

MISSION ANALYSIS ASPECTS FOR EARTH OBSERVATIONS MISSIONS

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From where all starts from...
Newton Laws and the restricted
two body equation of the motion

$$\vec{F} = m\vec{a} \quad \text{Newton's Second Law}$$

$$F_g = \frac{Gm_1m_2}{R^2} \quad \text{Newton's Law of Universal Gravitation}$$

$$\vec{F}_g = \frac{-\mu_E m}{R^2} \frac{\vec{R}}{R} \quad \text{Newton's Law of Universal Gravitation in Vector Form with Earth as Central Body}$$

($\mu_E = GM_{\text{earth}} = 3.986 \times 10^{14} \text{ m}^3/\text{s}^2$)

$$\frac{-\mu_E m}{R^2} \frac{\vec{R}}{R} = m\vec{a} = m\ddot{\vec{R}}$$

Combining Newton's Two Laws, assuming:

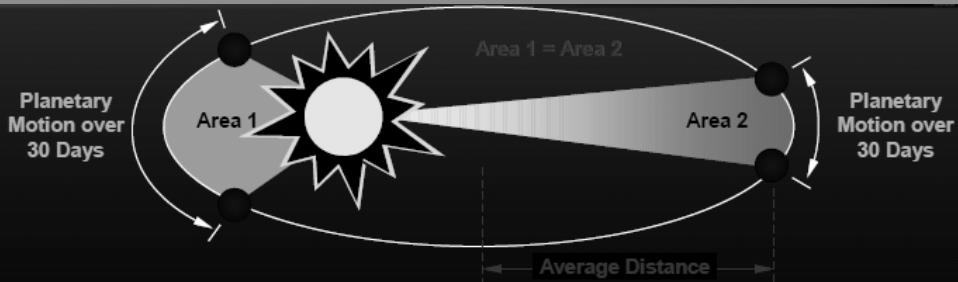
- (1) No perturbations (drag, earth's oblateness, other planets, etc.)
- (2) Bodies are spherically symmetric
- (3) $m_1 \gg m_2$

$$\ddot{\vec{R}} + \frac{\mu}{R^2} \frac{\vec{R}}{R} = 0$$

We Get the Restricted Two-Body Equation of Motion Which is a Second-Order, Non-Linear, Vector Differential Equation –

– Solution is a conical section: Circle, ellipse, parabola, hyperbola,

Keplero laws



- Kepler's First Law: The Orbits of Planets (or Satellites) are Ellipses with the Sun at a Focus
- Kepler's Second Law: The Orbits of the Planets Sweep Out Equal Areas in Equal Time
- Kepler's Third Law: The Square of the Orbit Period (The Time it Takes to Go Around Once) is Proportional to the Cube of the Average Distance to the Sun

Where:

$$P = 2\pi \sqrt{\frac{a^3}{\mu}}$$

P = Period (sec)

a = Semi-Major Axis (km)

μ = Gravitational Parameter (km^3/s^2) = GM_{earth}

G = Universal Gravitational Constant (Nm^2/kg^2)

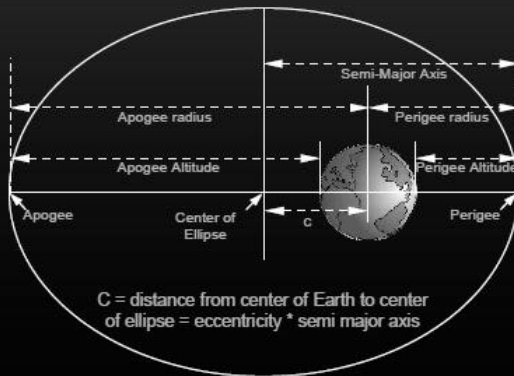
M_{earth} = Mass of the Earth (kg)

Summary of Orbital Elements



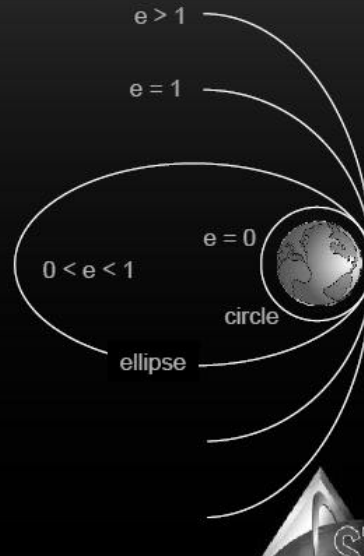
Element	Name	Description	Range of Values	Undefined
a	Semimajor Axis	Size	Depends on the Conic Section	Never
e	Eccentricity	Shape	e = 0: Circle 0 < e < 1: ellipse	Never
i	Inclination	Tilt, angle from unit vector to specific angular momentum vector	0° ≤ i ≤ 180°	Never
Ω	Right ascension of the ascending node	Swivel, angle from vernal equinox to ascending node	0° ≤ Ω ≤ 360°	When i = 0° or 180° (equatorial orbit)
ω	Argument of perigee	Angle from ascending node to perigee	0° ≤ ω ≤ 360°	When i = 0° or 180° (equatorial orbit) or e = 0° (circular orbit)
v	True anomaly	Angle from perigee to the spacecraft's position	0° ≤ v ≤ 360°	When e = 0 (circular orbit)

Orbit definition on its plane: Two parameters



c = distance from center of Earth to center of ellipse = eccentricity * semi major axis

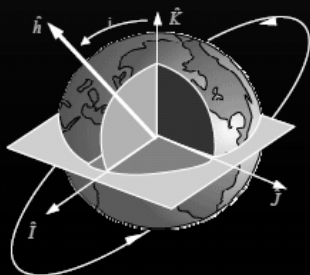
- Size Determination: Semi-Major Axis
- Shape Determination: Eccentricity



Inclination: the orientation of an orbit



- Tilt of Orbital Plane with Respect to Fundamental Plane (of Geocentric-Equatorial Coordinate System)
- Angle Between Specific Angular Momentum Vector ($\vec{h} = \vec{R} \times \vec{V}$) and the Vector Perpendicular to the Fundamental Plane Pointing Through the North Pole (K-axis)
- Ranges from 0° to 180°

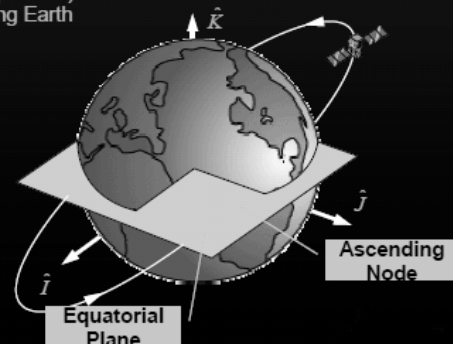
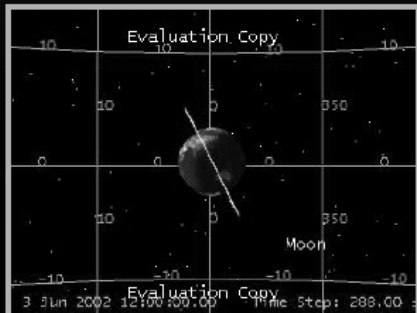


Inclination	Orbital Type	Diagram
0° or 180°	Equatorial	
90°	Polar	
$0^\circ \leq i < 90^\circ$	Direct or Prograde (Moves in the Direction of Earth's Rotation)	
$90^\circ < i \leq 180^\circ$	Indirect or Retrograde (Moves Against the Direction of Earth's Rotation)	

Right Ascension of the Ascending Node (RAAN): The "Twist" of an Orbit



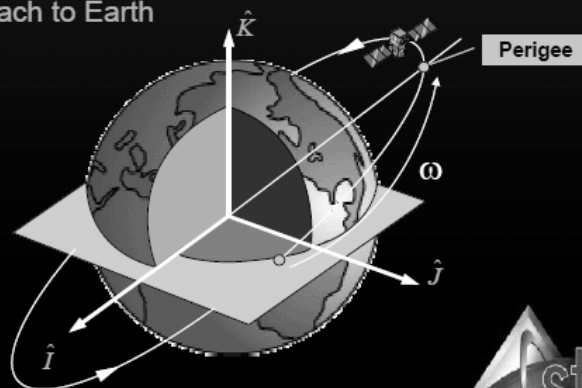
- Angle, Along the Equator, Between Principle Direction (i.e., First Point of Aries) and the Point Where the Orbital Plane Crosses the Equator, from South to North (The Ascending Node), Measured Eastward
- Not the Same As the Longitude of the Ascending Node
 - RAAN Relative to Inertial Frame (Geocentric-Equatorial)
 - Longitude of Ascending Node Relative to Rotating Earth
- Ranges from 0° to 360°



Argument of Perigee: The orientation of the orbit within the orbital plane



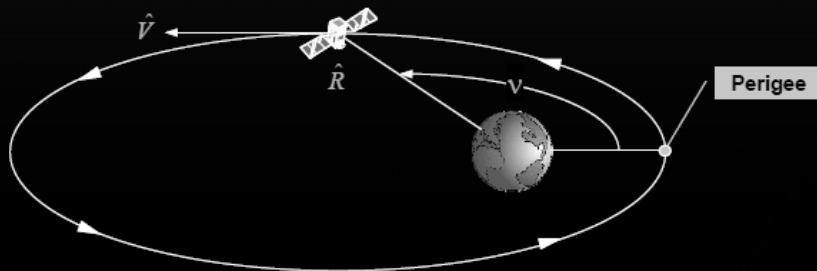
- Angle Along Orbital Path Between the Ascending Node and the Perigee
- Always measured Along the Orbital Path in Direction of Spacecraft Motion
- Perigee – Closest Approach to Earth
- Ranges from 0° to 360°



True anomaly: The location of a spacecraft in a orbit



- Angle Along Orbital Path from Perigee to Spacecraft's Position
- Always Measured Along Orbital Path in Direction of Spacecraft Motion
- The Only Orbital Element Set Parameter That Varies with Time as the Spacecraft Travels Around its Fixed Orbit, Assuming a Spherically-Symmetric Earth (A So-So Assumption)



Manoeuvres (1)

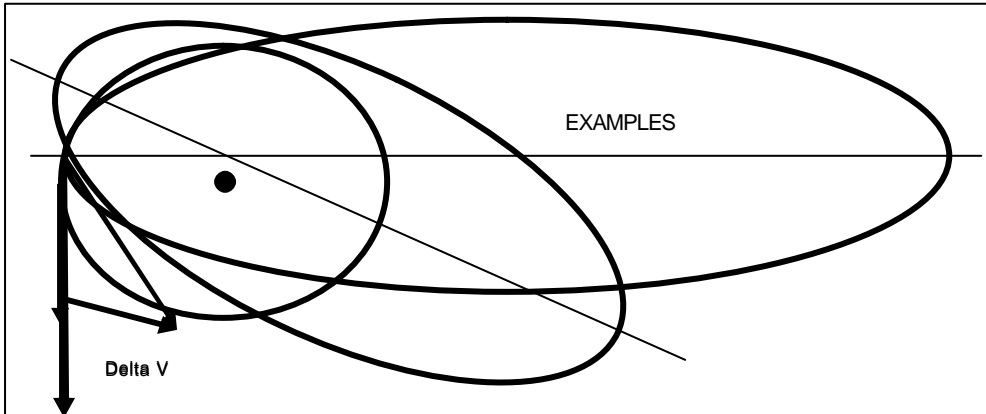


- For a given gravitational field, the orbital movement of a spacecraft is fully defined by 6 parameters:

- 5 GEOMETRIC ONES FOR DEFINING THE ORBIT
- + 1 DYNAMIC FOR DEFINING THE POSITION ON THE ORBIT

Or, equivalently, by any set of 6 independent parameters, such as ...

- THE 3 PARAMETERS DEFINING THE SPACECRAFT POSITION AT A GIVEN TIME
- THE 3 PARAMETERS DEFINING THE SPACECRAFT VELOCITY AT THE SAME TIME
- Thus, at a given time/position, a propulsive manoeuvre modifying the spacecraft velocity (in module and direction), also changes its orbit



The number and the intensity of the maneuvers modifying the spacecraft velocity and thus its orbit for the expected lifetime and beyond may have a significant impact on the mass due to the amount (and the nature) of propellant.

Orbit Perturbation: Earth Oblateness (1)

- The Earth is an oblate spheroid, lacking the perfect symmetry of a sphere
- This lack of symmetry means that the force of gravity on an orbiting body is not directed towards the centre of the earth
- As the gravitational field of a perfectly spherical body depends only on the distance from its centre, oblateness causes a variation also with latitude: this is called a zonal variation
- The dimensionless parameter which quantifies the major effects of oblateness on orbits is called J_2 , the second zonal harmonic: J_2 is 1.08263×10^{-3} for the Earth
- The Earth oblateness generates a perturbing acceleration, so that the orbit equation becomes:

$$\ddot{\mathbf{r}} = -\frac{\mu}{r^2} \hat{\mathbf{u}}_r + \mathbf{p}$$

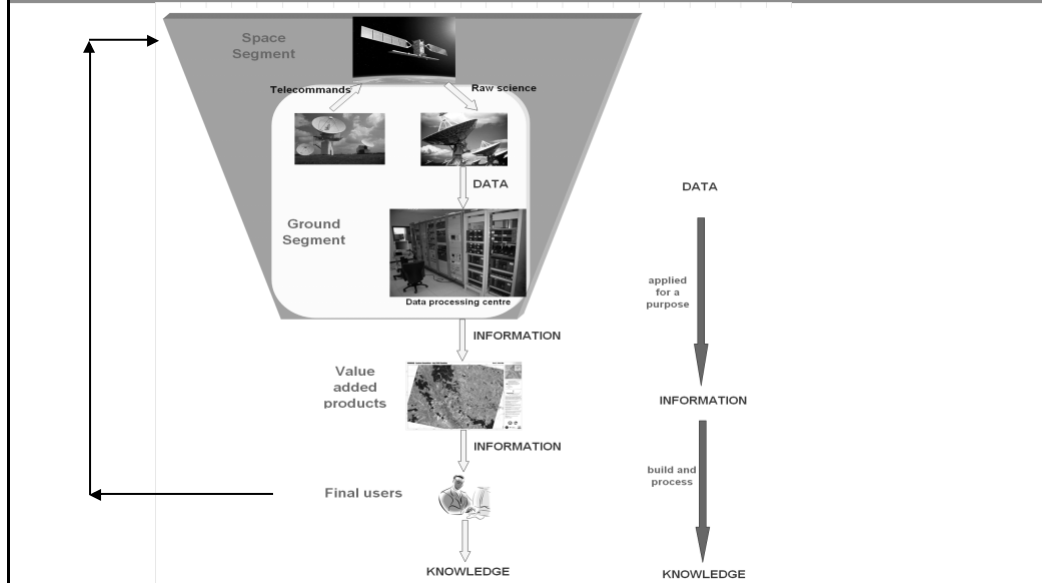
- The vector \mathbf{p} has component which are parallel, transversal and normal to the position vector \mathbf{r} describing the orbit \rightarrow it induce time changes in the orbital parameters
- Neglecting the mathematical details [Prussing and Conway (1993)], one can find that:
 - The time variation of the right ascension depends only on the component of the perturbing force normal to the (instantaneous) orbital plane
 - The rate of change of the argument of perigee is influenced by all three perturbation components

$$\dot{\Omega} = - \left[\frac{3}{2} \frac{\sqrt{\mu} J_2 R^2}{(1 - e^2)^2 a^7} \right] \cos i \quad \dot{\omega} = - \left[\frac{3}{2} \frac{\sqrt{\mu} J_2 R^2}{(1 - e^2)^2 a^7} \right] \left(\frac{5}{2} \sin^2 i - 2 \right)$$

- Spectrometric Observations
- Passive Observations, Microwave
- Active Observations, Microwave
- Passive Observations, Optical
- Active Observations, Optical
- Ionosphere and Atmosphere Sounding
- Electric and Magnetic Field (DC and VLF) Observations
- Gradiometric Observations

- The nature and the requirements associated to the observations imposes constraints on both the spacecraft and the mission design, which drive the complexity of the engineering solutions and the costs.

From User to the Spacecraft and back to the User again: From needs to data to information and knowledge



Main technical requirements for observations



- **Geographical Coverage**
- **Frequency of coverage of target areas**
- **Spatial and Spectral resolution**
- **Image Size and Quality**
- **Ground Stations Network available for Launch, Early Orbit Phase and routine operations**
- **Specific Illumination Conditions, local time**
- **Data Availability and Reliability**
- **Volume of data produced by the payload**
- **Data Rate**
- **Responsiveness, Acquisition Delay and Latency**
- **End-to-end performance (It shall be in units that are meaningful to the user not in units that are meaningful to the space engineer. E.g. Radiometry of the instrument is a unit meaningful to the space engineer but sea surface temperature is meaningful to the user).**

Some System Drivers



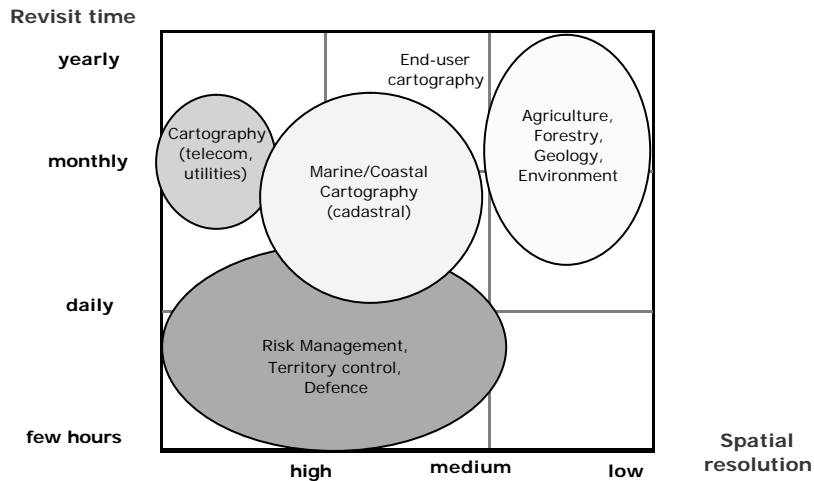
- **Mass and Volume of the Instrument and Spacecraft**
- **Budget constraints for manufacturing and operations during system lifetime**
- **Launch Vehicle cost and availability**
- **System reliability and availability**
- **Establishing timely continuity of data**
- **Compatibility between data sets of different generation of observations (calibration and validation) towards achieving long term data sets (e.g. for climatology applications)**
- **On-Board autonomy**
- **Magnetic Cleanliness**
- **Space Environment effects**

Main Performance for Earth Observation Systems



- **The system drivers identify the main mission parameters influencing the achievement of the required performance vs. cost, risk and schedule for both space and ground segment**
- **The system performance which impact on the orbit design process can be summarised in a limited number of peculiar figures of merit, such as:**
 - **Geographical Coverage**
 - **Revisit time**
 - **Response time**
 - **On-ground resolution (spatial and spectral)**
 - **Swath**

Typical Revisit Time vs Spatial Resolutions per categories of applications



Geographical Coverage and Revisit Time



- For a Satellite in Earth Orbit, the time required to complete one revolution is determined by its radial distance. Spacecraft in Low Earth Orbit (altitude ~700-800 km) require about 100 min for one orbit
- Many Earth Observation Missions require global coverage
- Hence the laws of orbital mechanics, in combination with the daily Earth Rotation, demand a space-time trade off: a shorter revisit interval implies less dense spatial coverage
- Under such constraint, it may not be possible with only one spacecraft to achieve the simultaneity required for fine spatial coverage and short revisit intervals
- In this cases, a constellation of spacecraft may be the only solution

Influence of Key Mission Parameters on EO System Design



Key Parameters	Affected Parameters
Geographic Coverage	Number of Satellites Payload Field Of View Altitude Orbit
Response Time	Number of Satellites Altitude Number and Locations of Ground Stations Access regions Communications Re-Scheduling and Processing Time
Revisit Time	Number of Satellites Altitude Access Region
On Ground Resolution	Wavelength/Aperture (Optical) Antenna Length/Bandwidth (SAR) Altitude Off-Nadir Pointing Angle
Swath	Telescope Field Of View (Optical) Focal Plane Array Size Data Rate Satellite Agility (Optical) Antenna Dimension (SAR)

Orbital Constraints: Optical and SAR Observations



- Low Earth Orbits of interest for Optical and SAR have an altitude ranging from ~400 km up to ~800 km. This range is imposed by the specific optical and SAR payloads limitations (upper bound) and the drag decay effects (lower bound)
 - For an optical payload the upper limitation is due to the difficulty of maintaining both high resolution and limited instrument dimensions with the increasing of the altitude (for a fixed optical aperture the ground spatial resolution linearly decreases with the altitude)
 - For a SAR payload the upper limitation is due to the difficulty of maintaining both high SNR and limited power demand with the increasing of the altitude (for a fixed transmitted power the SNR decreases with the cube of the altitude)
 - The exclusion of too low orbit altitudes is due to the drag effects that may limit the spacecraft lifetime and/or impose severe constraints on the propulsion subsystem

Elliptical Orbits



- Elliptical orbits in principle may offer coverage advantages in a specific terrestrial hemisphere. In fact, when the orbit is elliptical, the satellite stays for a greater period at the apogee crossing, so allowing a major coverage in the corresponding hemisphere
- Because of the altitude range restrictions the maximum apogee altitude that can be considered is ~800 km and the minimum perigee altitude is ~400 km
- This hypothetical orbit presents very small eccentricity, and consequently, presents also very few advantages in terms of coverage of a specific terrestrial hemisphere, while, on the other hand, presents all environmental perturbations problems associated to the elliptical orbits
- In general the use of elliptical orbits implies non-uniform coverage or satellite altitude and velocity variations → do not always guarantee adequate instrument performance

Circular Inclined Orbits



- The use of circular inclined orbits has been considered, specially for optical satellites in military application.
- However:
 - They cover only a limited latitude belt around the equator
 - The orbit plane rotation induced by the RAAN-rate causes a variation of the illumination conditions of the target sites during the satellite passage.
 - For a SAR system these orbits increase the system complexity (thermal control, solar arrays, etc) and costs.
- Therefore also the use of inclined orbits may be attractive for EO satellites aiming at specific latitude observations at expenses of limitation in illumination condition and system complexity

Circular Sun-Synchronous Orbits (SSO)



- SSO is the orbit which combines altitude and inclination in such a way that the satellite passes over any given point of the planet's surface at the same local solar time → The orbital plane makes a constant angle with the radial from the sun.
 - For that to occur, the orbital plane must rotate in inertial space with the same angular velocity of the earth in its orbit around the sun, which is 360° per 365.26 days, or $1.991 \cdot 10^{-7}$ rad/s, or 0.9856° per day (= time derivative of RAAN)
- During every orbit, the satellite sees any given swath of the planet under nearly the same conditions of daylight or darkness day after day and also has a constant perspective on the sun
- The use of circular SSO is convenient since it allows:
 - high latitude accessibility (it results to be quasi polar)
 - uniform coverage
 - limited satellite altitude and velocity variations
 - uniform Sun illumination conditions

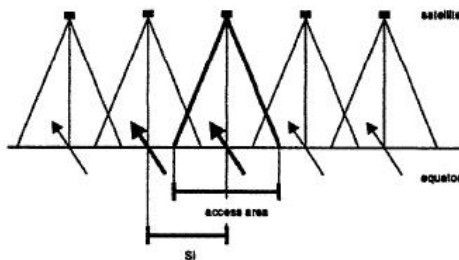
SSO properties



- In a SSO orbit the ground track pattern is completely defined by the number of orbits per day Q .
- By indicating with D the repeating cycle (number of days) it is possible to express Q as:
 - $Q = [Q] + I/D$; Note that $[]$ = integer part and I is an integer number ($I < D$).
- By indicating with S the fundamental interval (i.e. the angular equatorial distance between two successive satellite tracks) and with S_i the sub-interval (i.e. the angular equatorial distance between trace patterns day by day) we have:
 - $S = 360^\circ / Q$ and $S_i = S / D$

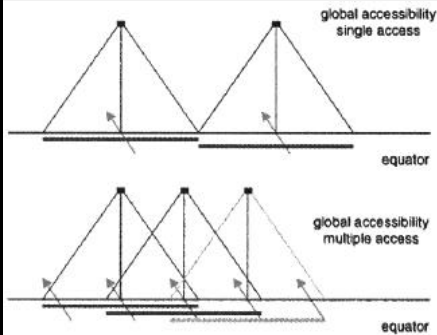
- The appropriate choice of I and D allows the selection of the desired observation scheme
- The choice of $I=1$ or $I=D-1$ (aka direct orbits or drifting orbits) allows to achieve a good sampling in space but not in time of the pointed targets (e.g. $I / D = 15 / 16$)
- The choice of $nI \pm 1 = D$ or $n(I - 1) \pm 1 = D$, (aka skipping orbits) allows to achieve a good sampling in time with a lower spatial resolution

Optical in SSO – Simplified Orbit Selection for a single S/C for global coverage



- The global accessibility is achieved if the instrument access at the equator is greater than the orbit basic sub-interval (the angular equatorial distance between trace patterns day by day), i.e.: $\text{Access Area} > \text{Si}$
- All the accessible sites should be potentially observed during the repeat cycle at least once time with a quasi-nadir observation geometry (i.e. low off-nadir looking angles) in order to reach the maximum performance (minimum spatial resolution, minimum image degradation due to the off-nadir observation)
- High repeat cycle length permits to implement incidence angle diversity → The higher is the repeat cycle length (D) and the lower is the extension of the basic sub-interval (Si), allowing the optical instrument to acquire the same target more times during the orbit cycle and with different incidence angles.

Optical in SSO – Simplified Orbit Selection for a single S/C for global coverage



- Incidence angle diversity is important in observing targets casting shadows depending from the sun vector angle.
- Multi-spectral acquisition can also exploit incidence angle diversity for classification tasks → the response of vegetation in the various bands also depends on the sun vector incidence.

- Incidence angle diversity can also be exploited by multi-spectral acquisition, for classification tasks: in fact the response of vegetation in the various bands does also depend on the sun vector incidence.
- Once that the global coverage criterion is satisfied with one satellite, the maximum revisit time is no greater than the repeat cycle interval

Optical in SSO – Simplified Orbit Selection for a single S/C for global coverage



- On the other hand the selection of an orbit with a repeat cycle interval which exactly fits the required revisit period is usually not preferred since, in such way, a certain site would be always viewed at the same incidence angle (up to 35° off-nadir, with image degradation)
- In case of a 2 satellite constellation, the preferred orbit will be a skipping orbit to provide an acceptable revisit time also in the case of availability of one operational satellites, and a repeat cycle sufficiently high in order to provide a quasi-nadir observation capability of the accessible sites within the orbit cycle
- The selection of a candidate orbit with the sub-cycle equal to the required revisit period and with a longer repeat cycle entails that the global accessibility shall be achieved by one operating satellite within the sub-cycle. This means that the following stronger condition must be verified:

$$\text{Access Area} > \text{Sub-Cycle Basic Sub-Interval}$$

Limitations for the Acquisition of Optical Image



- The spectral observation regions covered by the optical payloads (VIS, IR and UV/Vis regions) imply some inherent limitation for the image acquisition: they can only sense the sunlight part of Earth (except for IR bounds) so that one half of each orbit is useful for imagery yielding
- The image acquisition for the polar regions during solstices is critical due to the poor illumination condition of the scene: as a result, an optical satellite can only take places during, theoretically, less than 40 % of the orbit period in average
- The necessity to optimise the illumination condition of the Earth scene drives the selection for optical satellites of near-noon sun-synchronous orbits, since these orbits provide sufficient and near constant sun illumination of the Earth surface
- The cloud cover is known to be in the order of 30% to 70% of the time at all latitudes, except for very arid climatic zones: this effect further reduces the useful portion of the orbit period for optical satellites

Sentinel 2 System – Mission Requirements

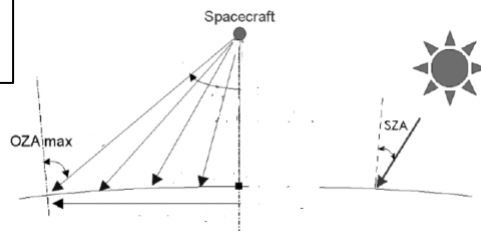


MIS-SYS-005	The Satellite shall consist of a platform and a MultiSpectral Instrument (MSI).
MIS-SYS-015	The Satellite shall allow imaging of the Earth in two observation modes for the MSI: <ul style="list-style-type: none">- Nominal observation mode: normal mode of operation, focused on the global and systematic coverage of the areas of interest specified in MSI-SYS-020 and with the revisit time specified in MIS-TI-005,- Extended observation mode: special observation mode to improve accessibility time as specified in MIS-TI-015, on an exceptional basis (typically 20 times per year, and at a maximum once per 10-day repeat cycle), for a limited period of time (maximum one orbit duration) and over a limited geographical area.
MIS-SYS-020	The Satellite shall allow systematic acquisitions of data over the following areas of interest for the MSI: <ul style="list-style-type: none">- The overall land surface located between -56° latitude and +83° latitude,- The EU islands (whatever their size) located between -56° latitude and +83° latitude,- Any island located at less than 20 km from the continental coastline and located between -56° latitude and +83° latitude,- All other major islands (greater than 100 km² size), located between -56° latitude and +83° latitude- The inland waters (rivers, lakes, closed seas) located between -56° latitude and +83° latitude- The Mediterranean sea

Sentinel 2 System – Application Requirements



MSI-OP-005	Sizing of instrument parameters (e.g. focal length) shall be performed considering the average orbital altitude over land areas in the northern hemisphere.
MSI-OP-010	Acquisition in the spectral channels is only required in the daytime part of the orbit, with Sun Zenith Angle lower than or equal to 75°.
MSI-OP-015	All raw data acquired during on-board calibration shall be transmitted to ground.
MSI-OB-010	The instrument shall provide spectral images at near-nadir direction (geocentric pointing). The observation zenith angle (OZA) of all samples acquired in the nominal observation mode shall be less than 15°
MSI-OB-015	The observation zenith angle (OZA) of all samples acquired in the extended observation mode shall be less than 35°
MSI-GE-005	The instrument swath width shall be larger than or equal to 290 km.

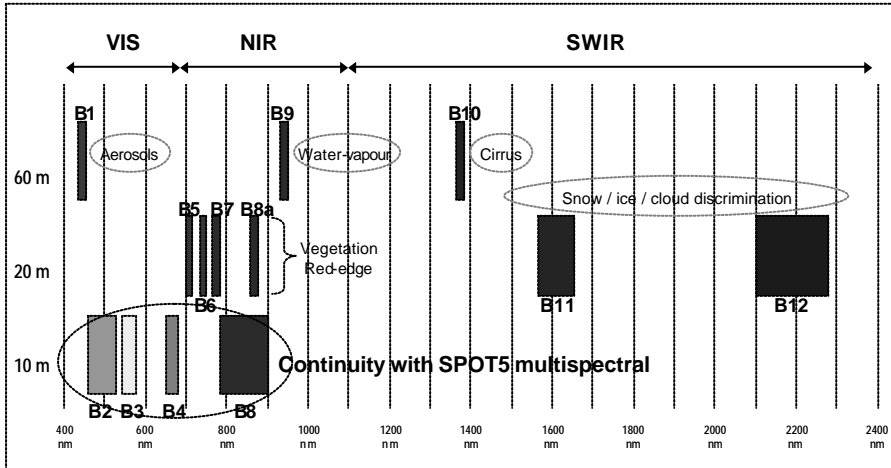


Sentinel -2 – Overall Mission Constraints



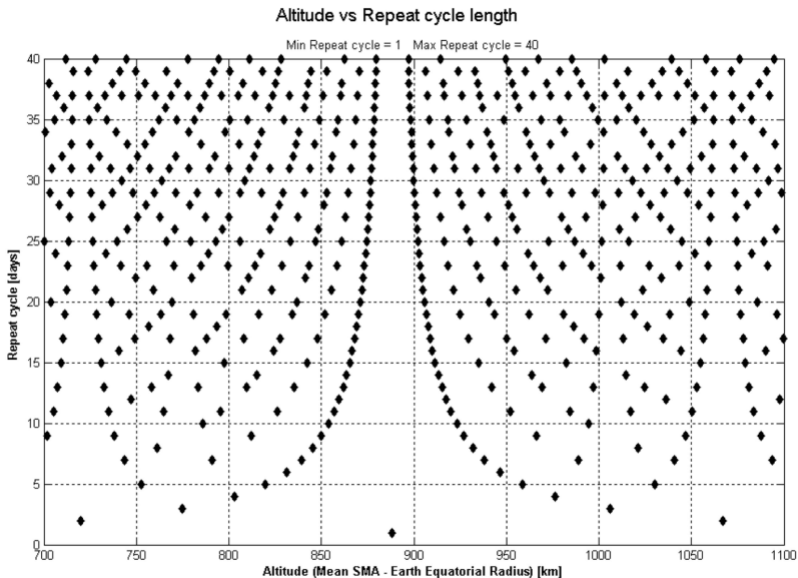
MIS-TI-005	The Sentinel-2 system shall provide a geometric revisit time better than or equal to 5 days over the areas of interest as specified in MIS-SYS-020 in the nominal observation mode with two operational satellites.
MIS-TI-010	The Sentinel-2 system shall provide a geometric coverage time better than or equal to 3 days (goal) to 5 days (threshold) over the areas of interest as specified in MIS-SYS-020 in the nominal observation mode with two operational satellites.
MIS-TI-015	The Sentinel-2 system shall provide a geometric accessibility time of 1 day (goal) to 2 days (threshold) for the imaging data over the areas of interest as specified in MIS-SYS-020 in the extended observation mode with two operational satellites.
MIS-TI-020	The Satellite design (in particular mass memory and downlink) shall be compatible with the ageing requirements associated to NRT data.
MIS-TI-025	The Satellite design (in particular mass memory and downlink) shall be compatible with a variation of the amount of MSI NRT data acquisition between 5% and 25% of the total amount of MSI data.
MIS-TI-045	In the event of loss of one satellite, it shall possible to maintain full geographical coverage of all the areas of interest with a geometrical revisit time better than or equal to 10 days, until a new satellite can be made operational in orbit.

Sentinel -2 Spectral Bands vs Spatial Resolution



Spectral bands versus spatial resolution

Orbit Determination Process Altitude vs Repeat Cycle Length



Orbit Determination Process Trade off (with simulation tools)



	OZA	Revisit	Swath	Access	1-SC	Contact
P	< 15°	<=5 days	< 300km	<=4 days	<=10 days	>=16 min
F	> 15°	> 5 days	> 300km	> 4 days	> 10 days	< 16 min

Orbit	OZA	Revisit	Access	1-SC	Swath	Contact
14+1/10	P	P	F			
14+1/9	P	P	F			
14+2/9	P	P	P	P	F	
14+3/10	P	P	P	P	P	P
14+4/9	P	P	P	P	F	
14+5/9	P	P	P	P	F	
14+7/10	P	P	P	P	P	F
14+7/9	P	P	P	P	F	
14+8/9	P	P	F			
14+9/10	P	P	F			
14+1/5	P	P	P	F		
14+2/5	P	P	P	F		
14+3/5	P	P	P	F		
14+4/5	P	P	P	F		

Definition of the Orbit



- Q=14+3/10 defines entirely the orbit. In fact:
 - Q=143 orbits per 10 days → 1 orbit is done in 6041.958 s

$$T = \frac{2\pi}{\sqrt{\mu}} (R_E + z)^{\frac{3}{2}} \quad - \quad R_E = 6378 \text{ km}, \mu = 398600 \text{ km}^3/\text{s}^2, T = 6042 \text{ s}$$

$$- \quad z = 794 \text{ km}$$

$$\dot{\Omega} = - \left[\frac{3}{2} \frac{\sqrt{\mu} J_2 R^2}{(1-e^2)^2 a^7} \right] \cos i \quad - \quad J_2 = 1.08263 \times 10^{-3}, e=0, a=R_E+z$$

$$\text{and } dO/dt = 1.991 \cdot 10^{-7} \text{ rad/s}$$

- $\cos(i) = -0.149143129 \rightarrow i = 98.557^\circ$

Selecting the Local Time #1

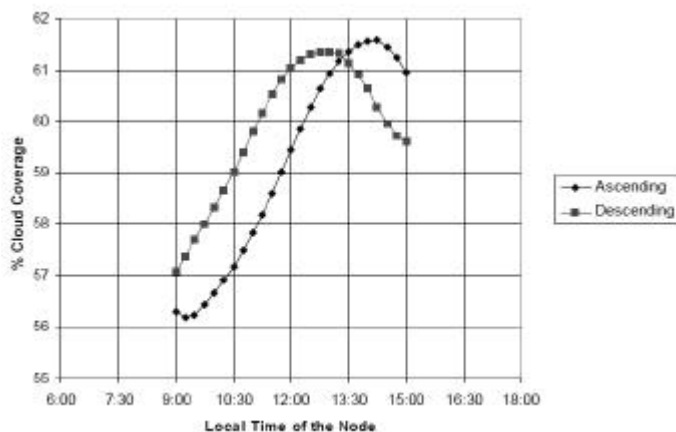


- Based on the limitation in the SZA (75 degrees at maximum), it is possible to determine the more adequate LTAN or LTDN for proper observation over Europe. The results show that the LTAN/LTDN that produce a near-noon condition over Europe are the best options
- In order to avoid the sun glint effect, the LTDN of 10:30 and the LTAN of 13:30 are good candidates, as they exhibit the same illumination conditions.
- Avoiding morning haze suggests using a LT > 10:00
- Sun glint is a phenomenon that occurs when the sun reflects off the surface of the ocean at the same angle that a satellite sensor is viewing the surface
- A cloud coverage analysis with real cloud data over Europe from Meteosat has been performed, taking one full year of observations
- It has been verified with real cloud data that the best times for optical observations of Europe in terms of cloud coverage are the early times in the morning. In general, the earlier the node crossing time, the higher our chances to get a clear picture of the surface

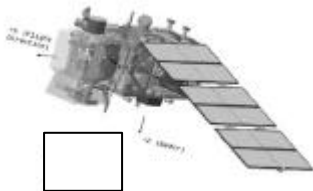
Selecting the Local Time #2



- Simulation shows that the orbit with LTDN 10:30 present less cloud coverage than LTAN 13:30. Therefore the proposed time for the node was LTDN 10:30.

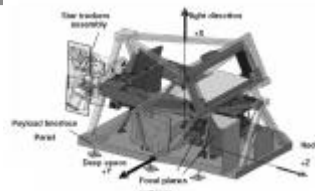


Sentinel -2 System description



Satellite

- Satellite mass: 1200KG
- Satellite power consumption: 1400W (1700W at Solar Array level, GaAs triple junction), 87Ah battery
- Hydrazine propulsion system (117Kg)
- TT&C using S band (64Kb/s up – 2018Kb/s down), with authenticated/encrypted commands
- X band mission data distribution (520 Mbits/sec)
- Mission data onboard storage: > 2.4 Tbits
- Optical Communication Payload
- Wheels, magnetometers, magnetorquers, star trackers, coarse sun and earth sensors, accurate Inertial Measurement Unit and GPS



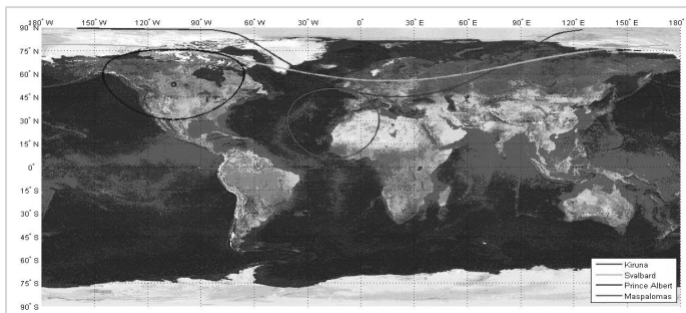
MultiSpectral instrument

- Filter based push broom imager (280KG, 1m³)
- Three mirrors silicon carbide telescope, with dichroic beam splitter
- Focal plane arrays: Si CMOS VNIR detectors, HgCdTe SWIR detectors passively cooled (190K)
- Onboard wavelet compression (~1/3)
- Integrated video & compression electronics (state of the art wavelet compression)
- Radiometric resolution 12bits
- Radiometric accuracy < 5%

Sentinel -2 Data Delivery



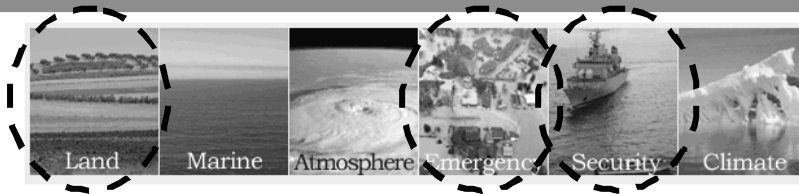
- Data delivered to 4 core GS within 1-3 hours after acquisition.
- X band data downlink with instrument data rate of 490 Mbit/s (after onboard wavelet compression)
- Laser Communication through geo terminal (can be operated simultaneously with the X band subsystem).
- 900 Gbyte per day (1000 CDs): cloud-free images will be further processed.



Core Ground Stations used for the simulation:

Kiruna,
Svalbard,
Maspalomas,
Prince Albert

Sentinel -2 Services



General services: Global carbon, Crop monitoring, Spatial planning (vegetation, urban), Forest monitoring, Water services, Soil erosion, large scale natural or man made disasters, surveillance of infrastructures

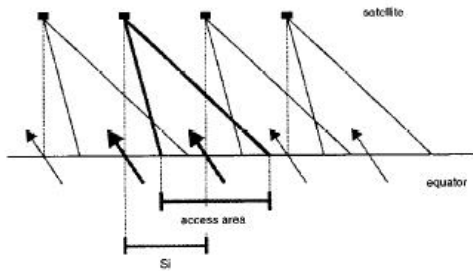
Thematic services: Sustainable management of developing countries, Nature protection services, support to humanitarian aid, Food security

SAR in SSO – Simplified Orbit Selection #1



- SAR payloads work independently of the sun illumination conditions: this allows the satellite to be injected in orbits which are unfavourable for optical satellites
- Moreover, since images can be obtained during the night and in presence of heavy cloud cover, the SAR satellites can operate for a good percentage of the satellite orbit period, spacecraft bus resources permitting
- The SAR payload is required to operate in multiple modes. Trade off between geometric resolution vs swath width and geometric resolution vs radiometric resolution are required.

SAR in SSO – Simplified Orbit Selection #2

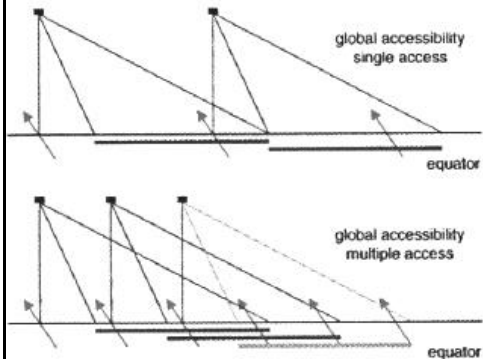


- The global accessibility is achieved if the instrument access at the equator is greater than the orbit basic sub-interval (the angular equatorial distance between trace patterns day by day), i.e.: Access Area > S_i

This criterion is conservative as it guarantees the accessibility for two times during the whole orbit cycle

- High repeat cycle length permits to implement incidence angle diversity. In fact, the higher is the repeat cycle length (D) and the lower is the extension of the basic sub-interval (S_i), allowing the SAR instrument to acquire the same target more times during the orbit cycle and with different incidence angles.

SAR in SSO – Simplified Orbit Selection #3



- Once the global coverage criterion is satisfied, the maximum revisit time is no greater than the repeat cycle interval.

- Within the set of orbits satisfying the global coverage criterion, this would suggest choice of the orbit with the shorter repeat cycle, but...

- ...an orbit with a repeat cycle interval which exactly fits the required revisit period implies that a certain site would be viewed with the same incidence angle, preventing the exercise of the multiple incidence angle option
- Therefore, the preferred orbit would be a skipping orbit having a repeat cycle sufficiently small to provide an acceptable revisit time while warranting an effective repeat cycle sufficiently high to allow multiple incidence angle imagery

SAR System Design Considerations #1



- Requirements on Power and Signal-to-Noise ratio, Resolution, Incidence angle, Swath Width, Wavelength, Polarisation, Calibration Accuracy and SNR further constraint the design of the SAR System.
- Additional constraints are imposed by the available platform resources and mission design such as Payload Mass and Volume, Power, Ephemeris/Attitude Determination Accuracy, Attitude Control, Downlink Data rate etc
- Given the above inputs, one determines the System Specifications, such as System Gain (losses), rms error versus frequency, receiver noise figure, System Stability (gain/phase versus time and temperature) etc
- Final design is the result of an iterative procedure

SAR System Design Considerations #2



- Assume that the measurable range of target backscatter coefficient (σ^0) and the wavelength λ are specified by the users.
- Assume that Mass and Power Budgets are constrained by the launch vehicle:
 - Maximum antenna area and the antenna gain G are limited by the mass
 - Maximum Radiated Power is limited by the available DC Power
 - Minimum Noise Temperature is determined by the Earth temperature (~ 300 °K) and the receiver noise figure
 - Slant Range R is determined by the imaging geometry and the platform altitude
- If we consider the single pulse Radar Equation for distributed target to derive the SNR (which is a typical and fundamental design requirement), we realise that there are not many degrees of freedom left...

$$SNR = \left(\frac{P_t \cdot G^2 \cdot \mathbf{I}^2}{(4p)^3 \cdot R^4 \cdot F_{op}} \right) \cdot \left(\frac{\mathbf{s}^0}{k \cdot T_n \cdot B_n} \right) \cdot \left(\frac{c \cdot t_p}{2 \cdot \sin \mathbf{h}} \right) \cdot \left(\frac{\mathbf{I} \cdot R}{L_a} \right)$$

- Available parameters to enhance the SNR:
 - Increase the Pulse Duration → Increase Average Power Consumption
 - Decrease the antenna length while increasing the width to keep G constant → reduce the swath width and increase the average power consumption due to the higher PRF required
 - Reduce system losses improving the antenna feed system or by inserting T/R modules into the feed to improve the system gain → increase power consumption and costs
 - Lowering the altitude produces a significant improvement of SNR → decrease the swath width

- All the options to improve the SNR and therefore the quality of imagery requires power and resources of the platform
- User performance specifications, radar system parameters and platform resources are strongly interlaced
- There is no universal algorithm that can optimise the design across the wide range of applications: the priority ranking of the system performance parameters depends on the data utilisation and consequently on the users.
- Final design is usually a compromise between available resources and user needs: designers can also request a modification in the given requirements to match available programmatic constraints

Case Study: Sentinel-1 Performance Requirements

<i>Mode</i>	<i>Access Angle</i>	<i>Single Look Resolution</i>	<i>Swath Width</i>	<i>Polarisation</i>
Interferometric Wide Swath	> 25 deg	Range 5 m Azimuth 20 m	> 250 km	HH+HV or VV+VH
Wave mode	23 deg and 36.5 deg	Range 5 m Azimuth 5 m	> 20 x 20 km Vignettes at 100 km intervals	HH or VV
Strip Map	20-45 deg.	Range 5 m Azimuth 5 m	> 80 km	HH+HV or VV+VH
Extra Wide Swath	> 20 deg.	Range 20 m Azimuth 40 m	> 400 km	HH+HV or VV+VH
For All Modes				
Radiometric accuracy (3 s)				1 dB
Noise Equivalent Sigma Zero				-22 dB
Point Target Ambiguity Ratio				-25 dB
Distributed Target Ambiguity Ratio				-22 dB

} Main modes

Sentinel-1 System

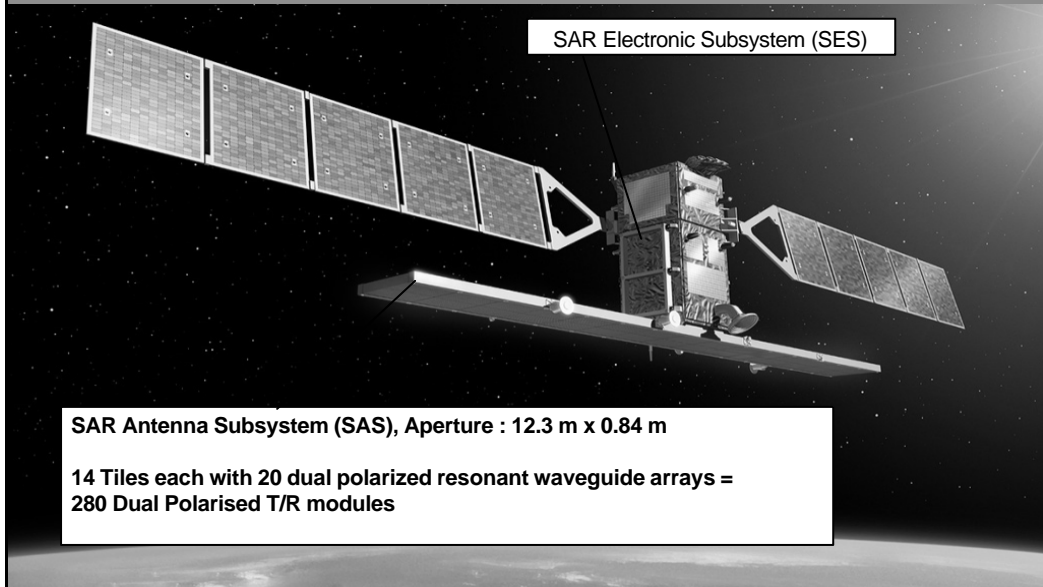
Space Segment

- A constellation of two satellites
- Nominal lifetime in orbit of 7 years (consumables for 12)
- Global coverage
- Near-Polar Sun-Synchronous dusk-dawn orbit @ 693km.
- Repeat Cycle 12 days, 175 orbit (14 + 7/12 orbit per day)
- ~60 GByte/orbit, ~ 1 TByte/day
- C-Band Synthetic Aperture Radar Payload
- Equipped with an Optical Communication Terminal for GEO laser link

Ground Segment

- S-Band station (Kiruna proposed), with a back-up for S/C contingencies
- Downlink currently assumes three X-Band receiving stations
- Alternative downlink via EDRS upon service availability

Instrument Accommodation on Spacecraft



Sentinel-1 Satellite System Sizing and Performance



Satellite Features	Performance Parameters
Overall Launch Mass	2298 kg (incl. 135 kg prop.)
Main Body Dimensions	3400 x 1340 x 1340 mm
Operational lifetime	7.25 years
Propellant lifetime	12 years
Operative autonomy	96 h
Attitude Profile	Geo-Centric and Geodetic, 3 axes stabilized. Nominal Attitude: Right Looking Continuous steering in Yaw, Pitch and Roll
Attitude accuracy and knowledge	Accuracy: 0.01° each axis. Knowledge: better than 0.003° each axis
Orbit Knowledge accuracy	10 m (3 sigma) each axis real-time processing. GPS data allow 5 cm in post-processing on ground.
Propulsion	Mono-propellant, 6 (orbit) + 8 (attitude) thrusters
Power	5980W SAW generated Power (EOL). 240 Ah Li-Ion battery. @ 65V
TT&C	S-Band, zenith/nadir antennas: 64 kbps U/L and 128/2048 kbps (switchable) D/L TLM Data
On-Bard Storage Capacity	1410 Gbit @ EOL
Data Downlink	X-Band (8.025 – 8.400GHz) - 2 x 260Mbps (useful data rate) 8PSK, 4D-TCM
Satellite Reliability & Availability	Reliability : 0.74 @ 7.25years. Availability :0.983

Summary of the Level 2 product Performance prediction



S1 Level-2 Product	Resolution	Performance	Units
Subsidence Rate	5 x 5/20 m2	1.3/1.3	mm/year
Land Cover Classification (2 dB contrast)	30 x 30 m2	90/75	% correct classification
Forest Non-Forest Classification	30 x 30 m2	98.6/75	% correct classification
Soil Moisture	100 x 100 m2	0.8/1.2	volume %
Flood Mapping	30 x 30 m2	93/79	% correct classification
Snow Cover Classification	30 x 30 m2	80/75	% correct classification
Ship Detection	5 x 20 m2	20/40	ship length (m)
Sea Surface Wind Speed	100 x 100 m2	0.4/0.8	m/s
Sea Surface Currents	5 Hz	30/30	cm/s

Sentinels 1-3: main sensor characteristics



Instrument	Mass (kg)	Mass stored (kilograms)	Average power	Data volume per orbit	Instrument I/F data rate (mass w/o compression)	Comments
C-Band SAR	700 kg	2,000 x 1,500 x 1800 mm ³	1,840 W	500 Gbits	660 Mbps	Down-track orbit preferred Mass including payload electronics
Ocean Colour Imager	130 kg	1,000 x 1,000 x 1,300 mm ³	100 W	30 Gbits	36 Mbps	No data compression Warning SSO to avoid Sun glint
Sea Surface Temperature	150 kg	1,300 x 1,000 x 700 mm ³	80 W	60 Gbits	26 Mbps	No data compression Warning SSO to avoid Sun glint
<u>Altimetry package</u>						
Radar Altimeter	60 kg	Ø 1.2 m antenna	80 W	40 Gbits	12 Mbps (SAR mode)	
Micro-radiometer	16 kg	600 x 600 x 300 mm ³	20 W	Negligible		
GNSS Receiver	5 kg		20 W	Negligible		For atmospheric correction For POD
MTI MultiSpectral Imager	150 kg	1,000 x 1,000 x 1,900 mm ³	80 W	375 Gbits	960 Mbps	Lossless compression already assumed 10:30 to 11:00 LT

–Thank you for
your patience!!!!