AN ATMOSPHERIC THERMODYNAMIC MODEL OF THE CONVECTIVE STORM PROCESS TYPES IN MENDOZA (ARGENTINA)

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Abstract: The DCPIM (Deep Convection Process Identification Model) index uses only surface meteorology data to forecast the convective storm class of Mendoza (Argentina). The DCPIM model did not guess right the forecast in about five percent of the studied cases. Then in order to improve the forecast model, we are adding vertical atmospheric information at the index calculation using the radiosonde on Santiago (Chile) and El Plumerillo (Mendoza). This index is calculated by correlating four surface variables: pressure P_S (mb), temperature T_S (°C), dew point DP_S (°C) and ground ultraviolet solar radiation index UV. Furthermore, two additional atmospheric variables at the 500 mb level were considered: temperature T_{500} in °C, and dew point DP_{500} in °C at 500 mb pressure level. The data was taken from radiosonde over Mendoza and Santiago (Chile). We collected 1551 samples, between September 2007 and April 2008. These data were statistically processed, obtaining a multivariate model for each storm convective process class (TPC) in Mendoza. From this correlation, we can observe that the class and severity of the storm convective process do not depend on the dew point at the 500 mb level (DP_{500}), but depend on surface dew point value. This is associated with the fact that the vertical ascendant movement of the circulating air feeds the storm process carrying the water vapor from the ground to upper levels. Moreover, the class and severity of the convective process depends on the vertical temperature difference between both levels T_S and T_{500}, and is associated with the heat flux transfer by thermal conductivity and natural convection. We conclude from the above result, that for higher values of the temperature difference and surface dew point, a more complex and severe storm convective process in Mendoza is expected. The thermodynamic calculations performed by the multivariate model were consistently compared with GOES satellite image, the C and S band radar, and its TITAN system.

1. INTRODUCTION

During the validation of the DCPIM index (Pérez and Puliafito, 2007), we find that during 5% of the studied cases the calculation failed to give a proper forecast. Therefore we began deeper research work in order to explain or improve the DCPIM model.

The previous version of the DCPIM index was developed only with surface meteorology data: surface pressure P_S (mb), surface temperature T_S (°C), surface dew point DP_S (°C) and ground ultraviolet solar radiation index UV. Therefore, vertical atmospheric variables at the 500 mb level from radiosonde launches (Mendoza, Argentina and Santo Domingo, Chile), were considered in the model. This study used 1551 samples from September 2007 to April 2008. These data were to improve the prediction ability of the storm convective process in Mendoza.

2. HYPOTHESIS

In order to complement the results of our previous research in the DCPIM work, we assumed that the storm convective process class does not depend only on surface conditions, but also strongly on 500mb atmospheric variables. This atmospheric pressure level is roughly coincident with the mean altitude of Los Andes Mountains. Every atmospheric system that comes from the west (Chile), passes over Mendoza at 500 mb, with the consequent production of mountain waves. Moreover the relationship between both levels (surface and 500 mb) is a strong indication of the convection possibility in Mendoza, and thus a way to improve the DCPIM results and the storm convective forecast model.

3. METHODOLOGY AND EQUIPMENT

Data sources used were as follow:

- **The web site www.weather.co:**

In this web site it is possible to find hourly surface meteorological data of Mendoza, measured at El

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Plumerillo Airport. We obtained the following surface data: dew point (R), atmospheric pressure (P), temperature (T) and the ultraviolet solar index (UV).

- **The web site www.contingencias.mendoza.gov.ar/rada:**

Here on-line TITAN system images from the radars of Mendoza are available. These images are upgraded every five minutes (Figure 1). From this site, it is possible to characterize and classify the convective process of Mendoza and also obtain important parameters like the maximal reflectivity.

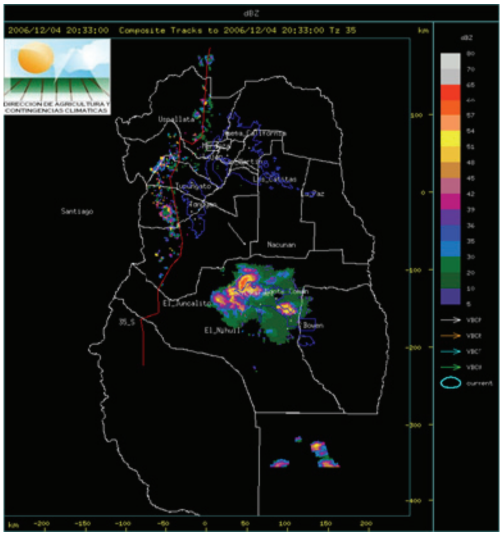

Fig. 1. www.contingencias.mendoza.gov.ar/radar web page with the TITAN systems images of Mendoza. The blue lines on the map show the limits of the hail defense area.

- **The web site www.meteofa.mil.ar:**

On this web site it is possible to access the GOES-12 satellites images (Figures 2 and 3).

- **The web site www.weather.uwyo.edu/upperair/sounding.htm:**

This page shows the radiosonde data. From this site we get all radionsonde information for both stations at Santiago de Chile and Mendoza (Argentina).

All this information was used to correlate the vertical sounding meteorological data, surface and 500 mb level information with the storm convective class present each day. The data was compiled in order to find a statistical relationship between them. For this study we have used surface hourly data and daily vertical data between September 2007 and April 2008.

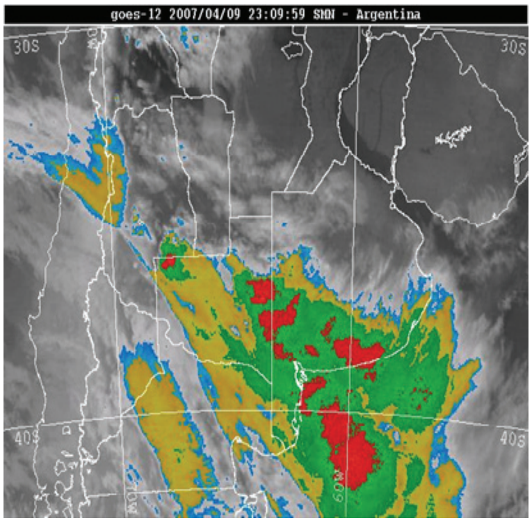

Fig. 2. www.meteofa.mil.ar web page with the GOES-12 image in the infrared frequency band.

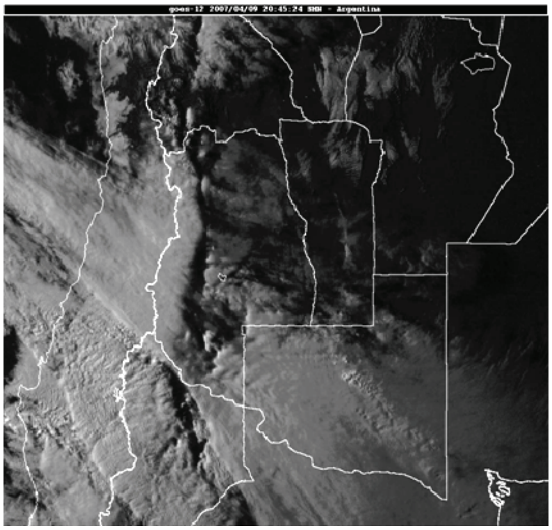

Fig. 3. www.meteofa.mil.ar web page with the GOES-12 image in the visible frequency band.

4. RESULTS

4.1 Statistical analysis

The correlation of surface and vertical information provided the estimation of a new index. This index was calculated by correlating four surface variables: pressure P_S (mb), temperature T_S in (°C), dew point DP_S (°C) and ground ultraviolet solar radiation index UV, and two additional vertical atmospheric variables at the 500 mb level. These were: temperature T_{500} (°C), and dew point DP_{500} (°C) at the 500 mb pressure level taken from radiosonde data over Mendoza and Santiago (Chile). The reasons for this choice are:

1. The 500 mb. level is coincident with the dumping of the west wind that come from Chile over Los Andes.
2. The previous studies determined that only temperature T_{500} and P_{500}, of all 500 mb level parameters have important correlation with the storm convective process class.

The data were statistically processed (Table 1 and Table 2); obtaining a multivariate model for each storm convective process class (TPC) in Mendoza.

A multiple linear regression fits the following relation between TPC and 3 independent variables:

$$TPC = -1.22422 + 0.0339936 \times T_S - 0.012635 \times T_{500} + 0.0896674 \times DP_S \quad (1)$$

$$TPC = -1.22422 + 0.012635\,(2.69 \times T_S - T_{500}) + 0{,}0896674 \times DP_S \quad (2)$$

The P-value in the ANOVA is less than 0.01, meaning that there is a statistically significant relationship between the variables at the 99% confidence level. The R-Squared statistic indicates that the model as fitted explains 34% of the variability in TPC. The adjusted R-squared statistic, which is more suitable for comparing models with different numbers of independent variables, is also 34 %. The standard error is 0.80 and shows the standard deviation of the residuals. The mean absolute error (MAE) of 0.63 is the average value of the residuals. The Durbin-Watson (DW) statistic tests the residuals to determine if there is any significant correlation based on the order in which they occur in the data file. Since the DW value is less than 1.4, there may be some indication of serial correlation. Since the P-value is less than 0.01, the highest order term is statistically significant at the 99% confidence level. Consequently, it is convenient not to remove any variables from the model.

Table 1: Multiple Regression Analysis

Dependent variable: TPC (Standard T)

Parameter	Estimate	Error	Statistic	P-Value
CONSTANT	-1.22422	0.125033	-9.79115	0.0000
TS	0.0339936	0.004024	8.44771	0.0000
T500	-0.012635	0.00398971	-3.1669	0.0015
DPS	0.0896674	0.00558786	16.0468	0.0000

Table 2: Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Model	384.694	3	128.231	200.73	0.0000
Residual	733.36	1148	0.638816		
Total (Corr.)	1118.05	1151			

R-squared	34.4075 %
R-squared (adjusted for d.f.)	34.2361 %
Standard Error of Est.	0.799259
Mean absolute error	0.633167
Durbin-Watson statistic	0.72772

The evaluation of TPC can be interpreted as follows. When TPC is lower than 1, severe hailstorm process are not present in Mendoza. A TPC value between 1 and 2, indicates that monocell process will be present in the region. If the value is between 2 and 3, we should expect unorganized multicell convective processes (Figure 4 a) in Mendoza. Values of TPC between 3 and 4, it indicate the presence of organized multicell convective process in the province (Figure 4 b). If TPC has values between 4 and 5, it indicates intermediate cell processes (Figure 4 c) in the zone. Finally, when the value is bigger than 5, we should expect the formation of a supercell process in Mendoza (Figure 4 d).

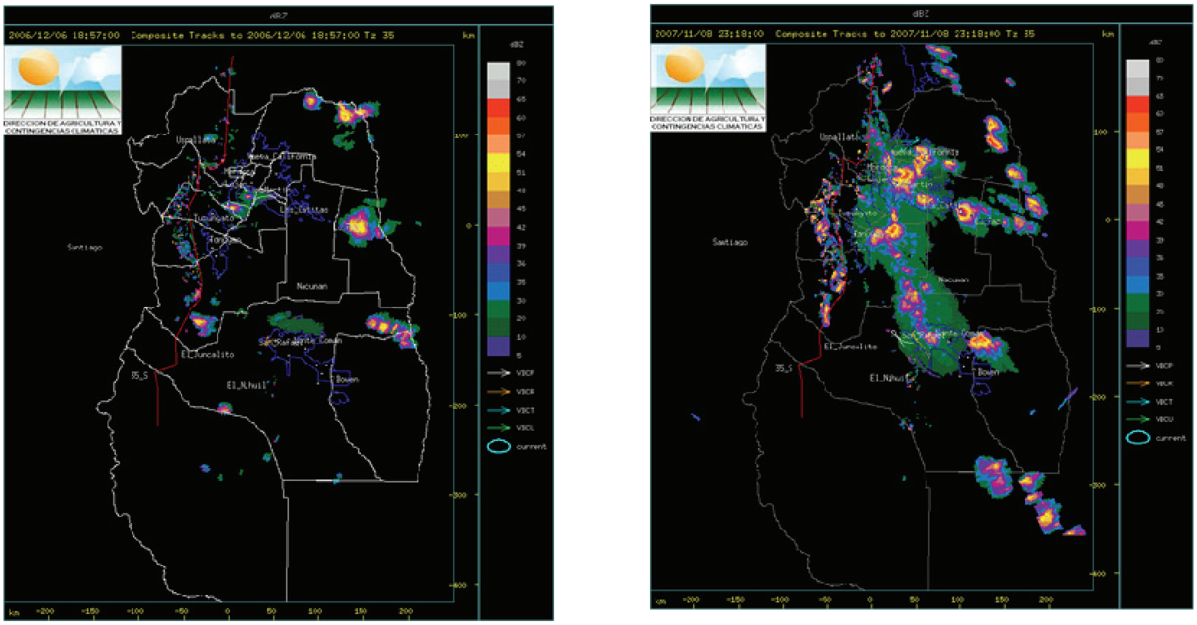

Fig. 4. (a) Unorganized multicells convective process (left); (b) Organized multicell convective process (right).

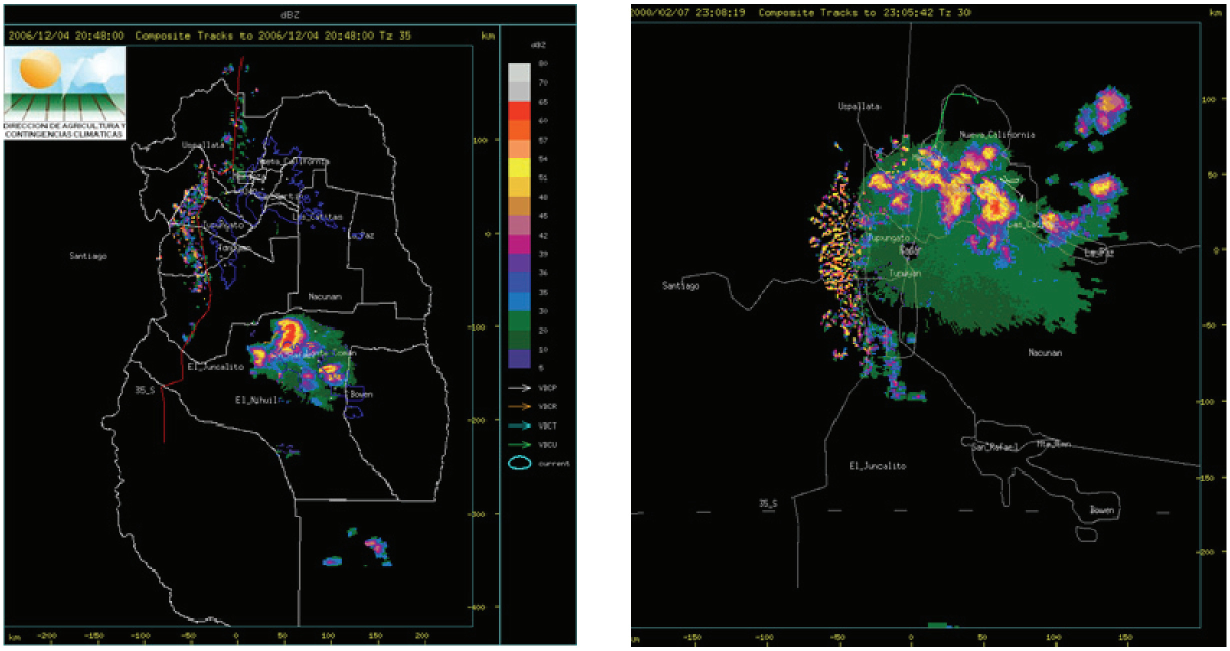

Fig. 4. (cont.)(c) Intermediate cell convective process (left), (d) Supercell convective process (right).

4.2 The natural convection and the thermal conductivity process

The natural convection equation (Zemansky, 1980) is:

$$\frac{Q}{t} = h.A.(T2 - T1) \tag{3}$$

where, the left side member is the heat over time unit flux, between two regions of the fluids that are at T_1 and T_2 temperatures; on the right side member, A is the cross section area at the heat flux direction and *h* is the natural convective coefficient which depends on the factors that follow:

1. Geometry and boundary conditions of the particular problem.
2. Sense and direction of the convection.
3. Properties of the fluid.
4. Fluid velocity that determines its movement regimen.
5. Different physical states (solid, liquid and gaseous) of the fluid; and its exchange rates.

The physical properties of the fluids depend on temperature and pressure, and the calculation of the convection coefficient *h* for each particular situation is a very complicated problem, because it must take into account all the factors described above. But, if the thermal conduction process produced from the temperature difference of the fluids is considered, equation (3) can be rearranged as follow:

$$\frac{Q}{t} = Um.A(T2 - T1) \tag{4}$$

where the total heat conduction coefficient U_m is:

$$\frac{1}{Um} = \left(\frac{1}{h1} + \frac{1}{h2} + \dots + \frac{1}{hi} + \dots + \frac{1}{hn} + \dots + \frac{x1}{k1} + \dots + \frac{xi}{ki} + \dots + \frac{xn}{kn}\right)$$

The h_i factor represents the individual convection coefficient of each different air layer through which must pass the heat flux. The x_i terms represent the thickness of these shells and the k_i are the thermal conductivity values respectively.

The term [0.012635 (2.69.T_S - T_{500})] in (2) corresponds to the temperature difference between the ground and 500 mb levels of Mendoza atmosphere. Then, we can associate with this term the temperature difference factor in equation (4). Also we can observe that the class and severity of the storm convective process depends on the vertical temperature gradient between both levels, which agrees with the above described heat flux in fluids due to the natural convection and thermal conduction. The factor that multiplies the surface temperature (T_S) is expressing that its statistical weight is higher than the 500 mb level temperature (T_{500}) on the vertical convection roll. On the other hand, this fact shows that in a storm convective process the surface temperature is more relevant than the temperature at 500 mb level. Finally, the constant value of the 0.012635 that multiplies the temperature gradient, can be assumed to be the media value of the *total heat conduction coefficient* U_m for the Mendoza atmosphere.

From the above correlation, we can observe that the class and severity of the storm convective processes do not depend on the dew point at 500 mb level (DP_{500}); but, on its surface value. This is associated with the fact that the vertical ascendant movement of the circulating air feeds the storm process carrying the water vapor from the ground to upper levels. Moreover, the class and severity of the convective process depends on the vertical temperature difference between both levels (T_S - T_{500}). This result is associated with the heat transfer by thermal conductivity and natural convection. In this way, the factor 2.69 that multiplies T_S suggests that the on surface temperature has a more important role in the convective vertical motion than the 500 mb level temperature. Then, in the storm convective process the surface temperature value is more relevant than its value at 500 mb level. Finally, if we observe the equations (2) and (4), the value 0.012635 that multiplies the temperature differences (equation 2) can be related to the U_m of the atmosphere in Mendoza. We conclude from the above results that for higher values of the temperature difference and surface dew point, more complex and severe storm convective processes in Mendoza are expected. The storm types predicted by thermodynamic calculation using the multivariate model consistently compared with storm types seen in GOES satellite images and the C and S band radar displays produced by the TITAN system.

4.3 Relevance of the water vapor

As shown in (2), the storm process class does not depend on the 500 mb level dew point value, but it does strongly depend on the surface dew point (Pérez, 2008). This result seems to be related to the fact that the storm convective process depends on the moist and the thermal available energy on the surface, in order to start the convection process, independently from the 500 mb level dew point value. It is well known that the surface dew point parameter has a threshold value of 12 °C in Mendoza. When the dew point value is lower than this threshold, it is improbable to have a severe storm present in the zone, and alternatively, when about the dewpoint is at the threshold or above, the convective process was severe for the same pressure and temperature conditions. This fact means that the water vapor on surface is the *"raw material"* that produces the storm clouds particles, and it is necessary to have a minimal amount of moisture in order to be able to trigger the deep convection process.

5. CONCLUSIONS

The previous version of DCPIM (Deep Convection Process Identification Model) index used only surface meteorology data to forecast the convective storm class in Mendoza (Argentina). But this model was not able to forecast correctly about five percent of the studied cases. In this paper an improvement to the above index was obtained by adding vertical atmospheric information. The main variables added are the temperature T_{500}, and dew point DP_{500} at the 500 mb pressure level taken from radiosonde data over Mendoza and Santiago (Chile). Orographic considerations and further theoretical analysis of the heat transfer for natural convection and thermal conductivity confirmed the relevance of including the temperature difference between these two levels. Moreover, observations showed that the class and severity of the storm convective process do not depend on the dew point at the 500 mb level (DP_{500}); but, they strongly depend on the surface dewpoint value. This is associated with the fact that vertical ascendant movement of the circulating air feeds the storm process carrying the water vapor from the ground to upper levels. Finally, through statistical analysis, we obtained the mean value for the total heat conduction coefficient U_m of the Mendoza atmosphere. The storm class predicted by the multivariate model consistently compared well with storm class based on GOES satellite image, and the C and S band radar, and its TITAN system.

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