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(54) **PROCESS FOR GENERATING SPATIALLY CONTINUOUS WIND PROFILES FROM WIND PROFILER MEASUREMENTS**

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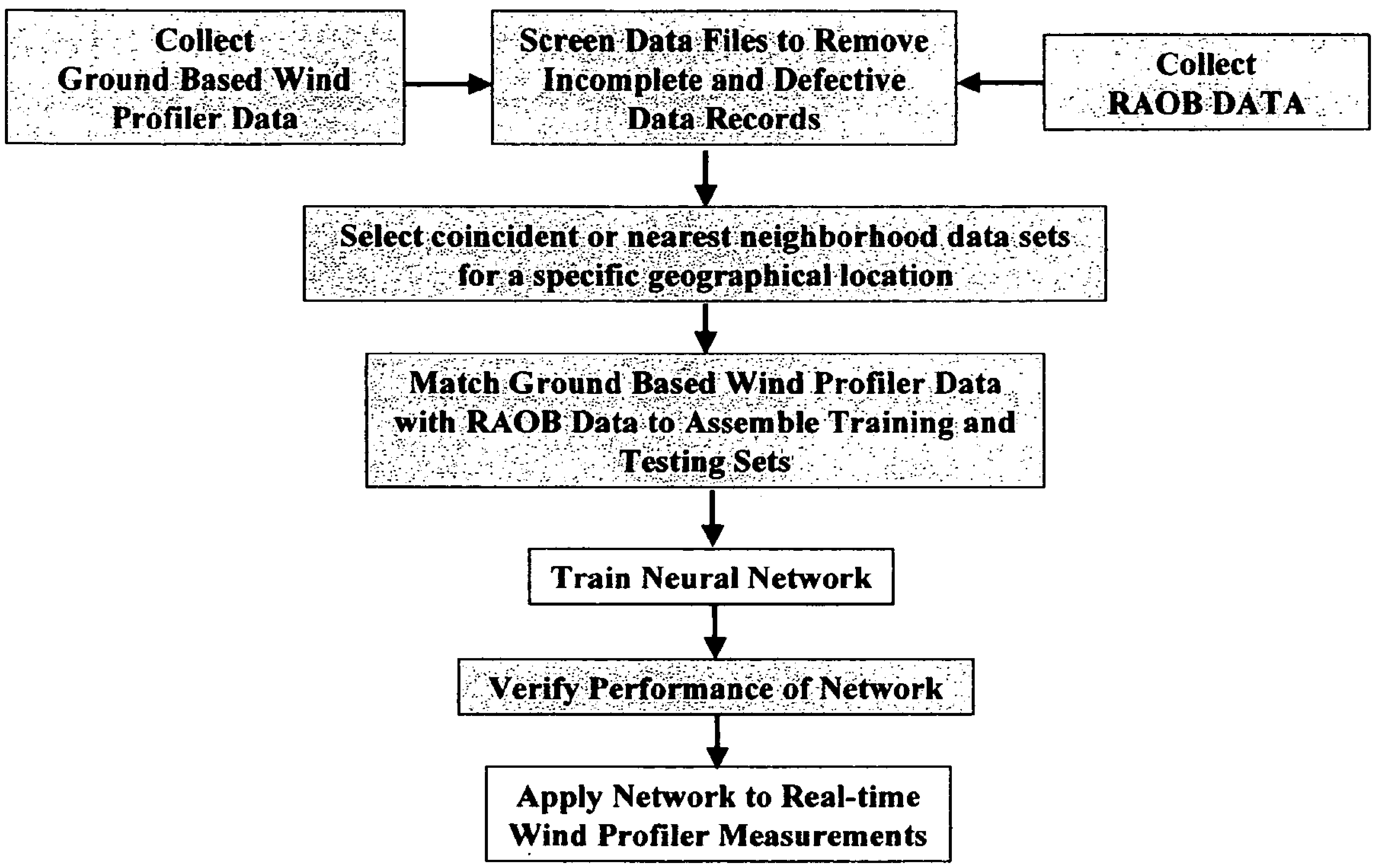
(52) **U.S. Cl.** .... **342/26 R**

(57) **ABSTRACT**

A neural network process for improving wind retrievals from wind profiler measurements is described. In this invention, a neural network is trained to retrieve missing or incomplete upper level winds from ground based wind profiler measurements. Radiosonde measurements in conjunction with wind profiler ground measurements for specific geographical locations are used as training sets for the neural network. The idea is to retrieve timely and spatially continuous upper level wind information from fragmented or incomplete wind profiler measurements.



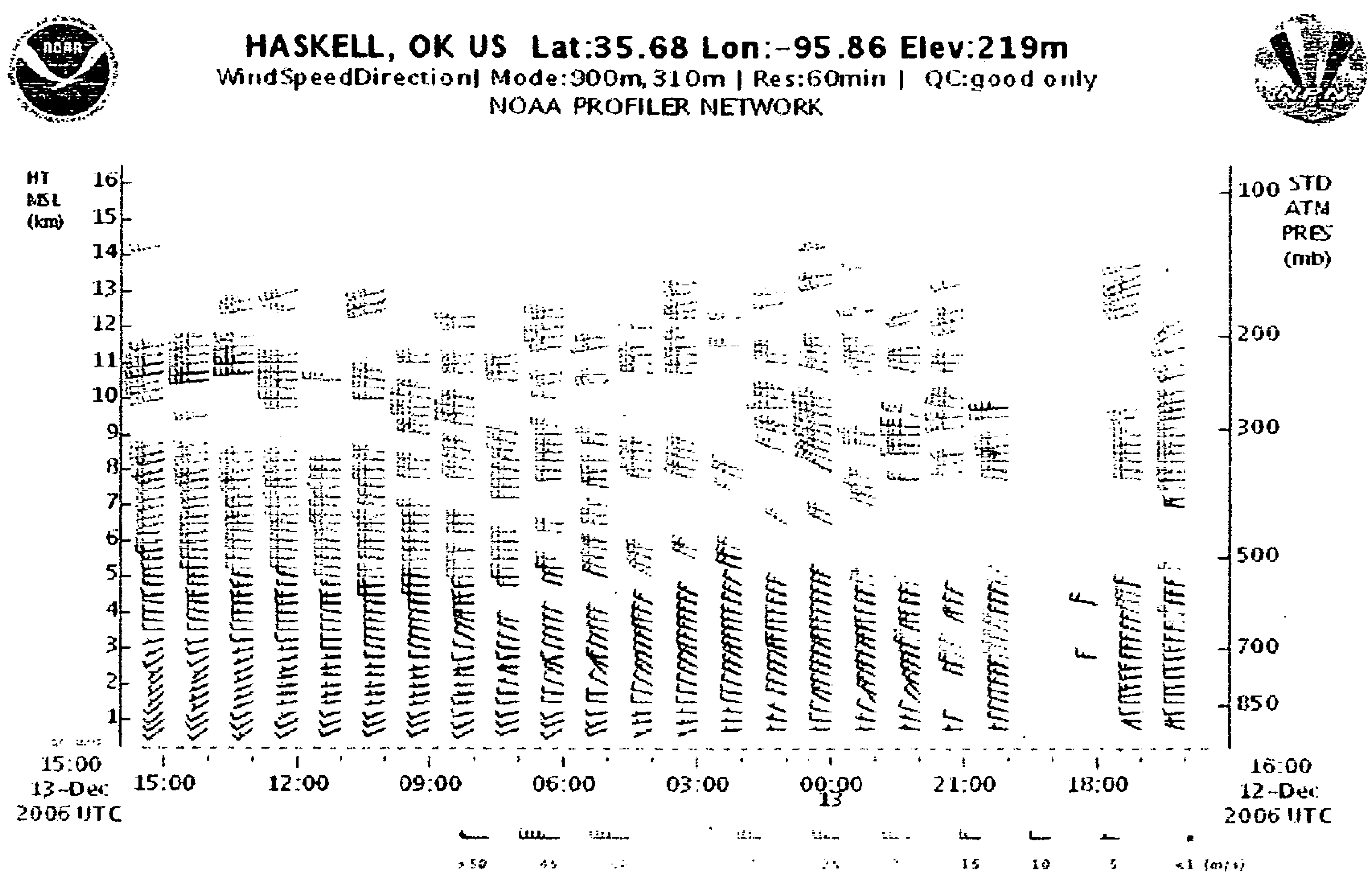
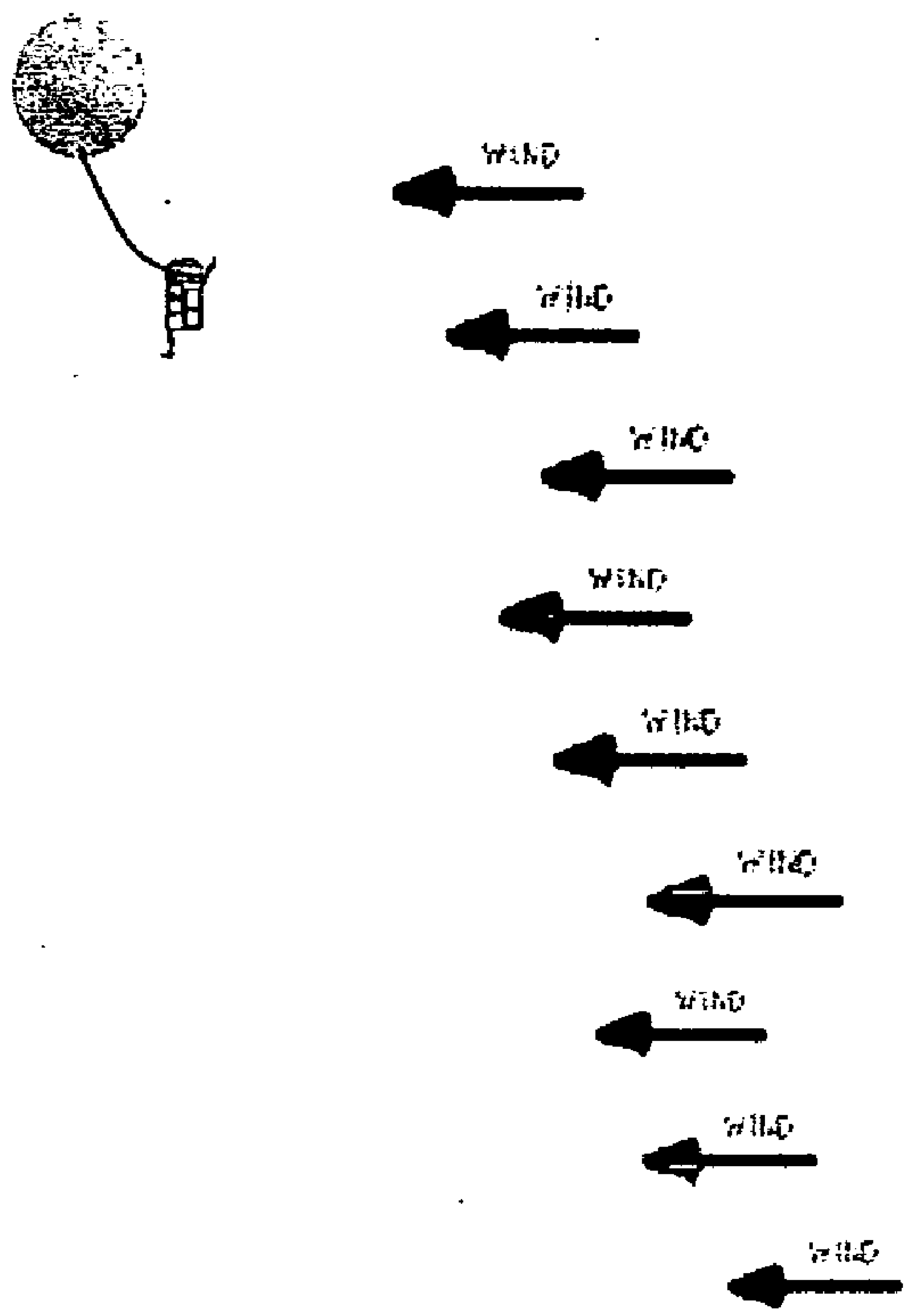
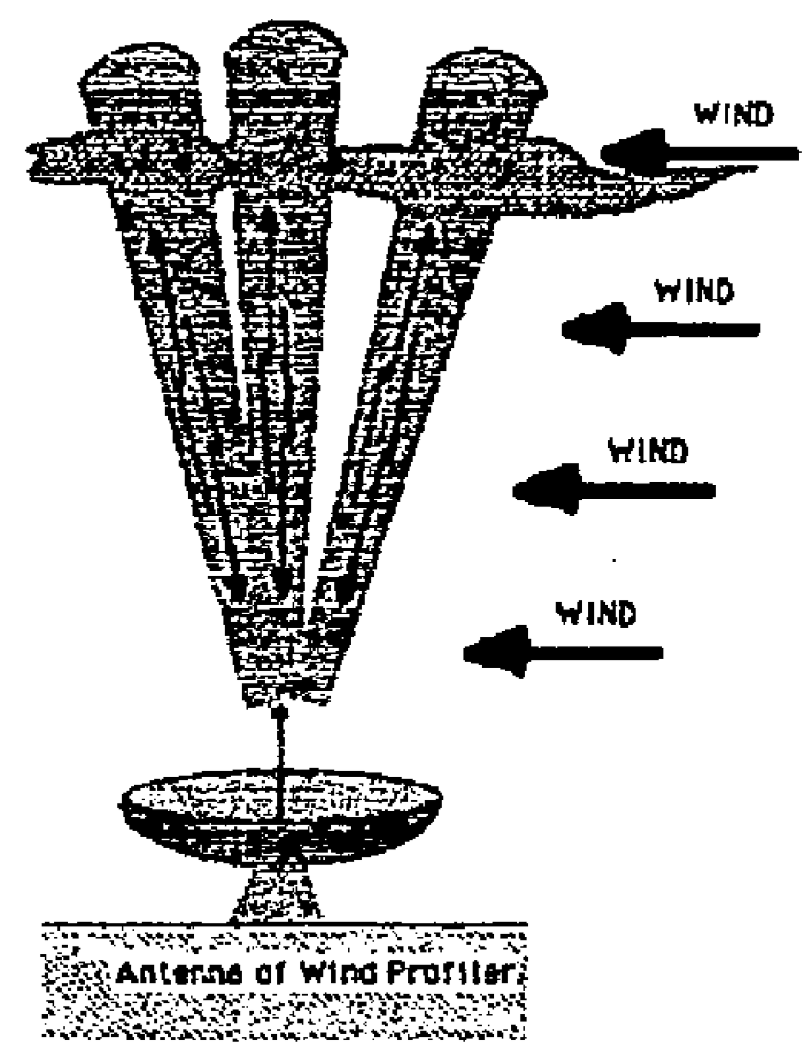

HASKELL, OK US Lat:35.68 Lon:-95.86 Elev:219m
WindSpeedDirection| Mode:900m,310m | Res:60min | QC:good only
NOAA PROFILER NETWORK
HT MSL (km)
STD ATM PRES (mb)
15:00 13-Dec 2006 UTC
16:00 12-Dec 2006 UTC
15:00
12:00
09:00
06:00
03:00
00:00
21:00
18:00

FIG. 1



Radiosonde System
to Measure winds.



Wind Profiler System
to Measure winds.

FIG. 2

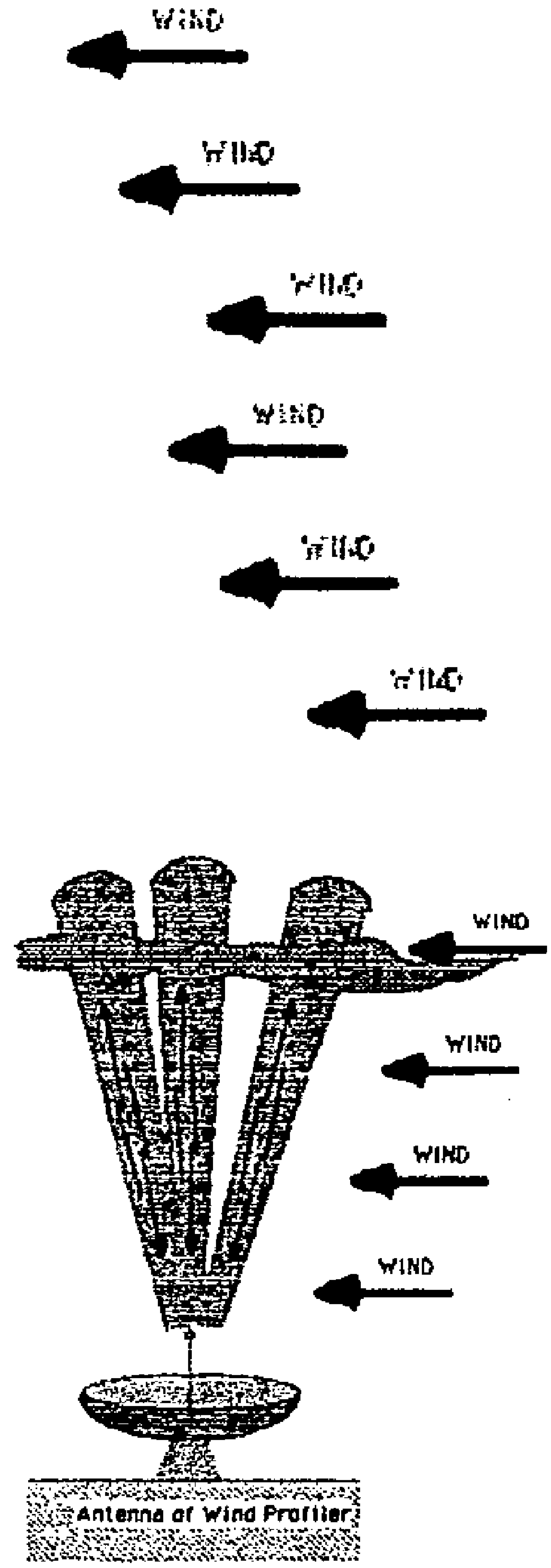
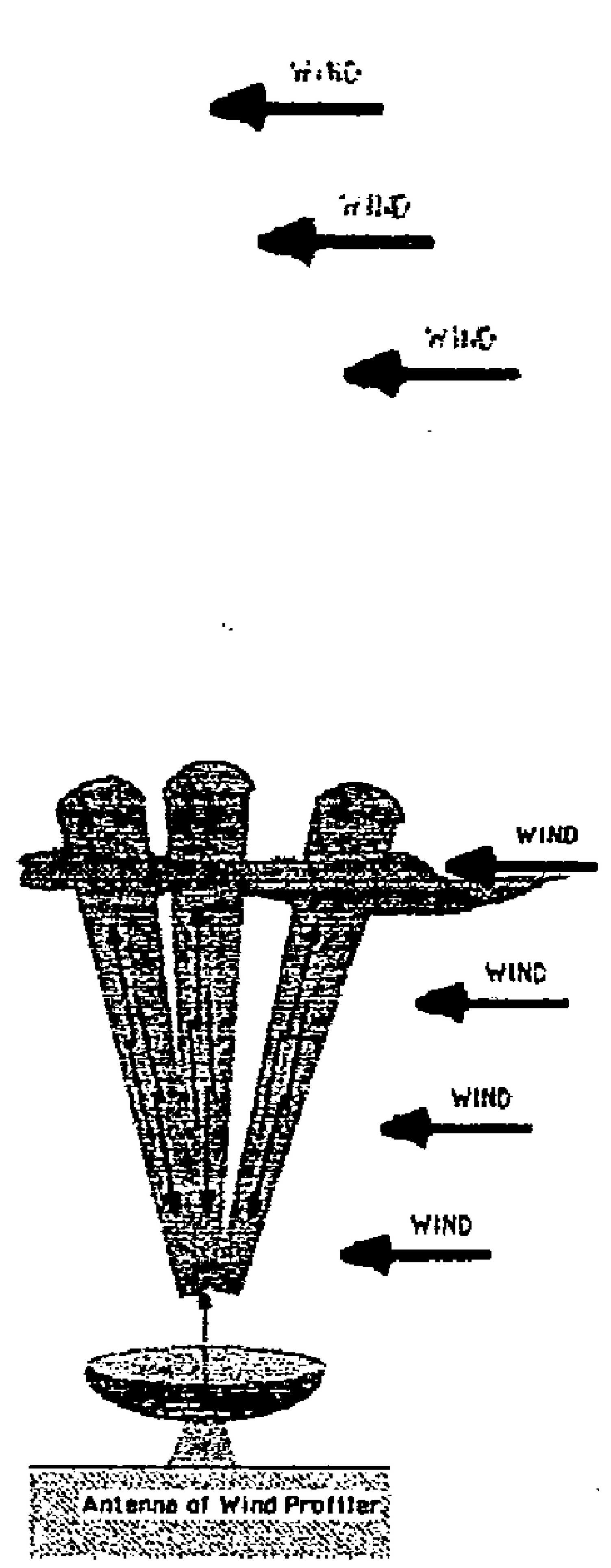
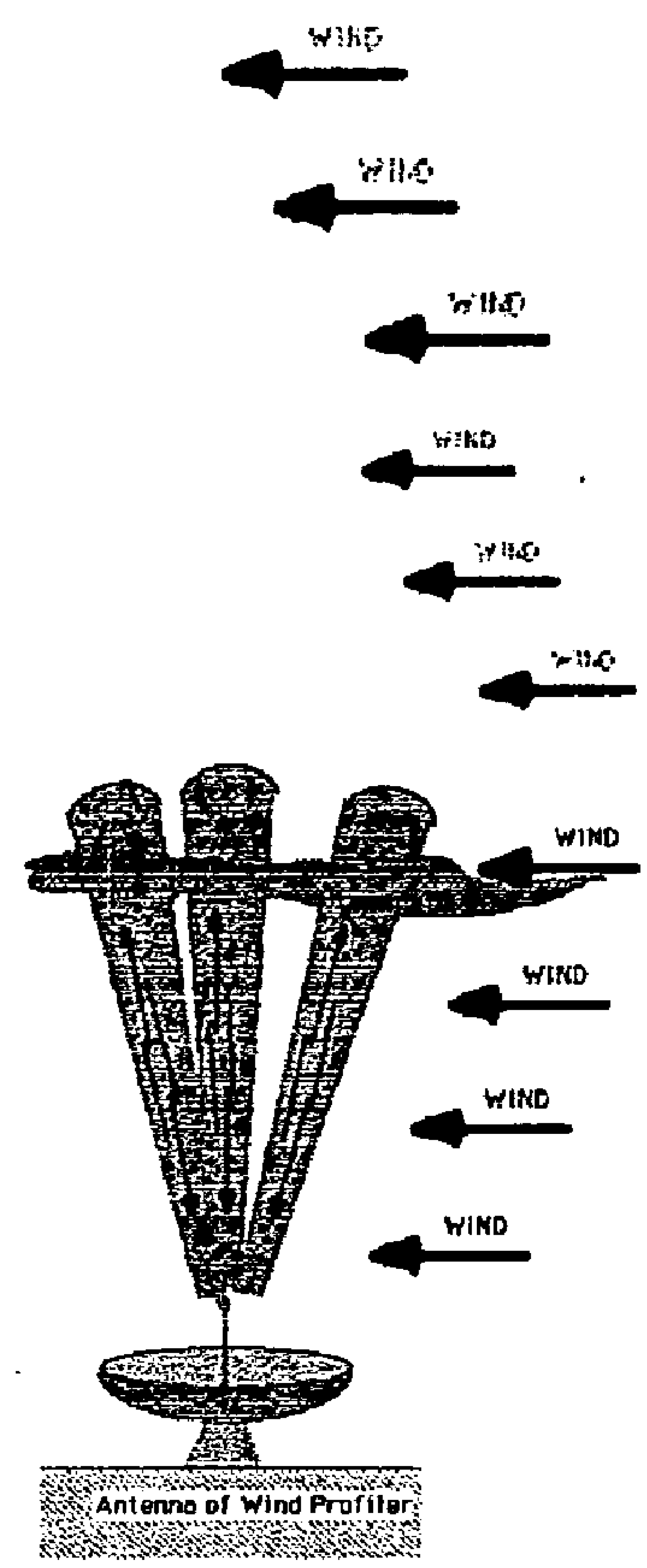

WIND
WIND
WIND
WIND
WIND
WIND
WIND
WIND
WIND
WIND
Antenna of Wind Profiler

FIG. 3



(a) Wind Profiler System



(b) Wind Profiler System with neural network to Measure winds.

FIG. 4

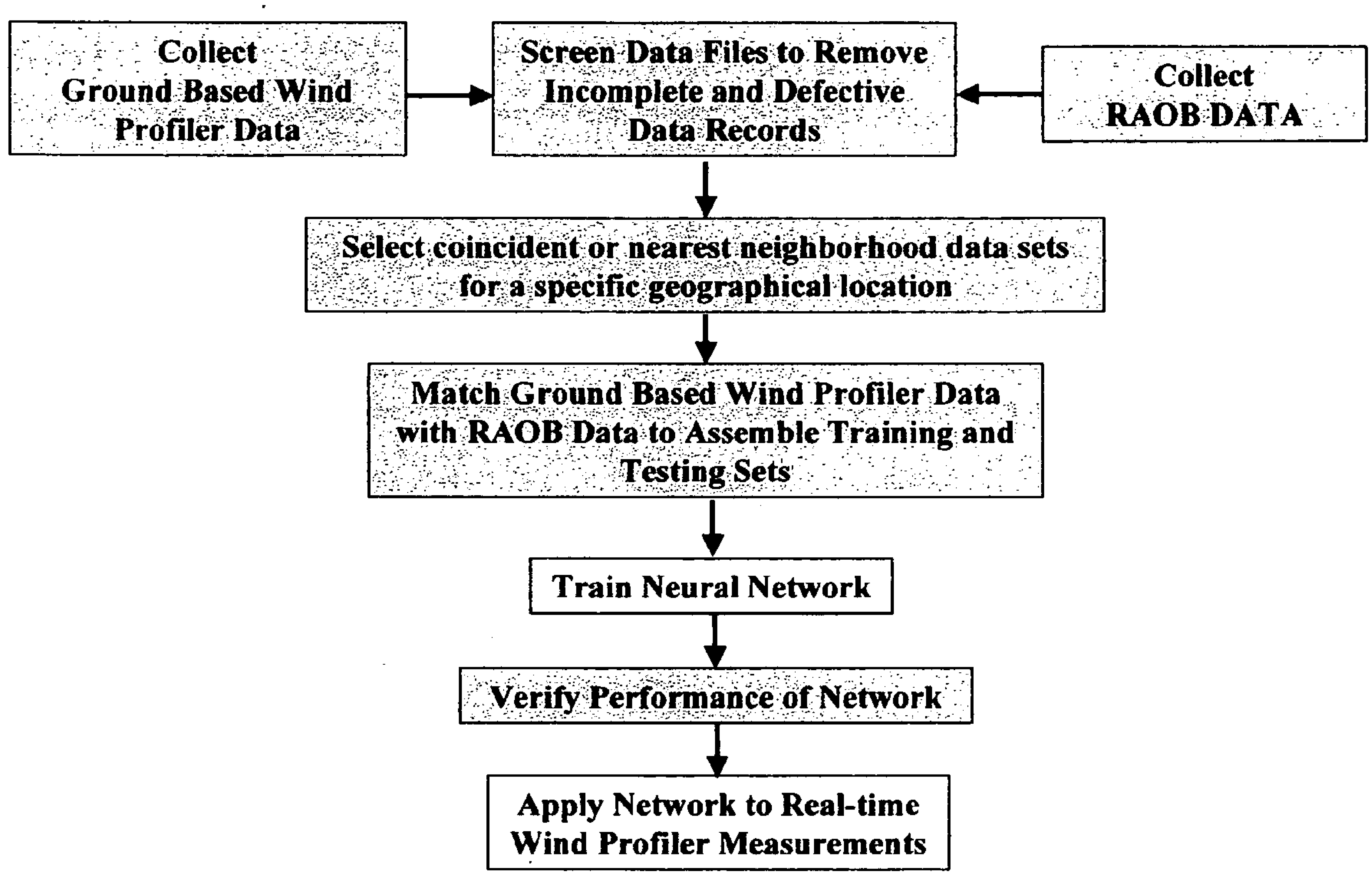

Collect
Ground Based Wind
Profiler Data
Screen Data Files to Remove
Incomplete and Defective
Data Records
Collect
RAOB DATA
Select coincident or nearest neighborhood data sets
for a specific geographical location
Match Ground Based Wind Profiler Data
with RAOB Data to Assemble Training and
Testing Sets
Train Neural Network
Verify Performance of Network
Apply Network to Real-time
Wind Profiler Measurements

FIG. 5

PROCESS FOR GENERATING SPATIALLY CONTINUOUS WIND PROFILES FROM WIND PROFILER MEASUREMENTS

OTHER REFERENCES

[0001]

PAT. NO.	Title
6,816,786	Space weather prediction system and method
6,581,008	Space weather prediction system and method
6,563,452	Apparatus and method for determining wind profiles and for predicting clear air turbulence
6,536,948	Determining temperature of a physical medium using remote measurement
6,405,134	Method and apparatus for predicting lightning threats based on radar and temperature data
6,067,852	Method and apparatus using slant-path water delay estimates to correct global positioning satellite survey error
6,061,672	Fuzzy logic neural network modular architecture
5,777,481	Ice detection using radiometers
5,648,782	Microburst detection system

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FIELD OF THE INVENTION

[0018] The present invention relates to improving retrievals of vertical profiles of horizontal winds from wind profiler systems. In particular, the objectives are (a) to extend the vertical measurement range of wind profilers, (b) to provide complete, continuous vertical wind profiles from fragmented wind measurements, and (c) to improve the accuracy of present day wind profiler systems using neural network methodology.

BACKGROUND OF THE INVENTION

[0019] Pioneer neural network research was conducted at the former Atmospheric Sciences Laboratory in the early 1990's (Measure & Yee, 1992). The research involved experimentation with neural network methods to retrieve temperature profiles from ground based microwave radiometers (Yee & Measure, 1992) as well as from satellite radiance measurements (Bustamante, etal, 1994). Neural networks were trained using simulated microwave radiometric measurements and archived radiosonde measurements to produce vertical profiles of temperature from the surface to approximately 10 kilometers.

[0020] The success of these earlier studies prompted wind vector retrievals using satellite radiances (Cogan, etal, 1997). Those experiments have yielded errors comparable to those achieved by other sounder based methods. Current studies involve the fusion of varied measurement sources to improve the upper level wind retrievals using neural network techniques. Neural networks are ideally suited for processing diverse data measurements and analyzing large data sets.

[0021] One of the salient features of wind profilers, in general, is that they can provide continuous time measurements without the extra expenditure of resources that a radiosonde would require. The disadvantages or limitations of wind profilers include limited range during adverse weather conditions, interference from insects and birds, false signals from other sources, and incomplete or missing data coverage. The following gives the more common wind profiler systems that are available in the commercial market.

Wind Profiler Systems

[0022] A. Sodar (sonic detection and ranging) systems are used to remotely measure the vertical turbulence structure and the wind profile of the lower layer of the atmosphere. Sodar systems are like radar (radio detection and ranging) systems except that sound waves rather than radio waves are used for detection. Other names used for sodar systems include sounder, echo sounder and acoustic radar. A more familiar related term may be sonar, which stands for sound navigation ranging. Sonar systems detect the presence and location of objects submerged in water (e.g., submarines) by means of sonic waves reflected back to the source. Sodar systems are similar except the medium is air instead of water and reflection is due to the scattering of sound by atmospheric turbulence.

[0023] Most sodar systems operate by issuing an acoustic pulse and then listen for the return signal for a short period of time. Generally, both the intensity and the Doppler (frequency) shift of the return signal are analyzed to determine the wind speed, wind direction and turbulent character of the atmosphere. A profile of the atmosphere as a function of height can be obtained by analyzing the return signal at a series of times following the transmission of each pulse. The return signal recorded at any particular delay time provides atmospheric data for a height that can be calculated based on the speed of sound. Sodar systems typically have maximum ranges varying from a few hundred meters up to several hundred meters or higher. Maximum range is typically achieved at locations that have low ambient noise and moderate to high relative humidity. At desert locations, sodar systems tend to have reduced altitude performance because sound attenuates more rapidly in dry air.

[0024] B. Radar (radio detection and ranging) systems are similar in principle to sodars except that radio frequencies are transmitted instead of sound waves. These systems tend to have longer ranges than the sodars but these systems can be very large physically and not as mobile.

[0025] C. Lidar (light detection and ranging) systems use Doppler frequency shifts in the light region of the electromagnetic spectrum. Typically, visible and infrared wavelengths of light are employed in these systems. One disadvantage in these systems is that infrared radiation can be absorbed under wet atmospheric conditions.

[0026] Some of the advantages of wind profiler systems are obvious compared to erecting tall towers with in-situ wind and temperature sensors. First, a wind profiler system can generally be installed in a small fraction of the time it takes to erect a tall tower except for large radar antenna systems. Sodar systems do have some drawbacks compared to tall towers fitted with in-situ wind sensors. Perhaps the most significant is the fact that sodar systems generally do not report valid data during periods of heavy precipitation.

[0027] All the wind profilers have certain limitations and atmospheric conditions play a very important role in the retrieval of reliable wind vectors. In many cases, it is difficult to obtain consistent winds at the maximum detectable heights of these remote sensors. A neural network has been developed to estimate upper level winds from these ground based wind profilers to extend their capabilities at a particular locale.

Radiosondes

[0028] While various efforts were attempted at remotely sensing the atmosphere with instruments onboard unmanned free balloons, the current type of radiosonde dates back to January 1930, when Pavel A. Molchanov, a Russian meteorologist, made a successful radio sounding into the stratosphere. He launched his radiosonde at Pavlovsk. His goal was a cheap, and expendable means of sounding the atmosphere for temperature, moisture and wind data.

[0029] Radiosondes were first used by the U.S. Weather Bureau in 1936. During that year a radiosonde network of several stations was inaugurated to obtain upper air soundings on a routine basis. This network replaced the kite and aircraft sounding programs. Currently, 70 radiosonde stations are distributed across the continental United States. Radiosondes are launched from these stations twice daily, just prior to 0000 and 1200 UTC. Radiosondes can be launched in almost any type of weather. While the radiosonde is reasonably durable, severe thunderstorms and heavy precipitation may cause instrument failure or radio interference.

[0030] Weather balloons measure the upper air at heights from near the ground up to 30 km. Weather balloons carry instrument packages called radiosondes high into the atmosphere that gather essential upper-air data needed to forecast the weather. These instruments are launched twice a day at 1,100 sites around the world. Temperature, humidity and air pressure are measured at various altitudes and transmitted via radio waves to a receiving station. Radio navigation supplies wind speed and direction at each altitude.

[0031] The biggest disadvantage of radiosondes is the expense and the timeliness i.e. it does not provide continuous measurements. Typically, radiosondes are launched twice a day, one in the morning and one in the evening. This does not cover the whole day in which significant weather events can occur. In terms of expense, once a weather balloon is launched, the balloon, the meteorological sensors, and the helium used to inflate the balloon is lost.

SUMMARY OF THE INVENTION

[0032] Accurate real-time upper level wind measurements can provide essential input into operational mesoscale models for their initialization and verification. Although there are a number of ground based wind profilers available (wind tracer lidar, doppler radar, and acoustical sounders), measuring upper level winds and obtaining a complete continuous vertical wind profile can be problematic and is highly dependent on favorable atmospheric conditions. In this invention, we use a neural network to retrieve upper level winds and to provide a continuous wind profile from ground based wind profilers. Radiosonde measurements in conjunction with wind profiler ground measurements for a geographical location are used as training sets for the neural network. The idea is to retrieve timely and continuous upper level wind information from incomplete or limited range wind profiler measurements.

Applications

[0033] Accurate and complete wind profiles are important for numerous applications. Some of these applications are summarized as follows:

[0034] Atmospheric boundary layer research

[0035] Air traffic warnings

[0036] Turbulence hazards

[0037] Input data to meteorological weather prediction models

[0038] Hazard waste transport and diffusion

[0039] Military operations and maneuvers

[0040] Wind energy analysis

[0041] Emergency response wind monitoring

[0042] Aircraft safety

[0043] Communications

[0044] Severe weather tracking

Neural Network Architecture

[0045] An overview of the neural network procedure is shown in FIG. **4**. Training the neural network would involve the collection of coincident wind profiler data and radiosonde wind data for a geographical site. These data would be filtered via algorithms that screen the data for missing fields and defective data records. If pertinent data is missing in any of the training set's data fields, that individual test case, i.e. wind profile, will be rejected for the purpose of training or testing. After extracting the wind direction and wind speed for selected height levels of interest, the wind parameters will be converted to U components (East-West) and corresponding V components (North-South) of the wind.

[0046] The algorithms discussed herein are not inherently related to any particular computer or other apparatus. Various general-purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct more specialized apparatus to perform the required method steps. In addition, the present invention is not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the invention as described herein.

[0047] The specific arrangements and methods herein are merely illustrative of the principles of this invention. Numerous modifications in form and detail may be made by those skilled in the art without departing from the true spirit and scope of the invention.

Major Components of the Wind Profiler Neural Network

[0048] The major components of the wind profiler neuron are described by seven major components, which make up the wind profiler neural network. These components are valid whether the neuron is used for input, output, or is in one of the hidden layers.

[0049] Component 1. Weighting Factors: The wind profiler neuron will receive many simultaneous inputs, primarily wind measurements at various atmospheric heights. Other inputs may include synoptic conditions and other meteorological parameters of interest. Each meteorological input will have its own relative weight, which gives the input the impact that it needs on the processing element's summation function. The neural response from the combined inputs will be an inferred wind vector at an atmospheric height where measured winds are missing.

[0050] Component 2. Summation Function: The first step in a wind profiler processing element's operation is to compute the weighted sum of all of the inputs. Mathematically, the meteorological inputs and the corresponding weights are vectors which can be represented as (i**1**, i**2** . . . in) and (w**1**, w**2** . . . wn). The total input signal is the dot, or inner, product of these two vectors. This simplistic summation function is found by multiplying each component of the i vector by the corresponding component of the w vector and then adding up all the products. Input**1**=i**1***w**1**, input**2**=i**2***w**2**, etc., are added as input**1**+input**2** + . . . +inputn. The result is a single wind value, not a multi-element vector. The summation function can be more complex than just the simple meteorological input and weight sum of products. The input and weighting coefficients can be combined in many different ways before passing on to the transfer function. In addition to a simple product summing, the summation function can select the minimum, maximum, majority, product, or several normalizing algorithms.

[0051] Component 3. Transfer Function: The result of the summation function is transformed to a working output through an algorithmic process known as the transfer function. In the transfer function the summation total can be compared with some threshold to determine the neural output. If the sum is greater than the threshold value, the processing element generates a signal. If the sum of the input and weight products is less than the threshold, no signal (or some inhibitory signal) is generated. Prior to applying the transfer function, uniformly distributed random noise may be added.

[0052] Component 4. Scaling and Limiting: After the wind profiler processing element's transfer function, the result can pass through additional processes which scale and limit. This scaling simply multiplies a scale factor times the transfer value, and then adds an offset.

[0053] Component 5. Output Function (Competition): Each wind profiler processing element is allowed one output wind value which it may output to other neurons. Neurons are allowed to compete with each other, inhibiting processing elements unless they have great strength. Competition can occur at one or both of two levels. First, competition determines which wind profiler neuron will be active, or provides an output. Second, competitive inputs help determine which processing element will participate in the learning or adaptation process.

[0054] Component 6. Error Function and Back-Propagated Value: In the wind profiler learning networks the difference between the current output and the desired output is calculated. This raw error is then transformed by the error function to match a particular network architecture. The artificial neuron's error is then propagated into the learning function of another processing element. The current error is typically propagated backwards to a previous layer.

[0055] Component 7. Learning Function: The purpose of the learning function is to modify the variable connection weights on the inputs of each processing element according to wind profiler neural based algorithm.

[0056] After neural network processing of the wind profiler training set, the weights would be calculated for each height level. The basic formulation would be as follows for the U and V components of the wind vector of interest:

$$U(\text{level of interest})=b(U)+U(\text{level1})*w1(U)+U(\text{level2})*w2(U)+\ldots+U(\text{level}n)*wn(U)$$

$$V(\text{level of interest})=b(V)+V(\text{level1})*w1(V)+V(\text{level2})*w2(V)+\ldots+V(\text{level}n)*wn(V)$$

[0057] where

[0058] U(level of interest)=U component of the wind at the level of interest i.e. level with the missing winds

[0059] V(level of interest)=V component of the wind at the level of interest i.e. level with the missing winds

[0060] b**1**=bias coefficient for the U component of the wind

[0061] b**2**=bias coefficient for the V component of the wind

[0062] w**1**(U) . . . wn(U)=weighting coefficients for the U component of wind corresponding to measured winds at specific levels

[0063] w**1**(V) . . . wn(V)=weighting coefficients for the V component of wind corresponding to measured winds at specific levels

FIGURES

[0064] FIG. **1** is a screen capture image of wind profiler measurements showing fragmented vertical wind profiles from a NOAA profiler network Doppler radar located in Haskell, Okla.

[0065] FIG. **2** is a diagram of measurements from a wind profiler system (Doppler lidar, sodar, radar, etc) and from a radiosonde system.

[0066] FIG. **3** is a diagram of measurements from a wind profiler system in an operational mode.

[0067] FIG. **4**. (a) Wind profiler systems can produce incomplete wind profiles due to signal contamination, signal noise, clutter, and other factors. (b) Using the wind profiler system and a neural network, a complete wind profile can be inferred with associated root mean square errors for a particular location.

[0068] FIG. **5** is a flowchart of one embodiment of a neural network training procedure using near coincident wind profiler and radiosonde measurements.

DESCRIPTION OF THE FIGURES

[0069] Features and advantages of the present invention will be apparent to one skilled in the art in light of the following detailed description in which:

[0070] FIG. **1** is a screen capture image of wind profiler measurements showing fragmented vertical wind profiles from a NOAA profiler network Doppler radar located in Haskell, Okla. The image depicts hourly wind profiles from near the surface to 14 km height.

[0071] FIG. **2** is a diagram of measurements from a wind profiler system (Doppler lidar, sodar, radar, etc) and from a radiosonde system. The wind profiler system measures winds in the lower atmosphere and the radiosonde system measures winds from near the ground to heights as high as 30 km depending on the atmospheric conditions. These near coincident measurements at geographical locations of interest will be used as the training set for the neural network.

[0072] FIG. **3** is a diagram of measurements from a wind profiler system in an operational mode. Using the trained neural network from the experimental setup in FIG. **2**, the new wind profiler algorithm would be capable of retrieving upper level winds, with associated root mean square errors, above the range limitations of the wind profiler instrument.

[0073] FIG. **4**. (a) Wind profiler systems can produce incomplete wind profiles due to signal contamination, signal noise, clutter, and other factors. In an operational mode, questionable wind vectors are discarded, thereby producing a fragmented wind profile with missing wind data. (b) Using the wind profiler system and a neural network, a complete wind profile can be inferred with associated root mean square errors for a particular location. Complete and continuous wind profiles are required by many weather modeling applications.

[0074] FIG. **5** is a flowchart of one embodiment of a neural network training procedure using near coincident wind profiler and radiosonde measurements. The performance of the trained neural network would be evaluated using test cases not used in the original training set.

DEFINITIONS

[0075] Neural Network—A neural network ("neural net") is a collection of nodes and weighted connections between the nodes. The nodes are configured in layers. At each node, all of the inputs into the node are summed, a non-linear function is applied to the sum of the inputs and the result is transmitted to the next layer of the neural network.

[0076] Radiosonde—The radiosonde is a balloon-borne instrument platform with radio transmitting capabilities. Originally named a radio-meteorograph, the instrument is now referred to as a radiosonde, a name apparently derived by H. Hergesell from a combination of the words "radio" for the onboard radio transmitter and "sonde", which is messenger from old English. The radiosonde contains instruments capable of making direct in-situ measurements of air temperature, humidity and pressure with height, typically to altitudes of approximately 30 km. These observed data are transmitted immediately to the ground station by a radio transmitter located within the instrument package. The ascent of a radiosonde provides an indirect measure of the wind speed and direction at various levels throughout the troposphere. Ground based radio direction finding antenna equipment track the motion of the radiosonde during its ascent through the air. The recorded elevation and azimuth information are converted to wind speed and direction at various levels by triangulation techniques. Modern day radiosondes have GPS tracking systems.

[0077] Rawinsonde—A rawinsonde (or radio wind sonde) is a radiosonde package with an attached radar reflector that permits radio-direction finding equipment to determine the wind direction and wind speed at various altitudes during the ascent of the package.

[0078] Wind Profiler System—In this document, a wind profiler system will refer to any embodiments of apparatus that measure winds remotely, specifically, this includes Doppler radar, Doppler lidar, sodar, etc.

CONCLUSION

[0079] A neural network process for improving wind retrievals from wind profiler measurements is described. In this invention, a neural network is trained to retrieve missing or incomplete upper level winds from ground based wind profilers. Radiosonde measurements in conjunction with wind profiler ground measurements for specific geographical locations are used as training sets for the neural network. The idea is to retrieve timely and spatially continuous upper level wind information from fragmented or incomplete wind profiler measurements. The neural network wind profiler process will generate reasonable estimated wind profiles that can be applicable to many types of weather and meteorological models, synoptic and global.

What is claimed is:

1. A process for generating spatially continuous vertical wind profiles from fragmented and/or incomplete wind profiler measurements comprising the steps of:

(a) transmitting and receiving wind profiler radar and/or sodar and/or lidar signals;

(b) obtaining coincident or near coincident radiosonde measurements of winds and other related meteorological parameters such as synoptic weather conditions, temperature, pressure, height, and moisture;

(c) collecting a series of coincident wind profiler and radiosonde measurements to be used as a training set for a neural network.

(d) Screening data files to remove incomplete and erroneous data records.

(e) Selecting coincident or nearest neighborhood data sets for specific geographical locations.

(f) Assembling neural network training and testing sets from archived wind profiler and radiosonde measurements.

(g) Training the wind profiler neural network for specific geographical locations.

(h) Computing the weighting coefficients for each level of interest using wind information at other levels as input.

(i) Computing root mean square (RMS) errors using test cases of wind profiler measurements.

(j) Archiving computed weighting coefficients and the associated RMS errors.

(k) Applying neural network to operational wind profiler measurements where profiles are fragmented or incomplete.

* * * * *