EYES ON THE POLES

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Imagine the possibility of a continuous hemispherical view of the polar regions of the Earth. Such a view would mean the world for climate change investigations, arctic shipping, high-latitude communication and last but not least, education and outreach. This project idea enables exactly that: it proposes the concept of a pole-sitter platform that is stationed along the polar axis of the Earth to generate a static 24/7 view of the poles to investigate, support and underpin sustainable development on a global scale.

POLAR OBSERVATION AND SUSTAINABLE DEVELOPMENT

CLIMATE CHANGE INVESTIGATIONS

The polar regions of the Earth play a critical role in shaping the Earth's climate. As such, they can provide answers to key questions concerning global climate change and its integral links with sustainable development. To obtain these answers, continuous data of the polar regions are essential to identify changes in the polar environment in terms of sea-ice coverage and thickness, to analyse long-term climate trends and to be able to model and predict future cryospheric processes.

ARCTIC SHIPPING AND TELECOMMUNICATION

The polar regions are also of importance from a geo-political point of view. It is expected that 30 percent of the world's undiscovered gas and 13 percent of its oil are located in the Arctic. Therefore, exploration of these areas will occur in the coming decades, especially with the opening of the northern sea routes, see Fig. 1, thereby providing a fast and economic passage between the Atlantic Ocean and the Pacific Ocean. Continuous polar observations will enable ship tracking and navigation as well as telecommunications to ensure sustainable development of these fragile regions.

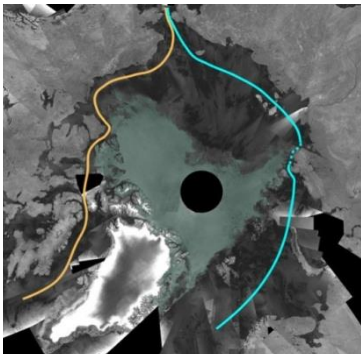


Fig. 1 Envisat mosaic showing opening of northern sea routes (credits: ESA)

EDUCATION AND OUTREACH

Finally, the polar regions are the symbol of global climate change and are therefore key in reaching out to the public, to raise awareness and gain support for sustainable development. In 1998, when proposing the L_1-point Triana mission, then-Vice President Al Gore already envisaged the power that a live, online image of the Earth's dayside from space would have on people's perception of sustainable development. Imagine the impact of a similar live image, but now of the polar regions, showing the contracting ice-sheets. Whether used in environmental campaigns or at schools, such an image will inspire and encourage people towards a change in the management of Earth's resources.

LIMITATIONS OF CURRENT POLAR DATA

Ever since the first polar orbiting satellite, Discoverer 1 (1959), a range of satellites have been launched to observe the polar regions, including satellites devoted to glaciology and ice-pack monitoring such as ESA's Cryosat-2 mission. Although enabling a high spatial resolution, the low-altitude of the polar orbits restricts satellites to observe only narrow swaths of the polar regions during each passage. Therefore, to obtain a full view of the polar regions, images from different passages have to be patched together to form so-called composite images or mosaics, which have poor temporal resolution, see Fig. 2. As an example, it takes CryoSat-2 33 days to obtain uniform coverage of the polar regions. For the applications mentioned in the previous section, which all require *continuous* coverage of the poles, current polar data clearly do not suffice.

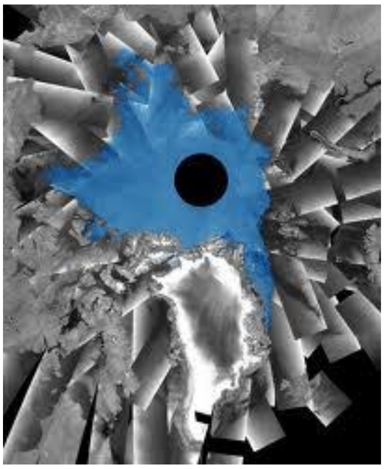
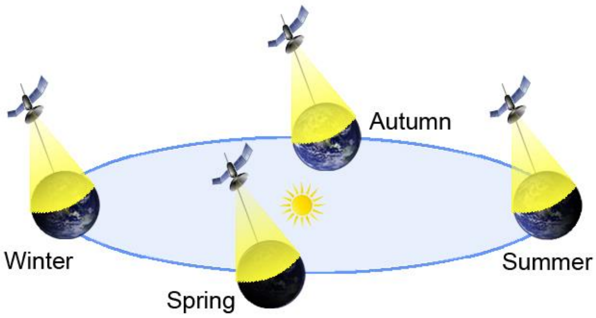


Fig. 2 Envisat mosaic showing swaths taken at each passage (credits: ESA)

SOLUTION: POLE-SITTER PLATFORM

The only platform that would be able to generate a true continuous and static view of the poles, is the so-called "pole-sitter", which, rather than orbiting the Earth, maintains a position exactly along the polar axis, see Fig. 3. In order to do so, it uses low-thrust propulsion to counterbalance the gravitational attraction of the Earth and Sun. The view that then can be achieved is shown in Fig. 3. Such a hemispheric view implies that a pole-sitter platform would not only benefit the polar regions, but northern Europe as well, where elevation angles of geostationary platforms are not sufficient to provide key services.



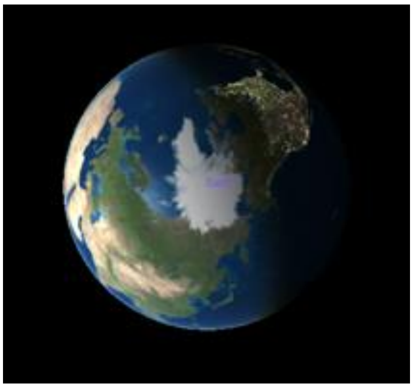


Fig. 3 Pole-sitter concept (left) and pole-sitter view in summer (right)

The pole-sitter platform truly is a groundbreaking and innovative idea that distinguishes itself from current polar observation infrastructure by being the only platform that, by itself, can enable the applications that are so key to sustainable development: global climate change investigations, ship tracking and navigation, high-latitude telecommunication and education and outreach. As such, the pole-sitter relates to each of the pillars of sustainable development: environment, economic and social + governance, as demonstrated in Fig. 4.

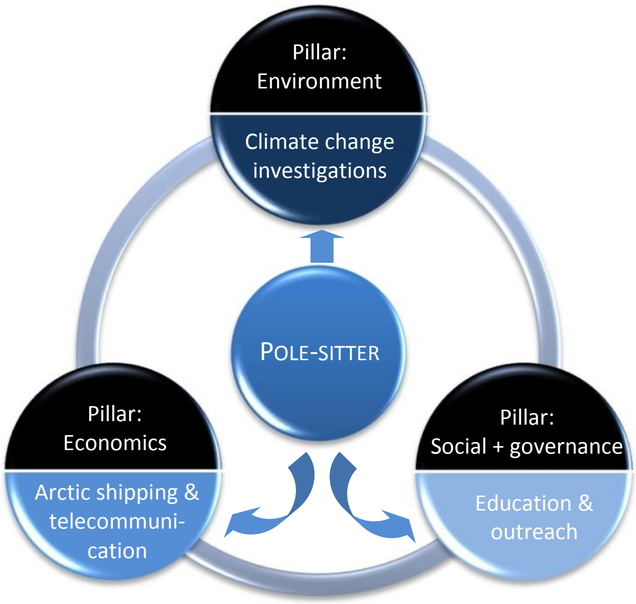


Fig. 4 Relationship between pole-sitter and pillars of sustainable development

ORBIT AND PROPULSION REQUIREMENTS

The key characteristic of the pole-sitter platform is the fact that it is continuously stationed along the polar axis of the Earth. Due to the tilt of the polar axis with respect to the ecliptic, its motion during the year can be described by a cone as shown in Fig. 5: the polar axis leans towards the Sun in summer and away from the Sun in winter.

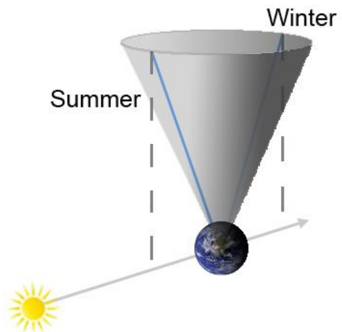


Fig. 5 Conical motion of polar axis

As mentioned, the pole-sitter platform will not be able to track this motion of the polar axis without some form of continuous propulsion. Here, solar electric propulsion (SEP) is proposed, which has been used successfully on missions such as ESA's SMART-1 and GOCE missions. The larger the Earth-to-pole-sitter distance, the smaller the required SEP force, but also the worse the spatial resolution of the observations. A balance is found in the pole-sitter orbit in Fig. 6, which minimises the acceleration but does not go too far from the Earth. While situated on the polar axis, the pole-sitter platform varies its distance to Earth between 2.3 (winter/summer) and 2.7 (autumn/spring) million km.

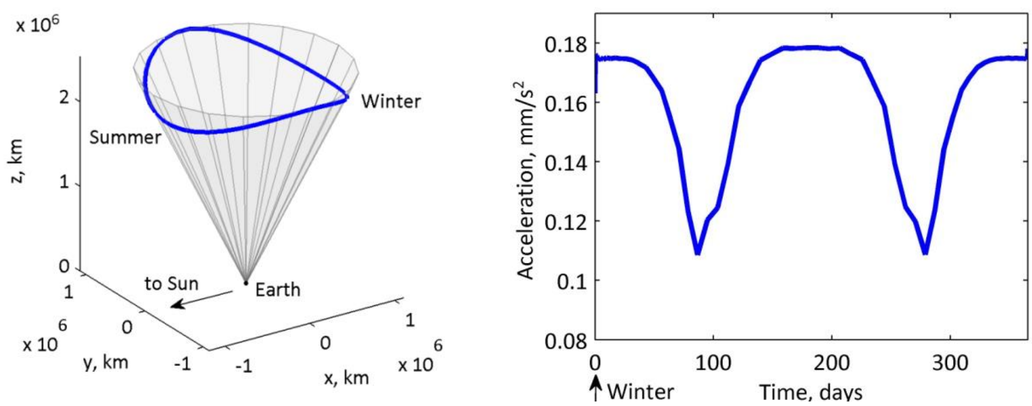


Fig. 6 Minimum acceleration pole-sitter orbit along polar axis cone

Mass budget

The dependency on a continuous acceleration impacts the pole-sitter platform design and mission lifetime. Still, the concept is highly feasible, which is demonstrated by the mass budget analysis in Table 1. To minimise risk, complexity and cost, a small platform mass of order 100-150 kg is envisaged, which can be launched as secondary payload, reducing cost even further.

The table shows that, for an instrument suite of 30 kg, a lifetime of 1 to 2 years can be obtained, depending on the initial platform mass. Furthermore, the table demonstrates that the propulsion requirements in terms of thruster mass, maximum thrust magnitude and maximum power consumption are all in agreement with previous and current SEP ion engine technology (e.g. NSTAR, NEXT, EADS Astrium RIT-10 and QinetiQ T5).

Table 1 Pole-sitter platform mass budget

	Initial mass	
	100 kg	150 kg
Payload mass, kg	30	30
Lifetime, yrs	1.1	2.1
Thruster mass, kg	7.8	11.8
Propellant mass, kg	16.4	42.5
Other subsystems, kg	42.4	60.0
Solar array area, m^2	2.9	4.3
Maximum thrust, mN	17.5	26.3
Maximum power, kW	0.39	0.59

Payload

To make optimal use of the available payload mass and to properly address the sustainable development applications of the pole-sitter, the instrument suite will have to be selected in consultation with Earth science specialists. This introduces a multidisciplinary approach between the engineering side of the pole-sitter, as presented here, and the requirements posed by the scientific community, which in its turn will be multidisciplinary since scientist from different fields such as climatology, geology, glaciology and cryology will be involved.

However, a preliminary payload can already be selected based on NASA's Galileo mission (1989), which was destined for Jupiter and its moons, but made an Earth fly-by at a distance comparable to that of the pole-sitter. With its solid state imaging instrument, it created the views shown in Fig 7. On a pole-sitter platform, such views would be ideal for climate change investigations and education and outreach. Although slightly heavy, 30 kg, 15 years of miniaturisation progress should bring the instrument's mass down to approximately 20 kg.

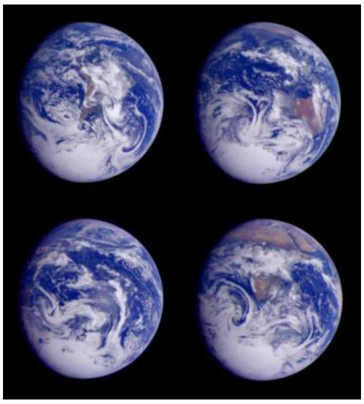


Fig. 7 Earth views by solid state imager on Galileo mission

This leaves 10 kg to comply with the pole-sitter applications in the field of arctic shipping and telecommunication. For this, a high-gain antenna and amplifier such as those used on the Intelsat-V telecommunication satellite are proposed, which would also allow downloading of the large data volumes for the live polar images.

VISITING BOTH POLES

Although there seems to be a focus on observing the arctic region, the Antarctic can benefit equally from the pole-sitter concept, where research activities are ongoing and communication capabilities are limited. Figure 8 shows the equivalent antarctic pole-sitter orbit as well as a transfer that allows visiting both poles with one single pole-sitter platform. The transfer leaves its arctic position after the arctic summer and arrives at its antarctic position just before the start of the antarctic summer, providing ideal observation conditions. Considering propulsion, this transfer is less demanding than the pole-sitter orbit itself, thereby putting no additional strain on the mission lifetime.

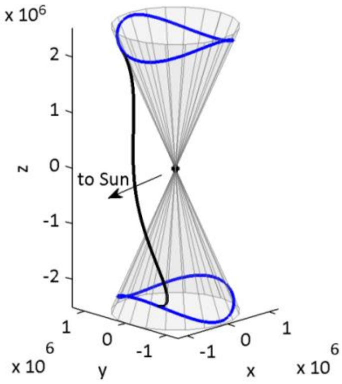


Fig. 8 Antarctic pole-sitter and transfer from north to south

REALISTIC IMPLEMENTATION AND EXPECTED RISKS

A final word is devoted to the realistic implementation and expected risks of the pole-sitter platform. Clearly, the project idea presented here requires the design, build and launch of a space platform. However by keeping the mass to a minimum and by using technologies that are far advanced on the technology readiness scale (TRL) (e.g. ion engine technology, flown payload suites) the development, schedule and cost risks are minimised. Once launched, operational risks are also kept to a minimum since, by being stationary, the pole-sitter does not need to be actively tracked by a ground station.

The main risk that can be identified is the fact that the mission depends on the successful operation of the ion engine. Without a propulsive force to counterbalance the Earth's and Sun's gravitational attraction, the mission will be lost. However, a feedback control investigation has shown that for engine failures of 20-35 days, the pole-sitter orbit can still be recovered, devaluating this main risk.

MORE INFORMATION

The pole-sitter concept has been published in 10 conference papers and 8 journal papers. While many papers detail specific elements of the pole-sitter concept, a complete overview can be found in:

- Heiligers, J., Ceriotti, M., McInnes, C.R., and Biggs, J.D., *Mission Analysis and Systems Design of a Near-term and Far-term Pole-sitter Mission*, Acta Astronautica, 2013, In Press, http://strathprints.strath.ac.uk/42540/
- Ceriotti, M., Heiligers, J., and McInnes, C.R., *Trajectory and Spacecraft Design for a Pole-Sitter Mission*, Journal of Spacecraft and Rockets, 2013, In Press, http://strathprints.strath.ac.uk/43503/

Furthermore, the pole-sitter concept has won multiple internal and external prizes, including the prestigious SET for Britain competition, which is held annually in the House of Commons in London to award the strongest scientific and engineering research being undertaken in the UK.

With the pole-sitter, the imagination of a continuous hemispherical view of the Earth's polar regions can become reality. The potential of such a view is enormous, ranging from environmental investigations to telecommunications, always closely linked to sustainable development. With a small satellite approach and high TRL technologies, the imagination can even become reality in the near-term, allowing us to soon turn our eyes on the poles!