The Wavemill Mission: Initial Proof-of-Concept Results and Needs from GlobCurrent

GlobCurrent
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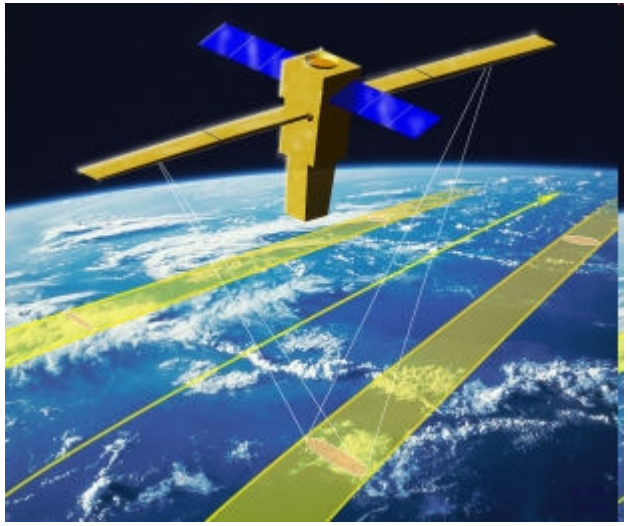
Contents

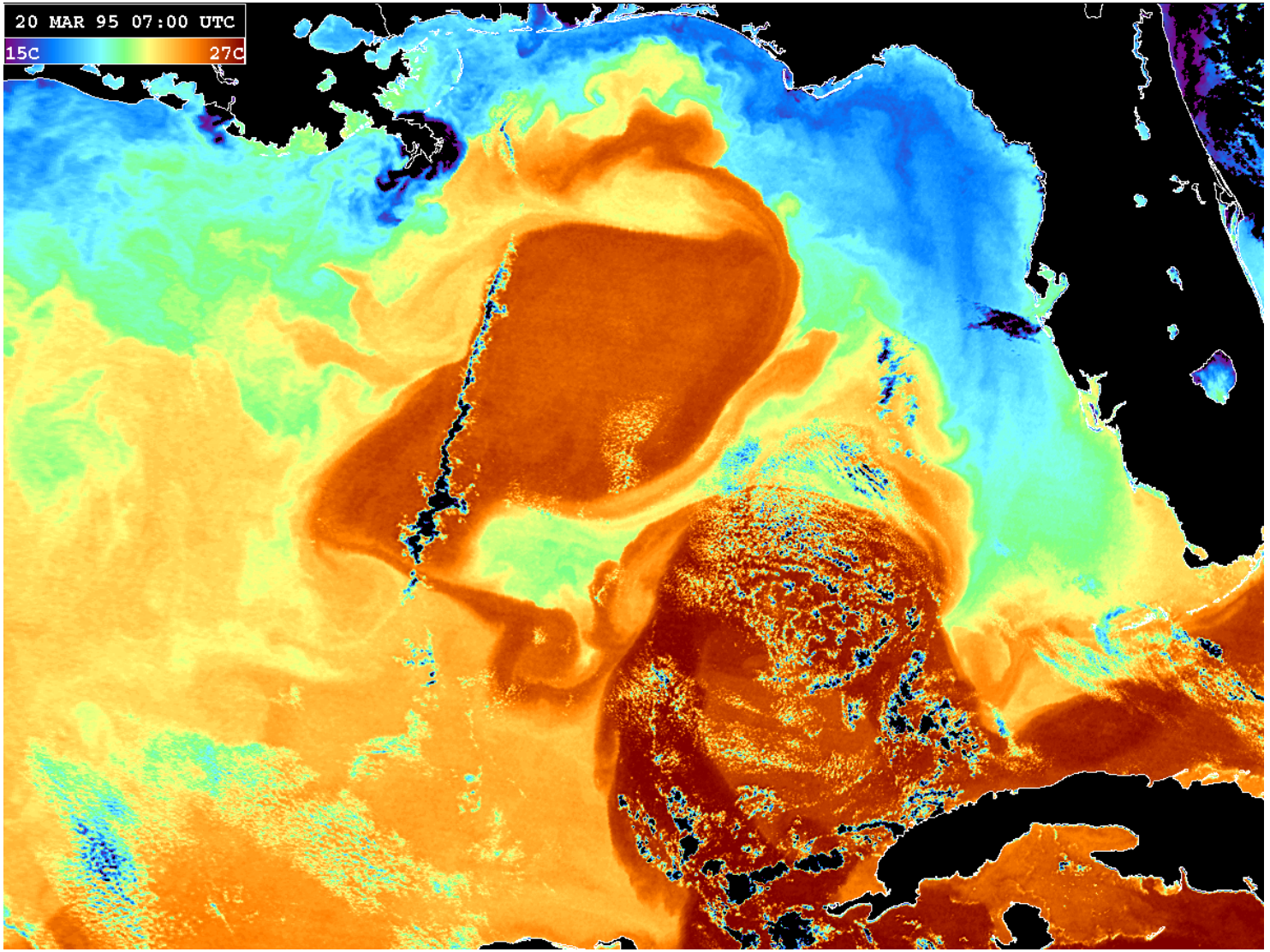
Introduction to Wavemill

- Wavemill is an RF instrument concept which uses hybrid (along- and across-track) interferometry for the direct measurement of 2D ocean surface currents
- Potential additional applications include inland water: lake height, river flow rate and ice freeboard
- The TRP funded feasibility study generated very promising results suggesting accuracies of better than 10cm/s and 5° for dual swaths of 100km to either side of the sub-satellite track



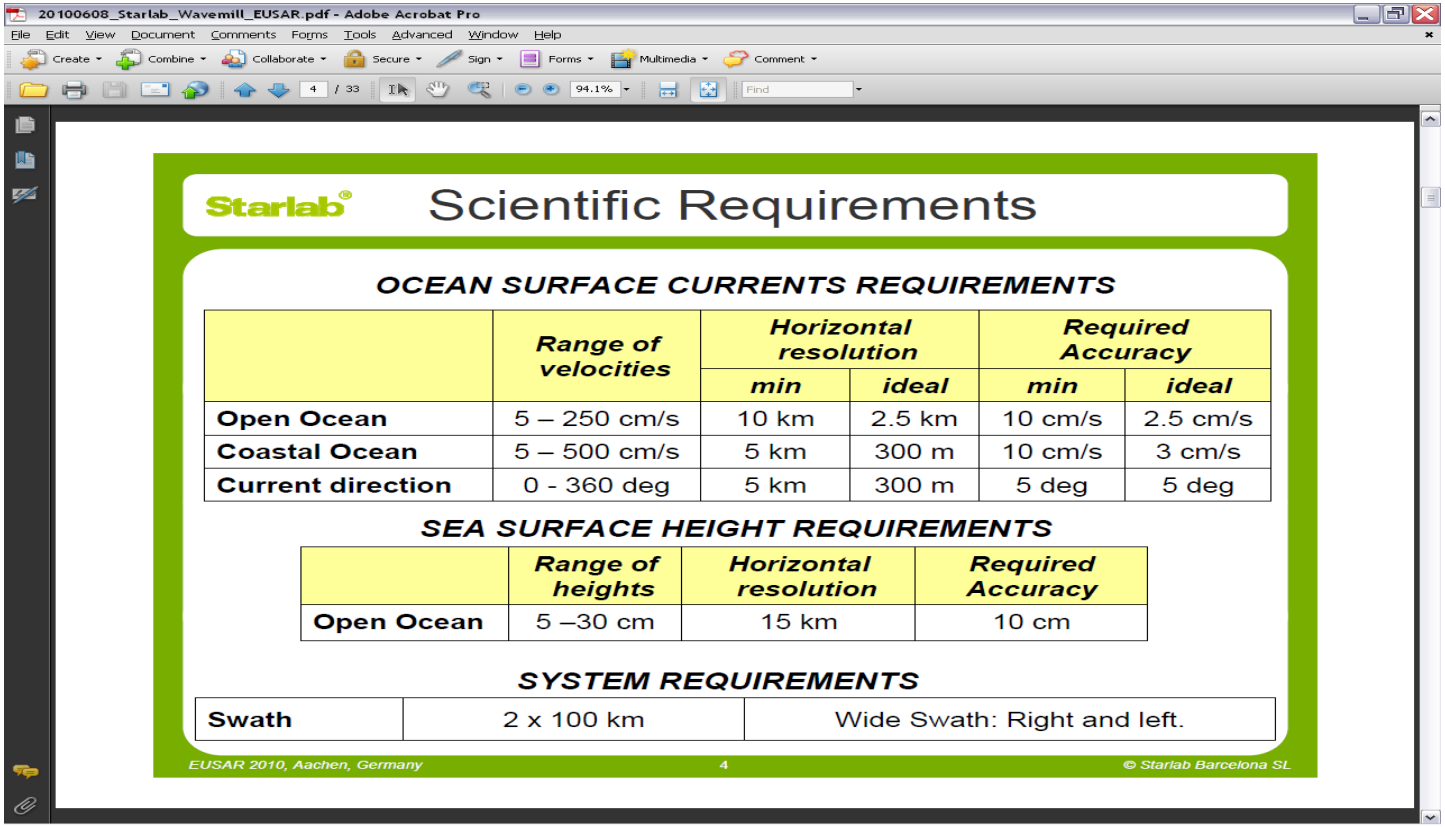
- On-board processing is required to reduce the high raw data rate
- The antenna development is due to start this year
- A demonstration campaign took place in October 2011
- A mission study (phase 0), planned for later this year, will capitalize on the findings of the scientific analysis to be covered in a soon to start GSP activity

Eddies in the Gulf of Mexico



User Requirements

OCEAN SURFACE CURRENT REQUIREMENTS



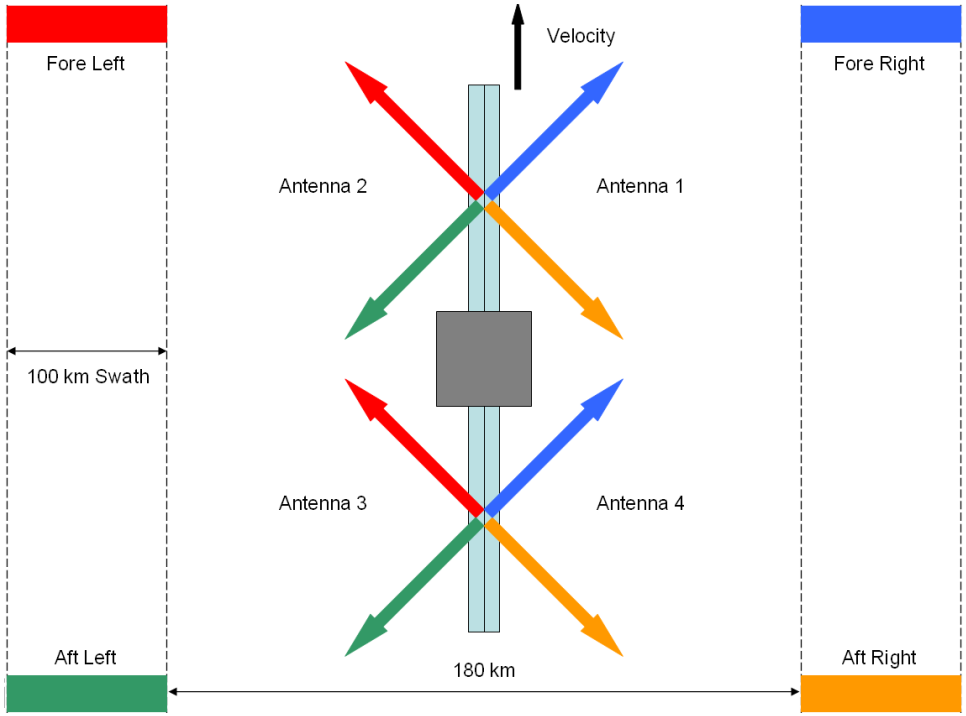
	Range of velocities	Horizontal resolution		Required Accuracy	
		min	ideal	min	ideal
Open Ocean	5 – 250 cm/s	10 km	2.5 km	10 cm/s	2.5 cm/s
Coastal Ocean	5 – 500 cm/s	5 km	300 m	10 cm/s	3 cm/s
Current direction	0 - 360 deg	5 km	300 m	5 deg	5 deg

	Range of heights	Horizontal resolution	Required Accuracy
Open Ocean	5 –30 cm	15 km	10 cm

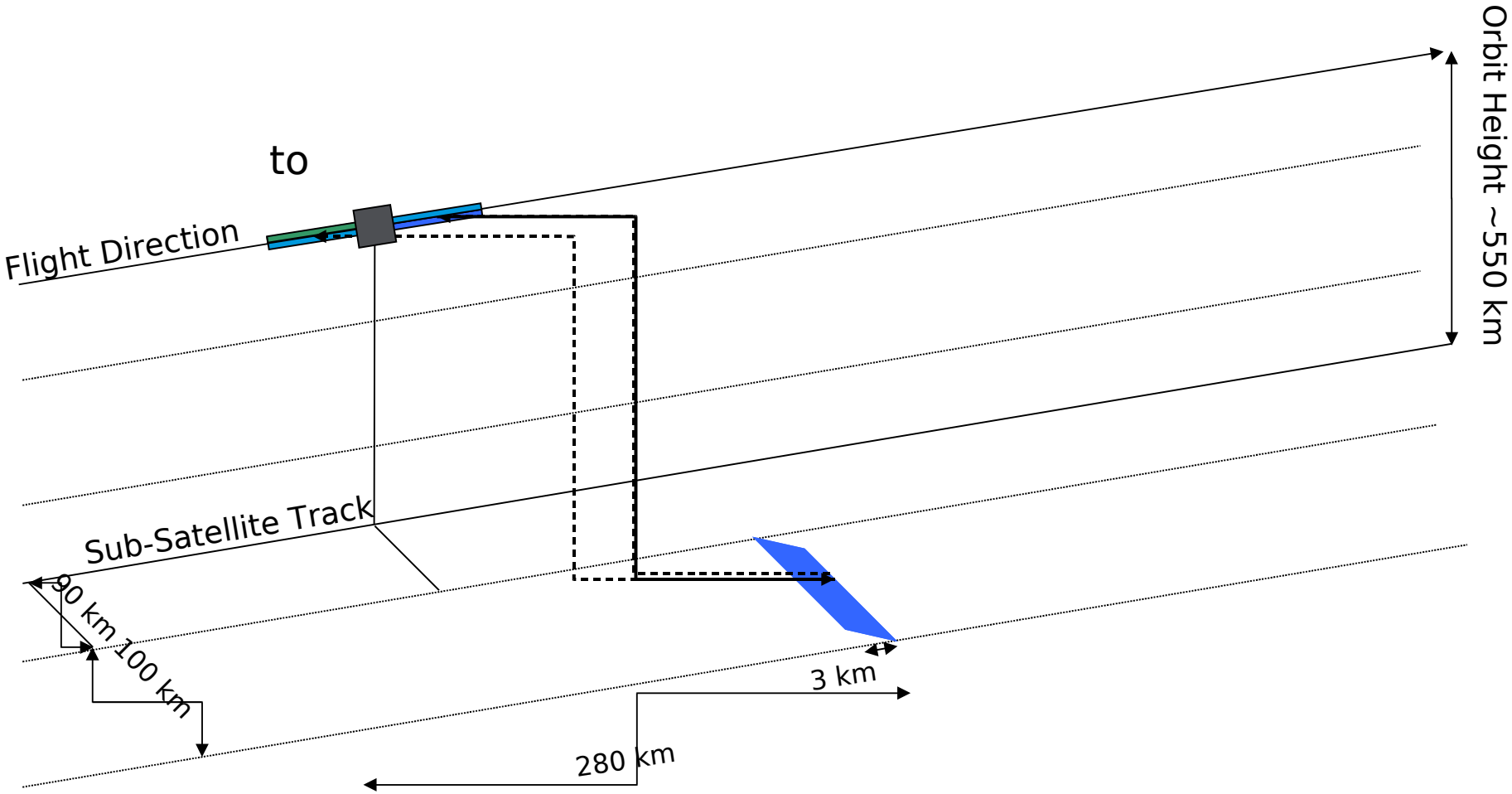
Swath	2 x 100 km	Wide Swath: Right and left.

Wavemill Concept

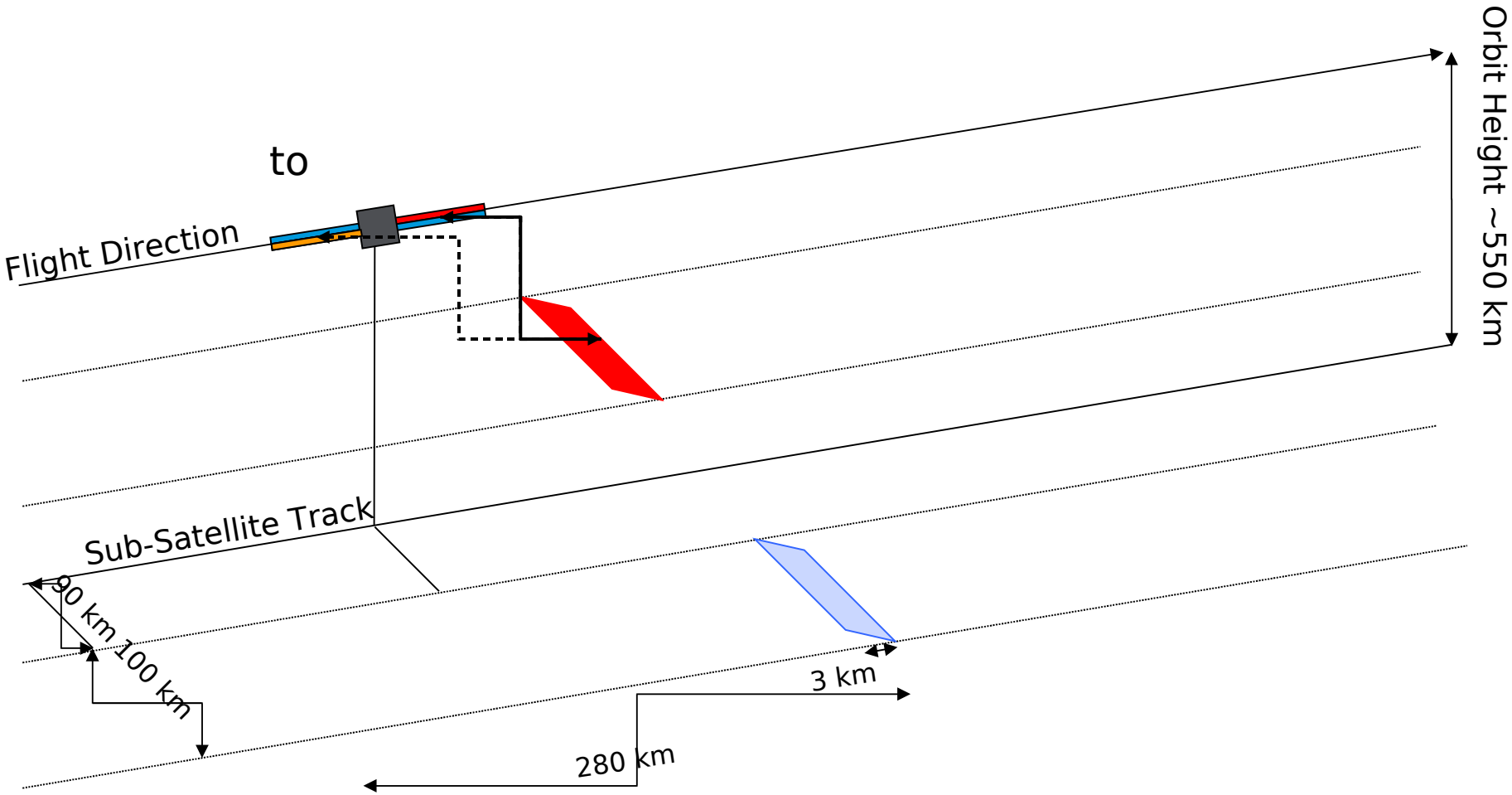
- **4 squinted** beams
  - Fore and aft
  - Right and left
- **2 observations** per beam
  - Bi-static
  - Mono-static
- 8 channels in total
- **Hybrid** interferometric SAR
  - Along-track
  - Across-track
- Multiple geophysical observations
  - Direct measurement in two dimens
  - Two independent observations (fore, aft) of **sea surface height**
  - **Scatterometric** data
- Independent **self-calibration** capabilities of interferometric baseline



Wavemill Operation



Wavemill Operation



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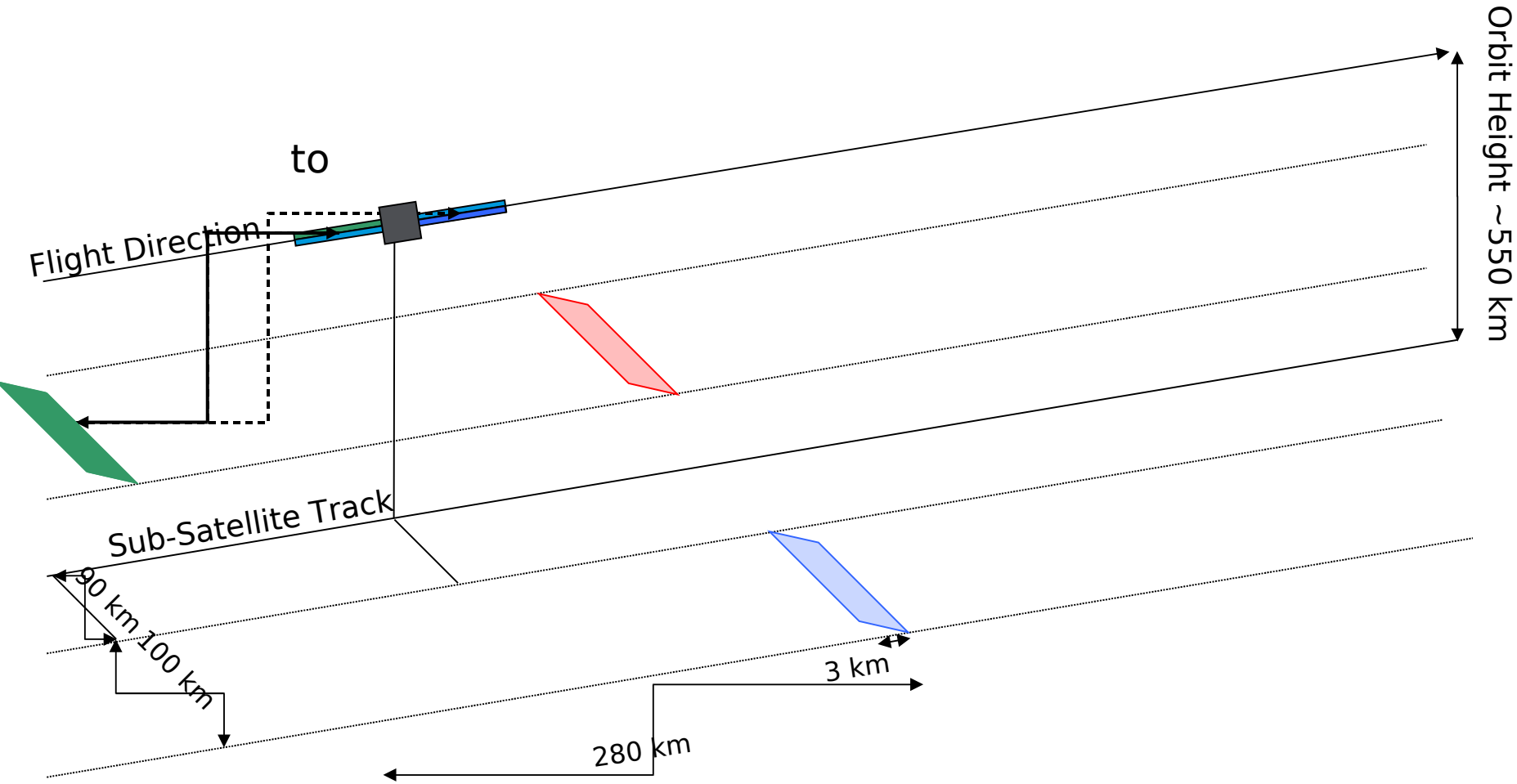

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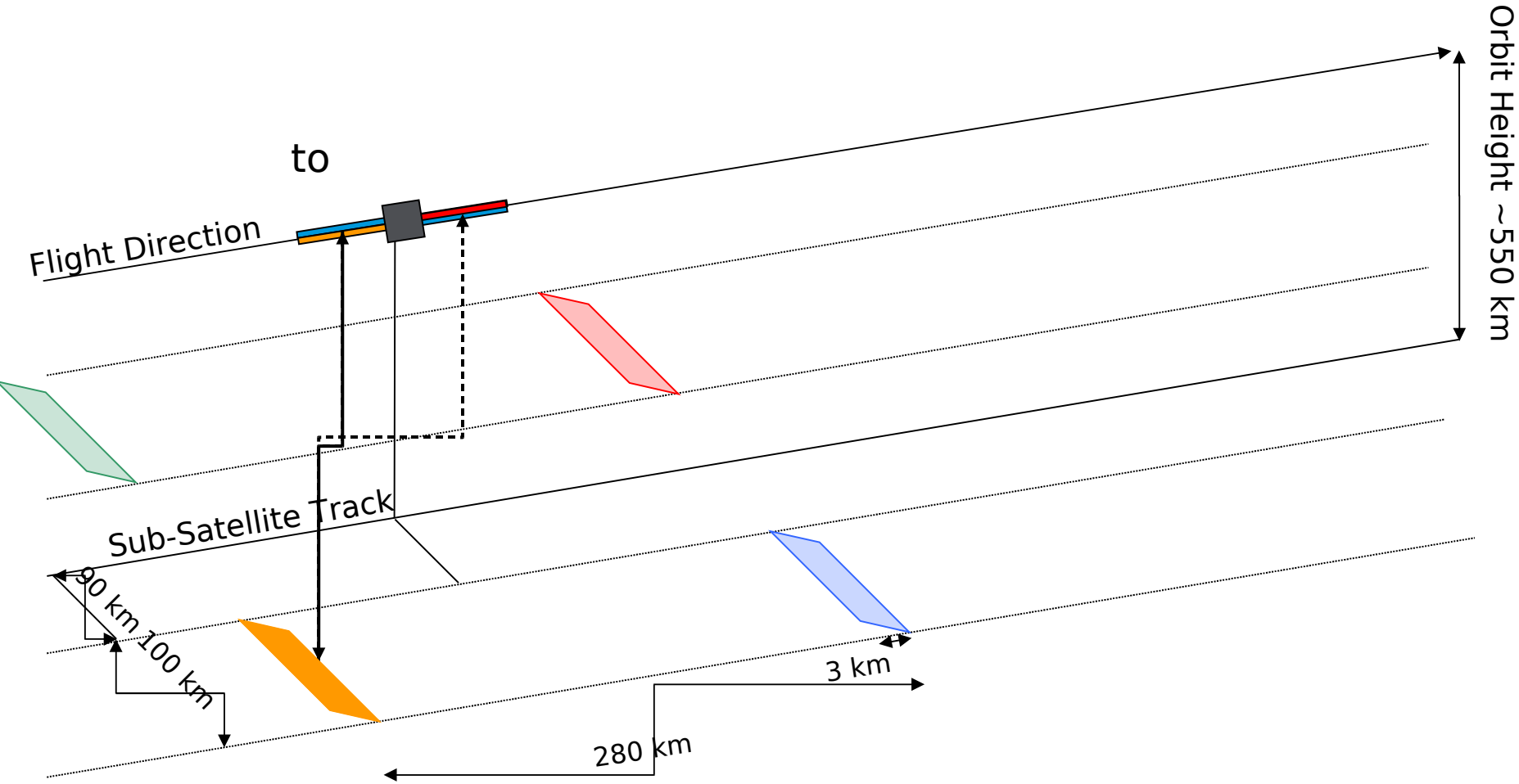
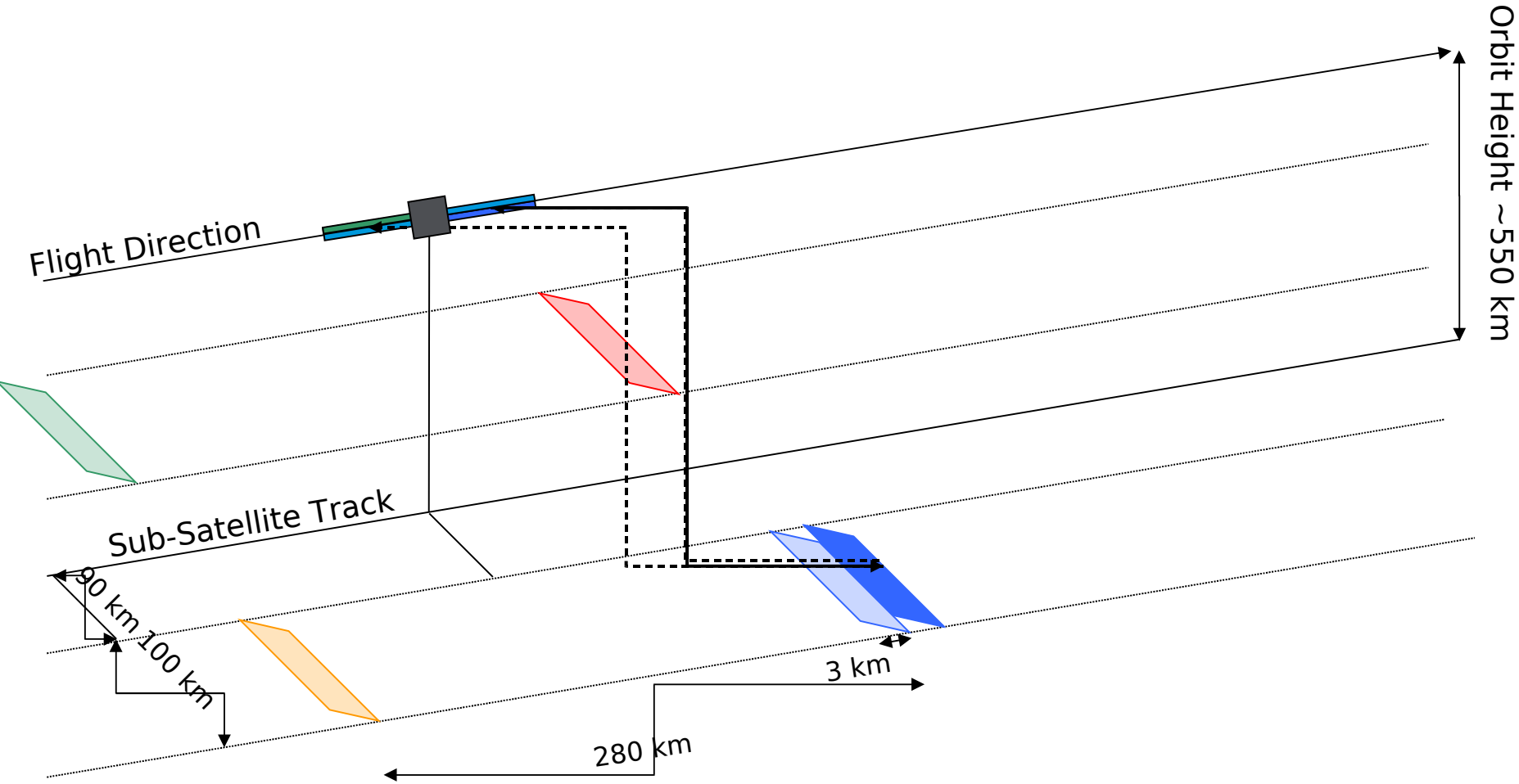


Wavemill Operation



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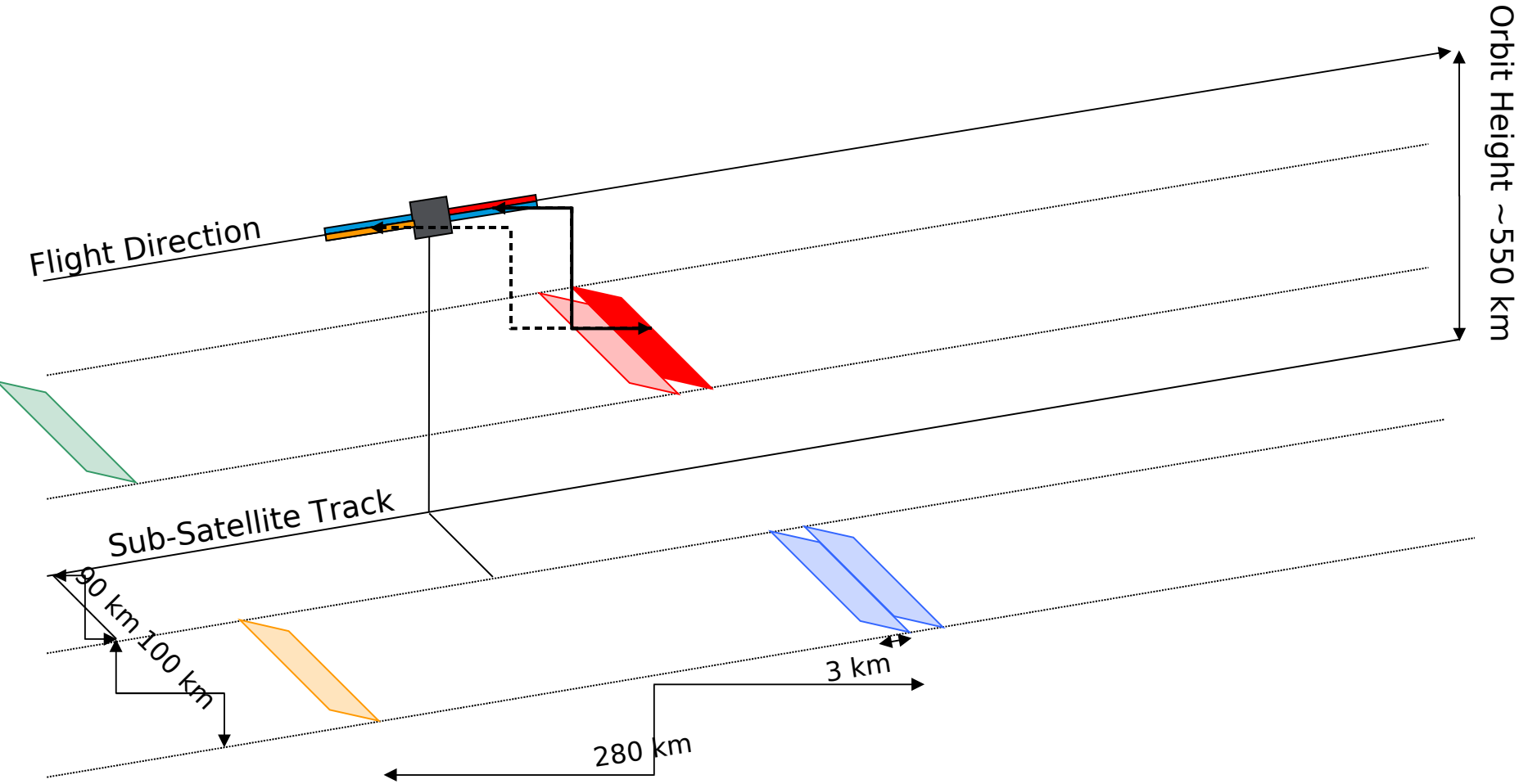

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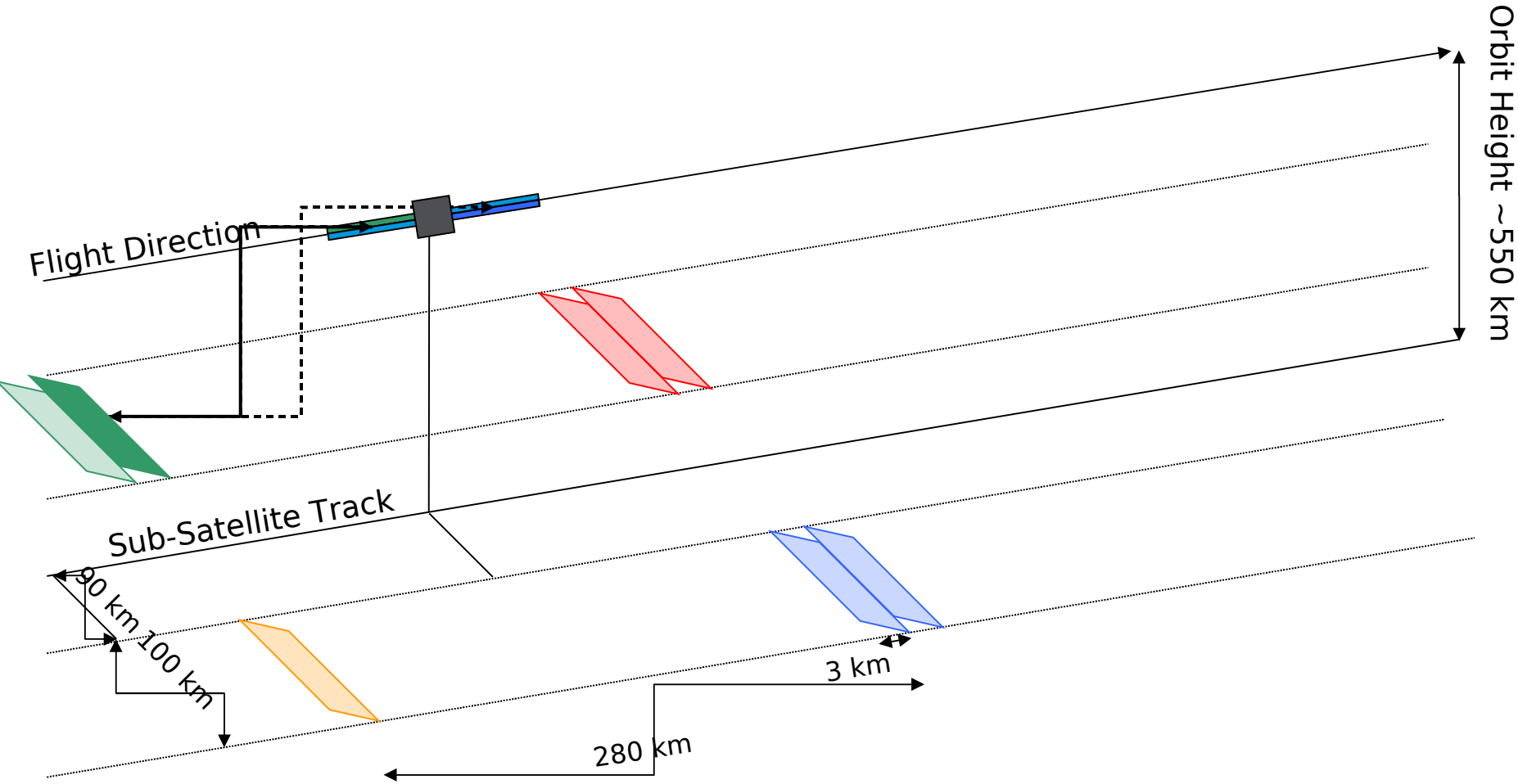
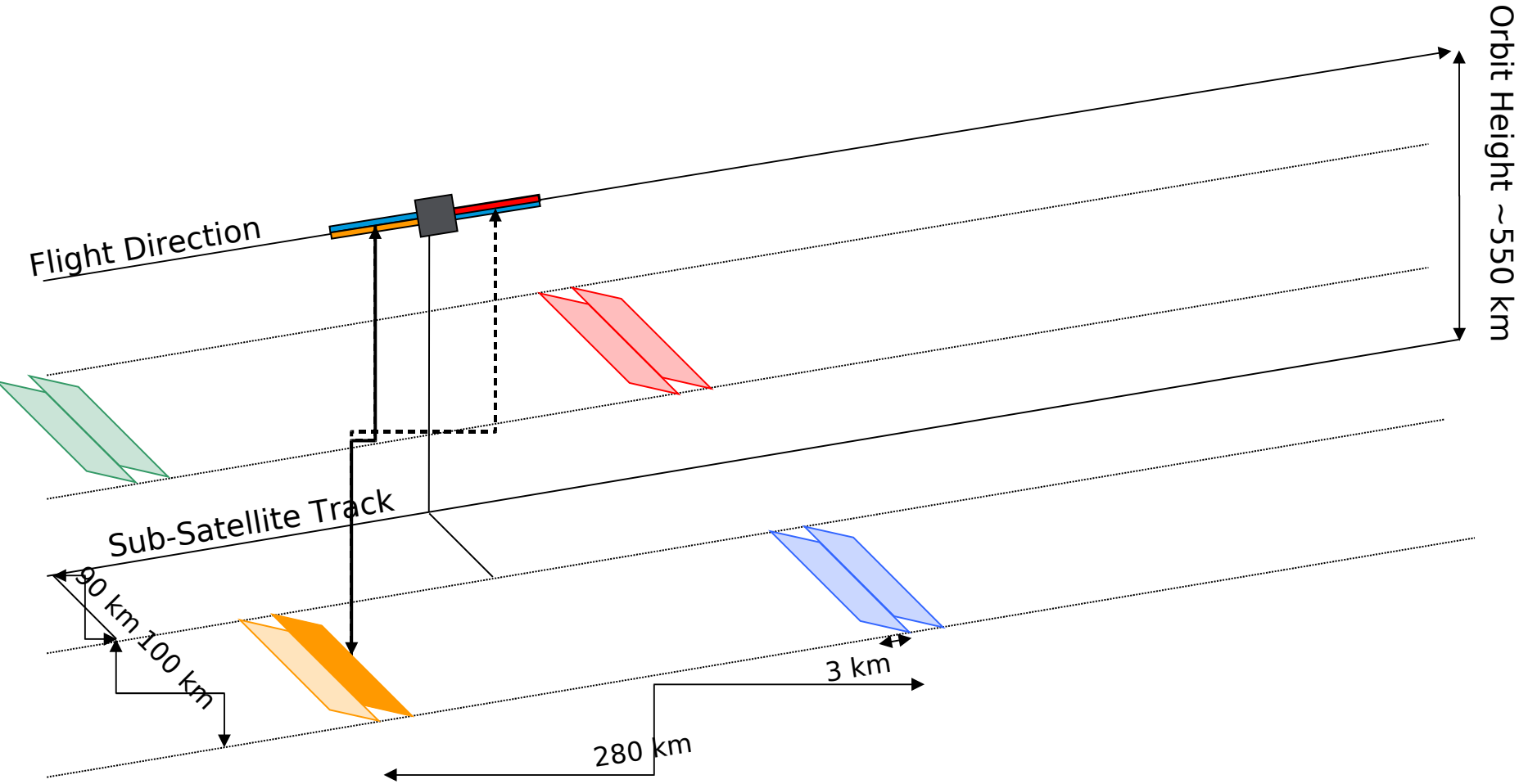
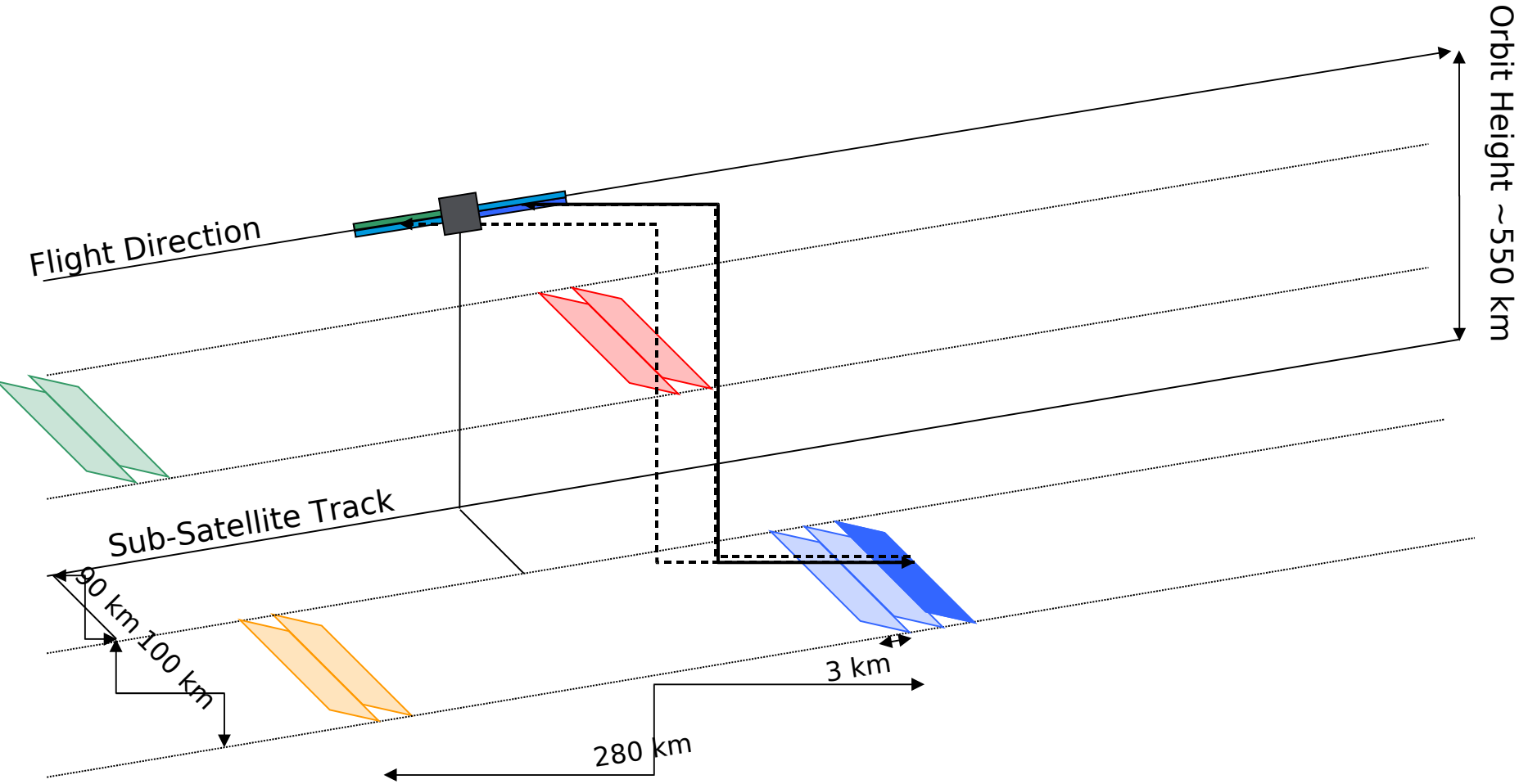


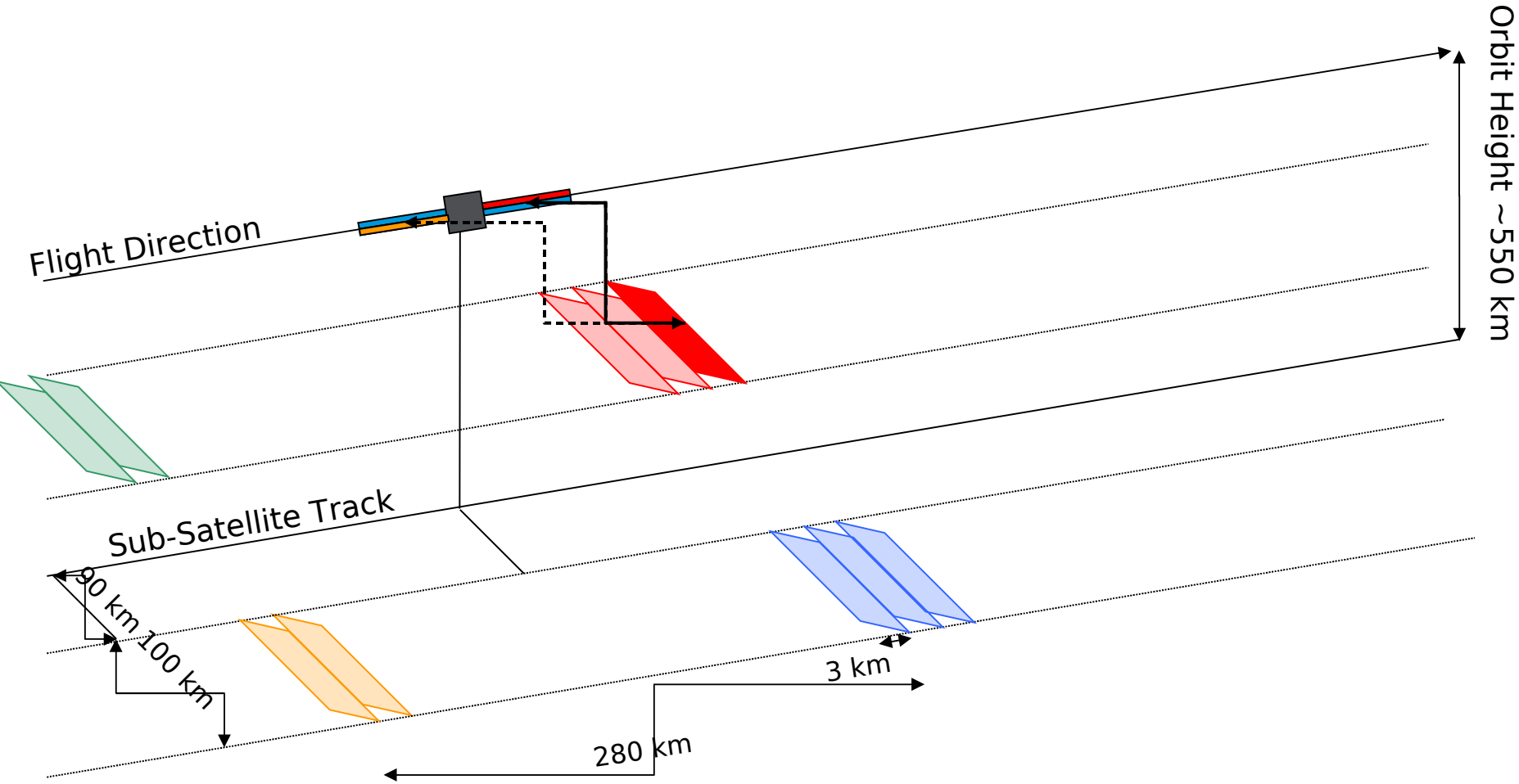
Wavemill Operation



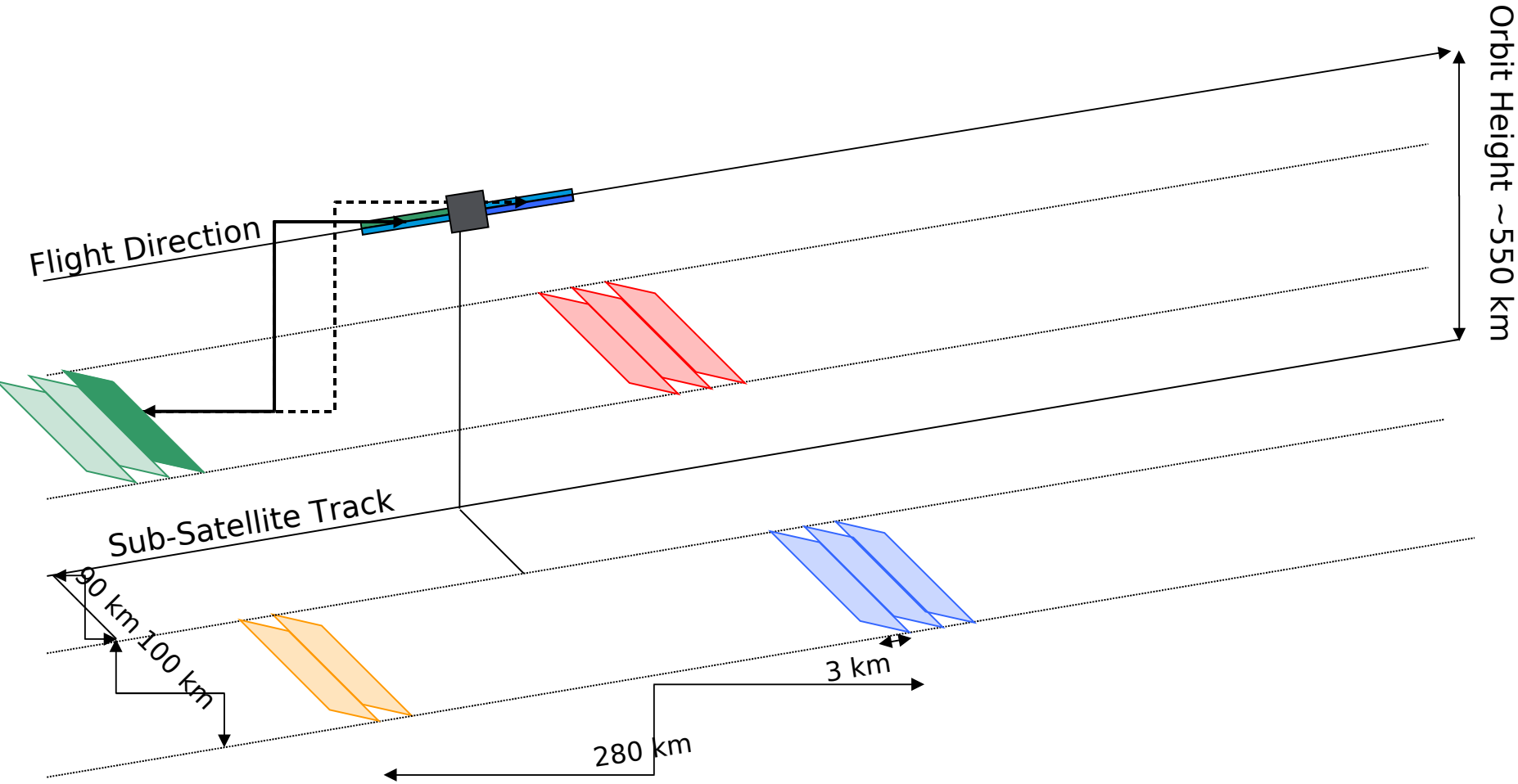
Wavemill Operation



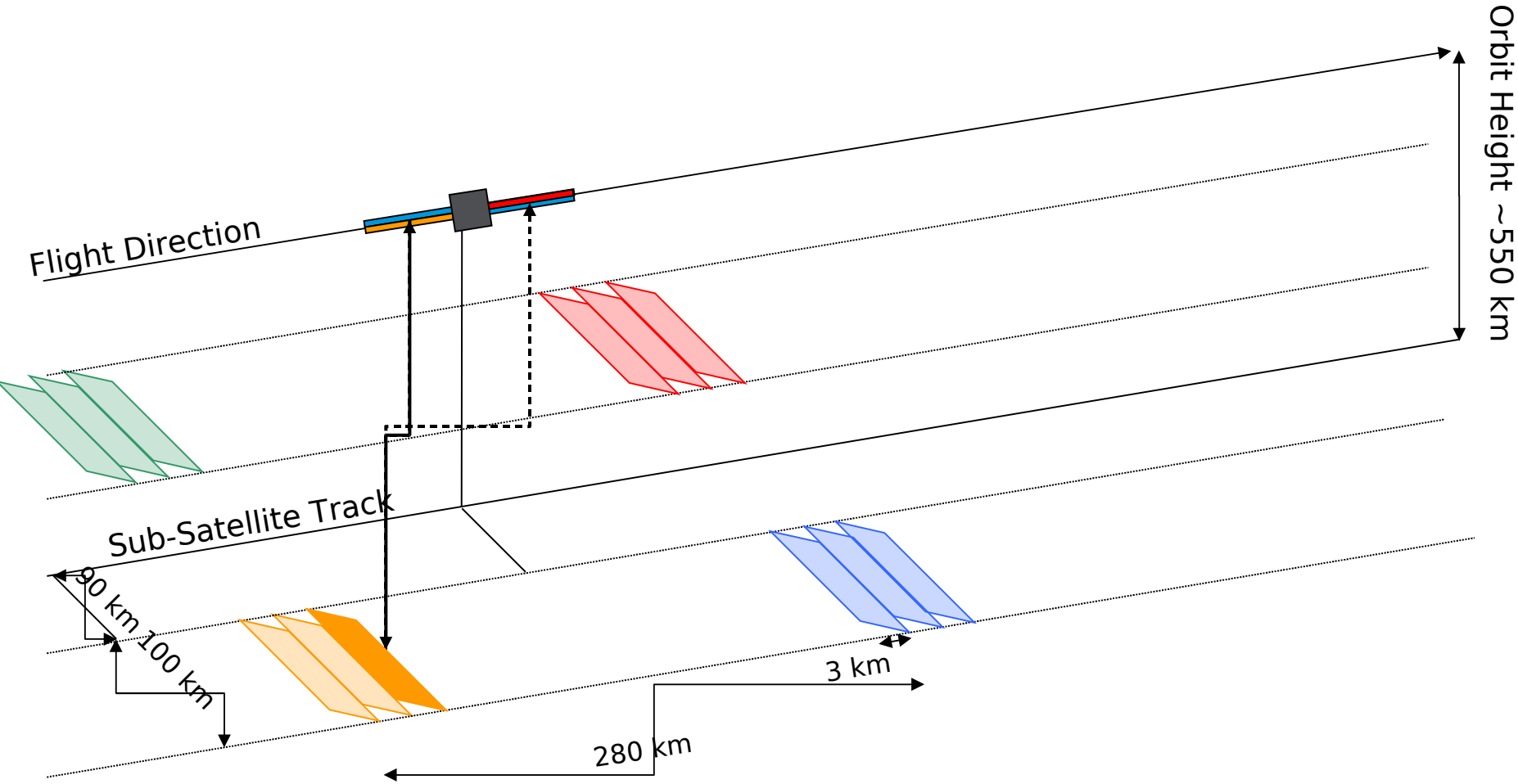
Wavemill Operation



Wavemill Operation



Wavemill Operation



Ocean Challenges

1. To quantify the interaction between variability in ocean dynamics, thermo-haline circulation, sea level and climate
2. To understand physical and bio-chemical air/sea interaction processes
3. To understand internal waves and the ocean mesoscale, its relevance to heat and energy transport and its influence on primary productivity
4. To quantify marine eco-system variability, its natural and anthropogenic physical, biological and geochemical forcing
5. To understand land/ocean interaction in terms of natural and anthropogenic forcing
6. To provide both model- and data-based assessments and predictions of past, present and future states of the oceans

Cryosphere Challenges

1. **Quantify the distribution of sea-ice mass and freshwater equivalent, assess the sensitivity of sea-ice to climate change and understand thermodynamic and dynamic feedback [systems] to the ocean and atmosphere**
2. **Quantify the mass balance of grounded ice sheets, ice caps and glaciers, partition their relative contributions to global eustatic sea-level change and understand their future sensitivity to climate change through dynamic processes**
3. **[…]**
4. **Quantify the influence of ice shelves, high-latitude river run-off and land ice melt on global thermo-haline circulation, and understand the sensitivity of each of these freshwater sources to future climate change**
5. **[…]**

Land Challenges

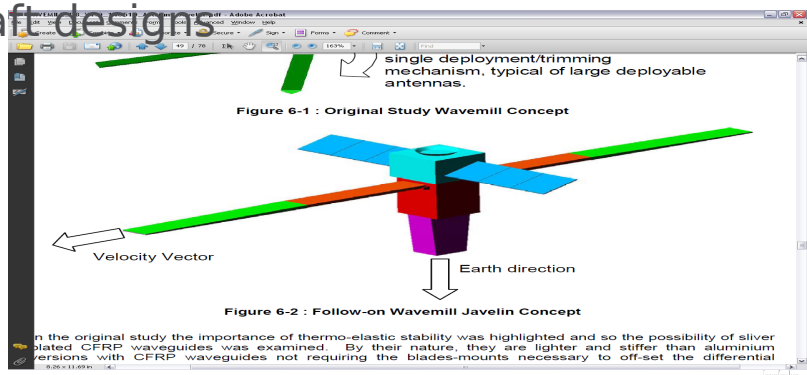
1. **Understand the role of terrestrial ecosystems and their interaction with other components of the Earth system for the exchange of water, carbon and energy, including the quantification of the ecological, atmospheric, chemical and anthropogenic processes that control these biochemical fluxes**
2. **[…]**
3. **Understand the pressure caused anthropogenic dynamics on land surfaces (use of natural resources, land use and land-cover change) and their impact on the functioning of terrestrial ecosystems**
4. **[…]**

Scientific Objectives

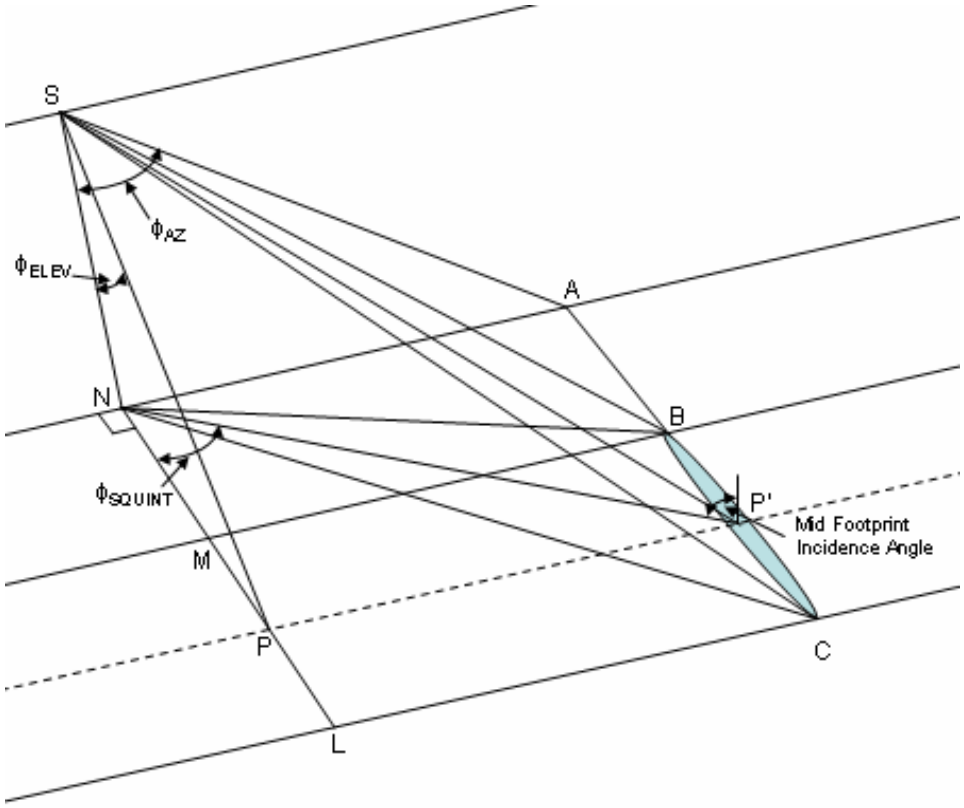
Wavemill Scientific Objectives	Primary or Secondary Objective	ESA's Living Planet Programme Challenges Addressed
1. Quantify and map (sub)-mesoscale (<0.1 – 10 km) ocean surface current vectors and their variability	P	Ocean Challenges 1, 2, 3, 4 and 5
2. Quantify and map (sub)-mesoscale sea surface height and its variability	P	Ocean Challenges 1, 2, 3, 4 and 5
3. Evaluate and reduce the uncertainty of (sub)-mesoscale ocean surface current variability measurements at regional and global scales	P	Ocean Challenge 1
4. Quantify and map ocean swell and waves at regional and global scales	P	Ocean Challenges 1, 2, 3, 4 and 5
5. Quantify and map the variability of sea ice, sea ice thickness and velocity	P	Cryosphere Challenges 1, 2 and 4
6. Quantify and map the size, velocity and the variability of icebergs	S	Cryosphere Challenges 1, 2 and 4
7. Quantify and map river flows and river flow variability	S	Land Challenges 1 and 3
8. Improve and validate numerical ocean circulation model and data-based assessment and prediction of ocean circulation	P	Ocean Challenges 1 and 5
9. Improve and validate hydrological models through data assimilation and improve freshwater inflow into the ocean.	P	Land Challenges 1 and 3

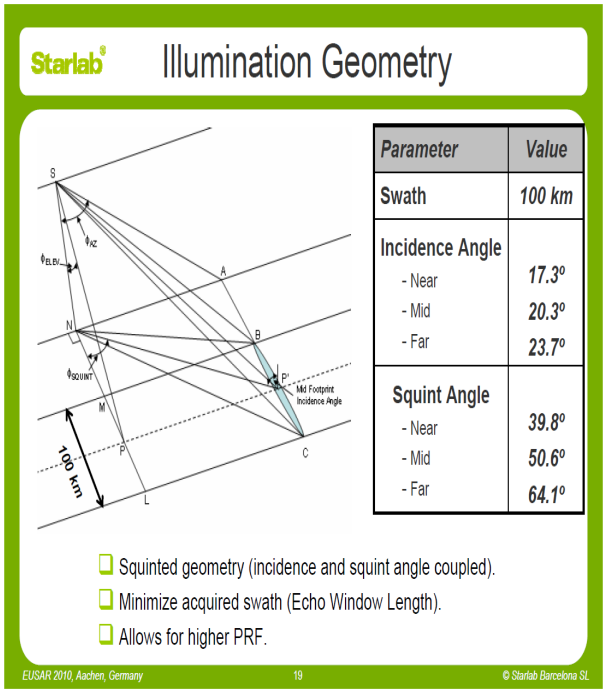
Feasibility Study

- TRP funded activity won by Starlab with Astrium and IFREMER
- KO Jan 2008 tasks were:
  - Determination of Scientific Requirements
  - System Analysis
  - Instrument Design
- Results were encouraging, CCN initiated to investigate ‘javelin’ concept using ‘leaky wave’ antennas
  - Completed July 2010
- Outcome of completed study plus CCN:
  - Basic scientific requirements for ocean currents
  - First cut instrument and spacecraft designs



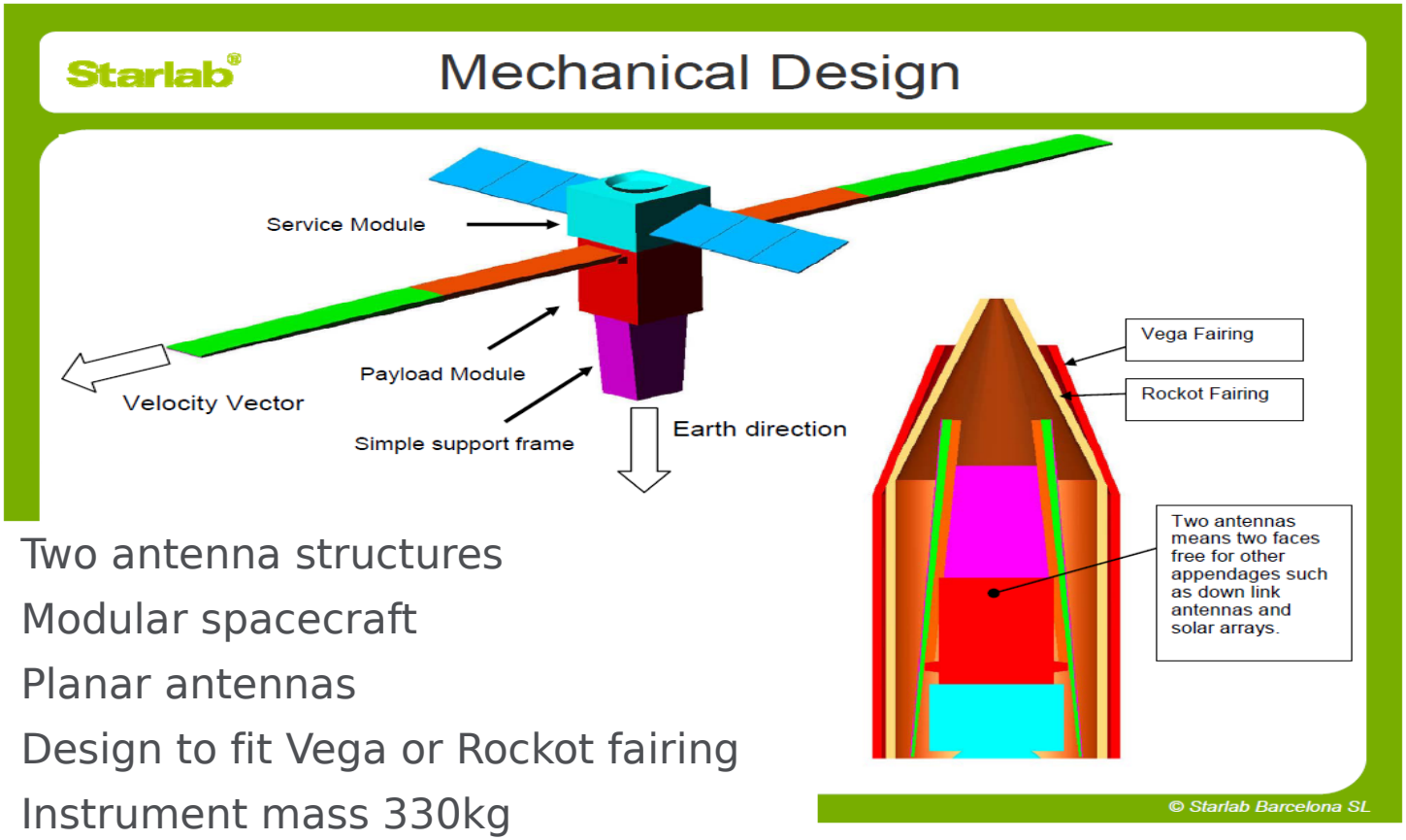
Illumination Geometry





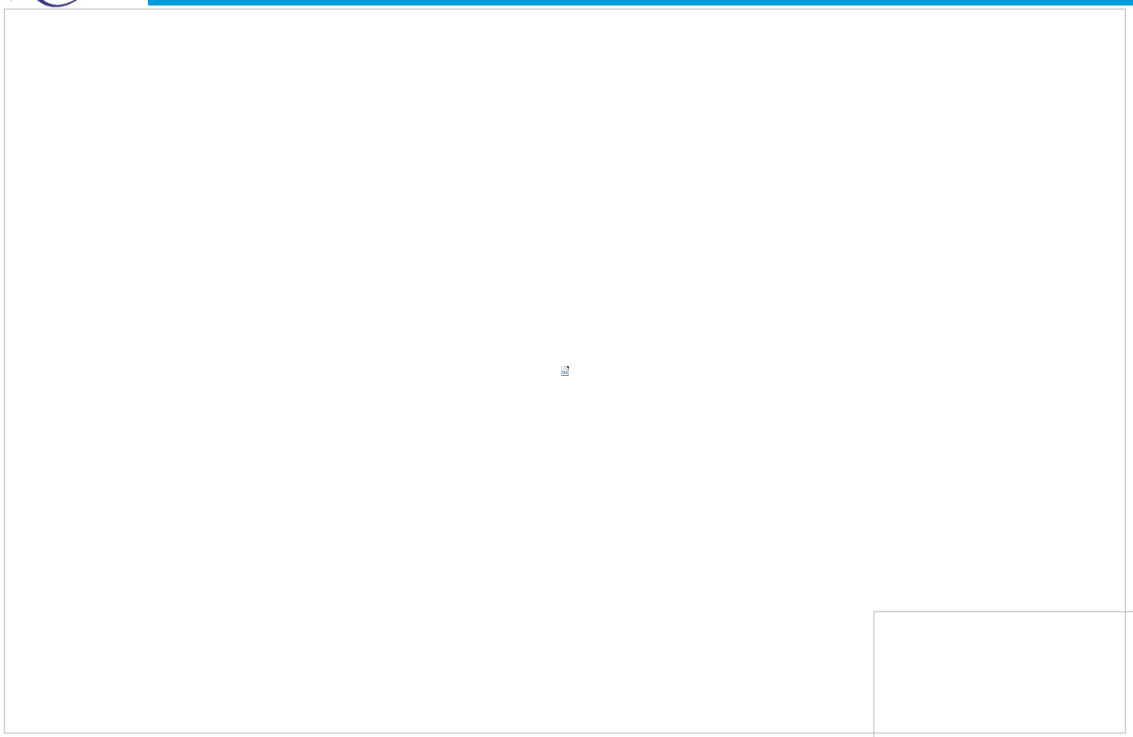
- Squinted geometry (incidence and squint angle coupled)
- Minimize acquired swath (Echo Window Length)
- Permits higher PRF

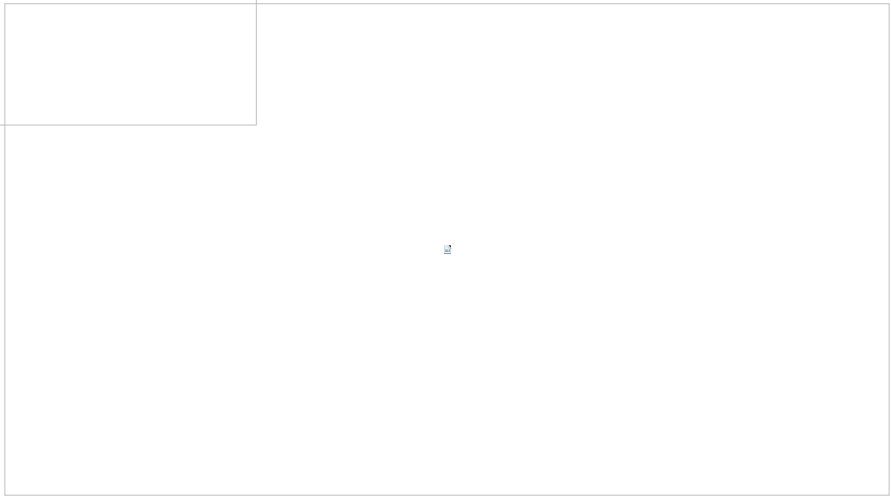
Mechanical Design



- Two antenna structures
- Modular spacecraft
- Planar antennas
- Design to fit Vega or Rockot fairing
- Instrument mass 330kg

Antenna Deployment



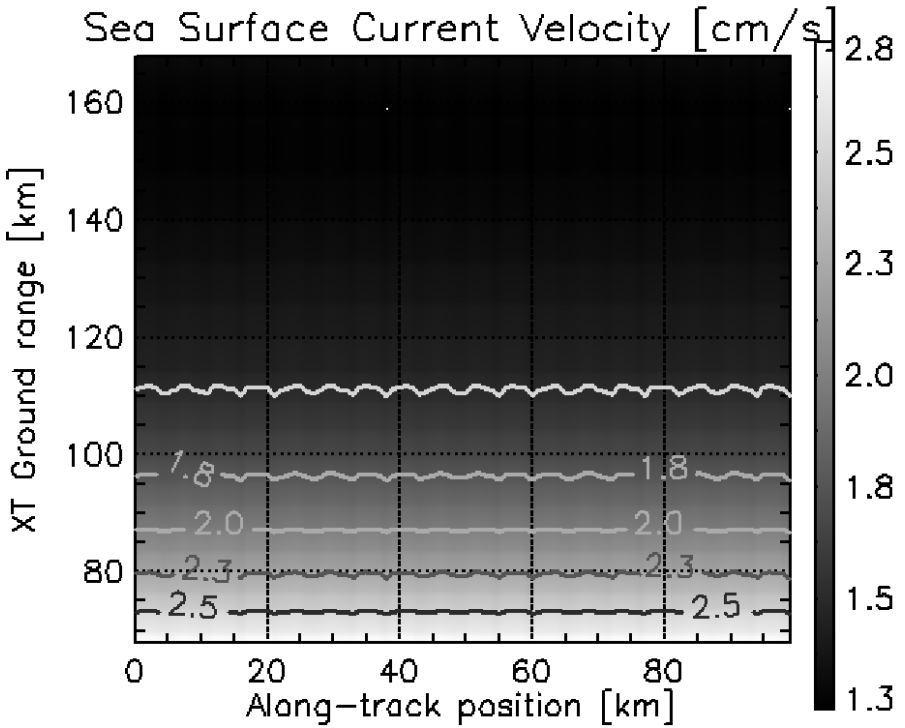


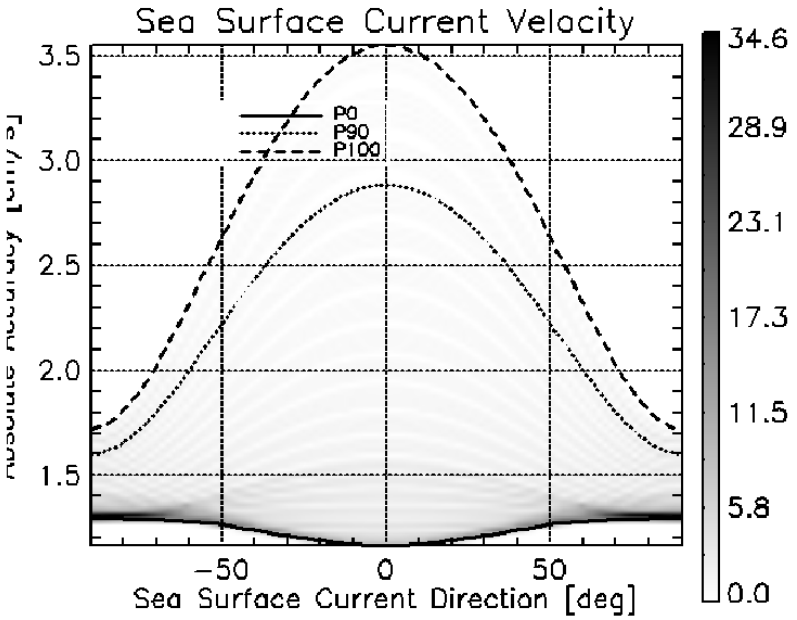
Instrument Requirements

Parameter	Value	Units	Remark
Sea Surface Currents			
Resolution	1 x 1	km	Scientific Requirements
Swath coverage	2 x 100	km	Scientific Requirements
Current speed accuracy	<0.1	m/s	Scientific Requirements
Current direction accuracy	<5	deg	Scientific Requirements
Range of current velocities	0.05 -5	m/s	Scientific Requirements
Sea Surface Height			
Resolution	15 x 15	km	WSOA
Swath coverage	2 x 100	km	
Absolute accuracy	< 10	cm	GOOS
Relative accuracy	< 1	cm	NOC

Sea Surface Current Velocity

- Absolute Sea Surface Current Velocity accuracy **< 3.6 cm/s** fulfilled for the whole swath and independently of current direction

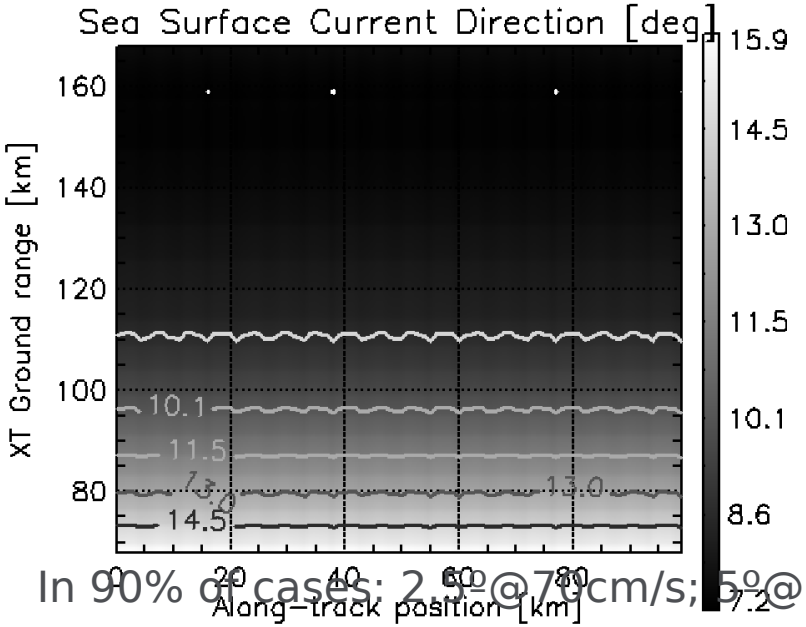


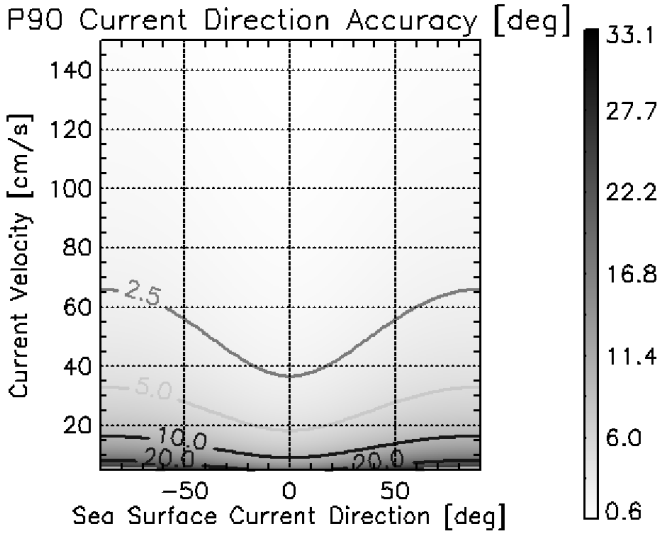


- 90% of the time, the worst case for the absolute current velocity accuracy is better than 2.9 cm/s

Sea Surface Current Direction

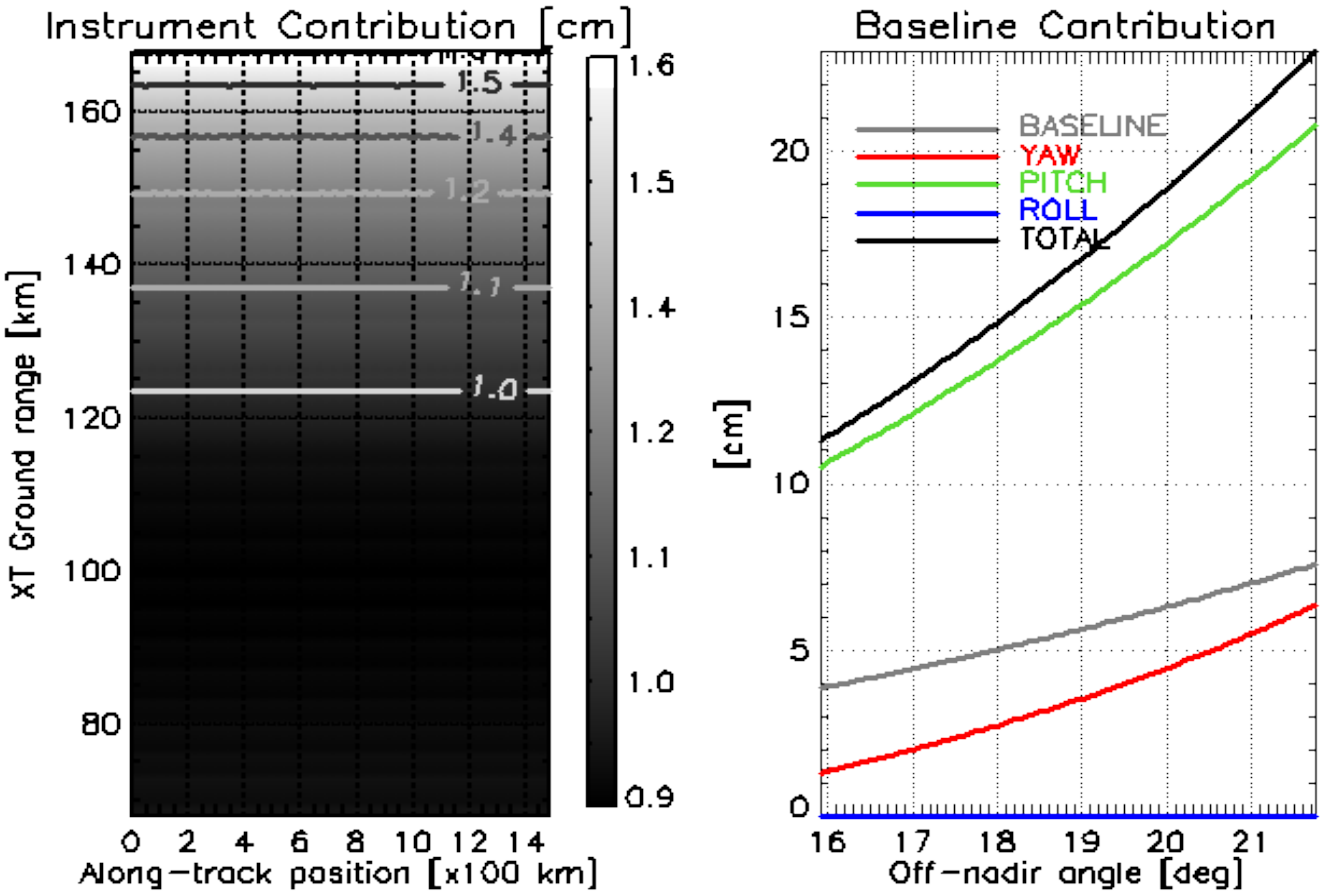
- Sea surface current direction depends on SSC velocity and direction
- This requirement cannot be defined independently of the sea surface velocity
- 5° requirement fulfilled independently of current direction for currents faster than 35 cm/s (90%)





- In 90% of cases: 2.5º@70cm/s; 5º@35cm/s; 10º@20cm/s; 20º@10cm/s

Sea Surface Height Accuracy 1/2



- Yaw=Pitch=Roll accuracy of 0.56µradian
- Baseline length accuracy of 0.01mm

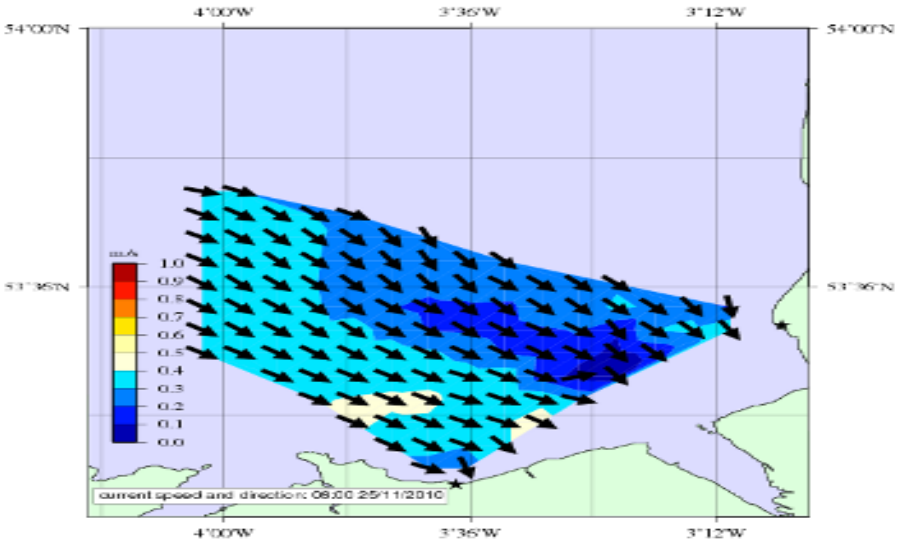
Sea Surface Height Accuracy 2/2

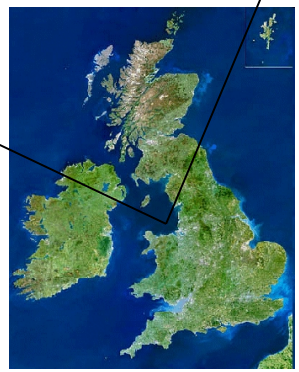
- Relative Sea Surface Height accuracy **< 1.5 cm** for the whole swath
- Contribution of pitch angle calibration to absolute accuracy budget responsible for the largest error, in particular at far range
- Absolute Sea Surface Height accuracy < 23.4 cm for worst case

Error Source	Near Swath	Mid Swath	Far swath
Precise orbit determination error [cm]	3	3	3
Troposphere correction error [cm]	3.5	3.5	3.5
Ionosphere error contribution [cm]	0.5	0.5	0.5
Electromagnetic bias error [cm]	2	2	2
Baseline length error [cm]	3.8	5.3	7.5
Baseline attitude – roll [cm]	0	0	0
Baseline attitude – pitch [cm]	10.5	14.5	20.6
Baseline attitude – yaw [cm]	1.3	3.1	6.3
Relative Height Error [cm]	***1.0***	***1.0***	***1.5***
Absolute Height Error [cm]	**12.4**	**16.6**	**23.4**

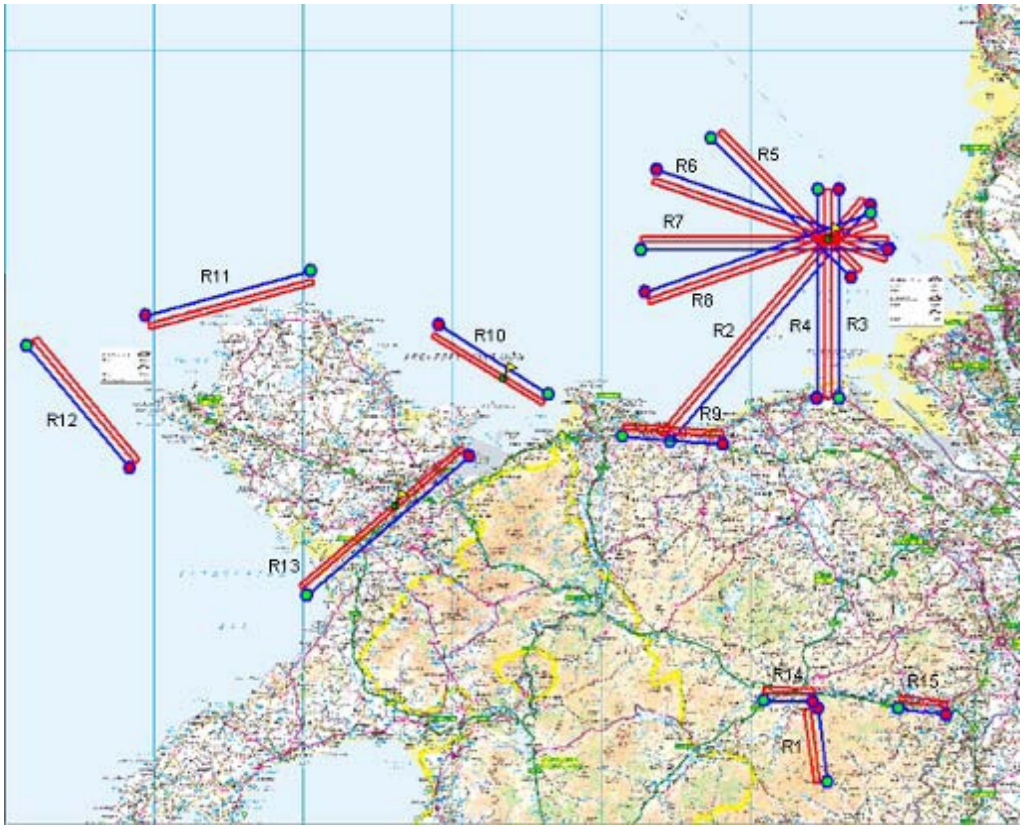
Proof of Concept Campaign

- Existing airborne interferometric SAR system prepared for Wavemill operation with squinted beams fore and aft
- Campaign flown over region with ground truth
  - HF radar, ADCPs, bathymetry
- Campaign flights over Liverpool Bay in October 2011
- Process hybrid and co-time data, extract surface currents
- Compare and validate results/instrument/processing and provide recommendations for spaceborne instrument
- Workshop - release data to scientific community



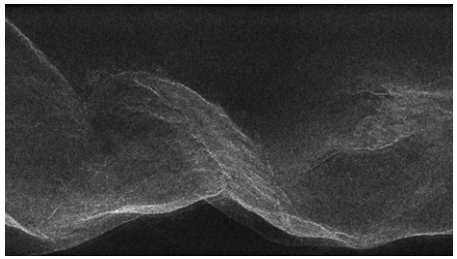


Proof-of-Concept Campaign



PoCC – First Results

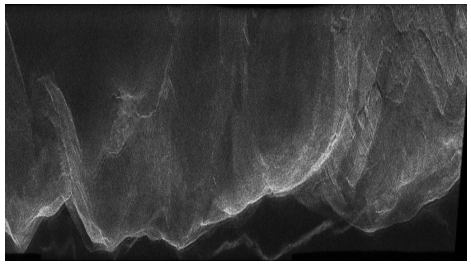
Javelin

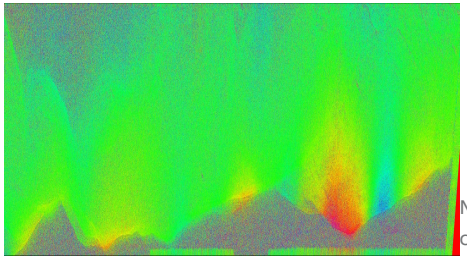


Berwyn Hills

Detected Image

Hybrid



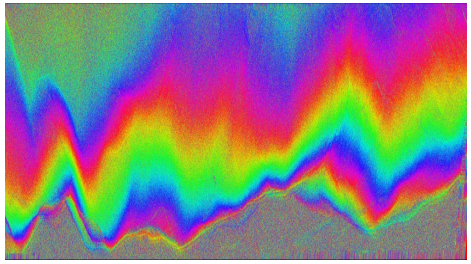


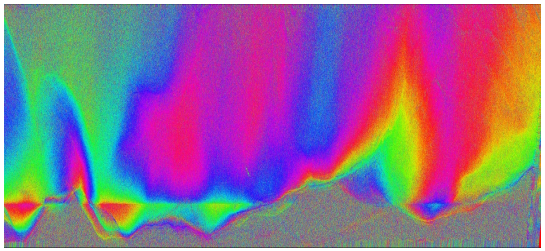
Interferogram

Same Doppler Centre Frequency

Co-located images (not co-time)

NOTE: No flat Earth phase change to correct in this case

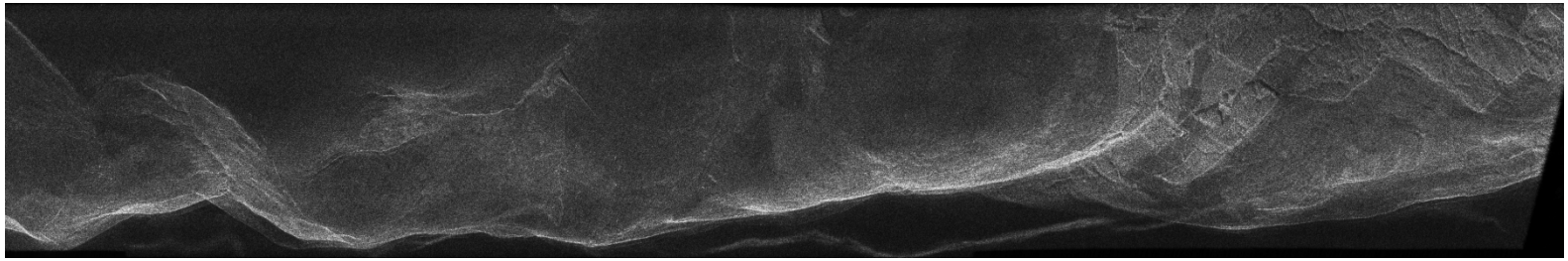




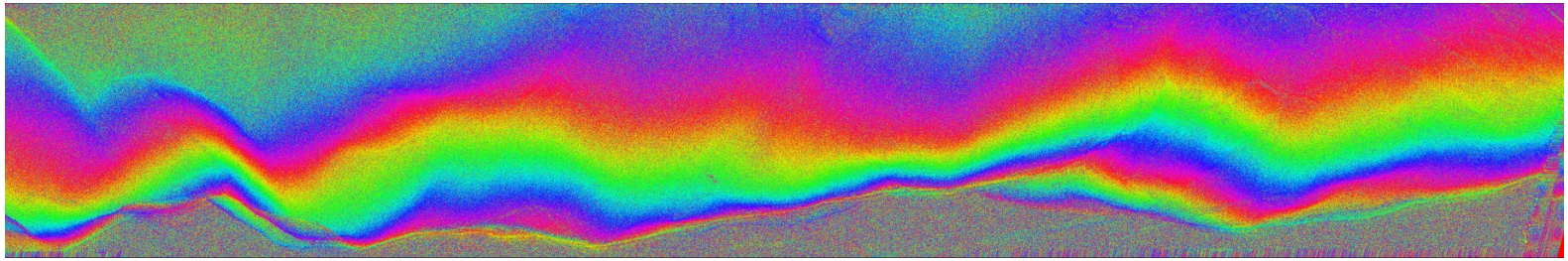
OS Map

PoCC – First Results

M1 Berwyn (Hybrid, Fore)

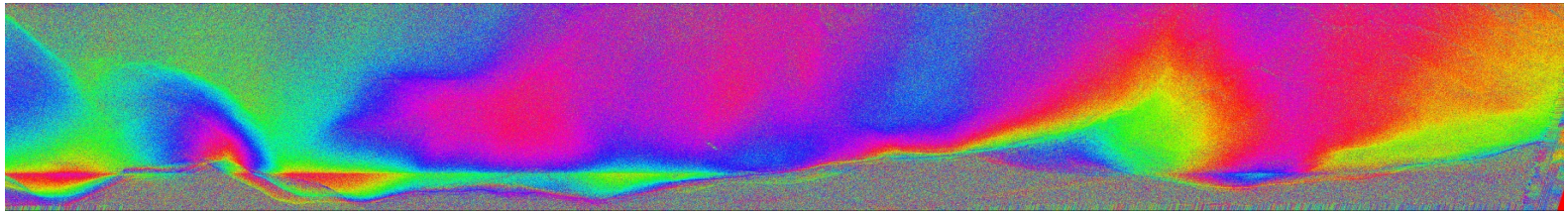


Image



Co-location Interferogram

Before flat earth removal

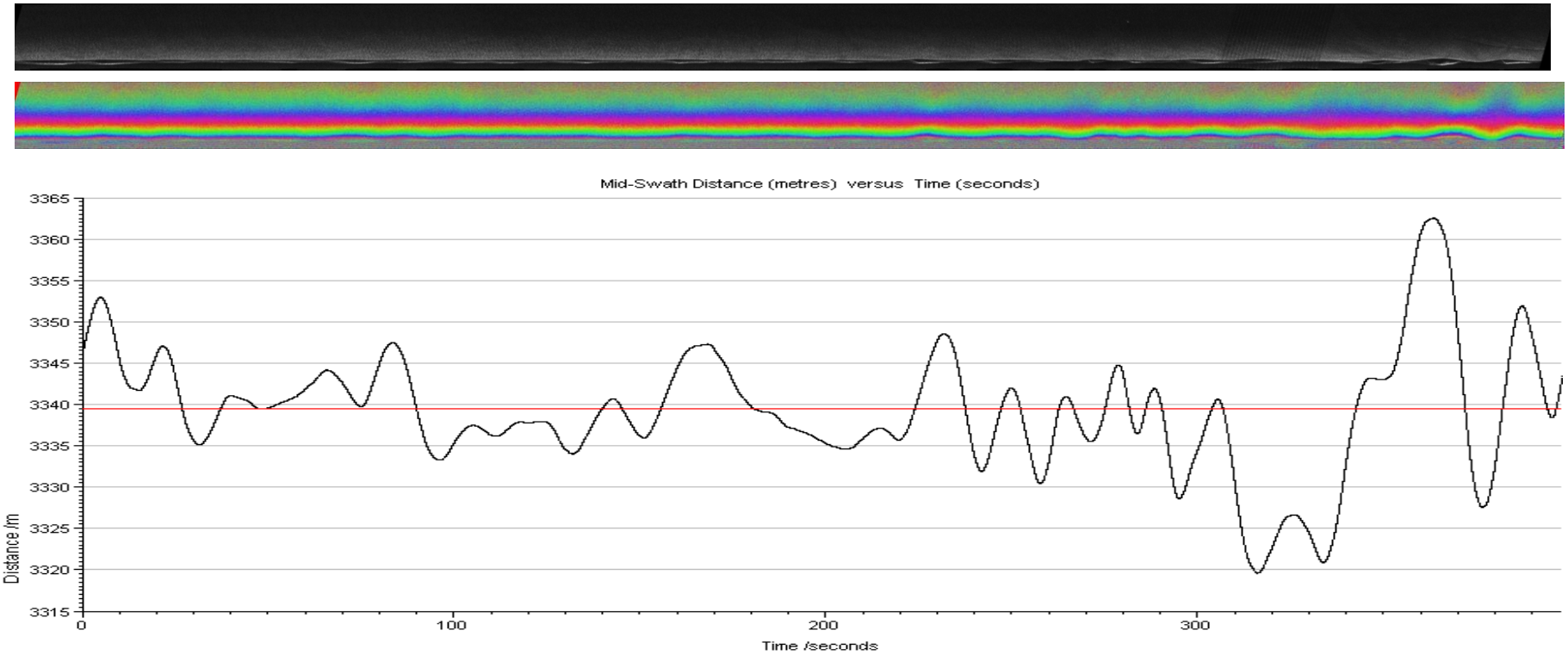


After flat earth removal

OS Map

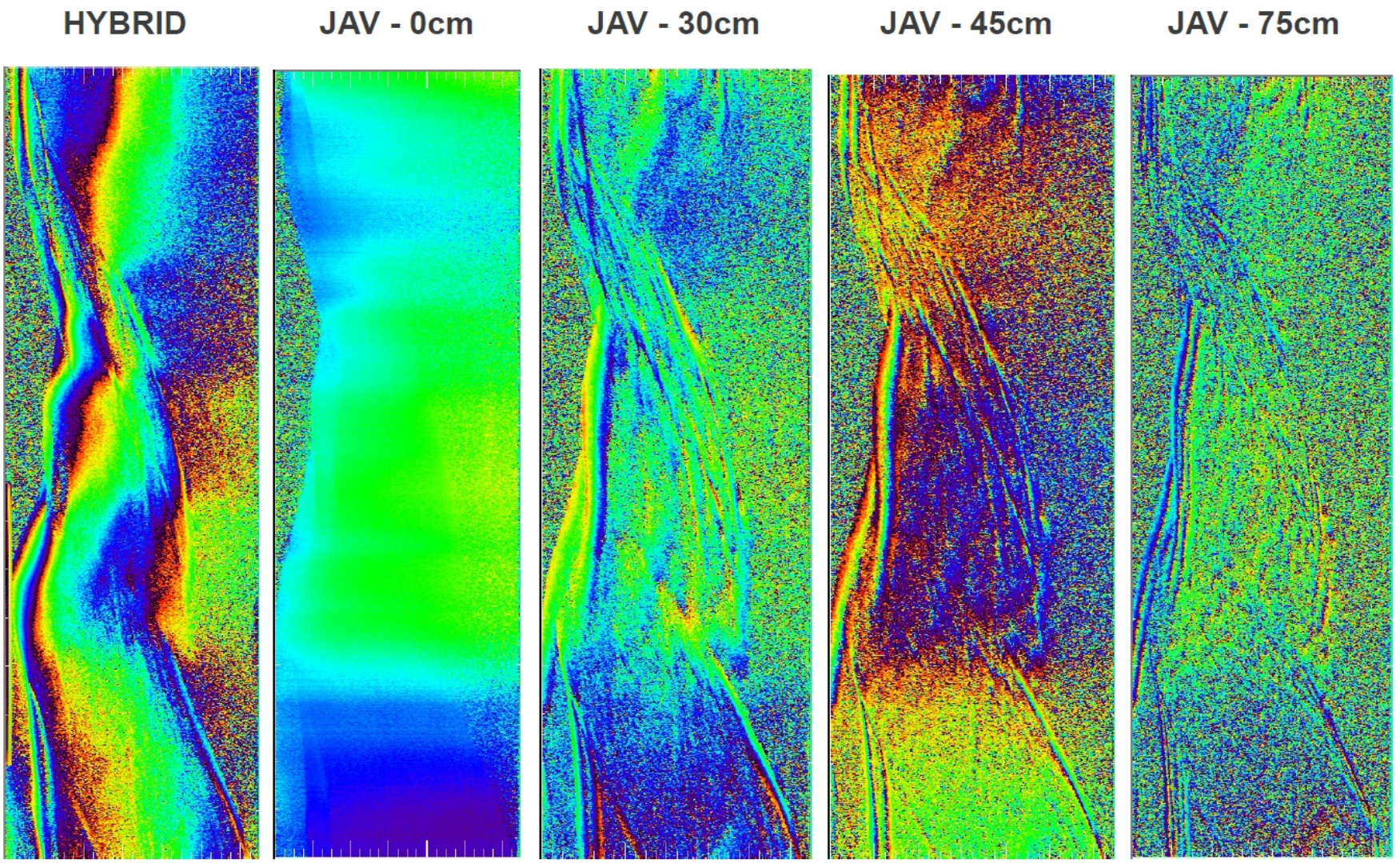
PoCC – First Results

M7 – Liverpool Bay Interferogram (no flat earth correction)



Interferogram is clean and free of large artefacts at mid-swath along the entire run

Real Aperture Processing



First Results: Ocean Currents

Pass R7 – Liverpool Bay 2D Preliminary Vector Field

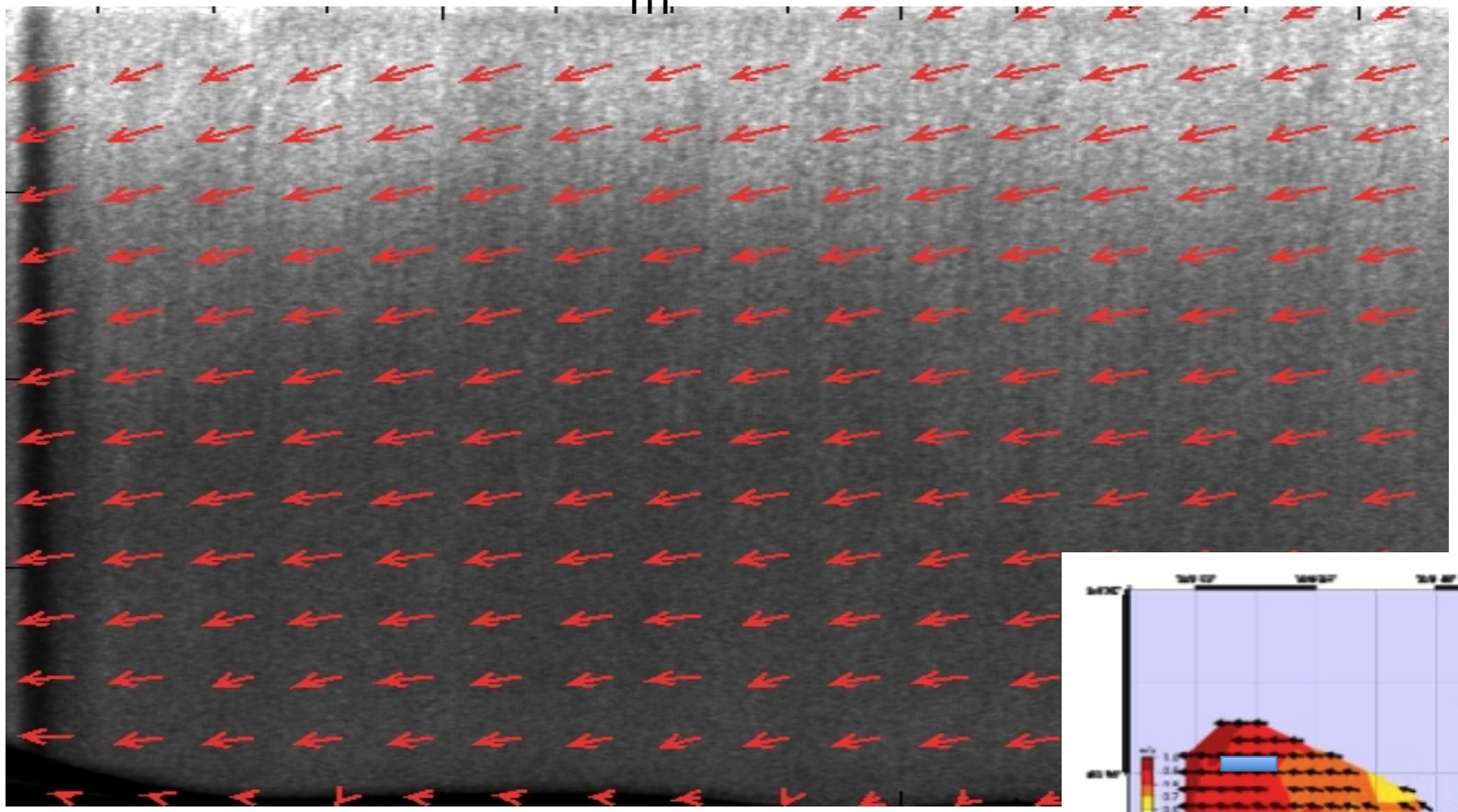
North

~ 2400 m

Along-track

~1200 m

Across-track



Each arrow averages ~100 x 150 m

Preliminary result. Starlab is currently working on the AT phase calibration (as of March 2012)

Next Steps

Product Assessment Study

- GSP activity about to be issued
- Tasks:
  - Review of Along-Track Interferometry – capability of ATI for current measurement, existing models, impact of wind and mitigation thereof
  - Validity of Scientific Products from a Wavemill Instrument
  - Scatterometry – extracting wind speed from Wavemill amplitude data
  - Additional Products – wave spectra, sea-ice, inland water/rivers
  - Synergy with other Instrument Data (e.g. conventional altimeter, thermal imager etc)

Mission Requirements

Feasibility Study

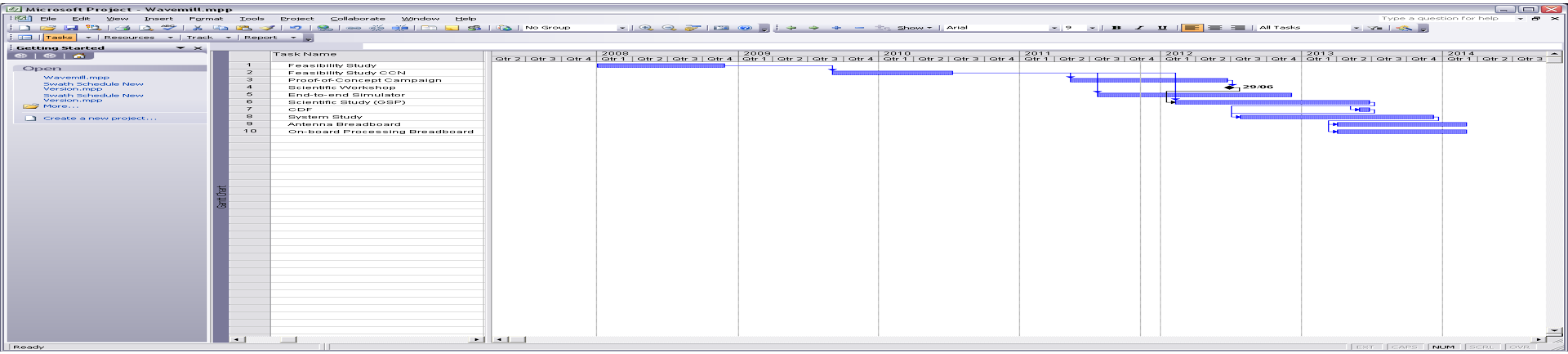
PoC Campaign

Product Assessment Study

Simulator

System Study

Planning



- Build science team
- Wavemill Science Workshop – 3rd quarter of 2012 at ESTEC
- Ultimate goal is to retire sufficient risk to allow a Wavemill Earth Explorer proposal to be acceptable – EE9?

Wavemill Needs from GlobCurrent

1. Clear ocean current product specification:
    - time-space scales
    - delivery timeliness
    - product format, metadata
    - Product content (u,v, uncertainty, gridded? Swath? flags?…) documentation
2. Priority target areas for high resolution surface current measurements (Global and regional regions of importance) as we cannot deliver everything everywhere all the time
    - What are we going to see at high resolution to help understand the mission data
3. Definition of approach to communicating uncertainties in products
4. A community that is familiar with using ocean surface current measurements and capable of using the Wavemill data in their systems
5. Identification of the scientific gaps in ocean surface current measurements that need to be filled by Wavemill mission
6. Complementary activities that can work with WaveMill to help refine the mission
7. Impact Studies on Wavemill data
8. Feedback on present missions and techniques

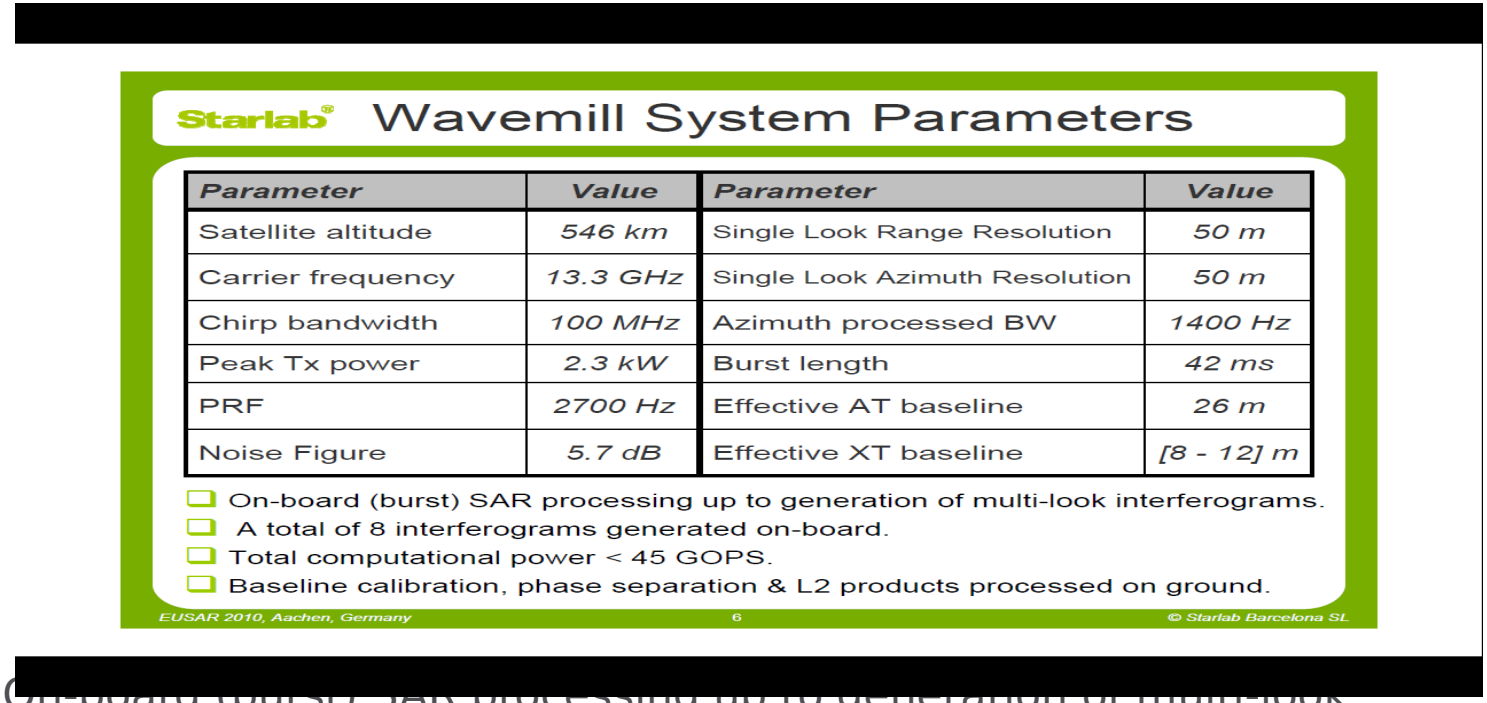
Conclusions

- The feasibility of a novel instrument able to provide 2D ocean surface currents measurements in addition to sea surface height has been demonstrated
  - Sea surface current velocity accuracy fulfills the 10 cm/s requirement. Estimated accuracy better than **3.5 cm/s**, even in the worst case, independent of sea surface current direction
  - Surface current direction accuracy inversely proportional to the sea surface current velocity
  - Sea surface current direction of 5º accuracy fulfilled independently of current direction for those currents faster than **35 cm/s** (90% of cases)
  - The relative sea surface height accuracy **< 1.5 cm** in the worst case
  - Absolute accuracy is driven by baseline attitude knowledge, in particular the pitch angle. The accuracy varies from 12.4 cm to 23.4 cm from near to far swath
- The data quality of PoCC is good, processing is on-going, scientific workshop later this year
- Obstacles in the way of an Earth Explorer are being addressed: scientific assessment, end-to-end simulator, antenna B/B, OBP, MRD, system study


Wavemill
Thank you for your attention!

Backup slides

Wavemill System Parameters



- On-board (burst) SAR processing up to generation of multi-look interferograms
- A total of 8 interferograms generated on board
- Total computational power < 45 GOPS
- Baseline calibration, phase separation & L2 products processed on ground

Risk Retirement Activities

In current TRP/GSTP plan:

1. Antenna breadboard
    - “Leaky wave” design – naturally squinted beams
2. On-board processing breadboard activity to cover the full on-board processing steps for Wavemill including:
    - SAR processing
    - Image registration
    - Co-time interferogram generation
    - Multi-looking
    - Flat earth correction
    - Hybrid interferogram generation
    - Hybrid phase separation

Based on FFT and processing chipsets (e.g. PowerFFT, Leon II)

End-to-end Simulator

- Development by Starlab (E) due to accrued know-how and proven competence in the development of relevant simulators (GNSS-R and WSOA)
- Structure:
  - Instrument model with configurable parameters (baselines, bandwidths, squint and look angles etc)
  - Sea surface state model (SWH, wind direction and strength, swell, fetch etc)
  - Processing (hybrid, co-time, interferogram generation, flattening etc)
- KO 5 July 2011, duration 18 months