A 4-Dimensional Computer Analysis Program for the Study of Atmospheric Dynamics

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October 1988

A 4-dimensional computer analysis program (4DCAP) is developed for the purpose of studying meteorological fields and conservative atmospheric properties from a database of analyzed observations and from the output of a mesoscale numerical model. The physical aim of the 4DCAP is the implementation of some recent conceptual models based on conservative atmospheric properties and complex interactions among internal dynamical processes for the study of midlatitude cyclone behavior, with special emphasis on the eastern Mediterranean (EM). The technical advantages of the 4DCAP are in providing a straightforward and fast method for viewing the meteorological fields on a PC screen in a sequence of time animation frames, showing the fields on standard isobaric surfaces, as well as on various cross-sections and on isentropic surfaces. For viewing 3-spatial-dimensional bodies, the 4DCAP employs a perspective viewing transformation which unlike most schemes is distance-conserving.

The input for the 4DCAP consists of:

1. A database obtained from ECMWF for the period November 1982 – December 1987, containing 1200 UTC and 0000 UTC analyzed fields of horizontal and vertical wind, temperature, relative humidity and geopotential height on a latitude/longitude grid of 2.5° covering the domain [0°–60°N, 0°–60°E] spanned on 7 mandatory isobaric levels.

2. The output fields of a 3-spatial-dimensions mesoscale model (PSU/NCAR) with grid interval of 20–50 km and 15 vertical levels currently under operational testing at Tel Aviv University.

The output of the 4DCAP includes:

1. Time animation of the variation of several atmospheric variables on conventional pressure levels and on vertical cross-sections. The user can choose any two points in the domain through which the cross-section is made to pass. The program then interpolates linearly the requested fields and plots the

topography with a resolution of 0.5°. Several fields can be shown on the same graph, using a combination of full, dashed and dotted lines for the contours. 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 standard fields) include: potential temperature, vorticity, potential vorticity, divergence and wind magnitude. 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 monthly/yearly averaged fields is also available.

In order to achieve a smooth animation sequence, the fields were interpolated between the available 1200 UTC and 0000 UTC data, to obtain a time step of 6 hours. With an IBM PC-XT compatible having a user memory of 640K, it was possible to show a sequence of 16 frames, i.e., 4 days with 6-hour time step, or 8 days with 12-hour time step. With a 10Mhz frequency, there appeared to be no problem with the time required to load the frame from memory to the screen address, due to a fast algorithm employed, and a delay was devised for slowing down the sequence. For viewing a larger number of frames, a provision for the direct loading of the frames from a hard disk was included. With this latter method, the sequence is slowed down to some extent, with the benefit of having the possibility to view the dynamics of extended periods of 10 days or more (depending on the size and free space on the hard disk). Currently, we are making use of the enhanced color graphics capabilities of an IBM-AT compatible at our disposal in order to extend the performance of the 4DCAP.

2. Perspective viewing (also in time-animation) of 3-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, and therefore, in order to illustrate the method, we looked at the body of relative humidity that exceeds 90% from the ECMWF dataset, which was assumed to represent the cloud body.

A brief description of the algorithm follows: The domain is divided into vertical columns, the size of the horizontal grid size of the data. Through each column, a linear interpolation is made to find the existing range or ranges of the spatial body. The program then prepares a set of visible (from the given viewing angle) surfaces of the body (identified by 3-dimensional points connecting the surface). A constant viewing *angle* approach is employed, rather than fixing a viewing *point*. This has the advantage of conserving distances, rather than decreasing the distances of far-away objects. Although the latter may be an advantage for artistically conveying the feeling of perspective to the viewer, we feel that the constant viewing angle approach is superior for scientific illustration of rather abstract dynamical bodies, whose size must be kept independent of their location.

A fast hidden surface algorithm is employed to sort the surfaces, such that hidden surfaces are drawn first on the computer screen, and subsequent surfaces obscure their view. The algorithm is rather fast, requiring on a 10 Mhz PC-XT only a few minutes (depending on the number of bodies found) for the whole domain of [0°–60°N, 0°–60°E] described above. The present study will focus in its later stages on 4-dimensional analysis of conservative properties, as the potential vorticity (PV), for the physical reasons given in detail below.

3. We plan to include graphic representation of meteorological features as jet streams and circulations, regions of latent-heat release and graphic diagnosis of several terms and residuals in the basic forecasting and energy equations, also in animation and perspective viewing.

The concept of potential vorticity was originally introduced by Rossby (1940). PV is proportional to the absolute vorticity component normal to a potential temperature (θ) surface, divided by the pressure difference (δp) 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. The significance of PV does not end with its importance as air mass tracer, but is also a key to a very powerful view of the dynamics. The invertibility principle of PV (e.g., Hoskins et al., 1985) guarantees that, under balance conditions, the distribution of PV along with the low level θ-distribution (and information on the total mass in isentropic layers) is sufficient to give all the standard meteorological fields (horizontal and vertical wind, temperature, and geopotential height) everywhere. Isentropic PV maps, in particular, are recognized as a natural diagnostic tool well suited to making dynamical processes directly visible to the human eye and to 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; Bleck, 1973; Holopainen and Rontu, 1981; McIntyre and Palmer, 1983, 1984; Bleck and Mattocks, 1984; Uccellini et al., 1985; Al-Ajmi et al., 1985; Clough et al., 1985, Hoskins and Berrisford, 1988), and in the diagnosis of atmospheric model simulations (e.g., Hsu, 1980; Dunkerton et al., 1981).

The 4DCAP approach, permitting fast computer analysis leading to a perspective viewing of the spatial distribution with animation for the time dependence, may be ideally suited to grasp the complex PV interactions present on cyclogenetic events, and contribute to their understanding. The 4DCAP has already proved to be an important research tool for our research team at Tel-Aviv University, currently involved in the investigation of the physical processes responsible for midlatitude cyclone development, and, in particular, on cyclogenesis in the EM. The EM is clearly a cyclogenetic region and the available large-scale weather prediction models tend to underestimate or ignore cyclonic development in this region, as was discussed in detail by Alpert and Warner (1986). Preliminary results appear in Alpert et al. (1988).

Methods for the 4-dimensional computer analysis of meteorological fields, such as our 4DCAP, may also provide a general contribution for the field of synoptic weather forecasting. Although much progress has been achieved in recent years in numerical forecasting, there are numerous examples of numerical underestimate and failure to forecast cyclonic intensification. Hoskins (1983) has warned against the unhealthy situation in which there is little contact between theoretical modeling on the one hand and observations and complex numerical modeling on the other hand. It has been suggested that synoptic analysis should begin to play a fuller part again (e.g., Hoskins, 1983; Keyser and Uccellini, 1987). Methods as the 4DCAP may offer a powerful synoptic analysis tool for testing recent conceptual models and evaluating the prediction capabilities of computer-models.

References

Al-Ajmi, D. N., Harwood, R. S. and Miles, T., 1985: A sudden warming in the middle atmosphere of the southern hemisphere. *Quart. J. R. Met. Soc., 111*, 359-389.

Alpert, P., B. U. Neeman and Y. Shay-El, 1988: Some characteristics of Mediterranean circulations.

Preprints, Palmén Memorial Symposium on Extratropical Cyclones, Amer. Meteor. Soc., Helsinki, 282-285.

Alpert, P. and Warner, T. T., 1986: Cyclogenesis in the Eastern Mediterranean. *WMO/TMP Report Series No. 22*, 95-99.

Bleck, R. and Mattocks, C., 1984: A preliminary analysis of the role of potential vorticity in Alpine lee cyclogenesis. *Beitr. Phys. Atmos.*, *57*, 357-368.

Bleck, R., 1973: Numerical forecasting experiments based on the conservation of potential vorticity on isentropic surfaces. *J. Appl. Meteor.*, *12*, 737-752.

Clough, S. A., Grahame, N. S. and O'Neill, A. 1985: Potential vorticity in the stratosphere derived using data from satellites. *Quart. J. R. Met. Soc. 111*, 335-358.

Danielsen, E. F., Bleck, R., Shedlovsky, J., Wartburg, A., Haagenson, P. and Pollock, W., 1970: Observed distribution of radioactivity, ozone, and potential vorticity associated with tropospheric folding. *J. Geophys. Res.*, *75*, 2353-2361.

Dunkerton, T. J., Hsu, C.-P. F, and McIntyre, M. E., 1981: Some Eulerian and Lagrangian diagnostics for a model stratospheric warming. *J. Atmos. Sci.*, *38*, 819-843.

Holopainen, E. O. and Rontu, L., 1981: On shear lines in the upper troposphere over Europe. *Tellus*, *33*, 351-359.

Hoskins, B. J. and Berrisford, P., 1988: A potential vorticity perspective of the storm. *Weather* (accepted for publication).

Hoskins, B. J., 1983: Dynamical processes in the atmosphere and the use of models. *Quart. J. R. Met. Soc.*, *109*, 1-21.

Hoskins, B. J., McIntyre, M. E. and Robertson, A. W., 1985: On the use and significance of isentropic potential vorticity maps. *Quart. J. R. Met. Soc.*, *111*, 877-946.

Hsu, C.-P. F., 1980: Air parcel motions during a numerically simulated sudden stratospheric warming. *J. Atmos. Sci.*, *37*, 2768-2792.

Keyser, D. and Uccellini, L. W., 1987: Regional models: Emerging tools for synoptic meteorologists. *Bull. Amer. Meteor. Soc., 68*, 306-320.

McIntyre, M. E. and Palmer, T. N., 1983: Breaking planetary waves in the stratosphere. *Nature, 305*, 593-600.

McIntyre, M. E. and Palmer, T. N., 1984: The 'surf zone' in the stratosphere. *J. Atm. Terr. Phys. 46*, 825-849.

Rossby, C. G., 1940: Planetary flow patterns in the atmosphere. *Quart. J. R. Met. Soc., 66*, Suppl., 68-87.

Uccellini, L. W., Kocin, P. J., Petersen, R. A., Wash, C. H. and Brill, K. F., 1984: The President's Day cyclone of 18-19 February 1979: synoptic overview and analysis of the subtropical jet streak influencing the precyclogenetic period. *Mon. Wea. Rev. 112*, 31-55.