Sentinel-1 C Model Phasing options

European Space Agency

Study conducted by

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Scope

1. A,B Models and C,D Models requirements consider the Sentinel-1 constellation is made up of two satellites, S1-C being launched to replace either S1-A or S1-B model
2. Design lifetime of S1 is 7 years, - with fuel designed for 12 years – S1-A was launched in 2014
3. A Long Term Scenarios (LTS) has been sketched, foresing the C Model to be injected and operated together with the A and B models, assuming the lifetime can be extended up to 10 years. With the target to (LTS quote) "*introduce flexibility to satisfy extra user needs (e.g. operational modes, revisit time)*"
4. The Scope of the study was to analyse the various options for the mission management authority to select from
5. The current presentation focusses more on the aspects for SAR users and scientists

Definitions of coverage, revisit and revisit-pass

Please notice that any "new C related" implementation of either phasing, revisit-pass, revisit or coverage of the Sentinel-1 mission Satellites shall be submitted to and validated by the S1 Mission "Mission Management" authority

1. **Coverage** : for a defined operation mode, coverage is defined at a particular latitude as the across-track range of targets that are observed with the requested system performance with a given set of operational parameters
2. **Revisit** time (geometrical) : is the time elapsed between consecutive observations of the same point on Earth by the satellite under any acquisition geometry, i.e. including different incidence angles
3. **Repeat-Pass** time interval is the time elapsed between observations of the same point on Earth by a satellite under the same viewing geometry on the same relative orbit, allowing SAR interferometry
4. **Phasing** is the angular separation between two Models placed in the same Orbital plane (unit: degree)

*Refer to slide **17** for information about the computation of Revisit, Repeat-pass and Phasing values proposed in this presentation*

Sentinel-1 orbital data and phasing options

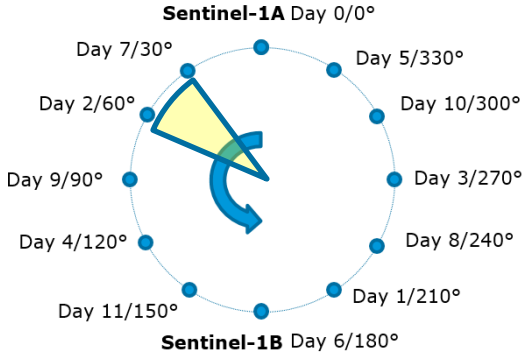
1. Current Sentinel-1 A and B
   a. 175 orbits/cycle, 12 day repeat cycle at the Equator
   b. Altitude: 693 km (equatorial), Inclination: 98.16°, Local Time of the Ascending Node: 18:00
   c. Two satellites separated by 180° in anomaly (180° Phasing)
   d. Max. Revisit time is **5.5** days at equator (comprised between **5.5** and **3.5** days in Europe and Mediterranean area)
   e. Repeat-pass time interval is **6** days, applying to all modes including the IW Mode ⇨ 1A data takes at day 0 can be reacquired 6 days later by 1B under the same geometry

2. Model C phasing options indicating S-1 A and B current phasing (0°–180°)

Having very similar A, B and C orbital plane, and, considering we aim at science acquisition **along the same earth fixed groun track**, there is a limited set of 12 phasing possibilities

the current figure shows those Sentinel-1 12 possibilities, indicating the Day within the repeat cycle (0 to 11) and the associated phasing value (from 0° day 0 to 330° day 5)

(also notice) each of these options is flying approximately 8 minutes and 30 seconds apart from the preceding one (latitude wise)



Phasing and Repeat-pass time relationship

1. Phasing and Repeat-pass time
   a. As seen in previous slide, allocating a phasing between models also allocates a day of the repeat cycle to each model (convention : day 0 is the day of A model)
   b. A to B Repeat-pass time is the maximum interval between those two days within the 12 days repeat cycle, i.e. 180° phasing of A and B defines days 0 and 6, thus a 6 days interval between A and B data takes acquired under identical geometry
   ➔ Notice that inserting the C model while keeping A and B phasing as it is will not improve – i.e. reduce - the maximum geometric Repeat-pass time interval,
   In that case C will be positioned on either side of 6 (1 to 5) or (7 to 10) keeping 6 days as the maximum interval
2. Presenting Phasing and Repeat-pass for the (A,B,C) Models : Triplets data
   a. (A,B,C) Phasing triplet displays the phasing option with a set of 3 phasing angles, e.g. (0°, **90°**, 180°) : **C** Model is displayed in **bold**,
   b. Geometric Repeat-pass time is deduced from the 3 models repeat cycle days triplet, e.g. (0-6-**9**) : **C** Model is presented in **bold**, the Repeat-pass time is the maximum interval between those 3 numbers (within the 12 days repeat cycle interval), 6 days in this above example ("6 day" interval between 0 and 6)

Sentinel-1 (A,B,C) assumptions and drivers

In the current presentation

1. Constellation "phasing" options are proposed under the following assumptions
   a. Sentinel-1 Orbital plane is unchanged : Altitude, Inclination and Local Time of the Descending Node being kept as they are
   b. All Sentinel-1 Model acquisition aim at science acquisition along the same earth fixed ground track, thus insuring acquisitions conditions (viewing geometry) are identical for all models

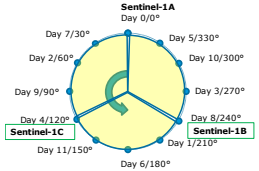
   ➔ For that purpose, each Sentinel-1 Model is operated using one of the 12 phasing options which associates [Day of the Repeat Cycle & Phasing] *Refer to slide #4*

2. Driver to the C model insertion into the existing (A,B)
   a. Improve Revisit time and Repeat pass time interval, not excluding B relocation,
   b. Account for time span between two downlinks over a Ground Station, and if possible, avoid requesting more than one antenna for Data Downlinks

S1-C added; LTS approach

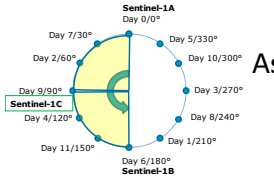
Adding *"flexibility to satisfy extra user needs"* has been evaluated through the phasing set-up of the Sentinel-1 constellation, two cases are studied in detail

1. Adding C, relocating B and keeping A as it is, having an equal (**120°**) phasing spacing
   a. Repeat-pass time : improved from 6 to 4 days
   b. Max. Revisit time : improved from 5.5 to 3.5 days



Symmetrical phasing

2. Adding C at (**90°**) phasing while keeping A and B phases as they are (0°,180°) does not reduce the maximum Repeat-pass time interval nor the Maximum Revisit time but improves the acquisition pattern of the Revisit time



Asymmetrical phasing

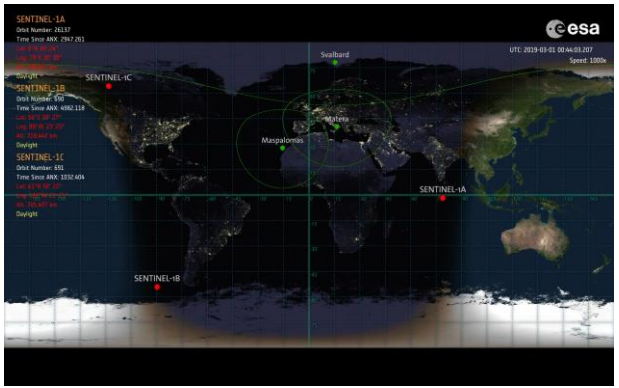
TBC Mission Management :

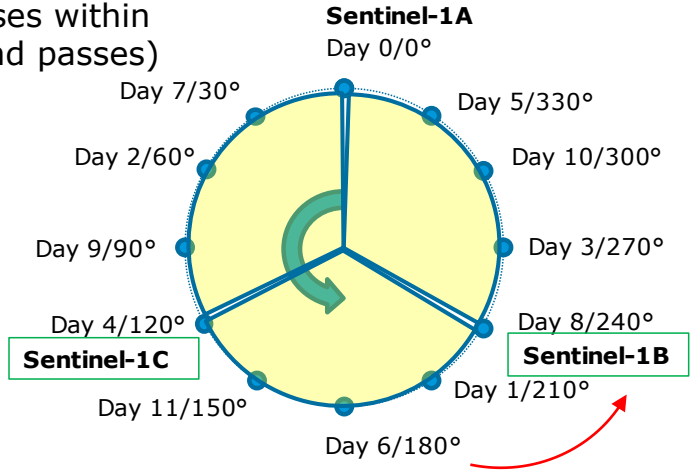
   a. can there be a relocation (B) in favor of a better (A,B,C) Repeat-pass / Revisit ?
   b. is that compatible with existing product archives (data access issue) ?

Sentinel-1 (A,B,C), C insertion, B relocation, A as is

1. 1C insertion, 1B relocation, 1A as is : improved Revisit and Repeat-pass
   a. Three satellites phasing (0°, **120°**, 240°)
   b. Revisit time sequence: (0-**4**-8) within the 12 days repeat cycle
   c. Max. Revisit time is **3.5** days at equator (comprised between **3.5** and **1.5** days for Europe and Mediterranean area)
   d. Repeat-pass time interval is **4** days

Providing an "equi-distribution" of ground downlinks passes within the approx. 100 minutes Orbit duration (see below ground passes)



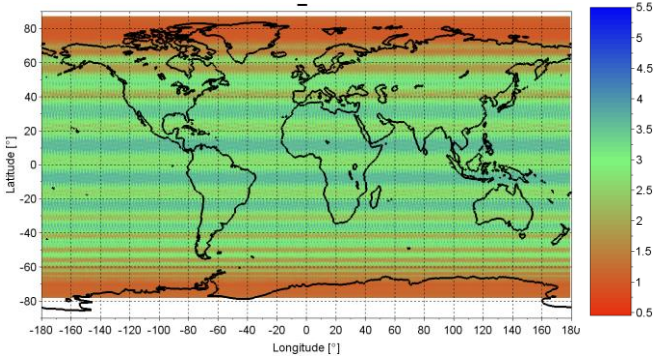


Sentinel-1 (A,B,C), C insertion, B relocation, A as is

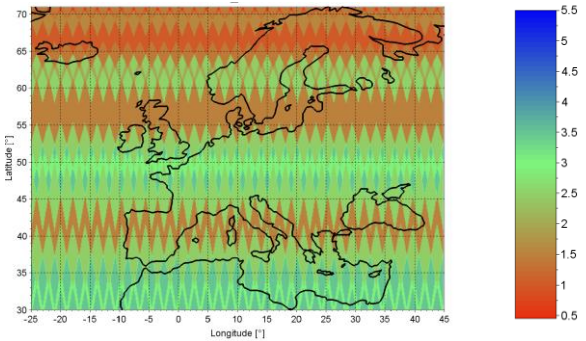
2. Maximum Revisit time at Equator, and Repeat-pass time interval
   a. Max Revisit time = **3.5** days
   b. Repeat-pass time = **4** days

3. Focus over Europe and Mediterranean area
   a. This second figure provides a view of the geometrical maximum Revisit time over Europe
   b. The three Models (0°, **120°**, 240°) Phasing option provides a Max. Revisit time between 1.5 ( ) and 3.5 ( ) days

Sentinel-1 (0°, **120°**, 240°) geometrical Max. **Revisit time**



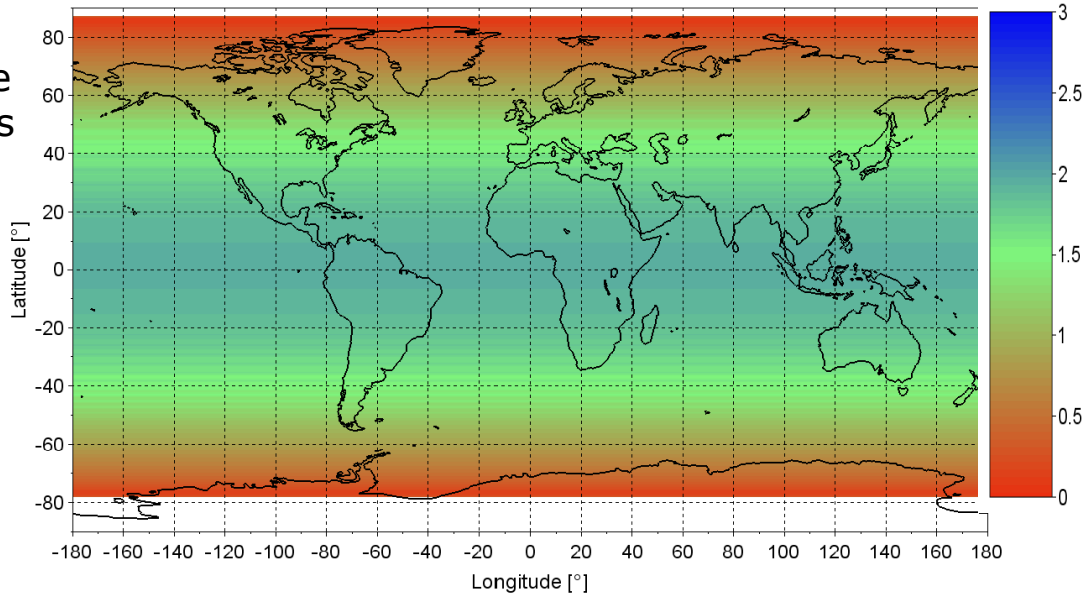
Europe view



Sentinel-1 (A,B,C), C insertion, B relocation, A as is

4. Average Revisit time map
   a. The averaging of revisit time over a repeat cycle improves the geometrical maximum revisit time values
   b. The three Models (0°, **120°**, 240°) Phasing option provides an average Revisit time between 0.5 ( ) and 1.75 ( ) days

Sentinel-1 (0°, **120°**, 240°)
average **Revisit time**

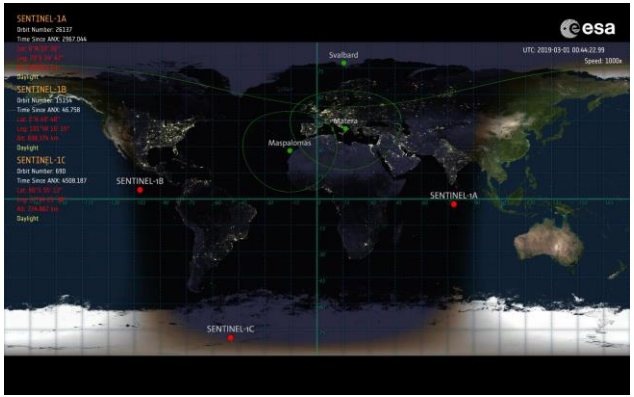


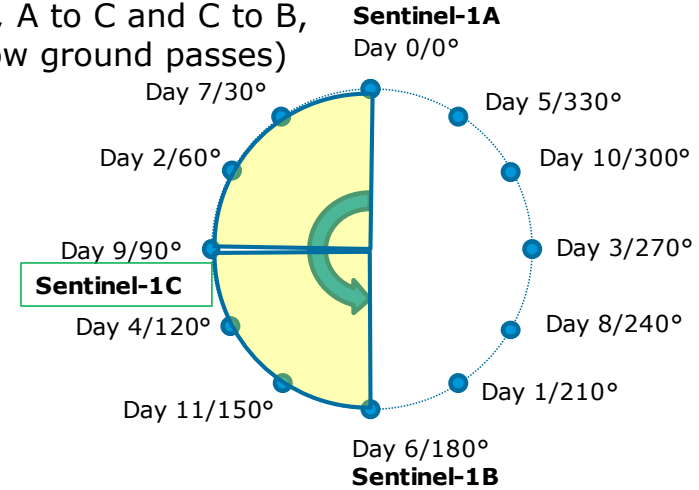
Notice the average revisit time computation depends on the number of models in the constellation, currently 3 (models phasing does not impact the average revisit time)

Sentinel-1 (A,B,C), C insertion, A&B as are

1. 1C insertion, 1A and 1B as are : improved revisit acquisition pattern
   a. Three satellites phasing (0°, **90°,** 180°)
   b. Revisit time: sequence: (0-6-**9**) within the 12 days repeat cycle
   c. Max. Revisit time is **5.5** days at equator (comprised between **5.5** and **1.5** days for Europe and Mediterranean area)
   d. Repeat-pass time interval is **6** days

Ground downlinks passes are approx. 25 minutes apart, A to C and C to B, within the approx. 100 minutes Orbit duration (see below ground passes)



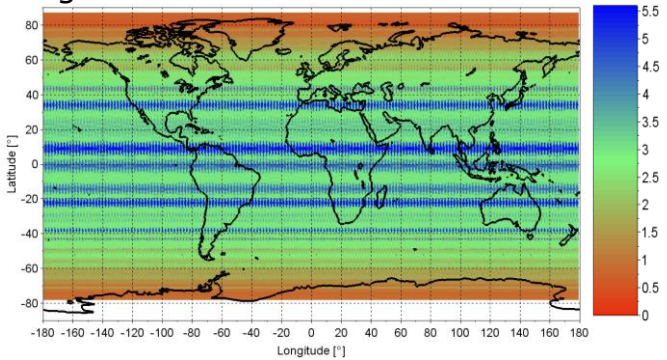


Sentinel-1 (A,B,C), C insertion, A&B as are

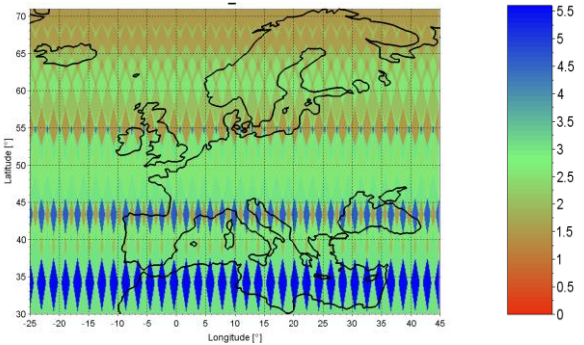
2. Maximum Revisit time at Equator, Repeat-pass time interval
   a. Max Revisit time = **5.5** days
   b. Repeat-pass time = **6** days

3. Focus over Europe and Mediterranean area
   a. This second figure provides a view of the geometrical Max. Revisit time over Europe (IW Mode)
   b. The three Models (0°, **90°**, 180°) Phasing option provides a Max. Revisit time between 1.5 ( ) and 5.5 ( ) days

Sentinel-1 (0°, **90°**, 180°) geometrical Max. **Revisit time**



Europe view



Sentinel-1 (A,B,C), C insertion, A&B as are

4. Average Revisit time map
   a. The averaging of revisit time over a repeat cycle improves the geometrical maximum revisit time values
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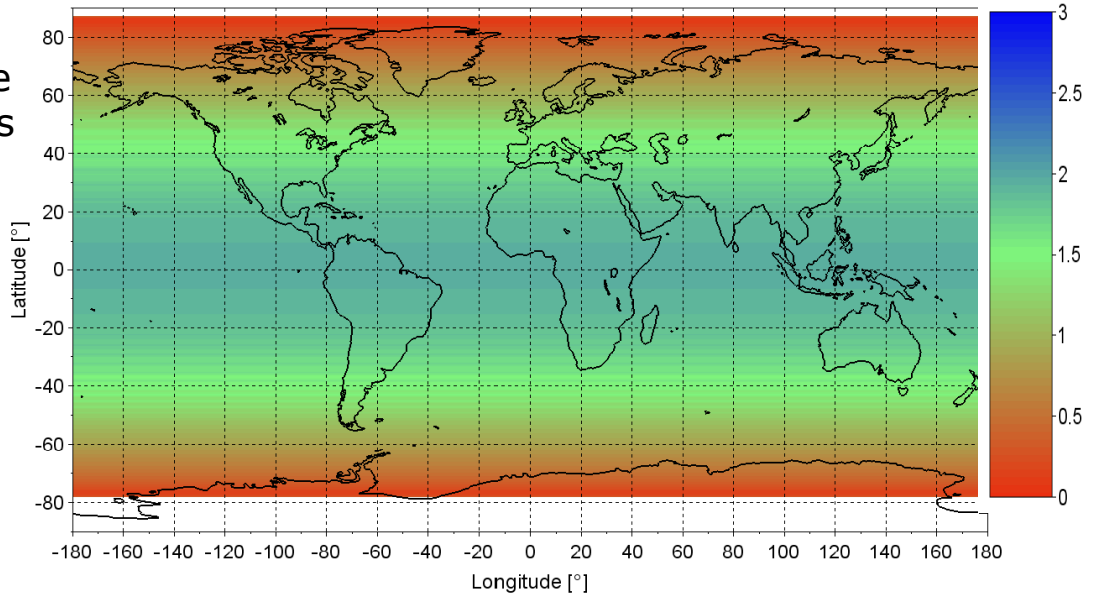
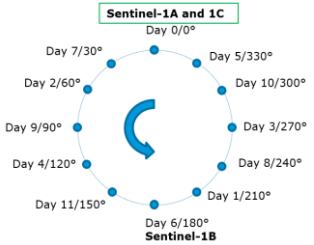
Sentinel-1 (0°, **90°**, 180°)
average **Revisit time**



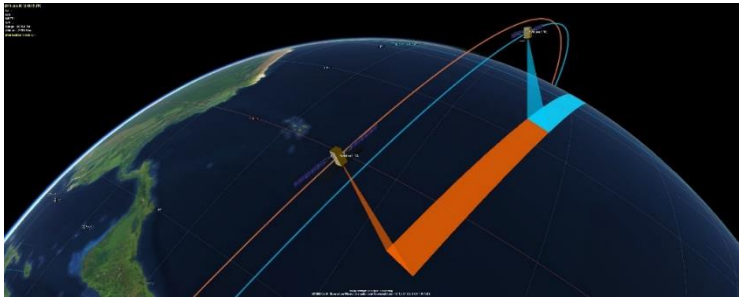
Notice the average revisit time computation depends on the number of models in the constellation, currently 3 (models phasing does not impact the average revisit time)

Sentinel-1 C : (C⇨A/B), C insertion to replace A

1. For instance, during the commissioning phase, Sentinel-1 C Model could be placed 300 seconds ahead of A Model, Day 0 of the 12 days repeat cycle, then might be "maneuvered" so to replace A for Routine (quasi Tandem phasing)



2. This commissioning configuration allows C and A models acquisitions to be performed within the same "tube", under the same viewing geometry while having identical acquisition modes activated



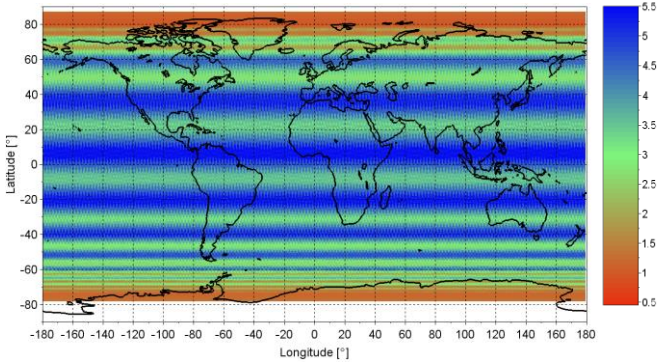
3. Rationale of the 5 minutes "distance"
   a. Both models can be operated without any data takes interference
   b. Both models operate within the Spacecraft Mean Local Solar Time specifications (17:55 - 18:05)
   c. Both models operate having the same ground track

Sentinel-1 C : (C⇨A/B) Revisit & Repeat-pass

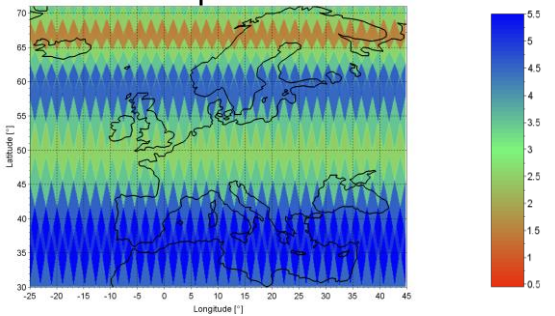
2. Maximum Revisit time at Equator, Repeat-pass time interval are unchanged for B and C (compared to A and B current)
   a. Max. Revisit time = **5.5** days
   b. Repeat-pass time = **6** days

3. Focus over Europe and Mediterranean area
   a. This second figure provides a view of the geometrical Max. Revisit time over Europe
   b. The two Models 180° Phasing option provides a Max. Revisit time between 3.5 ( ) and 5.5 ( ) days

Sentinel-1 C & B models geometrical Max. **Revisit time**



Europe view



Synthesis of geometrical Max. Revisit time patterns

2 models constellation

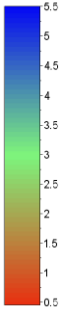
Sentinel-1 (0, 180°)
geometrical Max. **Revisit time**

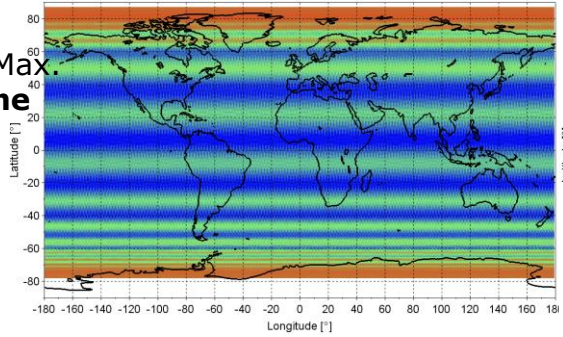
3 models constellation

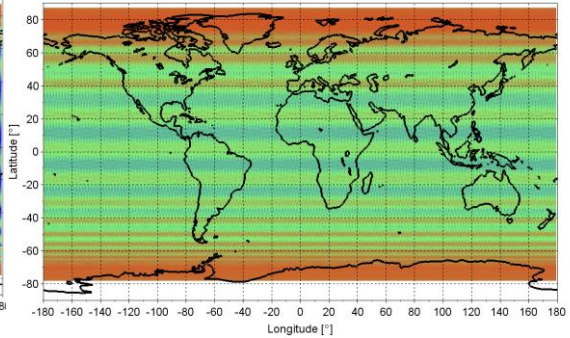
Sentinel-1 (0°, **120°**, 240°)
geometrical Max. **Revisit time**

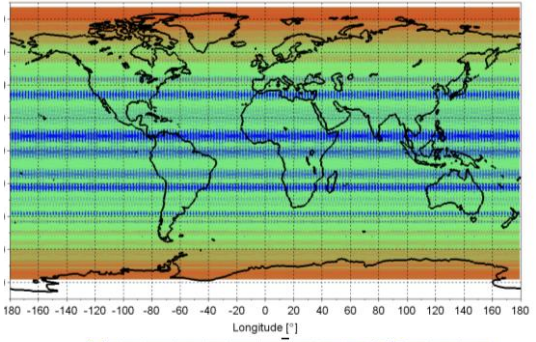
Sentinel-1 (0°, **90°**, 180°)
geometrical Max. **Revisit time**

Word
Geometrical Max.
Revisit time

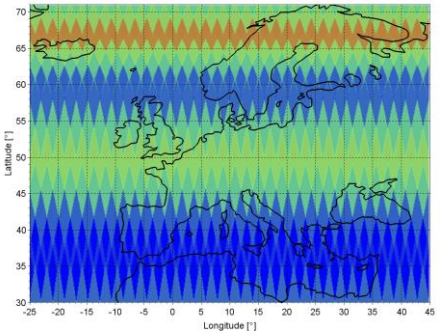


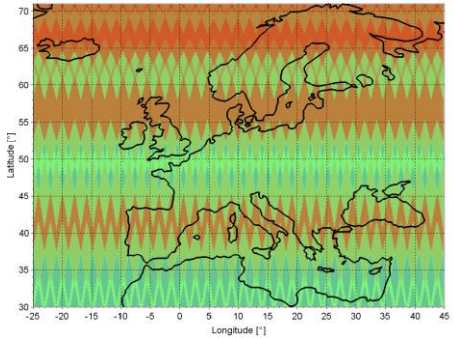


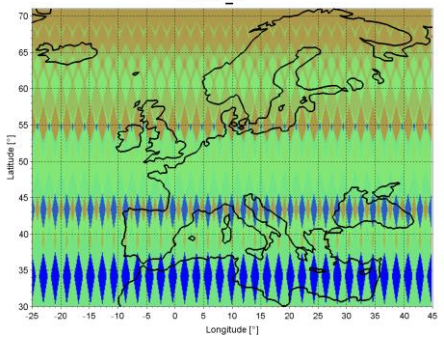




Europe
geometrical Max.
Revisit time







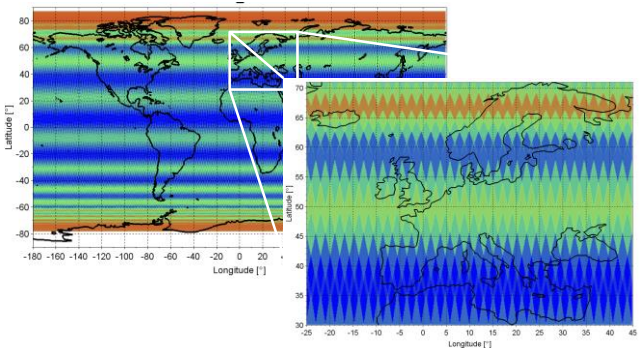
Revisit, Repeat-pass and Phasing computations

In the current presentation

1. Values of the "geometrical" Max. Revisit times are computed for IW Data takes under any acquisition geometry, i.e. under any incidence angle

   The simulation uses areas of 0.5 square degrees over a 24 days continuous acquisition (2 repeat cycles)

   This enables the display of a regular pattern of the Revisit time over the world and Europe

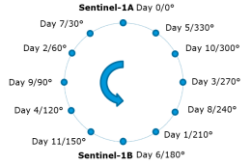


2. Though this computation shows regular pattern, one should keep in mind the progression within a 12 days repeat cycle is not regular in case of an "asymmetrical" constellation phasing, that is shown in the 3 following slides, providing IW Data takes acquisition progression over 1, 2 and 3 days

Symmetrical phasing acquisitions

Asymmetrical phasing acquisitions

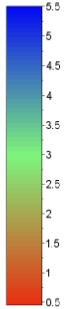
3. The Repeat-pass interval is valid for any latitude, its value is derived from the phasing options which associate a phase and a day in the Repeat cycle (slide 4) *Phase / Repeat-pass rule was provided Slide 5*

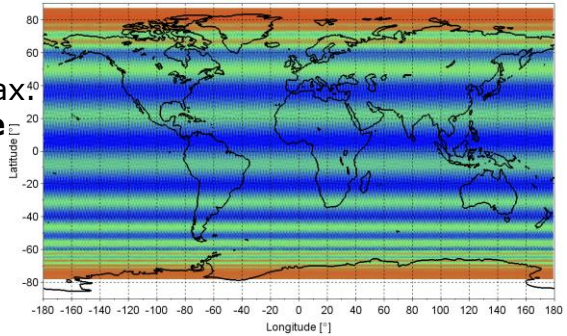


Sentinel-1 C : (C⇨A/B) Day 1, 2, 3 acquisitions

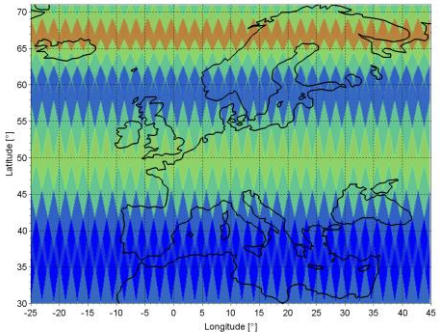
Sentinel-1 C & B models
geometrical Max. **Revisit time**

Word
Geometrical Max.
Revisit time





Europe
geometrical Max.
Revisit time

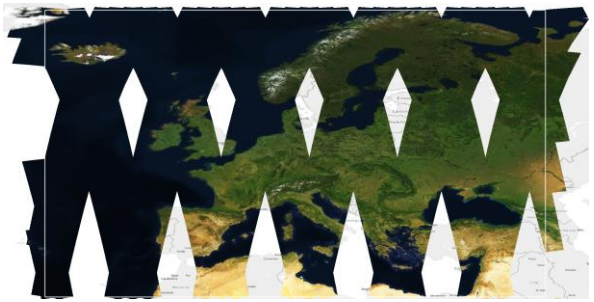


Symmetrical phasing : 0°, 180°
Regular acquisition pattern

Day 1 acquisition

Day 2 acquisitions

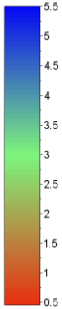
Day 3 acquisitions

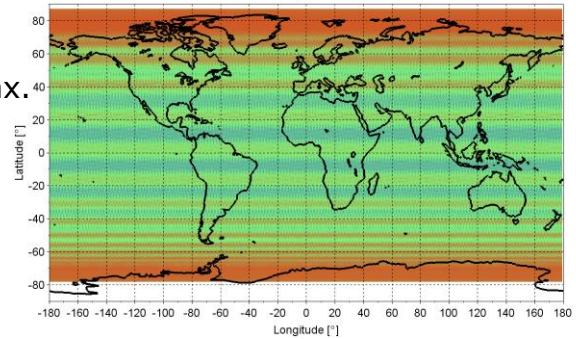


Sentinel-1 C : (A,B,C) (0°,120°,240°) – Day 1, 2, 3 Acq.

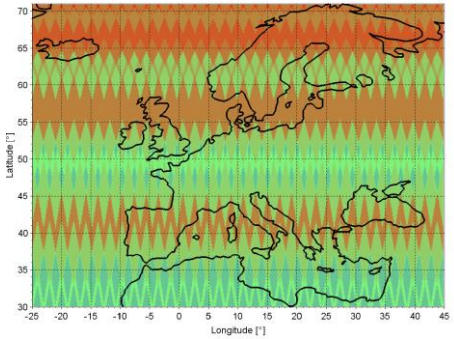
Sentinel-1 (0°, **120°**, 240°)
geometrical Max. **Revisit time**

Word
Geometrical Max.
Revisit time





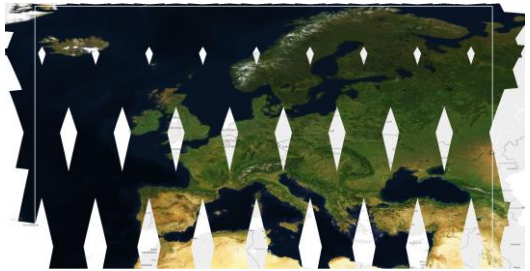
Europe
geometrical Max.
Revisit time



Symmetrical phasing (0°, **120°**, 240°)
Regular acquisition pattern

Day 1 acquisitions

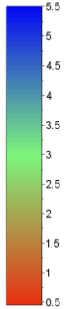
Day 2 acquisitions



Day 3 acquisitions

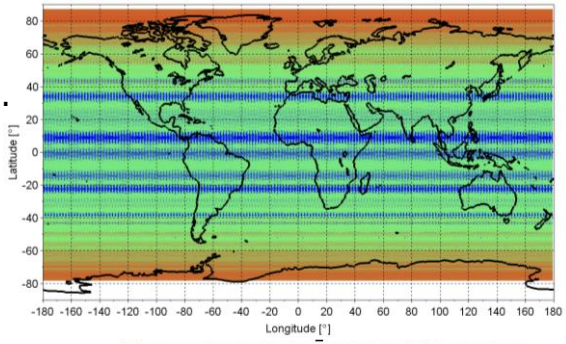
Sentinel-1 C : (A,B,C) (0°,90°,180°) – Day 1, 2, 3 Acq.

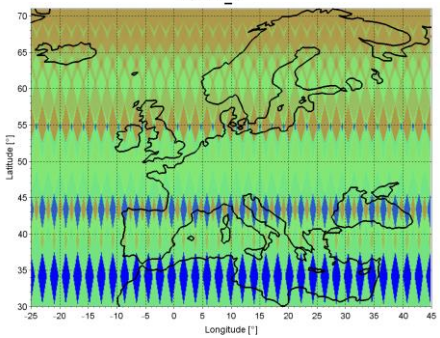
Word
Geometrical Max.
Revisit time



Europe
geometrical Max.
Revisit time

Sentinel-1 (0°, **90°**, 180°)
geometrical Max. **Revisit time**





Asymmetrical phasing (0°, **90°**, 180°)
Irregular acquisition pattern

Day 1 acquisitions

Days 2 acquisitions

Day 3 acquisitions

ESA Mission S-1 Observation scenario, average map

1. The Sentinel-1 web site ESA Mission Web site(*) defines an observation scenario through the provision of two maps which describe the overall Sentinel-1 constellation in terms of SAR mode, polarisation, observation geometry, revisit and coverage frequency, starting as of February 2018

   Next slide provides the relationship between this scenario Coverage and Revisit frequency with this presentation Revisit time and Repeat-pass interval

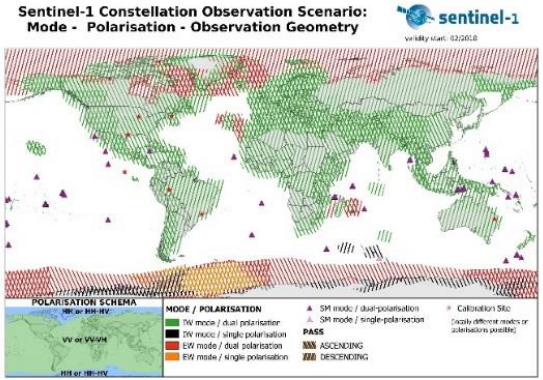
2. Until now, slides from the current presentation do not display the maximum Average Revisit time map which is computed using the Geometrical Revisit time pattern (map),

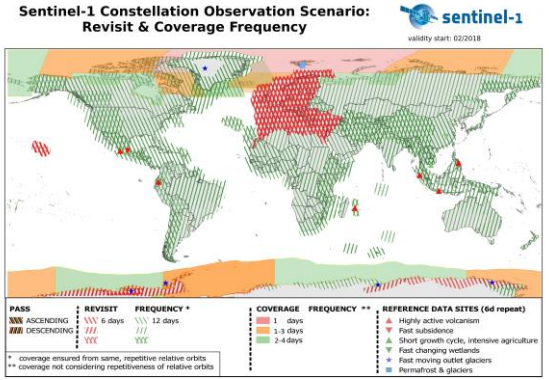
   This is shown in slide "after next", it is believed this map may cause a bias in the acquisitions interpretation through the smoothing of the "color scheme", thus it is not the preferred representation

(*) https://sentinel.esa.int/web/sentinel/missions/sentinel-1/observation-scenario

Observation scenario Revisit & Coverage frequency

The presentation does not intend to compute Coverage and Revisit frequency as defined by the Sentinel-1 web site (February 2018 version – see below figures), nevertheless providing inputs to theses through values of Revisit time and Repeat-pass time interval





(*) Refer to definitions provided in this figure

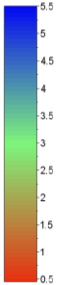
Revisit time and Repeat-pass time interval values provide minimum values of Coverage and Revisit frequency

Revisit time in this presentation defines the minimum possible value of Coverage Frequency (*) for areas sorted per latitude

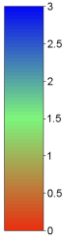
Repeat-pass time interval in this presentation defines the minimum possible value of Revisit Frequency (*)

Synthesis –geometrical & average Revisit time maps

Geometrical Max. **Revisit time**



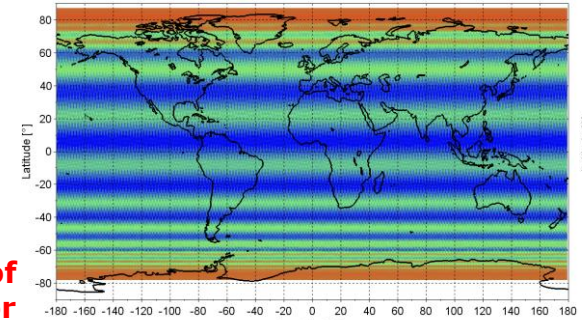
Beware of time color scales



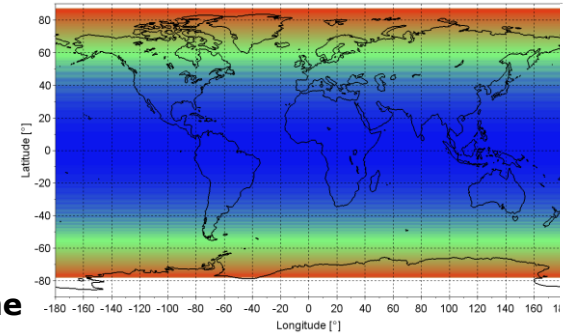
average **Revisit time**

2 models constellation

Sentinel-1 (0, 180°)
geometrical Max. **Revisit time**

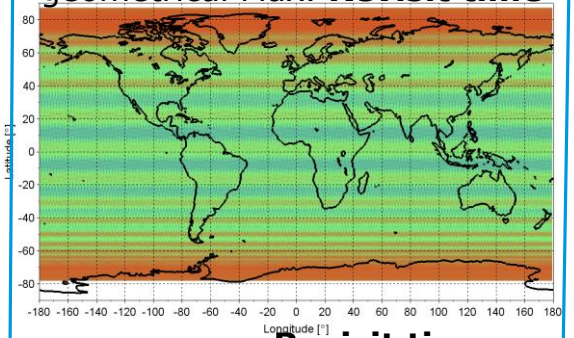


average **Revisit time**

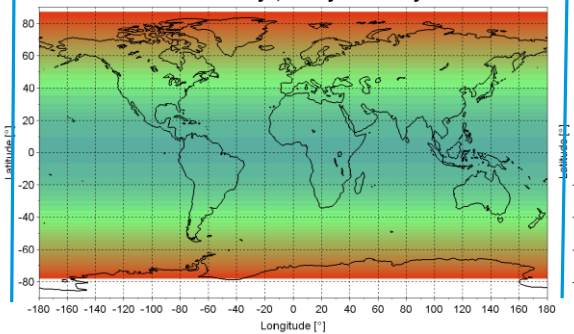


3 models constellation

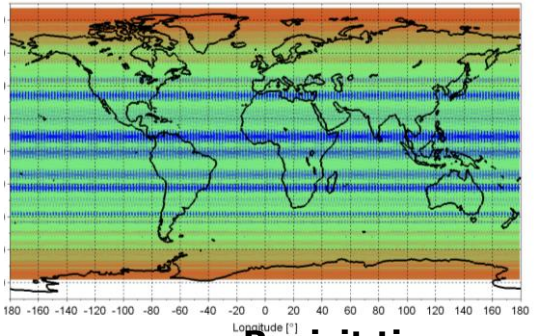
Sentinel-1 (0°, **120°**, 240°)
geometrical Max. **Revisit time**



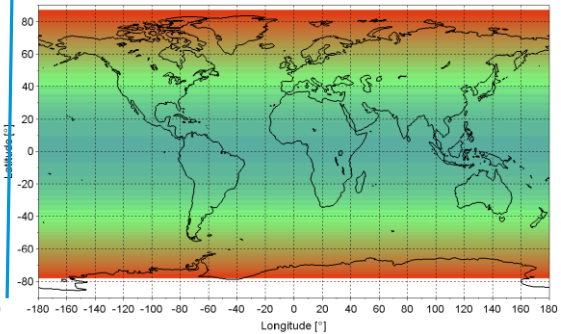
average **Revisit time**



Sentinel-1 (0°, **90°**, 180°)
geometrical Max. **Revisit time**



average **Revisit time**



Recap possible insertion options

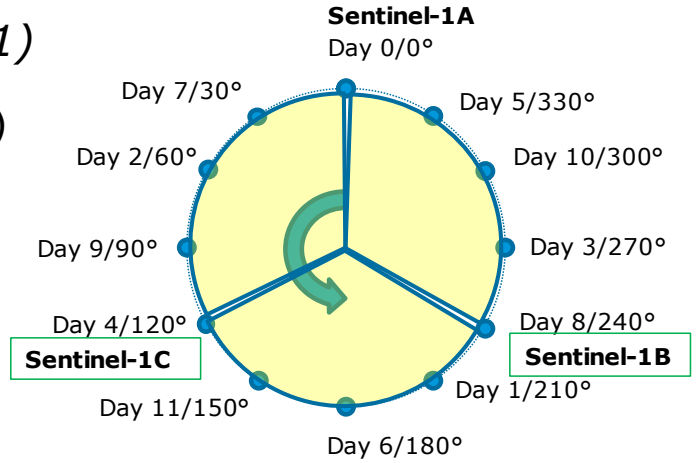
- 180 deg phasing retained

  3rd unit at:

  - Day 0, Phasing: 0 deg (= Day 6)
  - *Day 1, Phasing: 210 deg (= Day 5, 7, 11)*
  - *Day 2, Phasing: 60 deg (= Day 4, 8, 10)*
  - Day 3, Phasing: 270 deg (= Day 9)

- 180 deg phasing **not** retained

  - (A,B,C) (0°,120°,240°) = Day 0, 4, 8



180 deg phasing retained
3rd unit @ Day 0

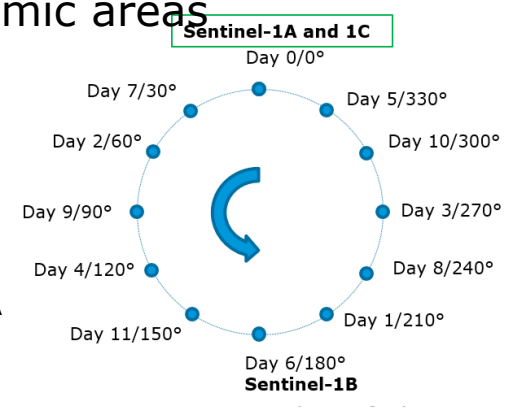
S1C (MLST @17:56) Leads S1A (MLST @ 18:01) by 5 minutes

Pro:

- S1C takes over role S1A; In case of longer anomaly S1C; S1A can take over
- More areas can be offered the 6 days repeat pass (or 12 days asc & desc)
- 5 minute repeat pass **interferometry** for high dynamic areas (remember ERS – ENVISAT Tandem @ 30')

Con:

- Groundstrations Matera & Mas Palomas for S1C (Svallbard has enough antenna's) ➔ less use of S1A



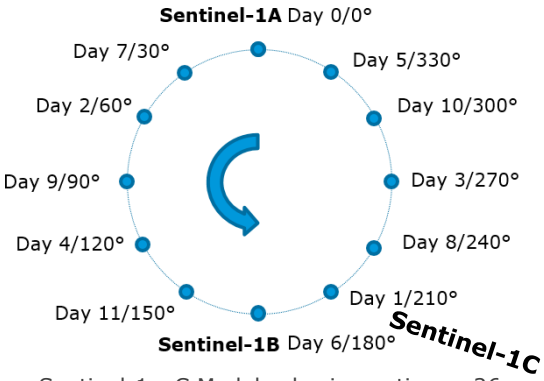
180 deg phasing retained
3rd unit @ Day 1

Pro:

- More observations , (compared to current; but not more regular)
- 1 Day Repeat pass **interferometry** (remember ERS-1 ERS-2 Tandem phase)

Con:

- Groundstrations Matera & Mas Palomas for S1C (Svallbard has enough antenna's) ➔ less use of S1A



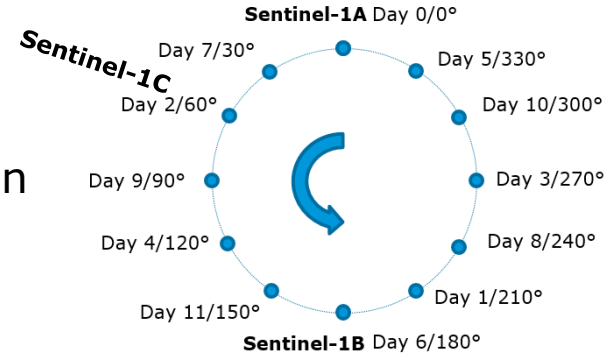
180 deg phasing retained
3rd unit @ Day 2

Pro:

- More observations , (compared to current; but not more regular)
- Groundstations Matera and Mas Palomas can be used for all Models

Con:

Please note this is the commissioning phase situation for the 0 – 120 – 240 deg option!
(S1A after commissioning to be moved to Day 10)



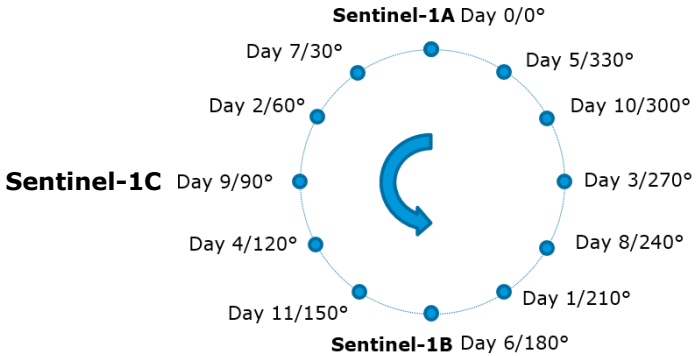
180 deg phasing retained
3rd unit @ Day 3

Analysed in detail.

Pro:

- More observations , (compared to current; but not more regular)
- Groundstations Matera and Mas Palomas can be used for all Models

Con:



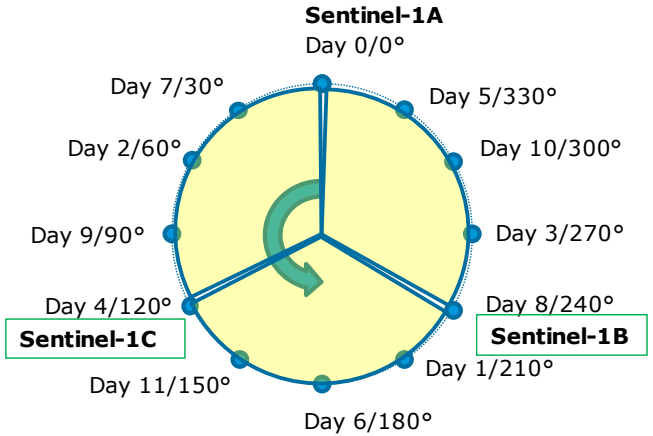
180 deg phasing not retained units at Day 0, Day 4 and Day 8

Analysed in detail

Pro:

- More observations , (compared to current; and more regular)
- Groundstations Matera and Mas Palomas can be used for all Models
- 4 days revisit can be offered (for limited areas)

Con:



Thank you

Here after backup slides

Sentinel-1 C Model phasing options context

1. The current phasing options analysis accounts for two approaches
   a. (C⇨A/B) : A,B Models and C,D Models requirements consider the Sentinel-1 constellation is made up of two satellites, C being launched to replace either A or B model
      Notice that formally next to be replaced is the A Model if considering the current lifetime of a model is 7 years and the A Model was launched in 2014
   b. (A,B,C) : the Long term Scenario (LTS) foresees C Model could be inserted and operated jointly with the A and B models having the assumption A and B Models lifetime can be extended up to 10 years
      The target of the 3 satellites constellation being to (LTS quote) "*introduce flexibility to satisfy extra user needs (e.g. operational modes, revisit time)*"
2. For each of the phasing possibilities, responding to above (1-a. and b.)
   a. This presentation provides the associated value of the Revisit and of the Repeat-pass time interval (*refer to the following slide for definition of Coverage, Revisit, Repeat-Pass and Phasing*)
   b. In case of the (C⇨A/B) option, it reminds operations to be undertaken in order to achieve A or B deorbiting

S1-C replacing S1-A; original baseline approach

1. S-1 C Model would be placed into the Mission Orbit plane at the start of the Commissioning phase, the phasing would
   a. enable the pursuing of nominal commissioning activities without interfering with the current A and B Models nominal operations
   b. target at best the replacement of either A or B model (A is default option)
   ➔ Two phasing options are foreseen
      - Quasi tandem phasing, C is injected 5 minutes ahead of A *(detail provided slide 16)*
      - any of the 8 available phasing days, days 0 and 6 excluded *(as presented slide 4)*
2. At end of commissioning, default option, C model replaces A model (C⇨A) and A Model is de-orbited, then depending on C commissioning phasing option
3. Reminder about the de-orbiting process (Mission Operation Concept)
   a. Replacing either A or B Model implies it shall be placed into a dedicated orbit by means of a set of orbital change manoeuvres
   b. This will occur at the end of the satellite operational life by providing the Spacecraft with the necessary Delta-V to allow its placement into the adequate orbit. This orbit is defined taking into account ESA's regulations on Space Debris.