Atmospheric Diabatic Heating Distributions Derived from a Combination of Satellite Sensor Data

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Why? To better understand the global hydrologic and energy cycles and the dynamics associated with latent heat releases. Precipitation flux is a key component of the water cycle linking the atmosphere and oceans/land surfaces at a rate of approximately 2.6 mm day−1. Globally, this precipitation flux is balanced by evaporation and condensation that represent a consumption of the sun’s energy to move liquid-phase water molecules to the vapor phase. Atmospheric circulations move the water vapor, which carries the sun’s energy in the form of latent heat, to regions of convergence where the vapor condenses and the latent heat is released to the atmosphere at a rate of about 96 W m−2. Globally, Regions of higher precipitation and latent heat, particularly in the tropics, are associated with the rising branches of global-scale atmospheric circulations. Therefore, variations of the large-scale patterns of precipitation and latent heating modulate atmospheric dynamics, which in turn have an impact on the distributions of precipitation in both the tropics and extra-tropics. By quantifying the 40 distributions of precipitation and latent heating using a series of estimates derived from low earth-orbiting satellite microwave radiometers, we hope to provide useful climate diagnostic data and ultimately, validation data for model-based analyses of large-scale heating distributions.

Preliminary Model Comparisons and Applications

Global Means

The Modern Era Retrospective-Analysis for Research and Applications (MERRA) utilizes the GEOS5 model, developed at NASA Goddard’s Modeling and Assimilation Office to assemble conventional observations as well as satellite radiance information to produce a long-term record (1979 – present) of the evolution of the Earth’s atmosphere. The over-arching objective of MERRA is to “provide the science and applications communities with state-of-the-art global analyses, with emphasis on improved estimates of the hydrological cycle, a broad range of weather and climate time scales”. Here, we compare the 15-year (1998 – 2008) average estimates of latent heat over ocean from TMI/VIRS to the corresponding MERRA reanalysis products.

At left are annual mean zonal average heating distributions and mean profile of heating from TMI/VIRS and MERRA over all seasons from 1998–2008. In the mid- to upper troposphere, the primary difference in heating is due to the difference in radiative cooling, which appears to be stronger in the TMI/VIRS product. Currently, boundary layer heating/cooling is only crudely parametrized in the MERRA product. Further study will be needed to understand TMI/VIRS-MERRA differences.

Madden-Julian Oscillation

The Madden-Julian Oscillation (MJO) is a large-scale, convectively coupled wave disturbance which accounts for the majority of intraseasonal variability in the tropics. The “active” phase of the MJO, associated with enhanced precipitation and a minimum of outgoing longwave radiation (OLR), is observed to propagate west to east at approximately 5 m s−1. The active phase of the MJO is collocated with anomalous low-level convergence and upper level divergence associated with an anomalous upward circulation that expands the globe. Shown in the diagram below at left is a classification of the propagation phase of the MJO, based upon an EOF analysis of time-lagged anomalies of OLR and zonal wind speeds at 850 and 200 hPa. RMM1 and RMM2 are the principal components of the first two EOFs (see Wheeler and Hendon, MWR, 2004). Using RMM1 and RMM2, the vertical propagation of one significant MJO event can be classified into one of eight phases. Using these principal components, we constructed the 1998-2008 TMI/VIRS-MERRA zonal average heating estimates by phase, and plotted the composite heating anomalies at 3 km altitude near right. The positive heating anomalies associated with enhanced convection are seen to propagate from the western Indian Ocean (phase 1) to the Maritime Continent (phase 4), to the central Pacific Ocean (phase 7). At far right are the vertical distributions of MJO diabatic heating anomalies from model-based analyses (ERA-Interim, MERRA, and CFS-R) and three TRMM heating algorithms (TRMM, SLH, and CSEH) plotted as functions of phase. The models show greater westward tilt of vertical heating structures relative to the TRMM estimates.

The MJO diabatic heating analysis was carried a step farther by looking at the available potential energy (APE) due to different processes. The diabatic heating contribution to APE is evaluated by taking the phase-averance of composite diabatic heating anomalies (Qd) and temperature anomalies (Td). The composite temperature anomaly is computed from 8 years of Atmospheric Infrared Sounder (AIRS) data (2002-2008). Note that biases in AIRS temperatures tend not to have a significant trend with cloud fraction for cloud fractions less than about 0.5 (see Tolin et al., JGR, 2006).

At far left are the TMI/VIRS composites diabatic heating vertical anomalies, and the corresponding AIRS temperature anomalies, for the eight phases of the MJO. Note that the AIRS temperature anomalies are slightly above and slightly ahead (to the east) of the TMI/VIRS-MERRA heating anomalies in the initial MJO phases. The temperature anomalies propagate further east relative to the heating anomalies in the later MJO phases.

At near left is the estimate of diabatic APE generation from the combination of TMI/VIRS and AIRS anomaly data, as well as an estimate of the same quantity based on an ECMWF reanalysis covering the TOGA/COARE period, Nov. 1992 – Feb. 1993 (see Yarnal et al., JGR, 2004). Not surprisingly, APE generation in the MJO is concentrated in the mid- to upper-troposphere over the Maritime Continent and western equatorial Pacific Ocean, where convective heating associated with the MJO is strongest. APE generation grows by way of TMI/VIRS at upper levels near the Americas and Africa. Note that the satellite-based estimates of APE generation from the ECMWF reanalysis estimates in terms of distribution and maximum generation rates.