A Lagrangian Interpretation of Three-Dimensional Tropical Cloud Structure: Blending ARM Microbase Retrievals with Satellite Data

A. M. Vogelmann, K. L. Johnson,
M. P. Jensen, M. A. Miller, and M. J. Bartholomew
Brookhaven National Laboratory
Upton, New York

M. P. Jensen
National Aeronautics and Space Administration
Goddard Institute for Space Studies
Columbia University
New York, New York

E. Boer
ERB Consulting
San Diego, California

Introduction

The Tropical Western Pacific (TWP), with its vigorous cloud activity, is an excellent location to investigate the relationships between cloud properties and radiative fluxes. To unlock such issues first requires a better understanding of what the observed structures of clouds are and how they affect the radiative fields. We address this topic by blending the complementary capabilities of the cloud vertical profiles from the Atmospheric Radiation Measurement (ARM) TWP active sensors with the two-dimensional (2D) horizontal view available from satellites.

We approach the problem using the following methodology:

1. Develop a prototype Microbase for the TWP, which uses ARM active sensors to provide vertical profiles of the cloud layer structure and the cloud ice-water and liquid-water contents.

2. Develop a Lagrangian cloud-clustering algorithm, which uses satellite data to identify cloud fields within the study region.

3. Relate the satellite cloud field statistics to the cloud properties available from TWP-Microbase.

The study region we focus on is the Manus ARM site from July to September 2003.

Prototype TWP-Microbase

Microbase is a value-added product that translates the cloud layers observed by the ARM active sensors (radar and lidar) into a continuous (24/7) set of cloud microphysical retrievals including cloud liquid-water content and ice-water content, and particle size (Miller et al. 2004). The Southern Great Plains (SGP) version of Microbase was modified to make a prototype TWP-Microbase by changing the reflectivity-ice water content transformation to that suggested by Jensen et al. (2002). This relationship is based on results from the Maritime Continent Convection Experiment (MCTEX). MCTEX was conducted from November 13 to December 10, 1995, over the Bathurst and Melville Islands (the Tiwi Islands), located approximately 50 km off the coast of Australia's Northern Territory.

Lagrangian Cloud Clustering and Classification Algorithm

These TWP-Microbase retrievals are related to the broader cloud field structure using satellite data and a Lagrangian cloud classification algorithm. Eulerian cloud classification algorithms, which are typically used, fix an analysis grid (geographically), and analyze the cloud properties within each grid. Lagrangian cloud classification algorithms estimate where the clouds are, and analyze the properties within each cloud.

The algorithm used is similar to the detection and spread algorithm by Boer and Ramanathan (1997). The algorithm uses satellite (infrared [IR]) brightness temperatures to detect (cold) convective cloud elements, and associates neighboring cloud pixels with each convective element through successive relaxations. The key difference in the current algorithm to that used by Boer and Ramanathan is the method used in the relaxations, which favors determining regions of associated cloud elements (cloud fields) rather than individual clouds. The algorithm is applied to geostationary operational environmental satellite-9 (GOES-9) Channel 4 IR data (full width at half maximum 10.2 to 11.2 μm). (GOES-9 was relocated to be over the TWP in the spring of 2003.) In a companion study, the algorithm is applied to data from moderate resolution imaging spectroradiometer over the TWP sites (Jensen et al. 2004).

Preliminary Results

Cloud Water Path Distributions

The treatments and assumptions used in the prototype TWP-Microbase retrievals require further investigation, refinement, and error analyses (particularly for the largest optical depths); however, the current algorithm can be used to illustrate a few points. Based on the three months of data from Manus, a cumulative frequency distribution of optical depth indicates that about 30% of the values are greater than an optical depth of 100. This optical depth is approximately the value where the commonly used passive visible and IR satellite remote sensing become problematic, since satellite retrieval errors are magnified where the reflectivity-optical depth relationship flattens/saturates. The cumulative integral of the total water path indicates that about 90% of the total water path is accounted for by optical depths beyond 100. While the exact shape of the distributions requires further investigation, the implications are that TWP-Microbase retrieval would provide information about the tropical cloud water content for the deepest clouds that is unavailable to the most commonly used satellite remote sensing technology used. This information could have strong implications for cloud evolution and longevity, which ultimately have first-order implications to cloud-radiative processes (i.e., is there a cloud present, and how optically dense is it?) Thus, such information provides a vital complement to the extensive 2D view offered by commonly used satellites.

Cloud Area and their Properties

Three months of retrievals from the prototype TWP-Microbase are collocated with results from the Lagrangian cloud-clustering algorithm. Since global cloud models operate in an Eulerian framework, Lagrangian analyses can provide important insights into the inherent scale of the clouds, and whether they are explicitly resolvable by the model grid or must be treated by subgrid-scale parameterizations. We find that a large fraction of the clouds have areas that are less than T42 (approximately 300 x 300 km), a horizontal grid resolution commonly used by global cloud models. Since such clouds are subgrid-scale, their accurate representation will rely heavily on the subgrid-scale parameterization used.

The cloud layering structure (from the prototype TWP-Microbase) was investigated as a function of cloud area. The preliminary results reveal consistent patterns in cloud layering structure and cloud area. For example, the dominant cloud layering structure for the largest clouds with cold convective cores appears to be deep convective turrets that practically fill the troposphere and which have little variation in their vertical structure. The consistency of the picture that emerged from this study suggests that the collocation of cloud area information with the TWP-Microbase data is a promising approach for exploring cloud structure and its dependence on the state of the tropical environment. This approach will be pursued further in future research.

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Corresponding Author

Andy Vogelmann, vogelmann@bnl.gov, (631) 344-4421

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