P1.11 ON PROVIDING A CLOUD-BALANCED INITIAL CONDITION FOR DIABATIC INITIALIZATION

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I. INTRODUCTION

Inclusion of clouds in an initial condition has been a long-term goal of many numerical weather prediction systems. The work with the ARPS model and ADAS initialization has been a notable example (Xue, et al., 2000). Work by Crook and Sun, 1997 has taken this even into the realm of the model adjoint. What we seek in this work is an a 3-D static analysis that can provide the kind of sophistication of the systems above, but at the same time run efficiently on small computer systems in local weather offices.

The Local Analysis and Prediction System (LAPS: McGinley, et al., 1991) was developed as a go-anywhere assimilation system for local weather offices. LAPS is a UNIX-based set of software designed to accept all sources of local data: satellite, mesonet, profiler, radar, aircraft, etc. and provide high resolution analyses on whatever computer hardware was available. LAPS has been ported to a number of sites worldwide. One of the unique components of LAPS is the cloud analysis (Albers, et al. 1996), designed to provide the user with a complete description of the cloud environment: bases, tops, coverage, liquid and ice distribution. This cloud scheme has been used and adapted by others (Zhang, 1999). In 2000 the LAPS effort was focused on extending the cloud scheme to do a complete analysis of water in all phases (WIAP) with an aim toward providing model initial conditions a complete description of the water environment and the motions and thermodynamics that sustain them.

2. THE LAPS ANALYSIS SCHEME

2.1 State variables

LAPS uses a two stage approach to analysis: a) a data combination step where data from many platforms is combined to satisfy basic geometric constraints through a combination of successive corrections methods (Barnes, 1964) and variationally applied splines (Albers, et al., 1996; McGinley, 1982); and b) a dynamic adjustment step that forces the fundamental equations (thermodynamic , motion, and continuity) to be satisfied within the domain to a desired level of accuracy (McGinley, 1987). Using integral constraints in the form of Sasaki (1970), only in discrete form, the solution fields are forced to satisfy dynamic constraints within some tolerable residual, and satisfy mass continuity constraints exactly.

The penalty function (J) for the state variables **u,v,** ω, and Φ **(**geopotentia**l) (**Eqn 1**)** in discretized form is given below.
The hatted quantities (^) are solution differences from the background field, while primed quantities (') are observational differences from the background. The (^) are the desired solutions…increments from the background gridded first guess. The background is the Eta model at 32 km resolution.

The standard procedure is to apply the variational operator to the penalty function and derive Euler-Lagrange equations that must be solved simultaneously. User-defined weights **O** (observations), **B** (background) are defined from known error characteristics of the first stage analysis and background model, respectively. Ideally **B** represents the actual error statistics from the background model. Weight μ adjusts the magnitude of the residual Eularian time tendencies of u and v relative to the other constraints and provides a balance among the mass and momentum fields. The term λ is a Lagrange multiplier that becomes another unknown. λ will

$$\begin{aligned} J = \sum_k \sum_j \sum_i & O_V(\hat{u}-u')^2 + O_V(\hat{v}-v')^2 + O_\omega(\hat{\omega}-\omega_c')^2 + O_\Phi(\hat{\Phi}-\Phi')^2 \\ & + \mu(\hat{u}_t)^2 + \mu(\hat{v}_t)^2 + \lambda(\hat{u}_x + \hat{v}_y + \hat{\omega}_p) \\ & + B_V\hat{u}^2 + B_V\hat{v}^2 + B_\Phi\hat{\Phi}^2 + B_\omega\hat{\omega}^2 \end{aligned} \qquad \text{Eqn 1}$$

ensure that continuity is satisfied to the limits of computational accuracy.

Fig. 2 shows the RMS equation of motion residual before and after the analysis process . RMS residuals are typically reduced by a factor of 100 for a value of m near 1.0 e 9 $s^4 m^{-2}$

The Eulerian time tendencies u_t and v_t given below in Eqn. 2a and b,

$$\hat{u}_t = -(u_b\hat{u}_x + \hat{u}u_{bx} + v_b\hat{u}_y + \hat{v}u_{by} + \omega_b\hat{u}_p + \hat{\omega}\,u_{bp}) - \hat{\Phi}_x + f\,\hat{v} - D(\hat{u}) \qquad \text{Eqn 2a}$$

$$\hat{v}_t = -(u_b\hat{v}_x + \hat{u}v_{bx} + v_b\hat{v}_y + \hat{v}v_{by} + \omega_b\hat{v}_p + \hat{\omega}\,v_{bp}) - \hat{\Phi}_y - f\,\hat{u} - D(\hat{v}) \qquad \text{Eqn 2b}$$

utilize background $(\,)_b$ fields so the non-linear terms become quasi-linearized with known estimates from the previous analysis step. Subscripts x, y, and p refer to horizontal (x,y) and vertical (p) derivatives.

2.2 Cloud analysis and microphysical retrieval

Albers, et al. (1996) describes the LAPS cloud analysis scheme. The process utilizes multi-spectral satellite data from GOES, radar, aircraft, surface reports, the LAPS temperature analysis, to derive a 3-dimensional estimate of cloud coverage. It utilizes hypothesized "cloud soundings" from the data sources and horizontal interpolation using a successive corrections method. The net result is a 3-D depiction of the cloud field. An additional step is the retrieval of cloud microphysical data using a version of the Smith-Feddes model described by Haines, et al. (1989). Clouds are typed utilizing

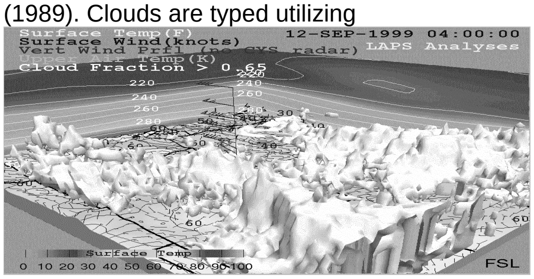

Fig 1: LAPS cloud analysis for 12 Sep 1999 at 0400 UTC. 3-D view looking NW shows cloud coverage (solid white surface) greater than 0.65, surface winds, temperatures a wind profile and temperature cross-section.

a lookup table based on stability and temperature, and from this information vertical motion is input as an "observed" quantity, also estimated from a look-up table. This "observed" quantity is ω'_c in Eqn. 1.

After solving the analysis equations we obtain an analysis that contains the liquid, solid, and vapor phases of water, the horizontal and vertical motions associated with the clouds, the corresponding adjustments of the mass field and hence, thermodynamic (hydrostatic) impact of the cloud.

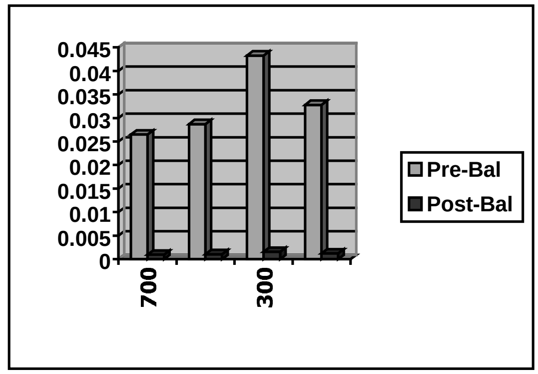

Fig. 2: RMS residuals (m s^{-2}) from momentum equation before (Pre) and after (Post) balancing process at 700, 500, and 300 hPa and over volume (DOMAIN). Residual is reduced by approximately two orders of magnitude. Data time is 2000 UTC May 1, 2001.

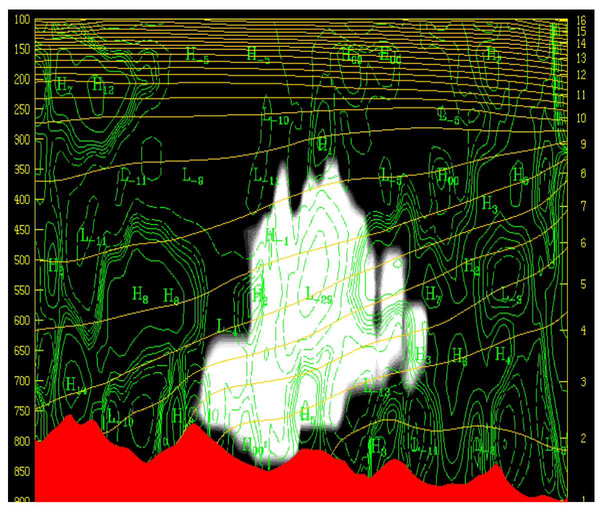

Fig 3. Cloud cover (image), omega (pa/sec x 0.1: dashed lines– upward) in S-N cross section from CO-NM border to N. WY, through Denver for 2 May 2001, 1200 UTC. Also shown are isentropes (lines slanting upward, left to right). A front was moving through Colorado this day. Upward vertical motions and clouds correspond well. Fields are after dynamical analysis.

A cross-section through a precipitating frontal zone is shown in Fig 3. Clouds and vertical motions are shown. This represents the initial condition that is used in the model hot start. It might be noted that the imposition of continuity coupled with the linking between mass and momentum and hydrostatic assumption, results in a thermal perturbation in the cloud area, even though there is not an explicit thermodynamic constraint.

3. **MODEL INITIALIZATION WITH LAPS**

The analysis described above with appropriate cloud attributes provided by LAPS was a candidate for generation of a model initial condition. These fields represent a state that contains cloud water and ice, the vertical and horizontal motions that sustain them, and a balance condition that ensures a smooth model start. The LAPS grids are interpolated to version 3 of MM5 and forecasts generated twice daily.

Figure 4 a-d shows a case for where the LAPS cloud analysis is shown in the initial condition and in the subsequent 1-hour forecast:

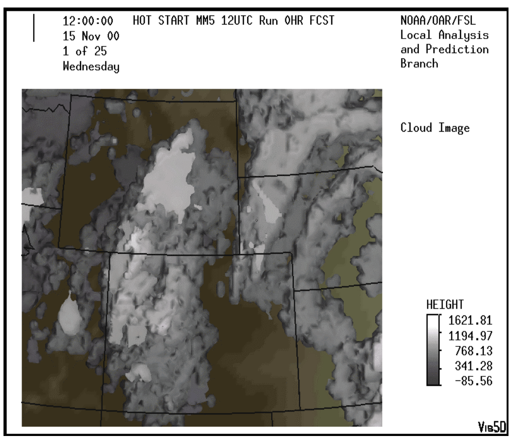

Fig 4a: LAPS cloud analysis for 15 Nov 00 12GMT. This case was a weak trough moving eastward from the Colorado-Wyoming border. A circulation was evident in the clouds in SE WY.

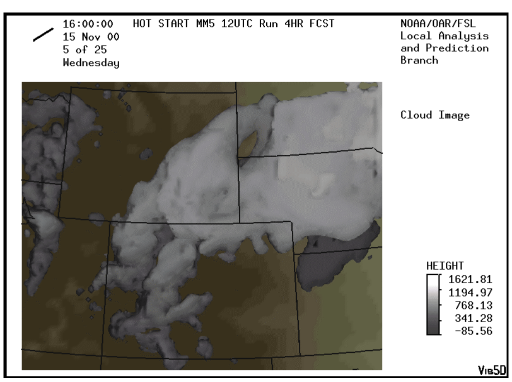

Fig 4b: MM5 4-hour cloud forecast for 15 Nov 00 16GMT. Figure below shows verifying IR cloud field. Note that most clouds are present very early in forecast. No spin up was necessary.

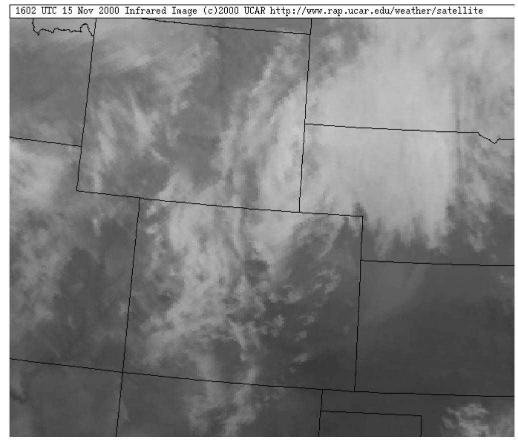

Figure 4c: IR satellite image for 15 Nov 00 16GMT

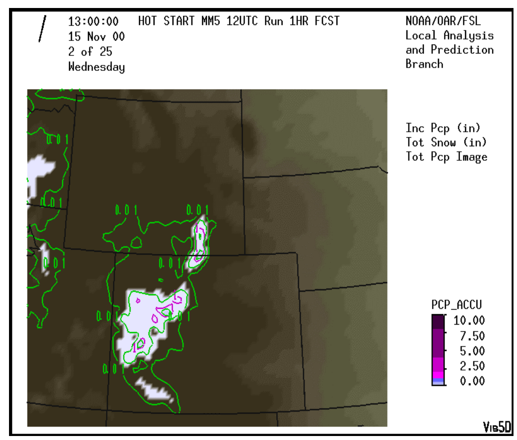

Fig 4d: One-hour MM5 preciptation forecast (snow and liquid) from LAPS initial condition illustrating a mature precipitation field early in the forecast. Contours indicate liquid equivalent (first contour 0.01 in) while the image shows snow accumulation.

4. **VERIFICATION RESULTS**

The hot start has been run for many months and has shown to provide superior verification from 0 to 9 hours over background-only initialized MM5 (which we term a “cold” start), or a three-hour nudging procedure (which we term a “wam” start). One disadvantage of the warm start is that it utilizes 3-hours of run time for the nudging procedure, thereby increasing the computer overhead for the operational cycle. Figure 5 shows verification for a 3-month period in the fall of 2000. We verified state variables at each grid point in three dimensions.

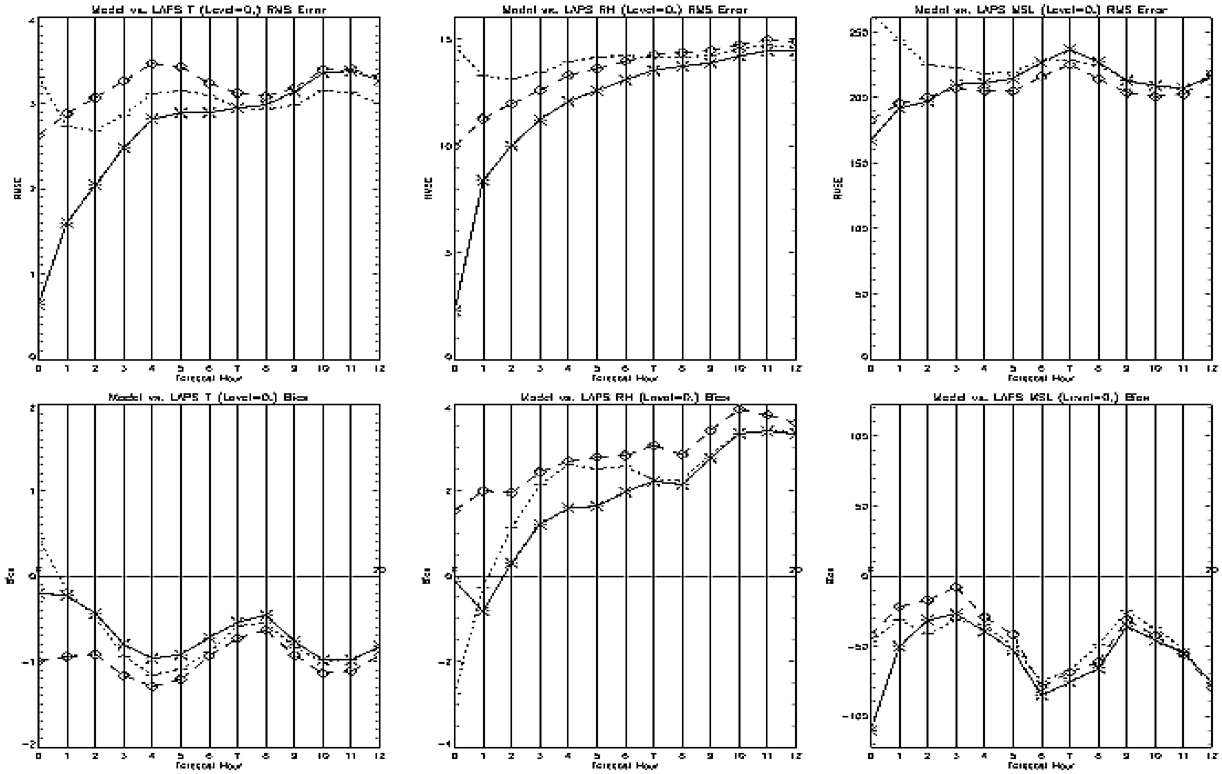

Fig. 5 : RMS (top row) and Bias errors (bottom row) for Temperature (C, 1st column), relative humidity (%, 2nd column) and surface pressure (mb, 3rd column.)Solid line is hot start, broad dash is warm start, dotted is cold start. Abcissa is forecast hour.

These results illustrate that starting the model with a cloud-consistent analysis makes significant improvement in the forecast for the first 6-9 hours. Additional results will be presented in other papers in this conference (Shaw, et al. 2001)

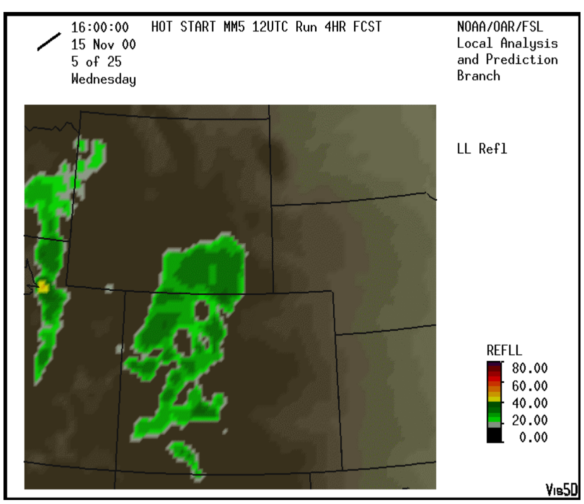

Fig 6a. Four hour reflectivity forecast for 15 Nov 00 at 16 GMT

The toughest measure of a model is to assess the point -specific forecast accuracy. As an example, Fig. 6a-b shows a forecast radar reflectivity at 4 hours (a) and the verifying radar (b) for the same time. Using pairs of products like these validation was conducted over the 3-mo. period (Fall, 2000) using a reflectivity threshold. Figure 7 a-c shows probability of detection for cloud (a), precipitation (b), and a moderate reflectivity threshold of 35dbZ (c). Note here that forecast longevity of the diabatic analysis initialization is much reduced over the state variables. Cloud validation is better than the cold start for the entire 12-h period. However, for radar echoes greater than 35 dbz, the value added of the initial condition is 3 hours; for measurable precipitation, 5 hours.

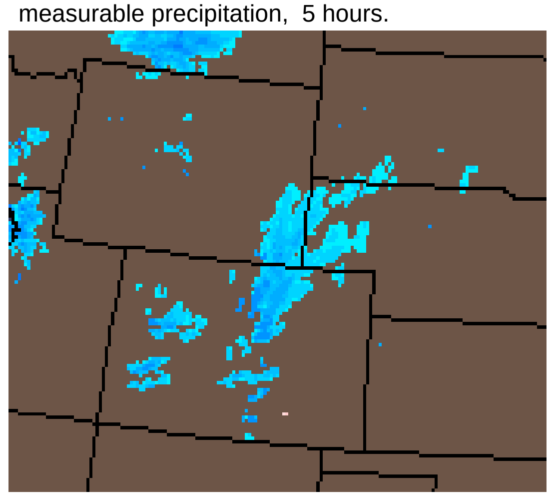

Fig 6b: Radar verification for 15 Nov 00 at 16GMT

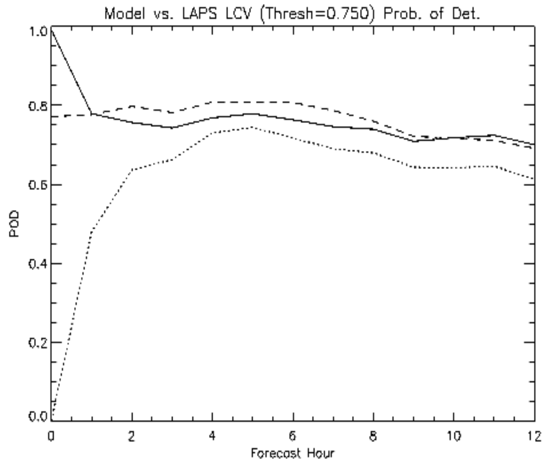

Fig. 7a: Probability of detection of clouds (threshold at 75%). Solid line is model run from diabatic initialization; dashed , nudging; dotted, background -only.

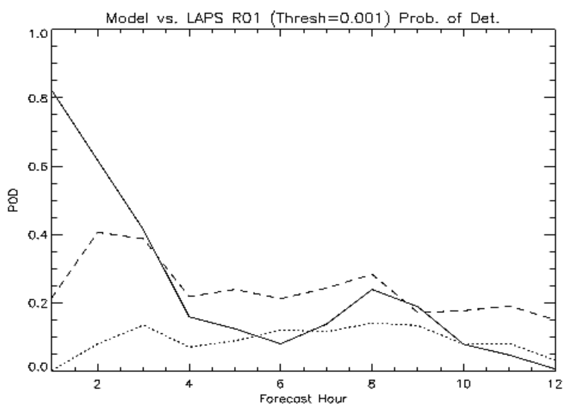

Fig 7b: Probability of detection of any precipitation. Solid, dashed, dotted as in Fig 7a

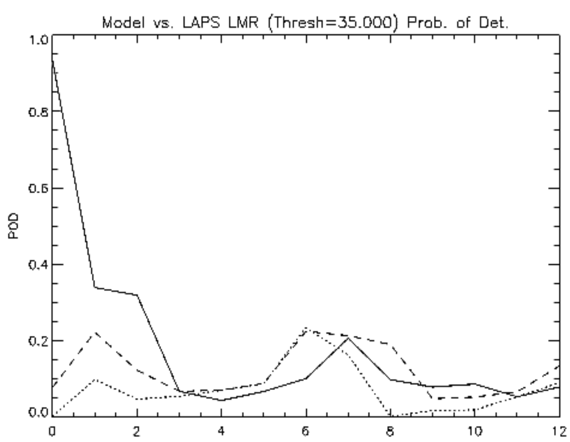

Fig 7c: Probility of detection for echoes greater than 35 dbZ. Solid, dashed, dotted key as in Fig 7a.

5. CONCLUSION

The diabatic analysis has shown some promise in defining the proper initial conditions for clouds in a numerical weather prediction model (MM5). Improved verification in a 3-mo. study has been shown. The state variables have seen the greatest improvement: up to 6-9 hours over initializing the model with background fields alone. This improvement is also seen in the cloud field forecasts. However, precipitation improvement only is only seen out to 3-4 hours. There appears to be a precipitation spindown problem. Experiments to improve the input cloud motion field by using a model instead of look-up tables are being considered.

6. REFERENCES

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