# Visualizing Atmospheric Fields on a Personal Computer: Application to Potential Vorticity Analysis

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## Abstract

A four-dimensional computer-analysis program for visualizing atmospheric fields on a personal computer is presented. The program can display, on screen, a fast-time animation of metorological fields on various surfaces or cross sections.

An example is given of the application of the program for a potential vorticity analysis in a deep polar air-mass intrusion in the Mediterranean. This example has been chosen for demonstration from several other previously investigated case studies. These studies involve a variety of standard, as well as nonstandard fields and have been used for teaching in the synoptic meteorology laboratory course at Tel Aviv University, and also for basic research.

## 1. Introduction

One of the major problems in grasping the full atmospheric structure, both from observation and model output, is the need to review a detailed spatial and temporal variation of various fields. These include, in addition to standard atmospheric fields, such as geopotential, temperature, humidity, etc., additional derived fields, such as vorticity, divergence, potential temperature, potential vorticity, and many others. In order to investigate the atmospheric situation at a given time we must look at each of these fields on several surfaces, e.g., isobaric, isentropic, and vertical cross sections. The number of surfaces/fields that has to be reviewed for a particular dynamic event increases sharply when the time dependency is considered.

In the course of studying the synoptic structures in the Mediterranean we have realized the need for a four-dimensional computer analysis program (4DCAP) which would meet the requirements stated in the preceding paragraph. The 4DCAP has color capability to distinguish among several fields, the ability to present these fields on any desired surface, and fast-time animation to capture the time evolution. A summary of existing similar programs for the display of meteorological information can be found, for example, in Grotjahn and Chervin (1984), Schlatter (1986), and Sherretz and Fulker (1988). The description of the current program appears in section 2. Section 3 illustrates the application of the 4DCAP for the investigation of an event of potential vorticity (PV) penetration in the eastern Mediterranean. The purpose of this section is to demonstrate a particular application of the 4DCAP in the study of a special nonstandard field on nonstandard surfaces.

## 2. Description of the 4DCAP

The input of the program consists of any data in gridded format from an analyzed observation set or from model output. We employ a CDC-990 mainframe computer for data storage and the computations of the various fields and surfaces, while the main task of preparing, displaying, and time-animating the output is performed by a IBM PC-AT with a color monitor. A fast-communication algorithm was developed to connect the CDC-990 to the IBM PC-AT, enabling the transfer of the information of a complete picture formed in a fraction of a second. This algorithm is based on a PC interrupt approach that activates communication whenever needed by executing a "terminate and stay resident" (TSR) program in the IBM PC-AT, while the latter is connected to the CDC-990 by a rather slow serial communication line of 4800-baud rate.

The 4DCAP can display several atmospheric variables on conventional and isentropic surfaces, as well as on vertical cross sections. The user can choose any two points in the domain which the cross section is made to pass through. The program then interpolates linearly the requested fields, and plots the topography with the desired resolution. Several fields can be shown on the same frame, using a combination of full, dashed, and dotted lines for the contours, each with a different color. The user can control the various parameters of the contour plotting and the contour interval, and can shade a requested range of values. Currently available fields (in addition to stan-

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dard fields) include potential temperature, vorticity, potential vorticity, divergence, and wind magnitude. New fields that the user may wish to investigate are readily programmed (in FORTRAN) into a "special field subroutine." Wind arrows on isobaric surfaces or on vertical cross sections have a size which is made to correspond to displacements for a requested period of time. An option for analyzing the total average fields, as well as the monthly/yearly averaged fields, is also available (see Alpert et al. 1989a, 1989b).

The 4DCAP can also display, in perspective, three spatial-dimensional bodies showing the folding properties of the variables (i.e., the fact that these variables are not single-defined on a horizontal surface, and therefore cannot be shown by the standard method of contours). Clouds offer a vivid example of such spatial bodies. We have therefore studied the body of relative humidity that exceeds 90% from the European Centre for Medium-Range Weather Forecasts (ECMWF) dataset, assuming that it represents the cloud body. For examples of averaged bodies of relative humidity, see Alpert et al. (1988). This option is currently only in monochrome.

The 4DCAP exhibits time-animation sequences automatically or manually. With the manual option the viewer can step forward and backward in time using the "left" and "right" arrow keyboard cursors. In addition, the "up" and "down" arrow cursors control the movement to upper and lower surfaces. In order to achieve a smooth animation sequence for analyzed datasets with a large time step, the 4DCAP has an option to interpolate the data in time to obtain a smaller time step. With the IBM PC-AT having a user-real memory of 1 Mbyte it is possible to show a sequence of 28 frames, i.e., 7 days with a 6-h time step, or 14 days with a 12-h time step. Currently, we work with the MS-DOS 3.3 operating system permitting access to 640 Kbytes of free memory and 384 Kbytes of extended memory, accessed by a virtual disk driver. We are now planning a memory extension, while the 4DCAP is being made compatible for the OS/2 operating system. Our configuration now includes an enhanced graphics adapter (EGA) card with its appropriate monitor having a 640 × 350-pixel resolution, with 16 colors out of a palette of 64 colors.

With a 10-MHz frequency, there appears to be no problem with the time required to load the frame from memory to the screen due to a fast employed algorithm, and a delay was devised for slowing down the sequence in the automatic mode. With the option of a zero delay, a time animation of 20 frames/sec is achieved. For viewing a larger number of frames, a provision for the direct loading of the frames from a hard disk is included. With the latter method, the sequences is slowed down to some extent, offering the possibility to view the dynamics of extended periods of more than 7 days [the only limitation being the free space on the hard disk (40 Mbytes in our case)]. A demonstration of the aforementioned capabilities was given at the Workshop on Graphics in Meteorology that was held at the ECMWF, Reading, England on 30 November–2 December 1988 (ECMWF 1988).

The following is a list of special characteristics of the 4DCAP:

1) easy access to a large multiyear dataset, including its time-averaged fields;
2) user-friendly choice of standard and nonstandard fields and cross sections;
3) straightforward access to a "special field subroutine" for the programming of additional special fields (of particular importance for research);
4) flexible choice of graphic display as, for example, number of fields, type of contour and its color, shading, interval, titles, and the color of background geography, topography, coordinates, etc.;
5) time animation with varying speed (up to 20 frames/sec) automatically or manually including the option to step to lower and upper surfaces when viewing horizontal sequences;
6) an option for perspective viewing of three spatial-dimensional bodies (monochrome); and
7) optimal distribution of the tasks between the mainframe (storage, calculations) and the IBM PC-AT (display, color, animation).

## 3. An example: deep polar air-mass penetration to the Mediterranean

In this section we illustrate the application of the 4DCAP method for the investigation of an event of potential vorticity (PV) penetration to the eastern Mediterranean (EM).

The concept of PV was originally introduced by Rossby (1940). PV is proportional to the absolute vorticity component normal to a potential temperature ($\theta$) surface, divided by the pressure difference ($\delta p$) between adjacent surfaces. In frictionless, adiabatic motion, PV is conserved on isentropic surfaces. When frictional and diabatic heating processes act, PV retains its value, to a good approximation, for a period of a few days, unless there is significant condensation. Isentropic PV maps are recognized as a natural diagnostic tool, well suited for making dynamical processes directly visible to the human eye and for making meaningful comparisons between atmospheric models and reality (Hoskins et al. 1985). Isentropic PV maps have been increasingly used in the diagnosis of observed atmospheric behavior (e.g., Danielsen et al. 1970; Uccellini et al. 1985; Hoskins and Berrisford 1988), and in the diagnosis of atmospheric model simulations (e.g., Hsu 1980; Dunkerton et al. 1981).

The isobaric and isentropic coordinate versions of PV, assuming hydrostaticity are

$$PV = -g\,(f\mathbf{k} + \nabla_p \times \mathbf{V}) \cdot \nabla_p\theta \qquad (1)$$

and

$$PV = -g\,(f + \mathbf{k} \cdot \nabla_\theta \times \mathbf{V})/(\partial p/\partial\theta) \qquad (2)$$

respectively, where $\mathbf{k}$ is the unit vertical vector, $\mathbf{V}$ is the three-dimensional (3-D) wind vector and $\nabla_p$ and $\nabla_\theta$ are the 3-D gradient operators in pressure (**P**) and isentropic $\theta$ coordinates, respectively, $f$ is the Coriolis parameter and $g$ the gravity constant. In the vertical cross sections Eq. (1) was applied, while for the isentropic maps we have adopted the isentropic formula (Eq. 2) which is more accurate in this case (B. Hoskins, personal communication 1988).

The event under consideration was characterized by an unusual deep polar air-mass intrusion to the EM reaching its extreme on 9–10 November 1982. The rainy weather, which persisted for a week in the beginning of November, supplied as much as 20% to 30% of the total annual precipitation at a time when the climatological rainy season had scarcely started. This event contributed to heavy rain in the inland stations (of particular interest in the semiarid areas) and was, in general, not forecast. Alpert and Reisin (1986) attempted to analyze the characteristics and dynamics of this unique event. Using conventional tools, they did not detect such features as tropopause folding and PV cutoff.

Figure 1 presents three time sequences of several fields on different surfaces, covering the period 7–11 November 1982, with a time interval of 12 h. The fields were analyzed from the ECMWF initialized analyses of the standard fields on seven mandatory levels with a horizontal grid interval of 2.5°. The left column of figure 1 shows the 315K isentropic PV (in brevity, IPV) and wind-vector arrows on the same isentropic surface projected over a Lambert conformal map centered over the EM. Values of IPV between 2 and 3 units (1 IPV unit $\equiv 10^{-5}$ m$^2$s$^{-1}$ K kg$^{-1}$) are shaded. The magnitudes of the wind-vector arrows represent 4-h displacements. This shading technique follows Hoskins et al. (1985), with the purpose of aiding the visibility of the transition from tropospheric to stratospheric air. At 0000 UTC 7 November (upper-left frame) a tongue of high IPV from northeastern Europe extends to the west reaching 10°E. Twelve hours later this tongue folds towards the east and its eastern portion is quickly advected with the strong winds of 25–30 m s$^{-1}$ above the north Caspian Sea at 0000 UTC 8 November. This maximum PV completely disappears on the next frame. The IPV tongue is now narrow and elongated and its edge is being cut off over west Turkey, and is advected to the EM on 0000 UTC 9 November, at the time when the extreme weather was reported in the region (see below). This particular maximum dissipates and does not appear in subsequent frames. However, a second maximum is the cutoff between the Black Sea and the Caspian Sea while the northern section of the tongue retreats to the northeast. This second cutoff is advected cyclonically in the *western* direction over Turkey, strengthening at 0000 UTC 10 November, and eventually dissipating 24 h later.

The right column of Figure 1 shows a vertical cross section along longitude 34°E of PV (full white) and potential temperature (dashed-dotted red). Values of PV between 1- and 1.5-PV units are shaded to represent mean tropopause values at midlatitides, Hoskins et al. (1985). The horizontal and vertical pressure coordinates extend from the equator to 60°N and from the ground to the top of the atmosphere. The topography is darkened at the bottom; one can notice the wide Anatolian ridge to the north of the Mediterranean basin (36°N–42°N), and the peak of Mount Sinai to its south (at ~29°N). The PV stratospheric extrusion positioned at a northern latitude at 0000 UTC 7 November (upper-right frame) gradually penetrates southward and downward reaching a most extreme extrusion at 0000 and 1200 UTC 9 November. Following Reed (1955) and Reed and Danielsen (1959) an extrusion of stratospheric air to the middle troposphere (500 to 700 mb) is considered to be a tropopause fold. From this date onward the intrusion weakens and rises. As with the classical cutoff cyclone in Peltonen's (1963) study, the tropopause dips down to at least 500 mb and the isentropes bow up in the troposphere towards the PV. This thermodynamic coupling is a necessary product for a balanced vortex structure as theoretically explained by Thorpe (1985). This structure persists throughout the PV penetration southward until the last frame (bottom right) at 0000 UTC 11 November.

In the middle column, the same vertical cross section at 34°E is presented, showing the wind vector in the vertical plane representing 6-h displacements (in green), in addition to the potential temperature (as in the right column). In order to obtain a general idea about the synoptic-scale moisture dynamics in the vertical cross section, the middle-column frames dis-

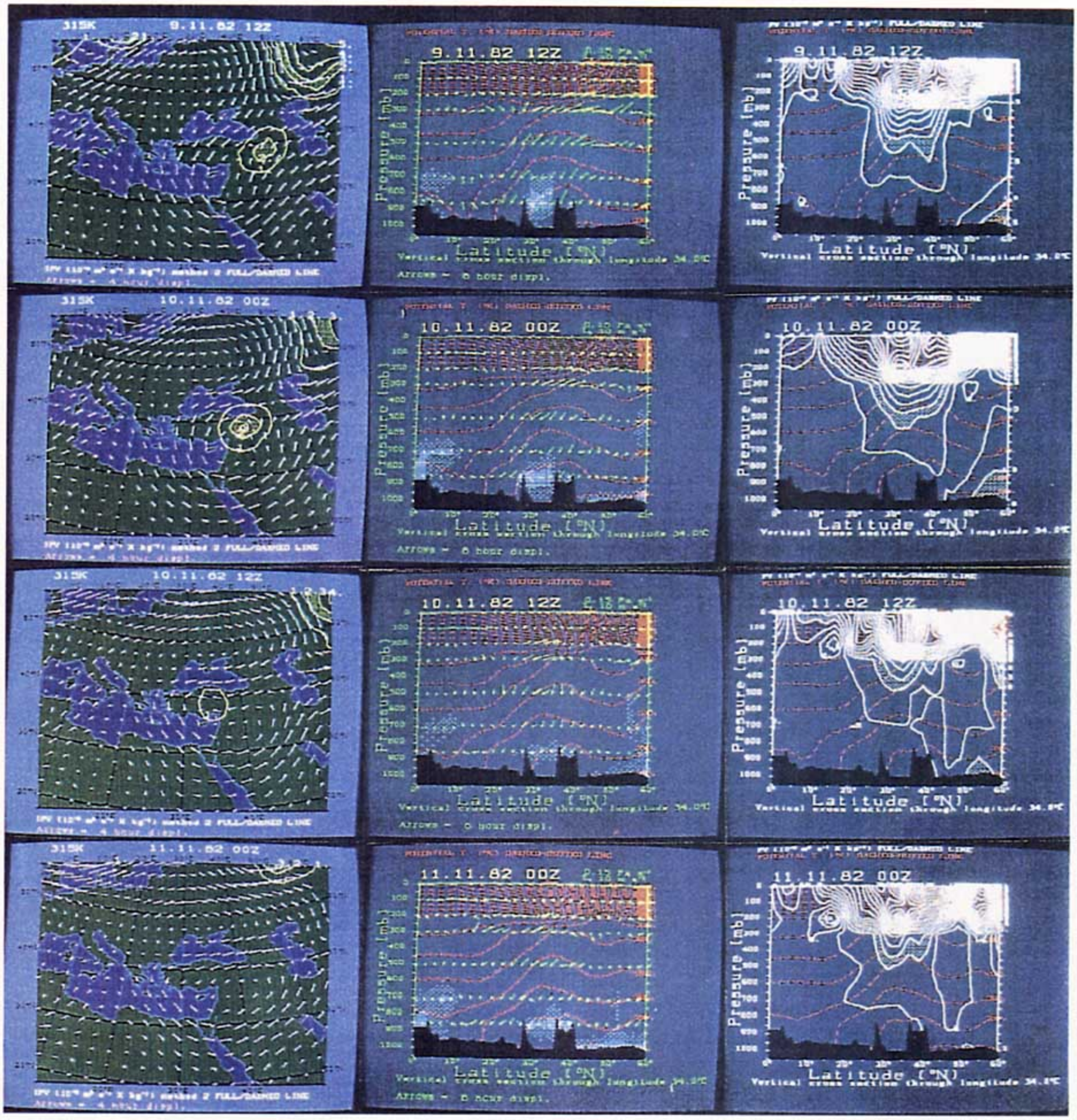


FIG. 1. Time sequences covering the period 0000 UTC 7–11 November 1982 with a time interval of 12 h of (left-hand columns) 315 K isentropic surface with PV contours (yellow) and wind-vector arrows (white) projected over a Lambert conformal map centered over the EM. Contour interval for PV is 1 PV unit. Values of IPV between 2 and 3 units (1 IPV unit $\equiv 10^{-5}$ $m^2s^{-1}K\ kg^{-1}$) are shaded. The magnitudes of the wind-vector arrows represent 4-h displacements; (middle columns)—a vertical cross section along longitude 34°E of wind vectors (green), potential temperature contours (dashed-dotted, red), and cloud of moisture (dotted shading, light blue, see text). The magnitudes of the wind vector arrows represent 6-h displacements. The contour interval for potential temperature is 10 K. The horizontal- and vertical-pressure coordinates extend from the equator to 60°N and from the ground to the top of the atmosphere. The topography (dark brown) is shown at the bottom; (right-hand columns)—same as middle cross section, showing PV contours (full, white) and potential-temperature contours (dashed-dotted, red). Contour interval for PV is 0.5 PV unit. Values of PV between 1 and 1.5 PV units are shaded (see text).

*(Figure 1 continued on following page.)*

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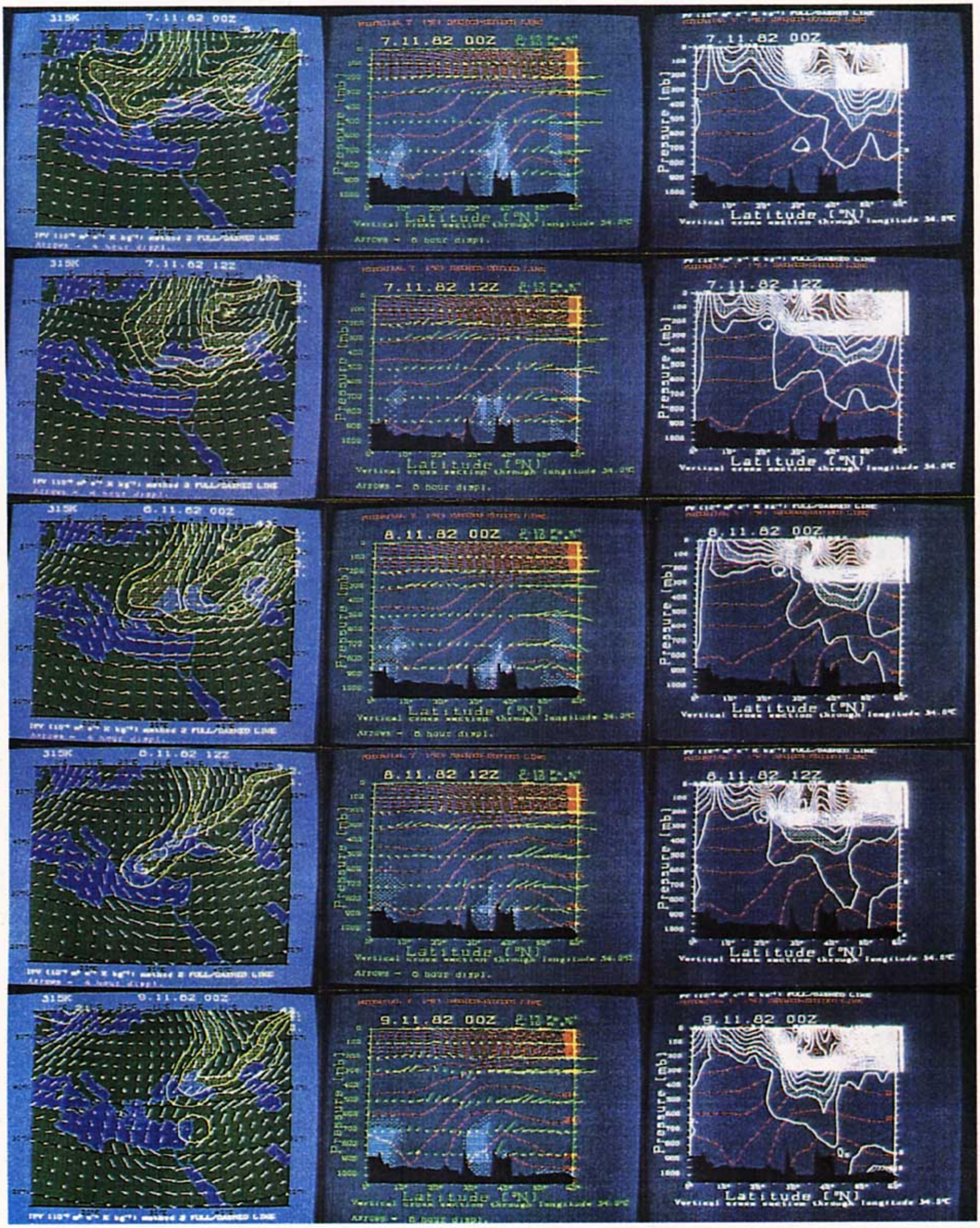
*(Figure 1 continued)*



play a gradually dotted shading of the relative humidity (above 75%), as given by the ECMWF initialized analysis. The dot density increases as the relative humidity rises.

At 0000 UTC 7 November a region of high moisture enwraps the Anatolian ridge (Turkey). Strong upward (northward) motion exists in this region contrasted by the downward (southward) winds to the north of the strong front as noticed by the sharp slope of the isentropes. As time evolves, this front, along with its cloud of moisture, gradually penetrates the Mediterranean basin. At 0000 UTC 9 November the moisture structure strengthens, probably in association with the high-maximum PV intrusion, as suggested by the right- and left-column frames for the same date. The most severe weather was reported at that time (see Alpert and Reisin 1986). From that time on, the southward (downward) flow of relatively cold air prevails in the Mediterranean basin and the moisture structure gradually becomes a shallow stratified layer.

On the computer screen, these time sequences portray a most vivid evolution enabling the viewer to grasp complex dynamic structures, otherwise difficult to detect. Switching the time animation on, the cloud of moisture comes into life and one can follow its movement and development. An example of another feature which can be detected with time animation, but which is difficult to discover otherwise, is a pulse of high winds on the 315 K IPV map series on figure 1 (left). This pulse rapidly moves from northeastern Europe at 0000 UTC 7 November towards Greece, then turning cyclonically eastward over Egypt in association with the aforementioned IPV climax at 0000 UTC 9 November.

## 4. Conclusions

In recent years, personal computers have been subjected to rapid technological advance, and, equipped with good graphical capabilities, they have become readily available at universities and research institutions. We have exploited the graphic capabilities of an IBM PC-AT for viewing meteorological data. Fast-communication software connects the IBM PC-AT with a mainframe computer employed for storage and number crunching. The main advantage of this system is its ability to compute and display on screen, in a time-animated sequence, various meteorological fields to be studied on various cross sections. We have focused in this paper on the potential vorticity, which, as demonstrated by several studies, may possess some advantages over standard meteorological fields. The PV example has been picked for demonstration in this paper from several other case studies which have been investigated, and which involve a variety of standard as well as nonstandard fields. It is expected that methods similar to the 4DCAP will increasingly become recognized as essential research tools, and perhaps also as diagnostic tools for forecasting, education, and other meteorological applications.

During the last year, the 4DCAP was used in the synoptic meteorology laboratory course at our department for the purpose of illustrating evolution of atmospheric dynamical fields. Judging from the enthusiastic reaction of the students participating in this course, we recommend the 4DCAP approach for teaching purposes.

Prospects for future work include adapting the program to a small computer unit not requiring a mainframe computer, thus enabling its availability in a broader user community.

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