Diurnal cycle of cloud cover in São Paulo derived from measurements of a low-cost sky-imager

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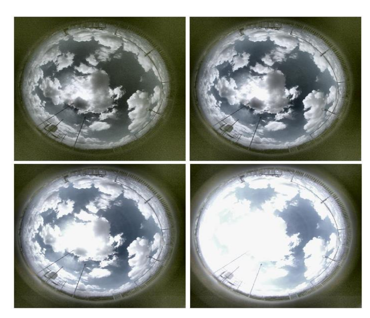
Introduction:

Clouds reflect part of the incident solar radiation, cooling the planet, but absorb the longwave radiation that would be lost to space, warming it. These effects on the energy budget are so important that a mere 1% increase in the albedo of low clouds would produce a negative forcing that cancels that of anthropogenic CO_2. Despite its importance, physical processes that control clouds are still not fully understood and there is a lack of continuous observations of high temporal and spatial resolution to resolve them. Climate models, for instance, fail in reproducing the diurnal cycle of cloudiness and precipitation. One instrument that can observe cloud cover with high temporal resolution is a sky imager.

In this study, we implemented an algorithm to combine four different exposed images into a single image of higher dynamical range (HDR). Following the work of Long et al. (2006), we used a threshold for the ratio between red and blue channels to distinguish between clouds and clear sky.

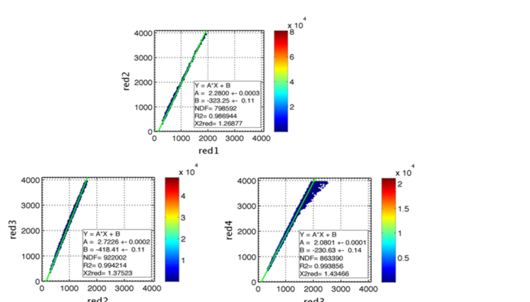
Skyimager

The skyimager consists of a regular digital camera, inside a metal housing with a fisheye lens attached on it. The camera used is a Blackfly 20E4-color, manufactured by point grey. The resolution is 1600x1200.



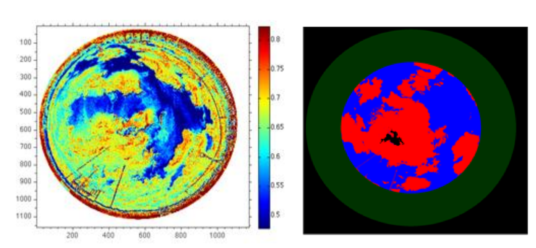
The controlling software takes four images with exposure times (100, 250, 700, 1500 ms). Combining these allows higher dynamic range (HDR). Final image that is not too bright, neither too dark.

We used the following equation for the HDR image: $HDR = \frac{1}{N}\sum_{i=1}^{N}\frac{LDR(i)}{relExp(i,1)}$

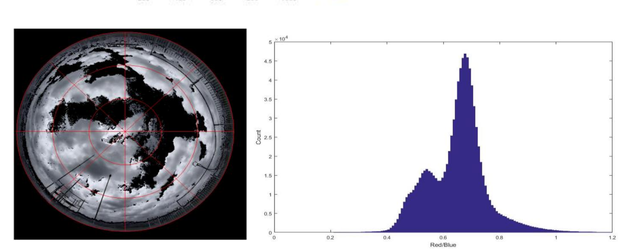


Relative exposure, for each color, was determined from a fit between the counts in consecutive images.
The background noise had to be removed, and was given by dark images.

Clouds detection

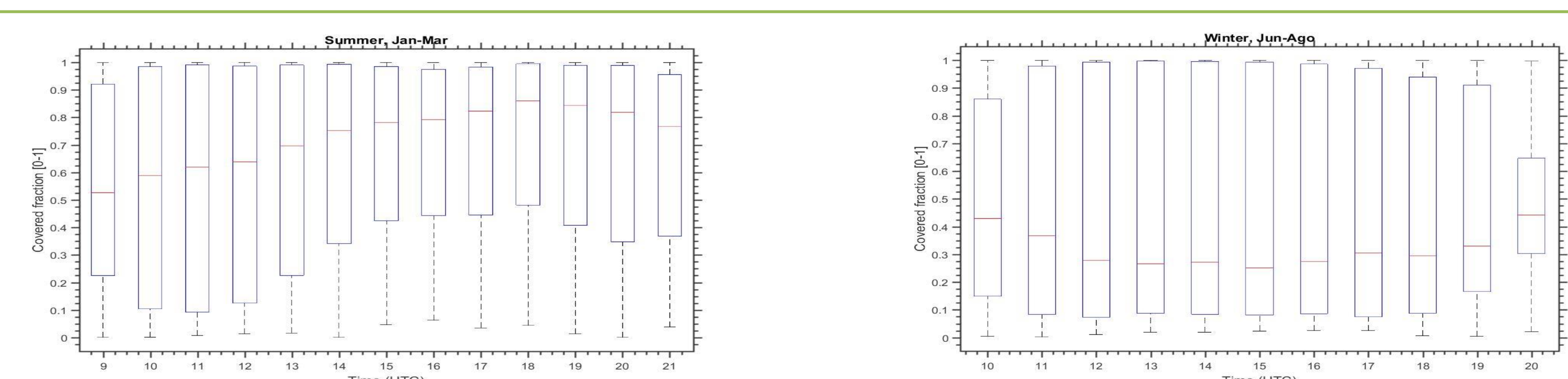


The sky reflects more blue light then the clouds. We calculated the ratio of red and blue for some images to select a threshold between clouds and blue sky.



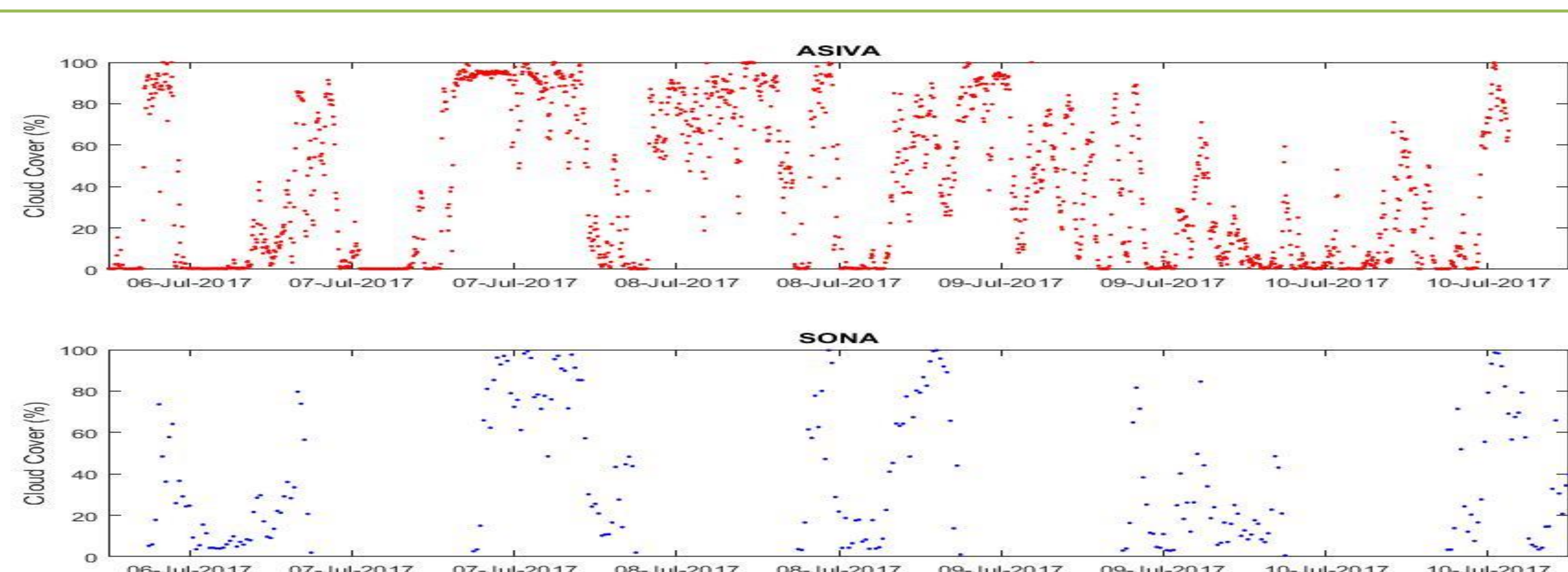
Because of the fisheye lens the image has a greater distortion in the regions far from the center, we only considered the pixels inside a 60º cone.

We made a study of the cloud cover in Sao Paulo, during the summer and winter of 2017.



Boxplot of showing the diurnal cycle of cloud cover measured with our instrument.

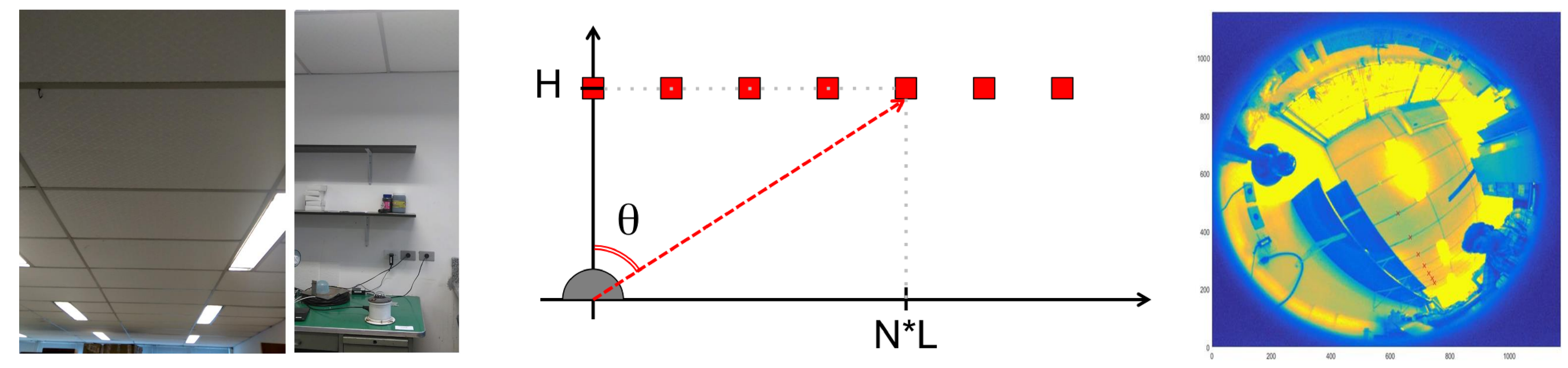
Comparing our measurements with those from a research instrument (ASIVA), operated by colleagues from UNIFESP at the same site and found similar results.



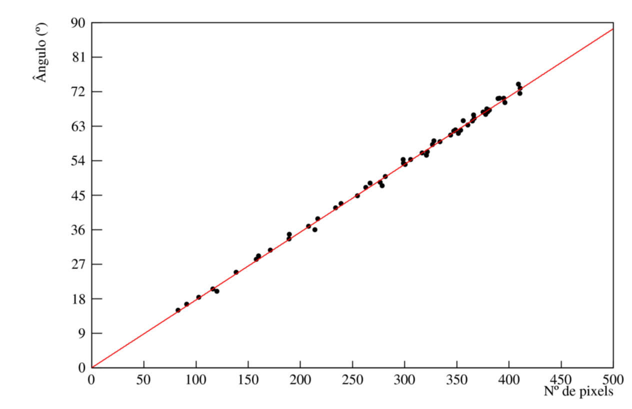
Comparison of cloud cover (%) measured with our instrument (below) and the All Sky Infrared Visible Analyzer (ASIVA, top).

Camera calibration

In order to obtain a more precise result it is necessary to obtain the viewing angles for each pixel of the instrument (lens + camera), and also characterize the sensor background noise.



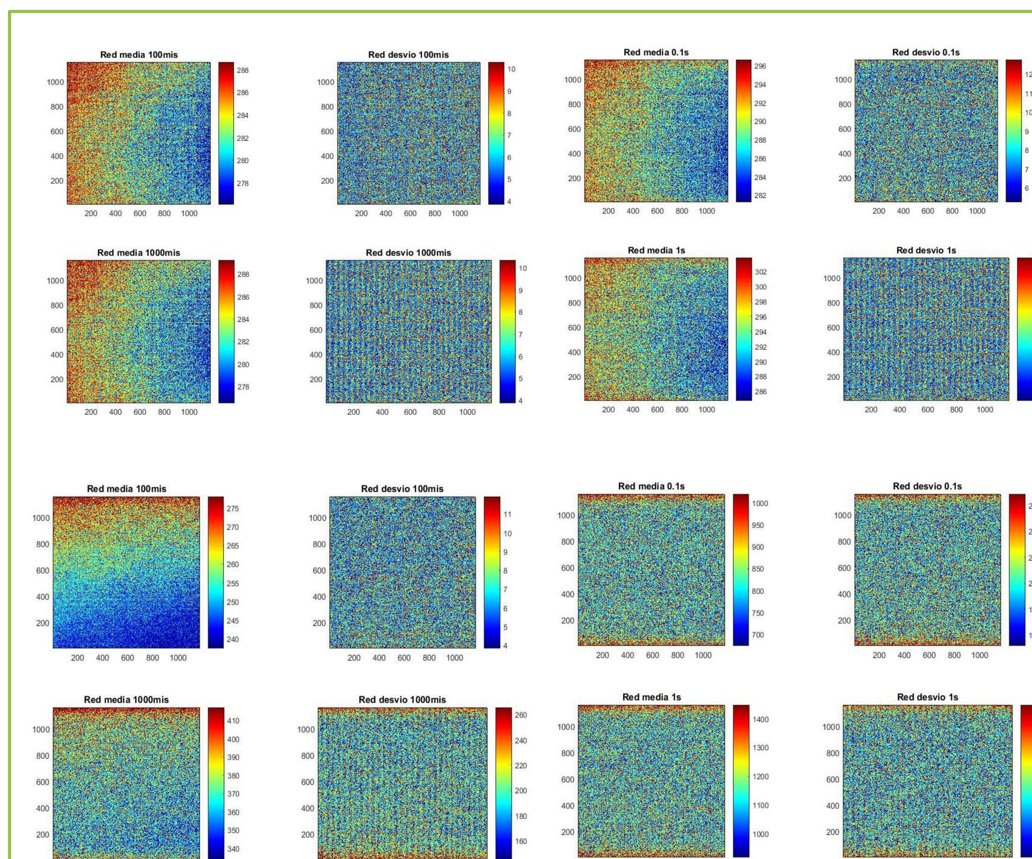
We use the lab ceiling as a reference to get the angular aperture of the fisheye lens.



The scatter plot of the angle as a function of the number of pixels showed a linear correlation as expected

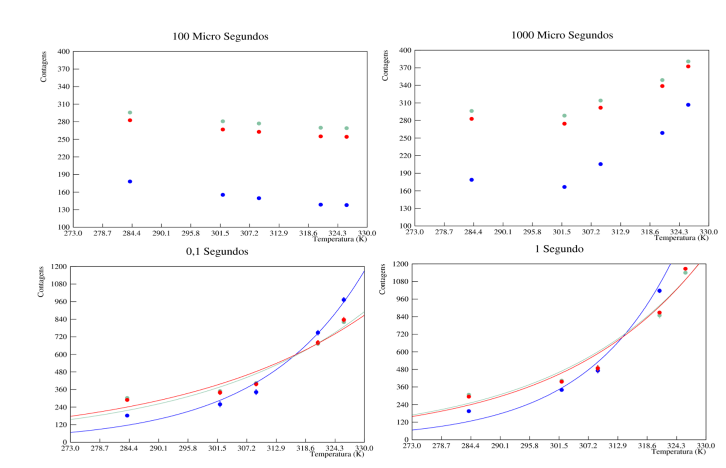
The coefficients of the linear adjustment were:
a = 0.176 (3) deg / pix and b = 0.017 (1) deg

Background noise



Background noise had a strange behavior measured at normal temperatures. Then we put the camera inside a refrigerator (10°C) to see how the background would change.

We also put the camera inside a greenhouse at different temperatures.



We have seen that background noise has normal behavior only at higher temperatures and longer exposure times. But the camera seems to have a standard background noise that causes a greater impact on ambient temperature and shorter exposure times.

Conclusion:

Combination of images into a single HDR was only possible after removal of BG noise. The R/B threshold we found (0.58) was similar to the value used by Long et al. (0.60).
Comparing this skyimager with a professional instrument showed a good result. We found a significant difference in the diurnal cycle of cloud cover during summer and winter.
The lens equation was successfully obtained, but we did not test it with clouds. The background noise of the camera seems to have a strong interference caused by the type of electronics the camera was made of. But this is less noticeable at higher temperatures.

Reference:

Long, C. N., J. M. Sabburg, J. Calbó, and D. Pagès, 2006: Retrieving Cloud Characteristics from Ground-Based Daytime Color All-Sky Images.J.Atmos. Oceanic Technol., 23, 633–652, doi: 10.1175/JTECH1875.1