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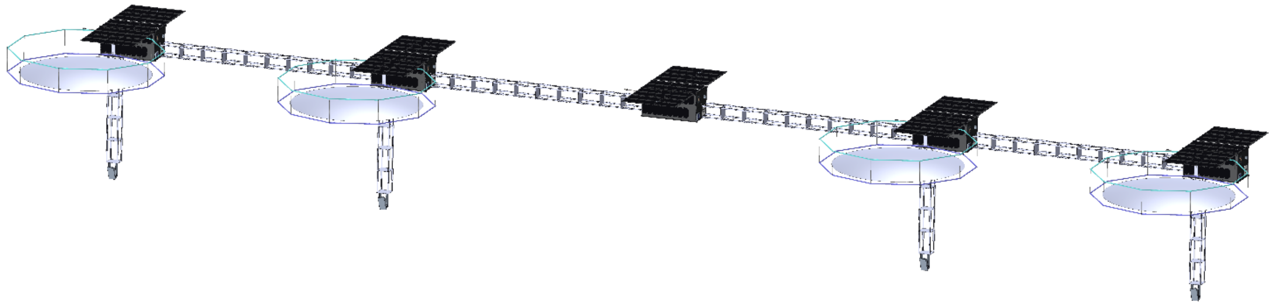

AltiCube+ - An Aggregated CubeSats Swarm for Long Fixed-baseline Radar Altimetry

Executive summary
Activity Type: Study

Innovative Mission Concepts Enabled by Swarms of CubeSats Campaign

Affiliations: TU Delft (Prime), COMET Ingeniería, ISISpace

Activity summary:
This report summarises the feasibility study result of AltiCube+, a low-cost long fixed-baseline radar altimeter solution based on CubeSats on-orbit assembly. Various altimeter concepts based on the AltiCube+ solution, including off-nadir SARIn and a Multiple-Input and Multiple-Output, have been explored, aiming at sub-kilometre cross-track resolution for water level monitoring. Key technologies on deployable structures, autonomous assembly and highly capable platform have been assessed. The final concept consists of five 16U CubeSats docking with each other to establish two side-looking interferometric altimeters, each with 6.6 meter baseline. The total cost is estimated to be less than 20M Euros.

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The Problem

Spaceborne radar altimeters have proven to be effective tools for measuring global water levels. In the coastal zone and over inland water bodies, increased cross-track resolution, better spatiotemporal coverage, and increased height accuracy are essential. Radar interferometry can be used to obtain sub-kilometre resolution over a swath at the expense of additional transmit power and a sufficiently long baseline to accommodate at least two antennas. A good example is the NASA's SWOT, a satellite with two 5-meters radar altimeter antennas on a 10-meters long boom, paid with 15 years' development time and more than one billion dollars cost. As a consequence, it is unlikely that oceanographers will ever get a much wanted high spatiotemporal revisit rate. However, if the cost of a single radar altimeter can be significantly reduced, then launching multiple systems to obtain a constellation with good spatiotemporal coverage could overcome the problem.

Proposed Solution

Instead of a distributed interferometric swarm requiring extremely high accurate time/attitude synchronizations and centimetre level formation maintenance, an innovative solution called AltiCube+, a low-cost long fixed-baseline radar altimeter solution based on CubeSats on-orbit assembly, has been proposed by a consortium led by TU Delft. The AltiCube+ solution consists of multiple 16U CubeSats. After an early operation and commissioning phase, these CubeSats will perform autonomous rendezvous and docking with each other via deployable booms to establish a long fixed-baseline, and then deploy antennas for an interferometric altimeter configuration. The uniqueness of AltiCube+ is on the potential scientific opportunities brought by two left and right looking interferometric altimeters with 6.6 meter baseline (total system length is 8.8 m) and the sustainability due to its significantly low cost (<20 MEuros) and short development lifecycle. If budget allows, multiple AltiCube+ systems with same or different altimetry capabilities can form a constellation to dramatically reduce the revisit time and, therefore, provide much better spatiotemporal coverage.

The Principle

The AltiCube+ system is a side-looking radar imaging instrument. The imager produces a two-dimensional radar map of the ground with a swath width in the order of tens of kilometres. A second antenna separated by a suitably chosen and well defined baseline from the first antenna produces a similar image. The cross-track baseline between the antenna phase centres ensures phase differences occur that for each resolution cell that are a function of the relative position of the scattering surface and the platform. The range and phase differences are used to determine the height of a target. The system consists of 5 nodes (16U CubeSats), two nodes operating an interferometer observing a swath on the left side, two other nodes observing the right side and a central unit for control, data processing and downlink, see Figure 1. The antennas are pointed in cross-track direction at small angle away from nadir, in the order of 2-4 degrees. The nodes can be fully identical if the cross-track pointing can be selected in the satellite, either by mechanical or electronic means. Electronic control (beam steering) seems the best solution as it allows fine tuning of the beams during the mission. Both interferometers can have a baseline of 6.6 meter.

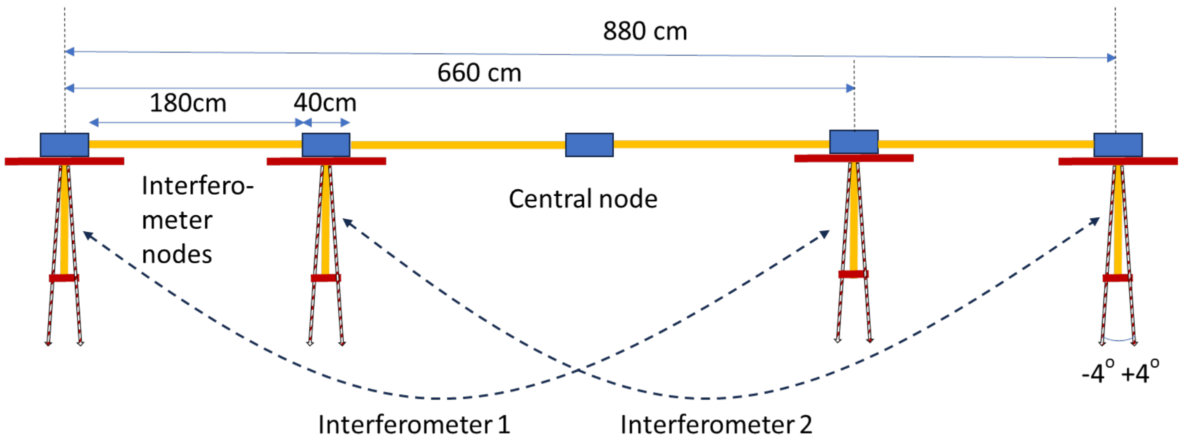


Figure 1: Principle of the AltiCube+ system with 4 radar nodes and a central control and processing unit. The reflector antennas are positioned under the platform. An offset feed antenna enables beam-steering to angles between -4 and +4 degrees, as indicated with arrows.

Specifications and Advantages

The key specifications are summarised in Table 1.

Table 1: Key characteristics

Characteristic	**Specification**
height accuracy	1.7 cm (ocean), 3.9 cm (inland water)
sample ground resolution	220 m along track x 577 m cross-track (ocean), 27 m along track x 241 m cross-track (inland water)
swath width	18 km
radar frequency	13.6 GHz
System	5 nodes of 16U CubeSats, docked via booms
Aggregated system length	880 cm width
System mass	5 x 18 = 90 kg
Payload antenna	Two interferometric radars with 660 cm baseline
Orbit	500 km SSO with an LTAN of 10:00h

The AltiCube+ system has specific advantages:

1) Contrary to SWOT, it has two separate interferometer systems, which both can look left and right of nadir. Each system has two transmitters, one in each node. A failure in a transmitter leads only to graceful degradation, not to a complete malfunction.

2) Its height error is efficiently reduced by using monostatic observations which perform a factor 2 better than the bistatic operation as used in SWOT. Moreover, the use of all transmit/receive combinations improves the height accuracy by a factor up to 2.5 compared to single transmitter bistatic operation.

3) It operates at Ku-band with a moderate transmit power (15 W peak per transmitter as compared to 1500 W for SWOT), which greatly reduces the cost of the system.

Key Technologies

Three key technologies, i.e. the deployable structures, autonomous assembly and highly capable platform, are addressed in the study.

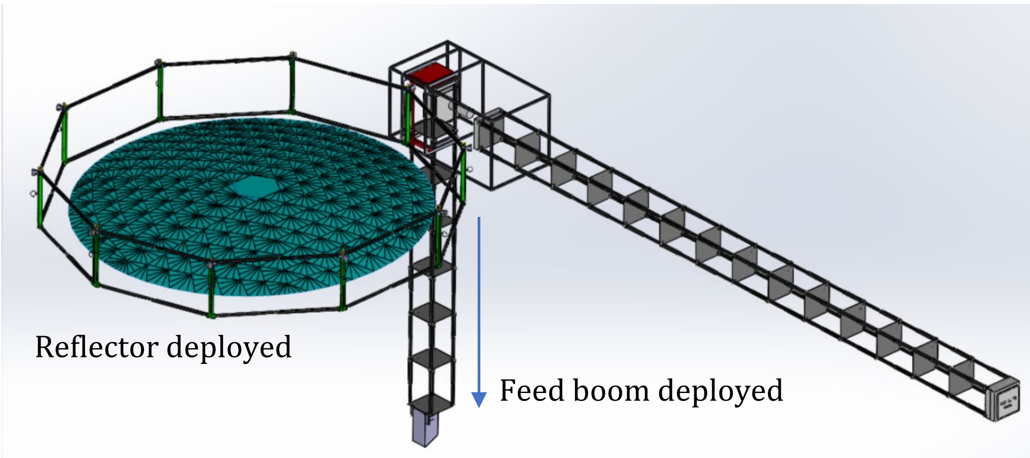
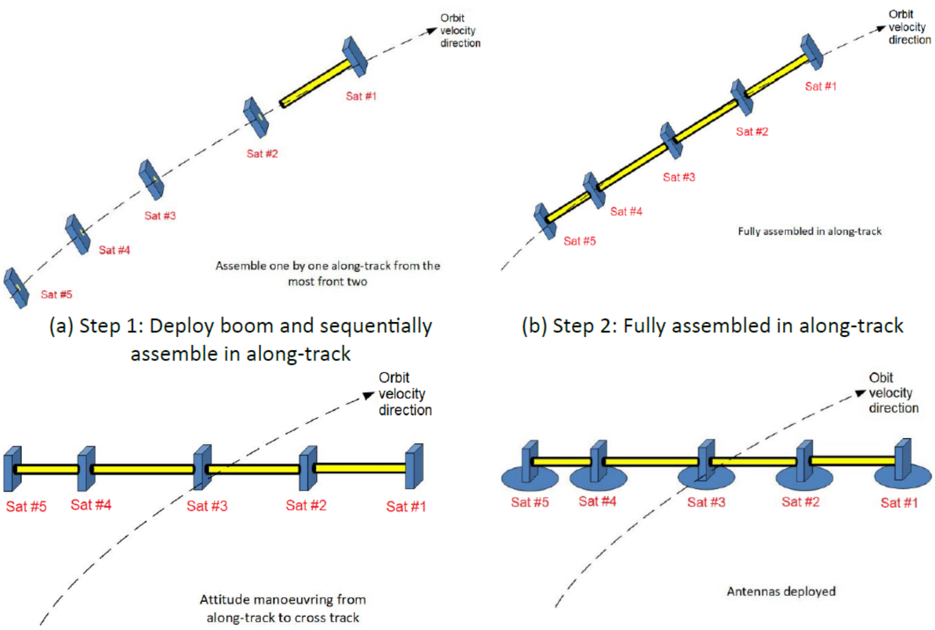


Figure 2: All structures deployed.



(a) Step 1: Deploy boom and sequentially assemble in along-track

(b) Step 2: Fully assembled in along-track

(c) Step 3: Attitude yaw 90° from along-track to cross-track

(d) Step 4: Altimeter antennas deployed for scientific operation

Figure 3: Autonomous assembly procedure.

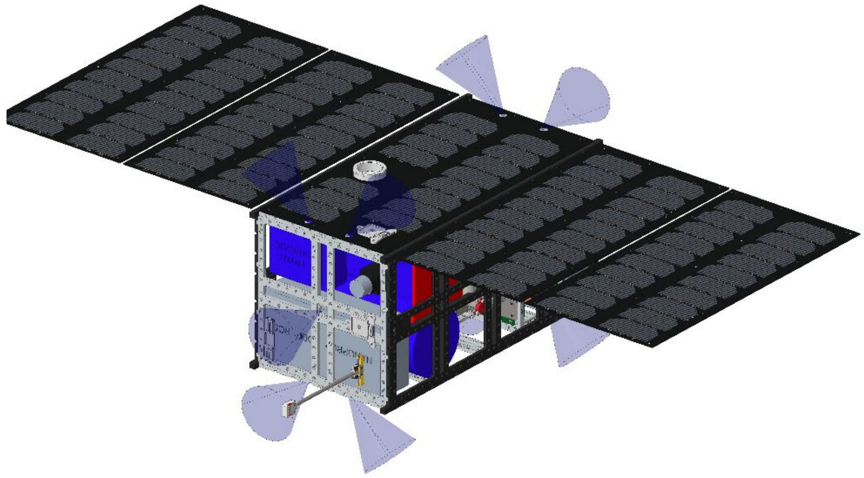


Figure 4: AltiCube+ radar-node CubeSat preliminary external view with RCS cones indicated

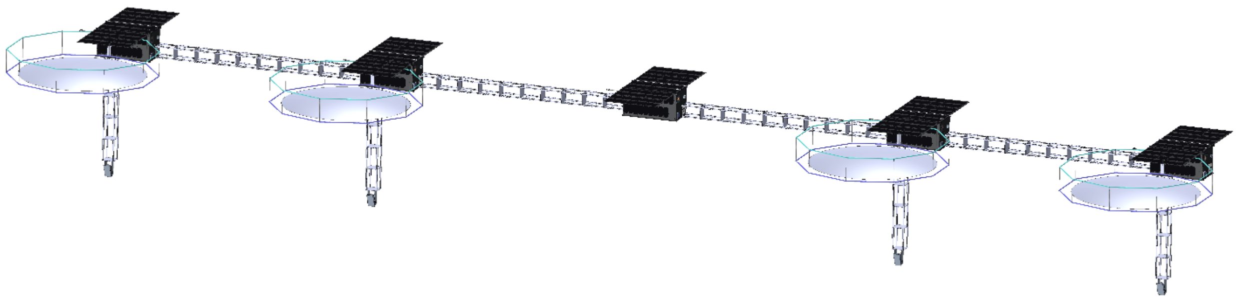


Figure 5: Fully assembled AltiCube+ system

Conclusions

The study shows AltiCube+ is a very challenging concept, but should be feasible if a few development risks are mitigated. It should be noted that many of the required developments have generic mission applications, potentially corresponding to other advanced CubeSat missions proposed or under development. It is therefore recommended to derisk the AltiCube+ mission by investing in the critical technology developments first while performing a follow-up study to reduce the uncertainties of the analysis. After final confirmation of the feasibility of AltiCube+ and maturing many components, they eventually have to be demonstrated in-orbit, before a full scale operational mission can be launched.