P11.4

A Historical Perspective of In-Situ Observations within Tornado Cores

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Abstract

Meteorological measurements within tornado cores have been attempted over the past several decades with varying degrees of success. This paper is an overview of in-situ measurements attempted within the violent region close to and inside a tornado. Very few diagnostic measurements exist of the atmospheric properties inside a tornado, and only instruments designed to withstand the extreme environments within the core could survive. Past meteorological measurements and measurements planned for future studies will be discussed.

Methodologies of placing these instruments in the paths of tornadoes will be discussed as this task is achieved with significant difficulty. Fielding strategies will be examined as they are key to a successful deployment.

Background

Since the late 1970s, researchers have attempted to make meteorological measurements within a tornado. Several instruments have been built and fielding campaigns attempted over the last 25 years of tornado research with varying degrees of success.

In-situ measurements within tornado cores are hard at best to attain, as it is difficult to place instruments in the paths of tornadoes, and the instruments themselves need to survive the hostile environments typical of tornadoes. Attempts have been made to deploy instruments that weigh from 200 kg to less than 2 kg in paths of tornadoes.

Meteorological Instruments Hit by Tornadoes

There have been several meteorological instruments that have been inadvertently hit by tornadoes over the last 110 years.

Barometric pressure drops of 82 mb and 10 mb during the 1896 St. Louis tornado were read by citizens as the tornado core passed over (Weather and Climate Modification, Heis 1974). Another measurement of 192 mb was taken of a tornado passage in Minneapolis in 1904 by a citizen's barometer. These measurements are questionable as to the readings were taken under considerable duress. Table 1 illustrates several pressure deficits that were recorded over the last 100^{+} years.

Table 1. Record of Known Measured Pressure Deficits in Tornadoes up to 1975. [a, b]

Tornado	Pressure Drop (mb)	Distance from Center[c] (m)	Remarks
Little Rock, 1894	13		
St. Louis, 1896	82	Very near center	Citizen's barometer reading
St. Louis, 1896	10	800	Weather Bureau
Minneapolis, 1904	192		Unofficial citizen's barometer reading (questionable)
Minneapolis, 1904	19		Weather Bureau
Sydney, Neb., 1951	16	Fringe of funnel	
Minneapolis, 1951	14	Fringe of funnel	
Dyersburg, Tenn., 1952	22	38	
Cleveland, 1953	8	213	
Fargo, N.D., 1957	12		Near center of tornado cyclone
Waterspout, 1958	21	Very near center	Waterspout passed over ship
Austin, Tex., 1959	5	214	
Newton, Kansas, 1962	34		Near center of tornado cyclone
Topeka, Kansas, 1966	21		290 ft from left or NW edge of extreme wind streak
Oklahoma City, 1970	10	400-800	NSSL meso network station
Lubbock, Tex., 1970	12	Near center	Not in suction spot
Springfield, Mo., 1971	12	Near center	

[a] The effects of instrumental damping on these measurements are unknown.
[b] Tepper and Eggert report additional measured pressure deficits of 6 to 12 mb within 1/2 mi of tornadoes.
[c] Center here refers to center of extreme damage, which may not coincide with center of vortex. (Source: “Weather and Climate Modification” edited by W.N. Hess, 1974)

Figure 1 shows a passage of a mesocyclone core over a barometric strip chart recorder that was located in Newton, Kansas on May 24, 1962 (Edwin Kessler, “Thunderstorm Morphology and Dynamics,” Volume 2, 1983).

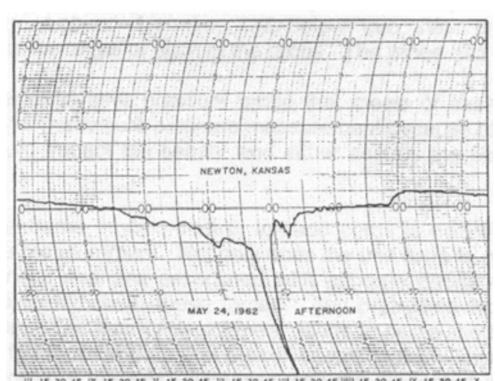

Figure 1. Surface pressure record of an intense tornado cyclone; abscissa is time, ordinate pressure from 28 in Hg in intervals of 0.1 in.

Meteorological Instruments that were Placed Within the Paths of Tornadoes.

Sound Chase

From 1976 to 1981, R. Arnold from the University of Mississippi attempted to deploy sound recording instruments near and within the paths of tornadoes (Bluestein, 1988). The focus was to record the unusual audio sounds generated by tornadoes.

On May 17, 1981, the Sound Chase crew intercepted and penetrated a rotating curtain of rain, stopping just short of a developing tornado (Figure 2). The tornado passed within meters of the large converted van owned by NSSL, known as “NSSL-1” (National Severe Storms Laboratory mobile intercept vehicle 1 shown in Figure 3).

Figure 2. Frame Grab of Tornado Passage on May 17, 1981 south of Tecumseh, OK during Sound Chase (Courtesy Tornado Project/ NSSL).

Figure 3. NSSL-1 used on "Sound Chase".

NSSL-1 also carried electric E-field meters and recorded E-fields as high as 13 KV/M (N. Rasmussen, personal communications) during the field experiment.

Rockets

During the spring of 1981, Stirling Colgate from Los Alamos National Laboratory and New Mexico Institute of Mining and Technology developed small 23 cm long model rockets to be launched into a tornado. The purpose was to measure pressure, temperature, ionization, and electric field variations along a trajectory penetrating a tornado (S. Colgate, 1982). A Cessna 210 aircraft was used with special instrumented rockets loaded under the wingspan which could be launched remotely within the cockpit. Colgate used radio telemetry to transmit the data back to a Z80 computer aboard the aircraft.

In accordance with FAA regulations, the rocket motor needed to contain less than 80 grams of propellant to meet the federal regulations of a non-lethal weapon. Figure 4 shows a schematic of the rocket (S. Colgate, 1982).

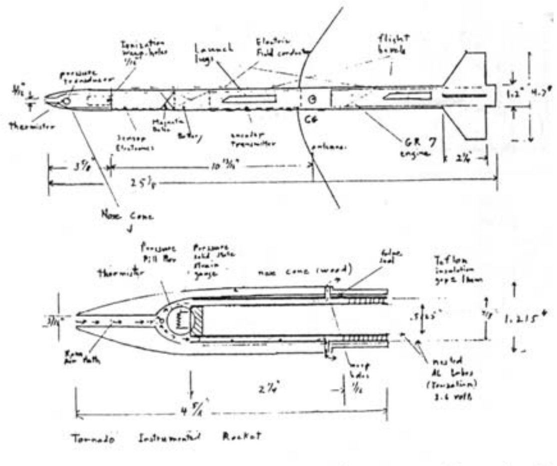

Figure 4. Reproduction of the original drawing shown in Colgate's 1982 paper submitted to "The 12th Conference on Severe Local Storms", January 11-15, 1982.

Colgate attempted to fire numerous rockets into a tornado, however none appeared to penetrate the tornado funnel due to significant factors including moisture saturating the propellant leading to misfires, and the extreme wind environments in the tornadoes.

Figure 5. Frame from a camera mounted on the Cessna 210 showing a rocket launch attempt on May 18, 1981 (Courtesy Tom Grazulis/Tornado Project and Stirling Colgate).

Figure 6 shows some of the data recovered from the Spring of 1981. The top trace shows ionization, the middle trace is electrical charge, and the bottom trace represents pressure. The noise spikes are likely caused by signal dropout and influence from nearby 60 Hz power lines (Colgate 1982).

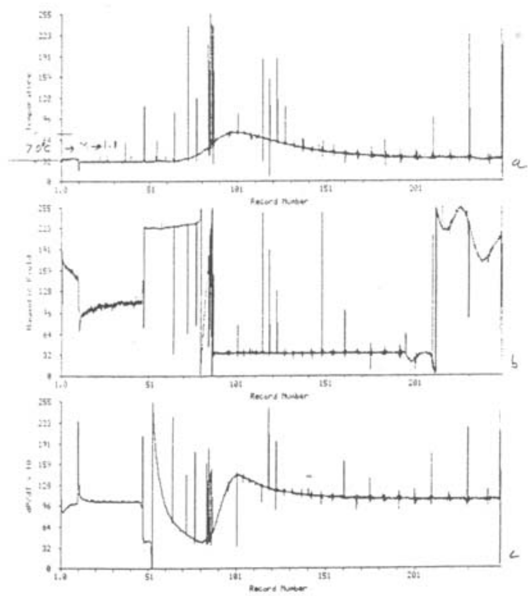

Figure 6. Some data results from rocket launches during the spring of 1981 (Colgate, 1982).

<u>In-situ Waterspout Measurements</u>

During the month of September, 1974, the first-ever in-situ measurements of a vortex took place over the Florida Keys using a specialized instru-mented research aircraft. Joe Golden has provided evidence that tornadoes and water-spouts are qualitatively the same, but differ in only certain quantitative characteristics (Golden, 1977). With the foregoing in mind, special airborne instrumentation was developed that could accurately measure the physical and kinematic variables across and within the boundaries of a waterspout.

Figure 7. Cone-shaped body for meteorological measurements (Church 1973).

The technique used to probe waterspouts consisted of towing an instrumented cone-shaped body (Figure 7) behind a light aircraft. The system measured dynamic and static pressure, temperature, and relative humidity (Church, 1973).

During a 12-day period from 16 September to 27 September, 16 waterspouts were penetrated by research aircraft (Golden, 1977).

<u>TOTO</u>

From 1972 through 1979, intercept teams from NSSL and the University of Oklahoma (OH) frequently succeeded in intercepting tornadoes each spring. Discussions between Al Bedard and Howard Bluestein suggested that it would be possible to drop a recording instrument in the paths of tornadoes (Bedard, 1982).

In an attempt to make meteorological surface observations of tornado cores, Al Bedard and Carl Ramzy developed the first In-Situ surface observation system called TOTO or TOtable Tornado Observatory (Bedard, 1982). Bluestein and several of his colleges named the probe after Dorothy's little dog Toto who was carried up into a tornado in The Wizard of Oz (Baum, 1900).

Figure 8. TOTO shown deployed.

The probe used hardened weather sensors to measure pressure, wind speed/direction, temperature and corona discharge. The data was recorded on mechanical impact recorders that recorded a data point every second.

Due to the large mass (400 kg) and size, the unit was stored on its side on rollers to deploy off the bed of a standard pickup truck using ramps. Once TOTO was rotated into position, the unit would activate using mercury switches. The deployment team was able to deploy TOTO in 30 seconds or less.

Intercept teams from the University of Oklahoma attempted to deploy TOTO directly into the path of tornadoes during the spring seasons of 1981-1983 (Bluestein, 1998). Teams from NSSL attempted to do the same during 1984 and 1985 (Burgess et al., 1985)

On April 29 1985, Lou Wicker and the NSSL crew almost succeeded near Ardmore, Texas, where the developing tornado passed by TOTO.

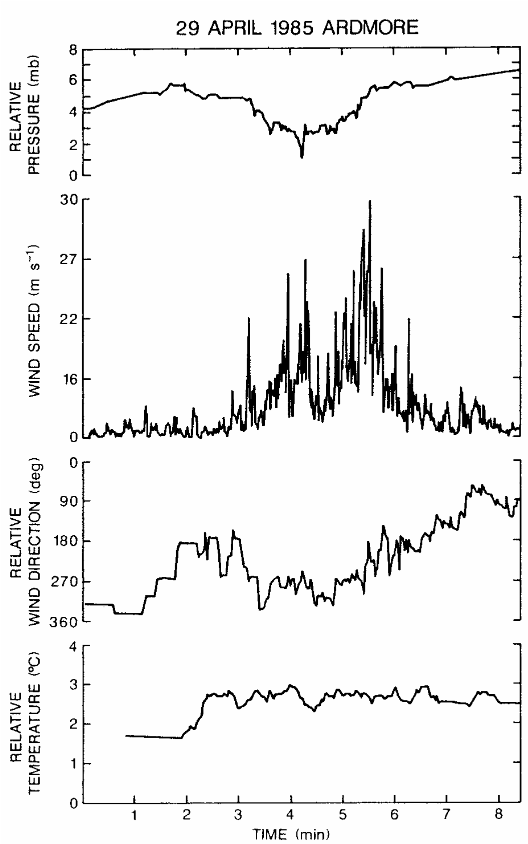

Figure 9. Data results recorded from TOTO on 29 April, 1985.

In March of 1983, TOTO was tested at a wind tunnel facility at Texas A&M University. The results show (Figure 9) that TOTO could tip over in wind speeds as low as 45 meters/second (Bluestein, 1998).

TOTO was decommissioned in 1986 and currently resides at the National Oceanic and Atmospheric Administration Headquarters in Washington, DC as a museum piece.

NSSL Turtles

Figure 10. NSSL Turtle (D Grazulis, Tornado Project).

Several small portable instrument recorders were developed at OU in 1987 and were fielded in the spring of the same year in Texas and Oklahoma (Brock, et al 1987). These instruments were called "Turtles" due to their overall shape/ appearance. The physical size of the units is 35 cm in diameter with a 25-kg lead weight that was molded around the inside circumference. (Figures 10 and 11).

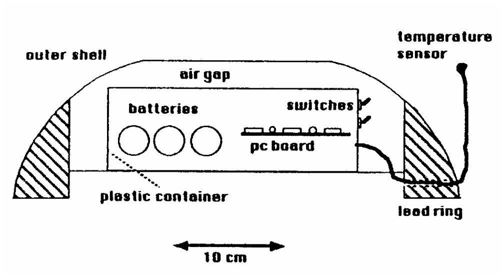

Figure 11. Schematic of the turtle showing mechanical/electrical position of components (Brock, 1987).

On May 16, 1986, a chase crew from the University of Oklahoma deployed several Turtles near the path of a storm that developed west of Wheeler, Texas. The recorded data from some of the instruments showed a gradual pressure drop during the first 30 minutes. It was the crew's interpretation that updrafts were passing over the southern deployment region. Figure 12 shows the temperature and pressure plots from that deployment (Brock, 1987).

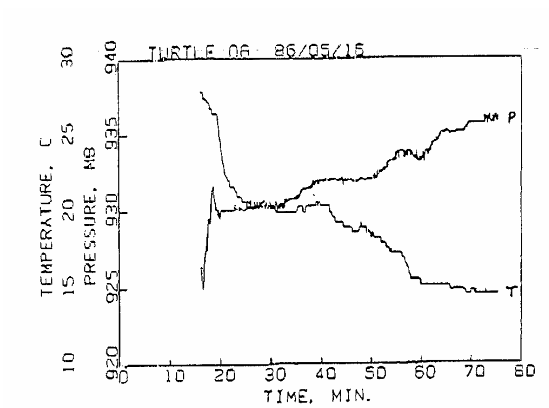

Figure 12. Data recovered from "Turtle 6" on May 16, 1986 (Brock, 1986).

SNAILS

Dr. Frank Tatom of Engineering Analysis, Inc. believes there is a specific seismic signal associated with a tornado (Tatom, 1995). Based upon several eye-witness accounts and various seismic recordings during tornado touch-down, Tatom investigated the possibility of using the seismic signals as a possible warning system. Several small probes were built, nicknamed "Snails" to be placed near the path of tornadoes to record the three-axis seismic vibrations of tornadoes, and atmospheric pressure fluctuations (Tatom, 2004, private communi-cation).

Figure 13. Number 5 Snail.

Figure 13 shows a Snail "deployed" on the ground. The small rectan-gular box is the three-axis geophone, while the dome on the right houses the recorder and battery. In 1997, several of these Snails were loaned to chasers for possible deployment opportunities.

On May 25, 1997, Tim Samaras deployed a Snail near a large tornado in south-central Kansas. The instrument recorded a strong signal as the tornado passed (Tatom, 2004, private communication).

DILLO-CAM

Charles Edwards constructed a probe that contained a single video camera (Figure 14), nicknamed "Dillo-cam" (Edwards, 2004, private communication).

The objective was to place the probe in the path of tornadoes to record the effects of tornado passage.

Figure 14. Charles Edwards "Dillo-cam".

The Dillo-cam was deployed on May 25, 1997 near Perth KS by Casie Crosbie. It was directly hit by a large tornado at sunset. The probe performed perfectly until the tornado passed overhead and the debris broke the glass viewing port. The camera lens area quickly filled with mud and debris, therefore blocking the viewing. It did, however, continue to record audio of the tornado passage.

A second version of the Dillo-cam was constructed in 1998. Dubbed "Dillo-Cam II", the probe had instruments to record wind speed, pressure, temperature, and relative humidity. The data was written directly to the hard drive of a laptop. The instrument also included a camcorder.

Dillo-cam II was deployed October 4, 1998 near Dover, OK and got within 400 meters of the tornado. Unfortunately, the battery connection came loose on the recorder, thus little data was recovered. The probe was deployed twice on May 3, 1999. The first attempt was southwest of Chickasha, Oklahoma, but the power switch was accidentally bumped off during deployment. The second deployment attempt on May 3rd was near Cogar, Oklahoma. The tornado dissipated before passage over the probe. The anemometer still recorded 15 meters/second as the remaining circulation passed overhead.

E-Turtles

Bill Winn of Langmuir Laboratory/ New Mexico Institute of Mining and Technology constructed a number of instruments to record the electric field, pressure and temperature of tornado cores (Winn, 1998). These probes, called E-Turtles were fielded in conjunction with project VORTEX in the spring seasons of 1994 and 1995.

On June 8, 1995, the New Mexico Tech team managed to deploy two E-Turtles on the edge of a large tornado near Allison, Texas. One of the probes measured a 50 mbar pressure deficit, Figure 15 (Winn, 1999).

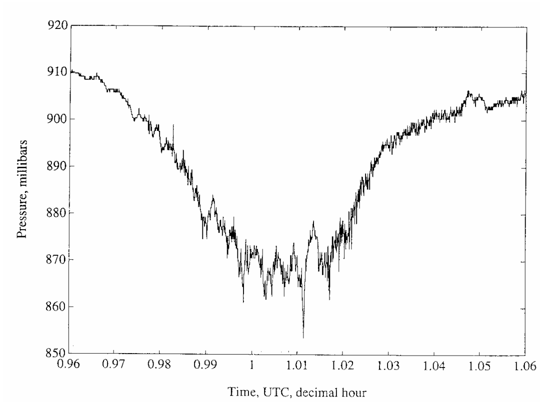

Figure 15. Pressure deficit recorded by an E-Turtle on June 8, 1995 (Winn, 1999).

HITPR

In 1997, Tim Samaras and associates from Applied Research Associates, Inc. (funded by DOC/NOAA) developed an instrumented probe to measure pressure, temperature, humidity, and wind speed/direction (Figure 16). Dubbed “HITPR” (Hardened In-situ Tornado Pressure Recorder), the probes have been fielded numerous times within tornado cores from 2002 to 2004.

Figure 16. HITPR Probe.

On June 24, 2003 the deployment team was successful on placing one HITPR probe directly in the path of a violent tornado that just destroyed the small hamlet of Manchester, South Dakota a few minutes prior (Lee, 2004). A pressure deficit of 100 mbar was measured as the tornado passed directly overhead (Figure 17).

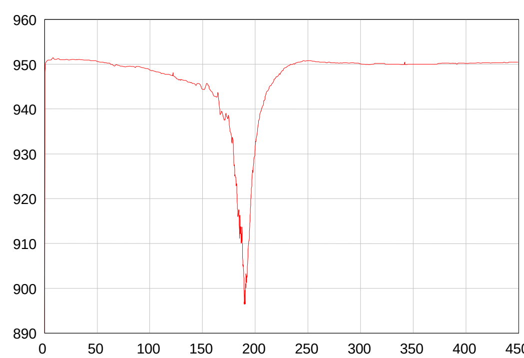

Figure 17. 100 mbar pressure deficit graph from June 24, 2003 tornado (Lee, 2004).

The tornado that went over Probe 3 on June 24, 2003 was rated an F4 by the National Weather Service in Sioux Falls, South Dakota.

Deployment Strategies used for successful in-situ deployments within tornado cores.

Deploying meteorological instruments within the potential paths of tornadoes is challenging at best. Significant factors including timing, road options/conditions, and visibility will likely hamper successful in-situ measurements. The safety margin of the deployment crew can be compromised by several factors that are beyond the control of the team.

Technological developments in recent years have facilitated deployment attempts. GPS mapping software that shows the team location in real time during the deployment attempt is extremely useful for road options, and the calculations of distances needed when choosing roads. Also, with wireless internet access, composite radar data that is gathered in the field helps to assess the direction and speed of storms to help make decisions on deployment locations.

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