Science, Technology and Security

January 2024

Published by the Future Issues and Technology (FIT) Research Cluster, RSIS. This Bulletin comes as a series of articles on science and technology from the angle of national security.

Near-Equatorial Orbits with Small and Very Small Satellites:
"Equatorial Sentinels" for the Environment | *Erick Lansard*

There is an urgent need to better understand the environmental phenomena that are threatening populations in equatorial regions: Typhoons, floods, earthquakes, tsunamis, volcanoes, wildfires, pollution, etc., due to climate change and geo-hazards are causing huge damage to societies and huge financial losses to economies. Forecast models exist but with limited accuracy, and the available data have poor sampling above equatorial regions, especially for fast-varying phenomena. To improve this situation, new data are necessary.

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1. Introduction

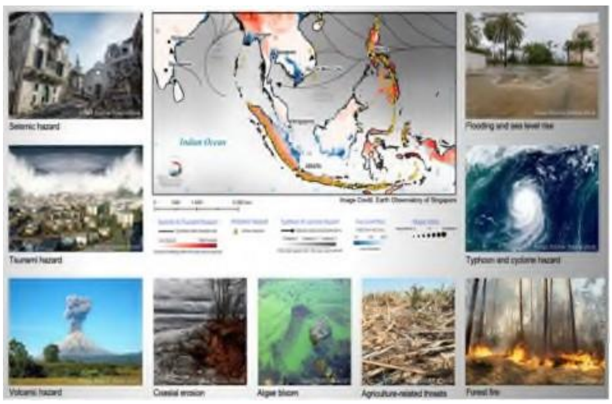

Figure 1. Environmental Threats above ASEAN Region

NTU/EOS, 2022.

The ASEAN region witnesses several atmospheric phenomena with potentially dramatic consequences. It is dangerous that the science behind many such risks is not well understood. Besides less well-known phenomena, several other threats are entirely unknown to us (e.g., seamounts landslides). The region also faces many challenges, such as successful decarbonisation, and modelling and forecasting complex weather phenomena.

A critical missing link in addressing these problems is the existing gap in space data above the equatorial region (sometimes also called equatorial belt). Current space systems in polar orbits belonging to the big space nations cannot fill this gap since they have inadequate revisit over the equatorial belt. This presents a unique opportunity because satellites that are launched into near-equatorial low-earth orbits (LEO) offer a revisit time of only 1.5 hours. To put this into perspective, one Equatorial Sentinel can do better than a constellation of 10 polar satellites. This is a huge advantage to be leveraged.

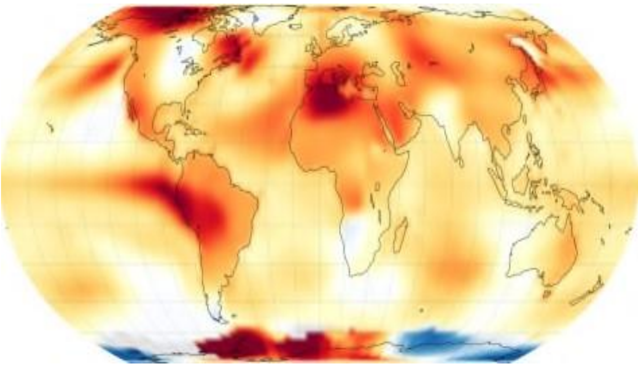

Figure 2. Temperature Rise

2020 Tied for Warmest Year on Record. NASA, 2021.

By enhancing our understanding of phenomena such as

- Extreme events
- Weather disruption
- Temperature and sea level rise
- Pollution

we can improve modelling and forecasting to provide better information to stakeholders to aid decision-making. This implies better mitigation of risks and adverse consequences to avoid ecosystem disruption.

Equatorial Sentinels will herald a new era with unprecedented amounts of accurate space data with unprecedented revisit time, enabling new applications and services. This digital gold mine, so to speak, could lead to new opportunities in the manufacturing industry, for instance, in constructing satellites, sensors and ground segments, but also in the service industry, leveraging new AI-driven data processing.

Besides the equatorial belt, Equatorial Sentinels will also benefit mid- to high-latitude countries. The equatorial data will help to improve global models. There is enormous scope for international, scientific and technological cooperation for the economic benefit of mankind.

2. Equatorial Sentinel Design and Strategy

Figure 3: Economic Development and Technology

"Economic Development & Technology" by Gerd Altmann via Pixabay is licensed under CC BY 4.0

Figure 4: Envisioned Equatorial Sentinel Constellation

Image from the author.

As discussed above, Equatorial Sentinels are critical against the backdrop of climate change and more specifically the associated extreme events, which are more and more frequent, more and more intense, and can occur at geographical locations that were untouched before. These are envisioned as a constellation of small and very small satellites to cope with major environmental threats over equatorial regions and beyond.

This constellation represents a way forward in combating global warming, pollution and extreme weather events by enabling us to better comprehend atmospheric, tropospheric and oceanic phenomena over the equatorial belt.

Equatorial Sentinels are envisaged as agents that gather and deliver quality data to powerful computers that develop high-performance predictive models based on physics-informed artificial intelligence and smart data.

2.1 Mission Design

Depending on the mission budget and objectives, there are the following broad categories for the space segment design:

2.1.1. High-End Missions

These large satellite missions prioritise sensor performance by using complex instruments. They are designed to be operated for long durations with relatively low risk to justify the high development costs. An example of these is the European Space Agency's Sentinels family of large satellites.

2.1.2. Low-End Missions

Low-end small satellite missions typically have reduced sensor performance as a trade-off to the medium to low development cost. Such satellites are designed to carry smaller instruments and operate for shorter durations with medium to low risk. However, these characteristics make such missions ideal for Equatorial Sentinel design.

2.1.3. Pathfinders and Demonstrators

These are high-risk missions executed by small and/or very small satellites (or CubeSats) designed to operate for a short duration. Such satellites are typically launched to demonstrate a new technology and/or the usefulness of new data and are ideal for paving the way for Low-End Missions. This makes them useful for future Equatorial Sentinel design.

As discussed above, low-end and pathfinder missions will always have trade-offs between scientific needs and sensor performance. These provide a unique opportunity to enhance System Design Technology, as seen in the evolution of sensor and bus technologies and the development of innovative architectures.

However, while efforts are being made to study and mitigate the trade-offs, they cannot be eliminated. Therefore, satellite design is highly dependent on the end users' needs.

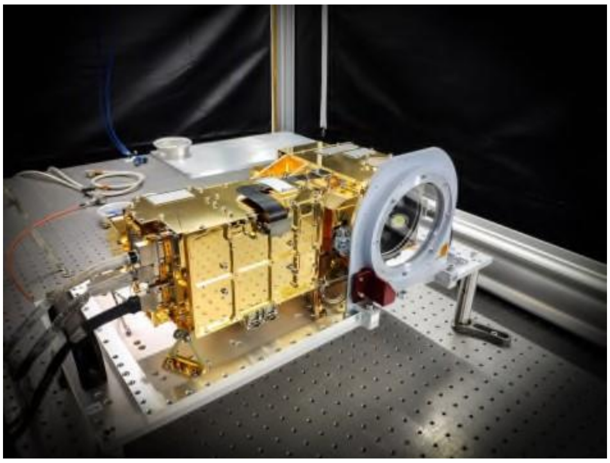

Figure 5. Sensor Satellite Sensor and Payload Design

SuperCam Mast Unit. NASA JPL, 2021.

It is evident from this discussion that mission design and system design are challenging and, therefore, require a paradigm shift in the mindsets of scientists, modellers, and space technologists. Revisit time and low cost should be emphasised rather than high-end sensor performance. Furthermore, the involvement of scientists and modellers early in the mission development cycle can be instrumental to mission definition.

2.2 From Data to Model Improvement: A 3-Step Strategy and Challenges

It is proposed that Equatorial Sentinels be leveraged through the following three-step approach:

Step#1: Create new sets of equatorial data with low-cost/very small satellites.

It is worth noting that high revisit with only one satellite is the crucial advantage to be exploited here. And although high-performance satellites are desirable, they are very expensive and in general unaffordable to equatorial countries due to their size and complexity.

Challenge#1: Small space sensors must have an acceptable reduced-performance range while retaining a high scientific value.

Step#2: Leverage existing satellite and other data to process new data and improve combined value.

There is great potential in using AI to perform cross-calibration and co- registration of small satellite data with existing polar or geostationary satellites (for instance) and other ground or airborne data to achieve unprecedented accuracy and precision.

Challenge#2: There is a dire need for physics-based AI models that can simulate future data. New assimilation/fusion algorithms must also be developed.

Step#3: Improve prediction models with new equatorial data.

Data analysis and machine learning techniques can be employed to iteratively fine-tune and improve the performance of parametric hybrid AI models.

Challenge#3: Extensive simulation is required to assess the real impact of new equatorial satellite data on the accuracy of the models.

3. Discussion

Equatorial Sentinels can herald an era of mutually beneficial cooperation at various levels, including:

3.1 At the Country Level

- Between local universities/research centres and government agencies:
  - Development of enabling space technologies for challenging scientific space missions.
  - Innovative space approach to tackle societal needs.
- Between local universities and local industry:
  - Joint development of scientific and experimental payloads/satellites.
  - Fast and cheap demonstration of new applications.
  - Technology transfer and spin-off opportunities.

3.2 At the Regional Level (ASEAN and Equatorial Countries):

- Each country can add its satellites to a “hybrid” constellation of Equatorial Sentinels:
  - Without any design or operational constraints, but
  - With a formal agreement to share data with other partners of the constellation.

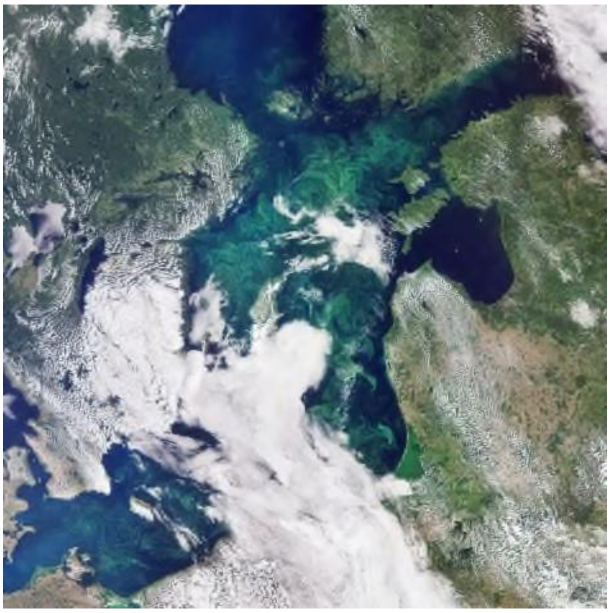

Figure 6. “Win-Win” Cooperation to Safeguard the Environment

Safeguarding Our Oceans. ESA, 2020.

3.3 At the International Level

- Between universities and space agencies: Equatorial data will benefit the world community.
- Between universities and private companies: New innovative business models have to be explored.

4. Conclusion

The existing socio-economic, environmental and scientific needs are enormous and urgent. Yet, it does not seem that we can tackle them on a foreseeable horizon. To reiterate, many severe environmental threats are looming over the equatorial region. As long as scientific models are still missing vital equatorial data, we are effectively blind to these threats.

Figure 7. Sentinels to Watch Over and Protect the Earth

Earth's Oceans. ESA, 2020.

The cost of satellite missions is prohibitively high, which limits our ability to address these pressing issues. However, as the Equatorial Sentinel concept demonstrates, affordable space solutions are being developed rapidly. Some of the crucial factors to leverage include:

- The great potential of satellites in near-equatorial orbits to track fast varying atmospheric phenomena.
- The invaluable synergy between small satellite missions and existing large polar/geostationary satellites that enhances their combined worth.
- The low cost and short development time of nanosatellites, combined with their low risk for in-orbit demonstration and high revisit.
- The rapid advancement of technology that has enabled high-impact instruments such as passive microwave radiometers to fly on board nanosatellites.

The new equatorial data provided by high-revisit satellites will benefit:

- Science: By providing new knowledge and better prediction models.
- Technology: Through the development of compact, high-performance and low-cost space sensors.
- Business: By creating new applications and services at the local, regional and global levels.
- Industry: Through the development of new operational systems and the ability to reuse technologies for other applications/missions.
- People: By providing better forecast/nowcast of environmental threats to aid decision-making for not just equatorial countries but also the rest of the world.

About the Author

Prof. Erick Lansard holds a Master of Engineering in Aeronautics & Space (1983), a Master of Science in Fluid Dynamics (1983) and a PhD in Space Geodesy (1987). He has over 3 decades on industry experience holding director-level positions in various projects and organisations, including Alcatel Space, Alcatel Alenia Space, Thales Alenia Space, Thales Research & Technology-France, Thales Solutions Asia, Thales Defense Mission Systems. Erick is also (Full) Professor of Nanyang Technological University (EEE School). Among other duties, Erick is distinguished life member of the Air & Space Academy and of the International Academy of Astronautics, AIAA Fellow, Alcatel-Lucent/Nokia Bell Labs Fellow and AAAF Emeritus. He has also chaired the International Astrodynamics Committee of the International Astronautical Federation. He has published over 60 papers and holds several patents in the field of space system engineering.

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