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Tracking Polar Mesospheric Clouds Using Unbinned Correlation Methods

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Abstract
We are experimenting with a correlation method that allows us to cross-correlate images that have geolocated pixels without having to bin the pixels and lose resolution. In addition to preserving resolution, this correlation method also allows us to perform transformations on the images that would be difficult to perform with other correlation methods. We are working on this correlation method in order to use cross-correlations to track polar mesospheric clouds (PMCs) using the data from the Cloud Imaging and Particle Size (CIPS) instrument on the Aeronomy of Ice in the Mesosphere (AIM) satellite.

Keywords
Polar Mesospheric Clouds, Unbinned Correlation, Cloud-Tracking, AIM satellite

Disciplines
Physics

Comments
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Tracking Polar Mesospheric Clouds Using Unbinned Correlation Methods

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Abstract

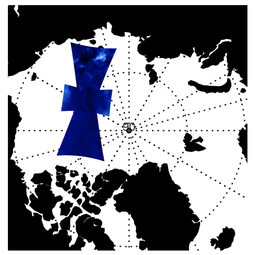
We are experimenting with a correlation method that allows us to cross-correlate images that have geolocated pixels without having to bin the pixels and lose resolution. In addition to preserving resolution, this correlation method also allows us to perform transformations on the images that would be difficult to perform with other correlation methods. We are working on this correlation method in order to use cross-correlations to track polar mesospheric clouds (PMCs) using the data from the Cloud Imaging and Particle Size (CIPS) instrument on the Aeronomy of Ice in the Mesosphere (AIM) satellite.

Polar Mesospheric Clouds (PMCs)

Polar mesospheric clouds (PMCs) are water ice clouds that form in the mesosphere under extremely cold temperatures. They are the highest clouds in the Earth's atmosphere, located at a height of about 83 kilometers, near the mesopause, which is the upper boundary of the mesosphere and the coldest region on Earth, reaching temperatures below 130 K. As the name suggests, PMCs only form near the poles, where the mesosphere is coldest, at latitudes greater than about 55°.

The AIM Satellite

The Aeronomy of Ice in the Mesosphere (AIM) satellite is a satellite in a nearly circular, 600-km, sun-synchronous orbit launched by NASA in 2007 and the first satellite whose main mission it is to study PMCs. It orbits the Earth almost 15 times per day. One of the main instruments on the AIM satellite is the Cloud Imaging and Particle Size (CIPS) instrument, which consists of four identical cameras arranged in a cross pattern. The CIPS instrument takes 27 images of a pole per orbit.



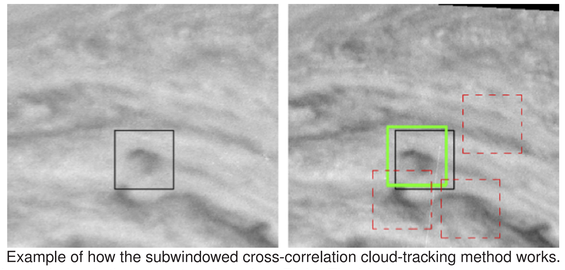
A projection of an image taken by CIPS onto the North Pole. A PMC can be seen on the top portion of this "bowtie" image.

Cloud-Tracking Using Cross-Correlations

We can employ cloud-tracking methods on the data gathered by CIPS in order to learn more about the mesosphere and PMCs. Cloud-tracking algorithms allow us to generate cloud velocity maps, which we can use to better understand the mesosphere's wind patterns. Similar algorithms could also help us track individual clouds in order to learn more about the formation and lifetimes of PMCs. The most common way to track clouds is by using cross-correlations between images of the same clouds taken at different times. The general procedure for this method is as follows:

1. We get two images of the same clouds taken at slightly different times (Δt apart) and set a template subwindow (i.e. area) around a cloud feature in the first image.
2. We define a search window in the second image and compare the template subwindow from the first image with every possible template-sized subwindow within the search window (each successive test subwindow is shifted by a pixel); a correlation coefficient is assigned to each of these test subwindows based on how well they compare with the template subwindow.
3. We determine which test subwindow most likely corresponds to the template subwindow and then generate a displacement vector between it and the template subwindow.
4. We divide the displacement vector by Δt in order to obtain a wind velocity vector.

Cloud-Tracking Using Cross-Correlations (cont.)



Example of how the subwindowed cross-correlation cloud-tracking method works. Left: The black subwindow is the template subwindow. Right: The black subwindow shows the original location of the template subwindow (from the left image), the dashed red subwindows show examples of test subwindows, and the green subwindow shows the correct test subwindow that most accurately matches to the template subwindow from the left image. *Note.* From Choi et al. 2007.

By performing this cross-correlation procedure for hundreds of different cloud features between the same two images, we can generate a wind velocity vector field.

Pearson Correlation Method

There are many different types of correlation coefficients that can be used to perform a cross-correlation. One of the simplest and most commonly used correlation coefficients is the Pearson coefficient, which is calculated as follows:

$$\mathrm{Corr}(\mathbf{x},\mathbf{y}) = \frac{\sum_{i=1}^{n} x_i y_i}{\sigma_x \sigma_y (n-1)}$$

where **x** and **y** are the subwindow vectors (which contain the brightness values of every pixel within the subwindows) that have had their means subtracted from them.

The main drawback of using the Pearson correlation method with the data from CIPS is that we must first bin the data and consequently lose some resolution.

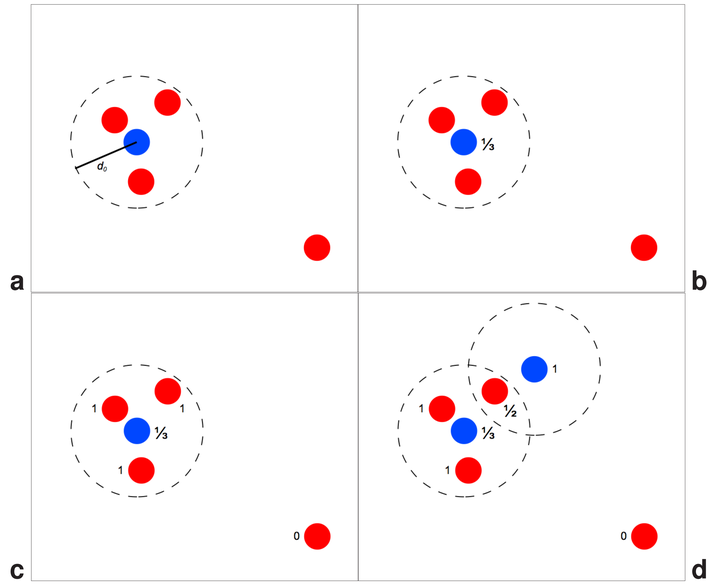
Dynamical "Rebinning" Correlation Method

In order to get around the issue of losing resolution due to binning data, we are working on a correlation method that does not require the data to be binned. This correlation method works by essentially "rebinning" the data dynamically as it performs the correlation (instead of before performing the correlation). This correlation coefficient is calculated using the formula

$$\mathrm{Corr}(\mathbf{x},\mathbf{y}) = \frac{\sum_{i=1}^{n_x}\sum_{j=1}^{n_y} x_i y_j w_{ij}}{\sigma_x \sigma_y \sum_{i=1}^{n_x}\sum_{j=1}^{n_y} w_{ij}}$$

where $w_{ij} = \begin{cases} \frac{1}{n_i}\frac{1}{n_j} & \text{if } d(i,j) \leqslant d_0 \\ 0 & \text{if } d(i,j) > d_0 \end{cases}$ is the weighting function, **x** and **y** have had their means subtracted from them, $d(i,j)$ is the distance between the ith pixel in **x** and the jth pixel in **y**, and d_0 is the distance threshold, n_i is the number of pixels in **y** that are within a distance d_0 of the ith pixel in **x**, and n_j is the number of pixels in **x** that are within a distance d_0 of the jth pixel in **y**.

Dynamical "Rebinning" Correlation Method (cont.)



Visual example of how the dynamical "rebinning" correlation method works. (a) For every subwindow X pixel (blue), we're finding how many subwindow Y (red) pixels are within a distance d_0 of it. (b) A weighting factor is assigned to each subwindow X pixel based on how many subwindow Y pixels are within d_0 of it. (c) To make the correlation symmetric, a weighting factor is also assigned to each subwindow Y pixel based on how many subwindow X pixels are within d_0 of it. Note that the subwindow Y pixel on the lower right has been assigned a weighting factor of 0 since it does not have any subwindow X pixels within d_0 of it. (d) This example is included to further illustrate the symmetry from (c).

Properties of the Dynamical "Rebinning" Correlation Method

In addition to preserving the data's original resolution due to the fact that the data doesn't need to be binned, this correlation method also gives us a great deal of flexibility in our cross-correlation. For example, since this correlation uses a double sum, we can now compare two differently-sized data sets, which means that we can compare two images that have different resolutions. In addition to this, we can perform transformations, such as rotations, on our subwindows more easily.

Conclusion

By tracking PMCs we hope to gain a better understanding of wind systems in the mesosphere, which is one of the regions of the atmosphere that we know least about. We can also learn more about PMCs themselves by tracking them. PMCs are believed to be a fairly recent phenomenon (the first known documentation of them dates back to 1885), and we have been observing an increase in their occurrence over the past few decades. It is thought that the warming of the lower atmosphere and the high emissions of methane in the atmosphere are increasing the production of these clouds, which means we could potentially use them as a miner's canary for climate change.

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