Geosynchronous SAR Technology – Learning from Hydroterra

(Back to SAR basics)

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CEOI Emerging Technologies Workshop

21 April 2021

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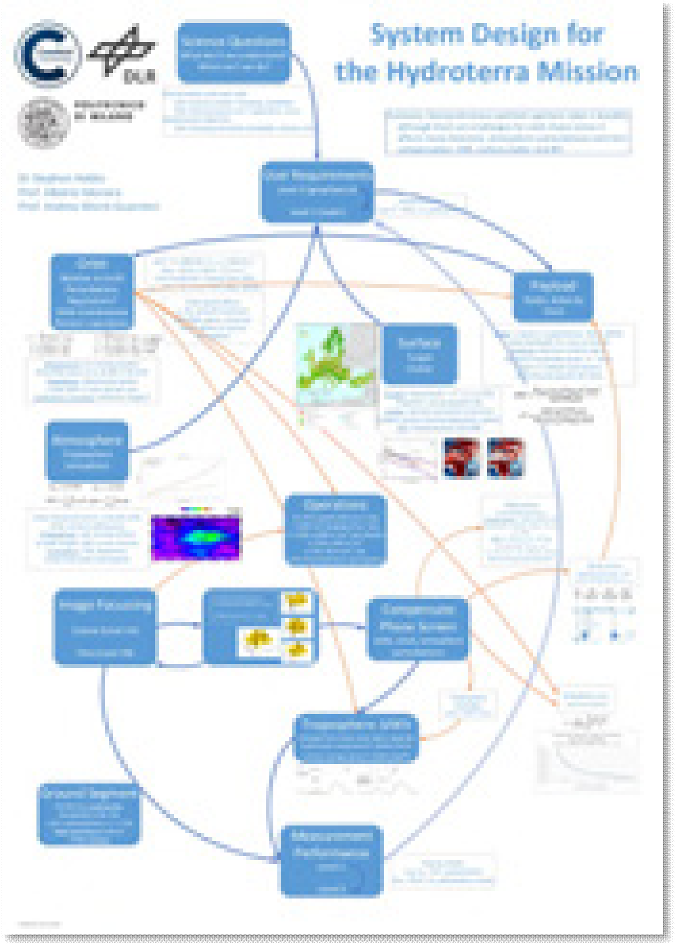
Outline

Lessons learned during the Hydroterra Phase 0 Study

1. Relearning SAR basics: airborne not LEO SAR
2. Achieving useful SNR
3. Geosynchronous orbit
4. Polarisation options for GeoSAR
5. Radar hardware challenges
6. Operations, an Earth Science Observatory

Discussion and Conclusions



System Design for the Hydroterra Mission

SAR Basics

More like airborne SAR than LEO SAR

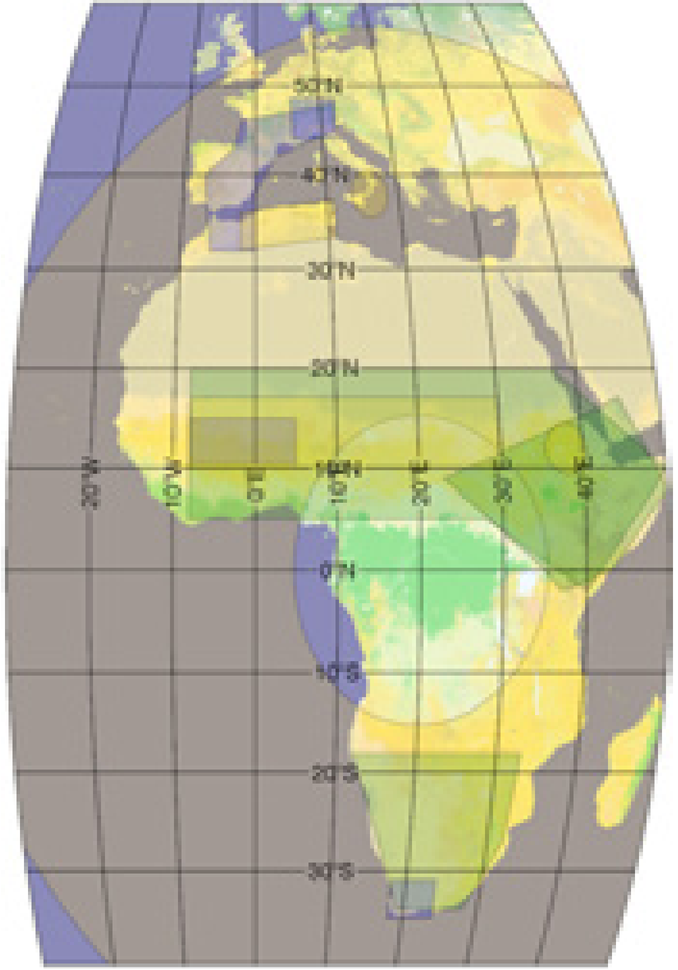
Can image area of interest whenever required

- Squint viewing and swept spotlight mode in general
- Integrate for long enough to build synthetic aperture needed for the desired spatial resolution (e.g. ~1 min to achieve 1 km resolution in C-band)
- “Zero Doppler” thinking from LEO SAR is not particularly helpful

Incidence angles range from ~20° up to ~65°

- Blind to sub-satellite area (rainforest, ocean are unstable anyway)
- Need high incidence for high latitudes (and LEO is good here)
- Regions with high incidence angles are usually most challenging because signals tend to be weaker

Very good low latitude coverage – complements LEO SAR



Earth disk from 20°E in GEO: shaded torus for 20° < incidence < 65°

Achieving Useful SNR

Aperture, power, integration time vs spatial – temporal resolution and coverage

From GEO it is a challenge to achieve a useful SNR

- Large aperture for high EIRP and to collect signal power
- High transmit power (few x 100 W RF; and low prf)
- Long integration time (= high integration gain)
- Coarse spatial resolution (few km – easy – to ~50 m – more challenging)
- Low relative orbit speed (m s^{-1} vs km s^{-1}) helps us

$$SNR = \frac{\bar{P}_t L_x A^2 \eta_t \eta_a \sigma^0 \cos\theta}{8\pi \, v_{az} \, \lambda \, R^3 \, F_n \, kT_s}$$

Lose factor ~40^3 wrt LEO SAR

Data: backscatter and InSAR products

- Multi-looking needed for most products
- Phase-based measurements are most robust – easier to retrieve from noise than σ^0

Interference / noise

- RFI and clutter (surface, atmosphere) both need careful management – and some surfaces cannot be imaged (e.g. water, wind-blown forest)

Orbit

Wide choice of orbits; Significant perturbations; Major influence on mission design

Geosynchronous orbit

- Inclination controls N-S motion
- Eccentricity controls E-W motion – useful to synthesis aperture
- Wide range of ground tracks is possible by relative phasing of inclination and eccentricity

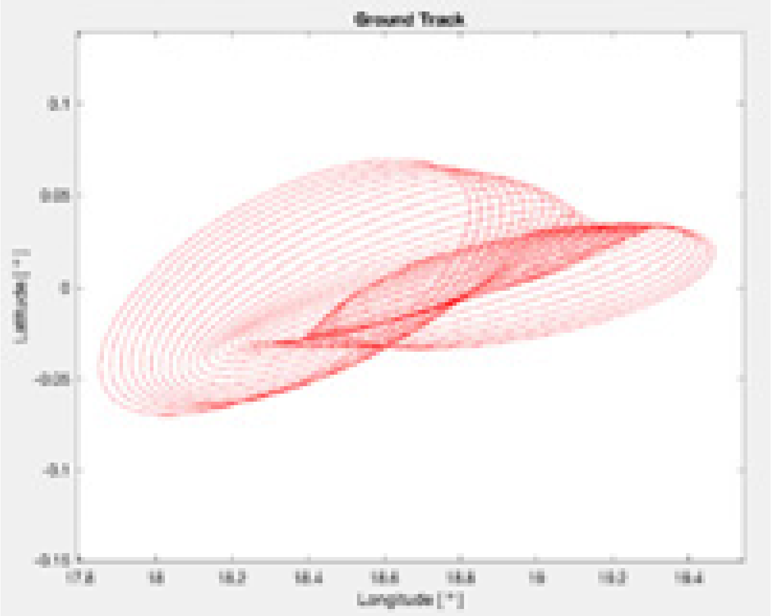
Ignoring short-term oscillations

Perturbations

- Luni-solar gravitational perturbations dominate (~50 m s^{-1} yr^{-1})
- Expensive to fight directly, but must be managed

Orbit determines relative velocity

- Orbit has a <u>major influence on mission design</u>:
  - Dwell time, importance of atmospheric perturbations, azimuth resolution, geographical coverage, payload requirements, size of image stack for interferometry, …



Example orbit ground track during 1 month with no control; InSAR requires orbit repeat within ~0.03° (~20 km) in latitude (baseline decorrelation, height ambiguity, etc.)

Polarisation

Compact or Quad-Polar are most attractive

Using the same GEO location for all target areas means that a rotation is needed from satellite axes (nominally East and North) to the local H, V components

For a single linear polarisation at the satellite this results in a position-dependent slant linear polarisation at most locations

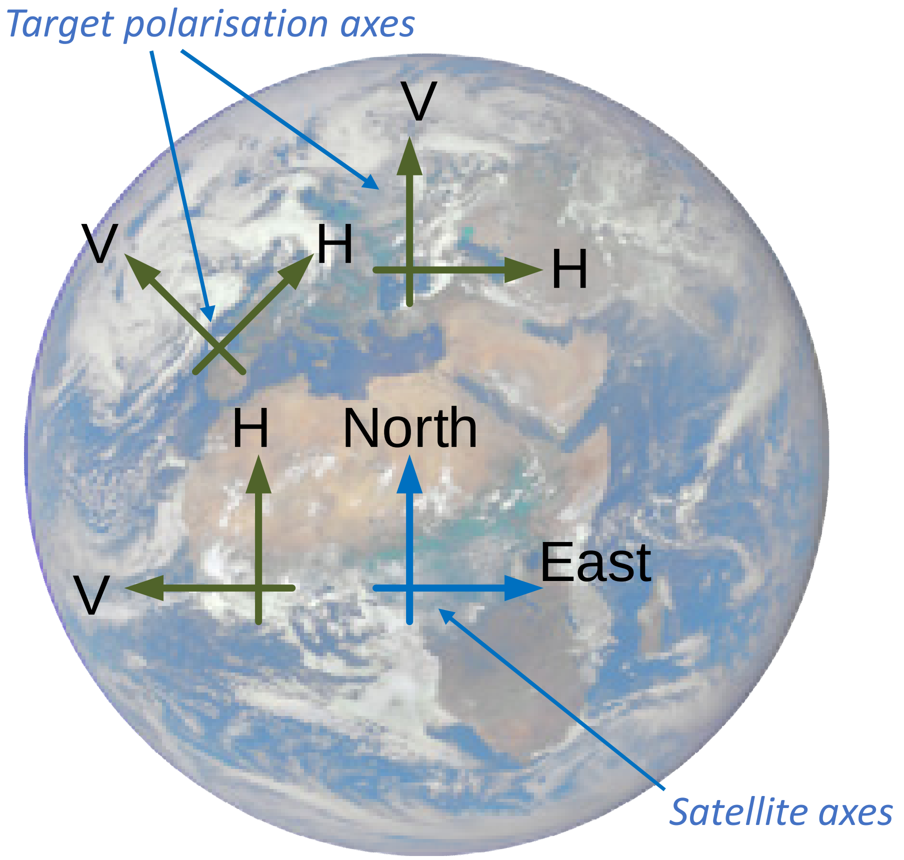
- Not satisfactory (and cross-polar term is too weak)

Compact-pol: transmit L or R, receive E, N → H, V

- Good signals in both channels
- "80% of the information" wrt quad-pol

Quad (full) polar

- Full polarimetric information, but need twice the power since transmitting two polarisations alternately and cross-polar terms are noisy (poor SNR typically)



A position-dependent rotation is needed to convert satellite polarisation components (N, E) to local H and V at the target

Hardware Requirements

Lightweight deployable antenna; RF components for high power / low prf

The main technology drivers for GEO radar are:

Antenna – large aperture area (circular is most suitable) – an obvious need

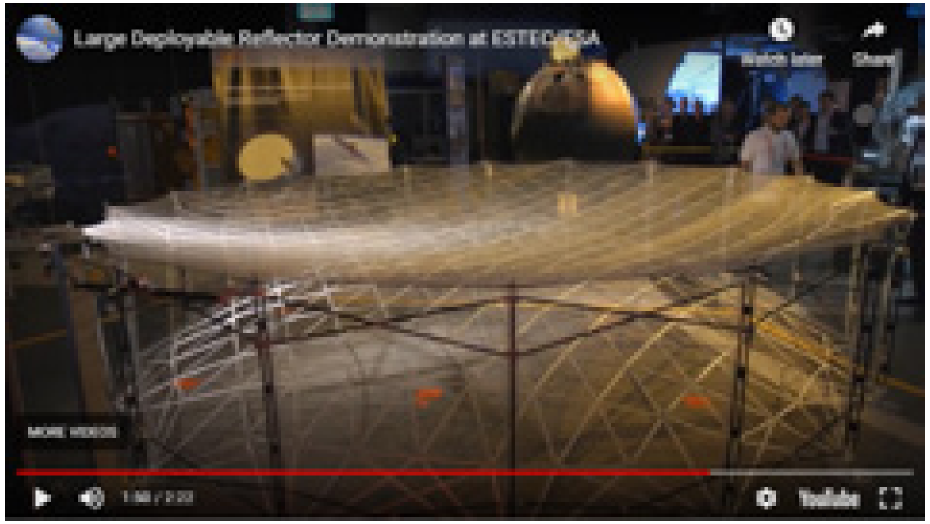
- Large, lightweight deployable reflector
- Low-cost (and European)

High RF power (C-band) – also obvious

- Components suitable for high power and low prf (~ few x 100 Hz) – “devil in the detail”

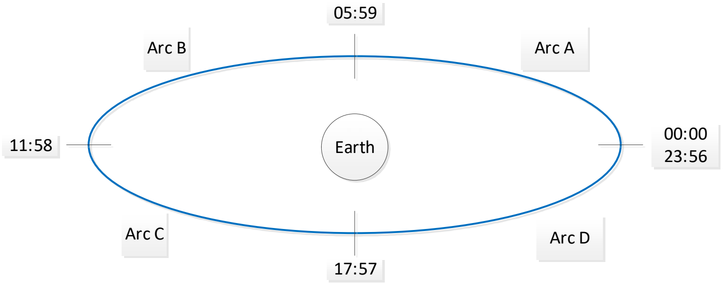
Getting to GEO

- Well-understood, but not cheap
- Electric orbit-raising is widely used – leaves spare power for SAR



LSS 5 m diameter deployable antenna deployed at ESTEC (2016)

Operations



Complex operations planning; Software-defined; Observatory concept

User requirements – combine several types of mission

- (a) Routine observations, (b) “Campaign” mode, (c) Rapid response for emergencies / opportunities

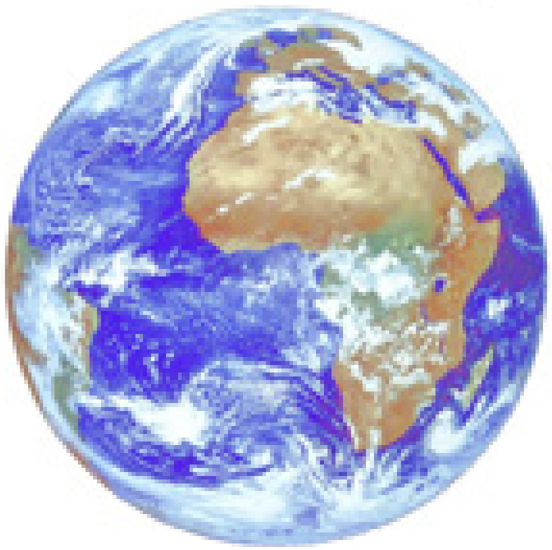
Multiple constraints – AI management task?

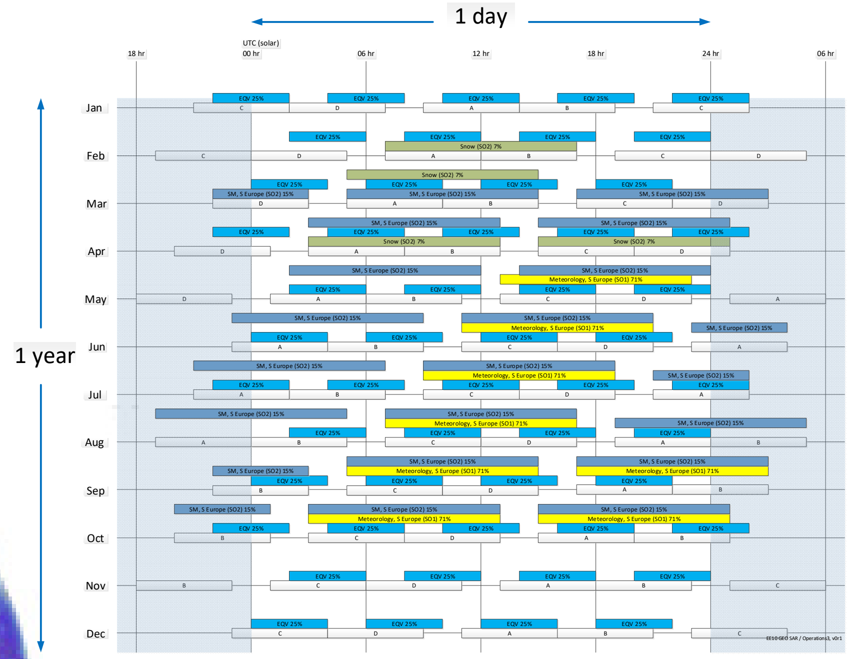
- Orbit maintenance, InSAR coherence, solar / sidereal periods, orbit turning points, sufficient #looks, …

Fully software-defined: no extra consumable

Earth science observatory

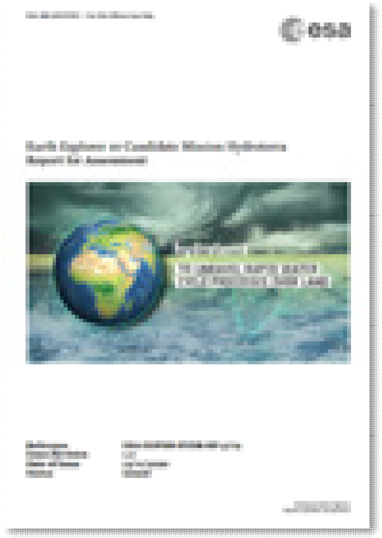
- Point to target of interest as and when needed; *users could book time as for an astronomical telescope*





Observations use the same orbit portion (sidereal period) to obtain InSAR products: hence drift of 2 hr per month in operations schedule (in solar time)

Discussion and Conclusions



Discussion

- ESA Earth Explorer Phase 0 study advanced our understanding significantly of both the science and the implementation
- Cost was Hydroterra's primary challenge – ~€300M (implied; but no published costs)
- Direct launch to GTO / GEO is preferred
  - LEO + EOR is possible, but gives minimal cost saving + marginal mass budget
- Science / technology: no show-stoppers, but some clear challenges

Even with Phase 0 scrutiny

Conclusions

- Team remain convinced of the science potential and technical innovation of GEO SAR
- Priorities:
  - Hardware development and de-risk (antenna, RF components)
  - E2E simulation incl. full product retrievals in realistic scenarios
  - Science maturation, incl. polarimetry options and benefits for Africa

Thank you

- To you, for your attention
- CEOI for early study funding
- ESA, for Phase 0 technical expertise
- Airbus, OHB, and other Phase 0 industry experts
- The Hydroterra science study team

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