A Comparison of Ground and Satellite Observations of Cloud Cover to Saturation Pressure Differences During a Cold Air Outbreak

R. J. Alliss and S. Raman
North Carolina State University
Raleigh, North Carolina

Introduction

The role of clouds in the atmospheric general circulation and the global climate is twofold. First, clouds owe their origin to large-scale dynamical forcing, radiative cooling in the atmosphere, and turbulent transfer at the surface. In addition, they provide one of the most important mechanisms for the vertical redistribution of momentum and sensible and latent heat for the large scale, and they influence the coupling between the atmosphere and the surface as well as the radiative and dynamical-hydrological balance.

In existing diagnostic cloudiness parameterization schemes, relative humidity is the most frequently used variable for estimating total cloud amount or stratiform cloud amount. However, the prediction of relative humidity in general circulation models (GCMs) is usually poor (Slingo 1980). Even for the most comprehensive GCMs, the predicted relative humidity may deviate greatly from that observed, as far as the frequency distribution of relative humidity is concerned. Recently, there has been an increased effort to improve the representation of clouds and cloud-radiation feedback in GCMs, but the verification of cloudiness parameterization schemes remains a severe problem because of the lack of observational data sets.

In this study, saturation pressure differences (as opposed to relative humidity) and satellite-derived cloud heights and amounts are compared with ground determinations of cloud cover over the Gulf Stream Locale (GSL) during a cold air outbreak.

Methodology

Saturation level pressures (p*) (i.e., lifting condensation level) are derived from ETA model analyses. For unsaturated parcels, p* is the intersection of the dry adiabat through the parcel temperature and the constant q line through the dewpoint temperature. For cloudy saturated parcels, it is the intersection of the moist adiabat through the parcel temperature with the q isopleth now equal to the total water mixing ratio (vapor + liquid). Another very useful parameter is the saturation pressure difference (SPD) which has been used to distinguish layers that are in and above the convective boundary layer (Betts and Albrecht 1987). Following Betts (1982), it is defined as

$$\text{SPD} = p^* - p \tag{1}$$

(the difference between air parcel pressure, p, and saturation level pressure, p*). The usefulness of this parameter has also been shown in Alliss and Raman (1995c). In this study, however, the degree of subsaturation of a given layer will be documented and compared with available surface-satellite observations of cloud cover. Negative values of SPD are directly related to subsaturation since $q < q_s$ (where q_s = saturation mixing ratio). Thus SPD may be viewed as the "potential" for parcel saturation.

The CO_2 slicing technique is used to calculate cloud top pressures and effective cloud amounts (Wylie and Menzel 1989). This technique has also been used to show seasonal and diurnal variations over the GSL (Alliss and Raman 1995a,b). For a complete description of both the satellite and SPD methods in estimating cloud fraction, the reader is referred to Alliss (1995).

Results

Since ETA model analyses/forecasts and satellite CO_2 radiances are available over the Western Atlantic Ocean the composite cloud fraction algorithms are used to test the performance during a cold air outbreak observed on 6 February 1995. Geostationary Operational Environmental Satellite (GOES-I) radiances are obtained to evaluate a composite cloud fraction for several locations in the GSL at 1800 UTC. Saturation pressure differences obtained from a six-hour forecast valid at 1800 UTC, 6 February 1995 are also used to estimate composite cloud fractions. On this day, the GSL is dominated by high pressure with an offshore flow of cold Polar air. Satellite imagery indicates the familiar cloud free zone between the Coast and Gulf Stream core. Employing the satellite and SPD algorithm to data at RDU, GSO, and HAT indicates clear sky at all locations, which agrees with surface reports. Figure 1 shows profiles of SPD at four locations. The four profiles are separated by 1 degree of longitude along 34 north latitude. The first profile (34N/78W) is nearest ILM. This profile shows extremely dry conditions with an average SPD of -203 mb. Thus, according to the algorithm, clear skies would be identified. ILM reports clear skies at 1800 UTC. The corresponding mean relative humidity for this layer is 27%. The second profile (34N/77W) indicates a moistening of the atmosphere below 900 mb compared with profile one. Although surface SPDs are approaching saturation, the layer as a whole remains too dry to support cloudiness (a2 = −184 mb). This position is approximately between the coastline and the Gulf Stream core. Profile three (34N/76W) indicates that intense modification of the airmass has begun. The mean SPD has increased from −184 mb to -40 mb, indicating scattered low clouds are probably present. For reference, the mean relative humidity of the layer is 78%. The profile at 34N/75W lies just east of the Gulf Stream core and indicates nearly saturated conditions from the surface to 700 mb. The mean SPD in this layer is approximately -10 mb. In this case the algorithm predicts a low overcast cloud within the 1000-700 mb layer. A mean relative humidity of 99% is also calculated at this time. According to satellite imagery, considerable low clouds are present. No clouds are observed above 700 mb as the atmosphere remains very dry and stable.

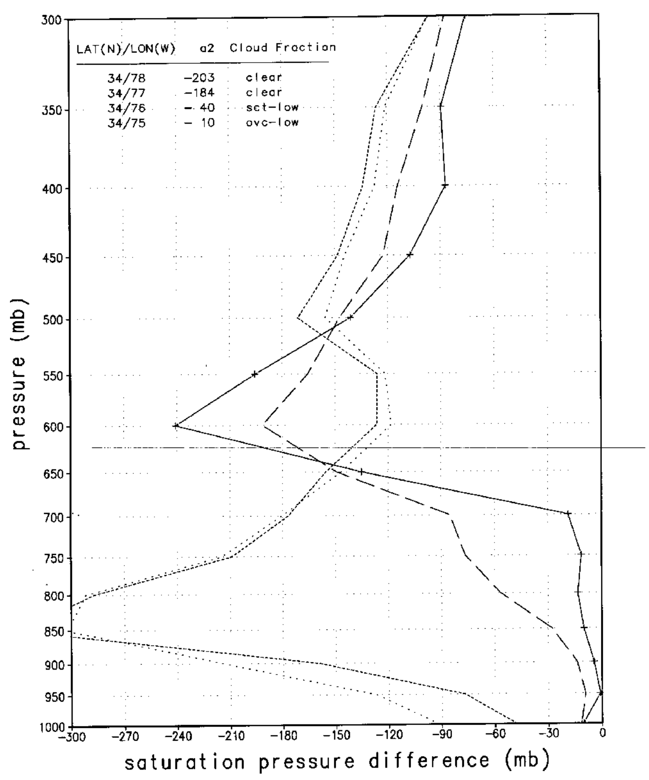

Figure 1. ETA model six-hour forecasts of SPD during the cold air outbreak observed on 6 February 1995 1800 UTC. The dotted line indicates the profile at 34N/78W, short dash (34N/77W), long dash (34N/76W) solid line (34N/75W). The value a2 is defined as the mean SPD in the 1000-700 mb layer.

The CO_2 slicing technique is used to determine a composite cloud fraction at the same four locations. Table 1(a-d) shows the histograms of satellite determinations. Entries in Table 1 are percentage values for a given category of all observations within the 50-km by 50-km grid over the given ground site. By applying the percentage values in Table 1 to thresholds (not shown) the composite reports are defined. Over ILM (34N/78W), 100% of the satellite observations indicate clear skies (Table 1a). This agrees with both ground reports and the SPD determinations. Clear skies are also indicated at 34N/77W as the satellite again reports 100% clear skies (Table 1b). At location three (34N/76W), the satellite detects the presence of some low clouds (Table 1c). In this case, only 30% of observations indicate clear sky; therefore a low opaque cloud cover is indicated. Of the 70% of low opaque clouds the satellite reports, the majority of the cloud top pressures are near 900 mb. Finally, at location four (34N/75W), the satellite sees 100% low opaque cloud cover with the average cloud top pressure near 750 mb (Table 1d). Unfortunately there were no surface reports over the ocean which contained cloud cover observations, therefore no direct validation could be made. However, based on a qualitative comparison with visible imagery, the two techniques appear to be performing well.

Acknowledgments

This work was supported by the Department of Energy under Contract 091575-A-Q1 with the Pacific Northwest National Laboratory.

Table 1. Histograms of satellite cloud determinations at (a) ILM, (b) 34N/77W, (c) 34N/76W and (d) 34N/75W at 1800 UTC, 6 February 1995.

	(a) Effective Cloud Amount			
Cloud Top Pressure (CTP)	**≤0.33**	**≤0.65**	**≤0.95**	**≤1.0**
CTP < 400	0	0	0	0
400 ≤ CTP < 700	0	0	0	0
700 ≤ CTP < 1000	x	x	x	0
CTP = 1000	100	x	x	x
Satellite reports clear skies.				
	(b) Effective Cloud Amount			
Cloud Top Pressure (CTP)	**≤0.33**	**≤0.65**	**≤0.95**	**≤1.0**
CTP < 400	0	0	0	0
400 ≤ CTP < 700	0	0	0	0
700 ≤ CTP < 1000	x	x	x	0
CTP = 1000	100	x	x	x
Satellite reports clear skies.				
	(c) Effective Cloud Amount			
Cloud Top Pressure (CTP)	**≤0.33**	**≤0.65**	**≤0.95**	**≤1.0**
CTP < 400	0	0	0	0
400 ≤ CTP < 700	0	0	0	0
700 ≤ CTP < 1000	x	x	x	70
CTP = 1000	30	x	x	x
Satellite reports low opaque cloudiness.				
	(d) Effective Cloud Amount			
Cloud Top Pressure (CTP)	**≤0.33**	**≤0.65**	**≤0.95**	**≤1.0**
CTP < 400	0	0	0	0
400 ≤ CTP < 700	0	0	0	00
700 ≤ CTP < 1000	x	x	x	100
CTP = 1000	0	x	x	x
Satellite reports low opaque cloudiness.				

References

Alliss, R. J. 1995. Satellite derived seasonal and diurnal variations of cloudiness over the Gulf Stream region and its relationship to saturation pressure differences, Ph.D. dissertation, North Carolina State University, Raleigh, North Carolina.

Alliss, R. J., and S. Raman. 1995a. Cloudiness and its relationship to thermodynamics during a developing East Coast winter storm, *J. Appl. Meteor.*, submitted.

Alliss, R. J., and S. Raman. 1995b. Diurnal variations in cloudiness over the Gulf Stream Locale. *J. Appl. Meteor.*, in press.

Alliss, R. J., and S. Raman. 1995c. Quantitative estimates of cloudiness over the Gulf Stream Locale using GOES-VAS observations, *J. Appl. Meteor.*, **34**, 500-510.

Betts, A. K. 1982. Saturation point analysis of moist convective overturning, *J. Atmos. Sci.*, **39**, 1484-1505.

Betts, A. K., and B. A. Albrecht. 1987. Conserved variable analysis of the convective boundary layer thermodynamic structure over the tropical oceans, *J. Atmos. Sci.*, **44**, 83-99.

Slingo, J. M. 1980. A cloud parameterization scheme derived from GATE data for use with a numerical model, *Quart. J. Roy. Met. Soc.*, **106**, 747-770.

Wylie, D. P., and W. P. Menzel. 1989. Two years of cloud cover statistics using VAS, *J. Climate Appl. Meteorol.*, **2**, 380-392.