<Constellation Mission>

Title: Ocean Climate CubeSat Constellation (OCCC) Mission

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Need

Climate change and extreme weather events inflict significant loss of life and financial damage, with 2 million casualties and $3.64 trillion in losses in US dollars between 1970 and 2019 [1]. A key factor of the aforementioned phenomena is the ocean-atmosphere interaction, which is poorly understood and often ignored in existing weather models due to the insufficient data coverage provided by modern weather satellites. The CubeSat constellation will conduct the mission better with integrating multiple observing sensors, multiple sensing platforms and better coverage area.

Mission Objectives

We have three objectives in our mission Ocean Climate CubeSat Constellation (OCCC). The primary objective is to understand the physical interaction between the ocean and the atmosphere and how this kind of interaction may induce disastrous weather such as tropical cyclones. Our secondary objective is a feasibility study on ocean weather forecasting.

Primary mission objective:

- Investigate the physical atmosphere-ocean interactions
- Study natural disasters related to the atmosphere-ocean interactions, such as cyclones and heat waves.

Secondary mission objective:

- Conduct ocean weather forecasting.

For the primary mission objective, we intend to study the physical part of ocean-atmosphere interaction as it is a very complicated process to comprehend. In the realm of physical interaction, the ocean transfers heat and moisture to the atmosphere, while the atmosphere provides driving force to ocean currents, and changes sea surface temperature (SST) and sea salinity. Such a coupled and complex system will require in situ measurements of dynamical properties of ocean and atmosphere simultaneously, including temperatures of ocean and atmosphere, ocean surface wind, and ocean aerosol. These measurements shall help to construct a more precise weather model for future weather forecasting.

In addition, we will study natural disasters connected to the physical atmosphere-ocean interaction such as tropical cyclones, El Nino, and heat waves. Current weather models are capable of predicting the paths of tropical cyclones, yet the formation of these tropical storms have been elusive. Our mission will be able to monitor the ocean and the atmosphere status throughout the lifetime of the cyclone. We can track the wind speed up to 50 m/s, atmosphere pressure from anticyclone to cyclone, the vertical profile of temperature from the sea to the atmosphere, and the aerosol particles that the ocean provides to the atmosphere.

For the secondary mission objective is a pilot study. We plan to use an IoT receiver to obtain the in-situ data for the GNSS-RO neutral atmosphere retrieval process. This assisting in-situ data may allow us to compute the target parameters on-board which can speed up the data retrieving process and reduce the data volume for telemetry. It will allow us to provide real-time ocean weather forecasts.

Concept of Operations

The mission will be implemented by a CubeSat constellation, ground-based remote-sensing platforms and ground stations. (**Fig. 1.**)

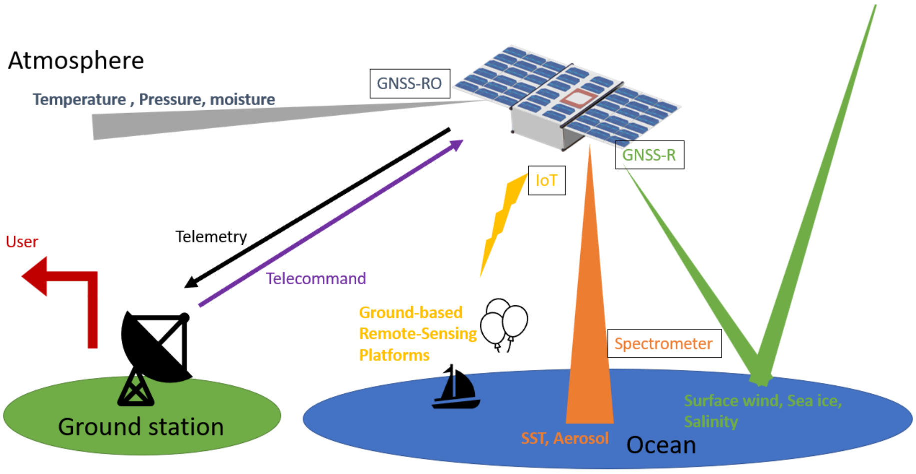


Fig. 1. CONOPS of Ocean Climate CubeSat Constellation (OCCC).

Ground Segment - Ground-based remote-sensing platform

Ground-based remote-sensing platforms are designed for in-situ measurements for calibration or assisting data. The platforms will include sounding balloons and buoys. We will use sounding balloons for atmospheric data and buoys for ocean data. The data will be transmitted by the LoRa transmitter and collected by our space segment via the LoRa receiver.

Ground Segment - Ground station

We employ a network of ground stations distributed globally in order to receive downlink data from the constellation in real-time.

Space-Segment Payloads:

GNSS-RO

Using descending Radio Occultation (RO), we can retrieve atmospheric temperature, moisture, and pressure of the troposphere by calculations done on the bending angle and impact index.

GNSS-R

By observing the sea surface GNSS bistatic scattering, we can derive Delay Doppler Maps (DDM) to retrieve sea wind speed, sea surface height, and sea ice. We can also obtain sea salinity by combining data with the radiometer.

Spectrometer - VIRR (Visible and InfraRed Radiometer)

By observing the visible and near-infrared channels, we can derive sea surface temperature (SST), which is used for contrastive calculation of cloud and ocean sensitivities. We use algorithms and tools including Multi-Channel SST (MCSST), the Aerosol AOD wavelength coefficient, the difference of temperature between cloud bands and VIRR (Visible and Infrared Radiometers) to obtain atmosphere correction data (ocean aerosol) and cloud data to mask area with cloud coverage.

Internet of Things (IoT) - LoRa Receiver

Collect data for calibration and onboard computing.

Launch

We expect to launch to LEO aboard the SpaceX Falcon 9 rocket or similar rockets.

Key Performance Parameters

- Spatial resolution: 1 km spatial resolution for all collected data to study the atmosphere-ocean interaction in the same scale.
- Time resolution: At 35 degree north latitude to 35 degree south latitude needs a temporal resolution better than 12 hour for tropical cyclone prediction.
- Global ocean coverage: The global ocean coverage shall achieve in a day for global weather models.
- Mission Lifetime: The mission lifetime shall be in 6 years for 1 year calibration and 5 years operation

Space Segment Description

OCCC are a custom 6U CubeSat with a mass of approximately 13.64 kg. Table 1 displays the mass,and power budget of the spacecraft. Fig.2. shows the simple CAD and flight coordinates of the spacecraft. The OCCC CubeSat have six subsystems and four payloads.(Fig.3.) Scientific payloads that are GNSS-RO, GNSS-R, Spectrometer, IOT. And the subsystems including structural and mechanical subsystem(SMS), Thermal Control Subsystem(TCS), electrical power subsystem(EPS), onboard data handling subsystem(OBDH), attitude orbit and control subsystem(AOCS), telemetry, tracking, and control subsystem(TT&C).

Table 1. The mass, and power budget of the spacecraft.

Subsystem	Mass	Power
Payload	19%	18%
SMS	23%	0%
TCS	2%	0%
EPS	21%	5%
OBDH	5%	4%
AOCS	25%	36%
TT&C	3%	36%
Total	13.64kg	55W

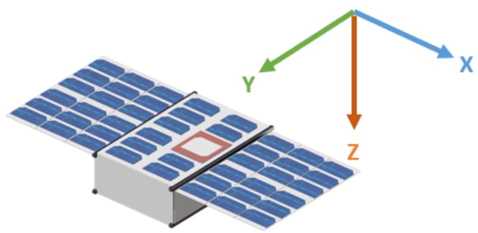


Fig.2. Flight coordinates of the spacecraft

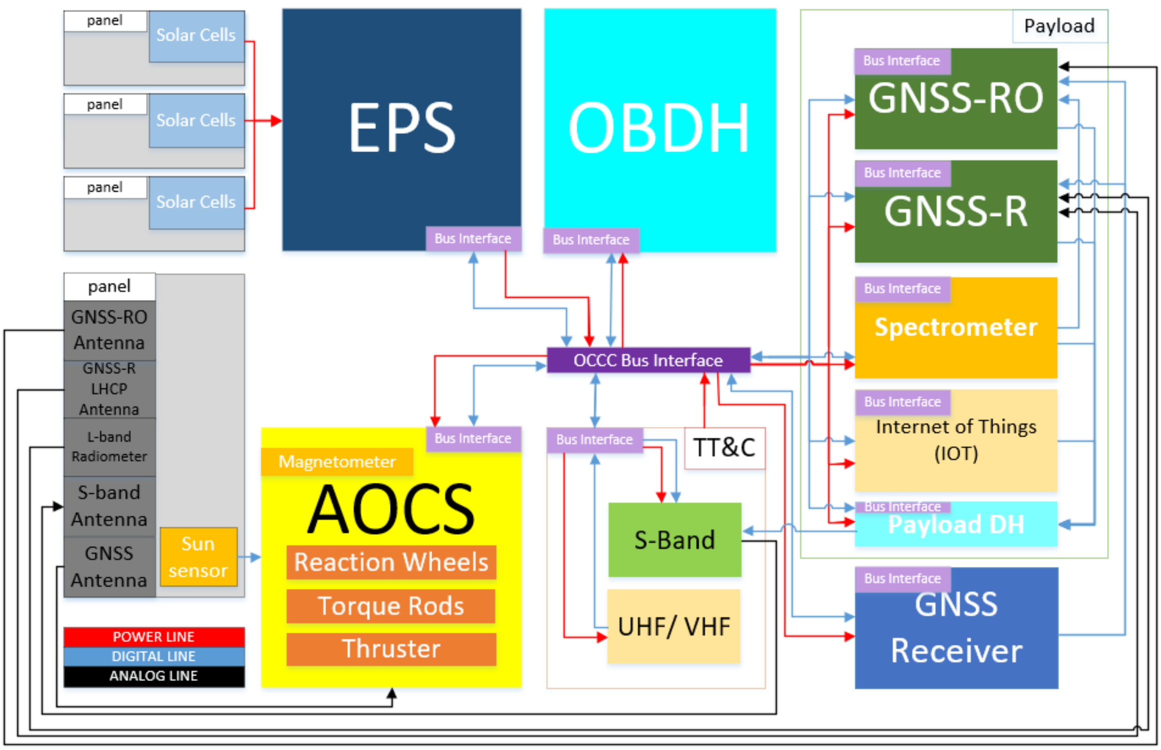


Fig.3. System Architecture of OCCC.

Payload:

GNSS-RO

The GNSS-RO payload requires L1 and L2 dual-band, high gain antennas (12.5dBi), reliable clock source, and compute module.

GNSS-R

The GNSS-R payload consists of 13 dBi nadir LHCP L-band antennas and L-band radiometers. Its data can be combined with radiometry data to derive sea salinity.

Spectrometer - VIRR (Visible and InfraRed Radiometer)

Table 2 shows the data we need to retrieve, the observed wavelength, and the algorithms we used to process these data.

Table 2. Spectrometer parameters, the observation wavelength, and the algorithms

Data	Wavelength (μm)	Algorithms
Sea Surface Temperature	10.3 ~ 11.3 11.5 ~ 12.5	Multi-Channel SST (MCSST)
Ocean Aerosol	0.53 ~ 0.68 0.84 ~ 0.89 1.55 ~ 1.64	The Aerosol AOD wavelength coefficient algorithm
Cloud Detection	3.55 ~ 3.59 10.3 ~ 11.3 11.5 ~ 12.5	Temperature difference between each band

Internet of Things

The IoT payload is based on LoRa, since it can transmit through a large distance, operate on low power, and is Doppler-tolerant.

Table 3. Key parameters of IoT payload

Spreading Factor	10	Coding rate	4 / 8
Noise Figure	8	Estimated data rate	152 bps
Bandwidth	31.25 kHz	Estimate maximum link margin	27.17 dB

Orbit/Constellation/Description

Our mission is to observe global atmospheric-ocean interaction, which requires global coverage of the ocean. Tropical cyclones usually occur at latitudes between 35 degrees north and 35 degrees south. Furthermore, according to the numerical models, 12 hours or better temporal resolution is required for cyclone weather prediction. Taking the ability of CubeSat orbiting into consideration, we separate the constellation into four launches, which are four-orbit planes with two polar orbits and two low inclination orbits (35-degree inclination) (Table 4.). The constellation can achieve global ocean coverage in a day and access the cyclone occurrence area for 6 hours at a time.(Fig. 2.)

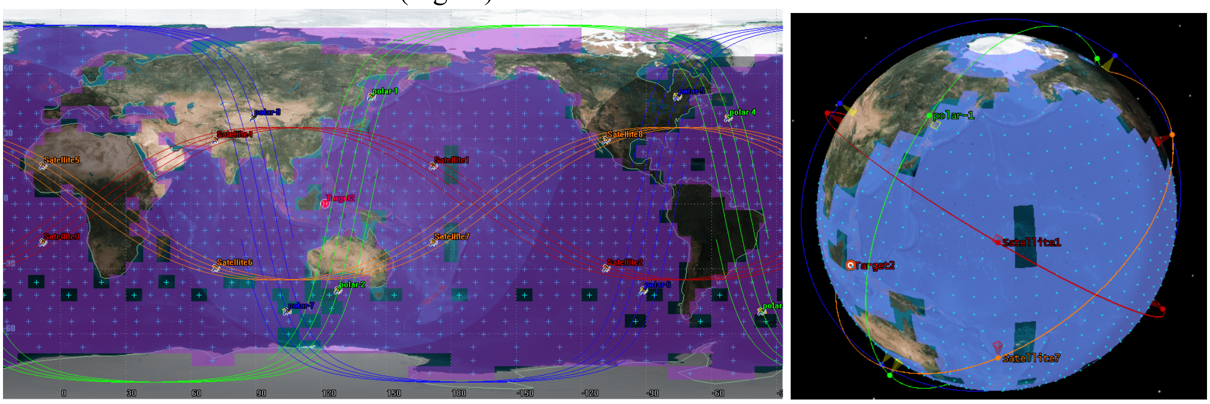


Fig. 2. Orbits of OCCC.

Table 4. Orbit element of the constellation

	Cluster 1 (Red)	Cluster 2 (Orange)	Cluster 3 (Green)	Cluster 4 (Blue)
Semimajor Axis (km)	6953.14	6953.14	6953.14	6953.14
Eccentricity (deg)	0	0	0	0
Inclination (deg)	35	35	97.69	97.69
Argument of Perigee (deg)	0	0	0	0

RAAN (deg)	0	180	289.05	70
True Anomaly (deg)	-90, 0, 90, 180	-90, 0, 90, 180	-90, 0, 90, 180	-90 ,0, 90, 180

Implementation Plan

OCCC will be developed by the Babui-Aerospace team, associated with several institutes including Taiwan Institute of Planetary Science and System Engineering (TIPSSE). We anticipate inviting NCKU, NCU, NTU to perform the sounding balloon. The institute of ocean science from NCU and ASIAA have lots of experience at buoy. We shall need ground stations to telecommand the satellite and telemetry the science data, the NCU and NCKU are also experienced. Assuming that NSPO can provide help and communicate with its overseas ground stations, global data downloads can be achieved. The following is the cost budget for each CubeSat.(Table 5.) From building to launching total cost 3,241,400 USD per CubeSat. In OCCC, we have 16 pcs 6U CubeSats to form a globally distributed constellation. The cost budget for OCCC is listed below.

Procedure	Unit Budget	Integration &assembly	Testing	Launching
Approximate cost (USD)	1,289,400	230,000	189,000	1,400,000

Table 5. Estimated Budget of OCCC

We design mission phases as shown in Fig. 3, according to the NASA Space Flight Project Life Cycle and the NASA CubeSat Launch Initiative. From mission objectives development, system design, building, system integration, testing, launching, operation, to disposal, the whole process takes about nine and a half years. The Table 6. is the top four risks in our mission. The first three risks are system risks that can be mitigated by tests. The fourth risk is that the IoT payload may face cyberattacks, which can be reduced by root key management, penetration tests, and frequent system updates.

Fig. 3. Mission phases of OCCC

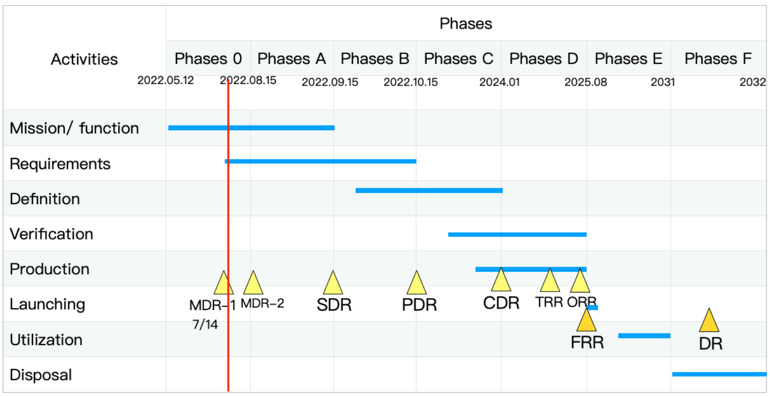
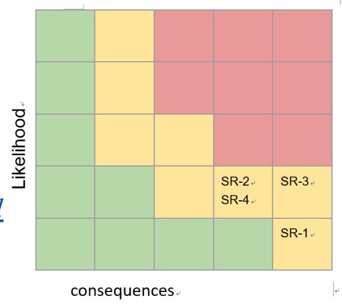


Table 6. Mission risks of OCCC

ID	Risk	Risk Management	Approach
SR-1	Not surviving launch environment	Test launch vehicle specifications	Watch
SR-2	Not surviving low earth orbit environment	Use hardware that can function on LEO and test hardware specifications	Mitigate
SR-3	Non deployment of solar panels	Stowed placement of solar panels and careful design	Mitigate
SR-4	IoT LoRa payload being attacked	Root key management and upgrade frequently	Mitigate



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