



Wavemill: a new mission concept for high-resolution mapping of Total Ocean Current Vectors

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Content of this talk

- Scientific motivation for measuring high resolution ocean surface currents and winds
- Measuring high-resolution currents from space
- The Wavemill instrument concept
 - Measurement principle
 - Airborne demonstration results
 - Ongoing retrieval and validation activities
- Developing Wavemill as a space mission
- Conclusions & way forward



Scientific motivation



- Ocean is dominated by ubiquitous oceanic features at the mesoscale and sub-mesoscale
 - Mesoscale (10-100km)
 - Sub-mesoscale (1-10km)
- Seen in high-res IR SST and ocean colour
 - but little/no data from space on ocean dynamics at these scales
- Relevant to upper ocean dynamics and atmosphere/ocean coupling
 - Horizontal and vertical mixing & transport, large scale ocean transport, ocean biology
 - Atmosphere/wave/ocean interactions

Sub-mesoscale, vertical transports and ocean biology

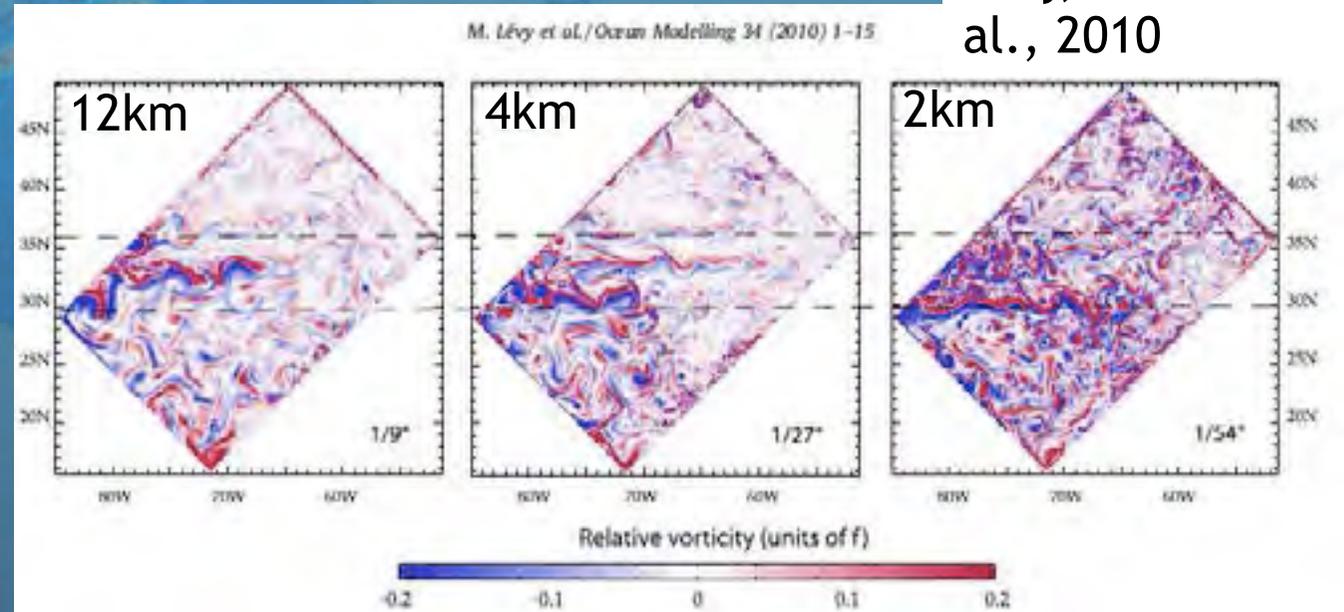
- Response of the ocean biosphere to climate change is one of the greatest uncertainties in climate predictions
- Growing evidence about the role of small scale oceanic features in vertical transports
 - 50% of the vertical transport of ocean biogeochemical properties takes place at scales $< 100\text{km}$ (Lapeyre and Klein, 2006)
 - Ageostrophic circulation resulting from perturbation of circular eddy flow lead to upwelling velocity $\sim 10\text{ m/day}$ (Martin & Richards, 2001)
 - Ekman pumping $\sim 0.5\text{ m/day}$
 - Eddy/wind interactions amplify eddy-induced upwelling (McGillicuddy et al., 2007)
 - Submesoscale processes along the periphery of eddies induce vertical velocities several times larger than those due to eddy/wind interactions (Mahadevan et al., 2008)



Impact on large scale ocean circulation

Levy, Klein et al., 2010

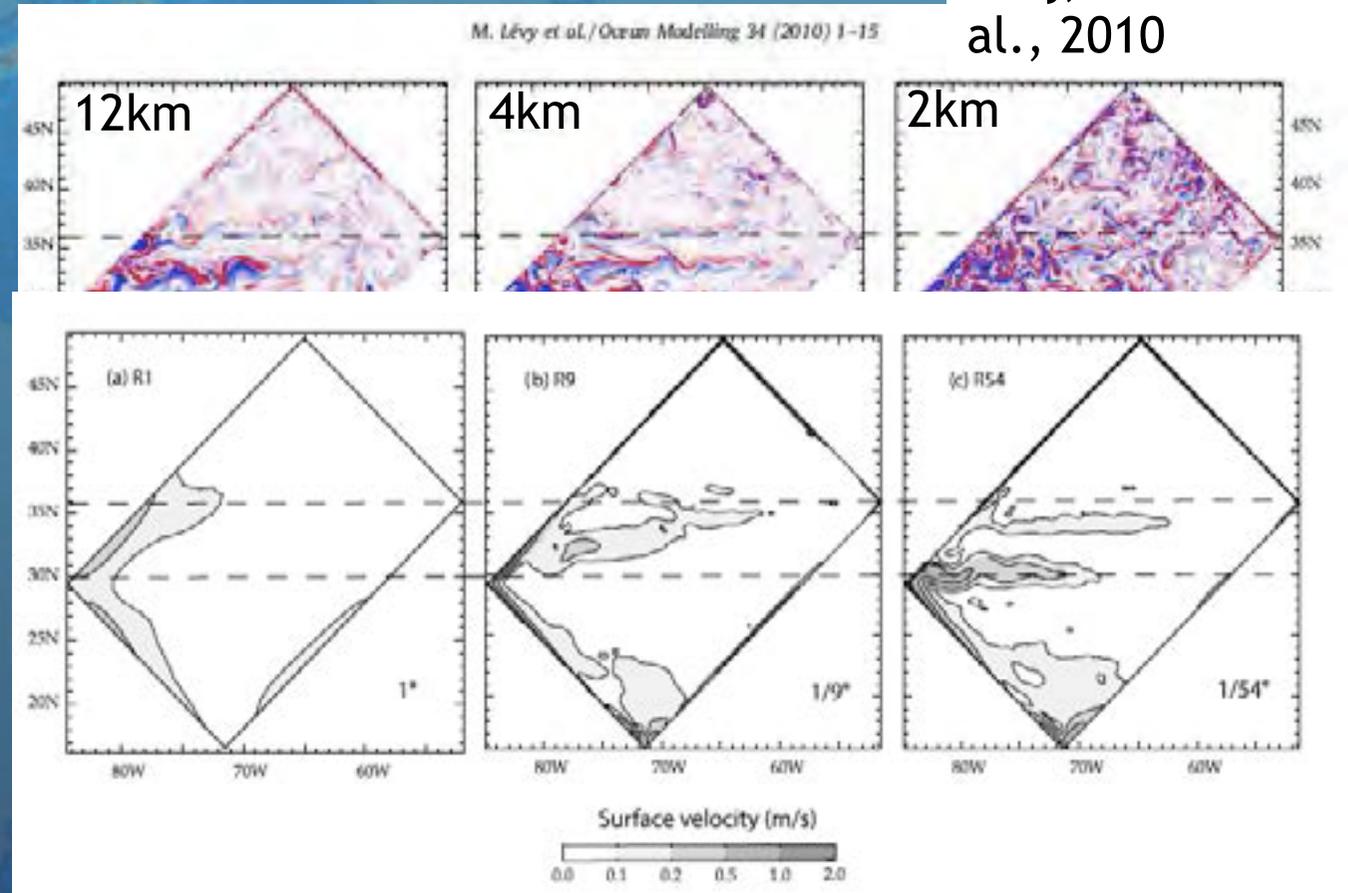
- 100 years ocean model run at 3 spatial resolutions
- Impact on:
 - large scale circulation
 - Meridional heat transport
 - Thermohaline circulation
 - restratification and mixed layer depth
 - biogeochemistry on basin scale



Impact on large scale ocean circulation

Levy, Klein et al., 2010

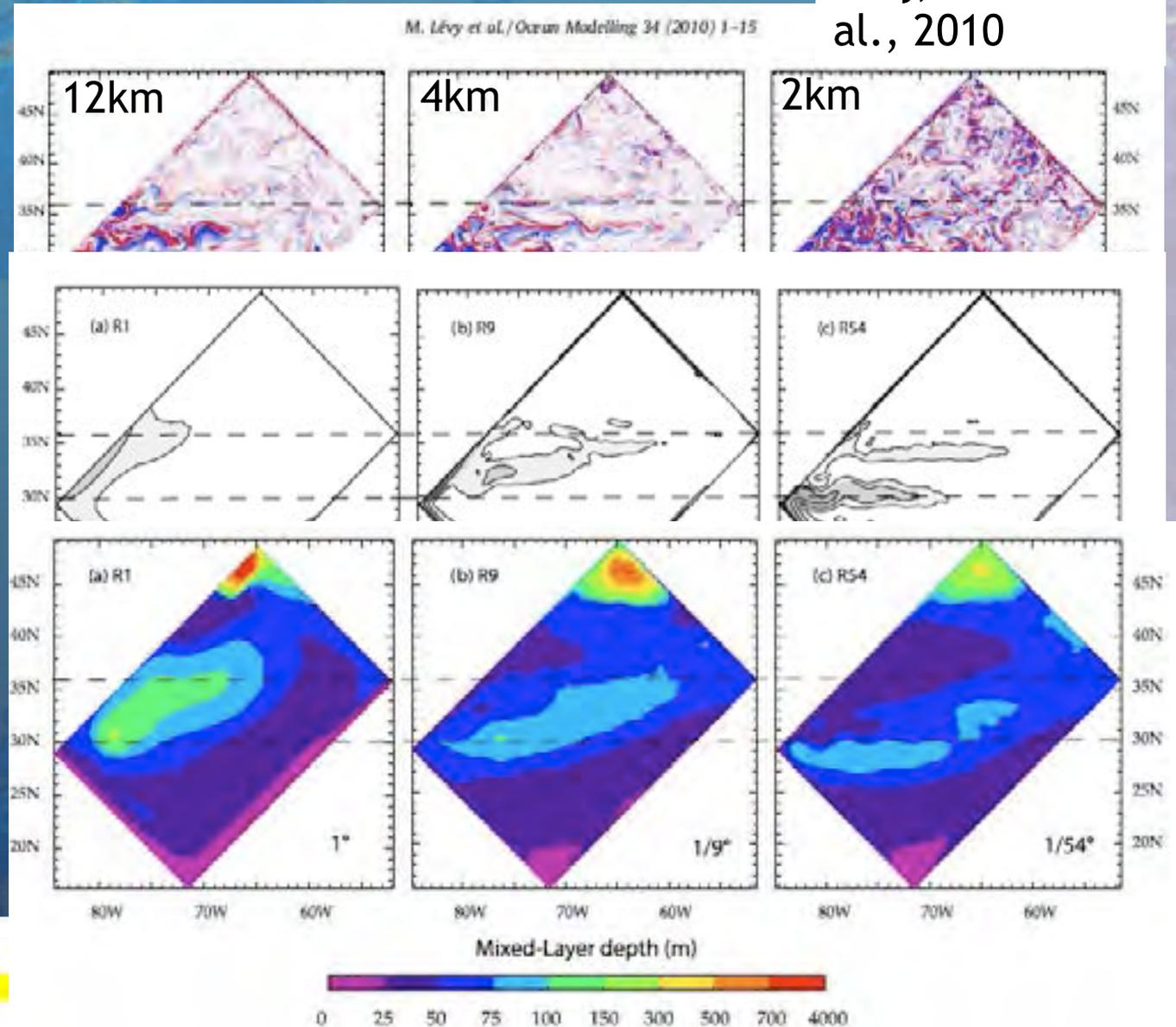
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Better data to test upper ocean dynamics theories on global scale

- Spectral slope of SSH from nadir altimeters
 - Noise at scales finer than 70 km revealed by Cryosat-2 SAR altimeter
- Ocean dynamic theories
 - geostrophic turbulence theory k^{-5}
 - SQG theory $k^{-11/3}$
- Altimeter for scales 70-250km $\sim k^{-4}$
 - SSH variability dominated by frontogenesis
- Resolving the mesoscale is the prime motivation for Surface Water & Ocean Topography mission

Xu & Fu, 2012

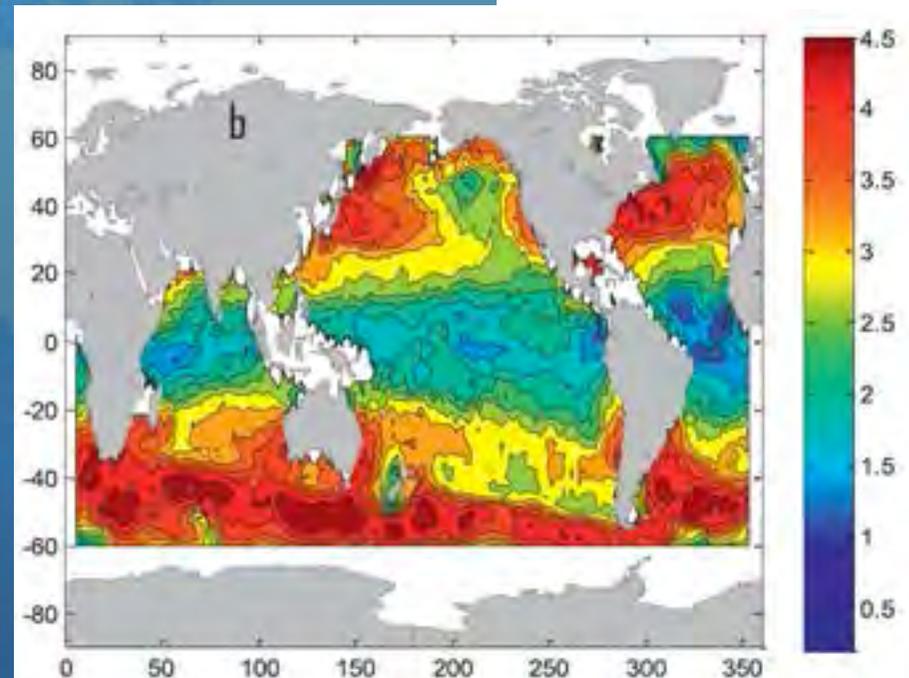
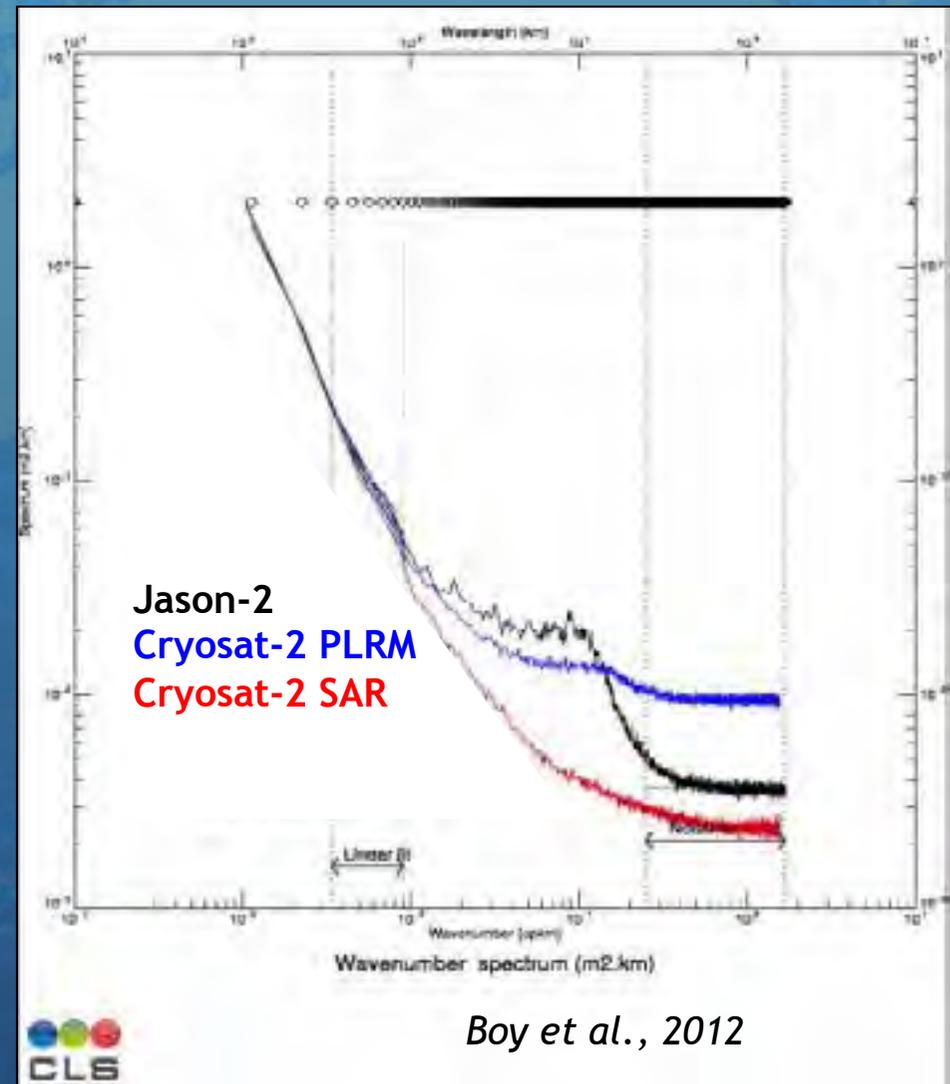


FIG. 3. The global distribution of the spectral slopes of SSH wavenumber spectrum in the wavelength band of 70–250 km estimated from the *Jason-1* altimeter measurements (a) before and (b) after removing the noise. The sign of the slopes was reversed to make the values positive.

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Measuring ocean surface currents from space



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Ifremer



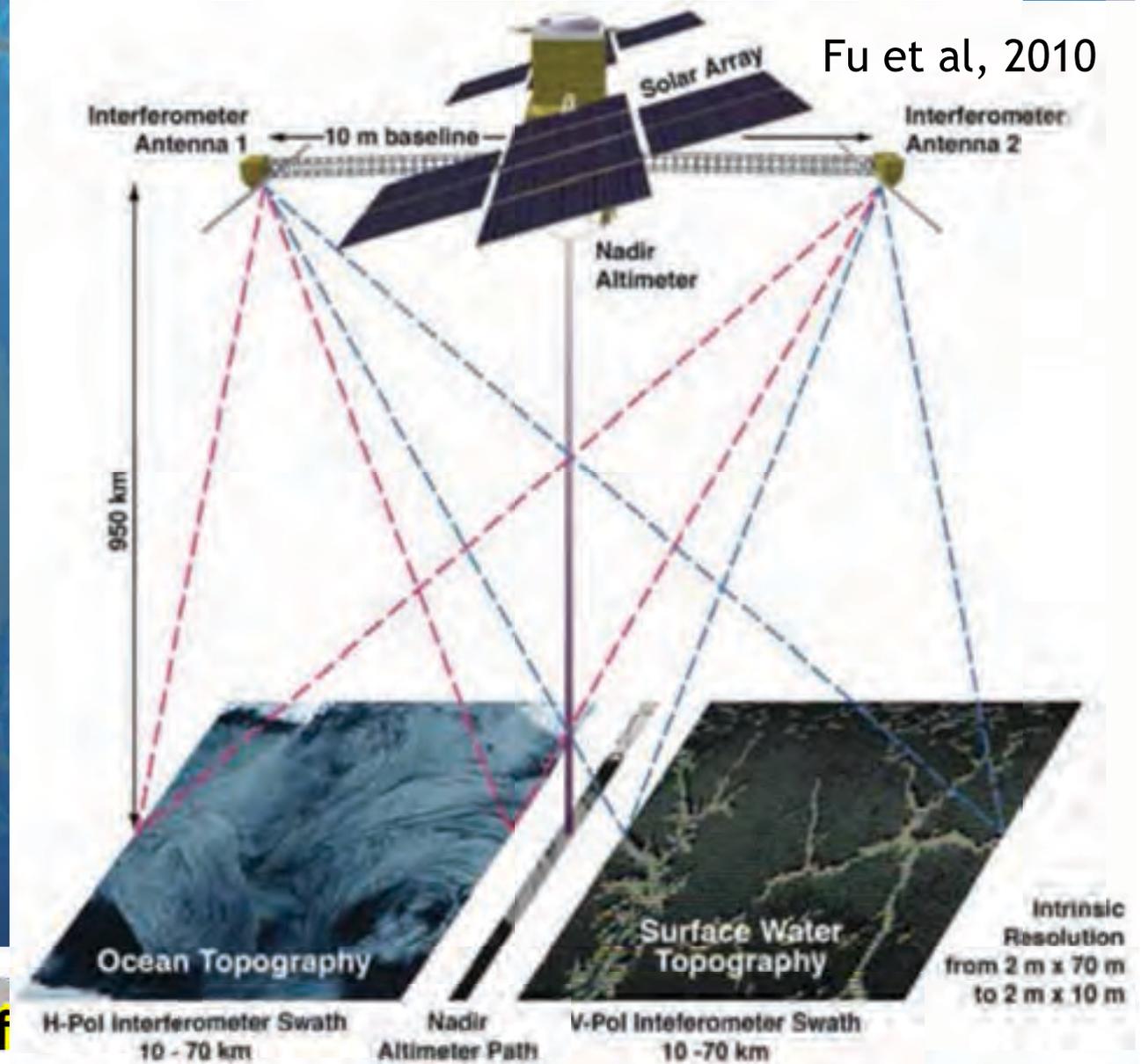
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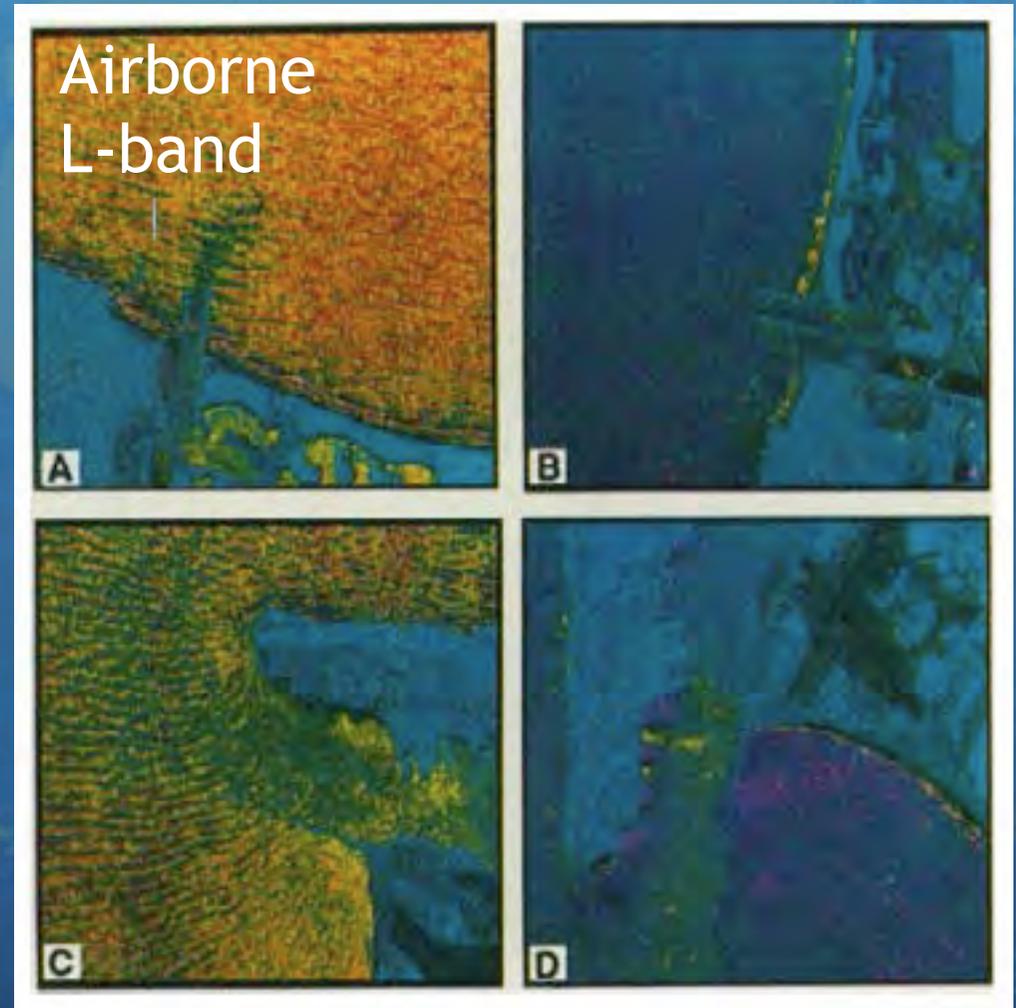
Surface Water & Ocean Topography mission (SWOT)

- Across-track interferometry (XTI)
 - Ka-band (~0.9 cm)
- 2D maps of SSH
 - geostrophic currents
- Goal Precision: 1cm @ 1km
- Ocean variability at 10-25 km scales



Airborne along-track SAR Interferometry

- ATI SAR
- Goldstein & Zebker, 1987
- Two quasi-simultaneous SAR images of the same scene
- Phase difference is related to surface displacement in the line of sight
- one current component only
- Includes unwanted wind and wave motions



Spaceborne ATI on TerraSAR-X

- Suchandt, Runge & Romeiser, 2010
- TerraSAR-X, Aperture-switching mode
- Tidal currents over Orkney Islands and Pentland Firth, Scotland
- 1km resolution
- 0.1-0.2 m/s accuracy after removing unwanted wind and wave effects
- One current component only

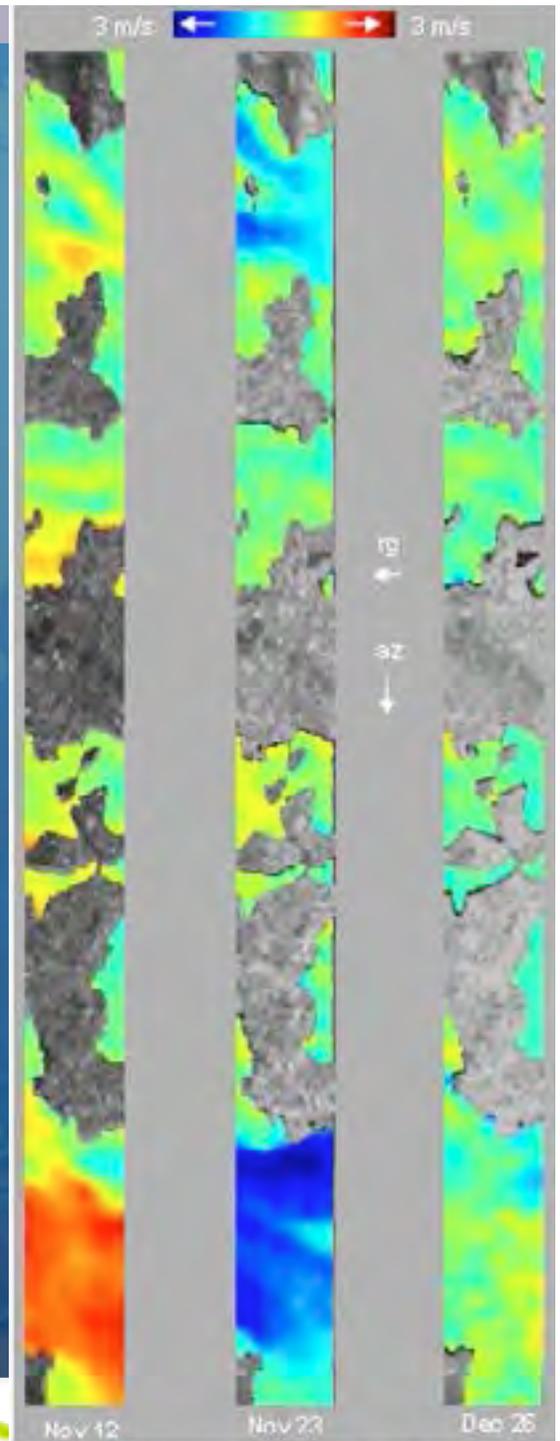


Fig. 3. Tidal currents measured with TerraSAR-X ATI around the Orkney Islands from Nov. - Dec. 2009.



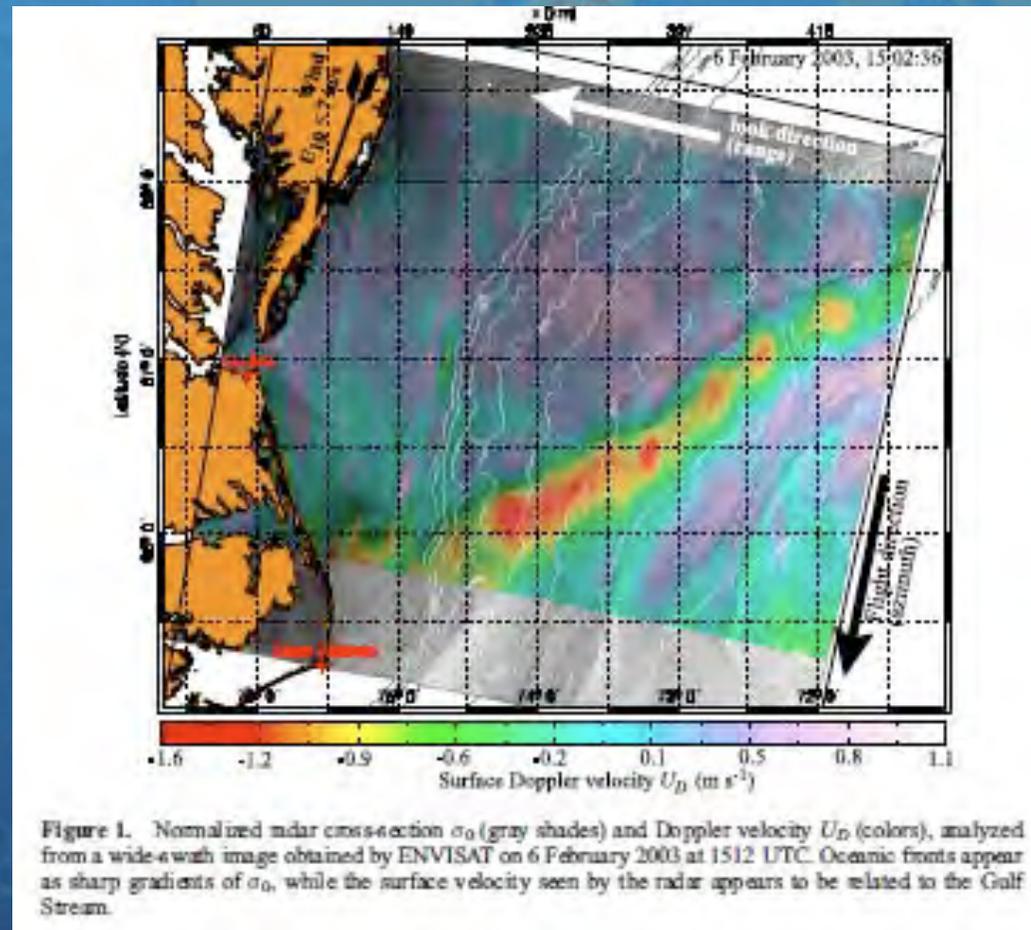
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SAR Doppler Centroid shift



- Chapron et al., 2005
- Developed and demonstrated with Envisat ASAR
- ~ 5 km resolution, 0.2-0.3 m/s accuracy
- One component only
- Also retrieval of winds from NRCS and Doppler frequency (Mouche et al., 2008; 2012)



Wavemill



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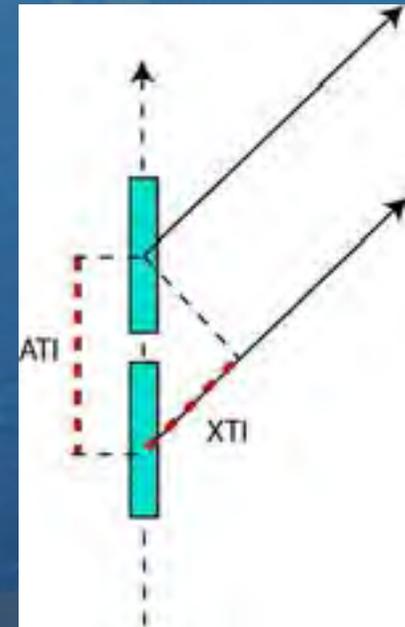
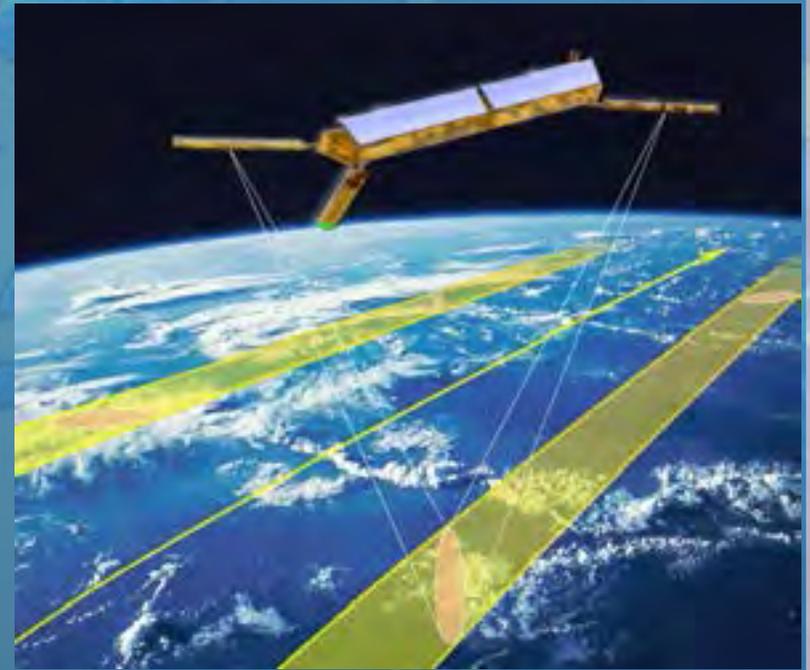
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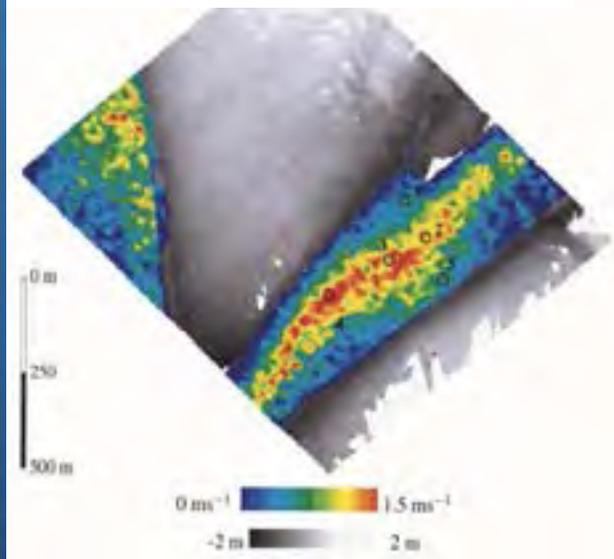
- Hybrid interferometric SAR
 - Both along-track and across-track interferometric baselines
 - Squinted beams; Ku-band
- “Wavemill” coined by Chris Buck (2005)
- Can measure total ocean surface current vectors and sea surface topography
 - Also wind vectors, swell & cryospheric applications
- Focus on high-res total ocean surface current vectors, high-res wind vectors and swell
- Requirements: 2 x 100 km swath
 - 1km resolution; 0.05 m/s accuracy



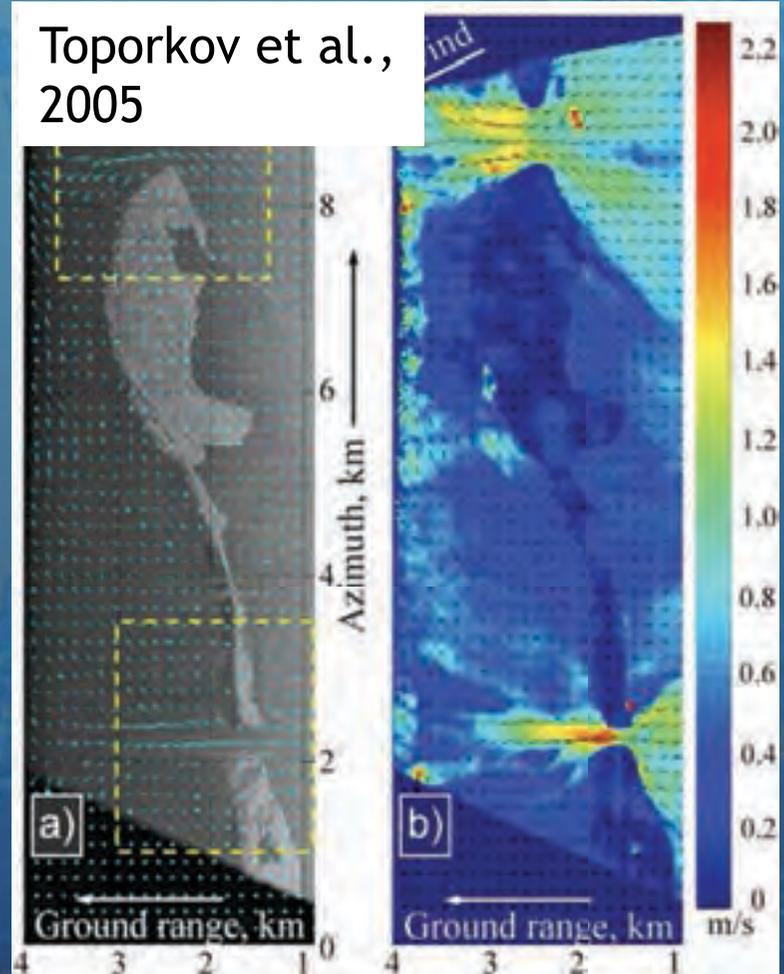
Airborne Hybrid SAR interferometry

- Siegmund et al., 2004: first airborne HTI
 - First demonstration of simultaneous measurements of elevation and currents
- Toporkov et al., 2005; Frasier et al., 2001

Siegmund et al. 2004



Toporkov et al., 2005

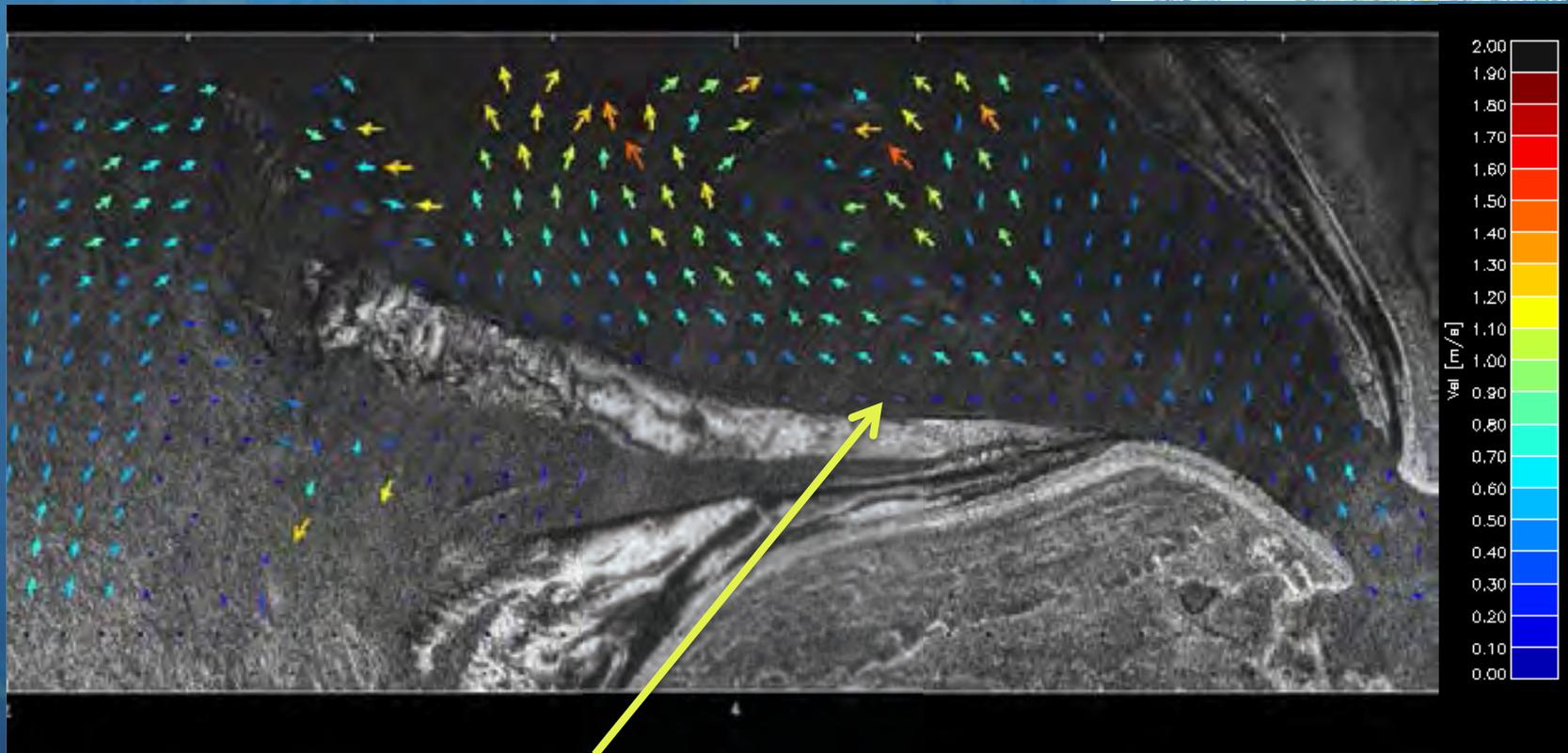


Wavemill airborne proof of concept



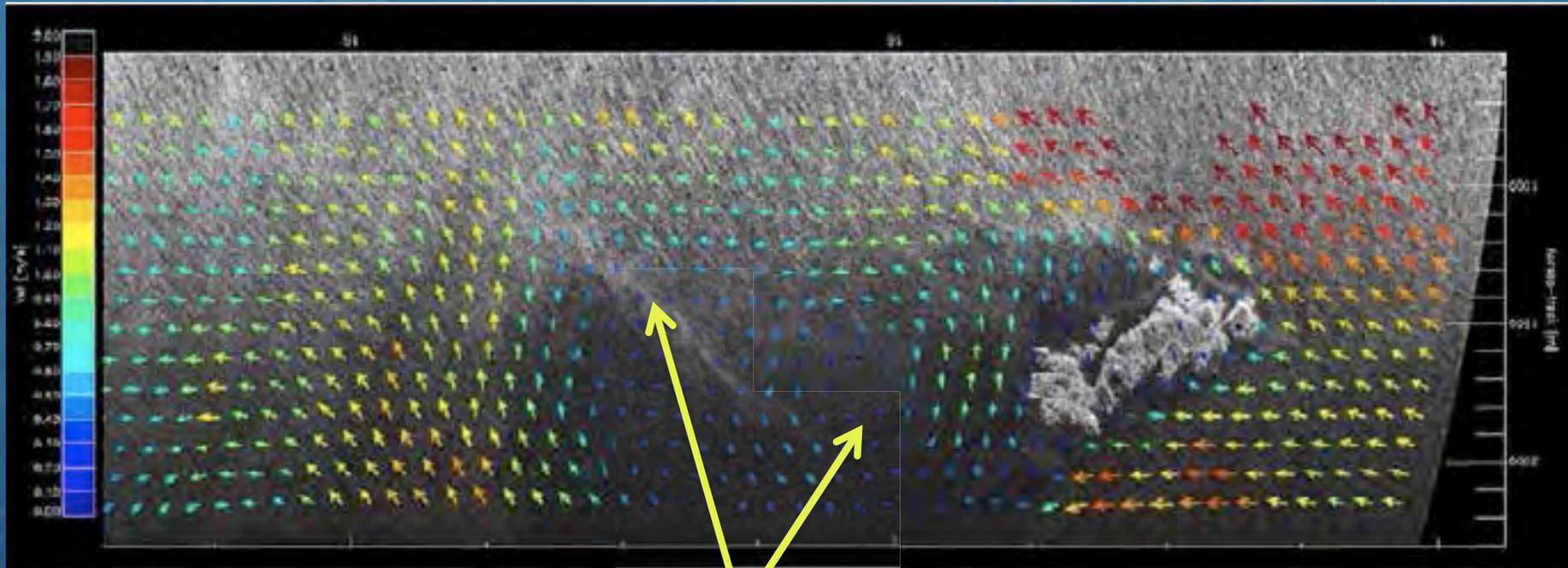
Wavemill airborne demonstrator

Over Menai Strait



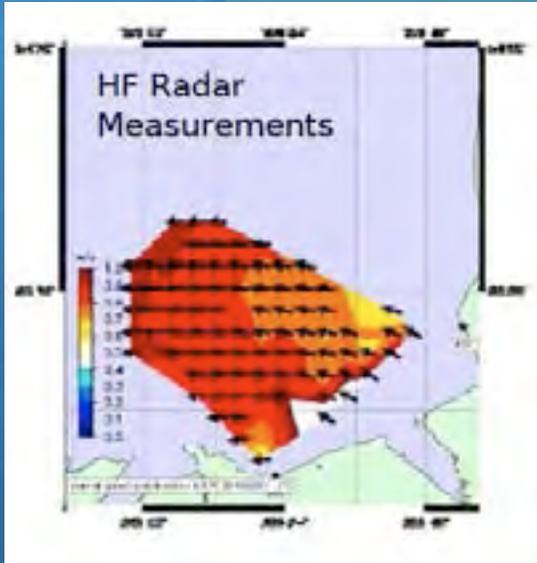
Measurements right up to the coast

Off Anglesey



Convergence and Eddy

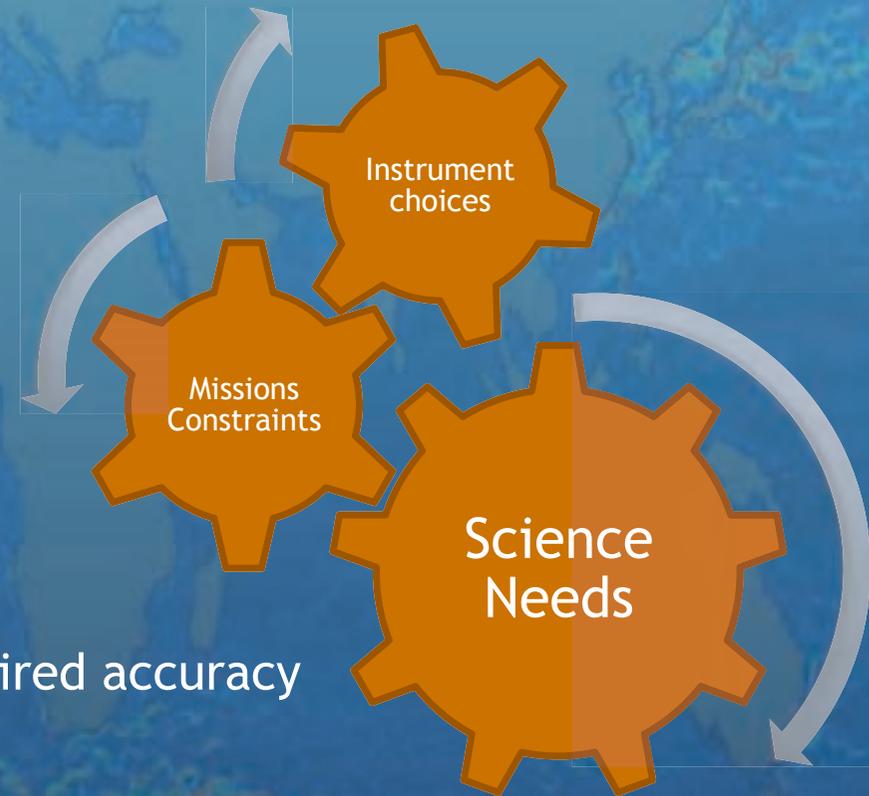
Validation over Liverpool Bay



- Comparison with HF radar and ADCP data
- Broadly consistent but further work needed to remove wind and wave effects
 - Work in progress in WaPA project

Developing Wavemill into a spaceborne mission

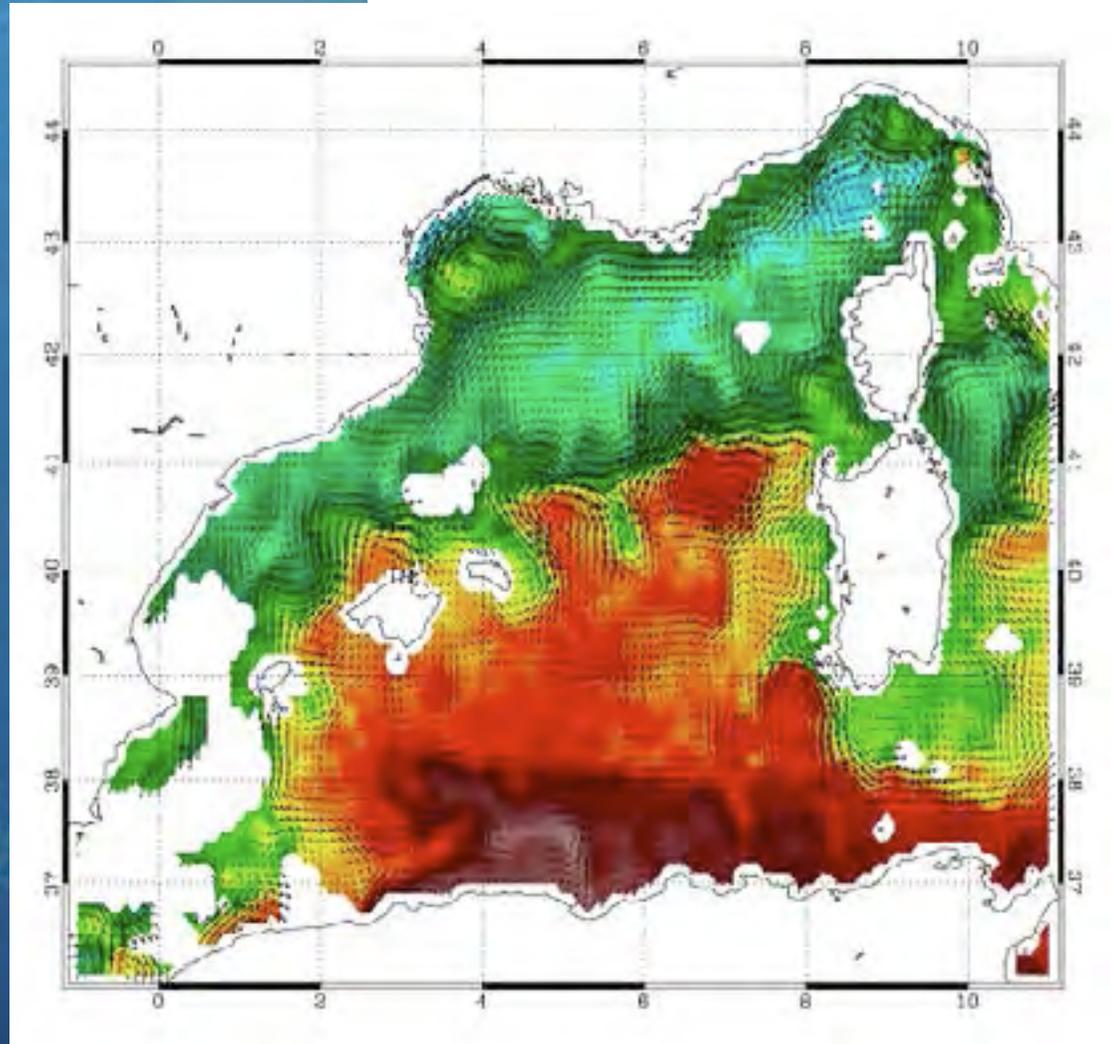
- Trade-offs between science needs and instrument & mission choices
- Large instrument, large power requirements, large data rates
- Instrument choices e.g.
 - Optimise instrument to deliver required accuracy
- Orbit choices & data acquisition:
 - re-visit time v global sampling
 - Synergy with other satellites



Synergy with SWOT

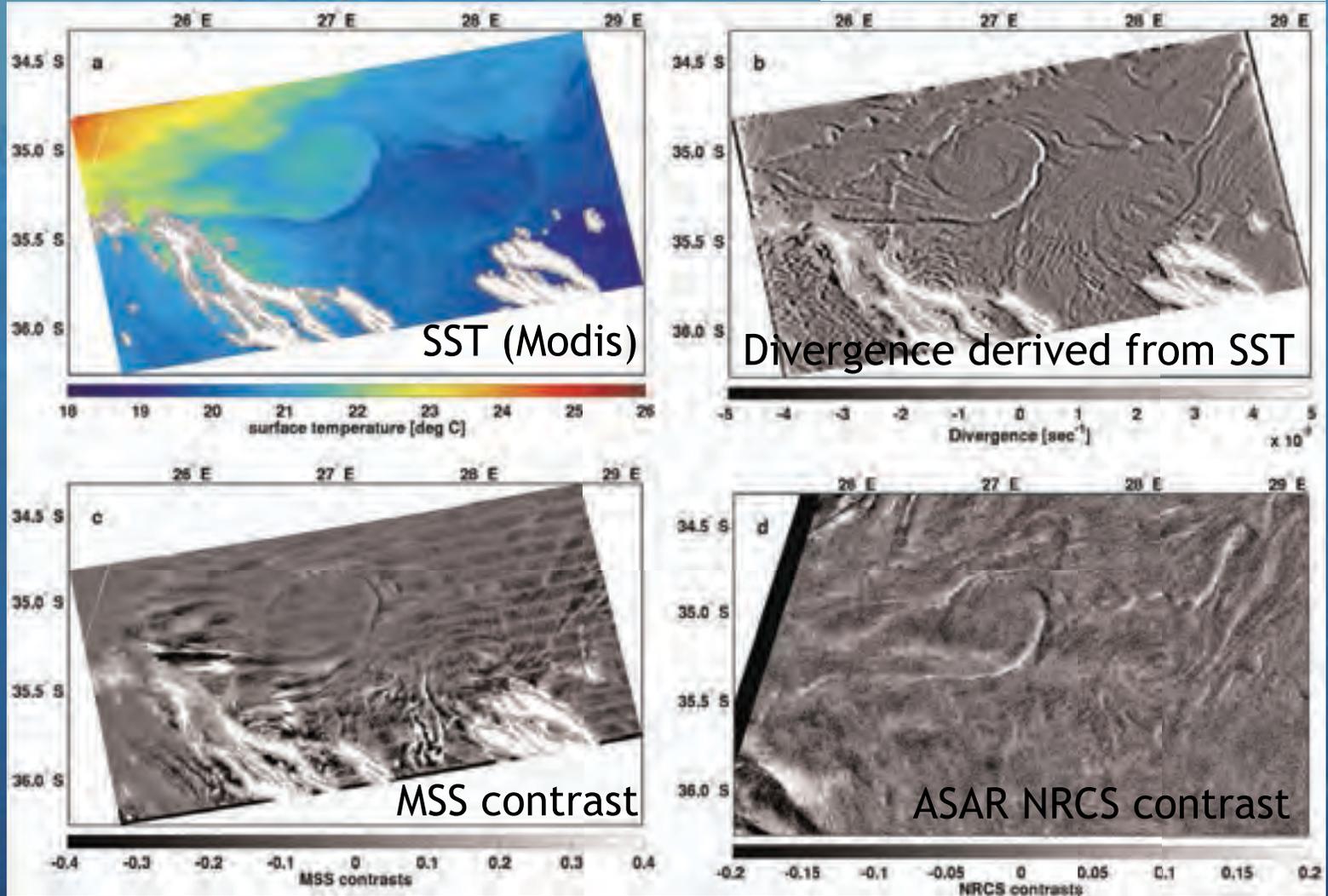
Isern-Fontanet et al., LPS 2013

- Example of reconstructed current field from SST and SSH in context of SQG theory
- Coincident 2D fields of SSH, total currents and winds at high resolution would deliver high scientific added value



Synergy with Sentinel-3

Kudryavtsev et al., 2012



Conclusions & Way forward

- Strong scientific requirement for new satellite observations of ocean dynamics at the mesoscale and sub-mesoscale
 - No means at present to measure total currents from space on these small scales
 - Recent research highlight the importance of ageostrophic currents and wind/eddy interactions.
- Wavemill is an innovative instrument promising to deliver high-resolution currents and winds, right up to the coast
 - Including ageostrophic currents
 - Coincident measurements of swell



Conclusions & Way forward

- Wavemill concept was successfully demonstrated in airborne flights over the Irish Sea
 - Ongoing work to validate against in situ data
- Strategies to retrieve both high-resolution current vectors AND high-resolution wind vectors currently being investigated in WaPA project
 - End-to-end numerical simulator
 - Theoretical modelling
- Science requirements are driving the development of the concept as a spaceborne mission



Way forward

- Wavemill will be submitted as a candidate mission to the next ESA Earth Explorer call
 - EE9 call is expected imminently (?)
- If you want to find out more about Wavemill, contact me
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 - National Oceanography Centre, Southampton, UK

