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THE CONVECTIVE PARAMETERIZATION SCHEME IN THE MESO ETA MODEL

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INTRODUCTION

The necessity for a method of forecasting convection accurately in numerical models has been known for many years, with numerous parameterizations developed to try to represent the processes which occur in nature. These processes are quite complicated and not well known, and thus these parameterizations do not fully capture all of the details that we as forecasters see in reality. This paper will discuss the current convective parameterization scheme in the Meso Eta model, and investigate potential strengths and weaknesses of this scheme in the Western Region.

BASIS OF THE SCHEME

The Meso Eta model employs a convective parameterization scheme developed by Betts and Miller (1986) and further refined by Janjic' (1994) (hereafter BMJ scheme). The primary objective of the parameterization scheme is to ensure that the local vertical temperature and moisture structures, which in nature are strongly constrained by convection, be realistic in the model (Betts 1986). Since convective regions have characteristic temperature and moisture structures which can be observed, they were used as a basis for a convective adjustment procedure. In the BMJ scheme, the temperature and moisture profiles at a given grid point are relaxed simultaneously toward a profile type which has been observed in nature. The model first checks for deep convection, and then for shallow convection. By relaxing the profiles at a grid point simultaneously, the model always maintains a realistic vertical temperature and moisture structure in the presence of convection. By doing this simple adjustment, it is believed that the subgrid-scale cloud and mesoscale processes which created these structures will be adequately represented. The BMJ scheme has been divided into both shallow and deep convective parameterizations.

SHALLOW CONVECTIVE SCHEME

Cumulus convection is a moist mixing process between the subcloud layer and drier air aloft, and not surprisingly, the thermodynamic structure tends towards a mixing line (Betts, 1986). Betts (1982) has defined the mixing line as a linear approximation between the two source regions, i.e. the subcloud layer and the drier air aloft. To determine the mixing line, saturation points are used. These saturation points are simply the locations where the parcels become saturated after lifting. The BMJ shallow convective parameterization uses this mixing line approach to create modified soundings reflecting the moist mixing process.

In the BMJ shallow convective parameterization, the most unstable parcel at each grid point is found, and the model calculates its lifted condensation level (LCL), which becomes the cloud base. This parcel is lifted to calculate the cloud top, which is simply determined as the last model level where the lifted parcel is warmer than the surrounding environment, i.e. at or just below the equilibrium level (EL). Additionally, the cloud top is forced to be below 450 mb, so that the shallow convective scheme doesn't modify the upper troposphere. The model then determines if the "cloud" is a) greater than 10 mb deep, b) less than 290 mb deep, and c) at least 2 model layers deep. If these criteria are satisfied at a grid point, a line connecting the saturation point of the cloud base with the saturation point of the cloud top is determined. This line is called the mixing line. If any of these criteria are not met, the grid point is skipped.

At this point, the model determines the modifications needed for the temperature profile. This is done simply by connecting the temperature at the model level just below cloud base up to the model level just above cloud top, keeping the slope of this line the same slope as that of the mixing line (Fig. 1). The profile is then connected to the remainder of the sounding below cloud base and above cloud top with no modifications applied anywhere else. At this point, the newly modified temperature profile is then corrected so that the net latent heat release is zero, which means that you end up with no precipitation produced by this process.

Next, the model determines which modifications are needed to create the moisture profile. This process is somewhat complicated, but basically the modified moisture profile is modified so that the following two constraints will be met:

1) No precipitation will reach the ground, i.e. the net latent heat release due to the moisture change is zero, or the total water vapor in the cloud is unchanged.

2) The total entropy change due to the shallow convective parameterization must be a small positive quantity. The entropy change due to the temperature change must be negative (since the temperatures cooled), therefore the entropy change due to the moisture change must be positive. In the model, the total entropy change is set to be 5% larger than the magnitude of the entropy change due to the change in temperature.

What this means, is that the moisture will be moved upwards, so that net drying will occur near the cloud base, and net moistening will occur near the cloud top. It mimics the process of condensation near cloud base (warming and drying), and evaporation near the cloud top (cooling and moistening), so that the net change in the sounding results in no precipitation. The model takes about 40 minutes to gradually apply these modifications to better simulate the convective process.

DEEP CONVECTIVE SCHEME

The BMJ deep convective parametization scheme is based on the observation that deep convection is a thermodynamically driven process that transports heat and moisture upward in order to remove or reduce conditional instabilities (Janjic 1994). Precipitation is usually produced during this process. The vertical transportation of heat and moisture is accomplished through the process of mixing, as with the shallow convection.

In the BMJ deep convective parameterization, the model first searches all the parcels within the lowest 130 mb of the model surface and finds the most unstable parcel at each grid point. Just like in the shallow convective parameterization, the model calculates the LCL of this most unstable parcel and calls the model layer below this point, the cloud base. The cloud base must be at least one layer above the lowest model layer and/or at least 25 mb above the middle of the lowest layer. If the cloud base does not satisfy these requirements, the cloud base is lifted accordingly. The parcel is then lifted to calculate the cloud top, which again is simply the model layer below or at the EL. If the depth of the cloud is greater than 290 mb, the deep convective parameterization will continue, otherwise this point will be checked to see if the shallow convective parameterization needs to be applied.

If the cloud is greater than 290 mb in depth, the model will then determine the modifications needed for the temperature profile. From the cloud base to the ambient (environmental) freezing level, the temperature profile is modified to be 90% of the slope of the moist adiabat which goes through the cloud base (Fig. 2). Betts (1982) found that the slope of the temperature profile in deep convection approached this slope as opposed to the slope of the moist adiabat. This suggested that the atmosphere remains slightly unstable, so that air rising in vigorous cumulus towers remains buoyant until its cloud water is converted to precipitation-size particles. From the ambient freezing level to the cloud top, a straight line is drawn to connect the points.

Next, the model determines which modifications are needed to create the moisture profile. To understand how the modified moisture profile is created, we need to define a term called saturation pressure deficit (DSP). Betts (1982) defined the saturation pressure deficit as the difference between the air parcel saturation level and the pressure level of that air parcel. Therefore, it is the distance (in Pa) that a parcel needs to be lifted to reach saturation.

It is at this point that the parameterization becomes somewhat more difficult to understand. A parameter is calculated called the "cloud efficiency" (Janjic 1994). This parameter measures the ability of the convective column to transport the enthalpy upward and at the same time produce as little precipitation as possible. At this point, an assumption is made that the convective forcing is proportional to an increasing function of the cloud efficiency. In this way, heavy precipitation which normally would just continue to develop and fall, could be modified in the case of low cloud efficiency. This was done in order to decrease the amount of spurious heavy rain bullseyes which occured occasionally over warm water, where there was an abundant source of low level moisture and instability, with no way to turn the precipitation off once it started.

Two extremes of cloud efficiency were determined for the deep convection parameterization: 1) a cloud that is in a predominantly mixing stage with high cloud efficiency and not much rainfall, and 2) a cloud that is in a predominately rain producing stage with low cloud efficiency. DSP's are assigned for these two extremes, so that any cloud efficiency will fit between them. The DSP values will also be slightly lower over water. Three anchor points in the cloud are assigned specific DSP's: 1) cloud base, 2) cloud top, and 3) the ambient freezing level. Typically over land, the DSP at cloud base is around -48 mb, the DSP at the ambient freezing level is around -70 mb, and the DSP at the cloud top is around -22 mb. All of the DSP's for all of the other layers in between are linearly interpolated between these anchor points. Since the DSP at the freezing level has the biggest magnitude, it will be the driest point of the moisture profile, which agrees with the findings of Betts (1986) of a theta-e minumum very near the freezing level. Given a temperature and a DSP profile, it becomes trivial to calculate the specific humidity, and the modified moisture profile.

Again, corrections need to be made to the profiles in order to conserve enthalpy. By doing this, we are saying that if it does rain, the net latent heat release will be in balance with the net moisture change due to condensation. Precipitation is directly calculated from the amount of latent heat produced by the modification of the soundings. If the precipitation is not positive, or if the entropy of the grid point decreases, the deep convection parameterization is aborted, and the shallow convective parameterization is used at that point. *Thus, the way to get precipitation out of the deep convective scheme is to have the modified moisture profile become drier and the modified temperature profile become warmer.* This means that the adjustment created warming and drying such that the net enthalpy is unchanged, but allowed for latent heat (via condensation) to be released and precipitation to fall out of the cloud. As with the shallow convective parameterization, these modifications to the airmass take about 40 minutes to occur to better simulate nature.

THE BMJ CONVECTIVE SCHEME IN THE WEST

Results with precipitation output from the Meso Eta model have been fairly positive with many case studies showing the improvement of the model resolution on the placement and amount of predicted precipitation (Burks and Staudenmaier 1996; Gartner, Baldwin, and Junker 1996; Schneider et al., 1996). However, verification of convective precipitation in the Western Region has been less impressive with serious deficiencies in the production of convective precipitation in areas of topography (Baldwin and Black 1996; Swanson 1995). Figure 3 is an example of a typical pattern of convective precipitation, indicating how convective precipitation appears to be limited to locations below 4000 feet in elevation. The remainder of this paper will investigate some of the potential strengths and weaknesses in the BMJ convective scheme.

The main strength of the BMJ scheme is that it couples simplicity with adequate skill in developing convection. Since numerical models are constrained to discrete time steps and resolutions, it is necessary to parameterize any physical process which occurs on a scale smaller than that resolvable by the model. The BMJ convective parameterization is purely a convective adjustment scheme. This means that once the parameterization is initiated, the atmosphere is adjusted towards a post-convective environment, with precipitation possibly developing. Convective adjustment is a simple and economical method (in terms of computer resources) of parameterizing convection. However, since it bypasses most of the physical processes involved, it has limited flexibility and will likely have increasing limitiations as model resolution continues to improve.

Since, convection is not explicitely created in the model, mesoscale features such as updrafts, downdrafts and associated momentum transfer to the surface are not accommodated. No changes are made to the wind shear profile or to the subcloud layer. This scheme is not linked in any way to the explicit cloud prediction scheme of the model, except through modification of the model relative humidity fields. Because of these limitations, convection in the model will likely not look realistic in terms of propagation or additional development due to outflow boundaries.

Because the BMJ scheme relies solely on instability for the generation of convection, this scheme should perform better than the Kuo scheme, which is currently used in the NGM model, in situations where daytime heating is the major contributor to convective initiation. This is because the Kuo scheme also relies on low-level convergence for convective initiation, which may not occur with the course resolution of the model. This also leads to the probability that the BMJ scheme will allow for a faster "spin-up", or development of convection in the model, after initialization, since convection is not initialized implicitely into the model initial fields. Currently, the only way thunderstorms will be initialized into the model, is if a large enough thunderstorm complex is captured in the initial data set, and continues to develop in the three hour assimulation procedure. Unfortunately, most of these complexes dissipate during this process, even if captured in the data field (Janish and Weiss, 1996). Because of this, a model with a faster "spin-up" time is generally preferred. Even with a faster "spin-up" time, convection will only develop in those areas which are unstable in the model. Thus, even if convection does develop rapidly in the model, it may be in a different location than where convection is really occurring.

The data which was used to develop the BMJ scheme was derived from a tropical field experiment (Betts 1986). This scheme was developed and tested with other airmasses, including an arctic airmass moving over warmer waters. However, all cases used were over water, and never over mountainous terrain. Thus, these cases all included deep moisture, especially in the lower layers, with sufficient instability leading to the development of deep convection. This differs greatly from the typical thunderstorms in the Western Region, with dry low levels, some mid-level moisture, and marginal instabilities mainly due to heating of the mountains. It appears that this difference may be somewhat to blame for the poor performance of the convective scheme in the West (Baldwin and Black, 1996, Gartner, Baldwin, and Junker 1996).

It appears that there are two likely candidates for this poor performance. The most likely is that because convection in the West is usually high-based, and not exceptionally deep, the limitation in the model that deep convection must be deeper than 290 mb may not be satisfied over higher terrain. This would explain why the parameterization appears to be better at elevations below 4000 feet, where deeper clouds are more likely to occur in the model. Thus, this grid point would be passed to the shallow convective parameterization, allowing the instability to be released without precipitation. The other candidate for potential problems with the convective scheme is that because moisture can be confined to shallow layers over the West in the summer convective season, it may not be resolved adequately with the more coarse resolution of the model mid-layers. Thus, when the convective scheme is checked, this moisture may become mixed out in such a way that the convective parameterization scheme fails. These ideas are being tested at NCEP and it is hoped that the convective prediction skill of the model over higher topography will improve once the problem is determined (M. Baldwin, personal communication).

CONCLUSION

The BMJ convective parameterization scheme has been investigated to determine how it operates in the Meso Eta model. Cumulus parameterization is far from a simple problem, and no parameterization scheme will accurately predict the location and movement of convection. It appears that the BMJ scheme, as it stands now, will not adequately forecast convection in the West, likely due to the differences between convection over topography in the Western Region and convection over the ocean. It is hoped that through a good understanding on how the convective parameterization works, forecasters will be able to better interpret precipitation output from the model.

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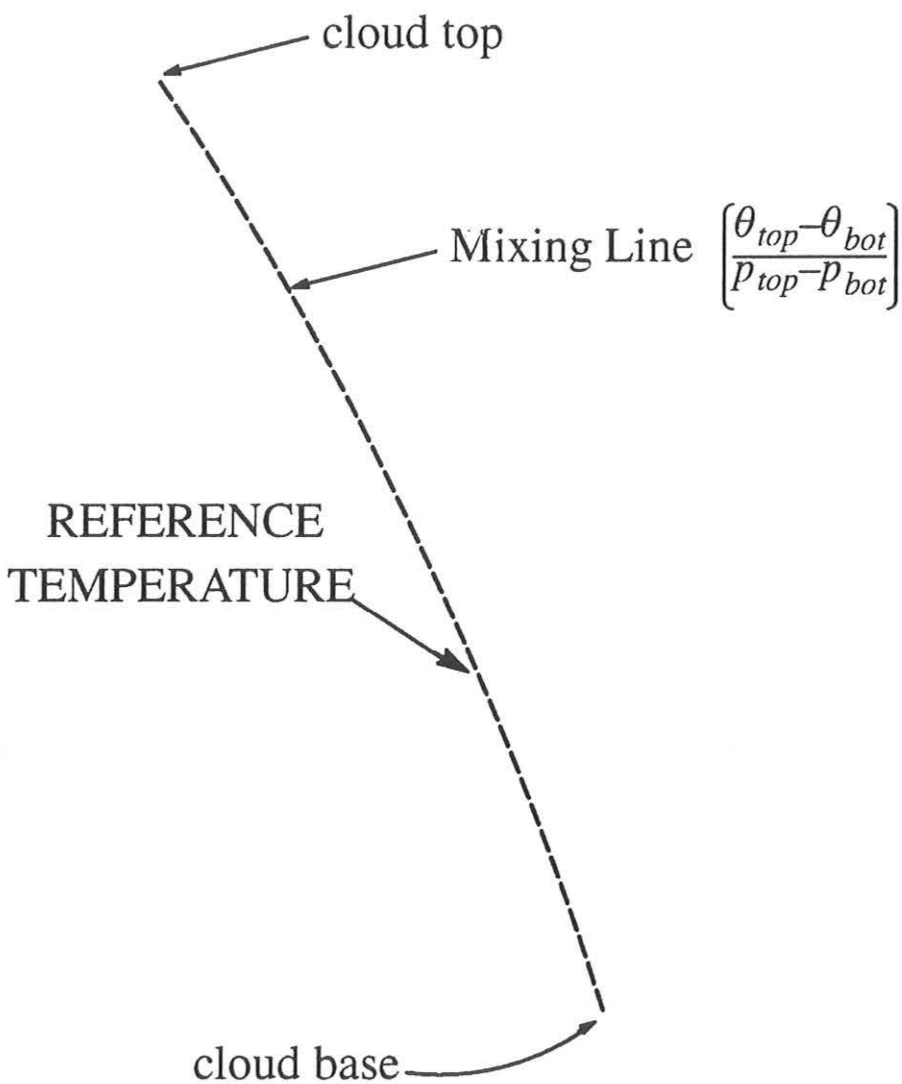
Construction of Temperature Reference Profile for Shallow Convection



Again, correct T_{ref} *assuming* $\Sigma(c_p \Delta T \Delta p) = 0$

Fig. 1

Construction of 1st Guess Temperature Reference Profile for Deep Convection

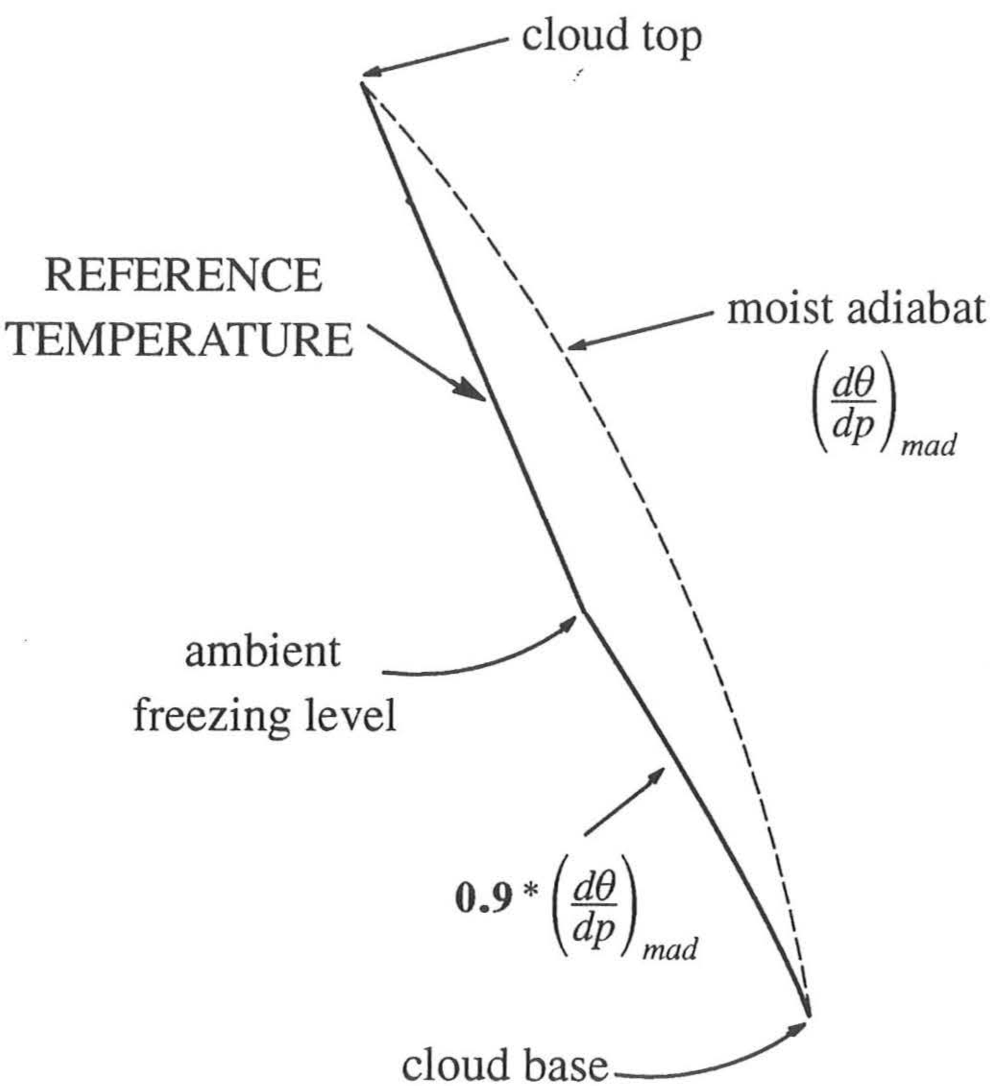


Fig. 2

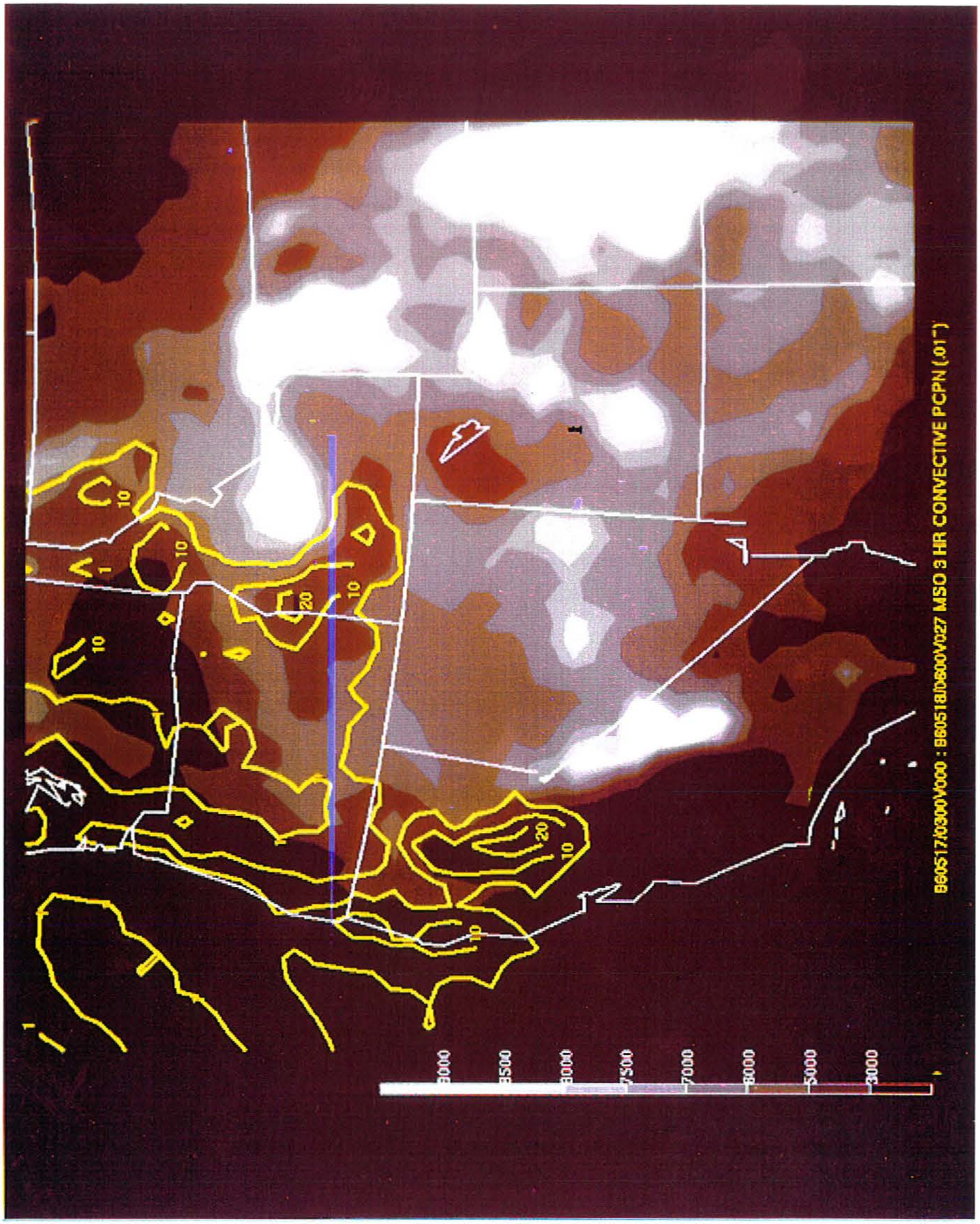

960517/0300V000 : 960518/0600V027 MSO 3 HR CONVECTIVE PCPN (.01")

Fig. 3