DROP: Dual Retrieval Of Precipitation

Team Blue

Summer School Alpbach 2010

Abstract

We propose DROP (Dual Retrieval Of Precipitation) as satellite mission to observe precipitation at mid and high latitudes. This mission intends to improve our understanding of the precipitation process and contribute to the understanding of the regional and global water cycles. A dual-frequency, dual-polarized scanning precipitation radar was designed to detect precipitation at mid and high latitudes with high accuracy. To provide information about precipitation for a larger observation area, the active radar system is supplemented by a passive microwave radiometer.

1 Introduction

The 2010 ESA Alpbach Summer School's program "New Space Missions for Understanding Climate Change" focuses on the development of new satellite missions providing new observations to fill gaps in the understanding of climate change. For this purpose the Blue Team, with the support of their and the roving tutors, has worked out the new satellite mission named "DROP". The DROP (Dual Retrieval Of Precipitation) mission is dedicated to observe precipitation at mid and high latitudes with high accuracy. This mission will fill a gap of observations and enhance the understanding of the precipitation process, which is strongly related and affected by climate change.

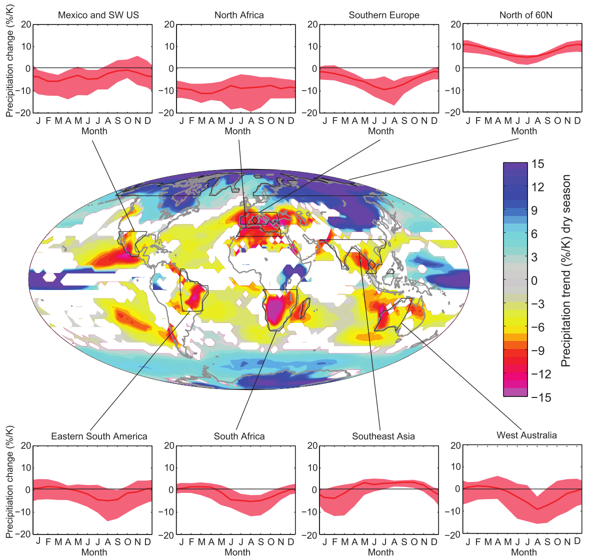


Figure 1: Projected precipitation change in precent per degree Kelvin relative to 1900–1950 from 22 AOGCMs (Solomon et al. 2009).

This report intends to demonstrate the importance of the DROP mission in the environment of a changing climate. The requirements and the methodology to improve quantification of precipitation and discrimination between the hydrometeor types are introduced. Furthermore, the technical details of the new mission and its components are illustrated.

2 Science Case

2.1 Scientific Background and Justification

Prediction of changes in the climate system are often based on general circulation models (GCMs), which are composed of complex subsystems, e.g., radiation, water transport, and atmospheric dynamics models. Physical equations are used in many of these sub-systems to describe the governing processes. In cases where physical knowledge is not adequately developed yet, parameterization schemes are often used to simulate the respective subsystem, such as cloud microphysics or convective precipitation. Evaluation of the performance of such parameterization schemes is often difficult and different implementations lead to disagreements between GCM results. Thus evaluation and subsequent improvement of such schemes is highly important to improve climate change predictions. Distribution and intensity of precipitation are predicted to change with increasing temperatures [Solomon et al. 2009]. For low latitude regions a decrease in precipitation of up to -15% per K of warming is predicted whereas in high latitude regions precipitation will increase up +15 % per K (Fig.1). These significant changes highlight the importance of precipitation within the context of climate change. Such predictions have quite large uncertainties which can only be reduced by improved process understanding and model evaluation. Precipitation is a key geophysical parameter within the global energy budget and water cycle. Understanding and actually measuring precipitation is important for climate modelling, weather predictions, oceanographic studies, agriculture, and resource management.

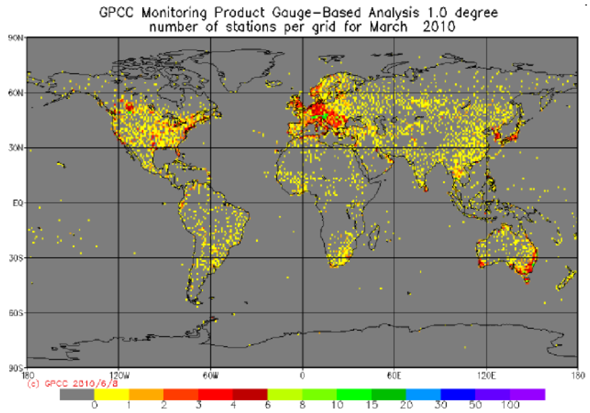


Figure 2: Precipitation gauge distribution on Earth (March 2010) (Courtesy of Global Precipitation Climatology Centre GPCC).

A significant uncertainty in global precipitation estimates stems from:

(a) a significant lack of in situ observations especially in higher latitudes and over oceans (cp. Fig. 2);

(b) intrinsic difficulties of measuring precipitation rates, and particularly snowfall, at any given location.

These fundamental problems make global precipitation estimates and evaluation of precipitation models difficult. A gap in the knowledge about the precipitation amount has been identified for high and (partly) for mid latitudes. In these regions precipitation events are dominated by snow fall and light precipitation rates.

2.2 Mission objectives

The DROP mission is focused on the observation of precipitation events with discrimination of rain and snowfall over mid to high latitude. The mission will improve the understanding of precipitation processes in a changing climate and contribute the understanding of regional and global water cycles by quantifying key variables as precipitation speed and rate. A further objective is to provide high quality data for the process and model evaluation on multiple scales including vertical cloud structure. Identification of hydrometeor types and measurement of hydrometeor speeds within clouds will improve our knowledge of cloud physics. The understanding of cryospheric processes will benefit by observations in polar regions.

2.3 Observation requirements

The DROP mission will provide observation of precipitation events especially at mid- and high latitudes for application in climatology, mainly to increase process understanding of precipitation. The definition of the observational requirements largely builds on the needs defined in international planning documents such as the IGOS Cryosphere Theme Report (Key et al., 2007) and the Report on satellite-based products of the Global Observing System for Climate (GCOS 2006). For observation of light precipitation events the following requirements where specified:

- the main observation area is between 30°N-90°N and 30°S-90°S
- a dynamic range of 0.1 to 20 mm/hr precipitation rate shall be observed
- 2 km spatial resolution is required at the local to regional scale, 10 km for large scale investigations
- the local time of the observation shall vary to build an unbiased data stack.

2.4 Methodology of Precipitation Rate Retrieval

To achieve the observational requirements of the planned mission, an instrument sensitive to snowfall and low rain rates at vertical resolution is needed. To retrieve this information the DROP mission includes a dual-frequency (W- and Ka-band), dual-polarized (VV and HH) Doppler radar. Furthermore, the mission includes a passive microwave radiometer, which allows observing a larger swath. The synergy of both instruments can be used to combine the high accuracy information to with the observation of a larger area. For quantification of precipitation using the active sensor the received (backscattered) signal has to be related to the precipitation rate. A major error source in the precipitation retrieval is the size distribution of the rain drops and ice particles. Dual-wavelength (e.g., Matrosov 1998) and/or additional Doppler spectrum measurements (e.g., Mace et al., 2002) will enable to compensate this effect. Using the dual-polarization information allows to estimate the shape of the scatterers which enables the discrimination of the different scatterer types. This unique 4 channel configuration of a space-born RADAR will improve the quantification of rain fall and snow fall.

Channel	18.7 GHz	23.8 GHz	36.5 GHz	54 GHz	89 GHz	118 GHz	150 GHz
Polarisation	H & V	V	H &V	H/V	H&V	H/V	H&V
Sensitivity	< 0.5 K	< 0.6 K	< 0.7 K	< 0.5 K	< 1.0 K	< 1.0 K	< 1.0 K
Absolute accuracy	1.5 K	1.5 K	1.5 K	1.5 K	1.5 K	1.5 K	1.5 K

Table 1: Sensitivity and absolute measurement accuracy for the passive microwave radiometer.

The microwave radiometer measures the brightness temperature at frequencies between 18.7 and 150 GHz, which are differently sensitive to the size of the hydro meteors and precipitation rate. The precipitation rate can be retrieved by matching the brightness temperature observations to theoretical values computed from radiative transfer calculations and mesoscale cloud model (e.g., Kummerow and Giglio 1994).

2.5 Measurement requirements

Parameter	Minimum	Maximum
Precipitation rate	0.1 mm	20 mm
True reflectivity	0 dBZ	45 dBZ

Table 2: Minimum required radar sensitivity range.

To fulfill the observational requirements in terms of data accuracy and dynamic range of sensitivity, the requirements for the two sensors were specified in terms of location and timeliness. The measurement requirements for the passive microwave radiometer are listed in Table 1, the minimum requirements for the RADAR sensitivity are listed in Table

2. The passive instrument has to be designed to achieve a spatial resolution of 10 km at 36.5 GHz. For the Radar the resolution shall be 2 km.

2.6 Instrumentation

The mission requirements lead to the design of a dual-spinner satellite. The payload will consist of two types of instruments, a seven-band Microwave Radiometer as a passive instrument (P) and a dual-band Doppler Radar as an active one (A).

Frequency (GHz)	35	94
Bandwidth (MHz)	1000	6000
Antenna Gain (dB)	52.6	52.6
Freq. Stability (MHz)	50	100
Polarization	h+v	h+v
Footprint (km x km)	5	2
Vertical resolution (m)	250	250
Number of channels	2	2
Input Power (W)	1500	1500
Received Power (W)	0.03	0.23
Pr/Pt (dB)	-46.81	-38.23
SNR (dB)	130	140
Mass (kg)	60 ± 10	
Power Needs (W)	85 ± 10	

Table 3: Details for the dual-band Doppler radar

The total of nine different frequencies will cover a wide range of the spectrum, which satisfies the scientific requirements for rain and snow detection and precipitation measurements. These are: 18.7, 23.8, 36.5, 89, 150 GHz and two more sounding frequencies of 54, 118 GHz for the radiometer, as well as 35, 94 GHz for the Doppler radar. Both instruments will use dual-channel detection for horizontal and vertical polarization. The orbital details and instrumental architecture is designed in such a way that allows the heavier passive instrument to perform a full rotation in 1.5 seconds, while the lighter active instrument can rotate 360° within 0.63 seconds, in order to compensate the angular momentum of the entire satellite. The altitude of the selected orbit is 481 km which corresponds to a ground track velocity of 7.1 km/sec.

Frequency (GHz)	18.7	23.8	36.5	89	150	50.0 53.0 54.0 55.0	118.75 ± 1.0 118.75 ± 1.5 118.75 ± 2.0 118.75 ± 4.0
Bandwidth (MHz)	200	400	1000	6000	3000	500	1000
Freq. Stability (MHz)	20	20	50	100	100	50	100
Polarization	h+v	h+v	h+v	h+v	h+v	h/v	h/v
Footprint (km x km)	19	15	10	3	2	7	3
Temperature noise (K)	0.5	0.6	0.7	1	1	0.5	1
Accuarcy (K)	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Number of channels	2	1	2	2	2	4	4
Mass (kg)	135 ± 15						
Power Needs(W)	120 ± 20						

Table 4: Details for the microwave radiometer

The main scientific requirement of high-resolution data is directly reflected to the size of the antennas, which lead the instrumental design to 2.5 m antennas for both passive and active instrument. Such an instrumental design gives a wide swath (1389 km with a scanning angle of 52.8 deg) for the passive instrument and a relatively smaller swath for the active (309 km with a scanning angle of 17.5 deg). This swath does not give us a full coverage at the geographical lower limit of the region of interest. The footprints of all 9 used frequencies give a range of 1.5 - 15 km spatial resolution respectively. The final decision is to use smaller antennas, which will lead in slightly lower spatial resolution. This will give us a smaller and more solid satellite design, with a 1.9 m and 2.0 m antennas and different rotation angle for the active instrument.

This design gives a wide swath (1389 km with a scanning angle of 52.8 deg) for the passive instrument but also a relatively wide swath for the active (417 km with a scanning angle of 23.0 deg). With this swath a full coverage across the whole region of interest is achieved. The antenna design and swath width for this scenario give:

Table 5: Antenna size and reciprocal swath for the instrumental setup

Antenna Diameter	2.0 m (P) and 1.9 m (A)
Swath	1389 km (P) and 417 km (A)

The footprints of all 9 used frequencies give a range of 2.0 km to 20 km spatial resolution respectively. Both the microwave radiometer and the Dual freqency Doppler radar will undergo a pre-launching calibration stage and followed by an in-flight calibration. Regarding the in-flight calibration, all the procedures will be done according to the available standards for instruments of CEOS. An intercalibration for the two instruments is planned at Dome-C (75° S, 123° E) in Antarctica with an average revisit time of one day and the relative calibration at the International Amazon Rainforest Site. The deep space will be used for cold calibration for both instruments, in addition hot calibration will be done using an onboard hot target. Complementary, we will perform a measurement over the Amazon Forest, Brazil, also with an average revisit time of one day. The absolute external calibration for the active instrument requires a pre-testing stage, because so far nor transponder nor corner reflectors have been used for Ka- and W- bands. Therefore the evaluation of the testing stage will determine the use of either corner reflector or transponder. The active Doppler radar needs an internal onboard calibration, for the two frequency channels. Validation of the data will be done using ground precipitation radar networks. Two major areas are foreseen for this purpose, one in the Northern hemisphere (Europe) and another one in the southern hemisphere (South America). Moreover, DROP datasets will use the overlap region with the TRMM mission. This region is situated between 30° and 35° on the northern and southern hemisphere. The datasets from the Global Historical Climatology Network (GHCN) or other networks are also suggested to be used for further data validation.

3 System Concept

3.1 Orbit

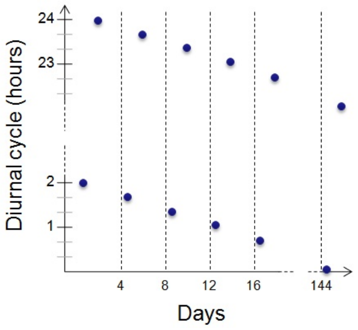


Figure 3: Diurnal cycle sampling after a full cycle of 144 days.

The orbit is constrained to a low-earth orbit in order to maximize the instrument performances, especially for the active Doppler radar. A trade-off with the satellite lifetime, decreasing with atmospheric drag, results in an altitude of 480km and a lifetime of 5 years, taking into account the solar activity. Orbit maintenance will be performed every week in order to cope with the altitude lowering of the altitude of 250 meters. This maintenance requires a ΔV of 0.15 m/s given by a propulsion subsystem. The inclination of the orbit is chosen to be away from the sun-synchronous case (97°) to get a better diurnal cycle time sampling. An inclination of 88° allows for coverage of the polar regions with a nodal plane shift of -0.265°/day. The orbit has therefore a repeat cycle of ground tracks of 4 days with a full coverage of the diurnal cycle within 144 days, sampled by 20 minutes apart. Statistical significance is ensured with at least 12 measures of a specific local time over a local area during the five years of the mission.

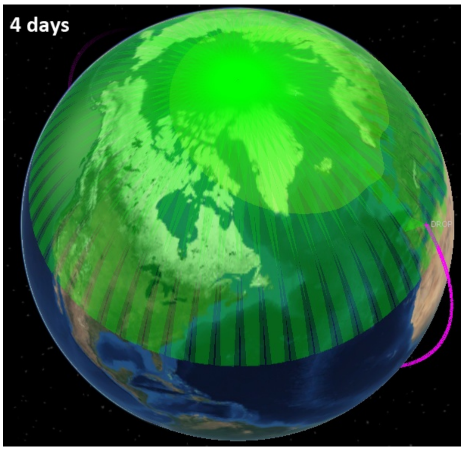


Figure 4: Full coverage over 30° latitudes with the active instrument.

3.2 Mission Architecture

3.2.1 Launch Segment

The launcher selection is driven by the satellite dimension and weight, and the launch associated costs. The mass and volume of the DROP satellite is compatible with several small launchers of the Rockot and Vega class. VEGA is in the design baseline, because it can launch a payload up to 1500 kg into orbits up to 700 km, and it has enough room to accommodate the DROP satellite.

3.2.2 Space Segment

The overall architecture of the DROP satellite consists of several subsystems as depicted in Figure 5.

The Attitude and Orbit and Control Subsystem (AOCS) is used for the initial determination of attitude and stabilization of the vehicle, during normal on-station operations to reorient the vehicle when required. Attitude correction is done by means of 3-axis reaction wheels with an angular momentum range of between 25 and 35 Nms and magnetic torques, which have a pointing accuracy of 0,01 deg. In addition, a redundant reaction wheel ensures reliability of the system. In order to supply sufficient telemetry data, the system includes a star tracker, sun sensor, inertial measurement unit and a GPS sensor. The propulsion subsystem is necessary for the injection error compensation, orbit maintenance manoeuvers, space debris contingency and an eventual de-orbiting maneuver (this propellant could be used to extend the satellite?s lifetime). The satellite is equipped with four 2 N thrusters, which use hydrazine (N2H4) propellant,

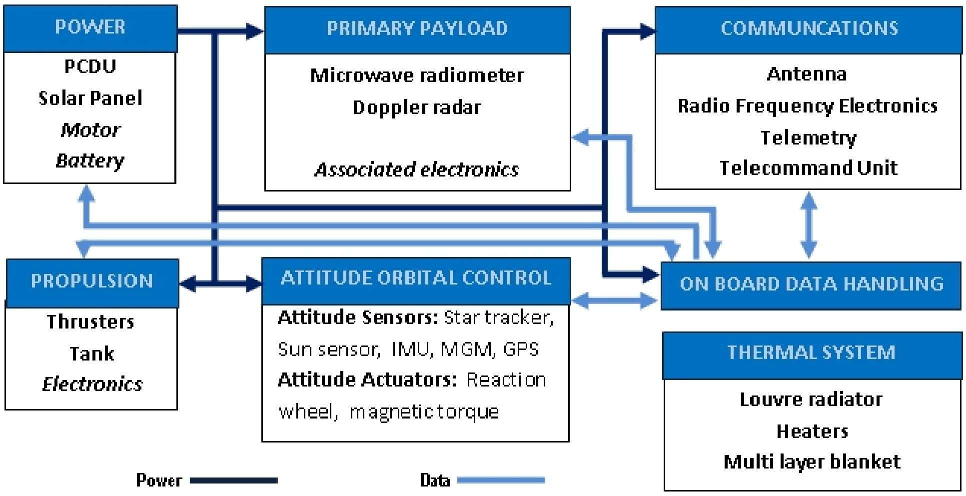


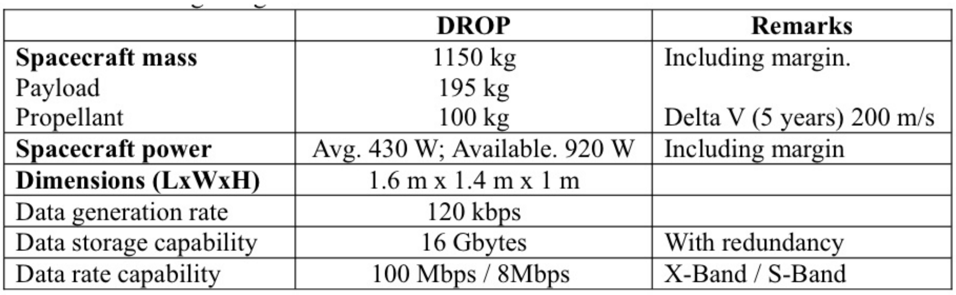
Figure 5: Architecture of the DROP satellite.

pressurized with nitrogen (N2) gas. In order to supply enough telemetry data, the subsystem includes: a pressure transducer, thermistors in the tank and in the thrusters. The system is made redundant allowing high level of reliability. The Thermal Control Subsystem is necessary because temperature varies depending on diurnal, year cycles and solar cycle. The Satellite face several eclipses due to diurnal cycle; solar flux has to be considered for winter solstice, summer solstice and equinox conditions; and the solar cycle period has been taken into account. The satellite is equipped with a dark 0,4 m^2 radiator in order to dissipate the heat produced by the payload and the platform units. Heat pipes transmit the heat from the high dissipation units to the radiator. Finally, multi layer insulation blankets are used to insulate the payload module and the platform. The Power Subsystem consists of a 2.6 m^2 two axis solar tracking array, which produces 410 W/m^2 at beginning of life (250 W/m2 end of life); and a battery module with 12 cells that each have a capacity of 33Ah. The average power demand is 433 W with maximum power available is 920 W (end of life) to account for peak power and eclipse periods. The payload produces 120 Mbps, which is managed by the On-Board Data Handling (OBDH) subsystem. The OBDH requirement is to handle data during two full orbits. The transferable data is 256 megabytes, which requires 3.336 Mbps net communication speed. Calculating with 40% additional redundancy and communication overheads, our downlink data speed must be at least 5.56 Mbps. An external non volatile memory device provide 16 GBytes storage capacity, which means that the OBDH can tolerate more than 2 blind orbits. The Telemetry Tracking and Command (TT/C) subsystems provide the communication between the satellite and the ground system. For this purpose, the satellite will use high-gain directional antenna for normal operational communication (X-band, 100Mbps). For start-up and standby command transmission, there will be also an omnidirectional antenna (S-band, 8Mbps). This antenna will also be able to temporally replace X-band antenna. The satellite configuration is shown in Figure 6.

3.3 Ground Segment

The ground segment will be based on the infrastructure being developed to support the Earth Explorer and other missions. The ground segment elements are:

- the Command and Data Acquisition Element (CDAE)
- the Mission Operations and Satellite Control Element (MSCE)
- the Processing and Archiving Element (PAE)



	DROP	Remarks
Spacecraft mass Payload Propellant	1150 kg 195 kg 100 kg	Including margin. Delta V (5 years) 200 m/s
Spacecraft power	Avg. 430 W; Available. 920 W	Including margin
Dimensions (LxWxH)	1.6 m x 1.4 m x 1 m	
Data generation rate	120 kbps	
Data storage capability	16 Gbytes	With redundancy
Data rate capability	100 Mbps / 8Mbps	X-Band / S-Band

Table 6: Satellite budget

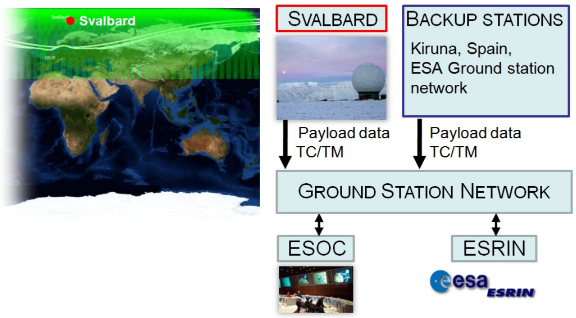
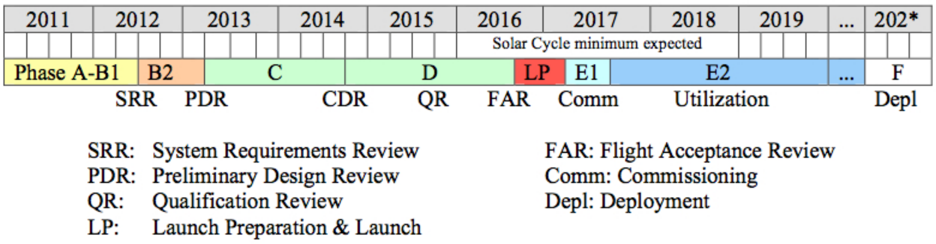


Figure 6: Scheme of the Ground Segment.

The CDAE will be located in Svalbard as the primary ground station, because the satellite has 100% availability in orbits because of its high latitude (78°). The data rate demand is estimated up to 10 Mbps. The minimal time for transmission per orbit is about two minutes. Therefore an X-band antenna is used. This is a medium gain antenna, with a data transmission capacity up to 100 mbps, and it steadily covers our demands. This station will be in charge of the TT/C functions. Kirun will be the secondary station. The MSCE will be located at ESOC providing mainly satellite monitoring and control functions. The PAE will be located in ESRIN implementing payload data acquisition from CDAE together with the acquisition of data from field segment.

subsectionMission Schedule

The timeline for our space mission is given in Figure 7. We foresee a time span of 6 years for development up to launch. High solar activity can complicate the operations of the satellite. Therefore, DROP will be launched around solar minimum, which is predicted to take place within the time span of 2016-2018., because solar cycles last on average 11 years but vary in length.



SRR: System Requirements Review
PDR: Preliminary Design Review
QR: Qualification Review
LP: Launch Preparation & Launch
FAR: Flight Acceptance Review
Comm: Commissioning
Depl: Deployment

Table 7: Mission Schedule

4 Mission Constraints

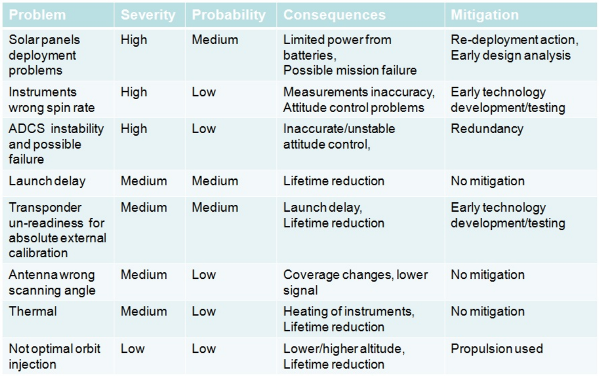
4.1 Cost

To evaluate the costs of a new mission is possible to proceed with a bottom-up estimation by dividing all the work to be done in packages and by estimating the price of each one of them. The estimations of the cost of a satellite, which is normally the most important cost of the overall space system, is a function of the satellite dry mass and of the innovation level. But the cost of the implementation of a mission is not only the cost of the satellite. A proper estimation of the cost of new space systems shall be include also some additional costs, such us launcher, satellite operations or data utilization. Accordingly with this, the analysis of the costs of DROP mission is as follows, with a total estimate price of 370 Million Euro (M):

- Satellite (including launch campaign and commissioning phase): 100 M
- Instruments (Dual-frequency Doppler radar and Microwave Radiometer): 90 M + 90 M
- Launcher (VEGA): 35 M
- Ground segment (including operational costs throughout the nominal life-time of 4 years): 20 M
- Algorithms and data processing: 2 M

4.2 Risk

The main risk of the mission is the possible un-deployment of the solar panels which would lead to a total failure. A partial deployment of the solar panels would limit the power resources. A possible re-deployment could be realized in a limited amount of time. Instrumental spinning rate failure could result into bad spatial sampling. Moreover, a possible attitude control problem could be encountered from this failure of spinning rate. Mitigation can be done by early testing and development. Technology readiness of the active instrument transponder for absolute external calibration can result in a launch delay. The launch schedule date is a critical issue, as the mission should start and operate during the solar cycle minimum. Inaccuracies in orbit injection would result in a reduced lifetime from the propellant used for altitude correction.



Problem	Severity	Probability	Consequences	Mitigation
Solar panels deployment problems	High	Medium	Limited power from batteries, Possible mission failure	Re-deployment action, Early design analysis
Instruments wrong spin rate	High	Low	Measurements inaccuracy, Attitude control problems	Early technology development/testing
ADCS instability and possible failure	High	Low	Inaccurate/unstable attitude control,	Redundancy
Launch delay	Medium	Medium	Lifetime reduction	No mitigation
Transponder un-readiness for absolute external calibration	Medium	Medium	Launch delay, Lifetime reduction	Early technology development/testing
Antenna wrong scanning angle	Medium	Low	Coverage changes, lower signal	No mitigation
Thermal	Medium	Low	Heating of instruments, Lifetime reduction	No mitigation
Not optimal orbit injection	Low	Low	Lower/higher altitude, Lifetime reduction	Propulsion used

Table 8: Overview of risk management.

4.3 Descope

Serious concerns about the impact of possible descopes were taken into account for the quality of the DROP mission. The first descope option is to exclude the Microwave Radiometer. This option would reduce the weight of the satellite by 30%. This leads directly to the lower cost of the overall mission by 25%, as well as the possibility to upgrade the other (active) instrument by increasing the size of the antenna. Removing the Microwave Radiometer will end up with a simplified satellite design, with one antenna and one instrument on board less which will lead to low power consumption and therefore smaller solar power panel. The remaining single-antenna satellite will not require any additional mechanism for adaption to the launcher. The disadvantage of this option is the loss of both temporal and spatial coverage, which causes quite a high risk of the scientific results of the mission, since the global coverage is essential for the climate statistics and the climate change understanding. The science impact of this descope option is therefore HIGH. The second descope is to select a Sun-Synchronous Orbit. This option will simplify the overall mission design and reduce the power system. In addition, it will reduce size and weight of the satellite by 15%. Although the complication of the mission is small, this option will induce bias on the retrieved data, since the temporal resolution over the same region will be lower. The science impact of this descope option is LOW.

5 Conclusion

The DROP mission's objective to provide high quality information about the precipitation process for mid- and high-latitudes has been extensively researched and analyzed.

The mission aims to enhance the understanding of precipitation processes and will help fill the knowledge gaps on a global level by working in conjunction with ground radar precipitation stations, previous, current and planned remote satellite observing platforms. The information gained from every orbit (every 95mins) will be fed into global climate models to produce a long extensive history of precipitation and aid in understanding of climate change. In addition, as precipitation is a major part of the water cycle, measurements can be fed in to regional climate models, to aid in a more extensive, accurate precipitation prediction which can have a socio-economic effect.

The DROP Mission Advantages are:

- Utilize both passive and active instruments for complementary information gathering
- High spatial resolution (less than 2 km)
- Wide, un-biased with time, swath to give required coverage
- Distinguish between snow and rain rates (0.1 20 mm/h)
- Precipitation drop rates at speeds (0-20 m/s)
- Distinguish between different hydrometeor types

With relation to the mission requirements instrumentation has been specified and a unique design of a remote, space based orbital platform has been proposed.

6 References

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