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

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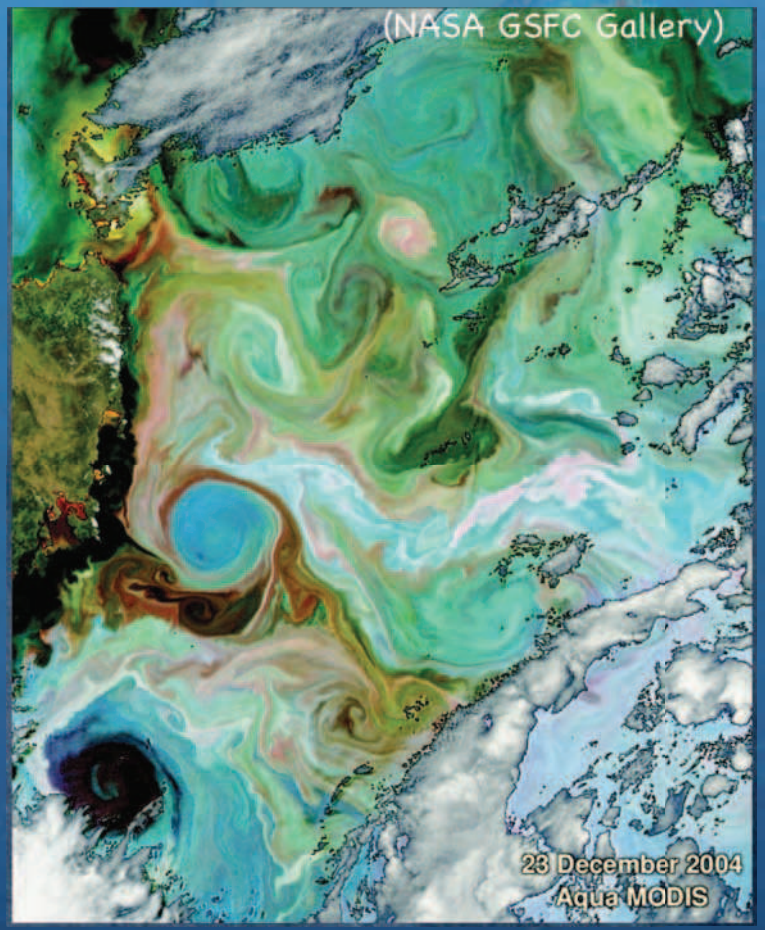
Content of this talk

- 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 atmopshere/ocean coupling
  - Horizontal and vertical mixing & transport, large scale ocean transport, ocean biology
  - Atmosphere/wave/ocean interactions

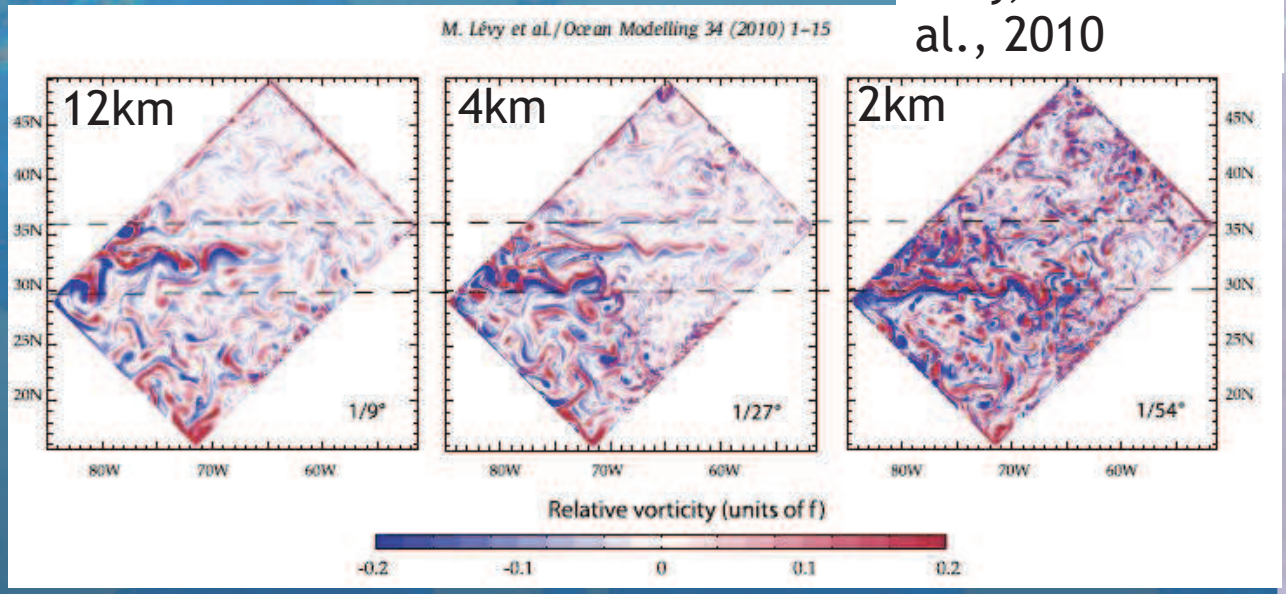
Sub-mesoscale, vertical transports and ocean biology

- 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 < 100km (Lapeyre and Klein, 2006)
  - Ageostrophic circulation resulting from perturbation of circular eddy flow lead to upwelling velocity ~ 10 m/day (Martin & Richards, 2001)
    - Ekman pumping ~ 0.5 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

- 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

Levy, Klein et al., 2010



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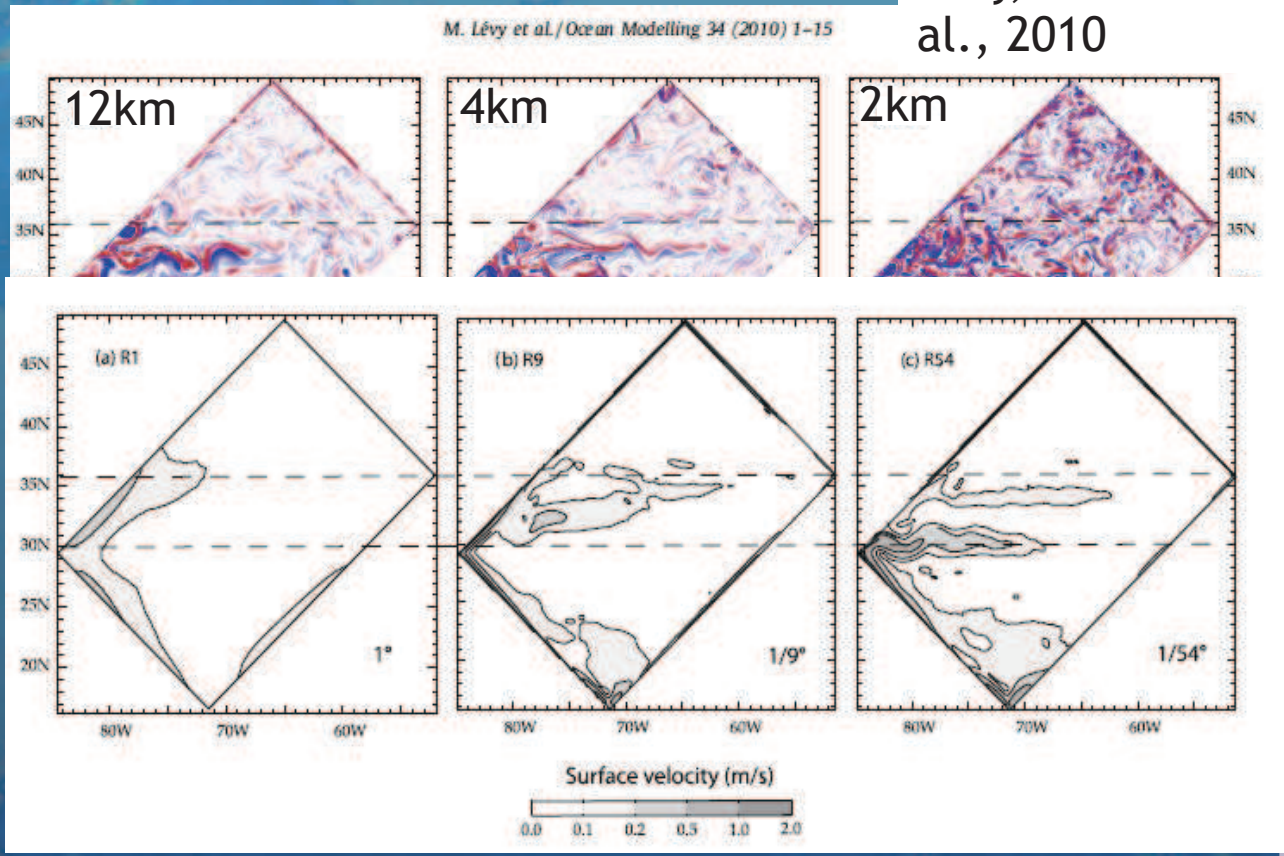

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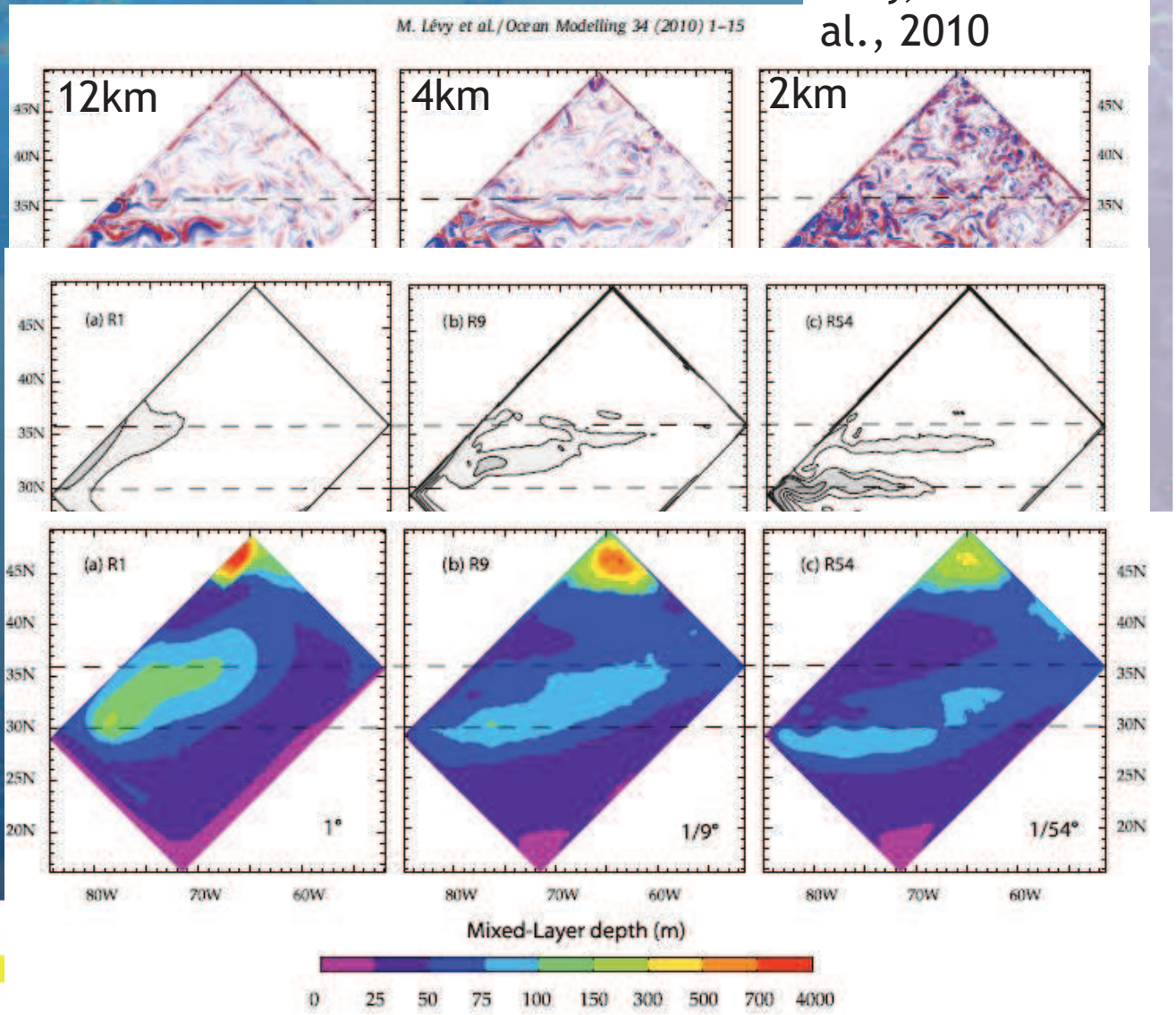

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Better data to test upper ocean dynamics theories on global scale

- 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 ~ k^{-4}
  - SSH variability dominated by frontogenesis
- Resolving the mesoscale is the prime motivation for Surface Water & Ocean Topography mission

Xu & Fu, 2012

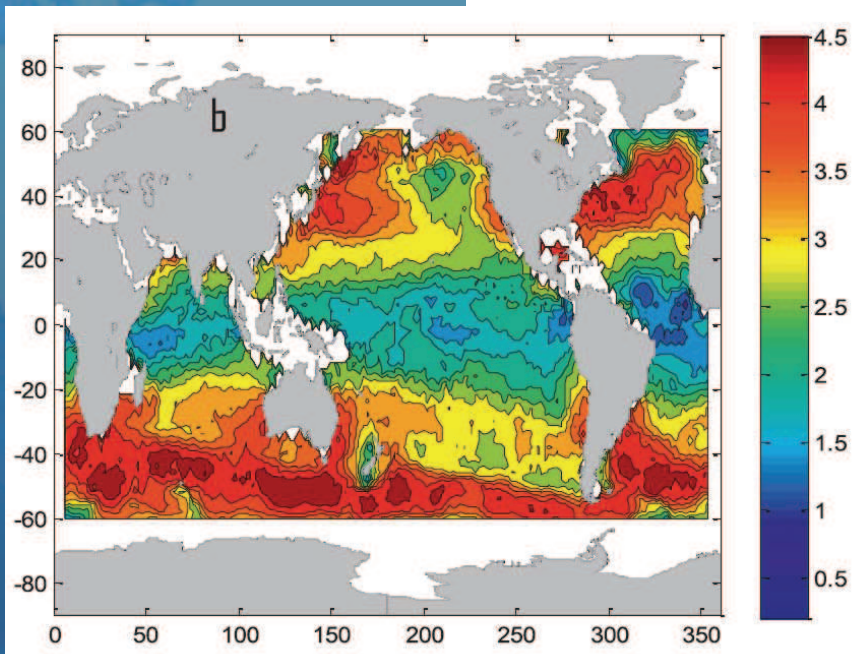

FIG. 3. The global distribution of the spectral slopes of SSH wavenumber spectrum in the wavelength band of 70–250 km estimated from the *Jason-1* altimeter measurements (a) before and (b) after removing the noise. The sign of the slopes was reversed to make the values positive.

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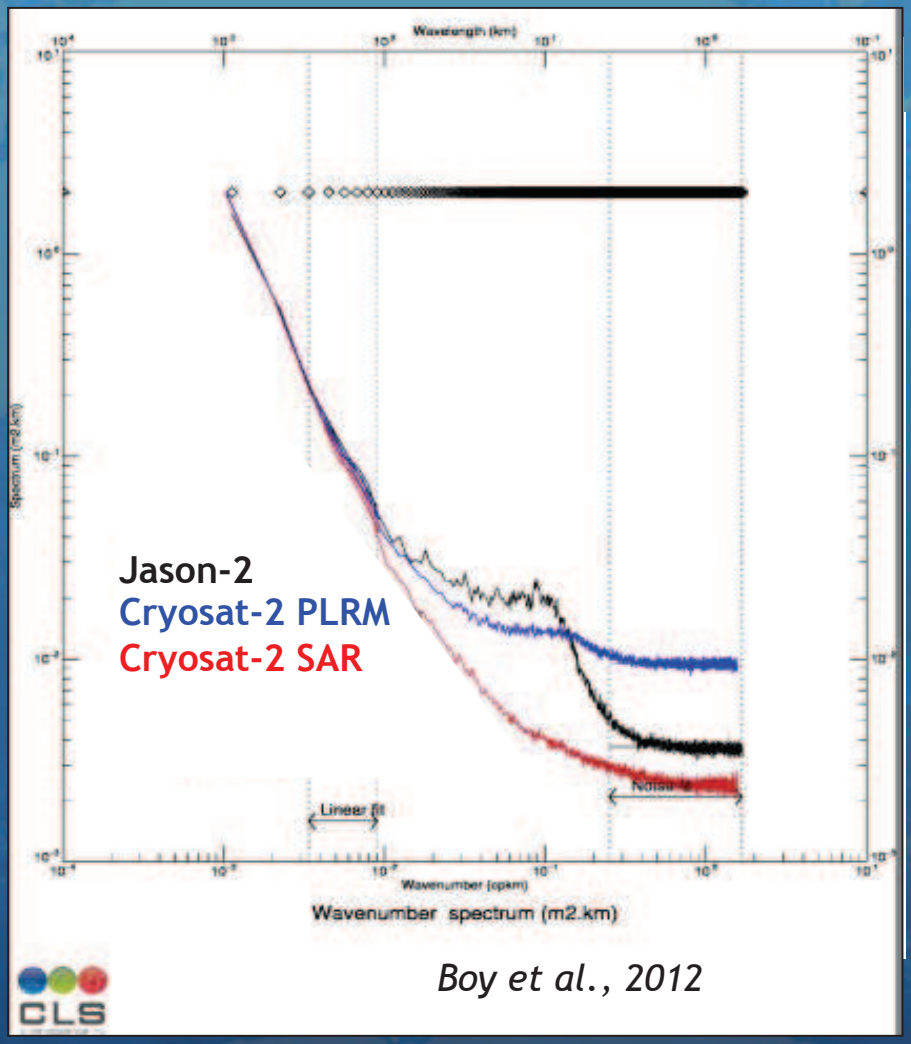

Boy et al., 2012

Measuring ocean surface currents from space

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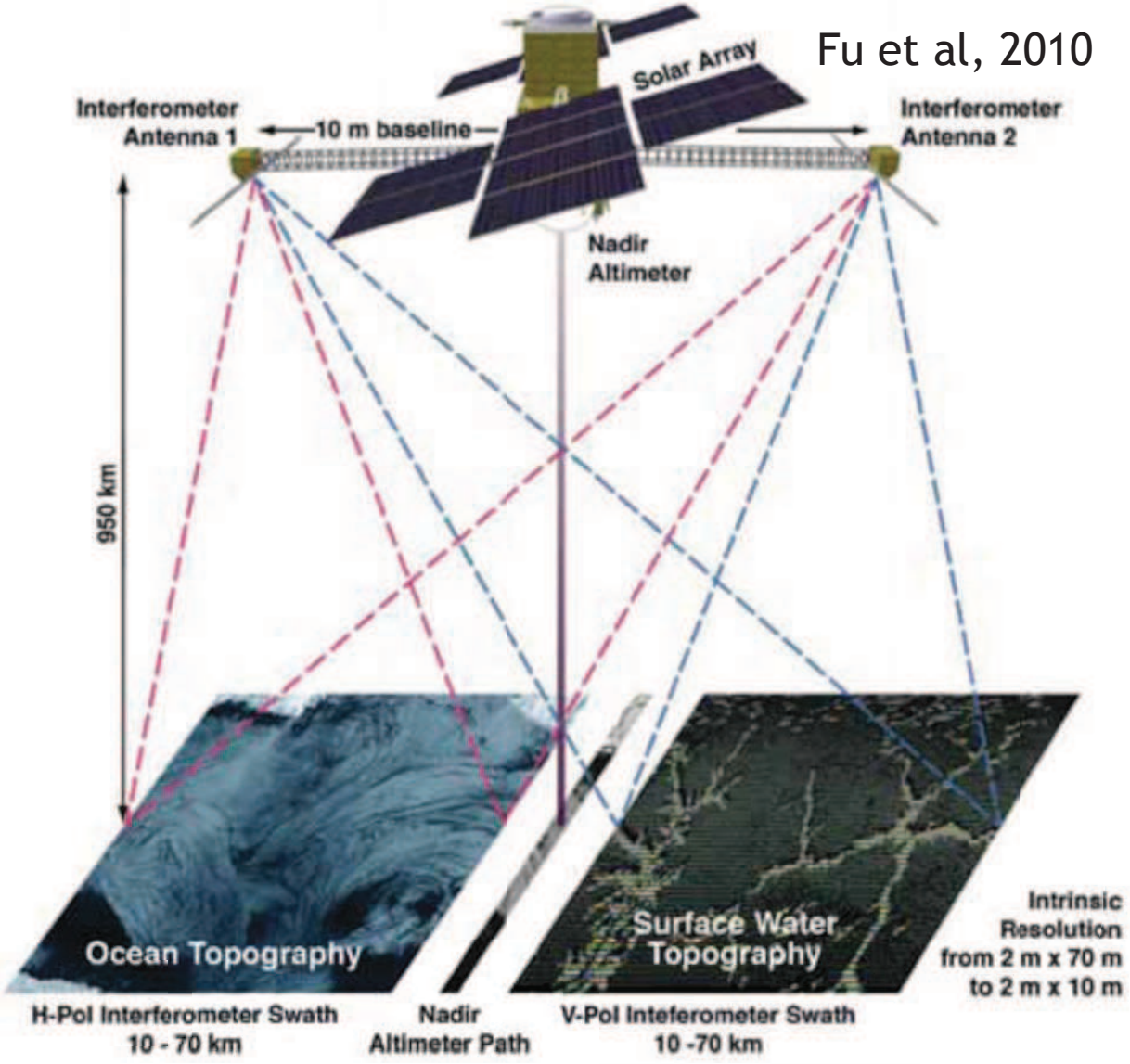
Surface Water & Ocean Topography mission (SWOT)

- 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

Fu et al, 2010



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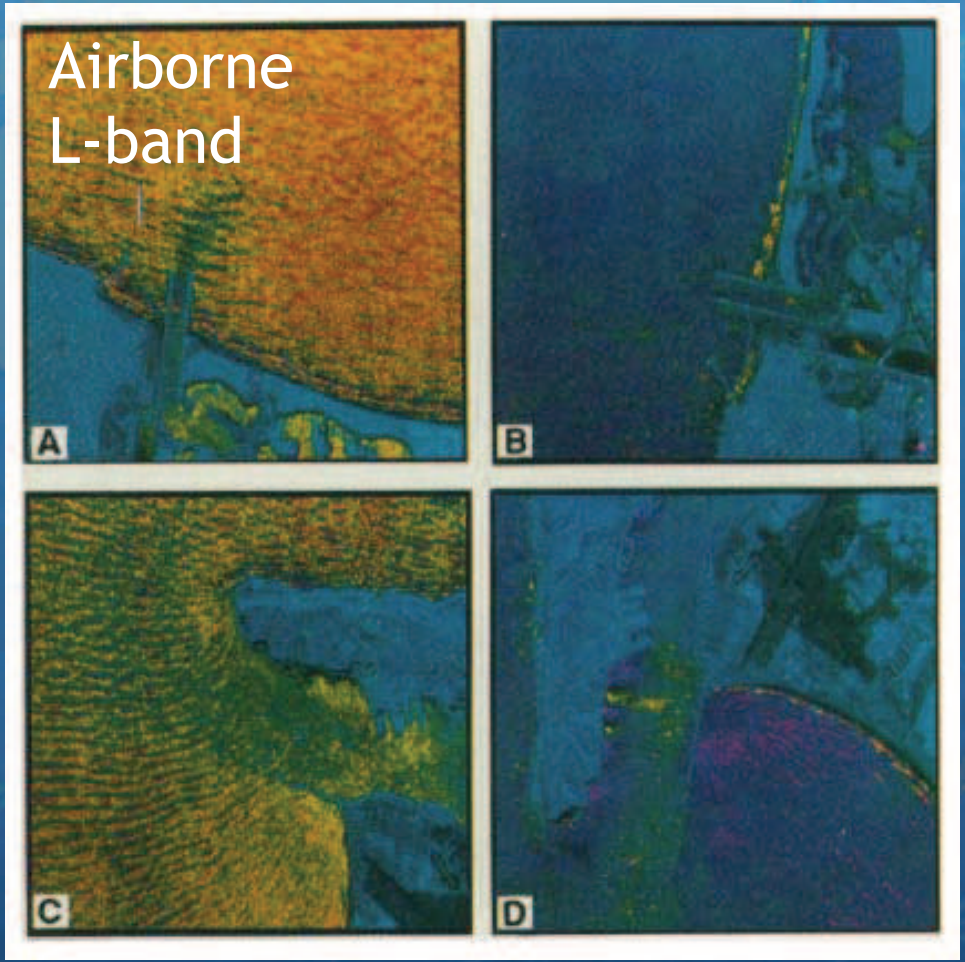
Airborne along-track SAR Interferometry

- 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



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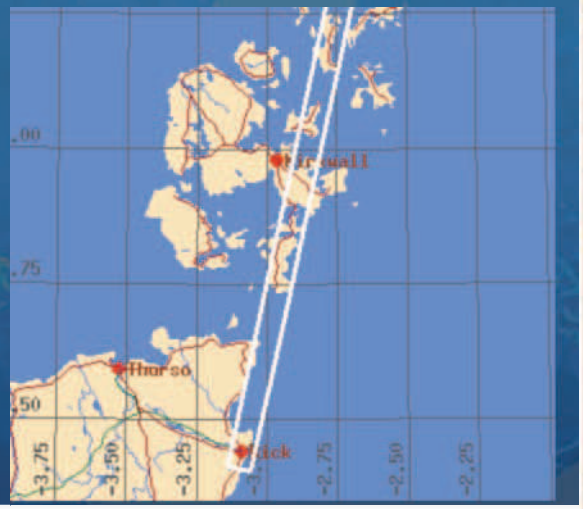
Spaceborne ATI on TerraSAR-X

- 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



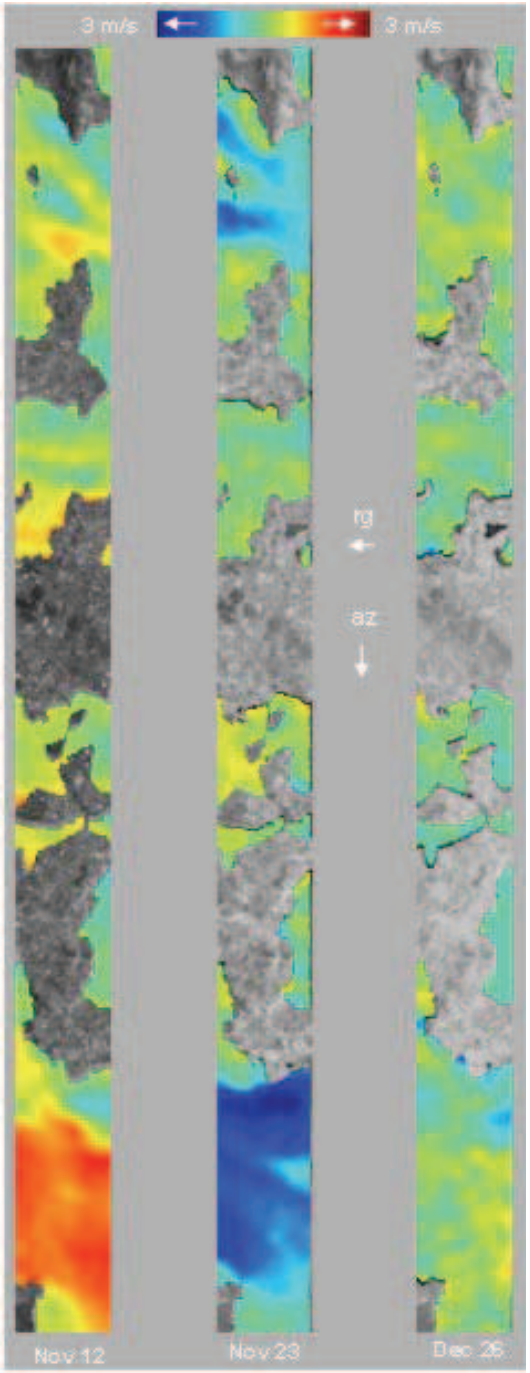


Fig. 3. Tidal currents measured with TerraSAR-X ATI around the Orkney Islands from Nov. - Dec. 2009.

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SAR Doppler Centroid shift

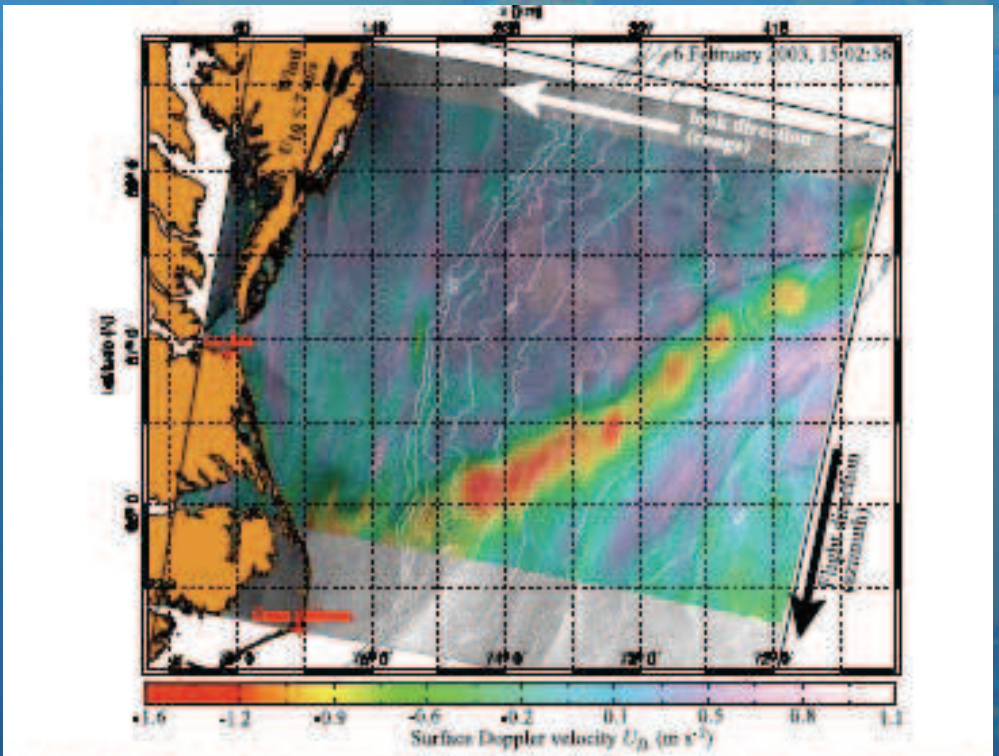

Figure 1. Normalized radar cross-section σ_0 (gray shades) and Doppler velocity U_D (colors), analyzed from a wide-swath image obtained by ENVISAT on 6 February 2003 at 1512 UTC. Oceanic fronts appear as sharp gradients of σ_0, while the surface velocity seen by the radar appears to be related to the Gulf Stream.

- 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)

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Wavemill

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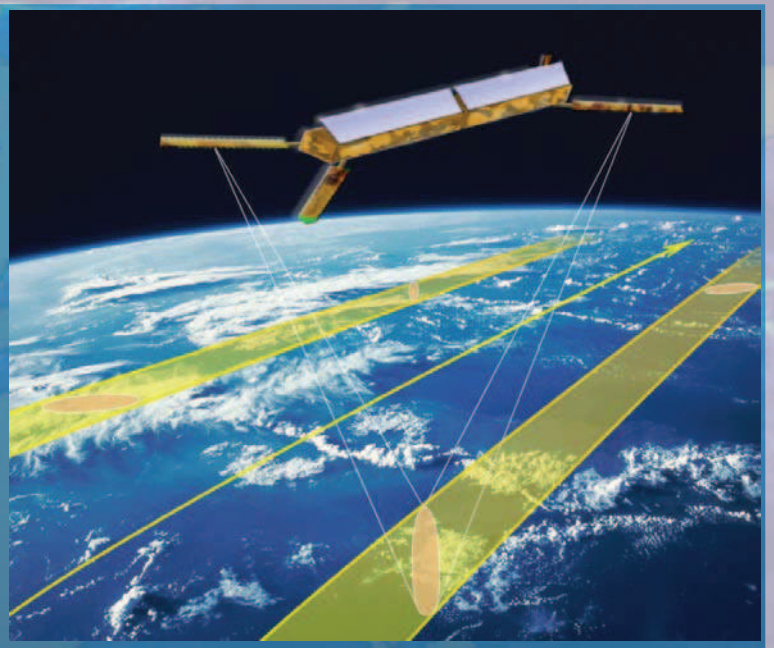
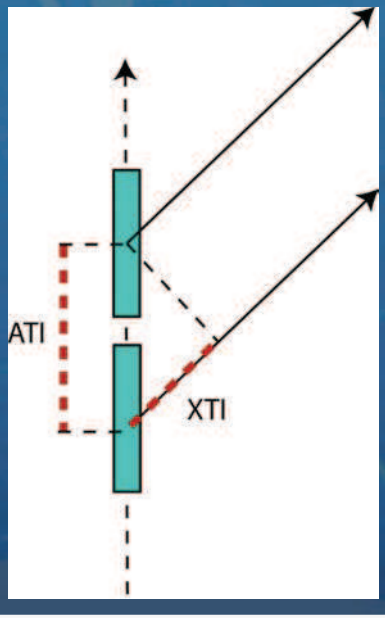


- Hybrid interferometric SAR
  - Both along-track and across-track interferometric baselines
  - Squinted beams; Ku-band
- "Wavemill" coined by Chris Buck (2005)
- Can measure total ocean surface current vectors and sea surface topography
  - Also wind vectors, swell & cryospheric applications
- Focus 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



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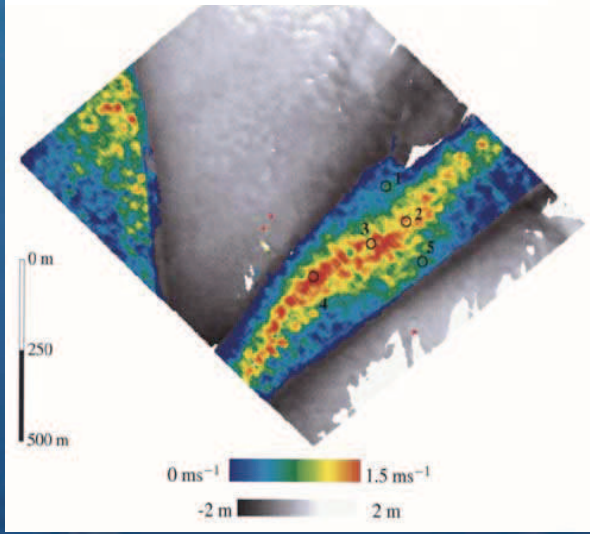
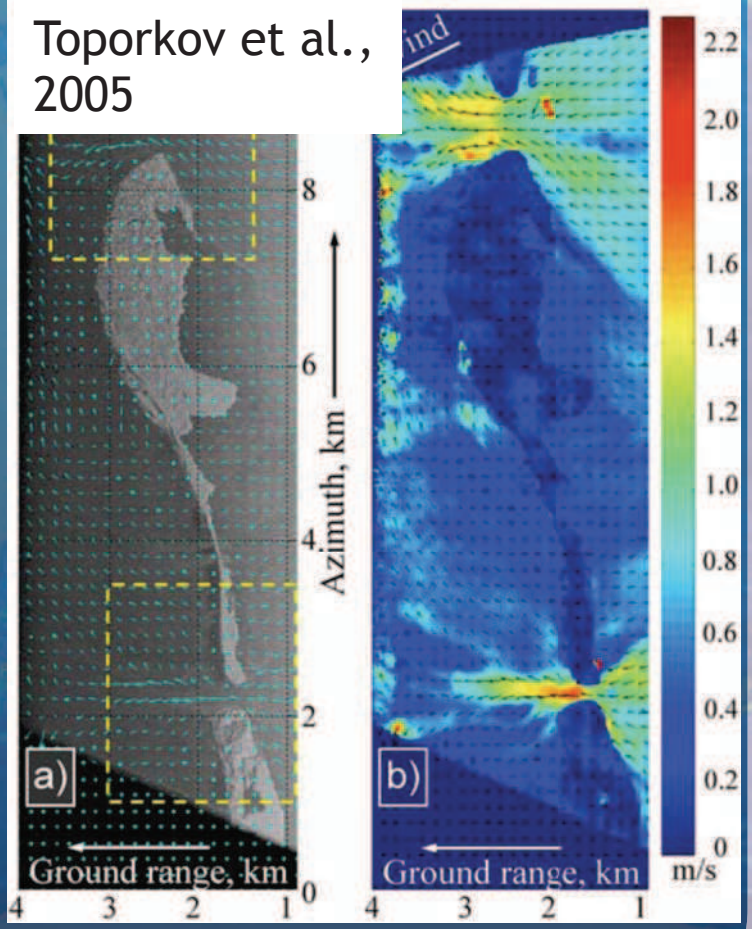
Airborne Hybrid SAR interferometry

- 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



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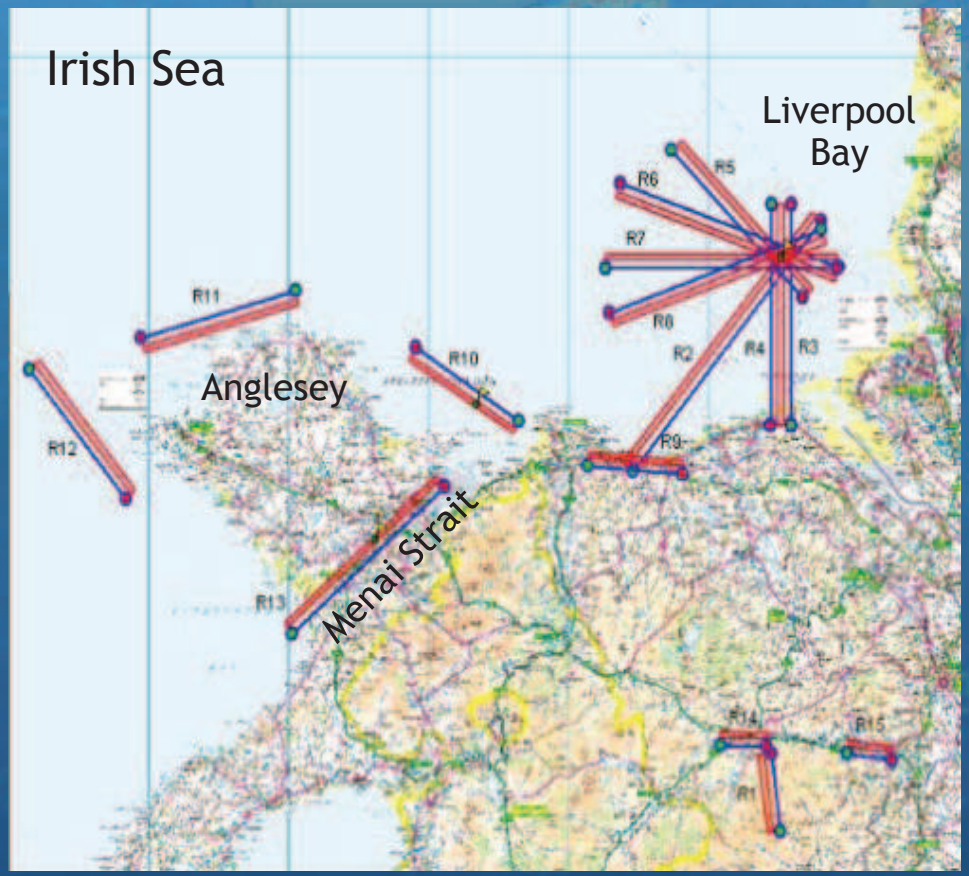
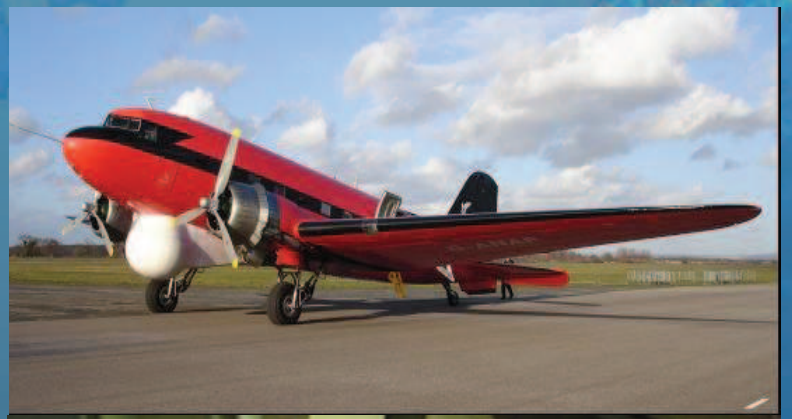
Wavemill airborne proof of concept





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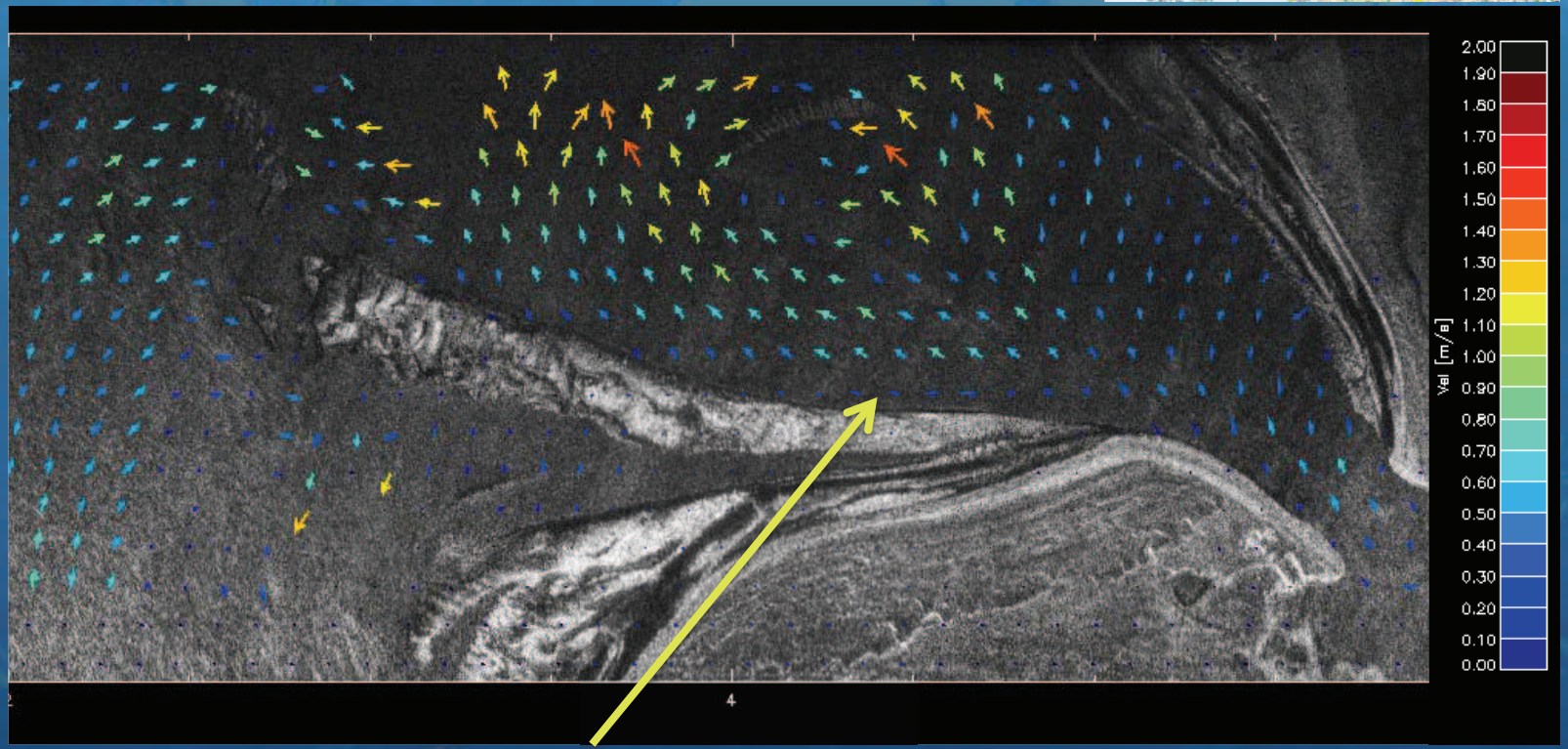
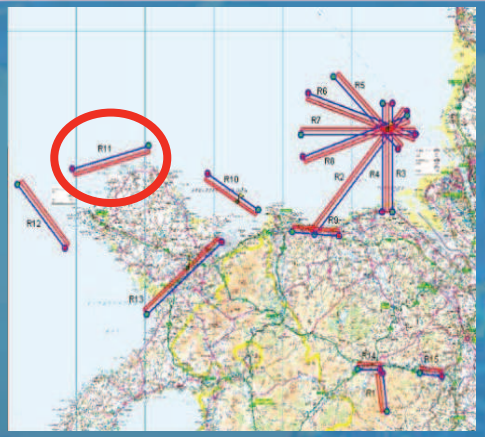
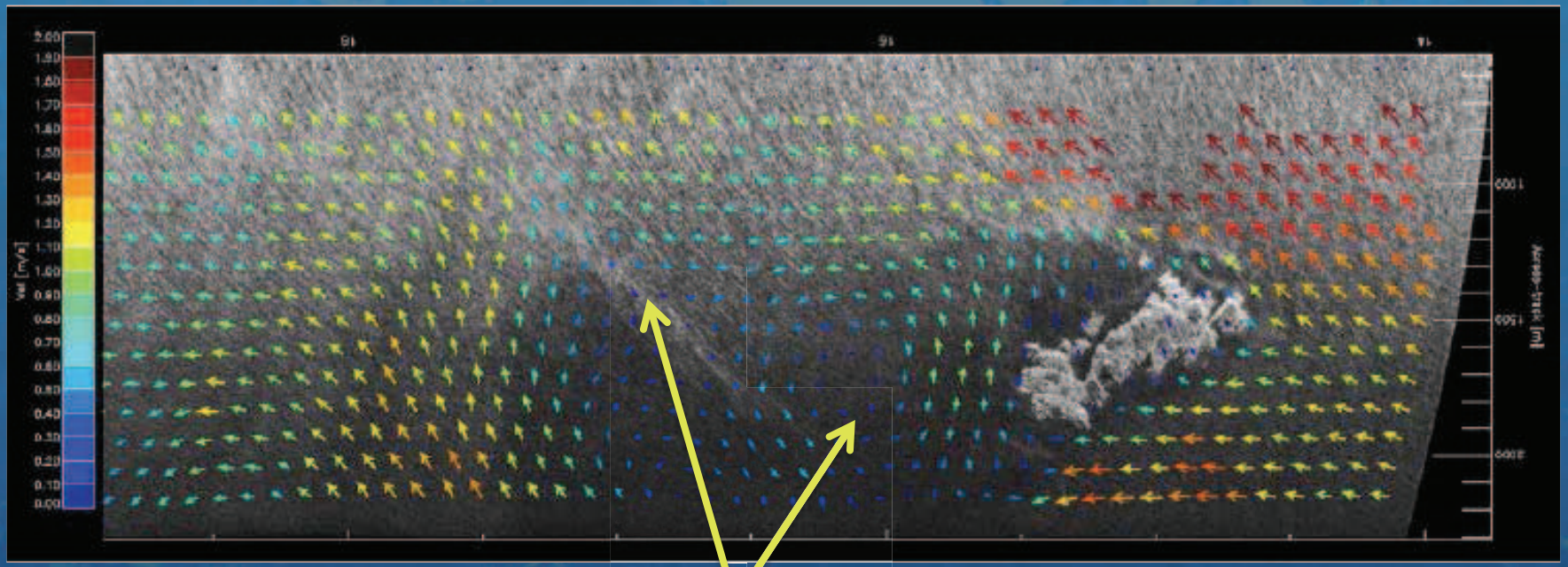
Over Menai Strait



Measurements right up to the coast

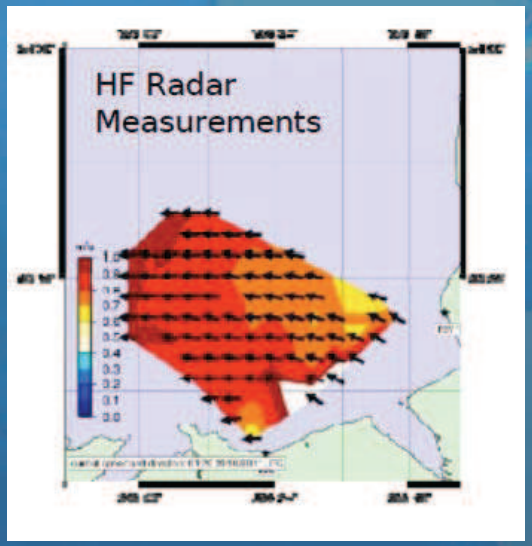
Off Anglesey

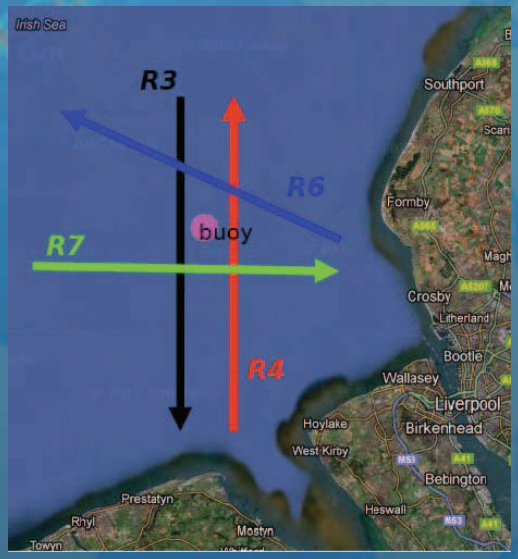




Convergence and Eddy

Validation over Liverpool Bay

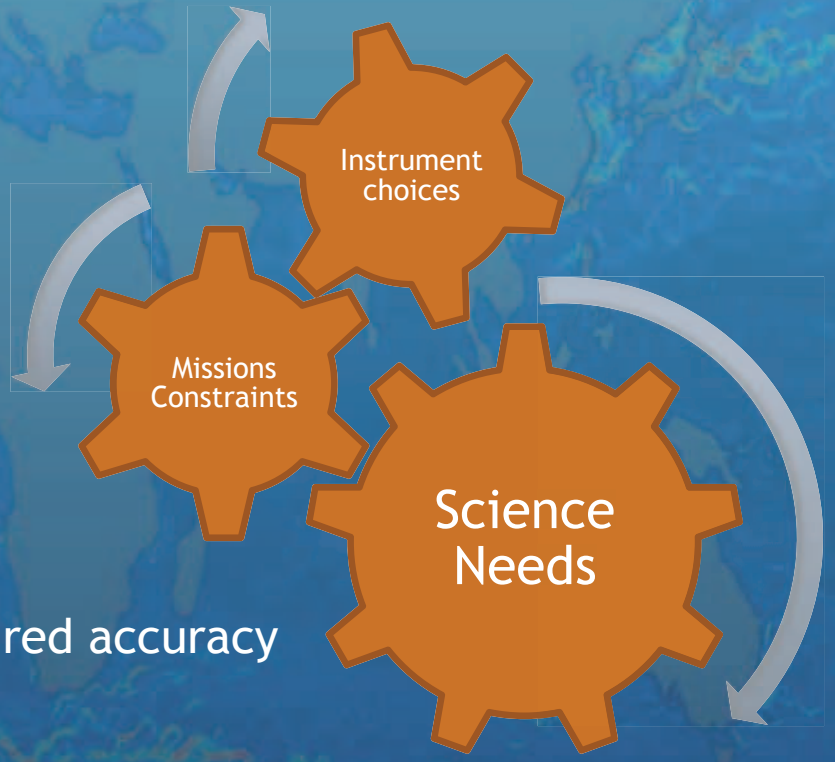




- Comparison with HF radar and ADCP data
- Broadly consistent but further work needed to remove wind and wave effects
  - Work in progress in WaPA project

Developing Wavemill into a spaceborne mission

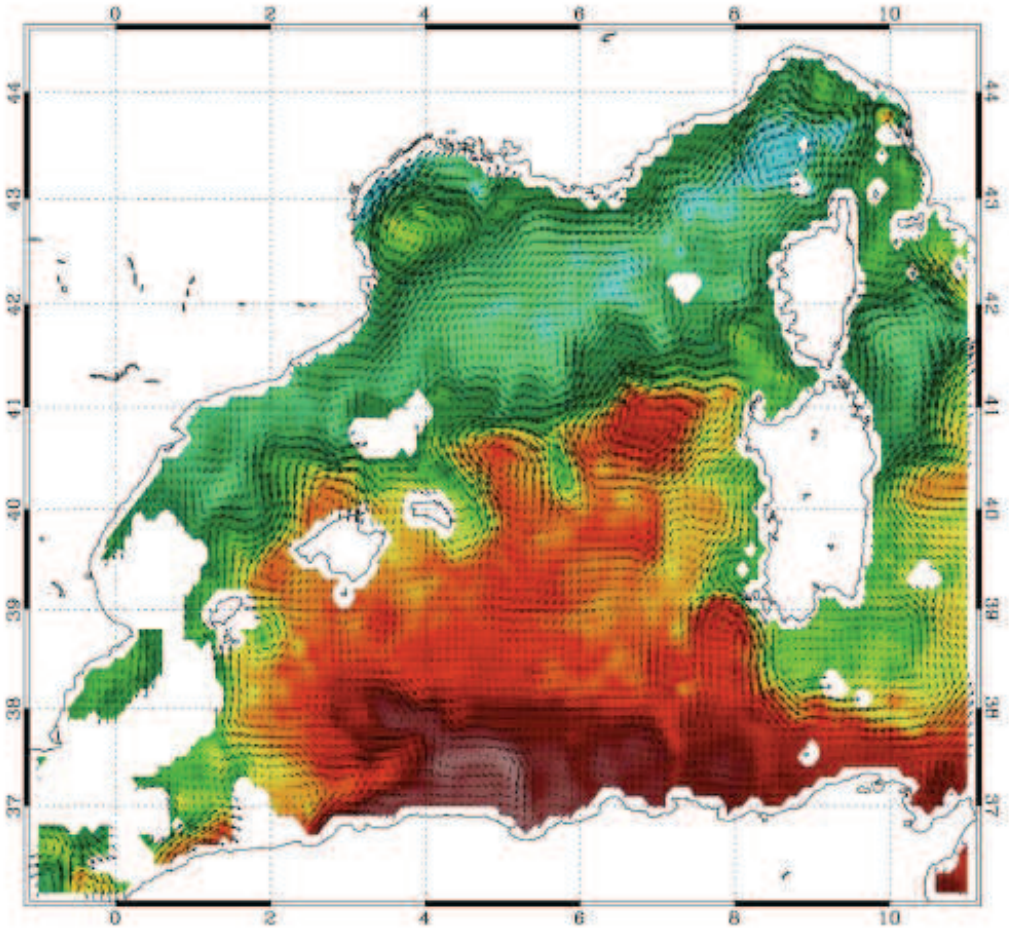
- Trade-offs between science needs and instrument & mission choices
- Large instrument, large power requirements, large data rates
- Instrument choices e.g.
  - Optimise instrument to deliver required accuracy
- Orbit choices & data acquisition:
  - re-visit time v global sampling
  - Synergy with other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



Synergy with SWOT

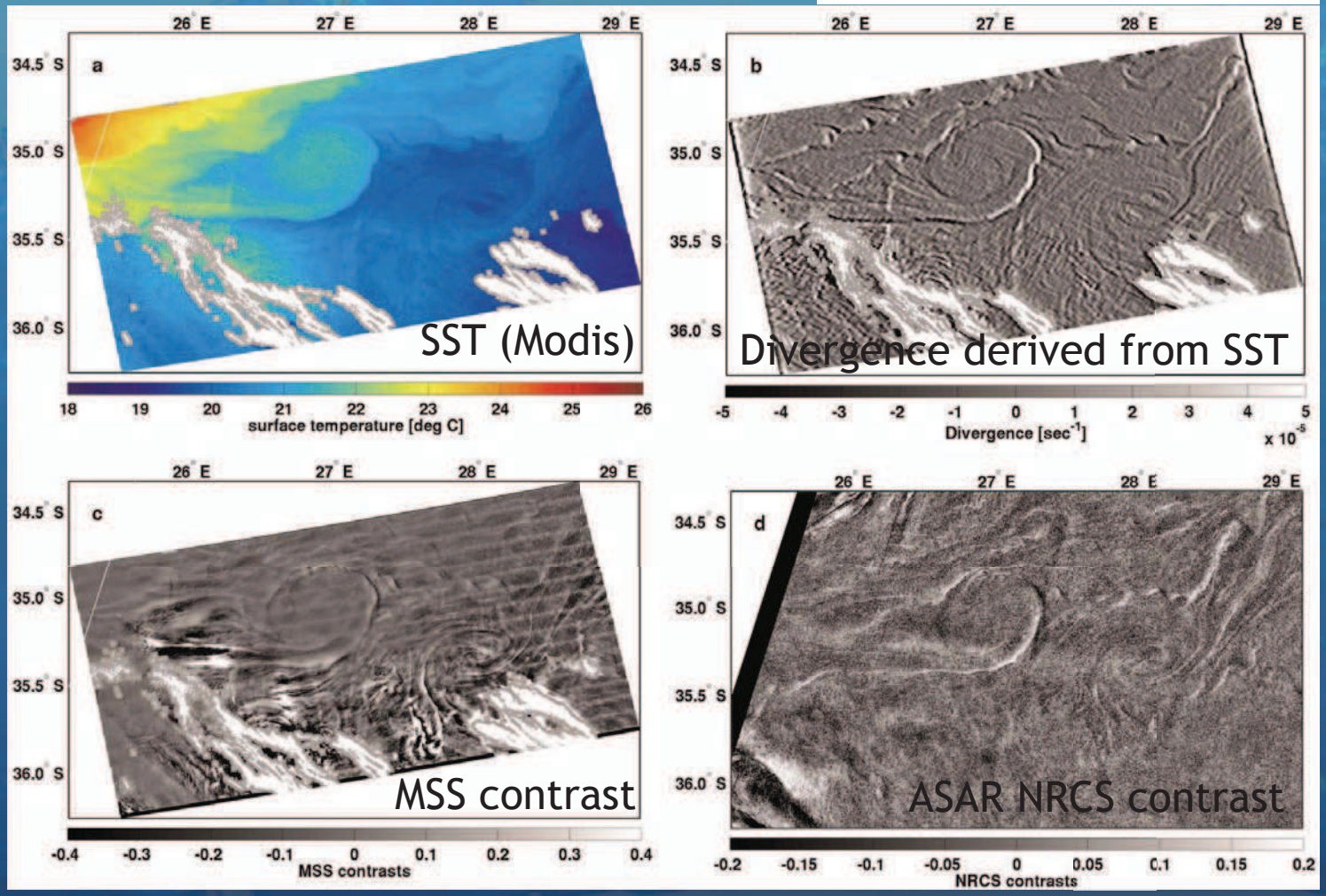
- Example of reconstructed current field from SST and SSH in context of SQG theory
- Coincident 2D fields of SSH, total currents and winds at high resolution would deliver high scientific added value

Isern-Fontanet et al., LPS 2013



Synergy with Sentinel-3

Kudryavtsev et al., 2012



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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
  - Christine Gommenginger
  - cg1@noc.ac.uk
  - National Oceanography Centre, Southampton, UK