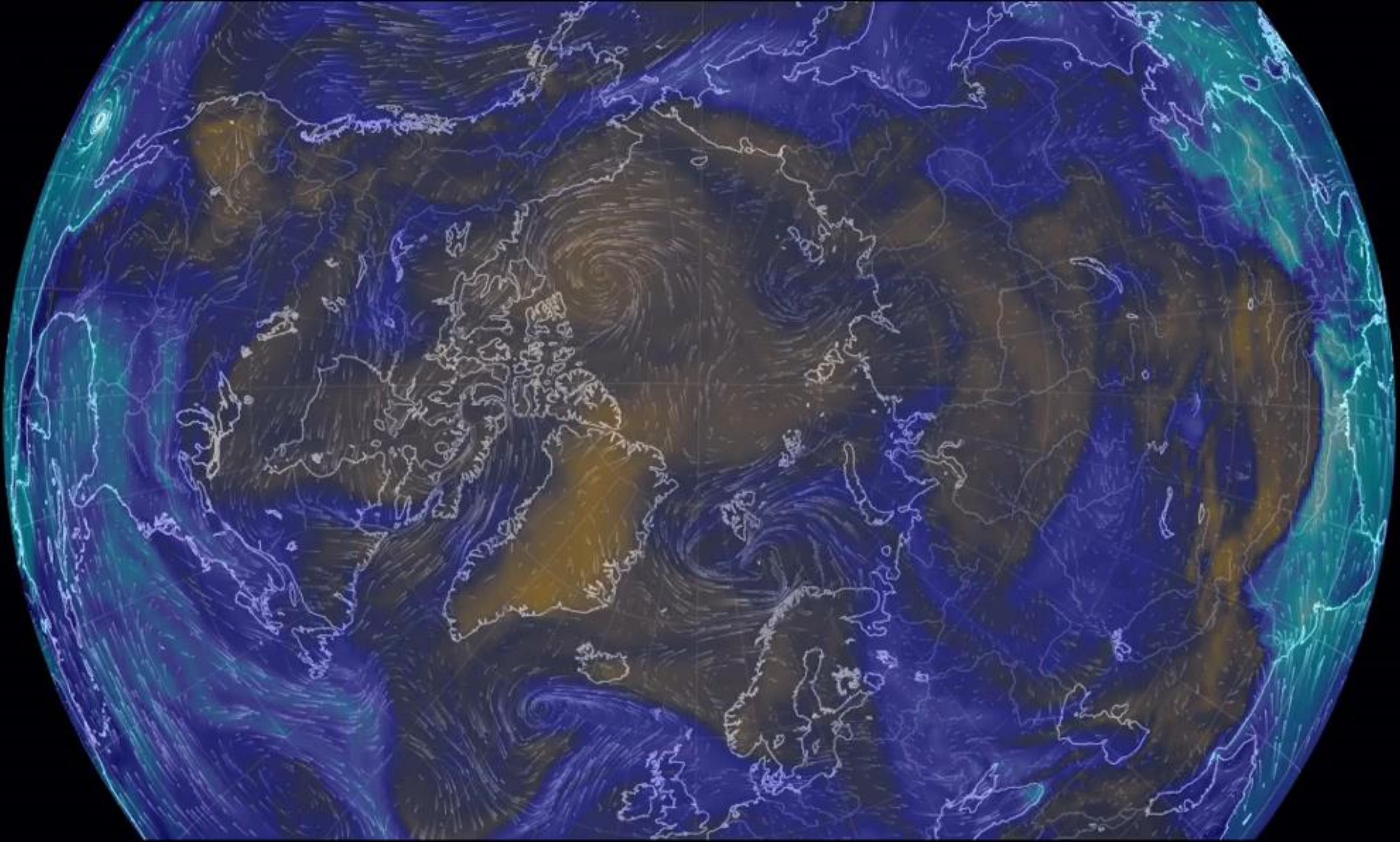


earth

Summer School Alpbach 2016

Satellite Observations of the Global Water Cycle

# PoPSAT

## Polar Precipitation Satellite

Team Blue

FFG

esa

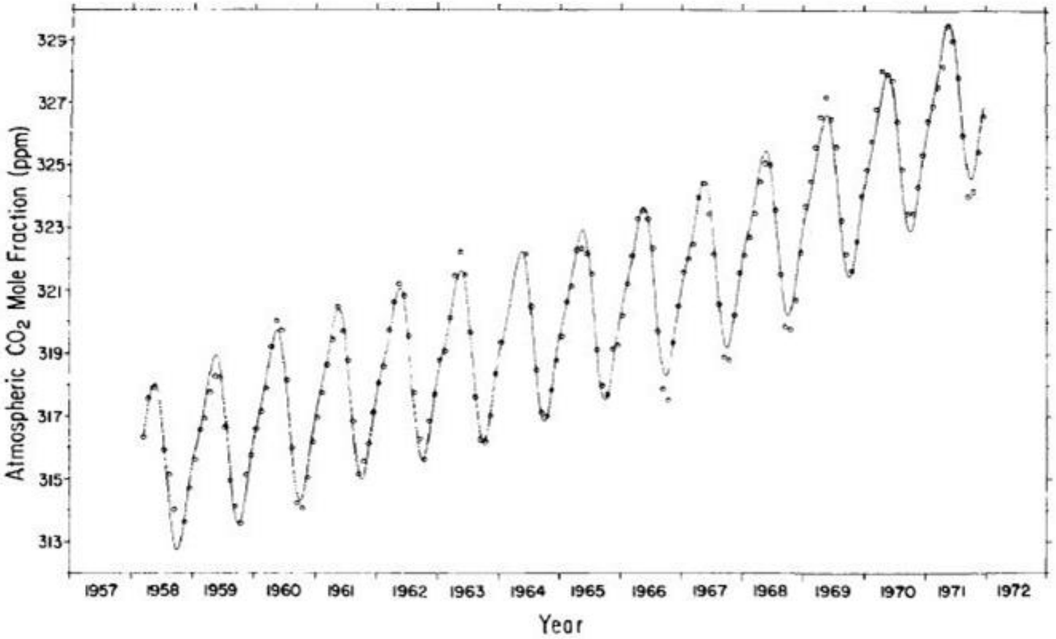
INTERNATIONAL SPACE SCIENCE INSTITUTE

AUSTROSPACE

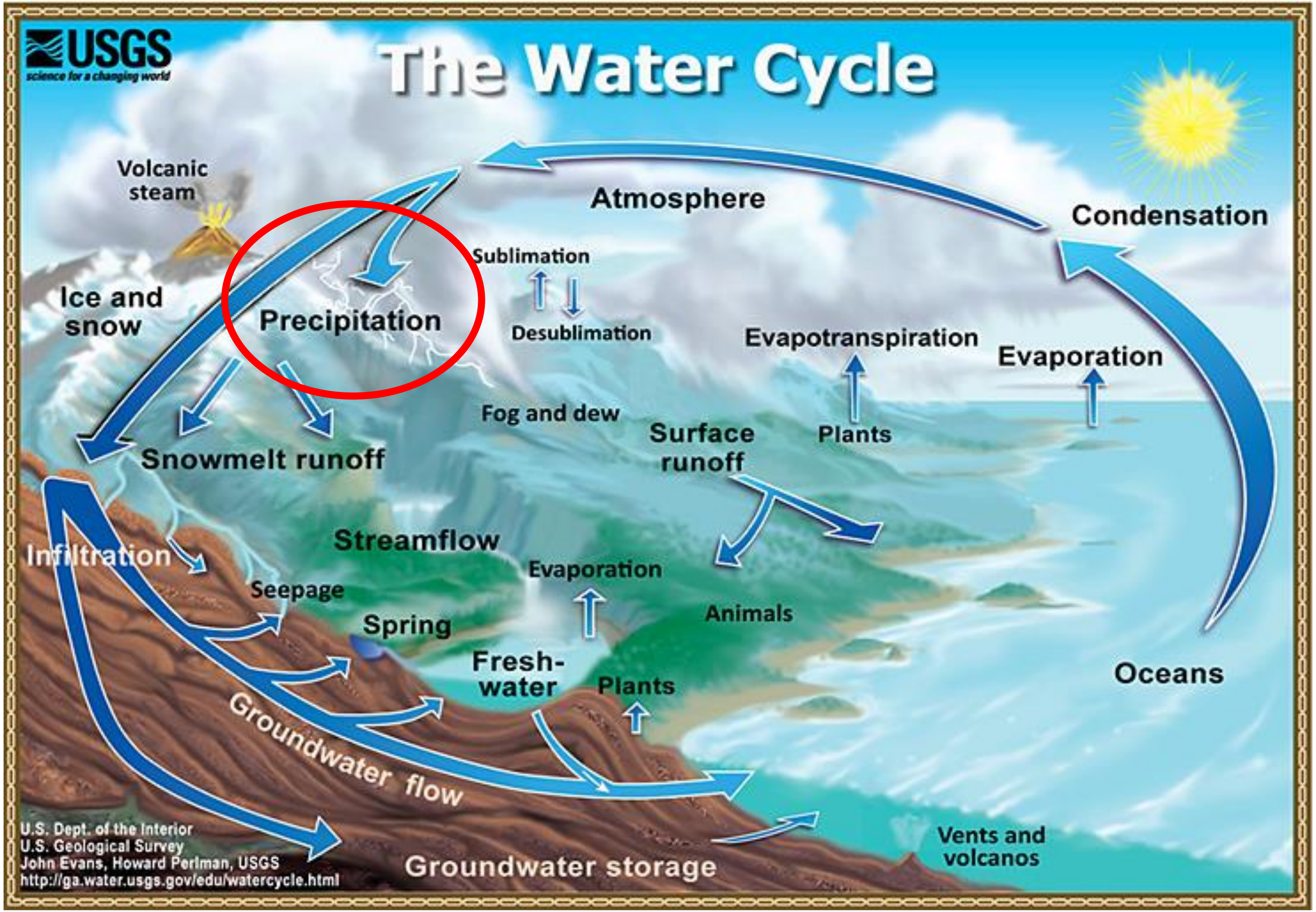
# I. Science

# Background

*The Blue Marble* - First full view of the Earth, taken by crew of Apollo 17, Dec 1972

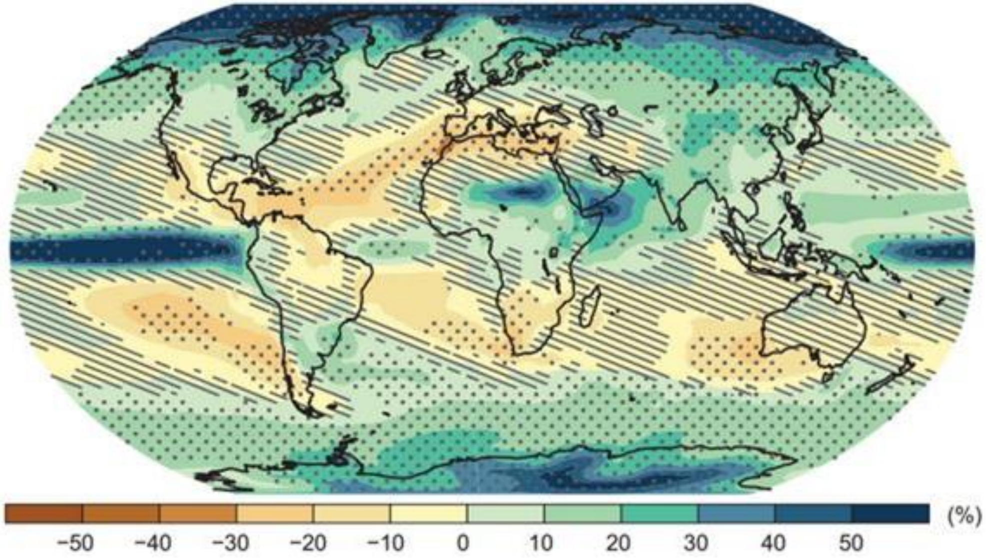


“Cubic trend function” of atmospheric $CO_2$ from Mauna Loa Observatory, Keeling et al. (1972)


USGS
science for a changing world
The Water Cycle
Volcanic steam
Atmosphere
Condensation
Sublimation
Desublimation
Ice and snow
Precipitation
Evapotranspiration
Evaporation
Fog and dew
Snowmelt runoff
Surface runoff
Plants
Streamflow
Infiltration
Evaporation
Seepage
Animals
Spring
Fresh-water
Plants
Oceans
Groundwater flow
Groundwater storage
Vents and volcanos
U.S. Dept. of the Interior
U.S. Geological Survey
John Evans, Howard Perlman, USGS
http://ga.water.usgs.gov/edu/watercycle.html

# Motivation

- Present observations and simulations estimate weather in high-latitudes will show the strongest response to climate change.
- Precipitation (snow, ice and rain) in high-latitudes will intensify in the future.
- Space observation is vital to produce globally consistent data including areas unreachable by in-situ measurements.



Average change in precipitation as % 2081-2100. IPCC (2013)
Note that the High latitudes show an increase of 30-50% average precipitation in 2081-2100.

# Science Objective

**Measure the precipitation in high latitudes at a scale compatible with mesoscale meteorological models.**

**Provide global information of snowfall to complement other missions.**

Identifying

I. Solid and liquid water particles
II. Stratiform and convective precipitation
III. 3-D Structure of precipitation systems

# Mission Application (1)

**Verification and Improvement climate/weather models by:**

- Gaining detailed understanding of weather processes (polar lows, convection, organised cold air outbreaks etc.)
- Spatial resolution compatible with mesoscale meteorological systems

- Improve precision of global measurement of snow
- Extend precipitation observations from previous missions up to high latitudes (TRMM,GPM)
- Complement precipitation observations in lower latitudes

# Mission Applications (2)

Polar Prediction Project (initiative of WMO within the WCRP) outlines the requirement for verification and parameterisation of climate/weather models of key polar processes, this includes precipitation as well as clouds.

**Socioeconomic**

Improvement of weather models → more accurate and reliable weather prediction:

- High latitude inhabitants
- Planning of shipping routes

# Scientific/Observation Requirements

| **SCIENTIFIC REQUIREMENT** | Threshold | Goal |
|---|---|---|
| **SR 1:** Precipitation range<br>Precipitation rate accuracy ≤ 2 mm/h<br>Precipitation rate accuracy > 2 mm/h | 0.5 to 20 mm/h<br>0.5 mm/h<br>20 % | 0.2 to 35 mm/h<br>0.2 mm/h<br>10 % |
| **SR 2:** Horizontal resolution | 4 km | 2 km |
| **SR 3:** Swath width | 150 km | 300 km |
| **SR 4:** Vertical resolution | 1 km | 200 m |
| **SR 5:** Vertical scanning extent | Approx. 18 km | |
| **SR 6:** Coverage of areas with latitude higher than 50° | Min. 90% | |
| **SR 7:** Total mission duration | 5 years | |

# Scientific/Observation Requirements

| **SCIENTIFIC REQUIREMENT** | Threshold | Goal |
|---|---|---|
| **SR 1:** Precipitation range<br>Precipitation rate accuracy ≤ 2 mm/h<br>Precipitation rate accuracy > 2 mm/h | 0.5 to 20 mm/h<br>0.5 mm/h<br>20 % | 0.2 to 35 mm/h<br>0.2 mm/h<br>10 % |
| **SR 2:** Horizontal resolution | 4 km | 2 km |
| **SR 3:** Swath width | 150 km | 300 km |
| **SR 4:** Vertical resolution | 1 km | 200 m |
| **SR 5:** Vertical scanning extent | Approx. 18 km | |
| **SR 6:** Coverage of areas with latitude higher than 50° | Min. 90% | |
| **SR 7:** Total mission duration | 5 years | |

# SR1: Identification of solid and liquid water particles, with enough precision to determine their detailed distribution in Polar regions.

| Parameter | Requirement | |
|---|---|---|
| | Threshold | Goal |
| **Precipitation range** (mm/h) | 0.5 to 20 | 0.2 to 35 |
| **PRECIPITATION RATE ACCURACY** | | |
| Precipitation rate ≤ 2 mm/h | 0.5 mm/h | 0.2 mm/h |
| Precipitation rate > 2 mm/h | 20 % | 10 % |

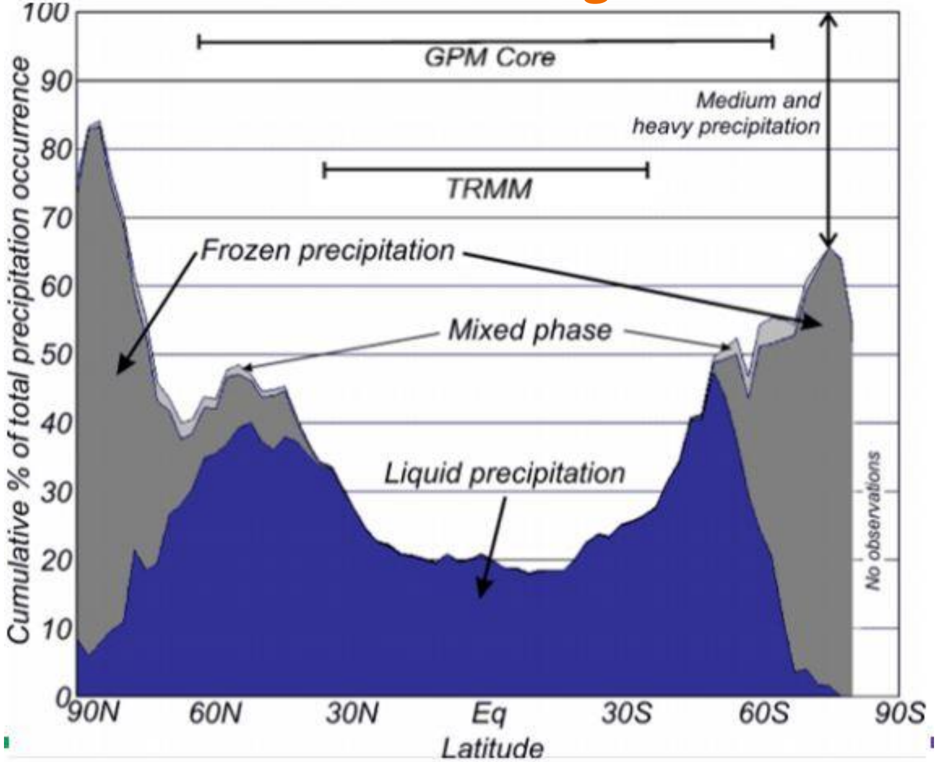


Figure 3 - Mean zonal occurrence of oceanic light precipitation as a percentage of total rainfall occurrence, EGPM (2004)

# Scientific/Observation Requirements

| **SCIENTIFIC REQUIREMENT** | Threshold | Goal |
|---|---|---|
| **SR 1:** Precipitation range<br>Precipitation rate accuracy ≤ 2 mm/h<br>Precipitation rate accuracy > 2 mm/h | 0.5 to 20 mm/h<br>0.5 mm/h<br>20 % | 0.2 to 35 mm/h<br>0.2 mm/h<br>10 % |
| **SR 2:** Horizontal resolution | 4 km | 2 km |
| **SR 3:** Swath width | 150 km | 300 km |
| **SR 4:** Vertical resolution | 1 km | 200 m |
| **SR 5:** Vertical scanning extent | Approx. 18 km | |
| **SR 6:** Coverage of areas with latitude higher than 50° | Min. 90% | |
| **SR 7:** Total mission duration | 5 years | |

**SR 2:**

Horizontal Resolution of 4 km (Threshold)/ 2 km (Goal) with a maximum deviance of 1 Km (System driver)

**SR 3:**

Swath width 150 Km (Threshold)/ 300 Km (Goal)

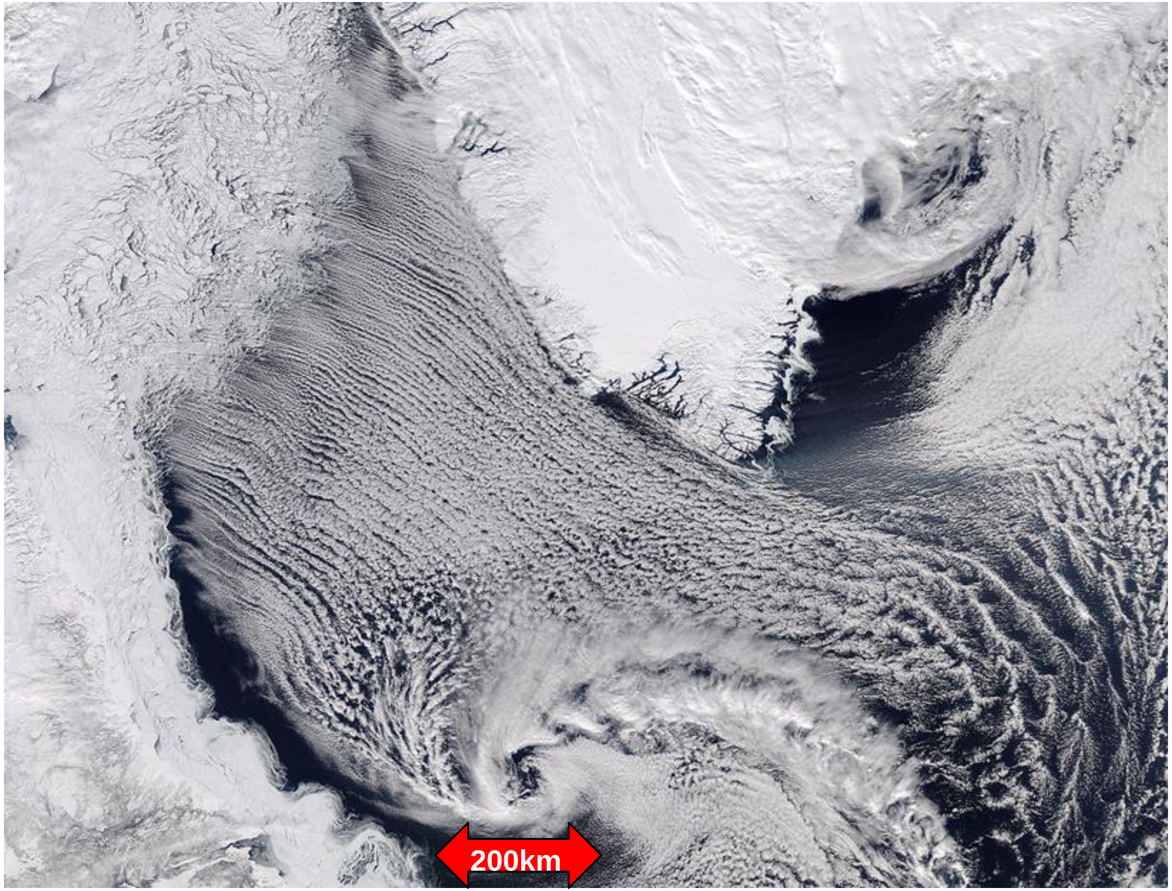


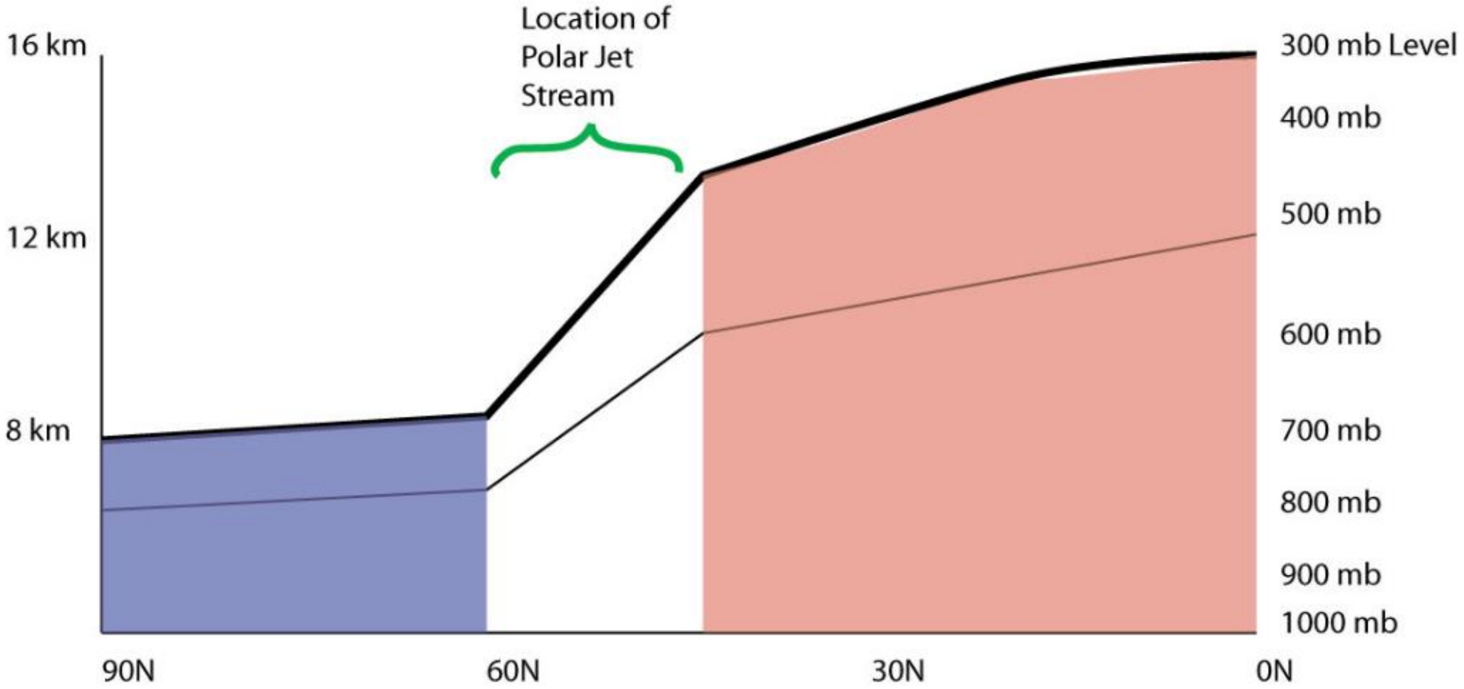
Image of a polar low of the South coast of Greenland

# Scientific/Observation Requirements

| **SCIENTIFIC REQUIREMENT** | Threshold | Goal |
|---|---|---|
| **SR 1:** Precipitation range<br>Precipitation rate accuracy ≤ 2 mm/h<br>Precipitation rate accuracy > 2 mm/h | 0.5 to 20 mm/h<br>0.5 mm/h<br>20 % | 0.2 to 35 mm/h<br>0.2 mm/h<br>10 % |
| **SR 2:** Horizontal resolution | 4 km | 2 km |
| **SR 3:** Swath width | 150 km | 300 km |
| **SR 4:** Vertical resolution | 1 km | 200 m |
| **SR 5:** Vertical scanning extent | Approx. 18 km | |
| **SR 6:** Coverage of areas with latitude higher than 50° | Min. 90% | |
| **SR 7:** Total mission duration | 5 years | |

**SR 4:** Vertical Resolution of 1 km (Threshold)/ 200 m (Goal)

**SR 5:** Vertical scanning extent of 18 Km



Mean vertical extent of the Troposphere in the northern hemisphere in the time of winter solstice. Note the change in Tropospheric height requiring a large vertical scan range.

# Scientific/Observation Requirements

| **SCIENTIFIC REQUIREMENT** | Threshold | Goal |
|---|---|---|
| **SR 1:** Precipitation range<br>Precipitation rate accuracy ≤ 2 mm/h<br>Precipitation rate accuracy > 2 mm/h | 0.5 to 20 mm/h<br>0.5 mm/h<br>20 % | 0.2 to 35 mm/h<br>0.2 mm/h<br>10 % |
| **SR 2:** Horizontal resolution | 4 km | 2 km |
| **SR 3:** Swath width | 150 km | 300 km |
| **SR 4:** Vertical resolution | 1 km | 200 m |
| **SR 5:** Vertical scanning extent | Approx. 18 km | |
| **SR 6:** Coverage of areas with latitude higher than 50° | Min. 90% | |
| **SR 7:** Total mission duration | 5 years | |

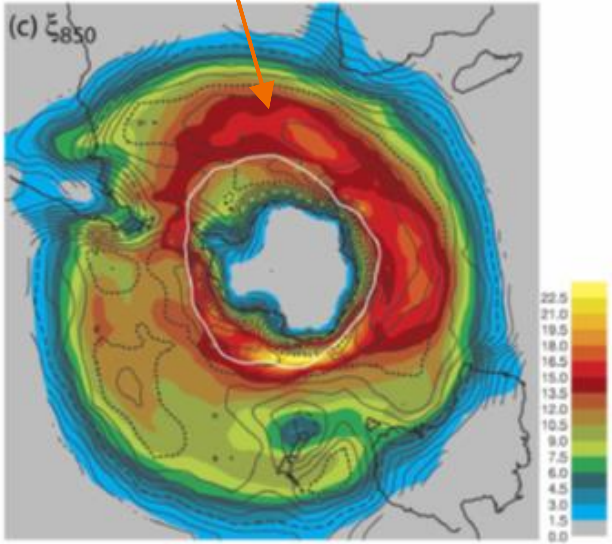
# **SR 6**: Coverage of 90% of the area of a latitude higher than 50° (System driver)

Cyclones spiral towards Antarctica

In both hemisphere the cyclone track density weakens near the poles

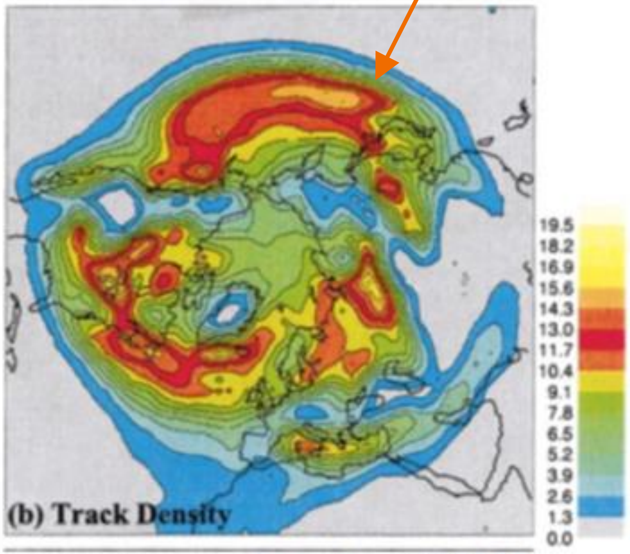
Complicated structure, with distinct regions of activity

**Southern Hemisphere Winter (JJA)**



Hoskins and Hodges (2005)

**Northern Hemisphere Winter (DJF)**



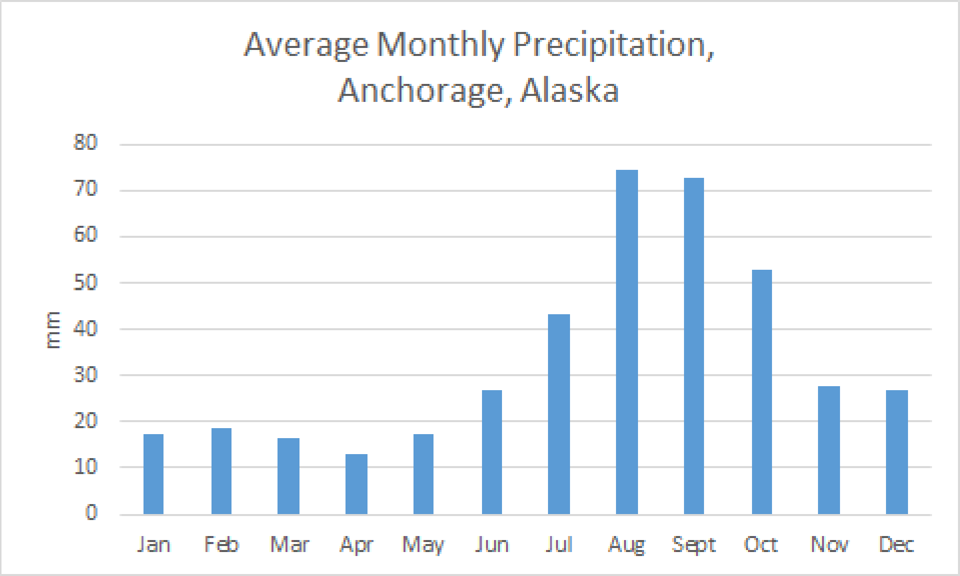
Hoskins and Hodges (2002)

# Scientific/Observation Requirements

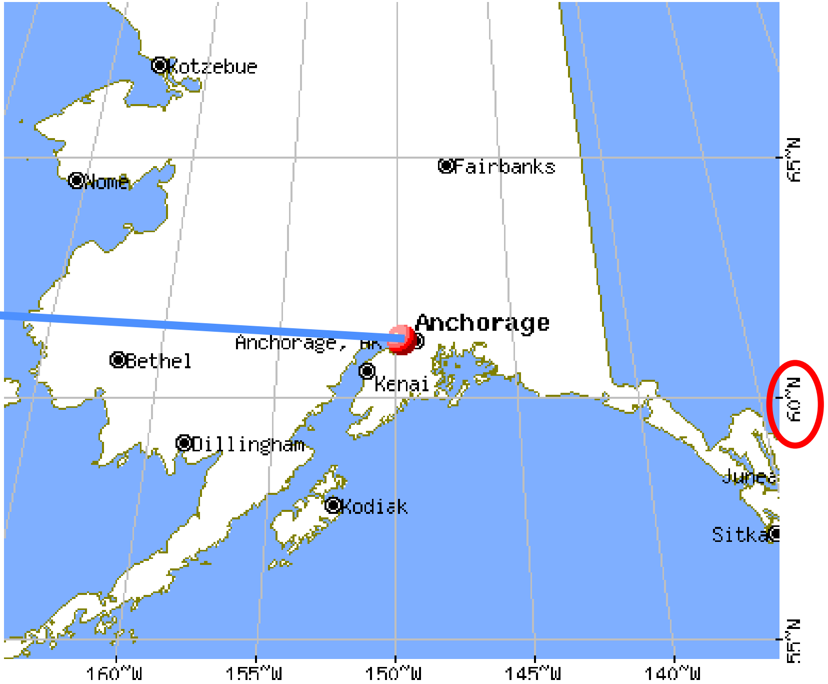
| **SCIENTIFIC REQUIREMENT** | Threshold | Goal |
|---|---|---|
| **SR 1:** Precipitation range<br>Precipitation rate accuracy ≤ 2 mm/h<br>Precipitation rate accuracy > 2 mm/h | 0.5 to 20 mm/h<br>0.5 mm/h<br>20 % | 0.2 to 35 mm/h<br>0.2 mm/h<br>10 % |
| **SR 2:** Horizontal resolution | 4 km | 2 km |
| **SR 3:** Swath width | 150 km | 300 km |
| **SR 4:** Vertical resolution | 1 km | 200 m |
| **SR 5:** Vertical scanning extent | Approx. 18 km | |
| **SR 6:** Coverage of areas with latitude higher than 50° | Min. 90% | |
| **SR 7:** Total mission duration | 5 years | |

# **SR 7:** Mission duration of min. 5 years

- Need of interannual comparison caused by the high dependency of weather processes on seasonal variations



Data by rssWeather

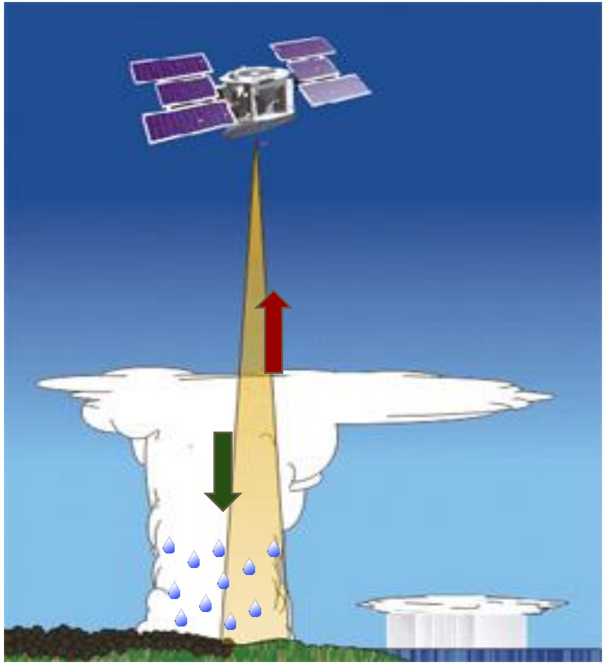


Location of Anchorage in southern alaska

# II. Measurement & Payload

# Objective: Measure Precipitation
# Medium: Radar

Credits: CEOS/ESA



**Principle:** Send an electromagnetic wave (pulse) toward a target (raindrops or snowflakes) and measure the backscattered wave power.

- Distance to the target deduced from the time of arrival of the backscattered wave.
- Received power depending on backscattering volume Vc, distance R, and volumic reflectivity Z

$$\overline{P}_r = \frac{P_t G_t G_r \lambda^2 V_c \overline{\eta}}{64\pi^3 R^4}$$

$$\overline{\eta} = \frac{\pi^5 |K|^2}{\lambda^4} Z$$

# Measurement Principle: Rain Reflectivity

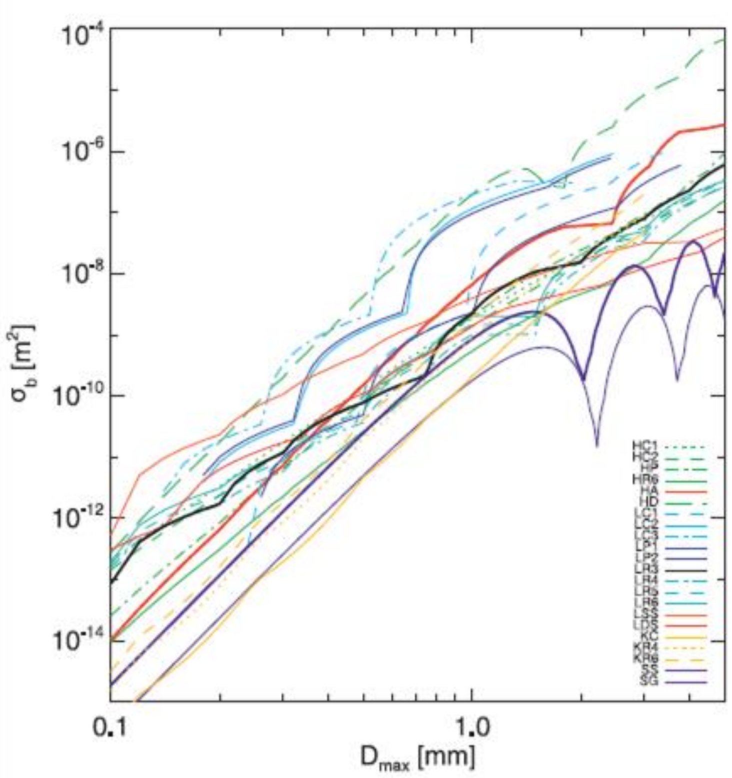
For spherical raindrops reflectivity depends on the distribution of the drops diameter in the backscattering volume: $Z = \int_0^\infty D^6 N_v(D) dD$

Reflectivity is generally expressed in dBZ: $dBZ \propto 10\, log \frac{Z}{Z_0}$

$Z_0$ is the reflectivity of one spherical drop of 1 mm diameter in 1 m3 of air

Assuming a given parametric distribution, or from empirical calibration, a relation between rain rate and reflectivity: $Z = aR^b$

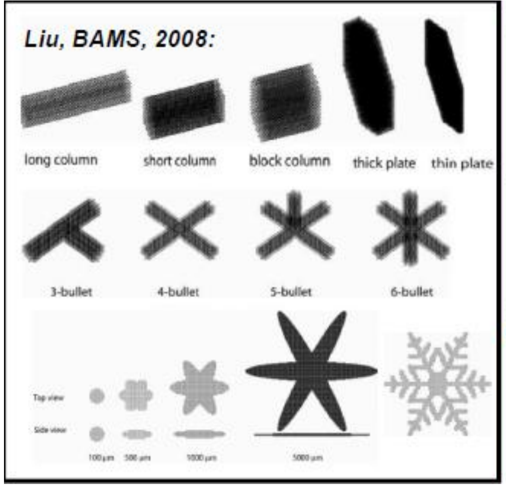
# Measurement Principle: Snow Reflectivity

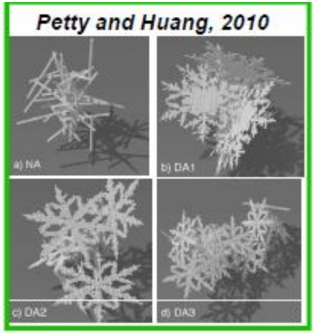


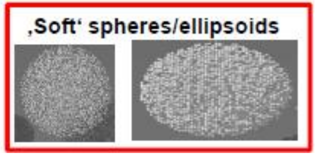
Kulie and Bernnartz 2009

For snow, a more complex problem:

- Snow generally have a lower reflectivity than rain
- Different flake shape = different reflectivity

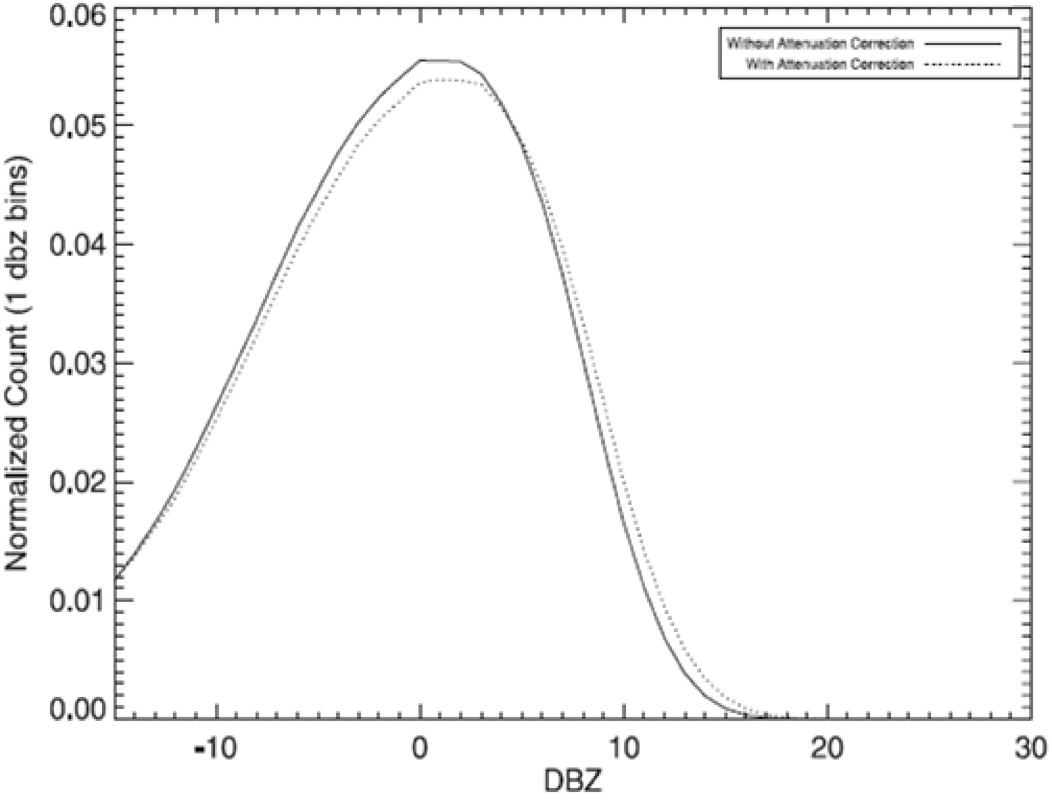

Liu, BAMS, 2008:


Petty and Huang, 2010

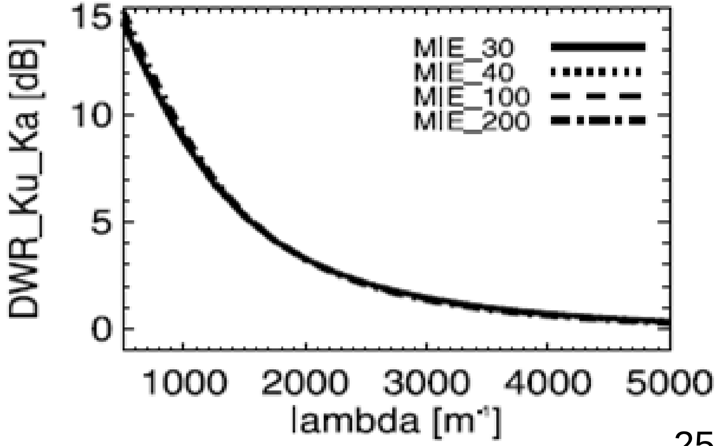

‚Soft‘ spheres/ellipsoids

# Solution: Dual-Frequency Ka/W Radar

- High frequencies, 35.5 and 94 GHz, for higher sensitivity
- Differential reflectivity for eliminating ambiguity on particles shape



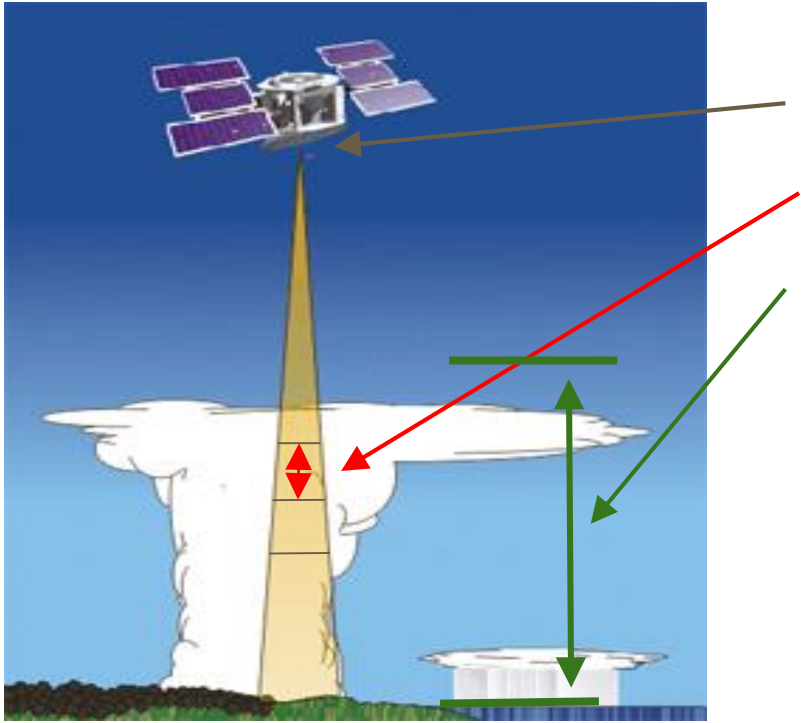
Kulie et al. 2010



Kneifel et al. 2011

# Requirements: Measurement to Instrument

Credits: CEOS/ESA



- Horizontal resolution → Antenna size
- Vertical resolution → Pulse width
- Vertical extent → Pulse Repetition Freq.
- Min. measurable reflectivity

→ Transmitted peak power

# Requirements: Measurement to Instrument

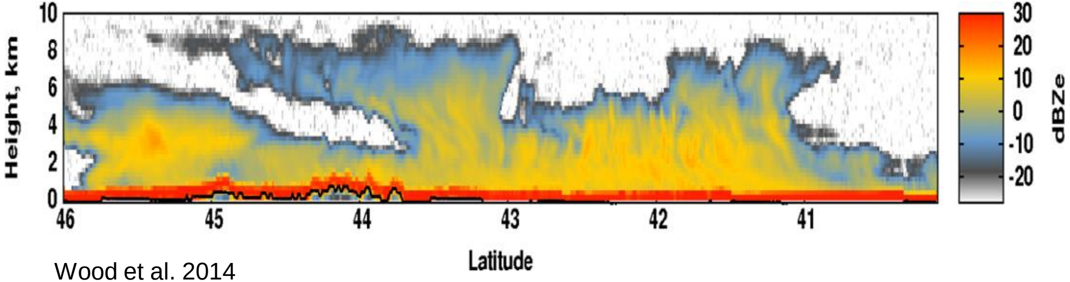
For **3D** reflectivity profiles: a **scanning** radar

-Vertical profile of volume reflectivity

-Vertical profile of precipitating liquid water and ice content

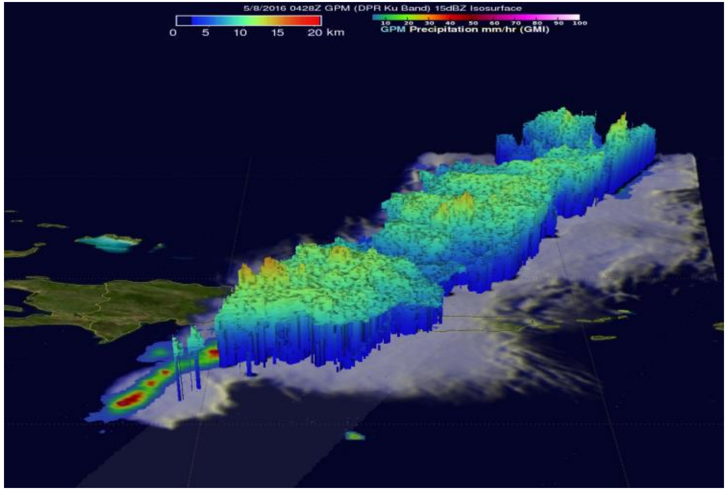
-Surface precipitation rate

Non-scanning: Cloudsat snow reflectivity profile



Wood et al. 2014

Scanning: GPM rain reflectivity profile



Credits: NASA/JAXA/SSAI, Hal Pierce

# Measurement Requirements

| **Measurements requirements** | **Driving requirements** |
|---|---|
| **MR1:** Dual-frequency active radar instruments shall be used to retrieve precipitation in accordance with the scientific requirements. | SR1, SR2, SR3, SR4 |
| **MR2:** A minimum reflectivity of 10 dBZ for the Ka-band radar and -10 dBZ for the W-band radar shall be detected by the radar instruments. | SR1 |
| **MR3:** A pulse duration of 3.3 microseconds shall be achieved by the radar instruments. | SR4 |
| **MR4:** A Pulse Repetition Frequency (PRF) of 4300 Hz shall be provided by the instruments. | SR5 |
| **MR5:** A scanning half angle of 18° shall be achieved by the radar instruments. | SR3, OR1 |

# Requirements: Measurement to Instrument

**Instruments characteristics:**

3.3 µs pulse → 500 m vertical res.        4300 Hz PFR → >20 km vertical extent

± 18° cross-track scanning → 300 km swath width

**KaRad (35.5 Ghz):**

- Phased array antenna 0.9m x 0.9 m, Gain: 49.6 dBi
- 600 W Peak Transmitted Power → 8.6W mean TP

→ 4 km horizontal res. at ground

→ 10 dBZ sensitivity for a SNR=3

**WRad (94 Ghz):**

- Phased array antenna 0.75 x 0.75 m, Gain: 55 dBi
- 1200 W Peak Transmitted Power → 17.2W mean TP

→ 2 km horizontal res. at ground

→ -10 dBZ sensitivity for a SNR=3

5 dBZ of sensitivity can be gained by noise reduction (averaging)

# Instrument Specifications (Options 1 & 2)

**Ka/W Dual Band Radar**
Conical Scanning at 18 degrees incident angle

Main reflector diameter: 1.8m
Frequencies: 36 Ghz / 84 Ghz
Power Consumption : 520 W
Mass (TBC): 400 kg
Dimensions: 2 m x 2 m x 3 m (TBC)

**Rotating dual reflector system with stationary feed horn(s)**
Required rotation speed to achieve the horizontal resolution is too high (~100 RPM) for reflector mass
→ Stability and lifetime problem

Image credits: nasa.gov, BATC

# Instrument Specifications (Options 1 & 2)

**Stationary reflector with rotating feed horn(s)**

Slower rotation speed for lower mass

Quad polarization (V & H)

Rotary joint is challenging

Limited antenna diameter (~1.4m)

Need ~6 beams per frequency in order to obtain adjacent tracks on ground

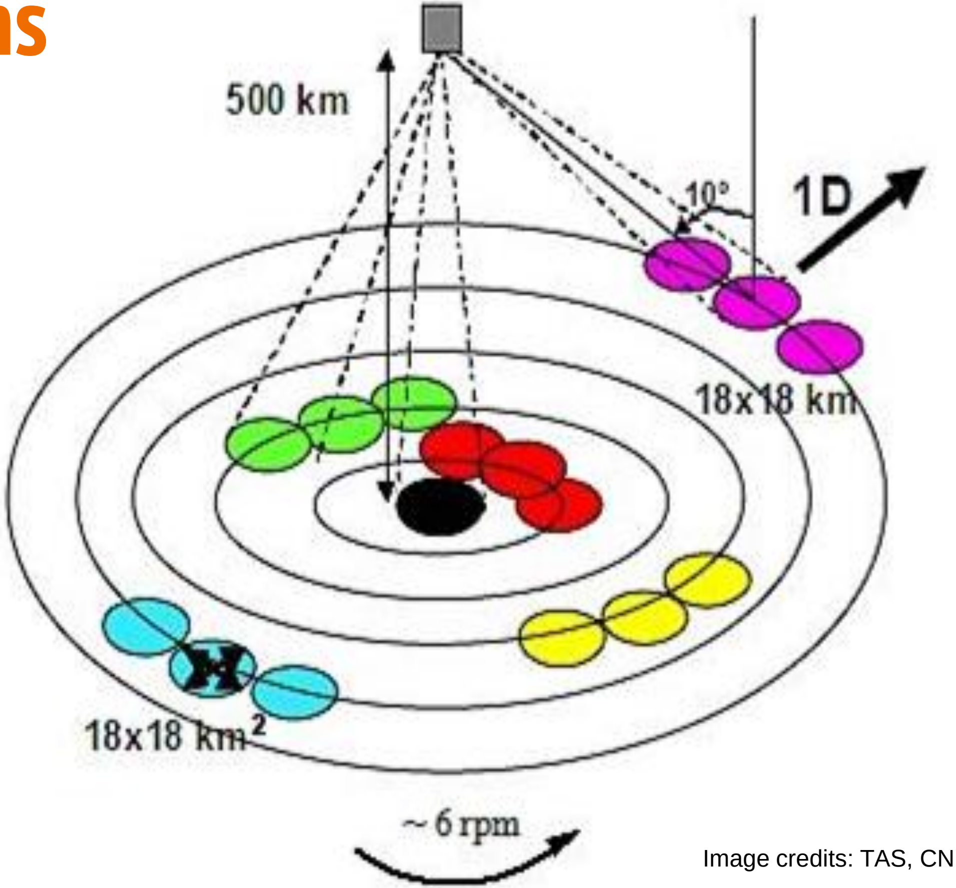


Image credits: TAS, CNES

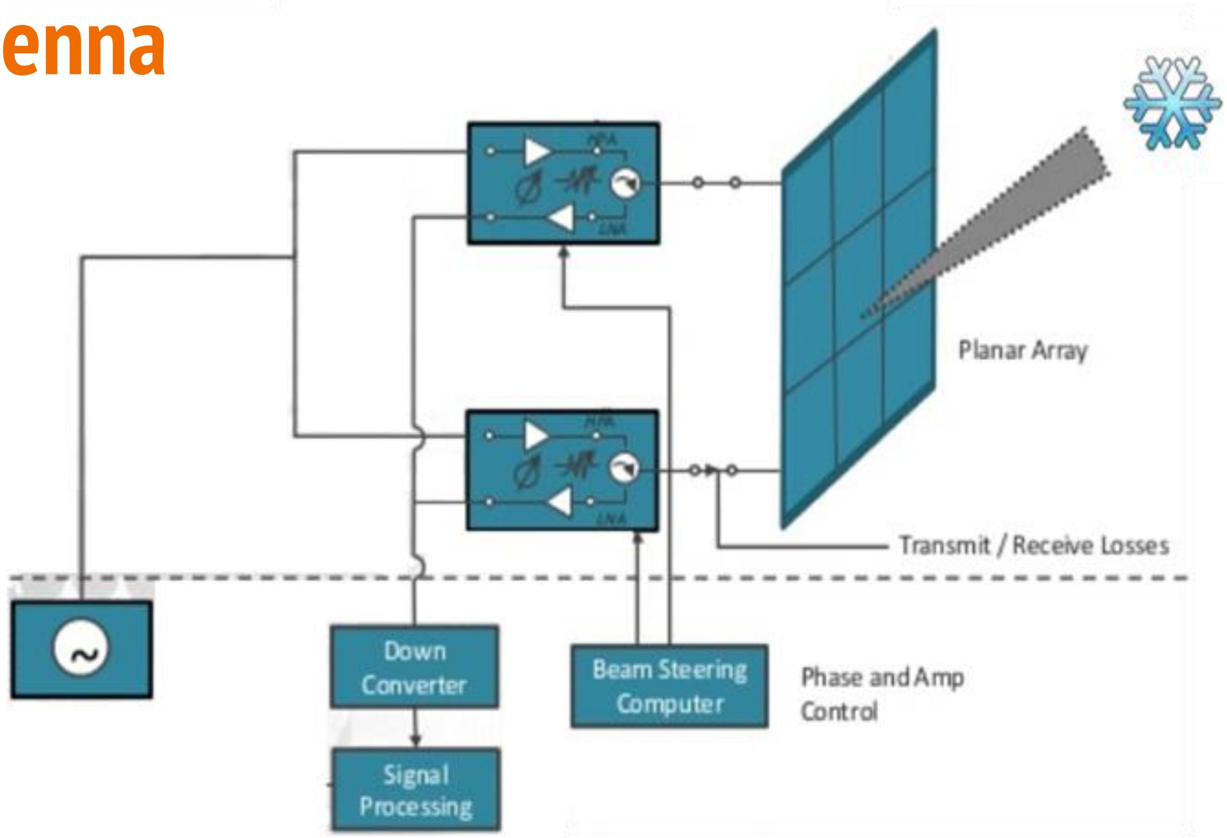
# Instrument Options

| | Option 1 | Option 2 | **Option 3** |
|---|---|---|---|
| Band | Ka/W | Ka/W | Ka/W |
| Scan | **Rotating reflector** conical scan at 18° | Stationary reflector with **rotating feed horns** at 18° | **Phased-array cross-scanning** |
| Polarimetric (V&H) | Yes | Complicated | No |
| Antenna size | D = 1.9  m | D = 1.4 m (d) | 0.9 x 0.9 m / 0.75 x 0.75 m |
| Mechanical & electrical limit | Rotating reflector ~100 rpm | Multiple parallel RF channels (rotary joint issue) | Adaptation development needed for space-borne W-band phased array antennas |
| | 🚫 | 🚫 | ✚ |

# Phased Array Antenna

An **array of antennas** whose effective radiation pattern can be altered by phasing the signal of the individual elements.

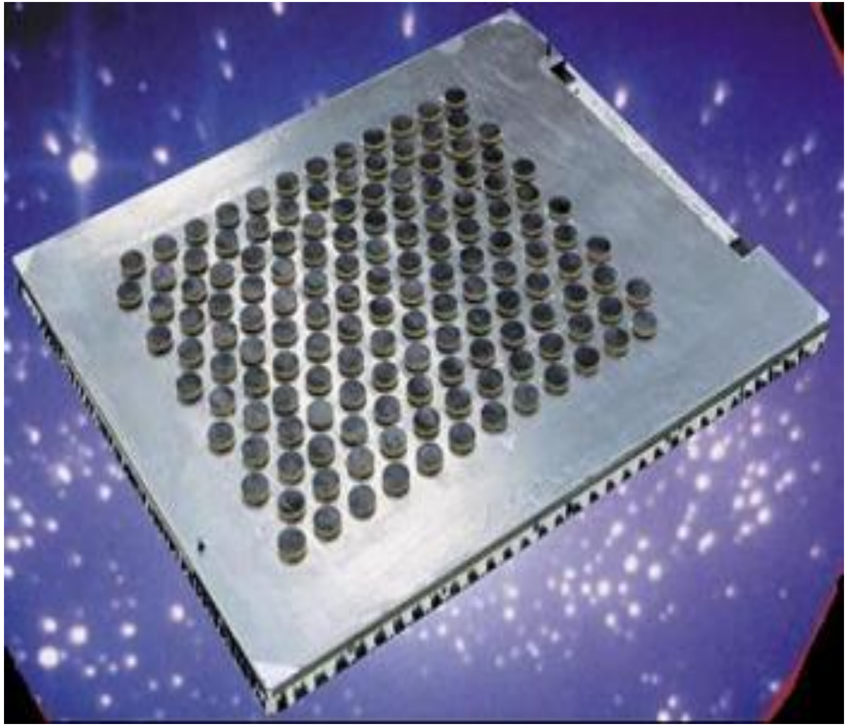
The **radiation pattern** can be reinforced in a given **direction** and electronically steered → eliminates the need for moving parts



# Phased Array Antenna

The proposed instrument is a **uniform planar array** containing 20x20 elements in the W band and 15x15 elements in the Ka band.

**Reliability**: If one antenna fails, the rest continue to function → collective pattern is slightly modified (graceful degradation)



# Instrument Requirements

| **Instruments requirements** | **Driving requirements** |
|---|---|
| **IR1:** A maximum payload mass of 700 kg (including margins) shall not be exceeded. | MR1 |
| **IR2:** The radar instruments shall be able to operate with a 1.4% duty cycle. | MR2, MR3, MR4 |
| **IR3:** The radar instruments shall present a noise figure of 1.5. | MR2 |
| **IR4:** The power required by the payload instruments shall not exceed 700 W (including margins). | MR1, MR2 |
| **IR5:** The antennas shall exhibit the following dimensions:<br>● 0.9m x 0.9m x 0.7m for the Ka-band radar<br>● 0.75m x 0.75m x 0.7m for the W-band radar | MR2 |
| **IR6:** The following peak transmitted powers shall be provided by the radar instruments:<br>● 600 W for the Ka-band radar<br>● 1200 W for the W-band radar | SR1 |

# III. Mission Profile

# Orbit Requirements

| **Instruments requirements** | **Driving requirements** |
|---|---|
| **OR1:** The selected orbit shall be able to provide the required coverage. | SR6 |
| **OR2:** The selected orbit shall be able to provide the required power for the whole mission duration. | IR4 |

# Target Orbit - Final Choice

Sun Synchronous Orbit

LTDN 6:00 DawnDusk (Incli. 97.25°)

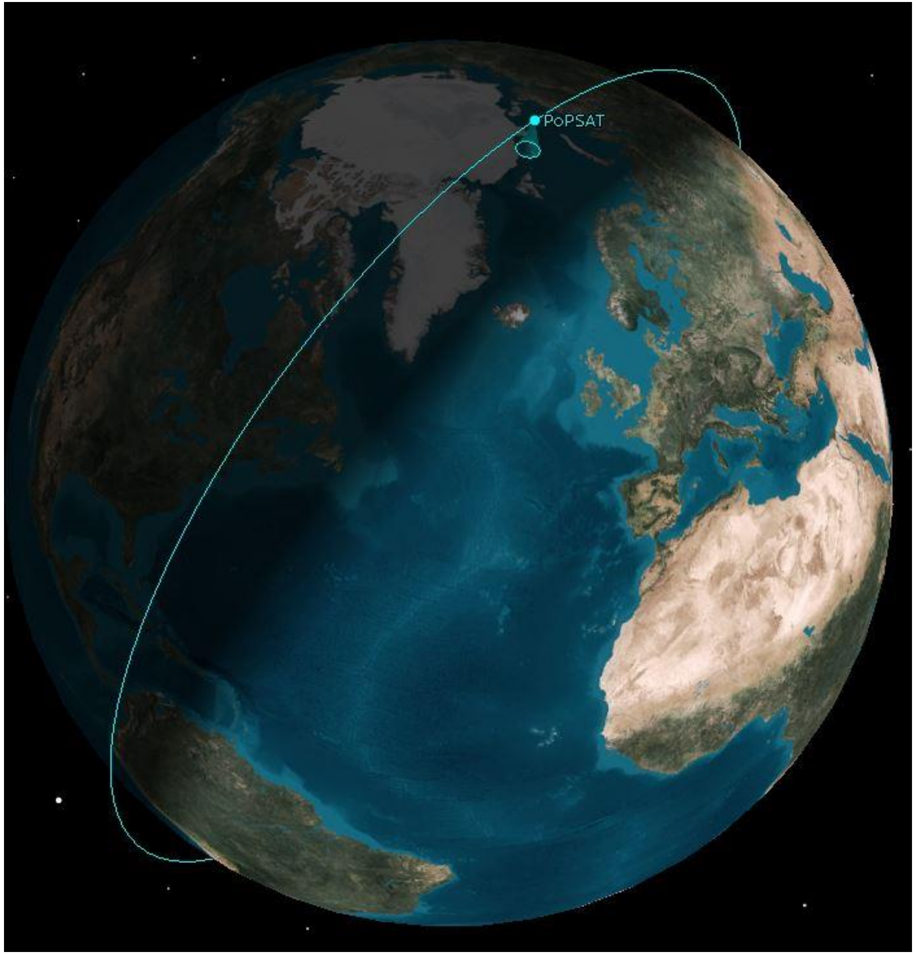
Altitude: 460 km

Eclipse from May - Aug

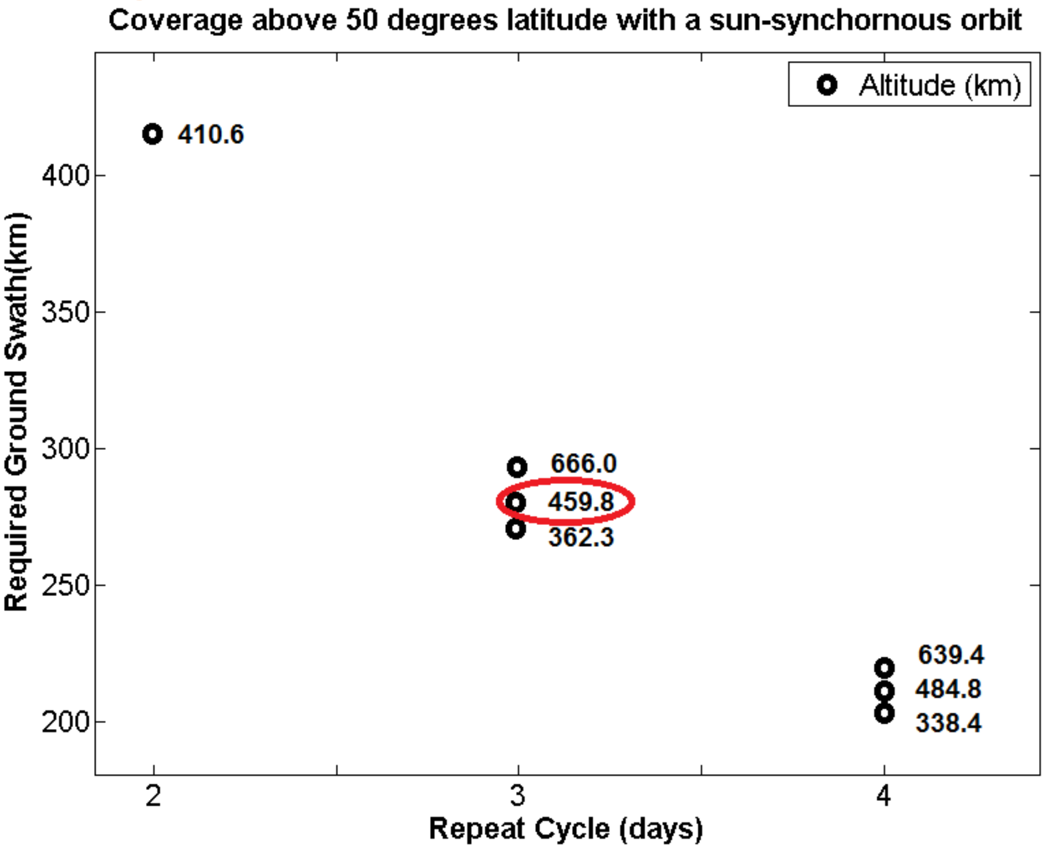
Mean eclipse: 19.6 min

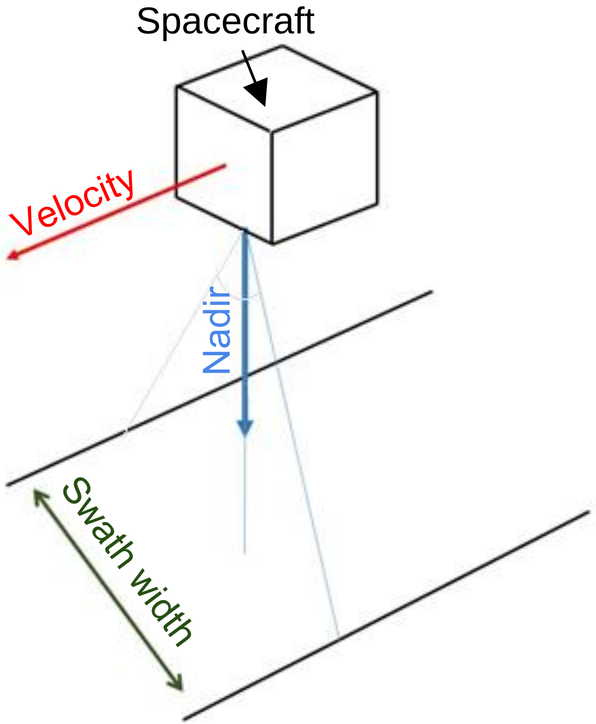
Max. eclipse: 23.8 min

Period: 93.7 min (15.3 Orbits per day)



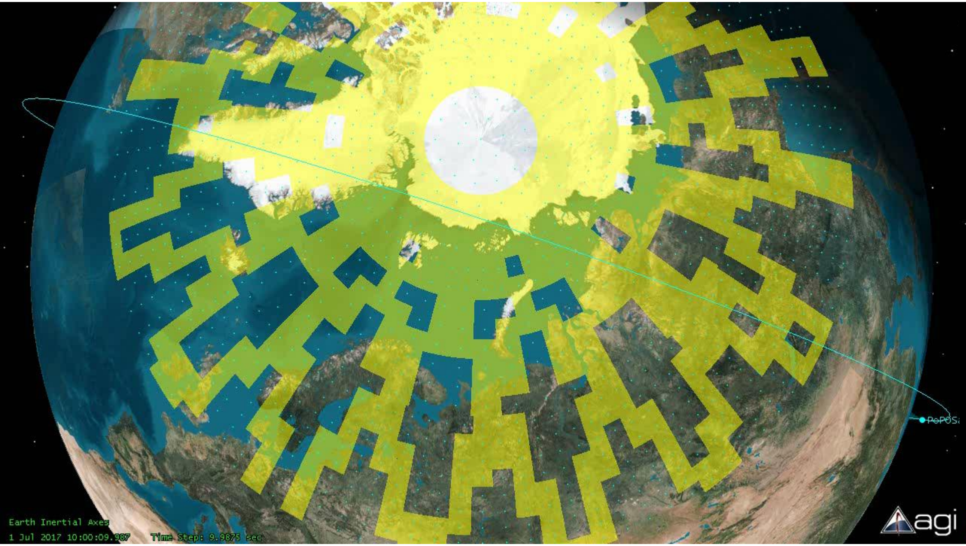
# Target Orbit - Trade-Off



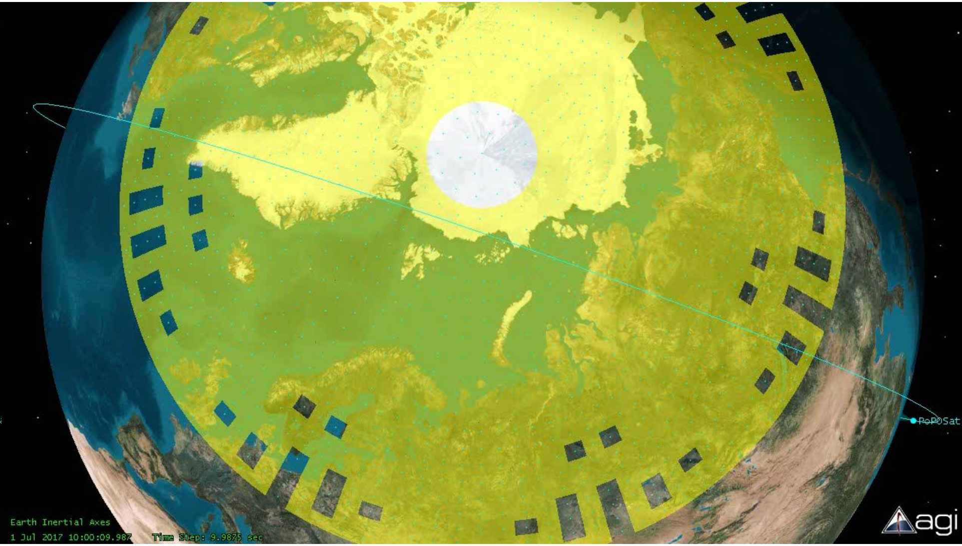


# Coverage

**24h** observation time: **51**% coverage >50ºN



**72h** observation time: **92**% coverage >50ºN



# Radiation Environment

| **Al absorber thickness** | | | | |
|---|---|---|---|---|
| **Shielding [mm]** | **Area density [g/cm²]** | **Total [krad]** | **Margin** | **Total with margin [krad]** |
| 1 | 0.27 | 24.8 | 100 % | 49.6 |
| 2 | 0.54 | 7.07 | 100 % | 14.14 |

Total Ionizing Dose for 5 year 460km SSO

Non critical altitude for radiation hardened components

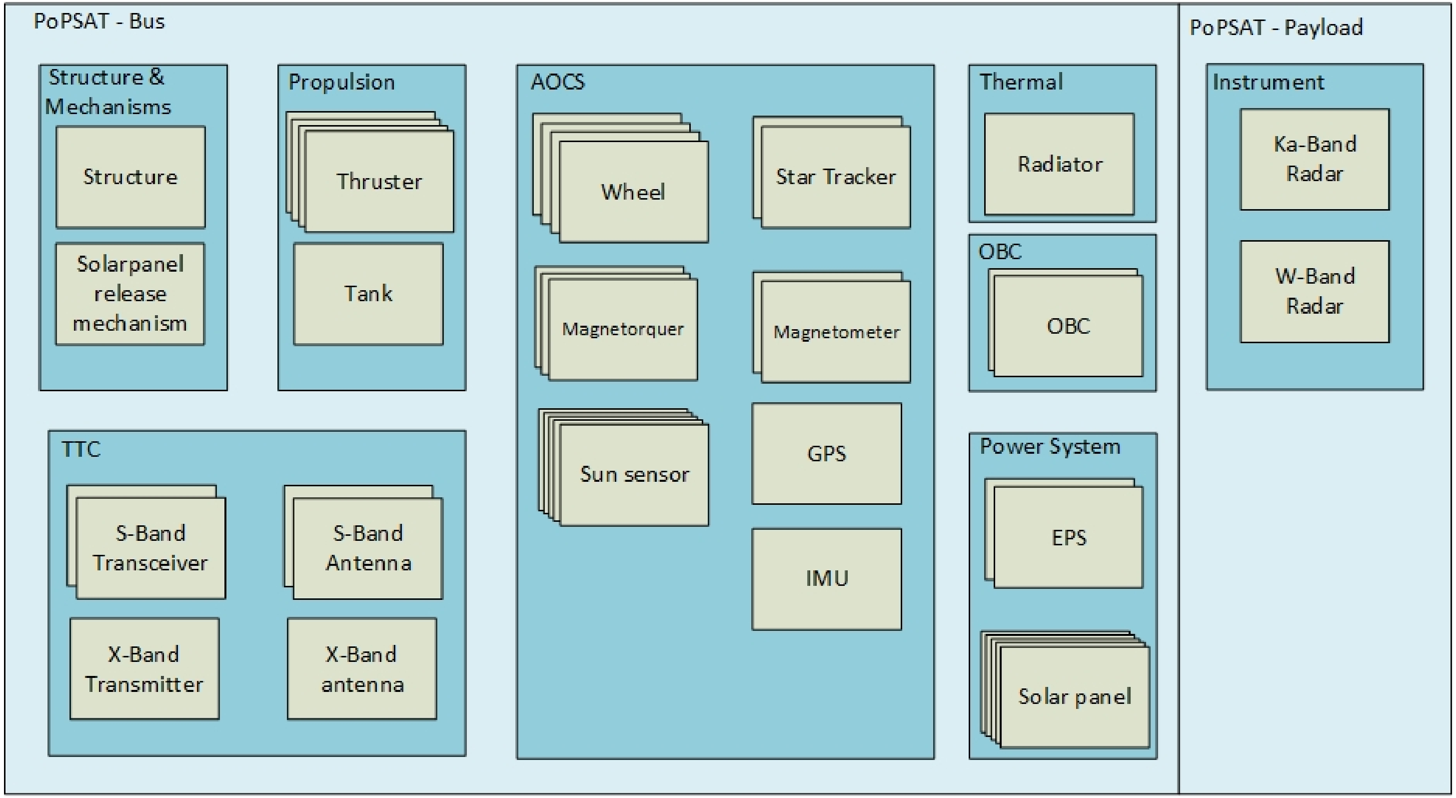
Critical subsystems (e.g. star tracker) are available in cold redundancy

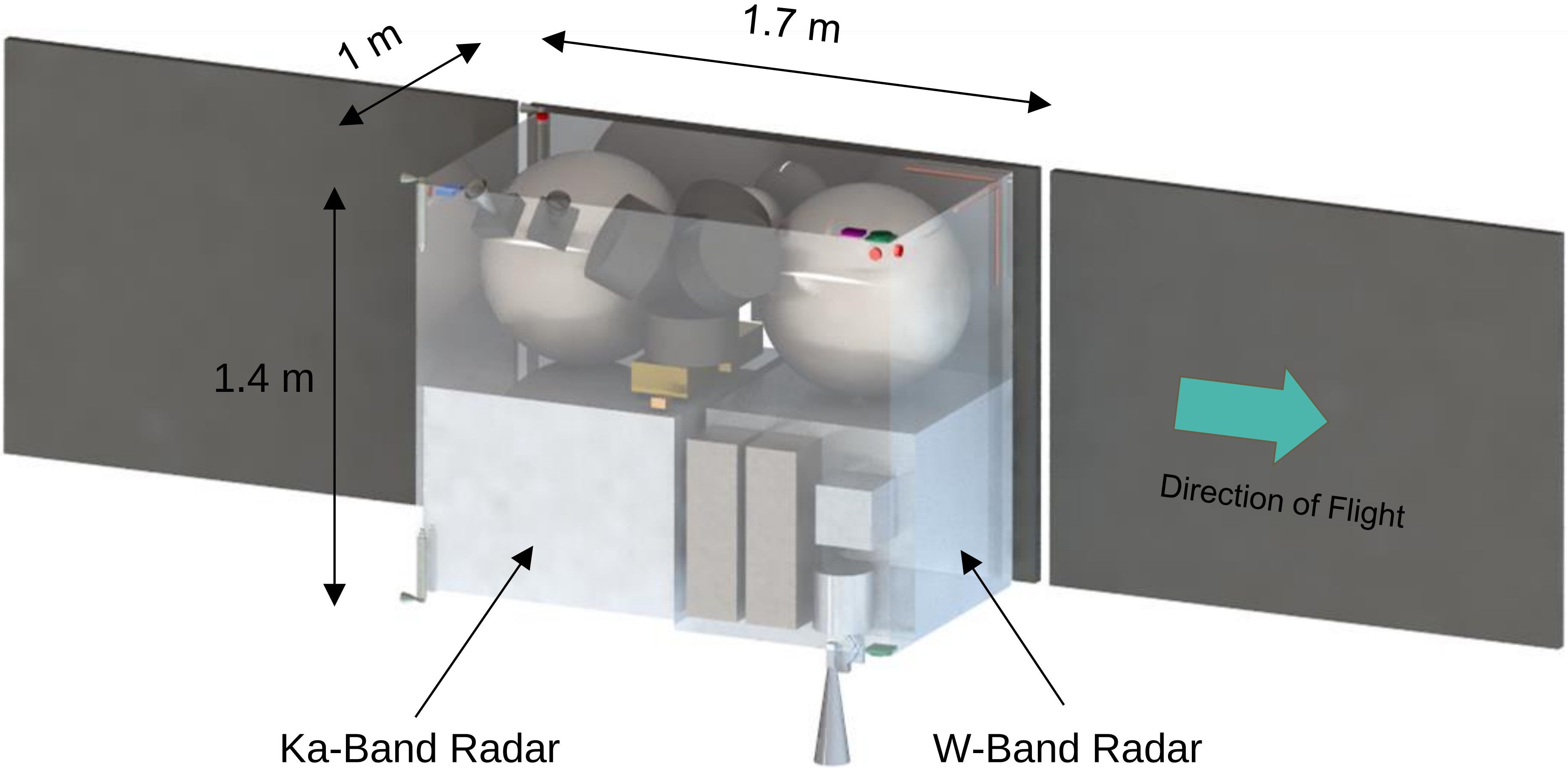
# IV. Spacecraft

# Configuration Requirements

| **Configuration requirements** | **Driving requirements** |
|---|---|
| **CR1:** The payload instruments have to point towards Earth. | SR1, SR2, SR3, SR4, SR5 |
| **CR2:** Ensure free field of view for the payload instruments. | SR1, SR2, SR3, SR4, SR5 |
| **CR3:** Ensure access to deep space for sensors. | BR6, BR7, BR8 |
| **CR4:** The Earth-pointing side of the satellite shall provide allocation for the S-band and X-band antennas. | BR3 |
| **CR5:** The satellite volume in undeployed configuration shall fit the Soyuz fairing envelope. | IR1, IR5 |

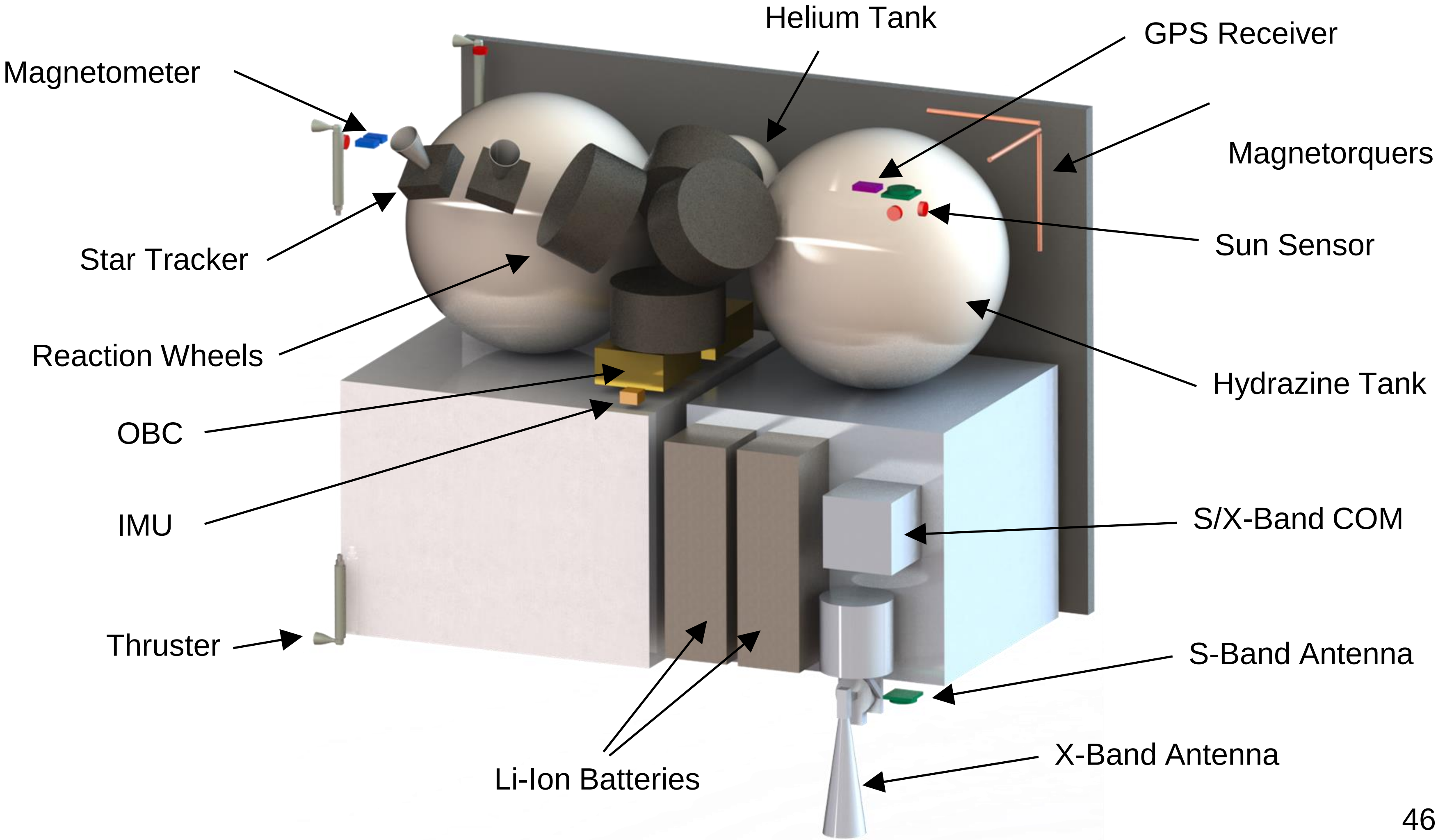
# Satellite Model





Ka-Band Radar

W-Band Radar


Helium Tank
GPS Receiver
Magnetometer
Magnetorquers
Sun Sensor
Star Tracker
Reaction Wheels
Hydrazine Tank
OBC
IMU
S/X-Band COM
Thruster
S-Band Antenna
X-Band Antenna
Li-Ion Batteries

# Envelope & Launcher

- ❑ Total Satellite Mass: **2.4 t**
- ❑ SSO (460 km) performance of *Soyuz*: **4.6 t**

⇒ **Dual Launch**: PoPSAT fits both in the *top* and *bottom* compartment plus a **2.2 t** secondary payload

---

⇒ **Cut-down** of launch cost from 75 M€ to **40 M€**

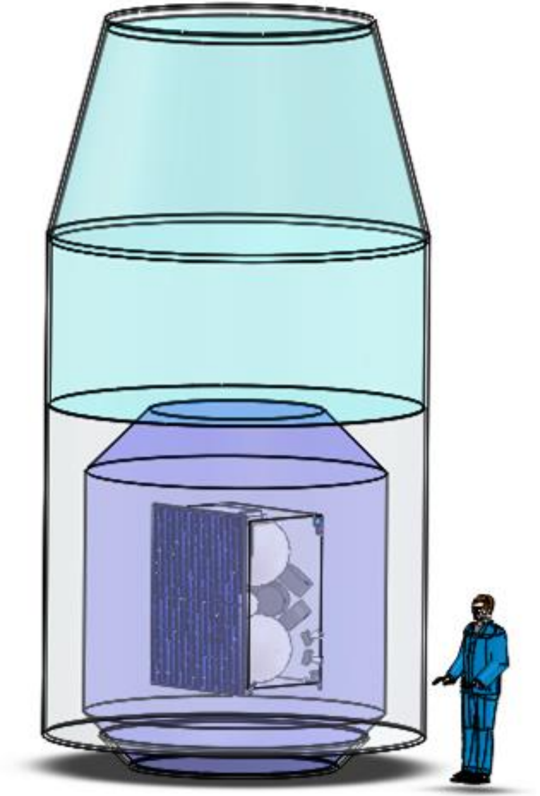
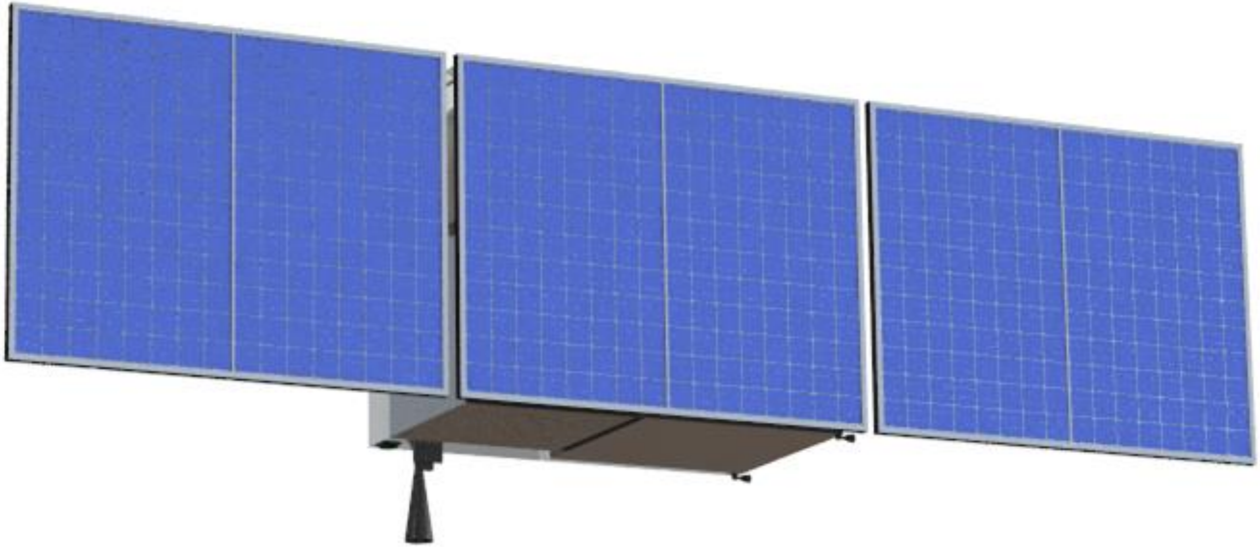


Figure - PoPSAT in Soyuz Envelope

# Power Subsystem Requirements

| Subsystem requirements | Driving requirements |
|---|---|
| **BR1:** Primary power shall be able to supply 1200 W on average during whole mission. | MR1, MR2 |



# Power Subsystem

Credit: Solaerotech

Regulated bus (28 V)

Credit: Saftbatteries

Subsystems

Source: triple-junction GaAs solar cells (efficiency: 30%)

Power distribution

Storage: two Li-Ion batteries with a total capacity of 965 Wh

Solar array size: 8.3 m² ⇨ Power production capability:

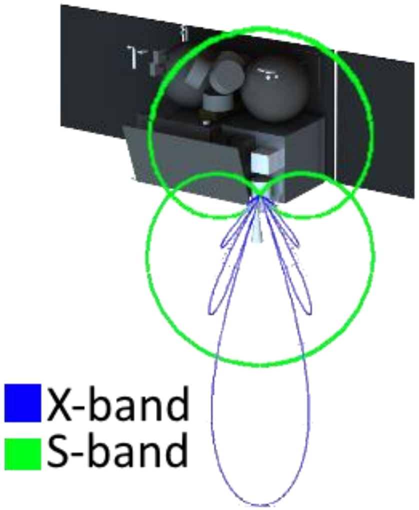
- Begin-of-Life: 272 W/m²
- End-of-Life: 224 W/m²

# Telecommunication System Requirements

| **Subsystem requirements** | **Driving requirements** |
|---|---|
| **BR3:** The communication subsystem shall be able to achieve a data rate of 100 Mb/s. | SR2, SR3, SR4 |
| **BR4:** The subsystem shall be able to store at least 30 GB data. | SR2 |

# Communication

- Two patch antennas for TT&C for communication in any direction
- High gain horn antenna with pointing mechanism for X-band



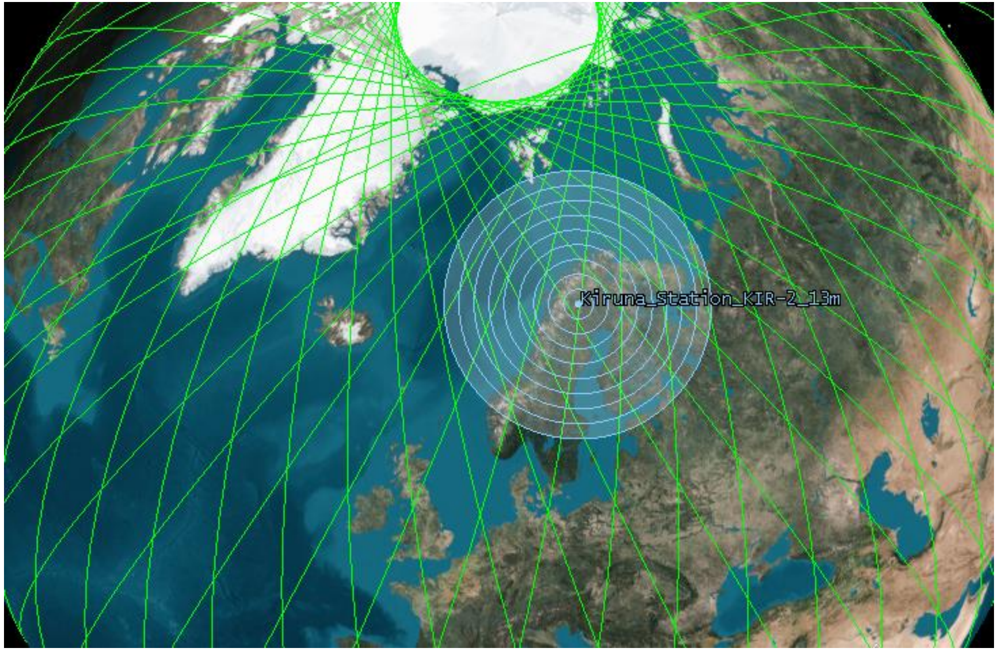
PoPSAT radiation pattern, 2016

# System Budget - Link

|  | **S-band up** 4 kb/s | **S-band down** 8 kb/s | **X-band down** 100 Mb/s | **Unit** |
|---|---:|---:|---:|---|
| **EIRP** | 69 | 0 | 21 | dBW |
| **Transmission loss** | -169 | -169 | -180 | dB |
| **G/T** | -38 | 21 | 36 | dB/K |
| **Eb/No** | 43 | 30 | 26 | dB |
| **Required Eb/N0** | 3 | 3 | 10 | dB |
| **Margin** | 40 | 27 | 17 | dB |

# Ground Station Segment

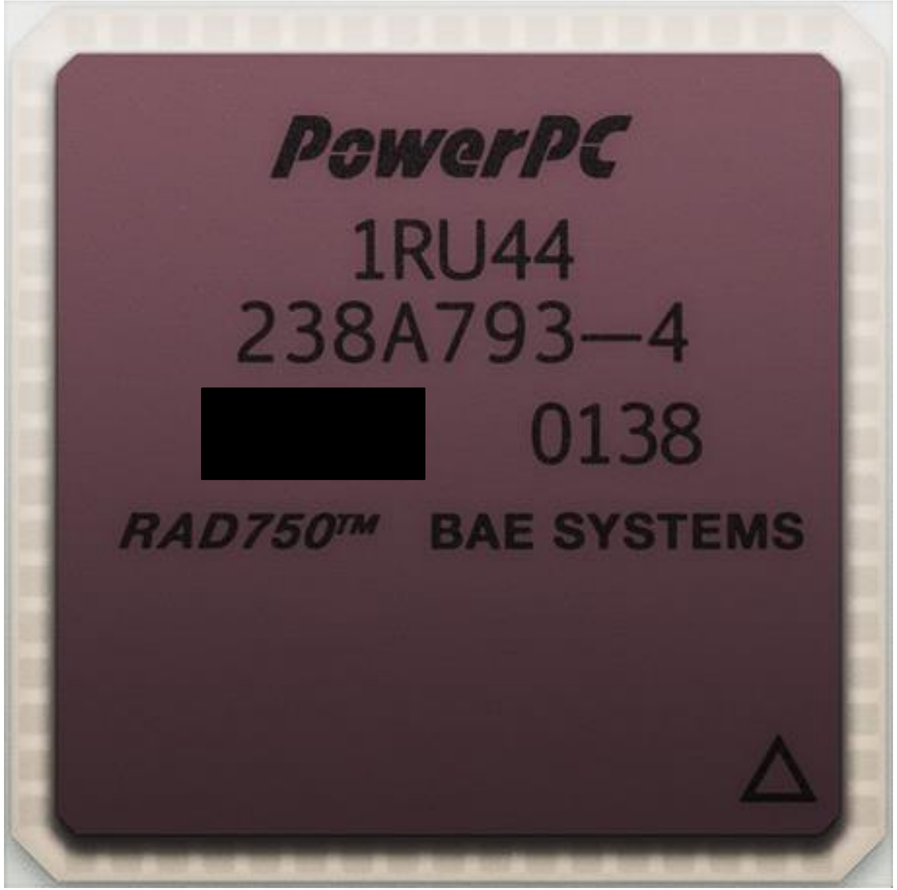
- Kiruna estrack ground station
    - 7-8 passes per day
- S-band for TT &C
    - 4 kb/s up, 8kb/s down
- X-band for instrument data
    - 3 GB downloaded once per day at 100 Mb/s



# On-Board Computer

The spacecraft OBC performs the calculations for attitude control, payload control function and can receive commands.

Temp range: -55° to 70°
Rad hard: 100 krads
Power: 10 W
Mass: 1.6 kg
Price: €180,000



# AOCS & Propulsion System Requirements

| **Subsystem requirements** | **Driving requirements** |
|---|---|
| **BR6:** During science operation, the S/C shall have an absolute pointing accuracy of better than 400 arcsec for at least 94.5% of the operational time. | SR1, SR2, MR5 |
| **BR7:** During science operation, the S/C shall have a pointing knowledge of better than 60 arcsec for at least 95.4% of the operational time. | SR1, SR2, MR5 |
| **BR8:** During science operation, the S/C shall have a pointing stability of better than 3.50 deg/s. | SR1, SR2, MR5 |
| **BR9:** Propulsion subsystem shall provide the required thrust for all the propulsive maneuvers to be performed by the S/C. | SR1, SR2, MR5 |

# AOCS & Propulsion System

- 3 axis stabilisation + Nadir pointing

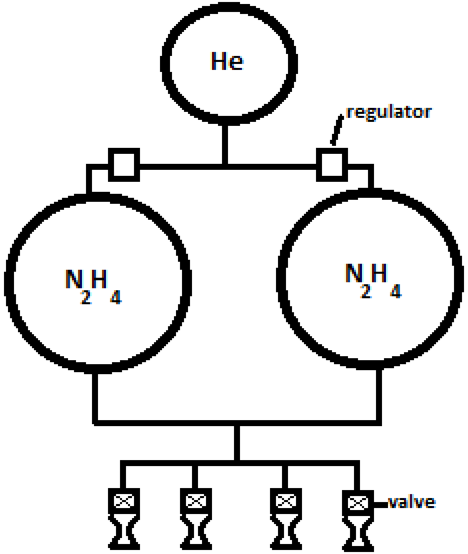
- Attitude determination:

| **Sensors** | **Units** | **Resolution** |
|---|---|---|
| Sun sensor | 5 | 0.3 deg |
| Star Tracker | 2 | 30 arcsec |
| Magnetometer (3 axis) | 2 | 0.5 deg |
| IMU | 1 | 1 deg/h (TBD) |
| GPS (position) | 1 | Position: 10 m<br>Velocity: 0.1 m/s |

- Attitude control:

| **Components** | **Units** | **Characteristics** |
|---|---|---|
| Reaction Wheels | 4 | Max torque: 215 Nm<br>Max momentum: 15 Nms |
| Magnetorquer | 3 | Dipole moment: 6 Am2 |
| Thrusters | 4 | 20 N |

- Propulsion diagram:



# Thermal Control System Requirements

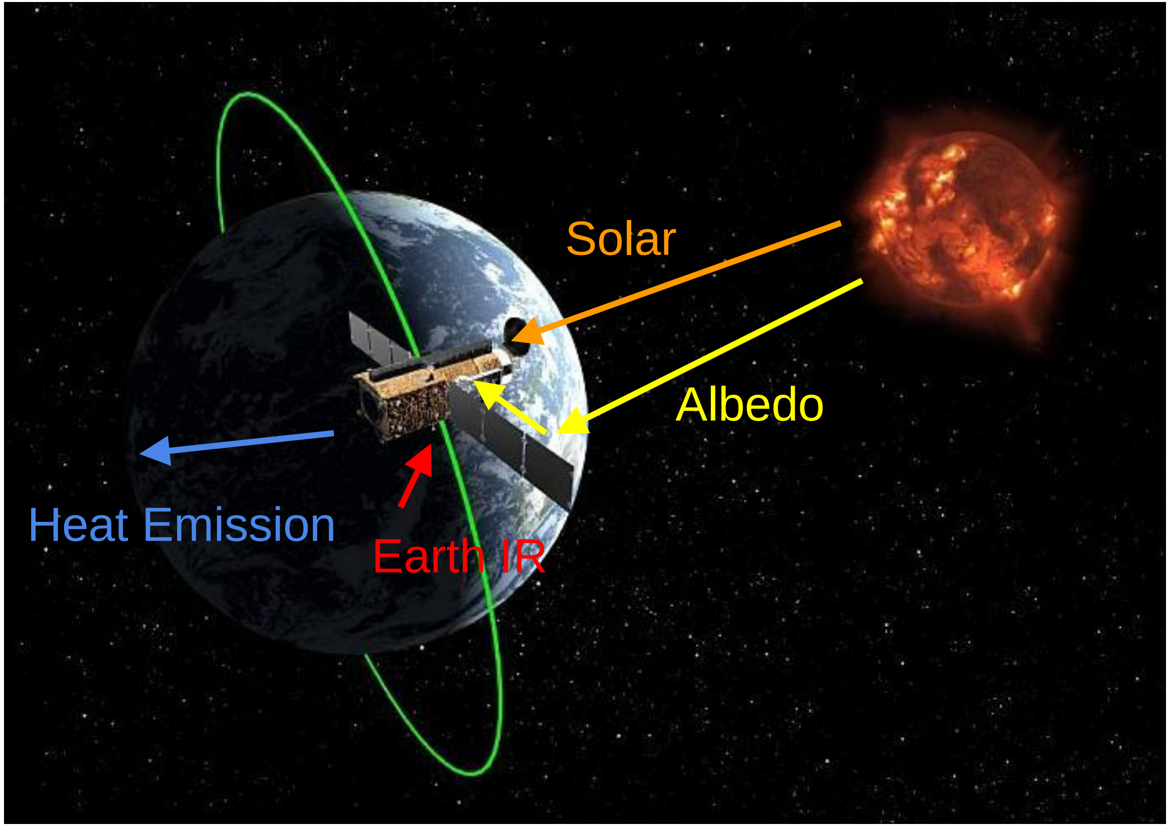
| Subsystem requirements | Driving requirements |
|---|---|
| **BR5:** The thermal control system shall control that all subsystems operate within their required temperature ranges and shall be designed to ensure a temperature of approx. 25°C throughout the whole mission lifetime. | MR1 |

# Thermal Control System

- Thermal model based on sun synchronous orbit of 3 axis stabilized S/C

- MLI on the surface facing the sun

- Aluminized Kapton + teflon radiator on the side facing deep space



# Thermal Control System

| Worst case hot/cold | Hot Case | Cold Case |
|---|---|---|
| **Power dissipated** | 600 W | 300 W |
| **Solar radiation** | 1420 W/m$^2$ | 0 W/m$^2$ |
| **Temperature with passive TC** | 49° C | 14° C |
| **Temperature with radiator and heater** | ~25° C | ~25° C |

- A teflon radiator facing deep space of 1.3 m$^2$
- During eclipse, heaters are needed to provide temperature stability.
- Operational and survival temperature range for the payload has yet TBD.

# Satellite Operating Modes

| | AOCS | AOCS safe | COMM | Data download | Thermal | OBC | PL |
|---|---|---|---|---|---|---|---|
| **LEOP** | ✗ | ✓ | ✓ | ✗ | ✓ | ✓ | ✗ |
| **Nominal** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Safe** | ✗ | ✓ | ✓ | ✗ | ✓ | ✓ | ✗ |
| **Station Keeping** | ✓ | ✓ | ✓ | ✗ | ✓ | ✓ | ✗ |
| **End of life** | ✗ | ✓ | ✓ | ✗ | ✗ | ✓ | ✗ |

Always possible to send TC to the satellite

# System Budget - ΔV

- For a lifetime of 5 yr (Solar flux 150):

| Manoeuvre | Delta v (m/s) | Unit level margin % | Total (m/s) |
|---|---|---|---|
| **Launcher dispersion** | 35 | 5% | 37 |
| **Stationkeeping** | 168 | 10% | 185 |
| **Re- or Deorbit** | 0 | 10% | 0 |
| **Safe Mode Reserve** | 34 | 5% | 35 |
| **Collision avoidance** | 10 | 5% | 11 |
| **Total** | **247** | | **267** |

- No active orbit removal → natural deorbiting within 4 years

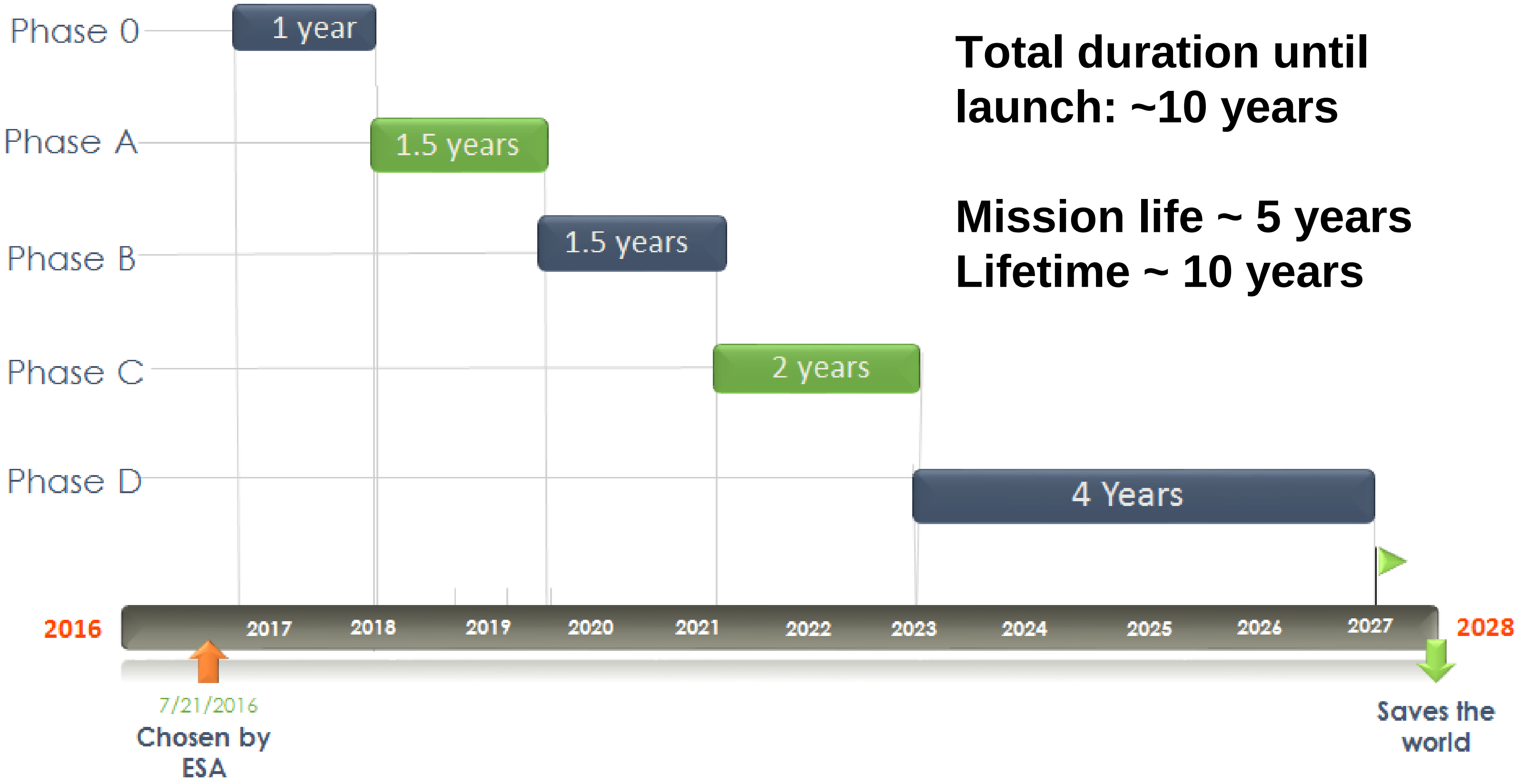
# System Budget - Mass

| **PoPSAT** | **Component** | **Mass w/o margins [kg]** | **Applied Margin [%]** | **Mass with Margin [kg]** | **Percentage of Dry Mass [%]** |
|---|---|---|---|---|---|
| **Subsystems** | AOCS | 42 | 10 | 46 | 3 |
| | TTC, Antennas | 11 | 10 | 12 | 1 |
| | OBC | 86 | 10 | 94 | 7 |
| | Power, Battery, Harness | 227 | 10 | 250 | 17 |
| | Structure & Mechanisms | 348 | 10 | 383 | 26 |
| | Propulsion | 36 | 10 | 39 | 3 |
| | Thermal | 34 | 10 | 38 | 3 |
| **Payload** | | 520 | 50 | **780** | **40** |
| **Propellant** | | 219 | 10 | 241 | |
| **Launcher** | **Launch Vehicle Adapter** | 110 | 5 | 116 | |
| | **Dry Mass / kg** | 1303 | | | |
| | **System Level Margin** | 20 % | | 20 % | |
| | **Total Mass / kg** | | | 1999 | |
| | **Total Mass with SLM / kg** | | | **2398** | |

# System Budget - Power

| **PoPSAT** | **Component** | **Power w/o margin [W]** | **Unit level margin [%]** | **Power [W]** |
|---|---|---|---|---|
| **Subsystems** | AOCS | 100 | 5% | 105 |
| | TTC, Antennas | 45 | 10% | 50 |
| | OBC | 48 | 5% | 50 |
| | Power Battery Harness | 74 | 5% | 78 |
| | Structure & mechanisms | 9 | 10% | 10 |
| | Thermal | 49 | 5% | 52 |
| | Propulsion | 72 | 10% | 80 |
| **Payload** | | 550 | 10% | **605** |
| | | 974 | | 1057 |
| | System level margin | | 10% | |
| **Total** | | 1071 | | **1163** |

# Timeline



**Total duration until launch: ~10 years**

**Mission life ~ 5 years**
**Lifetime ~ 10 years**

# Critical Risks

| Risk index | Magnitude & Acceptability |
|---|---|
| > 20 | Maximum => unacceptable |
| 15-20 | High => unacceptable |
| 10-15 | Medium => acceptable |
| 5-10 | low => acceptable |
| < 5 | minimum => acceptable |

| **Development risks** | | | | |
|---|---|---|---|---|
| **Event** | **Consequence** | **Probability** | **Severity** | **Overall Risk** |
| Development of the W-Band phase array antenna | need more effort in the development phase | 3 | 2 | **6** |
| Improvement of Ka-Band radar instrument to a higher performance | need more effort in the development phase | 2 | 2 | **4** |

# Costs

| **PoPSAT** | **Item** | **M€** | % of total |
|---|---|---|---|
| 1 | Project Team | 35 | 6.3 |
| 2 | Industrial Cost | 178 | 31.7 |
| 3 | Mission Operations | 40 | 7.1 |
| 4 | Science Operations | 25 | 4.5 |
| 5 | Payload | 175 | 31.2 |
| 6 | Launcher (Soyuz) shared | 40 | 7.1 |
| 7 | Contingency | 68 | 12.1 |
|  | **Total** | **561** |  |

Estimation for a mission lifetime of 5 years

# Feasibility & Technology Readiness

**Feasibility:**

Heritage on Ka-band (phased array) and non scanning W-band radar technology is available from the GPM and Cloudsat missions.

**Technology Readiness scale:**

- Use of space qualified hardware or parts with a high TR Level
- Ku and W radars are used for precipitation and cloud research
- Development of phased array for W-band is needed

**Scientific readiness:**

Scientific readiness level and data retrieval readiness level  is high because of the heritage from GPM and Cloudsat and from airborne experiments.

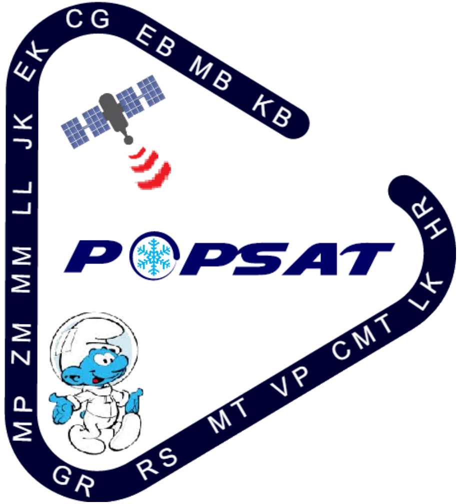
# Conclusion

**PoPSAT** is a satellite operating in a low earth orbit with an innovative dual-band radar in order to measure precipitation.

**It will:**

- Be the first mission to observe high resolution 3-D structure of precipitation systems in high latitudes.
- Provide the first precise measurements on snowfall from space
- Provide data for advancing and validating the parameterisation of precipitation processes in meteorological and climate modelling.
- Collect complementary data to operational meteorological satellites.

# THANK YOU !

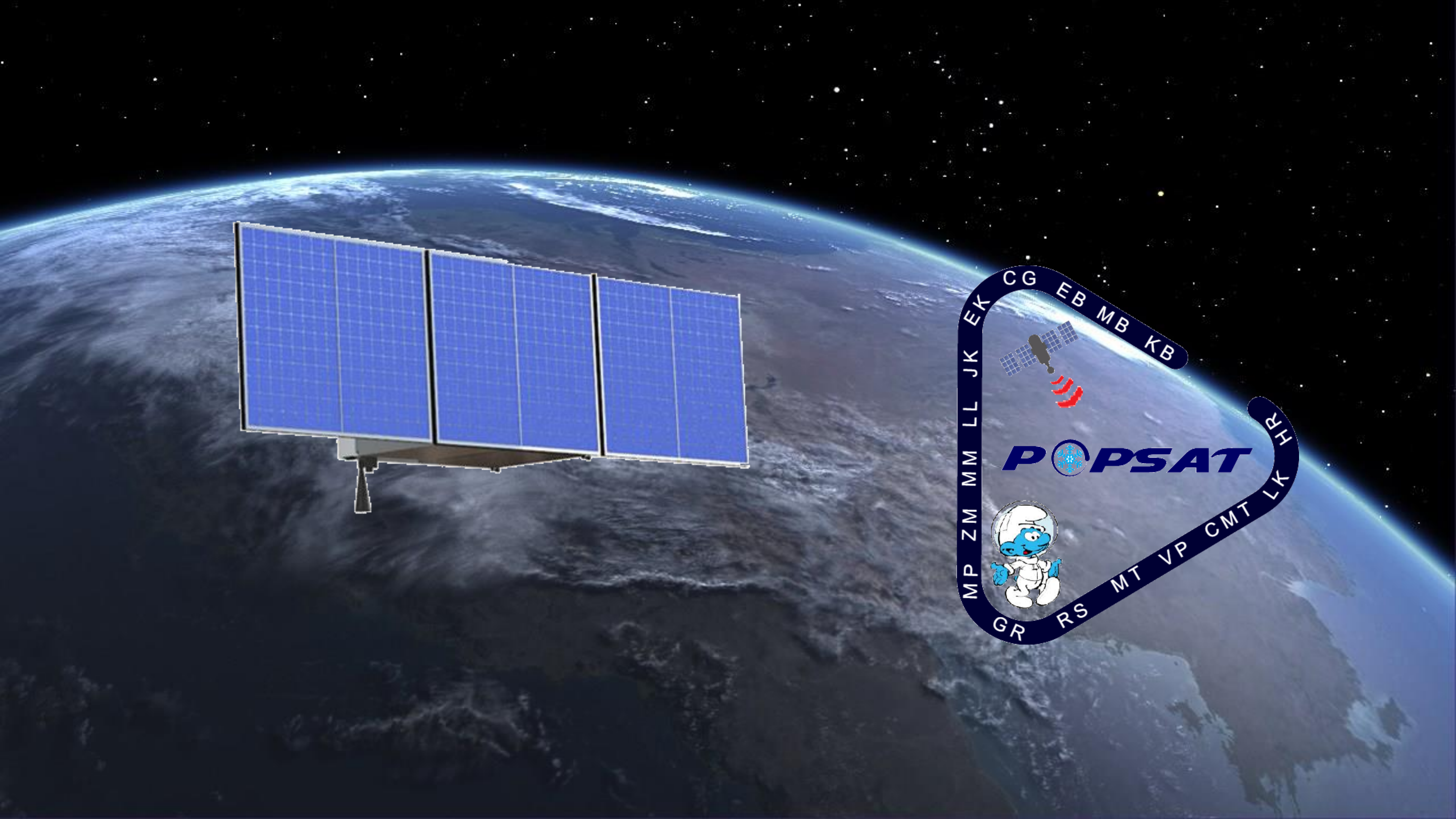


# Acknowledgements

Helmut Rott
Luzius Kronig

Marcus Hallmann
Tommaso Parrinello
Carsten Scharlemann
Arnaud Czaja

Matthias Drusch
Antonio Ciccollela
Erik de Witte
Michaela Gitsch
Peter Falkner
Anton Ivanov
Miguel Aguirre


CG EB MB KB
HR LK CMT VP MT RS GR
MP ZM MM LL JK EK
POPSAT

# Extra Slides

# Descoping - Option 1 (Mission Cost %86)

| | Ka-Band Current | Ka-Band Descoped | W-Band Current | W-Band Descoped |
|---|---|---|---|---|
| Swath Width | 300 km | 150 km | 300 km | 150 km |
| Range resolution | 500 m | 1000 m | 500 m | 1000 m |
| Horizontal res. | 4 km | 4 km | 2 km | 4 km |
| Peak T. Power | 600 W | 500 W | 1200 W | 1000 W |
| Antenna size | 90 x 90 x 70 cm | 70 x 70 x 70 cm | 75 x 75 x 70 cm | 41 x 41 x 70 cm |
| Number of ant. elements | 225 | 196 | 400 | 196 |
| Mass (estimated) | 280 kg | 240 kg | 240 kg | 200 kg |
| Instrument Pw. Con. | 300 W | 280 W | 250 W | 240 W |
| Instrument Cost | 100 % | 80 % | 100 % | 70 % |

# Descoping - Option 2 (Mission Cost %71)

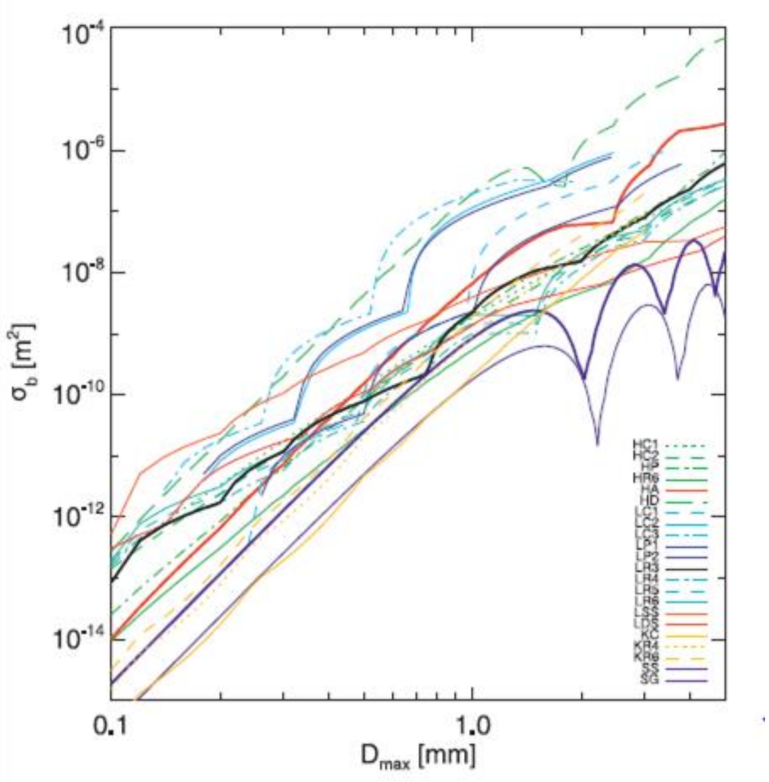
| | Ka-Band Current | Ka-Band Descoped | W-Band Current | W-Band Descoped |
|---|---|---|---|---|
| Swath Width (km) | 300 | N/A | 300 | 150 |
| Range resolution (m) | 500 | 1000 | 500 | 1000 |
| Horizontal res. (km) | 4 | 4 | 2 | 4 |
| Peak T. Power (W) | 600 | 160 | 1200 | 1000 |
| Antenna size (cm) | 90 x 90 x 70 | 100 (diameter) | 75 x 75 x 70 | 41 x 41 x 70 |
| Number of ant. elements | 225 | N/A | 400 | 196 |
| Mass (estimated) (kg) | 280 | 200 | 240 | 200 |
| Instrument Pw. Con. (W) | 300 | 250 | 250 | 240 |
| Cost (estimated) (%) | 100 | 40 | 100 | 70 |

# AOCS

| **Disturbance torques** | |
|---|---|
| Gravity Gradient = Tg | 9,99E-05 |
| Solar radiation = Tsp | 7,38E-10 |
| Magnetic field = Tm | 5,02E-05 |
| Aerodynamic = Ta | 1,34E-04 |

| **Kinetic momentum accumulation** | |
|---|---|
| Hg | 5,68E-01 |
| Hsp | 6,68E-07 |
| Hm | 1,21E-01 |
| Ha | 7,62E-01 |

# Backscattering model



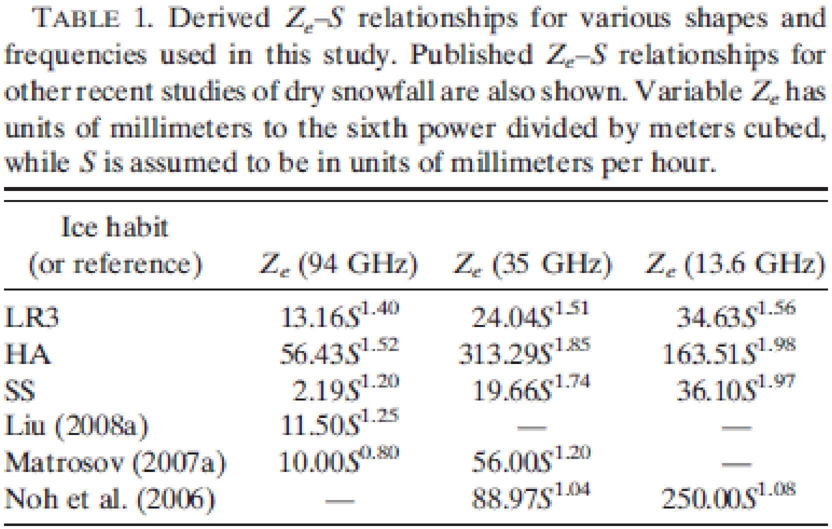
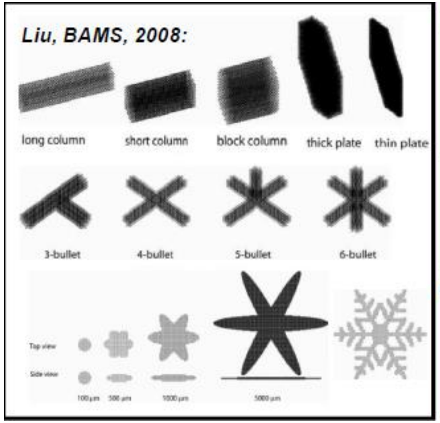
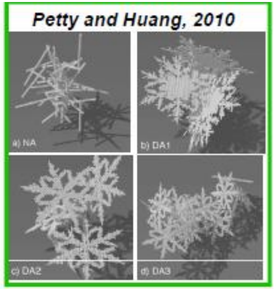


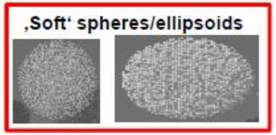
TABLE 1. Derived $Z_e$–$S$ relationships for various shapes and frequencies used in this study. Published $Z_e$–$S$ relationships for other recent studies of dry snowfall are also shown. Variable $Z_e$ has units of millimeters to the sixth power divided by meters cubed, while $S$ is assumed to be in units of millimeters per hour.

| Ice habit (or reference) | $Z_e$ (94 GHz) | $Z_e$ (35 GHz) | $Z_e$ (13.6 GHz) |
|---|---|---|---|
| LR3 | $13.16S^{1.40}$ | $24.04S^{1.51}$ | $34.63S^{1.56}$ |
| HA | $56.43S^{1.52}$ | $313.29S^{1.85}$ | $163.51S^{1.98}$ |
| SS | $2.19S^{1.20}$ | $19.66S^{1.74}$ | $36.10S^{1.97}$ |
| Liu (2008a) | $11.50S^{1.25}$ | — | — |
| Matrosov (2007a) | $10.00S^{0.80}$ | $56.00S^{1.20}$ | — |
| Noh et al. (2006) | — | $88.97S^{1.04}$ | $250.00S^{1.08}$ |

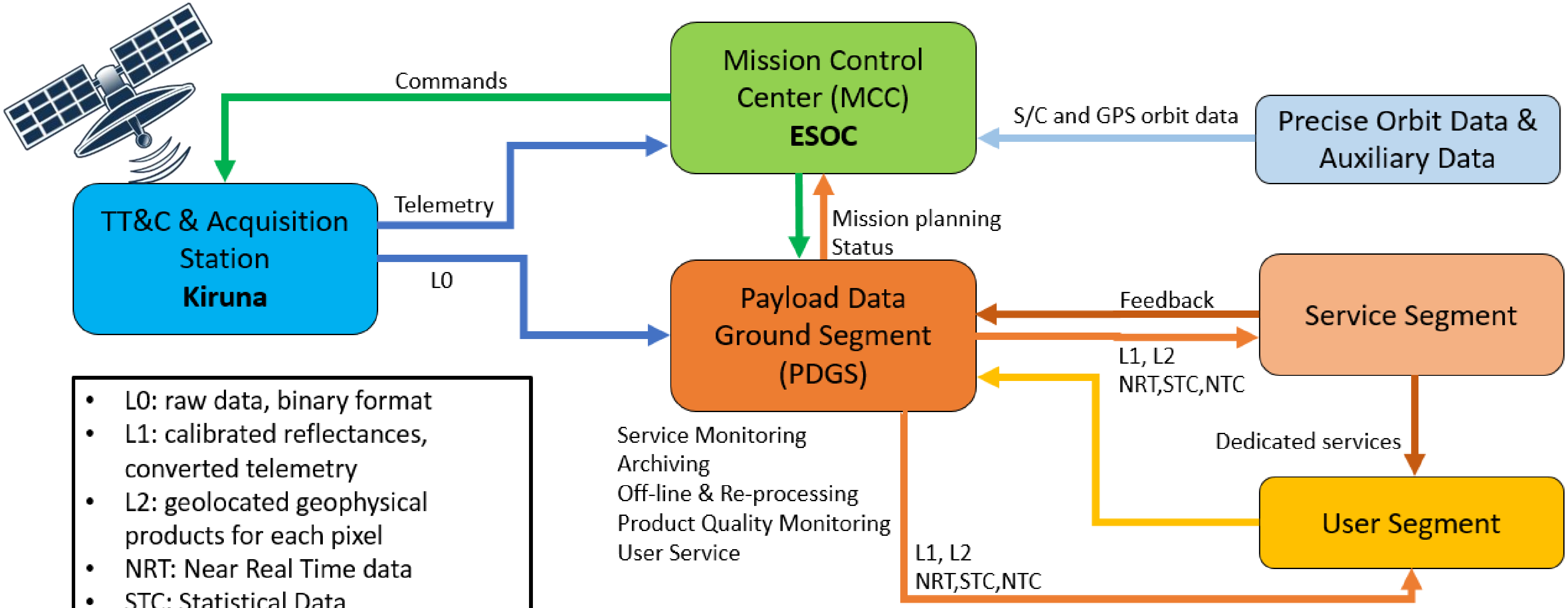
(Kulie et Bernnartz,2009)







# Mission Data Flow



Mission Control Center (MCC)
**ESOC**

Commands

Telemetry

S/C and GPS orbit data

Precise Orbit Data & Auxiliary Data

TT&C & Acquisition Station
**Kiruna**

L0

Mission planning
Status

Payload Data Ground Segment (PDGS)

Feedback

Service Segment

L1, L2
NRT,STC,NTC

Dedicated services

Service Monitoring
Archiving
Off-line & Re-processing
Product Quality Monitoring
User Service

User Segment

L1, L2
NRT,STC,NTC

- L0: raw data, binary format
- L1: calibrated reflectances, converted telemetry
- L2: geolocated geophysical products for each pixel
- NRT: Near Real Time data
- STC: Statistical Data Correspondents
- NTC: Non Time Critical data