Remote Sensing Identification of Tornado Tracks in Argentina, Brazil, and Paraguay

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ABSTRACT: This paper describes a series of tornado tracks which were identified for the first time over a region that covers part of eastern Paraguay, southwestern Brazil, and northeastern Argentina, and is known as the Paraná Basin. The tracks are clearly observable on 1965 black-and-white aerial photographs (1:60,000 scale) and on some of the early 1970s Landsat imagery. The largest trajectories are up to 70 km long and 2 km wide. The severe deforestation that occurred in the region in the late 1960s obliterated, almost completely, the tornado scars, which barely appear on more recent remote-sensing products.

INTRODUCTION

THE REGION COVERED by this paper encompasses part of southwestern Brazil, eastern Paraguay, and northeastern Argentina and is broadly delimited by the following geographic coordinates: 24°00′-27°30′S by 52°-56°30′W.

In 1979, the author conducted a geological photointerpretation program covering eastern Paraguay. This work was carried out essentially using aerial photographs at the scale of 1:60,000, taken in 1965, in conjunction with Landsat imagery dating from the early 1970s. During the program, attention was drawn to a series of anomalies of the regional vegetation cover occurring in the form of elongate swaths with a predominant northwest-southeast orientation, practically devoid of arboreous vegetation, and which contrasted very sharply with the surrounding forested terrain.

Figure 1 shows a stereo pair illustrating one of such areas in Paraguay, as first spotted on the 1965 aerial photos. The tridimensional examination of this area provides a good view of the lack of trees along the light-toned strip. At the time the photos were taken, regional vegetation was made up mostly of a widespread forest, essentially a subtropical rainforest with trees 20 to 30 m high and 0.30 to 0.80 m in diameter, with some larger trees mixed in.

For some time the author, being a geologist, worked with the idea that the deforested strips lying in Paraguay could be caused by some kind of geobotanical stress phenomenon. The identification, however, of the same kind of features lying in Argentinian and Brazilian territories, allied to the scanning of the literature pertaining to the bordering region and to world-wide meteorological phenomena, provided the means for a more complete assessment of the matter and to reach the conclusion that the severe linear forest destruction, viewed both on the 1965 aerial photos and early 1970s imagery, was produced by the activity of tornadoes, the deforested strips being the physical manifestation of their trajectories. The multitemporal monitoring of the Brazilian part of the region using aerial photos taken at different times (1943, 1952 to 1957, 1960, 1962, 1964,

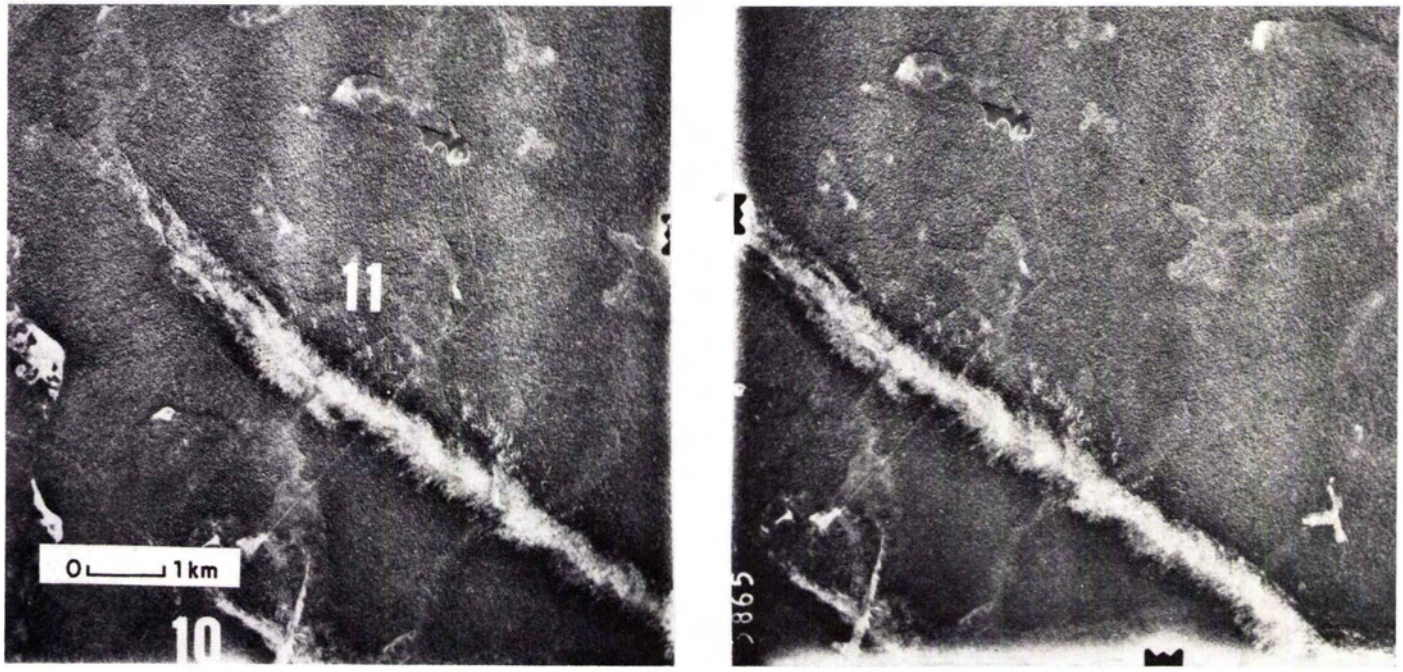


FIG. 1. Stereo pair of the 1965 aerial photos showing two parallel deforested swaths (10-11) in sharp contrast with the heavily forested surroundings (eastern Paraguay).

PHOTOGRAMMETRIC ENGINEERING AND REMOTE SENSING,
Vol. 54, No. 10, October 1988, pp. 1429–1435.

0099-1112/88/5410–1429$02.25/0

and 1965) indicated that most of the tracks present on the 1965 photos dated from some time between June 1964 and July 1965 (Figure 2). References to violent wind thunderstorms (erroneously named typhoons) which occurred from May to July 1965, with the destruction of the forested cover along extense linear northwesterly swaths in southwestern Brazil, were encountered in the regional physiographical literature (Maack, 1968) and led to the conclusion that at least part of the series of tornado tracks under examination was produced at that time.

The identification of the referenced tornado tracks on regional remote-sensing products was a pioneer achievement. In Argentina, monitoring of tornadic activity has been carried out systematically since 1971, but such studies have been aimed mostly at the direct ground assessment of the damage caused by the phenomena. In Paraguay and Brazil very little official work is known to involve the registry of the activity of tornadoes, their existence being unknown to the public in general.

In 1986, at the Latin American Remote Sensing Symposium, held at Gramado, Brazil, the author made the first communication of his discoveries.

GENERALITIES ON TORNADOES

The following statements have been taken from Nalivkin (1983), one of the leading tornado researchers:

> "Tornado is a very rapidly rotating air funnel hanging from a cumulonimbus cloud. Most research on tornadoes has considered them independent of thunderstorm clouds. Only in recent years have a few workers paid attention to the close relationship between tornadoes and vortex formations in the clouds. The main phenomenon is the vortex formation in the clouds, the tornado being a secondary formation, originating in the cloud and hanging down to the earth's surface in the form of a funnel (as illustrated in Figure 3, after Hoecker (1960)). The funnel is the main component of a tornado. It has a spiral vortex consisting of very rapidly rotating air. Generally water and dust are entrained in the air. Due to this, the funnel can be clearly seen in the cloud. It is known as a funnel-forming cloud or tuba. Not all the funnels are well observed. They can have a typical trunk-shaped form but in many times in wide tornadoes they are ill-defined and diffuse. The wind speed in the walls is the most important feature in the tornado and determines its main properties. This speed differs widely and changes quickly, even in the same funnel, but the most important feature is that frequently it is extremely high, often exceeding the speed of sound in the air (1,200 km/h). The internal cavity of hurricanes varies from a few kilometers to tens of kilometers, but in tornadoes it is a thousand times less, i.e., from a few metres to a few hundred metres. Likewise the dimensions of the tornadoes are small as compared to those of hurricanes. Snake-like and rope-like tornadoes display the minimum width, of the order of a few metres, and maximum length. Trunk-shaped, funnel-like and columnar tornadoes are wide and short. The average width, from calculations for 2,000 tornadoes in the USA comes to 350-400 m. The length of the track is also short. In the USA the maximum length, correctly measured, was 470 km; here 270 people were killed. Calculations showed that the average length of 1,000 tornadoes is of the order of 20 km. Hills, forests and lakes do not serve as barriers to tornadoes. After emerging from the hills, tornadoes often reach unusual force. Passing over forests, tornadoes damage and uproot hundred-year-old trees, leaving behind narrow swaths of destruction."

One of the regions of the world where tornadoes have been most thoroughly studied is the central United States. According to Flora (1953), during a period of 35 years, from 1916 to 1950, 5,204 tornadoes were recorded, having killed 7,961 people. Figure 4 shows a map (Finley, 1881) with a series of tornado tracks in the central United States, one of which, Irving, is 150 km long. It is interesting to compare this map with that of Figure 5, which shows the tracks referenced in the present paper.

THE PARANÁ BASIN TORNADO TRACKS

The map of Figure 5 presents 24 of the main tornado tracks identified by the author in the Brazil/Paraguay/Argentina region and Table 1 gives their general parameters.

As observed, the lengths and widths vary enormously, the largest features being 70 km long and 2 km wide. The most extensive continuous tracks of this study are track 9, most of which is situated in Paraguay, and track 23, lying in Brazil. The widest track is that of site 5, Paraguay, which presents a maximum width of 2 km.

The 1965 airphoto (Figure 6) discloses the southern portion of track 5, which presents a great change in width, from almost

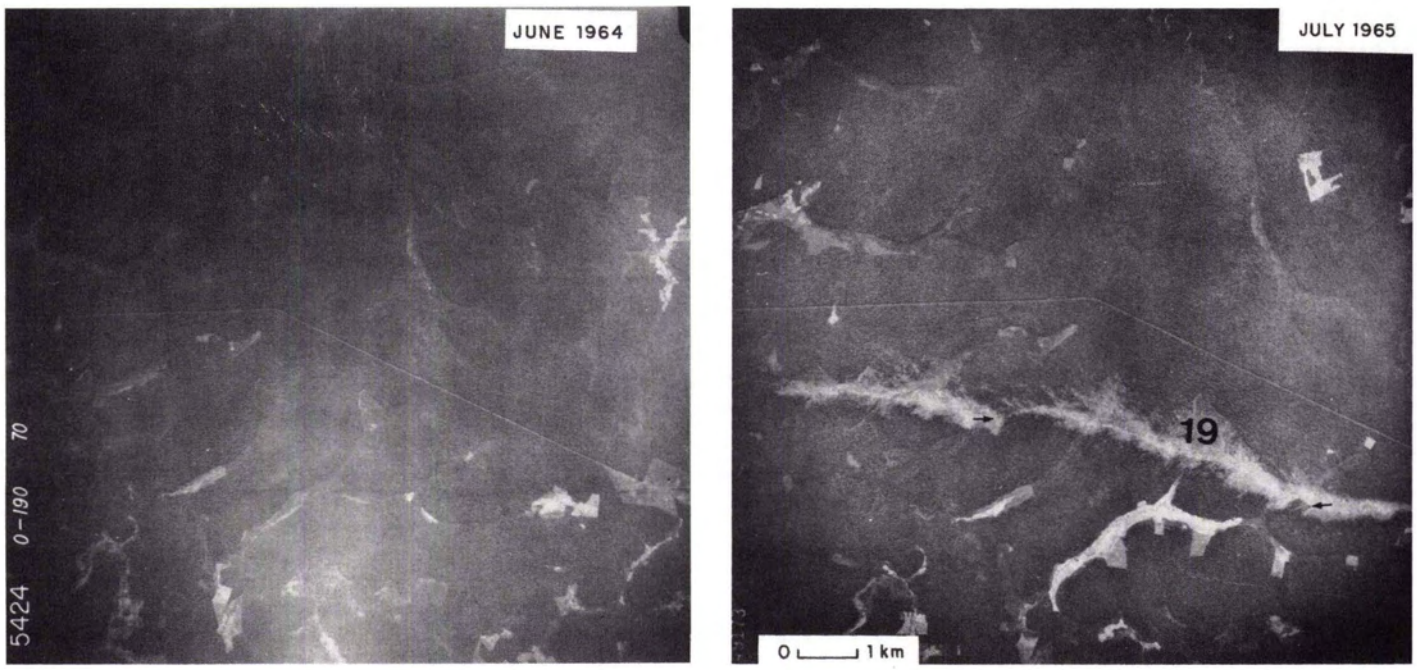


FIG. 2. Two aerial photos of the same area (19) in southwestern Brazil, taken in June 1964 and July 1965. The latter reveals a deforested swath with sharp boundaries.

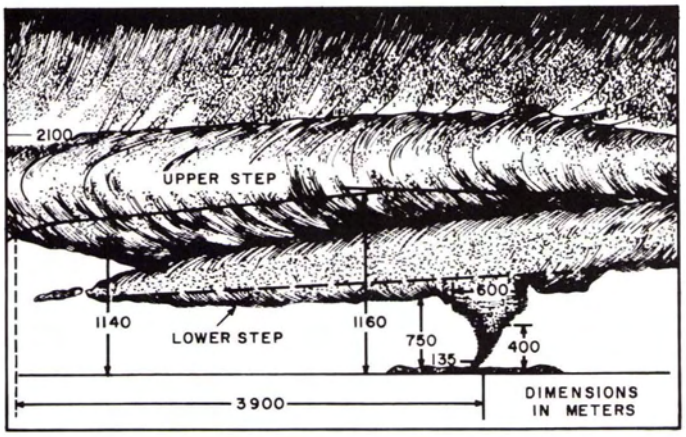


FIG. 3. Structure of a tornado cloud, Dallas, 1957 (Hoecker, 1960, Figure 7) illustrating the close relationship between the tornado and the mother cloud.

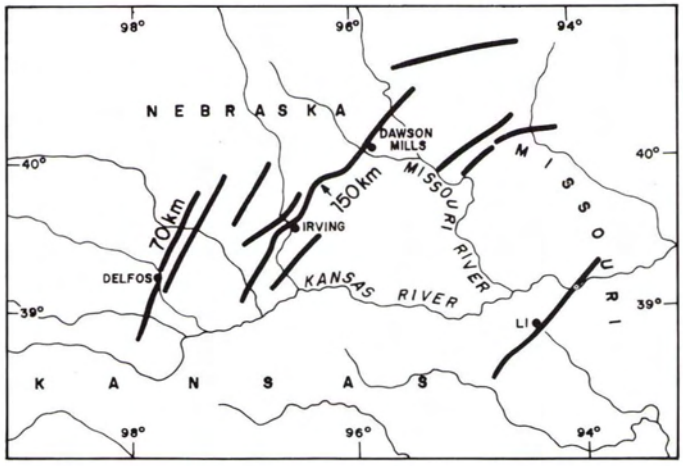


FIG. 4. Map showing a series of tornado tracks in the central United States (Finley, 1881), one of which, Irving, is 150 km long.

2 km in the north to a couple of hundred metres in the south. The form of the trajectories is usually very sinuous, such as the southeastern part of the referenced track.

Another very conspicuous feature is the light-toned line that occurs along the center of most of the tracks, probably representing a zone of extreme destruction; it shows abrupt offsets, such as that indicated by the arrow in Figure 7 (1965 aerial photo of track 5). The very sharp limits of the zone of destruction in regards to the undisturbed area, such as observed in Figure 2 (track 19), is another peculiar parameter. According to Nalivkin, "the sharply defined, almost smooth, dense wall of the funnel is one of the important, unique properties of the tornado." This researcher cites the astonishing case in which, after the passage of a tornado, a dead chicken on a destroyed farm was found with feathers on only half of its body, the rest having been plucked off by the wind. Another example is that of Kansas, where a tornado uprooted a large apple tree 30 cm in diameter and broke it into pieces but left untouched a beehive with bees, lying one metre away from the apple tree.

Following are the summarized descriptions of some of the most relevant tracks of the present study.

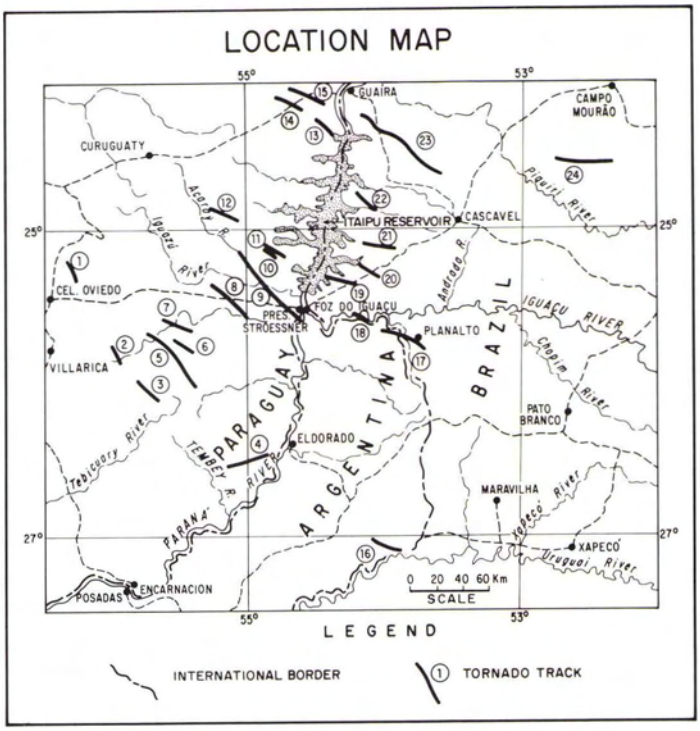


FIG. 5. Map showing the 24 main tornado tracks identified by the author in the region under consideration.

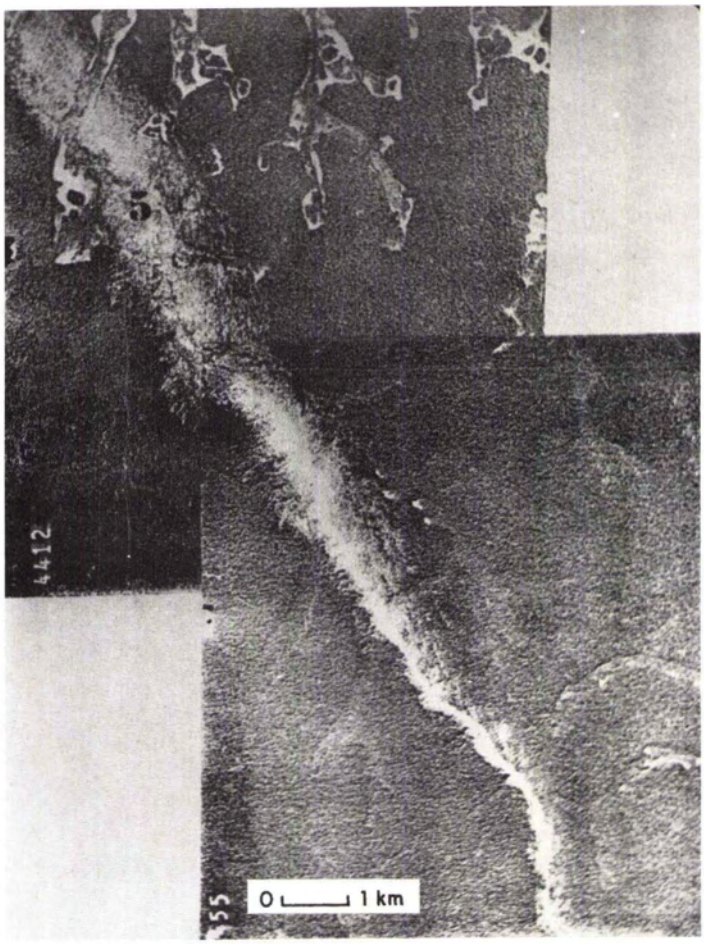


FIG. 6. The southeastern part of track no. 5 which presents a great change in width and a rather sinuous trajectory (1965 airphoto, eastern Paraguay)

TABLE 1. GENERAL PARAMETERS OF THE TRACKS

Track (No.)	Max. Length (km)	Max. Width (km)	Location (country)
1	8	0.2	Paraguay
2	7	0.2	Paraguay
3	20	0.4	Paraguay
4	30	1.0	Paraguay
5	40	2.0	Paraguay
6	13	0.5	Paraguay
7	17	0.5	Paraguay
8	35	1.0	Paraguay
9	70	1.5	Paraguay/ Argentina
10	7	0.3	Paraguay
11	17	1.0	Paraguay
12	12	1.0	Paraguay
13	6	0.4	Paraguay
14	10	0.5	Paraguay
15	24	0.7	Paraguay
16	17	0.9	Argentina
17	30	0.2	Brazil/ Argentina
18	9	0.3	Brazil/ Argentina
19	20	0.6	Brazil
20	8	0.4	Brazil
21	20	0.7	Brazil
22	8	1.9	Brazil
23	70	1.2	Brazil
24	30	0.5	Brazil

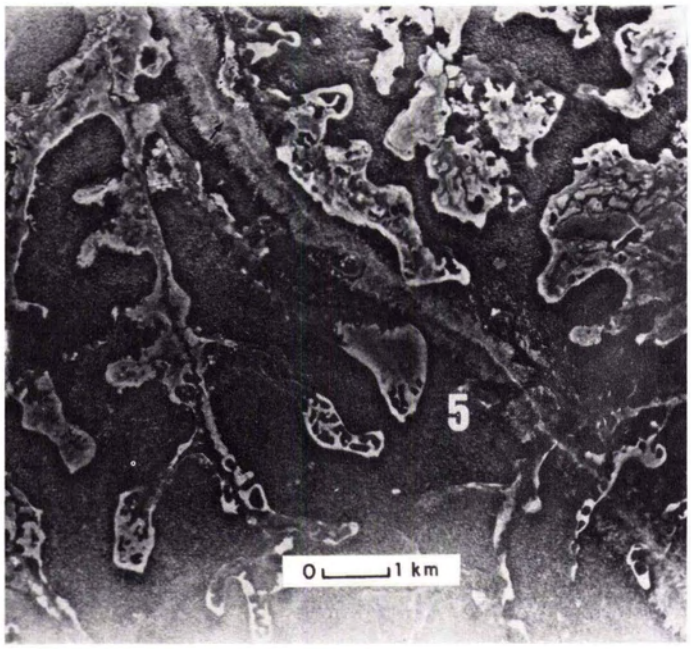


FIG. 7. Part of track no. 5 disclosing the very characteristic light-toned central line with abrupt off-sets as shown by an arrow (1965 airphoto, eastern Paraguay).

TRACK 23 (BRAZIL)

This feature, which is shown on the map of Figure 8, has a length of 70 km and represents one of the two most extensive tracks of this study. Its sinuous form and its continuous change in width are some of its most characteristic properties. Although lying in a rather inhabited region, the tornado did not hit any of the numerous small towns and villages lying close to its path.

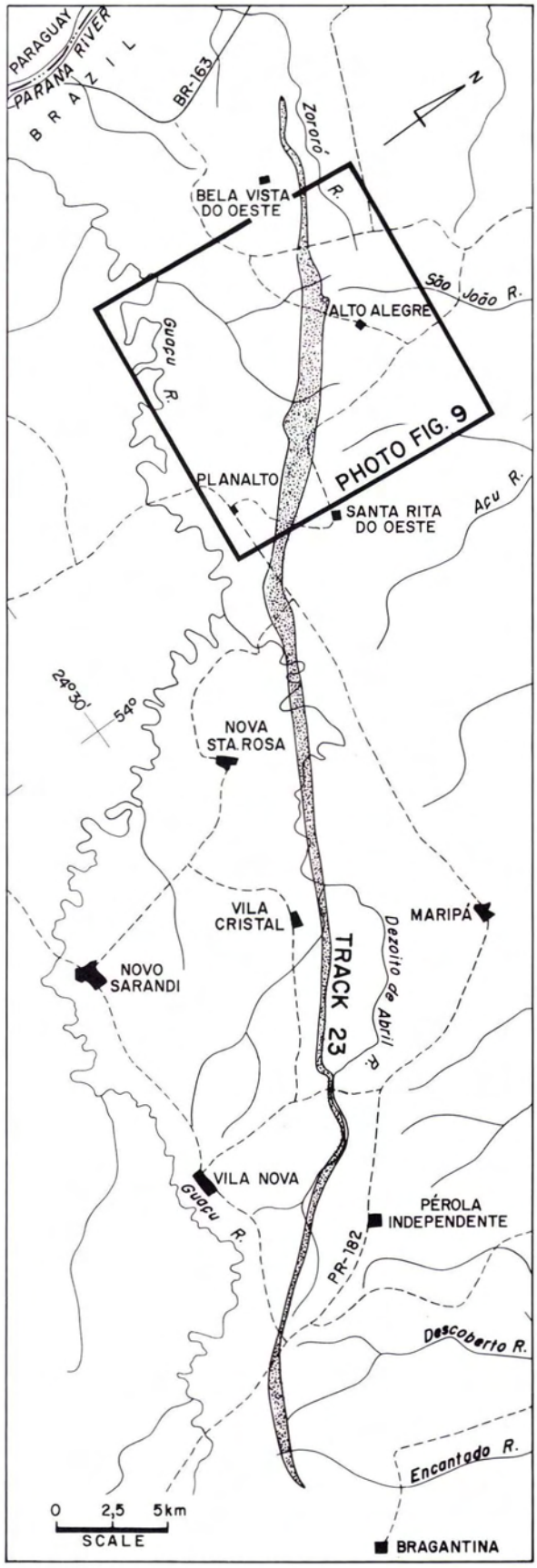


FIG. 8. Map of track 23 (southwestern Brazil) compiled from 1965 aerial photos. Square shows area shown on airphoto of Figure 9.

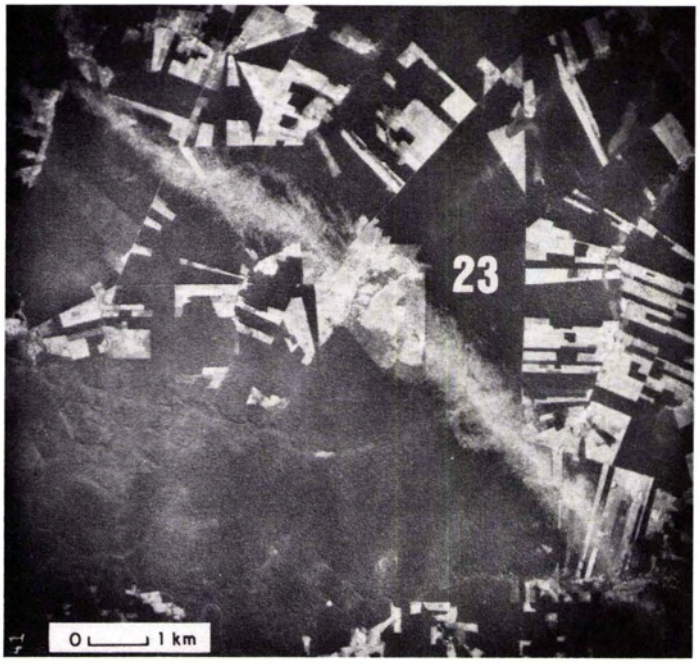


FIG. 9. Part of track 23 at the site of its widest path (1965 airphoto).

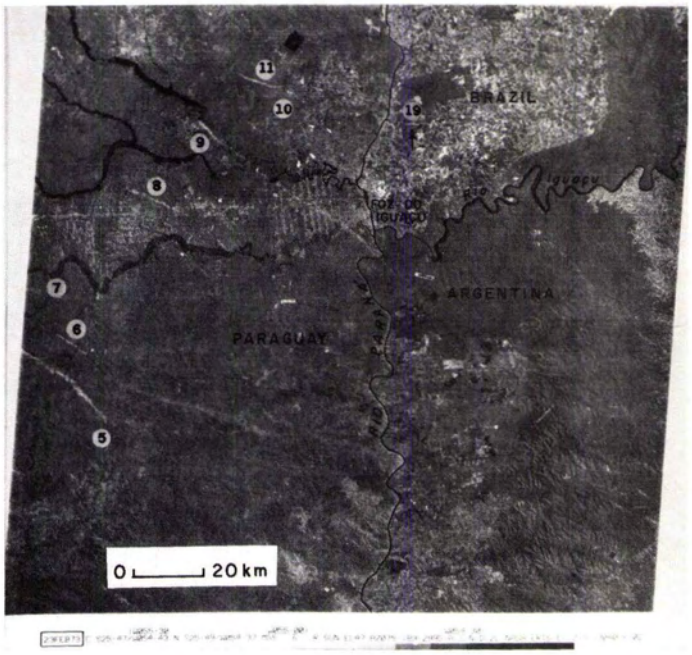


FIG. 10. A 1973 Landsat image (MSS band 6) showing several tornado tracks lying in Paraguay and Brazil (no. 19). Intense human deforestation in Brazil depleted all other pre-existing tracks, such as track 23.

Part of this track is disclosed on a 1965 airphoto (Figure 9), the site being that of its widest path (1.2 km). This tornado track is no longer visible on the early 1970s Landsat imagery because at that time that part of the Brazilian territory had already suffered intense human deforestation, the scar having been deleted by such activity (see Figure 10 ahead).

TRACK 9 (PARAGUAY/ARGENTINA)

This is the other 70-km long tornado path of the study and it may be considered one of the most striking examples of linear forest destruction in the region. It is readily observable on the 1965 airphotos as well as on the early 1970s satellite imagery, because the Paraguayan bordering territory was, at that time, still relatively untouched by human activity. In Figure 10, which depicts a Landast image taken in 1973, this track is remarkably outstanding and can be traced easily from the Argentinian Iguazu Falls region across the border into Paraguay. The same image also illustrates very well several other tornado tracks occurring in Paraguay, most of which are parallel to each other in a northwesterly direction. Only one track is perceived in Brazilian territory, track 19 (already displayed in Figure 2), still untouched by the surrounding intense human deforestation.

In Figure 11, a 1982 Landsat image of the same region is also shown, for the sake of comparison with the earlier one. In such later times human activity in Paraguay was much more intense and the tracks present on the 1973 image are partially absent on the 1982 image. This more recent image also reveals two new features. One is a new tornado track (No. 4), nonexistant in 1973, that bears an unusual northeasterly direction; the multitemporal assessment of the Landsat imagery of this area showed that it appeared on the images in late 1978. The other new feature displayed by the 1982 is the huge Itaipu reservoir that is situated in the north. The location of that hydroelectric plant amidst the region of tornadic activity (see map of Figure 5) represents a constant risk to possible damage caused by the tornadoes, such as the destruction of power lines, etc.

TRACK 16 (ARGENTINA)

This track, which lies in Argentina close to the Brazilian border, is distinguishable both on the 1965 aerial photo shown in Figure 12 and on the 1972 Landsat image presented in Figure 13. The area is situated in an Argentinian Forest Park, that being the reason for the preservation of the tornado scar up to recent times. Across the border, in Brazilian territory, the widespread light-toned areas indicate the intense human deforestation that

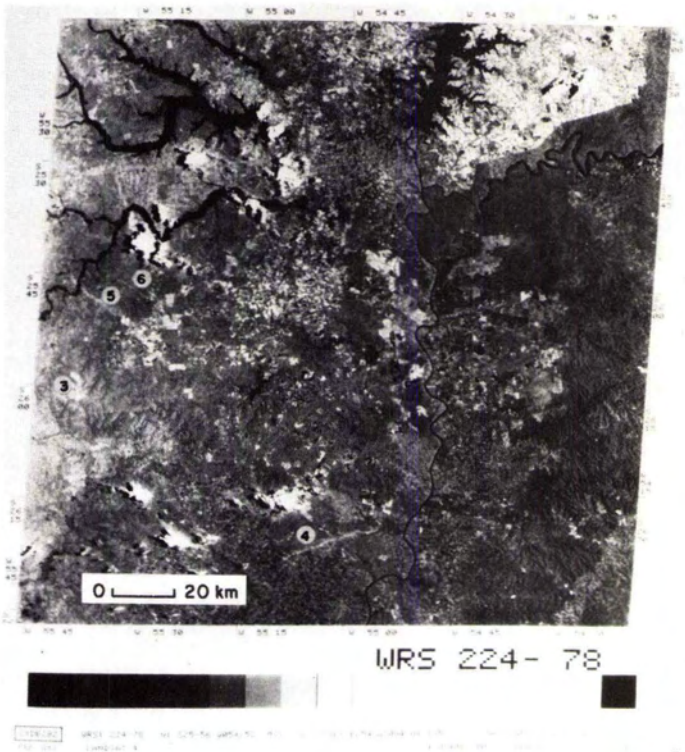


FIG. 11. A 1982 Landsat image (MSS band 6) taken after human activity in Paraguay had depleted part of the tracks of the previous figure. A new track (no. 4) appeared, with an unusual NE-SW direction.

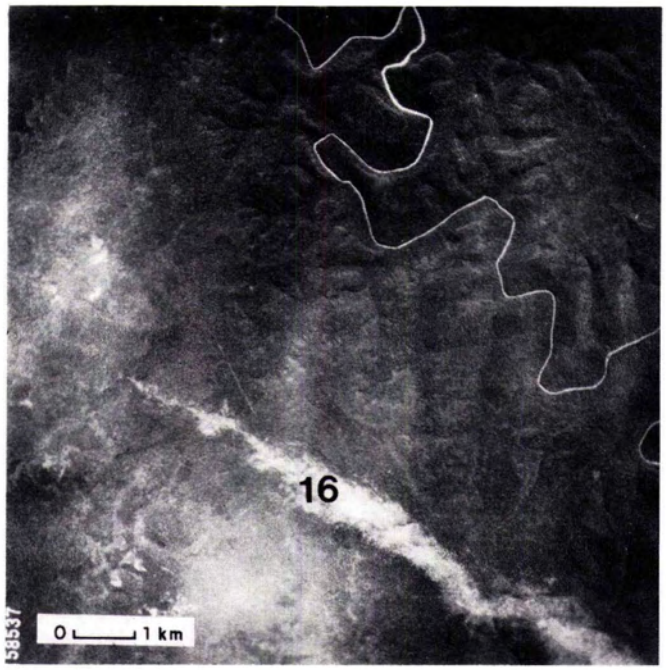


FIG. 12. Track 16, occurring in an Argentinian Forest Park, as shown on a 1965 airphoto.

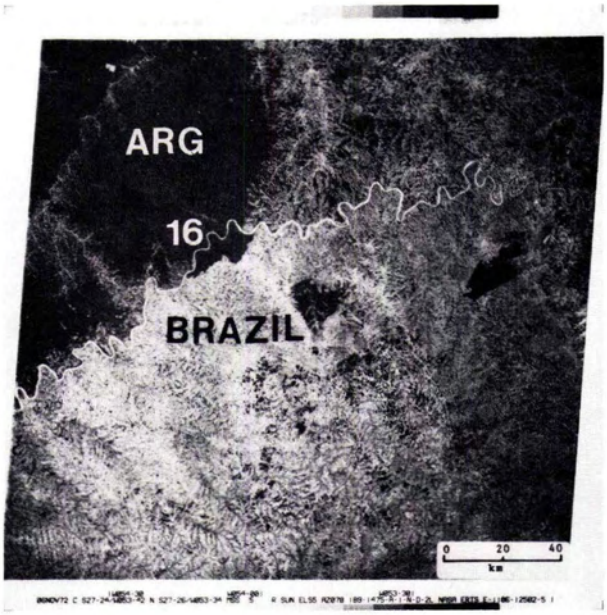


FIG. 13. The same track of the previous figure shown on a 1972 Landsat image (MSS band 5). In Brazil, human deforestation was total, thus depleting all possible pre-existing tracks.

took place in the late 1960s in that region and which deleted all possible pre-existing tornado tracks. A scene taken in March 1986 by the recently-launched French satellite, SPOT, still shows very clearly the tornado path.

Forested areas constitute the best environment for the identification of tornado tracks on remote-sensing products. Similarly to track 16 and to most of the others referenced in the present study, a color-infrared airphoto illustration of a track of a tornado that struck through the Allegueny National Forest in

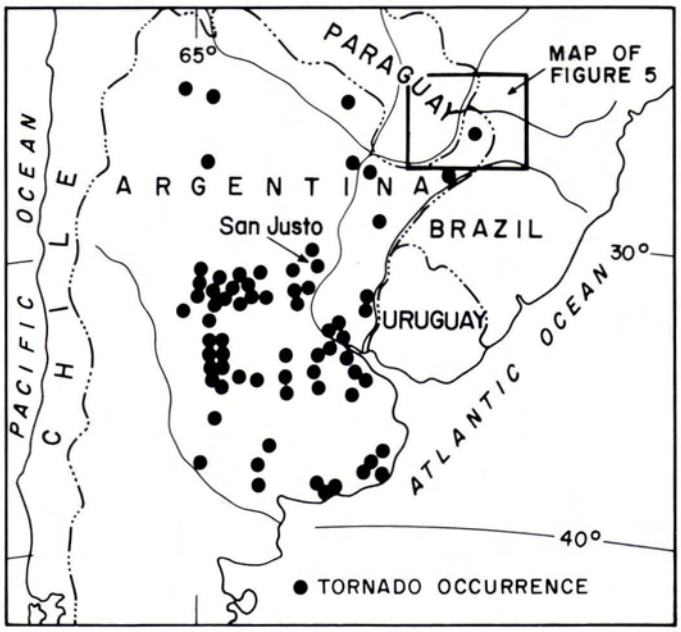


FIG. 14. Map of the main tornado occurrences in northeastern Argentina as compiled by Schwarzkopf and Rosso (1982); the location of the area covered by the present study is also shown.

northwestern Pennsylvania (May 1985) was shown on the cover of the February 1986 issue of *PE&RS*.

NEWS OF TORNADOES IN BRAZIL, PARAGUAY, AND ARGENTINA

Severe damage caused to towns and villages by storms accompanied by high-speed winds are periodically reported throughout southwestern Brazil. One such hazard took place in October 1984 when a great part of the town of Maravilha (see location on map of Figure 5) was damaged: hundreds of houses were destroyed and six people were killed by this probable tornado activity.

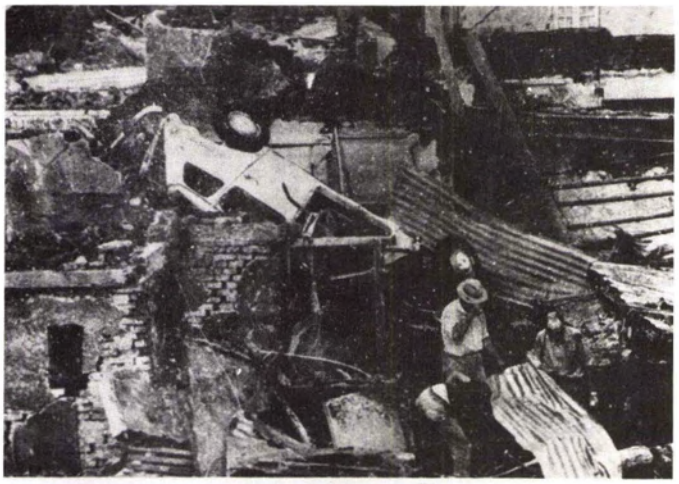
Several cases of damage caused by tornadoes and severe storms were studied by Blessmann (1986), a leading researcher of wind hazards in the south of Brazil. The most severe destruction occurred in Lajeado, State of Rio Grande do Sul, on 5 October 1967.

During the first semester of 1987 an unusually large number of hazards caused by storm and wind activity (probable tornadoes) was reported in southwestern Brazil.

The Brazilian National Meteorological Department does not register much information on the tornadic activity in the country, probably on account of the general public's inability to recognize such phenomena.

In Paraguay the matter is also poorly documented; however, reference (personal communication by M.L. Schwarzkopf) is made to a tornado (waterspout) that, coming from the Paraná River, struck the town of Encarnación (see location on map of Figure 5) on 20 September 1926 and caused a great disaster with a large number of deaths.

Tornado activities in Argentina, on the other hand, are very well documented and such is due to the fact that the Meteorological Department of Buenos Aires University has been studying the matter deeply since 1971 (Schwarzkopf and Migliardo, 1973, 1976). Specific publications on tornadoes and severe storms are being made public on a six-month basis. The studies demonstrate that over a 50-year period (1930 to 1979), of a total number of 646 reported cases, 439 were classified as damaging storms, 130 as possible tornadoes and 77 as tornadoes. The



Daños ocasionados en la localidad de San Justo (Provincia de Santa Fe) por el tornado ocurrido el día 10 de enero de 1973

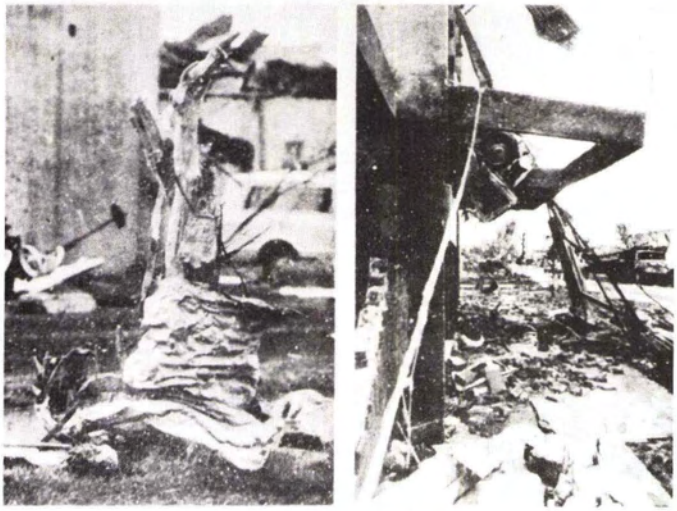


FIG. 15. Copies of photos showing the San Justo 1973 tornado destruction as presented by Schwarzkopf and Migliardo (1973).

mean path length (38 cases compiled) is 10 km and the mean width 180 m, with 68 percent of the cases ranging from 5 to 20 km in length and from 50 to 700 m in width.

Figure 14 reproduces a map published by Schwarzkopf and Rosso (1982), on which the main Argentinian tornado occurrences of the period 1930 to 1979 are registered. The area covered by the present paper is situated at the northeastern part of the region compiled by those researchers.

One of the most severe tornado destructions in Argentina occurred on 10 January 1973, at San Justo (see location on map of Figure 14) when 65 people were killed. Figure 15 illustrates copies of photos of the destruction caused by this hazard as displayed in Argentinian publications.

FINAL CONSIDERATIONS

The Paraná Basin may be considered a tornadic region, similar to many others; however, the method of data collection in poorly inhabited regions, such as those depicted in this paper, does not guarantee a complete coverage of the phenomena because the greatest factor influencing the statistical record of the number of tornadoes and severe storms reported is the population density.

As it has been stated throughout this paper, tornado tracks are less discernible on remote-sensing products once the forested cover is removed. Most of the tornado tracks shown in this paper are not recognizable nowadays, and their identification on the 1965 airphotos and early 1970s satellite images was a unique happening that might not be repeated in the future.

REFERENCES

Blessmann, J., 1986. *Acidentes Causados Pelo Vento*, third edition, Editora da Universidade Federal do Rio Grande do Sul, 81 p.

Dyer, R.C., 1986. Rastros de Tornados no Sudoeste do Brasil, Leste do Paraguai e Nordeste da Argentina, *Anais do Simpósio Latino-Americano de Sensoriamento Remoto*, Gramado, RS, Brasil, pp. 589–603.

Finley, J.P., 1881. *Report on the Tornadoes of May 29 and 30, 1879, in Kansas, Nebraska*, Prof. Paper of the Signal Service, No. 4., 116 p.

Flora, S.D., 1953. *Tornadoes of the United States*. Oklahoma, 194 p.

Hoecker, W.H., 1960. *The Dimensional and Rotational Characteristics of the Tornadoes and their Cloud System*. Res. Pap. No. 41, Weather Bur. United States, pp. 53–113.

Maack, R., 1968. *Geografia Física do Estado Paraná*, Curitiba, Brasil, 450 p.

Nalivkin, D.V., 1983. *Hurricanes, Storms and Tornadoes*, Rotterdam, A.A. Balkema, 597 p.

Photogrammetric Engineering and Remote Sensing, 1986. Cover Photo of photograph submitted by Pat Clancy, U.S. Army Corps of Engineers, Vol. 52, No. 2.

Schwarzkopf, M.L., and R.C. Migliardo, 1973. O Tornado de San Justo, Província de Santa Fe, *Meteorológica* No. 4, Vol. 1.

———, 1976. Aspectos Estatísticos de la Occurrencia de Tornados em la República Argentina, *Geodacta*, Vol. 8, No. 1.

Schwarzkopf, M.L., and L.C. Rosso, 1982. Severe Storms and Tornadoes in Argentina, *Proceedings, 12th Conference on Severe Local Storms*, San Antonio, Texas, pp. 59–62.

(Received 8 April 1988; accepted 26 April 1988; revised 7 June 1988)