SEASTAR: a new mission concept for high-resolution imaging of ocean surface current and wind vectors from space

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& the international SEASTAR team

1 National Oceanography Centre, NATURAL ENVIRONMENT RESEARCH COUNCIL
2 Ifremer
3 AIRBUS DEFENCE & SPACE
4 Centre for EO Instrumentation
5 esa

SEASTAR

A mission to study ocean submesoscale dynamics and small-scale atmosphere-ocean processes in coastal, shelf and polar seas

Proposed by

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With support from (20 people max)

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(10) LOCEAN, Institut Pierre Simon Laplace, France;
(11) KNMI, The Netherlands;
(12) Nansen Environmental and Remote Sensing Center (NERSC), Norway;
(13) Northern Research Institute (NORUT), Norway;
(14) Rutgers University, USA;
(15) University of Melbourne, Australia;
(16) The Met Office, UK;
(17) RSMAS, University of Miami, USA;
(18) University of Southampton, UK;
(19) University of Victoria, Canada;

SEASTAR for ESA EE10

- Submitted March 2018 to ESA Earth Explorer 10 call for mission ideas
- Led by NOC and Ifremer
- Airbus Defence & Space Ltd (UK)
- Proposal team 20 people (limited)
- Full SEASTAR team counts over 70 scientists and engineers
-

SPOILER ALERT !

SEASTAR NOT selected for EE10 despite excellent reviews

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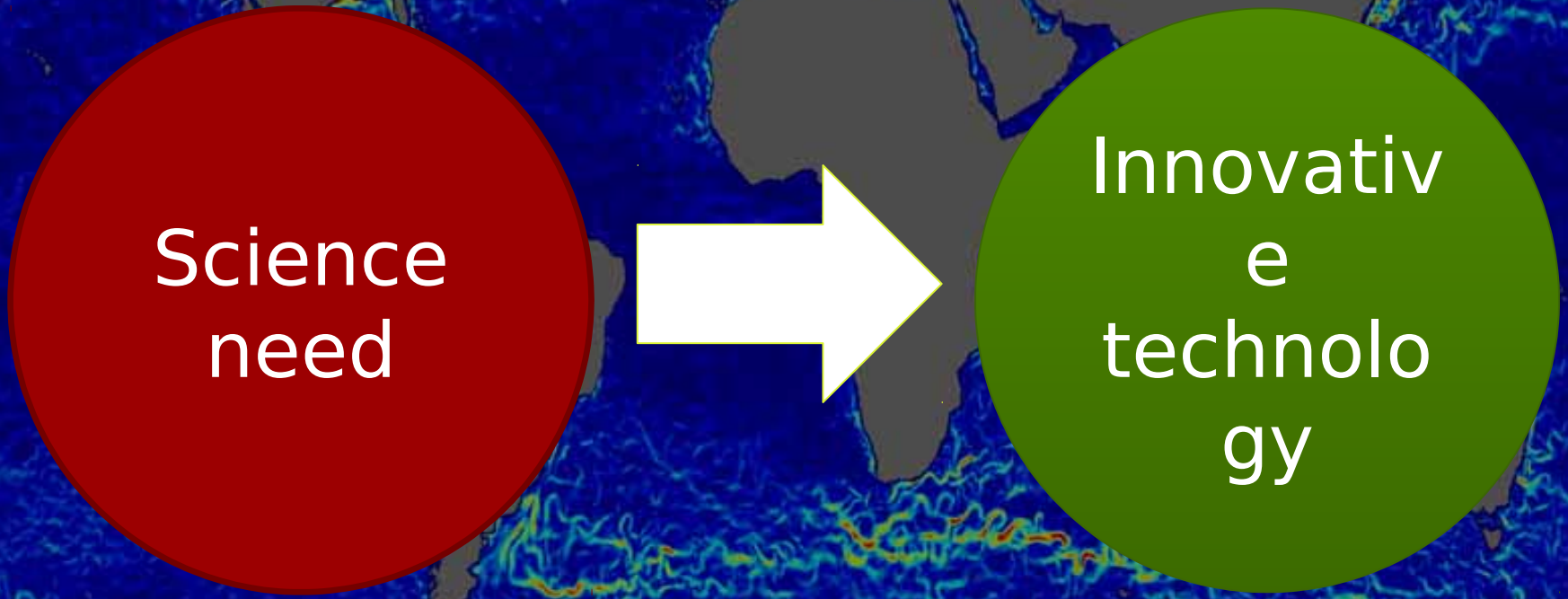
- The End ?
- Non!
- Let’s recall what ESA has just turned down…

…and see what we do next…

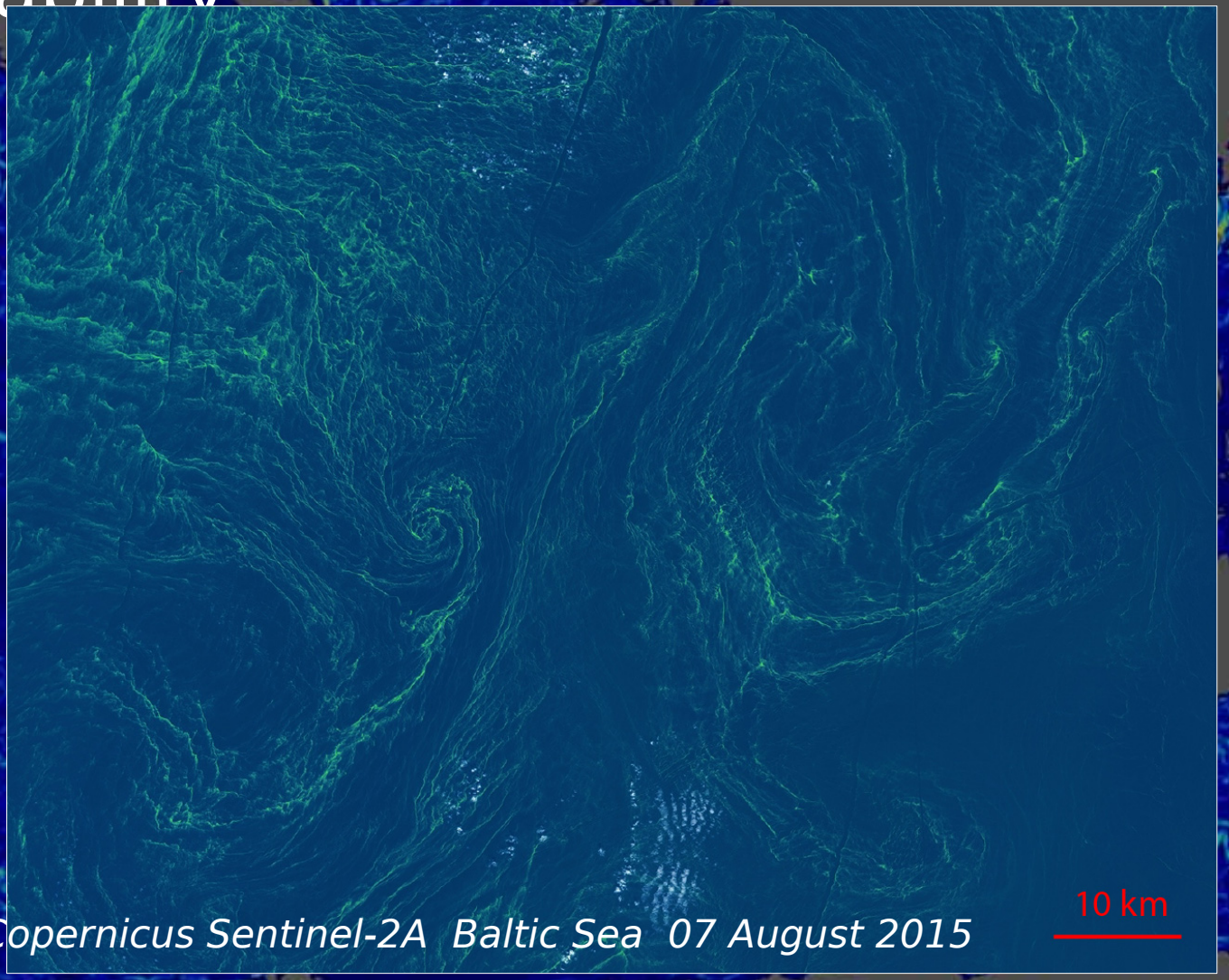
ESA Earth Explorer philosophy
(my understanding until recently)

- "Scientific excellence with innovative technology"



Requirements for Science Readiness levels and Technology Readiness levels

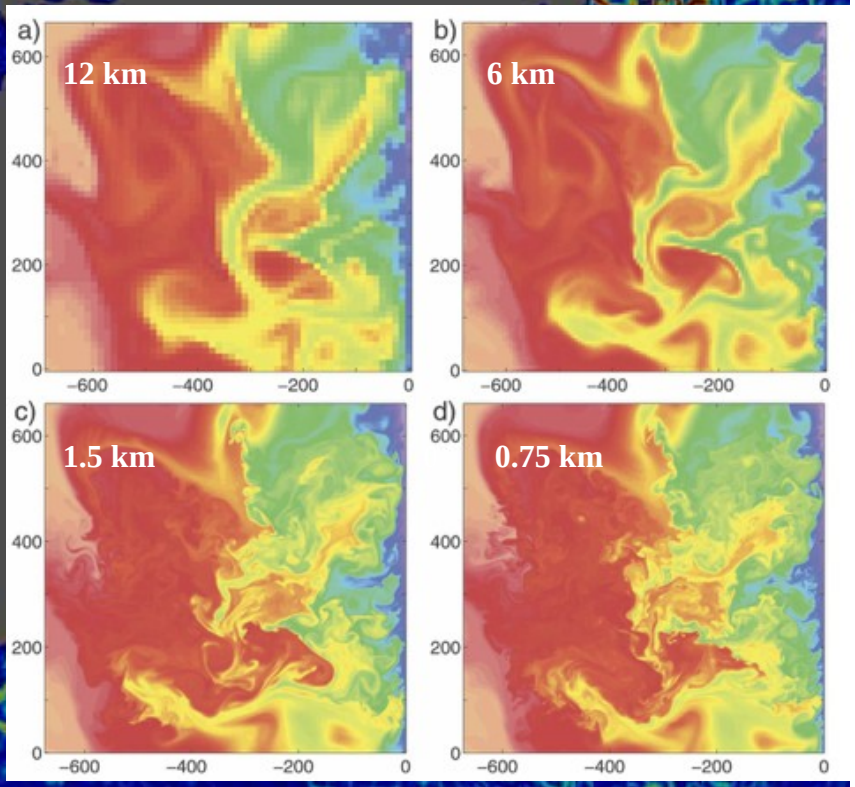
Motivation: Small scale ocean variability



Copernicus Sentinel-2A Baltic Sea 07 August 2015

The need for 1km resolution in the ocean ?

- Numerical models predict that ocean dynamics change dramatically ~ 1km scales
  - Atmosphere/ocean coupling
  - upper ocean mixing & vertical transport
  - high impact on ocean biogeochemistry
  - Key role of ageostrophic currents & surface winds
- Significant impact of 1km scale features on global & climatic scales
  - Impact on models used for forecasting and climate projections
  - Synoptic observations needed for better parameterisations in models



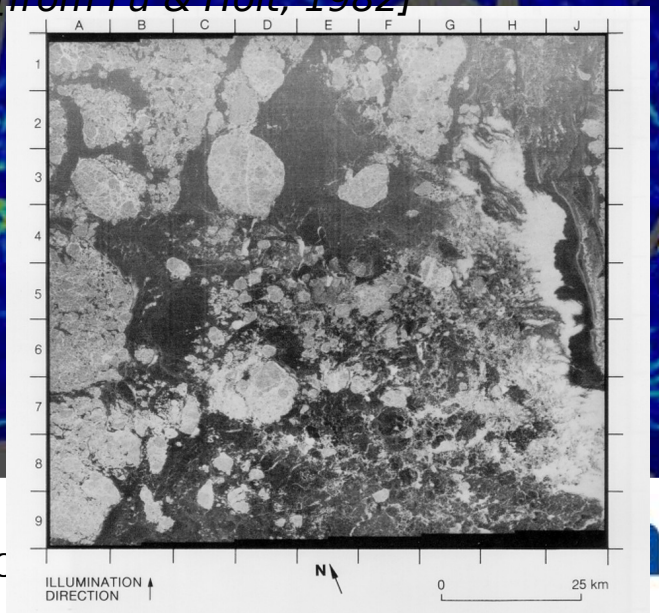
Model sea temperature at 10m depth [After Capet, McWilliams et al., 2008]

Role of 1km scales in coastal, shelf & polar seas ?

- Coastal/shelf seas dominated by small scales
  - more dynamic & more varied processes than open ocean
    - e.g. changing bathymetry, coastlines, tides…
  - more relevant to human activities
    - E.g. Fisheries, coastal erosion, maritime transport, pollution..
  - Need for new synoptic measurements of currents, winds and waves to support high-resolution coastal/ shelf models

- Currents, winds and waves in polar seas
  - Responsible for sea ice breakup, floes size distribution & dynamics of ice growth/decay
  - scientifically and strategically important regions
  - Very remote and challenging environment
  - Need for new synoptic measurements of currents, winds and waves to develop and improve high-resolution polar models

Seasat L-band SAR over sea ice [from Fu & Holt, 1982]



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SEASTAR scientific objectives

- Prime objective
  - "to address the observational gap for synoptic measurements of ocean surface currents and winds at the critical 1 km scales that are required to understand, model and forecast ocean submesoscale dynamics, air-sea interactions and small-scale processes in coastal, shelf and polar seas"

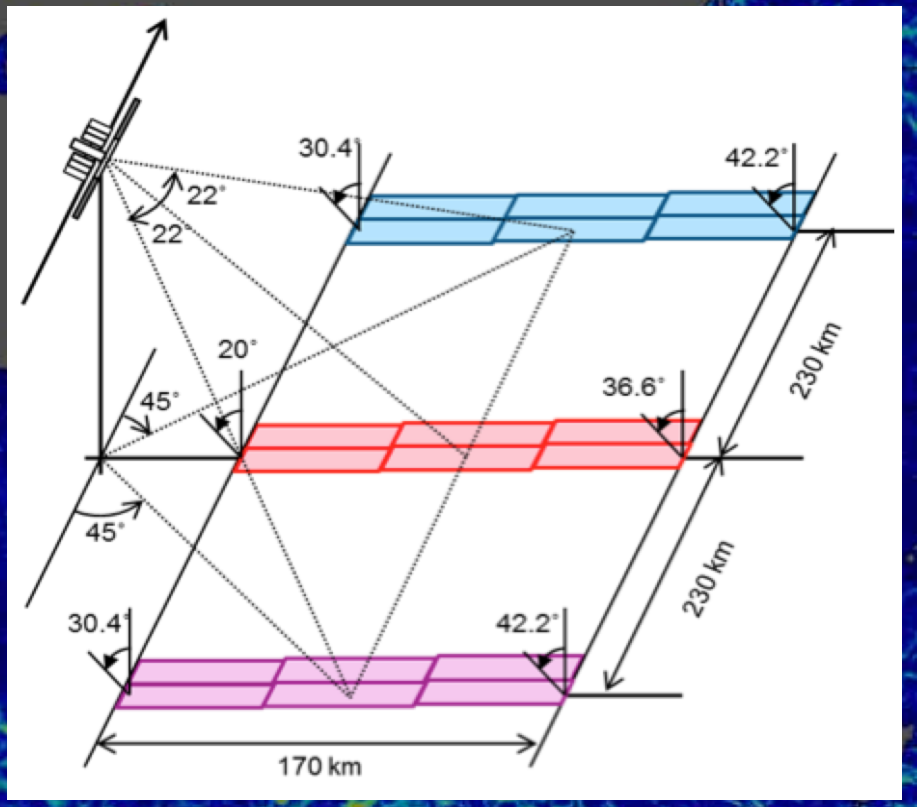
- Secondary & tertiary objectives (not mission drivers)
  - Improved sea ice drift vectors & directional wave spectra in coastal and Marginal Ice Zones
  - river flow speed & wind/currents over inland waters

SEASTAR mission concept

- Squinted Along-Track Interferometric SAR
  - Active microwave radar (Ku-band)
  - Uses Doppler shift between two successive SAR images to directly estimate ocean surface motion in two orthogonal lines-of-sight
- Unique new spaceborne observing capability for:
  - TOTAL surface currents (including ageostrophic currents)
  - total surface current VECTORS in a single-pass
  - high-accuracy current data at 1 km resolution
  - synoptic two-dimensional maps of the current field
  - Current vectors collocated with wind vectors and wave spectra
- Systematic mapping of ocean currents and winds at 1km resolution of coastal, polar and shelf seas and selected open ocean sites of special scientific interest

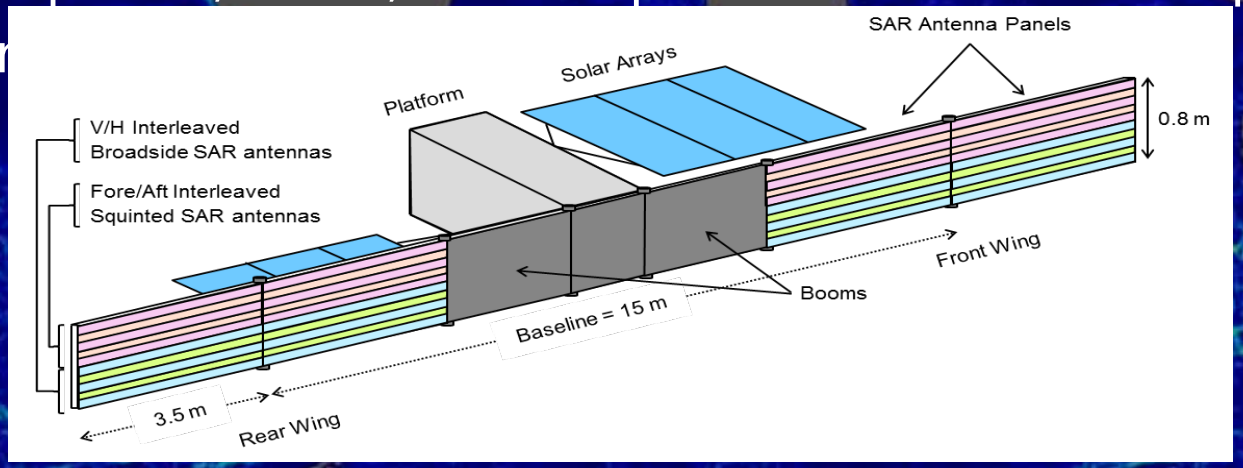
SEASTAR technical concept

- Squinted ATI SAR
  - Ku-band
  - Three azimuth looks (ASCAT-like)
  - Two squinted beams ± 45◦ from broadside (VV)
  - One broadside beam (VV & HH)
- 1 x 170km swath
  - 30 deg incidence (mid-swath)
  - Single-Look-Complex images: 30m x 150m (range x azimuth)
  - L2 product resolution: 1km



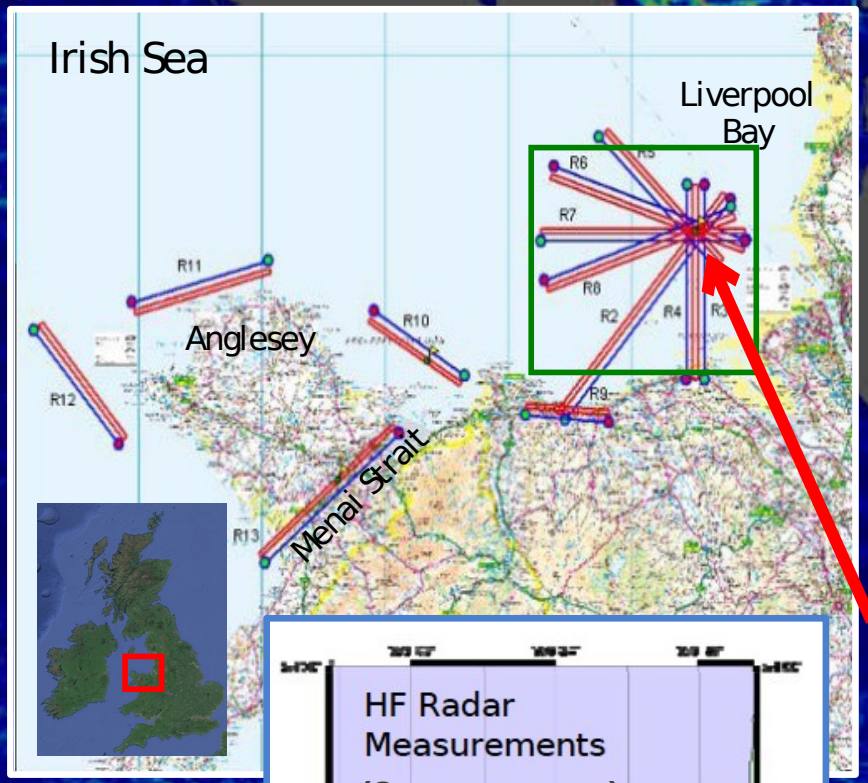
SEASTAR technical concept

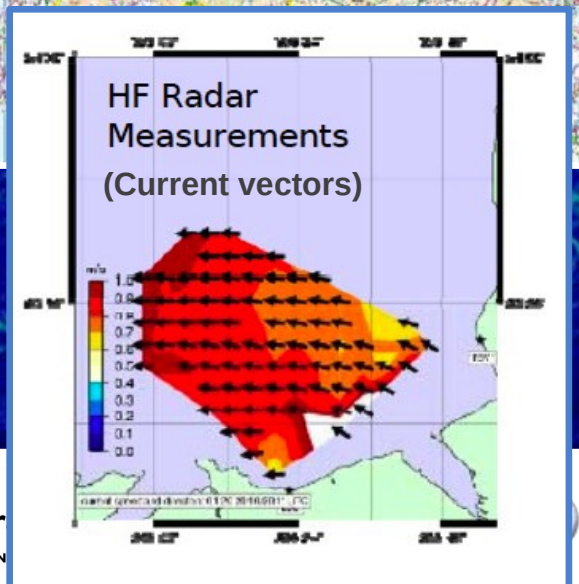
- Physical baseline: 15 m
- Multiple trade-offs to satisfy EE10 constraints, eg:
  - Single-sided operation (lighter structure to satisfy mass budget)
  - Operation only in coastal, shelf and polar seas (to drastically reduce power, mass, data requirements & cost compared to earlier



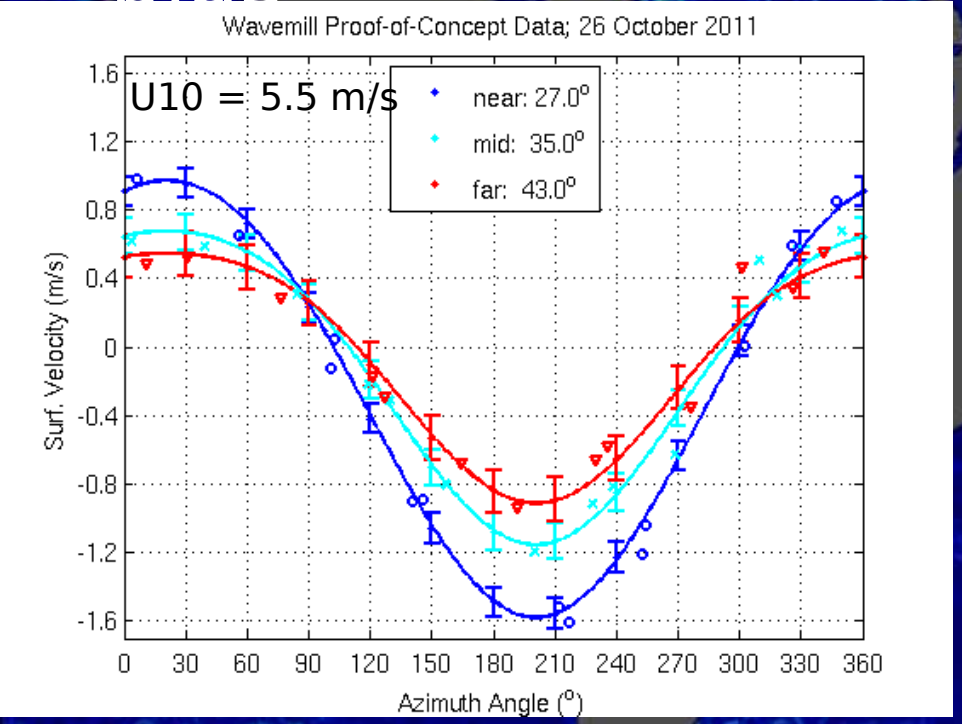
Scientific readiness: airborne demonstration

Martin et al., JGR, 2016

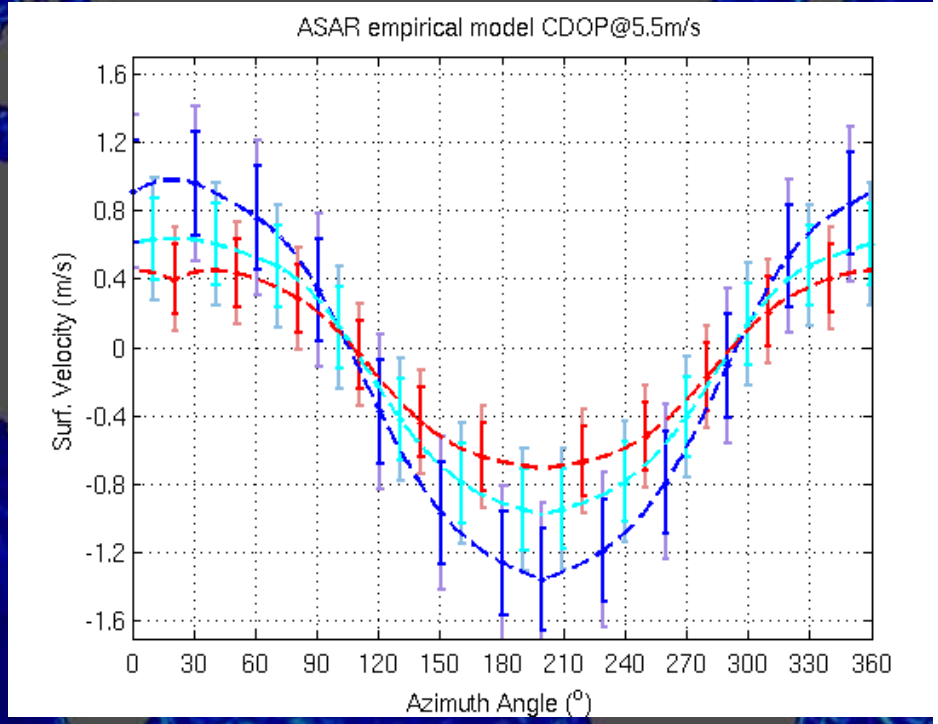




Scientific readiness: Wind-wave induced bias



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



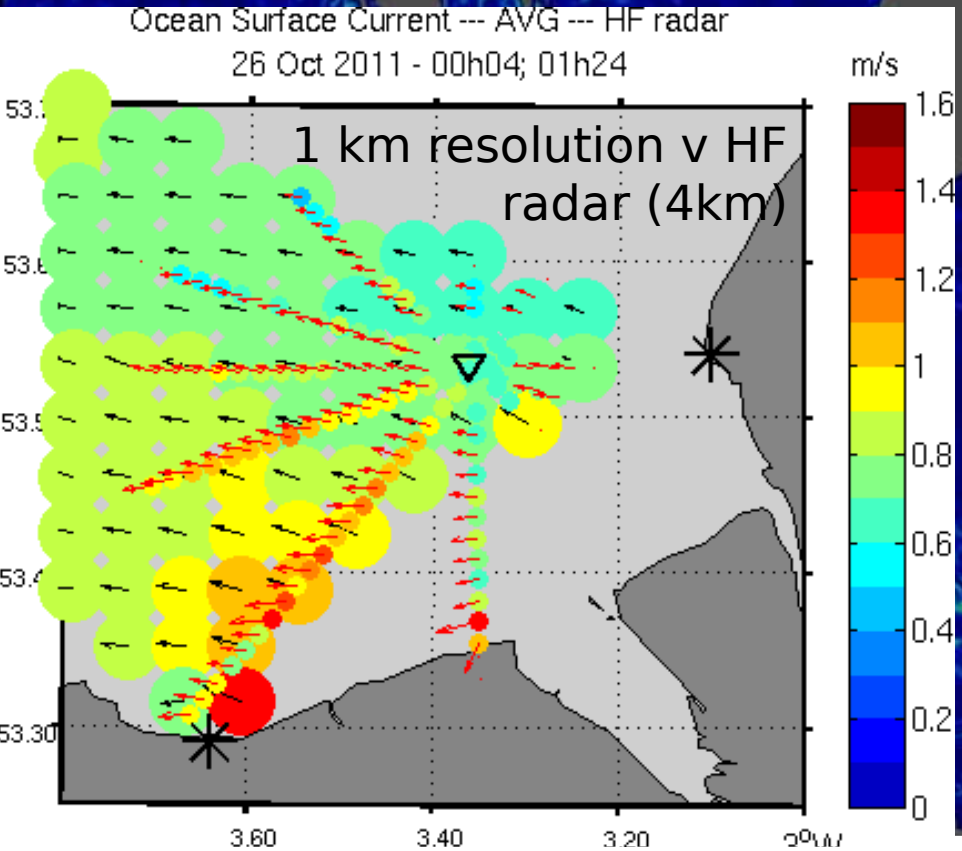
[Mouche et al., 2012] based on C-band Envisat ASAR satellite data

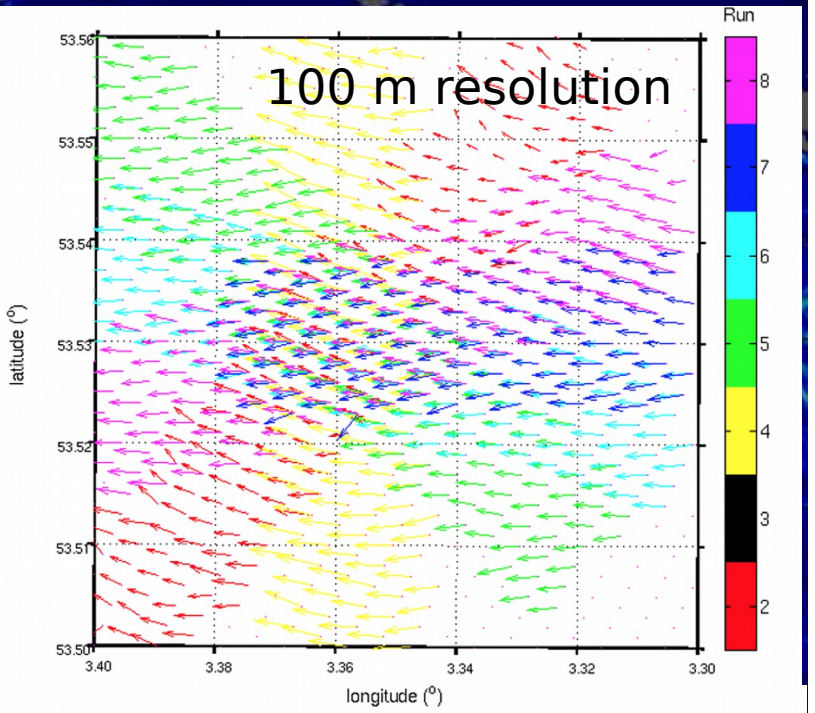
Microwave Doppler signals are dominated by effects of wind and waves on surface scatterers, which need to be removed to retrieve surface currents.

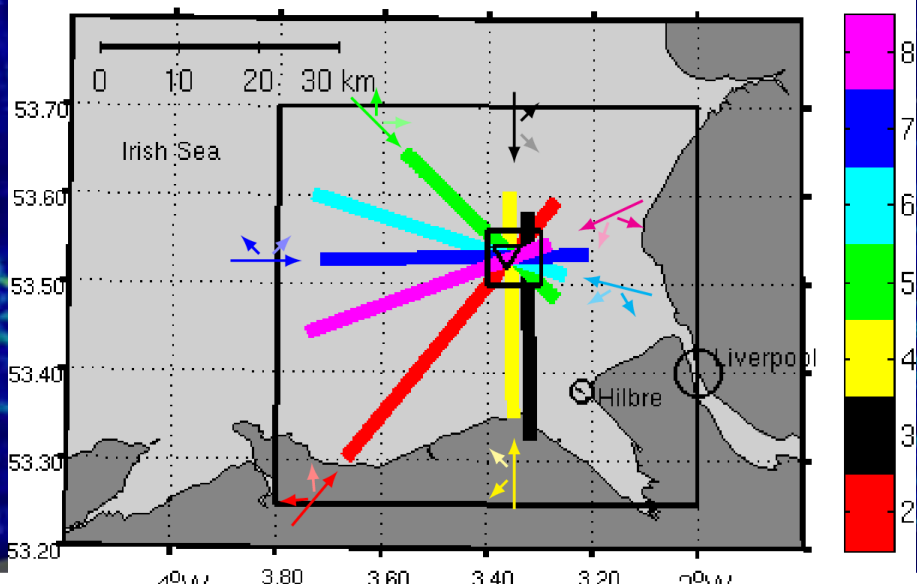
This applies to ALL Doppler radar signals over the ocean

Scientific readiness: Validation against independent data

Martin & Gommenginger, RSE, 2017







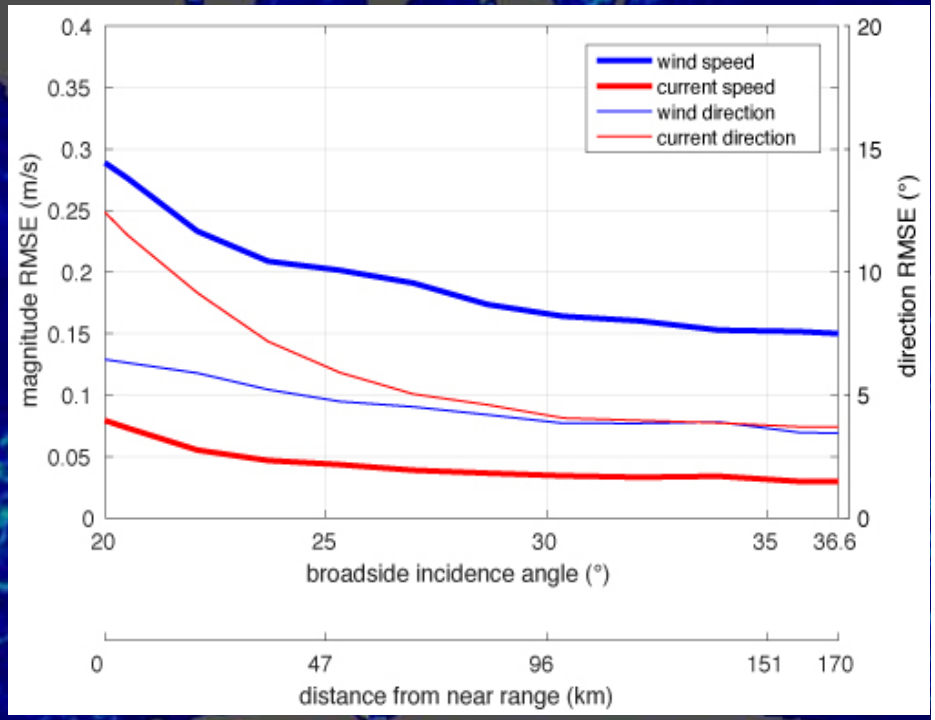
Typical performance for current vectors @ 1.5 km resolution against HF radar: RMSE better than 0.1 m/s; 7°

Scientific readiness: Geophysical inversion & performance assessment

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

Martin et al., RSE, 2018

- Bayesian approach to quantify performance for different instrument configurations and noise
- Working with Airbus to identify optimal instrument specifications
  - E.g. identified need for third-azimuth look to unambiguously retrieve both wind and current vectors
- Very good performance of proposed instrument specifications!



See talk by Adrien Martin on Thursday 13:50

Centre for EO Instrumentation

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- So…? Where did it go wrong ?

- The synopsis of the recommendations by the selection committee read:

"ACEO considers that SEASTAR is a unique Mission Idea as it would be the first along-track Ku-band (13.5 GHz) side-looking interferometric SAR in space, with a capability to produce 3 azimuth beams (fore, aft, and broadside) aiming at 2D ocean surface current measurements and wind vectors at 1 km resolution with unprecedented accuracy.

The Mission Idea is judged by ACEO to be of very high quality and clarity, which fulfils the scientific evaluation criteria. Further, the Mission Idea is highly innovative and highly complementary with SKIM (EE9 candidate) as a medium-resolution current-wave interaction mission candidate. Also, the proposed roadmap for technology pre-developments is deemed credible.

Nevertheless, ACEO recognises that the mass and power consumption and complexity of the payload require a large customised platform, which is expected to drive the cost of the SEASTAR Mission Idea.

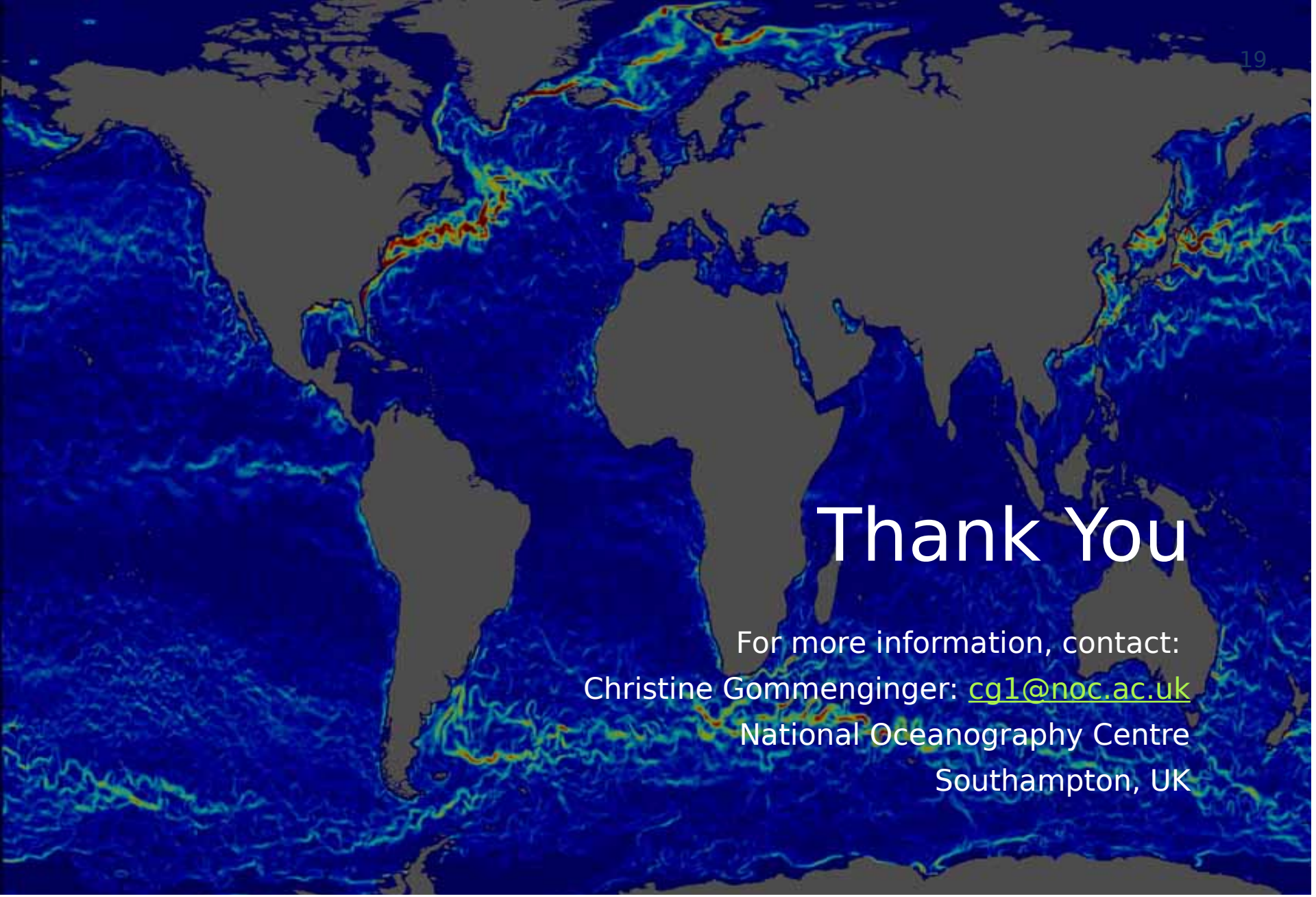
ACEO recommends to potentially pursue other avenues for this mission due to high likelihood to exceed the target cost for EE10."

What next ?

- SEASTAR has high scientific merit, widespread support across multiple disciplines and countries, high scientific and technological maturity
  - This is not the time to give up !
  - *“The only thing they could find wrong with it is the money!”*
- SEASTAR remains the only mission concept able to address the observational needs for high-resolution ocean surface current and wind vectors in coastal, shelf and polar seas
  - Complementary with SWOT, SKIM and DopplerScatt/WaCM
- We are now looking for “other avenues” to take this concept towards implementation, including outside ESA

Summary & Outlook

- SEASTAR is a highly-innovative mission concept proposed to ESA EE10 deliver high-accuracy two-dimensional maps of ocean surface current and wind vectors at 1km resolution
- Uniquely able to fill the observational gap to understand, model and forecast ocean submesoscale dynamics, air-sea interactions and small-scale processes in coastal, shelf and polar seas
  - Complementary with SWOT, SKIM and DopplerScatt/WaCM
- SEASTAR reached high levels of scientific & technological maturity…
- …but was not selected by ESA for EE10 due to a perceived likelihood of exceeding EE10 target cost
- Now looking for “other avenues” to take SEASTAR towards implementation and launch



Thank You

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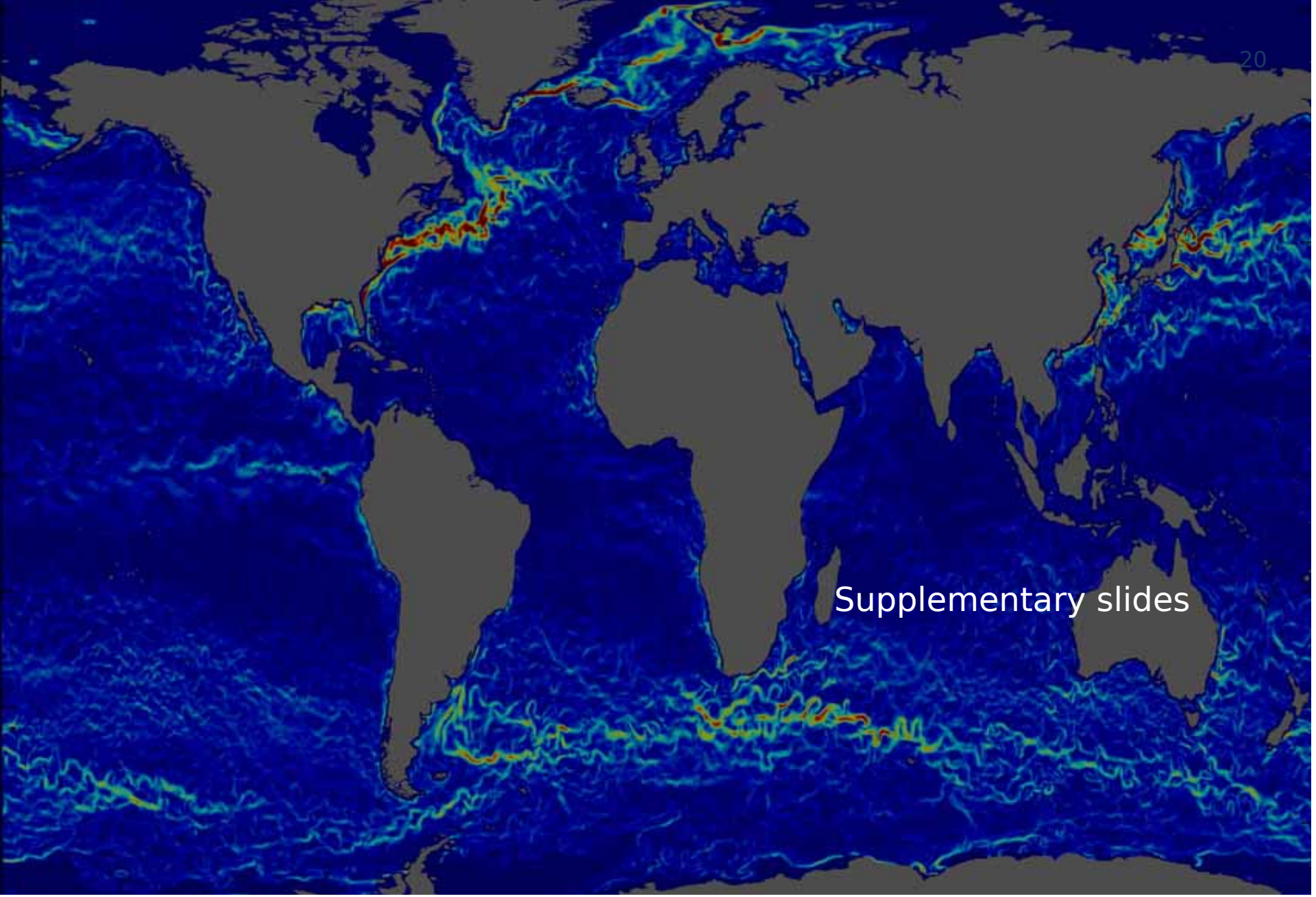

Supplementary slides

From ATI to SEASTAR

- ATI -> squinted ATI -> Dual-Beam Interferometer -> Wavemill -> OSCM -> SEASTAR

	Dual-beam interferometer (DBI) *[174]*	Wavemill	OSCM	SEASTAR
Status	Airborne	Concept & Airborne	Concept	Concept & Airborne
Doppler-related observables	Current Vectors	Current Vector and Sea Surface Height	Current Vectors	Current Vectors and Wind vectors
Beams	2 squinted beams	2 squinted beams	2 squinted beams	2 squinted beams + 1 broadside beam
Swath	Dual-sided 1-5km (airborne)	Dual-sided 2 x 100km	Dual-sided 2 x 100km	Single-sided 1 x 170km
Mid-swath incidence (from nadir)	70°	20°	30°	39°(squint)
Polarisation	C-band; VV	Ku-band ; VV	Ku-band ; VV & HH in squinted directions	Ku-band ; VV (squint) + VV&HH (broadside)
Product resolution	100 m (airborne)	1km	4km	1km

Table 2: Characteristics and differences between different squinted ATI instruments and concepts

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	SEASTAR	Conventional SAR	TanDEM-X ATI	SWOT	EE9 SKIM	DopSCAT /WaCM
2D map of current vector field	✓	One component only (radial)	One component only (radial)	✓	✓	✓
Total ocean surface current	✓	Needs ancillary input for sea state (WASV) correction	Needs ancillary input for sea state (WASV) correction	Geostrophic currents only	✓	✓
1km resolution	✓	✓	✓	10-15 km	Doppler: 6km OSCV: 40 km	25km/5km
OSCV RMS Error	0.1 m/s at 1km	S1: 0.4 m/s at $2km^2$	0.1 m/s at 1km	No requirement on currents	0.1 m/s at 40km	0.2m/s at 25km
Coincident wind vector map	✓	Needs ancillary input for wind direction	Needs ancillary input for wind direction	Wind speed (TBD)	No wind measurement	✓
Coincident directional wave spectra	✓	✓	✓	SWH only	✓	No wave measurement
Valid close to coast	✓	✓	✓	Geostrophy not generally applicable in coastal waters	Not aimed at coastal zone; performance degrades near land	Not aimed at coastal zone