



An Intercomparison Study of MODIS-Derived and WRF-Simulated Cloud Data

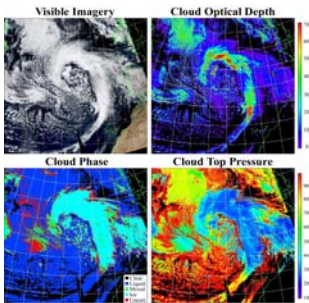
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INTRODUCTION

The direct impact that clouds have on sensible weather conditions makes it critically important that numerical weather prediction (NWP) models realistically simulate their properties and structural evolution. Although substantial improvements have been made in recent years, cloud microphysical parameterization schemes remain one of the largest sources of uncertainty in NWP models. In order to validate regional or global model simulations, it is necessary to utilize cloud observations taken from geostationary or polar-orbiting satellites. Satellite radiances and satellite-derived cloud products, such as cloud top pressure (CTP), cloud optical thickness (COT) and cloud water path (CWP), are routinely available on a near-global basis from a variety of sensors. In this study, we will examine the ability of different combinations of cloud microphysics and planetary boundary layer (PBL) parameterization schemes implemented in the Weather Research and Forecasting (WRF) model to realistically simulate the cloud properties associated with an extratropical cyclone that developed over the North Atlantic Ocean. Cloud data from high-resolution (4-km) model simulations will be compared to cloud products from the Moderate-resolution Imaging Spectroradiometer (MODIS) in order to determine which schemes perform best at cloud-resolving scales.

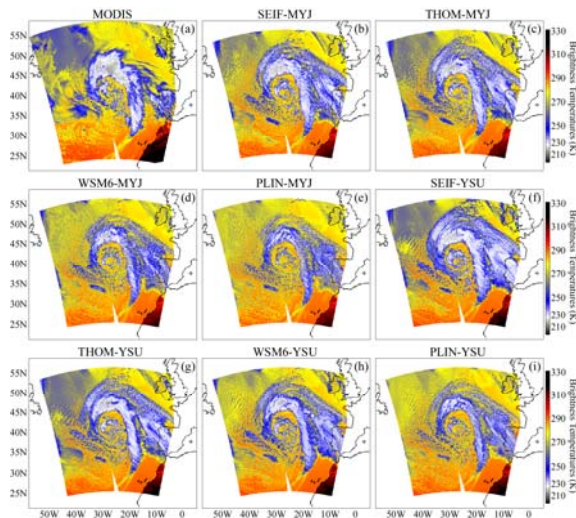
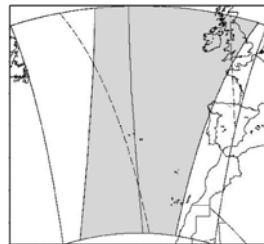


CASE STUDY DESCRIPTION

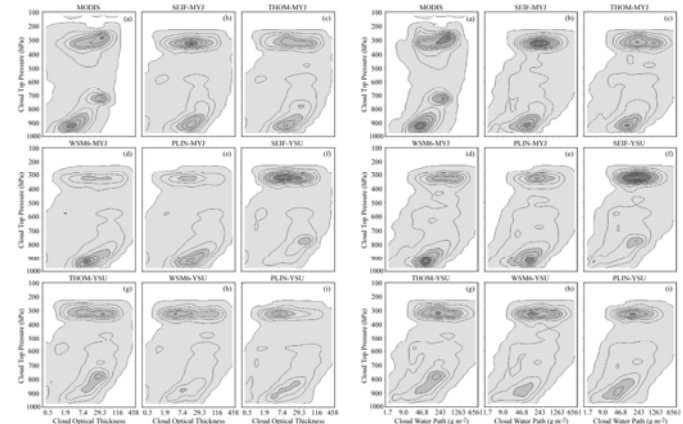
The visible satellite imagery reveals a mature occluded cyclone characterized by a prominent comma-shaped cloud shield, with an extensive region of broken low-level cloud cover to the west and southwest. An arc of optically thick clouds extends around the northern periphery of the cyclone with an additional band of deep convective clouds along the cold front. Optically thin cirrus clouds extend to the east of the cyclone with locally thicker clouds evident over the Iberian Peninsula. A thick stratocumulus cloud deck associated with an area of cold-air advection is also present to the northwest of the cyclone.

MODEL SIMULATIONS

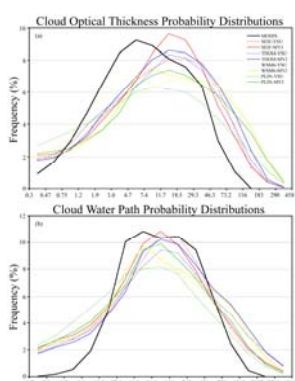
Eight model simulations were performed using four microphysics (SEIF, THOM, WSM6, and PLIN) and two PBL (MYJ and YSU) schemes implemented in version 2.1.2 of the WRF model. No cumulus parameterization scheme was used, therefore, all clouds were explicitly predicted by the microphysics scheme. The simulations were initialized at 00 UTC on 24 March 2005 using 1° Global Data Assimilation System analyses and then run for 18 hours on a single 1000 x 1000 grid point domain with 4-km horizontal grid spacing and 50 vertical levels. The model domain and geographical coverage of 3 MODIS overpasses is shown to the right.



As a first step in evaluating the realism of the model-simulated cloud fields, the observed and simulated 11 μm MODIS brightness temperatures are shown above. A detailed comparison indicates that the PBL and cloud microphysics schemes both exert a strong influence on the spatial distribution of the simulated clouds. For instance, compared to the WSM6 and PLIN simulations, the upper-level cloud shield covers a larger area when the SEIF and THOM microphysics schemes are used. Likewise, for a given microphysics scheme, slightly cooler brightness temperatures occur within the cloud shield when the YSU PBL scheme is employed. The model simulations also exhibit substantial variability within the stratocumulus cloud region to the northwest of the cyclone. The MODIS brightness temperatures indicate that these clouds have a relatively uniform appearance over a large geographical region. The WSM6 and PLIN simulations, however, failed to reproduce these features and are instead characterized by a heterogeneous cloud deck containing large clear areas between the cumulus cells. By comparison, the THOM and SEIF simulated brightness temperatures have a more uniform appearance that better matches the observations. Simulations employing the YSU PBL scheme generally outperformed the MYJ scheme within this region, particularly for the SEIF and THOM simulations.



The simulated and observed COT – CTP and CWP – CTP probability distributions are shown above. All of the model simulations realistically capture the height of the upper-level clouds, though it is evident that the heights are too low for some of the optically thicker clouds (COT > 30). The downward height bias is consistent with the slightly warmer brightness temperatures within the deep convection to the north and east of the cyclone center. Simulations employing the YSU PBL scheme generally contain more upper level clouds than those using the MYJ scheme, which demonstrates that vertical fluxes generated by the PBL schemes effect all of the clouds in the column, not just those in the boundary layer. The mid-level maximum associated with the stratocumulus cloud deck is poorly predicted by all of the simulations except for the SEIF-YSU simulation. The warmer brightness temperatures to the northwest of the cyclone indicate that the simulated cloud top heights are too low relative to the observations. The lack of mid-level clouds suggests that the PBL schemes generate insufficient vertical mixing, which prevents the cloud-topped boundary layer from reaching its proper depth within this region. In the lower troposphere, the model simulations contain fewer (more) optically thin (thick) clouds than the MODIS dataset. Although simulations employing the MYJ PBL scheme tend to overestimate the optical thickness of the low-level clouds, it is clear that these simulations contain a more realistic depiction of the low-level clouds than those using the YSU PBL scheme. The simulated CWP data more closely resembles the MODIS observations, particularly in the lower troposphere. A detailed inspection of the MODIS cloud data revealed a tendency for relatively large effective radii to occur along the edges of optically thin cumulus clouds in the western portion of the domain. Since the MODIS CWP is proportional to the product of the COT and effective radius retrievals, it is likely that the apparent biases partially offset each other and therefore result in a higher CWP in these regions.



Since differences in the simulated cloud top pressure distributions complicate the inter-comparison of the COT and CWP datasets, the total probability distributions for each variable are shown to the left. Overall, the model simulations generally contain fewer (more) optically thin (thick) clouds than the MODIS dataset. The tendency for MODIS to underestimate the COT along cloud edges and within cumulus cloud regions partially accounts for the shift toward optically thinner clouds in the MODIS distribution. Although the microphysics schemes may overestimate the thickness of the simulated convective clouds (COT > 40), it is more likely that the MODIS observations are too low in this region since optical measurements saturate for thicker clouds. The simulated and observed CWP data exhibit better agreement, although differences still exist across the entire distribution. For instance, the simulated datasets contain a higher frequency of clouds containing small quantities of cloud condensate (CWP < 15), most of which occurred within the cumulus cloud region to the west of the cyclone. There is a clear distinction between the various model simulations, with the SEIF and THOM microphysics schemes generally characterized by cloud properties that more closely match the MODIS observations. For a given microphysics scheme, the YSU PBL scheme tends to produce more (less) optically thin (thick) clouds than the MYJ PBL scheme.

The simulated and observed radiative cloud phase probability distributions are shown to the right. Compared to the MODIS observations, the model simulations generally contain fewer liquid clouds, a higher frequency of ice clouds and clear pixels, and a comparable number of mixed and uncertain clouds. The extensive geographical coverage of the simulated cloud shields accounts for the overabundance of ice clouds and contributes to the lower frequency of liquid clouds. Most of the mixed phase and uncertain cloud retrievals occurred to the west of the cyclone and within gaps in the cloud shield.

