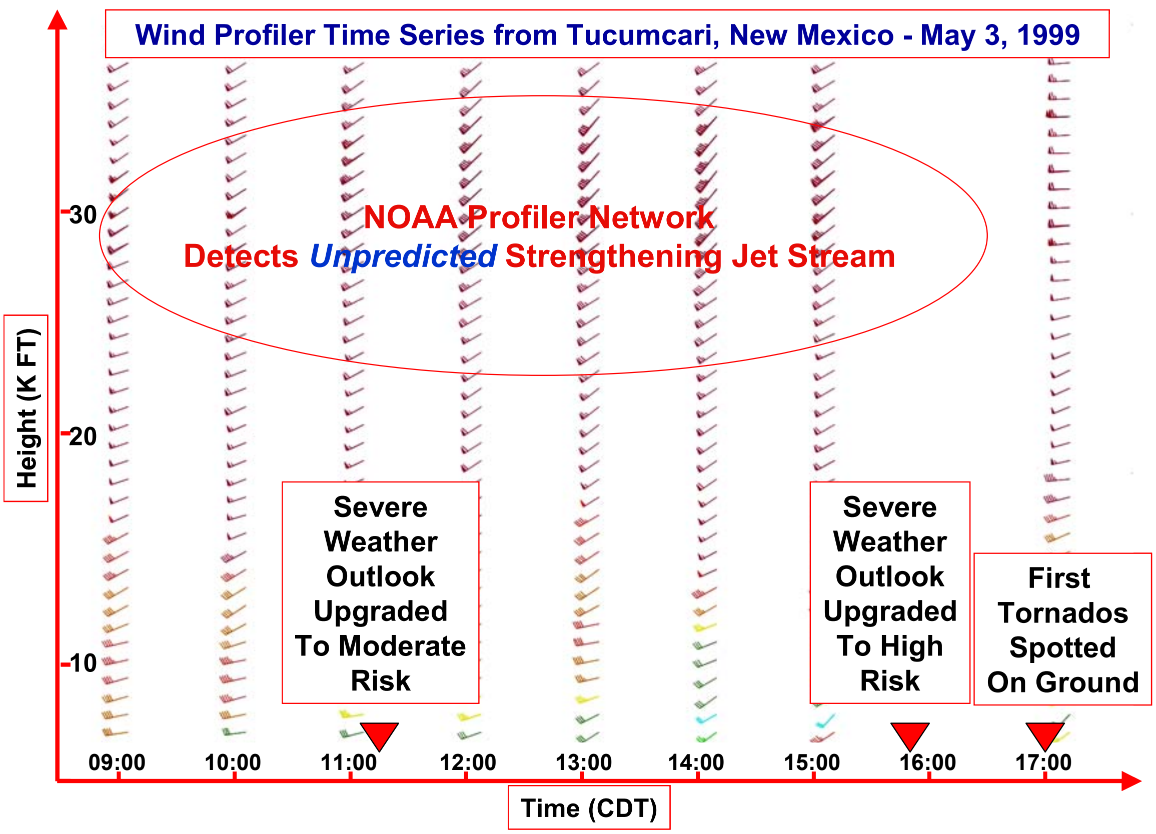
Response to the Senate Appropriations Committee

Cost and Operational Effectiveness Analysis for the NOAA Profiler Network



U.S. Department of Commerce
Donald L. Evans, Secretary

National Oceanic and Atmospheric Administration
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Undersecretary of Commerce for Oceans and Atmosphere and NOAA Administrator

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Cover: Time-height graph of atmospheric winds from the NOAA Profiler Network (NPN) station at Tucumcari, New Mexico, on May 3, 1999 showing the jet stream strengthening from 60 mph to 110 mph in just five hours from 10:00 Central Daylight Time (CDT) to 15:00 CDT. Early detection of this jet stream by the NPN allowed the National Weather Service's Storm Prediction Center to upgrade the threat of tornados from "slight" to "high" giving the public advanced notice to this dangerous situation. Over 70 tornados were observed in Oklahoma and Kansas from this single event.

Time axis is from 09:00 CDT to 17:00 CDT. Height axis is from ground level to 40,000 feet. Wind speeds and directions are indicated by wind barb symbols. (Courtesy of the NOAA Office of Oceanic and Atmospheric Research, Forecast Systems Laboratory)

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May 2004

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1.0 Executive Summary

> **Updating the existing NOAA Profiler Network (NPN) is the most cost-effective alternative.**
>
> - **Recent studies show NPN winds improve severe weather warnings and forecasts adding minutes to warning lead time for tornadoes and flash floods.**
> - **Modifying the existing network delivers the best over-all wind profiling performance.**
> - **Terminating NPN costs degrades severe weather warnings, watches capability, and short-range weather prediction.**
> - **Radiosonde performance could be made similar to NPN performance, but the cost would be prohibitive.**

1.1 Overview. This Cost and Operational Effective Analysis (COEA) is provided in response to a request by the Senate Appropriations Committee to compare the "… cost to upgrade the NOAA Profiler Network (NPN) over the next decade versus the short, medium, and long-term costs of ending the NPN program" (see Annex H for full text). The analysis answers two questions: 1) Are the NPN winds beneficial to NOAA National Weather Service (NWS) operational products and services; and 2) Is the NPN, including the cost to upgrade the network, the most cost-effective strategy for NWS operations?

A wind profiler is a vertically pointing Doppler radar which measures winds at various altitudes in the atmosphere above it every few minutes. The NPN consists of thirty-five wind profilers located mostly in the central U.S. and Alaska (see Fig. 1.1-1), each providing wind measurements also known as "wind profiles" containing 64 measurements through 16 kilometers above ground every six minutes.

When the NPN radar transmitters were installed in 1988, the NPN was authorized to use the 404 mega hertz (MHz) by the National Telecommunications and Information Administration (NTIA) for experimental use. Subsequently, NTIA has given usage of the 404 MHz frequency to a future series of search and rescue satellites (SARSAT) and granted the NPN permanent use of 449 MHz To comply with NTIA frequency regulations, NOAA must change its thirty 404 MHz wind profilers to 449 MHz by the end of the decade when the new SARSATs are expected to become operational.

The NPN is primarily deployed over the central U.S. and Alaska.

Figure 1.1-1 NOAA Profiler Network Station Locations

1.2 Analysis. Recent studies in 2003-4 document that high-temporal-frequency NPN wind profiles significantly improve performance in several NWS operational product and service areas for stations within the NPN:

- *Warnings:* NPN winds improve probability of detection (+27%), decrease false alarm rate (-20%), and improve lead time (+14%) for tornado warnings, as well as severe thunderstorms, flash floods, and winter storms (Wolf 2004). They also improve warnings related to aviation and fire weather.
- *Watches and Outlooks:* NPN winds improve watch and outlook accuracy for severe weather by 13% (Weiss 2002).
- *Numerical Weather Prediction:* NPN winds improve 0-12 hour wind forecasts with a 20% improvement at 3 hour forecast (Benjamin et al 2004).

Given these demonstrated weather warning and forecast benefits, an analysis was done to *determine the best strategy for acquiring wind-profile information in terms of performance and cost*. In other words, is the NPN, including the cost to upgrade the operating frequency of the network, the most cost-effective way to obtain these important wind profiles? To answer this question, a performance and cost analysis of the NPN and a range of alternatives for providing wind profile information was completed.

NPN saves lives by providing reliable early warning.

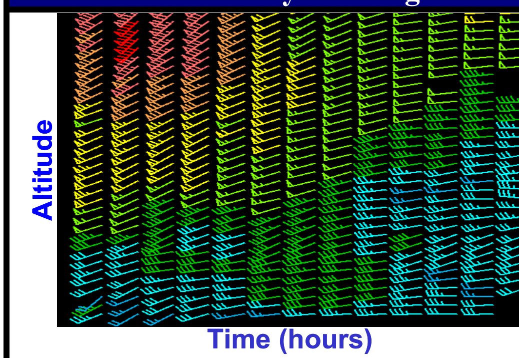

Figure 1.1-2 High Frequency Winds

1.3 Alternatives Considered. As shown in Figure 1.2-1, the analysis considered the two alternatives directed by the Senate Appropriations Committee: Changing the NPN operating frequency and maintaining the current network (Alternative 1) and terminating the NPN network (Alternative 2). The study also considered replacing the network with either existing or new technologies potentially capable of providing the necessary amount, timeliness, and accuracy of wind profile data. The additional alternative technologies considered were: Existing (Alternative 3a) and additional (Alternative 3b) use of radiosondes (weather balloons), automated aircraft reporting (Meteorological Data Collection and Reporting System (MDCRS)) (Alternative 4), WSR-88D Doppler radar (Alternative 5) , and object tracking by Geostationary Operational Environmental Satellite (GOES) (Alternative 6).

Alternative 1	**Change operating frequency of current NPN system**	**Sec. 4.1**
Alternative 2	**Terminate NPN without replacement**	**Sec. 4.2**
Alternative 3a	**Replace NPN system with existing radiosondes**	**Sec. 4.3**
Alternative 3b	**Replace NPN system with additional radiosondes**	**Sec. 4.3**
Alternative 4	**Replace NPN system with MDCRS aircraft observations**	**Sec. 4.4**
Alternative 5	**Replace NPN system with WSR-88D Doppler radar**	**Sec. 4.5**
Alternative 6	**Replace NPN system with GOES object trackers**	**Sec. 4.6**

Figure 1.2-1 Alternatives Evaluated

1.4 Methodology. Six independent attributes were used to judge wind-profiling system performance : 1) frequency of observation, 2) geographic coverage, 3) vertical reach, 4) horizontal spacing, 5) number of vertical levels, and 6) measurement accuracy. The relative value of each of these attributes was determined through a questionnaire submitted to a panel of weather professionals from academia, private industry, and NOAA (see Annex A). A single performance number was generated for each evaluated system. The annualized cost for development, production and deployment, and operations and maintenance for each alternative was determined. The ratio of performance to total cost was calculated to provide a measure of effectiveness.

1.5 Results. The results of this COEA demonstrate that high-frequency winds benefit several important NWS missions: severe weather warnings (for tornadoes, flash floods, and winter storms), watches, and short-term forecasts. These products are important for public safety, aviation, and wildfire support. A cost-effectiveness analysis shows that sustaining the NPN, including upgrading the frequency, is the most cost-efficient method of obtaining high-frequency wind profiles. Figure 1.5-1 depicts the cost and performance of each alternative. The NPN (Alternative 1) provides the best overall wind profile performance since no alternative provides equal or higher performance at lower cost. The only feasible way to approach NPN performance with an alternative system is by significantly increasing the frequency of radiosonde balloon launches from once every 12 hours (Alternative 3a) to hourly (Alternative 3b), but the cost is fourteen times greater. The remaining alternatives, winds from commercial aircraft (MDCRS) (Alternative 4), volume-averaged winds from WSR-88D Doppler weather radar (Alternative 5), and GOES object (e.g., clouds) tracking (Alternative 6) cost less but have much lower performance.

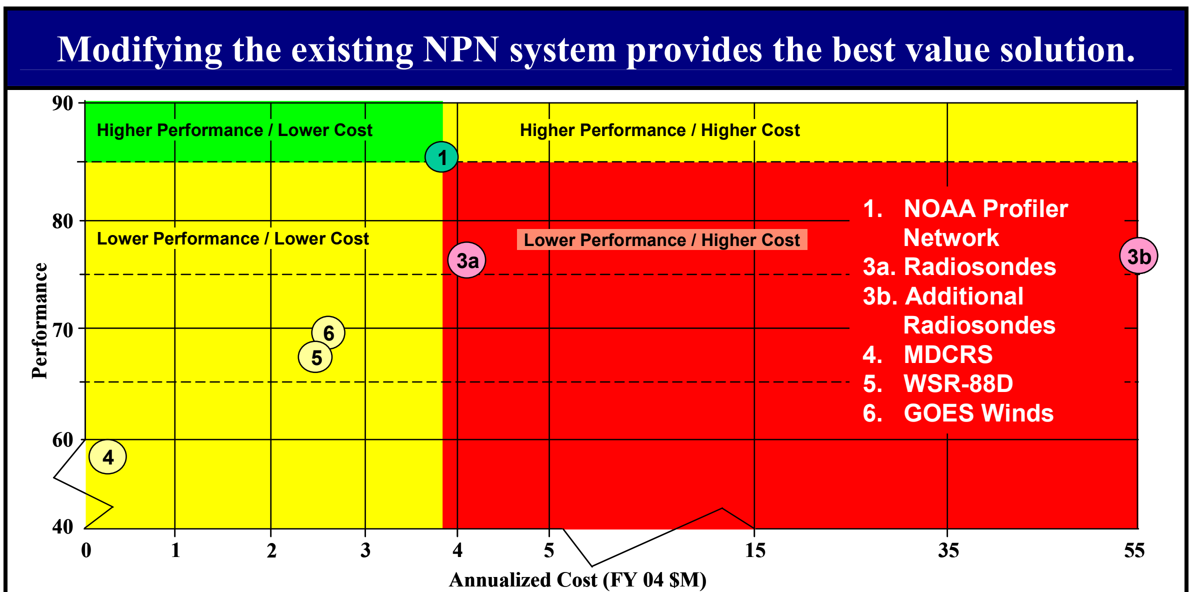

Figure 1.5-1 Results of Cost/Performance Analysis

2.0 Introduction to the NPN.

The NPN uses three radar beams to measure winds.

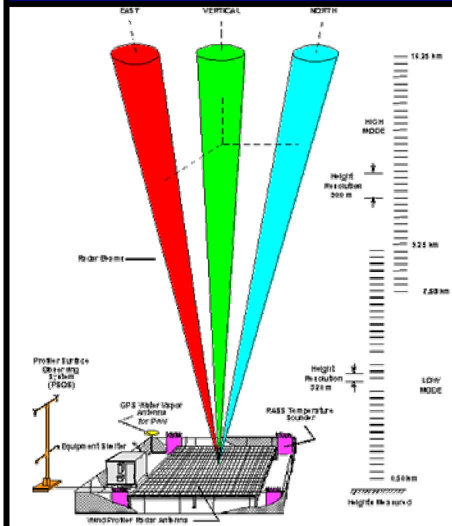

Figure 2.0-1 NPN Radar Beam Geometry

The NPN consists of thirty-five wind profilers (30 operating at 404 MHz and 5 operating at 449 MHz) located mostly in the central U.S. (Fig. 1.1-1). The major components of the system, illustrated in (Fig. 2.0-1), occupy about one-quarter acre. Each site has power, landline, and voice communications, environmental control, and capacity to add additional meteorological sensors.

2.1 NPN System Components

A wind profiler is a vertically pointing Doppler radar that measures atmospheric winds directly above the site. A profiler consists of four components: a transmitter, an antenna, a receiver, and a data processor (Fig. 2.1-1). The transmitter sends out pulses of electromagnetic energy at a certain frequency (404 MHz in the case of the NPN) in three directions: east, north, and vertical. When the signal encounters small amounts of turbulence in the clear air, energy is returned to the antenna where it is detected by the receiver. The data processor measures the time it takes for the signal to return, and computes the range or height of the turbulent layer. If the turbulent parcel of air is moving, then the frequency of the returned signal is increased or decreased (the Doppler effect) in proportion to the velocity and direction of the air relative to the radar. The signals measured in the three beams are processed into the horizontal wind speed and direction at each altitude.

The NPN major system components

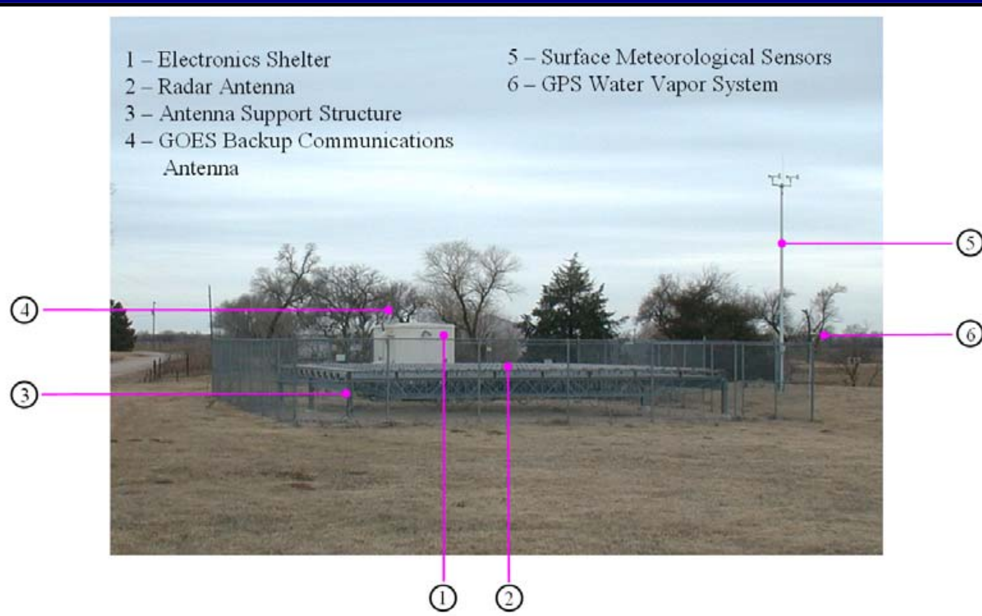

Figure 2.1-1 NOAA Profiler Network System Components

2.2 Rationale for NPN Frequency Change.

By the end of 2008, the NPN must be upgraded to operate at a different frequency because of interference with signals from new search and rescue (SAR) satellites, which will begin operating before the end of the decade. Currently, two polar-orbiting satellites are equipped with SAR receivers to detect distress signals from downed aircraft, lost hikers, floundering boats, etc. The SAR beacons operate at the same 404 MHz frequency as does the NPN. Consequently, the NPN wind profiling radars must turn off whenever a satellite with SAR capabilities (SARSAT) is overhead to avoid potential interference. However, as shown in Figure 2.2-1, this only occurs about 90 minutes per day, or 6% of the time the radars operate.

Current NPN profiler raw data transmissions

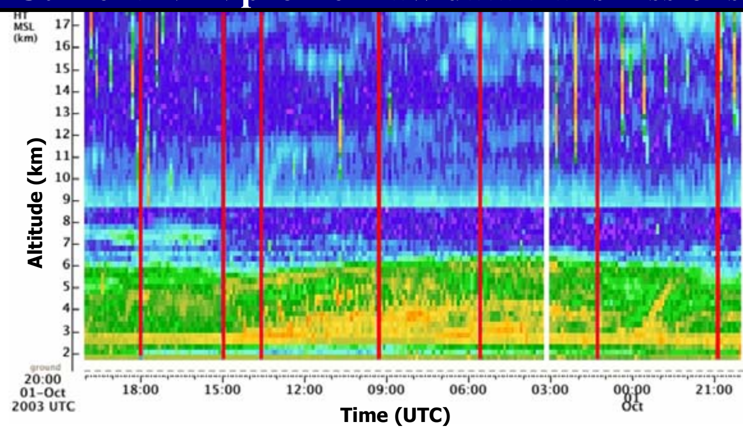

Figure 2.2-1. Raw data from NPN profiler. Vertical red bars show when a SARSAT satellite is overhead and transmitter turns off (less than 6% of the time).

The European Space Agency will begin launching a constellation of satellites called *Galileo* in 2005. Intended for Global Positioning System (GPS) applications, these satellites will also have a SAR capability that operates at 404 MHz frequency. These SARSATS will be in the sky for hours instead of minutes at a time, and there will be about 10 satellites in view simultaneously by late FY07 or early FY08 as opposed to only one or two as is the case today. Under these conditions, NPN profilers operating will have to shut down more than 23:30 hours per day, as illustrated in Figure 2.2-2, rendering the network virtually useless. The solution is to change the operating frequency to the non-interfering 449 MHz, a protected, assigned frequency for wind profilers.

Galileo era NPN profiler raw data transmissions

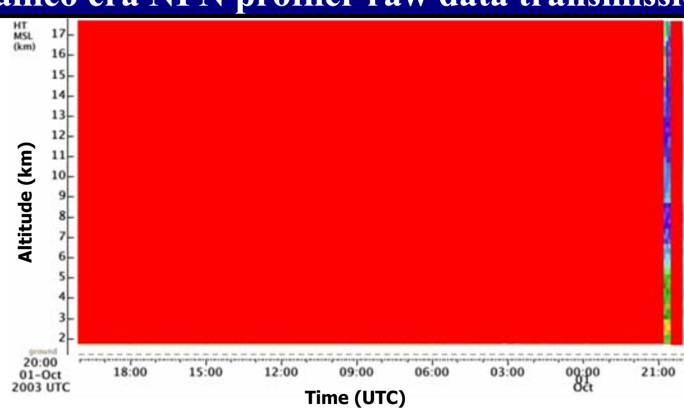

Figure 2.2-2 *Galileo* Satellite Era Profiler Shutdown Duration
Red = **System Shutdown**

3.0 Benefit of NPN Winds to NWS Operational Products and Services

Weather forecasters use wind profiles of the atmosphere for a variety of analytical forecasting tasks. In addition, wind profiles are used as input for numerical (computer) weather models that predict clouds, precipitation, and temperature. Wind profiles also provide important indicators of where severe weather such as tornadoes and winter storms may form, requiring weather advisories, watches, or warnings. Weather forecasters also use wind data for issuing aviation Significant Meteorological (SIGMET) advisories and to predict wildfires.

The traditional observing system used to obtain wind profiles is the balloon-based radiosonde network, which provides wind profiles every **12 hours** across the Nation at a spatial resolution of approximately one profile every 400 km. In contrast, wind profilers provide wind profiles every **six minutes** at a spatial resolution of approximately one profile every 250 km. The high temporal and spatial resolution wind profiles are found to improve NWS operational warning, watch and outlook, and numerical forecast products.

3.1 Warnings – A recently completed study (Wolf 2004) shows that the NPN wind profile information improves NWS operational warning performance statistics. Figure 3.1-1 from this study presents average tornado warning performance statistics for representative samples of NWS Weather Forecast Offices (WFOs) within and outside the NPN, as well as for all WFOs (national average) over the five years from 1999 through 2003. Comparison of the statistical elements listed (Probability of Detection, False Alarm Rate, Critical Success Index, and Lead Time) shows that WFOs within the NPN on average performed better for the four elements than those outside and the national average. A study by Wolf and Howerton (2003) using NPN wind data in NOAA's Warning Event Simulator indicates that these performance differences can be attributed to the improved forecaster "situational awareness." The time-critical NPN wind information helps forecasters more quickly detect environmental changes critical to the formation of tornadoes and other severe weather. **In summary, NPN wind data make forecasters more aware of changing weather situations enabling them to issue more accurate and longer lead-time warnings.**

Without NPN, tornado warning accuracy will be substantially degraded

	WFOs Within NPN*	WFO National Average	WFOs Outside NPN*
Probability of Detection	0.79	0.72	0.62
False Alarm Rate	0.68	0.74	0.85
Critical Success Index	0.29	0.24	0.14
Lead Time (Minutes)	12.9	11.5	9.5

Figure 3.1-1. Accuracy Performance Measures for Weather Forecast Offices, 1999 through 2003 (Wolf 2004).

* Selected Weather Forecast Offices in areas where tornadoes occur often

In addition to tornado warnings, NWS issues warnings for other high-impact weather with significant influence to the Nation's economy. For most of these warnings, studies indicate the NPN frequently provides information which improves these warnings. Examples are:

- Winter Storms: Forecasters use the NPN winds to identify surges of warm moisture air over cold fronts to anticipate formation of snow bands ahead of strengthening low pressure systems and better interpret numerical model-based winds and associated model-based winter storm forecasts. NPN winds showing a warm air surge helped forecasters in Wichita, Kansas, issue a winter storm warning six hours earlier than it would have without the NPN information.

- Aviation Weather Forecasts: Aviation Weather Center (AWC) forecasters use NPN winds to improve predictions of turbulence and wind-shear conditions. AWC forecasters used NPN winds to cancel a SIGMET warning for turbulence 90 minutes earlier than forecast, after the NPN showed decreasing winds and safe conditions in the warning area. This allowed air traffic controllers to use valuable airspace which would be otherwise closed. Because NPN winds help pilots avoid hazardous weather, the risk of crew and passenger injury in minimized. Using the NPN, forecasters identify and predict strong low level winds carrying moisture from the Gulf of Mexico into the Midwest. This results in better predictions of low clouds, low visibilities, and thunderstorms, which, in turn, reduces flight hazards and minimizes delays.

- Fire Weather Forecasts: Forecasting changes to surface wind speed and direction is essential in predicting fire and smoke plume behavior. NPN winds are used to help deploy and protect "hot-shot" fire-fighters from being over-run by wildfires driven by unpredicted winds. In Albuquerque, New Mexico, meteorologists used the NPN winds to detect a developing "mountain-gap" wind event allowing them to forecast increasing winds near the fire just as an urban wildfire was spreading. Because this wind event was well forecast, fire managers were prepared for the changing wind's impact on the fire and were able to safeguard homes in the area with no injuries to the fire fighters. NPN winds also help the U.S. Forest Service safely plan and execute prescribed burns helping to reduce fuels for future fires and safe-guard property and valuable timber. Scheduling burns so that the smoke plume does not drift over populated areas minimizes the impact to public health, especially to people sensitive to soot.

3.2 Watches – A 2002 study showed that the NPN is a critical source of information which materially improves forecasts of severe thunderstorms and specifically improves NWS Storm Prediction Center (SPC) watch and outlook products. The beneficial effect of NPN winds on SPC watches is illustrated in Figure 3.2-1 taken from a study by Weiss (2002). The figure shows that a 15 percent improvement in SPC watch accuracy occurred with the deployment of the NPN between 1988 and 1992. During this same time period no other new services and technology were fielded. The study concluded that the NPN winds are essential in monitoring rapidly changing conditions that characterize severe weather situations.

Storm Prediction Center (SPC) watch accuracy improvement

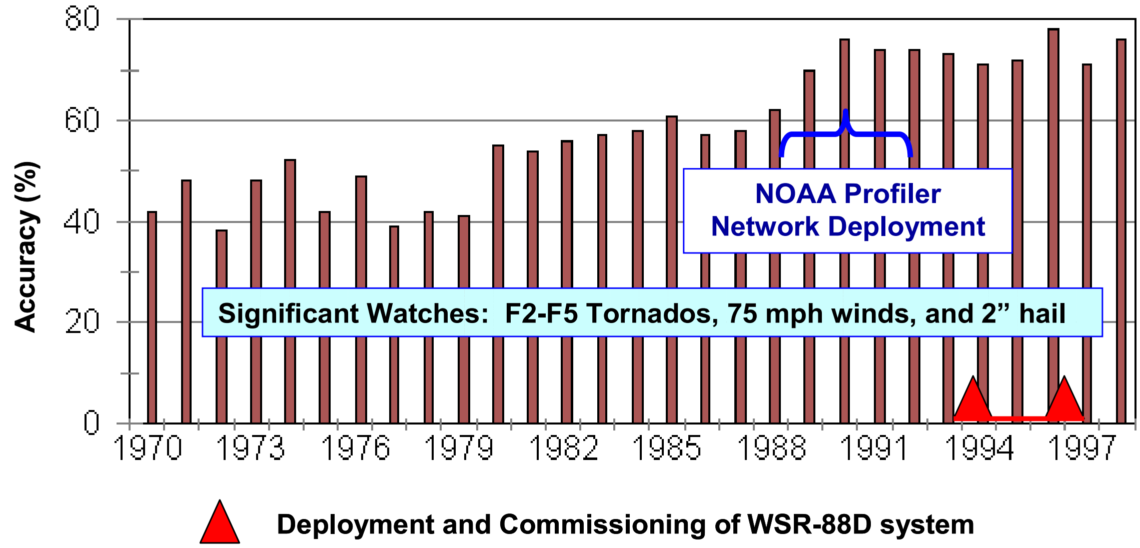

Figure 3.2-1 SPC Watch Accuracy Improvement Following NPN Deployment

3.3 Weather Model Forecasts – In a study entitled, “The Value of Wind Profiler Data in U.S. Weather Forecasting,” (Benjamin et al. 2004) assessed the impact of NPN wind data on numerical weather prediction. They determined the that addition of NPN wind profile data to the weather data base improved accuracy of three-hour wind forecasts by an average of 20% near 10,000 ft (see Fig. 3.3-1). Moreover, the study showed major impacts during inclement winter storms with the NPN winds reducing wind forecast errors by 6.0 to 8.0 meters per second in the extreme. Wind errors occasioned by addition of profiler data directly translate to a positive impact on the air travel industry in the form of decreased fuel consumption and weather delays (Clifford 2003 and Lindsey 1998).

Wind forecasts from computer guidance significantly improved by NPN winds.

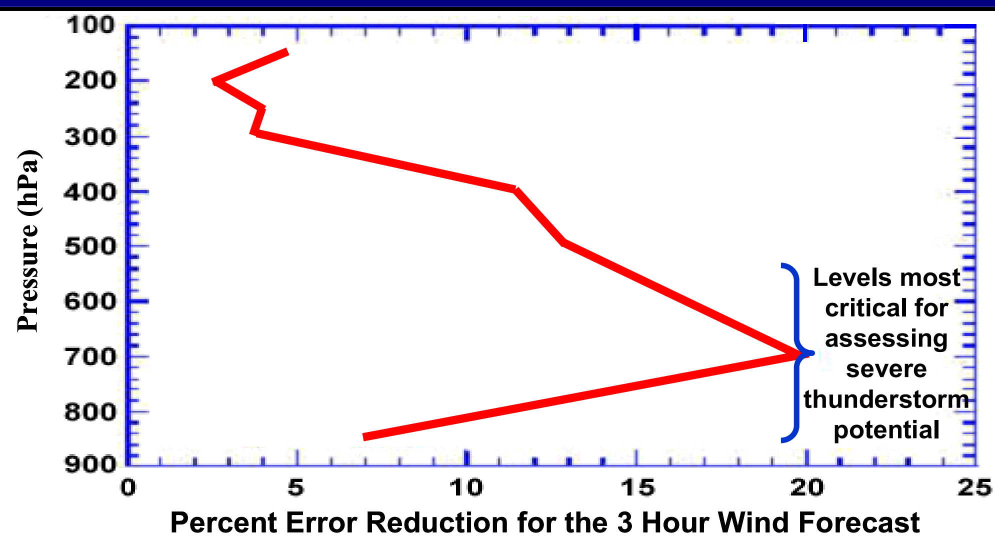

Figure 3.3-1 Percent increase in the error of three-hour wind forecasts when NPN data are not allowed to influence the model prediction. (Benjamin et al 2004)

In summary, access to NPN winds allowed forecasters to detect subtle environmental changes conducive to the formation of severe weather minutes to hours earlier then they would have otherwise. As a result, severe weather warnings, watches, and forecasts were disseminated to emergency managers and the public minutes to hours earlier, allowing the public and economic interests to take mitigating actions in advance of severe weather.

4.0 Analysis

Given these demonstrated weather warning and forecast benefits, the remainder of the *COEA focuses on determining the best strategy for meeting NWS requirements for wind-profile information in terms of performance and cost*. In other words, is the NPN, including the cost to upgrade the operating frequency of the network, the most cost-effective way to obtain these important wind profiles? To answer this question, a performance and cost analysis of the NPN and a range of alternatives for providing wind profile information was constructed.

4.1 Performance Model: Six independent attributes were used to judge wind-profiling system performance: 1) frequency of observation, 2) geographic coverage, 3) vertical reach, 4) horizontal spacing, 5) number of vertical levels, and 6) measurement accuracy. Frequency of observation is the number of profile reports per day. Geographic coverage is the size of the area covered by the alternate wind-profiling systems relative to the area covered by the current NPN (See Fig. 1.1-1). Vertical reach specifies the altitude range (measured in kilometers) of the observing system between the surface and 16-km altitude. Horizontal spacing (density) is measured by the number of observing locations within the area covered by the NPN. Vertical spacing is measured by the number of levels at which reports are available from the surface to 16-km altitude. Accuracy of the wind measurement is the measuring system root mean square wind error. For all these measures except the last, larger numbers represent improved performance.

The relative importance of these six wind-profiling system performance attributes was determined for four NWS operational product and service areas by surveying eleven weather professionals from academia, private industry, and NOAA (names and biographies in Annex A). The four product and service areas were: 1) warnings, 2) short-range forecasts, 3) watches, and 4) numerical weather prediction (NWP). These four areas were chosen because of their primary importance to the NWS mission – saving lives and property. Figure 4.1-1 shows the highest priority attributes as determined by the panel of weather professionals. The indicated split in priorities mandates that most effective wind observing system must be a strong performer in both update frequency and geographic coverage to meet the cross section of NWS missions.

The contribution of the six performance attributes to an overall performance score was modeled by assigning a weight to each of the four product and service areas according to their operational importance. These weights were: 40% for warnings – because warnings are most important for public safety, 30% for short-range forecasts, 20% for watches, and 10% for short-range NWP.

Finally, a single performance number (see Annex B) was generated for each evaluated system on a normalized scale from 0 to 100, with 100 being perfect. The annualized cost for development, production and deployment, and operations and maintenance for each alternative was also determined. The ratio of performance to total cost was calculated to measure effectiveness.

NWS Mission	Most Important Attribute
Short-Range Forecasts	Update Frequency
Warnings	Update Frequency
Watches	Geographic Coverage
Short-Range Numerical Weather Prediction	Geographic Coverage

Figure 4.1-1 Most Important Mission Performance Attribute

4.2 Performance Results.

Figure 4.2-1 provides the performance results averaged over all four NWS product and service areas. The NPN is the highest performer with a score of 85.2. Radiosondes score well relative to the NPN, but only twice per day soundings significantly affect their ability to support short-term forecast and warning missions. An increase in the frequency of launches to 24 times per day, does little to narrow the gap in performance scores between NPN and radiosondes because of NPN's 6-minute updates. The score for MDCRS suffers from the low density of airports within the central U.S. and infrequent soundings. WSR-88D radars are less effective than profilers or radiosondes because of too few vertical levels and lack of vertical reach in clear weather. GOES object tracking scores well mainly because it provides frequent and plentiful wind measurements, but GOES winds tend to appear in large horizontal clusters, not in vertical stacks, a handicap for measuring wind shear.

A modified NPN system delivers the best performance.

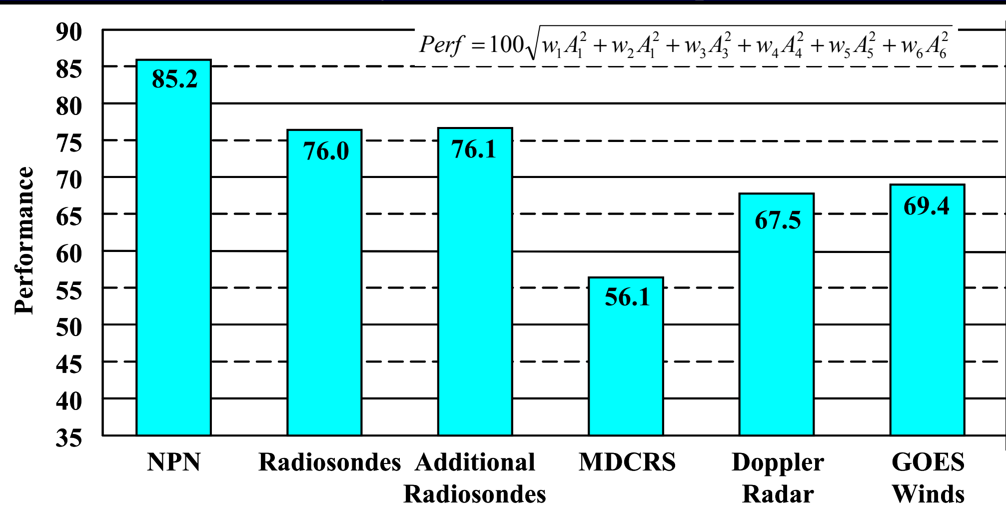

Figure 4.2-1 Comparative Performance of Wind Profiler Systems

4.3 The Cost Model.

The annualized total cost of each of the six alternative wind-profiling systems was calculated by averaging future development, acquisition, operations, and maintenance (see Annex E for calculation details). Of the six system costs shown in Figure 4.3-1, MDCRS is least costly and adding radiosondes is most costly.

Annualized costs include all lifecycle elements.

- **Development**
- **Production and Installation**
- **Operations and Maintenance**

Using additional radiosondes is the most expensive alternative.

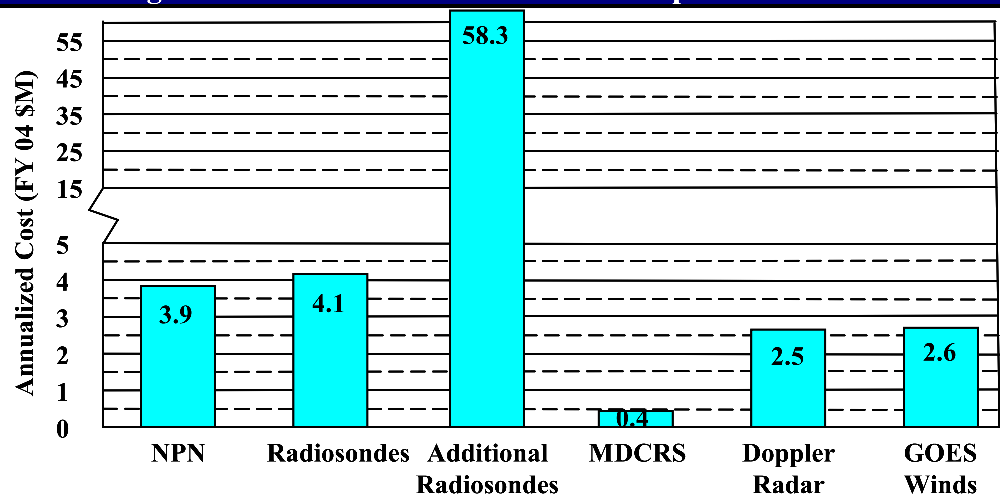

Figure 4.3-1 Cost of Alternatives for Obtaining Wind Profiles

4.4 Results of Analysis.

The result of this analysis is a plot of cost versus performance (Fig. 4.4-1), with quadrants defined using the NPN performance and cost as a center point. Any system that costs less and performs better than NPN falls in the green zone and is preferred. No system fits this category. Higher-cost, higher-performance and lower-cost, lower-performance alternatives lie in the yellow zones and are worth considering. Higher-cost, lower-performance options well inside the red zone should be avoided. The existing Radiosonde system (2) is about 11% lower in performance than NPN and approximately 8% more expensive. Adding enough radiosonde launches to attain hourly frequency of observation (3) does not significantly reduce the overall performance gap with the NPN, but increases annualized cost by more than 14 times. Though the annualized cost of alternatives (4), (5), and (6) is 30% to 90% lower than that for NPN profilers, the performance of these alternatives is between 21% and 41% percent worse, and none of them has even the potential to match the performance of NPN profilers.

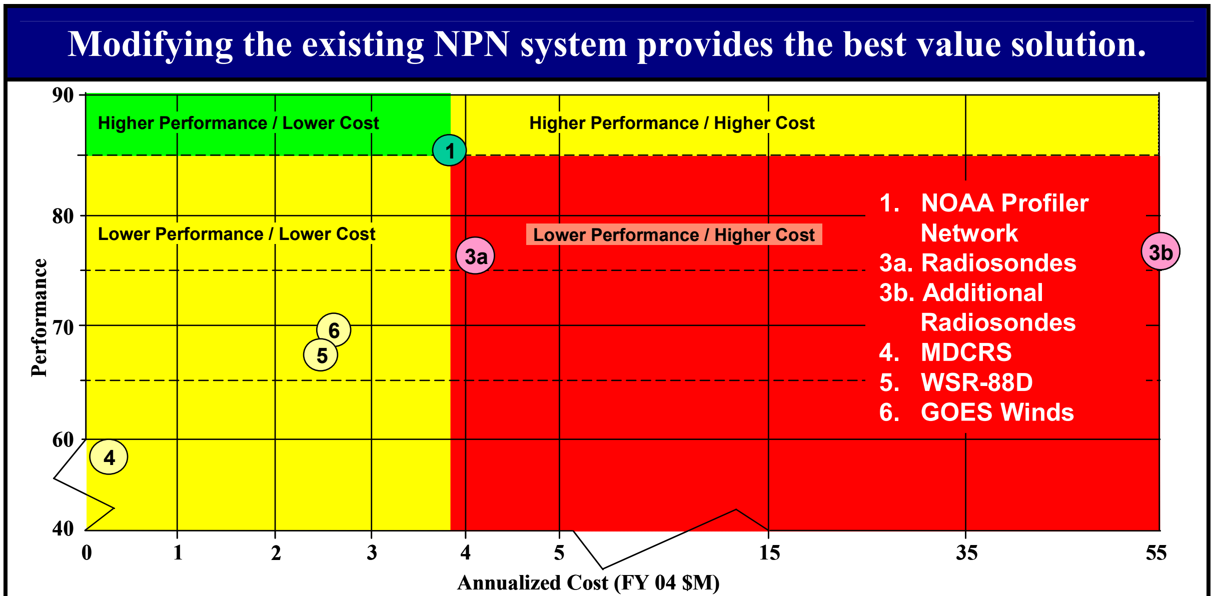

Figure 4.4-1 Results of Cost/Performance Analysis

5.0 Discussion of Options

5.1 Retain Current NPN; Change Operating Frequency.

This option will continue operation of all 35 NPN profilers. Continued operation of the NPN requires conversion of 30 of the 35 profilers from 404 MHz to the assigned and protected frequency of 449 MHz. The other five, located in Colorado, New York, and Alaska, already operate at 449 MHz. Figure 5.1-1 shows the major components that must be changed. To insure NPN data continuity, the conversion must be finished prior to completion of the *Galileo* satellite constellation. The first of these satellites is scheduled to be launched late in 2005; completion of the full constellation of 27 is scheduled to occur in 2008.

A refurbished NPN ensures that the NWS maintains its ability to issue earlier severe weather watches, make them more location- and time-specific, and reduce the false alarm rate of warnings. Moreover, continued availability of NPN data will sustain improvements in the accuracy of computerized weather forecasts and establish the foundation for resolving day-to-day forecasting problems in NWS offices.

The cost of this alternative is $13.2 Million to upgrade the 30 NPN operating sites, plus annual operations and maintenance costs of $3.2 Million (FY 04 $) for the network. Cost breakdowns for the frequency conversion, including its certification and coordination with other users of the frequency, any required environmental studies, and annual operations and maintenance are in Annex C. Over the next twenty years, the annualized cost of for the NPN is $3.9M (see calculation in Annex D).

Only modest modifications to NPN are required.

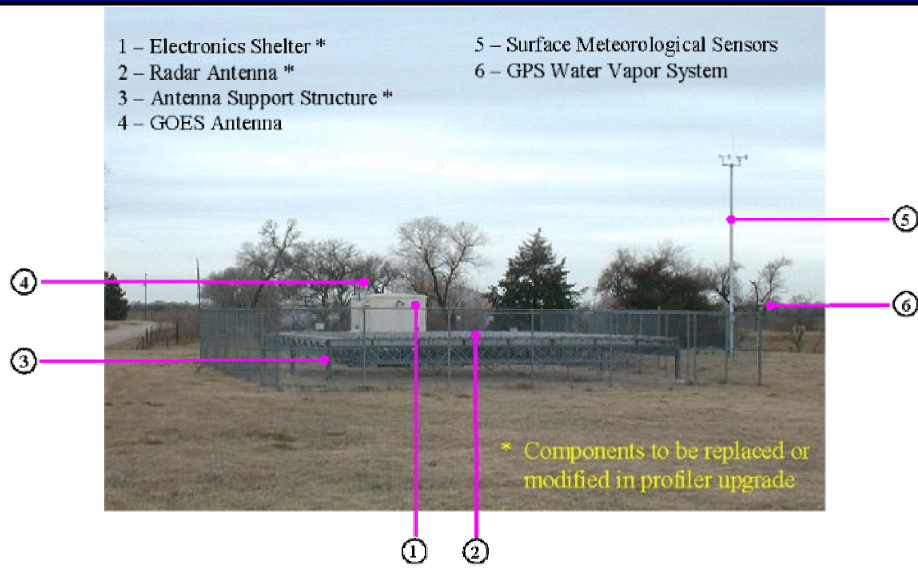

Figure 5.1-1 Major Components of a 404 MHz Wind Profiler, Highlighting Components That Must Be Modified or Replaced to Operate at 449 MHz

5.2 Terminate NPN Program.

This option takes the NPN out of service including sites like the one shown in Figure 5.2-1. Costs and impacts of this alternative include equipment disposal, site clean up, NPN Hub replacement, and impact on short-term forecasts, warnings, watches, and weather model guidance from loss of NPN wind observations and NPN complementary observations.

5.2.1 Cost of termination

This requires vacating the NPN sites, disassembling and disposing of equipment, and returning sites to their original condition. Two contractor estimates have been received for this work, one for $42,628 per site and the other for $27,918 per site. Another $10,000 per site would be needed for soil testing and removal if necessary. Taking an average of these estimates, the cost to clear, clean, and restore the sites and to manage the contract is $1.7M. The functions included in site shutdown are listed in Annex F.

Cost of equipment disposal and site remediation is $1.7M.

Figure 5.2-1 NPN Sites Are Generally Small and Will Require Limited Remediation

5.3 Replace NPN with Radiosonde Data.

The radiosonde (weather balloon) is the only observing system that provides a complete set of atmospheric measurements (wind, temperature, pressure, and moisture) from surface to mid-stratosphere (above 70,000 feet). Radiosondes have historically been the standard against which other observations are compared. They are also used to verify numerical weather prediction models. However, there are drawbacks to using radiosondes as a replacement for NPN.

The radiosonde's key limitation for warnings and short-term forecasts is its launch interval: once every 12 hours. By contrast, NPN radars deliver a vertical wind profile every six minutes, permitting forecasters to monitor rapidly changing weather conditions in detail. Launching radiosonde balloons (Fig. 5.3-1) even at hourly intervals is both costly and impractical. It would require a large increase in labor and a twelve-fold increase in the cost of expendable items that include the balloon, helium gas, and an instrument package. The incremental cost of hourly balloon launches at the 25 sites within the NPN boundaries would be $54.2M per year. This compares with the $4.5M annualized cost of operating the GPS Radiosonde system for two launches per day at the same 25 sites.

A second shortcoming of radiosondes is that accuracy of the wind measurement suffers whenever strong winds carry the balloon close to the horizon (a tracking problem). Accurate measurement of strong winds in the vicinity of the jet stream is important for diagnosing aircraft turbulence. This second problem may be solved through use of Global Positioning System (GPS) technology beginning in 2005.

Furthermore, additional radiosonde stations would be required to replicate the horizontal density of observations provided by NPN. Increasing the horizontal resolution of radiosonde sites would take years and millions of dollars for construction of new balloon shelters and installation of ground tracking stations.

Radiosondes provide high quality data twice daily.

Figure 5.3-1 Radiosonde Launch at WFO Tampa, Florida

5.4 Replace NPN with Data from the MDCRS

Automated observations from commercial aircraft are another important source of wind profiles. Through the MDCRS system, nearly 90,000 reports of wind and temperature are received each day, most of them from flight altitudes between 25,000 and 41,000 feet. This provides very good high-altitude coverage for about 60% of the country. Four passenger and two freight carriers participate in this program, with freight carriers providing the majority of nighttime data. Currently the government pays for only half of the communications costs and does not have to pay for the aircraft sensors, thus making this an inexpensive source of wind data.

MDCRS provides significant cruise altitude data; however, data at lower altitudes, collected during ascent and descent, are relatively sparse. Further, as seen in Figure 5.4-1, MDCRS provides non-uniform geographic and sparse coverage over the Northern Rockies and western Great Plains. Weather, schedules, and individual airline practices lead to variability in reporting. For example, large storms lead to numerous flight cancellations. Pilots carrying passengers generally try to avoid turbulence and foul weather, which means that fewer reports come from bad weather areas, where they are most needed.

Most MDCRS profiles contain data from only a few altitudes. Package carriers, the predominant source of nighttime data, do not fly on weekends. The costs associated with the current MDCRS system are low, annualized at $0.35M. However, this program relies partly on the good will of commercial carriers, and one cannot expect them to add flights at additional locations and times to generate the data that would be a viable alternative to NPN wind data.

Aircraft soundings leave significant gaps in the western Great Plains.

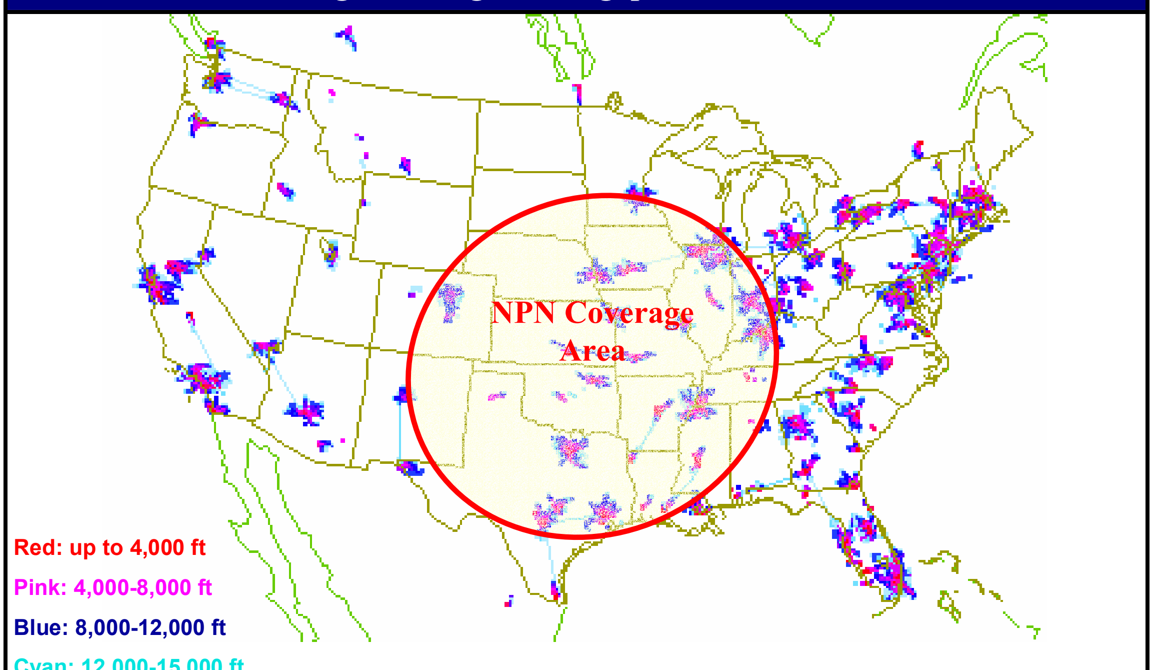

Figure 5.4-1 24 Hours of Aircraft Ascent and Descent Reports

5.5 Replace NPN with WSR-88D Doppler Weather Radar Data.

Doppler weather radars are unexcelled at providing highly detailed information on air motions inside of precipitating clouds under conditions ranging from light snowfall to severe thunderstorms. These systems provide data at five-minute intervals and scan the atmosphere at 14 elevation angles from 0.5^o to 19.5^o above the Earth's horizon. Doppler radars are an essential source of information for issuing severe weather warnings.

However, Doppler weather radars do not provide useful information about wind speed and direction unless a sufficient number of targets such as dust, large aerosols, large cloud droplets or ice crystals, insects, or precipitation are present in the air. In clear air, the strength of the radar return from altitudes above 10,000 feet is usually too small to be detected. It is also difficult to make wind measurements during the winter when insects are not present in large numbers. More importantly, data are not collected at elevation angles above 19.5^o or below 0.5^o. As shown in Figure 5.5-1, this means the radar cannot detect low-level air motion, no matter what the atmospheric conditions are, at distances greater than about 60 miles because of the curvature of the Earth. And, because of the 19.5^o maximum elevation, the radars cannot survey a large volume of atmosphere directly over the site. As a consequence, WSR-88D radars can only provide something approximating a traditional wind profile from the lower 10,000 feet in the atmosphere under most conditions.

Though the annualized cost of providing wind profiles from the existing Doppler radar network is only $2.5M, the physical limitations of the system do not permit it to replace the information lost if the NPN were to shut down.

WSR-88D radars point more horizontally than vertically.

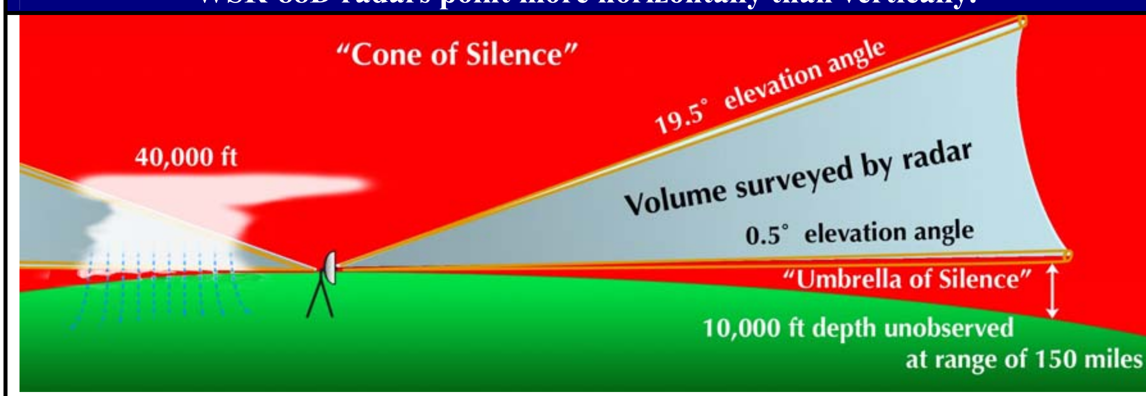

Figure 5.5-1 WSR-88D Radar – Red Area Includes Cone and Umbrella of Silence Where Radar Beam Cannot Detect Winds.

5.6 Replace NPN with GOES Object Tracking Data

As shown in Figure 5.6-1, it is possible to use successive images generated by GOES satellites to track targets and thus infer the speed and direction of the wind that moved the target. Object tracking requires the presence of an observable target (e.g., a cloud) that retains its identity between successive image frames, typically separated by 15 minutes. Because some clouds are anchored to the terrain (e.g., mountain-wave clouds), care must always be taken to select features that move with the wind. Winds estimated by tracking targets do not come in vertical stacks but rather in large horizontal clusters that are determined by the distribution of clouds. Clouds at different levels yield estimated winds at different levels, but seldom at the same geographic location.

Though the movement of a target can be accurately determined, the height of the target is estimated from a measurement of the cloud-top temperature. Since our knowledge of the relationship between atmospheric temperature and altitude is imprecise, the accuracy of the height of the target can only be approximated (rather than measured) and this degrades the accuracy of the inferred wind observation.

There are no additional sensors or instruments planned to be added to the GOES satellites that will improve the accuracy and amount of GOES winds; thus, there is no ability to generate the data that would be lost with the termination of NPN. The annualized cost of GOES object tracking is $2.6M.

Object tracking requires clouds or water vapor tracers;
altitude determination is coarse.

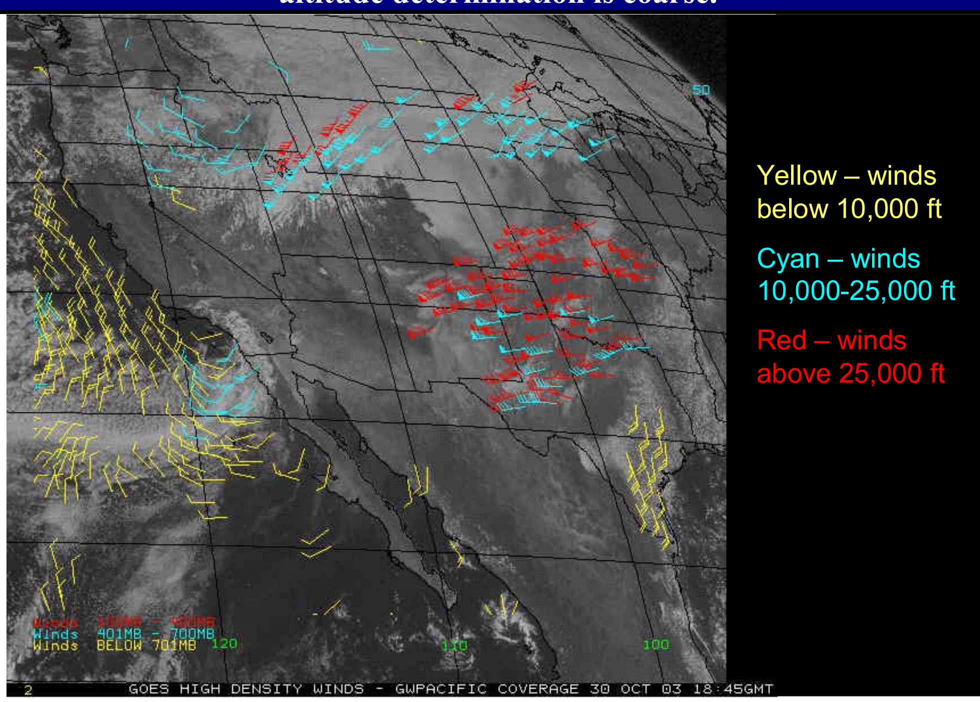

Figure 5.6-1. A Typical Selection of Winds Estimated from Target Tracking

5.7 Replace NPN with other Expanded Capabilities

This is not an option for several reasons. In the case of MDCRS, the number of ascent/descent soundings varies significantly according to time of day and day of the week, extensive bad weather causes flight cancellations, and the number and geographic distribution of airports is fixed. The vertical profiles of wind provided by Doppler radars are severely height limited unless there are thick clouds or precipitation. The operating wavelength of the radar is unsuitable for detecting clear-air winds much above 10,000 ft. The instrumentation aboard GOES satellites will not change for at least several years. The inability to see through clouds limits the number of levels at which winds can be derived. In a given small area, the wind can be determined at only a few levels at best. Our effectiveness model didn't fully characterize the negative impact to mission operations when, for a variety of reasons, the observation frequency of MDCRS, Doppler radar, or the GOES object tracker system becomes irregular. By contrast, NPN profilers consistently measure winds every six minutes, seven days a week.

6.0 Discussion and Conclusion

This Cost and Operational Effective Analysis (COEA) is provided in response to a request by the Senate Appropriations Committee to compare the "… cost to upgrade the NOAA Profiler Network (NPN) over the next decade versus the short, medium, and long-term costs of ending the NPN program."

Recent studies over the past year indicate there is benefit from the high-temporal-frequency wind profiles observed by the NPN to operational weather warning and forecast performance in NWS. Operational product and service areas benefiting from NPN wind profiles include:

- *Warnings:* NPN winds improve probability of detection, false alarm ratio, and lead time for warnings of tornadoes, severe thunderstorms, flash floods, and winter storms. They also improve warnings related to aviation and fire weather.

- *Watches and Outlooks:* NPN winds improve watch and outlook accuracy for severe weather.

- *Numerical Weather Prediction:* NPN winds improve 0-12 h wind forecasts.

Given these demonstrated weather warning and forecast benefits, this COEA focused on determining the best strategy for meeting NWS wind-profile information requirements in support of NOAA's forecast and warning mission in terms of performance and cost. The analysis considered the seven alternatives: 1) Changing the NPN operating frequency and maintaining the current network, 2) terminating the NPN network using 3a) existing and 3b) additional radiosondes, 4) automated aircraft reporting (MDCRS), 5) WSR-88D Doppler radar and 6) object tracking by GOES satellite.

The COEA results show that the best combination of performance and cost is to maintain the NPN system and modify its frequency so as not to interfere with reception by SARSAT satellites of signals from Search and Rescue beacons. While the other systems have individual attributes that may exceed the capability provided by NPN, there are significant physical or cost impediments that preclude their use in lieu of NPN.

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