4-D CLOUD WATER CONTENT FIELDS DERIVED FROM OPERATIONAL SATELLITE DATA

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1. INTRODUCTION

In order to improve operational safety and efficiency, the transportation industry, including aviation, has an urgent need for accurate diagnoses and predictions of clouds and associated weather conditions. Adverse weather accounts for 70% of all air traffic delays within the U.S. National Airspace System [1]. The Federal Aviation Administration has determined that as much as two thirds of weather-related delays are potentially avoidable with better weather information and roughly 20% of all aviation accidents are weather related [2]. Thus, it is recognized that an important factor in meeting the goals of the Next Generation Transportation System (NexGen) vision is the improved integration of weather information. The concept of a 4-D weather cube is being developed to address that need by integrating observed and forecasted weather information into a shared 4-D database, providing an integrated and nationally consistent weather picture for a variety of users and to support operational decision support systems. Weather analyses and forecasts derived using Numerical Weather Prediction (NWP) models are a critical tool that forecasters rely on for guidance and also an important element in current and future decision support systems [3]. For example, the Rapid Update Cycle (RUC) [4] and the recently implemented Rapid Refresh (RR) Weather Research and Forecast (WRF) models provide high frequency forecasts and are key elements of the FAA Aviation Weather Research Program. Because clouds play a crucial role in the dynamics and thermodynamics of the atmosphere, they must be adequately accounted for in NWP models. The RUC, for example, cycles at full resolution five cloud microphysical species (cloud water, cloud ice, rain, snow, and graupel) and has the capability of updating these fields from observations [4]. In order to improve the models' initial state and subsequent forecasts, cloud top altitude (or temperature, T_c) derived from operational satellite data, surface observations of cloud base altitude, radar reflectivity, and lightning data are used to help build and remove clouds in the models' assimilation system. Despite this advance and the many recent advances made in our understanding of cloud physical processes and radiative effects, many problems remain in adequately representing clouds in models [5]. While the assimilation of cloud top information derived from operational satellite data has merit, other information is available that has not yet been exploited. For example, the vertically integrated cloud water content (CWC) or cloud water path (CWP) and cloud geometric thickness (ΔZ) are standard products being derived routinely from operational satellite data [6,7]. These and other cloud products

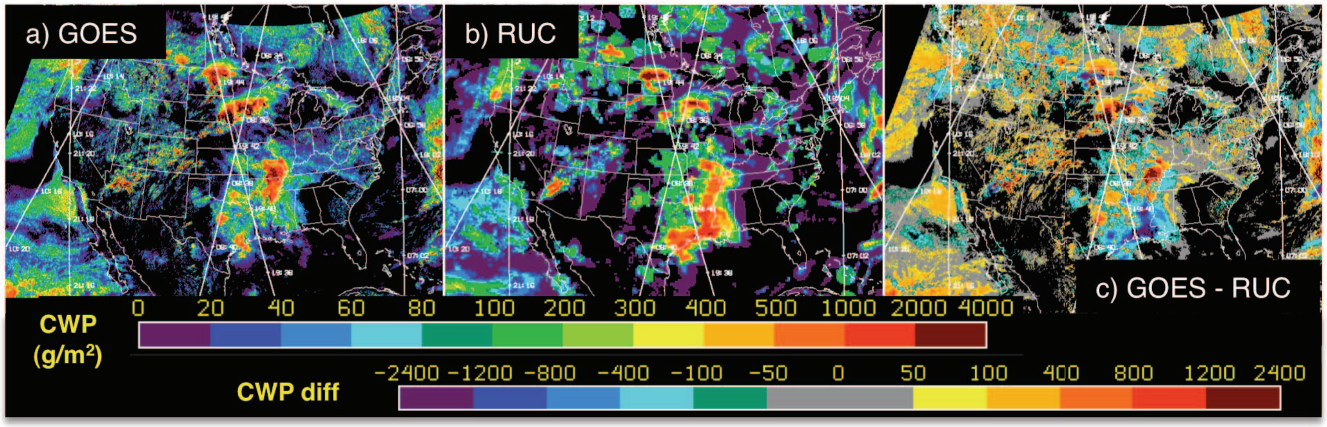

Figure 1. Cloud water path derived from (a) GOES, (b) RUC and (c) their difference at 20 UTC on May 6, 2008

have been validated under a variety of conditions [8-12]. Since the uncertainties have generally been found to be less than those found in model analyses and forecasts, the satellite products should be suitable for data assimilation, provided an appropriate strategy can be developed that links the satellite-derived cloud parameters with cloud parameters specified in the model. In this paper, we briefly outline such a strategy and describe a methodology to retrieve cloud water content profiles from operational satellite data. Initial results and future plans are presented. It is expected that the direct assimilation of this new product will provide the most accurate depiction of the vertical distribution of cloud water ever produced at the high spatial and temporal resolution needed for short term weather analyses and forecasts.

2. MOTIVATION AND METHODOLOGY

The CloudSat cloud profiling radar is providing unprecedented data describing the vertical structure of cloud systems across the Earth [13]. These data are being used to evaluate the representation of clouds in models and to evaluate cloud parameters derived from passive satellite data. Figure 1 shows an instantaneous comparison of CWP derived from GOES data with CWP derived from profiles of cloud water mixing ratio determined in the RUC analysis (0-hr forecast) valid at 20 UTC on May 6, 2008. The white lines represent the location of the CloudSat overpasses on this day. Overall, the magnitude of CWP shown in figures 1a and 1b are quite comparable. Comparison of domain average CWP (not shown) over a period of several months reveals that the model and observations agree to a level of about 30% for most cloud types. However, the large instantaneous differences shown in panel (c) suggests that significant differences exist between the models diagnosis of the distribution of cloud water compared to that found in the satellite observations. Figure 2 illustrates this further, depicting the vertical profile of cloud water content derived from CloudSat (figure 2a) and the corresponding profiles found in the model gridpoints below the satellite track (figure 2b). Figure 2c shows the corresponding CWP derived from the model, CloudSat and GOES. This portion of the track can be found in Figure 1 extending from southeast to northwest from a point in eastern Nebraska to a point north of the Canadian border. While the

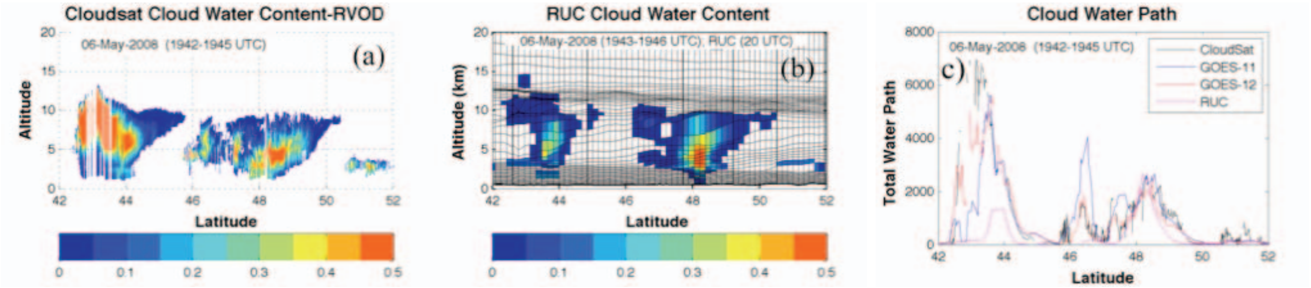

Figure 2. Cloud water content (g/m^3) profiles derived from (a) the CloudSat cloud profiling radar, (b) the RUC 0-hr forecast. Cloud water path (g/m^2) from CloudSat, RUC and GOES at ~20 UTC on May 6, 2008 (c).

cloud boundaries are represented reasonably well by the model in this case, the density of cloud water is poorly described compared to CloudSat, particularly in the southern cloud system. CWP derived from GOES, however, tracks remarkably well over a large range of CWPs. Clearly, the RUC and other weather analysis systems could benefit significantly if timely information on clouds, such as that provided by CloudSat, were available at high temporal and spatial resolution. Because CloudSat is nadir pointing with a very small footprint, direct assimilation of CloudSat cloud water content profiles in NWP would be limited to a very small percentage of the models time and space domain. However, since good correspondence is found between the GOES and CloudSat CWP, a strategy is being developed that integrates the information that CloudSat provides on cloud vertical structure with cloud parameters derived from operational satellite imagers that have the advantage of high temporal resolution with broad spatial coverage. In the approach taken here, characteristic or climatological CWC profiles are derived for a variety of cloud types from CloudSat data. The cloud types are defined by cloud parameters typically retrieved from operational satellite data (i.e. T_c, CWP, and ΔZ). CWC shape factors are derived for each cloud type by binning the CloudSat CWC/CWP ratio as a function of distance below cloud top. The shape factors are stored in look-up tables, which are then used in a retrieval system to derive CWC profiles that are constrained with the CWP and ΔZ derived from the imager data.

3. RESULTS

Figure 3 shows the mean shape factors derived from CloudSat data taken during April-June, 2008 over the domain shown in figure. 1. These shape factors were derived for clouds with ΔZ between 2 km and 4 km and also binned as a function of CWP and Tc. Similar results have been tabulated for thinner and thicker clouds (not shown). Figure 4 depicts the CWC profile derived from GOES-12 when applying the appropriate shape factors to the GOES-derived cloud parameters corresponding to the case shown in figure 2. The level of agreement between the GOES-derived CWC profile and that derived from CloudSat is very encouraging. Refinements to this technique are a work in progress. A statistical evaluation and progress toward model assimilation of this new product will be presented at the meeting.

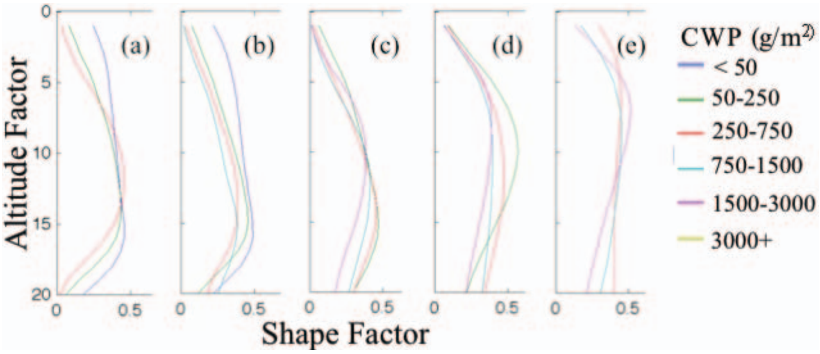

Figure 3. Mean cloud water content shape factors derived from CloudSat data taken over the CONUS in April-June, 2008 for 2-4 km thick clouds as a function of altitude below cloud top and for different CWP's and cloud top temperatures (a) $T_c < 220$*K, (b) 220 K <* T_c *<235K, (c) 235K <* T_c *<250K, (d) 250K <* T_c *<273K, and (e)* $T_c > 273$*K*

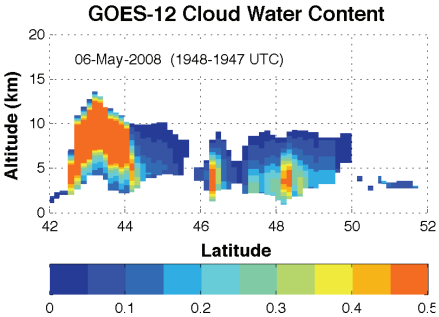

Figure 4. Cloud water content profile derived from GOES-12 on May 6, 2008

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