurement Unit (IMU):  $4\mu\text{rad} \Rightarrow < 3 \text{ cm/s}$
- Mis-registration errors
  - $< 1 \text{ cm/s}$
- Instrument noise
  - $< 2 \text{ cm/s}$

