Evaluating the Performance of the MRF Subgrid-Scale Cloud Fraction Parameterization: Examination of Two Significant Stratiform Cloud Events Over the ARM SGP

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Introduction

As part of a collaborative effort with the National Centers for Environmental Prediction (NCEP), the University of Utah continues to archive (daily) column data from the NCEP Medium Range Forecast (MRF, note that the since April 2002, the MRF and AVN models have been combined into a single system referred to as the Global Forecast System or MRF) model. Data are currently collected at model grid points corresponding to 16 sites (4 of which directly coincide with Atmospheric Radiation Measurement (ARM) facilities at Manus, Nauru, Barrow, and the Southern Great Plains (SGP) Central Facility [CF]). The archive, which dates back to November 2000, consists of twice daily (00 and 12 Greenwich Mean Time [GMT]) 48 hour MRF forecasts, and once daily Global Data Assimilation System analyses (00, 06, 12, and 18 GMT) and forecasts (03, 09, 15, and 21 GMT).

We focus here on the short-term prediction of subgrid scale cloud amount and cloud properties as diagnosed from MRF forecast hours 24-48. We have begun to identify large-scale low-level (i.e., <4 km) stratiform cloud events in order to evaluate model performance under conditions whereby one might expect a subgridscale cloud parameterization to perform well. The stratiform events are identified using the Dong et al. (1998) retrieval criteria to flag ‘potential’ stratus periods. Herein we examine two such extended (significant) periods (we are looking at others) from 15 GMT 12 December to 00 GMT December 13, 2001, and a second period from 00 GMT December 16, to 06 GMT December 17, 2001. There were six stratiform cloud events in December 2001 that meet the Dong retrieval criteria, however only the two presented here occur over periods >24 h.

To evaluate MRF cloud fraction, we use merged moment millimeter cloud radar data from the SGP. These merged moment data are created using a statistical mask which selects the best reflectivity estimate from the mmcr's 4 modes (low clouds are flagged using ceilometer data, Clothiaux et al. 2000). We choose a one hour 'window' surrounding the MRF forecast time, and cloud is identified as present if the reflectivity > -40 dBz. Tests where the minimum reflectivity threshold was reduced to -50 dBZ and where the time window over which the cloud fractions were estimated showed no appreciable differences for these two events.

MRF Cloud/Microphysical Parameterizations

In May 2001, the MRF transitioned to a prognostic large-scale cloud scheme and the Xu-Randall (1996) subgrid-scale cloud fraction scheme the latter of which depends on both relative humidity (RH) and cloud water/ice (previously MRF clouds were computed from RH alone), i.e.,

$$C = \overline{RH}^{p}\left[1 - \exp\left(\frac{-\alpha_{o} q_{l}}{\left[(1-\overline{RH}q_{vs}\right]^{\gamma}}\right)\right], \text{if } RH < 1$$

where $\alpha_o \leq =$ 2000, $p = \gamma = 0.25$ and q_l and RH are the liquid/ice water and RH, and q_{vs} is the saturation mixing ratio

The MRF radiation scheme, assumes that all cloud layers are **randomly overlapped**, with clear-sky fraction, A, defined by where the calculation of proceeds from the top of the atmosphere downward. The **effective cloud amount** (C_{tot}) is then defined as:

$$C_{tot} = 1 - \sum_{k=k_{top}}^{k=1} A_k$$

C_{tot} is used to normalize the cloud amount in the cloudy portion of the atmospheric column and then the normalized cloud amount is used to scale the optical depth for the cloudy sky radiation calculations.

The MRF radiation scheme parameterizes the effective radius, r_e, over land using the linear relation, where T_c = layer cloud temperature °C. The effective radius increases as the layer mean temperature decreases, varying from 5 μm at 0°C to 10 μm at -20°C. The MRF assumes that the condensate is water if T > 0°C, and ice if T < -20°C, with mixed phase μ-physics in-between.

Synoptic Patterns

December 12-13, 2001

The period was characterized by a nondescript (weak) surface pressure gradient and a broad region of near saturated low-level conditions across Oklahoma, Northwest Texas, and Kansas (surface dew points are close to near 70°F along the Texas coast, Figure 1). 700 hPa charts (below) indicate an upper level low over New Mexico with southwest flow over the ARM SGP until the trough axis slides east of area. The low-level stratus dissipate as the 700 hPa through axis passes east of the ARM SGP.

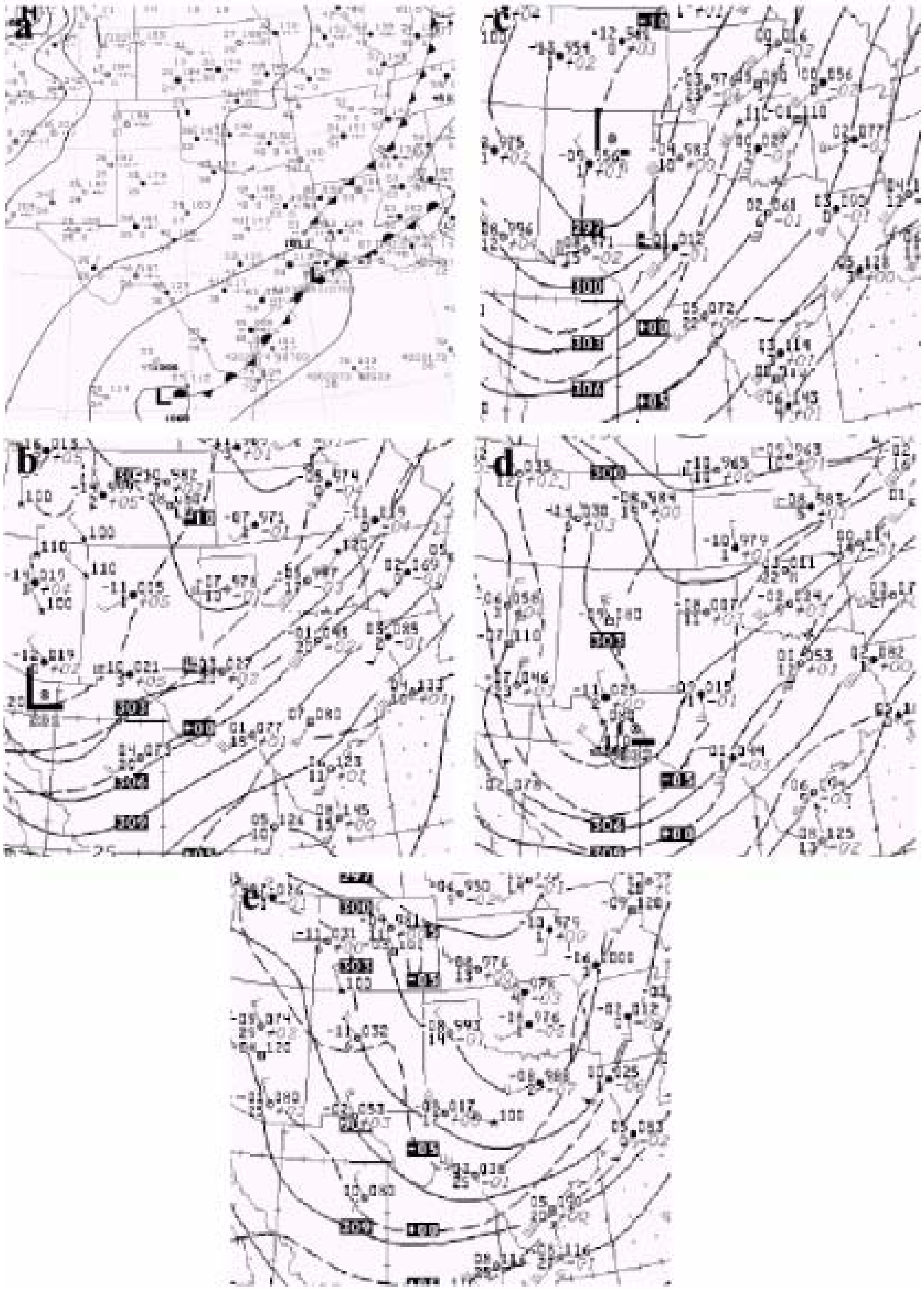

Figure 1. Sea-level pressure analysis 12 GMT December 13 (a), 700 hPa analyses for: 12 GMT December 12 (b), 00 GMT December 13 (c), 12 GMT December 13 (d), and 00 GMT December 14 (e).

December 16-17, 2001

The period was characterized by a more significant surface pressure gradient, a broad region of southerly flow off the western GOM, near saturated low-level conditions across Oklahoma, all of Texas and Kansas with surface dew points in excess of 70°F along the Texas coast, and a well-defined surface warm front over Central Texas (Figure 2). 700 hPa charts (below) indicate an upper level low over Arizona with southwest flow over the ARM CART until the trough axis slides east of area. Similar to the 12-13 stratus case, the passage of the upper level system brings about the end of the low-level stratiform clouds for the period.

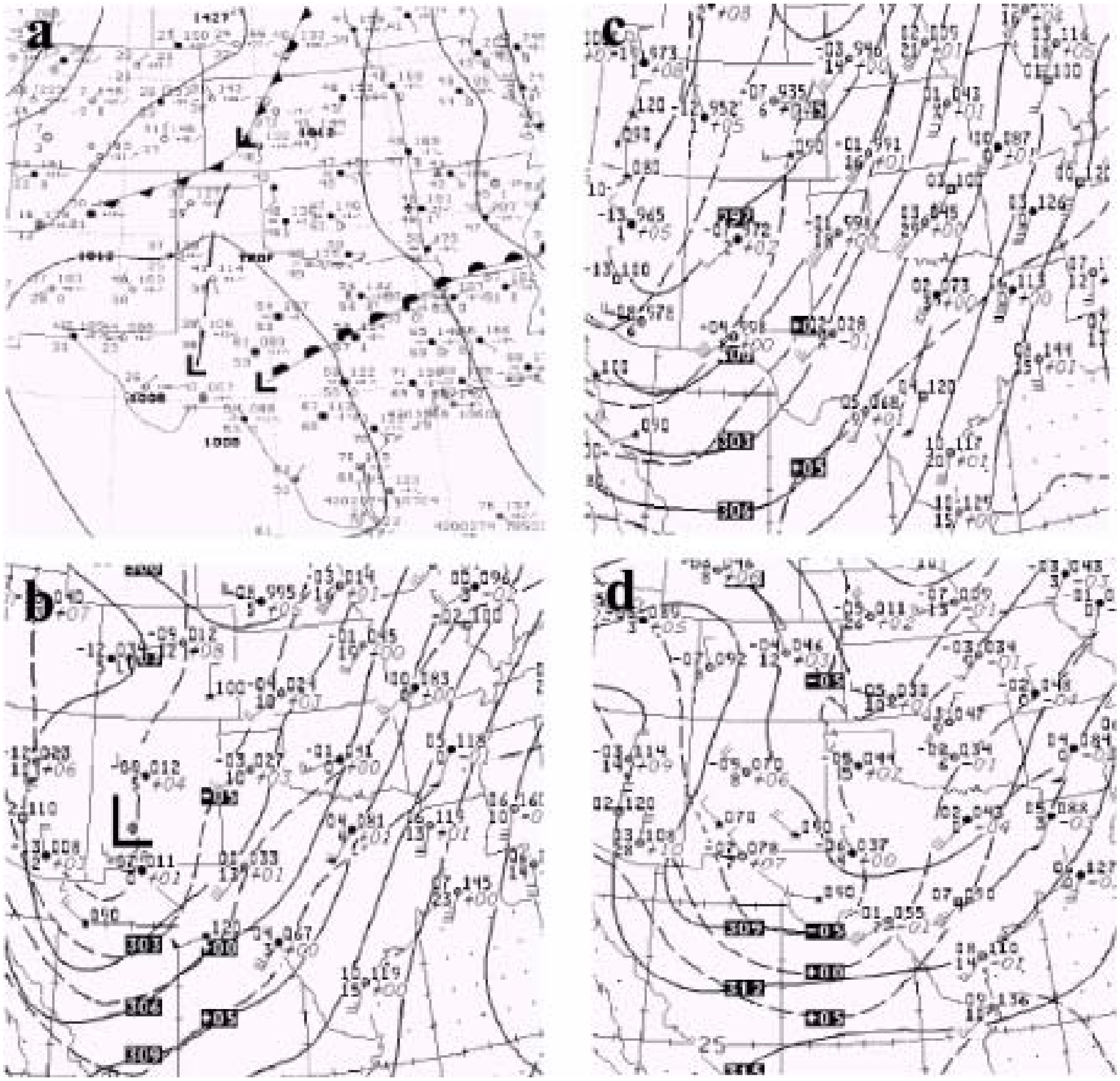

Figure 2. Same as in Figure 1 but for December 16-17, 2001 at: 06 GMT December 16 (a), 00 GMT December 16 (b), 12 GMT December 16 (c), and 00 GMT December 17 (d).

Discussion

Two significant stratiform cloud events occurred within a week of one another in December 2001 in addition to four "other" events of lesser extent during the month. By identifying stratiform cloud events over the ARM SGP CART, we ultimately hope to better understand how the MRF subgrid-scale cloud fraction and cloud properties for low-level stratus impact the model radiation. Albeit two ostensibly similar events, model performance (especially subgrid-scale cloud fraction) varies considerably - and despite our attempt to isolate cases where one might anticipate some success on the part of the MRF, the December 12 - 13 event generally under-predicts low-level cloud amount (i.e., below 2 km. Figure 3), and over-predicts mid-level cloud amount (2-4 km). In part, this may be due to insufficient model resolution (note that the vertical distribution tends to be smoother than observed). We intend to examine whether subgrid stratiform cloud fraction estimates have improved since the MRF vertical resolution has increased (from 42 to 64 levels on November 1, 2002).

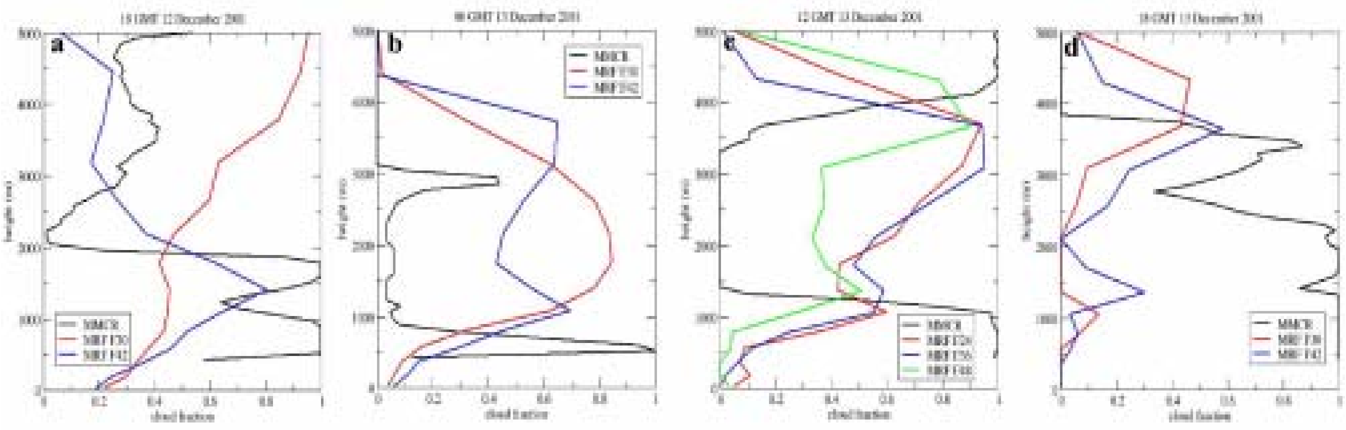

Figure 3. MRF cloud fraction profiles (red, blue, green) for a sequence of forecast cycles for December 12-13, 2001, including 18 GMT December 12 (a), 06 GMT December 13 (b), 12 GMT December 13 (c), and 18 GMT December 13 (d). The mmcr (observed cloud fraction) is given by the solid black line.

Because the large-scale RH and the prognostic cloud water/ice are inputs to the Xu-Randall cloud fraction parameterization, we focus on each herein. When compared against ARM soundings, the MRF often fails to capture the inversion layer (in the December 12-13 case, Figure 4), or when it does – it does not resolve the vertical gradient, magnitude or depth. For both events (December 16-17 not shown), the MRF under-predicts the RH throughout the lower troposphere (i.e., below ~750 hPa), and often overestimates the RH in the mid-troposphere (750-600 hPa) – especially for those cases where the model does not capture the inversion. Model performance, for forecast hours 24-48, does not necessarily improve as the forecast hour decreases.

When compared to the mmcr (i.e., apply the ROL assumption to the mmcr cloud fraction profile), the MRF tends to under-predict the effective cloud amount (C_{tot}, values in blue denote MRF forecast time in Table 1) for the December 12-13 event, while for December 16-17 event it is in good agreement. However, despite the good agreement for the December 16-17 effective cloud amount, it is obvious that the vertical distribution of clouds for the mmcr and MRF differ (Figure 5). In particular in the midlevels

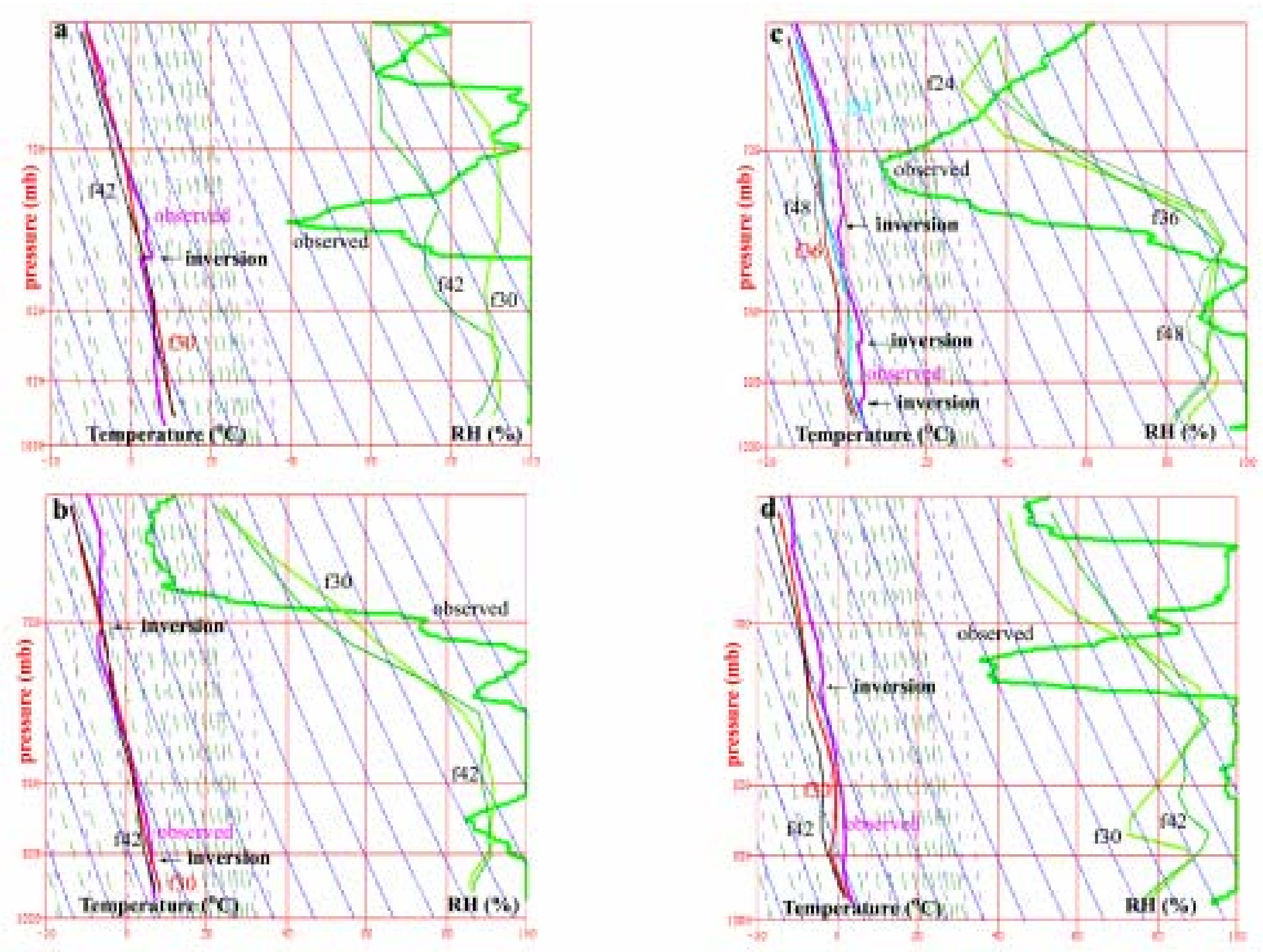

Figure 4. Observed (temperature purple, RH thick green) and model (MRF) soundings for December 12-13, 2001. Model soundings are for consecutive forecast cycles (12 h cycle). CF sounding 1729 GMT December 12 and model forecasts valid at 18 GMT (a), CF sounding 0530 GMT December 13 and model forecasts valid at 06 GMT (b), CF sounding 1128 GMT December 13 and model forecasts valid at 12 GMT (c), and CF sounding 1730 December 13 and model forecasts valid at 18 GMT (d).

(above ~3km) where the MRF is slow to produce the midlevel cloud deck observed by the mmcr (the mmcr observes the midlevel cloud deck from 00 GMT December 16 to 00 GMT December 17, while the MRF does not produce comparable subgrid-scale clouds until 00 GMT December 17).

When compared to the retrieved liquid water content profile (Dong et al. 1998) averaged over 1 h windows centered on the MRF forecast time, the MRF profiles appear to be biased low; however, the error bars associated with the retrieved LWC often include the MRF values (Figure 6).

We also compare model predicted effective radii profiles with those retrieved by Dong et al. (1998) and Frisch (1995). Here too we tend to see model forecast values less than their “retrieved” counterparts with some of the forecast values within the error bars of the retrieved values (Figure 7).

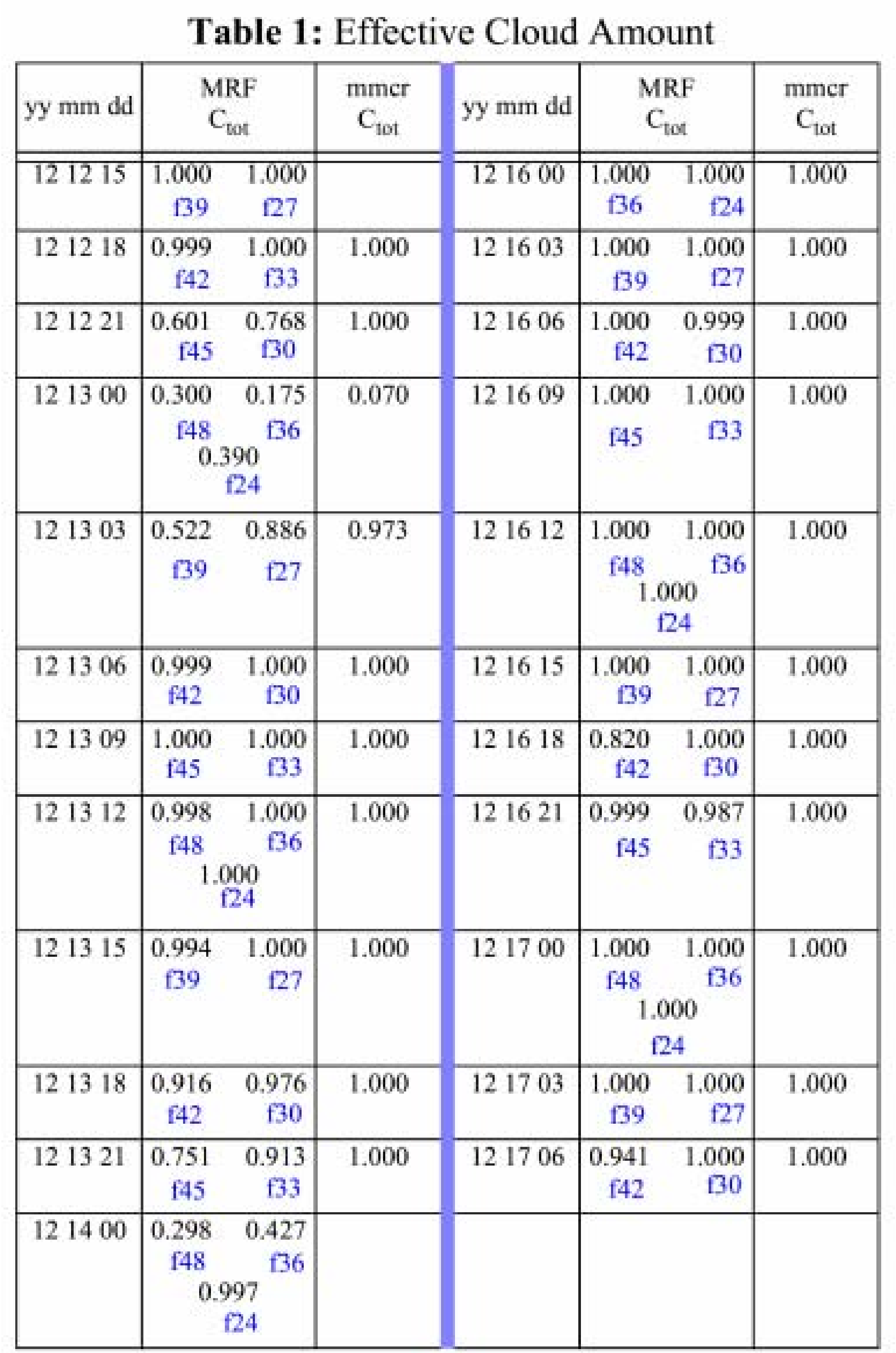

Table 1: Effective Cloud Amount

yy mm dd	MRF C_{tot}	mmcr C_{tot}	yy mm dd	MRF C_{tot}	mmcr C_{tot}
12 12 15	1.000 1.000 f39 f27		12 16 00	1.000 1.000 f36 f24	1.000
12 12 18	0.999 1.000 f42 f33	1.000	12 16 03	1.000 1.000 f39 f27	1.000
12 12 21	0.601 0.768 f45 f30	1.000	12 16 06	1.000 0.999 f42 f30	1.000
12 13 00	0.300 0.175 f48 f36 0.390 f24	0.070	12 16 09	1.000 1.000 f45 f33	1.000
12 13 03	0.522 0.886 f39 f27	0.973	12 16 12	1.000 1.000 f48 f36 1.000 f24	1.000
12 13 06	0.999 1.000 f42 f30	1.000	12 16 15	1.000 1.000 f39 f27	1.000
12 13 09	1.000 1.000 f45 f33	1.000	12 16 18	0.820 1.000 f42 f30	1.000
12 13 12	0.998 1.000 f48 f36 1.000 f24	1.000	12 16 21	0.999 0.987 f45 f33	1.000
12 13 15	0.994 1.000 f39 f27	1.000	12 17 00	1.000 1.000 f48 f36 1.000 f24	1.000
12 13 18	0.916 0.976 f42 f30	1.000	12 17 03	1.000 1.000 f39 f27	1.000
12 13 21	0.751 0.913 f45 f33	1.000	12 17 06	0.941 1.000 f42 f30	1.000
12 14 00	0.298 0.427 f48 f36 0.997 f24				

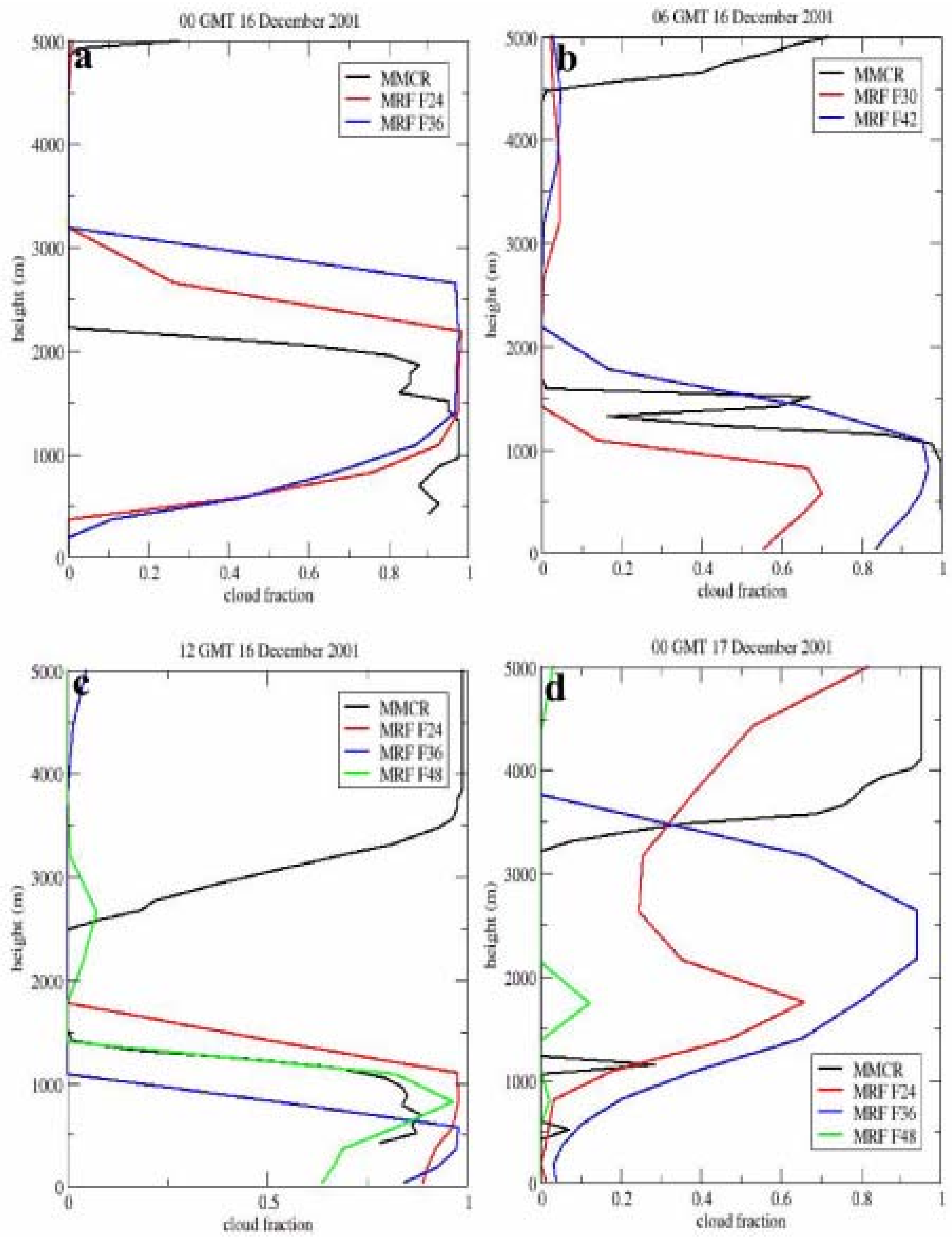

Figure 5. Same as in Figure 2 but for December 16-17, 2001 and 00 GMT December 16 (a), 06 GMT December 16 (b), 12 GMT December 16 (c), and 00 GMT December 17 (d).

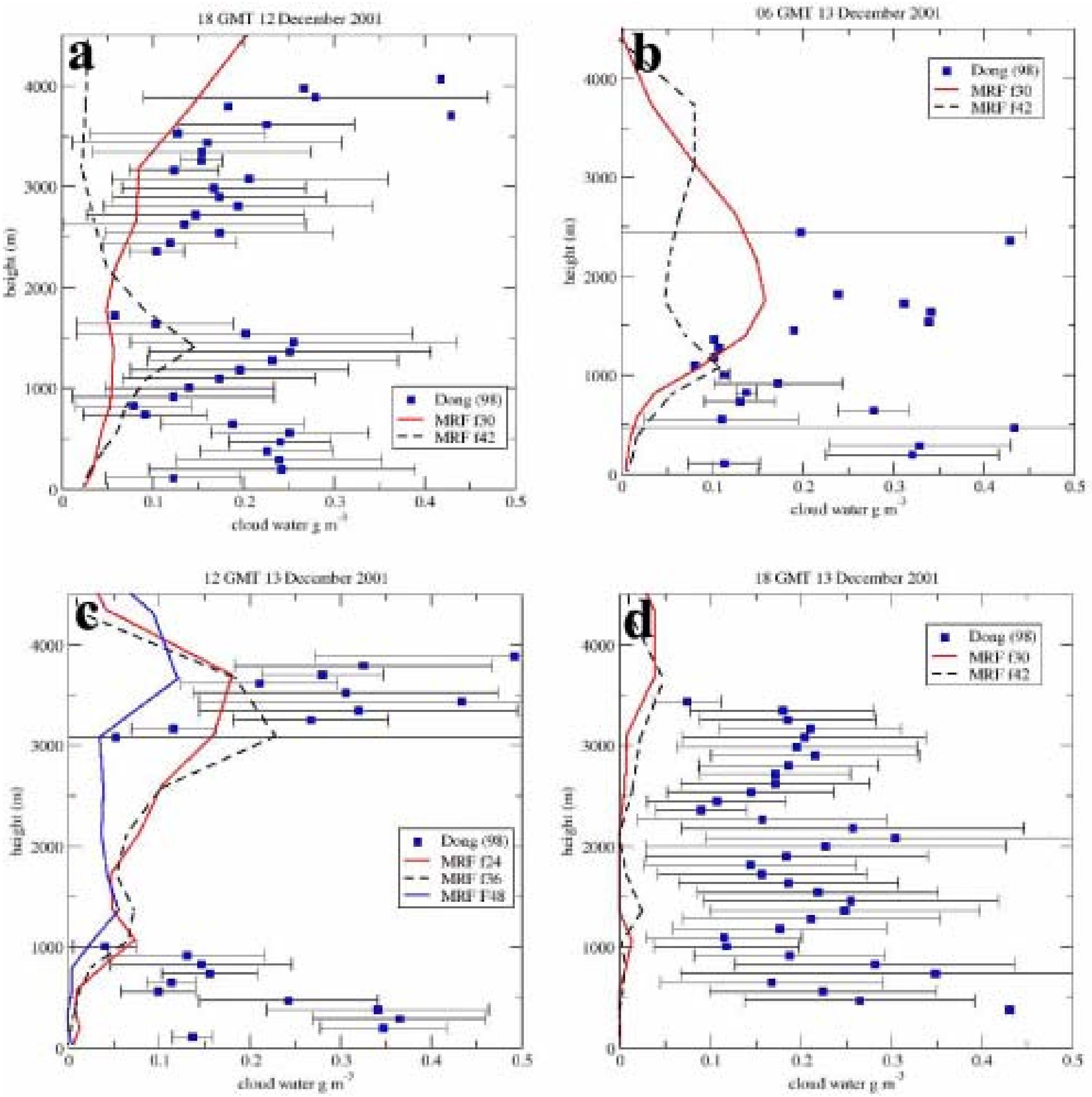

Figure 6. MRF liquid water content (blue/red, g m^{-3}) versus that retrieved by Dong et al. (1998, blue squares) for December 12-13 2001 at 18 GMT December 12 (a), 06 GMT December 13 (b), 12 GMT December 13 (c), and 18 GMT December 13 (d).

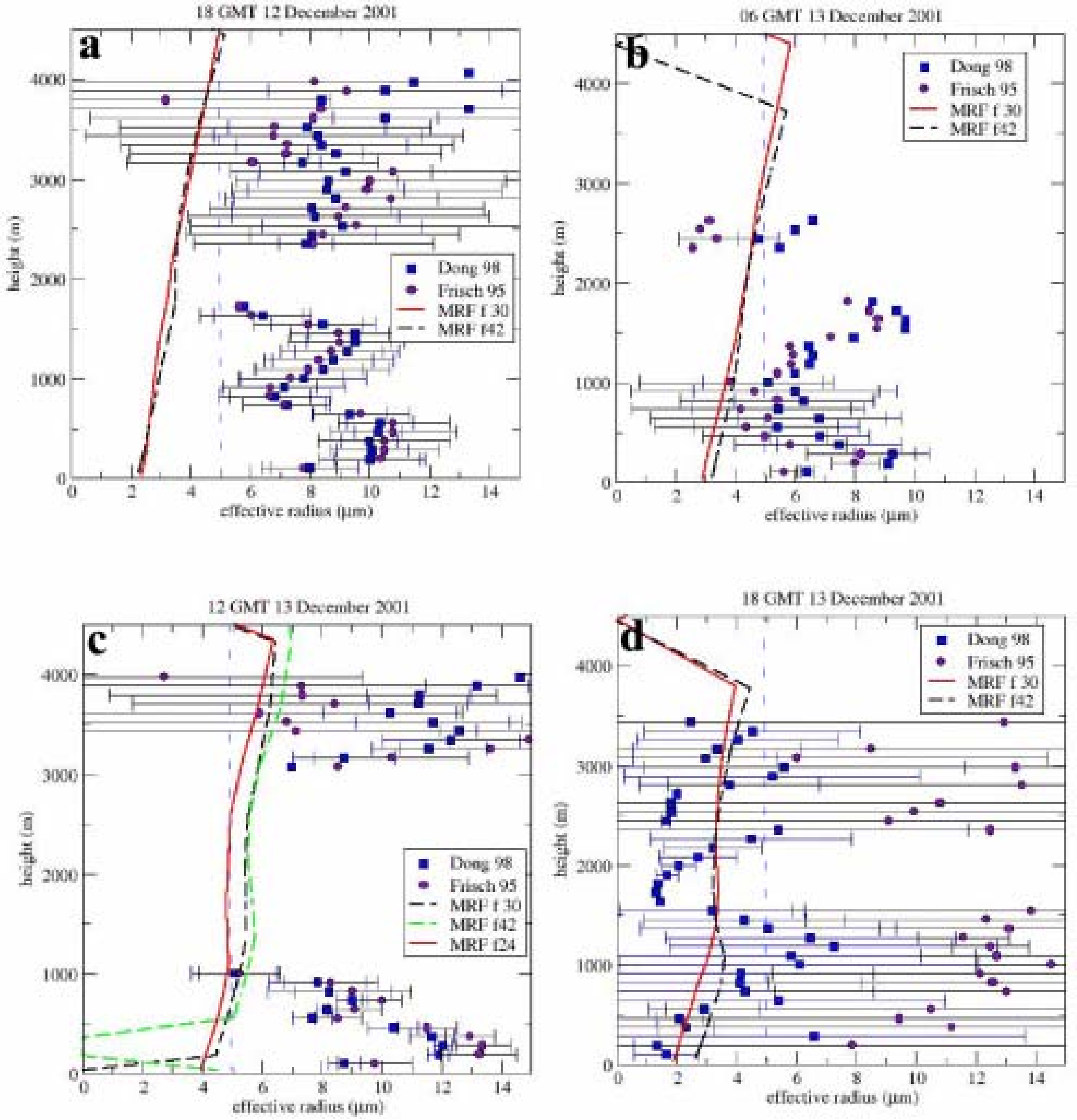

Figure 7. Retrieved effective radii, r_e (Dong et al. 1998, blue squares, Frisch 1995, purple circles) and forecast (30 h and 42 h). Blue dashed line denotes T = 0°C/5µm radius for MRF.

Summary

Ultimately, we hope to extend the study to include many stratiform cloud events and to begin to evaluate the impact of both the cloud optical properties and cloud fraction on the radiative flux calculations. In order to perform the latter task, we intend to extract the MRF radiative scheme to run "offline" experiments.

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