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SEVERE STORMS

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ABSTRACT

The role of jet streams in the development of severe storms was analyzed. Local variations of flow resulting from rapid changes of geostrophic velocity along the air trajectory or inertial instability can produce cold advection. The cold advection occurs in regions which frequently have severe storms. An analysis of the National Severe Storms Laboratory meso-network data for 1968 and 1969 was performed. Although inertial instability was present in the network, local deviations in wind direction and cold advection were not detected.

INTRODUCTION

The role of jet streams in the development of severe weather is not clearly defined. One theory on severe weather states that strong vertical wind shear present in the vicinity of jet streams produces high-level outflow which enhances the development of convective clouds (Newton, 1962). Another theory (Beebe and Bates, 1955) suggests that vorticity advection in jet streams produces patterns of high-level divergence which increase vertical motions and lead to severe weather. However, this theory requires that the jet maximum be stationary. This requirement is not justified by observations (Reiter, 1961). Also, some recent studies indicate that patterns of high-level divergence and outflow are not necessary for severe storm development (Barnes, 1970).

Cold advection at high levels is another mechanism which could lead to severe storms. Because both temperature gradients and wind speeds are large in jet streams, the potential for strong advection is high. However, in large scale analyses of jets, the air flow and temperature gradient are apparently perpendicular. Consequently, no advection would be anticipated. However, deviations from the main air flow may develop in local regions which escape detection in large scale analyses. Such deviations may result in cold advection. The purpose of the present study was first to see whether local deviations from a main air current have a theoretical basis, and secondly to determine the patterns of advection which could develop.

LOCAL DEVIATIONS OF AIR FLOW*

Two mechanisms have been studied that could lead to local deviations of flow from a main current. The first results from large variations of horizontal velocity along air trajectories observed in the vicinity of jet maxima, and the second involves deviations resulting from inertial instability. Both mechanisms produce deviations which could cause cold advection downstream and to the right of jet maxima.

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Deviations arising from rapid changes of geostrophic wind speed

Large variations of horizontal velocity are observed in the vicinity of jet maxima. If a parcel moves through this region without immediately adjusting its speed to the changing field, the parcel will deviate from its original path.

The first and second equations of motion for a frictionless flow can be written as follows:

$$\frac{du}{at} = f\ (v-v_g) \tag{1}$$

$$\frac{dv}{at} = f\ (u_g-u) \tag{2}$$

where f is the Coriolis parameter. When a parcel with velocity components u and v moves into a field of geostrophic velocities u_g and v_g, deviations from its original path will develop from the accelerations $\frac{du}{at}$ and $\frac{dv}{at}$.

In order to determine the importance of these parcel accelerations, trajectories of parcels in a hypothetical jet stream were computed.

A suitable schematic description of a jet's geostrophic velocity field can be given as follows:

$$u_g = Ae^{-Bx^2-Cy^2} \tag{3}$$

where x and y are orthogonal and x is along the jet axis. $x = y = 0$ at the center of the jet maximum. The constant A is the magnitude of the maximum u_g. The constants B and C determine the shape of the velocity distribution. Because the wind is geostrophic, the height, Z, of a pressure surface is given by,

$$z = -\frac{f}{g}\int_0^y Ae^{-Bx^2-Cy^2}dy + F(x) \tag{4}$$

where g is gravity, and $f(x)$ is set to zero, so that $z = 0$ when $y = 0$. When $y > 0$, Z will be negative, and when $y < 0$, Z will be positive. The y-component of the geostrophic velocity is given by

$$v_g = \frac{g}{f}\frac{\partial z}{\partial x} = +\ 2\ ABx\ e^{-Bx^2}\int_0^y e^{-cy^2}\ dy \tag{5}$$

The constants B and C were chosen such that the isotachs of the velocity distribution would be elliptical in shape. At $x = y = 0$, $u_g = 100$ m sec^{-1}; at $y = 0$, $x = 500$ km, $u_g = 40$ m sec^{-1}, and, at $x = 0$, $y = 300$ km, $u_g = 40$ m sec^{-1}.

After the geostrophic fields were derived, trajectories of parcels were computed from equations (1) and (2). The time step was 100 sec.

The deviations were small. A parcel starting at $x = y = 0$ moves downstream and slightly to the right (looking downstream). Within 350 km from the origin, the parcel obtains a transverse velocity of a magnitude slightly greater than 1 m sec^{-1}. This small deviation may be significant. Looking downstream from a jet maximum, one can usually observe cold air to the left of the axis and warm air to the right. Consequently, the computed trajectory would produce some cold advection.

Deviations produced by inertial instability

Inertial instability is another factor which can contribute to transverse displacements in the vicinity of jet maxima. If the wind shear in the transverse direction on an adiabatic surface exceeds the Coriolis acceleration, the flow is inertially unstable. According to Van Meighem (1951), if a parcel in this field is given an initial transverse velocity v_o, the parcel will accelerate in the transverse direction and will follow a path given by:

$$x = v_o/f\ (1 - \cosh |\nu|\ t) \qquad (6)$$

$$y = v_o/\nu\ \sinh |\nu|\ t \qquad (7)$$

where t is the time, and ν is given by

$$\nu^2 = f\ (f - \frac{\partial u}{\partial y}) \qquad (8)$$

The transverse gradient of velocity can approach $-2f$ to the right of jet maxima (Reiter, 1961). Figure 1 shows trajectory calculations with initial transverse velocities of -1, -5, and -10 m sec^{-1}. From relatively small transverse velocities, large displacements can result. Because colder air is located

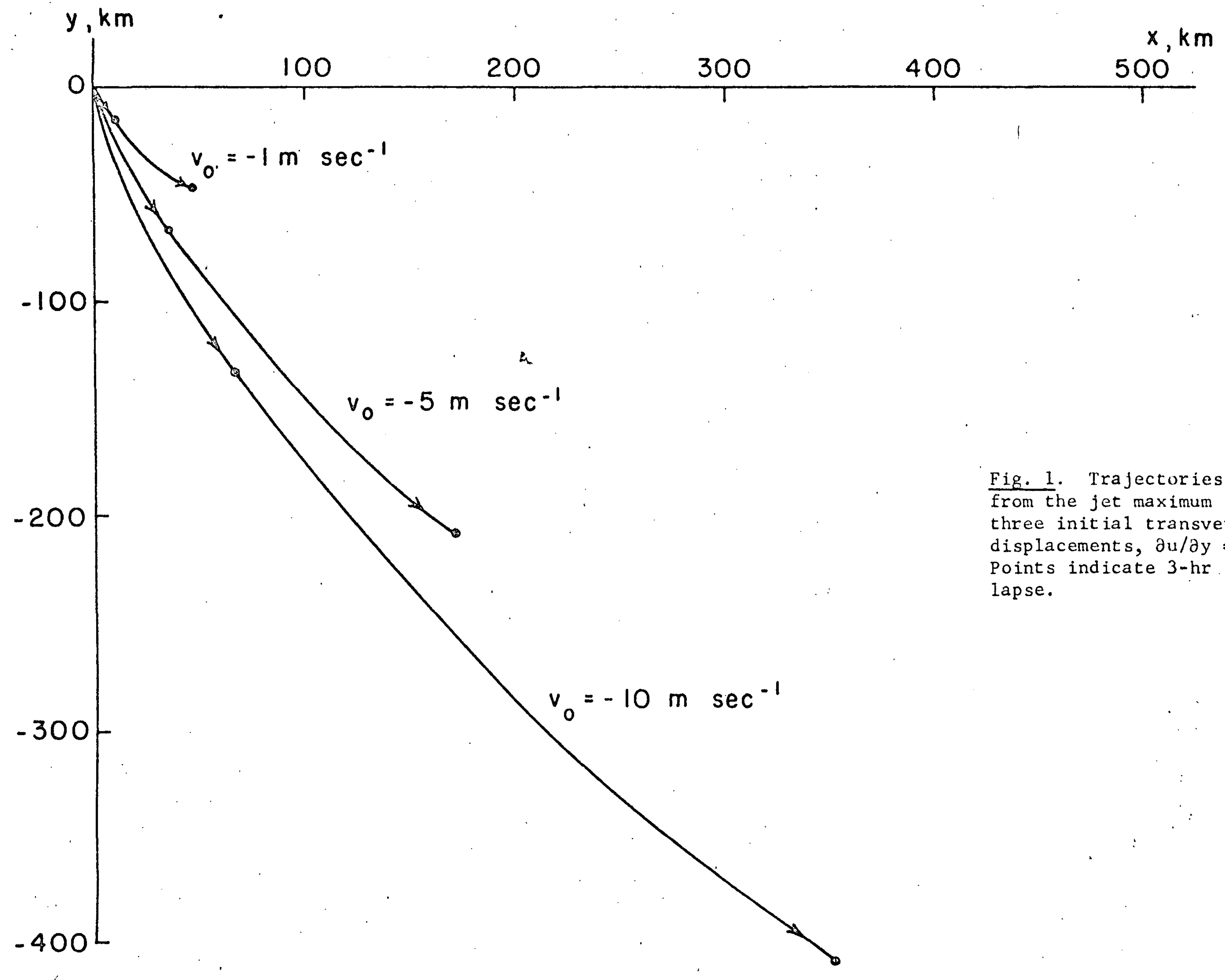

Fig. 1. Trajectories from the jet maximum for three initial transverse displacements, $\partial u/\partial y = 2f$. Points indicate 3-hr time lapse.

closer to the axis, cold advection is a strong possibility downstream and to the right of the jet maximum.

LOCATION OF SEVERE STORMS WITH RESPECT TO JET MAXIMA

Both inertial instability and ageostrophic accelerations can produce cold advection in the same region. A study was made to see whether severe weather occurs more frequently in that region.

The study was performed on severe weather which occurred within 4 hr of 1200 GMT during the period of January 1970 to April 1970. The distance and angular displacement of the severe weather from the jet maxima were noted. The angular displacement was measured clockwise from the axis. Table I shows the results. All storms occurred within 90° of the jet maximum. This is the same region in which cold advection is predicted by local deviations of flow.

OBSERVATIONS OF STORMS ON THE NSSL MESO-NETWORK

The most direct test of any theory related to small scale storms requires the examination of data on a similar scale. In recent years, the National Severe Storms Laboratory (NSSL) has provided useful data on severe storms occurring in central Oklahoma during the months of April, May, and June. The data collected by the NSSL meso-network during 1968 and 1969 was analyzed. Three storms in each year were analyzed for the presence of inertial instability, local deviations of wind direction, and mid-level cooling.

The occurrence of anticyclonic shear which would be sufficiently large for the development of inertial instability is rarely revealed in large scale analyses. For instance, the last column in Table I lists the shear measured on the synoptic scale at 500 mb for cases of severe storms occurring near jets. In these analyses the shear was always less than the Coriolis parameter. However, an examination of the meso-network data revealed that very large anticyclonic shear may frequently occur on the small scale in the vicinity of local storms. Within one hour of the storm's passage through the network, inertial instability became a distinct

Table I

Date	Weather	Time (GMT)	Location	Dist. from Max. (N.M.)	Direction from Max.	Shear ($sec^{-1} \times 10^{-4}$)
1/6/70	Tornadoes	1505-1635	Fla. Panhandle	330	040°	-0.16
1/15/70	"	1200	Ft. Pierce, Fla.	Max. over region		
2/1/70	"	1330-1530	N.E. Texas	180	090°	-0.39
2/3/70	"	1230-1615	S. Fla.	390	090°	-0.14
3/3/70	"	1200-0215	C. Texas	350	017°	-0.16
3/5/70	"	1540-1732	Fla. Panhandle	200	050°	-0.12
3/17/70	"	0745-1430	E. Texas- S. La.	Max. over region		
3/19/70	"	1200	W. Ala.	600	025°	-0.16
3/19/70	Severe R	1200	N. Miss.	800	025°	-0.16
3/20/70	Tornado	1330	S.W. Ill.	560	070°	-0.10
3/29/70	1.5" Hail	1100	S. Car.	240	030°	-0.25
4/1/70	1.75" Hail	0930-1230	C. Ala.	400	015°	-0.13
4/5/70	Funnel aloft	1245	Miami, Fla.	800	025°	-0.18
4/16/70	Funnel cloud	1310	Lubbock, Tex.	110	090°	-0.32
4/18/70	Tornadoes	0245-0945	Tex. Panhandle	150	023°	-0.15
4/18/70	Severe R	1230	W. Missouri	450	031°	-0.11
4/19/70	Tornadoes	0900-1230	C. La.	150	090°	-0.20
4/23/70	Severe R & Tornadoes	1000-1400	N. Kentucky- W. Va.	600	027°	-0.21
4/24/70	Severe R & Tornadoes	0920-1230	Tenn., Ky., Miss., Ala.	320	020°	-0.13
4/25/70	Tornadoes	1100-1300	N.E. Texas	180	090°	-0.11
4/29/70	3/4" Hail	1430	Abilene, Tex.	145	023°	-0.14
4/30/70	Tornadoes	0700-1015	Okl., Ark., Kan., Mo.	240	020°	-0.21

possibility. On April 22, 1968, the magnitude of the anticyclonic shear was 3.4×10^{-4} sec^{-1}. On May 13, 1968 the shear was 4.4×10^{-4} sec^{-1}, and on May 31, 1968 the shear was 3.5×10^{-4} sec^{-1}. All measurements were made near the 500 mb level. Jets were present on the large scale during April 22 and May 13; however, no jet was in the vicinity on May 31. It is interesting that local inertial instability can develop not only when a jet is present on the large scale but also when it is absent.

Although inertial instability was revealed in the small scale, no local deviations of wind direction from the large scale were detected. The storms analyzed appeared to originate outside the meso-network. Deviations from a main current are thought to be most important in the initiation of the severe weather. It is quite possible that deviations of flow occurred outside the meso-network at the time of storm development. Considering the magnitude of the anticyclonic shear, the expectation of these deviations is reasonable.

A detailed analysis of temperature and moisture was also performed. In four of the six cases analyzed, cooling between 450 mb and 750 mb occurred in portions of the network 1 hr prior to the precipitation. This cooling was instrumental to the destabilization of the air. Table II shows these results. The origin of the cooling may have been due to evaporation rather than cold advection, because relative humidities were quite low prior to the cooling. In Table II, the stability is expressed in terms of the average temperature difference between the environment and a parcel lifted moist adiabatically from the Lifting Condensation Level (LCL). The LCL was determined from the mean mixing ratio and temperature of the lowest kilometer.

CONCLUSIONS

Theoretically, local deviations of wind direction can develop from either large accelerations of flow or inertial instability. These deviations would produce cold advection in a region which frequently contains severe storms.

Although cold advection and local variations of wind direction were not found in the meso-scale analysis, large anticyclonic shear was measured. This shear produces inertial instability in the region. The results of the present study are not necessarily inconsistent with the theory. The storms did not appear to be generated within the network. Consequently, local deviations of flow may have occurred outside the analyzed region, and in that region the storm development was initiated.

Table II

Date	Station	Period	Layer of Cooling (mb)	Average Initial Temp.diff. / Final Temp. difference	Average Initial Rel.Hum.
5/31/68	Rush Springs	1500-1600 CST	750-450	-1.6 / -3.3	41.9
4/26/69	Minco	1400-1550 CST	650-450	-0.8 / -4.1	61.9
5/6/69	Express-way ARPT.	1240-1410 CST	750-450	-1.6 / -3.3	41.4
5/7/69	Chickasha	1903-2015 CST	750-550	+0.8 / -1.9	48.5

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