RADIATION AND CLOUD PARAMETERIZATION AT THE NATIONAL METEOROLOGICAL CENTER

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1. INTRODUCTION

There are several operational numerical weather prediction models being used at the National Meteorological Center (NMC). A T80 global, spectral, medium-range forecast (MRF) model (Kanamitsu, 1989) is run twice-a-day (to 10 days at 00Z), and a regional, grid-point, short-range nested grid model (NGM) (Hoke et al., 1989) is run twice-a-day (to 2 days). An experimental regional (ETA) model (Mesinger, 1988; Janjic, 1990) is also being run daily.

Currently these models parameterize radiation and cloud processes differently. The global MRF and the regional ETA models use a radiation parameterization developed at GFDL by Fels and Schwarzkopf (1975, 1991), while the regional NGM uses one developed by Harshvardhan et al. (1987). The cloud parameterizations are diagnostic schemes based on the work of Slingo (1987); and, while the MRF model employs both stratiform and convection cloud-types (Campana and Caplan, 1989), the NGM diagnoses only the stratiform type (Tuccillo, 1988).

We plan to unify the radiation and cloud parameterizations in future NMC operational models as was done with the experimental ETA model radiation. This paper will focus on the MRF model's parameterizations, since they are becoming NMC standards. The next section discusses recent changes to the MRF longwave radiation scheme. Section 3 describes adjustments to the MRF cloud parameterization in order to diagnose marine stratus. The final section discusses NMC's planned use of cloud databases to objectively tune its cloud parameterization. Since a number of people are responsible for work described in each section, their names will be acknowledged in each section title.

2. RADIATION PARAMETERIZATION

(S. Fels, D. Schwarzkopf, GFDL; K. Campana, B. Katz, NMC)

The radiation parameterization used in the MRF model has been developed at GFDL (Table 1), and during many years of cooperative effort, it has evolved to its current state. The shortwave (SW) scheme has changed very little over the years; however, recent activity at GFDL will provide NMC with both improved treatment of clouds and added accuracy (increase in the number of spectral intervals) in a future parameterization (D. Schwarzkopf, personal communication). The longwave (LW) parameterization has undergone a number of changes over the years, many of which have emanated from Fels and Schwarzkopf's participation in the Intercomparison of Radiation Codes in Climate Models (ICRCCM).

In the MRF model, radiation calculations are made twice per model-day. The SW processes are calculated using a latitude daylight-mean cosine solar zenith angle, and the diurnal cycle is approximated by a cosine zenith angle weighting at each model computation-point, at each model time-step (Documentation, 1988). The infrequent radiation calculations were made originally in order to save computational time, but work at NMC (Katz) and GFDL (Schwarzkopf) have made the code quite efficient (time of 10^{-3} sec per 18-layer column on the Cyber 205). It is anticipated that more frequent radiation calculations will become operational by Spring 1991.

A new MRF LW parameterization (Schwarzkopf and Fels, 1991), developed at GFDL using recent laboratory data and ICRCCM intercomparisons, became operational in the global model during February 1990. In brief, Schwarzkopf and Fels treat the H_2O lines more accurately, by reducing widths of the spectral bands, extend the effects of the water vapor

Table 1

(GFDL) Radiation Parameterization in NMC's MRF Model

Longwave	
H_2O	- 'Exact' approach for CTS term.
	- Emissivity approach for exchange term (Fels and Schwarzkopf, 1975; Schwarzkopf and Fels, 1990).
H_2O continuum	- Roberts etal 1976.
CO_2	- precalculated transmission functions, table look-up with 2nd order correction in temperature (Schwarzkopf and Fels, 1985).
O_3	- one interval random band model (Rodgers, 1968).
CLOUDS	- random overlap.
	emissivity= 1., 1., .3-.6 for L, M, H cloud.
Shortwave	
H_2O	- 9 spectral intervals (Lacis and Hansen, 1974).
CO_2	- Sasamori etal (1972).
O_3	- Lacis and Hansen, 1974.
CLOUDS	- random overlap.
	- bulk reflectivity .69, .48, .21 for L, M, H cloud.
	- bulk absorptivity .035, .02, .005 for L, M, H cloud (not in O_3 band).
	- multiple reflections computed.
SFC ALBEDO	- background over land from Matthews, 1985.
	- zenith angle dependent over water (Payne, 1972).

continuum from 18μ to 25μ, and replace the previous 1-band H_2O/CO_2 overlap with 2 narrower bands. The clear-sky results are more accurate, relative to line-by-line (LBL) computations, than the older scheme (Fig. 1 from Schwarzkopf and Fels, 1991).

The impact of the new scheme on the radiative heating rates is to reduce LW cooling both in tropical/subtropical regions below 800 mb and, at all latitudes, in the middle and upper troposphere above 400 mb, while increasing LW cooling elsewhere. These differences are on the order of 10% of the LW heating rates, themselves, and are several tenths of deg K/day in zonal means (Fig. 2). Changes to top-of-the-atmosphere (TOA), outgoing, LW flux are small (1-2 W/m^2). Changes to downward LW surface flux are somewhat larger (5-10 W/m^2), where the new parameterization produces increased flux in clear-sky regions and decreased flux in low-cloud areas.

The largest impact on the MRF model forecasts is to the zonal mean atmosphere, primarily temperature (Campana, 1990). Differences in zonal mean temperatures (Fig. 3) are consistent with changes to the radiative heating rates. They result in slightly lower (1-2 m) 500 mb heights, which is an increase in model error, and slight increases in 200 mb heights, as well as warmer (.25° - .5°K in 5 days) lowest model layer temperatures over subtropical/tropical oceans, both of which are reductions in model error. Effects of the slight changes to the atmospheric stability implied in Fig. 3 are difficult to find in precipitation forecasts.

Synoptic forecasts using either LW parameterization are virtually identical out to 5 days. Hemispheric 500 mb height anomaly correlations between forecasts, rather than the normal forecast- verification correlation, show values of .99 at 5 days for a number of forecasts. Even at day 10 for one of the cases, the correlations are .97 and .96 in northern and southern hemispheres respectively. The small impact is insignificant relative to forecast skill at these time ranges.

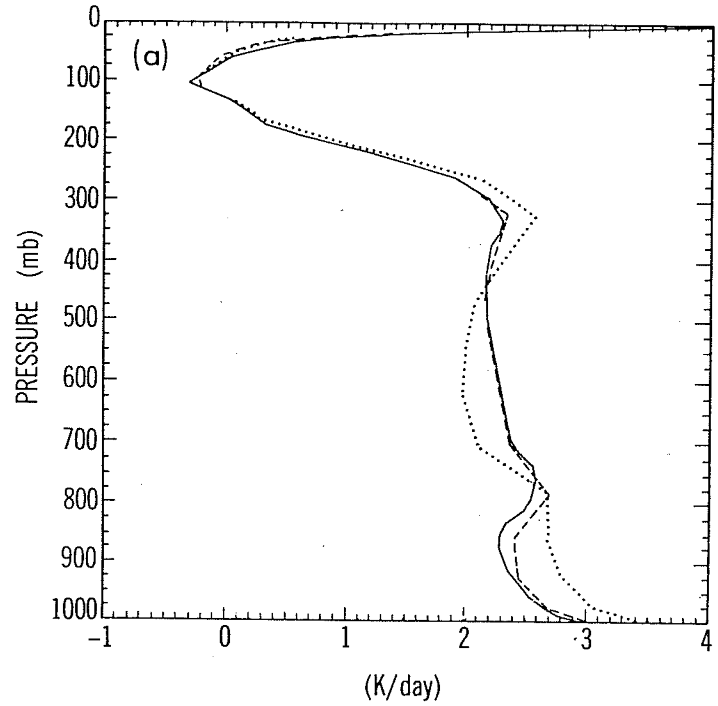

Fig. 1 Cooling rates (°K/day) for McClatchey tropical profile. Solid line is GFDL line-by-line, dotted is previously operational LW result, dashed is new LW result. (Courtesy D. Schwarzkopf from Schwarzkopf and Fels, 1991).

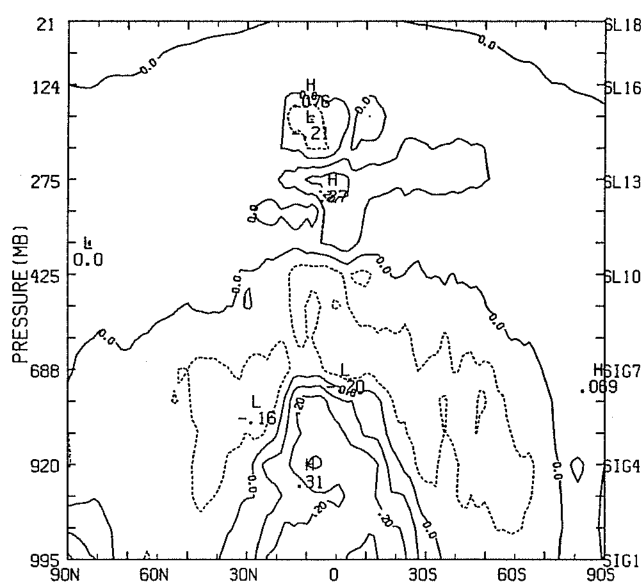

Fig. 2 Zonal mean LW heating rate differences (°K/day) (New-Old) GFDL scheme, in model sigma layers. 00Z 3 Nov 1989. Contour interval = 0.1 °K/day, negative values are dashed.

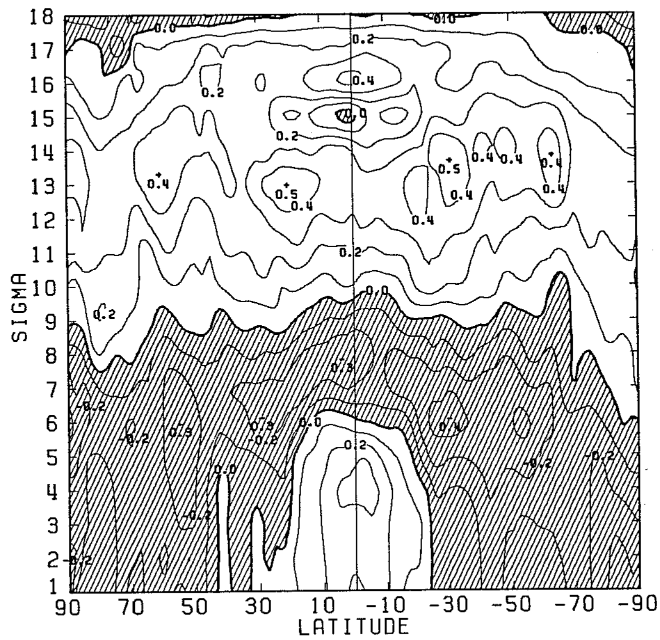

Fig. 3 Zonal mean temperature differences (°K) at forecast day-5 (New-Old) GFDL scheme, in model sigma layers. 00Z 3 Nov 1989. Contour interval = 0.1 °K, negative values are shaded.

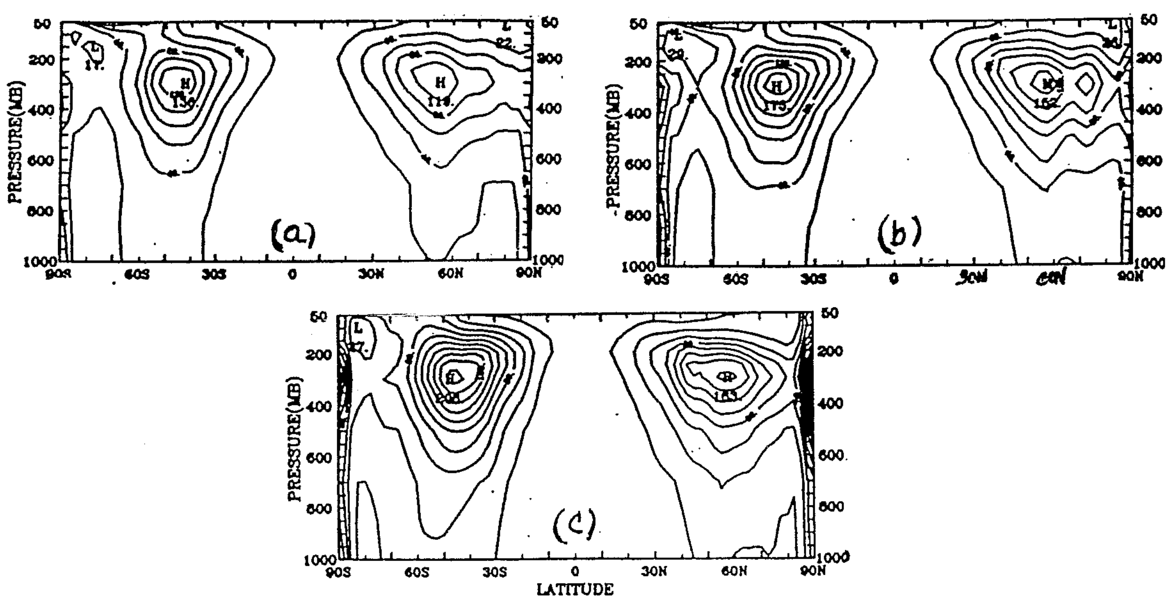

Fig. 4 Zonal mean transient eddy kinetic energy for 12 cases in Oct 1988.

a. MRF day-5 forecast with zonal mean cloud.

b. MRF day-5 forecast with model-diagnosed cloud.

c. Observed (valid at forecast verifying times).

3. CLOUD PARAMETERIZATION

(K. Campana, NMC, A. Kumar, A. Leetmaa, NMC-CAC)

Clouds exert a strong, often dominant, effect on radiation processes. Their horizontal variations create gradients of atmospheric radiative heating rates and surface fluxes which may influence forecasts of synoptic features. These cloud-generated gradients appear to assist maintenance of baroclinic wave strength via potential-to-kinetic engery conversion processes (Slingo and Ritter, 1985), which, in turn, result in better 5-day anomaly-correlation scores (Slingo, 1987). At NMC, incorporation of more realistic clouds, relative to zonal mean climatological clouds, has produced improved zonal mean transient eddy kinetic energy (Fig. 4, from G. White, NMC). Improvements to the 5-day forecast are found primarily in the zonal mean atmosphere, in surface and TOA radiative fluxes, and in the cloud field itself. Reduction in the model systematic error contributes to overall model improvement through better initial analyses from the global data assimilation system (Kalnay et al. 1990). Improvements to regional model forecasts due to changes in the cloud parameterization are also found in the near-surface sensible weather (K. Mitchell, personal communication).

Unification of all cloud-related processes through use of a liquid water model variable has begun (P. Caplan, NMC, personal communication), however, its implementation awaits further experimentation. Currently, model clouds are diagnosed from forecast variables in a manner similar to Slingo (1987), and they interact with the forecast model only through radiative effects on atmospheric temperature and surface fluxes.

Stratiform clouds (Fig. 5) are computed from model relative humidity (RH) and vertical motion, and may be one of three types (high, H, middle, M, low, L). Cloud fraction, C_k, is computed in all model layers, k, using Slingo's (1980) quadratic relation

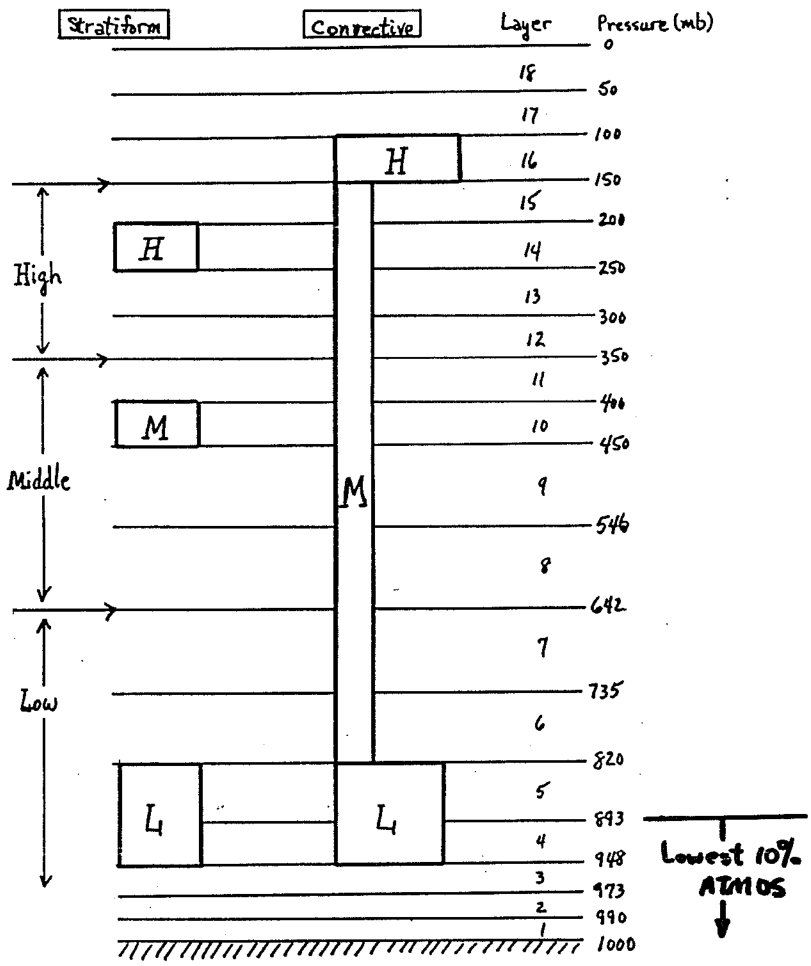

Fig. 5 Schematic representation of MRF model-diagnosed clouds (18 layer model). Model layer-interface pressures are for a surface pressure of 1000 mb.

$$C_k = 0 \qquad\qquad RH_k < RH_c$$

$$C_k = \left(\frac{RH_k - RH_c}{1 - RH_c}\right)^2 \qquad\qquad RH_k \geq RH_c \tag{1}$$

where the critical relative humidity, RH_c, is set to 0.8 for all cloud domains. Within each H, M, or L domain, the model-layer containing the maximum value of C_k is designated as the cloud top. Since radiative heating rates currently are held fixed for 12 hours, strong LW cloud-top cooling in thin model layers near the earth's surface can be deterimental to the forecast. Thus restrictions are imposed for low cloud-types, which reduce the magnitude of the LW cooling. The diagnosed cloud is required to be at least 90 mb thick and its top is placed above the lowest 10% of the atmosphere. In these multi-layer clouds, net LW flux within the cloud is forced to vary linearly between cloud top and bottom values; thus smoothing the heating rate profile within the cloud layers.

To offset a tendency to diagnose excessive low stratiform cloud, a cloud reduction factor based on vertical velocity is used. The factor varies between 0 and 1 as vertical velocity varies between .0005 mb/sec and -0.0005 mb/sec. Thus strong descent will cause dissipation of a model-diagnosed cloud. High stratiform cloud is not permitted in the top 3 model layers (approx. 150 mb) or above the model tropopause. The latter is estimated as the model-layer containing a first occurrence of $\partial\theta/\partial p$ < 0.25 deg/mb (θ is potential temperature, p is pressure).

Deep cumulus clouds are diagnosed identically to Slingo (1987), wherever the forecast convective precipitation rate, P, exceeds 0.14 mm/day. Convective coverage, CC, is obtained from Slingo's (1987) relation, CC = a + b ln P, where CC is allowed to vary between 0 and 0.8. In regions where both stratiform and convective clouds are diagnosed to co-exist, the convective type takes precedence. The cloud is modeled by vertically stacking 3 stratiform clouds - where a single layer of high cirrus (C_H = .25CC), supported by a multi-layer convective tower (C_M = .25CC), is sitting on low cumulus (C_L = .75CC). High cloud is not permitted in the upper 2 model layers. If the convection is deep enough (extending above 400 mb) and strong enough (P>1.6mm/day), C_H becomes an anvil and is recomputed using Slingo's linear relation in CC (here C_H can be as large as 1.0).

One of the known deficiencies of the present cloud parameterization is too little fractional coverage relative to observed data (Figs. 6, 7). Typical global mean total cloud fractions of 0.4 are significantly less than values of 0.5-0.6 in Nimbus 7 and ISCCP climatologies. The next section describes an objective technique which should alleviate this general underestimate of cloudiness. A second deficiency is lack of marine stratus off the west coasts of continents, in regions where it is expected climatologically. This has proved troublesome for extended coupled ocean-atmosphere model experiments. Differences between Oberhuber (1988) April climatology of net-SW surface flux and model monthly mean data for April 1989 (Fig. 8) show serious model overestimates off the North and South American coasts. A 'rule-of-thumb' is that a monthly mean anomaly of $\pm$ X W/m^2 in surface flux will result in a sea-surface temperature change of $\pm$ 1°K per month in a mixed ocean layer of X meters in depth (R. Reynolds, NMC-CAC, personal communication).

Since the present stratiform cloud parameterization does not search the lowest 10% of the atmosphere for clouds (see Fig. 5), it will miss the low-level marine stratus layer. However in regions that are climatologically favorable for marine stratus, the MRF model does show characteristics of these clouds in its lower atmosphere; that is, a well-mixed layer topped by dry subsiding air above a low-level inversion (Fig. 9). The inversion height rises in elevation away from the

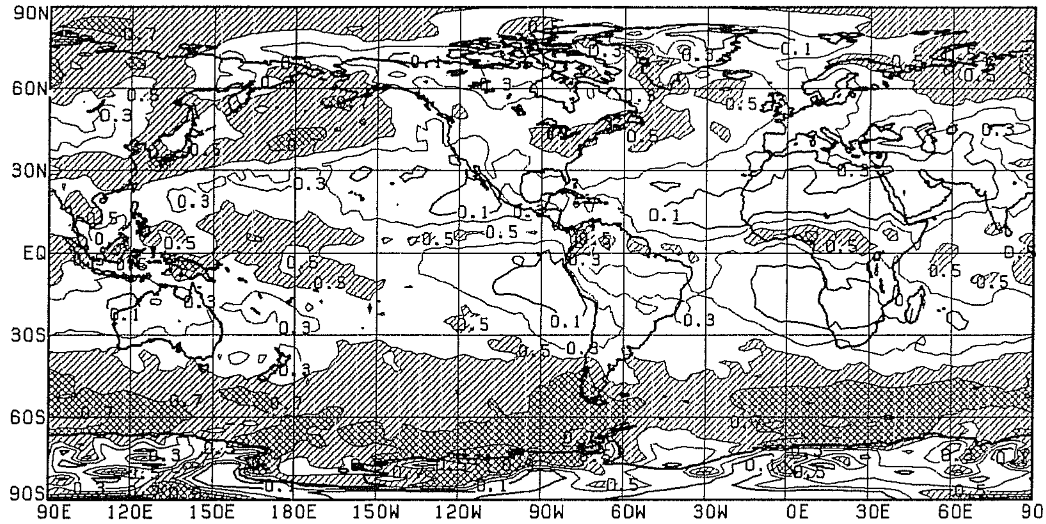

Fig. 6 Monthly mean total cloud fraction for May 1990, from 26 MRF model (12-36) hour forecasts. Total cloud obtained by randomly overlapping H, M, L cloud. Contour interval = 0.2, light shading for values greater than 0.5, dark shading for values greater than 0.7.

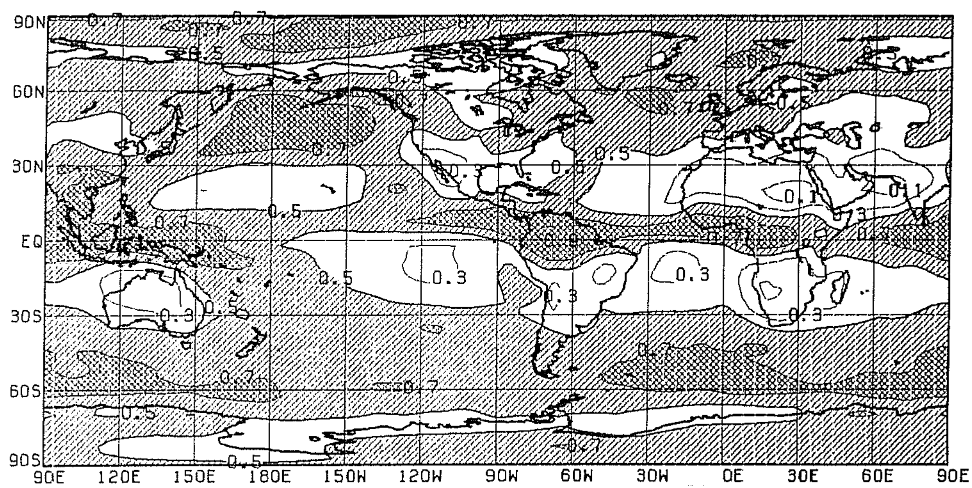

Fig. 7 Monthly mean total cloud fraction for May, from Nimbus 7. Yearly average of 1980-1984. Contours as in Fig. 6.

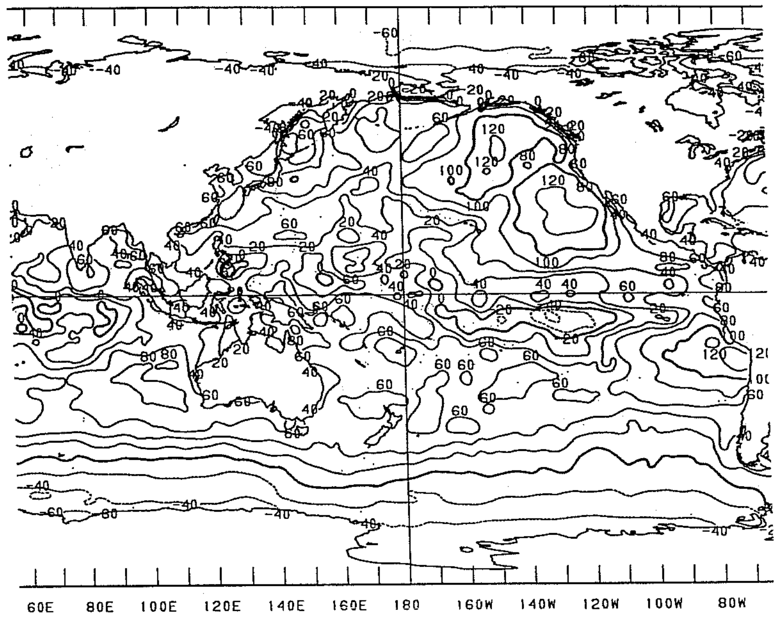

Fig. 8 Net shortwave surface radiative flux difference (W/m^2) for April 1989; (MRF forecast-Oberhuber climatology). MRF values from monthly mean of the (12-36) hour forecasts. Contour interval = 20 W/m^2. (courtesy R. Reynolds, NMC-CAC).

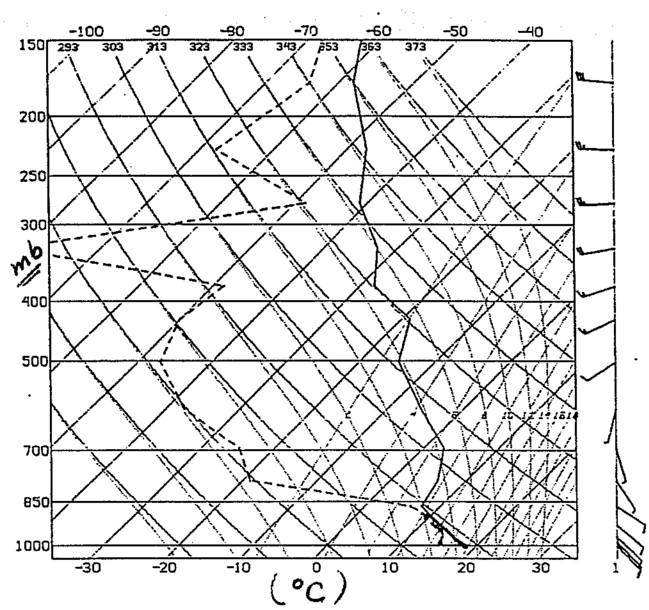

Fig. 9 Temperature-dewpoint sounding at (19.8 S, 88.9°W) at 24 hours for MRF forecast from 00Z 2 May 1989. (courtesy S. Esbensen, R. Reynolds).

coast, which is supported by climatology (Heck et. al., 1990). Fig. 10 shows $\partial\theta/\partial p$ computed between model layers for a forecast mean-atmosphere, and the largest values (hatched) are found in higher layers of the model atmosphere away from the coasts.

Beneath the model inversion there is ample moisture for the stratiform cloud calculation in Eqn 1. Below 850 mb, zonal mean relative humidity is generally greater than 70% and remains so during the forecast (Fig. 11). Higher values of relative humidity tend to be found in lower model layers under these inversion-capped regions than in other oceanic areas. Thus, it is possible to use the characteristics of marine stratus to determine likely regions for these clouds, and then use the operational cloud scheme to search for C_k, (Eqn 1) in the lowest 10% of the atmosphere (excluding the bottommost layer). That is, look for regions:

1. over the ocean, with
2. $\partial\theta/\partial p < (\partial\theta/\partial p)_{CRIT}$ in the lowest 10% of the atmosphere,
3. which are capped by dry layers above the inversion base ($RH < RH_c$). The value of $(\partial\theta/\partial p)_{CRIT}$=-0.05 °K/mb, has been obtained by inspecting mean model-layer data in T40 and T80 experiments. Attempts to use instantaneous vertical velocity to define regions of subsidence above the low-level inversion were unsuccessful, as both upward and downward motions were found.

There are two other aspects of the marine stratus formulation to be noted. The use of a vertical velocity filter for the low cloud makes an assumption that the clouds are frontal in nature. Since this is not the case here, the filter is removed for marine stratus calculations. Also, the cloud scheme does not guarantee that the layer of maximum C_k will occur at the inversion base; therefore, these low-level clouds are thickened upward through the lowest 10% of the model atmosphere in adjacent model layers where $C_k > 0$.

A comparison of low-cloud fraction for a 12-day T80 MRF model

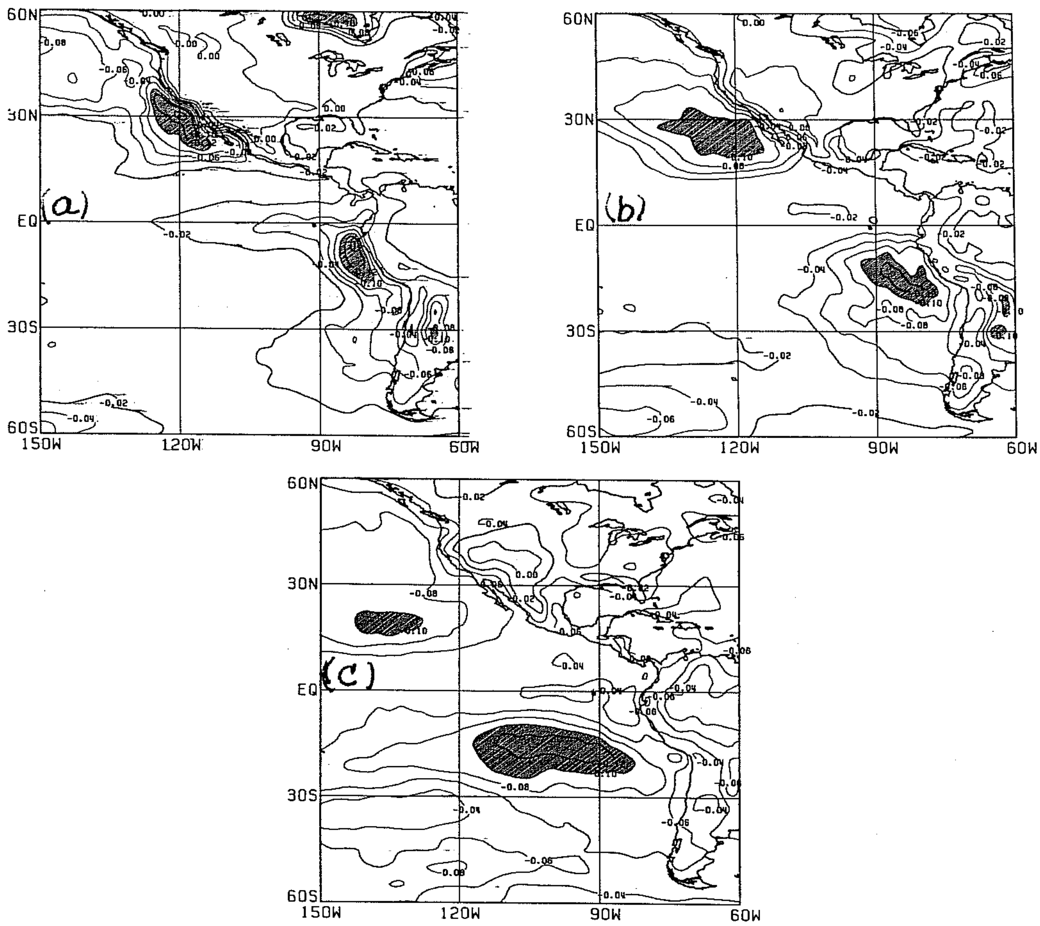

Fig. 10 Lapse rate ($^{\partial\theta}/_{\partial p}$) between model layers for a 12-day, T80, forecast mean-atmosphere (00Z, 10 June 1990). Units are °K/mb, contour interval = 0.02 (shading for values less than -0.1) a. layers 3,4 b. layers 4,5 c. layers 5,6

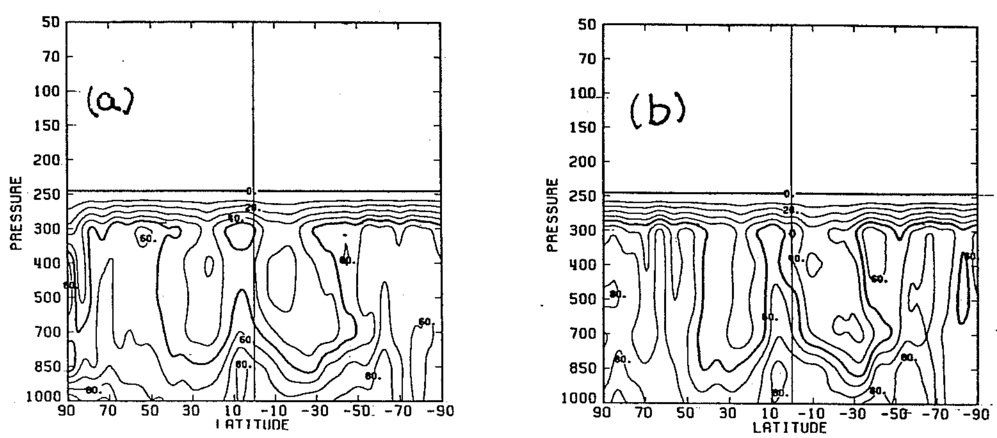

Fig. 11 Zonal mean relative humidity in pressure (up to 300 mb) from T80 operational model. Contour interval = 10%.

a. 1 day forecast

b. 12 day forecast, 00Z 10 June 1990.

forecast using either the operational (Fig. 12a) or the new cloud parameterization (Fig. 12b), shows that the latter depicts marine stratus in climatologically expected regions (Heck et al., 1990). Zonal mean cross-sections of cloud fraction (Fig. 13) show the similarity of the two schemes, except in latitudes where marine stratus has formed (20°-40° latitude). Larger values of tropical high cloud in the new marine stratus test are related to a slight increase in convection. Comparison of zonal mean total cloud for the two experiments (a mean of all forecast days) with Nimbus-7 June climatology shows the marine stratus test to be closer to climatology (Fig. 14).

There is a corresponding decrease in downward SW surface flux in the marine stratus regions, of order 30-40 W/m^2 in the zonal mean. On a regional scale the decrease is greater than 100 W/m^2 (Fig. 15), which is of the same order as the positive anomaly shown in Fig. 8. Improvements to the net surface fluxes are evident in a 3½ month coupled ocean-atmosphere experiment. Figure 16 shows weekly averaged data, estimated four independent ways, for a region in the tropical Pacific Ocean. This region lies on the southern boundary of the model's persistent marine stratus in the northeast Pacific Ocean. The data from the ocean analysis model is a residual flux, computed for the case of an unchanging sea surface temperature (SST) after considering all below-surface oceanic flux. This residual, by implication, provides a reasonable estimate of the "observed" surface flux. The data from the coupled experiment using the new marine stratus formulation is quite similar to this residual. The large differences between the uncoupled atmospheric model estimates (the topmost line in Fig. 16) and the three others reflect both a lack of marine stratus and an incomplete spin-up of the hydrological cycle in the 12-36 hour forecasts. The use of more realistic cloud in the atmospheric model contributes to the success of the 3½ month SST forecast, where errors are generally less than 1°K over large areas of the tropical Pacific.

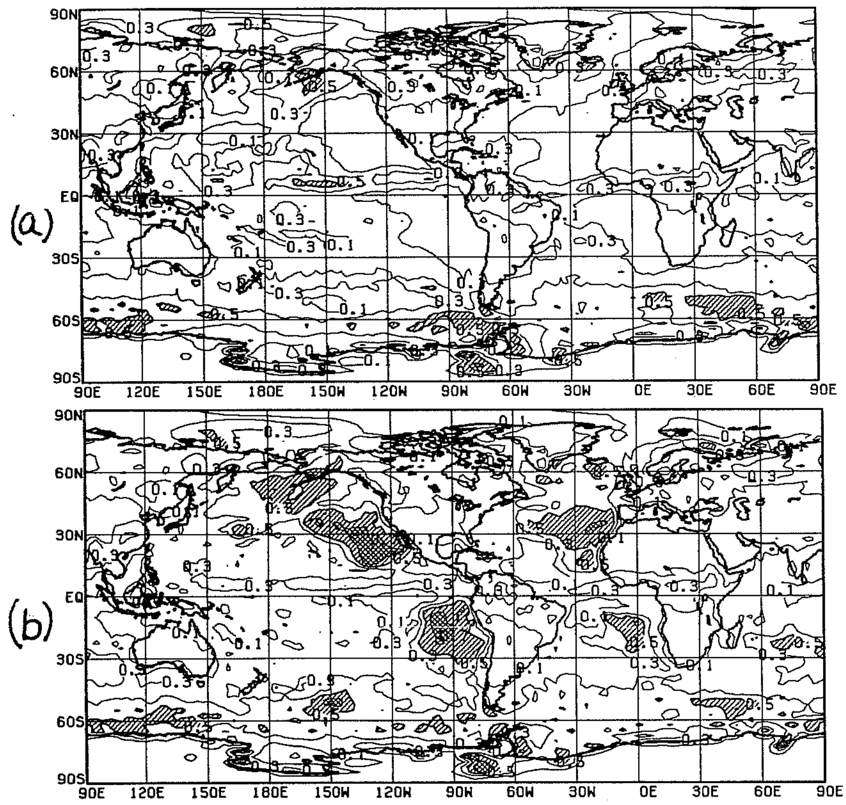

Fig. 12 Mean low cloud fraction averaged over a 12-day T80 model forecast for 00Z 10 June 1990.

a. operational cloud scheme.

b. new (marine stratus) cloud scheme.

Contour interval = 0.2, shading ≥ 0.5, dark shading ≥ 0.7.

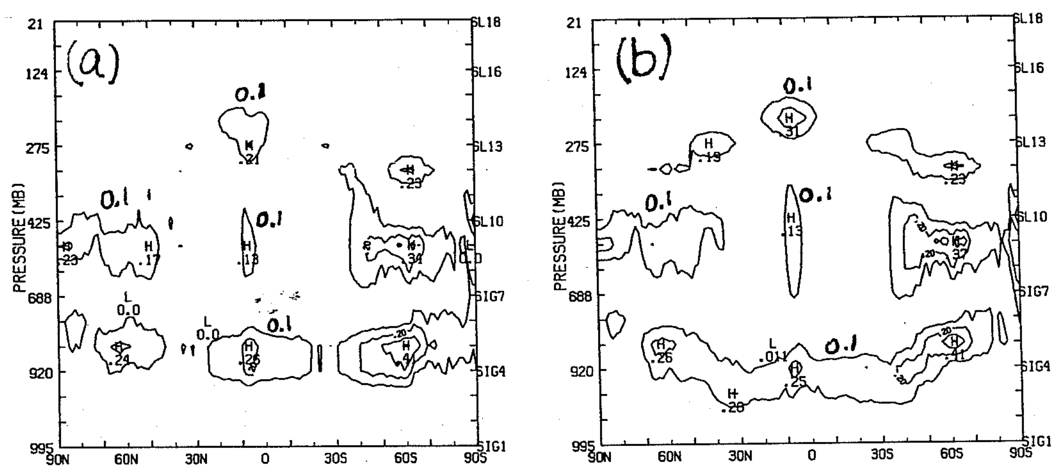

Fig. 13 Zonal mean cloud fraction in model sigma layers (pressures are layer values for surface pressure = 1000 mb). 12-day mean for 00Z, 10 June 1990, T80 forecast. (contour interval = 0.1)

a. operational cloud scheme.

b. new (marine stratus) cloud scheme.

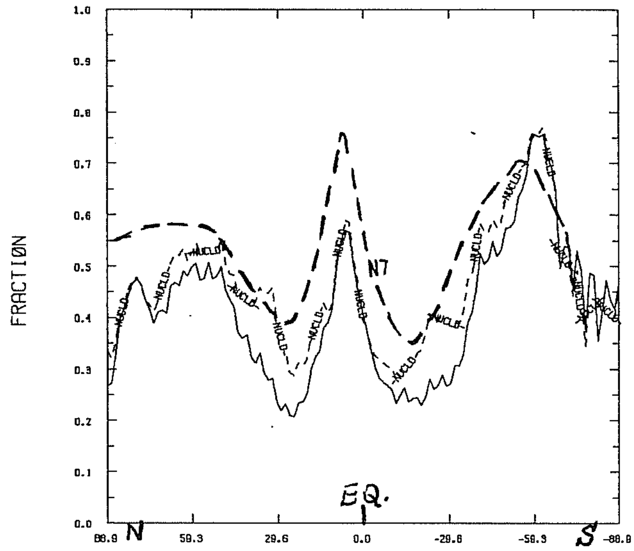

Fig. 14 Zonal mean total cloud fraction for T80 model 12-day mean: operational (solid); new, marine stratus (short dashes); Nimbus 7 June (1979-1984) climatology (long dashes). Model total cloud obtained by randomly overlapping cloud-types.

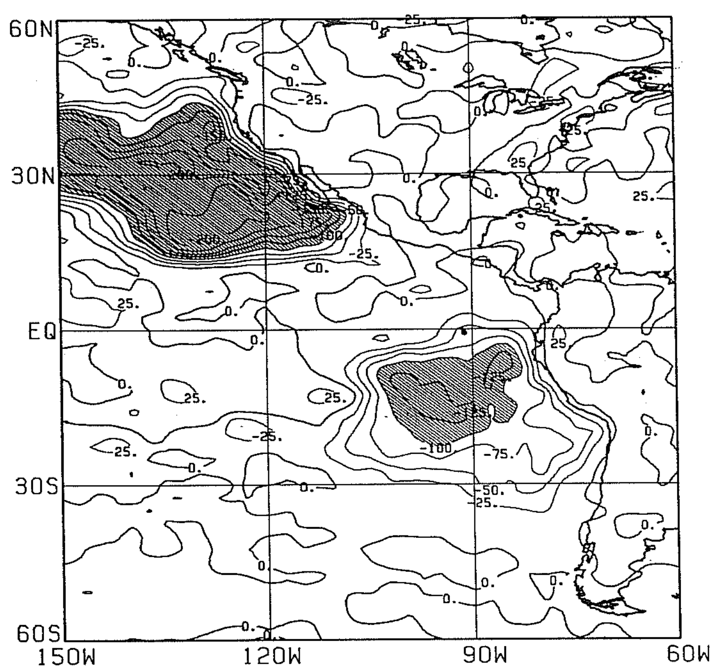

Fig. 15 Downward shortwave surface radiative flux difference (W/m^2) for 12-day mean T80 forecast from 00Z 10 June 1990. (New-Old) cloud test. Contour interval = 25 W/m^2, shaded areas are less than -100 W/m^2.

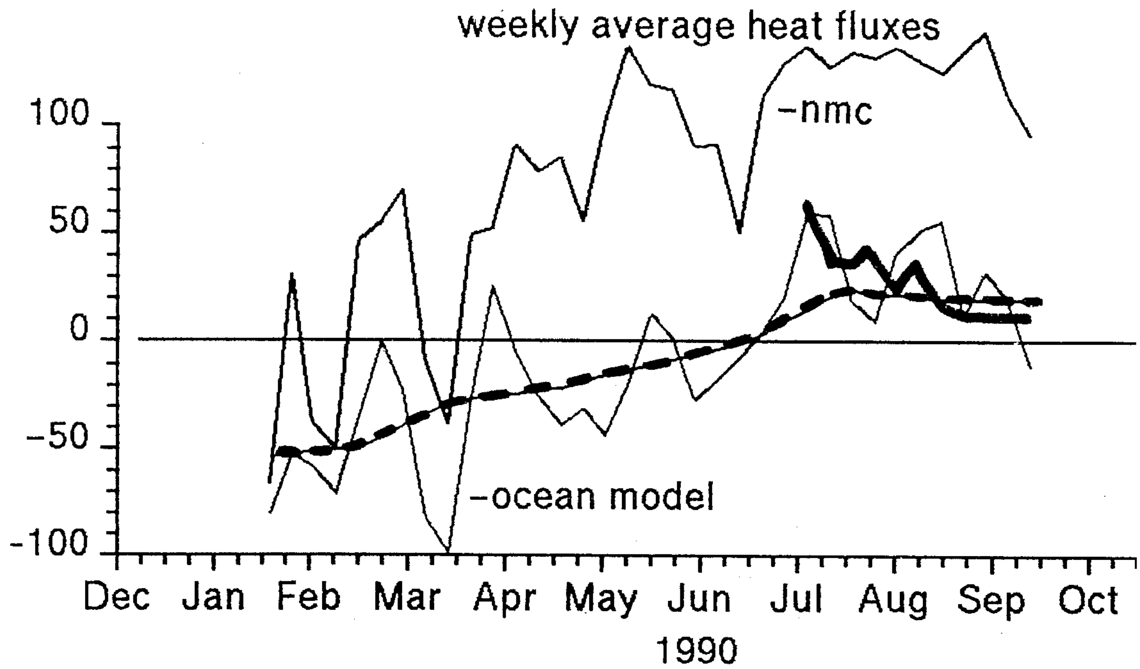

Fig. 16 Weekly-averaged net heat flux (W/m^2) at oceanic surface for region in Pacific Ocean bounded by 10°N, 20°N, 150°W, 110°W. Topmost curve is from 12-36 hour forecasts of NMC's operational global model. The solid-dashed curve is from Oberhuber's (1988) climatology. The light solid curve is from the estimates using NMC/CAC's ocean analysis system. The short heavy curve for July-September is from NMC's coupled ocean-atmosphere model experiment.

There is also a tendency for the atmospheric temperature profiles to show sharper inversions in marine stratus regions for the new cloud test (Fig. 17). This is a result of persistent LW radiative cloud-top cooling. However, there does not to appear to be a general lowering of the inversion level with time.

The impact of incorporating marine stratus into the MRF model is minimal in the synoptic forecast. Anomaly correlations between the two forecasts at 500 mb are quite high (.99 at day 7; .90 at day 12) and systematic effects on precipitation are difficult to find. This is not unexpected since the new clouds are confined to ocean regions where surface temperatures are held fixed. There are however larger surface sensible and latent heat fluxes (Fig. 18) in the marine stratus regions, where air-sea temperature differences have increased (the dashed lines in Fig. 17 show a colder lower atmosphere).

The marine stratus changes to the cloud parameterization are made within the context of the current operational scheme. They will be part of a set of MRF model updates that are planned for Winter 1990/91. In essence, a 4^{th} stratiform cloud-type has been defined. In the future, the techniques that are used to depict this type of boundary layer cloud could be extended to include parameterization of other shallow clouds whose characteristics might be observed in forecast model data - e.g. shallow cumulus activity associated with large sensible heating into cold air outbreaks over warm water.

4. CLOUD DATABASES

(K. Campana, K. Mitchell, NMC; S.K. Yang NMC-CAC)

The underestimate of the present MRF model-diagnosed cloud, noted earlier (Figs. 6, 7, 14), is directly related to a lack of fine-tuning of the parameterization. The cloud algorithm uses a number of tuneable parameters (e.g. RH_c, vertical

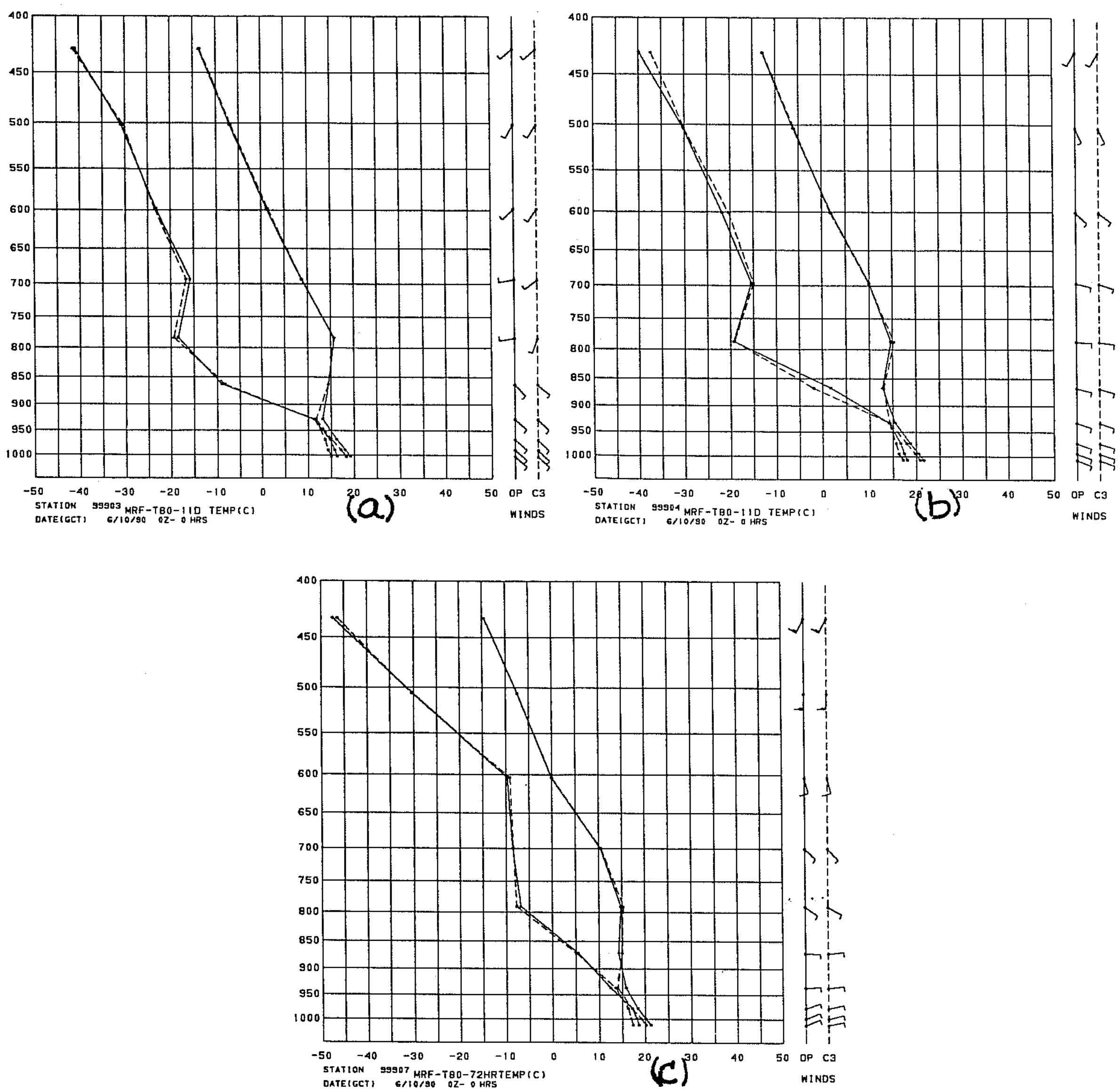

Fig. 17 Temperature-dewpoint soundings for 12-day mean atmosphere for T80 forecasts from 00Z 10 June 1990. Operational (solid) and new cloud scheme (dashed). a. (15°S, 90°W), b. (15°S, 100°W), c. (20°N, 130°W)

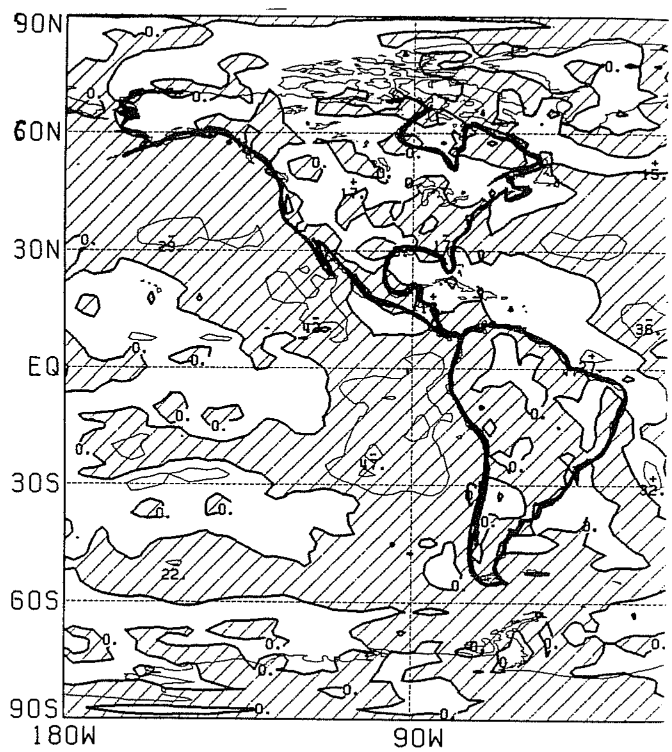

Fig. 18 Mean (12-day) surface latent heat flux difference (W/m^2); (New-Old) cloud tests for 00Z 10 June 1990. Shaded areas for increased flux. Contour interval = 25 W/m^2.

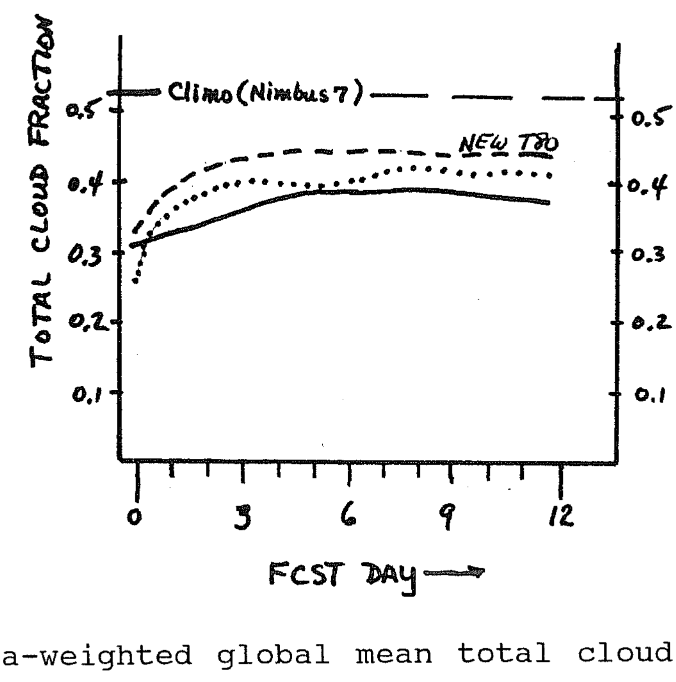

Fig. 19 Area-weighted global mean total cloud fraction as a function of model forecast-hour. Operational T80 (solid), operational T40 (dotted), new cloud T80 (dashed).

velocity constraint for low cloud), which were given their current values (RH_c = 0.8, vertical velocity less than 0.0005 mb/sec) because the resulting clouds "looked about right". Obviously that general statement needs refinement. To truly obtain clouds which "look about right", it is necessary to objectively tune the cloud parameterization using independent cloud observations.

There is a tendency for the model-diagnosed clouds to "spin-up" during the early part of a forecast, simply because they are reacting to the spin-up of model variables themselves. At the initial time, the MRF model convective cloud-fraction is obtained from the 6-hour forecast made during the previous analysis cycle (implemented Autumn, 1989), while stratiform clouds are computed from initial data. Area-weighted global mean data from T40 and T80 experiments (10 June 1990) show that the spin-up is generally complete by days 3-4 (Fig. 19). After that period, zonal mean cloud fraction is relatively constant. With an objective tuning processes, relevant cloud-diagnosing parameters could be made a function of time.

Fine-tuning procedures are not only valuable for the cloud parameterization development phase, but they also will be useful for adjusting the cloud scheme if there are any seasonal changes to the observed cloud, or if the forecast-model system changes - e.g. changes to model resolution, numerics, or physical parameterizations. As an example, effects of horizontal resolution changes on the cloud scheme are seen in comparisons of T40 and T80 results for operational model tests (Fig. 20). Comparison of zonal mean cross-sections of cloud fraction shows results similar to those obtained by Kiehl and Williamson (1990). There is a significant reduction in cloud fractional amount with an increase in horizontal resolution, especially in the subsiding subtropical atmosphere. Global mean total cloud fraction of .44 for the T40 run drops to .39 for the T80 test.

Both Rikus and Hart (1988) and Mitchell and Hahn (1990) report success with related objective cloud tuning techniques in

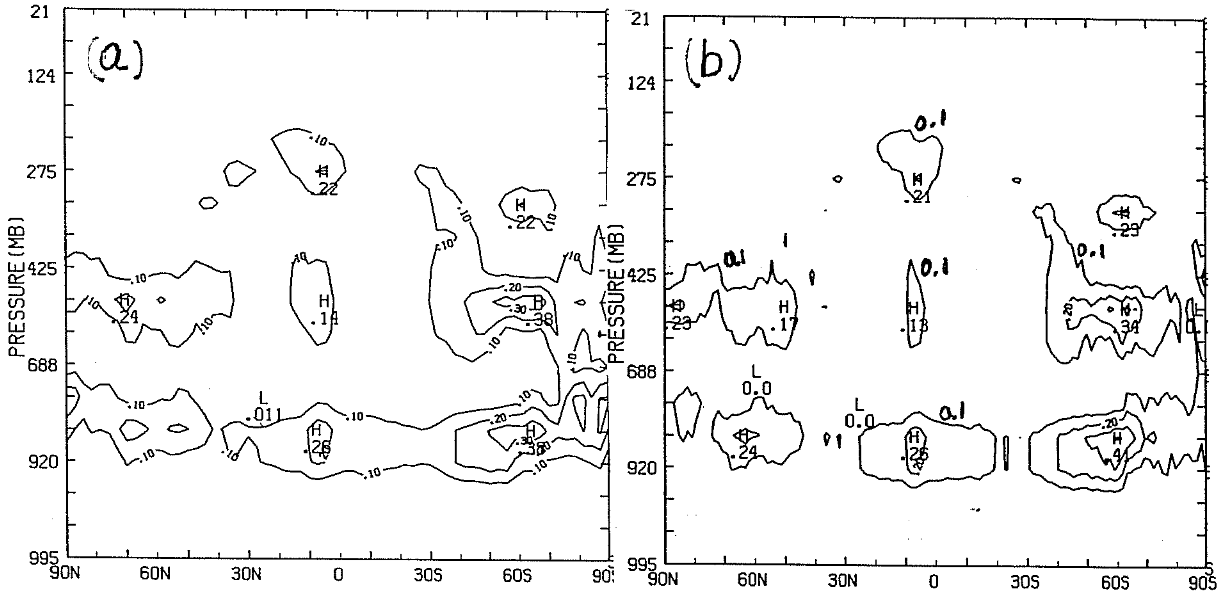

Fig. 20 Zonal mean cloud fraction in model sigma layers. 12-day mean for 00Z 10 June 1990 (contour interval = 0.1).
a. T40 forecast
b. T80 forecast

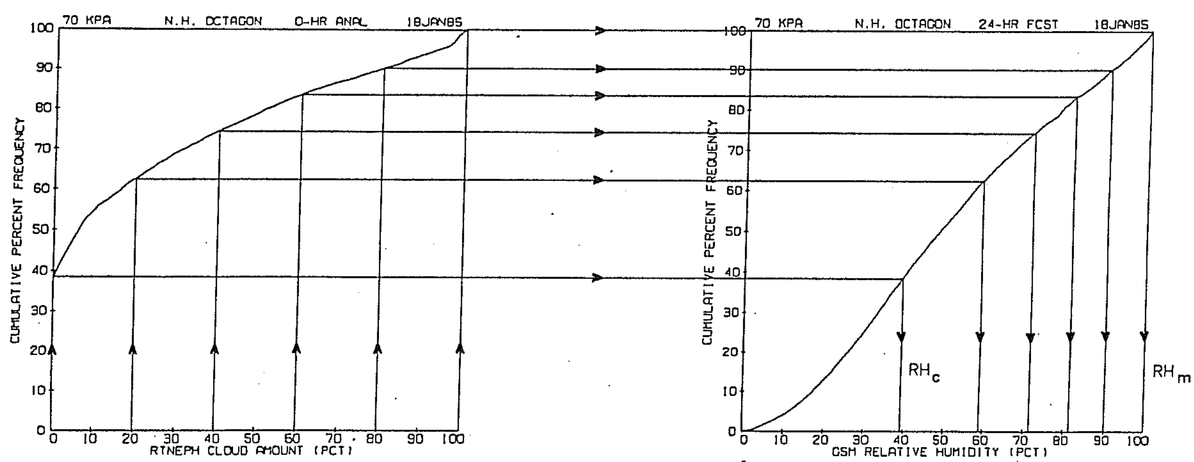

Fig. 21 Schematic of mapping cumulative frequency of cloud analysis (left) onto cumulative frequency of RH from forecast model (right) for a particular pressure level over a specified horizontal domain (courtesy, K. Mitchell, NMC; see Mitchell and Hahn, 1990).

determining cloud-relative humidity relationships (recall Eqn 1) for their models. By assuming that observed cloud fraction is strongly related to model relative humidity (RH), they attempt to preserve key statistical properties of the cloud observations in the cloud-RH functional relationships. The Mitchell and Hahn method begins by calculating cumulative frequency distributions of both model RH data and independent cloud observations on the same horizontal domain for the same valid time. Then the frequency distribution of the cloud analysis is projected, or mapped, onto that of the RH data (Fig. 21) yielding both a quasi-continuous specification of cloud fraction as a function of model RH, as well as an objective estimate of RH_c. Mitchell and Hahn show results for different pressure levels (Fig. 22) for their model, and the cloud fraction-RH relationship appears approximately quadratic in the upper levels, but RH_c is considerably less than 0.8. If it is assumed that other cloud-scheme parameters such as model convective precipitation rate or low-level inversion strength are strongly correlated to cloud fraction, one should be able to tune those relationships as well.

The desired independent cloud database is being developed by NOAA, (see paper by L. Stowe elsewhere in these workshop proceedings), and it will be useful for continuously tuning and validating the cloud parameterization[1]. We are currently embarking on a feasibility study, to test Mitchell and Hahn's technique, using Air Force RTNEPH cloud analyses (Kiess and Cox, 1988). The RTNEPH data will be compacted to the forecast model grid using methods described by Yang et.al. (1990). Initial plans are to study the cloud-RH relationships as functions of time, cloud type (H, M, or L), and region. Air Force expertise in the realm of cloud verification will also be utilized where possible.

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[1]The cloud database will be useful for other purposes as well - e.g. improving initial analyses - i.e. tropical divergent winds, RH in no data regions, surface radiative fluxes (inserting cloud directly into the model during the analysis cycle). Also to create pseudo-satellite cloud loops for forecasters - i.e. merging cloud observations with model forecast clouds.

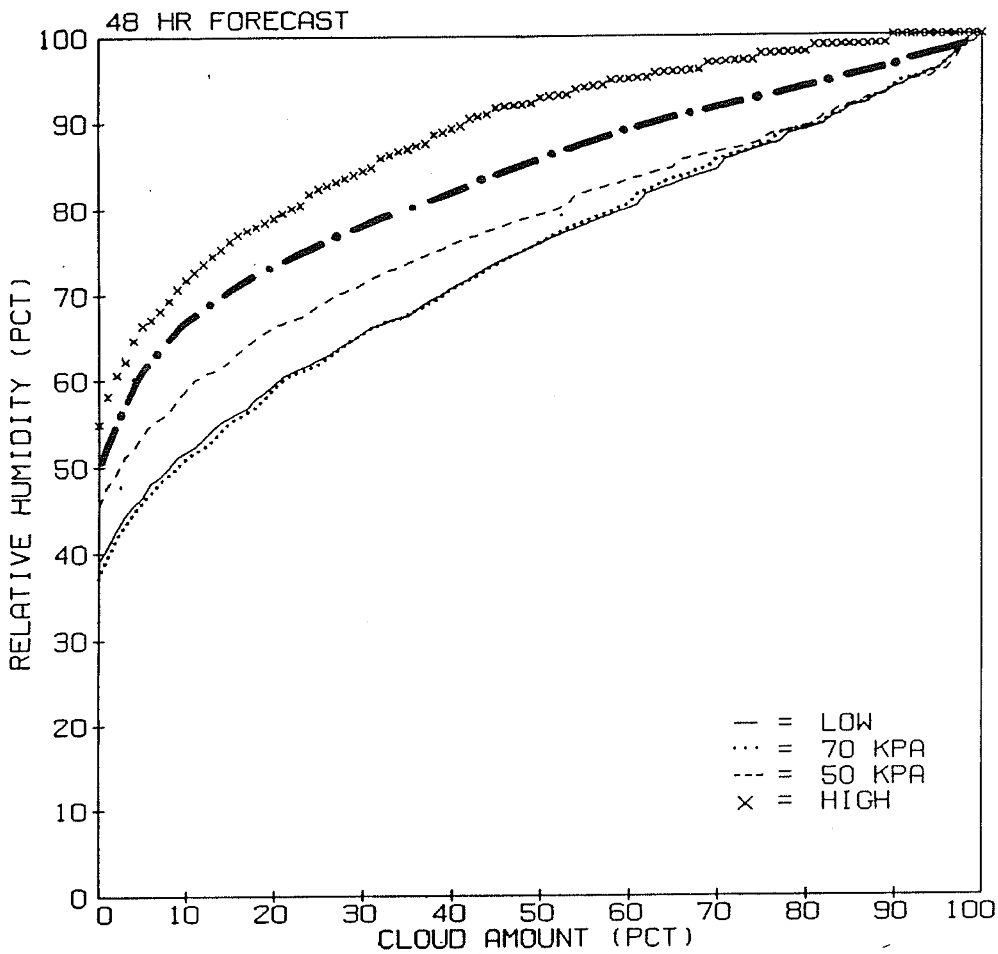

Fig. 22 Cloud-RH functional relationships on pressure levels, over subset of northern hemisphere, as derived by Mitchell and Hahn (1990) - courtesy, K. Mitchell, NMC. Low is for combined 100, 85 kPa, High is for combined 40,30 Kpa. Slingo (1980) quadratic relation for RH_c=50% shown as dot-dashed line.

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