
C³IEL MISSION

CLUSTER FOR CLIMATE AND CLOUD IMAGING OF EVOLUTION AND LIGHTNING

C³IEL MISSION, PAYLOAD FEATURES AND SYSTEM REQUIREMENTS

18 AUGUST 2019
VERSION 0.53

TABLE OF CONTENTS

TABLE OF CONTENTS.....	3
LIST OF FIGURES.....	5
PART I: C³IEL MISSION FEATURES.....	1
1 INTRODUCTION	2
1.1 PURPOSE AND SCOPE	2
2 C³IEL MISSION – AN OVERVIEW	3
2.1 MISSION GOALS.....	3
2.2 SCIENTIFIC EXPERIMENT OF C ³ IEL MISSION.....	3
2.3 C ³ IEL MISSION SCENARIO	3
PART II: SCIENTIFIC AND TECHNICAL REQUIREMENTS.....	5
3 C³IEL SCIENTIFIC MISSION FEATURES	6
3.1 C ³ IEL MISSION MAIN FEATURES.....	6
3.2 PRIMARY SCIENTIFIC GOALS	6
3.2.1 <i>Clouds Mission</i>	6
3.2.2 <i>Water Vapor Mission</i>	6
3.2.3 <i>Synergy of Clouds and Water Vapor Missions</i>	7
3.2.4 <i>ZEUS Mission and its Synergy</i>	7
4 END-TO-END C³IEL CONCEPT AND WORKSHARE	8
4.1 SEGMENTS OF C ³ IEL SYSTEM	8
4.2 SPACE SEGMENT	9
4.3 GROUND SEGMENT	9
4.4 GROUND STATIONS NETWORK.....	9
4.5 CONTROL, MISSION AND EXPERTISE GROUND CENTERS	9
4.6 C ³ IEL WORKSHARE	10
5 C³IEL'S MISSION DEFINITION DELIVERABLES	12
5.1 MAIN GOALS OF MISSION	12
5.1.1 <i>C³IEL Scientific Measurements</i>	12
5.2 MISSION CLOUDS INSTRUMENTATION GOALS	13
5.3 WATER VAPOR CAMERA(S) SCIENTIFIC REQUIREMENTS	15
5.4 ZEUS LIGHTNING MEASUREMENTS	16
5.5 NANOSATELLITES' POWER MANAGEMENT	18
5.6 CONCEPT OF UPDRAFT CALCULATIONS VS TIME.....	18
5.6.1 <i>From raw images to Updraft vs Time</i>	19
5.6.2 <i>From Updraft to Climate</i>	19
6 MISSION PRODUCTS	20
6.1 DATA PRODUCTS DESCRIPTION	20
6.2 LEVEL 0	20
6.3 LEVEL 1	20
6.3.1 <i>CLOUD IMAGERS</i>	20
6.3.2 <i>WATER VAPOUR IMAGERS</i>	20
6.3.3 <i>LIGHTNING IMAGERS</i>	20

6.3.4	LIGHTNING PHOTOMETERS.....	20
6.4	LEVEL 2.....	21
6.4.1	CLOUD IMAGERS.....	21
6.4.2	WATER VAPOUR IMAGERS.....	21
6.4.3	LIGHTNING IMAGERS.....	21
6.4.4	LIGHTNING Photometer.....	21
7	DEVELOPMENT PHASES.....	22
7.1	PROJECT PHASES.....	22
7.1.1	Project Pre-Formulation.....	22
7.1.2	Project Formulation.....	22
7.1.3	Project Implementation.....	22
7.2	PROJECT PRE-PHASE A: CONCEPT STUDIES.....	22
7.3	PHASE A: CONCEPT AND TECHNOLOGY DEVELOPMENT.....	23
7.4	SUMMARY OF PROJECT PHASES.....	25
	PART III: SYSTEM REQUIREMENTS.....	27
8	SYSTEM REQUIREMENTS).....	28
8.1	SCIENTIFIC SYSTEM REQUIREMENTS.....	28
8.1.1	Top-level requirements.....	28
8.1.2	The scientific objectives.....	28
8.2	NANOSATELLITE REQUIREMENTS.....	28
8.2.1	scientific instrumentation for the three nanosatellites.....	29
8.3	TOP LEVEL MISSION REQUIREMENTS.....	29
8.3.1	Orbital Requirements.....	30
8.3.2	Launcher Requirements.....	30
8.4	FUNCTIONAL REQUIREMENTS.....	30
8.4.1	Payload Subsystem.....	30
8.4.1.1	Cloud.....	30
8.4.2	Bus Subsystem.....	31
8.4.3	Electrical Power Subsystem.....	31
8.4.4	Attitude AND ORBIT Control and Determination Subsystem.....	32
8.4.5	Communications Subsystem.....	32
8.4.5.1	Command and Telemetry.....	32
8.4.6	Thermal Control.....	32
8.4.7	Structural and Mechanical.....	32
8.4.8	Propulsion Subsystem (TBF).....	33
8.4.9	Flight Software.....	33
8.5	PERFORMANCE REQUIREMENTS.....	33
8.5.1	Payload Subsystem.....	34
8.5.1.1	Cloud.....	34
8.5.2	Bus Subsystem.....	34
8.5.3	Attitude and orbit Control and Determination Subsystem.....	34
8.5.4	Communications Subsystem.....	35
8.5.4.1	Command and Telemetry.....	35
8.5.4.2	Beacon.....	35
8.5.5	Command and Data Handling Subsystem.....	35
8.5.6	Thermal Control Subsystem.....	35
8.5.7	Structural and Mechanical.....	35
8.5.8	Propulsion Subsystem.....	36
8.5.9	Flight Software.....	36
8.6	PHYSICAL CHARACTERISTICS.....	36
8.7	ENVIRONMENTAL REQUIREMENTS.....	36
8.8	STRUCTURAL AND MECHANICAL VERIFICATION REQUIREMENTS.....	36
8.9	ELECTROMAGNETIC COMPATIBILITY VERIFICATION REQUIREMENTS.....	37
8.10	ELECTRICAL FUNCTION VERIFICATION REQUIREMENTS.....	37

8.11	VACUUM AND THERMAL VERIFICATION REQUIREMENTS	37
------	----------------------------------------------------	----

LIST OF FIGURES

FIGURE 3.1:	MISSION DELIMITED TO $\pm 65^\circ$ SOLAR ZENITH ANGLES SHOWING SCENARIO ZONE AND TWO MEASUREMENT CYCLES	5
FIGURE 3.2:	OVERALL C ³ IEL CONCEPT WITH SPACE AND GROUND SEGMENTS	8
FIGURE 5.1:	ACCUMULATED LIGHTNING HITS OVER TIME.....	17
FIGURE 5.2:	UPDRAFT CALCULATIONS ALONG TIME	18

PART I: C³IEL MISSION FEATURES

1 INTRODUCTION

C³IEL - Cluster Climate and Cloud Imaging of Evolution and Lightning, is a bi-national France-Israel satellite mission, led by CNES and ISA. Mission is to be supported by both French and Israeli governmental funds to be launched in 2024. Operation is planned for at least two years.

The main goals of the mission are to realize the unique set of instrumentation capabilities for measuring cloud updrafts (Clouds), detecting the distribution of Water Vapor (WV) in the Region-of-Interest, and tracking the electrification of clouds (Zeus). These combined capabilities takes advantage of the unique synergy between the instruments and will yield first order insight of processes needed to understand the energetic balance and circulation in our climate system. This research mission will serve as a demonstrator showing the way of increasing the skill in both weather and climate prediction by future operational satellites.

1.1 PURPOSE AND SCOPE

C3IEL mission is an interdisciplinary, day and night, clear and cloudy skies observation and measurement system, based on three distributed multi instrumental nanosatellites.

This document defines the requirements and design specifications for C3IEL system, its functional and technical descriptions, required performance capabilities, mechanical and electrical interfaces, data requirements, environmental conditions, and requirements verification.

2 C³IEL MISSION – AN OVERVIEW

The C³IEL system includes a train of two (or three) nanosatellites, designed and built on the CubeSat standard. These 6U nanosatellites carry the payloads. During the mission, all the nanosatellites will operate synchronously as a concerted distributed instrumentation system and perform identical types of measurements while pointing at the same ground pixel.

2.1 MISSION GOALS

The goals of the mission are:

- ❖ ***To quantify - for the first time - the competing roles of cloud updrafts aerosols on clouds' radiative effects and their influence on climate.***
- ❖ ***To document the 3-dimensional structure of Water Vapor distribution at the vicinity of clouds and the interactions with cloud dynamic evolution.***
- ❖ ***To observe and map the relationships and synergy of lightning with convective clouds cloud updrafts during thunderstorms, with the synchronized instrumentation of clouds and lightning.***

The resulting scientific products will be significantly better in understanding the leverage clouds have on weather, thunderstorms and climate, thus leading to improved forecasts and significant reduction in uncertainties of manmade impacts in comprehending climate changes.

2.2 SCIENTIFIC EXPERIMENT OF C³IEL MISSION

The nanosatellites of C³IEL system will be engaged in the scientific clouds experiment, i.e. in stereoscopic imaging of cloud tops with VIS cameras to study the evolution of convective cloud updrafts, tracking their evolution with time. Cloud measurements are conducted at daytime.

The novelty of a distributed instrumentation set, results in a synergic picture of the observed phenomena of clouds properties, i.e., cloud evolution and electrification processes and their interactions with the ambient 3-dimensional distribution of water vapor.

The only practical way to measure cloud properties at a global scale is from satellites, but there has been practically no measurements until now that obtained cloud updrafts and their interactions with water vapor and lightning.

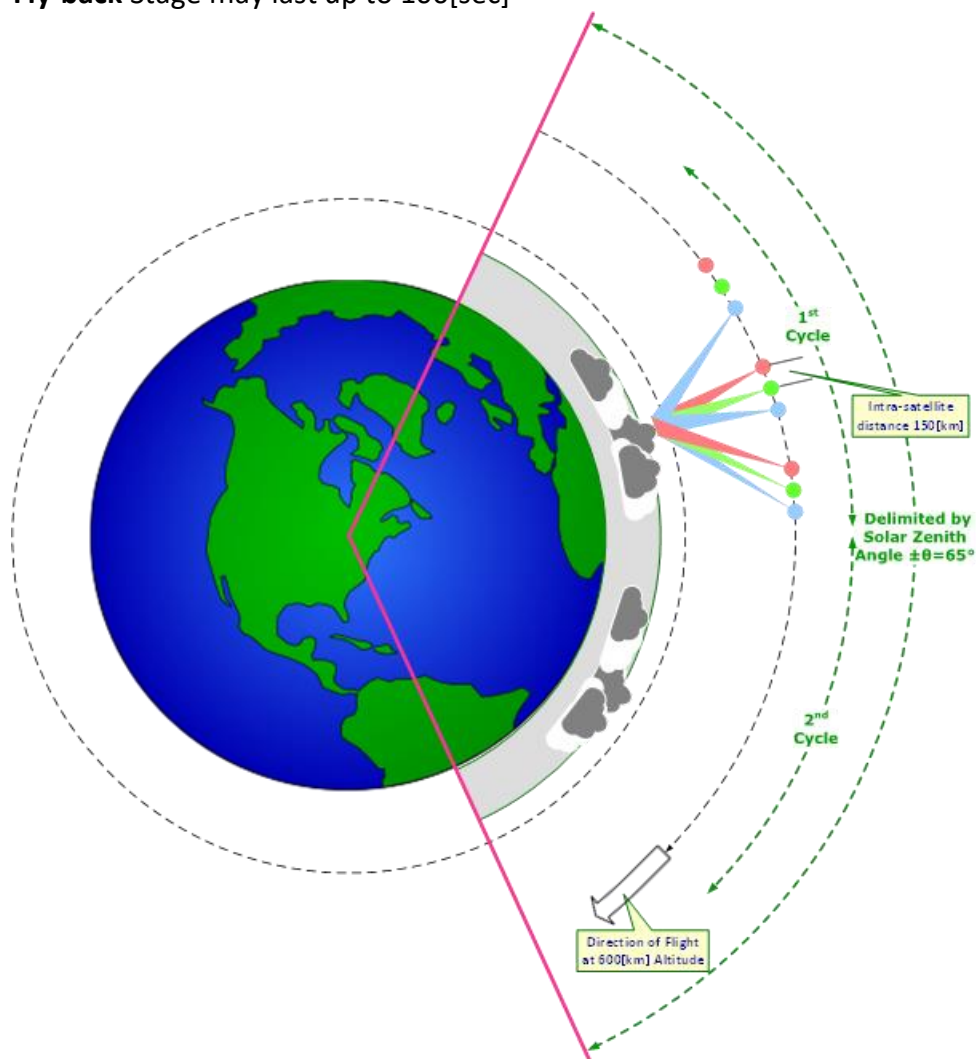
2.3 C³IEL MISSION SCENARIO

While flying in an along-track orientation, satellites overpass a Region-of-Interest (ROI) of clouds, sweeping the selected areas from -60° off-nadir, to nadir, and continuing to $+60^\circ$ off-nadir (red, green and light blue looking angles).

A typical scenario of the mission that demonstrates the scientific experiment, is defined by the Scenario Zone that may have several measurement Cycles. The Scenario Zone is bounded by the Solar Zenith angles of $\pm 65^\circ$. In the Scenario Zone the satellites cover a sectional arc along the orbit.

The major parameter of the scenario are:

- A **Cycle** is a sectional arc along the orbit that can last up to 300[sec] and is subdivided into measurement three **Stages**:
- **Search and Acquire** Stage that may last up to 20[sec] and measures a part of single section, leading satellites are in use.
- **Track and Measure Stage** that may last up to 200[sec] and measures in shots of 5 to 20 second. During this stage all satellites are in use.
- **Fly-back** Stage may last up to 100[sec]



*Figure 2.1: Mission delimited to $\pm 65^\circ$ Solar Zenith angles showing **Scenario Zone** and two measurement **Cycles***

PART II: SCIENTIFIC AND TECHNICAL REQUIREMENTS

3 C³IEL SCIENTIFIC MISSION FEATURES

We elaborate on the features of the scientific mission and include proposed measurements scenarios. The synergy between Clouds updrafts and Water Vapor measurements, and the resulting synergetic Zeus electrifications is described.

3.1 C³IEL MISSION MAIN FEATURES

The main features of C3IEL mission and its scenario parameters are:

- A cluster of 3 or 2 nanosatellites (Clouds)
 - Size of nanosatellites 6U (CBE)
 - Nanosatellite platforms will be developed and provided by FR
 - Nanosatellite payloads will be developed and provided by IS
- Nominal lifetime of mission is 2 years
 - An option for additional one year extension
- LEO Sun-Synchronous Orbit (SSO)
 - Orbit altitude ~600 [km]
 - At 13:30 local hour for high cloud activity.
- Nanosatellite pointing knowledge accuracy of 0.1° (1σ) during mission's data collection (i.e. over 200s).
- Nanosatellite pointing knowledge variation (1σ) over 200s is $50\mu\text{rad}$
- Nanosatellite pointing stability (1σ) of 0.1° over 200s
- Pointing agility for each nanosatellite: from -60° through 0° (nadir) and up to 60° along track (Clouds)
- Each nanosatellite has to capture simultaneously the same scene during data acquisition and mission's accumulation time.
- Currently, an electrical propulsion system is planned for formation keeping.

3.2 PRIMARY SCIENTIFIC GOALS

During the mission, the primary goals of the various parts of the payloads are described in the following sections.

3.2.1 CLOUDS MISSION

Daytime stereoscopic observation and mapping of convective clouds' 3-dimensional evolution, including updrafts. By consistent and simultaneous imaging at three consecutive angles, while all members of the cluster are pointing at the same ground pixel during the overpass time.

3.2.2 WATER VAPOR MISSION

Multispectral retrieval and tomography of the 3-dimensional structure of water vapor, by evaluating two neighboring spectral ranges and measurement of temperature gradients, during daytime in clear and/or cloudy skies.

3.2.3 SYNERGY OF CLOUDS AND WATER VAPOR MISSIONS

The 3-dimensional distribution of water vapor in the vicinity of clouds strongly affects clouds updrafts and longevity by affecting and indicating the rate of clouds evaporation and mixing with the ambient.

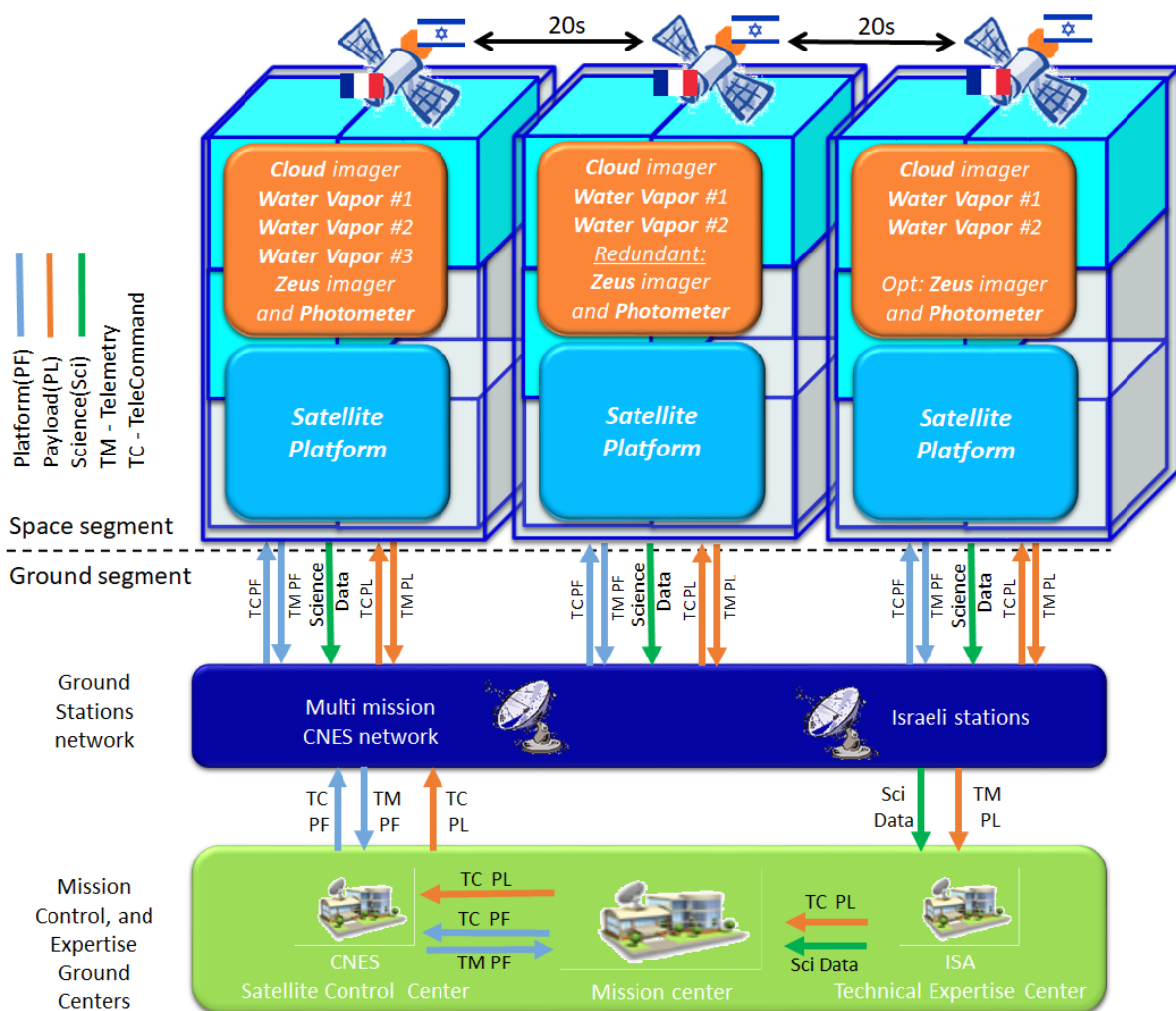
3.2.4 ZEUS MISSION AND ITS SYNERGY

Observe, measure and map lightning activity during thunderstorms that scale with clouds and have synergy with Clouds, due to the fact that lightning are caused primarily by strong updrafts at the super-cooled portions of clouds. Aforementioned activity will be recorded in daytime and night in clear and/or cloudy skies

4 END-TO-END C³IEL CONCEPT AND WORKSHARE

C³IEL - Cluster Climate and Cloud Imaging of Evolution and Lightning, is a joint bi-national France-Israel satellite mission, led by CNES and ISA. Mission is to be supported by both French and Israeli governmental funds to be launched in 2024. Operation is planned for at least two years.

The overall End-to-End concept of C³IEL mission is depicted in Figure 3.2, followed by a



short description of each of the segments that are functional in the mission operation.

Figure 3.2: Overall C³IEL concept with Space and Ground Segments

4.1 SEGMENTS OF C³IEL SYSTEM

The segment of the system are:

- Space Segment
- Ground Segment

- Ground Stations Network
- Control, Mission and Expertise Ground Centers

4.2 SPACE SEGMENT

Three¹ satellites are launched into the same orbit, separated from each other by 20 seconds and imaging the same scene.

Each satellite of the space segment is composed of a FR platform and an IS payload.

- Satellite platform (PF)
- Satellite Payloads (PL)

The payload(s) in each satellite will be exactly the same, at least in terms of interfaces (electrical, mechanical, mass, data rate, ...) with the platform.

CNES and ISA agree to design, build and implement 3 (or 2, see footnote) exact same satellites.

The reasoning behind it has several folds:

- A coherent single concept for all satellites
- Same set of requirements for all satellites
- One development phase for all satellites
- No need for multiple types of EMs
- Single verification and testing set for all satellites

4.3 GROUND SEGMENT

- Ground segment composed of:
 - Ground Stations Network
 - Multi mission CNES network
 - Israeli Station
 - Mission Control, and Expertise Ground Centers
 - CNES Satellite Control Center
 - Mission center
 - ISA Technical Expertise Center

4.4 GROUND STATIONS NETWORK

Ground stations Network is based on:

- The multi mission CNES stations network and
- The IS stations located in different sites.
- Each station interfaces to either FR or IS satellites as required during the mission.
- Stations are used for the TM/TC of the platforms (PF) and TM/TC and science data of the payloads (PL)

4.5 CONTROL, MISSION AND EXPERTISE GROUND CENTERS

Control, Mission and Expertise Ground Centers include:

- CNES Satellite Control Center, used for operations of the FR satellite platforms and IS payloads.

¹ The number of satellites is yet to be confirmed (3 or 2). Likewise, the presence of the water vapor cameras and lightning imagers and photometers on the satellites has to be confirmed, according to their impact on the scientific value and cost of the mission.

- Mission center used for programming of the platforms and the payloads and for processing of payloads' data.
 - The scene of mission, as observed by all satellites changes every 300 seconds. The different scenes for, say, a week (TBC) are selected on ground. The mission scheduling based on these scenes is elaborated on ground and sent to the satellite, say, every week (TBC).
- ISA Instrument Technical Expertise Center used for monitoring of the quality of the instruments.
- CNES System Technical Expertise center used for monitoring the performance of the system (payloads + platforms).

4.6 C³IEL WORKSHARE

The workshare and responsibilities of the joint CNES – ISA mission appears in the C³IEL workshare sharing of responsibilities table.

Table 1 C³IEL workshare Sharing of Responsibilities

	CNES side	ISA side
Requirements	Requirement established in common for: <ul style="list-style-type: none"> • Mission - mission requirement document <ul style="list-style-type: none"> ○ Including ground processing • System - System requirement document <ul style="list-style-type: none"> ○ System interfaces <ul style="list-style-type: none"> ▪ Ground - ground ▪ Ground - space • Satellites - satellite requirement document <ul style="list-style-type: none"> ○ Satellites interfaces <ul style="list-style-type: none"> ▪ Platforms - payloads instruments 	
Platforms	Full <ul style="list-style-type: none"> • Conception/development based on the common requirements • Equipment procurement • Assembly/integration/tests of platforms 	
Payloads		Full <ul style="list-style-type: none"> • Conception/development based on the common requirements • Equipment procurement • Assembly ,integration and tests of payloads for platforms
Satellites	Full <ul style="list-style-type: none"> • Full integration of the satellite <ul style="list-style-type: none"> ○ Platform integration • French participation 	Full <ul style="list-style-type: none"> • Full integration of the payload • Israeli participation
	Combined Integration <ul style="list-style-type: none"> • Platform (FR) with Payload (IS) integration 	

	CNES side	ISA side
Satellite control center	Full <ul style="list-style-type: none"> Conception/development Assembly/integration/tests Operations of the FR platforms 	Partial <ul style="list-style-type: none"> Participation in Control and Operations of IS payloads
	Combined Operations <ul style="list-style-type: none"> Operations of FR Platform with IS Payload (IS) 	
Instrument Technical Expertise Center		Full <ul style="list-style-type: none"> Conception/development Assembly/integration/tests Monitoring of the quality of the instruments
System Technical Expertise Center	<ul style="list-style-type: none"> Conception/development Assembly/integration/tests Monitoring of the performance of the satellite system 	
Mission control center	<ul style="list-style-type: none"> Mission development and definition Conception/development Assembly/integration/tests Mission scheduling (platforms and payloads) Mission IOT for science results Science data processing 	
Stations network	<ul style="list-style-type: none"> Sharing of the FR and IS stations network TM/TC for payloads and platforms 	
	Partial <ul style="list-style-type: none"> Operation of CNES station 	Partial <ul style="list-style-type: none"> Operation of ISA Station
Payloads qualification and validation	Partial <ul style="list-style-type: none"> Participation in qualification and validation of payloads 	Full <ul style="list-style-type: none"> Qualification and validation of all payloads in the system
System qualification and validation	<ul style="list-style-type: none"> Qualification and validation of all components of the system 	
Science	<ul style="list-style-type: none"> Joint FR / IS Science Team 2 FR / IS co-PIs Sharing of all data at all levels (from L0) with no delay between FR and IS teams 	

5 C³IEL'S MISSION DEFINITION DELIVERABLES

5.1 MAIN GOALS OF MISSION

C³IEL mission is based on a cluster of three or two satellites that are developed for performing the following scientific missions:

- To investigate and research sources of climatic effects that are caused by competing special effects on the evolution of clouds and the Water Vapor contents in the atmosphere properties.
- Mission will quantify the effects of cloud updrafts and the impacts of surrounding water vapor on cloud properties including radiative effects and their climatic influence.
- An additional goal of the mission is to research the vertical structure of the atmospheric water vapor and its effects on the radiative field due to:
 - The atmosphere's temperature profiles.
 - The influence of content of water vapor
 - Estimate the resulting radiative field on cloud dynamics and evolution.

5.1.1 C³IEL SCIENTIFIC MEASUREMENTS

Main requirements for each C³IEL's nanosatellite as reflected by the scientific requirements of the mission are given in Table 1.

Table 2 Requirements for C³IEL's nanosatellite

Parameter	Requirement
Mass	8 to 20 kg
Measurement conditions	<ul style="list-style-type: none"> • Day measurements • Cloudy Skies • Pointing agility along track: <ul style="list-style-type: none"> ○ - 60° to 0° (nadir) ○ 0° (nadir) up to +60°
Estimated return time (Distance passed)	<ul style="list-style-type: none"> • Up to 100s (CBE ~750km) <ul style="list-style-type: none"> ○ Get ready for next measurement pass
Pointing control (1σ)	< 0.1 deg
Pointing knowledge (1σ)	0.1 deg
Pointing accuracy In/Out of measurement	<ul style="list-style-type: none"> • During measurement <ul style="list-style-type: none"> ○ < 0.02 deg / For 2msec (CBE) Image taking time

Parameter	Requirement
	<ul style="list-style-type: none"> • Out of measurement <ul style="list-style-type: none"> ○ < 1.5 deg (CBE) / For 2 to 5 sec (CBE) No image taking
Pointing stability (1σ)	<ul style="list-style-type: none"> • During measurement <ul style="list-style-type: none"> ○ < 0.02 deg / For 2msec (CBE) Image taking time • During no measurement <ul style="list-style-type: none"> ○ < 1.5 deg / For 2 to 5 sec (CBE) No image taking
Steady state power consumption	77W(CBE) for a 8 kg, 6U nanosat
Payload mass memory capacity <ul style="list-style-type: none"> ○ With ECC (Error Correction Code) 	<ul style="list-style-type: none"> • PL Overall : 256Gbit <ul style="list-style-type: none"> ○ Clouds ○ Water Vapor ○ Lightning
Volume	6U (8U TBF)
Operational conditions	Day and Night
Position knowledge (1σ)	10m (to be approved by FR)
Velocity knowledge (1σ)	40 cm/s (CBE)
Recovery from De-tumbling mode	< 6000 s

5.2 MISSION CLOUDS INSTRUMENTATION GOALS

Clouds have an important effect on the earth's climate due to their absorption, emission, and reflectance of radiation. Their formation process, chemical and physical properties are critical for predicting earth's present and future radiative field.

The water droplets within the clouds are formed by condensation of water into an initial seed particles called Cloud Condensation Nuclei (CCN). CCN can come from particles directly emitted to the atmosphere, like dust, pollen, sea salt, and soot. Alternatively, CCN may form via homogeneous nucleation, a process in which solid particles are formed directly out of the coagulation of gas phase molecules in the atmosphere.

The main requirements of experimenting with stereoscopic imaging of the dynamic motion of clouds, is by measuring the behavior the cloud peaks with visual imaging camera in each nanosatellite and study the evolution of cloud updrafts.

This is performed by taking sweeping -60 degrees, to nadir, to +60 degrees, when satellites are in on-track orientations. The mission will be accompanied by simultaneous measurements of the water vapor in the surrounding atmosphere.

Scientific spectral requirements for imagers of Clouds mission are detailed in Table 2.

Table 3 Scientific Requirements for Cloud Imager

Parameter	Requirements	Comments
Number of instruments	3 ²	A cloud imager per payload
Wavelength [nm]	620 - 670	
FWHM *(nm)	50	Could be even larger upon specific request
Detector size and Spectral Range	To be optimized 10 bit monochrome	Visible Spectrum 0.4-1.0[μm]
SNR	>200 (TBF) ³	
Local time	13h30	
Time of Overpass [sec]	200	Per satellite
Solar irradiance (W.m-2)	1533	
Lmin-Lref-Lmax (W.m ⁻² .sr ⁻¹ .μm ⁻¹)	10 - 200 - 550	
Configurable sampling time interval between consecutive images [sec]	5, 10, 15, 20	With design goal to add capability to adjust the sampling time from 1 to 20 sec
Max zenith view angle [°]	-65 to +65	
Swath [km X km]	80 x 45	At nadir
Spatial resolution (m)	Typical 20 at nadir (up to 50)	
Resultant resolution of calculated Cloud updraft rate	<ul style="list-style-type: none"> 0.5 [m/s] to 1 [m/s] over 200 [sec] 	Horizontal and vertical development rates
FOV	<ul style="list-style-type: none"> 30[km] X 30[km] Fields of view canted 15 degrees from sun 	<ul style="list-style-type: none"> Fields of view canted 15deg when the sun is in the back
Relative payload-to-platform pointing alignment error	< 1e-3[°]	<ul style="list-style-type: none"> 0.1[km] for one nanosat 0.2[km] for two nanosats At altitude of 600[km]

* FWHM: Full Width at Half Maximum

² The number of satellites is yet to be confirmed (3 or 2). Likewise, the presence of the water vapor cameras and lightning imagers and photometers on the satellites has to be confirmed, according to their impact on the scientific value and cost of the mission.

³ To be finalized after feasibility study of Clouds' imager

5.3 WATER VAPOR CAMERA(S) SCIENTIFIC REQUIREMENTS

Table 4 Scientific Requirements for Water Vapor Image

Parameter	Requirements	Requirements	Requirements
Number of payload	Three Payloads	Two Payloads	Single Payload
Water Vapor Wavelength (nm) Preferred configuration as per the number of sats	<ul style="list-style-type: none"> #1: 1025, 1130, 1365 <p><u>Redundant</u></p> <ul style="list-style-type: none"> #2: 1025, 1130 #3: 1025, 1365 	<p><u>Option A:</u></p> <ul style="list-style-type: none"> #1: 1025, 1130, 1365 #2: Redundant WV <p><u>Option B:</u></p> <ul style="list-style-type: none"> #1: 1025, 1130 #2: 1025, 1365 	<ul style="list-style-type: none"> #1: 1025, 1130, 1365
Filter Width (nm) as related to camera wavelength⁴	20 - 20 - 30	20 - 20 - 30	20 - 20 - 30
Detector size and Spectral Range	<ul style="list-style-type: none"> To be optimized 10 bit monochrome SWIR Spectrum 		
SNR	TBD	TBD	TBD
Number of images	Sampling time interval is synchronous to clouds imager		
Max view zenith angle(°)	65		
Swath (km x km)	Not less than clouds swath 80 x 45		
Spatial resolution (m)	75, 125, or 250 (keep less than 250)		

⁴ The FWHM[nm] (Full Width at Half Maximum) of the filters for the Water Vapor cameras should be designed for maximum transfer within the specified bandwidth with minimal leakage or overspill to the side-lobes.

5.4 ZEUS LIGHTNING MEASUREMENTS

Table 5 Zeus Lightning Measurements

Parameter	Requirement	Comments
Spectral Range	Visible Spectrum	0.4-1.0 μ m
CCD sensor	Filtered at 777.4 nm	Acquisition time 2 - 100 ms (TBF)
Collection filter	1-2 nm	
Detector size	Size to be optimized 10 bit monochrome	
FOV	Same as for Clouds	
Measurement conditions	From 0° (nadir) Up to 60° along track	
Sampling rate And Observation mode	<ul style="list-style-type: none"> • At daytime <ul style="list-style-type: none"> ○ Timed with Cloud imager and triggered on photometer • At night time <ul style="list-style-type: none"> ○ Triggered on Photometer OR ○ Rolling shutter 	
Spatial resolution[m]	100m to 500m at nadir	Optical design needs to meet the requirement.
Viewing time	CLOUD viewing time +/-~40 sec	
Number of instruments per payload	1	
Expected products	Image of captured lightning flashes	

Table 6 Scientific Requirements for the ZEUS Photometers

Parameter	Requirements	Comments
Wavelength	337, 391, 777.4, 400-900	
Filter width	10 nm	Design goal of 2nm
Integration time	20 kHz to 50 kHz	
Day / Night	Day/night	
FOV diameter	Matching size to lightning imager	A baffle might be considered

Number of instruments per payload	At least 1	Design goal of 4 (1per band)
Power	Less than 4[W] [TBC]	
Weight	[TBF]	
Required on-board processing	Triggering	
Expected products	<ul style="list-style-type: none"> • Multispectral time series of optical signal in FOV • Flag of occurrence of lightning flash in FOV 	

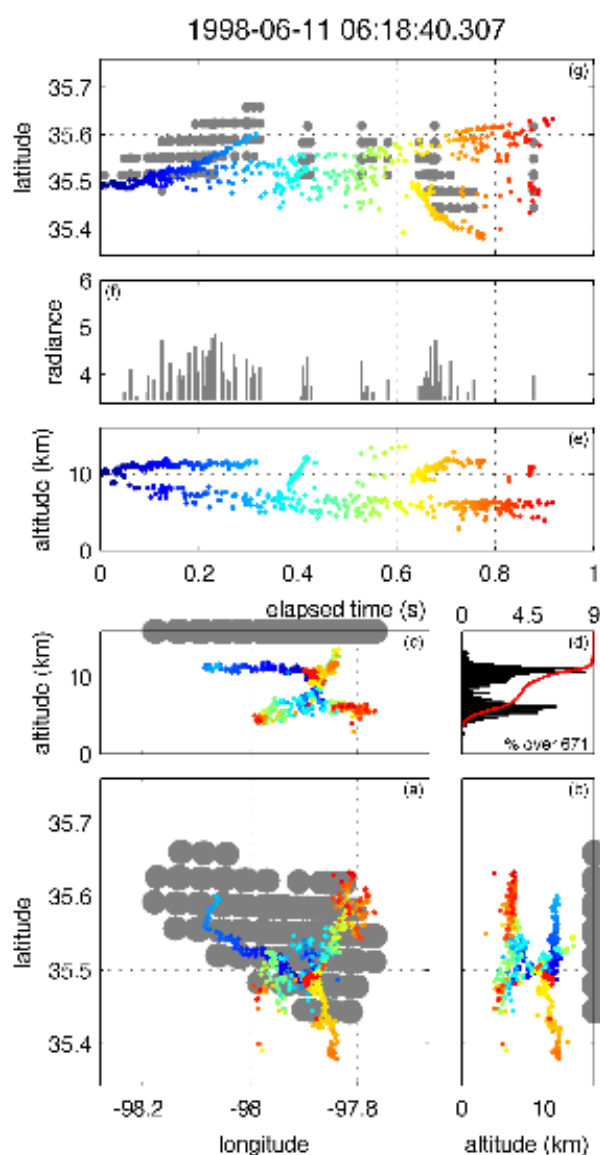


Figure 5.1: Accumulated lightning hits over time

5.5 NANOSATELLITES' POWER MANAGEMENT

The configuration of the 6U nanosatellites was displayed in the previous section. Power availability is:

- 6U Deployable Nanosat
 - Volume: 10×20×30cm
 - Mass: Less than 12kg
 - Battery capacity 77 Wh (CBE)
 - Nominal solar panels power 50W (CBE)

5.6 CONCEPT OF UPDRAFT CALCULATIONS VS TIME

The main requirements of Clouds mission is to perform stereoscopic imaging of the dynamic motion of clouds. The stereoscopic imaging will result from measuring the behavior of cloud peaks using VIS cameras in order to evaluate and extrapolate the updraft behavior of the clouds.

The main goals are to realize the unique set of instrumentation capabilities for measuring cloud updrafts (Clouds), detecting the distribution of Water Vapor (WV), and tracking the electrification of clouds (Zeus). The measurements take advantage of the unique synergy between the instruments and will yield insight of processes needed to better understanding the energetic balance in our climate system.

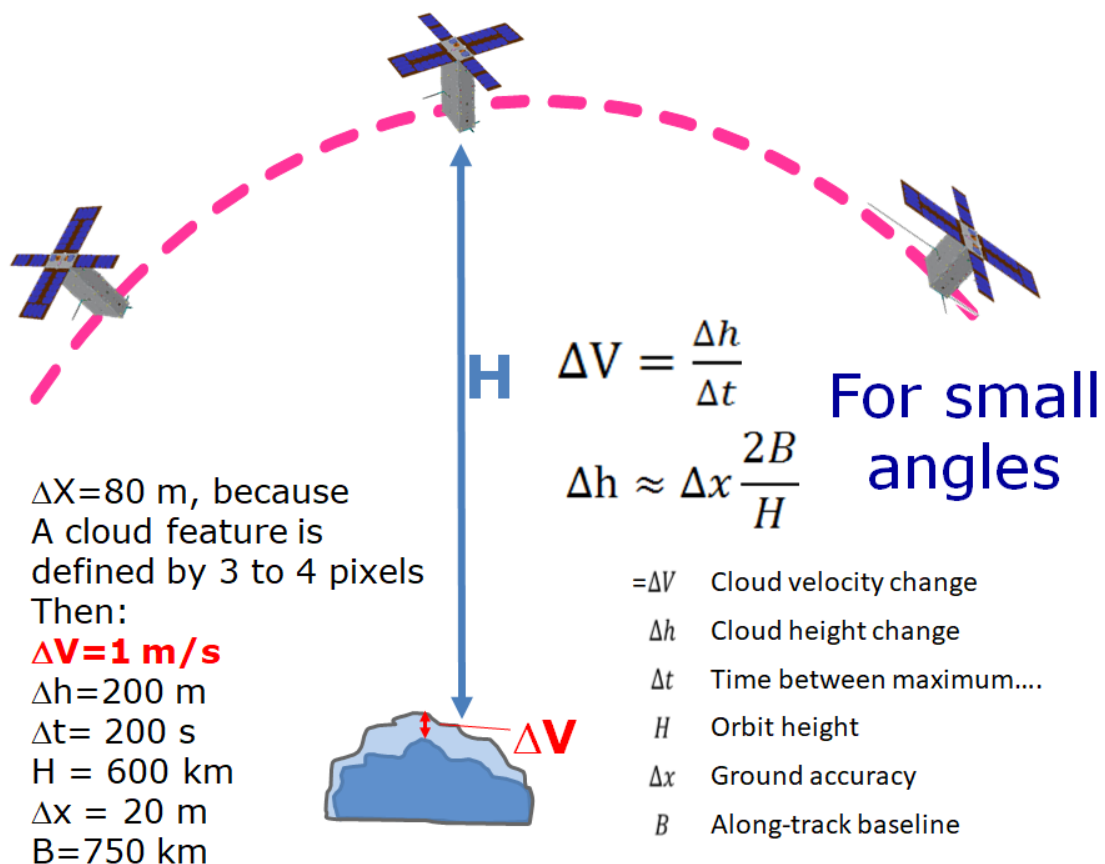


Figure 5.2: Updraft calculations along time

5.6.1 FROM RAW IMAGES TO UPDRAFT VS TIME

Input are the raw captured images from the distributed instruments.

The available parameters of each images are:

- The imagers' pose in six degrees of freedom (DOF) and their uncertainties
 - 3 DOF for location
 - 3 DOF for orientation
 - Uncertainty of each degree of freedom
 - Alternatively, per image values in case uncertainty change vs. time
- Time of acquisition
- Satellite's velocity during acquisition time
 - Tumbling velocity
- Additional supporting parameters, if available:
 - Imager sensor temperatures
 - Sun intensity (from sun sensors)

5.6.2 FROM UPDRAFT TO CLIMATE

Basic Resultant Outputs:

- Radiometric correction
- Geometric correction:
 - Correction of the camera's intrinsic parameters based on the above-said geometric calibration.
 - Assessment of each camera 6-DOF pose parameters, their covariance and uncertainties resulting from satellite's sensors data.
 - Fine-tune the parameters of the camera's 6DOF, their covariance and uncertainties, using alternate multi-view computer vision methods
 - For 3D envelope of cloud detection, relate each measured pixel to a ray in space and represent the information in a common Earth-observation software format.

Optional Advanced Output:

- Reconstruction of 3D stereoscopic shape of cloud envelop based on simultaneous images from the satellites.
- Assign quality measures of the 3D-shape reconstruction, such as:
 - Reconstruction uncertainty of each point on the envelope
 - Reprojection error
 - Blind-spots.
- Estimation of 3D motion fields of cloud envelopes
- Assign quality measures of the motion fields
- Retrieve air-motion velocities within the cloud
 - Especially, retrieve the vertical updraft speeds.

6 MISSION PRODUCTS

6.1 DATA PRODUCTS DESCRIPTION

Level 0 and Level 1 are radiative quantities; Level 1 are 2D image calibrated radiances for each wavelength.

Level 2 are retrieved products with a first level named 2A corresponding to products retrieved for each acquisitions. Level 2B corresponds to the sequence of measurements and includes the temporal derivation for the CLOUD product and a third dimension for the water vapour retrieval.

6.2 LEVEL 0

- Raw Image data from all the acquisition devices (i.e. Cloud and Water Vapor Imagers)
- Raw Lightning images and continuous values from the photometer measurements along with the times of lightning detection

6.3 LEVEL 1

- The Level 1 consist of normalized physical correction values and radiance corrected from instrumental and observational artifacts and re-projected in a 3D geo space based on latitude and longitude.

6.3.1 CLOUD IMAGERS

- **Level 1A** : Time series for each sequence of multi-stereoscopic images of clouds with radiometric correction (N satellites x K views per overpass).
- **Level 1B**: Time series for each sequence of geo-located images with geometric correction and geometric attributes (N satellites by K view par overpass)

6.3.2 WATER VAPOUR IMAGERS

- **Level 1A**: Time series for each sequence of multi-angle reflectance of the scenes with radiometric correction (3 channels x N satellites x K views per overpass).
- **Level 1B**: Time series for each sequence of geo-located multi-angle reflectance of the scenes with geometric correction and geometric attributes

6.3.3 LIGHTNING IMAGERS

- **Level 1**: 2D geo-referenced Optical Amplitude as a function of time. With optional radiometric correction.

6.3.4 LIGHTNING PHOTOMETERS

- **Level 1**:

Continuous values from the photometer along with the times of lightning detection

6.4 LEVEL 2

6.4.1 CLOUD IMAGERS

- **Level 2A:** Time series of cloud top and cloud envelop surfaces for each sequence (K views per overpass).
- **Level 2B:** Vertical cloud top development velocity and 3D motion vectors of cloud development

6.4.2 WATER VAPOUR IMAGERS

- **Level 2A:** Total column water vapor amount above cloud or ground surface
- **Level 2B:** 3D reconstructed water vapor density fields

6.4.3 LIGTHNING IMAGERS

- **Level 2:** Events, groups, flash Flash rate during viewing time

6.4.4 LIGTHNING PHOTOMETER

- **Level 2:** Flash density

7 DEVELOPMENT PHASES

7.1 PROJECT PHASES

The formulation of a space project and its implementation are defined as a flow of phases that are sub-divided into the project incremental steps. Each phase of the project is described by its:

- Purpose
- Typical activities and their interim products
- Reviews

The project incremental steps for Pre-Phase A and Phase A are detailed in the following sections, while Table 6 summarizes the project's phases. The respective goals of each phase is given in following sections.

7.1.1 PROJECT PRE-FORMULATION

- Pre-Phase A: Concept Studies (completed)

7.1.2 PROJECT FORMULATION

- Phase A with Phase A +
 - Phase A: Concept and Technology Development
 - combined with
 - Phase A+: Breadboards and engineering units
- Phase B: Preliminary Design and Technology Completion

7.1.3 PROJECT IMPLEMENTATION

- Phase C: Final Design and Fabrication
- Phase D: System Assembly, Integration and Test, Launch
- Phase E: Operations and Sustainment
- Phase F: Closeout

7.2 PROJECT PRE-PHASE A: CONCEPT STUDIES

Purpose

To produce a broad spectrum of ideas and alternatives for missions from which new programs and projects can be selected. Determine feasibility of desired system; develop mission concepts; draft system-level requirements; assess performance, cost, and schedule feasibility; identify potential technology needs and scope.

Typical Activities and Products

- Review/identify any initial customer's requirements or scope of work, which may include:
 - Mission
 - Science
 - Top-level system

- Identify and involve users and other stakeholders
 - Identify key stakeholders for each phase of the life cycle
 - Capture and baseline expectations as Needs, Goals, and Objectives (NGOs)
 - Define measures of effectiveness
- Develop and baseline the Concept of Operations
 - Identify and perform tradeoffs and analyses of alternatives (AoA)
 - Perform preliminary evaluations of possible missions
- Identify risk classification
- Identify initial technical risks
- Identify the roles and responsibilities in performing mission objectives (i.e., technical team, flight, and ground crew) including training
- Develop plans
 - Develop preliminary SEMP
 - Develop and baseline Technology Development Plan
 - Define preliminary verification and validation approach
- Prepare program/project proposals, which may include:
 - Mission justification and objectives;
 - A Concept of Operations (ConOps) that exhibits clear understanding of how the program's outcomes will satisfy mission objectives;
 - High-level Work Breakdown Structures (WBSs);
 - Life-cycle rough order of magnitude (ROM) cost, schedule, and risk estimates; and Technology assessment and maturation strategies.
- Satisfy MCR entrance/success criteria from NPR 7123.1

Reviews

- MCR
- Informal proposal review

7.3 PHASE A: CONCEPT AND TECHNOLOGY DEVELOPMENT

Purpose

To determine the feasibility and desirability of a suggested new system and establish an initial baseline compatibility with the strategic plans. Develop final mission concept, system-level requirements, needed system technology developments, and program/project technical management plans.

Typical Activities and Their Products

- Review and update documents baselined in Pre-Phase A if needed
- Monitor progress against plans
- Develop and baseline top-level requirements and constraints including internal and external interfaces, integrated logistics and maintenance support, and system software functionality
- Allocate system requirements to functions and to next lower level
- Validate requirements
- Baseline plans
 - Systems Engineering Management Plan
 - Control plans such as the Risk Management Plan, Configuration Management Plan, Data Management Plan, Safety and Mission Assurance Plan, and Software Development or Management Plan (See NPR 7150.2)

- Other cross-cutting and specialty plans such as environmental compliance documentation, acquisition surveillance plan, contamination control plan, electromagnetic
- interference/electromagnetic compatibility control plan, reliability plan, quality control plan, parts management plan, logistics plan
- Develop preliminary Verification and Validation Plan
- Develop and baseline mission architecture
 - Develop breadboards, engineering units or models identify and reduce high risk concepts
 - Demonstrate that credible, feasible design(s) exist
 - Perform and archive trade studies
 - Initiate studies on human systems interactions
- Initiate environmental evaluation/National Environmental Policy Act process
- Develop initial orbital debris assessment (NASA-STD-8719.14)
- Perform technical management
 - Provide technical cost estimate and range and develop system-level cost-effectiveness model
 - Define the WBS
 - Develop SOWs
 - Acquire systems engineering tools and models
 - Establish technical resource estimates
- Identify, analyze and update risks
- Perform required Phase A technical activities from NPR 7120.5 as applicable
- Satisfy Phase A reviews' entrance/success criteria from NPR 7123.1

Reviews

- SRR
- MDR/SDR

7.4 SUMMARY OF PROJECT PHASES

Table 7 Project Phases

Phase of Project	Purpose	Activities and Products	Reviews
<p>Pre-Phase A Concept Studies</p>	<ul style="list-style-type: none"> • Research a broad spectrum of ideas and alternatives for missions • Determine feasibility of desired system • Develop mission concepts • Draft system-level requirements, assess performance, cost, and schedule feasibility; • Identify potential technology needs, and scope 	<p>System concept feasibility studies</p> <p>simulations, analysis, study reports, models, and mock-ups</p>	<ul style="list-style-type: none"> • MCR • Informal proposal review
<p>Phase A Concept and Technology Development</p> <p>Phase A with Phase A +</p> <p>Phase A + Breadboards and engineering units</p>	<ul style="list-style-type: none"> • Determine feasibility suggested new system • Establish an initial baseline compatibility with plans • Develop final mission concept • system-level requirements • Needed system technology developments • Project technical management plans • Develop breadboards and engineering units or models to reduce high risk concepts 	<ul style="list-style-type: none"> • System concept definition • Simulation analysis • Engineering models • Mock-ups <p>Deliver working breadboards and engineering units for feasibility studies</p>	<ul style="list-style-type: none"> • SRR • MDR/SDR
<p>Phase B Preliminary Design and Technology Completion</p>	<ul style="list-style-type: none"> • Define project in enough detail to establish an initial baseline capable of meeting mission needs. • Develop system structure end product requirements • Generate a preliminary design for each system structure end product. 	<ul style="list-style-type: none"> • End products in mock-up form resulting in: <ul style="list-style-type: none"> ○ Specification ○ Interface documents ○ Prototypes 	<ul style="list-style-type: none"> • PDR • Safety review
<p>Phase C Final Design and Fabrication</p>	<ul style="list-style-type: none"> • Complete detailed system design • associated subsystems • operations systems • Fabricate hardware • Code software. • Generate final designs for each system structure end product 	<ul style="list-style-type: none"> • End product detailed designs • End product component fabrication • Software development 	<ul style="list-style-type: none"> • CDR • PRR • SIR • Safety review

Phase of Project	Purpose	Activities and Products	Reviews
<p>Phase D System Assembly, Integration and Test, Launch</p>	<ul style="list-style-type: none"> Assemble and integrate system Hardware Software developing confidence that it is able to meet the system requirements Launch and prepare for operations Perform system end product implementation, assembly, integration and test, and transition to use. 	<ul style="list-style-type: none"> Operations-ready system end product with supporting related enabling products 	<ul style="list-style-type: none"> TRRs Sys ATP ORR, FRR System functional and physical configuration audits Safety review
<p>Phase E Operations and Sustainment</p>	<ul style="list-style-type: none"> Conduct the mission Meet initially identified need Implement mission operations plan 	<ul style="list-style-type: none"> Desired system 	<ul style="list-style-type: none"> PLAR CERR DR System upgrade review Safety review
<p>Phase F Closeout</p>	<ul style="list-style-type: none"> implement systems decommissioning/disposal plan Perform analyses of returned data and returned samples 	<ul style="list-style-type: none"> Product closeout 	<ul style="list-style-type: none"> DRR

PART III: SYSTEM REQUIREMENTS

8 SYSTEM REQUIREMENTS

8.1 SCIENTIFIC SYSTEM REQUIREMENTS

8.1.1 TOP-LEVEL REQUIREMENTS

- [SR-1] A cluster of 3 or 2 nanosatellites (Clouds)
 - [SR-1.1] Size of nanosatellites 6U (CBE)
 - [SR-1.2] Nanosatellite to be provided by FR
- [SR-2] Nominal lifetime of mission is 2 years
- [SR-3] LEO Sun-Synchronous Orbit (SSO)
 - [SR-3.1] Orbit altitude ~600 [km]
 - [SR-3.2] At 13:30 local hour for high cloud activity.
- [SR-4] Nanosatellite required pointing accuracy of 0.1° (1 sigma) during mission's data collection.
- [SR-5] Pointing agility for each nanosatellite: from - 60° through 0° (nadir) and up to +60° along track (Clouds)
- [SR-6] Each nanosatellite shall simultaneously capture the same scene during data acquisition and mission's accumulation time.
- [SR-7] Currently an electric propulsion is planned (CBE)

8.1.2 THE SCIENTIFIC OBJECTIVES

- [SR-8] Simultaneous spatial and stereoscopic observation of cloud updrafts
- [SR-9] Retrieve spatial and tomographic observations of Water Vapor absorption to be used for atmospheric profiles and to obtain temperature distribution through the atmosphere
- [SR-10] Lightning mapping at high resolution in combination with clouds updraft and Water Vapor profiles.

8.2 NANOSATELLITE REQUIREMENTS

- [SR-11] The nanosatellites provided by FR
- [SR-12] Respective payloads provided by IS
- [SR-13] Satellites and payloads shall operate spatially and temporally in completely concerted time synchronization based GPS 1PPS signal
- [SR-14] All tasked shall operate in synchronization
 - [SR-14.1] Time tagged measurements
 - [SR-14.2] Data collection, over the exact same ground position
- [SR-15] Typical distance between any 2 satellites is ~150km(CBE)
- [SR-16] Maximum distance between any 2 satellites is ~300km(CBE)

- [SR-17] Time tagged observations shall be taken at times ranging between 5s to 30s (configurable) intervals (CBE is 20s, i.e. ~150km).
- [SR-18] Overall observation time of a single pass shall last up to 200s (CBE ~1500km)
- [SR-19] Estimated return time shall be not larger than 100s (CBE ~750km) in order to prepare for next consecutive pass
- [SR-20] Clouds imager observation coverage shall be at least 80km x 45km at nadir

8.2.1 SCIENTIFIC INSTRUMENTATION FOR THE THREE NANOSATELLITES

- [SR-21] Clouds - Spatial and temporal time synched stereoscopic data accumulation
 - [SR-21.1] Visual imager central wavelength of 670[nm] and filter width of ± 50 [nm]
 - [SR-21.2] Spatial resolution of 20[m]
- [SR-22] Water Vapor - Spatial and temporal time synched stereoscopic data accumulation with respective wavelengths and filter widths
 - [SR-22.1] Wavelength bands: 1000-1050[nm]; 1115-1150[nm]; 1360-1400[nm]
 - [SR-22.2] Respective filter width: 20[nm]; 20[nm]; 30[nm]
 - [SR-22.3] Spatial resolution shall be 75[m] to 250[m] with design goal to keep it less than 250m (TBF)
- [SR-23] Zeus optical lightning imager
 - [SR-23.1] Sensor for imaging at 777.4[nm]
 - [SR-23.2] Collection filter of 1 - 2[nm]
 - [SR-23.3] Spatial resolution of 0.1 to 0.5[km]
 - [SR-23.4] Acquisition time – Continuous observation triggered on ZEUS photometer or on Clouds

8.3 TOP LEVEL MISSION REQUIREMENTS

- [SR-24] The mission main goals are to demonstrate and study:
 - [SR-24.1] The ability to quantify the competing roles of cloud updrafts and aerosols on cloud radiative effects and their influence on climate.
 - [SR-24.2] The effect of the vertical structure of the atmospheric gaseous species on the atmosphere's temperature profiles and its radiative field.
 - [SR-24.3] The influence of water vapor, CCN precursors and other atmospheric species, on cloud dynamics and evolution.
- [SR-25] The mission shall comprise of 3 (or 2) nanosatellites.
- [SR-26] The mission shall be launched as a secondary payload to reduce launch costs.
- [SR-27] Mission operational lifetime shall be no less than twenty four months.
- [SR-28] Each Satellite shall be powered off following integration and throughout launch operations.
- [SR-29] Each Satellite shall be capable of being placed in a state of storage without requiring maintenance for a period of twelve months.
- [SR-30] Each Satellite shall be designed for an overall probability of success of 80% at the end of its design life.

- [SR-31] Each Satellite shall be compliant with standard requirements for limiting orbital debris.
- [SR-32] Each Satellite shall have at least the following operational modes:
 - [SR-32.1] NORMAL Mode is the nominal operational mode for Each Satellite.
 - [SR-32.2] SAFE Mode provides maximum sun exposure to the solar array and a satellite configuration that ensure batteries charging and ground communication capability.

8.3.1 ORBITAL REQUIREMENTS

- [SR-33] The actual orbit of the satellite cluster shall be determined by the availability of a suitable launch, conforming to the orbit requirements, stated herein:
 - [SR-33.1] The satellites shall fly on Low Earth Orbits (LEO).
 - [SR-33.2] The perigee altitude shall be larger than 500 km.
 - [SR-33.3] The apogee altitude shall be smaller than 800 km.
- [SR-34] Sun-synchronous orbit (SSO) with local time ascending node (LTAN) of 13:30±30 min.
- [SR-35] The nominal reference orbit for design, until the final orbit is known, shall have an altitude of 600 km and inclination of 97.8 deg.

8.3.2 LAUNCHER REQUIREMENTS

- [SR-36] Satellites shall be injected into the designated orbit by a commercial launcher as a secondary payload.
- [SR-37] All 3 satellites shall be launched with the same launcher.
- [SR-38] Satellites shall be inserted into their designated orbital planes directly from the launcher.
- [SR-39] The Launcher shall have a capability of injecting at least 100 kg into the required orbit with the following accuracy:
 - [SR-40] Altitude: better than 35 km (3 sigma)
 - [SR-41] Inclination: better than 0.1° (3 sigma)

8.4 FUNCTIONAL REQUIREMENTS

8.4.1 PAYLOAD SUBSYSTEM

8.4.1.1 Cloud

- [SR-42] The payload will be able to detect cloud using on-board software.
- [SR-43] The payload shall generate images off target sites, for geolocation purposes.
- [SR-44] The payload shall detect Water vapor profiles
- [SR-45] The payload shall quantify the total atmospheric columns above the target sites of the above materials.

8.4.2 BUS SUBSYSTEM

- [SR-46] Each Satellite shall be autonomously activated after deployment from the launch vehicle.
- [SR-47] Each Satellite shall maneuver autonomously to a stable attitude after deployment from the launch vehicle.
- [SR-48] Each Satellite shall acquire autonomously the sun after deployment from the launch vehicle.
- [SR-49] Each Satellite shall autonomously enter an attitude that maximizes sun exposure after attitude stabilization.
- [SR-50] Each Satellite shall be capable of being commanded into any operational mode from the ground.
- [SR-51] Each Satellite shall autonomously transition to SAFE mode upon detection of any fault that threatens the health and safety of Each Satellite.
- [SR-52] Each Satellite shall transition out of SAFE mode only after command from the ground.
- [SR-53] Spacecraft autonomous functions shall be performed using on-board software.
- [SR-54] Each Satellite shall record all autonomous operations to the telemetry log.
- [SR-55] Each Satellite shall report detection of out-of-limit conditions for monitored systems in the telemetry log.

8.4.3 ELECTRICAL POWER SUBSYSTEM

- [SR-56] The Electrical Power Subsystem (EPS) shall provide a single point (common) ground within the power subsystem.
- [SR-57] The EPS shall provide power generation, power control, energy storage and distribution to Each Satellite.
- [SR-58] The EPS shall manage solar panels providing at least TBD watts at EOL during full Sun visibility.
- [SR-59] The EPS shall provide conditioned electrical power for all Spacecraft operational modes during eclipse conditions.
- [SR-60] The EPS shall provide battery management and load shedding control.
- [SR-61] The EPS shall provide short circuit protection or current limitation for each switchable power circuit.
- [SR-62] The EPS shall provide protection from over voltage and under voltage conditions.
- [SR-63] Each Satellite shall be capable of being powered from an external source while on the ground with or without batteries installed.
- [SR-64] The EPS shall at a minimum monitor and report in telemetry logs the switch positions, current, and voltage levels for each circuit at the power distribution point.
- [SR-65] The capacity of each battery of a payload of a satellite shall be 1.25 times the nominal charge / discharge profile at the end of each Satellite design life.

- [SR-66] The EPS shall be capable of electrically bypassing failed battery cells.
- [SR-67] Satellite battery shall provide the power during 35-minute-long eclipses without performance degradation of any sort.

8.4.4 ATTITUDE AND ORBIT CONTROL AND DETERMINATION SUBSYSTEM

- [SR-68] Each Satellite shall be three-axis stabilized.
- [SR-69] Each Satellite shall use the global positioning (GPS) time as primary satellite time reference.
- [SR-70] Each Satellite shall be capable of receiving a ground-based satellite reference time and time correction coefficients.
- [SR-71] Each Satellite shall generate an on-board ephemeris based on the GPS.
- [SR-72] Each Satellite shall be capable of receiving a ground based ephemeris update.
- [SR-73] Each satellite shall be capable of performing orbit and attitude maneuvers during umbra.

8.4.5 COMMUNICATIONS SUBSYSTEM

8.4.5.1 Command and Telemetry

- [SR-74] The communications subsystem shall provide two-way RF communications for uplink of command and control data and downlink of payload data and satellite health and status data.
- [SR-75] The communications subsystem shall comply with Israeli Ministry of Communication (IMOC) Spectrum Standards.
- [SR-76] The Communications Subsystem shall comply with International Telecommunication Union (ITU) spectrum utilization and sharing requirements.
- [SR-77] The primary communications system shall be capable of being enabled and disabled (switched ON or OFF) via ground command.

8.4.6 THERMAL CONTROL

- [SR-78] Each Satellite shall remain thermally stable, under stable attitude control, and operationally functional within its design requirements.
- [SR-79] Each Satellite shall be thermally safe for continuous operations in all operational modes.
- [SR-80] Each Satellite shall have a thermal control system that monitors and reports in the telemetry log the temperatures of subsystems on Each Satellite.

8.4.7 STRUCTURAL AND MECHANICAL

- [SR-81] Each Satellite structure shall be compatible with a CubeSat standard.
- [SR-82] Each Satellite structure shall include a structural mounting interface that is isolated from mechanical and thermal disturbances from the Satellite

- [SR-83] Each Satellite shall be designed to permit full range deployment of solar panels after ejection from a pod without any need of ground control intervention.

8.4.8 PROPULSION SUBSYSTEM (TBF)

- [SR-84] The propulsion system shall provide thrust for keeping the satellite in cluster flight as well as for the nominal orbit maintenance.
- [SR-85] Contingency fuel of at least 25% shall be used.

8.4.9 FLIGHT SOFTWARE

- [SR-86] Satellites flight software shall be reprogrammable on orbit.
- [SR-87] Satellites shall monitor software tasks to detect for infinite loops or stalled processes.
- [SR-88] Satellites flight software shall detect and correct single bit memory errors.
- [SR-89] Satellites stored commands shall be unaffected by a flight software upload.
- [SR-90] Satellites flight software shall store the version identifier of reprogrammable software onboard.
- [SR-91] Satellites shall preserve contents of the telemetry log after rebooting or power cycling.
- [SR-92] Satellites shall initialize flight software and begin operations without the need of a ground based command.
- [SR-93] Satellites processor shall execute a restart of its software in response to a ground command.
- [SR-94] Satellites flight software shall provide a capability to store and execute absolute-time command sequences.
- [SR-95] Satellites flight software shall provide a capability to store and execute relative-time command sequences based on internal timeframe.
- [SR-96] Satellites flight software shall execute real-time commands before executing stored commands.
- [SR-97] Satellite flight software shall provide the capability to store multiple time-tagged command sequences.
- [SR-98] Satellites flight software stored command sequences shall be modifiable by ground command.
- [SR-99] Satellites flight software command sequences shall be enabled, disabled or canceled by ground command.
- [SR-100] Satellites flight software shall be capable of placing the contents of the stored command buffer into the telemetry log.
- [SR-101] Satellites flight software shall uniquely identify stored command sequences.
- [SR-102] Satellites flight software shall use the unique command sequence identifier to report the status of each actively executing command sequence in telemetry.

8.5 PERFORMANCE REQUIREMENTS

8.5.1 PAYLOAD SUBSYSTEM

- [SR-103] The payload structure shall be of sufficient strength and stiffness to maintain structural integrity during ground testing and transportation and launch.
- [SR-104] The payload structure shall provide a mounting interface to the satellite bus.
- [SR-105] The payload shall be thermally stable while in operational modes.
- [SR-106] The payload shall be capable of being reset on orbit.
- [SR-107] The payload shall continuously monitor its health and safety.
- [SR-108] The payload shall be designed to operate and meet all design requirements for twelve months following commissioning on orbit.
- [SR-109] The payload shall be capable of being placed in a state of storage without requiring maintenance for a period of twelve months.

8.5.1.1 Cloud

- [SR-110] The payload measurement condition shall be:
- [SR-111] Cloudy
- [SR-112] Day time
- [SR-113] The payload FOV shall be *30 km × 30 km*
- [SR-114] The payload spatial resolution shall be 20 – 30 m
- [SR-115] The payload Spectral Range shall be in VIS
- [SR-116] Radiometric Range and Resolution (SNR or NedT) shall be 1%
- [SR-117] The payload sample rate shall be 20 s.
- [SR-118] The payload shall take at least 3 images of the same cloud.
- [SR-119] The payload shall detect a cloud vertical velocity change of at least 1 m/s.
- [SR-120] Payload swath shall be at least 20 km.
- [SR-121] All instruments of the payload on the satellites shall be time-synchronized to 1PPS
- [SR-122] All optical viewing instruments of the payload, on the satellites, shall be canted at 15° eastward, so that the field of view is directed to the solar backscattering angle of the sun.

8.5.2 BUS SUBSYSTEME

- [SR-123] Each Satellite shall be capable of operating safely without any ground intervention for a period of 72 hours.
- [SR-124] Each Satellite's lifetime shall be at least two years. Design goal shall be for at least three years.

8.5.3 ATTITUDE AND ORBIT CONTROL AND DETERMINATION SUBSYSTEM

- [SR-125] Each satellite shall have two possible inertial modes:
- [SR-126] Nadir pointing.
- [SR-127] Sun pointing

- [SR-128] Each Satellite shall perform maneuvers to any inertial attitude meeting pointing requirements and stabilize within TBD seconds.
- [SR-129] Maximum allowed pointing errors (per axis) shall be less than 100 arc second (3 sigma). (CBE)
- [SR-130] Each satellite shall be able to determine its position and velocity vectors using a GNSS receiver with an RMS accuracy better than 10 m for X, Y, Z.

8.5.4 COMMUNICATIONS SUBSYSTEM

- [SR-131] Radio frequency link margins shall be at least TBD dB in all operational modes.
- [SR-132] Link budget shall be calculated for maximum slant range of TBD km.

8.5.4.1 Command and Telemetry

- [SR-133] Each Satellite shall transmit a minimum of TBD % of real-time and recorded telemetry to the ground segment.
- [SR-134] The primary communications system shall have a bit error rate (BER) at operational data rates of less than or equal to $1E-6$ after demodulation and error correction.
- [SR-135] The primary command uplink shall be at least TBD.
- [SR-136] The primary downlink shall at a minimum be TBD.

8.5.4.2 Beacon

- [SR-137] Each Satellite shall be capable to transmit a beacon signal.
 - [SR-137.1] Beacon data rate shall be at 1Hz

8.5.5 COMMAND AND DATA HANDLING SUBSYSTEM

- [SR-138] Each Satellite shall be capable of storing at least 5 days (5x24 hours) of spacecraft telemetry data at the maximum onboard telemetry rate.

8.5.6 THERMAL CONTROL SUBSYSTEM

- [SR-139] The Thermal control subsystem shall secure ambient temperature within the satellites with the following constraints:
 - [SR-139.1] Minimum temperature shall be more than 0° C.
 - [SR-139.2] Maximum temperature shall be less than 40° C.
 - [SR-139.3] Temperature measurements shall be with accuracy better than 1° C

8.5.7 STRUCTURAL AND MECHANICAL

- [SR-140] Each Satellite structure shall be sufficiently stiff to meet the axial and lateral frequency requirements as defined in GSFC-STD-7000.
- [SR-141] Each Satellite structure shall be of sufficient strength and stiffness to maintain structural integrity and withstand all launch and launch vehicle separation environments as defined in GSFC-STD-7000.

- [SR-142] Each Satellite structure shall be of sufficient strength and stiffness to maintain structural integrity and withstand all ground testing, handling, transportation, and mission on-orbit environments as defined in GSFC-STD-7000.

8.5.8 PROPULSION SUBSYSTEM

- [SR-143] Section To Be Completed

8.5.9 FLIGHT SOFTWARE

- [SR-144] Each Satellite flight software stored command capability shall store up to 72 hours of spacecraft command sequences.
- [SR-145] Satellites flight software shall be capable of executing commands with an accuracy of 100 milliseconds or less.

8.6 PHYSICAL CHARACTERISTICS

- [SR-146] Structure shall be a standard 6U CubeSat.
[SR-146.1] Optional structure of 8U CubeSat shall be considered.
- [SR-147] The Satellites configuration shall be identical.
- [SR-148] Each Satellite's mass shall be less than 10 kg. Design goal is less than 8 kg to reduce launch costs.
- [SR-149] The Satellites' bus shall be designed using space-proven COTS sub-systems and components for the extent possible.
- [SR-150] There shall be at least one ground station, in Israel that will enable telemetry and control of the satellites.
- [SR-151] The Satellites shall conform to all applicable standards for the Nanosatellite Launch Adapter System.

8.7 ENVIRONMENTAL REQUIREMENTS

- [SR-152] All subsystems shall be qualified at acceptance levels for Thermal Cycle, Thermal Vacuum Cycle, Vibration, and Shock Testing as defined in GSFC-STD-7000.
- [SR-153] The satellite bus and payload electronics shall be capable of correcting for single event memory corruption caused by radiation.
- [SR-154] The spacecraft and payloads shall be capable of operation in LEO without unrecoverable failure due to radiation effects.
- [SR-155] All subsystems shall endure at least 10 kilorad of total dose radiation without any degradation.

8.8 STRUCTURAL AND MECHANICAL VERIFICATION REQUIREMENTS

- [SR-156] Verification shall be based on PFM methodology for one of the satellites and FM for the other two.
- [SR-157] Random vibration tests shall be conducted on the integrated Satellite bus, payload system, and the final spacecraft assembly.

- [SR-158] Random vibration tests shall cover frequency ranges from 20 to 2000 Hz.
- [SR-159] Random vibration test items shall be subjected to random vibration along each axis for one minute each.
- [SR-160] Random vibration test qualification and acceptance test levels will be determined in accordance with GSFC-STD-7000.
- [SR-161] The mass properties of the integrated spacecraft shall be determined by measurement.
- [SR-162] The following mass properties shall be determined:
 - [SR-163] Weight
 - [SR-164] Center of gravity
- [SR-165] Subsystem qualification tests shall be performed for each mechanical operation.
- [SR-166] The integrated Satellite shall be tested to demonstrate that each mechanical device is installed correctly and that there are no interference problems that will adversely affect the mission.

8.9 ELECTROMAGNETIC COMPATIBILITY VERIFICATION REQUIREMENTS

- [SR-167] Radiated emission tests shall be performed on Satellites transmitters to identify electro-magnetic interference.
- [SR-168] The integrated Satellites shall be tested for stray magnetic fields which may affect the on-board magnetometers.

8.10 ELECTRICAL FUNCTION VERIFICATION REQUIREMENTS

- [SR-169] Electrical interface tests shall be performed on each component and subsystem prior to integration to verify that interface signals follow the correct signal path and are within acceptable limits.
- [SR-170] Electrical harnesses shall be tested to verify proper routing, impedance, isolation, and workmanship prior to integration.
- [SR-171] An aliveness test shall be performed prior to and following integration to verify that the component or subsystem is functioning.
- [SR-172] A Comprehensive Performance Test (CPT) shall be conducted on each component and subsystem following environmental testing to demonstrate that components meet performance requirements within allowable tolerances.
- [SR-173] CPT shall be conducted at the hot and cold extremes of the thermal-vacuum test for both maximum and minimum input voltage.

8.11 VACUUM AND THERMAL VERIFICATION REQUIREMENTS

- [SR-174] All components and subsystem assemblies shall be subjected to thermal-vacuum tests that demonstrate function at temperatures ten degrees higher and lower than expected flight temperatures.

- [SR-175] The integrated Satellites shall be subjected to thermal-vacuum tests that demonstrate function at temperatures five degrees higher and lower than expected flight temperatures.
- [SR-176] Thermal-vacuum tests shall, at a minimum, subject the hardware to four complete thermal cycles.
- [SR-177] Thermal-vacuum tests shall incorporate a period for out-gassing.
- [SR-178] CPT shall be performed at each hot and cold soak plateau of a thermal cycle.