FACTORS AFFECTING THE SEVERITY OF THUNDERSTORMS AND THEIR RELATIONSHIP WITH AGRICULTURE

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Abstract *The severity of a thunderstorm can be judged in many ways. The main area of focus on this study is, however, its dynamical intensity, which can be expressed in terms of the strength and lateral dimensions of the vertical drafts. Related to these criteria are other factors, such as penetration of the updraft above the tropopause level, the strength of the surface winds, and to some extent, the maximum hail size. Surface rainfall, conversely, is not always well correlated with dynamical intensity, nor is lightning frequency. It is as such, quite probably justifiable to think of the dynamical severity in many cases as being related to the degree of steadiness of the dynamical organization. Although it has long been recognized that severe thunderstorms are favoured by strong convective instability, abundant moisture at low levels, strong wind shear usually veering considerably with height, and to some extent, a dynamical lifting mechanism, that can release instability. By analysing the main components, the vertical thermodynamic structure, the wind shear and veer and the amount and type of precipitation, forecasters are able to correctly predict the needed actions in order to mitigate severe weather events and to secure agriculture and agriculture-related industries. This paper discusses the aggravating factors of thunderstorms from a theoretical point of view with regard to agriculture, especially to the situation in the western and north western part of Romania.*

Keywords*: thunderstorms, agriculture, severe weather events, hail, squalls*

INTRODUCTION

The dynamical building block of a thunderstorm is the cell, which is a compact region of relatively strong vertical air motion. The usual way of identifying the overall extent of cells is by visual observations of cumuliform turrets during early stages of their evolution before the development of precipitation and, thereafter, by radar observations of the associated volumes of precipitation. As such, most thunderstorms are composed of short-lived units of convection. The lifetime of an individual cell averages about an hour, during which time it may travel around 20 km in the direction of the upper winds in which it is embedded. A storm consisting of a sequence of such cells may, however, persist for several hours.

A thunderstorm consists of three stages, mainly named cumulus stage, mature stage and dissipating stage.

The cumulus stage in cell development is characterized by updrafts throughout. They cause the cell to grow upward as entrainment of drier ambient air takes place across its boundaries. As the cell builds up, a large amount of moisture condenses and precipitation particles grow. The precipitation begins descending and an associated downdraft starts to develop. The mature stage is characterized by precipitation reaching the ground. An updraft and downdraft coexist side by side, the downdraft being best developed in the lower portions of the cloud. The downdraft brings cold air in the rain area toward the ground, where it produces a diverging pool of cool air. The leading edge of the cloud air forms a micro-cold front, characterized by an abrupt change of temperature and wind direction, but also an increase in pressure. Above this outflow, new cells tend to develop.

The cell enters the dissipating stage when the updraft is replaced by a downdraft. This spreads throughout the entire cell and then weakens and disappears. At the same time, the cold dome of downdraft air near the surface subsides and the winds decrease. Supercells are mainly recognized by certain characteristics, both visual and by using remote sensing equipment. Most basic distinguishing feature is the circulation that is not only large and intense but also virtually steady state, with updraft and downdraft coexisting to each other's advantage for a long period of time, mainly for more than 30 minutes. As such, the nature of an individual thunderstorm complex is determined by the number, type, distribution and mode of propagation of the cells from which it is built. Some storms contain only one kind of cell. Others contain a mixture of ordinary cells or a supercell of long duration. Multicell storms and line storms consist of a number of cells, with successive cells usually forming on the right flank as viewed along the direction of travel of the storm.

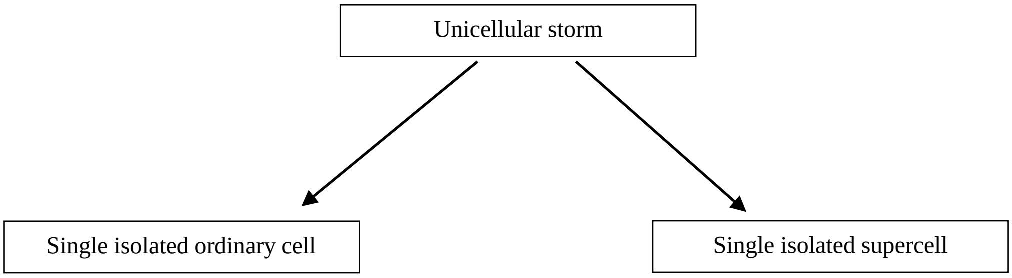

Fig. 1. Classification of thunderstorm types

Figure 1 shows a simple classification of thunderstorm types. The primary classification relates to the basic cell type, which is either single isolated ordinary cell or single isolated supercell. The main distinction between single isolated ordinary cells and single isolated supercell is the presence of a vertical rotating flow of air, the mesocyclone. This distinction, in the case of supercells gives the strength needed in order for tornadoes to form.

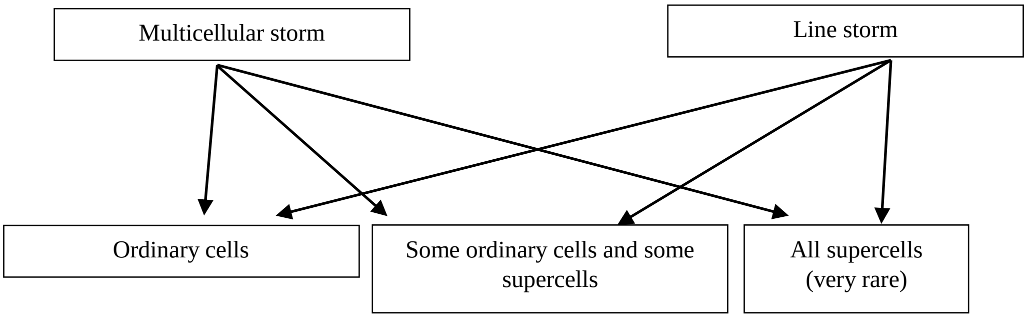

Fig. 2. Classification of thunderstorm complexes

Another distinction which is to be made, is the one between multicellular storms and line storms. The multicellular storms are also known as compact cluster of cells, while line storms are laterally aligned cells (fig. 2)

MATERIALS AND METHODS

This study is meant to be a hybrid between theoretical and operational meteorology. By discussing the main physical characteristics of thunderstorm thermodynamics and combining them with operational meteorology classifications and forecasting techniques, agriculture-related severe weather is to be determined. The most discussed aspect is strongly bound to both thermodynamics and agriculture, in means of tornado genesis and air column stability. By using extensive operational bibliography together with operational observations, some measurements are presented in order to bring into attention the hazard imposed by both non-tornadic and by tornadic supercells.

RESULTS AND DISCUSSIONS

The importance of strong convective instability, resulting from cold air aloft and high humidity air at low levels, is obvious. As such, all kinds of severe thunderstorms tend to be associated with temperature excess of 4°C or more at the 500 hPa level (MARWITZ, 1972). A little less obvious but nevertheless important for severe convection is the existence of a lid of warm dry air capping the boundary layer. A stable lid near the 800 hPa level is also a feature of the environment for thunderstorms producing large hail (FAWBUSH & MILLER, 1953). Air parcels lifted from the surface can be seen to acquire very large temperature excesses when lifted above the lid. Such a lid has the effect of inhibiting premature release of convective instability and enables a high wet bulb potential to build up at low levels. This sets the stage for the development of vigorous deep convection when the air at the low levels is subjected to large-scale ascent (CARLSON & LUDLAM, 1968). Vigorous convection is particularly likely to occur where the air at low levels flows out from under the lateral boundary of the lid. Even when a strong lid is not present, however, the boundary layer may still be influenced by vigorous entrainment of relatively dry warm air at its top associated with strong buoyancy generation of turbulence. As a result, the boundary layer, which is typically 2 km deep in thunderstorm situations, is characterized by a weak increase in virtual potential temperature with height (except for the super adiabatic layer within 100 to 200 meters of the ground) and a substantial decrease in mixing ration with height. Thus, it is quite usual on thunderstorm days for the air with the highest web bulb potential to be situated at the lowest levels despite the existence of slight static stability.

Differential advection often further increases the vertical gradient of moisture near the ground. Together these factors cause the lifting condensation level and the convective instability to depend critically on whether a surface value of moisture or a layer-averaged value is applicable. Established updrafts can transfer high wet bulb potential air from near the surface to cloud base with negligible modification by entrainment, in which case the near-surface value of the mixing ration is applicable. On the other hand, the initiation of fresh convection is likely to depend more on the average characteristics of the convectively stirred boundary layer. Thus, the large lapse of mixing ratio offers a distinct advantage to establish convection. By inhibiting the initiation of deep convection that might otherwise compete with any existing thunderstorm updraft, this helps an existing storm to remain intense and more nearly steady state. Boundary layer subsidence which is sometimes produced ahead of intense storms can have a similar effect (BARNES, 1978).

Another factor that appears to influence thunderstorm severity is the nature of the vertical wind shear. The weak-shear hodograph indicates a short-lived thunderstorm, which consists of a single ordinary cell. As such, it is also probably representative of poorly organized multicell storms that do not become intense.

Strong shear hodographs are characteristic of severe hail-producing thunderstorms, as such a multicell cluster or even a supercell. The importance of strong shear is that, for a storm cell traveling at the speed of the wind in the middle troposphere, the low-level air has a strong component of relative motion toward the approaching storm.

This means that the magnitude of the inflow can be properly matched by the magnitude of the buoyant updraft. In the absence of suitable shear, the inflow will be insufficient to sustain any vigorous updraft that might result from large thermal instability. These ideas have been expressed quantitatively in terms of a bulk convective Richardson number (MONCRIEFF & GREEN, 1972).

The Richardson number is defined as the ratio of available potential energy produced by buoyancy to available kinetic energy produced by shear (MONCRIEFF & GREEN, 1972). A low value of the Richardson number owing to strong to strong lo-level shear accompanying strong thermal instability favours maintenance of a vigorous and nearly steady-state convective circulation. The importance of this kind of Richardson number as a criterion for the possibility of development of a quasi-steady supercell storm is further supported.

A strong tropospheric wind shear, although necessary for a persistent storm, is not the only factor that determines whether a steady-state supercell will develop. The most significant differences in the wind profile associate with supercell and multicell storms is the strength of the sub cloud winds and the amount of veering with height, especially at low levels.

The mean sub-cloud environmental wind associated with supercells is greater than 10 ms^{-1}, and its direction is backed by more than 60 degrees with respect to the mean environmental wind. The development of precipitation has a major effect on the dynamics of thunderstorms. Both fall speed differences of different precipitation particles and terminal fall speed changes of a given population of particles can lead to accumulation of precipitation in certain parts of a storm.

Although precipitation concentrations as high as 20 to 30 gm^{-3} probably do not occur extensively, large volumes with concentrations of up to $10gm^{-3}$may be common (SULAKVELIDZE et al., 1967). Drag produced by a $4gkg^{-3}$ of precipitation would have an effect equivalent to the negative buoyancy associated with a virtual temperature deficit of 1°C.

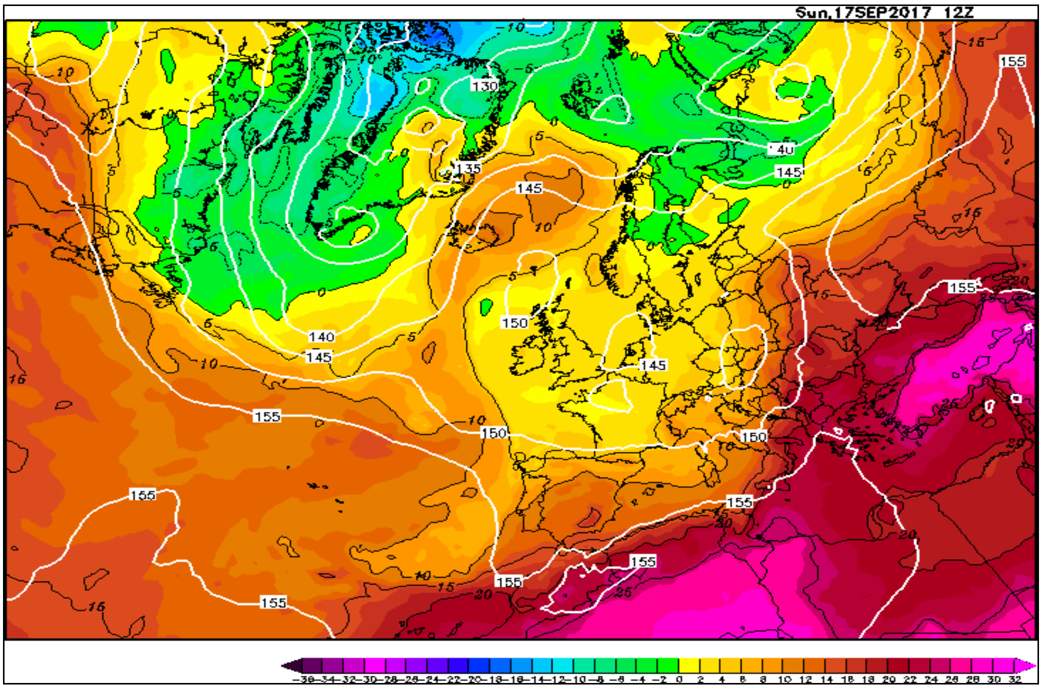

Fig. 3. Temperature and geopotential height at 850 hPa for 17th of September 2017, 12.00 UTC

In the case of the instability which affected the western part of Romania on the 17th of Septmeber 2017, it is noted that the temperature gradient enhanced the instability conditions and thus wind speed reached 30 to 35 ms^{-1} at Timişoara weather station (figure 3).

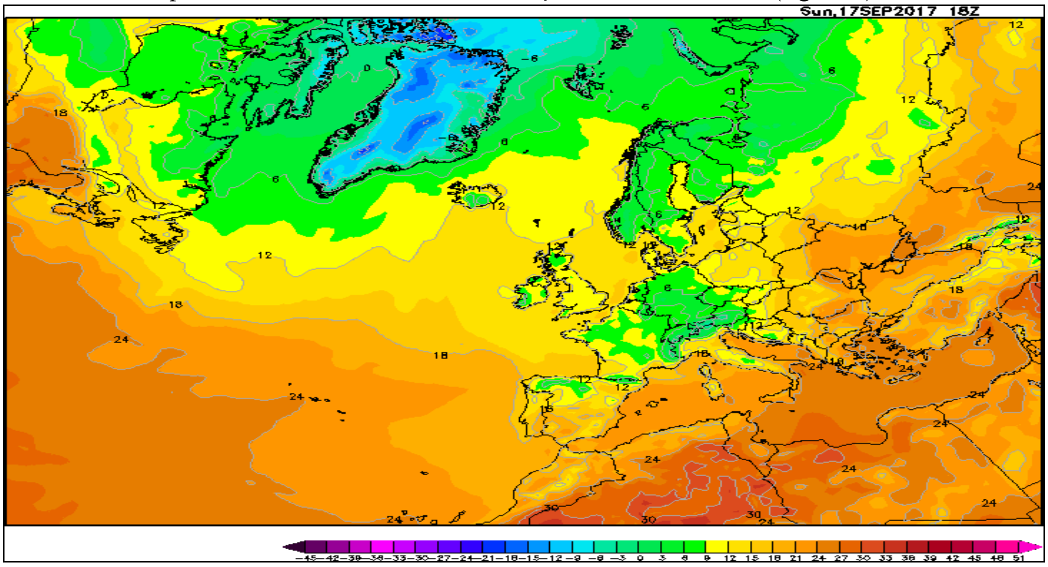

Fig. 4. Temperature at 2 meters, 17th of September 2017, 18.00 UTC

The temperature difference which was observed after the passing of the cold front is to be observed in figure 4. As such, these differences imply an fast increase of speed with regard to the downward movements of the air.

Such a mixing ratio corresponds to a concentration of only around $3gm^{-3}$ in the lower troposphere and around $2gm^{-3}$ in the upper troposphere. Thus water-loading effect can significantly impede an updraft or, alternatively, help sustain a downdraft. The evaporation of the precipitation will further intensify a downdraft by chilling it. The generation of a strong downdraft in turn stimulates the development of an adjacent updraft, which may become intense, especially if the two can coexist side by side without mutual interference. Development of severe thunderstorms therefore require that the storm can become organized in such a way as to:

1. Minimize the accumulation of precipitation in the updraft;
2. Facilitate the transfer of precipitation from the updraft where it is generated into adjacent downdrafts that can be fed continuously with dry and potentially cold air;

One way of minimizing water loading in the updraft is for the updraft to pe inclined. Mathematical models suggest that in the case of an essentially vertical updraft of moderate intensity the development of high concentrations of precipitation is likely temporarily to convert the updraft into a downdraft (SRIVASTAVA, 1967). As such, further development of precipitation accompanying regenerations of the updraft then repeats the cycle, and a pulsating circulation is produced resembling the succession of updrafts in an ordinary multicell storm. In an inclined updraft, however, the amount of water loading is decreased because the horizontal component of the motion of the updraft air relative to the motion of the cell carries the precipitation across the updraft and this limit the residence time of particles within it (BROWNING, 1962). If an updraft is inclined in the up-shear direction, then the precipitation falling out of the rear can generate a strong downdraft, provided the shear enables cold, dry middle-level air to enter the downdraft region and sustain it. The concept of a combination of wind shear and a tilted updraft enabling the updraft and downdraft to be maintained continuously without serious interference, thereby enhancing the overall energy of the storm (BROWNING & LUDLAM, 1962). When the inflow approaches the right flank of the storm, the most of the precipitation falls out on the left flank. This gives rise to a stable side-by-side, updraft-downdraft couplet, however the basic requirement for the water-loading effect to be transferred from the updraft to the downdraft is still fulfilled.

Another way of minimizing precipitation accumulation in the updraft is for the conversion of cloud water into precipitation to proceed inefficiently (MONCRIEFF & GREEN, 1972). One indication of this kind of inefficiency is the presence of what is known as a weak echo vault. Because radar echo from a thunderstorm is caused by precipitation grown in an updraft, meteorologists for a long time tended to identify radar echo too closely with the actual updrafts, apparently forgetting that there is a lag between initial condensation in the updraft and development of radar-detectable precipitation. It was signalled that a vault-shaped region of weak echo in the core of severe thunderstorms are to interpreted as symptoms of intense updrafts (BROWNING & DONALDSON, 1963). Updrafts in these vaults are so strong, although they are filled with cloud, precipitation does not have time to form within them before the air in the updraft has risen to very high levels. As such, any precipitation formed in weaker updrafts on the flanks of the vaults does not have any opportunity of penetrating into them. Later research has concluded that vaults are common in the more severe storms in very specific environment. As such, those type of storms have to be supercell severe storms (DENNIS, 1971). The presence of a well-developed vault, much of the cloud water is exhausted into the thunderstorm anvil as small ice crystals. Thus, the overall precipitation efficiency, defined as the ratio of the surface precipitation output to the water vapor input can be very low in vaulted supercell storms. It would be wrong to assert that this could be the sole cause of this kind of organization, for it must be remembered that it is because of the intense and relatively sustained nature of the updraft that a vault is able to develop in the first place. However, it seems that there is an important feedback mechanism that, along with rotation, helps make a supercell different from an ordinary cell to some extent in kind as well as in degree.

Besides significant amount of precipitation, damaging wind gusts and hail, another risk imposed by thunderstorms upon agriculture is the formation of tornadoes (GRANDIA & MARWITZ, 1975). They develop within regions of vertical vorticity that are associated sometimes with the sheared boundaries of updrafts, especially at the updraft-downdraft interface and sometimes with rotation of the entire updraft. Most severe tornadoes appear associated with rotating updrafts. There are also many updrafts that rotate without producing tornadoes. Significant rotation of the updraft as a whole is confined mainly to supercells. The updraft in a severe-right moving supercell (SR supercell) rotates cyclonically. Visual observations sometimes show cyclonic rotation of the main cloud base (BARNES, 1970), and occasionally also of the updraft column (DAVIS-JONES et al., 1976). The rotation is thought to account for the development of the characteristic radar hook echo as precipitation particles descend through it. More strictly, it is the interaction between a cyclonically rotating updraft and a downdraft that yields the hook shape. The origin of cyclonic rotation within an updraft is attributed to the tilting of the horizontal component of vorticity in the inflow. The strong veer of the wind with height in the relative low-level inflow gives a component of vorticity along the mean inflow direction that can be as great as $1*10^{-2}s^{-1}$ (MĂRĂZAN, 2018). It is to note that the component is measured relative to the moving storm cell, it therefore becomes larger after the onset of rightward cell motion, so that the anomalous motion of a supercell may in fact lead to increased rotation of the updraft rather than be the result of it.

CONCLUSIONS

The aim of this study was to present both a theoretical as well as a practical approach to agriculture-related severe thunderstorms. By complying theoretical thermodynamics with operational meteorology and agrometeorology, the main objective was to determine the factors that account for agriculture-related severe weather, especially for tornado genesis and supercell formation and structure. Another aspect discussed in this paper is the location of the precipitation inside a supercell and the role of the vault in supercell dynamics. Of course, more research is needed for better understanding the dynamics of thunderstorms, especially thunderstorms-related hazards in a changing climate.

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