G-CLASS Hydroterra: an Earth Explorer mission for Water Cycle Science

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4 September 2019

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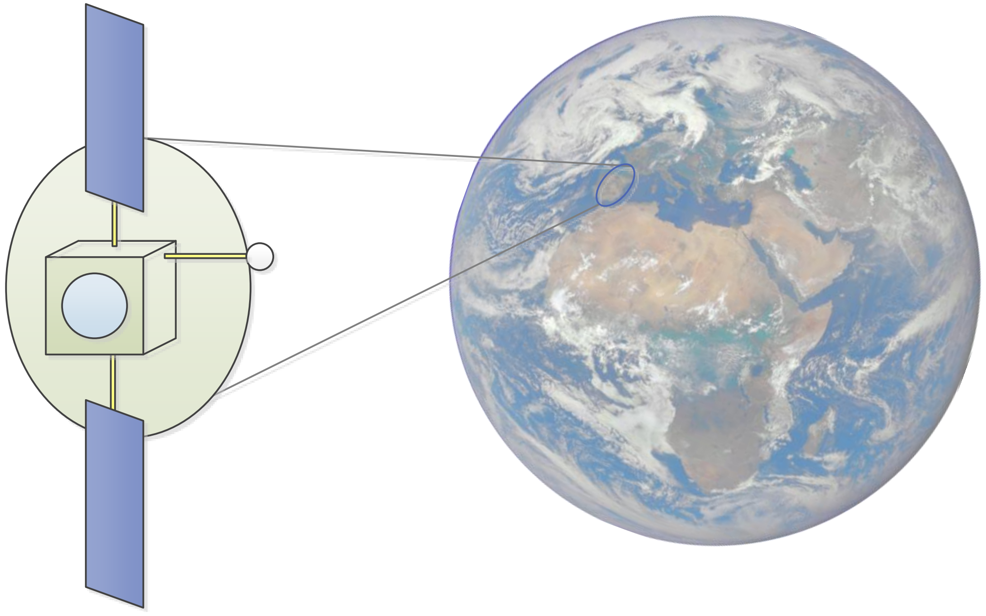
- *A step change in temporal sampling and versatility for Earth Observation*

G-CLASS is now Hydroterra



1. G-CLASS Hydroterra

A mission to observe and understand rapid processes of the water cycle over land

Hydroterrra builds on the heritage of earlier **geosynchronous radar** mission proposals

- GeoSAT (ESA Earth Explorer 8 proposal)
- GeoSTARe (ESA Earth Explorer 9 proposal)

Hydroterrra benefits from recent studies which have matured the mission concept including

- Radar clutter field observations and simulation – needed for E2E mission simulation
- Radio Frequency Interference assessment
- Soil moisture retrieval for high incidence angles

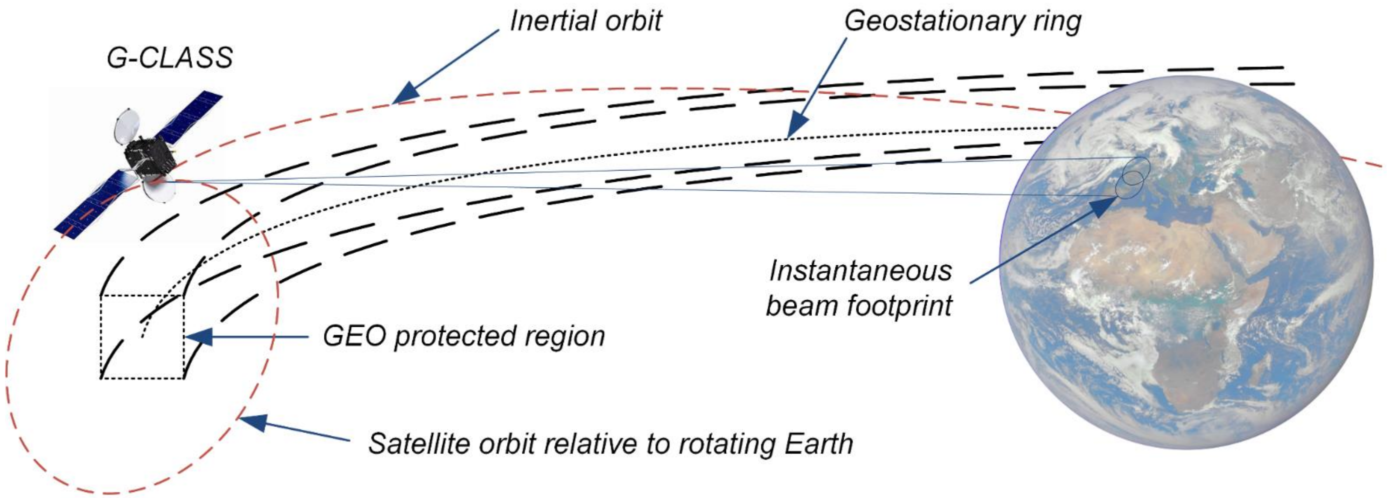
Explicit science focus on the rapid / diurnal water cycle over land – exploits the mission concept's strengths

G-CLASS Hydroterra mission concept

Science drivers require persistent observation of the water cycle

Persistent: use a constellation (expensive) or geosynchronous orbit (feasible, but not global)

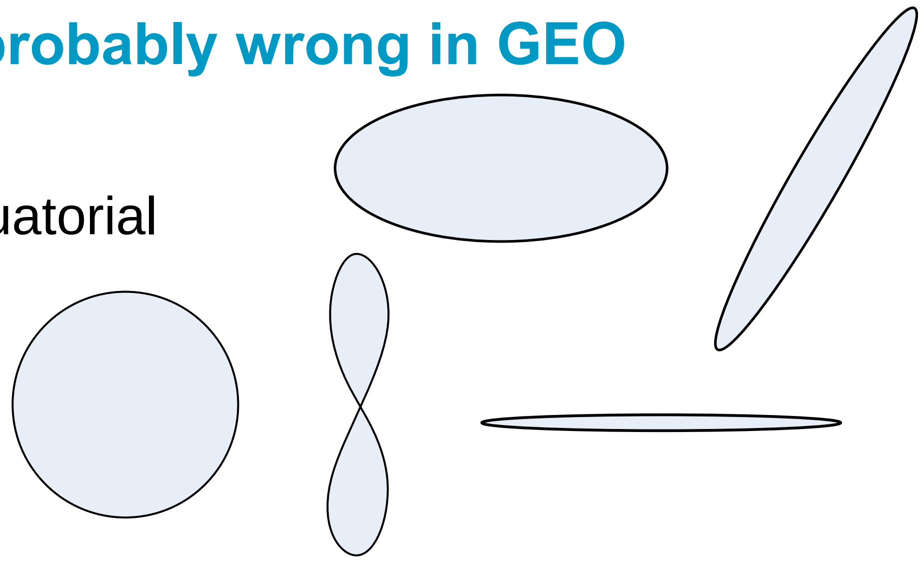
Water cycle: use microwaves (all weather, sensitive to liquid and vapour phases of water)



Geosynchronous Radar is the G-CLASS Hydroterra mission concept

Geosynchronous Radar – Is special

Some of what you've learned about satellite radar is probably wrong in GEO



Orbits in GEO

- Relative orbits may be ellipses, figure of 8, inclined or equatorial
- Inclination controls North-South motion
  Eccentricity control East-West motion

Long integration times

- Instead of < 1 s (LEO) we integrate for minutes to hours
- Phase corrections (atmosphere, orbit) needed for long t_{int}; unstable targets are incoherent

Imaging almost decoupled from the orbit

- See Africa and Europe continuously, so we can image just by pointing (excluding sub-satellite zone; only 17.4° across the whole Earth disk)
- Use spotlight or swept SL: beam steering (and not the satellite velocity) determines coverage
- Integration time and pointing determine azimuth resolution: all under user control

2. G-CLASS Hydroterra Science

Focus on the diurnal water cycle – play to GeoSAR's strengths

Secondary objective of "fast" ground motion in general (earthquake, volcano)

Measurements expected:

- Atmosphere: integrated water vapour (affects refractive index)
- Surface: backscatter phase and amplitude

1. Diurnal water cycle
   a. Rapid hydro-meteorological processes – exploit frequent images (~15 min repeat time) at ~1 km resolution
   b. Diurnal variation of surface moisture (SM, intercepted precipitation, snow; at resolutions from 1 km down to below 100 m)
2. Ground motion – frequently monitored, so fast processes observed directly

G-CLASS Hydroterra Science Objectives

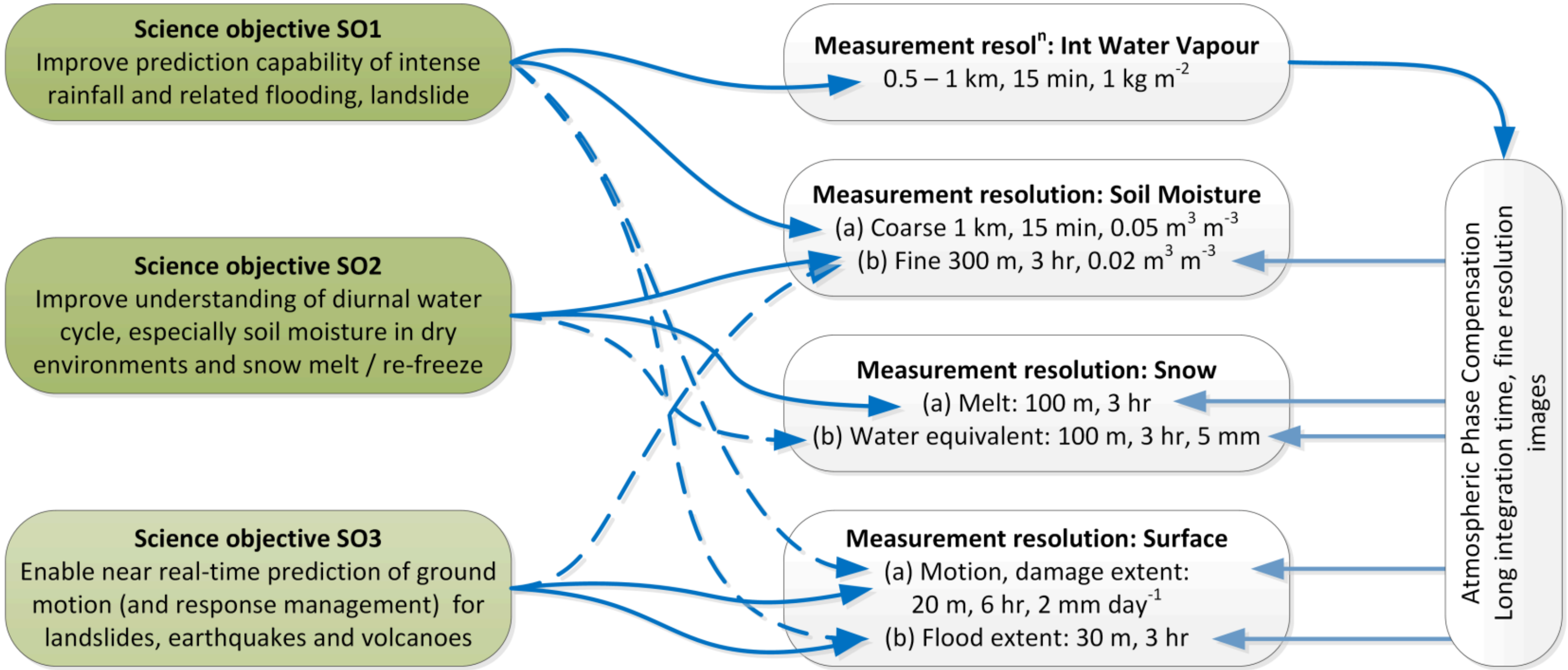
Primary science focus is the diurnal water cycle

SO1: Rapid weather processes and their impact (e.g. flood, landslide)

SO2: Diurnal water cycle processes (snow amount and melting, surface moisture)

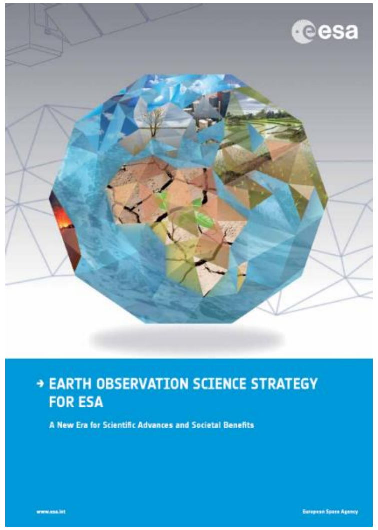
“Secondary” objective:

SO3: Ground motion – landslides, earthquakes and volcanoes



Hydroterra science objectives and related measurement needs (these are now being reviewed and consolidated)

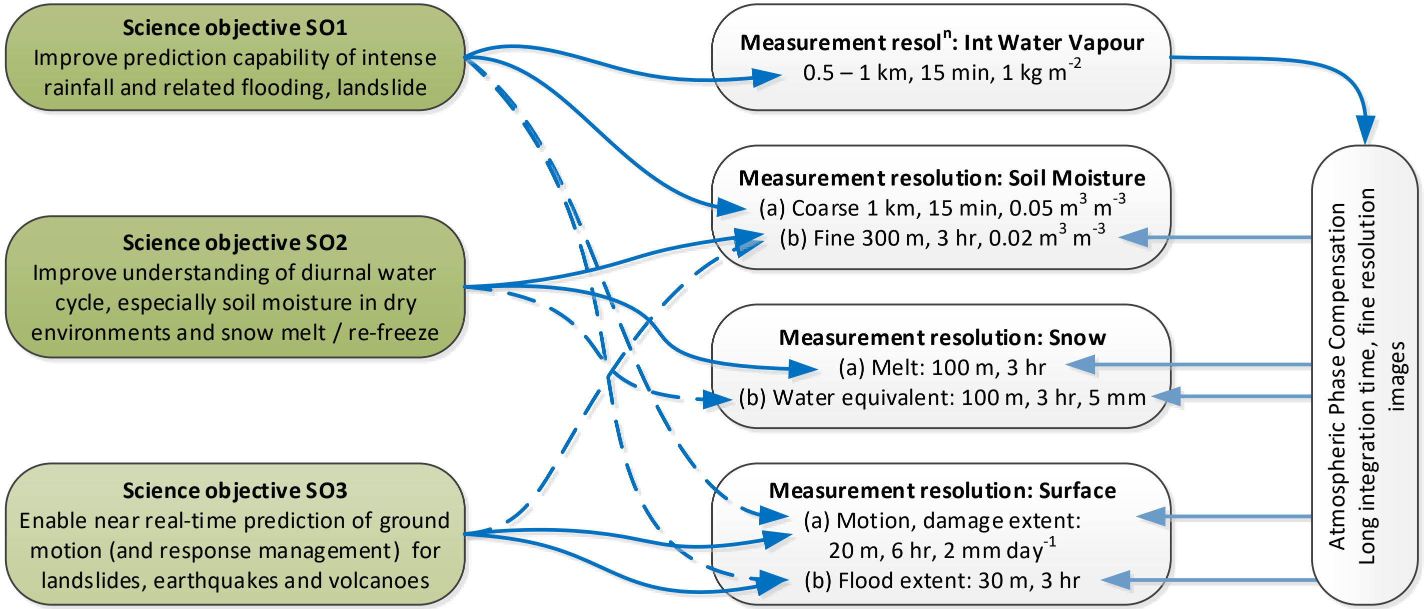
Water Cycle Science - ESA



Fundamental to life on Earth and to human society

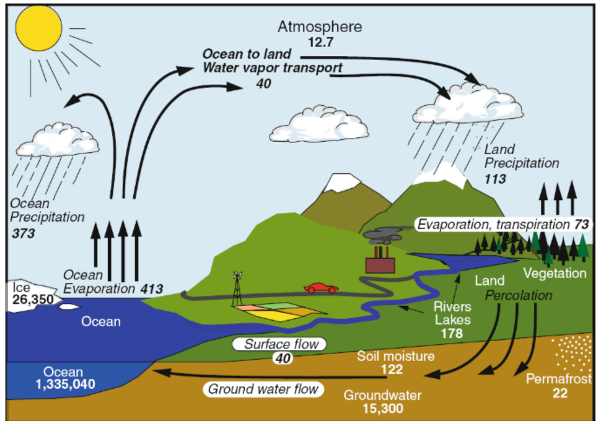
ESA Science Strategy challenges:

- **A1, A2, A4, C3, L2, L5 and G1** (all have water cycle links),
  - E.g. A1 = Processes linking water vapour and the hydrological cycle with radiation
- Other reviews of science needs also support the diurnal water cycle goals
- **Science Objectives** and the corresponding **measurement requirements** are summarised as:



Science Case Snapshots

Water cycle (Trenberth, 2014)



Each of these areas is being critically reviewed and updated

Hydro-meteorology

Fine spatial and temporal resolution of atmospheric integrated water vapour support hydro-meteorological science and applications, and developing fine resolution NWP (calibration, validation, initialisation)

"Fast" ground motion

Rapid response imaging of ground motion (landslides, earthquake, volcanoes) enables new science and to demonstrate real-time services for the first time

Surface moisture hydrology

Images every few hours allow diurnal changes in "surface wetness" – soil and vegetation water – to be observed directly – new insights into diurnal water cycle processes for hydrological science and applications

Land cryosphere processes

Frequent InSAR acquisitions enable estimating snow mass and diurnal melt / freeze cycle – important for water management, hydrology and meteorology

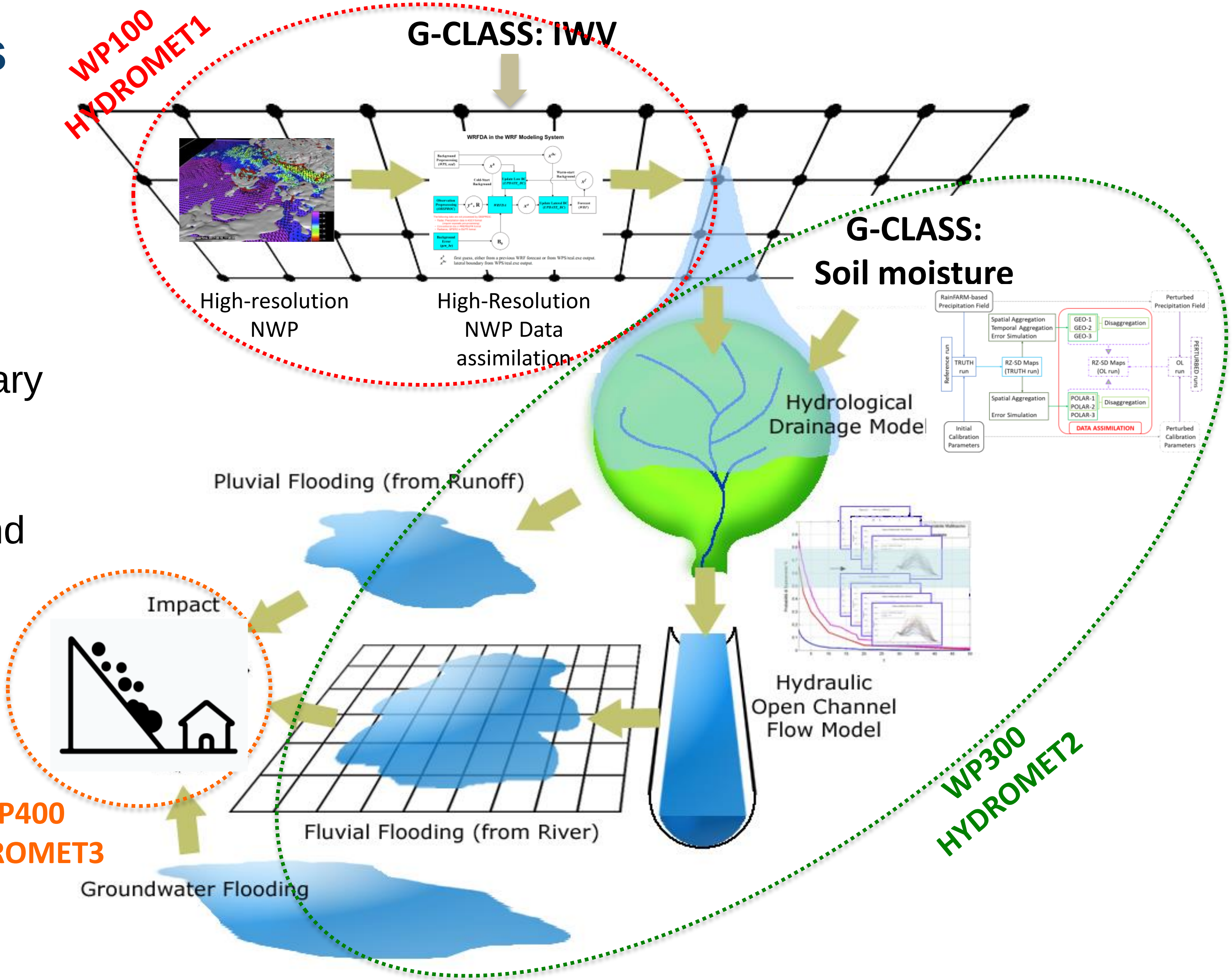
Bingham mine collapse

Science goals support each other

Although we identify discrete science WP to exploit disciplinary strengths, we recognise the overlapping themes

- IWV, soil moisture, ground motion (landslides)

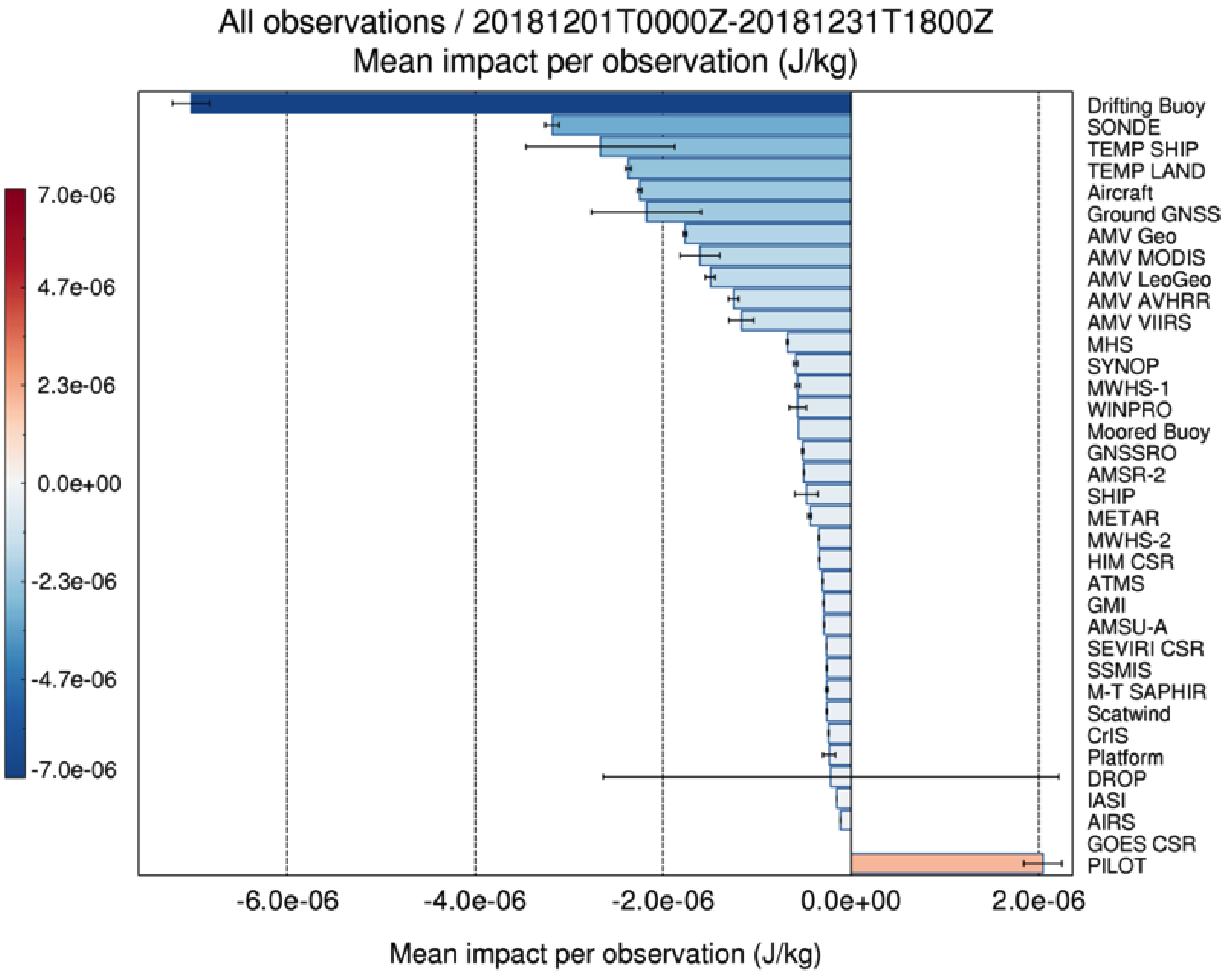
- These work together especially for applications



Evidence for impact of IWV?

Ground GNSS measurements of vertical IWV contribute significant value per observation to weather forecasts

- We expect similar data which Hydroterra could provide also to add significant value to forecasts



Science observations: familiar and new

We plan to use established measurement techniques, and exploit new capabilities

Established techniques

- Soil moisture from backscatter (σ^0)
- Atmospheric phase delay
- Wet / dry snow contrast
- Etc.

But all these are available with dramatically improved temporal sampling

- Directly observe surface processes
- Able to resolve fast processes, e.g. earthquake pre-cursors, rebound

New capabilities

Measure rates of change to resolve separate processes, e.g.

- Intercepted precipitation evaporating
- Soil drying
- Plant moisture content

InSAR phase changes hint at this

Rapid responsive imaging

- ~Real-time disaster response is possible

Soil moisture estimation using phase

- Soil and vegetation phase centres may move during the day

3. Societal Benefits

A strength of G-CLASS Hydroterra is its potential for significant societal benefits

ESA was today congratulated for the services provided by its latest mission Hydroterra. Images from Hydroterra helped emergency staff predict the development of floods so that citizens were evacuated safely in advance of the water's rise. Hydroterra had allowed meteorologists to forecast the detailed track of the storm that caused all the damage, and the first signs of the landslide which closed the railway and main road from the west also came from Hydroterra. "Our citizens never knew how useful space could be." was how the mayor summed up the city's review of the Great Storm of 2028 for ESA.

1. SO1: Intense storms, mitigate weather impacts
2. SO2: Water resource management – agriculture, etc.
3. SO3: Ground motion monitoring becomes real-time
4. Africa
   a) Better coverage than Sentinel-1
   b) Region is poor in surface infrastructure so space makes a difference

G-CLASS Hydroterra Applications

Exceptionally versatile

Image for ~1200 min / day

- ~1000 spots 400 km across (1 km resolution) per day
- 250 spots at 250 m resolution, etc.

- *User chooses where and when*

Hydro-meteorology

Frequent imaging of region ~1000 km

Water resource management

Agriculture, health, energy, …

Ground motion

Landslides, Earthquake, volcano

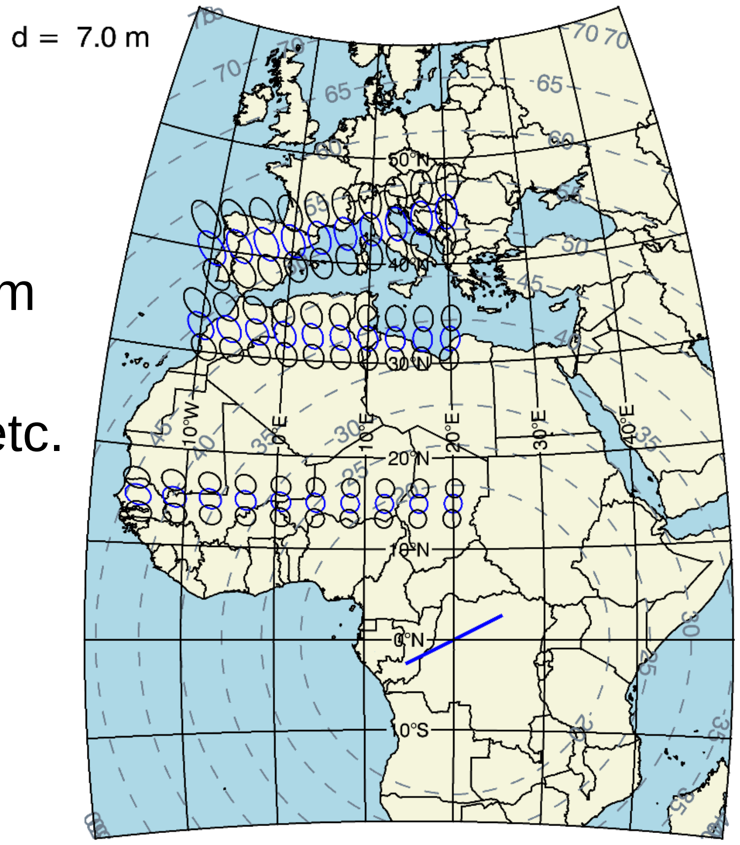
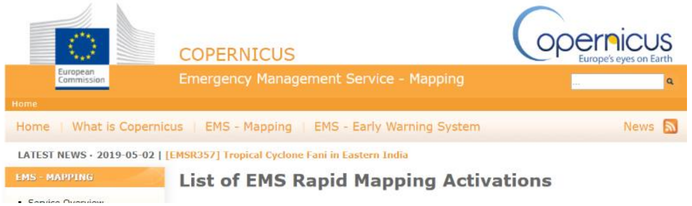
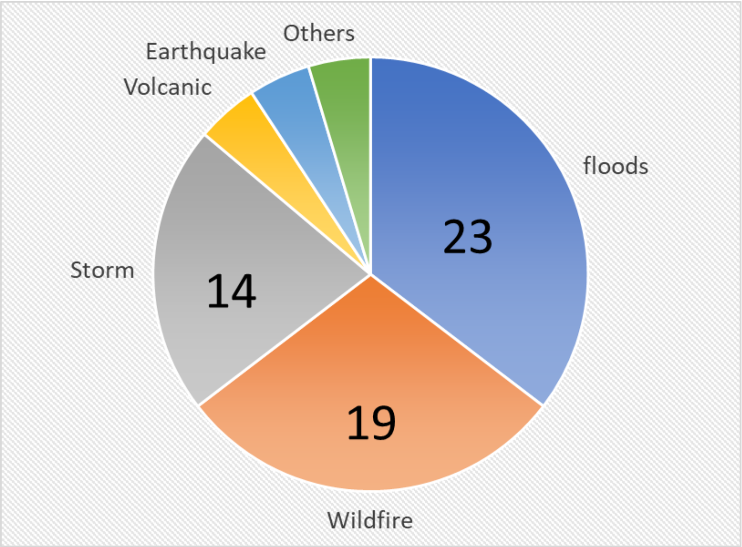


Figure above shows expected spot size vs latitude (using multiple beams increases coverage, e.g. by factor 3)

G-CLASS Hydroterra for temporal zoom



Activations in 1 year, sorted by type



G-CLASS Hydroterra and public benefits

In May 2018 to May 2019 there were:

- 68 world-wide activations of Copernicus EMS https://emergency.copernicus.eu/mapping/list-of-activations-rapid
- 19 were not in Europe or Africa, or not within Hydroterra monitoring capabilities (epidemic, mass movement, …)
- the remaining 49 could be well addressed by monitoring coherence (currently adopted by Copernicus EM) or coherent change detection (CCD)
- If we assume 1-2 days per event, Hydroterra could provide systematic rapid intervention mapping to 70% of all the activations by devoting 15-30% of its observation capabilities, i.e. a modest demand

If the hazard "acceleration period", extreme weather conditions, or disaster, is faster than S1A&B revisit of 3-6 days as it is expected, G-CLASS Hydroterra will have a unique, complementary role as temporal zoom.

Mission update under consideration for G-CLASS Hydroterra:

(1) add “CCD” as Level-2 products

(2) Include on-demand temporal zoom capabilities in applications and scenario

EO for Africa

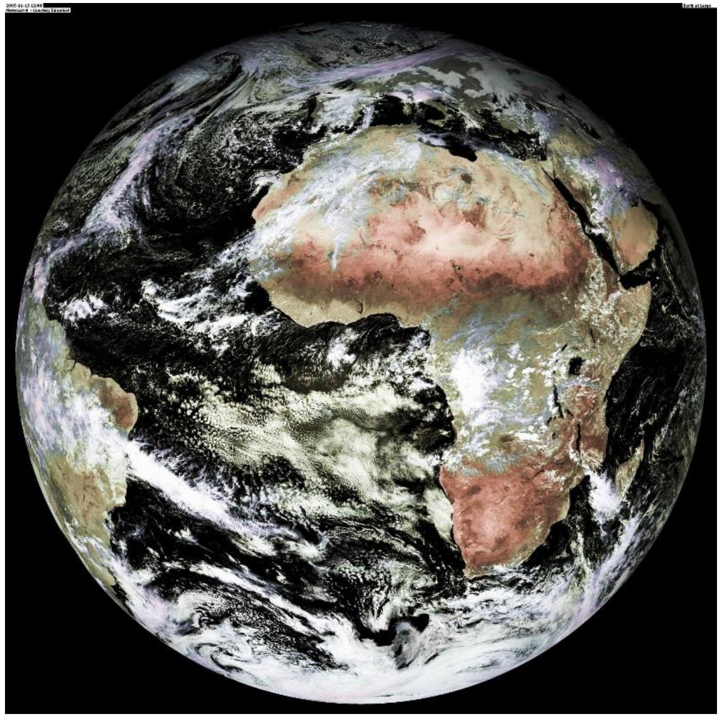
A GEO satellite is ideally placed to serve Africa

There are significant needs for improved services for Africa over the next few decades

- Lack of surface infrastructure means that space-based services add even more value

A GEO satellite could

- Significantly improve coverage of Africa
- Target specific areas at key moments (~rainy seasons, monsoon periods, etc.)
- Support both government and commercial services



Meteosat image from GEO

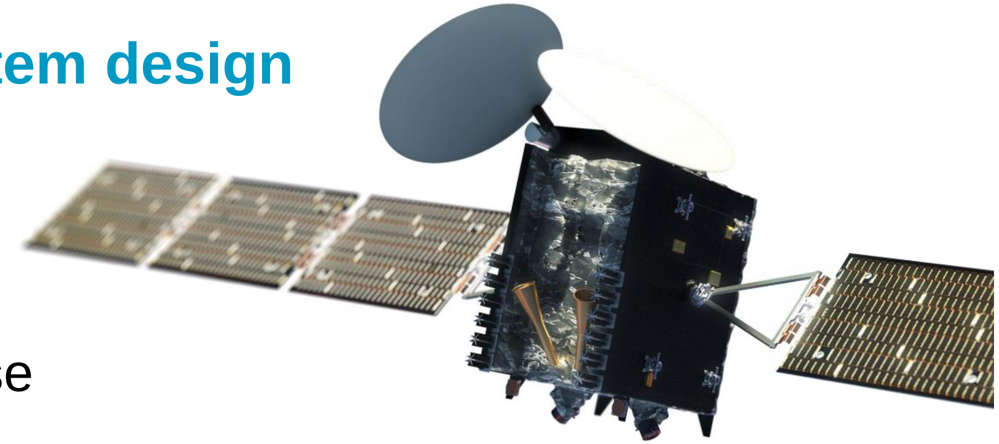
Sentinel-1A+B coverage of Africa is 1 image per 12 days (Jan 2018); LEO coverage is good near the poles but poor at low latitudes

4. Mission Implementation

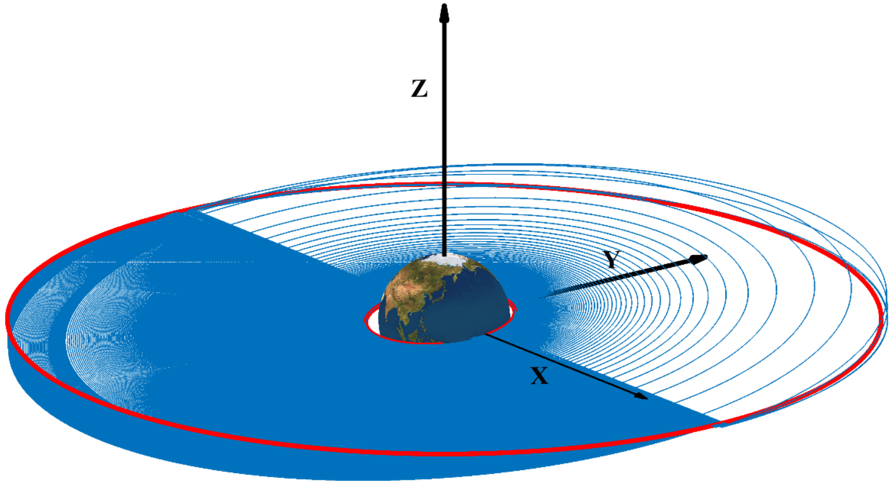
Use conventional technology, but with a novel system design

Satellite

- Use one of the standard small GEO s/c
- Vega-C launch to GEO, then electric propulsion to raise the orbit to GEO (already a standard technology for commercial s/c)
- 1 - 2 kW electrical power for payload
- Compatible with deployable antennas of 3 – 10 m diameter
- Payload mass: few hundred kg
- Downlink <100 Mbit s^{-1}
- Beam steering using reaction wheels – all electric, so no fuel consumed



SSTL VAMP GEO s/c (SSTL)

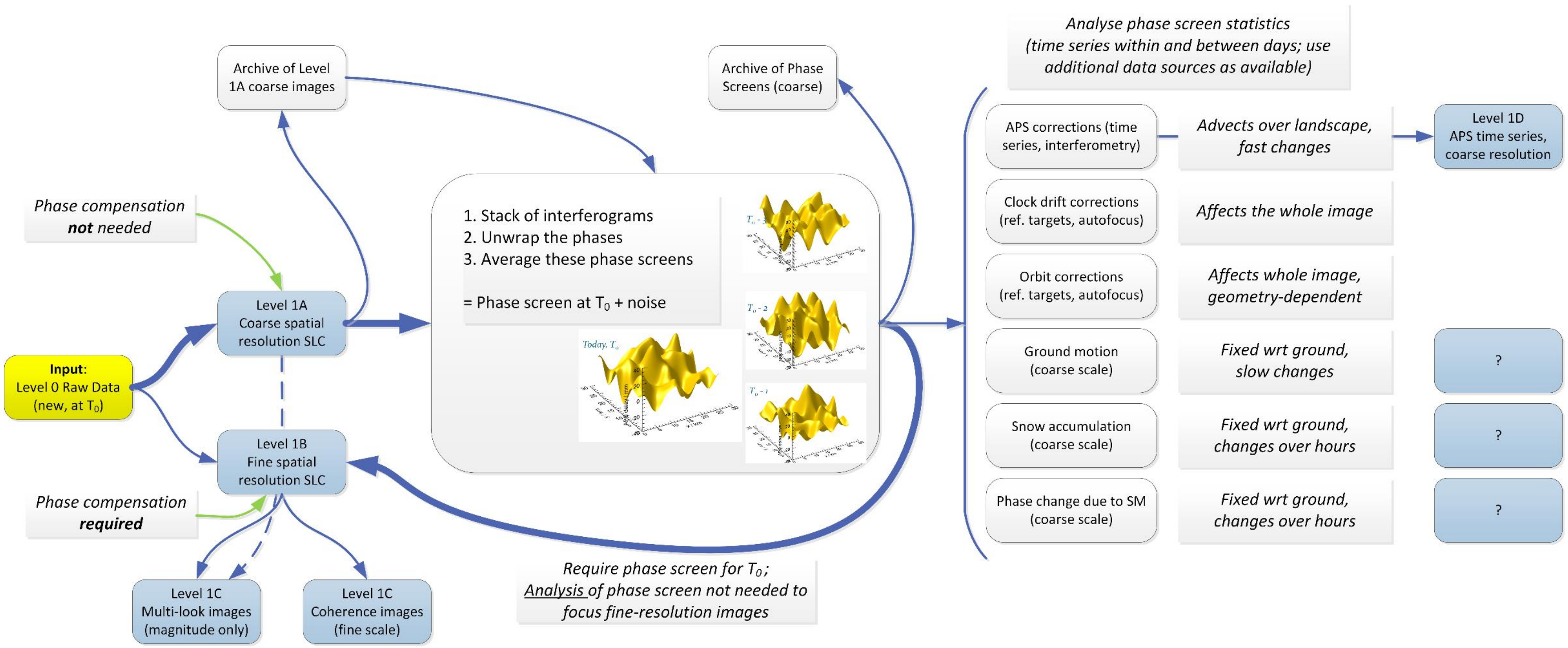


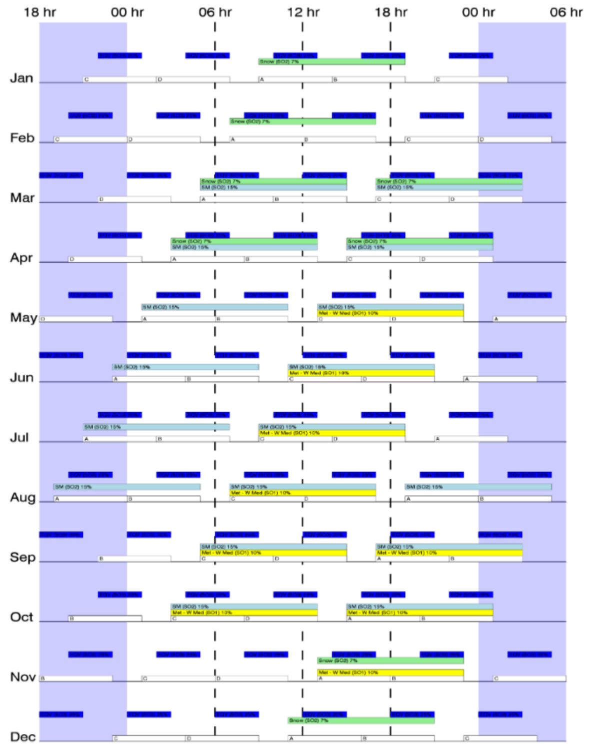
Example low-thrust transfer from LEO to GEO

Operations and Data Processing

The ground operations, data processing and operations have been assessed and seem feasible

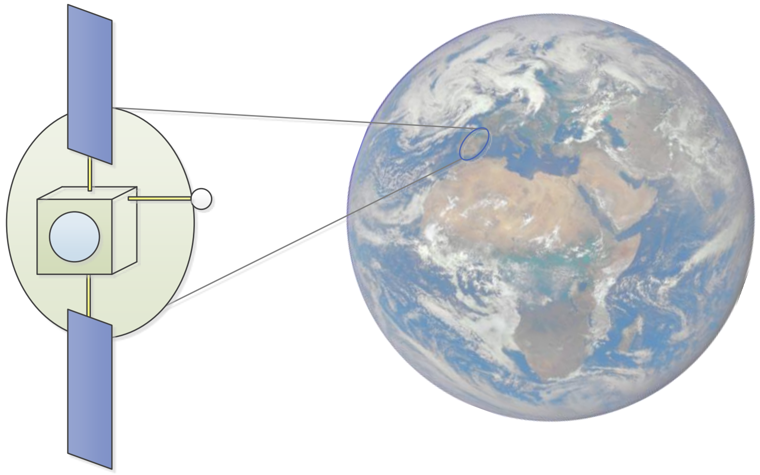
- Data quantities are modest relative to Sentinel
- Existing algorithms / systems provide most of the functions needed





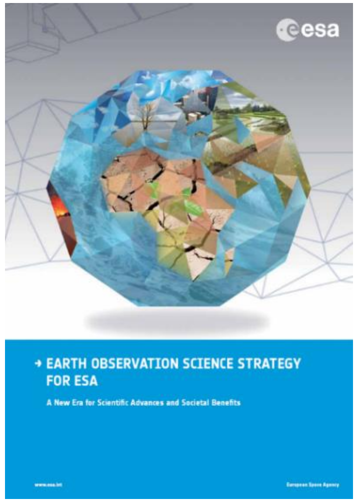
Operations planning responds to changing science needs through the year and by time of day

Conclusions



Hydroterra is an exciting opportunity for Europe to develop an innovative EO system expected to have important scientific and societal benefits

- Science focus is the diurnal water cycle over land
- Implementation is based on existing technology, with an innovative system design
- Mission cost is an important challenge
- Broad and direct societal benefits, especially for Africa
- Complements LEO Earth observation
- Challenges identified: most affect the level of performance, not feasibility



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G-CLASS Hydroterra

Thank you for your attention

We have an exciting mission to work on