ALBEDO MEASUREMENT USING PHOTODIODES ON A HIGH-ALTITUDE BALLOON

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BEXUS 25: The IRIS Project
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ABSTRACT

The surface albedo of Earth was named as one of the Essential Climate Variables (ECV) by the Global Climate Observing System in 2003. The reason for this is strong impact of albedo in terms of radiative forcing. Especially the effects of the albedo in the arctic, e.g. with the ice-albedo feedback loop, play an important role and need to be investigated further. The land surface albedo is usually investigated using satellite measurements. In the last years many improvements to the estimation of albedo using satellite measurements have been made. Especially the development of bidirectional reflection distribution models, that were developed alongside MODIS, have contributed a great deal to the improvement of albedo estimation. However, the estimation is not perfect and still needs improvement. Bond Albedo is defined as the ratio of incident and outgoing radiation. Therefore, we are planning to take direct albedo measurements with a high-altitude balloon as part of the BEXUS 25 mission. In order to take the measurement, we employ two sensor boxes with multiple photodiodes. One of the sensor will be looking upwards, while the other will be looking downwards. This will allow us to find the ratio of incident and outgoing light. We will take measurements in the entire visible range as well as in the IR up to 2.5µm. Additionally, we will have photodiodes for more specific spectral ranges, such as green light around 500nm. This will allow us to obtain more information about the surface properties. For example, the red edge can be observed using the red and NIR spectral bands. With these direct albedo measurements the albedo estimates by satellites should be improved. The experiment is made in a straightforward way, so that it can be easily flown more than once and on smaller balloons as well. That would give more data and more accuracy for the improvement of satellite models and could also lead to long-term measurements of arctic albedo measurements. Which could give more clarity about possible long-term trends.

1. INTRODUCTION

IRIS consists of an apparatus which aims to measure the incoming radiation from the Sun and Earth's reflection, otherwise stated the albedo, in order to determine local albedo variations, throughout the troposphere and the stratosphere. IRIS will be mounted on a High-Altitude Balloon, in order for the experiment to meet its scientific objectives. The supreme aim is to firstly estimate and then contribute to the elimination of the error accumulated in remote sensing measurements.[6]
The Arctic circle can be considered and studied both as an independent or an integrated system. As in all climate systems, ocean, landmass and atmosphere are linked with a direct and complex interaction. The Arctic's characteristics and basic climatic features are influenced by the Albedo and Earth's thermal emissivity creating a domino effect between the surface energy budget, the atmospheric heat budget and circulation, the hydrologic cycle and vegetation mosaic.[2][3]

The albedo is a non-dimensional, unit-less quantity, which indicates the quality of reflectance a surface can return. The bond albedo specifically, is a measure of the ratio of incident to reflected radiation. It is considered as a fundamental atmospheric parameter that has deep implications on the energy balance and consequently on climate change. The energy budget is directly affected by the albedo, as it holds a key role in the process by which our planet achieves an equilibrium between the solar radiation which enters the atmosphere and then is afterwards re-emitted in considerably longer wavelengths.[2][7]

Variety and quality of the local vegetation, atmospheric composition, type of clouds found throughout the troposphere and stratosphere, the Solar Zenith Angle (SZA) and the wavelength of incoming light from the Sun, as well as, atmospheric extinction are all factors that influence deterministically the albedo. Hence, it is of great interest to further investigate thoroughly into how they influence the temperature equilibrium of our planet,

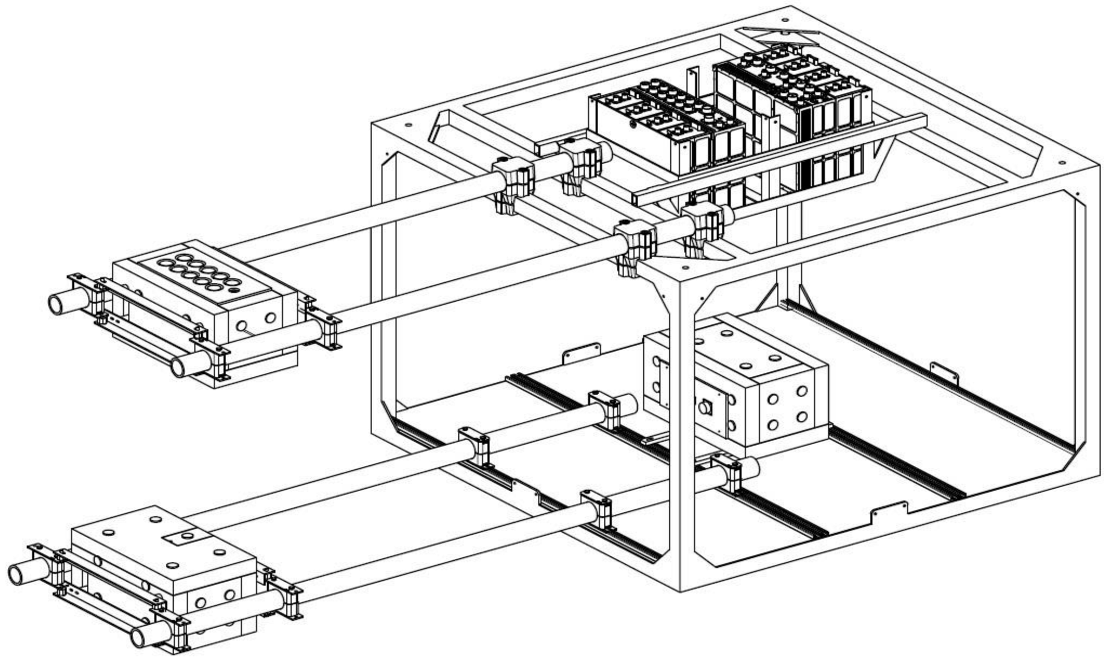

Figure 1: Mechanical design of the experiment

such as the relation between the chlorophyll levels and albedo variations and as the variations and distinguishment between snow and/or cold cloud albedo. [3][4][5]

In order for IRIS's scientific objectives to be met, a high-altitude balloon (HAB) is required. The balloon launches in October 2017 from launched from the European launch site ESRANGE (67°52′59″N21°07′00″E), which is situated near the town of Kiruna in Sweden, 200 kilometres north of the Arctic Circle. It will reach an altitude of approximately 30 km, where ambient temperature can drop to minimum value of -60 degrees C and pressure 5.5894E+2. The flight time duration is strongly depended on the speed of wind, and its three parts are estimated to last; ascent phase is ~1h30, float time 3h and descent ~30mins. After traversing through the atmosphere over the Lapland to Finland, the experiment is expected to be collected from Finland, where a helicopter by the SSC is expected to collect and return the experiment to the ESRANGE.[1]

2. MECHANICS

IRIS consists of three boxes: the "brain box" -which contains the data storage device and the main control unit- and two identical "sensor boxes" that incorporate the optical system that will perform the measurements; namely, a set of 10 photodiodes - and their associated filters and lenses - and a video camera, all mounted on the same side of the box.

All three boxes have the same dimensions, and whenever possible, the components have been used. The desired result leads to the simplification of the design and allows many spare parts to be used as redundancies.

The brain box will be placed within the gondola, directly attached to the gondola frame. On one side of the gondola there will be four parallel polycarbonate booms (PC) which will hold the two sensor boxes, as can be seen on the sketch below: this material was chosen so that the booms will break in case of hard landing, thus protecting the gondola from shock forces that could deform it. The booms will be held respectively from the top and the bottom faces of the gondola with clamps, and their sensor boxes will be attached to them so that their sensor arrays are facing upwards and downwards -respectively- to effectively measure the radiation reflected from each direction. Each of the three boxes is made up by an aluminium frame covered by Styrofoam thermal insulation, which helps keeping the internal electronic components within their operational temperature ranges. By mounting the sensor boxes on the booms, measurements taken by the top sensor array will be less affected by interference from the presence of the balloon; while the bottom one would not be affected, it should also be mounted on a boom to place it as close as possible to the parallel and horizontal position of the top sensor array.

In addition to the thermal insulation, one electrical heater mounted on a radiator, is located inside each box, along with a thermometer, forming up an active thermal control system meant to provide control over the internal temperature of the boxes as the conditions of the surrounding environment change during the flight. The two sensor boxes and their booms are also covered by a layer of reflective material, to reduce the amount of heat received from the Sun. Computer simulations, namely in the MATLAB environment, were used to design this thermal control system.

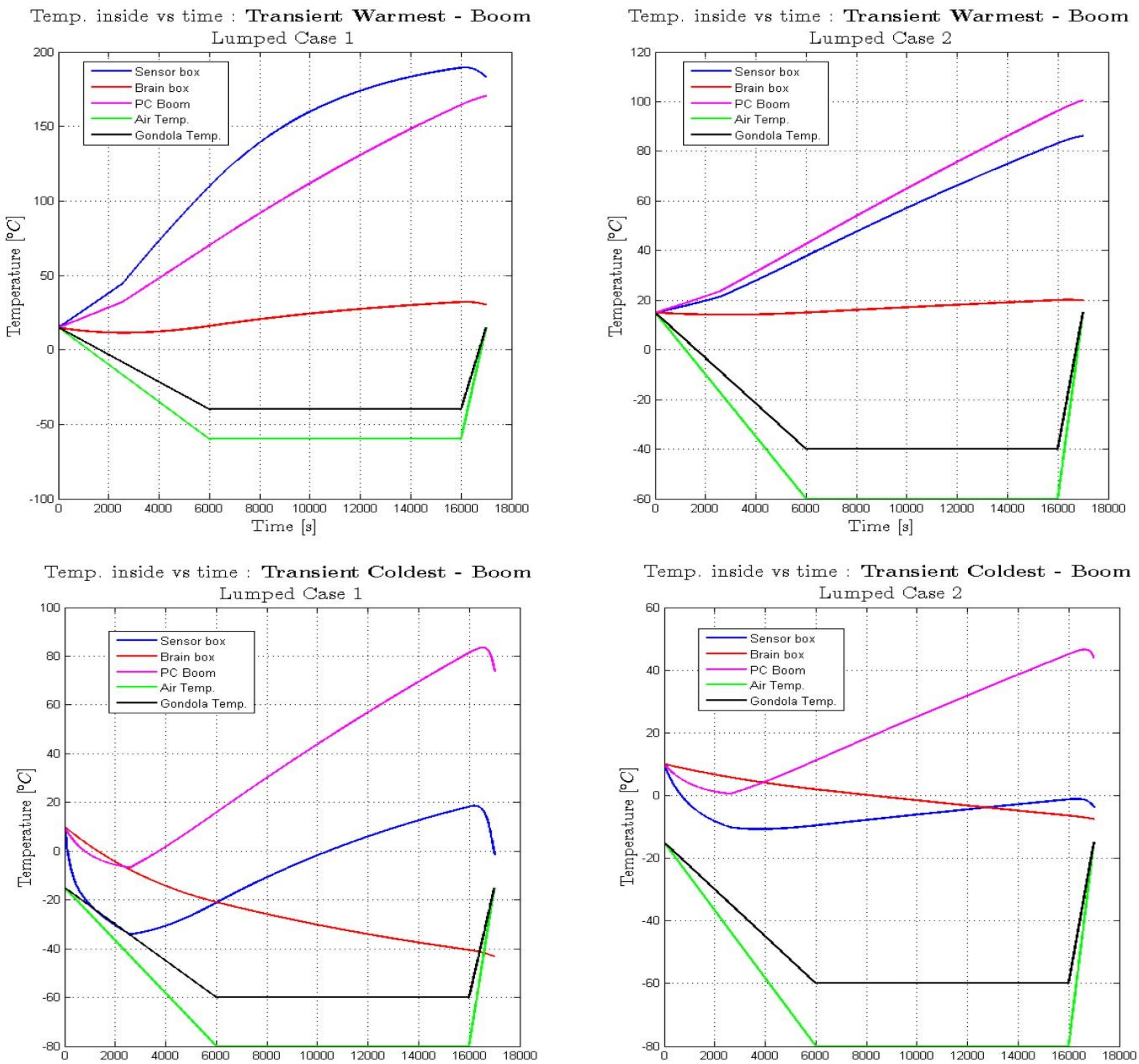

Figure 2: Thermal Simulations

For these, two cases -coldest and warmest- were considered, where external temperatures and relevance of each type of heat transfer -radiative, convective and conductive- varied between the two cases. The purpose of these calculations was to estimate the interior temperature of the different boxes of the experiment during the whole flight, for both cases. To facilitate the calculation of transient analysis, two subcases of "lumped analysis" were studied for both the coldest and the warmest cases: one where the inner aluminium plates and the electronics they hold have infinite thermal conductivity (which results in uniform temperature), and one where each whole box is one single solid of infinite thermal conductivity. Therefore, the solution for each case rests between the results of both subcases. Some of the results obtained are shown on the graphs in fig. 2.

3. OPTICS

The optical system is a critical part of the design to fulfil the requirements of the experiments. As it is desired to

measure the terrestrial (bond) albedo, it is necessary to distinguish between the incoming and the reflected solar irradiance. In order for this this goal to be achieved, two identical optical systems are needed: The area observed by each optical system is considered to be semi-spherical. One which looks upwards and observes the upper semi-sphere, measuring the incoming radiation, and a second one facing downwards which measures the reflected radiation from the Earth's surface in the lower semi-sphere. Another part of the requirement is to measure the albedo in different wavelength bands. The different bands will allow a detailed estimation of the changes of the albedo. Specifically, it can reveal how different surfaces, as well as the present atmospheric conditions can affect the albedo.
For the scientific requirements to be met, the light is captured using a combination of lenses, filters and photodiodes. These components are located in the two sensor boxes on the booms, as detailed in section 2. Two broadband photodiodes will be used without filters to give an overview over the whole solar spectrum in two parts, from 400-1100nm and from 1000nm to 2500nm. These two bands cover the most parts of the solar spectrum, especially the most energetic parts. In addition to the broadband several other channels covering multiple smaller wavelength bands are installed using lenses and filters. The small bands used are for Aerosols (430-440nm), blue channel (450-500), green channel (510-590nm), red channel (610-690nm), Near-Infrared (NIR) channel (850-890nm), two more IR channels (1350-1390nm and 1550-1650nm) as well as a mid-IR (MIR) channel (2000-2500nm). The different channels will allow an investigation of various phenomena, such as calculating the vegetation index using the red and the NIR bands as well as confirming reflective properties of snow, such as a drop in reflectivity in the IR spectrum compared to clouds. The photodiodes used in the visible as well as the NIR spectrum are of the silicon type while the IR photodiodes are two types of Indium-Gallium-Arsenide photodiodes.

The outermost part of the optical system is the lenses. The lenses are fisheye lenses that significantly increase the field of view of the whole system. A large field of view, just short of 180 degrees is required. Such a large field of view is required because the light from all directions needs to be captured. Especially during launch time in October the sun can be very low above the horizon. In fact, it does not rise more than 15 degrees above the horizon in the second half of October (include latitude and other details). Therefore a lot of light might come from closely above the horizon with a low elevation angle and this needs to be detected by the optical system. A full 180 degree field of view is not required because the ratio between the upper field of view and the lower one is measured. The light captured by both parts at 180 degrees should be very similar and thus will not contribute to any difference between the total irradiance measured by the system, e.g. the difference between the light coming from 179 degrees SZA and 181 degrees should be rather similar and thus not produce any differences in the ratio. The fisheye lenses are designed and assembled using a combination of different simpler lenses. The lenses are designed in a way that allows for the inclusion of optical filters, as it is required for the narrow bands. The filters require a nearly perpendicular incidence angle (around 90 degrees). Otherwise the center-wavelengths of the filters could be shifted towards shorter wavelengths. Therefore the light is collimated before passing through the filter. Afterwards it is focused onto the photodiode using another lens.

4. ELECTRONICS

The start of the electronical equipment is at the photodiodes. Depending on the irradiance, the photodiodes generates a certain amount of electrical current. The current is passed through an operational amplifier, that is used as a current to voltage converter and that signal is then converted to a digital value using a single ended 15-bit ADC. This value is transferred via a I2C-bus to the microcontroller that is present in each of the two sensor boxes. For this experiment, an Arduino Nano in each sensor box was sufficient. Along with the irradiance, the temperature between the photodiodes are also measured, this is to ensure that any temperature variations in the photodiodes current is taken into consideration. The microcontroller also manages the temperature inside the box by utilizing the mentioned temperature sensors along with a heater.

The center box or "Brain Box" consists of a Raspberry Pi ver2 B+, that is chosen due to its computational power, low power consumption and for not having any wireless options such as Bluetooth and WiFi which with some bad luck could disturb other experiments. When needed, the "brain box" will call for data from the two sensor boxes, and it is received by using an ordinary USB connection, which is somewhat altered for easier cable management. The "Brain box" also handles the two cameras that are used, a GPS, two different temperature sensors along with a barometer to get a rough estimation of the altitude. The data gathered are stored on a normal SD-micro card, that is used by the Raspberry Pi. For safety, some of the data will also be sent down using the downlink to the ground station. If something were to cause the Raspberry Pi to crash during the flight, an external watchdog was also implemented into the design.

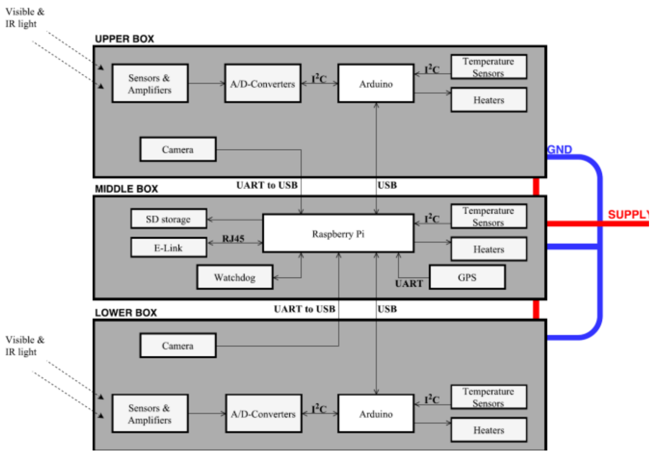

Figure 3: Electronics Design

5. SOFTWARE

As mentioned, the experiment will feature two Arduino Nano microcontrollers, a Raspberry Pi computer and different peripherals (GPS, cameras). The Arduino nano microcontrollers will collect the analog data and relay it to the Raspberry Pi, which will then sort and store the information in different files.

The connection with the Raspberry Pi will be done through USB 2.0 in the hardware level, and will feature NMEA 2000-like protocol to communicate on the software level. This is the same protocol GPS peripheral uses. For collecting the video input, the cameras will be connected directly to the Raspberry Pi collecting images and storing them in the SD card.

A fraction of the data will be relayed back to ground segment for tracking, monitoring and pre-process some of the information. Additionally, the ground station can issue commands to the Raspberry Pi in the event of malfunction. In the event of the data being corrupted or not stored properly, the transmitted data will help in recovering some of it for later analysis.

Both the Arduino Nano microcontrollers and the Raspberry Pi feature big enough buffers to ensure the data collection rate and transmission is fast enough to ensure the design data rates for the experiment.

6. EXPECTED RESULTS AND DATA ANALYSIS

The data from the sensors will be used to compute the irradiance that comes in from the sun and that is reflected from the surface and lower part of the atmosphere. After data retrieval, by comparing the values of each of the symmetrical sensor layouts, positioned on the top and bottom booms, the bond albedo can be calculated. The measurements during the ascent phase will indicate the change of the albedo during the change in altitude.

The scattering and reflectance of the light around the area of each optical system is considered homogeneous. However, the non-homogeneity of the several types of soil causes distortions, thus it is hard to distinguish between the represented data, obtained from the satellite measurements. This is because the homogeneity of the ground is directly connected with the variability of the ground topography. The more homogeneous the ground is, the less variable the ground topography is, providing more compatibility between the in-situ and the remote sensing measurements. As a consequence, factors such as the spatial resolution, the monitored area overlapping, and radiometric corrections are some of the main factors that influence the quality of satellite albedo measurements. For this reason Bidirectional Reflectance Distribution Function (BRDF) models are used to more effectively simulate the observed surface and eliminate the data drift error accumulated in the measurements due to the distortions caused by the non-homogeneity of the types of the surfaces measured.

A model for atmospheric radiative transfer analysis (RT) will be used to produce the results from the different radiative components that are coming in onto the surface, as well as the outgoing reflected flux, at the according radiation conditions. These RT models are important for satellite measurements, as they are used for the retrieval of the data. By comparing the measured values with the model results, both the model and the in-situ measurements can be evaluated. If the obtained measurements and the modelled values are in disagreement, further data analysis could reveal where the error is located and eventually contribute to the improvement of the model. An improved radiative transfer model will help to also improve the accuracy of satellite measurement evaluation.

7. CONCLUSION/OUTLOOK

Albedo has been named as a climate essential variable. As such it is vitally important to have good coverage of measurements as well to improve already existing methods. In this paper a student experiment has been presented which is supposed be kept simple and robust.
The design of the experiment has been finished and is now under construction. The launch will happen in October, then it will be shown if the design. Furthermore the data analysis plan has to improve for a possible comparison with satellite data. Because this experiment should provide high quality data over a small spatial and temporal range. This can be combined with the global repeated coverage by satellites to improve the overall coverage of albedo measurements.

8. REFERENCES

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