5.4 A COMBINED ATMOSPHERIC WATER DATA SET FOR HYDROLOGY STUDIES

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ABSTRACT Current limitations in observations of atmospheric water in its gas, liquid and solid phases are central to many unresolved questions in hydrology and climate science. Several of the instruments in NASA A-Train satellite constellation of the Earth Observing System (EOS) measure atmospheric water quantities useful in resolving these questions. These instruments include the Atmospheric Infrared Sounder (AIRS), the Advance Microwave Scanning Radiometer for EOS (AMSR-E) and the Moderate-resolution Imaging Spectroradiometer (MODIS) all on Aqua, plus the Microwave Limb Sounder (MLS) on Aura, the Advanced Microwave Sounding Unit-B (AMSU-B) on the NOAA-16 satellite, and the CloudSat radar. We are combining these observations into a long-term data record as part of NASA Energy and Water Cycle Study (NEWS) program. AIRS, AMSR-E, MODIS and MLS all measure water vapor. MODIS and AIRS measure cloud fraction, top pressure and top temperature, while MODIS and AMSR-E observe cloud liquid water. MLS and the AMSU-B determine the presence of ice clouds. When launched, CloudSat will obtain profiles of cloud liquid and ice water. Because these satellites fly in formation as part of the A-Train, these measurements are made with overlapping spatial coverage and time coincidence of a few minutes or less. These sampling characteristics preserve the instantaneous relationship between water vapor, cloud liquid and cloud ice. The merged data set will provide observational constraints on atmospheric numerical models of the hydrologic cycle. Some of challenges inherent in this work include reconciling similar quantities observed by different instruments, placing observations from different sampling grids into useful formats, merging data sets with different height coverage, and distilling relevant quantities from very large data sets of several years' duration. We will give examples of applications of this data set to atmospheric processes, focusing on the Madden-Julian Oscillation and other aspects of tropical deep convection.

1. INTRODUCTION

The following extended abstract describes work contained in a talk to be presented at the American Meteorological Society 14th Conference on Satellite Meteorology and Oceanography Conference, Atlanta Georgia on 31 January 2006.

The National Aeronautics and Space Administration (NASA) has implemented a constellation of satellites, known as the A-Train. The A-Train currently includes the Aqua spacecraft launched in May 2002, and Aura spacecraft launched in July 2004. The CloudSat spacecraft is scheduled for launch in November 2005. The A-Train satellites are in a sun-synchronous orbit with a southward (northward) equator crossing time of 1:30 AM (PM). The satellites are spaced by less than 15 min in time, so their instruments sample the same horizontal field of view nearly simultaneously.

We have been supported as part of NASA Energy and Water-cycle Study (NEWS) project (see http://wec.gsfc.nasa.gov/) to create a data set merging atmospheric quantities from a variety of instruments in the A-Train. The current data record is large (many terabytes) and heterogeneous, without common data grids. Little effort has gone into intercomparing the data sets from the A-Train instruments. The data set resulting from this effort will be made publicly available for analysis by researchers in the atmospheric and hydrologic sciences. It is intended to be considerably simpler to use than the current A-Train data record while preserving information.

Critical steps in creating this data set are reconciling observations from the several instruments and placing them on a common spatial grid along the orbit track. In the following sections we describe the A-Train instruments, the intercomparison of retrieved quantities, estimation of product uncertainties, spatial collocation methods, and some possible data analyses.

2. THE A-TRAIN INSTRUMENTS

The Atmospheric Infrared Sounder The AIRS experiment includes three cross-track

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scanning instruments on Aqua. The AIRS instrument is a 2378 channel infrared spectrometer (Aumann et al. 2003). AIRS operates with two microwave instruments: the Advance Microwave Sounding Unit (AMS) and the Humidity Sounder for Brazil (HSB); see Lambrigtsen and Lee (2003) for a description. HSB stopped operating on February 6, 2003. The AIRS retrieval method utilizes a combination of infrared and microwave instruments to infer surface temperature, cloud top properties, profiles of temperature and water vapor, and minor gas information (Susskind et al. 2003; Susskind et al. 2005). Water vapor, temperature and cloud properties will be incorporated into the NEWS data set. The validation of these properties is proceeding, with retrieval performance and yield described in Gettelman et al. (2004), Hagan et al (2004), Fetzer et al. (2004), Divakarla et al. (2005), Tobin et al. (2005), Susskind et al. (2005) and Fetzer et al. (2005). AIRS retrievals have a nominal 45 km horizontal spacing at nadir, and 1-2 km in the vertical. The AIRS water vapor is limited to tropospheric altitudes, though AIRS temperatures extend into the mesosphere. The AIRS horizontal resolution is 45 km at nadir in a swath ~1650 km wide.

Moderate Resolution Imaging Spectroradiometer Aqua MODIS observes atmosphere and surface properties with 36 spectral bands at visible and infrared wavelengths. MODIS infers cloud properties at horizontal resolution as fine a 1 km. It is also provides retrieved temperature and water vapor information at horizontal resolution of 5 km. One version of MODIS is carried aboard the Terra spacecraft, launched in December 1999, but not part of the A-Train. Terra MODIS atmospheric quantities were partly validated in King et al. (2003), Platnick et al. (2003) and Gao et al. (2003). The MODIS swath width is 2330 km.

Advanced Microwave Scanning Radiometer for EOS AMSR-E is a conical scanning sensor detecting sea surface temperature, precipitable water vapor, cloud liquid water, and surface winds over ocean (Shibata et al. 2003). It retrieves several other quantities over land and ice, but they are not utilized in this study. The microwave frequencies used by AMSR-E are insensitive to non-precipitating clouds. AMSR-E is an important source of water vapor in cloudy regions over oceans where AIRS and MODIS cannot sound. AMSR-E is available as a gridded product with 0.25-degree longitude-latitude resolution. The AMSR-E swath is 1440 km wide.

The Microwave Limb Sounder MLS on Aura is a limb scanning microwave radiometer observing temperature, water vapor and trace gases from the upper troposphere into the stratosphere (Froidevaux et al. 2005). MLS also infers cloud ice water in the upper troposphere Jiang et al. (2004) describe water ice cloud distributions in an earlier version of MLS. These observations are made in a vertical plane through the scanning swath of the above three instruments.

CloudSat will measure profiles of cloud liquid and water conference (Stephens et al. 2002). CloudSat measurements are made in a vertical plane similar to that of MLS.

Advance Microwave Sounding Unit-B AMSU-B is on the NOAA-16 satellite, roughly 30 minutes behind the other A-Train satellites. It is sensitive to cloud ice, which is represented by a binary flag.

3. INTERCOMPARISON OF RETRIEVED QUANTITIES

The instruments described above observe a number of similar temperature, water vapor, and cloud quantities. An important part of our NEWS work is intercomparison of these quantities. Some of these comparisons have been completed or are in progress. Here we describe some results, and plans for further comparisons.

Temperature The AIRS temperatures will be the foundation of our data set. They have been extensively validated with in situ observations and model comparisons (Fetzer et al. 2004, Gettelman et al. 2004, Divakarla et al. 2004, Tobin et al. 2005, Susskind et al. 2005). Several other studies are currently in peer review.

Water Vapor We have compared two pairs of water vapor data sets from the above suite of instruments: total water vapor from AIRS and AMSR-E (Fetzer et al. 2005), and upper tropospheric water vapor from AIRS and MLS (Froidevaux et al. 2005). The primary conclusion of Fetzer et al. (2005) is that AIRS has significant sampling biases, with the sign and magnitude of those biases dependant upon the types of cloud present. Figure 1 shows one result of that comparison. The most prominent features are a

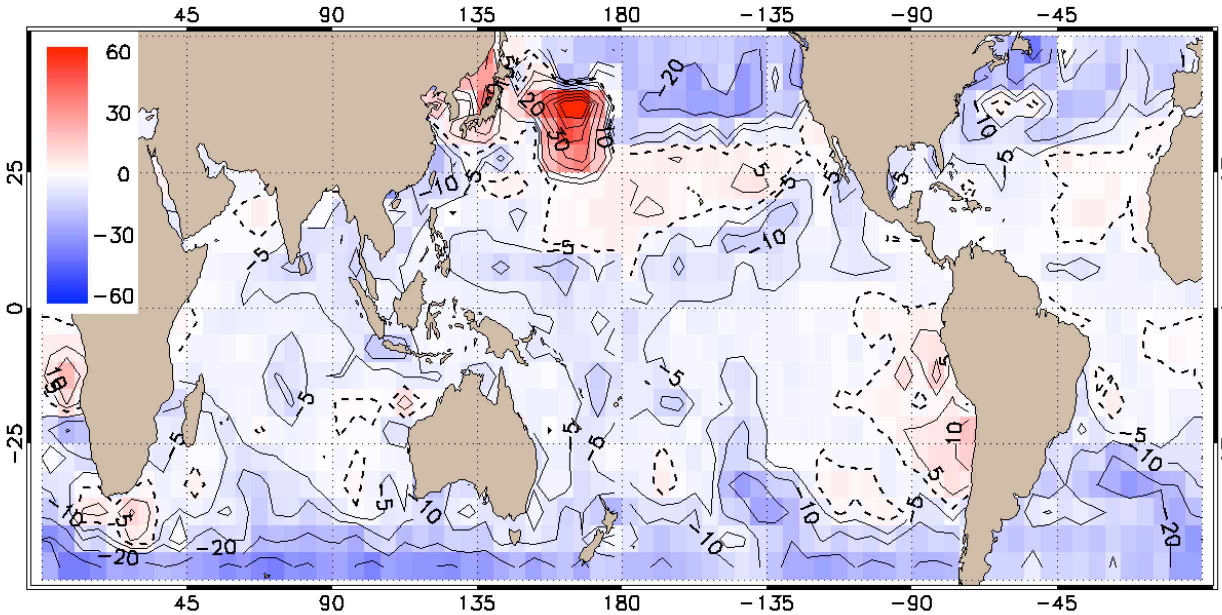

Figure 1. Percent difference between AIRS and AMSR-E mean precipitable water vapor, relative to AMSR-E mean, for the period 19 December 2002 to 9 January 2003.

large wet bias of >50% in AIRS to the east of Japan, a dry bias of ~20% in the Northeast Pacific and Southern Oceans, and a moist bias of ~10% in subtropical stratus regions. These biases are related to a variety of cloud types in Fetzer et al. (2005). As noted there, the combination of quantities from the A-Train will help classify and quantify the properties of those clouds. Froidevaux et al. (2005) compared AIRS and MLS at 316, 215 and 147 hPa where biases are as great as 25% and RMS differences are as great as 73%. One of the major short-term goals of our NEWS effort is a better understanding of the differences between MLS and AIRS in the upper troposphere. We anticipate that some conditions and regions will lead to significantly better agreement. A. Eldering and M. Garay of the Jet Propulsion Laboratory are comparing precipitable water vapor from AIRS, MODIS, AMSR-E and the Tropospheric Emission Spectrometer (TES) as part of TES validation activities.

Cloud Top Properties An initial intercomparison of AIRS and MODIS cloud properties has been performed by Kahn et al. (2005) using the data matching algorithm of Li et al. (2005). Comparing cloud quantities places particular demand on matching of fields of view from different instruments since cloud fields are so heterogeneous. See Cracknell (1998) for a discussion of these challenges. Kahn et al. compare brightness temperatures reconstructed from the AIRS and MODIS cloud top properties. Kahn et al. show qualitatively good agreement for low, thicker clouds. High, thin clouds lead to poorer agreement – this is apparently due to differing responses to cirrus by the two instruments. One short-term priority of the NEWS activity is direct comparison of AIRS and MODIS cloud properties. One possible approach is a comparison conditional upon cloud type (e. g. Xu et al. 2005), rather than the more common spatio-temporal limits. This will permit a more systematic comparison, and is consistent with the conclusions of Fetzer et al. (2003) discussed above.

Cloud Water Substance Several A-Train instruments provide estimates of water substance. AMSR-E retrieves cloud liquid water column, MODIS retrieves cloud liquid and ice optical depth, and MLS and AMSU-B provide a water ice flag. Limited in situ information makes these quantities particularly difficult to validate. Also, until CloudSat is launched, comparison between them and other A-Train measurements is challenging because observations are unique to each instrument. For example, several instruments measure water vapor, but only AMSR-E measures cloud liquid water, and only MODIS measures cloud water optical depth. Both MLS and AMSU-B flag ice water, but these are experimental products. Nevertheless, comparisons can be made based on plausibility. Kahn et al. (2005) show good agreement between the MLS cloud flag and high, cold clouds observed by AIRS. We anticipate comparing AMSR-E cloud liquid water with AIRS and MODIS cloud top properties. We will also compare MODIS cloud water optical depth with AMSR-E cloud liquid water path. CloudSat will be useful in confirming the water substance estimates from other A-Train instruments, in the narrow strip where CloudSat is available. However, a fully validated and consistent cloud water substance data set from all A-Train instruments will entail considerable effort.

4. DATA MERGING AND ESTIMATION OF UNCERTAINTIES

Our data product will require merging of similar products from multiple data sets. For example, our water vapor product will be derived from a combination of water vapor from AIRS, MLS, AMSR-E, and possibly MODIS. We also anticipate cloud top properties from AIRS and MODIS. Merging these data sources will require knowledge of the uncertainties on the retrieved quantities. To partially address this requirement, we have begun development of an optimal estimation algorithm based on the TES retrieval scheme of described in Bowman et al. (2002) to supplement the current operational algorithm of Susskind et al. (2003). This should aid in understanding the information content of AIRS clouds, temperature and water vapor. This information is particularly important in understanding the AIRS retrievals in the boundary layer (Fetzer et al. 2004) and in the upper troposphere (Gettelman et al. 2004) where AIRS becomes insensitive to water vapor and will be merged with MLS.

5. PLACEMENT ON A COMMON SPATIAL GRID

One of the activities we will pursue is placing the quantities on a common, nested grid of 0.25 degree in latitude and longitude. The grid density will depend upon the quantity of concern. We anticipate a relatively coarse grid of 0.25 or 0.5 degree for temperature and water vapor, but 0.125 degree for cloud quantities. There are several methods for addressing. We anticipate two fundamental techniques: interpolation and subsampling or averaging. Different techniques are appropriate for different quantities, depending on their scales of variability. Here are the anticipated techniques for temperature, water vapor and clouds.

Temperature is the most smoothly varying quantity we will include in our data set. Consequently, we anticipate linear or bilinear interpolation onto a grid of 0.5-degree horizontal resolution.

Water Vapor has higher horizontal variability than temperature. Fetzer et al. (2005) show that sampling, rather than interpolation, is sufficient to show very good agreement in total water vapor from AIRS and AMSR-E. AIRS will provide the basic water vapor data source for the NEWS product. Above ~200 hPa MLS water vapor extends into the stratosphere. In addition, MODIS observes tropospheric water vapor profiles at finer horizontal resolution than AIRS. But, as noted by King et al. (2003), the MODIS water vapor absolute values are not reliable but its horizontal gradients are plausible. We will examine if MODIS can be used to interpolate the AIRS data to a finer horizontal resolution, especially in convective regions.

Clouds have the highest horizontal variability of any of the quantities we will consider. Fortunately, MODIS also reports cloud properties of at 1 or 5 km horizontal resolution, depending on the quantity. This should permit either averaging or subsampling down to a resolution of ~1/8 degree, or roughly 12 km.

6. POSSIBLE SCIENCE ANALYSES

A combined data set from the A-Train instruments will enable a number of analyses not currently possible with individual data sets. Some of these are being supported through the NEWS project and are described in the NEWS website presented above. Also, we have proposed to examine the Madden-Julian Oscillation in the NEWS data set as a follow-on analysis to Tian et a. (2005). Our data product will be particularly useful in creating moist thermodynamic statistics as a function of cloud type, using classification information from all the instruments combined. These are expected to aid in improvements in convective parameterization in numerical models (Tao et al. 2003).

7. CONCLUSIONS

Our NEWS research presents several scientific and technical challenges. The latter include staging, accessing and processing several very large data sets and making them readily available. We anticipate meeting these challenges through careful analyses, as described above, and collaboration with information processing experts. We anticipate considerable progress from these activities. NASA has made a significant investment in remote sensing capability, presentnig many opportunities to exploit the resulting data products. The potential benefits of these activites are considerable. Realistic prediction of atmospheric hydrologic processes remains an outstanding challenge in geophyics. Improved in hydrologic prediction will lead to considerable societal benefit.

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