Flux Ratio Detection of Global Thin Cirrus Clouds

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A cheaper and more effective method for cirrus cloud detection for use in the NASA CubeSat program

Cirrus clouds often appear invisible to the naked eye, but nonetheless create significant negative feedback to amplify global climate change as result of their large opacity in the infrared. The general consensus in the climate science community is that they are difficult to detect and estimates of their global coverage (or increase over time) are difficult to make. While some new detection methods exist, such as satellite imaging in the 1.38 μm band, we are interested in finding a more effective and easier detection method. Our method of imaging uses an all-sky astrophotography camera and combinations of bandpass filters. Thin cirrus clouds, made almost exclusively of ice crystals, should directly reflect sunlight and therefore have the same filter flux ratios as the sun. Clouds with higher moisture content will have different filter flux ratios. Standard astronomical photometric techniques are applied to the images to determine flux ratios. Preliminary results show that good detection of cirrus clouds on bright, clear days occurs with use of the 82a blue, 11 yellow, or LRGB luminance filter alone or in combination. Future work will include more data collection, testing more filters, establishment of a permanent camera installation at the University of Oregon with an automated filter wheel and the inclusion of a cirrus-detecting camera system on a NASA CubeSat.

What are cirrus clouds?

Figure 1 (above)[1] and 2 (poster background)[2]. Often called "mares' tails," cirrus clouds can indicate an incoming storm or front[1]. They can appear tail-like as above, or wispier with less definition, as in the background of this poster. Images courtesy of NOAA and NASA.

- High altitude clouds (≥ 15 km)[1]
  - Composed of ice crystals[1]
- Usually "wispy" in appearance
  - Reflect some sunlight
- Absorb & re-emit infrared radiation back to the Earth

Cirrus clouds and climate change

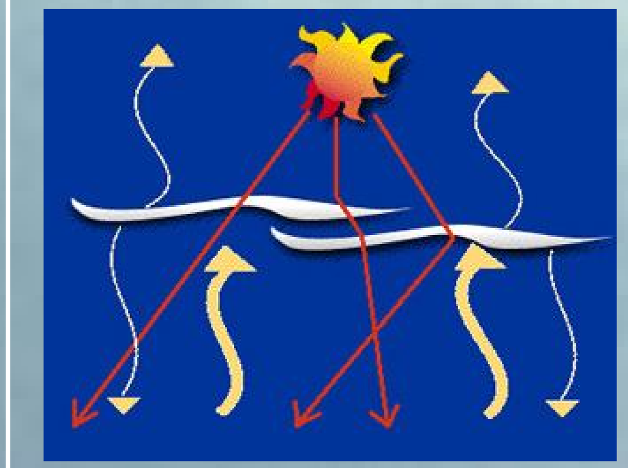


Figure 3. Solar radiation and cirrus clouds. Image courtesy NASA[3].

The Earth has a radiation budget. Energy enters via solar radiation and exits as thermal radiation.

Cirrus clouds have a **radiative forcing** effect:

1. Reduce incoming sunlight via reflection from ice crystals, leading to surface **cooling**
2. Ice particles have a high cross-section to the thermal infrared radiation from the Earth, leading to atmospheric **heating.**

The warming effect of cirrus dominates the cooling effect[3].

Detection challenges

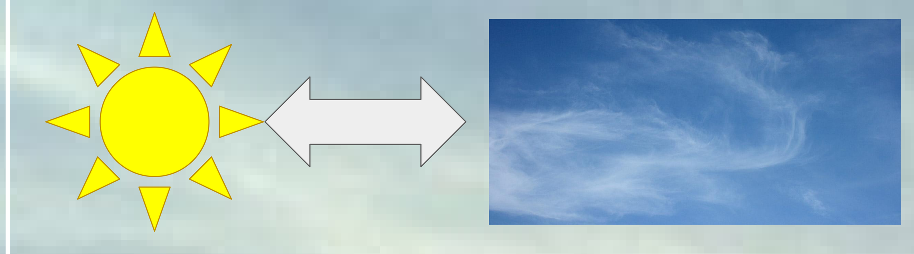
Method: detection from satellites using infrared radiometry
Problem: Optically thin cirrus clouds produce only a small infrared signal enhancement and can be barely distinguishable from clear sky[4]

Method: Spectral imaging in the 1.38 µm channel on LANDSAT-8 to detect sunlight reflected from cirrus clouds without interference from ground radiation (the atmosphere is opaque at this wavelength)
Problem: May generate false signals from airplane contrails as well as snow and ice on mountaintops[5]

Our approach

We use the UBV filter system from optical astronomy to detect cirrus clouds. Because cirrus clouds reflect sunlight, they will have the same "filter flux ratios" as the Sun.

"Filter flux ratio" refers to the ratio of the photon flux of an image taken with one filter as compared to the flux of the same image taken with another filter.



Cirrus clouds will have the same flux ratios as the sunlight they reflect.

Plotting photon flux within a certain range will thus display only the cirrus clouds.

> Other clouds will have a different flux ratio signature due to their higher moisture content.

Image capture

Figure 4. For mobile image capture, we use an Orion All-in-one astrophotography camera and several astronomy filters.

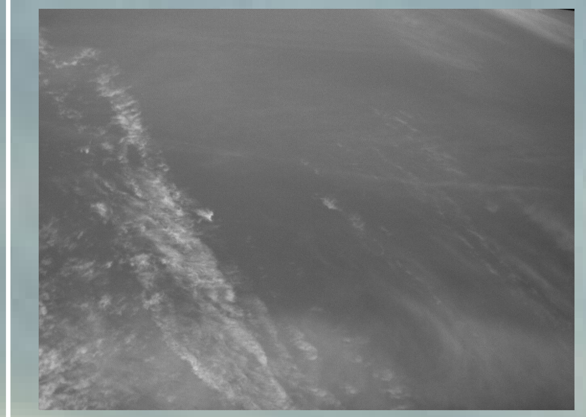
Figure 5. An Orion StarShoot All-Sky camera will be installed on a building roof at the University of Oregon. A custom filter wheel will be remotely controllable.

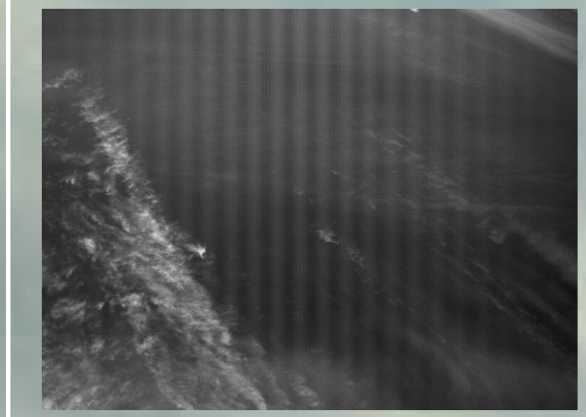
Image analysis with astronomy techniques

Using batch processing with Python, pyRAF, DS9:

1. Identify background sky level
2. Obtain grid-based photometry for each image
3. Identify a baseline level of cloud detection
4. Compare filter flux ratio by comparing image photometry

Preliminary cloud detection and flux ratio analysis





It's easy to get a general idea of which filters produce higher photon counts or clearer contrast using just our eyes. To find the flux ratios, numerical analysis is needed.

Figure 6. Mix of cirrus clouds and other clouds with filter Orion 11 yellow (top left), Orion 82a blue (bottom left) and Orion extra narrowband S-II (top right).

Different clouds correspond to different filter flux ratios. Given an image of multiple clouds as above, if we plot photon counts in a certain flux ratio range, only altocumulus clouds (e.g.) will be visible. If we examine a different flux ratio--the same as for the sun--cirrus clouds will be visible.

Using data analysis techniques, we can show the parts of an image where clouds were detected. This is a preliminary step. To look for filter flux ratios, we will compare these images using different filter combinations. The images below are of the same cloud field and have their counts summarized below. In these examples, counts are given in photons per 300 px box. Note that not all of the clouds in the image are cirrus clouds. When we examine the flux ratios, the detection grids will look different at different ratio values.

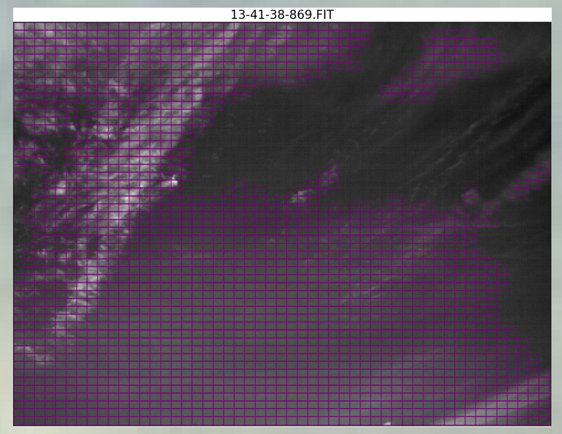


Figure 7. Cloud field with Orion 82a blue.
Detection threshold: 15194.1
Highest count: 25471.5

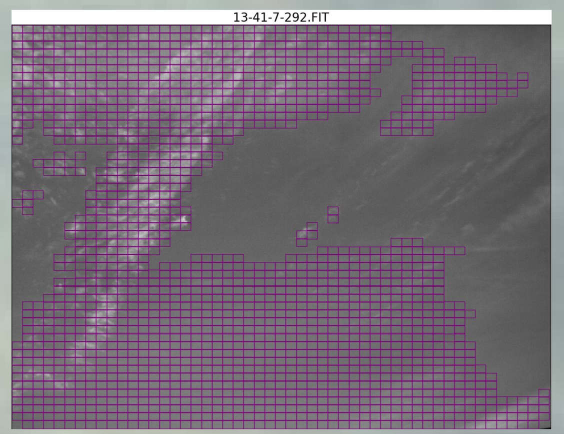


Figure 8. Cloud field with Orion 11 yellow.
Detection threshold: 11527.9
Highest count: 18204.5

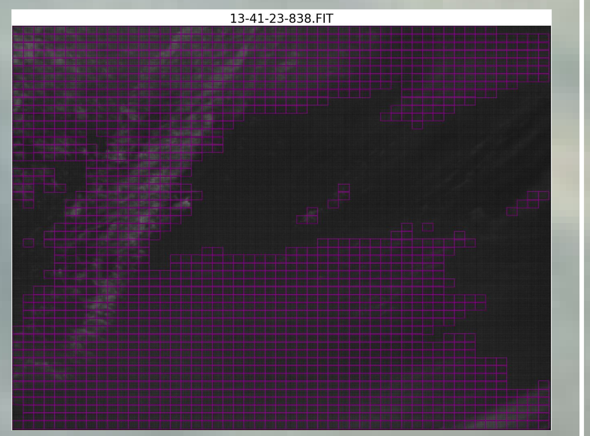


Figure 9. Cloud field with Orion 15 yellow.
Detection threshold: 5279.7
Highest count: 11095.0

Future Work

- Complete analysis of current data set and identify filter flux ratios for variety of combinations
- Obtain more image data sets at lower resolutions for faster computation
- Improvement of code base; error control, GUI creation
- Collaboration with Portland State University to install camera system on NASA CubeSat mission (as funding allows)

References

[1] LeFevre, Karla. "Making Heads of Mares' Tails." *NASA Earthdata.* NASA, 11 Oct. 2013.
[2] Cangi, Eryn. "Cirrus clouds over Eugene." 2016. Bitmap.
[3] Graham, Steve. "Clouds & Radiation." NASA Earthdata. NASA, 1 Mar. 1999.
[4] Brocard et. al. 2011
[5] Hutchison & Choe 1995