COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 02-2

NSF 02-2

FOR CONSIDERATION BY NSF ORGANIZATION UNIT(S) (Indicate the most specific unit known, i.e. program, division, etc.)

ATM - MESOSCALE DYNAMIC METEOROLOGY

FOR NSF USE ONLY

NSF PROPOSAL NUMBER

0241037

DATE RECEIVED	NUMBER OF COPIES	DIVISION ASSIGNED	FUND CODE	DUNS# (Data Universal Numbering System)	FILE LOCATION
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SHOW PREVIOUS AWARD NO. IF THIS IS
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NAME OF ORGANIZATION TO WHICH AWARD SHOULD BE MADE

University of Oklahoma Norman Campus

AWARDEE ORGANIZATION CODE (IF KNOWN)

0031849000

ADDRESS OF AWARDEE ORGANIZATION, INCLUDING 9 DIGIT ZIP CODE

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1000 Asp Avenue, Room 314
Norman, OK. 73019

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IS AWARDEE ORGANIZATION (Check All That Apply)
(See GPG II.C For Definitions) ☐ FOR-PROFIT ORGANIZATION ☐ SMALL BUSINESS ☐ MINORITY BUSINESS ☐ WOMAN-OWNED BUSINESS

TITLE OF PROPOSED PROJECT **Severe Convective Storms and Tornadoes**

REQUESTED AMOUNT	PROPOSED DURATION (1-60 MONTHS)	REQUESTED STARTING DATE	SHOW RELATED PREPROPOSAL NO., IF APPLICABLE
$ 692,400	36 months	02/01/03	

CHECK APPROPRIATE BOX(ES) IF THIS PROPOSAL INCLUDES ANY OF THE ITEMS LISTED BELOW
☐ BEGINNING INVESTIGATOR (GPG I.A)
☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.6)
☐ HISTORIC PLACES (GPG II.C.9)
☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.C.11)
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Exemption Subsection ________ or IRB App. Date ________
☐ INTERNATIONAL COOPERATIVE ACTIVITIES: COUNTRY/COUNTRIES INVOLVED (GPG II.C.9)
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☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

PI/PD DEPARTMENT

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CERTIFICATION PAGE

Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 02-2. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

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By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Appendix A of the Grant Proposal Guide.

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Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

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Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

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The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

AUTHORIZED ORGANIZATIONAL REPRESENTATIVE	SIGNATURE	DATE
NAME **Jennie I Parker**	**Electronic Signature**	**Aug 9 2002 12:14PM**

TELEPHONE NUMBER	ELECTRONIC MAIL ADDRESS	FAX NUMBER
405-325-6054	**gradora1@ou.edu**	**405-325-6029**

*SUBMISSION OF SOCIAL SECURITY NUMBERS IS VOLUNTARY AND WILL NOT AFFECT THE ORGANIZATION'S ELIGIBILITY FOR AN AWARD. HOWEVER, THEY ARE AN INTEGRAL PART OF THE INFORMATION SYSTEM AND ASSIST IN PROCESSING THE PROPOSAL. SSN SOLICITED UNDER NSF ACT OF 1950, AS AMENDED.

PROJECT SUMMARY

The main objective of this proposed research project is to improve our understanding of the kinematics and dynamics of severe convective storms and tornadoes, and of their formation. It is anticipated that this project will ultimately lead to a more accurate prediction of severe weather events. The objective will be met primarily through an analysis of data collected in both previous and continuing field experiments, including IHOP (International H2O Project), and through numerical simulation experiments.

Mobile Doppler-radar datasets from field experiments will be analyzed to detail the structure and evolution of tornadoes and their parent vortices, and the vertical circulation associated with the dryline, a feature along which severe convective storms are often initiated. In particular, why some supercell storms produce tornadoes, while others do not, will be investigated. The dynamics of convective-storm interaction and the role of the intersection of a dryline with a baroclinic boundary in triggering convective storms will be investigated using controlled numerical-model simulation experiments.

In addition, it is proposed that two new radar systems be tested for use in severe storm/tornado research: One is a mobile, military, rapidly scanning, phased-array Doppler radar that is being converted for meteorological use; the other is an existing system that it is proposed be fitted with a spaced antenna, which could provide transverse-wind measurements in addition to line-of-sight wind measurements. If the new radar systems are successful, then much higher quality datasets will be available for analysis. Our proposed efforts involve collaborative technology development with engineers at another institution.

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Appendix Items:

*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

1. Results from Prior NSF Support

a. NSF award number: ATM-9912097
Amount: $489,057
Period of support: 1 June 2000 – 31 May 2003

b. Project title: Studies of Severe Convective Storms and Tornadoes

c. Summary of results:
Work on the prior NSF grant included studies carrying over from the previous grant in addition to the new work proposed using mobile W-band and X-band Doppler radars. Ongoing studies consisted mainly of the analysis of airborne Doppler radar data from VORTEX (Verification of the Origins of Rotation Experiment) (Rasmussen et al. 1994). Also supported by the grant were a few studies of opportunity not anticipated at the outset of the project.

  i. A mobile W-band Doppler radar developed at the Microwave Remote Sensing Lab. (MIRSL) at Univ. of Mass. (Amherst) was used to probe a number of tornadoes and their parent vortices during small field programs conducted by graduate students and the P. I., in collaboration with engineers and graduate students at the Univ. of Mass. The experiment was held in the Plains during the springs of 1999-2002. The purpose of the experiment was to determine tornado structure and document tornado formation. From ground-based velocity-track display (GBVTD) analyses of a tornado on 5 June 1999, it was found that the radius of maximum wind decreased/increased as the tornado intensified/dissipated. Evidence was found that the tornado was two-celled when it was most intense. The azimuthal wind component was dominated by wavenumber-two disturbances. Cyclonic vortices only 100-200 m across were common along what is thought to be the leading edge of the rear-flank downdraft; during tornadogenesis, one of the vortices was located at the nose of the gust front along a bow-shaped echo. This project also involved collaboration with personnel at NCAR.

  ii. Airborne Doppler radar data collected by ELDORA (Electra Doppler Radar) on 8 June 1995 during VORTEX continued to be analyzed and the work was completed; the analyses documented, in detail, cyclic tornado formation. It was found that the rear-flank gust front appears to play a major role in determining the location of the next vortex in the series. The relative motions of the updraft and vorticity maxima (produced by the tilting of low-level horizontal vorticity) were most important; the cyclic tornadogenesis process was associated with a mismatch between the horizontal motion of successive tornadoes and the horizontal velocity of the main storm-scale updraft and downdraft. Low-level updraft-relative flow seemed to be the most important factor in determining tornado motion. This work supported a graduate student who received a Ph. D.

  iii. ELDORA data collected on 22 May 1995 during VORTEX continued to be analyzed and the work was completed; the analyses documented a nontornadic supercell that produced large hail. It was found that the storm exhibited a few unusual features: an elevated jet flanked by strong cyclone-anticyclone couplet and a deep convergence zone. The formation and potential importance of these features were investigated using numerical simulation experiments. This work supported a graduate student who received an M. S.

  iv. ELDORA data collected on 3 June 1995 during VORTEX were analyzed and the work was completed; the analyses documented clear-air motions in and around the intersection of the dryline and a surface baroclinic boundary (triple point). A transverse secondary circulation was found; a maximum in rising motion was found at the western edge of the dewpoint gradient. The Doppler analyses were corroborated by in situ data collected aboard the aircraft. North of the triple point a residual dryline secondary circulation (RDSC) was found elevated above the cold pool. This work supported a graduate student who received an M. S. and who is now working on his Ph. D.

v. A numerical simulation experiment was carried out that demonstrated that the evolution of supercells in a homogeneous environment depends upon the orientation of the vertical-shear profile with respect to the orientation of the line along which convection is initiated. It was found that shear oblique to the line of forcing is most apt to support neighboring cyclonic supercells within the line, but also supports an anticyclonic supercell at the downshear end of the line; shear normal to the line of forcing is favorable for the maintenance of a squall line with isolated supercells at either end; shear parallel to the line of forcing is favorable for isolated supercells only on the downshear end of the line. The process of storm collision was examined in detail. This work involved collaboration with a colleague at NCAR.

vi. On 24 May 1998 a mesocyclone associated with a tornadic supercell passed almost directly over a Doppler wind profiler in Oklahoma. This serendipitous event allowed the analysis of the vertical wind component, and at some times, the horizontal wind component, as a function of height in and just outside the storm. A technique was developed to remove hydrometeor fall-speed contamination. An updraft near and in the mesocyclone, as strong as 50 m s^{-1}, was flanked by weak downdrafts at low levels. Evidence was found of significant modification of the horizontal wind structure away from the updraft and of storm-generated buoyancy waves in the surrounding environment. This work supported a graduate student who received an M. S.

vii. The wind and temperature profiles composited with respect to each quadrant in surface cyclones and anticyclones were computed for the eastern two-thirds of the U. S. Hodographs and soundings were also composited with respect to season, geographic region, time of day, and, for cyclones only, intensity. Vertical profiles of the static-stability parameter were also composited with respect to season and quadrant for both cyclones and anticyclones. A diurnal variation in hodographs was found, which showed up in both cyclones and anticyclones as a rotation in the counterclockwise direction between 00 and 12 UTC, above the boundary layer. The variation was hypothesized to be in part due to a tidal oscillation and in part due to radiative-thermal effects. In the mean, a well-pronounced equatorward-directed low-level jet was resolved in the northwest quadrant of surface cyclones. This work was done in collaboration with a former M. S. student, supported in small part by this grant, who is now at the Storm Prediction Center.

viii. A new, mobile X-band radar was developed by engineers at MIRSL and tested in the springs of 2001 and 2002. Doppler and dual-polarization datasets were collected in tornadic and nontornadic supercells in 2002. The tracking radar echoes by correlation (TREC) technique was used to determine the wind field in the “owl horn” radar-echo signature, which was found in several developing supercells. It was found that the “horns” are related to outflow boundaries. Graduate students at OU, engineers and graduate students at the Univ. of Mass., and the P. I. collaborated on this work. This work is supporting an OU graduate student who is working on his M. S.

ix. The mobile W-band radar was used to collect boundary-layer, clear-air data in a vertical plane across the dryline during IHOP (International H_2O Project) in spring, 2002. Graduate students at OU, engineers and graduate students at the Univ. of Mass., and the P. I. collaborated on this work. The mobile W-band radar was also used briefly in Arizona in 2002 to probe dust devils during an experiment conducted by a colleague at Univ. of Arizona. Data were collected on several dust devils at close range.

x. The P. I. organized a ground-based mobile instrument workshop at NCAR for NSF. A summary of the findings and recommendations were published.

xi. The P. I. collaborated with colleagues at other universities and at NSSL on various other studies and review papers. The studies are summarized in papers listed below. They included a review of mobile radar observations for the Atlas Symposium, a review of the accomplishments of the late T. Fujita on tornadoes and severe thunderstorms for the Fujita Symposium, a review of tornadoes for an Amer. Meteor.

Soc. Monograph, a case study of storm development related to dryline structure on 16 May 1991, and a simple theory for the maximum wind speeds expected in waterspouts. Other publications listed below resulted from work mostly completed in a prior NSF grant.

d. Publications resulting from the NSF award

Bluestein, H. B., 2000: A tornadic supercell over elevated, complex terrain: The Divide, Colorado storm of 12 July 1996. *Mon. Wea. Rev.* , **128**, 795-809.

Crawford, T. M. and H. B. Bluestein, 2000: An operational, diagnostic surface energy budget model. *J. Appl. Meteor.*, **39**, 1196-1217.

Bluestein, H. B., and M. L. Weisman, 2000: The interaction of numerically simulated supercells initiated along lines. *Mon. Wea. Rev.* , **128**, 3128-3149.

Bluestein, H. B., and A. L. Pazmany, 2000: Observations of tornadoes and other convective phenomena with a mobile, 3-mm wavelength, Doppler radar: The spring 1999 field experiment. *Bull. Amer. Meteor. Soc.*, **81**, 2939-2951.

Forbes, G. S., and H. B. Bluestein, 2001: Tornadoes, tornadic thunderstorms, and photogrammetry: A review of the contributions by T. T. Fujita. *Bull. Amer. Soc.*, **82**, 73-96.

Bluestein, H. B., B. A. Albrecht, R. M. Hardesty, W. D. Rust, D. Parsons, R. Wakimoto, and R. M. Rauber, 2001: Ground-based mobile instrument workshop summary, 23-24 February 2000, Boulder, Colorado *Bull. Amer. Meteor. Soc.*, **82**, 681-694.

Renno, N. O., and H. B. Bluestein, 2001: A simple theory for waterspouts. *J. Atmos. Sci.*, **58**, 927-932.

Lehmiller, G. S., H. B. Bluestein, P. J. Neiman, F. M. Ralph, and W. F. Feltz, 2001: Wind structure in a supercell thunderstorm as measured by a UHF wind profiler. *Mon. Wea. Rev.*, **129**, 1968-1986.

Hane, C. E., M. E. Baldwin, T. M. Crawford, R. M. Rabin, and H. B. Bluestein, 2001: A case study of severe storm development along a dryline within a synoptically active environment. Part I: Dryline motion and an Eta Model forecast. *Mon. Wea. Rev.*, **129**, 2183-2204.

Bluestein, H. B., and S. G. Gaddy, 2001: Airborne pseudo-dual-Doppler analysis of a rear-inflow jet and deep convergence zone in a supercell. *Mon. Wea. Rev.,* **129**, 2270-2289.

Davies-Jones, R. P., R. J. Trapp, and H. B. Bluestein, 2001: Tornadoes. *Severe Convective Storms*, Meteor. Monogr., 28, no. 50 (C. Doswell III, ed.), Amer. Meteor. Soc., 167-221.

Bluestein, H. B., and P. C. Banacos, 2002: The vertical profile of wind and temperature in cyclones and anticyclones over the eastern two-thirds of the United States: A climatology. *Mon. Wea. Rev.*, **130**, 477-506.

Hane, C. E., R. M. Rabin, T. M. Crawford, H. B. Bluestein, and M. E. Baldwin, 2002: A case study of severe storm development along a dryline within a synoptically active environment. Part II: Multiple boundaries and convective initiation. *Mon. Wea. Rev.*, **130**, 900-920.

Weiss, C. C., and H. B. Bluestein, 2002: Airborne pseudo-dual Doppler analysis of a dryline-outflow boundary intersection. *Mon. Wea. Rev.*, **130**, 1207-1226.

Dowell, D. C., and H. B. Bluestein, 2002a: The 8 June 1995 McLean, Texas storm. Part I:

Observations of cyclic tornadogenesis. *Mon. Wea. Rev.* (in press)

Dowell, D. C., and H. B. Bluestein, 2002b: The 8 June 1995 McLean, Texas storm. Part II: Cyclic tornado formation, maintenance, and dissipation. *Mon. Wea. Rev.* (in press)

Bluestein, H. B., and R. M. Wakimoto, 2002: Mobile radar observations of severe convective storms. *Atlas Symposium Monograph*, Amer. Meteor. Soc. (accepted)

Bluestein, H. B., C. C. Weiss, A. L. Pazmany, W.-C. Lee, and M. Bell, 2003: Tornadogenesis and tornado-vortex structure in the Bassett, Nebraska supercell of 5 June 1999: W-band Doppler-radar observations. *Mon. Wea. Rev.* (to be submitted)

Wakimoto, R. M., H. Murphey, D. C. Dowell, and H. B. Bluestein, 2003: The Kellerville tornado during VORTEX: Damage survey and Doppler radar analyses. *Mon. Wea. Rev.* (to be submitted)

2. Introduction

a. Motivation and major scientific issues

Severe convective storms and tornadoes can destroy lives and property. Two major scientific questions concerning severe convective storms and tornadoes are as follows:

1. Why do some storms produce tornadoes while others do not? In particular, since supercell storms account for much of the severe weather associated with convective storms, why do some supercells produce tornadoes, while others do not?
2. What determines whether or not a storm forms? If it does, what controls the mode of storm organization?

In order to answer the above questions, tornado formation in supercells and convection initiation must be documented by observing systems and replicated by controlled numerical simulation experiments. The main objectives of this proposed research project are to analyze existing datasets, collect new ones, test new instruments that may be used to collect improved datasets, and to conduct numerical simulation experiments for idealized situations.

Much of what we know about tornado formation and tornado structure comes from Doppler-radar analyses interpreted in the context of highly idealized laboratory and numerical simulations (e.g., as summarized in Davies-Jones et al. 2001; Bluestein and Wakimoto 2002). Doppler radar observations have been collected and analyzed at fixed sites (e.g., Brandes 1978: Dowell and Bluestein 1997), from aircraft (Wakimoto et al. 1998: Wakimoto and Liu 1998: Zeigler et al. 2001; Dowell and Bluestein 2002a,b), and from ground-based mobile platforms (Bluestein et al. 1996; Bluestein and Pazmany 2000; Wurman and Gill 2000; Wurman 2002; Bluestein et al., 2003). Unfortunately, it is relatively rare that tornadogenesis is documented by networks of fixed-site radars, since the likelihood is low that tornadogenesis will occur close to the small areas resolved in multiple-Doppler networks. Even when tornadogenesis has been documented, the spatial resolution is usually limited to storm-scale features and motions near the ground are not resolved owing to the curvature of the earth.

Airborne Doppler radars have documented tornado formation, but the instruments are incapable of documenting what happens in the lowest several hundred meters (where important interaction of the tornado vortex with the ground occurs) owing to ground-clutter contamination, and the spatial and temporal resolutions (~300 m, passes by the storm every 5 min) are more appropriate for storm-scale motions.

Mobile, ground-based systems have been successful in documenting tornadoes and tornadogenesis on numerous occasions. The advantages of mobile radars are that they can be brought close enough to tornadoes that high-resolution datasets are collected, motions in the lowest few hundred meters can be resolved, and the likelihood of data collection is increased over what is possible with fixed-site radars. The main disadvantages of ground-based mobile systems are that is sometimes difficult to keep up with storms long enough to be able to document the entire tornadogenesis process.

Our understanding of convection initiation, like our understanding of tornado formation, has been limited in large part by our ability to observe meteorological fields on small enough time and space scales. During IHOP (International H_2O Project), wind, temperature, and moisture data were collected on short time and space scales by many different platforms along boundaries along which storms sometimes formed (http://www.joss.ucar.edu/ihop). The datasets collected offer opportunities to observe instances in which storms were initiated and instances in which they were not.

It is proposed to continue our studies of supercells, their formation and organization, and tornado structure and formation using mobile Doppler radars and controlled numerical experiments. Continuing studies of data collected in previous experiments, new field experiments conducted on a very small scale (i.e., inexpensively with few participants) and the testing of new radar techniques in collaboration with a group of engineers at the University of Massachusetts (Amherst), along with new numerical-simulation experiments are proposed. Some of the data to be analyzed will come from the IHOP. This proposal is closely related to another NSF proposal submitted by Dr. Andrew Pazmany at the University of Massachusetts.

b. Tornado formation and structure

Tornado formation sometimes occurs aloft in a supercell and then builds down to the ground; other times it forms in a column at all altitudes simultaneously, depending on the vertical profile of convergence (Trapp and Davies-Jones 1997; Trapp 1999; Trapp et al. 1999). The source of tornado vorticity in supercells is thought to be horizontal vorticity in the boundary layer that is tilted and subsequently stretched (e.g., as described for storm-scale vortices by Rotunno and Klemp 1985; Wicker and Wilhelmson 1995). While tilting can occur across an updraft alone, tilting between an updraff and downdraft, or across a downdraft may be more significant because the vorticity is not advected upward as quickly early on while it is being stretched (Davies-Jones and Brooks 1993; Walko 1993)). Supercell tornadoes are related to storm-scale mesocyclones. However, there does not seem to be much difference between the structure of tornadic and nontornadic mesocyclones (Trapp 1999; Wakimoto and Cai 2000). Wicker and Wilhelmson (1995) found numerical evidence that tornadogenesis can be initiated by an upward-directed perturbation pressure force that occurs when mesocyclone strength increases above cloud base. It has been suggested, however, that secondary vortices forming along a ring of higher shear in the mesocyclone may form when the swirl ratio is high, and become tornadoes (Wakimoto et al. 1998). The role of solenoidally generated horizontal vorticity as air parcels follow the edge of an evaporatively cooled pool of air has not been conclusively established (Markowski 2002; Markowski et al. 2002). Using data from the W-band Doppler radar, in the only case of tornadogenesis “captured” to date, a small-scale vortex, on the order of 100-200 m across, coincided with the leading edge of a bow-shaped echo along what appeared to be the rear-flank downdraft of the storm (Bluestein et al. 2003). Such vortices seem to be common along the rear-flank downdraft, and might become the seeds for tornadoes within the mesoyclone (Bluestein et al. 1996). Thus, tornado formation could involve an interaction between small-scale vortices and the mesocyclone. How the small-scale vortices propagate with respect to the main updraft in the supercell could determine whether or not a vortex grows to tornado intensity, undergoes cyclical development, or becomes a long-lived tornado (Dowell and Bluestein 2002b). In the case of the latter, there is some evidence that storm interactions might play a role in matching the updraft velocity to the velocity of the small-scale vortices that might grow into tornadoes. From an observational perspective, observations are needed to test the aforementioned theories on both the scale of the tornado vortex (100-500 m) and the mesocyclone (2-5 km). A narrow-beam W-band radar can provide the former, while an X-band or C-band radar can provide the latter.

Tornado structure in laboratory and numerical simulation models is controlled primarily by the swirl ratio, a measure of the relative amount of rotational flow to updraft in the vortex (Rotunno 1984; Davies-Jones et al. 2001). When the swirl ratio is low, the tornado is one-celled, with an updraft in the center and a downdraft surrounding the updraft; when the swirl ratio is high, the tornado becomes two-celled, as air is sucked downward in the center, an updraft encircles the central downdraft, and a downdraft is found at larger radii from the center. In high-swirl vortices, multiple vortices appear. Radar observations have only begun to reveal the character of tornado vortices in nature. Many more are needed to piece together the variety of structures in real tornadoes and how they relate to their environment, and to assemble a climatology of tornado properties. The use of a narrow-beam W-band radar is particularly advantageous because it can resolve the 10-m scale features in 100-m scale tornadoes that characterize the vortex. Finally, a narrow-beam is essential to resolving the flow of the tornado near the ground, in the lowest 10 m, where turbulent friction plays a dominant role. It is thought that the highest wind speeds occur just above the surface (Lewellen et al. 1997; Wurman and Gill 2000).

c. Convective-storm initiation and storm organization

When a capping inversion or stable layer produces significant convective inhibition (CIN), heating in the boundary layer and/or lifting along a boundary along which there is low-level convergence, are/is necessary to lift air to its level of free convection (LFC) and trigger convection (Crook and Klemp 2000). Convergent boundaries are made visible on radar when insects collect along the convergence zones (Wilson and Schreiber 1986; Wilson et al. 1994).

Severe convective storms sometimes form along the dryline, a surface boundary separating moist, marine air capped by a stable layer, from dry, warmer, well-mixed continental air. They seem especially likely to form when the dryline intersects a baroclinic boundary at the surface. The vertical circulation about a dryline has been likened to an “inland sea breeze”(Sun and Ogura 1979). Discussions of issues pertaining to convective intiation along the dryline are found in numerical (e.g., Ziegler et al. 1997) and observational (Ziegler and Rasmussen 1998; Hane et al. 1997) studies. A residual dryline circulation (RDSC) may be found above the cold pool associated with an outflow boundary that interects the dryline (Weiss and Bluestein 2002).

Once storms are triggered, there are a number of modes that organized convection in strong shear can take place (e. g., Bluestein and Jain 1985; Bluestein and Parker 1993). Bluestein and Weisman (2000) demonstrated how even when convective cells are initiated along a line, the ultimate mode of convective organization can depend upon the orientation of the vertical shear vector with respect to the line of forcing.

d. Summary of problems to be addressed

It is proposed that the following scientific problems be addressed:

i. What is the sequence of events that precedes tornadogenesis in a supercell on short time and space scales?
ii. What is the detailed wind structure in a tornado throughout its life cycle? Especially, what is the wind field on a fine scale below 500 m?
iii. What is the nature of vertical circulations about the dryline on very fine spatial scales?
iv. What controls the nature of vertical circulations near the intersection of a dryline and a baroclinic boundary at the surface?
v. What controls the organization of convective storms once they have been triggered?

3. Research Plan and Methodology

a. Analysis of existing data

Datasets from recent field experiments will be analyzed. The following datasets have been selected for analysis from a large sample of possible datasets, based upon their quality, completeness, and potential for yielding significant results:

i. The Stockton, KS tornado: W-band Doppler radar data documented most of the life history (the first few minutes of tornadogenesis were missed while the radar was being set up) of a tornado near Stockton, KS on 15 May 1999 (Bluestein and Pazmany 2000). This dataset is similar to that of the 5 June 1999 tornado in Nebraska, the analysis of which has just been completed and a manuscript describing it has been submitted to *Mon. Wea. Rev.* Sector scans at low elevation angle were collected every 10-20 s. The temporal continuity of the dataset is excellent. The advantage of this dataset is that a rich array of features such as an "umbilical"cord of reflectivity connecting the tornado to the rest of the hook echo, spiral bands, and occasional multiple vortices were visually evident. Our focus will be on applying the GBVTD (ground-based velocity track display) technique, used on tropical-cyclone Doppler radar data, to determine properties of the mean tornado vortex and the contributions from higher-wavenumber disturbances (Lee et al. 1999). A discussion of how the center of the (tornado) vortex is located and effects of errors in doing so on the resultant analysis are found in Lee and Marks (2000). This work will be carried out by M. Kramar.

ii. The Happy, TX tornado: W-band Doppler radar data documented some of the mature stage and part of the dissipation stage of a tornado as it passed through Happy, TX on 5 May 2002. This dataset is significant in that not only were sector scans taken at low elevation angle, but some vertical cross sections (RHIs – range-height indicators) were taken through the tornado. With boresighted video documentation available, it should be possible to determine how far above the ground the highest wind speeds were located, and what the relationship was between reflectivity, the Doppler wind field, the debris cloud, and the condensation funnel. GBVTD analyses of the sector-scan data will also be applied to determine properties of the mean vortex and contributions from higher-order wavenumber disturbances. This work will be carried out by M. Kramar and/or the P. I.

iii. Dust devils: On 25 May 1999 near Tell, TX dust devil data were collected in conventional pulse-pair mode with the W-band radar at close range (within 1.5 km). Donut-holes in reflectivity and spiral-band features were resolved. In addition, on 30 and 31 May 2002, W-band data were also collected in dust devils near Eloy, AZ. The radar was brought to Arizona to participate in a dust-devil experiment conducted by Nilton Renno and others, during a brief time-period when severe-storm activity was not expected in the Plains region. GBVTD analyses of the sector scan data will be applied to determine properties of the mean vortex and contributions from higher-order wavenumber disturbances. Although dust devils are not as intense as tornadoes, it is believed that analysis of the properties of the former will provide insight into the interaction of any small-scale vortex with a boundary. This work will be carried out by the P. I.

iv. Supercells on 23 May 2002 and 4 June 2002 near Borger, TX and Matador, TX, respectively: Datasets were collected of volume scans of dual-polarization, conventional reflectivity, and Doppler velocity data. The former storm had a tornado reported while the radar scanned it, but was not visible from the vantage point of the radar, about 10-15 km away. The dataset is unique in that dual-polarization data are available while there was a tornado reported. The P. I. is aware of work in progress at NSSL on correlating tornadoes with dual-polarization signatures. Dual-polarization data can help characterize the nature of the particles in a convective storm (e.g., Zrnic and Ryzhkov 1999). In this study, the data were collected at very close range. Both storms appeared to be high-precipitation supercells. The latter storm hit the radar with golfball-to-baseball size hail shortly after data collection. It is proposed that TREC be used in conjunction with the Doppler data to determine the two-dimensional wind field. M. Kramar (a graduate student on the project), with help from J. Tuttle at NCAR, was successful in applying TREC (tracking radar echoes by correlation) (Rinehart and Garvey 1978; Tuttle and Gall 1999) to supercell data from the 2001 storm-season archive and in obtaining a storm-scale horizontal wind field exhibiting temporal and spatial continuity, and which appeared to be physically reasonable. This work will be carried out by M. Kramar.

v. Vertical circulations along the dryline: Clear-air W-band Doppler-radar data were collected in the Oklahoma Panhandle, in the boundary layer, on 22 May, 9 June, and 10 June 2002 in conjunction with IHOP. On 3 June 2002 data were collected across a front with IHOP. The data were collected while the radar truck was driven back and forth across the dryline (or front) and the antenna scanned in the vertical plane. The speed of the truck was matched to the scanning rate of the radar so that it will be possible to analyze the data using pseudo-dual Doppler analysis techniques (Jorgensen et al. 1996) in the vertical plane. The position and orientation of the radar beams is known via the GPS (global positioning system) data recorded along with the Doppler data. These datasets will be meshed with airborne, pseudo-dual Doppler data collected by the ELDORA, downward-looking W-band radar data aboard the Wyoming King Air aircraft, mobile mesonet data, and S-pol data, whenever possible (see http://www.joss.ucar.edu/ihop for a detailed description of the IHOP platforms and the data they collected). We will collaborate with PIs in charge of the other instruments whenever possible. This work will be done mainly by C. Weiss as part of his Ph. D. thesis research. (The other component to his research is numerical, as discussed below.)

vi. R. Tanamachi, a new graduate student who has worked at the Univ. of Wisconsin, Madison and in the field during IHOP with the Atmospheric Emitted Radiance Interfermometer (AERI) (Feltz et al. 1998), will analyze the temperature and water-vapor data retrieved from the instrument during IHOP. The initial objective of her work will be to quantify the thermodynamic variability near boundaries and convective storms.

b. Numerical simulations

i. C. Weiss, as part of his Ph. D. research, is using the Advanced Regional Prediction System (ARPS), a three-dimensional, nonhydrostatic, storm-scale model (Xue et al. 2000), to simulate the vertical circulation about the intersection of the dryline with a baroclinic boundary oriented normal to the dryline. Observational work had indicated that the dryline vertical circulation produced solenoidally may have been advected up and over the low-level cold pool associated with the intersection of the dryline and an outflow boundary (Weiss and Bluestein 2002). This elevated circulation, named the residual dryline secondary circulation (RDSC), is thought to be responsible for the triggering of convective storms. Having successfully reproduced the numerical dryline experiments of Peckham and Wicker (2000), C. Weiss is now incorporating a cold pool into the simulation. Sensitivity experiments will be conducted to determine what controls the intensity and location of the RDSC in the simulations.

ii. The P. I. will continue his collaboration with M. Weisman at NCAR on studying convective organization using numerical simulation experiments. Preliminary work has been done with the Klemp-Wilhelmson model (Klemp and Wilhelmson 1978) in setting up convection-interaction experiments.

Bluestein and Weisman (2000) have shown how neighboring storm interactions can affect convective organization. Dowell and Bluestein (2002b) have speculated that the timing of the collision of outflow from a nearby storm can affect tornadogenesis. Numerical experiments in which a new cell is triggered near an old cell can be done. It is proposed that the timing between cells, their spacing, etc. be varied and the resulting behavior noted and explained. Since the old Klemp-Wilhelmson model will no longer be available on a CRAY at NCAR after Sept. 2002, it will be necessary to continue the experiments on a new machine; M. Weisman has not tested out completely the operation of the old model on the new machine. The possibility of working with another model (e.g., WRF – Weather Research and Forecast Model) will be considered. However, it may take a considerable amount of effort to develop model diagnostics that already exist with the old model, whose physics are sufficient for our purposes. This work will be initiated by the P. I. and then transferred to a future graduate student such as R. Tanamachi.

c. Small field experiments

It is proposed that relatively inexpensive field experiments involving only a handful of participants (about 6-9) be conducted each spring (mid to late April- mid to late June) in the Southern Plains, as in past years. The main expenses are gasoline and lodging for out-of-town particants. The P. I. has over 25 seasons of field experience in nearly annual field storm-intercept field experiments. On a typical day, a decision is made in the morning whether or not to operate; if the necessary conditions for tornadoes are present or forecast to occur within about 300 km from home base, the storm-intercept teams travel to a target area of approximately 100 km X 100 km (Bluestein 1999). Information from local radio and television stations, NOAA weather radio, and obtained online using a laptop computer connected to the internet, is used to pinpoint our target storm or area. A nowcaster is helpful when available, but not absolutely necessary.

Operations can be moved farther north and west if necessary, especially during early June when severe activity typically migrates to Kansas, Nebraska, Colorado, and far west Texas. It is advantageous to continue annual field operations because there are significant variations in the frequency of occurrence of tornadoes and supercells that make it very difficult to ensure the success of the experiment in any given year. If the yield is low on severe activity, and the storm intercepts teams miss an event or two as a result of, for example, forecasting error, an incorrect choice of routing, lack of roads, or instrument failure, then continuing field operations increase the chance for success. By operating mostly from our home base in Norman, OK, most of the participants can save on living expenses. Operating ground-based mobile systems is much less expensive than operating airborne platforms and very much less expensive than conducting large field experiments, while still maintaining productivity.

Participants will be, as in the past, mainly graduate students and the P. I. The students gain valuable field experiments each year. With the yearly turnover of students, it is also desirable to include a mix of experienced participants and new participants, who need to gain field experience.

It is proposed to continue the core of our studies using the truck-mounted, W-band Doppler radar designed and built at the University of Massachusetts by A. Pazmany and his group. This radar system has been field tested and successfully used in its current configuration since 1999 (Bluestein and Pazmany 2000). The main advantage of the radar is its narrow-beamwidth antenna (0.18^{o} half-power beamwidth), which allows for cross-beam resolution on the order of 10 m at 3.2 km; along the beam resolution determined by the pulse length is 15 m. In polarization-diversity pulse-pair mode (PDPP) (Pazmany et al. 1999), the maximum unambiguous Doppler velocity is ± 79 m s^{-1}, which allows for easier processing of high-speed data at tornadic wind speeds. The range of the radar is 10 km; when targets are within 1.5 km, only conventional pulse-pair processing is possible. Efforts will be undertaken to remain beyond 1.5 km of tornadoes anyway for safety reasons.

Data are post-processed at University of Massachusetts and archived in universal format for easy viewing and editing using NCAR's SOLO software. A limited real-time display of Doppler velocity and of reflectivity are available on an A scope and as B-scans, to enable the operator to monitor data quality and confirm vortex signatures, etc. The W-band radar is used mostly to probe tornado structure. Sector scans at the lowest elevation angle possible are first collected, usually every 10-20 s, depending on the angular width of the sector selected. A boresighted video camera on the antenna and video monitor facilitate accurate scanning. Range-height (vertical) cross sections are also collected if the tornado visually appears to be relatively steady. An important advantage of the W-band radar system over that of lower resolution (i.e., having 1^{o} beamwidths) X-band systems, is the ability to resolve motions near the ground, in the important surface layer (Lewellen et al. 1997). A disadvantage is that when a tornado is embedded in very heavy precipitation, attenuation can be a significant problem unless the tornado is at very close range. In the past, attenuation has not usually been a problem. Velocity-azimuth displays are also taken to determine the boundary-layer wind hodograph in the vicinity of the area upstream from the updraft region in supercells (Bluestein and Pazmany 2000). In clear air, the scatterers are presumably insects (Wilson et al. 1994).

Data from the primary W-band system will be augmented by data collected in a truck-mounted X-band system. The first reflectivity-only system was completed by the University of Massachusetts group and tested in 2001 by our group. Built using an inexpensive marine radar as its core and leveraged with funds from other projects, the radar system was upgraded to include Doppler velocity and dual-polarization measurements (Z_{DR} and K_{DP}) (Zrnic and Ryzhkov 1999). Differential reflectivity Z_{DR} can provide information about the shape of scatterers; specific differential phase K_{DP} can provide information about information about liquid water and rain rate along the propagation path. Using an antenna having a half-power beamwidth of 1.25^{o} and a range resolution in the along-beam direction of 150 m, the system has proven to be valuable for surveillance, thereby allowing us to navigate to the updraft region of a supercell more easily, especially when it is too far away to see. The radar has been successfully used at ranges beyond 100 km. In addition to its use in guiding the W-band radar, it can be used to obtain dual-frequency measurements in tornadoes and mesocyclones, which can provide estimates of the sizes of water droplets (Pazmany et al. 2001). To the best of the P. I.'s knowledge, this radar system is one of two mobile, dual-polarization, X-band radars (Bluestein et al. 2001), and the only one being used primarily to probe severe convective storms.

In addition to using the W-band and X-band systems as in the past, it is proposed that our group test a rapid-scan X-band system currently being modified and a to-be modified version of the existing mobile X-band radar. The rapid-scan radar is a mobile, X-band, phased-array system (AN/MPQ-64) developed by the U. S. Army and now supported by the Office of Naval Research (ONR). This radar system is truck mounted and has a range resolution of 150 m; the effective half-power beamwidth is 2^o, which allows for storm-scale spatial resolution. A. Pazmany at the University of Massachusetts (Amherst) is participating in equipping the radar with a weather data processor that can record volume images of the reflectivity and Doppler velocity fields. The antenna mechanically rotates every 2 s (at 30 rpm) and can scan 90^o in elevation electronically and backscan in azimuth 5.2^o to be able to dwell and eliminate beam smearing. It is anticipated that the full 90^o elevation range will not be needed; so, after averaging independent samples, twelve beams in the radar system will be used to cover elevation angles from 0-24^o around a circle every 10 s (a minimum of five independent samples will be averaged; it is necessary to average over a number of samples to reduce Rayleigh fading and converge to a precise reflectivity and Doppler velocity estimate in each sample volume). At a range of 20-40 km from a storm, the storm can be probed from the ground up to 8-16 km. Thus much of the storm will be sampled.

The rapid-scan radar has a number of advantages over that of the conventional, mechanically scanning radar. First, the tornadogenesis process, which takes place on very short time scales (a few min or less), can be resolved, at least on the storm scale. With the currently used W-band radar, scans at only one elevation angle take 10-20 s; with the rapid-scan radar, much of the entire volume of the tornado's parent vortex will be resolved every 10 s. Secondly, there will be no smearing of the beam, owing to the electronic scanning in elevation and electronic backscanning in azimuth. Thirdly, owing to rapid updates in the Doppler velocity field, it might be possible to retrieve the full three-dimensional wind field using various techniques (e.g., Gao et al. 2001). Data from the radar system could be used to initialize numerical cloud models. Others are active in these efforts and we would certainly make our data available to those requesting them. A recent National Research Council report supports the development of phased-array techniques for possible use in future operational radar systems (Smith et al. 2002). The National Severe Storms Laboratory (NSSL) is modifying a larger, fixed-site, S-band phased array system. Collaboration with engineers with their system is proposed, with intercomparisons and the possible setting up of a mobile, dual-Doppler network when a storm is nearby. It is therefore suggested that testing out a mobile, phased array system to map out the wind field in supercell storms, hopefully while a tornado is forming, would not only lead to an increased understanding of tornadogenesis, but also could be used to improve tornado forecasting. Operating in clear air, it may also map out the boundary-layer winds when clear-air scatterers (bugs) are present, as they usually are in the plains during the spring. An alternative version of a mobile, rapid-scan, X-band Doppler radar (Rapid DOW) is being designed and built by J. Wurman and collaborators (Bluestein et al. 2001).

A second technological development that we would like to test is that of spaced antenna radars (Holloway et al. 1995; Lataitis and Doviak 1995). Spaced-antenna profilers have been used to estimate the three-dimensional wind in the atmosphere. The technique makes use of the turbulent properties of the air and the assumption that the statistical properties of the wind field are carried downstream by the wind, at least for very short distances, on the spatial scale of the antenna. It is proposed that the transverse-wind component (normal to the beam) be estimated using this technique on storm data. A. Pazmany and his group will modify their existing mobile, X-band radar by installing at smaller, 1 m antenna, which has a beamwidth of 2.2^{o}. The along-beam resolution will still be 150 m. Questions remain about the accuracy of the retrieved cross-beam wind component (Lataitis and Doviak 1995). It is proposed that we conduct an intercomparison of the spaced-antenna radar data with mobile, dual-Doppler data. If the technique works, then it will be possible to determine the three-dimensional wind field more easily than by setting up mobile dual-Doppler networks; having to position only one radar rather than two will simplify data collection and increase the chance of success in capturing tornadogenesis. The cost of adding on spaced antenna technology is relatively small because the mobile radar already exists. The X-band radar could be converted back and forth, over night, from a dual-polarization, conventional Doppler system to a spaced-antenna system.

It is envisioned that future tornado observational work might make use of the spaced-antenna X-band system to document storm-scale evolution, while the W-band system is used to document tornado structure; the W-band radar data would be nested within the larger-scale domain of the X-band radar. The relative merits of using a rapid-scan radar vs. a spaced-antenna, mechanically scanning radar need to be assessed. Our proposed field experiments will be the preliminary step in doing so. It may also be possible to combine two rapid-scan X-band systems to collect rapid-scan dual-Doppler data. It is suggested that continued development and testing of new radar techniques and the refinement of existing ones is a prerequisite to any future large tornado field program involving many components, of which mobile radars is but one.

d. Serendipitous case studies and sub-projects

As in the past, the P. I. and his students may analyze other cases (e.g., Lehmiller et al. 2001, studying dust devils in Arizona for a few days in 2002) and work on other sub-projects, not noted explicitly in this proposal. Such work adds to the output of the planned work and allows for spontaneously stimulated ideas to be tested.

e. Tentative work schedule

The following is an estimate of the three-year research plan:

Year 1

- Complete analysis of Stockton, KS tornado and Borger, TX and Matador, TX storms. M. Kramar will finish his M. S. thesis. Manuscripts will be prepared for *Mon. Wea. Rev.*
- Complete analyses of dust devils; P. I. will prepare a manuscript for *Mon. Wea. Rev.*
- C. Weiss will continue to analyze IHOP data for his Ph. D. thesis; in particular, he will do pseudo-dual Doppler analyses of W-band data across the dryline for

several cases; he will analyze data from other IHOP sources when appropriate; he will also continue his numerical simulations of the intersection of a dryline with a baroclinic surface boundary using the ARPS model.

- R. Tanamachi will work with AERI data to identify temporal and spatial changes in the thermodyamic profile of near-storm environments; she will also learn to use a three-dimensional cloud model (ARPS, WRF, or Klemp-Wilhelmson). She will also use other data sources from IHOP when necessary.
- C. Weiss, M. Kramar, R. Tanamachi, the P. I., personnel from Univ. of Mass., and OU student volunteers will participate in spring 2003 field experiments with the mobile W and X-band Doppler radars, with the objective of collecting tornado data. (If the rapid-scan radar is available, it will be field tested for 2-3 weeks.)
- The P. I. will continue to work on storm-interaction numerical experiments with M. Weisman at NCAR, possibly passing them on to R. Tanamachi.
- The P. I. will finish analyses of the Happy, TX tornado and prepare a manuscript for *Mon. Wea. Rev.*.

Year 2

- If M. Kramar decides to take his Ph. D. qualifier exam, and passes, he will be looking for a Ph. D. research topic; otherwise, a new student will be hired, who will work to acquire expertise in working with the TREC and GBVTD software packages. If there is a new student, he/she will continue analyses of the best datasets collected in spring 2003. M. Kramar and the P. I. will prepare a manuscript based on his M. S. thesis for *Mon. Wea. Rev.*
- C. Weiss will finish his thesis research.
- R. Tanamachi will continue her numerical simulation experiments and work with the AERI datasets and other data from IHOP.
- C. Weiss, M. Kramar/new graduate student, R. Tanamachi, personnel from Univ. of Mass. and NRL, the P. I., and OU student volunteers will participate in a field experiment in spring 2004, with the mobile W and X-band radars and the rapid-scan radar. If possible, efforts will be coordinated with NSSL activities. Data will be collected in supercells and tornadoes. If the spaced-antenna is available, the mobile, conventional-scanning, X-band radar will converted so that the spaced-antenna can be tested.

Year 3

- C. Weiss's thesis work will be summarized in a few manuscripts and submitted to *Mon. Wea. Rev.*
- M. Kramar's/new graduate student's work on data analysis of mobile radar data will be continued (if M. Kramar continues on for a Ph. D.) or completed (if the new graduate student is working on an M. S. degree)
- When C. Weiss leaves, a new graduate student will be hired to work on mobile

Doppler radar data analysis.

- Robin Tanamachi will complete her M. S. and consider working on a Ph. D.
- The P. I.'s three graduate students, the P. I., personnel from Univ. of Mass. and NRL, and OU student volunteers will participate in a field experiment during the spring of 2005, involving the mobile X-band radar (with a spaced-antenna system), the mobile W-band radar, and the rapid scan radar. The objectives will be to capture tornadogenesis with all three radars. Efforts will be made to coordinate with NSSL activities, if possible.
- The P. I. will continue to work on data analyses of the mobile radar data and numerical simulation experiments in collaboration with M. Weisman at NCAR.

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Wakimoto, R. M., and C. Liu, 1998: the Garden City, Kansas, storm during VORTEX 95. Part II: The wall cloud and tornado. Mon. Wea. Rev., 126, 393-408.

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Wakimoto, R. M., and H. Cai, 2000: Analysis of a nontornadic storm during VORTEX 95. Mon. Wea. Rev., 128, 565-592.

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Weiss, C. C., and H. B. Bluestein, 2002: Airborne pseudo-dual Doppler analysis of a dryline-outflow boundary intersection. Mon. Wea. Rev., 130, 1207-1226.

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Wilson, J. W., T. M. Weckwerth, J. Vivekanandan, R. M. Wakimoto, and R. W. Russell, 1994: Boundary layer clear-air radar echoes: Origin of echoes and accuracy of derived winds. J. Atmos. Oceanic Technol., 11, 1184-1206.

Wilson, J. W., and W. E. Schreiber, 1986: Initiation of convective storms at radar-observed boundary-layer convergence lines. Mon. Wea. Rev., 112, 673-685.

Wurman, J. , 2002: The multiple-vortex structure of a tornado. Wea. Forecasting, 17, 473-505.

Wurman, J. and S. Gill, 2000: Finescale radar observations of the Dimmitt, Texas (2 June 1995), tornado. Mon. Wea. Rev., 128, 2135-2164.

Xue, M., K. K. Droegemeier, and V. Wong, 2000: The Advanced Regional Prediction System (ARPS)-A multiscale nonhydrostatic atmospheric simulation and Prediction tool. Part I: Model dynamics and verification. Meteor. Atmos Phys., 75, 161-193.

Ziegler, C. L., T. J. Lee, and R. A. Pielke, 1997: Convective initiation at the dryline: A study. Mon. Wea. Rev., 125, 1001-1026.

Ziegler, C. L., and E. N. Rasmussen, 1998: The initiation of moist convection at the dryline: Forecasting issues from a case study perspective. Wea. Forecasting, 13, 1106-1131.

Ziegler, C. L. , E. N. Rasmussen, T. R. Sheperd, A. I. Watson, and J. M. Straka, 2001: Evolution of low-level rotation in the 29 May 1994 Newcastle-Graham, Texas, storm complex during VORTEX. Mon. Wea. Rev., 129, 1339-1368.

Zrnic, D. S., and A. V. Ryzhkov, 1999: Polarimetry for weather surveillance radars. Bull. Amer. Meteor. Soc., 80, 389-406.

BIOGRAPHICAL SKETCH

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a. Professional Preparation

M. I. T. Electrical Engineering B. S., 1971
M. I. T. Electrical Engineering M. S., 1972
M. I. T. Meteorology M. S., 1972
M. I. T. Meteorology Ph. D., 1976

b. Appointments

Professor (1990 ß present), Associate Professor (1983), Assistant Professor (1979), Visiting Assistant Professor (1976), University of Oklahoma
Visiting Scientist at NCAR, MMM Division (1982-1985, 1989-2003)
Visiting Scientist at UCAR/COMET (1991)
Visiting Scientist at NOAA/AOML/Hurricane Research Division (HRD) (1984)

c. Publications

i. related to project

Bluestein, H. B., and S. G. Gaddy, 2001: Airborne pseudo-dual Doppler analysis of a rear-inflow jet and deep convergence zone in a supercell. Mon. Wea. Rev., 129, 2270-2289.
Bluestein, H. B., and M. L. Weisman, 2000: The interaction of numerically simulated supercells initiated along lines. Mon. Wea. Rev., 128, 3128-3149.
Bluestein, H. B., and A. L. Pazmany, 2000: Observations of tornadoes and other convective phenomena with a mobile, 3-mm wavelength, Doppler radar: The spring 1999 field experiment. Bull. Amer. Meteor. Soc., 81, 2939-2951.
Bluestein, H. B., S. G. Gaddy, D. C. Dowell, A. L. Pazmany, J. C. Galloway, R. E. McIntosh, and H. Stein, 1997: Mobile, 3-mm wavelength, pulsed Doppler radar observations of sub-storm scale vortices in a supercell. Mon. Wea. Rev., 125, 1046-1059.
Bluestein, H.B., W. P. Unruh, D. C. Dowell, T. A. Hutchinson, T. M. Crawford, A. C. Wood, and H. Stein, 1997: Doppler-radar analysis of the Northfield, Texas tornado of 25 May 1994. Mon. Wea. Rev., 125, 212-230.

ii. other significant publications

Bluestein, H. B., and P. C. Banacos, 2002: The vertical profile of wind and temperature in cyclones and anticyclones over the eastern two-thirds of the United States: A climatology. Mon. Wea. Rev., 477-506.
Hutchinson, T. A. and H. B. Bluestein, 1998: Prefrontal wind-shift lines in the Plains of the United States. Mon. Wea. Rev., 126, 141ß166.
Bluestein, H. B. and D. R. MacGorman, 1998: Evolution of cloud-to- ground lightning characteristics in the Spearman, Texas tornadic supercells of 31 May 1990. Mon. Wea. Rev., 126, 1451- 1467.
Bluestein, H. B. and T. M. Crawford, 1997: Mesoscale dynamics of the near-dryline environment: Analysis of data from COPS-91. Mon. Wea. Rev., 125, 2161- 2175.
Bluestein, H. B. and D. A. Speheger, 1995: The dynamics of an upper- level trough in the baroclinic westerlies: Analysis based upon data from a wind-profiler network. Mon. Wea. Rev. , 123, 2369 - 2383.

BIOGRAPHICAL SKETCH

(This is a continuation page)

d. Synergistic Activities

Authored trade book on severe thunderstorms and tornadoes
Authored two-volume textbook on Synoptic-Dynamic Meteorology
Tested and used mobile observing platforms, especially for W-band and X-band Doppler radars; organized community-wide NSF workshop on mobile instruments
Presented invited testimony for Subcommittees on Basic Research and Energy & the Environment, U. S. House of Representatives, Wash., D. C. (1999), Tornadoes: Understanding, Modeling, and Forecasting
Supercell Storms
Appeared in IMAX film (STORMCHASERS) and in numerous television programs on tornadoes; am being filmed for new NOVA program on PBS television

e. Collaborators & Other Affiliations

i. Collaborators (last 48 months)

Mike Baldwin, NSSL
Mike Bell, NCAR
Bob Davies-Jones, NSSL
Wayne Feltz, CIMMS, Univ. of Wisconsin, Madison
Greg Forbes, The Weather Channel
Steve Gaddy, NWS, Grand Forks, ND
Carl Hane, NSSL
Wen-Chau Lee, NCAR
Paul Neiman, NOAA/ETL
Andrew Pazmany, Univ. of Massachusetts
Robert Rabin, NSSL
F. Marty Ralph, NOAA/ETL
Nilton Renno, Univ. of Arizona
Jeff Trapp, NSSL/NCAR
Roger Wakimoto, UCLA
Morris Weisman, NCAR

iii. Graduate Advisor

Frederick Sanders, MIT (ret.)

iv. Thesis Advisor Sponsor (nine advised last five years)

Andrew Wood, OCS Peter Leptuch, OU
Todd Crawford, WSI Matthew Kramar, OU
Steve Gaddy, NWS, Grand Forks, ND
Peter Banacos, SPC
David Dowell, NCAR/ASP
Gregor Lehmiller, Koch Energy Co.
Christopher Weiss, OU

SUMMARY PROPOSAL BUDGET

YEAR 1

ORGANIZATION **University of Oklahoma Norman Campus**	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Howard B Bluestein**	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Howard B Bluestein - PI	0.00	2.00	2.00	$ 49,034	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	2.00	2.00	49,034	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	1.00	0.00	0.00	6,000	
3. (3) GRADUATE STUDENTS				52,500	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				107,534	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				22,397	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				129,931	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) Data Storage Devices $ 4,000 Laptop PC 2,000 TV/VCR combination 200					
TOTAL EQUIPMENT				6,200	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				15,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				2,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				7,500	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				6,183	
TOTAL OTHER DIRECT COSTS				15,683	
H. TOTAL DIRECT COSTS (A THROUGH G)				166,814	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) MTDC (Rate: 45.5000, Base: 157931)					
TOTAL INDIRECT COSTS (F&A)				71,859	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				238,673	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 238,673	$

M. COST SHARING PROPOSED LEVEL $ 11,597 AGREED LEVEL IF DIFFERENT $

PI/PD NAME **Howard B Bluestein**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Jennie parker**	Date Checked	Date Of Rate Sheet	Initials - ORG

***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

YEAR 2

ORGANIZATION **University of Oklahoma Norman Campus**	FOR NSF USE ONLY PROPOSAL NO.	DURATION (months) Proposed	 Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Howard B Bluestein**	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Howard B Bluestein - PI**	0.00	1.00	2.00	$ 37,879	$
2.					
3.					
4.					
5.					
6. (**0**) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (**1**) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	1.00	2.00	37,879	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (**0**) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (**1**) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	1.00	0.00	0.00	6,180	
3. (**3**) GRADUATE STUDENTS				55,125	
4. (**0**) UNDERGRADUATE STUDENTS				0	
5. (**0**) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (**0**) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				99,184	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				18,532	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				117,716	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **Data Storage Devices** $ 4,000					
TOTAL EQUIPMENT				4,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				15,450	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (**0**) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				2,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				7,500	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				6,422	
TOTAL OTHER DIRECT COSTS				15,922	
H. TOTAL DIRECT COSTS (A THROUGH G)				153,088	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 45.5000, Base: 146271)**					
TOTAL INDIRECT COSTS (F&A)				66,553	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				219,641	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 219,641	$

M. COST SHARING PROPOSED LEVEL $ **12,177**	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME **Howard B Bluestein**	FOR NSF USE ONLY INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Jennie parker**	Date Checked	Date Of Rate Sheet	Initials - ORG

*ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET

SUMMARY PROPOSAL BUDGET

YEAR 3

ORGANIZATION **University of Oklahoma Norman Campus**	**FOR NSF USE ONLY** PROPOSAL NO.	DURATION (months) Proposed	 Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Howard B Bluestein**	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. **Howard B Bluestein - PI**	0.00	1.00	2.00	$ 42,348	$
2.					
3.					
4.					
5.					
6. (0) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	1.00	2.00	42,348	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (1) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	1.00	0.00	0.00	6,365	
3. (3) GRADUATE STUDENTS				57,881	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				106,594	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				20,381	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				126,975	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) **Data Storage Devices** $ 4,000					
TOTAL EQUIPMENT				4,000	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				15,914	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				2,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				7,500	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				6,671	
TOTAL OTHER DIRECT COSTS				16,171	
H. TOTAL DIRECT COSTS (A THROUGH G)				163,060	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE) **MTDC (Rate: 45.5000, Base: 156102)**					
TOTAL INDIRECT COSTS (F&A)				71,026	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				234,086	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 234,086	$

M. COST SHARING PROPOSED LEVEL $ 12,786	AGREED LEVEL IF DIFFERENT $		
PI/PD NAME **Howard B Bluestein**	**FOR NSF USE ONLY** INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Jennie parker**	Date Checked	Date Of Rate Sheet	Initials - ORG

***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

SUMMARY PROPOSAL BUDGET

Cumulative

ORGANIZATION **University of Oklahoma Norman Campus**	**FOR NSF USE ONLY** PROPOSAL NO.	DURATION (months) Proposed	 Granted
PRINCIPAL INVESTIGATOR / PROJECT DIRECTOR **Howard B Bluestein**	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title, A.7. show number in brackets)	NSF Funded Person-mos. CAL	ACAD	SUMR	Funds Requested By proposer	Funds granted by NSF (if different)
1. Howard B Bluestein - PI	0.00	4.00	6.00	$ 129,261	$
2.					
3.					
4.					
5.					
6. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET JUSTIFICATION PAGE)	0.00	0.00	0.00	0	
7. (1) TOTAL SENIOR PERSONNEL (1 - 6)	0.00	4.00	6.00	129,261	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0.00	0.00	0.00	0	
2. (3) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	3.00	0.00	0.00	18,545	
3. (9) GRADUATE STUDENTS				165,506	
4. (0) UNDERGRADUATE STUDENTS				0	
5. (0) SECRETARIAL - CLERICAL (IF CHARGED DIRECTLY)				0	
6. (0) OTHER				0	
TOTAL SALARIES AND WAGES (A + B)				313,312	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COSTS)				61,310	
TOTAL SALARIES, WAGES AND FRINGE BENEFITS (A + B + C)				374,622	
D. EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $5,000.) $ 14,200					
TOTAL EQUIPMENT				14,200	
E. TRAVEL 1. DOMESTIC (INCL. CANADA, MEXICO AND U.S. POSSESSIONS)				46,364	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS 1. STIPENDS $ 0 2. TRAVEL 0 3. SUBSISTENCE 0 4. OTHER 0					
TOTAL NUMBER OF PARTICIPANTS (0) TOTAL PARTICIPANT COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES				6,000	
2. PUBLICATION COSTS/DOCUMENTATION/DISSEMINATION				22,500	
3. CONSULTANT SERVICES				0	
4. COMPUTER SERVICES				0	
5. SUBAWARDS				0	
6. OTHER				19,276	
TOTAL OTHER DIRECT COSTS				47,776	
H. TOTAL DIRECT COSTS (A THROUGH G)				482,962	
I. INDIRECT COSTS (F&A)(SPECIFY RATE AND BASE)					
TOTAL INDIRECT COSTS (F&A)				209,438	
J. TOTAL DIRECT AND INDIRECT COSTS (H + I)				692,400	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPG II.C.6.j.)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 692,400	$

M. COST SHARING PROPOSED LEVEL $ 36,560 AGREED LEVEL IF DIFFERENT $

PI/PD NAME **Howard B Bluestein**	**FOR NSF USE ONLY** INDIRECT COST RATE VERIFICATION		
ORG. REP. NAME* **Jennie parker**	Date Checked	Date Of Rate Sheet	Initials - ORG

C ***ELECTRONIC SIGNATURES REQUIRED FOR REVISED BUDGET**

Budget Justification Page

A. Support is requested for two summer months and two academic months for the PI. The latter are required so that the PI can extend his one-semester sabbatical leave (fall 2002) to two semesters (the PI is a visiting scientist at NCAR/MMM until 1 April 2003). The additional two months of support will allow the P. I. to participate in field operations, continue data analysis, and begin numerical simulations (by collaborating at NCAR). During years 2 and 3, only one academic month support is requested each year to enable the P.I. to spend more time on the project. In year 3 the P.I.˜s 9-month salary will go up by $10K (in addition to other possible merit increases) owing to a transfer of funds from a professorship to his base pay.

B. Support is requested for one month for a programmer to assist with computer and computer network related issues. Support is also requested for three graduate students: Continuing Ph. D. student C. Weiss; continuing M. S. student M. Kramar, who may become a Ph. D. student; new M. S. student R. Tanamachi, who is female, and whose gender is underrepresented in atmospheric sciences. Support is also requested for a new student in year 2 if M. Kramar does not pursue a Ph. D. Student salaries are assumed to increase 5% each year, which is more than the rate assumed for the increase of most other items (3%), because students will be moving up in pay level independent of inflation.

D. Upgrades to the current computer equipment will be needed; in particular, additional data storage devices will be purchased (an old disk is failing and massive amounts of new Doppler data will need to be stored). The equipment is spread out over three years in anticipation that storage units will decrease in price and increase in capacity with time. Also, a new laptop (dedicated to the GPS on board the W-band radar truck) is needed to make full use of GPS software and a small TV/VCR is needed to play back videos from the boresighted video camera on the W-band radar.

E. Support is requested for domestic travel by the P. I. and three graduate students to scientific conferences and workshops and for travel support (gas, lodging while away from home) during storm-intercept field operations. Support is also requested for gas, lodging, and per diem for one NRL employee who will operate the rapid-scan radar. Expenses associated with the U. Mass. mobile W-band and X-band trucks, and their personnel expenses will be borne by the U. Mass. grant.

G. Support is requested for tapes, CDs, film, videotapes, cell phone time, and other expendable supplies. Publication costs (page charges) for three publications/year @ $2500/publication. Other direct costs include tuition for the fall, spring, and summer semesters (5.11% of salary during the fall and spring semesters; the Graduate College cost shares the additional 22.09%), the project phone, maintenance fees, research data costs (WSR-88D data CDs, satellite data, etc.) weather data line fees, and software licensing fees.

Current and Pending Support

(See GPG Section II.D.8 for guidance on information to include on this form.)

The following information should be provided for each investigator and other senior personnel. Failure to provide this information may delay consideration of this proposal.

Investigator: **Howard Bluestein**

Other agencies (including NSF) to which this proposal has been/will be submitted.

Support: ☒ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **Studies of Severe Convective Storms and Tornadoes**

Source of Support: **National Science Foundation**
Total Award Amount: $ **489,057** Total Award Period Covered: **06/01/00 - 05/31/03**
Location of Project: **Norman, OK**
Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **0.50** Sumr: **2.00**

Support: ☐ Current ☒ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title: **Severe Convective Storms and Tornadoes**

Source of Support: **National Science Foundation**
Total Award Amount: $ **692,400** Total Award Period Covered: **02/01/03 - 02/28/06**
Location of Project: **Norman, Oklahoma**
Person-Months Per Year Committed to the Project. Cal: **0.00** Acad: **1.00** Sumr: **2.00**

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Sumr:

Support: ☐ Current ☐ Pending ☐ Submission Planned in Near Future ☐ *Transfer of Support
Project/Proposal Title:

Source of Support:
Total Award Amount: $ Total Award Period Covered:
Location of Project:
Person-Months Per Year Committed to the Project. Cal: Acad: Summ:

*If this project has previously been funded by another agency, please list and furnish information for immediately preceding funding period.

FACILITIES, EQUIPMENT & OTHER RESOURCES

FACILITIES: Identify the facilities to be used at each performance site listed and, as appropriate, indicate their capacities, pertinent capabilities, relative proximity, and extent of availability to the project. Use "Other" to describe the facilities at any other performance sites listed and at sites for field studies. USE additional pages as necessary.

Laboratory:

Clinical:

Animal:

Computer: **Sun Ultra 1 workstation with 675 MB internal memory and 38 GB of external memory**
HP Color Laserjet 4550
Toshiba Satellite laptop PC with 5 GB of memory
MacIntosh Powerbook G4 laptop

Office:

Other: ____________________

MAJOR EQUIPMENT: List the most important items available for this project and, as appropriate identifying the location and pertinent capabilities of each.

SLR cameras (Nikon FM and FM-II, Pentax 67) with various lenses
Sony TRV50 mini-DV camcorder
tripods
voice microtape recorder

OTHER RESOURCES: Provide any information describing the other resources available for the project. Identify support services such as consultant, secretarial, machine shop, and electronics shop, and the extent to which they will be available for the project. Include an explanation of any consortium/contractual arrangements with other organizations.

Computer facilities (other workstations and printers) in the School of Meteorology at the University of Oklahoma; real-time access to data from the network of WSR-88D radars, the Oklahoma Mesonet, NOAA wind profilers, meteorological satellites, surface data, upper-air data, and various computer models. Copying facilities at the Univ. of Oklahoma.
Secretarial and computer support.

FACILITIES, EQUIPMENT & OTHER RESOURCES

Continuation Page:

COMPUTER FACILITIES (continued):

MacIntosh Powerbook G4 with 40 GB/384 MB memory
Epson scanner
Lexmark printer