Waves from radar altimetry satellites

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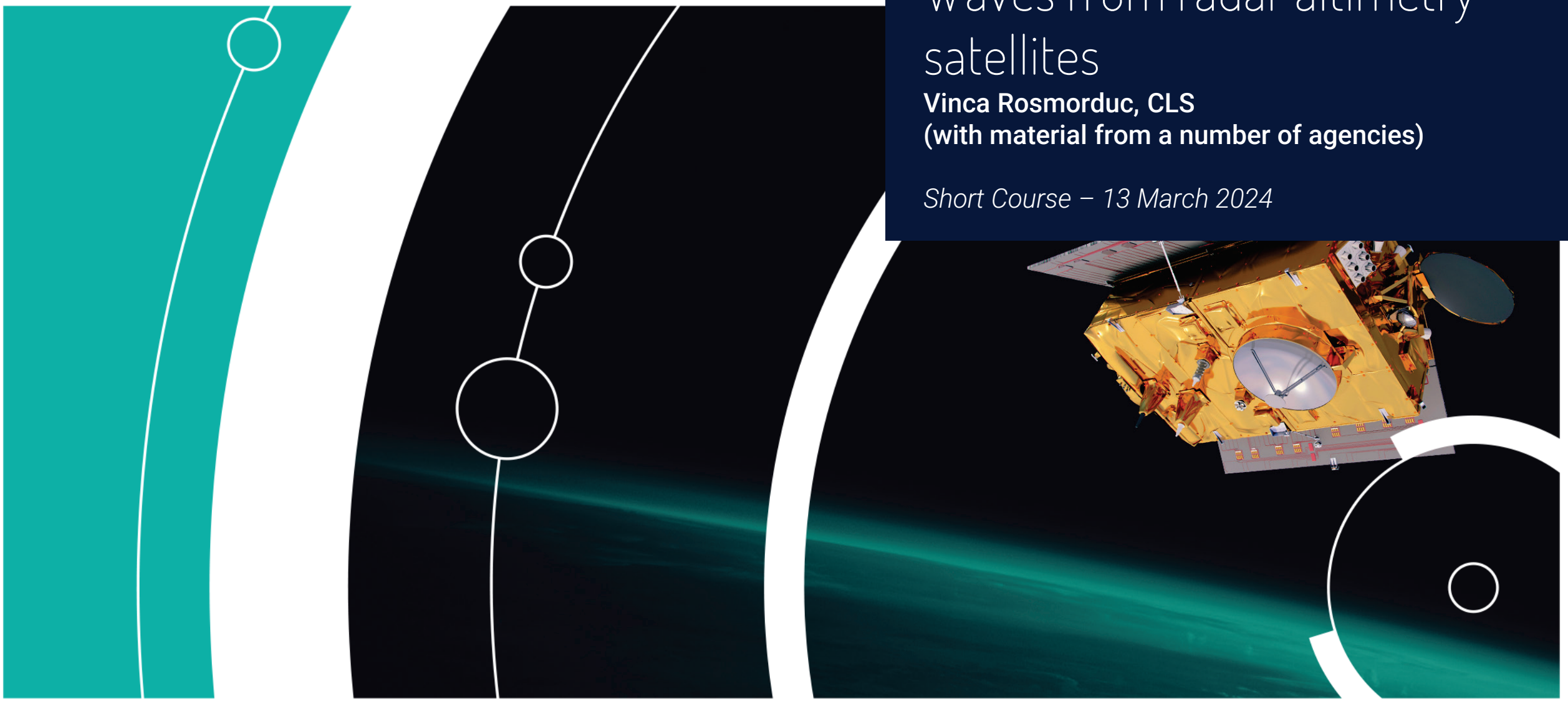
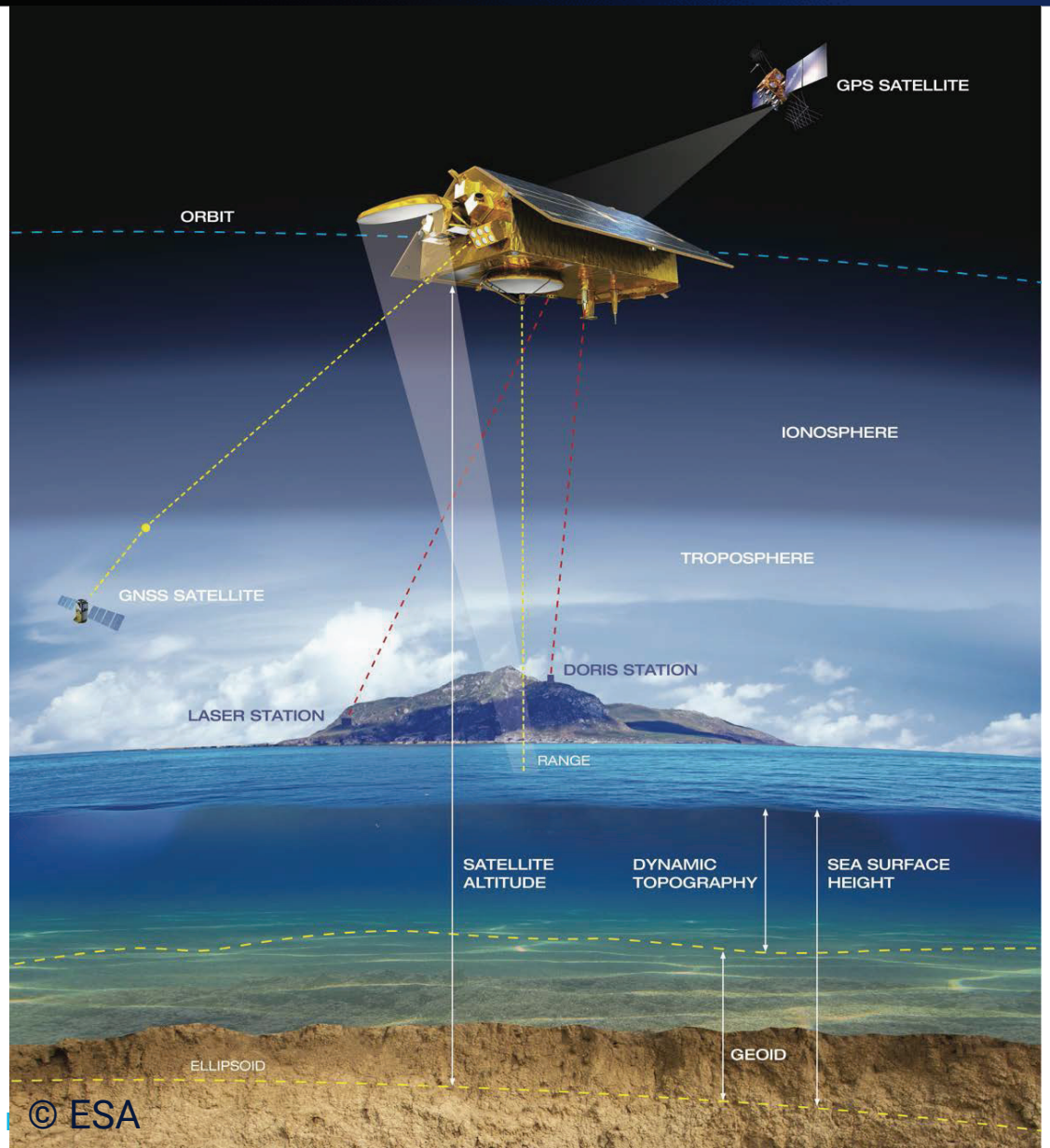
(with material from a number of agencies)

Short Course – 13 March 2024



The principle of Altimetry



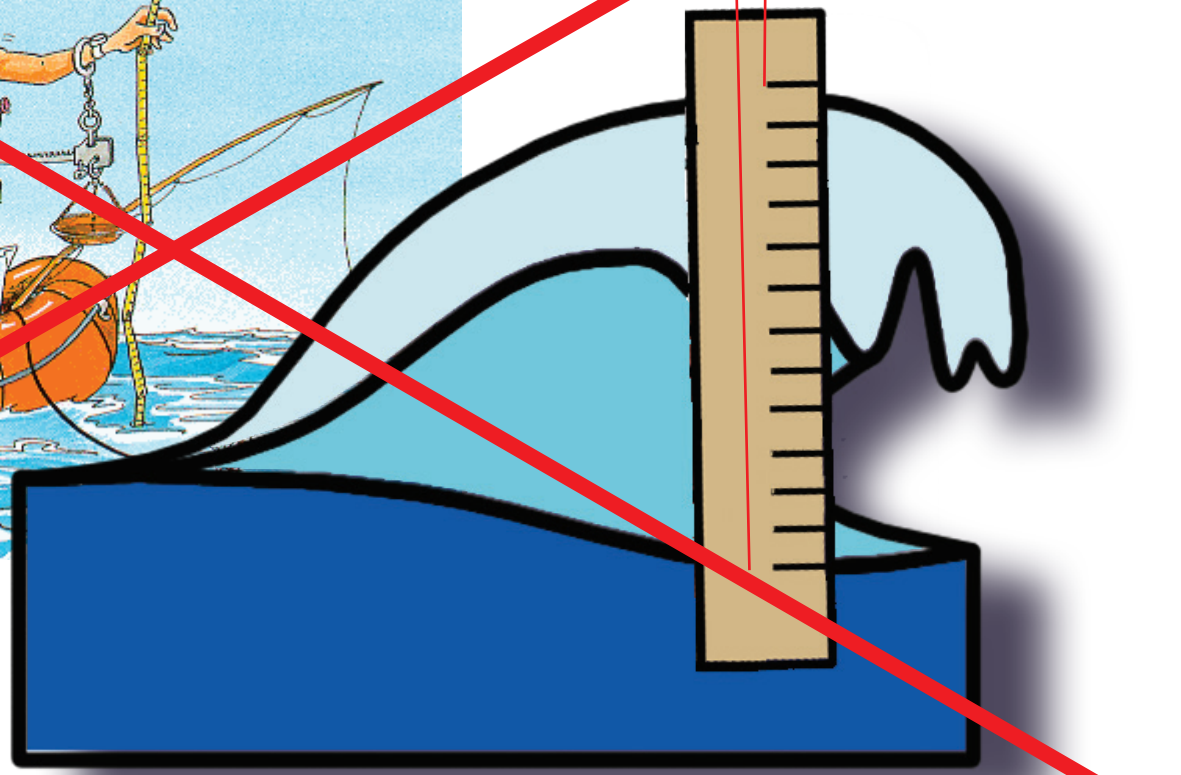
- Altimetry is meant to retrieve “Sea Surface Height”
  This is the **difference** between the **satellite-to-ocean range** (calculated by measuring the signal’s round-trip time) and the **satellite’s position on orbit** with respect to an arbitrary reference surface (a raw approximation of the Earth’s surface, called the reference ellipsoid)
- See dedicated short courses

- BUT:
  what about WAVES??

Wave retrieval?

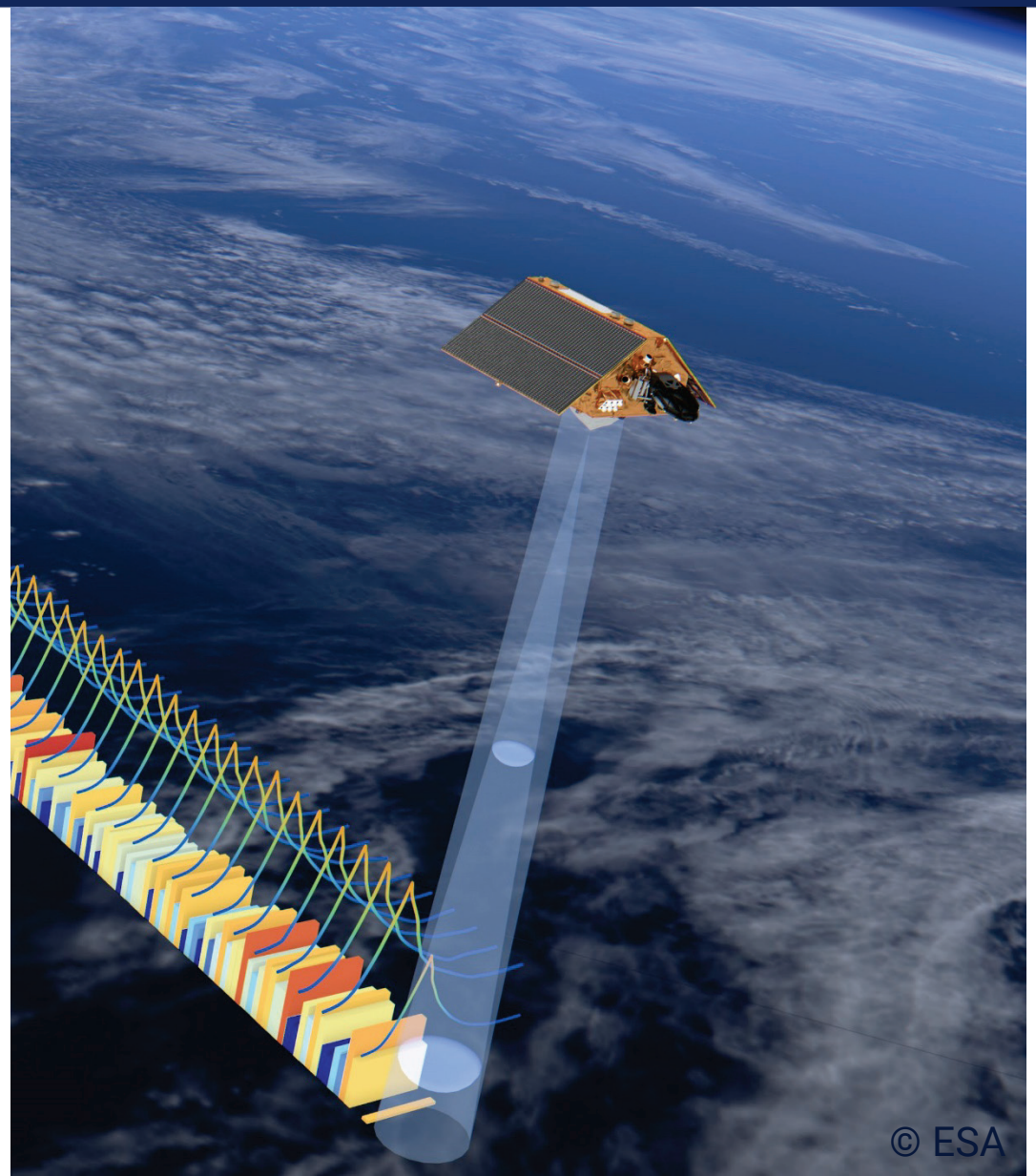
raconte-moi l'espace

SAIS-T QUE LES SATELLITES SONT PLUS EFFICACES QUE TOI ?

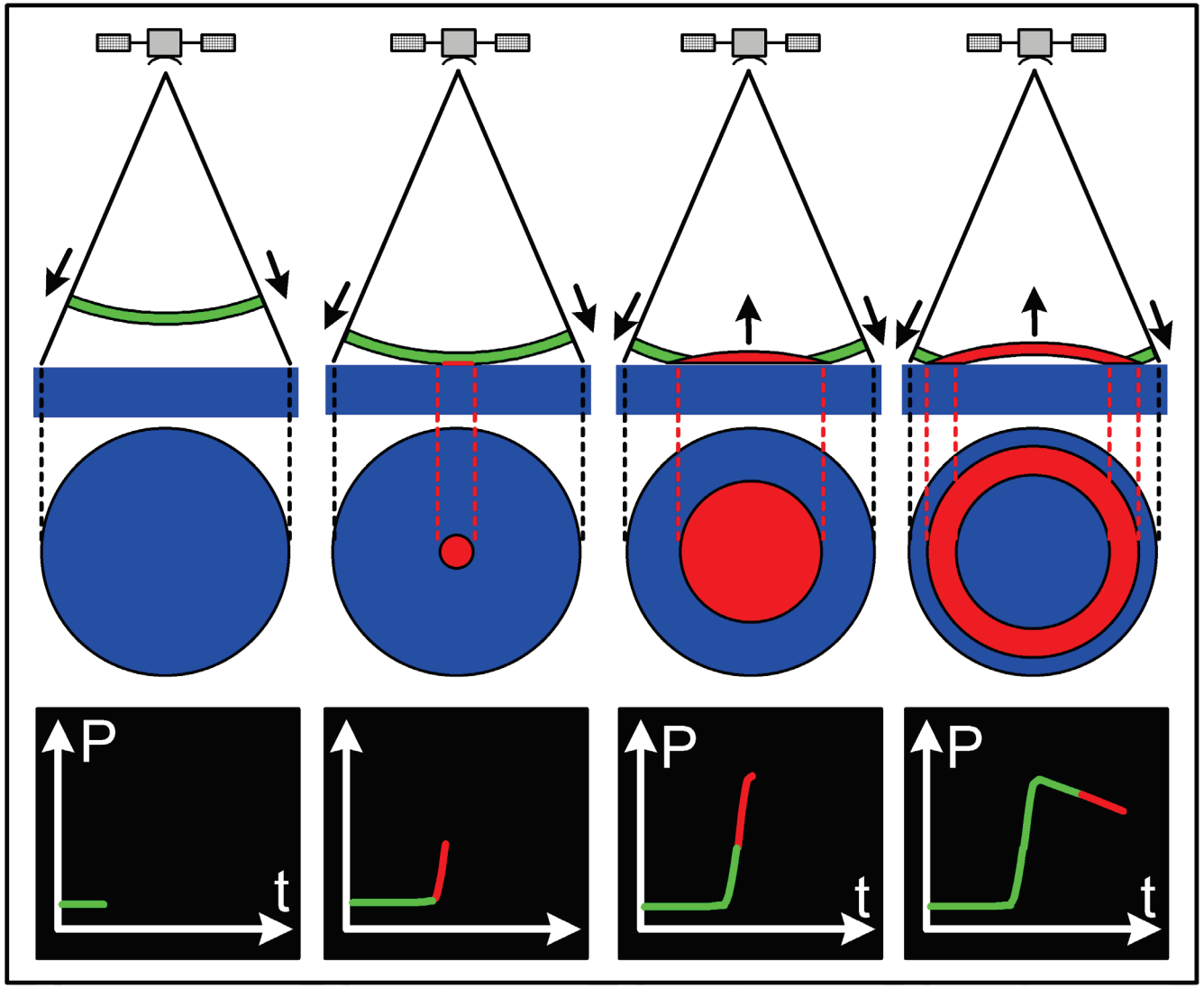


Not that way…

- Because :
  - Satellite beam is not a thin line…
    (its footprint is about 10 km in diameter,
    1-2 km at least are used in the analysis)
  - Measurements are averaged anyway (over 1s, i.e. 7 km along the track, or 1/20 s, 350 m), to remove white noise. Individual measurements are not used
  - Anyway, it would be too anecdotic
    (one wave measured over a lot)
- So, how?:
  the way the radar wave is reflected on the ocean surface is largely shaped by wave at the footprint level



Analysis of radar (averaged) “echoes”: waveforms

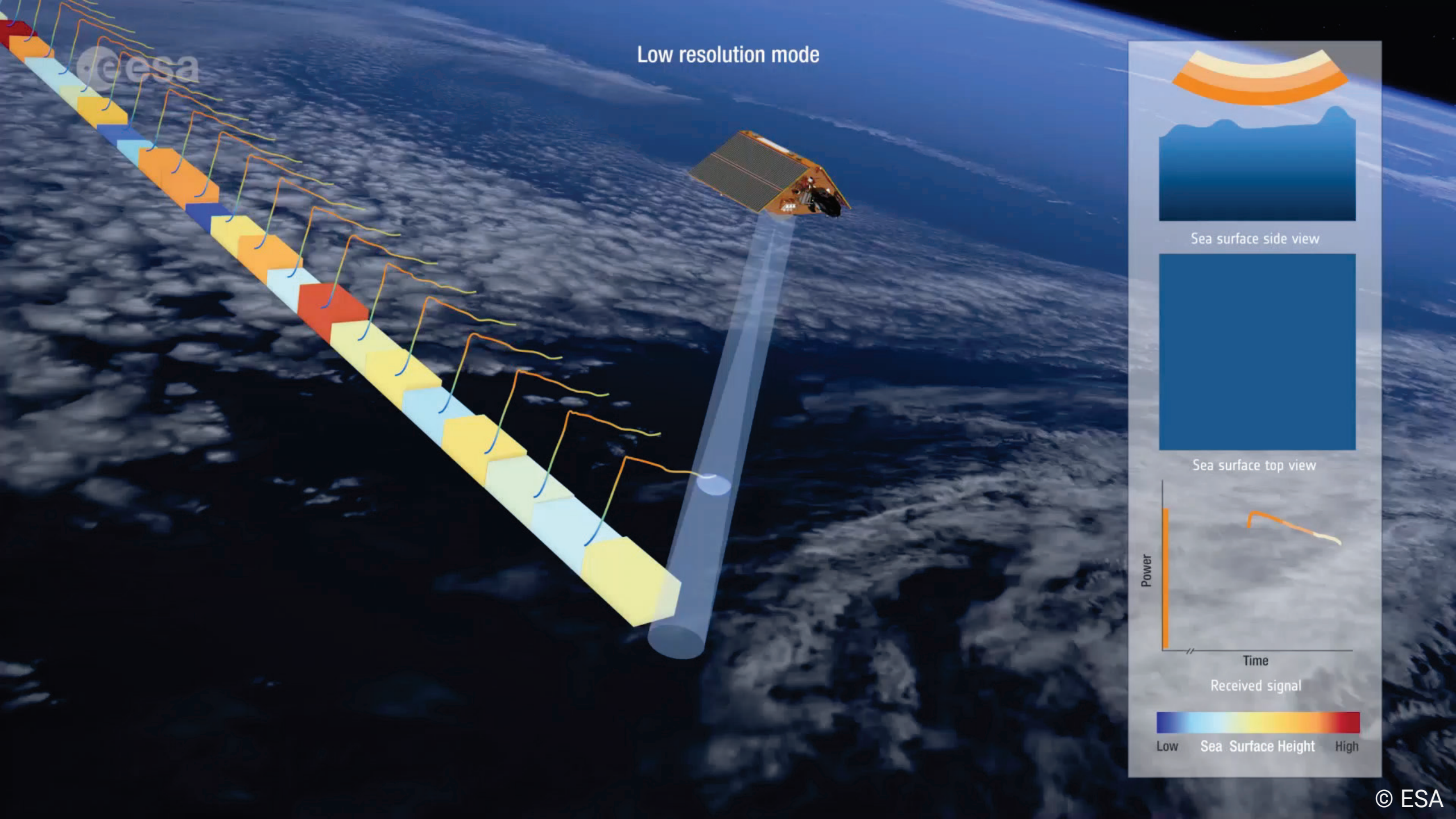


Satellite

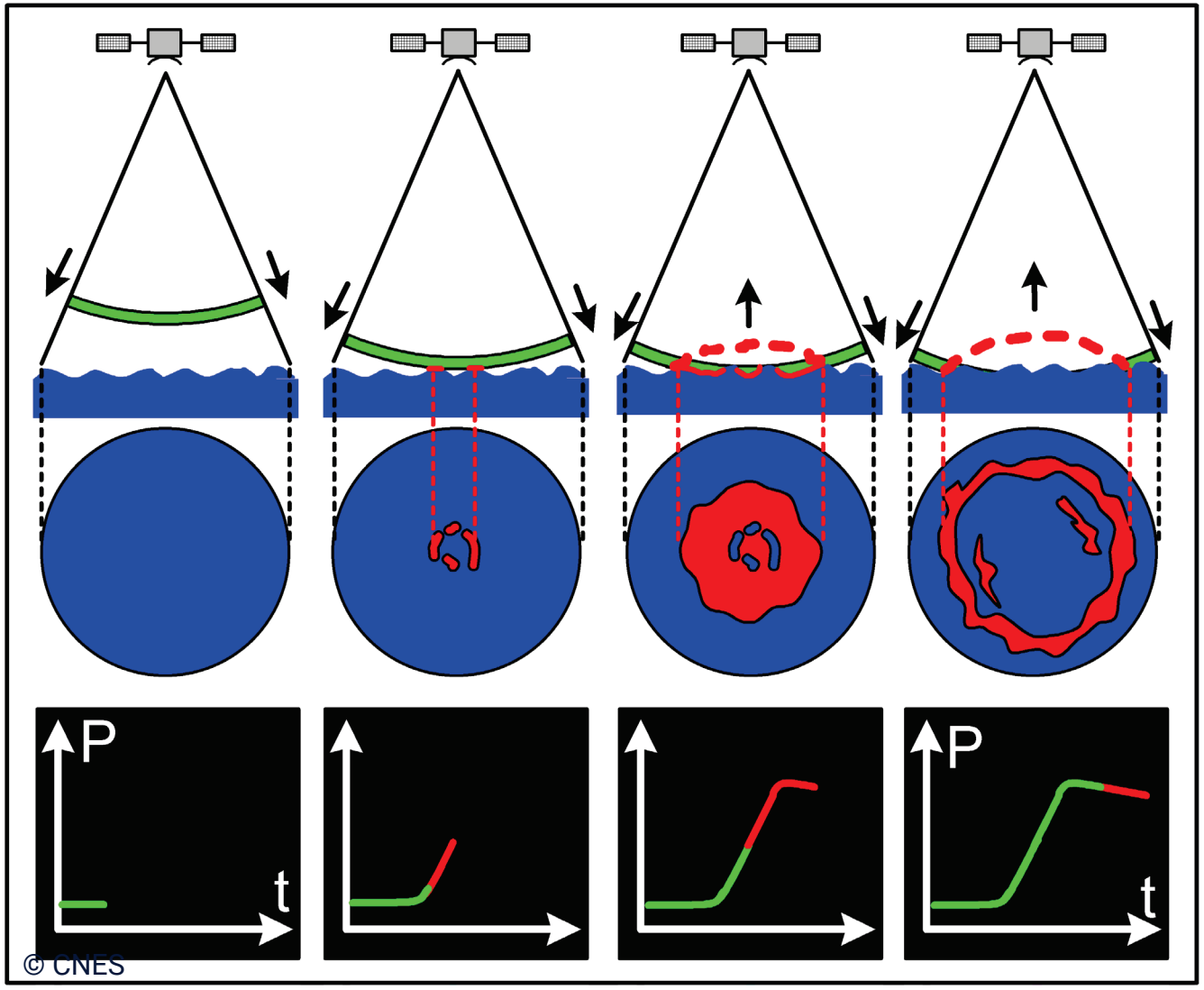
Radar wave

Radar wave as seen from above the surface

Shape of the power as received back by the onboard radar with respect to time


Low resolution mode
Sea surface side view
Sea surface top view
Power
Time
Received signal
Low
Sea Surface Height
High

Waveforms, Classical altimeter: Rough sea



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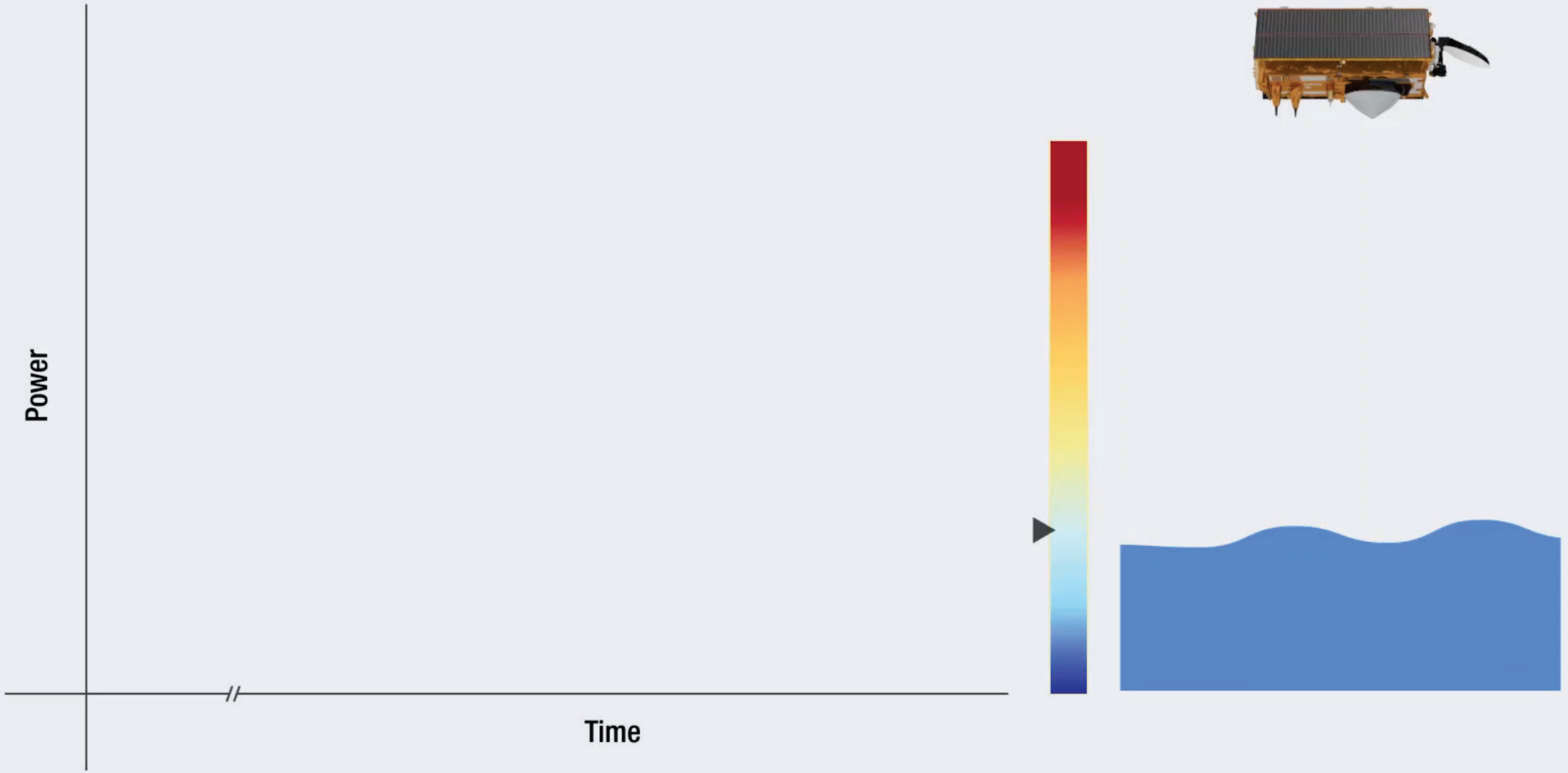
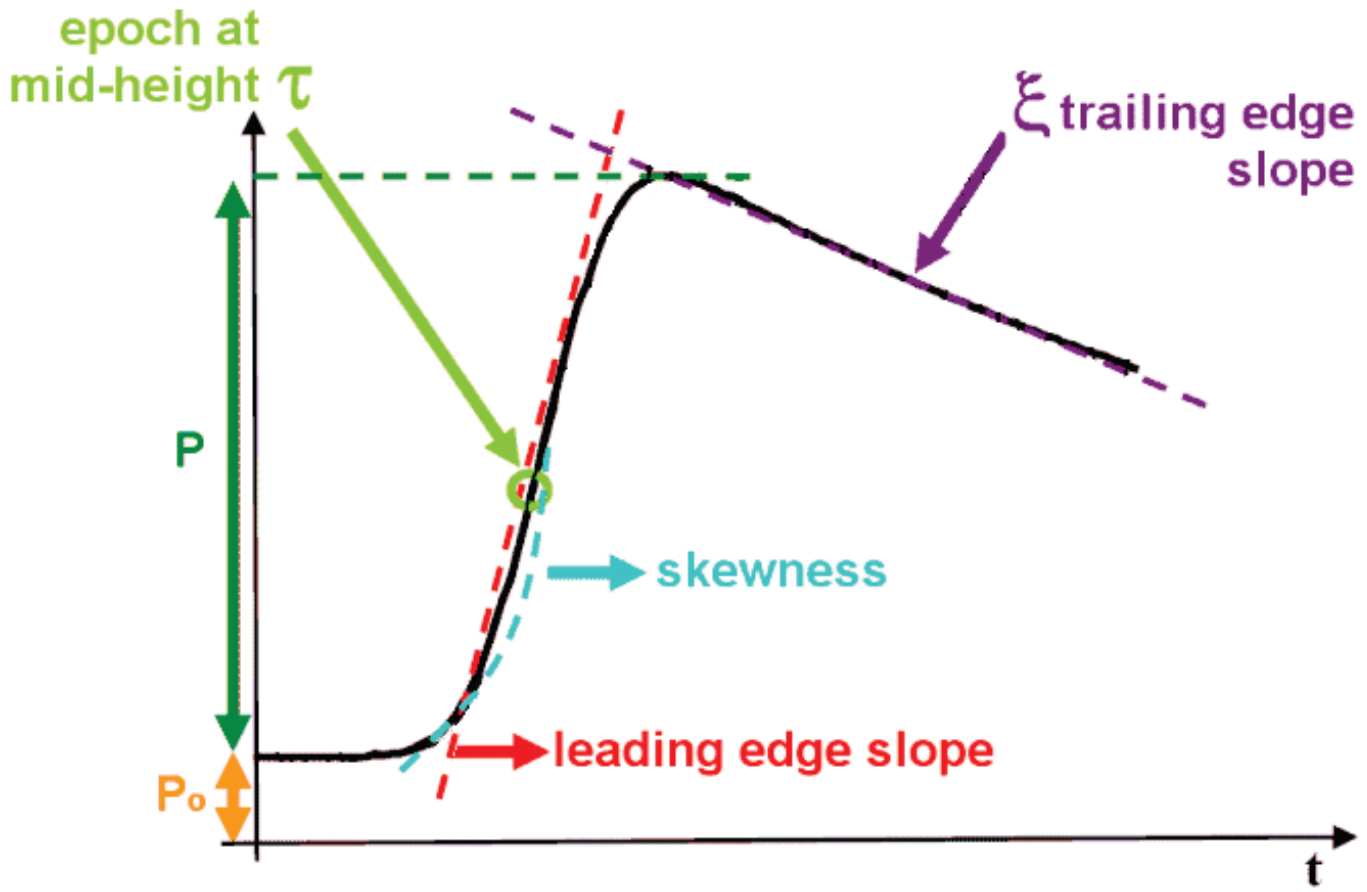
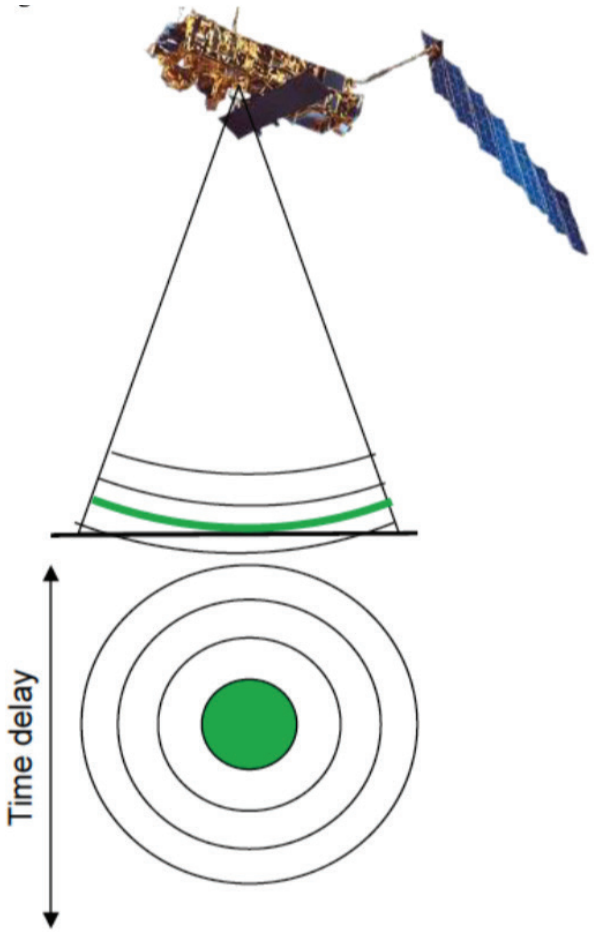


Waveform over ocean

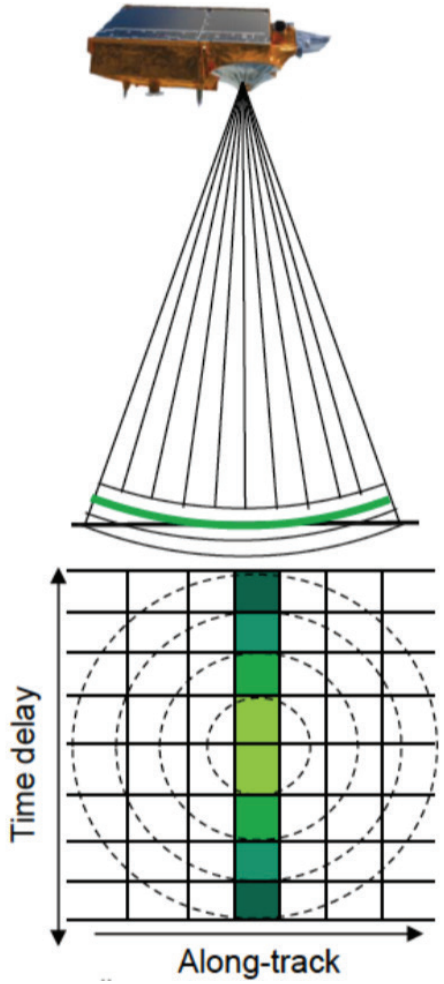


Theoretical waveform over ocean ("Brown model", classical altimetry). Significant wave height is computed from the leading-edge slope.

“SAR-Mode” on Cryosat2, Sentinel-3, Sentinel-6



Classical altimeter
(or Low Resolution Mode)



SAR mode

- Higher emission rate than previous (classical) altimeters
- Frequency received used to compute direction of the beam (Doppler shift)
- Coherence of the signal sent for about 2.5 s

➔ Split radar footprints in “slices”, data over each slice averaged using different satellite positions

➔better SSH accuracy

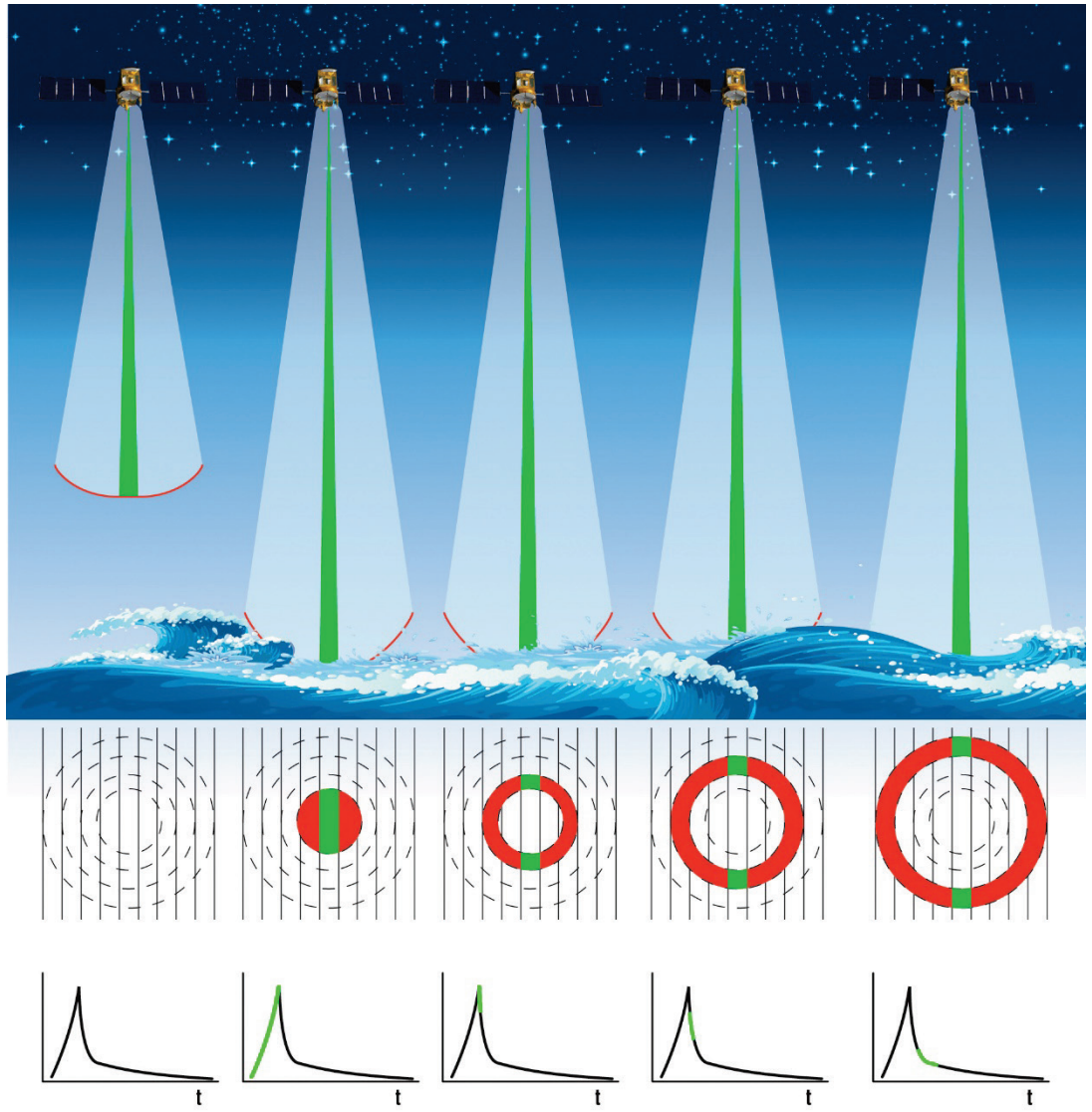
Analysis of radar "echoes": SAR waveforms

- Analysis of the Doppler shift in the radar echoes

→Footprints cut in "slices"

→Higher along-track resolution

Basis stay the same.



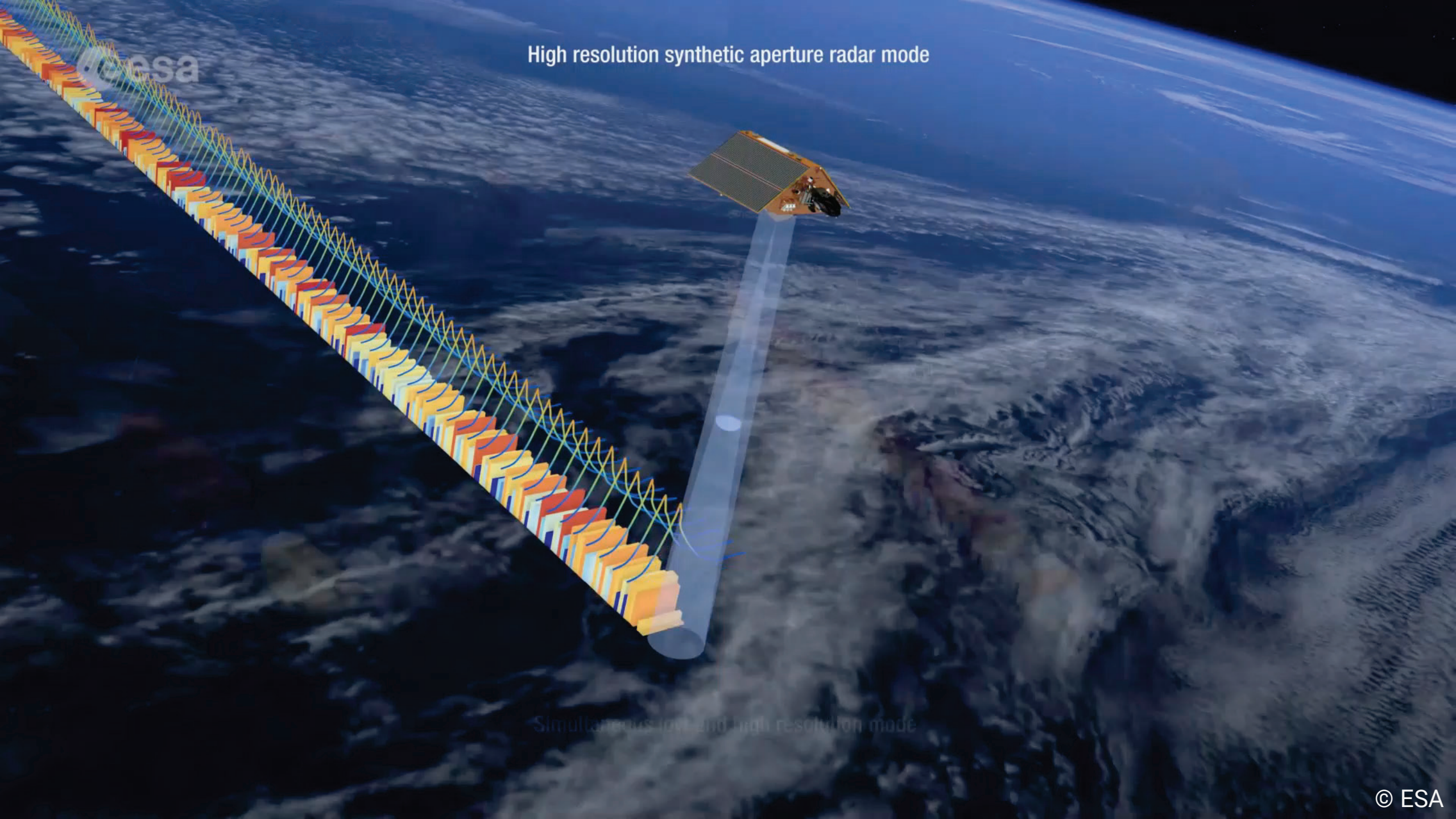
How an echo is "built"

Satellite

Radar beam

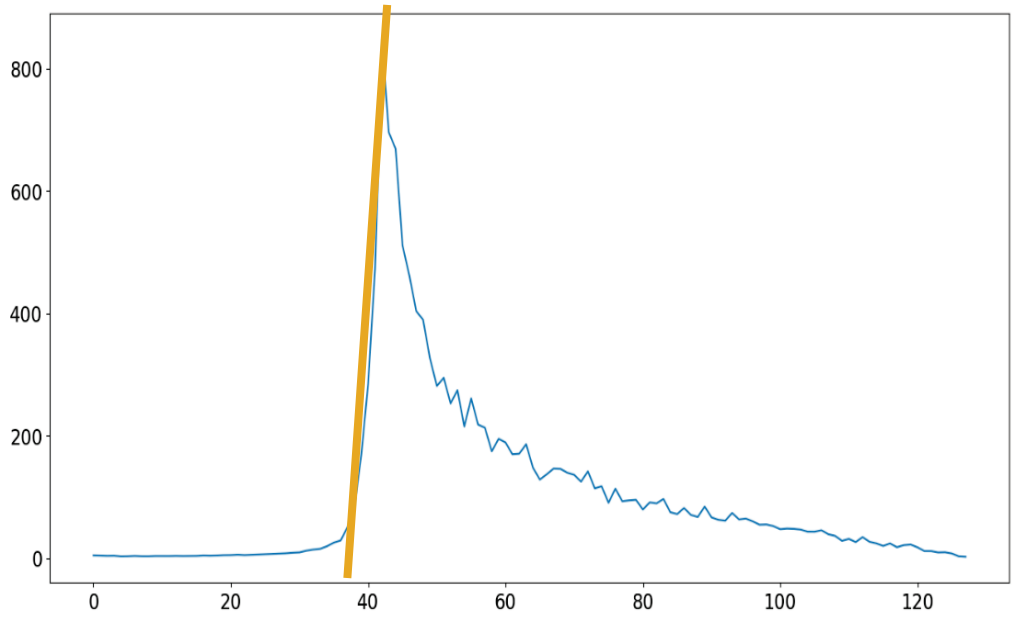
Radar signal as seen from above the surface

Shape of the power as received back by the onboard radar with respect to time ("waveform")

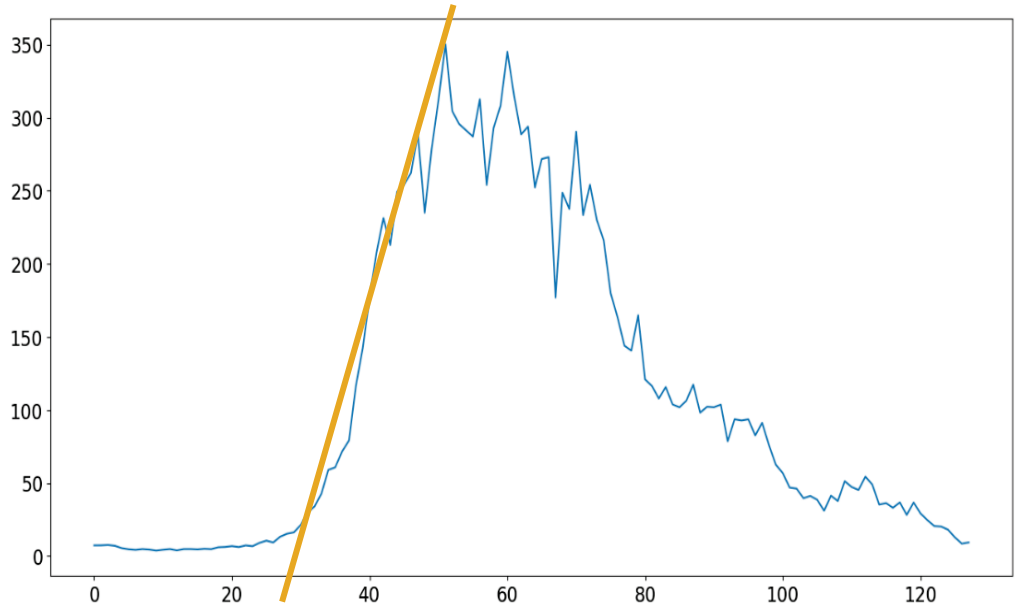

High resolution synthetic aperture radar mode
esa
Simultaneous low and high resolution mode

A “real” case of SWH waveforms (storm Domingos)

“normal” sea



15-m SWH sea



Two “waveforms” taken on Nov. 4, 2023 by Sentinel-3B. Left outside the storm, right over the worst of the storm over North-East Atlantic (see notebook demo later)

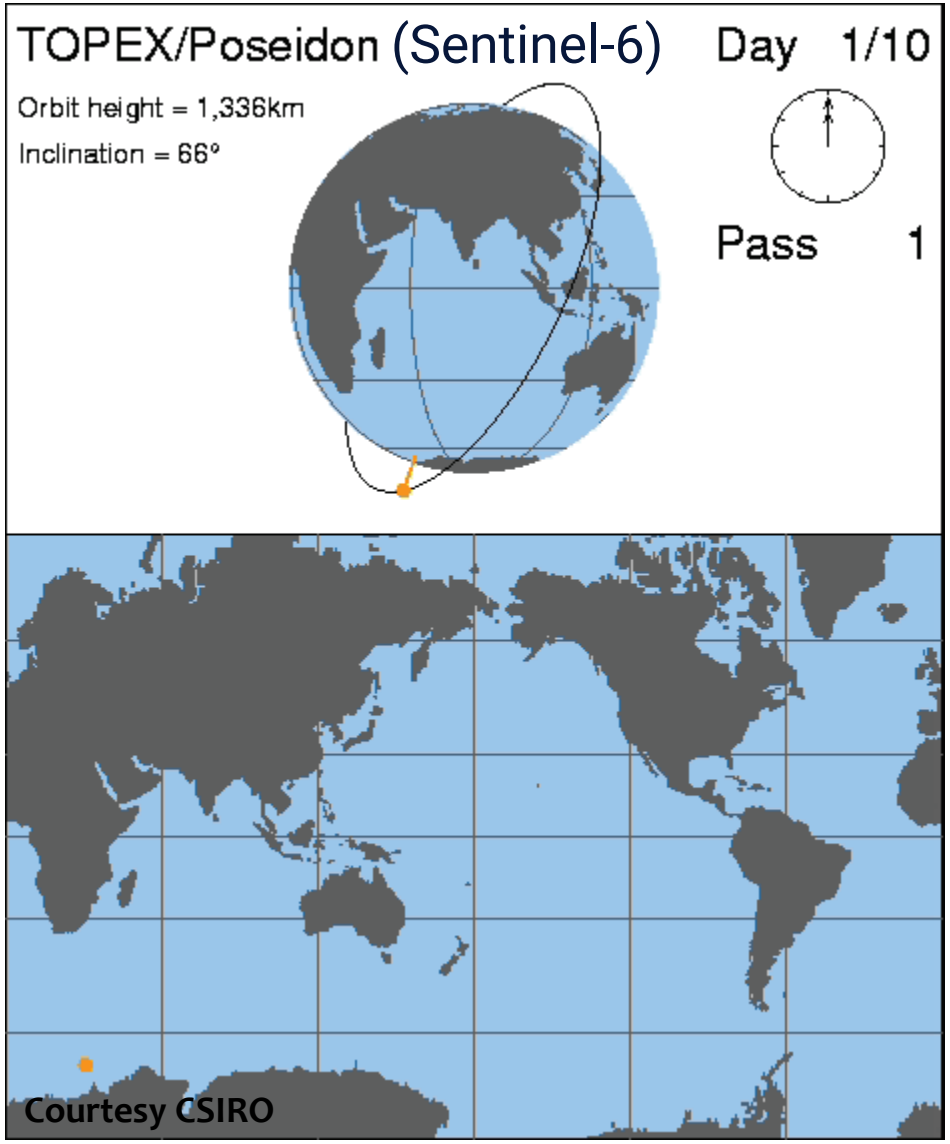
Accuracy

- Accuracy of SWH depends on the wave height;
  the higher the wave, the larger the error on the measurement
- Typically for SWH: 10% or 0.5 m down to 4-5% or 0.1 m
  (whichever is greater)
- Does not improve much with STC (vs NRT), nor with NTC
  (precision of orbit determination not essential, contrary to
  SSH)

Applications of Significant wave height measurements from altimetry

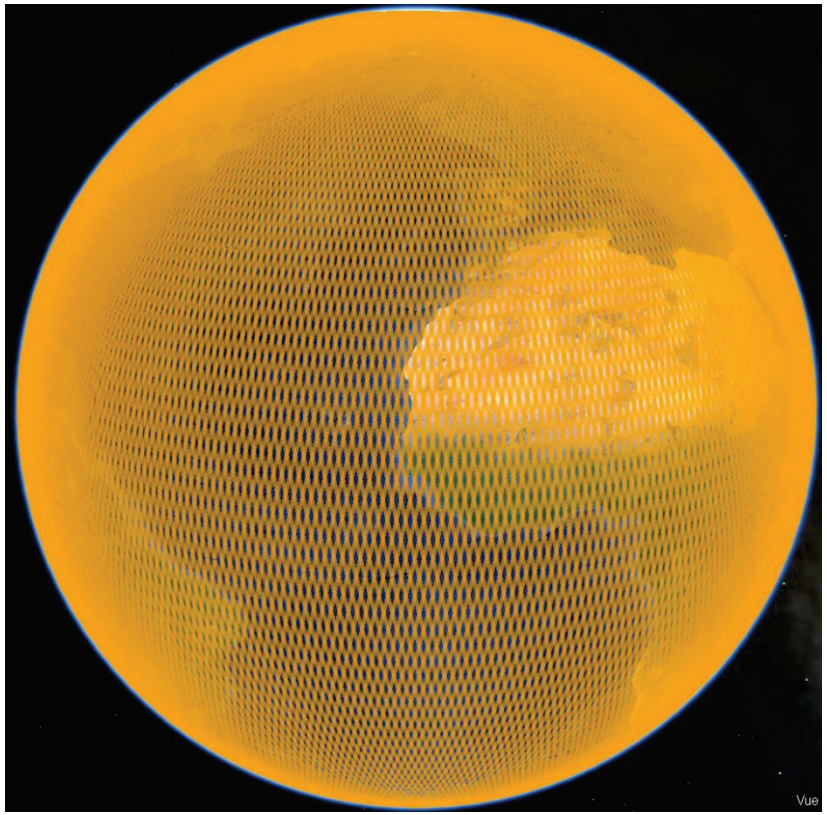
- Operational measurement of waves? Well, yes and no:
  - No: the satellite goes over the same point “only” every cycle (10 days at least, up to 28 days depending on the satellite), so not all the surface of the ocean is covered at all time

!! Nadir altimetry is not imagery

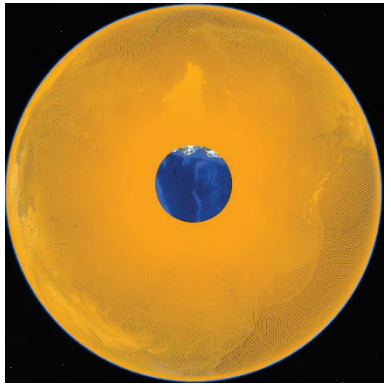


NB. altimetry data = a narrow thread of measurements just beneath the satellite.

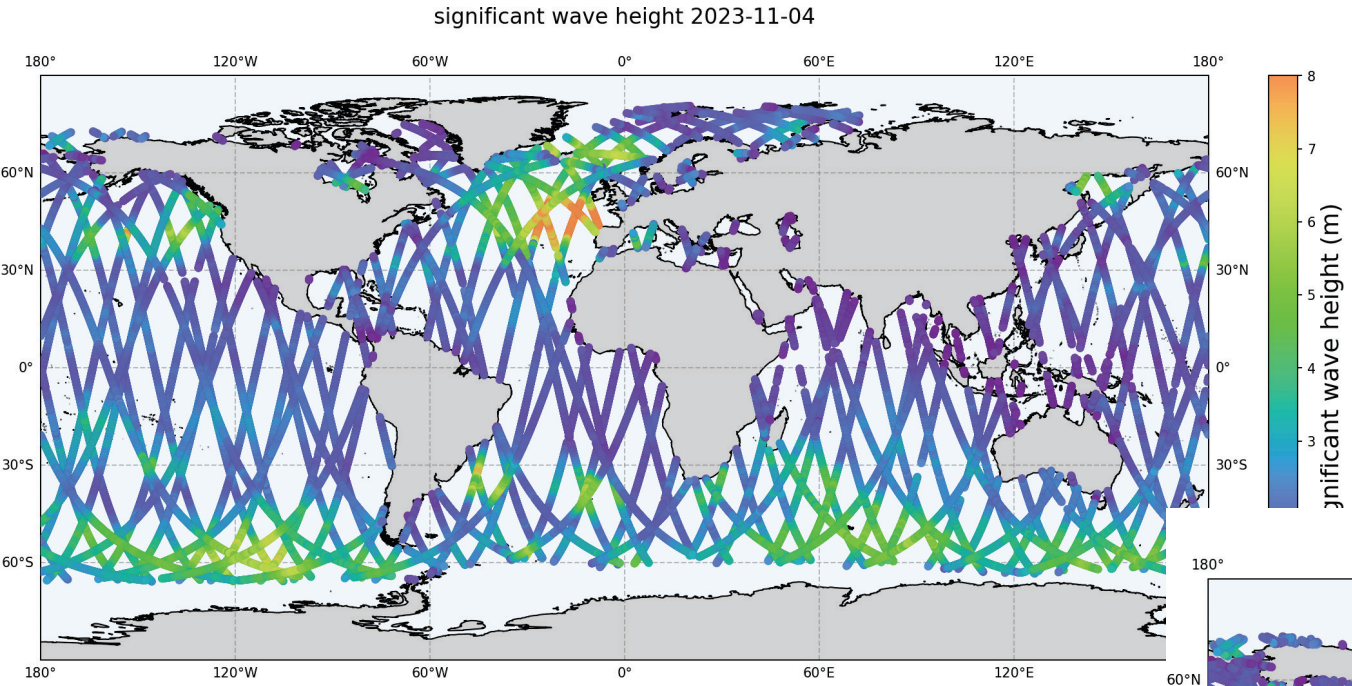
“along-track” data



Sentinel-3:
27-day track revisit

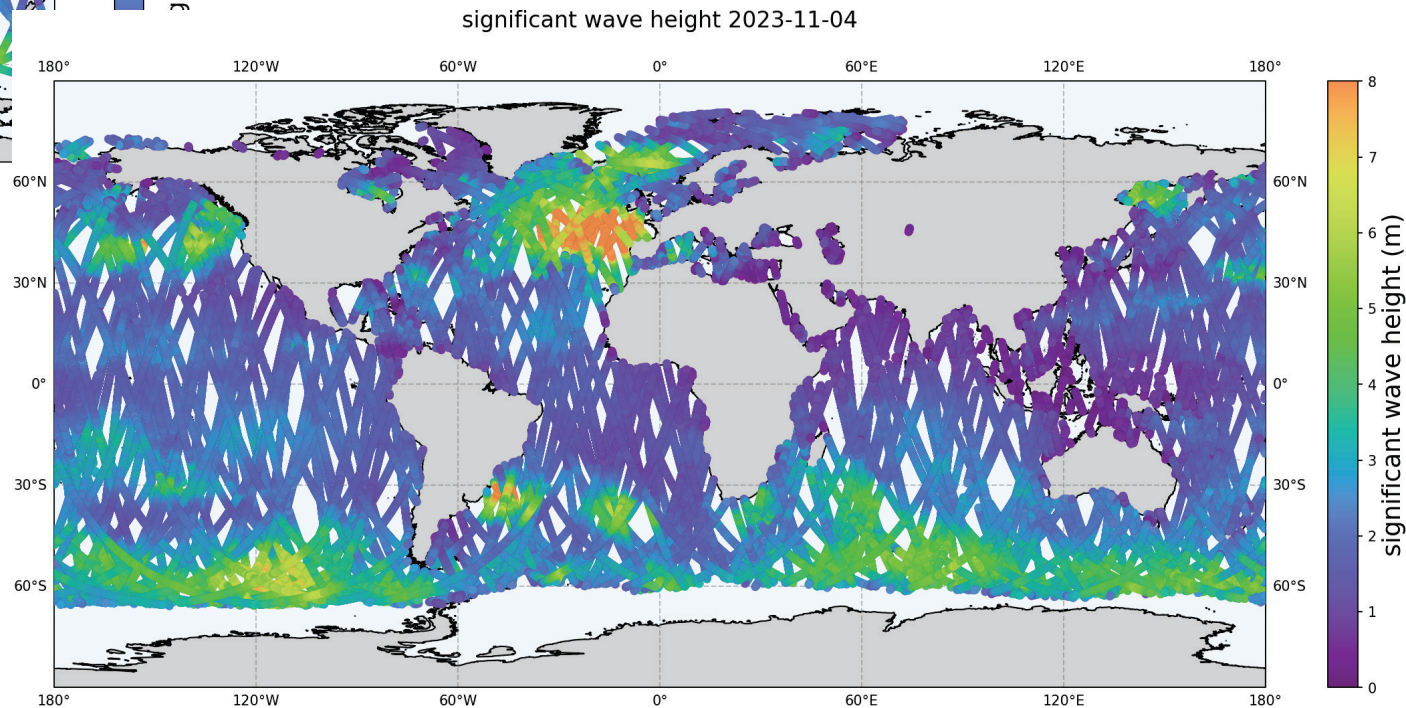


Coverages



One day of measurements taken by 3 satellites (Sentinel-3A&B, Sentinel-6 Michael Freilich)

One day of measurements taken by nine available altimetry satellites at that time (Cryosat-2, CFOSat, HY-2B&C, Jason-3, Saral, Sentinel-3A&B, Sentinel-6 Michael Freilich)



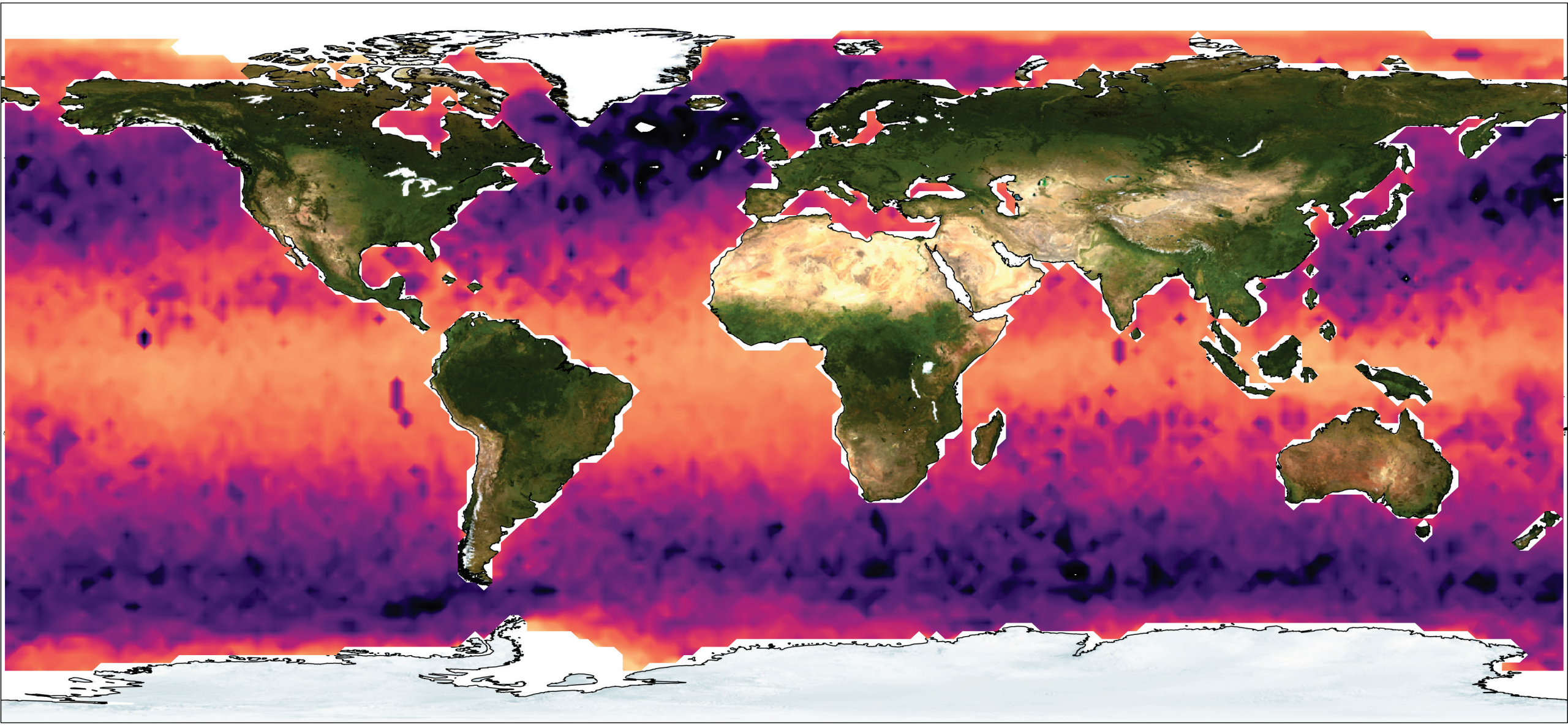
Applications of Significant wave height measurements from altimetry

- Operational measurement of waves
  - the whole surface of the ocean is not covered at all time (the satellite goes over the same point “only” every cycle (10 days at least, up to 35 days or even one year, depending on the satellite))
  - but SWH from altimetry can be assimilated within ocean wave models…
  - And if a satellite goes over your region of interest in the right time frame, with operational missions you have data 2 hours maximum after measurements

Applications of Significant wave height measurements from altimetry

- Climatologies
  - Twenty years of continuous, intercalibrated SWH measurements now available
    Thirty years of continuous data available all in all, but not intercalibrated for SWH
  - With synoptics, systematic and global capabilities
  - Can be used
    - Research
    - Knowledge of extreme (including return time estimates),
    - Open ocean conditions to coastal model for infrastructure planning

Maximum significant wave heights



0 3 6 9 12 15 18

m

From Copernicus Marine Service L4