WEATHER, CLIMATE, AND ENERGY

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Panel 2

Advances in Weather/Climate Science and Services

POSITION PAPERS

Government Development of National Weather Products and Services

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Forum Questions

1. What are the near-term advances anticipated in weather science and services?
2. How can those advances be applied to the energy sector needs?

Introduction

The government through the National Oceanic and Atmospheric Administration (NOAA) is supporting research necessary to provide strategic and tactical information to assist the operations of the US energy sector. This research will aid the improvement of both NOAA and private sector services that respond to the needs of the energy sector. The government effort is primarily in response to the *National Energy Policy Report*. NOAA has identified four critical areas: 1) Electrical load forecasting; 2) Optimizing energy operations management; 3) Fuel distribution infrastructure; and 4) Risk management. NOAA's weather products and services development is focusing on

- Improving ***daily temperature forecasts*** for electrical load forecasting and risk management
- Improving ***severe weather forecasting*** to reduce service disruption
- Improving ***river flow forecasting*** to optimize hydropower operations
- Improving ***atmospheric constituent forecasting*** to optimize power generation operations
- Improving ***geomagnetic storm forecasting*** to economically manage the electrical grid system

Approach

The research will rapidly prototype and demonstrate new service capabilities for weather, space weather, hydrologic, and air quality information that can assist the energy industry to improve efficiency, reduce cost and minimize risk. This service demonstration will show how new meteorological services can fill gaps in needed strategic and tactical information for the energy sector that are presently unmet. The goal is to deliver a suite of products that have been identified as necessary and integral components of the energy sector's decision process and, where appropriate, to partner with private sector services to sustain these operational products.

The NOAA effort will provide a complete demonstration of service improvements in limited regions within the continental U.S. These will likely include the Northeastern U.S. from Maryland through Maine and Texas. Other regions will be developed following the initial demonstration. The initial region will be selected following discussion with industry representatives and other interested parties.

Energy Sector Critical Areas

Load Forecasting

The energy industry has identified the need for increased accuracy in daily and seasonal temperature forecasts. According to Del Jones, reporting in *USA Today* (June 19, 2001), the annual cost of electricity could decrease by at least $1 billion if the accuracy of weather forecasts improved by one-degree

Fahrenheit. Underestimating daily temperature forecasts result in costly spot market payments for electricity, or the risk of unscheduled brown-outs or rolling blackouts in markets that are unable to meet the additional, unplanned demand. For example, Jones reports that

> "The Tennessee Valley Authority (TVA) generates 4.8% of the USA's electricity. Forecasts over its 80,000 square miles have been wrong by an average of 2.35 degrees the last 2 years, fairly typical of forecasts nationwide. Improving that to within 1.35 degrees would save TVA as much as $100,000 a day, perhaps more. Why? On Monday at 5:30 a.m., TVA's forecast for today called for an average four-city high of 93 degrees in Memphis, Nashville, Knoxville and Chattanooga, rising from 71 degrees at 6 a.m. TVA has scheduled today's power generation based on this forecast and will bring on line a combination of hydro, nuclear, coal, wind, natural gas and oil plants as temperatures rise. It will buy wholesale electricity if that costs less than generating its own power. Gas plants are more expensive to operate than nuclear or coal, so TVA will fire up its "peakers" only when it expects demand to be very high. If the average temperature comes in 1 degree hotter, rising to 94, TVA's customers will demand 450 more megawatts. There would be no time to fire up an idle gas plant, and the cost of last-minute wholesale electricity could skyrocket. "There are times when electricity is $80 (per megawatt hour) a day ahead and $800 to $8,000 24 hours later," says Robert Abboud of RGA Labs, which helps utilities with complex decisions. On the other hand, if the four-city temperature comes in a degree cooler than forecast, TVA may have fired up a plant unnecessarily, or bought electricity a day in advance that will go wasted. Temperature is most important, but utilities can also benefit from accurate forecasts of cloud cover and humidity. Timely forecasts of lightning, the top cause of outages, let them position repair crews. Long-range forecasts of 30 days let them plan maintenance."

In addition, sub-seasonal to seasonal forecasts of temperature and precipitation contribute to fixing the long-term contract prices of electricity, gas, heating oil and other energy products.

More accurate temperature and precipitation forecasts require higher resolution numerical models, and denser, more comprehensive observing networks. Improved seasonal forecasting, which links extreme weather events with climate variability, will refine seasonal estimates of energy requirements and with better hemispheric observing networks, data assimilation techniques and global weather models will provide improved extended range guidance for weather regime shifts beyond week-one to sub-seasonal time scales, affecting load forecasting and stream flow forecasting related to hydropower generation.

Improving daily temperature and precipitation forecasts can be accomplished through the regional implementation of local numerical weather prediction (NWP). Local NWP depends on several things: numerical models with high temporal and spatial resolution, such as MM5 or the newly developed Weather Research and Forecasting (WRF) model, accurate boundary conditions from regional and larger scale models, rapidly updating data assimilation, and high resolution local observing networks. The cost of achieving nationwide service improvements in local NWP is prohibitively expensive for both the public and private sectors, but might be achievable through appropriate partnerships between the National Weather Service (NWS), universities and private weather companies. Up to twelve local NWP nodes could be developed at the NWS Regional Forecast Offices (RFOs). The RFOs could provide access to the regional products of the National Centers for Environmental Prediction (NCEP) with the non-federal partners operating their own local NWP models or working with the research branch of NOAA, or both, to develop specific client services while aiding in the overall improvement of the public weather services. New local and regional data can be obtained from several sources including regional implementation of the modernized Cooperative observing (COOP) network, regional implementation of the Advanced Hydrological Prediction Service (AHPS), and private observing networks owned and operated by the energy industry and others. These same data and NWP models will also provide improvements in the accuracy of severe weather forecasts.

Optimizing Energy Operations Management

Optimizing energy operations management requires the ability to select the optimum mix of fuels and sources of energy in a well-determined operating environment to meet demand at minimum cost and minimum waste. This is a complex process that must consider numerous factors, including the availability of electrical power from the spot market and long term contracts, the availability of electrical power from local and regional generating units operating under air quality and other constraints, the integrity of the electrical grid, base load generation, distributed generation strategies, unit maintenance, and the management of hydroelectric power and water resources. Such interwoven issues require new predictive tools to anticipate and manage energy resources and operations. For example, if longer-lead time forecasts are available for temperature and precipitation, energy needs and supplies can be estimated more accurately. Similarly, power-plant peaking operations on a regional basis might be timed to coincide with meteorological condition favorable for dispersal of emissions, allowing decisions to be made that optimize the energy operations strategy.

The sites of new fossil fuel power plants can also be optimized through improved knowledge of the background atmospheric constituents. Existing studies have provided information on the specific processes by which power plant emissions impact air quality and the influence of local meteorology and the mix of natural and mad-made emissions on the formation and distribution of air pollution. This, and similar region specific, information can be used to inform decisions on power generation options (e.g., unit size, central vs. distributed generation, and fuel) power plant siting, and the selection of control technologies.

Hydroelectric reservoir operators, to maximize energy planning strategy months in advance, can use long-term water volume forecasts. An example of potential savings is found in a study conducted by Georgia Tech and the Hydrologic Research Center of La Jolla, California for the Folsom Reservoir in California. The U.S. Bureau of Reclamation operates the power generation facility in the Folsom Reservoir dam. The study analyzed the savings that would have been realized between 1981 and 1987 if the reservoir had been operated according to the Bureau's documented rules but with forecasts that included accuracy information. Annual savings for the production of energy by Folsom Dam were $2.72M. River-forecast services, for example, can be improved using advancements in river modeling, in climate predictions and in quantitative precipitation forecasts, to provide customers with information to balance hydroelectric power generation and water resource management. In addition to improvements in the hourly forecasts of river flow, the seasonal outlook is critical to water resource planning, balancing water demands, i.e., hydropower generation, water supply and habitat maintenance. NOAA has developed and deployed, on a limited basis, a new Advanced Hydrological Prediction System (AHPS) to provide short- to long-range predictions of water flowing into major reservoirs generating hydroelectric power. Now NOAA can provide river forecasts up to six months ahead for major reservoirs, and can provide information describing the reliability of those forecasts, enabling hydropower reservoir operators to optimize their short-term power production and their long-term energy planning. This service is currently implemented and proven in portions of the upper Mississippi and Ohio Rivers, and is expanding over the next several years.

Another important area is space weather. NOAA is planning to improve the forecasts of geomagnetic storms to refine the accuracy and timing of these events reducing false alarms and the disruption of normal operations. The goal is to cut from 24 to 16 hours the forecast window of onset of geomagnetic storms; providing localized warnings of the effects of geomagnetic storms; and improving the forecasts of storms' intensities and durations to minimize unnecessary load shedding from the electric grid and to avoid trip-outs and equipment damage, all of which contributes to unscheduled brownouts and blackouts.

NOAA is also developing reliable atmospheric constituent forecasts, which provide options for the operation of power generating facilities in a manner that optimizes efficiency while minimizing the production of air quality degrading ozone, particulates and other trace gases. For example, atmospheric constituent forecasts and atmospheric transport information is critical when operating plants in attainment and non-attainment regions. A plant situated within an attainment region may adversely impact energy production operations in an adjacent, downwind non-attainment region due to the transport of pollutants into the non-attainment region. Power plants operate within the state air quality implementation plan. To avoid exceeding the standards, the plants, at times, have to alter their power generation fuels, fuel mixtures, or facilities. It can cost as much as a quarter of a million dollars to switch from coal to natural gas plant, in addition to the higher fuel costs associated with natural gas. Accurate and timely atmospheric constituent forecasts can provide information for advance decision-making. NOAA is planning to rapidly prototype an atmospheric constituent forecast system to demonstrate the utility of this information in adaptively managing conventional fossil fuel powered electrical generation facilities. These products will be applicable to both day-to-day operations and long term planning of both the industry and the States.

Severe weather is also an issue. NOAA hopes to demonstrate reductions in the uncertainty in load capacity of power-line transmission by increasing the accuracy of temperature and wind information. Under-forecast high temperatures and light winds, which increase power-line resistance, result in significant lost power over long distances, which contribute to unscheduled brownouts and blackouts in critical markets. Greater accuracy in the track and intensity of severe storms, such as hurricanes is also critical to better plan for the quantity and location of assets required for post-storm repair of utility infrastructure damage.

Summary

NOAA is responding to the needs of the energy industry through the implementation of a research program designed to rapidly improve services. In particular, the agency recognizes the potential economic benefits of improving daily and seasonal temperature and precipitation forecasts, air quality forecasts, and geomagnetic storm forecasts. To demonstrate this, the agency is embarking on a cooperative research program with industry partners to quantify the value of improved services in limited geographical regions, which will help to develop a public-private strategy for service improvements nationwide.

Government Development of National Climate Products and Services

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1. Energy-related applications of climate

Observations and Data Products Requirements

Climate and weather data and products have been requested by energy-related businesses and industry for use in planning, design and operations. It can be argued that the nation's economic competitiveness is dependent on reliable climate information expected over the lifetime of infrastructure needed to fuel the economy e.g., commercial buildings, residences, power plants, transmission lines, etc. The effective operation of many systems requires historical and real-time information about weather and climate with a high degree of accuracy and reliability. For example, the American Society of Civil Engineers and the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) use historical weather and climate data to develop standards that affect the design of energy producing and consuming systems. These data are calculated retrospectively, but used prospectively over the expected lifetime of the systems. Recently, the American Society of Civil Engineers working with the American Homebuilding Association and NOAA's National Climatic Data Center (NCDC) were responsible for the development of a new home building standard related to the depth and insulation needed to protect buildings from frost damage and loss of heat. The American Homebuilding Association estimates that the newly developed standards have saved $330M annually in energy costs or 586,000 MW hours of energy per year.

Other examples of data requirements relate to the Weather Risk Industry. Contracts between Power Companies and Re-Insurance Companies hedge against unexpected climate and weather. Climate data and products are used both to develop and settle contracts for the efficient distribution of risk, with some estimates suggesting $12 billion of annual contracts. Industry leaders have stated that recent climate variations and extremes and more demanding customer requirements, render much of the climate information they now receive inadequate to support the rapid changes associated with today's national and global business environments. When uncertainty about the data and information cannot be quantified or are unreliable, investors are unwilling to provide the capital necessary to guard against the risk of unusual weather or climate. It has also been clearly expressed by some in the industry that when data sets are not provided in a timely manner, contracts are not settled, and the industry does not operate efficiently.

During the past five years the energy industry has petitioned NOAA to develop more appropriate heating and cooling degree day normals. Climate Normals at the NCDC have traditionally been calculated retrospectively every ten years based on the previous 30-year period of record, e.g., 1951-80, 1961-90, 1971-2000, but are often applied prospectively. Many in the energy sector use Normals to prospectively determine multi-year as well as seasonal energy requirements and operating conditions. Engineers and business decision planners have made it quite clear that the present method of providing climate normals is inadequate to support the Nation's economic competitiveness and financial decision making needs. The American Engineering Society and the American Society of Heating, Refrigeration, and Air Conditioning for Engineers (ASHRAE) have indicated that changes in climate are to the point where the typical 30-year Normals can no longer adequately support the planning horizons for national standards. The industry has asked that normals be available on a variety of time scales, generated dynamically, rapidly accessible, and updated on a regular basis using the most current data.

Reliable data, where it is needed, when it is needed, is another essential component of managing long-term risk. The energy sector has identified significant shortcomings in understanding past trends and climate change over the U.S. and surrounding regions. These shortcomings include inadequate documentation of operations and changes over the life of the network, insufficient overlapping observations when new instruments are installed, and not using well-maintained, calibrated high-quality instruments. This increases the level of uncertainty for government and business decision-makers who are formulating both short term plans and longer range strategic policies and plans.

Seasonal and Interannual Energy-related Climate Outlooks

If we could routinely provide seasonal and longer climate outlooks with 100% reliability without error there would be little need for the use of past weather and climate data. We are no where close to this ideal today and, given the chaotic nature of climate, this will never be completely achieved. Nonetheless, even with the reliability of present day outlook products many users have been able to take advantage of the skill in the present-day climate outlooks. This has been especially noteworthy during the recent El Nino event. The current products produced by NOAA's Climate Prediction Center (CPC) include:

- Heating and cooling degree day weekly tables of observed degree days, departures from normal & last year (anomalies), accumulated seasonal totals, and accumulated departures - for over 360 cities, and population weighted by state, region and nation. These are available for the last calendar week by early Monday at CPC's web site.
- A heating and cooling degree days weekly forecast table. This is for the same parameters as above, based on an 8-day maximum- minimum temperature product, but only for population weighted states, regions and nation. This is available for the current calendar week by late Monday at CPC's web site.
- Heating and cooling degree day monthly (latest calendar month) table of the same parameters as above. This is available by the 3rd of the following month at CPC's web site.
- Weekly and season-to-date observed and weekly projected degree day tables and graphics for 102 U.S. climate regions (aggregated climate divisions). This includes departures from normal (anomalies). Available for previous calendar week by early Monday at CPC web site.

- A family of Excessive Heat Index Outlook products for days 3-7, 6-10, and 8-14. Included are graphics with the Maximum Heat Index and Probabilities of: 3 days $85EF, 2 days $90EF and 1day $95EF for each of the three forecast ranges.

The CPC also produces a number of experimental climate outlooks which includes:

- A probability of Exceedance Experimental (mean) Temperature Forecast graphic for each 3-month season out to one year based on 102 climate regions. The graphic shows contours of normal seasonal temperature and contours of the shift in the center of the probability distribution from climatology in the form of a temperature anomaly for the season.
- Probability of Exceedance Mean Temperature Outlook curves for each 3-month season for each

of the 102 climate regions. Includes normal, observed, forecast, and error envelope curves permitting selection of any threshold probability value or range of values for a selected temperature.

- Probability of Exceedance Heating Degree Day Outlook curves for each 3-month and one 5-month season (Nov-Mar) for the same 102 climate regions and same parameters as for temperature above.
- Climate outlook tables for temperature and degree days for 65 of the largest metropolitan areas in the U.S. These are down-scaled from seasonal outlooks interpolated to102 U.S. Climate Regions. Tables give the forecast and climatological mean, and the exceedance threshold values for given probability levels (98, 95, 90, 80, 70, 60, 50, 40, 30, 20, 10, 5, and 2 percentile levels). The forecasts are for specific airport observation sites, because risk managers primarily "hedge" and verify against official airport temperature data.

2. Near-term advances anticipated in climate science and services

New Observations and Data Products

NOAA will overhaul the current traditional methods and procedures used to compute Normals. It will deliver the means to generate a variety of Next-generation Climate Normals, such as heating and cooling degree days, freezing degree days, and other related statistics deemed important to the energy community. The normals will be calculated on a variety of time scales, i.e., hourly, daily, weekly, monthly, seasonally, annually, yearly, one or more decades, etc. This work is expected to produce products over the next two years to enable users to generate heating and cooling degree day and other normals on demand for any reference period with appropriate data corrections. Experimental products are already developed for temperature, but more algorithms will be developed to allow for users to dynamically create tailored Normals via a Web interface. NOAA expects to provide the capability to readily combine probabilistic information with climate model scenarios of future climate for use with on-demand Next-generation normals. The outcome will provide more appropriate statistics for planning purposes.

Computed normals will be based on station data with the fewest time-dependent biases possible These biases arise due to station moves, instrument changes, observation practices, or exposure changes. The normals will be based on serially complete (no missing data) data so that the normals accurately reflect the average climatic conditions for any given period of record.

Indices can be used to help explain energy usages. For example, NCDC is also generating a Energy Demand Temperature Index on a routine basis. This index has been related to residential energy usage and is found to be very well correlated to energy demand in this sector. The Energy Demand Temperature Index is based on a population weighted national temperature. The population weights are based on the 2000 census and the Index can be used to assess national residential energy demand based on unusual weather. The Index uses both heating and cooling degree days based on a 65EF base.

NOAA expects to modernize its Cooperative (COOP) Observer Network and implement its new Climate Reference Network (CRN) over the next several years. NOAA is anticipating the installation of new temperature and precipitation sensors at all of its cooperative observing sites, which now totals approximately 8000 stations. The COOP network provides daily temperature and precipitation data at a density that enables resolution of the effects of local climate variability. It has the longest history of any observing network in the USA and is the backbone of all studies of temperature and precipitation variability. Although the sensors do an excellent job in capturing significant weather and climate anomalies, they were never intended to deliver real-time data, nor data with sufficient accuracy to confidently resolve long-term climate trends without substantial adjustment to the data. So, to complement this critical high density network the CRN will be a long-term observing network that will serve as the Nation's Benchmark Climate Reference Network. High quality data from CRN sites will be used to provide the best possible information about short and long-term changes in surface air temperature and precipitation, including means and extremes. Fully implemented, the network will consist of approximately 250 geographic locations (500 paired instrument suites, a primary site and a backup site) strategically selected to capture the representative climate regimes across the Nation. Coupling the CRN data with the high density COOP data and other networks will enable the energy-related business and industry to get access to highly resolved data free of time-dependent biases that have confounded many analyses of climate variability and change. The CRN data will also be used in real-time operational climate monitoring activities, research related to climate changes, input into weather forecasts, and for placing current climate anomalies into a historical perspective. These data will be transmitted hourly and accessible on-line via the Worldwide Web (WWW). Present plans call for all CRN stations to be located outside of urban areas which can be affected by local heat islands, thereby confounding the cause of changes in the climate record, but it is possible to place some additional CRN stations in major metropolitan areas to measure changes where people use energy.

Seasonal and Interannual Energy-related Climate Outlooks

NOAA's CPC has plans for improvements in existing products and the development of new products. This includes:

- Improved skill in seasonal outlooks by improved physically based climate models. (Long term goal at 5-10 years)
- Expansion of the NCDC Energy Demand Temperature Index to include an outlook through the coming winter (for the contiguous U.S., based on population weighted degree days). (Short term goal - Winter 2001-02 or 2002-03)
- Grid cell seasonal outlooks for every 3-month period out to one year. (~2003)
- Graphical displays of the tables in the experimental forecasts that provide the forecast and climatological mean, and the threshold values exceeding given probability levels (98, 95, 90, 80, 70, 60, 50, 40, 30, 20, 10, 5, and 2 percentile levels). (2002)
- Extreme Wind-Chill family of products for days 3-7, 6-10, and 8-14 based on an 8-day forecast product. (Available experimentally during Winter 2001-02.)
- Use of composites and non-normal distributions to expand the Probability of Exceeding Thresholds concept to the probabilities of conditions "off the mean" and probabilities of extreme events, e.g., cold waves. (2002-03)

Each of the operational, experimental, and planned products have been developed in response to requests from the energy community. All will be directly useful by some segment of that community, and many will have additional indirect benefits. For example, temperature and precipitation seasonal outlook probabilities for grid cells produced in a standard format are useful for verification, for comparison with other operational and experimental outlooks, and for other sectors such a water resources and hydrology for improving river and stream flow and reservoir levels. More accurate hydrological outlooks would benefit the energy community. For example, where trade- offs between water resource use for hydro-power, irrigation, and the fishing industry are necessary, e.g., the Pacific Northwest. Present plans call for increasing emphasis on probabilistic outlooks for weather and climate extremes. Increased skill in the prediction of the frequency, duration and intensity of cold outbreaks during winter, would greatly increase the value of winter outlooks to the energy community. NOAA plans to emphasize outlooks with complete probability distributions since this permits user flexibility in selecting relevant thresholds or ranges for either the probabilities or variables of interest.

Present and Future Capabilities of Private Providers of Weather and Climate Information Products and Services – Presentation Summary

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INTRODUCTION

This presentation will provide a brief summary of current and potential future applications of weather and climate information to energy – related markets. Because of time constraints, the discussion will be largely focused on potential future applications in various power and natural gas markets. However, it is well known that weather and climate can have significant effects on all energy markets, and those effects will perhaps be addressed elsewhere in this workshop.

The current generation of weather and climate information services includes operational information and forecasting information services and a variety of consulting services. Commercial information services include a variety of data, graphic, analysis, and image products with value-added features, including operational quality management. Commercial operational forecasting services in the U.S. are generally based on observational data collected and distributed by the US National Weather Service. Private forecasters also make use of the analysis and forecast products from the NWS in preparing their forecasts. With the NWS products as a baseline, the private weather and climate services offer a variety or specialized analysis and forecast services tuned in various ways to their market requirements. These commercial forecasts may be based on processing of grid point data from the NWS numerical model outputs, or on the results of numerical models that are operated commercially. These commercial models may be either dynamical numerical models, statistical models, and/or algorithmically computed consensus outputs from the results of expert forecasters.

Current consulting services include interpretations and adjustments of historical observations, assessments of different possible weather and climate scenarios, forensic and litigation services, and many other analyses of weather and climate information directed to the particular operational requirements of commercial customers.

Future services of private corporations serving energy customers will focus largely on greatly improved weather forecasting services, as well as on a much tighter integration of weather and climate information into the operations of customer organizations. The current generation of services provides too high a percentage of the information in the language of the meteorologist and/or climatologist and not enough information directly showing the impacts of weather and climate phenomena on business operations, financial and operational risk management, and other areas critical to the customers.

POTENTIAL FUTURE DEVELOPMENTS

Advances in information technology and numerical modeling

Weather and climate forecasting services can be improved in a variety of ways. First, the continuing significant improvements in information technology offer the potential for private organizations to run greatly enhanced dynamical and statistical numerical weather and climate prediction models without having to wait for NWS model outputs. These developments have already occurred on a small scale, but this trend is likely to accelerate. While the NWS has computing facilities that have generally been beyond the reach of commercial companies, the NWS has many requirements to serve an extremely broad range of users. Conversely, a commercial organization can focus on specifically defined markets and need not run the full range of forecast models needed by the NWS.

For example, a commercial organization can use the developing clustering capabilities of high-performance PC-based systems to attain supercomputer performance on specialized models. Such capabilities offer the possibilities for competitive differentiation of their services whereas these companies were previously forced to rely on the NWS model runs. The continuing deregulation in the electric power industry and the advent of location – based marginal power pricing provide increased incentive for specific weather forecast focused on operating region of interest to power traders and risk management. The economic value of the trading and hedging in power contracts appears to justify the investments in the production capabilities for specialized weather and climate forecasting based on the information technology platforms.

Improved measures of forecast performance

Furthermore, measure of forecasting skill and historical track records of forecasting organizations must be adapted to their requirements to the power natural gas industries to a more specific level than they are today. Rather than on relying on traditional skills scores expressed in weather and climate terms, the customers need decision-oriented measures. These include, for example, forecasting skill in specific power load and natural gas demand geographical regions. Another useful measure is the forecast skill scores in operationally relevant weather regimes (e.g. quantitative measures of forecasting accuracy concerning periods of very hot weather) or for unusual weather conditions that have market relevance (e.g., hurricanes in the Gulf of Mexico can affect some of the futures prices for natural gas.) Forecasts about forecasts are also useful (e.g., a forecast of when the NWS 6-10 day forecast will change levels in certain regions also has market relevance).

Extreme Event Simulations for Risk Management Strategy Evaluation

Additional types of services that can be provided include the results of sophisticated modeling and simulation systems. For example, modern risk management programs rely on extensive "stress – testing". For financial investment risk management, this stress testing can involve the use of models based on extreme market events. The analogous stress testing of portfolios of energy-related contracts can involve the use of models of extreme weather events. Realistic models of extreme weather conditions that could occur even though the simulated observations may be beyond the historical ranges (e.g., record temperatures) can be used as inputs into hypothetical trading/hedging strategies and portfolios positions. This type of simulation technique can be used to develop quantitative estimates of potential financial risks in alternate trading strategies. These simulation outputs are not intended to be specific forecasts, but rather, they describe the boundaries of what could occur in executing a trading or hedging strategy. These weather and/or simulations are artificial, although physically realizable, and they can provide a more thorough test of risk management strategies than would be possible through the direct use of historical information. Combined with new developments in "extreme value theory" private weather and climate organizations can provide significant value to traders and risk managers by showing the potential effects of record weather and climate events on their management strategies.

Design of Weather- and Climate-Linked Securities

Private weather and climate information service providers will also be increasingly involved in the design and development of weather – linked financial securities. The current forms of weather derivatives are largely based on accumulated heating or cooling degrees days during a defined period of time. While appropriate for some types of risk management, these degree-day weather derivatives can be inadequate for large-scale risk management because of the lack of affordable scalability and/or because the accumulation of degree-days is not a good match the types of weather sensitivity of a corporation. For example, extreme events may cause greater risk than a sustained period of somewhat above normal temperatures, even though that sustained period may produce more cooling degree-days. Furthermore, because contract pricing is often based on sometimes inadequate models (e.g. Black-Scholes lognormal models of price variations or statistical calculations such as the historical standard deviations of observed data), these contracts are sometimes perceived as too expensive for the amount of risk protection provided.

Newer approaches to designing weather and climate-linked securities will be focused more directly on the risk profiles of particular customers. This focus will have the advantage of developing risk instruments that more relevant to the needs of particular customers. However, they can be so specialized that there is little chance of developing a market with the liquidity to attract large-scale trading. Balancing the needs of individual customers with the market needs for large-scale liquidity will have to be resolved before these weather-linked securities are traded like other forms of financial instruments.

A newly developing class of weather- and climate-linked securities combines multiple triggers (e.g., based on both temperature and precipitation events) in order to reduce risk premiums. The valuation and pricing of these securities requires significant expertise in weather and climate modeling and analysis in order to determine the joint probabilities of multiple trigger events.

CONCLUDING REMARKS

In summary, the future developments of private weather and climate information services will be far more computationally intensive than they are today. Furthermore, they will be much more tightly integrated with the weather sensitivities of the risk management strategies of their customers.

The developments that will help to enable these advances include the rapid increases in the cost-performance ratios of new information technologies. Combined with steady improvements in our understanding of the relevant scientific phenomena and the mathematics of risk modeling and analysis, there are many areas in which we can expect new services to develop.

ADVANCES IN WEATHER/CLIMATE RESEARCH AND SERVICES: ROLE OF UNIVERSITY RESEARCH

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This presentation will summarize and illustrate the applied research contributions that U.S. "Research Universities" potentially can make to increase understanding of the linkages between weather/climate variability and energy demand, availability, and price. Little research on this issue has been performed by atmospheric scientists or other specialists. The potential contributions would draw on the global uniqueness of U.S. Research Universities, which involves the combination of a strong tradition of fundamental research in individual disciplines (including atmospheric science) with the close proximity of specialists in many other relevant disciplines. The presentation will also stress that the envisaged research will require general guidance and specific data and information from various components of the energy sector (private and public). Without this involvement of the energy sector, much of the potential for U.S. Research Universities to identify key linkages between weather/climate and energy will not be realized.

The building of knowledge, for its own sake, has long been a major responsibility of faculty in the U.S. Universities that accordingly became known as Research Universities. Much of the research has been financed by entities outside of the Universities, particularly federal government agencies. In the case of the fundamental atmospheric science research that now has potential relevance to the applied issue of the relations between weather/climate and energy, this funding has come from a wide range of federal agencies -- in fact, much more support has come from NSF and NOAA than DoE, while some of the work financed by seemingly irrelevant agencies (e.g., USEPA, NASA) may also be relevant. This fundamental research, which has spanned a plethora of topics, has produced an accumulation of products and tools that can now be applied to assess the atmosphere's role for energy demand, availability, and price. Those products and tools include:

Data sets that contain important historical information on weather and climate variability that affected past energy demand, availability, and price. At one extreme, those data sets document the day-to-day variability during the last 50 years of surface maximum and minimum temperatures and precipitation across large regions (e.g., from individual states to all of North America east of the Rocky Mountains and south of 55°N) with fine spatial resolutions (e.g., 15-65 miles). At the other extreme, there are data sets that provide comprehensive information on the structure and behavior of the entire global atmosphere for the same 50-year period. Together, these data sets offer strong potential for establishing relationships between atmospheric behavior and surface climate patterns that affect energy demand, availability, and price.

Considerable insight into and practical familiarity with the ***advanced statistical techniques*** must be employed to establish the above relationships. Such statistical research will identify the principal patterns of atmospheric behavior that produce surface weather and climate extremes that have the greatest impact on energy demand, availability, and price. Most importantly, this analysis of past climate variability will provide part of the foundation for predicting climate-energy relationships for future seasons, years, and decades.

The great ***computer modeling capabilities*** that have been developed over recent decades provides the other part of the foundation for the above predictive work. This predictive modeling capability now extends from the broad-scale atmospheric flow across the entire globe at one extreme, down to highly detailed treatments of atmospheric process and conditions over and at the surface of much smaller regions (e.g., southern Great Plains). Most importantly, considerable emphasis now is being placed on using the global-scale models to feed (or drive) the regional-scale models.

To reiterate, the above data sets, statistical methods, and computer models produced in Universities by several decades of curiosity-driven basic atmospheric science research are now available to be applied to the key societal issue of the importance of weather/climate variability for energy demand, availability, and price. Part of the atmospheric science research needed to establish those linkages was mentioned above…but only part. For the work to provide the needed results, there also must be the contribution of general guidance and specific data and information from the energy sector (both public and private), along with the involvement of other specialists with expertise in disciplines that deal with additional factors that impact energy demand, availability, and price (e.g., finance and economics, human behavior, public policy, and international relations).

Concerning the need for input from the energy sector, an immediate priority is the development of comprehensive data sets for energy demand, availability, and price that cover as many years as possible. Potential contributors include not only private companies engaged in energy generation, trading, and distribution, but also national and perhaps international agencies that have planning, coordinating, and regulatory roles. The availability of these energy data sets will permit their combined statistical analysis with weather/climate data. Only through such analyses will it be possible to establish the needed relationships between weather/climate conditions and energy demand, availability, and price. The lack of such energy data will greatly (probably fatally) curtail that work. It is also imperative that the research using the combined data sets involves collaboration between atmospheric scientists and other specialists with understanding of the non-atmospheric factors that influence energy demand, availability, and price. The needed specialists should have insight into finance and economics, human behavior, public policy, and international relations.

Only in U.S. Research Universities does this "other" expertise exist side-by-side with major atmospheric science research programs. The challenge is to form long-term partnerships between these different specialists to define and pursue the research agenda for the relations between weather/climate and energy. Those partnerships must feature strongly another unique attribute of Research Universities…energetic and highly capable graduate students…whose Thesis/Dissertation research simultaneously would provide them with broad preparation for careers in the energy industry. Because interdisciplinary research has fewer theoretical guidelines/signposts and often requires more flexible thinking than traditional inquiry within a single discipline, strong recruitment and careful selection of graduate students will be essential.