Sentinel-1 Mission Operations Concept

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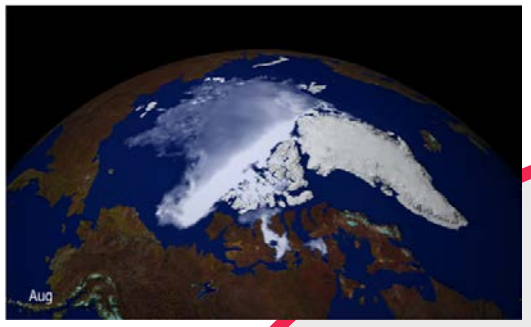
European Space Agency

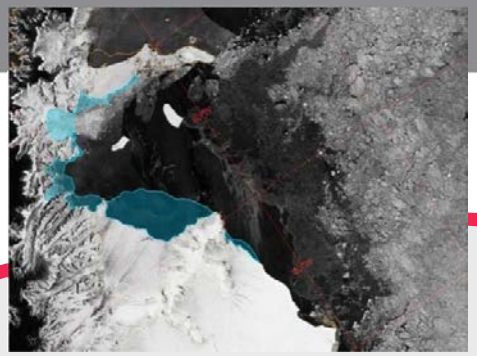
Sentinel–1: C-band SAR mission

- ✓ **Data continuity of ERS and ENVISAT missions**
- ✓ **GMES radar imaging mission for ocean, land and emergency services**
- ✓ **Applications:**
  - monitoring sea ice zones and the arctic environment
  - surveillance of marine environment (e.g. oil spill monitoring)
  - maritime security (e.g. ship detection)
  - wind, wave, current monitoring
  - monitoring of land surface motion (subsidence, landslide, tectonics, volcanoes, etc.)
  - support to emergency / risk management (e.g. flooding, etc.) and humanitarian aid in crisis situations
  - mapping of land surfaces: forest, water and soil, agriculture, etc.

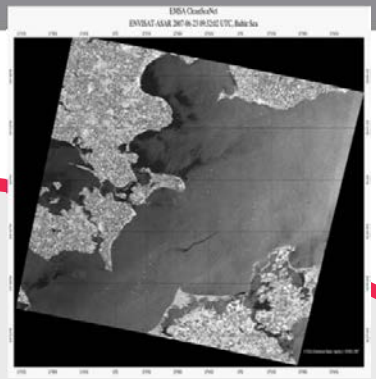
A wide range of applications



Arctic ice extent
August 2009
(Credit: MyOcean)

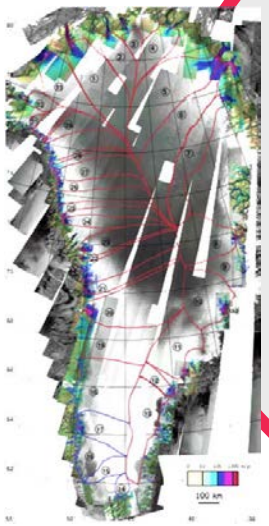


Larsen ice shelf loss between
2002 and 2009
(Credit: Polar View)



Oil spill detection
and Surveillance
(Credit: EMSA)

Ship detection
(Credit: ESA)

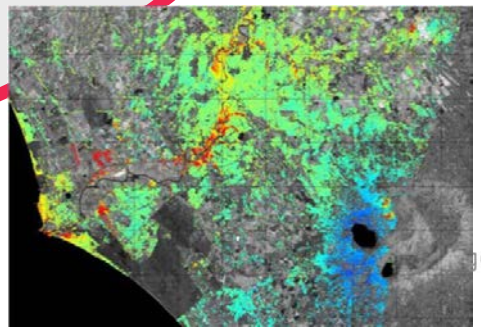


Acceleration of
Greenland glaciers flow
(Credit: Rignot et Al)

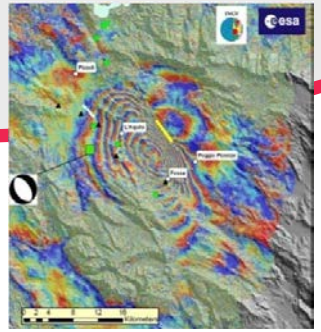
C-band SAR observations to support a wide range of applications

Land use
(Credit: ESA)

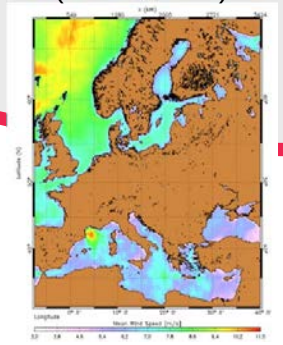
Subsidence map
1992-2006
(Credit: Terrafirma)



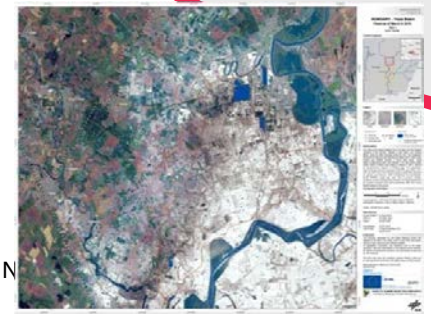
Earthquake
analysis
(Credit: INGV)



Mean wind speed
from 2005 to
2009
(Credit: CLS)



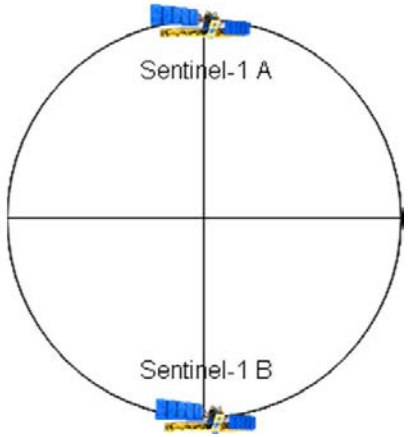
Emergency
management: flooding
(Credit: SAFER, DLR)

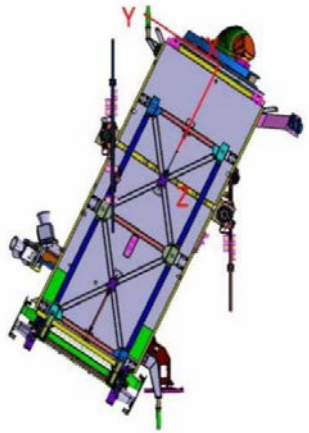


ESA UN

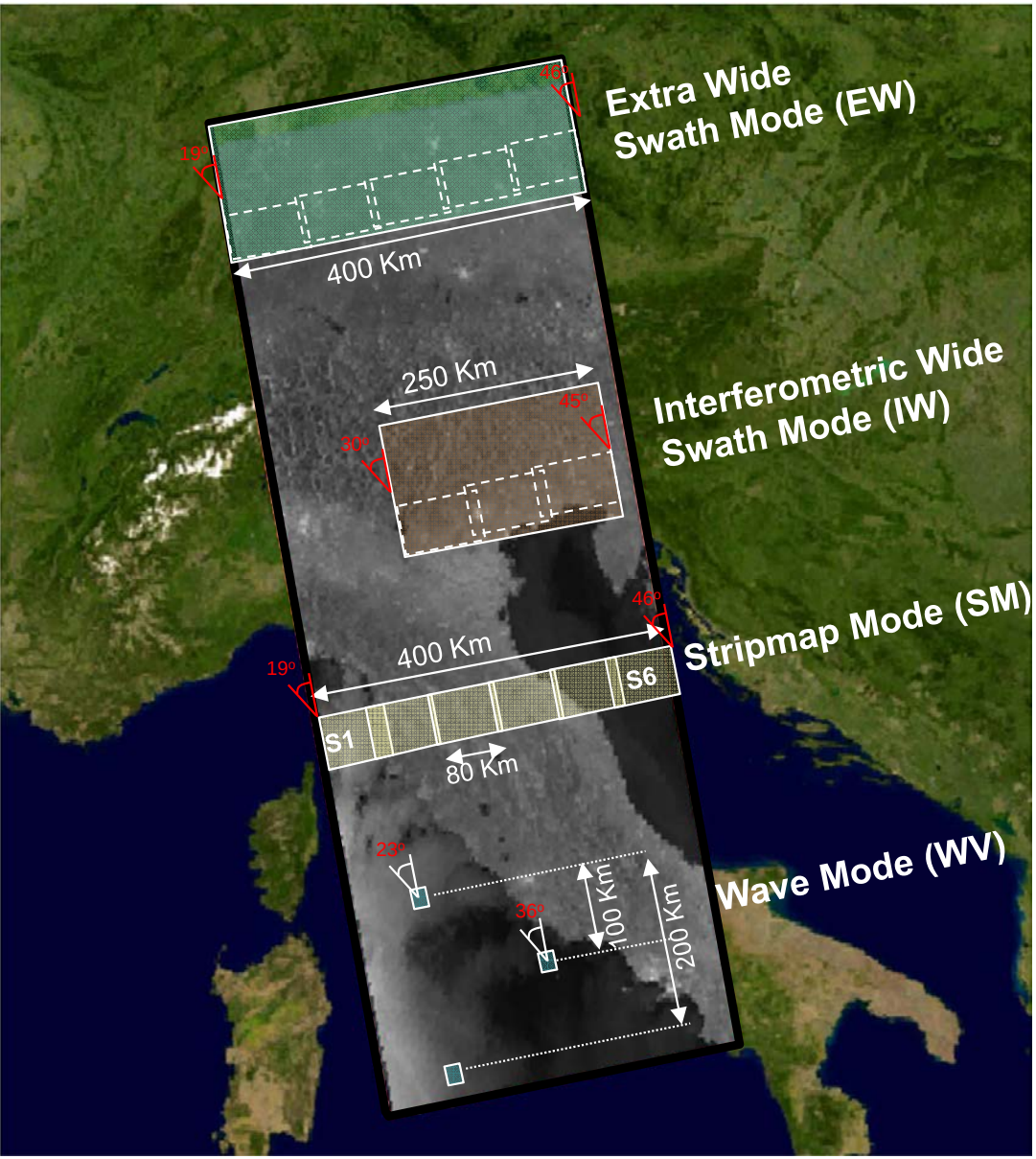
Sentinel-1 Mission Facts

- Constellation of two satellites (A & B units)
- C-Band Synthetic Aperture Radar Payload (at 5.405 GHz)
- 7 years design life time with consumables for 12 years
- Near-Polar sun-synchronous (dawn-dusk) orbit at 698 km
- 12 days repeat cycle (1 satellite), 6 days for the constellation
- Both Sentinel-1 satellites in the same orbital plane (180 deg phased in orbit)
- On-board data storage capacity (mass memory) of 1400 Gbit
- Two X-band RF channels for data downlink with 2 X 260 Mbps
- On-board data compression using Flexible Dynamic Block Adaptive Quantization (FDBAQ)
- Optical Communication Payload (OCP) for data transfer via laser link with the GEO European Data Relay Satellite (ERDS)
- Launch of Sentinel-1A scheduled for October 1st, 2013 (Sentinel-1B launch subject to EC funding)





Sentinel-1 SAR Modes



Sentinel-1 SAR can be operated in 4 exclusive imaging modes with different resolution and coverage:

Mode Rate	SAR Mode
High Bit Rate (HBR)	IW
	EW
	SM (S1 → S6)
Low Bit Rate (LBR)	WV

Polarisation schemes for IW, EW and SM:

- single polarisation: HH or VV
- dual polarisation: HH+HV or VV+VH

For Wave mode: HH or VV

For all of these operating modes, the same family of products is available to the users.

European Space Agency

Planned operational ESA Sentinel-1 products - L1 characteristics

Acq. Mode	Product Type	Resolution Class	Resolution [Rng x Azi] [m]	Pixel Spacing [Rng x Azi]	No. Looks [Rng x Azi]	ENL
SM	**SLC**	-	**1.7 x 4.3 to 3.6 x 4.9**	**1.5 x 3.6 to 3.1 x 4.1**	1 x 1	1
	GRD	FR	9 x 9	4 x 4	2 x 2	3.9
		HR	23 x 23	10 x10	6 x 6	34.4
		MR	84 x 84	40 x 40	22 x 22	464.7
IW	**SLC**	-	**2.7 x 22 to 3.5 x 22**	**2.3 x 17.4 to 3 x 17.4**	1	1
	GRD	HR	20 x 22	10 x 10	5 x 1	4.9
		MR	88 x 89	40 x 40	22 x 5	105.7
EW	**SLC**	-	**7.9 x 42 to 14.4 x 43**	**5.9 x 34.7 to 12.5 x 34.7**	1 x 1	1
	GRD	HR	50 x 50	25 x 25	3 x 1	3
		MR	93 x 87	40 x 40	6 x 2	12
WV	**SLC**	-	**2.0 x 4.8 and 3.1 x 4.8**	**1.7 x 4.1 and 2.7 x 4.1**	1 x 1	1
	GRD	MR	52 x 51	25 x 25	13 x 13	139.7

- **For Ground Range Products, the resolution corresponds to the mid range value at mid orbit altitude, averaged over all swaths.**
- **For SLC SM/IW/EW products, the resolution and pixel spacing are provided from lowest to highest incidence angle. For SLC WV products, the resolution and pixel spacing are provided for beams WV1and WV2.**
- **For SLC products, the range coordinate is in slant range. All the other products are in ground range.**

Main objectives of the Sentinel operations strategy

- Provide data to GMES services and for utilisation by ESA / EU Member States according to their specified requirements

- Ensure systematic and routine operational activities:
  - ✓ with a high level of automation
  - ✓ with pre-defined operations to the maximum extent possible

- Establish a conflict free operations profile, therefore anticipate conflict resolution, in particular with the elaboration of pre-defined mission observation scenarios

Sentinel-1 observation scenario objective

Implement a pre-defined and conflict-free observation plan, aiming at fulfilling, to the maximum feasible extent, the observation requirements from:

- the GMES services
- the use by ESA / EU Member States

In addition, on best effort basis and in order to ensure some continuity of ERS/ENVISAT, requirements from the science community are also considered, as well as contribution to international cooperation activities.

→ Need to find *a priori* the solutions on the potential conflict among users (e.g. different SAR operation modes / polarisation required over same geographical area)

Sentinel-1 Observation Requirements

Two main categories of services / applications:

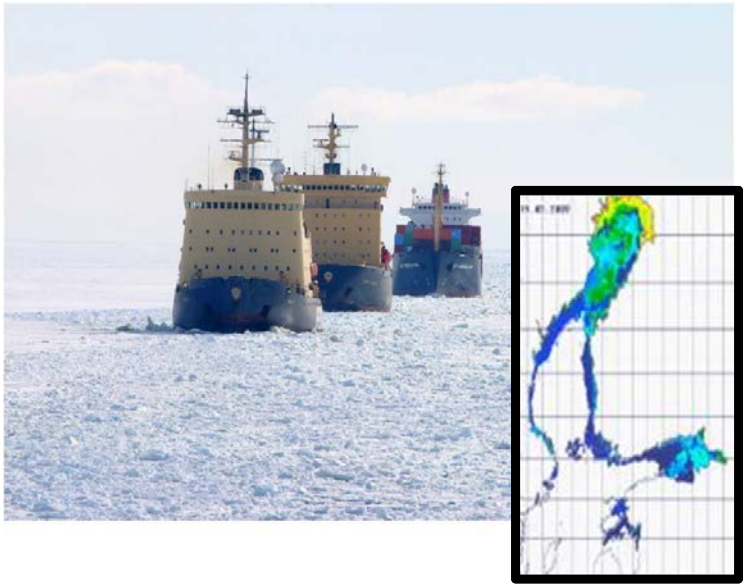
→ Services / applications over oceans, seas and sea-ice areas

→ Services / applications over land

In addition, on top of the pre-defined scenario, emergency observations not part of the pre-defined plan may be accepted in exceptional cases only.

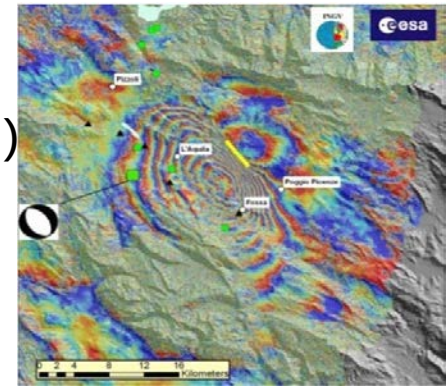
Sentinel-1 services over oceans, seas and sea-ice areas

- These services require quasi real time or near real time data, typically in less than 3 hours, and in some cases in less than 10 min.
- Quasi real time services or services requiring data within 1 hour from sensing rely on the support from collaborative ground stations
- These “monitoring” types of service require systematic or very frequent (e.g. daily) observations
- These services include, e.g.:
  - ✓ Sea-ice and iceberg monitoring
  - ✓ Oil spill monitoring
  - ✓ Maritime security information services (incl. ship detection)
  - ✓ Wind, wave, current monitoring



Sentinel-1 services and applications over land

- These services or applications cover a wide range of different thematic domains
- They do not generally require data in quasi real time, few of them require data in 3 hours NRT
- Related data are planned to be recorded on-board and downloaded to the core ground station network (direct transmission to collaborative stations may however be made in Europe)
- These services / applications include e.g.:
  - ✓ risk management in support to flooding (reference data set)
  - ✓ “security” services in the GMES framework
  - ✓ land motion / geo-hazard monitoring with InSAR (seismic hazards, volcanoes, landslides, subsidence / inactive mines, coastal lowland and flood defence)
  - ✓ glacier, snow monitoring
  - ✓ large ice sheet monitoring (Greenland, Antarctica, in particular to support climate change studies)
  - ✓ river and lake ice monitoring
  - ✓ global forest mapping (e.g. in support of REDD / GFOI)
  - ✓ global / regional land mapping (incl. for food security, crop monitoring, land cover and change monitoring, soil moisture, etc.).



Examples of Sentinel-1 operations constraints (list not exhaustive)

Instrument operations constraints:

- SAR modes exclusivity (incl. polarisation schemes)
- SAR mode transition time (2.4 sec.)
- SAR duty cycle (25 min/orbit for the 3 high rate modes)

Data transmission / acquisition constraints:

- Huge volume of data, potentially up to 2.4 TB/day with the two satellites
- Data rate versus X-band downlink capacity (use of on-board data compression – FDBAQ)
- Data downlink conflict between RT data transmission in dual-polarisation and download of on-board recorded data
- On-board memory sizing (1410 Gbits)
- X-band duty cycle (max. 30 min/orbit, max. 20 min consecutive)
- X-band downlink switches (X-Band system specified for a total of 150,000 operation cycles)

Process for collecting and implementing the Sentinel-1 observation requirements

Category	Source of Requirements	Status / Comments / Issues
GMES Services	- Extrapolation of Data Access Data Warehouse requirements - Direct discussions with GMES services and EMSA	- Requirements available from key current GMES services and EMSA - Issues: o GMES services which will be operational in 2014+ ? o "perimeter" of GMES services
National (public) services (in accordance with GSC Prog. Declaration)	- Discussions with Delegations - Reply to Collaborative GS questionnaire (GOCG)	- Requirements available from ~13 Member States (AT, CND, DE, DK, E, FIN, F, GR, I, NO, PT, RO, UK) - Some require clarification and/or consolidation - Reply to collaborative GS questionnaire
Scientific use, on-going ESA projects, continuity of ERS/ENVISAT	- Recommendations from scientists at key SAR workshops (FRINGE, SEASAR), Sentinel-2 workshops, SEN4SCI, etc. - ESA GSE Projects (e.g. Polar View, MARISS, Terrafirma, GMFS, etc.) - Glob-series projects, CCI, SEOM, etc. - Extrapolation of ERS/ENVISAT projects	Some requirements available. Continuous process. Requirements to be implemented in 2014.
International Initiatives, International cooperation	- GEO, CEOS, IGOS, FAO, FCT, GFOI, REDD, PSTG, IICWG, GCOS, CliC, TIGER, DRAGON, Geo-hazard Supersites, etc. - Requests from international partners (e.g. US (NOAA / NASA / USGS), Australia, China, etc.)	Some requirements available (e.g. NOAA). Requirements to be implemented in 2014
Other incl. use for commercial VA	- EARSC, etc.	

Sentinel-1 observation scenario

High level strategy during Full Operations Capacity

• Optimum use of SAR duty cycle (25 min/orbit for 1 satellite), taking into account the various constraints (e.g. limitation in number of X-band RF switches, mode transition times)

• Wave Mode continuously operated over open oceans, with lower priority w.r.t. the other high rate modes

• IW or EW modes operated over pre-defined geographical areas:

- ✓ Over land: pre-defined mode is IWS
- ✓ Over seas and polar areas, and ocean relevant areas: pre-defined mode is either IWS or EWS

• The Full Operations Capacity is reached with the 2-satellite constellation

Preliminary Sentinel-1 Observation Scenario

-

First 6 months of the ramp-up phase

First 6 months scenario – Scope, Assumptions and Constraints

- Availability of operations funding is assumed
- Assumed current Sentinel-1A launch window: Oct. to Dec. 2013
- Ramp-up starts at end of the satellite commissioning phase (3 months after Launch for S1)
- An average capacity of 6 min/orbit of data download is assumed
  → may lead to much higher SAR duty cycle in high data mode depending on mode / polarisation / timeliness requirements (e.g. 25 min of EWS single pol)
- A clear priority to GMES services and GMES use, as well as to National services and use by ESA / EU Member States versus any other use
- Scenario to be considered **preliminary and indicative** as based on current GMES and National services requirements

  → may be refined up to the start of the exploitation phase at IOCR

Scenario overview – Europe and European waters

- Full coverage in IWS single polarisation VV of European land and seas is performed at each repeat cycle in both ascending and descending (with some exceptions around Baltic Sea during sea-ice period)

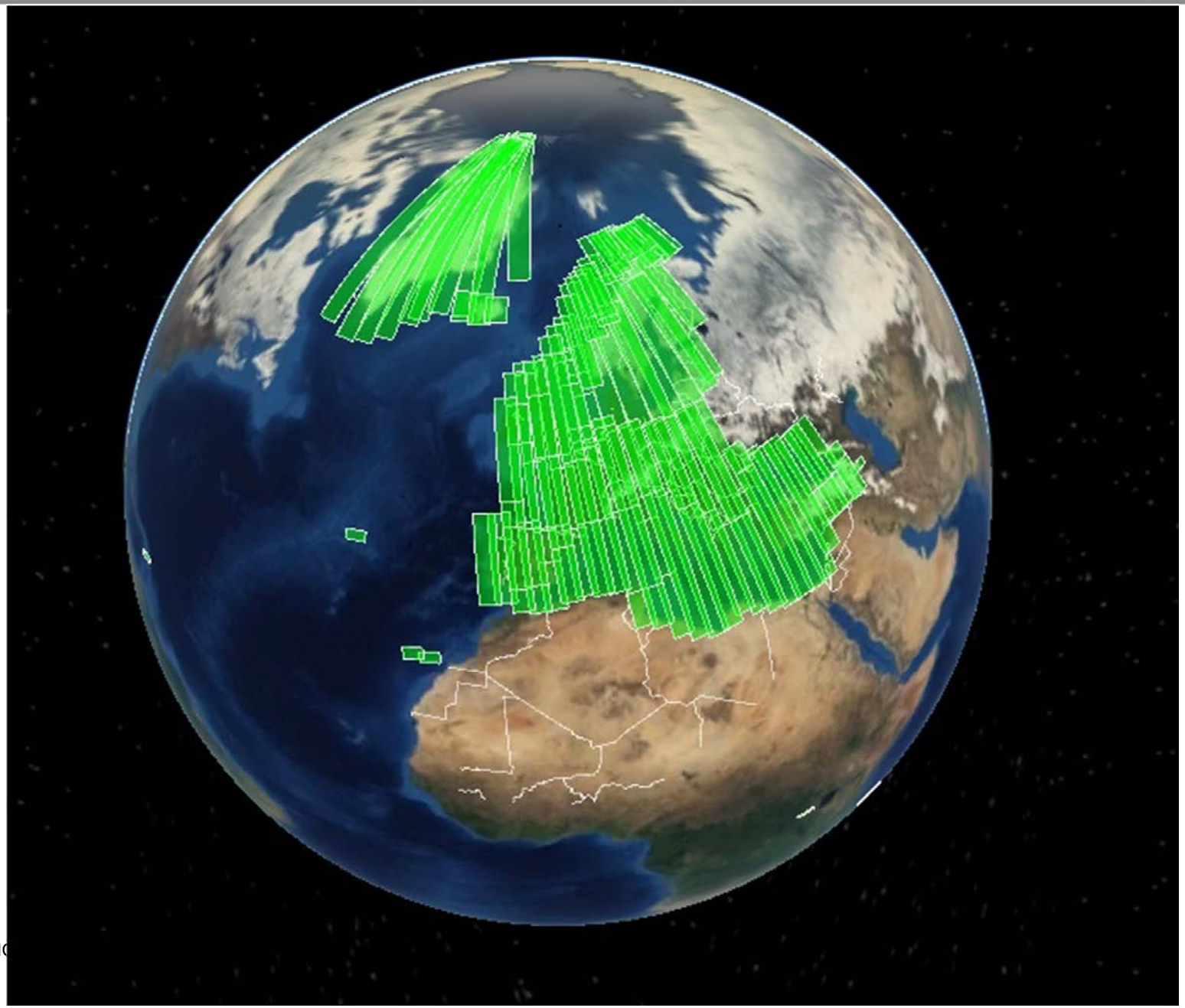
- (Quasi)-systematic use of all passes in EWS HH+HV in both ascending and descending to support MyOcean / national sea-ice monitoring requirements

- Specific strategy used over / around Greenland to accommodate both the ice sheet requirements (IWS) and the MyOcean / Danish requirements for sea-ice / iceberg monitoring (EWS), alternating observations during several repeat cycles

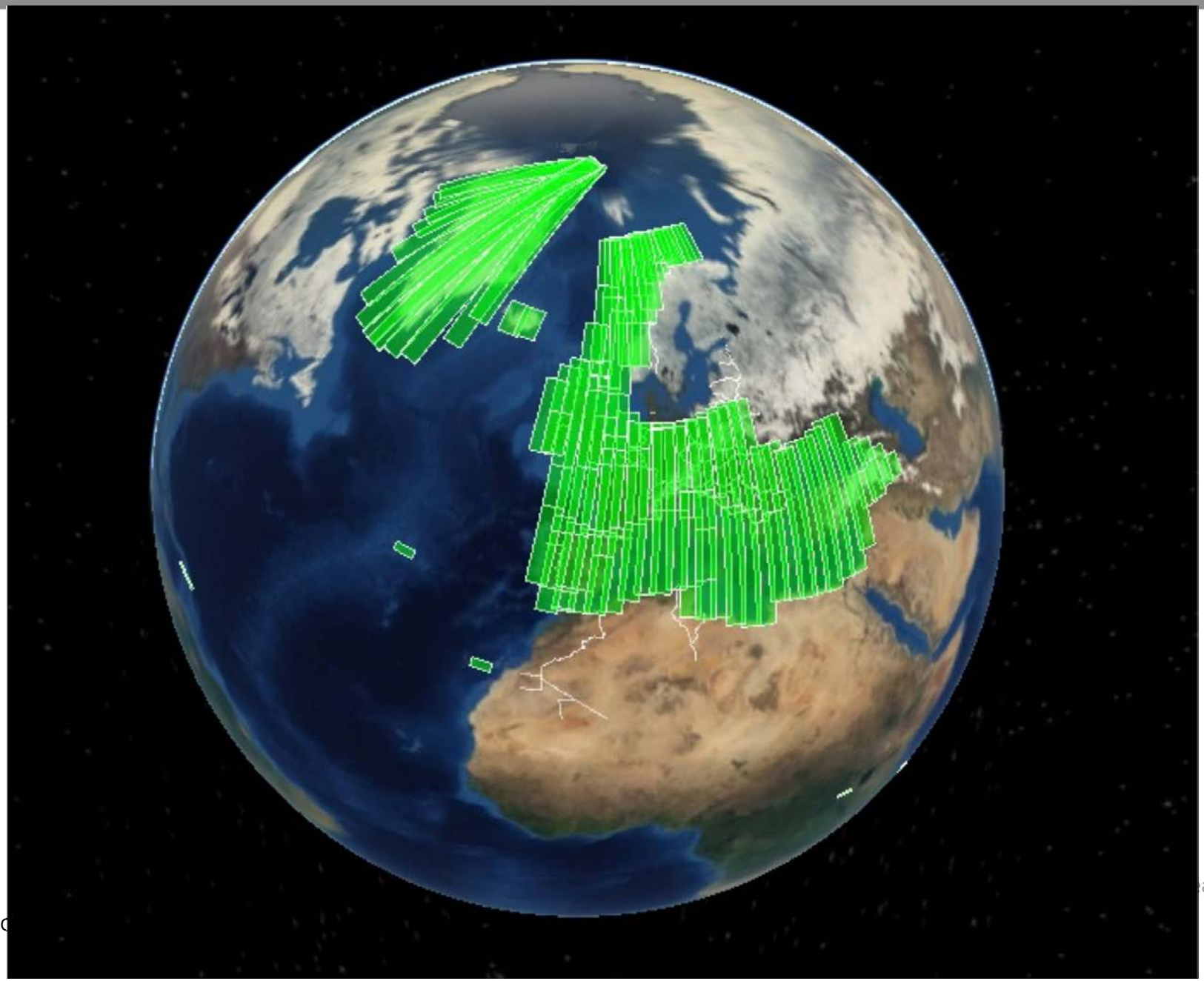
- Specific strategy used for the Baltic during sea-ice season (EWS), coordinated with observation over surrounding land areas (IWS) to avoid mode switch

- On the European western waters, use EWS VV+VH to support oil spill monitoring and sea state (wind, wave, current).

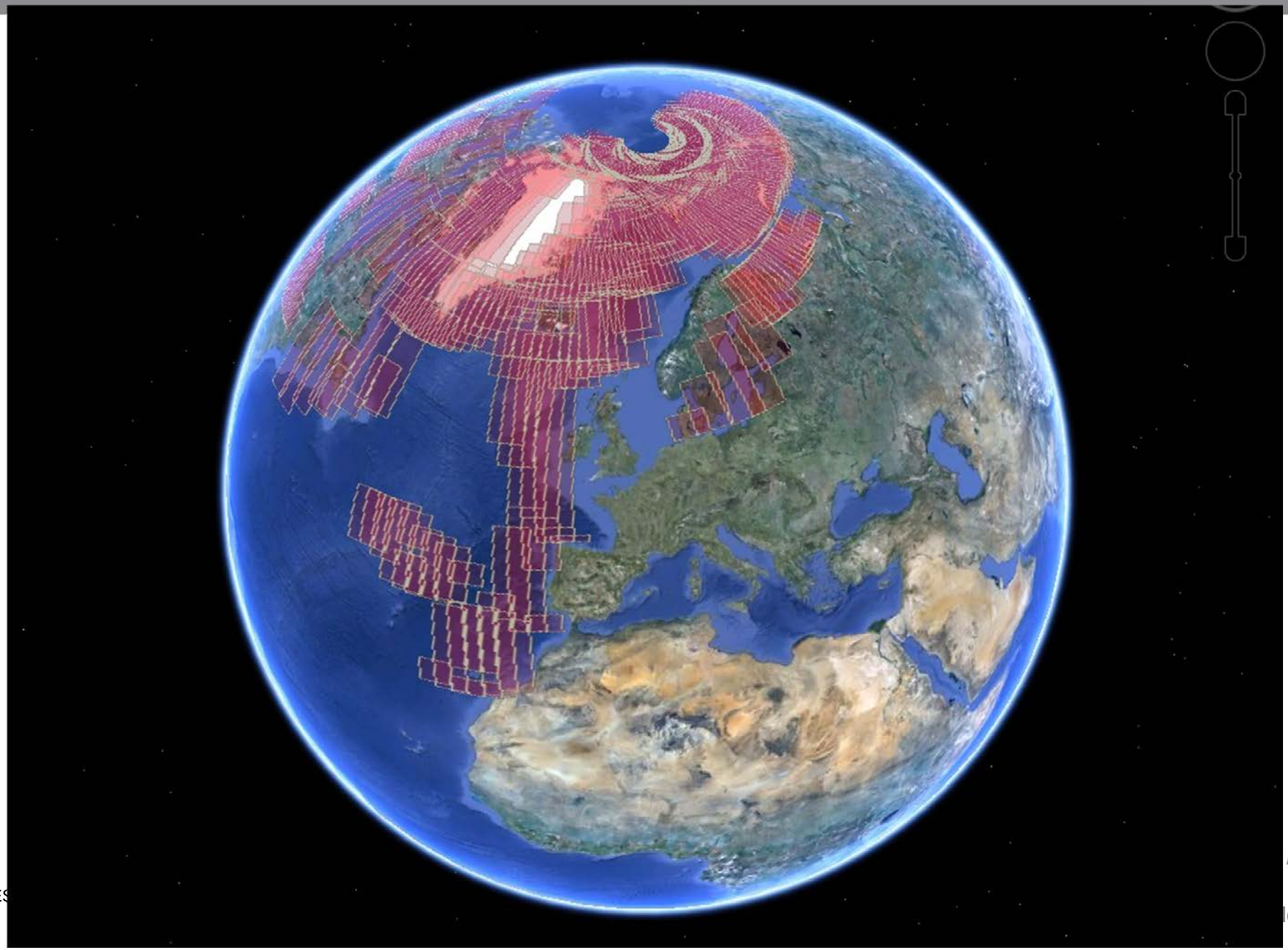
Europe and European waters – IWS, ascending orbits (January), 12 days



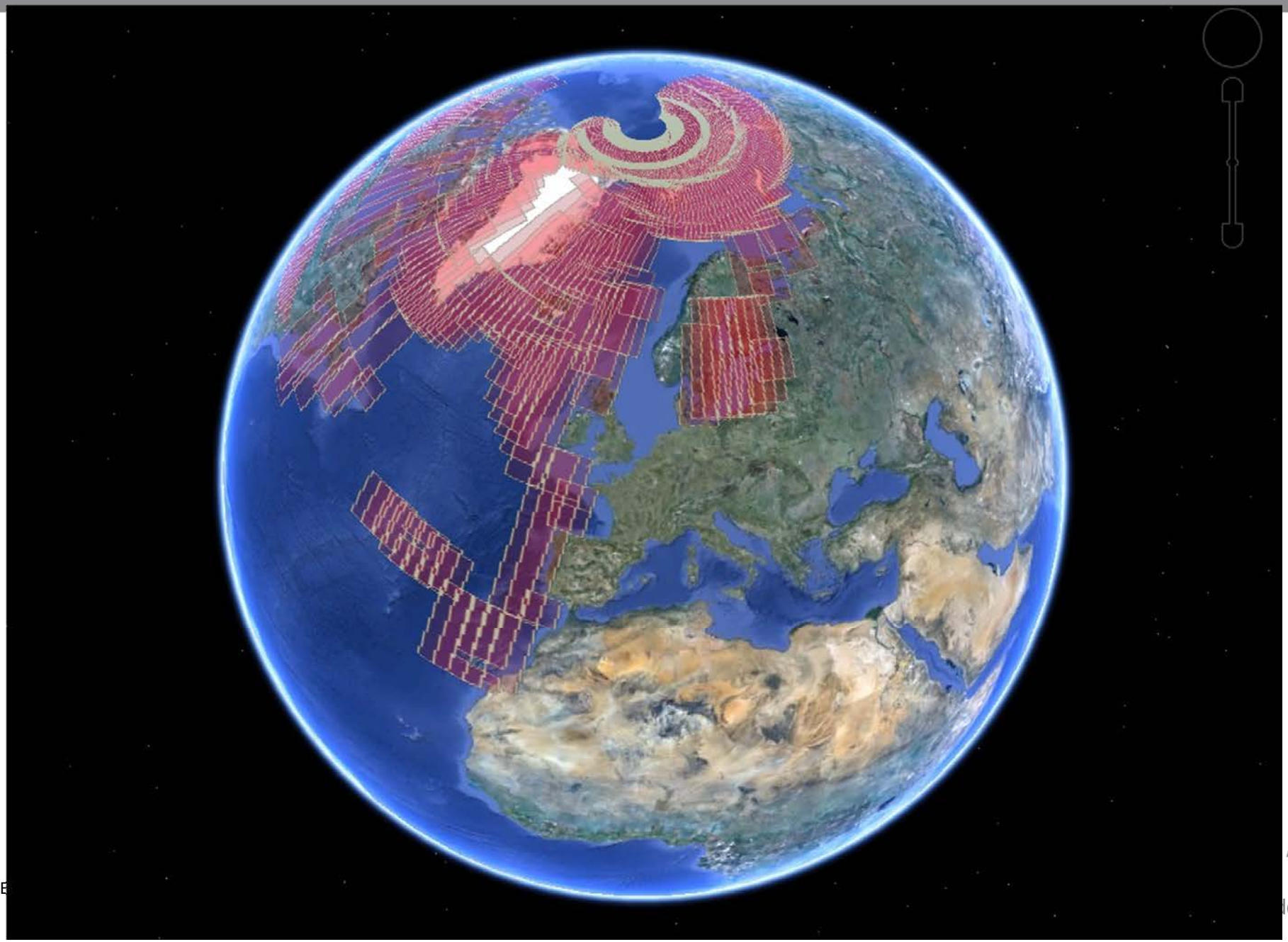
Europe and European waters – IWS, descending orbits (January), 12 days



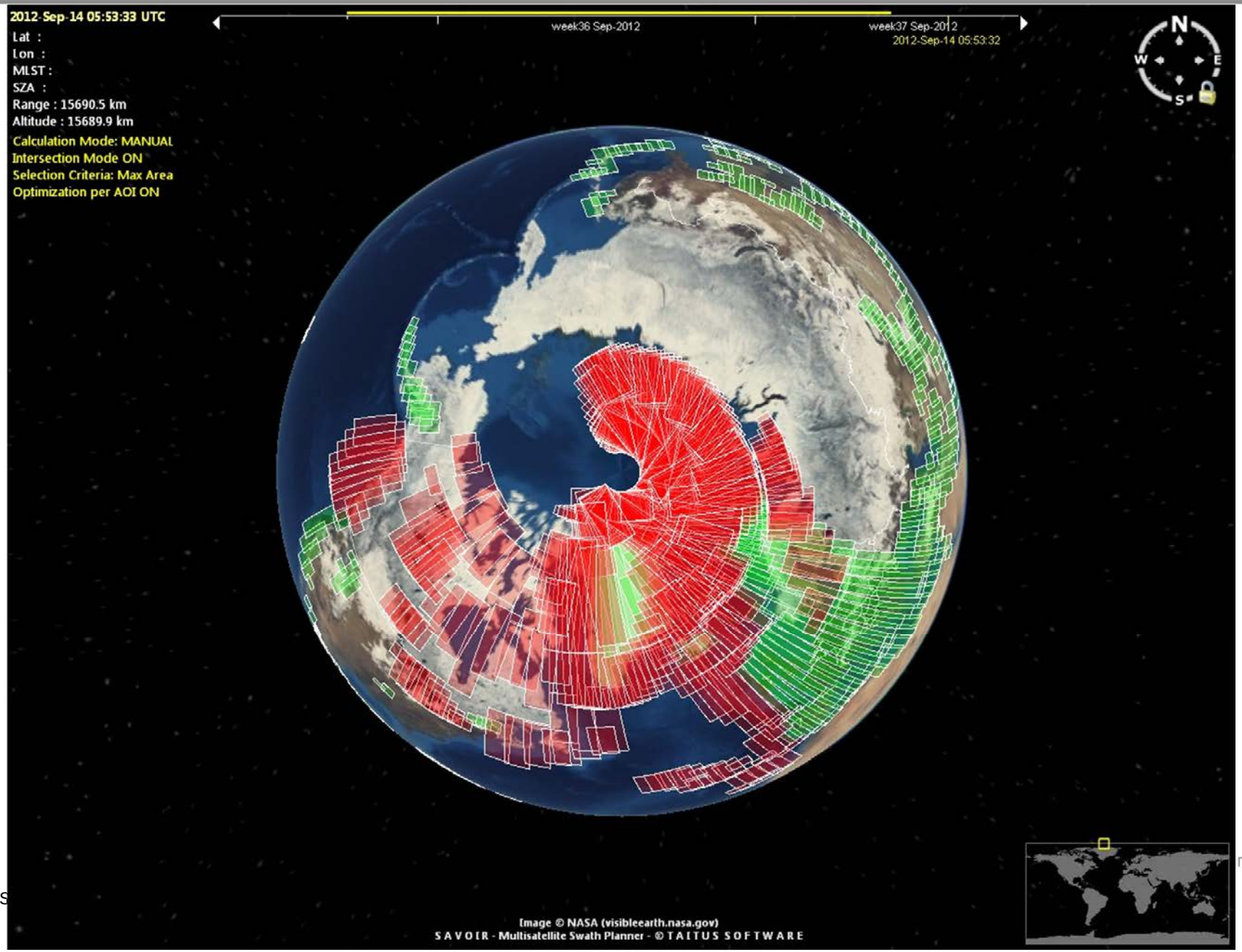
Europe and European waters – EWS, ascending orbits (January), 12 days



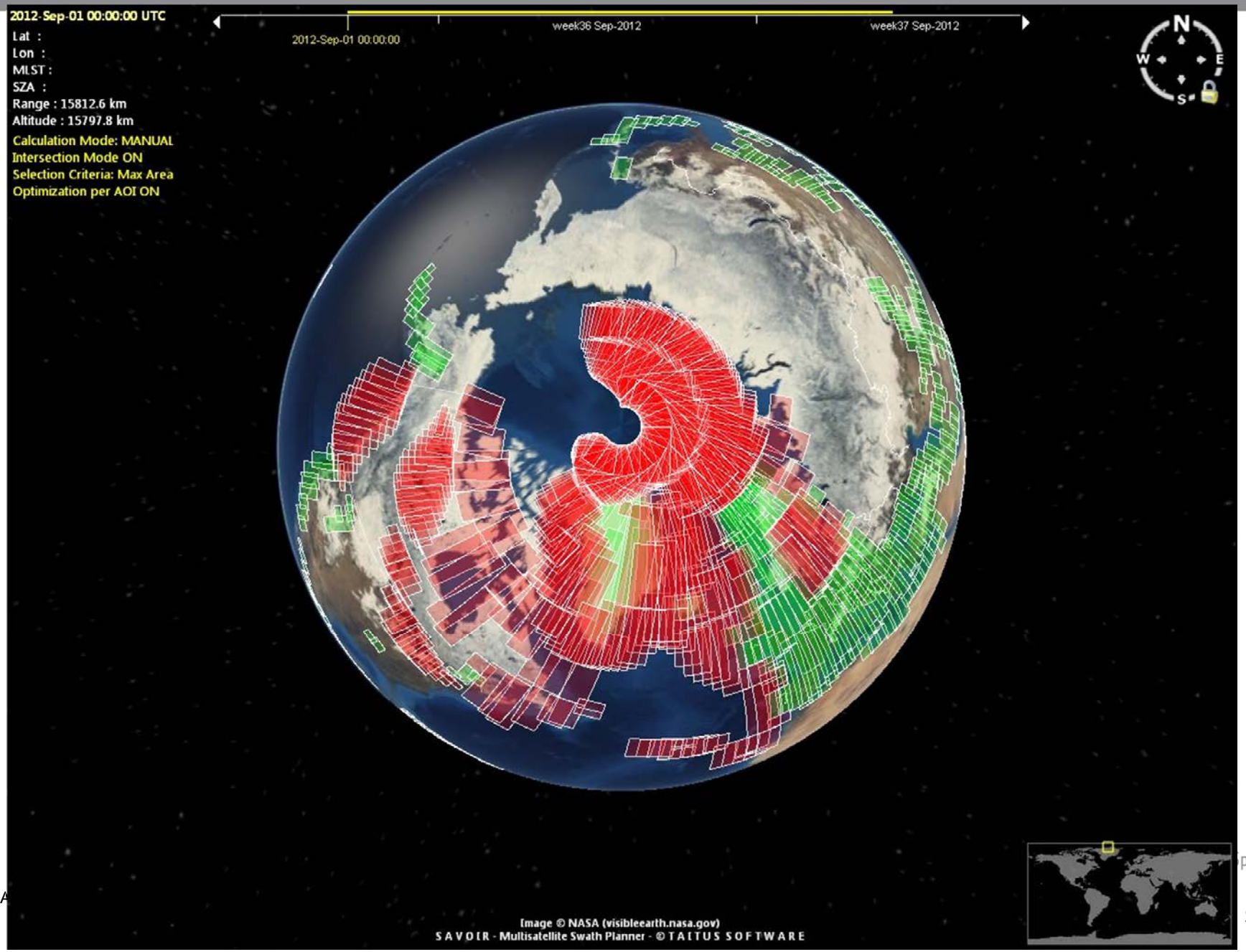
Europe and European waters – EWS, descending orbits (January), 12 days



North pole –
EWS and IWS, ascending orbits, 12 days



North pole –
EWS and IWS, descending orbits, 12 days



Scenario overview – Outside Europe

• MyOcean sea-ice / iceberg operational service in Southern Ocean around Antarctica (EWS HH, NRT 3 hours), also covering national requirements on the subject areas – Revisit similar to Envisat past activities as starting point

• Background reference data for GMES Emergency and GMES Security Services
→ areas are still be consolidated, but represent limited SAR resources as 1 or 2 reference product is to be provided per year

• Regular observations to support Volcano monitoring at global level, starting with EVOSS selected volcanoes (IWS VV, both ascending and descending passes)

• Regular observations to support Canadian operational services, in particular sea-ice monitoring services (EWS HH+HV ideally) and some sea-state monitoring activities (EWS VV+VH), outside of / in complement to Radarsat-2 observations

Scenario overview – Outside Europe (cont'd)

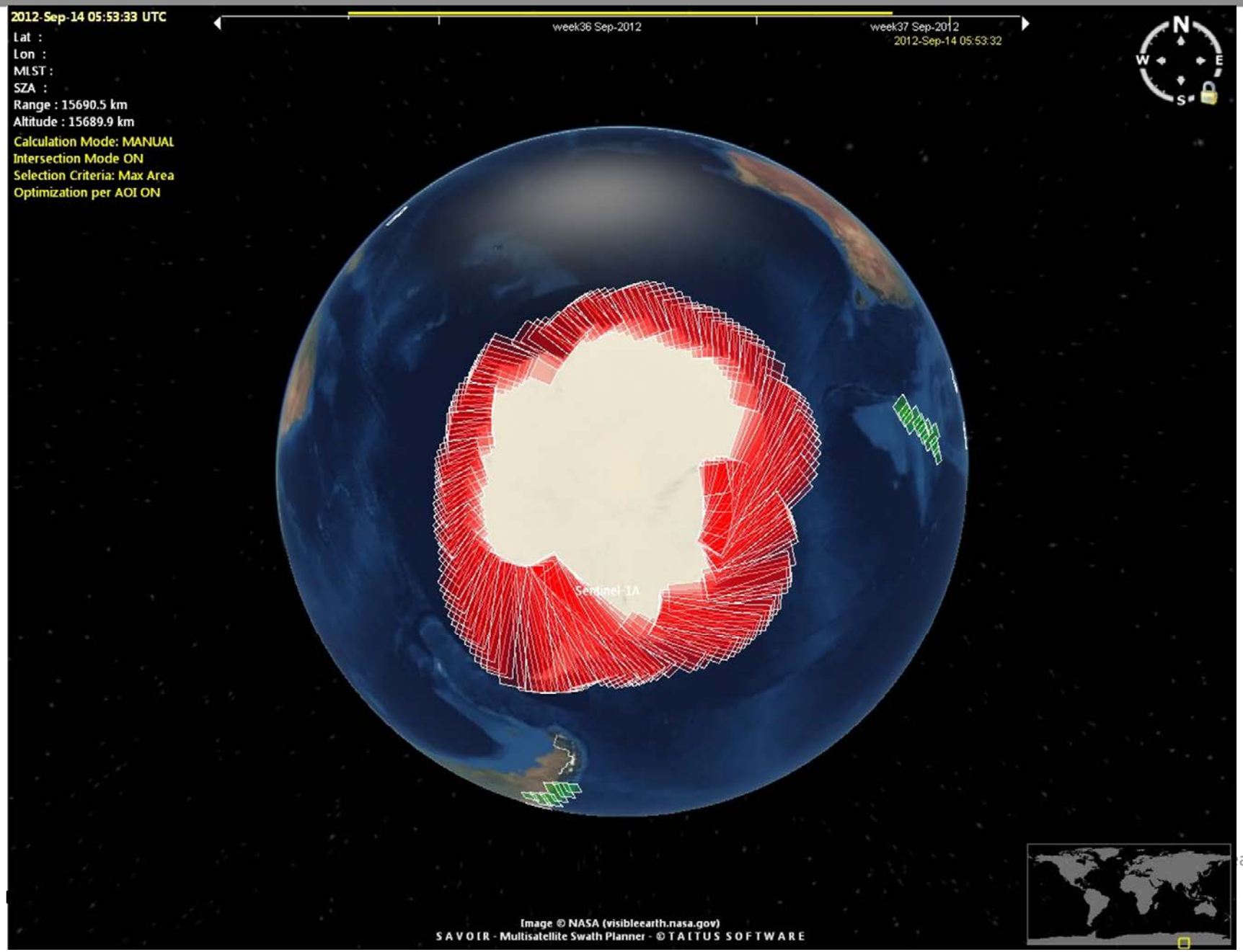
- Seasonal observations to support National activities over Antarctica (IWS HH or SM HH implemented as campaigns during 3 to 4 consecutive repeat cycles) and in the Western Arctic (EWS HH+HV)

- Systematic observation (every repeat cycle) both in ascending and descending passes to support InSAR on major tectonic areas and geo-hazard supersites worldwide (IWS VV or HH)

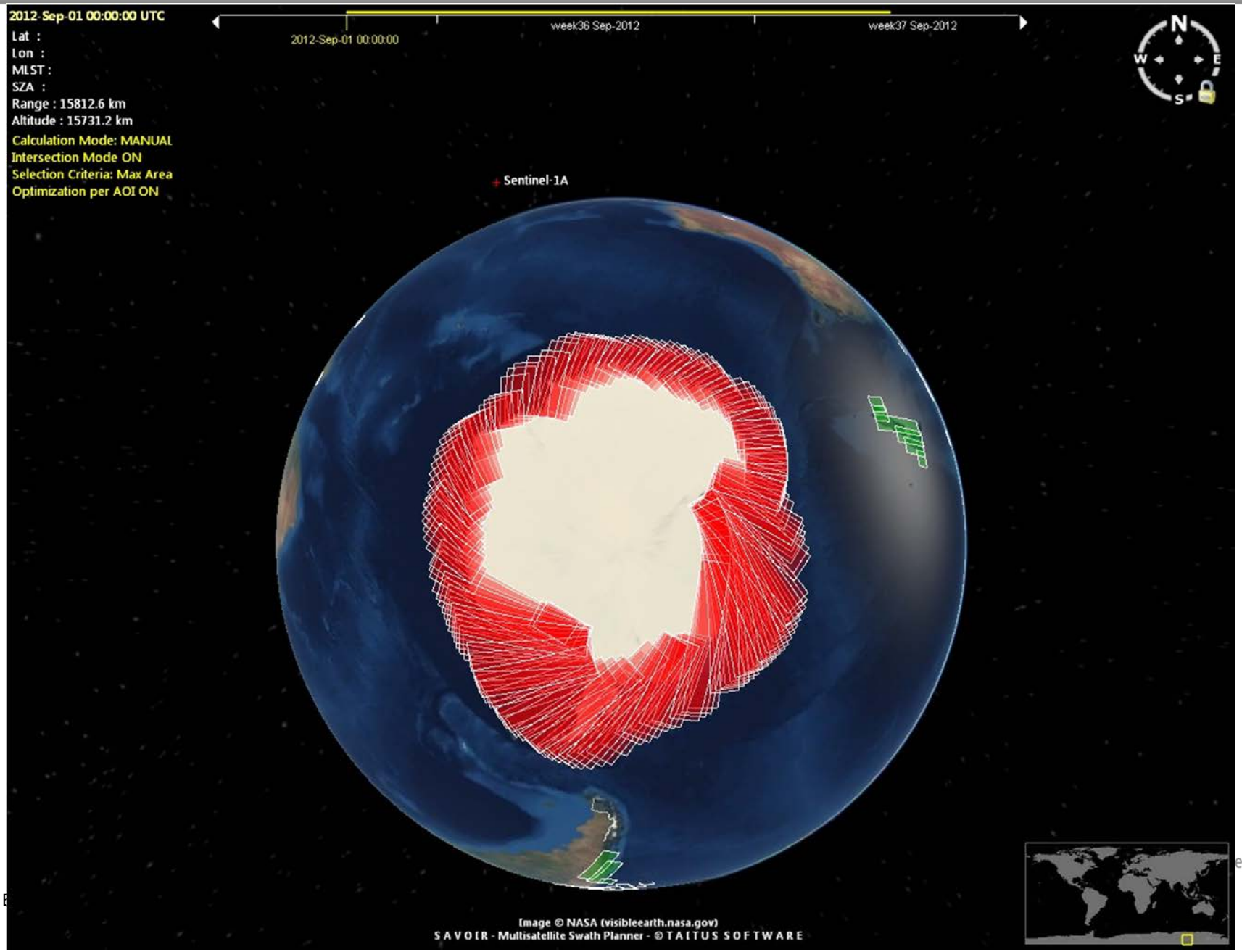
- Regular observations to support National overseas territories / dept. operational services (maritime surveillance) with local collaborative stations starting with Kerguelen (IWS HH)

- One campaign to support forest monitoring international activities (IWS VV+VH), starting with some observations over REDD participating countries

South pole –
EWS and IWS, ascending orbits, 12 days

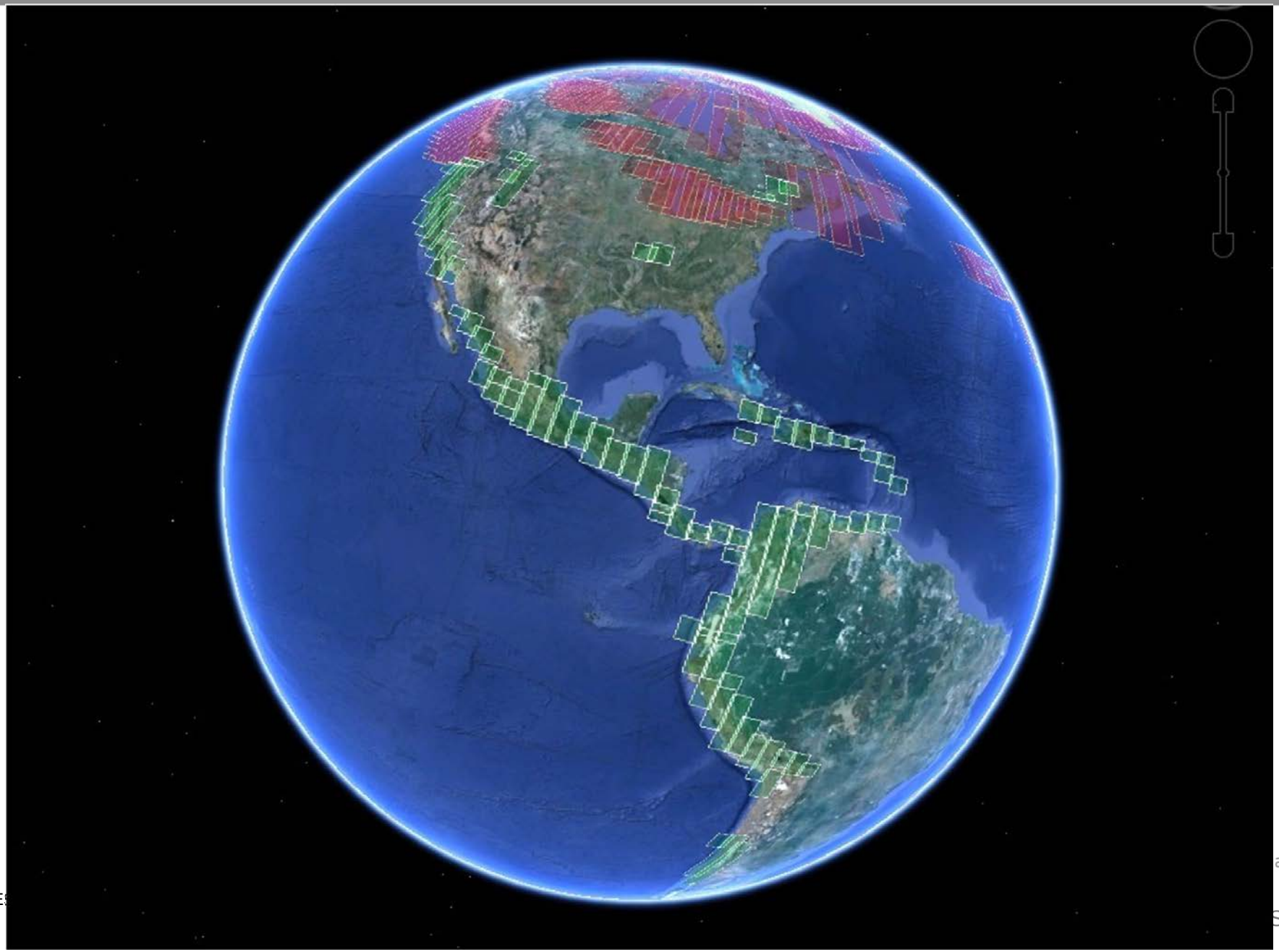


South pole –
EWS and IWS, descending orbits, 12 days



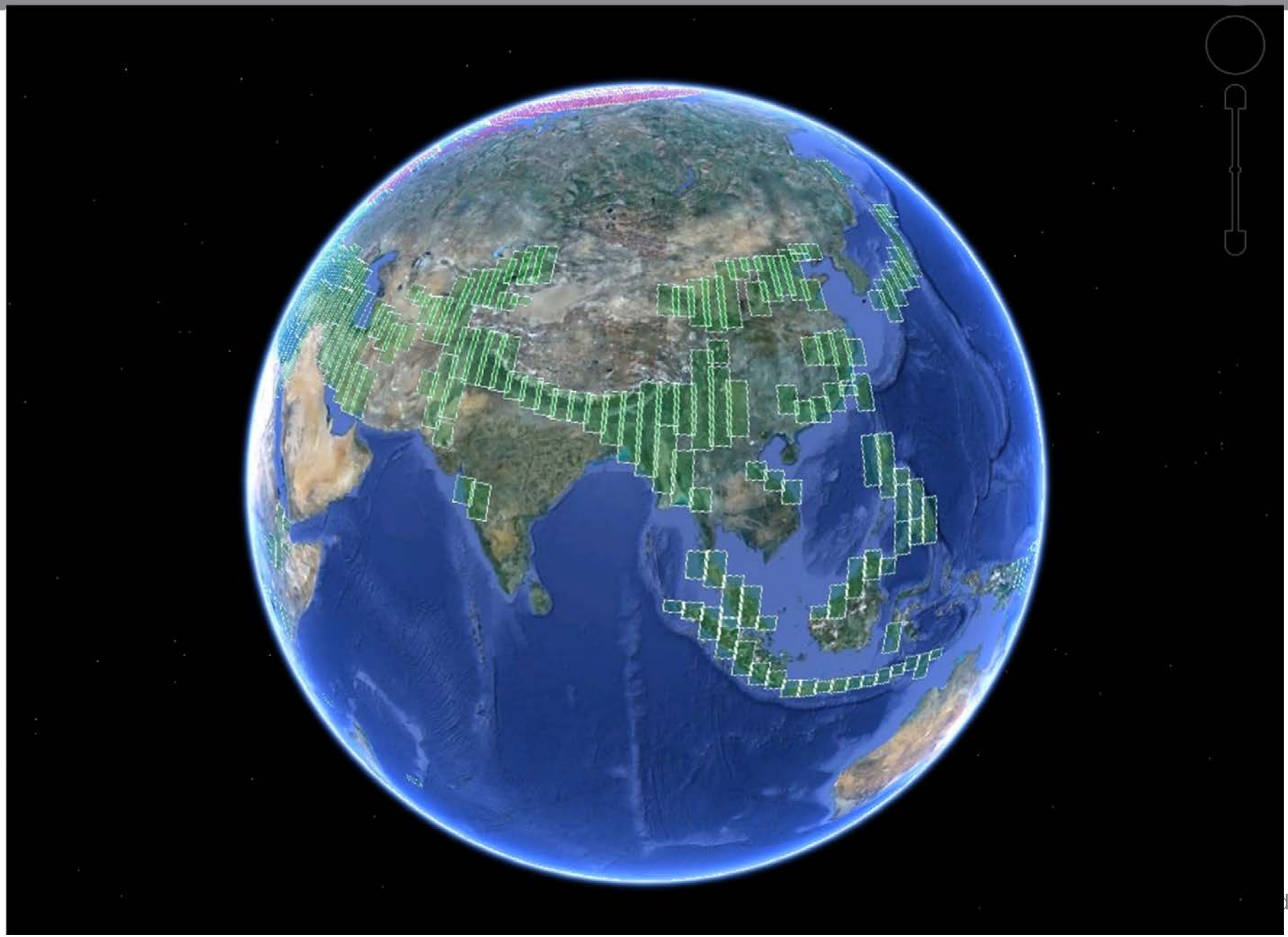
Americas –
EWS and IWS, ascending orbits, 12 days

Americas –
EWS and IWS, descending orbits, 12 days

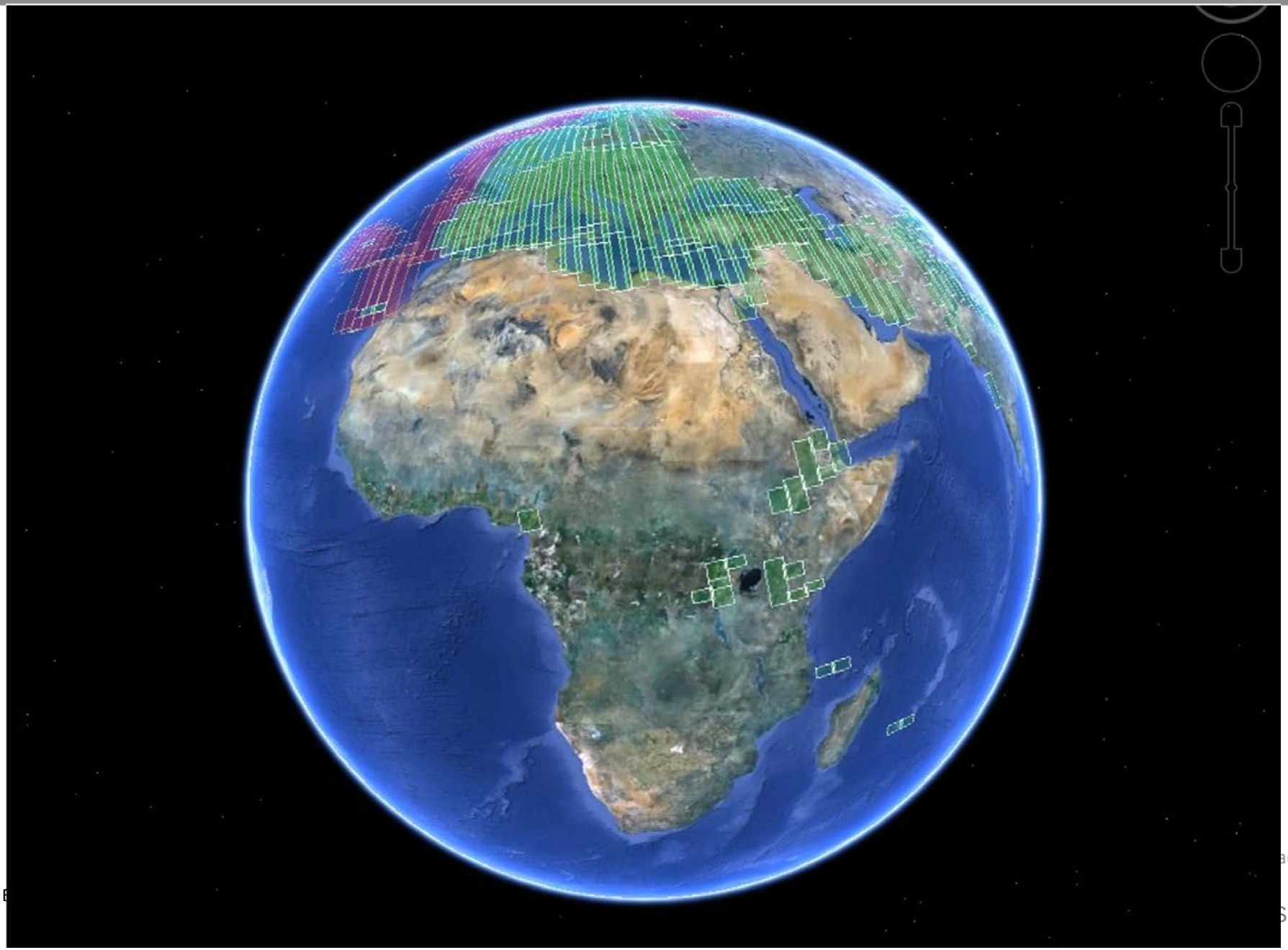


Asia –
EWS and IWS, ascending orbits, 12 days

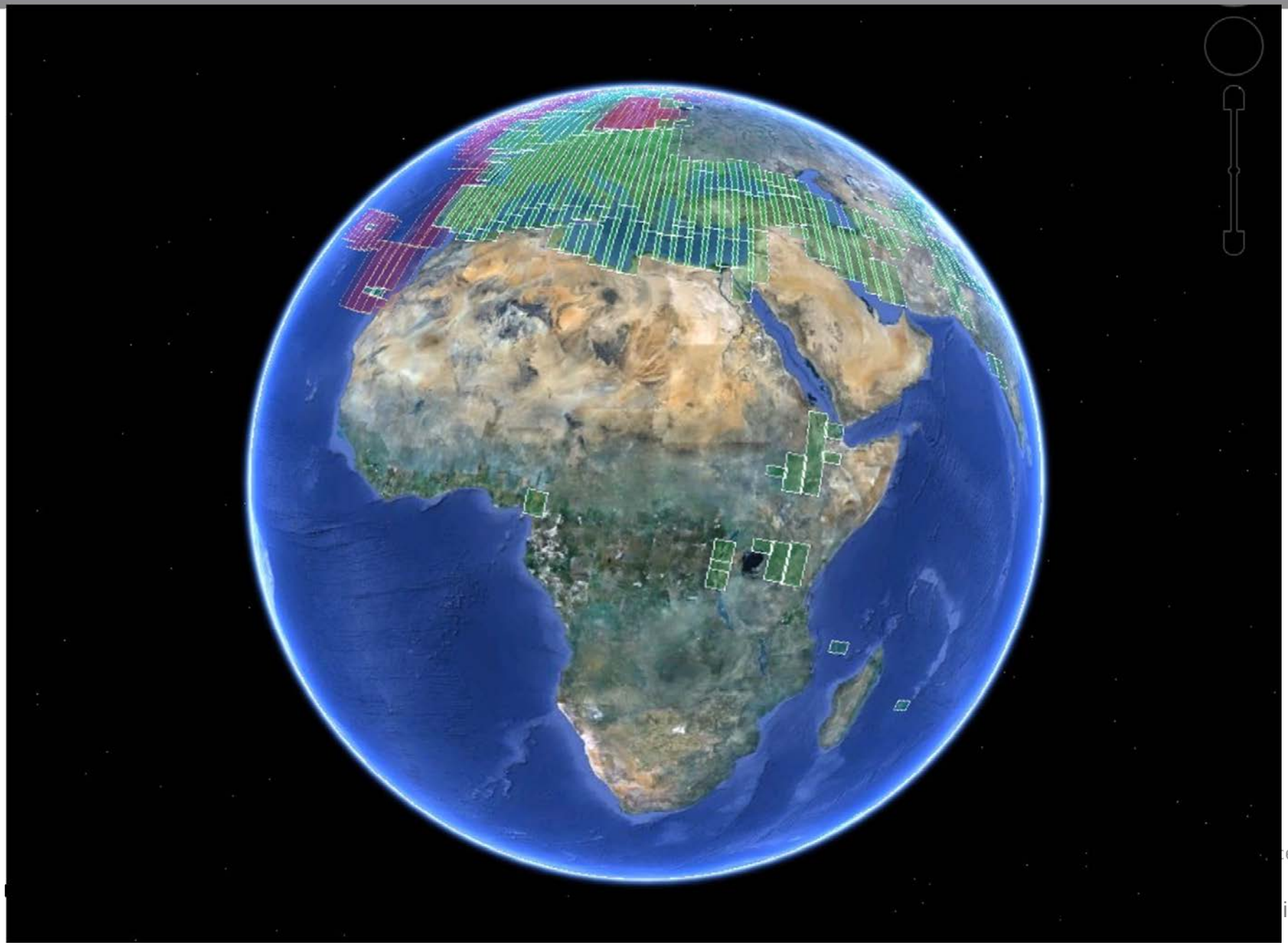
Asia –
EWS and IWS, descending orbits, 12 days



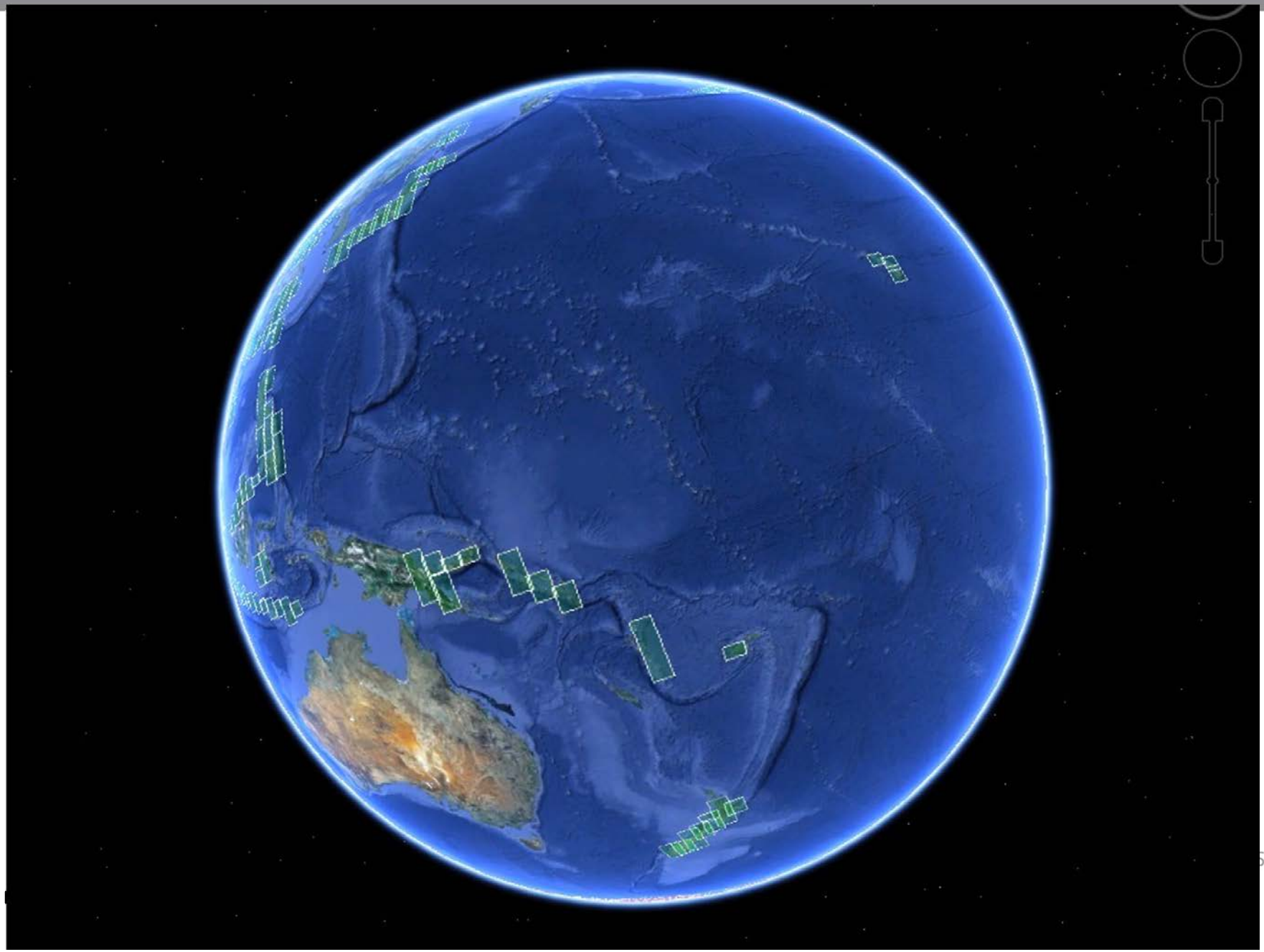
Africa –
EWS and IWS, ascending orbits, 12 days



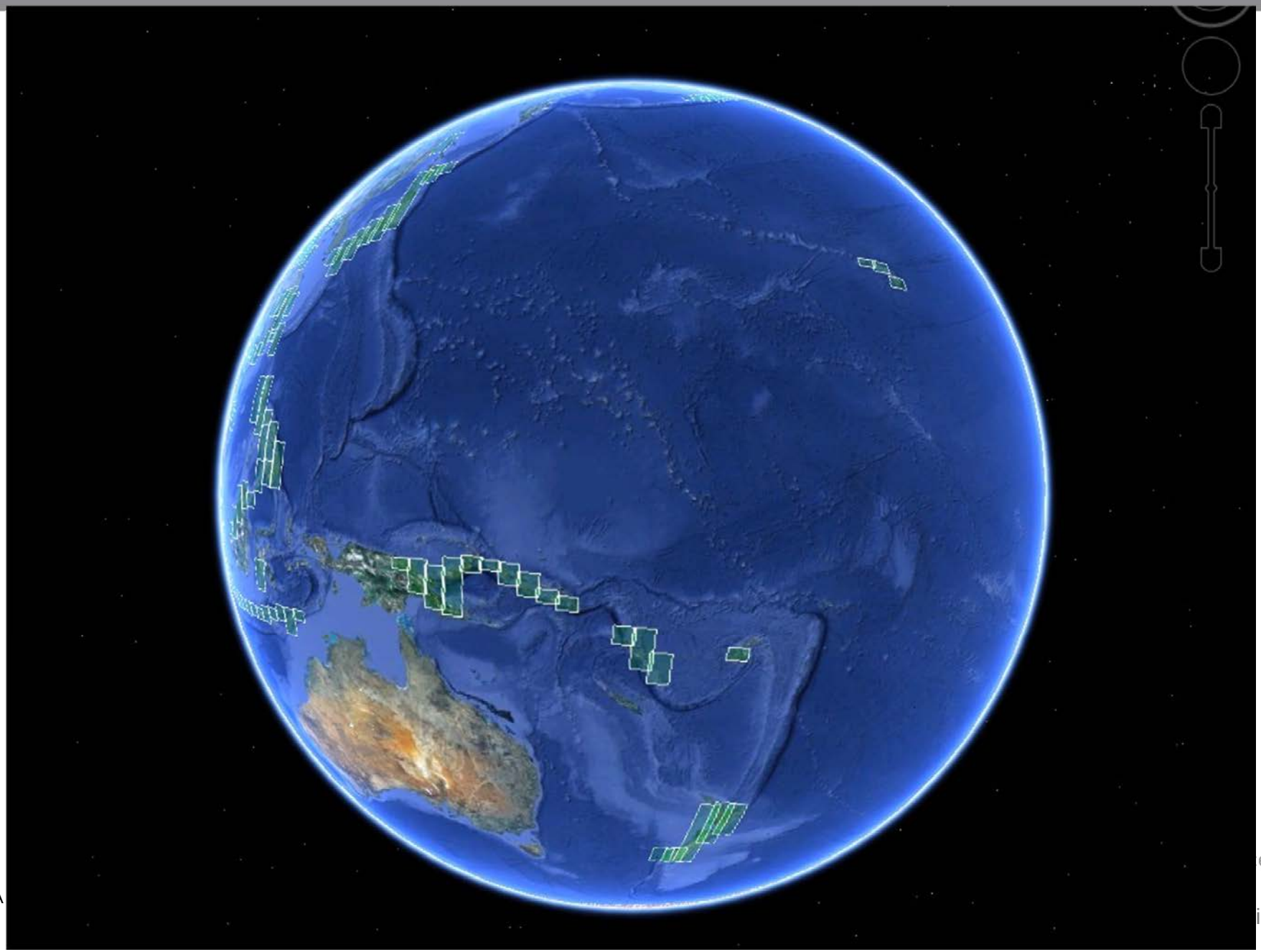
Africa –
EWS and IWS, ascending orbits, 12 days



Pacific –
EWS and IWS, ascending orbits, 12 days



Pacific –
EWS and IWS, descending orbits, 12 days



Remarks

Polarisation:

Over land, it is planned to systematically use the same polarisation scheme for a given area, to guarantee data in the same conditions for routine operational services and allow frequent InSAR

Mode:

The default mode over land is IWS. Specific requirements (some are national requirements) ask for the use of the SM mode over some particular areas, e.g.:

- volcanoes
- zones of special interest in Antarctica like the Peninsula or other Antarctica ice shields
- at global level (e.g. one mapping per year of all land areas in SM).

→ As a general principle, the use of the SM mode in the standard observation plan will be limited to the specific cases where there is no other "competing" use.

Limitations with one satellite

The Sentinel-1 mission relies on a 2-satellite constellation, allowing to solve the vast majority of potential conflicts and to fulfill the necessary revisiting requirements.

High level strategy to fulfil observation requirements for services over LAND during Full Operational Capability

→ Baseline mode of operations: IW, if possible in dual-polarisation (HH+HV). Single polarisation HH however sufficient for most INSAR operational applications

• Systematic (or very frequent) mapping of the whole Europe

• Systematic (or very frequent) mapping of tectonic / subsidence / landslides / volcano areas to support operational services based on INSAR
→Need to provide pairs in both ascending / descending passes

• Regular mapping of areas prone to risks to acquire strategic background data (e.g. for flood)

• Regular mapping of areas to support GMES security services

• Regular mapping or ice sheets (Greenland, Antarctica), polar coastal regions and of relevant areas for glacier and snow monitoring (based on season)

• Regular global/regional coverage of all land areas supporting among others forest mapping (e.g. REDD / GFOI), land cover change, crop monitoring, soil moisture, etc. based on seasonal requirements: frequency of coverage is TBD

Sentinel-1 observation scenario evolution during the operations phase

The Sentinel-1 observation plan will evolve based on:

- The inclusion of the 2nd Sentinel-1 satellite leading to the Full Operational Capacity of the missions with the 2-satellite constellation
- The gradual use of the EDRS system to complement the data downlink capacity
- The evolution of the requirements from the services (GMES, National, etc.)
- The constraints on the space and ground segment resources (e.g. core and collaborative ground station networks)
- The contribution of (and interoperability with) the Radarsat Constellation Mission from CSA

➔ A procedure will be set up to perform a regular update of the S-1 observation plan during routine operations

Concluding remarks

- The Sentinel-1 mission will provide continuity to ERS and ENVISAT C-band SAR with improved performance and revisiting

- Sentinel-1 will be operated with a predefined routine observation plan currently under definition, fulfilling in priority the requirements from the GMES services and from ESA / EU Member States

- This observation plan will be regularly refined to take into account the system capability and constraints, as well as the evolution of user requirements.