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N85-32478

1.8A SYNOPTIC-SCALE DYNAMICS WITH VERTICAL VELOCITY

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BACKGROUND

Radar measurements of all three of the atmospheric velocity components by the MST technique date from all the pioneering work of WOODMAN and GUILLEN (1974). The radar horizontal velocities have been compared with other standard measurements, such as radiosonde winds, in a number of studies and are now finding widespread acceptance within the meteorological community for research and operational forecasting purposes (e.g. LARSEN and ROTTGER, 1982; CARLSON and SUNDARARAMAN, 1982; LARSEN, 1983). Perhaps the single most interesting report recently is that the MST profiler winds are turning out to be one of the most useful pieces of data for predicting upslope snowfalls (SCHLATTER, 1984) in the cold-season forecasting study of the PROFS Program (REYNOLDS, 1983). By contrast, the vertical velocities measured by MST radars have received relatively little attention, despite the facts that direct continuous measurement of vertical velocity is unique (i.e., it cannot be done with radiosondes) and that the vertical velocity is intimately linked with the dynamics of the atmosphere.

Indeed, for many forecasting applications the vertical velocity is the single most important variable, yet it is usually inferred indirectly from other dynamical variables. The ST radars now available have the potential to change this situation, and the next section reviews some of the results from vertical velocity measurements which have direct application in synoptic-scale dynamics.

In the third section I consider some of the remaining research questions which should be addressed before plans are made to fully exploit this technology. In the final section, I discuss a few potential applications of this technology for synoptic-scale analysis and forecasting.

SYNOPTIC-SCALE RESULTS ON VERTICAL VELOCITY

By synoptic-scale, we mean those motion systems that operate on scales from several hundred to a few thousand kilometers, and will focus attention on them while realizing that there is interaction among motion systems of all scales. For example, jet stream and frontal systems are usually considered synoptic-scale features, but the principal benefits of vertical velocity measurements in these cases seem to lie in understanding their interaction with smaller scales. As reviewed by GAGE (1983), jet streams are a locus for turbulence and internal gravity wave activity, and ST radars are helping to define the interaction processes at work there. Also, LARSEN and ROTTGER (1982) have reviewed the application of ST radar data, including vertical velocities, to the study of frontal passage events. Again, a primary use of the vertical velocity data appears to be in studying the mesoscale processes along the frontal boundary. However, the vertical velocity data may have application on a larger scale as well, as seen next.

Figure 1 (from LARSEN and ROTTGER, 1982) shows the sequence of events during a warm frontal passage at SOUSY. The vertical velocity ahead of the front is clearly upward on the average, while that behind the front is downward, as expected. Eyeball averaging the values in Figure 1b gives mean magnitudes on the order of 10 - 20 cm s^{-1}, up or down, which are not at all unreasonable compared with classical models (PALMEN and NEWTON, 1969).

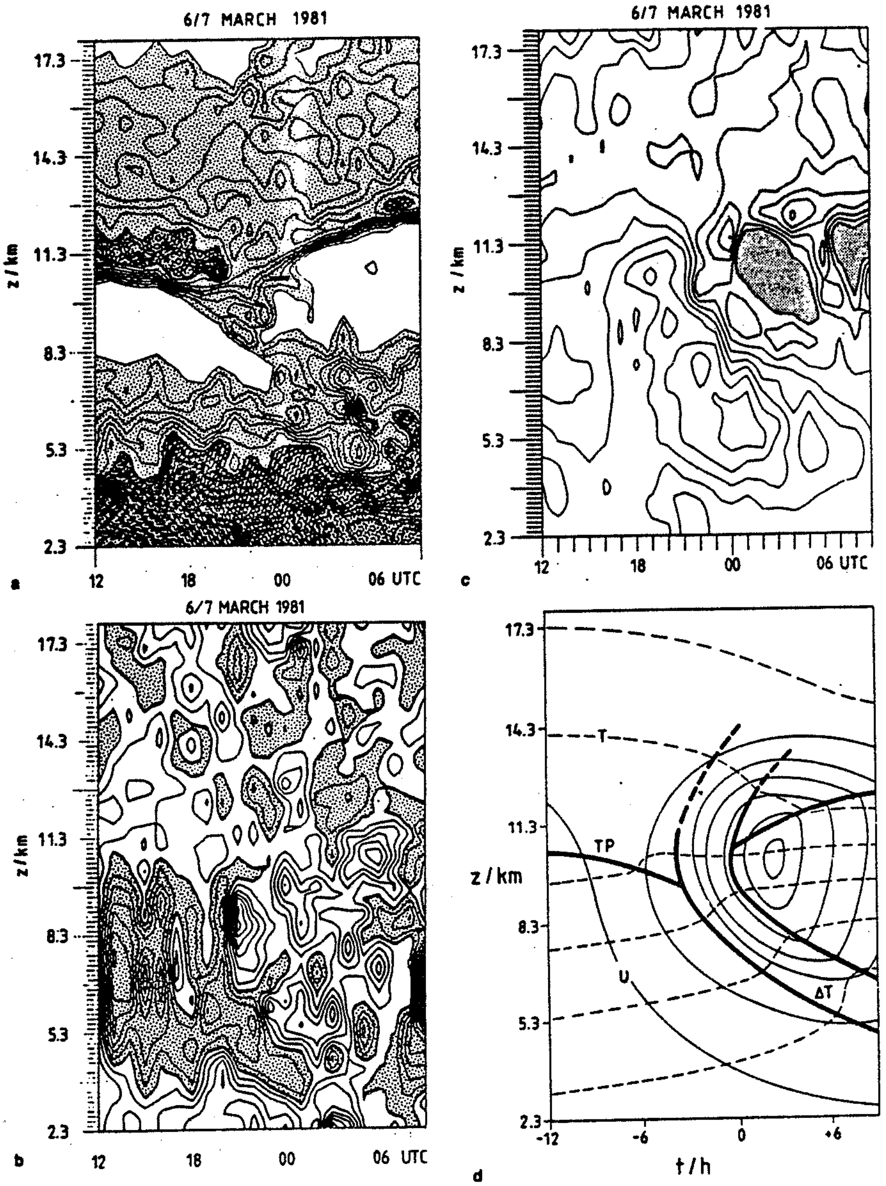

Figure 1. Frontal passage at SOUSY radar (after LARSEN and ROTTGER, 1982). (a) Reflectivity; interval 2 dB. (b) Vertical velocity; interval 7.5 cm/s; shading indicates downward. (c) Wind speed; interval 2.5 m/s; stippled is missing. (d) Classical frontal model.

Time average values of the ST measured vertical velocity in Alaska, Colorado and France have been compared with vertical velocities computed by the adiabatic, kinematic, and quasi-geostrophic omega equation methods by NASTROM (1984) and NASTROM et al., (1984). Some of the results (e.g. Figure 2) are very encouraging, and suggest that the ST radar data can provide reliable estimates of the synoptic-scale vertical velocity over a station. The success of these comparisons under general synoptic conditions has not yet been demonstrated, however, due to the siting of the available ST radar stations. All radars are located in or near rough, mountainous terrain. It has been established (ECKLUND et al., 1982; NASTROM et al., 1984) that flow over mountains increases the variance of the vertical velocity, and may induce standing lee waves. This meteorological "noise" can swamp the synoptic-scale signal at times as shown in Figure 3 from Platteville, Colorado. Note that Platteville is east of the Rockies. In the two panels in the lower right of Figure 3, the wind was strong and from the west, and the comparison is poor; in the two panels in the lower left, the wind was from the east, across the plains, and the comparison is good. In the top four panels, the statistical standard error of the mean (SE) is given by SE = $\sigma/\sqrt{N}$, where σ is the standard deviation and N is the number of independent observations. When the winds are from the east, over the plains, σ is relatively small; SE is then small enough that the visual comparison looks encouraging. The important point is that, at Platteville, the radar can measure the synoptic-scale vertical velocity with acceptable error limits under certain conditions.

There were three ST radars installed for ALPEX, in France near the mouth of the Rhone (BALSLEY et al., 1983), in a triangular array about 5 km on a side. When the wind was from the south, off the sea, these radar results also compared well qualitatively with each other and with the indirectly computed vertical velocities (Figure 4). Although the quantitative comparisons are not always perfect, the values fall within statistical error limits. Based on the available results, it appears that ST radars can provide reasonable estimates of the synoptic-scale vertical velocity.

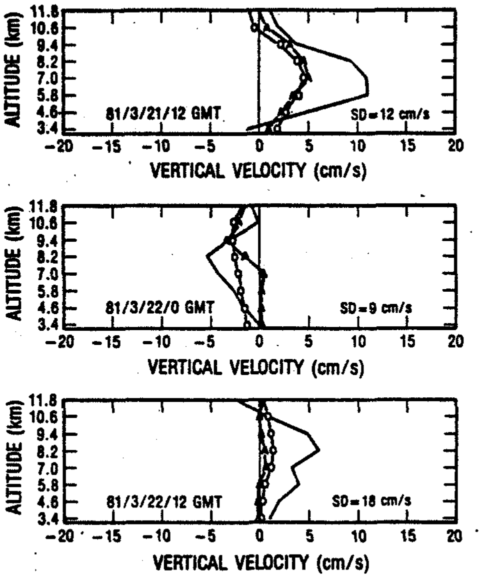

Figure 2. Vertical velocity at Platteville radar (after NASTROM, 1984). Solid line is 9-hour radar average, A is from adiabatic method, O is from omega equation.

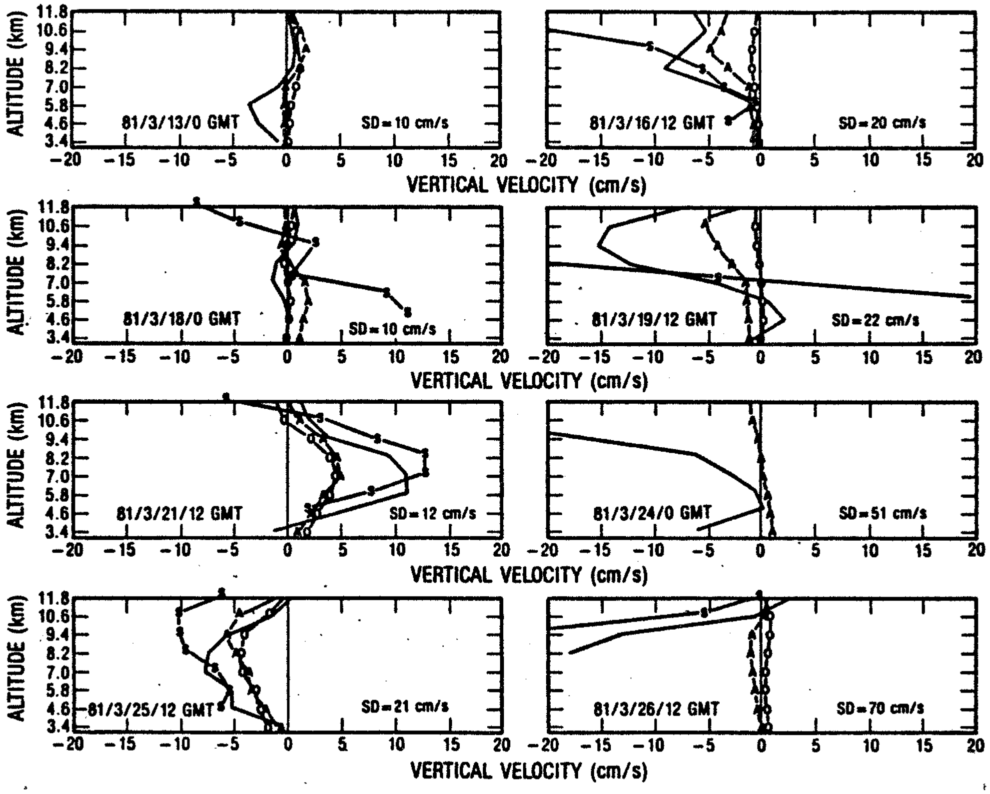

Figure 3. As is Figure 2; S is Sunset radar 9-hour average.

In order to generalize the above results, an ST radar(s) should be sited in the central plains for several months. The measured vertical velocities should be compared with indirectly computed vertical velocities and with proxy indicators of vertical motion such as weather radar echoes and satellite cloud pictures. If this technology were demonstrated under general conditions, it would surely be accepted and used by the meteorological community. It could, for example, enhance the usefulness of major research efforts such as the upcoming STORM project.

EXAMPLES OF APPLICATIONS

When established, this technology could also enhance operational synoptic-scale analysis and forecasting. For example, a number of "rules of thumb" used by forecasters are rooted in the dynamical equations for vertical motion (e.g., strong positive vorticity advection aloft; low level convergence/high level divergence). If a forecaster could monitor the vertical velocity field in real time, his successful warnings would be improved. It is during the critical zero to six hour time frame where credible forecasts of severe weather have the greatest impact on protecting life and property, and it is precisely in this time frame where continuous observations of the vertical velocity can help a station forecaster the most. Under current procedures, the raw radiosonde data are available an hour or two after the scheduled file time (00Z or 12Z), but centralized analyses of vorticity, divergence, or the most simple NWP model forecasts are not available for several hours. Then, for the next 12 hours the forecaster can only "adjust" these products based on the weather actually being

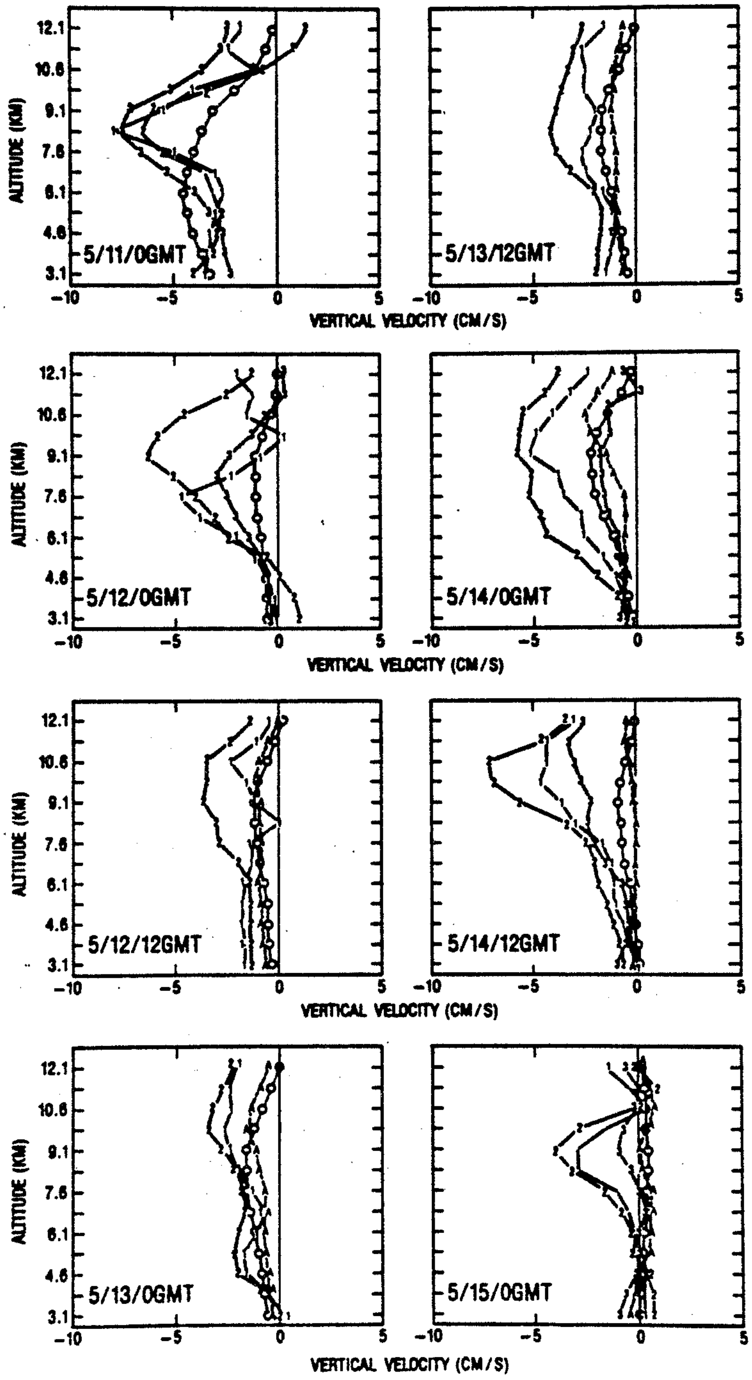

Figure 4. As in Figure 2, except radar data from 3 sites in France (ALPEX).

observed. With continuously available vertical velocity profiles he could monitor storm movement and development in real time -- the nowcasting approach. The application of vertical velocity data would extend beyond the single station forecaster to centralized use also.

On a centralized scale, the horizontal and vertical velocity data from a network of ST radars could be used to initialize and update regional NWP models (limited-area or window models). Present NWP are formulated to run without vertical velocity data because it is not available; they could be recast to take advantage of this new information, and might be improved in the process.

Of course, measurements of the synoptic-scale vertical velocity should also be useful for research purposes. A single station could provide time histories of the vertical motion in baroclinic storm systems, and over a period of months would permit more realistic descriptive models to be formulated. A network of ST radars might be used to estimate diagnostic variables such as fluxes of heat, momentum, or mass: or, perhaps more importantly, measurements of the vertical velocity would permit us to estimate other variables, such as diabatic heating rates, now only indirectly computed.

The list of possible applications for synoptic-scale purposes could be longer and another list of meso-scale applications could be given. However, I believe the case is already firmly made for anticipating the possible benefits of direct measurement of the synoptic-scale vertical velocity.

SUMMARY

In summary, results from ST radars in Colorado and France strongly suggest that the synoptic-scale vertical velocity can be detected. Before plans are made to exploit this capability in major field programs, the vertical velocity should be checked under more general conditions than previously possible -- perhaps with a brief experiment in the central plains states. Once convincingly demonstrated under general conditions, this new technology will improve our ability for synoptic-scale analysis and forecasting in both single station and centralized operations.

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