Title: Cloud Height Mission

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( ) We apply for Student Prize.

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Need

Extreme natural events like severe storms, desert dust or volcanic eruptions can seriously jeopardize the safety of the air traffic. To prevent encounters of airplanes with dangerous clouds it is necessary to be able to accurately measure the top of clouds, which is impossible using currently operational satellites.

Air traffic is vulnerable when it comes to extreme natural events. For instance, although 2010 Eyjafjallajökull volcanic eruption on Island was not particularly large compared to the 1991 Pinatubo eruption (~20 times more erupted material) or the 1815 Tambora eruption (~500 times more), it totally paralysed the air traffic in Europe because of our inability to make an exact prediction of volcanic ash dispersion. The International Air Transport Association (IATA) stated that the total loss for the airline industry as a result of the airspace closure during the eruption of Eyjafjallajökull was around €1.3 billion (BBC News, 21/04/10): over 95,000 flights had been cancelled all across Europe during the six-day travel ban (BBC News, 21/04/10), with later figures suggesting 107,000 flights cancelled during an 8 day period, accounting for 48% of total air traffic affecting roughly 10 million passengers [1]. The paralysed air traffic caused also further costs such as delayed business meetings, but such losses are difficult to measure.
State of the art ash dispersion models are very sophisticated but the accuracy of their predictions is limited by the unacceptably low quality information on the eruption source parameters [2]. The crucial parameter is the ash cloud height. This was presented Heinold et al. [3] that showed for Eyjafjallajökull eruption, how different emplacement heights of the ash into the atmosphere influences the ash dispersion. The ash was transported to Denmark over very similar path regardless of emplacement height. For emplacement height of 5–6 km it dispersed further to the East of Denmark in the direction of Baltic states, while for an emplacement height of 7–8 km dispersion turned towards England. The reason for that is the wind field that can strongly vary with height. Significant differences in the wind velocity or significant differences of the wind direction are possible across height intervals of less than 500 m. This kind of images are impossible to achieve by current state of the art methods. Ground based methods have many limitations. Satellite data are often used to estimate the ash cloud top height, most commonly using the brightness temperature or CO_2 absorption method. Their accuracy is usually worse than 1000 m. In addition, these methods do not work in the stratosphere.
Although our main motivation is observation of volcanic ash because of huge financial loss in the last years, the proposed retrieval (see "space segment") can be easily used in any type of aerosol or meteorological cloud monitoring. Sand storms are especially dangerous during take-off and landing, thus it is necessary to know their top height that usually corresponds also to its thickness. High convective clouds may cause extreme shear wind conditions that can endanger a plane at its usually safe cruising altitude. It is thus necessary to detect the rapid rising "storm towers".

Cloud Height Mission Objectives

The main purpose of the Cloud Height Mission (CHM) is to increase aviation safety by helping to avoid interaction of aircrafts with possible hostile atmospheric conditions.

OBJECTIVE 1

To serve aviation safety, CHM focus on estimating the vertical extent of clouds using stereoscopy. Stereoscopic heights may contain systematic errors caused by wind using satellite instruments having several cameras like MISR. To account for this systematic error, a pair of images has to be taken simultaneously [4]. This is possible using at least two satellites directing the camera to the same point on Earth. The required accuracy of cloud top height estimate is better than 200 m (operational methods based on brightness temperature or CO_2 absorption have an accuracy of about 1000 m). For operational monitoring, we need a swath of at least 700 km. The same requirements are valid for volcanic, dust, and storm clouds.

OBJECTIVE 2

Besides aviation needs, the CHM products are especially interesting for meteorologists. In some countries, like Midwest USA, a lot of effort is dedicated towards observation of convective clouds (*Cumulonimbus*) that might develop in so called super cells. Tops of such clouds can reach heights of over 20 km making them a source of dangerous severe weather, such as hail, heavy precipitation, or tornadoes [5]. Thus we plan on monitoring the top height of meteorological clouds to enhance severe weather warning service. The required accuracy is again 200 m.

OBJECTIVE 3

To be able to provide additional data to the scientific community working on fine scale modelling, the temporal evolution of volcanic, dust and severe weather clouds has to be observed. If requested, CHM will provide 5 height estimates within one minute.

Concept of CHM Operations

The concept of operations will follow the scheme:

LAUNCH SEGMENT	SPACE SEGMENT	
Launch: Satellites will be put in orbit.	**Formation flight** Satellites will start to flight in large formation and with correct orientation	**Stereoscopy scanning** Satellite will start the cloud/ash scan operations and the dynamic observation
	The operation of rendezvous and flight formation will be controlled from the ground.	Ground stations will receives the data from the satellite and will proceed to the analysis
	GROUND SEGMENT	

The core of CHM is the observation of clouds independent of its origin. To determinate their height, we will use a stereoscopy system based on two satellites flying in formation at a distance of 400 km covering a swath of 700 km. Both satellites will carry two cameras (see fig. 1: red lines show the field of view of cameras on satellite 1 and orange on satellite 2 in fig. 1). Using automatic image matching, we can estimate which pixels on a pair of images match. For such a pair we will estimate the parallax. From the parallax it is easy to compute the cloud height.

Each satellite will have one camera directed into its own nadir. The second camera on both satellites will be directed into nadir of the other satellite. This will allow simultaneous observations of clouds. If the observations are not simultaneous, the wind can influence the height estimation. For instance, if a cloud moves 120 km/h it moves 2 km within 1 min. If observations with a 45° angle are available with 1 min apart between both measurements, the parallax error can be as large as 2 km (depends on the direction of the wind in relationship to the satellite track) causing a height error of maximal 2 km. Because both satellites carry two cameras it is also possible to observe the **temporal evolution of the cloud**. The evolution of volcanic and severe weather clouds is not well known, thus we plan using full frame sensors on both satellites. This will allow observations of a short time dynamics of a cloud for a period of about 60 seconds.

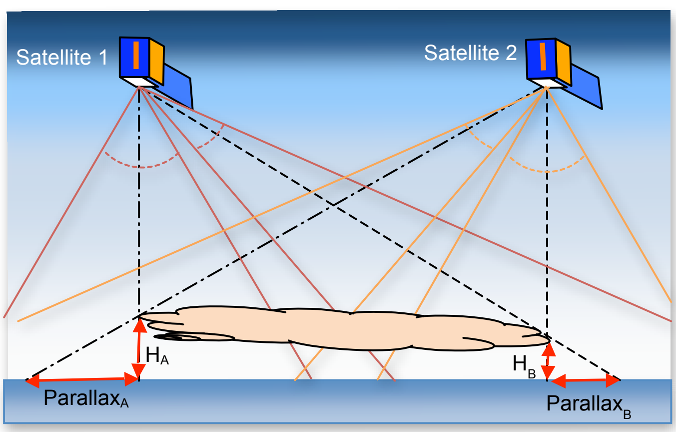


Fig. 1. Scheme of CHM formation flight: red lines show the field of view of both cameras on satellite 1 and orange on satellite 2. Dash-dot (dashed) lines both observe point A (B) on the cloud. The observed position of this point depends on the viewing angle of the satellite causing a parallax. This can be easily converted to height H of the cloud.

CHM Key Performance Parameters

	FUNCTIONAL PARAMEETERS
F 1.1	At least two satellites need to fly in formation
F 1.2	Image need to be taken simultaneously
F 1.3	Cameras need to point the same point on Earth
F 2.1	Satellites need to monitor clouds
	PERFOMANCE PARAMEETERS
P 1.1.1	ADCS has to be adequate to perform <1.5° precision
P 1.1.2	Ground segment based control for re-burn maneuver
P 1.2.1	A synchronized system will start and stop images for both satellite
P 1.3.1	A swath of at least 700 km is need
P 2.1.1	Accuracy of height estimation better than 200 m
P 2.1.1	Short time dynamics period of ~60 s (at least 5 image pairs) or optional in real time video
P 3.1.1	Scan the Territory with separated systems

CHM Ground Segment Description

Processing from the compressed images (level 1 data) to the level 2 data (parallax, height estimation, accuracy estimation) and level 3 data (average heights of clouds over long term, volcanic eruption rate estimation) will be done on the ground.

As the project has international relevance we expect to have access to multiple ground stations and therefore possibly large access time. The ground station will also eventually work on uplink for command the orbital correction.

CHM Space Segment Description

The CHM space segment consists in a formation of two satellites. Both satellites are realized with the same architecture and subsystems. On board on each satellite are mounted two cameras with 50 mm lens and off-shelf B-G-R-NIR sensor.

An optional upgrade of the system is to replace one sensor on each satellite with a thermal sensor: a pair of cameras in the visible spectrum would observe nadir of the first satellite and the thermal cameras would observe nadir of the second satellite. Thermal sensors used in thermal cameras are relatively cheap, thus they have been considered for micro satellites already in the past [6]. The problem is their coarser spatial resolution (at the same swath width as a sensor in visual spectrum) that reduces also the vertical accuracy. This would affect also short period cloud dynamics monitoring. On the other hand, thermal sensors would provide data from thermal cameras also during night time, which is not possible for sensors operating in the visible spectrum.

To perform pointing maneuvers the ACDS exploits three reaction wheels and three magnetorquer. The attitude determination is obtained with solar sensor and magnetometer.

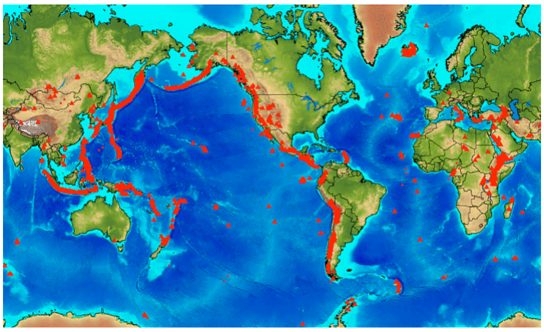
The on-board computer compresses the data that are transmitted on ground for processing. In this way it's possible to reduce the software operation in space and minimize the downlink data size. Standard data acquisition is done once per minute, on demand high temporal resolution over selected area (even video).

SPACECRAFT (launch excluded)					
Component	**Description/Function**	**Mass (g)**	**Power**	**Dimension**	**Cost(1 sat)**
Structure	Aluminum	5000	/	300x300x300	TBC
Camera	Primary Payload	1500x3	1.54 W	100x100x100	TBC
ADCS	Air Coil Magnetorquer Reaction wheels	300 2000	<2 W 3 W	300x300x10 mm 60x60x50 mm	TBC
Propulsion system	Cold gas	2000	-	50x50x200 mm (Tank)	TBC
TX/RX	VHF /UHF /S-BAND	800	10 W	200x200x10mm	TBC
Thermal Control	Passive	/	/	-	
Sensors	Specific design	300	<1 W	-	TBC
OBDH	Specific design	300	<1 W	200x200x10mm	TBC
Power System	Batteries	2000	2A@24V	200x200x200	TBC

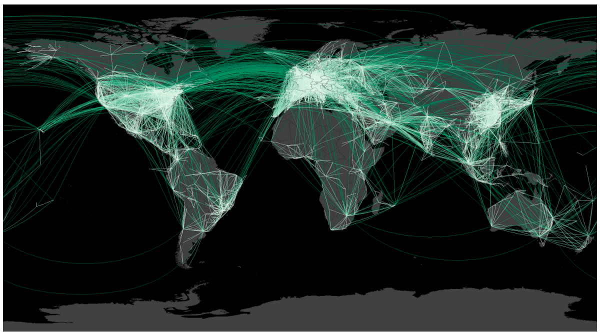
	Solar panels (4 side)		Battery 1A@5V	mm 300x300	
TOTAL		< 20 Kg			200k E TBC
POWER SYSTEM					
Average Power	< 2 W				
Peak Power	< 12 W (during transmission)				
Battery Pack	2A@24V ca 50W peak available power				
Solar Panels	1A@5V				

CHM Orbit/Constellation Description

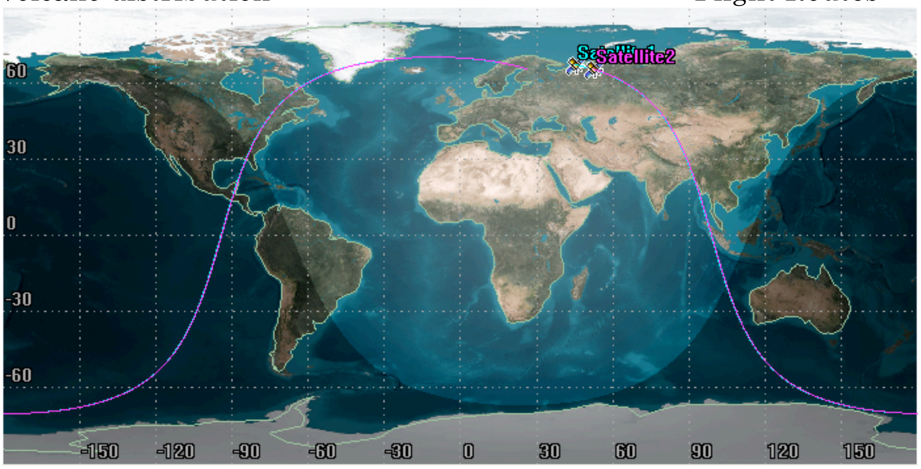
The CHM fleet of two satellites will fly in the same orbit with a distance between them of 400 km on the height of 600 km and about 70° of inclination, to have best conditions for the observation. Low inclination is for our purposes acceptable, because there are not many volcanoes or extremely high meteorological clouds at high latitudes. This provides coverage of most volcanic hot spots as well as meteorological events, but also most important flight routes.



Volcano distribution



Flight Routes



Orbit example

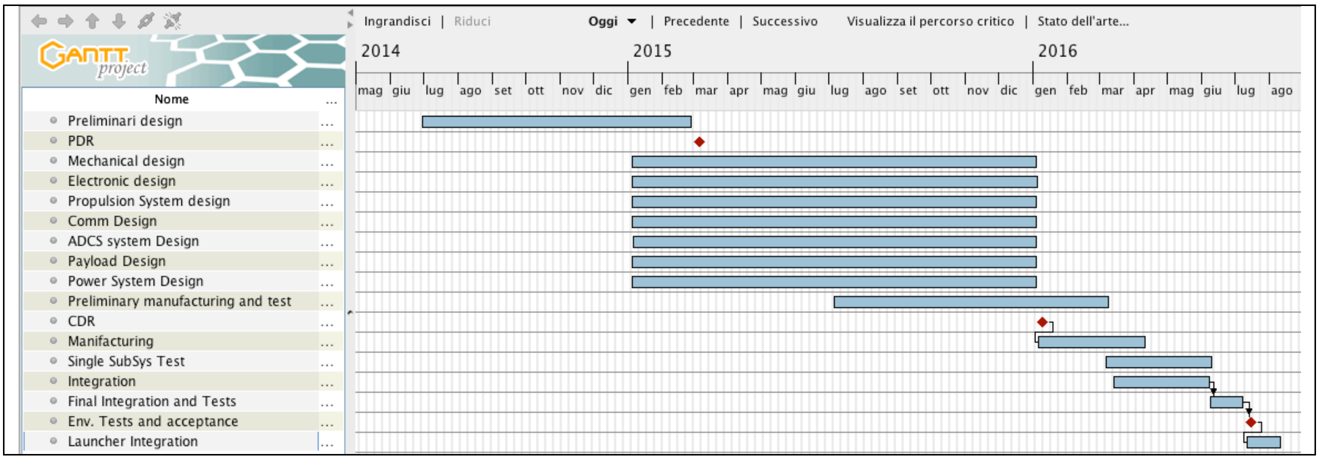
CHM Implementation Plan

Considering the huge loss following the 2010 Eyjafjallajökull eruption, the potential financier's network is worldwide and we expect to collect the capital necessary for the kickoff (much lower than the loss for the eruption) before the PDR, during the preliminary design of the experiment. The mission is scheduled in 25 months.

The preliminary design phase is scheduled to be rather long allowing for a detailed drafting of all requirements, parameters and risks. It further allows for detailed consideration of all the technical aspect of the mission including decisions which subsystems could be chosen "off the shelf" and which need to be designed and where it would be possible to start collaborations. Finally a precise estimate of costs will be done during this time.

At the end of the preliminary design phase ths subsystem design will be finalized for presentation at the PDR. The PDR will give the direction to complete the design phase and start to build and test the first prototype of the subsystems. The prototype will be presented at the CDR where the final proptotype will be approved.

From there, it will be possible to start the models (engineering, test, flight) of the spacecraft, test an integrated it. Achived the final integrations and environmental tests, it will be possible to integrate the satellites with the launcher. The schedule is flexible and in future it will be necessary to develop it in deeper way: augmenting the reviews, assigning the tasks to teams and counting the "man work hour".



The risk register table needs to be considered (as the plan of the project) preliminary. During the project development (in particularly during the Preliminary Phase Design) it will be possible to mitigate these risks and to identify more critical aspect and their mitigation.

RISK	GRADE	PREVENTION
Ground station without access	Low	The project is based on having a large number of ground station due the international interest of the mission
Sensors failure	Low	Selecting of components with space heritage
Launch System failure and loss of both satellite	Medium	Selection of high reliability launch system
Propulsion System Failure	Medium	Mission designed to have a minimum useful lifetime also without the propulsion.
Pointing maneuver failure	Medium	Optimize control algorithm
One of satellite fails in orbit	High	In this case the primary mission will be not accomplished but it will be possible to use it for normal observation with two cameras that still allows estimates of cloud top height if the wind field is known. One more satellite could be built and put in stand-by during the first years of the mission.

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