Final Report of the Weather and Climate Team

Kelvin K. Droegemeier (Chairman)
Kenneth C. Crawford
Elbert W. (Joe) Friday
James F. (Jeff) Kimpel
Kathleen Miller
Bill Nations
Dennis O'Brien
Lindy Ritz
John T. Snow
Jean Vieux
Don Wood

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Executive Summary

Private industry today is the most rapidly growing segment of the U.S. weather and climate enterprise. About one-third of the Nation's $10 trillion economy is sensitive to climate variability and weather, and the overall value of weather and climate information is in the range of billions to tens of billions of dollars. The potential for economic development in weather and climate, over the next decade, could be as large as $10B.

The weather and climate enterprise in Oklahoma consists of nearly 700 professionals across a dozen State and Federal organizations, along with a few small private companies. The State and Federal entities collectively expend more than $60M annually and have a yearly impact on Oklahoma's economy of approximately $100M. This enterprise would rank in the top 5% of payrolls within Oklahoma if it were entirely a private corporation. During the past 15 years, owing mostly to external grants and contracts, the employee base of the State and Federal organizations has quadrupled and its expenditures have increased by more than 650% – *without any specific emphasis on economic development or private enterprise.*

Based upon huge Federal investments made in Oklahoma during the past four decades, more than $500M in physical infrastructure, national prominence in education, research, operations and training, and several new Federally-funded projects totaling more than $150M, *Oklahoma is uniquely positioned to build a component of its economy around weather*. It can do so by addressing two key barriers for which it is ideally suited: the inadequacy of the current atmospheric and hydrologic observing network, and limited effectiveness in converting meteorological data into decision making information for end users. With emphasis on radar, the foundation of the Oklahoma weather enterprise 43 years ago and the focus of new major projects, our vision is for Oklahoma to become

- *the* international leader in the development, testing, manufacture, application, maintenance and support of radar technology in the civilian and military sectors;
- *the* national hub where radar data from a wide variety of systems (National Weather Service, Military, Federal Aviation Administration, television stations) are collected, synthesized with other data, distributed, and stored;
- *the* international leader in creating weather-related products and decision support tools for a wide variety of application areas and end users; and
- *the* international focal point for end user training and support.

The expected outcome after 2012 is a thriving commercial, research and educational enterprise that focuses on a broad array of radar technologies across a broad spectrum of users, and is the recognized hub for the collection, storage, and distribution of weather and climate data and tools. Approximately 1000 new jobs – paying twice the State's average income – will have been created (250 within the next 2-3 years), with sales approaching $2.4 billion. Oklahoma-based companies will have grown in alignment with major external corporations, a significant software and user support infrastructure will be supplemented by hardware and component manufacturing, and major corporations will

have established a presence in Oklahoma to take advantage of the National Weather Center that soon will emerge from the Oklahoma Weather Center.

To reach this bold but achievable goal, we make the following recommendations:

Recommendation #1: Provide Targeted Financial Support to Help Grow the Oklahoma Weather Center as it Transitions Into the National Weather Center

- **Why is this important?** The Oklahoma Weather Center has been extremely successful in obtaining competitive Federal grant funds, and matching funds from private industry, to support major new initiatives in weather research and development. However, a concomitant funding stream from State Government is absolutely essential for meeting needs that *other sources cannot provide*.

- **Who should take action?** State Government should work with Higher Education to develop a strategy for targeted investments in weather-related research and development activities that will lead to economic growth.

- **What needs to be done?**
  - Provide funding to open and operate the new National Weather Center, which is scheduled to open in early 2006 ($3.5M);
  - Reinstate and expand the Oklahoma State Regents for Higher Education research matching program for externally sponsored grants and contracts as a means for increasing the ability of faculty to compete for Federal funding;
  - Fulfill matching commitments on pending endowed chairs and professorships, an action which is vital for hiring new faculty in meteorology, electrical engineering, and computer science;
  - Provide funding for new faculty lines, student fellowships, and infrastructure targeted toward radar and other weather-related activities ($2.5M);
  - Provide funding for enhanced physical facilities, equipment, and technical support staff for radar research, development, and commercialization ($12M);
  - Actively promote the new National Weather Center on a national scale, with funding for a distinguished visiting scientist program, high quality brochures, sizeable ads in the nation's leading newspapers, and television commercials on national networks. Oklahoma must market weather on a grand scale ($0.2M);
  - Begin an initiative to develop a National Weather Museum, to be located next to the National Weather Center. In conjunction with the Fred Jones, Jr. Art Center (local resource for the fine arts), the Sam Noble Oklahoma Museum of Natural History (State museum of humanities and natural science), the National Weather Museum would easily attract thousands of visitors each year. ($20M)

- **How should it be implemented?** Legislative action is required to appropriate funding for most of the actions recommended above, with the Oklahoma State Regents for Higher Education directing these funds toward weather-related activities.

Recommendation #2: Intensify Efforts to Create and Grow, Strong Academic-Corporate Partnerships

- **Why is this important?** Universities are the focal point for research and development, research and development represent the foundation for economic growth, and private enterprise is the means by which research and development outcomes are brought to the marketplace and jobs are created. Consequently, success in building a component of Oklahoma's economy around weather and climate will require strong alliances, both formal and informal, between the academic and private sectors not only within Oklahoma but nationally and around the world.

- **Who should take action?** Higher Education should take the lead in reaching out to Private Industry, making known the vast resources of academia and creating a *culture* in which academia and industry can work together effectively for the benefit of both.

- **What needs to be done?**
  - Create and implement a more effective strategy for marketing higher education resources (people, facilities, knowledge) to industry in the context of economic development, both within Oklahoma and beyond its borders;
  - Develop workshops to help both industry and academia understand the nature of public-private partnerships, including but not limited to issues associated with intellectual property, conflict of interest, and the creation of spin-off companies;
  - Assist in establishing stable funding streams from major corporations and intensify efforts to obtain external grants and contracts from Federal agencies;
  - Provide additional resources to the Oklahoma Center for the Advancement of Science and Technology, and the Oklahoma Technology Commercialization Center, to encourage the commercialization of academic research outcomes;
  - Establish alliances with the industrial-military complex including national laboratories and foreign governments.

How should it be implemented? The Chancellor for Higher Education, working through the Oklahoma State Regents for Higher Education, should take the lead in organizing a plan, in consultation with presidents and technology development officers of

Oklahoma's higher education enterprise. Involvement by OCAST, OTCC, and especially local economic development organizations and Chambers of Commerce is absolutely essential.

Recommendation #3: Expand the Involvement of Existing Oklahoma Corporations in Weather-Related Activities and Work to Create New Companies

- **Why is this important?** Owing to financial barriers, existing weather-related Oklahoma companies, all of which are relatively small, are disadvantaged from participating in research and other activities that would help them grow, contribute to economic development, and serve as role models for creating and attracting other companies. In addition, Oklahoma economists have asserted that the State has experienced limited growth because the economy is dominated by government jobs owing to insufficient private investment. Because a weather- and climate-based economy inherently involves public-private partnerships, Oklahoma must expand the role played by private industry.

- **Who should take action?** State Government should address a few key issues to encourage private sector growth in weather- and climate-related activities.

- **What needs to be done?**
  - Reduce or eliminate of the cost to access real time radar and other fee-based data under the control of local sources, and the cost to participate in organizations that cultivate public-private partnership (e.g., the Sasaki Applied Meteorology Research Institute at OU);
  - Allow private companies in Oklahoma to provide commercial services without having to compete with taxpayer-sponsored services;
  - Encourage out-of-state companies that contract in Oklahoma to work with and help grow small Oklahoma companies;
  - Encourage out-of-state companies to relocate to Oklahoma and to work with existing companies to grow the Oklahoma weather enterprise;
  - Expand research and development tax credits to small Oklahoma weather-related businesses;
  - Provide Oklahoma companies, especially small ones, with favored occupancy rates in the new National Weather Center Commercial Partners Neighborhood buildings;
  - Support related hydrologic research, in collaboration with the Oklahoma Water Resources Board, that is directed at producing a scientifically-based decision system for local and State-wide water resource management.

- **How should it be implemented?** The actions described above are relatively inexpensive and for the most part can be instituted as *policy*. Tax credits may require minor changes to existing laws.

1. The U.S. Weather and Climate Enterprise: A Big-Picture View of a Unique Economic Development Opportunity

a. Economic and Societal Impacts of Weather, Climate Variability

Some $3.9T of the nation's $10T GDP is sensitive to weather and climate.

The U.S. Bureau of Economic Analysis (BEA) estimated in 1998 that *more than a third* of the nation's $10 trillion economy, as measured by the gross domestic product, is sensitive to weather and climate (Appendix A)[1,2,3]. This sensitivity typically is defined as "the possibility of injury, damage to property, or financial loss owing to severe or extreme weather events, unusual seasonal variations such as heat waves or droughts, or long-term climate variability."[3] In reality, the huge economic impact cited above arises not from relatively intermittent and extreme events (e.g., Hurricane Andrew), the one-time impact of which is large and highly visible in the media, but rather from the *cumulative impact* of less visible, more benign events (e.g., afternoon thunderstorms delaying commercial air traffic over an entire summer).

Owing to its focus on economic impacts, the BEA analysis excluded loss of life. For extreme weather hazards that include floods, hurricanes, tornadoes, lightning, and extreme heat and cold but exclude winter storms or hail, loss of life averaged 876 persons per year during the 1990s (Appendix B).[4] Additionally, adverse weather conditions cause more than 7000 traffic fatalities and more than 450,000 injuries annually.[12] Transportation agencies spend about $2B annually for snow and ice control and $5B for infrastructure repair that is attributable to weather.[12]

Weather and climate impacts can be mitigated to avoid loss, or exploited to maximize gain, in a variety of ways. Although certain events produce unavoidable consequences (e.g., hail-related crop loss), indirect mitigation often is possible – in the case of agriculture and energy, via weather derivatives (see Section 1c). In other situations, the value of accurate guidance is more direct.

For example, clothing retailers use seasonal climate forecasts to manage inventories, while commercial airlines use very short term (0-4 hour) forecasts to minimize cancellations (the average cost of which is approximately $40,000 per flight)[5], delays, and diversions (the average cost of which is approximately $150,000 per flight) [5]. In the mid- to late-1980s, 16 member airlines of the Air Transport Association (a commercial aviation trade group) reported average annual costs of $269M owing to flight delays and cancellations[5]. In the area of energy, delays or cessation of operations on a single production oil rig in the Gulf of Mexico – of which there are several thousand – can cost $250,000 per day[5]. A one-degree error in the forecasted high temperature can lead to more than a gigawatt (one billion watts) impact on energy generation over a six-state region in the upper-Midwest and a half-gigawatt impact over Florida alone[6].

An especially important component of weather and climate impacts is water, particularly the prediction of its fate upon reaching the ground via hydrologic models and decision

support systems. Not only is water important in the context of floods, which currently is the largest killer among weather-related events, but also with regard to resource management, hydroelectric power generation, and environmental quality. Prior to the NEXRAD Doppler radar network, which provides quantitative estimates of precipitation rates down to relatively small spatial scales, little incentive existed to develop sophisticated hydrologic forecast models. Such models, using NEXRAD data as input with detailed terrain and land cover data, now exhibit greater reliability in predicting both the time and location of flooding[13] – and the associated economic impacts potentially are enormous. As an example, the Texas Medical Center, which is extremely vulnerable to flooding and endured a loss of $1.6B (about one third of which was deemed preventable) owing to Tropical Storm Allison, has installed a Flood Alert System developed jointly by Vieux and Associates (an Oklahoma private company) and Rice University in Houston.

Water resource management, led in Oklahoma by the Oklahoma Water Resources Board, also is vitally important to economic development, particularly in the context of drought and the sharing of water between municipalities. Water management policies must be apolitical, based upon sound scientific reasoning in order to avoid handicapping cities that seek to develop or important businesses having substantial water needs for which guaranteed provision is essential. The science of hydrology, for which Oklahoma has notable strength in both academia and the private sector, is poised to develop and market advanced technologies for improving water management and thus to serve as an underpinning for economic development.

Remarkably, some entire industries are weather and climate sensitive, particularly transportation, public utilities, retail trade, and construction (see Appendix A). The manner in which improved weather, climate and hydrologic forecasting capabilities can mitigate loss, and create the opportunity for gain, is discussed in Sections 1c-d.

b. Participants and Their Roles: A Changing Landscape

The U.S. weather and climate enterprise (hereafter assumed to include hydrology as well) consists of three principal sectors: 1) academia; 2) private industry; and 3) Federal and state governments. Although each tends to be distinct with regard to mission, operating philosophy, and constituency, considerable overlap exists. For example, academia educates future researchers, operational practitioners, and private sector employees while creating new insights from basic and applied research as well as developing new technologies for use by both of the other sectors.

Commercial weather companies collectively generate approximately $500M in annual revenue.

Private industry, which today is the most rapidly growing segment of the weather and climate enterprise – consisting of over 400 commercial weather companies that collectively generate approximately $500M in annual revenue[2,7] – is the primary mechanism by which weather

and climate information is conveyed to users. (In most cases, the base information comes from the Federal government; private companies create value-added products and services that are location- and industry-specific.)

Whereas the private sector component of the triad at one time consisted almost exclusively of weather forecasting services companies, it now encompasses entities that develop weather technology (e.g., forecast models, decision support software, and visualization systems – often as spin-offs of university-based activities) and provide support for weather risk management. Private weather companies also conduct research, though mostly of a targeted nature and directed toward immediate or near-term product lines. (Note that the Federal investment in weather-related research is about 17% of the total budget for Federal weather activities.)[7]

The Federal government operates the National Weather Service, which manages an extensive array of observing technologies and collects associated observations. It also operates a suite of sophisticated computer prediction models and issues forecasts and warnings – all as part of its Congressionally-mandated mission to protect life and property and provide services that are of value to business and industry. In FY 2002, the Federal government expended about $2.7B for meteorological operations and related research, mostly through the National Oceanic and Atmospheric Administration (NOAA) [7]. At the state level, all but three states have a state climatologist, and various state agencies (e.g., the Oklahoma Climatological Survey, located at the University of Oklahoma) collect, process and make available information for the wellbeing of its constituents. Weather modification and environmental quality (water, air, and sub-surface) have strong linkages as well to state climatology offices and other state agencies.

The value of information generated by the U.S. weather and climate enterprise is in the range of billions to tens of billions of dollars.

In total, "the value of information generated by the U.S. weather and climate enterprise, including the media as well as financial services (e.g., weather derivatives; see Section 1c), is in the range of billions to tens of billions of dollars[7]" (figures specific to Oklahoma are discussed in Section 2).

During the past few years, the provision of meteorological and hydrological services in the U.S. has been undergoing a profound change, with the private sector emerging as the dominant player in creating and delivering customized weather, climate, and flood guidance.

During the past few years, the provision of meteorological and hydrological services in the U.S. has been undergoing a profound change, with the private sector emerging as the dominant player in creating and delivering customized weather, climate, and flood guidance. This transformation has been driven principally by four developments[8,9]: (1) significant improvements in the accuracy and reliability of weather and climate forecasts, due in large part to improvements in forecast models, the observing systems that drive them, forecasting methodologies, and our understanding of the atmosphere; (2) a growing recognition by industry that weather and climate information, appropriately applied, can

lead to significant loss reduction or economic advantage; (3) the ready availability of sophisticated numerical weather and climate prediction model software and inexpensive, powerful computers for running them; and (4) tremendous advances in communications and related technology, including wireless networks, cellular phones, personal digital assistants, and GPS. These technologies provide for the virtually instantaneous delivery of information in text and graphical form to any location on Earth.

A related factor in this transformation continues to be the slow and cumbersome process by which technology moves from the research to the operational sector, and the inability of the Federal government to respond rapidly to major changes in technology – a response that, in the private sector, often can be nearly instantaneous.

The configuration of forecasting technology operated by private industry can now be customized for particular decision making needs or the "problem of the day or hour."

All of these factors are leading private meteorological companies, and even large weather-sensitive industries such as energy and transportation, to operate their own numerical forecasting systems (which, importantly, continue to depend upon data from the National Weather Service) [8,9] and hire staffs of meteorologists. The specific configuration of technology operated by the private sector – in sharp contrast to that of the National Weather Service – can be customized for particular decision making processes or modes of operation. Thus, instead of simply repackaging National Weather Service information, private companies now can generate new forecast products on a time-schedule, and in a configuration, appropriate to their particular needs. Perhaps most importantly is the fact that users of the information can change the configuration of the forecast system to respond to the particular "problem of the day or hour." This capability has become recognized as crucial for certain industries and can be a determining factor in gaining a competitive edge in the marketplace.

c. <u>Weather and Climate Guidance: Mitigating Loss and Creating Benefit Through Sound Decision Making</u>

The first daily weather maps and forecasts in the U.S. were made available for general use by the Army Signal Corps in the 1870s[2]. During the century that followed, major technological developments, including the upper-air balloon, weather radar, satellites, and the digital computer, led to automated forecasting based upon sound physical principles and reliable observations. Yet all those advances combined do not equal the strides made over only the past two decades, during which the NEXRAD Doppler radar and ASOS surface observing networks were installed and major improvements were made to computer models and other aspects of the National Weather

More sophisticated forecasting techniques, a better understanding of the atmosphere, and improved warning technologies and communications systems (especially the Internet) have improved substantially the overall value of weather and climate information.

Service's infrastructure. In fact, today's 72-hour computer weather forecast is as accurate as 36-hour forecasts were only 20 years ago[10], and major climate patterns such as El Niño and La Niña can be spotted months in advance. Tornado warning lead time has more than doubled, and the average lead time for flash flood warnings has risen from about 10 minutes in the early 90s to nearly an hour today. (Note that the false alarm rates for both tornado and flash flood warnings remain high.) The Antarctic ozone hole, and major oscillations in the upper atmosphere that herald short-term climate fluctuations, now are understood and can be predicted with reasonable certainty. Consequently, more sophisticated forecasting techniques, a better understanding of the atmosphere, and improved warning technologies and communications systems (especially the Internet) have improved substantially the overall value of weather and climate information.

Application of this information takes many forms. For example, agriculture has developed a sophisticated system for risk management that involves producers, futures, insurance, weather information, distributors, and consumers[3]. The energy industry created weather derivatives, which are "instruments used by companies to hedge their risk of weather-related losses. The basic concept is that risk is exchanged with insurance or futures contracts in markets that respond to world events, weather and climate change, and supply and demand. The investor who sells a weather derivative accepts this risk by charging a premium to the purchaser. If no event occurs, the investor obviously profits, as do traditional insurance companies. However, if an event does occur, then the buyer of the derivative profits, which differs from traditional insurance."[11] Weather derivatives now are being traded as commodities, with an estimated total value of over $4B[3].

In the end, the only useful forecast in the context of objective decision making is that of a probabilistic nature – because risk management involves the statistical likelihood that an event will occur, and because no forecast can be made with complete certainty. In that regard, considerable effort is being directed toward developing statistically reliable probabilistic forecasts and applying them to decisions in which a threshold of tolerance can be stated as a probability.

d. Future Directions and Opportunities for Economic Development

What is the potential for economic development in weather and climate, and in what areas are investments expected to yield the greatest return? Although opinion differs somewhat, this question can best be answered – in a broad context – by comparing current knowledge and forecasting capabilities for various events with the potential risk posed by them. Figure 1.1 shows schematically this information for a broad array of weather and climate events/phenomena. The greatest economic development potential exists for the largest separation between current skill (black) and risk (grey), namely, intense local weather such as thunderstorms, and much longer-term events such as seasonal, annual, and decadal climate change both regionally and globally.

The potential for economic development in the weather and climate enterprise over the next 10 years could be as great as $10B.

Although it is difficult to place a monetary figure on the potential for economic development in the weather and climate enterprise, a tripling of the total private sector revenue (from $500M to $1.5B) over the next 10 years does not seem unreasonable. Considering the impact of weather and climate on military operations, homeland security (e.g., the transport of airborne hazards), and the care of an increasingly industrialized world, the figure no doubt will be much higher – perhaps as large as $10B.

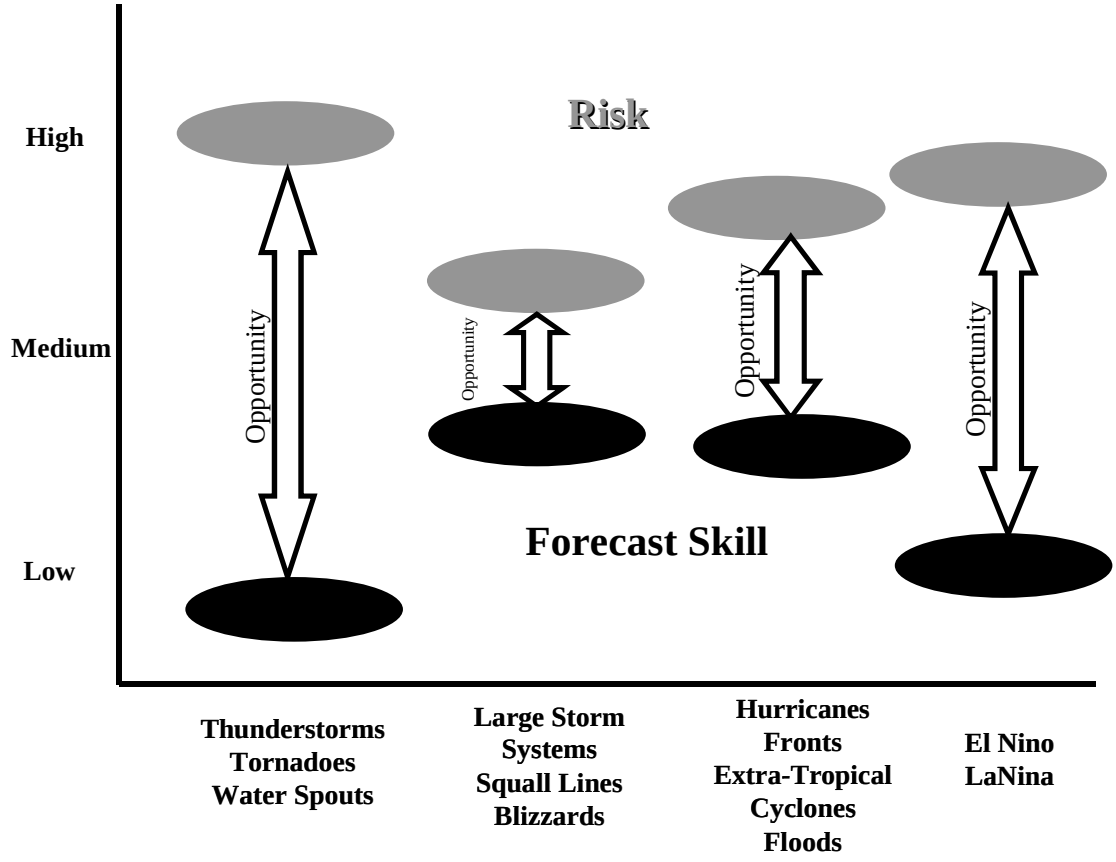

Figure 1.1. A comparison between the forecast skill associated with, and potential risk posed by, a variety of weather and climate phenomena. Adapted from a recent paper by J. Dutton.[3]

As the nation and the world become increasingly dependent upon – and thus vulnerable to disruptions in – advanced technology (power and communications grids and satellite systems, automated transportation systems, precision agriculture, alternative fuels), the degree of weather and climate sensitivity will continue to grow, as will the need to manage risk and use weather and climate for strategic advantage.

Two major impediments exist to realizing the opportunities shown in Figure 1.1, and Oklahoma is ideally positioned to address both in the context of economic development.

The first is the inadequacy of the current atmospheric and hydrologic observing network, and the second is limited effectiveness in converting meteorological data into useful decision making information for end users.

Two major impediments exist to realizing the opportunities posed by weather and climate for economic development, and Oklahoma is ideally positioned to address both: the inadequacy of the current atmospheric and hydrologic observing network, and limited effectiveness in converting meteorological data into decision making information for end users.

With regard to the first point, although weather, climate and hydrologic prediction models and decision support tools are quite sophisticated, their ultimate capability is limited by the data that drive them. The old adage "garbage in, garbage out" certainly is relevant. Consequently, those who are developing new observing technologies, and making better use of those in existence today, will be at the front of the economic development line. Furthermore, exceptional human talent – which clearly is the most important commodity – must be readily available, along with effective partnerships among all three "legs" of the weather and climate enterprise stool: academia, industry, and government.

With regard to the second point, converting meteorological data into decision making information, and conveying this information to end users while supporting them with powerful decision support tools and training in their use, is the backbone for making effective use of weather and climate information. Failure to connect the "last mile" (i.e., to bring data, products, and training to the end user) vastly diminishes the usefulness of weather and climate information, as has been shown conclusively by the Oklahoma Climatological Survey (see Section 2b).

2. Evolution and Current Status of Weather and Climate Activities in Oklahoma

a. History

The weather enterprise in Oklahoma began formally in 1960 with funding by the National Science Foundation of a proposal to create a meteorology curriculum in the OU Department of Physics. Two years later, the National Severe Storms Project (NSSP), then located in Kansas City, Missouri, established its Weather Radar Laboratory on OU's North Campus. This laboratory became the focal point for studying severe spring storms, and in 1963 it was decided that the NSSP as a whole would operate more efficiently in Norman, and would benefit by being in close proximity to the new meteorology group at OU. The move of the NSSP to Norman was completed in 1964, at which time it was renamed the National Severe Storms Laboratory (NSSL).

This nascent partnership between OU and the Federal meteorology community foreshadowed the development of the largest meteorological education-operations-research enterprise of its kind in the world, the nation's third largest concentration of meteorological talent, and an environment that has both attracted and produced some of

the world's leading authorities on the atmosphere, the latter including directors of the National Weather Service and National Hurricane Center, Oklahoma's first member of the National Academy of Sciences, and a Space Shuttle Astronaut.

The meteorology community in Oklahoma today consists of nearly 700 professionals across a dozen organizations (see Appendix C for a list of organizations and historical timeline). Collectively known as the Oklahoma Weather Center (http://owc.ou.edu) and soon to be known as the National Weather Center (Section 2c), this confederation of Federal and State institutions expends more than $60M annually and has an economic impact of approximately $100M. If the Oklahoma Weather Center were a private company, it would rank in the top 5% of payrolls within Oklahoma. During the past 15 years, the number of people in the Oklahoma Weather Center has quadrupled, and its expenditures have increased by more than 650%!

The anchor of the Oklahoma Weather Center, OU's School of Meteorology, is ranked first in the nation in severe weather research. It has the most students – 360 undergraduates and 80 graduates – of any academic meteorology program in the nation. It boasts four endowed chairs and one endowed professorship (no other meteorology program has even one), and four times more Industry Graduate Fellowships from the American Meteorological Society than its nearest competitor. Nine of its recent doctoral graduates have been awarded faculty positions in the U.S. and abroad, and the School offers the only masters degree program in the nation geared toward employment in the private or other service-oriented sectors. In 1988, School of Meteorology faculty received funding to establish one of the National Science Foundation's first 11 Science and Technology Centers, the Center for Analysis and Prediction of Storms. It pioneered the application of computer models to predict thunderstorms and today is helping develop the next-generation forecast model for the National Weather Service and U.S. Military.

The meteorological community in Oklahoma today consists of nearly 700 professionals. The associated economic impact is approximately $100M. If the Oklahoma Weather Center were a private company, it would rank in the top 5% of payrolls within Oklahoma. During the past 15 years, the number of people in the Oklahoma Weather Center has quadrupled and its expenditures have increased by more than 650%!

The Oklahoma Weather Center operates more than $500M in infrastructure including the nation's premiere state-wide environmental monitoring system, the Oklahoma Mesonet; one of the world's three Department of Energy Atmospheric Radiation Measurement test beds; several research radars including two NEXRAD prototypes and several mobile Doppler radars; and one of the most powerful supercomputers in the Big-12. Indeed, the atmosphere above Oklahoma is the most extensively observed anywhere on Earth, and thus numerous observational field programs locate in Oklahoma year-round to take advantage of its unique remote sensing

The Oklahoma Weather Center operates more than $500M in infrastructure.

instrumentation. For this same reason, the National Weather Service uses its Norman Area Forecast Office as the proving ground for new technology prior to deployment nationwide. In fact, it has been estimated that 70-80% of the severe weather warning technology used by the National Weather Service was developed in the Oklahoma Weather Center.

b. Links to Industry, Benefits to Oklahomans and the World

The Oklahoma Weather Center leads the nation in creating weather and climate partnerships with private industry. In 1996, the Center for Analysis and Prediction of Storms established a $1M alliance with American Airlines to apply computer-based weather prediction technology to hub and enroute thunderstorm forecasting. When that project was completed in 1999, the Center led the creation in Norman of a private company, Weather Decision Technologies, to commercialize its intellectual property and that of other organizations (Weather Decision Technologies was ranked 6th among the top 50 performing companies in the Oklahoma City area in 2003). In 2001, several Oklahoma Weather Center entities entered into a $10.6M partnership with the Williams Energy Marketing and Trading Company to customize weather and climate forecasting technologies for applications in energy – a partnership that remains the largest ever consummated between an academic meteorology program and private company.

The Oklahoma Weather Center leads the nation in creating weather and climate partnerships with private industry.

In spring 2003, Weathernews International established an around-the-clock aviation weather forecasting operation in Norman that services airlines worldwide. In September, 2003, Weathernews signed a lease with OU to become an anchor tenant and occupy half of a new, 50,000 square foot building to be constructed on the University's Research Campus South. This building will house the Weathernews operations headquarters, which will move from California to Norman in August 2004.

"For over four years, I have envisioned Oklahoma as the setting for Weathernews' next phase of growth in the U.S. I believe that the unique partnerships we have forged with other private, public and academic organizations in Oklahoma will help further the research and development of meteorological services to aid people and businesses all over the world."

- Hiro Ishibashi, Global Chairman and CEO of Weathernews, the world's largest private weather company

It is important to recognize that existing private weather-related companies in Oklahoma already have achieved notable success and are poised for substantial growth. For example, Vieux & Associates, a Norman-based company that uses weather radar data in flood forecasting decision support systems, and Weather Decision Technologies, have together received hundreds of thousands of dollars in Small Business Innovation Research Grants from the National Science Foundation as well as grants from the Oklahoma Center for the Advancement of Science and Technology – all involving

stiff national competition. Further, these same Oklahoma companies, which are experiencing success at the national level, are becoming quite prominent in the international marketplace.

Benefits obtained by the citizens of Oklahoma from the Oklahoma Weather Center are broad and reach every county in the State, principally through the efforts of the Oklahoma Climatological Survey. The Survey trains and provides severe weather decision tools, including real time data, to most of the State's emergency managers. This system, known as OK-FIRST, won in 2001 the Innovations in Government Award from the Kennedy School of Government at Harvard. OK-FIRST has been credited with saving numerous lives during the past several years, including several on May 3, 1999. The Survey also operates an award-winning education program, including a yearly Mesonet Science Fair which impacts hundreds of teachers and students across Oklahoma. Other Oklahoma Weather Center education programs have received national acclaim and continue to serve as role models for other institutions.

Another example in which activities of the Oklahoma Weather Center reach across the entire State is the Oklahoma Wind Power Initiative (http://www.seic.okstate.edu /owpi/). A joint project between OU and OSU, the goal of the Wind Power Initiative is to initiate and strengthen opportunities for long-term economic benefits associated with wind power in Oklahoma. Based upon years of archived wind observations from the Oklahoma Mesonet, the Wind Power Initiative is evaluating wind resources in Oklahoma to identify prime areas for locating wind turbines; evaluating infrastructure components (transmission lines, roads) that would be needed for the construction and maintenance of wind farms and for transmitting the power generated to markets where the demand resides; and studying Federal and State incentives for renewable energy. Although wind power represents only a tiny fraction of the energy now generated in the U.S. each year, dramatic decreases in production costs are making it a competitive alternative to fossil and other fuels. The American Wind Energy Association[14] predicts that wind power eventually may generate 20% of the nation's energy.

The Oklahoma Weather Center has a substantial international dimension as well. The Cooperative Institute for Mesoscale Meteorological Studies, a joint Federal government-OU research institute that represents a crucial and formal link between the academic and Federal sectors, conducts summer institutes on regional climate assessment and prediction for the Pacific and Atlantic regions. It generates drought forecasts for a number of African nations and is heavily involved with regional climate assessments in the context of agricultural production.

The Oklahoma Weather Center has a substantial international dimension.

The Korea Meteorological Administration and government of Spain use Oklahoma Weather Center computer forecast technology to predict devastating precipitation in mountainous terrain, and numerous other countries either use or are evaluating technologies for use, particularly surface mesonetworks. For example, data ingest and quality assurance software developed by the Oklahoma Mesonet is being used for the surface observing network in Quebec (http://quebec.ocs.ou.edu).

c. Building a National Weather and Climate Enterprise in Oklahoma

The University of Oklahoma is launching a Weather Radar Initiative that will create a program of international excellence in research, education, operational application, and commercialization of radar.

A number of multi-million dollar, long-term projects recently were launched within the Oklahoma Weather Center, many of which involve weather radar – the foundation upon which the Oklahoma weather and climate enterprise was built. Recognizing the opportunity afforded by these efforts, particularly with regard to economic development, the University of Oklahoma is launching a Weather Radar Initiative that will create a program of international excellence in research, education, operational application, and commercialization of radar. The underpinning for this Initiative is an existing project that is developing the follow-on to the NEXRAD Doppler weather radar. Known as the Phased Array Radar (PAR) and led by the National Severe Storms Laboratory in Norman, it involves partnerships with OU, Lockheed-Martin Corporation, the U.S. Navy, and the Federal Aviation Administration. The new radar is expected to greatly improve the warning and prediction of hazardous weather and will be able to track aircraft as well.

A number of multi-million dollar, long-term projects recently were launched within the Oklahoma Weather Center.

OU is a major partner in a new National Science Foundation Engineering Research Center – the Center for Collaborative Adaptive Sensing of the Atmosphere (CASA) – that is developing inexpensive Doppler radars that can be placed on cellular towers or buildings. (Note that the University of Oklahoma is the only institution ever to have established an NSF Science and Technology Center that later helped create an Engineering Research Center.) These radars will collaborate with one another to optimally sense multiple atmospheric targets at very fine scales. Although this center, which is expected to generate from $70 to $100M in research funding over the next ten years, is brand new, it already has captured the attention of the U.S. Defense and Homeland Security Departments. In particular, they are interested in the ability of the radars to sense – for the first time – the detailed four-dimensional wind, temperature, and moisture structure above the ground. Accurate measurement of these quantities, in concert with data collected by ground-based sensors, is expected to increase significantly the ability of computer models to predict the movement of airborne chemical, radiological and biological hazards.

Another new multi-million dollar National Science Foundation project, known as Linked Environments for Atmospheric Discovery (LEAD), is developing grid computing and data management environments that will allow scientists and students to access, prepare, predict, manage, analyze, and visualize a broad array of meteorological information independent of format and physical location. A transforming element of LEAD is the ability for analysis tools, forecast models, and data repositories to function as dynamically adaptive, on-demand systems that can change configuration rapidly and automatically in response to the evolving weather; respond immediately to user decisions

based upon the weather problem at hand; and steer remote observing systems to optimize data collection and forecast/warning quality.

Oklahoma continues to pioneer the use of mobile Doppler radars to study tornadoes and hurricanes at close range, and is seeking to establish a National Mobile Observing Facility. The Oklahoma Climatological Survey is leading an initiative to modernize the National Weather Service Cooperative Observer Network. Involving more than 8000 surface monitoring stations, this initiative would greatly improve the availability and quality of observations for use in forecasting and warning, drought monitoring, and air quality monitoring, and could evolve into another major support center located in Oklahoma.

The National Weather Center building, being constructed in Norman, will be the premiere facility in the world supporting academic, research, and operational weather activities. The Commercial Weather Partners Neighborhood, a series of buildings next door, will house private weather forecasting and technology companies.

Owing to critical space shortages in accommodating these and other activities, and in an effort to more fully realize the benefits of co-locating operations with research and education – as envisioned in the early 1960s – the State of Oklahoma and the Federal government are together constructing a new $67M facility to house all State and Federal weather entities in Oklahoma (Appendix D). This building, named the *National Weather Center* in 1999 by President Clinton following the May 3rd tornado outbreak, will be the premiere facility in the world supporting academic, research, and operational weather activities.

A unique facet of the National Weather Center is the Commercial Weather Partners Neighborhood, a series of buildings to be located next to the National Weather Center that will house private weather forecasting and technology companies. This strategic positioning will (a) facilitate the commercialization of National Weather Center technologies, and thus economic development, based not upon resources imported from elsewhere, but rather upon those conceived and developed in Oklahoma; (b) serve as a mechanism for private industry to tap into the intellectual and physical assets of the National Weather Center, thereby creating new opportunities locally and also attracting companies to Oklahoma; (c) provide a pipeline of professional employees that remain in Oklahoma; and (d) expose students to the commercial aspects of the weather and climate enterprise as part of their educational experience. The latter is particularly important as private industry has become, and no doubt will remain, the dominant employer in the areas of weather and climate.

3. Oklahoma: A State Ready to Capitalize Upon Weather and Climate

Oklahoma is blessed with a wealth of natural resources, particularly oil and natural gas. Along with agriculture, livestock, aviation, and a significant military infrastructure, these assets have long served as the foundation of Oklahoma's economy. Another natural

Research and development is the essential foundation for economic development. Having established a weather and climate research and operational services enterprise that is unique in the world, and having pioneered public-private partnerships that created dozens of jobs in Oklahoma, the Oklahoma Weather Center is poised to fully exploit weather and climate for substantial long-term economic development.

resource available to Oklahoma – unique because it is inexhaustible and insensitive to market fluctuations or world events – is weather. Research and development is the essential foundation for economic development, and having established a successful weather and climate research and operational services enterprise, and having pioneered public-private partnerships that created dozens of jobs in Oklahoma, the Oklahoma Weather Center is poised to fully exploit weather and climate for substantial long-term economic development.

Why weather and climate? First of all, much of the technology developed by the Oklahoma Weather Center is "home grown" – that is, conceived in Oklahoma, tested in Oklahoma, but used across the nation and around the world. The growing sensitivity of nations and industries to weather and climate indicates that the value of this technology will continue to grow, not only in the context of saving lives and property but also in providing a strategic economic advantage to industry. *Oklahoma has something unique to offer, and there exists an increasing demand for it.*

Second, weather and climate represent high-tech areas that have strong links to and dependencies upon other high-tech areas, many of which are found in Oklahoma. They include computing, networking, software development, manufacturing, and training. Thus, *weather and climate will not evolve in isolation, but can serve as a catalyst for other potential growth areas in the State – all in the context of a knowledge-based economy.*

Third, weather is a vital element in military operations and homeland defense, with the military-industrial complex poised to expend billions of dollars on observing and forecasting technologies. Such activities usually take the form of public-private partnerships of the type in which the Oklahoma Weather Center already has become involved. The U.S. Department of Homeland Security, Department of Energy, and Department of Defense (Defense Threat Reduction Agency) chose Oklahoma City as the site of two chemical and biological release experiments in 2003 because of the Oklahoma Weather Center and in particular the Oklahoma Mesonet. By virtue of several military bases in Oklahoma, along with the Federal Aviation Administration's Mike Monroney Aeronautical Center and the Oklahoma Space Port, *the Oklahoma weather and climate enterprise is positioned to make significant inroads to the military-industrial complex.*

Finally, weather and climate feed other application areas, including hydrology, air and water quality, environmental stewardship, transportation, energy, space flight, manufacturing, and health. *Oklahoma can strategically align weather and climate with such areas to the benefit of all.*

Oklahoma has something unique to offer in weather and climate, and there exists an increasing national demand for it.

Weather and climate will not evolve in isolation, but can serve as a catalyst for other potential growth areas in the State – all in the context of a knowledge-based economy.

The Oklahoma weather and climate enterprise is positioned to make significant inroads to the military-industrial complex.

The infrastructure required to establish weather and climate as an economic development focal point already exists, but decision methodologies and support tools must keep pace.

Oklahoma can strategically align weather and climate with other areas for the benefit of all.

The necessary mechanisms exist to move forward and notable barriers have been removed.

It's simply time to get started.

Why now? The congruence of numerous factors make *now* the right time to pursue economic development in Oklahoma centered around weather and climate.

First, advances in our understanding of the atmosphere have improved substantially the quality of weather and climate forecasts. *Weather and climate guidance has demonstrable practical value.*

Second, weather and climate-sensitive industries recognize this value and, in the struggle to survive in highly competitive markets, must take every measure possible to minimize exposure and maximize profit. *A compelling national need exists and is growing.*

Third, computer, communications, and visual display technologies have advanced at extraordinary rates and now are extremely affordable, thus providing an infrastructure over which to deliver and make decisions with weather and climate information. However, the technological gap that exists between societal and business decisions made by laymen, and the potential to improve those decisions, remains unacceptably large owing to the lack of decision support tools. For example, when the focus is improved flood warnings in local communities, the methods employed today are, by-and-large, the same as those used during the 1980s. Although new tools have been developed in Oklahoma, they have not been implemented nationally. *Consequently, the infrastructure required to establish weather and climate as an economic development focal point already exists, but decision methodologies and support tools must keep pace.*

Fourth, universities (especially public) now are viewed as engines of economic development; both State and Federal laws have been enacted during the past 20 years to facilitate public-private partnerships and bring the benefits of research to the general public. Furthermore, organizations now exist, such as the Sasaki Applied Meteorology Research Institute at OU, whose purpose is to facilitate linkages between the academic and industrial sectors. *Thus, the necessary mechanisms exist to move forward and notable barriers have been removed.*

Finally, the Oklahoma Weather Center has grown to "critical" mass in several areas, providing a stable foundation upon which to build. *It's simply time to get started*.

4. Blueprint for Economic Development Centered Around Weather

a. Vision

Our vision for economic development in Oklahoma builds upon the foundation of research, development, education and operations excellence already in place, and it directly addresses the two key barriers to economic progress noted in Section 1d: insufficient observations and failure to connect the "last mile" to end users who make critical decisions using weather and climate information. Specifically, our vision is for Oklahoma to become:

VISION

During the next 10 years, Oklahoma will become

- *the* international leader in the development, testing, manufacture, application, maintenance and support of radar technology in the civilian and military sectors;
- *the* national hub where radar data from a wide variety of systems (National Weather Service, Military, Federal Aviation Administration, television stations) are collected, synthesized with other data, distributed, and stored;
- *the* international leader in creating weather-related products and decision support tools for a wide variety of application areas and end users; and
- *the* international focal point for end user training and support.

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- *the* international focal point for end user training and support.

In each of these areas, Oklahoma corporations – those now in existence as well as new ones – are expected to play a vital role, and recommendations are offered in Section 5 to help achieve this goal.

b. Rationale

Radar was the focus of the weather enterprise in Oklahoma when it began as a small project some 43 years ago, and from what now is the Oklahoma Weather Center has emerged a number of key radar-based technologies that have saved countless lives and millions of dollars. They include the nation's operational Doppler weather radar network (NEXRAD), the first mobile Doppler weather radars and their improved successors, a

Okalahoma Weather Center activities have created hundreds of jobs and brought hundreds of millions of dollars to Oklahoma – without a specific or intentional emphasis on economic development. The Oklahoma Weather Center now is poised to leverage its huge Federal and private R&D investment for economic development

national facility for NEXRAD operations, support and training, an award-winning decision support system that puts products from NEXRAD and other data into the hands of emergency managers, and a new information technology system for transmitting NEXRAD data to anyone anywhere via the Internet. Combined, these efforts have created hundreds of jobs and brought hundreds of millions of dollars to Oklahoma – without a specific or intentional emphasis on economic development.

However, true economic development occurs not via reliance on Federal funding, but when private industries emerge to provide high-paying jobs for increasing the State tax base. Thus, in contrast to 43 years ago, the Oklahoma Weather Center today is poised to leverage its huge Federal and private R&D investment for economic development. In doing so, it will

- impact **other information-based sectors** including computing, telecommunications, data storage, visualization, and component manufacturing;
- have a direct impact on the **citizens of Oklahoma**, the nation and world by providing information for protecting life and property, mitigating financial loss, and using weather and climate for strategic economic advantage; and
- provide mechanisms for **sustained growth** of a more diverse and market-insensitive Oklahoma economy and thus the creation of more public funds.

Radar is ideally suited today as a *new focal point* – one for economic development in Oklahoma – because it

- represents an area of excellence already present in Oklahoma that has saved hundreds of lives nationwide, garnered significant new Federal and private sector funding, and already is proven to be a significant component of Oklahoma's economy;
- is the only technology presently available that can observe the three-dimensional atmosphere with fine detail, thus providing information that is unique to a broad array of applications;
- requires continuous high-tech research and development in both science and engineering, thus involving higher education in a significant manner;
- is of intense interest, both in a military and civilian context, to some of the world's largest corporations, including Lockheed-Martin, Raytheon, and IBM, with all of whom Oklahoma has formal partnerships in radar;
- has only begun to be used as a space-based weather sensor, thus providing significant opportunity for the future;
- requires sophisticated software to process the enormous quantities of data produced, thus providing a basis for high-tech software development jobs;

- serves as the foundation for creating decision support systems to manage risk in a wide variety of weather-sensitive industries;
- is the primary data source for fine-scale computer-based weather forecasting, which is a major component of the Oklahoma Weather Center in demand nationally and internationally;
- is ideally suited for proof-of-concept testing in Oklahoma's severe and rapidly changing weather;
- has strong linkages to and dependencies upon other high-tech areas already present in Oklahoma, including parallel computing, data storage, wired and wireless networking, visualization, and grid computing;
- requires maintenance, training, and user support facilities, many of which already exist in Oklahoma and can serve as the blueprint for future growth; and
- has significant industrial and high-tech (chips, circuit boards, antennas) manufacturing components, all of which can be accommodated in Oklahoma.

No other State or set of organizations is today positioned to accomplish that which is proposed herein because the Oklahoma Weather Center does not wait for opportunity to happen – it creates its own.

c. Competition

A number of institutions around the country enjoy success in the development and application of weather radar and related technologies, notably the National Center for Atmospheric Research (Boulder, CO), Lincoln Laboratory (Lexington, MA), the University of Massachusetts (Amherst, MA), Colorado State University (Fort Collins, CO), and Florida State University (Tallahassee, FL). However, Oklahoma is singularly unique owing to its mixture of academic, Federal/State research, and Federal/State operational elements; its national leadership role in NEXRAD, mobile radars, and radar-related information technology; its ability to turn radar data into life-saving information for emergency managers and first responders; and its geographic location in the center of the most severe weather on Earth. No other State, or set of organizations, has at this moment the potential to accomplish that which is proposed herein – because the Oklahoma Weather Center does not wait for opportunity to happen: it creates its own.

By 2007, the National Weather Center will lead the world in radar research and education, and be positioned to become the international focal point for radar commercialization and application as well as data management and distribution.

d. Strategy

2004-2007. During the current early prototyping phase of the new radar technologies already being developed here, the Oklahoma Weather Center can begin to establish an associated economic foundation by creating strategic partnerships with a number of groups, especially private companies, and by adding human talent. The University of Oklahoma already has created a Strategic Plan for Attaining International Leadership in Weather Radar and is ready to execute it immediately. *The expected outcome by 2007 is a*

National Weather Center that leads the world in radar research and education, and is positioned to become the international focal point for commercialization and application as well as data management and distribution.

2008-2012. By 2008-2012, some of the new technologies now being developed are expected to be ready for production, with initial customers that include television stations, the U.S. Military, the U.S. Department of Homeland Security, municipalities, power and electric utilities, and foreign governments. Oklahoma must work to create facilities for manufacturing these radars; establish a software development enterprise in the areas of signal processing, data quality control, data transmission and management, data synthesis and assimilation, atmospheric hazard detection, decision support, and visualization; build centralized user support facilities that orchestrate data acquisition and quality control and perhaps oversee maintenance and upgrade services; strengthen its ongoing research and development program via successful competition for Federal grants as well as private contracts; develop a user training operation that includes distance learning and the production of instructional materials; and create a data distribution and archival facility that serves all user communities. *The expected outcome by 2012 is an established and growing commercial enterprise with emphasis on growth of existing Oklahoma companies and a significant software development effort geared toward initial operational status of maturing radar technologies.*

The expected outcome by 2012 is an established and growing commercial enterprise with emphasis on growth of existing Oklahoma companies and a significant software development effort geared toward initial operational status of maturing radar technologies.

Beyond 2012. Beyond the approximate first decade of this initiative, we envision continued growth in the creation of user products and tools, as well as new directions in radar technology, particularly clear-air sensing. Such capabilities will allow for the three-dimensional mapping of temperature and moisture, in addition to winds, at high spatial and temporal resolution. The potential payoff is vastly improved computer-based weather forecasts (and thus financial value to the private sector), the ability to track hazardous materials, and pollution forecasting. Achieving this goal will require substantial ongoing research and development, partnerships with industry, and possibly an entirely new type of radar.

Beyond the next 10 years, Oklahoma will possess a thriving commercial, research and educational enterprise that focuses on a broad array of radar technologies across a broad spectrum of users, and be the recognized hub for the collection, storage, and distribution of weather and climate data and tools.

We also envision that Oklahoma will be the virtual portal for the distribution of data and associated user tools from all types of radars, including those operated by the Federal Aviation Administration, U.S. Military, and the commercial sector, as well as from other environmental observing technologies. Although the raw data themselves have value, Oklahoma is uniquely positioned to *combine data* from all observing platforms into

gridded, assimilated data sets, from which can be extracted information for a broad spectrum of decision making needs.

The expected outcome after 2012 is a thriving commercial, research and educational enterprise that focuses on a broad array of radar technologies across a broad spectrum of users, and is the recognized hub for the collection, storage, and distribution of weather and climate data and tools. Oklahoma-based companies will have grown in alignment with major corporations, a significant software and user support infrastructure will be supplemented by hardware and component manufacturing, and major corporations will have established a significant presence in Oklahoma to take advantage of the entire National Weather Center enterprise.

5. Recommendations

Recommendation #1: Provide Targeted Financial Support to Help Grow the Oklahoma Weather Center as it Transitions Into the National Weather Center

- **Why is this important?** The Oklahoma Weather Center has been extremely successful in obtaining competitive Federal grant funds, and matching funds from private industry, to support major new initiatives in weather research and development. However, a concomitant funding stream from State Government is absolutely essential for meeting needs that *other sources cannot provide*.

- **Who should take action?** State Government should work with Higher Education to develop a strategy for targeted investments in weather-related research and development activities that will lead to economic growth.

- **What needs to be done?**
    - Provide funding to open and operate the new National Weather Center, which is scheduled to open in early 2006 ($3.5M);
    - Reinstate and expand the Oklahoma State Regents for Higher Education research matching program for externally sponsored grants and contracts as a means for increasing the ability of faculty to compete for Federal funding;
    - Fulfill matching commitments on pending endowed chairs and professorships, an action which is vital for hiring new faculty in meteorology, electrical engineering, and computer science;
    - Provide funding for new faculty lines, student fellowships, and infrastructure targeted toward radar and other weather-related activities ($2.5M);
    - Provide funding for enhanced physical facilities, equipment, and technical support staff for radar research, development, and commercialization ($12M);
    - Actively promote the new National Weather Center on a national scale, with funding for a distinguished visiting scientist program, high quality

brochures, sizeable ads in the nation's leading newspapers, and television commercials on national networks. Oklahoma must market weather on a grand scale. ($0.2M);

- Begin an initiative to develop a National Weather Museum, to be located next to the National Weather Center. In conjunction with the Fred Jones, Jr. Art Center (local resource for the fine arts), the Sam Noble Oklahoma Museum of Natural History (State museum of humanities and natural science), the National Weather Museum would easily attract thousands of visitors each year ($20M).

- **How should it be implemented?** Legislative action is required to appropriate funding for most of the actions recommended above, with the Oklahoma State Regents for Higher Education directing these funds toward weather-related activities.

Recommendation #2: Intensify Efforts to Create and Grow, Strong Academic-Corporate Partnerships

- **Why is this important?** Universities are the focal point for research and development, research and development represent the foundation for economic growth, and private enterprise is the means by which research and development outcomes are brought to the marketplace and jobs are created. Consequently, success in building a component of Oklahoma's economy around weather and climate will require strong alliances, both formal and informal, between the academic and private sectors not only within Oklahoma but nationally and around the world.

- **Who should take action?** Higher Education should take the lead in reaching out to Private Industry, making known the vast resources of academia and creating a *culture* in which academia and industry can work together effectively for the benefit of both.

- **What needs to be done?**
  - Create and implement a more effective strategy for marketing higher education resources (people, facilities, knowledge) to industry in the context of economic development, both within Oklahoma and beyond its borders;
  - Develop workshops to help both industry and academia understand the nature of public-private partnerships, including but not limited to issues associated with intellectual property, conflict of interest, and the creation of spin-off companies;
  - Assist in establishing stable funding streams from major corporations and intensify efforts to obtain external grants and contracts from Federal agencies;

- Provide additional resources to the Oklahoma Center for the Advancement of Science and Technology, and the Oklahoma Technology Commercialization Center, to encourage the commercialization of academic research outcomes;
- Establish alliances with the industrial-military complex including national laboratories and foreign governments.

How should it be implemented? The Chancellor for Higher Education, working through the Oklahoma State Regents for Higher Education, should take the lead in organizing a plan, in consultation with presidents and technology development officers of Oklahoma's higher education enterprise. Involvement by OCAST, OTCC, and especially local economic development organizations and Chambers of Commerce is absolutely essential.

Recommendation #3: Expand the Involvement of Existing Oklahoma Corporations in Weather-Related Activities and Work to Create New Companies

- **Why is this important?** Owing to financial barriers, existing weather-related Oklahoma companies, all of which are relatively small, are disadvantaged from participating in research and other activities that would help them grow, contribute to economic development, and serve as role models for creating and attracting other companies. In addition, Oklahoma economists have asserted that the State has experienced limited growth because the economy is dominated by government jobs owing to insufficient private investment. Because a weather- and climate-based economy inherently involves public-private partnerships, Oklahoma must expand the role played by private industry.

- **Who should take action?** State Government should address a few key issues to encourage private sector growth in weather- and climate-related activities.

- **What needs to be done?**
  - Reduce or eliminate of the cost to access real time radar and other fee-based data under the control of local sources, and the cost to participate in organizations that cultivate public-private partnership (e.g., the Sasaki Applied Meteorology Research Institute at OU);
  - Allow private companies in Oklahoma to provide commercial services without having to compete with taxpayer-sponsored services;
  - Encourage out-of-state companies that contract in Oklahoma to work with and help grow small Oklahoma companies;
  - Encourage out-of-state companies to relocate to Oklahoma and to work with existing companies to grow the Oklahoma weather enterprise;
  - Expand research and development tax credits to small Oklahoma weather-related businesses;

- Provide Oklahoma companies, especially small ones, with favored occupancy rates in the new National Weather Center Commercial Partners Neighborhood buildings;
- Support related hydrologic research, in collaboration with the Oklahoma Water Resources Board, that is directed at producing a scientifically-based decision system for local and State-wide water resource management.

How should it be implemented? The actions described above are relatively inexpensive and for the most part can be instituted as *policy*. Tax credits may require minor changes to existing laws.

6. Expected Outcome

What level of economic growth can be expected *in Oklahoma* from weather and climate? In relation to major industries such as pharmaceuticals, energy, and automobile manufacturing, to name but a few, revenue generated by weather and climate is comparatively small. However, as shown in Figure 1.1, tremendous potential exists for economic development, particularly in the context of intense, short-term weather events and much longer-term climate fluctuations both globally and regionally.

Weather represents one of the few immediate opportunities to create jobs in Oklahoma that raise the per capita personal income, with the majority of these jobs paying at least twice the State's average personal income.

Table 6.1 summarizes our estimates of new jobs and revenue across several services sectors for the short (0-5 years), medium (5-10 years), and long (beyond 10 years). These projections are based upon a new study, representing an update to work commissioned in 1998 by the Norman Economic Development Coalition[16], of more than 100 U.S. and international corporations that provide, to the global weather industry, the services indicated in the table. Note that weather represents one of the few opportunities to create jobs in Oklahoma that raise the per capita personal income, and that a majority of these jobs will pay at least twice the State's average personal income.

Sector	Short Term (0-5 yrs)		Medium Term (5-10 yrs)		Long Term (beyond 10 yrs)	
	Sales	Employees	Sales	Employees	Sales	Employees
Software Development	$15M	20	$37.5M	50	$60M	80
Information Technology	$30M	30	$60M	60	$80M	80
Training	$5M	10	$10M	20	$10M	20
Support Services	$15M	30	$30M	60	$40M	80
Manufacturing	$250M	50	$1,000M	200	$1,750M	350
Operations	$15M	30	$30M	60	$50M	50
Research & Development	$50M	50	$150M	150	$250M	250
Totals	**$380M**	**220**	**$1.32B**	**600**	**$2.24B**	**910**

Table 6.1. Estimated economic growth for the weather and climate enterprise in Oklahoma, by sector, over three successive periods.

7. Implementation and Oversight

A vision as multi-faceted and bold as that articulated herein will require substantial coordination and oversight at multiple levels. Fortunately, the basis for such an infrastructure already exists: The Oklahoma Weather Center. However, to serve effectively in this capacity it must be appropriately formalized and properly structured. An opportunity to do so exists as the Oklahoma Weather Center transitions into the National Weather Center, and the University of Oklahoma already has formulated a plan for achieving this goal and is prepared to execute it immediately.

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Appendix A.

Weather and Climate Sensitive Components of the U.S. Gross Domestic Product (in billions of dollars)[3].

Industries (1987 standard industrial classification)	GDP components ($ billion)	Weather sensitive components ($ billion)
Agriculture, forestry, and fishing	**135.8**	**135.8**
Farms	79.0	79.0
Agricultural services, forestry, and fishing	56.7	56.7
Mining	**127.1**	**109.6**
Coal mining	10.1	10.1
Oil and gas extraction	99.5	99.5
Other mining	17.5	0.0
Construction	**463.6**	**463.6**
Manufacturing	**1,566.6**	**—**
Transportation and public utilities	**825.0**	**786.5**
Transportation		
Railroad transportation	22.9	22.9
Local and interurban passenger transit	18.7	18.7
Trucking and warehousing	126.0	126.0
Water transportation	14.8	14.8
Transportation by air	93.0	93.0
Other transportation	38.5	0.0
Communications	281.1	281.1
Electric, gas, and sanitary services	230.0	230.0
Wholesale trade	**674.1**	**—**
Retail trade	**893.9**	**893.9**
Finance, insurance, and real estate	**1,936.2**	**379.1**
Security and commodity brokers	144.2	144.2
Insurance carriers	167.7	167.7
Insurance agents, brokers, and service	67.3	67.3
Other finance, insurance, real estate	1,557.1	—
Services	**2,164.6**	**261.2**
Hotels and other lodging places	86.5	86.5
Auto repair, services, and parking	93.9	93.9
Amusement and recreation services	80.8	80.8
All other services	1,903.4	—
Statistical discrepancy	–130.4	—
TOTAL FOR PRIVATE INDUSTRY	**8,656.5**	**3,029.6**
Federal government	**387.0**	**—**
State and local government	**829.5**	**829.5**
TOTAL GROSS DOMESTIC PRODUCT	**9,872.9**	**3,859.1**

Appendix B.

Impact of Extreme Weather Events in the United States[4].

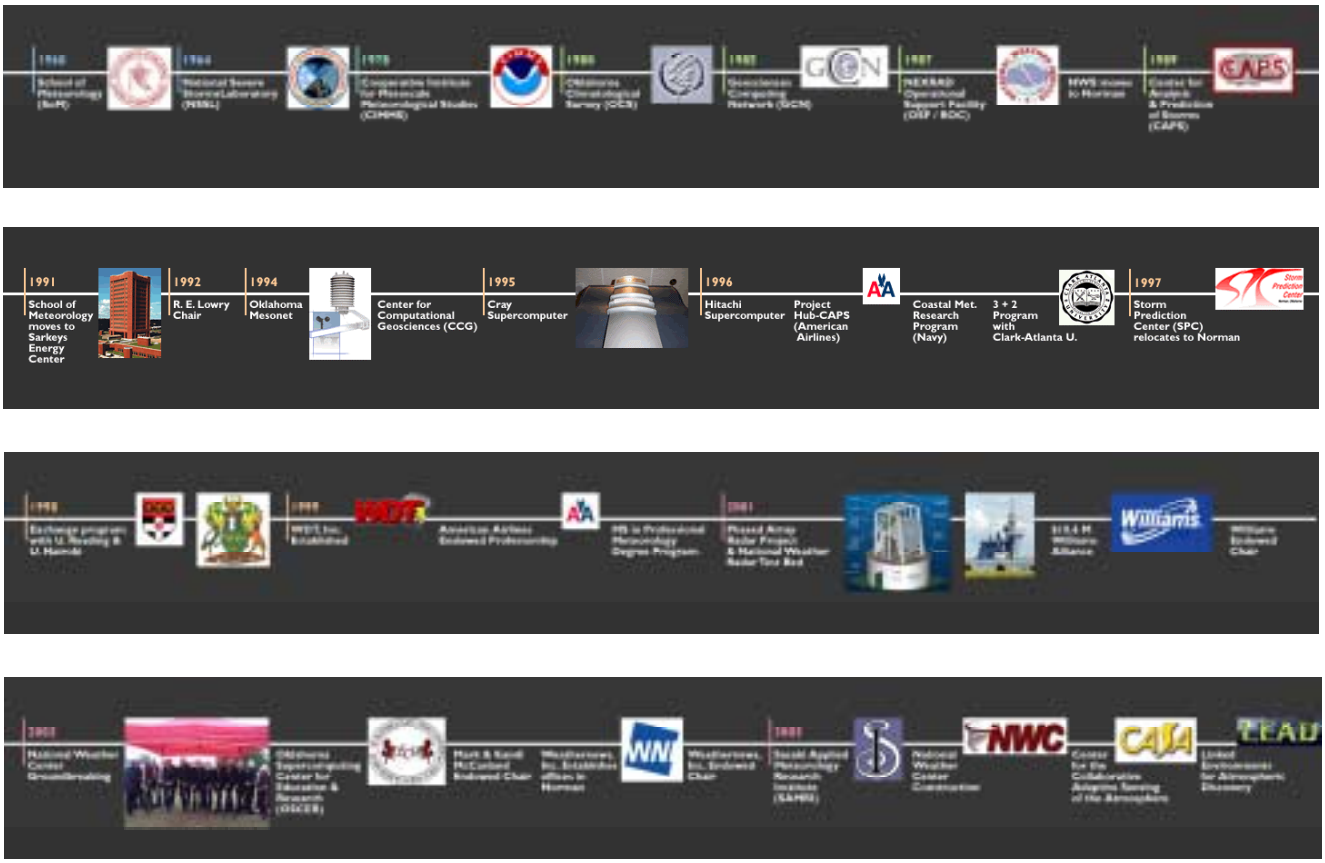
Event	Annual mean loss of life (19xx–1989)	Annual mean loss of life (1990s)	Annual mean 1999 $ loss (19xx–1989)	Annual Mean 1999 $ loss (1990s)
Floods	95[1] (1903–89)	98[1] (1990–Mar 2000)	$1.8B[2] (1903–89)	$5.3B[2] (1990–99)
Hurricanes	173[3] (1900–89)	21[4] (1990–2000)	$5B[5] (1900–89)	$5.4B[6] 1990–2000)
Winter storms		57[6] (1995–2 Nov 2000)		$329M[6,8] (1995–2 Nov 2000)
Tornadoes	97[7] (1950–89)	56[8] (1990–2 Nov 2000)	$1.2B[9] (1950–1989)	$777M[9] (1990–99)
Extreme heat	412[10] (1979–89)	282[11] (1990–98)		$85M[6,12] (1995–2 Nov 2000)
Extreme cold	393[13] (1979–89)	292[14] (1990–98)		$368M[6,13] (1995–2 Nov 2000)
Lightning	88[16] (1979–89)	69[17] (1990–98)		$38M[6,18] (1995–2 Nov 2000)
Hail		1[18] (1995–2 Nov 2000)		$938M[6] (1995–2 Nov 2000)
Annual averages	**1258** (not including winter storms or hail)	**876**		**>$13B**

*2000 damages are in unadjusted 2000 $.

Each year, adverse weather conditions cause more than 7000 traffic fatalities and more than 450,000 injuries. Transportation agencies spend about $2B annually for snow and ice control and $5B for infrastructure repair that is attributable to weather.[12]

Appendix C.

The Oklahoma Weather Center: Four Decades of Excellence and International Leadership



State of Oklahoma Organizations
University of Oklahoma School of Meteorology
Center for Analysis and Prediction of Storms
Cooperative Institute for Mesoscale Meteorological Studies
Oklahoma Climatological Survey
Department of Geography
Environmental Verification and Analysis Center

Federal Government Organizations
National Severe Storms Laboratory
NEXRAD Radar Operations Center
National Storm Prediction Center
National Weather Service Forecast Office
Warning Decision Training Branch
NASA Space Grant Consortium

Appendix D.

The National Weather Center (Scale Model)
(see also http://owc.ou.edu)