CEOI 5th and 6th Open Calls
Final Review

Wavemill CEOI Mission and Instrument Study

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British Medical Association
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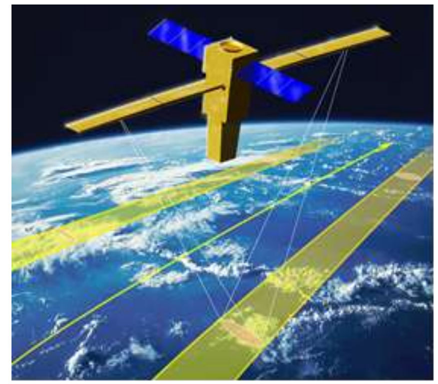
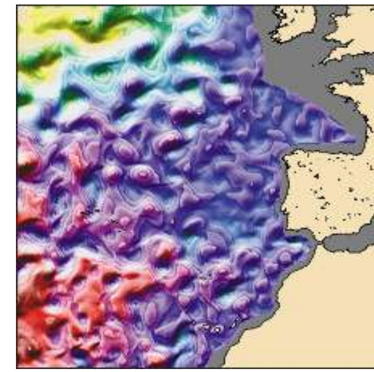
Introduction

- Wavemill is a mission/instrument concept for a space-borne ***interferometric synthetic aperture radar (SAR)***





- Key objectives measure:
1. Sea surface currents
2. Sea surface winds
3. Sea surface height

- It accomplishes this via a unique along track (AIT) and cross track (XTI) interferometry simultaneously

- Science case
  - Currents have important consequences to many stakeholders – e.g. climate change modelling, meteorology, shipping, ocean commerce.
  - There is no present-day global measure of accurate, regular-repeat, global currents.
- Project partners:
  - The National Oceanography Centre (NOC, Southampton), via Dr Christine Gommenginger, is providing input to help define science requirements.

Technical work – Overview

- Main goal of this study was to advance the overall mission-system and instrument design.
- An overriding constraint for this mission is that it fit within the VEGA launch fairing which is expected to be the imposed as ESA's Earth Explorer 9 launch vehicle.
- There were **six specific critical areas:**

- ❑ Help define mission baseline science requirements
- ❑ Assess different orbital options
- ❑ Review key antenna design
- ❑ Reduce overall mass/power of the mission concept
- ❑ Develop a platform design that fits within the VEGA
- ❑ Decide on data processing options

Technical work – Science requirements

- Meeting established between NOC's Christine Gommenginger and Astrium Ltd. to determine *baseline science requirements*
- Key topics included timeliness of data retrieval, accuracy of measurement (currents, sea surface height and winds), mission lifetime, data products, orbital coverage, etc.
- One key example….. ocean current accuracies…

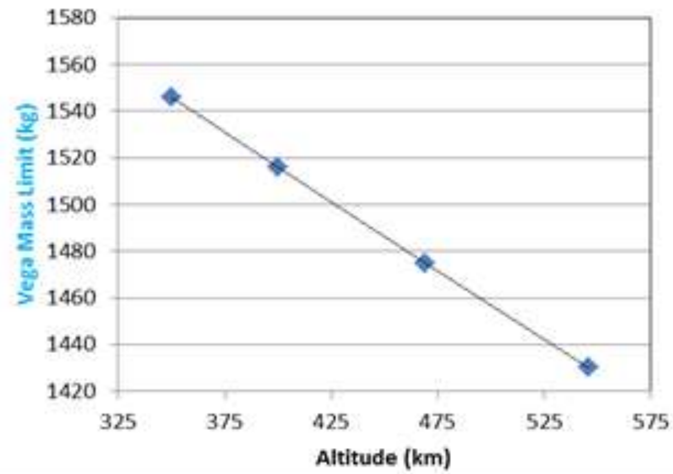
Key Science Requirements and Associated Drivers			
Topic and MRD Req. Identifier	**Description**	**Mission/System Drivers**	**Instrument Drivers**
OPEN OCEAN SURFACE CURRENTS: (MRD: WM-REQ: 140 TO 160)	Open ocean currents 2.5-500 cm/s, with horizontal resolution of 1.0-2.5km, and sampling of 5-10 days.	10-day sampling is best to-date, but at 100's km apart. Sampling drives orbit selection. At the moment no real current sampling, implying no hard lower limits.	Numbers for current retrieval accuracy have been optimistic since no wave or sea-state correction was included. Needs end-to-end simulation

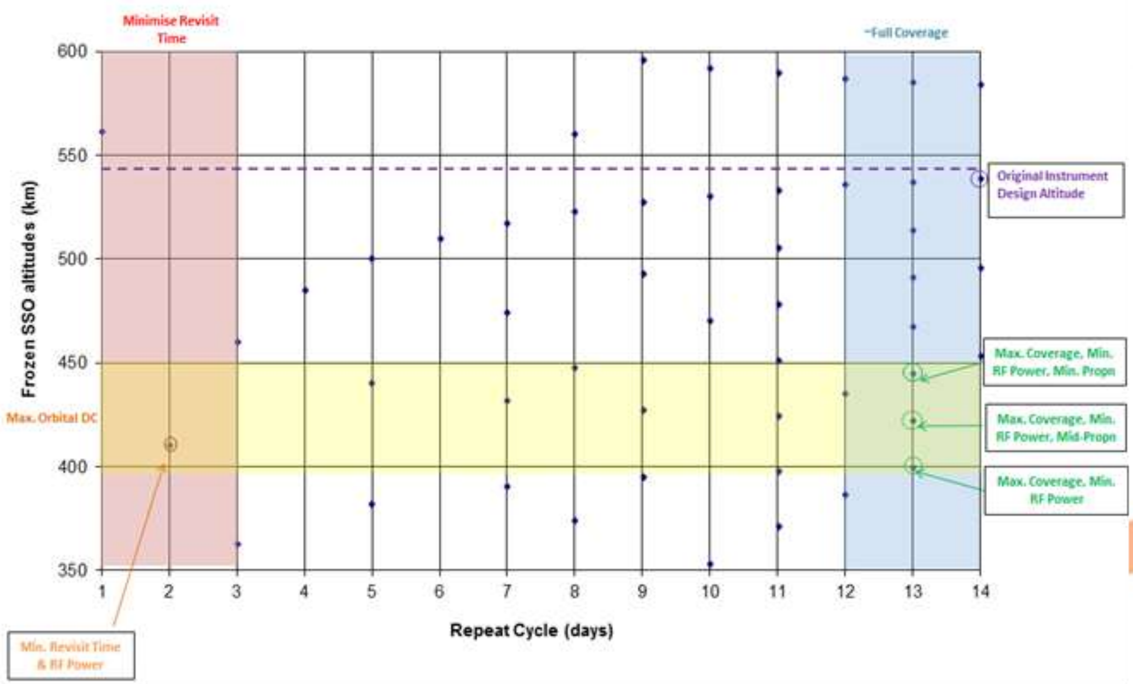
Key Science Requirements and Associated Drivers			
Topic and MRD Req. Identifier	**Description**	**Mission/System Drivers**	**Instrument Drivers**
TIMELINESS: (MRD: WM-REQ: 40 TO 70)	Timeliness: Non-Real-Critical (NTC) data shall be within 30-days, Short-Time-Critical (STC) within 48-hours, Near-Real-Time (NRT) within 3 hours (Prob. =75%), and 6 hours (Prob. = 95%).	Typical, but shall not drive the mission. Current products are the most time critical. This requirement impacts on-board data storage systems and the downlink rate, particularly given the high data-throughput.	N/A
SURFACE CURRENTS: (MRD: WM-REQ: 140 TO 160)	Open ocean currents 2.5-500 cm/s, with horizontal resolution of 1.0-2.5km, and sampling of 5-10 days.	date, but at 100's km apart. Sampling drives orbit selection. At the moment no real current sampling, implying no hard lower	Numbers for current retrieval accuracy have been optimistic since no wave or sea-state correction was included. Needs end-to-end simulation
COASTAL OCEAN CURRENTS: (MRD: WM-REQ: 170 TO 220)	Costal ocean currents of 5-500cm/s, with an accuracy <5cm/s, and horizontal resolution of 0.3-2.5km, over 0-360° range at <10° accuracy. Sampling of 5-10 days.	At moment there is no extensive coastal current sampling, implying no hard upper limits.	Smaller cell resolution near coast is important (~50m), but requires a higher SNR.
SEA SURFACE HEIGHT: (MRD: WM-REQ: 230 TO 250)	Sea Surface Height (SSH) with an absolute accuracy with the swath of <25cm, and relative accuracy of 2cm. Relative SSH spatial average of 1-10km to measure mesoscale (~100km)	Wavemill will be a sea-current mission, not SSH. 25 cm is absolute height of swath, 2cm relative accuracy within swath. Must measure mesoscales at <1-10km resolution.	Absolute accuracy requirements flow down to how accurately the phase centres of the antenna can be measured. 25cm implies 0.125mm, but must be re-assessed. This accuracy level is technically challenging.
OCEAN WAVES AND SWELLS: (MRD: WM-REQ: 260 TO 360)	Significant wave height (HS) to 0.25-20m, with accuracy of 0.25m or 5% of HS.	Requirements met if SSH and Current requirements met.	N/A
WIND VECTOR OVER OCEAN: (MRD: WM-REQ:	Open ocean 3-70m/s, accuracy of 1.5m/s for 3-20m/s, over 0-360°.	N/A	N/A

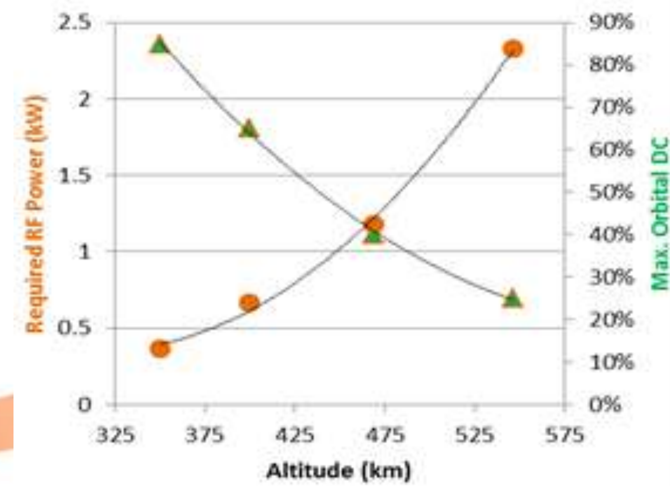
Key Mission/Instrument Requirements and Flow-Down			
Topic and Req. Identifier	**Description**	**Mission/System Drivers**	**Instrument Drivers**
MISSION LIFETIME: (MRD: WM-REQ: 960 TO 970)	The Wavemill mission shall be 6 years in duration: 3 years nominal + 3 years extended. A 12 month science mission is a minimum.	Mission needs to be minimum 3-5 years to be a serious EE9 contender.	N/A
DATA PRODUCTS: (MRD: WM-REQ: 1010 TO 1020)	Mission shall produce Single-Look-Complex (SLC) data with no on-board processing.	Both data-downlink for unprocessed data, and on-board processing is very challenging. Will NEED ~1% raw data for calibration etc.	Cycling instrument in different duty cycles can effect component lifetimes.
OPERATION MODES: (MRD: WM-REQ: 1060 TO 1200)	Two different modes: Full Swath with two swaths, and Wave Mode with swaths spaced at some TBC along track distance.	Full Swath data-rate is going to be too high in standard configuration. Wave Mode spacing of 100km misses mesoscale and is useless.	Cycling instrument components (e.g. High Power Amplifier HPA) in Wave Mode can positively affect data/power rate, but negatively affect component lifetimes.
GLOBAL COVERAGE: (MRD: WM-REQ: 1210 TO 1290)	Wavemill should cover inland waters.	Small area compared to oceans, but operationally hard to switch on over certain lakes/rivers.	N/A
ORBIT: (MRD: WM-REQ: 1210 TO 1290)	The orbit shall allow for mesoscale measurement at Latitude 45° N/S, with spatial and temporal resolution of 1-50km and 5-10 days respectively.	Will meet requirement based on global coverage, but could lead to reduced resolution at higher latitudes	N/A
ORBIT DETERMINATION: (MRD: WM-REQ: 1040)	Wavemill shall be capable of precise pointing w.r.t satellite using Precise Orbit Determination (POD) system.	POD system must be able to provide antenna required TBC stability to meet science requirement.	SAR instrumentation will not function without effective POD.
LAUNCH VEHICLE: (MRD: WM-REQ: Unspecified in MRD)	Wavemill shall be of sized both in terms of mass and dimensions, to fit a VEGA class launch vehicle	Solar array and radiator sizing for required power, plus mass are all critical in Wavemill concept.	Instrument power requirements drive available SA and radiator sizing.

Technical work – Orbital trade-off

- Previous studies had nominal altitude at 546 km.
- For mostly mass/power considerations, a lower altitude is better. Instrument power reduces with reduced duty-cycle (DC).
- *Ideal choice is now near a 400km, 13-day repeat, dawn-dusk, Sun-Sync orbit.*

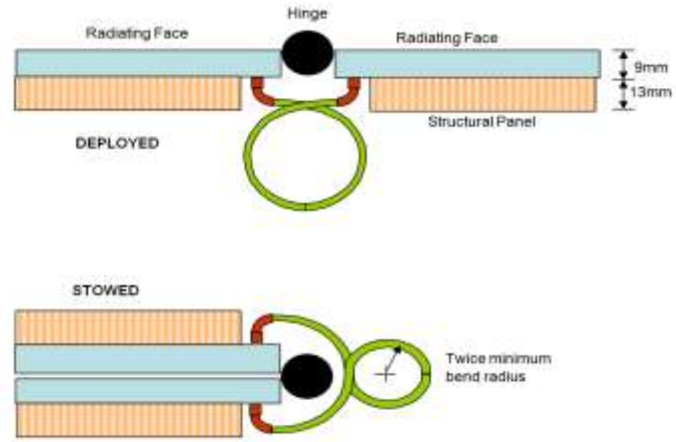


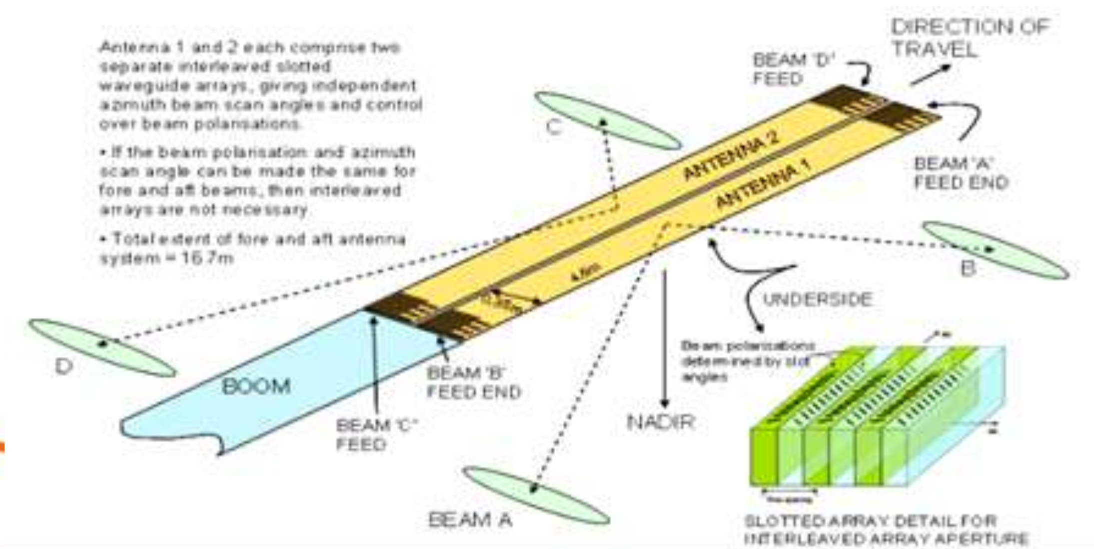


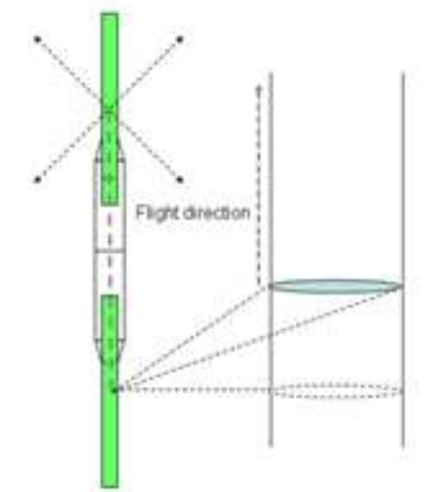


Technical work – Antenna design review

- Antenna design review focused on reducing power, mass and size of instrument payload
- Antenna baseline length is ~17m, so a folding-joint design was investigated
- Losses due to fold are present but acceptable
- Investigating CFRP antenna structure resulted in little mass advantage (~20kg), but introduces unwanted thermo-elastic and manufacturing complexities.







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Technical work – Mission Mass/Power

- Previous studies were significantly (~25%) over launch mass/power limits, and packaging was problematic.
- Re-analysis of critical subsystems, reduction in orbit altitude, reduction in operational duty cycle, incorporation higher efficiency antenna components, etc.
- Mass and power now fall within limits compatible with the VEGA launcher while keeping signal/science return from instrument constant.

Overall Mass Budget

Subsystem	Current Best Estimate (kg)	Design Maturity Margin (kg)	Total CBE + DMM (kg)
Data Handling Subsystem	47.0	4.6	51.6
Power Subsystem	121.8	13.3	135.1
Harness	60.0	18.0	78.0
X Band Communications Subsystem	10.9	0.9	11.7
S-Band Communications Subsystem	9.9	0.8	10.7
AOCS	112.0	5.6	117.6
Structure	197.8	39.6	237.4
Thermal Subsystem	70.7	16.9	87.7
Propulsion	18.7	1.4	20.1
PLATFORM / SERVICE MODULE TOTAL	**648.8**	**101.0**	**749.8**
Payload	313.5	62.2	375.6
PAYLOAD / PAYLOAD MODULE TOTAL	**313.5**	**62.2**	**375.6**
DRY TOTAL	**962.2**		**1125.4**
System Mass Margin		15%	1294.2
DRY TOTAL (incl. System Margin)			**1294.2**
Propellant			153.9
Residuals + Uncertainty			1.6
Pressurant			0.2
WET MASS			**1449.9**
Launch Vehicle Adapter (VEGA Users Day July 2012)			70.0
WET MASS incl. Launch Vehicle Adapter			**1519.9**
Launch Vehicle Capability	**VEGA Manual at 400km**		**1516.7**
Mass Margin to Launch Vehicle Capability			**-3.2**

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Launch Vehicle Capability	**VEGA Manual at 400km**	**1516.7**
Mass Margin to Launch Vehicle Capability		**-3.2**

Required Solar Array Power

Parameter	Symbol	Value
Average power during daylight and eclipse (W)	P_d, P_e	1607.9
Orbital altitude (km)	h	400
Eclipse duration (min)	T_e	21.3
Daylight duration (min)	T_d	71.0
Design lifetime (years)	L	5
Path efficiency during eclipse	X_e	0.9118
Path efficiency during daylight	X_d	0.94
Power needed from SA (W)	$P_{SA} = \dfrac{\dfrac{P_e T_e}{X_e} + \dfrac{P_d T_d}{X_d}}{T_d}$	**2240.4**
SA Area (m^2)	-	**10.8**
Corresponding SA Mass (kg) (w. 20% margin)	-	**44.0**
Resultant Radiator Area for Thermal Dissipation (m^2)	-	**8.4**

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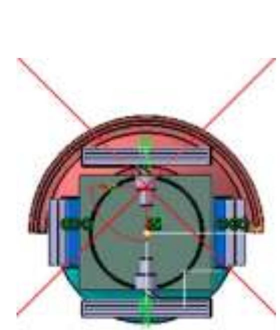
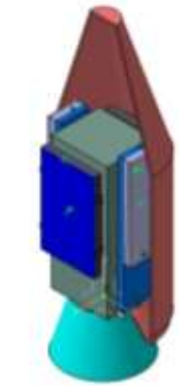
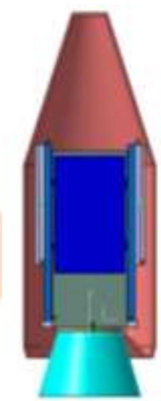
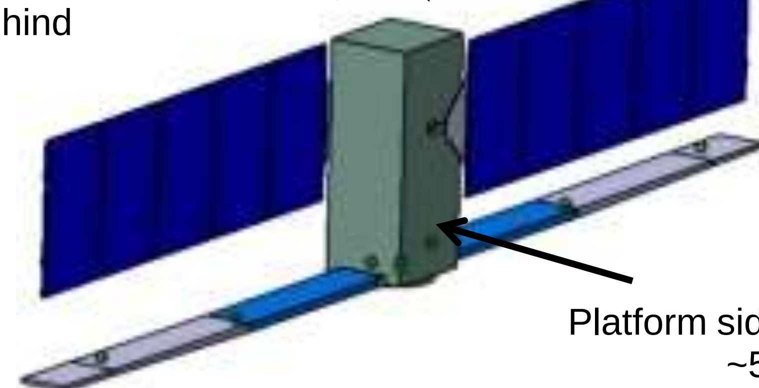
Technical work – Platform design

- Key constraint was to fit within VEGA fairing
- Folding antenna design improved packaging efficiency considerably
- Power available from solar array area is now *more* than that required by platform/payload
- Limiting factor is free structure area for radiators
- Overall, a feasible configuration for VEGA









Technical work – Data Handling/Processing

- Instrument output is in the range of 1 – 3 Gbits/s, depending on the compression scheme employed
- For comparison, the fastest X-band data-rate is around 0.5Gbits/s. Given a window of only of 5-10 minutes exists for downlink, downlinking raw data is not a viable option.
- One possible solution: Pre-process the raw data on-board, and directly produce the interferograms before downlink. This could reduce the required data-rate to ~20 - 30 Kbits/s.
- Downside: Requires real-time knowledge of platform/antenna attitude and baseline-length

Achievements/positioning

Achievements against goals:

- Overall study aim was to advance our the Wavemill concept at system and instrument level, adding to that state of understanding of each critical area.

- Particularly from the mission-systems side, we now have for the first time, a credible baseline mission for Wavemill.

Positioning achieved:

- We are now in a good strategic position to bid for the ESA Wavemill Phase-0, and build up a mission concept moving forward to the Earth Explorer 9 call.

Knowledge exchange:

- Significant exchange occurred between the team members from Astrium and the NOC during the science requirement discussions.

Achievements/positioning

UK Capability enhancement:

- Through this study, Astrium Ltd. has enhanced its position as a possible instrument prime, as well as possibly contributing to the platform components/design.

- NOC's Christine Gommenginger has been further identified as a possible UK candidate as the science PI for Wavemill.

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Roadmap/Future Steps

- Creation of in-house software to directly model squinted SAR echo data and translate that to achievable science data.
- Further development of a baseline laser metrology system will need to be performed, and a development schedule constructed.
- Longer term, the Ku-band klystron will have to be space qualified.
- The RF components on the transmit path such as the filters and switches will require development to higher power handling
- A bottom-up structural analysis will need to be performed.
- Bread-boarding of the antenna system will need to be completed and is currently undergoing a definition phase for a future study.

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