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Instrumentation and computer capabilities for improving sodar data acquisition

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A computer program has been developed to exploit the multimedia capabilities of a personal computer for a new design of sodar (sonic detection and ranging) data acquisition and control system with minimized hardware elements. Advantages include trouble-free, cost-effective and user-friendly sodar data acquisition using any standard computer. The new design overcomes limitations due to using an add-on data acquisition card with conventional computer-controlled sodar. The data can be processed to produce online display of the dynamics of prevailing atmospheric boundary layer thermal structures and inversion/mixing depth for environmental applications.

1. Introduction

Sodar (sonic detection and ranging) is an acoustic remote sensing technique that provides a pictorial view of the dynamics of atmospheric boundary layer (ABL) thermal structures in real time and space. It works on the principal of acoustic echo sounding. A high power audio tone burst of fixed frequency (2 kHz) is transmitted in the atmosphere and backscattered acoustic waves from turbulent regions occurring along the path of propagation are received and processed to produce a facsimile display of the dynamics of the prevailing thermal structure in real time and space. The data are rich in information and have potential application in communication, aviation, air pollution, ABL research and heat flux studies (Singal *et al*. 1981, 1982, 1994, Cinque *et al*. 2000, Strunin and Tetsuya 2005, Pan and Chengiai 2008).

Sodar has been recognized as a useful tool for delivering site-specific air pollution meteorological data on inversion/mixing heights and stability class, which are necessary in dispersion modelling for environment impact assessment (EIA). In many experimental campaigns particular emphasis is given to the detection of thermally stable layers and inversions within the lower troposphere and their temporal development (performed with parallel mixing layer height retrievals from a Sodar). Such elevated layers influence the diurnal variations of air pollution and the solar ultraviolet radiation reaching the ground (Varotsos *et al*. 1995, Kondratyev and Varotsos 1996, Katsambas *et al*. 1997, Alexandris *et al*. 1999, Tzanis and Varotsos 2008). As it is a

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transportable, cost-effective technique for providing continuous data, the use of sodar data for EIA has been recommended by the Environment Protection Agency (EPA) in the United States and Central Pollution Control Board (CPCB) in India (CPCB 1998, Varotsos *et al*. 2003, Ferm *et al*. 2005, 2006, Tzanis *et al*. 2008). Efforts are being made to improve the technology in its ease of operation, maintenance and data quality, and to maximize deliverables (Gaynor 1994, Pal *et al*. 2007, Contini *et al*. 2008).

A conventional monostatic sodar was developed at the National Physical Laboratory (NPL) in 1975 (Singal *et al*. 1975). It was upgraded to a computer controlled sodar system in 1981 (Gera and Singal 1993). It has been successfully operating at NPL, New Delhi since its development. The existing system design incorporates the use of a commercially available data acquisition card (ADC) compatible with an industry standard architecture (ISA) slot. However, with emerging smart card technology for high speed data acquisition and the new generation Pentium series computers with no ISA slot, upgrading the technology is considered essential.

Thus, there is a need to upgrade the technology to improve compatibility with new-generation computers, improve the ease of operation and produce a maintenance-free system that can deliver ready-to-use air pollution meteorological data inputs for dispersion modelling in EIA. The focus should be on minimizing hardware needs and maximizing the harnessing of computer capabilities. The data acquisition technology has been developed on the LabVIEW platform, which uses virtual instrumentation software to eliminate the requirement for several pieces of electronic circuits. The newly designed system has been successfully developed and used in several field experiments.

2. Design features

Sodar works on the principle of acoustic echo sounding, and the hardware and software requirements for this are discussed below.

2.1 *Hardware needs*

The hardware needs to include a suitable mechanism to vertically transmit a high power audio burst of short duration (100 ms), and receive the backscattered sound signals using a directional sodar antenna. A control mechanism is required for synchronization of transmitting and receiving signals. Thus, hardware requirements include a computer processing unit (CPU), a sodar antenna to transmit and receive the acoustic signal, and suitable electronics for signal pre-conditioning, before processing by the CPU to produce facsimile records and deliverable data.

2.2 *Software considerations*

Program development tools such as Simulink or LabVIEW can be used for instrumentation development depending upon the availability, cost considerations and expertise of the individual. We have used the graphic user interface (GUI) of the LabVIEW platform program development tool to develop a customized virtual instrumentation software program for sodar data acquisition. The various items of electronic circuits, such as oscillator, pulse generator and bandpass filter, have been embedded in the virtual instrumentation through software design.

The flow chart of the program in figure 1 shows the logical approach used to achieve different functions required for sodar data acquisition. At the start of the program user input is required to select the operational parameters of transmission frequency – duration of tone burst (t), data sampling rate, start and stop time for data acquisition and pulse repetition frequency (PRF). The initial time delay or the dead time is set before starting to capture the actual data. This dead time is required to avoid false signals due to ringing of antenna and ground clutter, etc.

The various parameters can be selected as per the default settings, or entered by clicking buttons displayed on the output screen, as illustrated in table 1. The selected parameters are stored in the system memory and the program execution for actual data acquisition starts at the pre-selected start time, or at any time by clicking the start button.

With the start of data acquisition, the program delivers a square pulse at the parallel port of the computer system. This pulse is used as a timing synchronizing reference to transmit and receive the signal for each scan. The trailing and leading edges of the pulse are used to activate a relay which in turn acts as transmit/receive (T/R) switch for the sodar antenna shown in figure 2. The leading edge of the pulse switches the antenna to the transmit mode and subsequently a sine wave burst of desired frequency and duration is delivered at the speaker out terminal of the computer system. The burst is fed to the antenna via a power amplifier.

The trailing edge of the pulse switches the antenna back to receive mode and commands the CPU to start sampling data until the scan period of pulse repetition time is reached. The leading edge of the next pulse commands data acquisition to stop, and the CPU to be reset for the next scan of data acquisition. Data capturing starts again after the trailing edge of the pulse. The cycle keeps repeating until the end time given by the user.

2.3 *Program development criteria*

The software development criteria for the sodar system are:

(1) user-friendly approach for selection of operational parameters;
(2) reference signal for synchronization of transmit and receive signals;
(3) data processing logic for online display of 3D facsimile echograms; and
(4) automated creation of a file name, data storage in specified directories, data saving in case of power failure, and automatic restart of data acquisition with selected operational parameters.

2.4 *Harnessing computer capabilities*

In view of the above features, the built-in soundcard capabilities of computer systems are suitably harnessed to achieve the functional instrumentation requirements for sodar data acquisition. The soundcard provides the necessary input/output interfacing and the codec acts as a master control for data acquisition.

The software application directs the codec (via CPU) to sequentially generate and deliver a square pulse of desired duration at the parallel port of the computer system, and subsequently a desired sine frequency burst at the speaker out terminal of the computer system. This pulse is used to energize T/R switch relay, as shown in figure 3.

The burst amplitude can be controlled through the multimedia capabilities of the computer. The burst from the speaker out terminal of the computer is fed to the antenna (transducer) via an external power amplifier. The transducer converts the

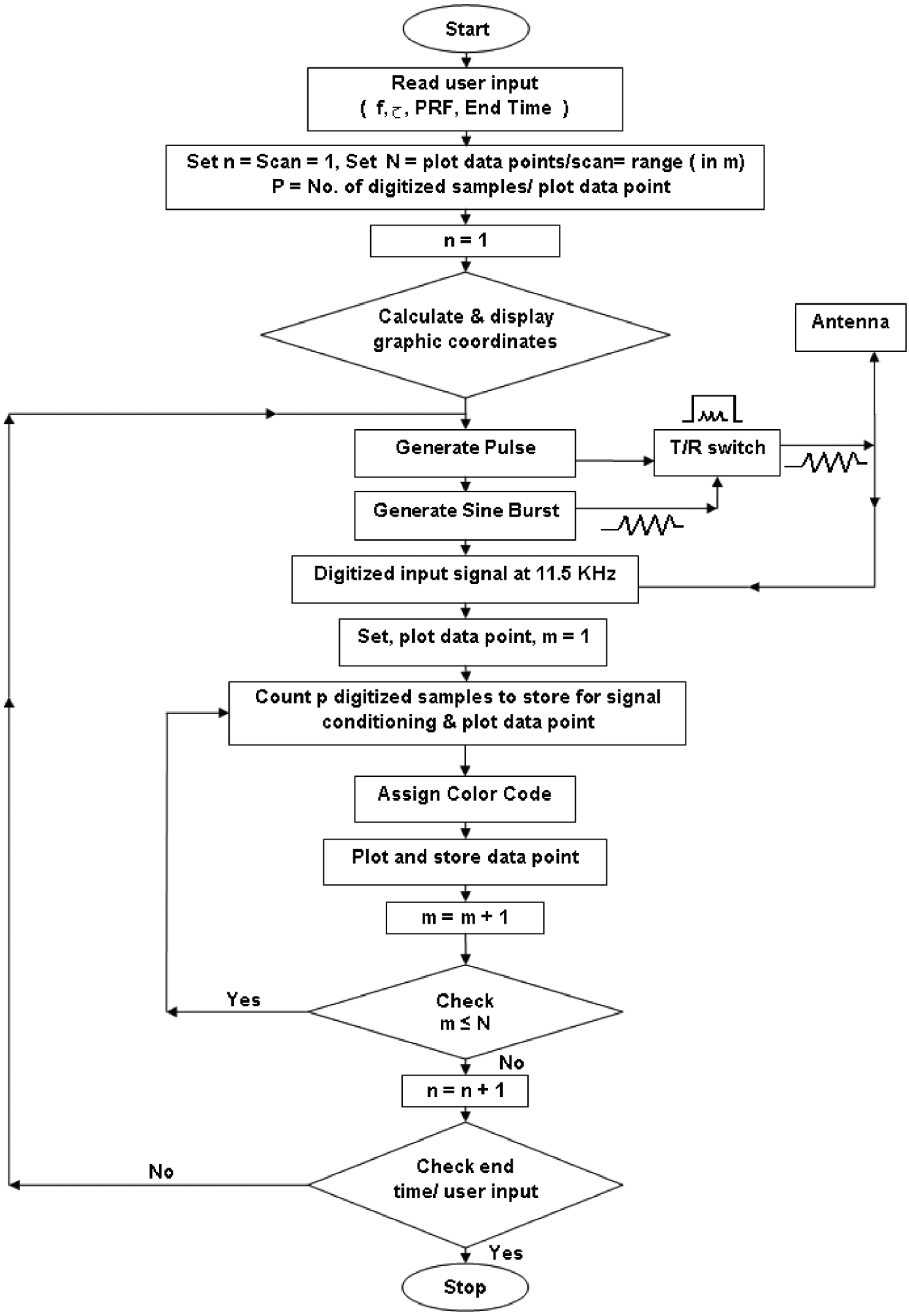

Figure 1. Flow chart of the logic used for sodar data acquisition.

Table 1. Sodar specifications and operational parameters.

Sodar	Parameters
Transmitted power (acoustic)	15 W
Pulse width	100 ms
Pulse repetition period	6 s
Operational range	1000 m
Receiver bandwidth	50 Hz
Operational frequency	2250 Hz
Sodar antenna	1.2 m parabolic dish surrounded by acoustic cuff
Receiver sensitivity	0.5 μV
Recorder	Standard printer

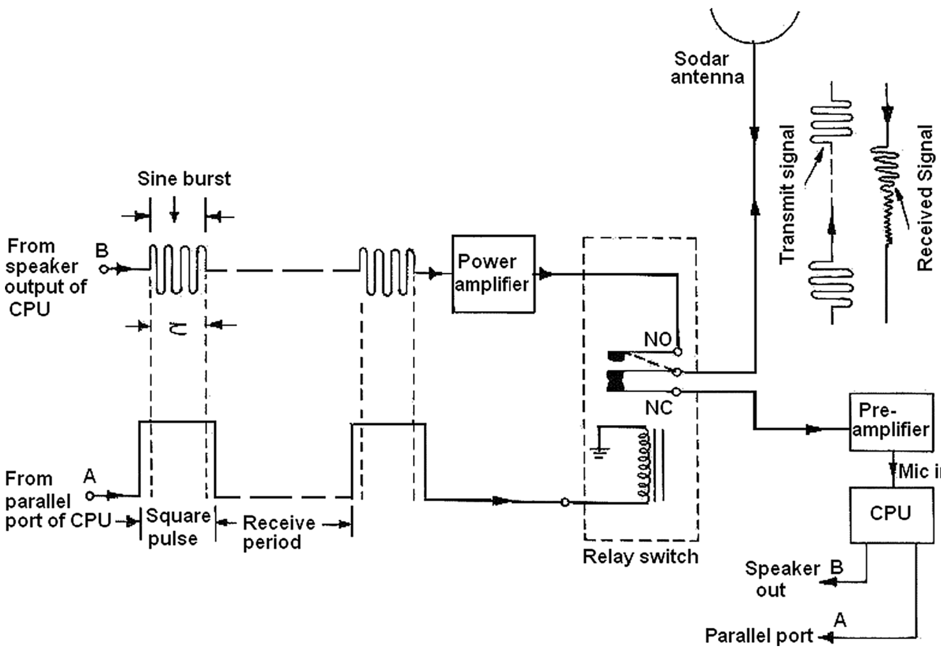

Figure 2. Schematic representation of synchronization of transmit and receive signals.

electrical energy input to sound power output. The antenna transmits a high power sound burst in ABL. The propagating sound waves are scattered from turbulent regions of temperature and wind fluctuations occurring along the path of propagation. The backscattered acoustics waves or the so-called sodar signal are picked up by the antenna, conditioned in a pre-amplifier and fed as analogue input signal at the mic input terminal of the computer.

The analogue signal is digitized by the codec at the standard conversion rate of microphone, of 11.025 kHz with 8-bit resolution and minimum bunch sampling of 2^8 or 64 data point at a time. These 64 data points correspond to a sampling time period of $x = 64 \times 1000/11025$ ms, which in turn offers a sampling height resolution of about 1 m for facsimile plots. In practice, the stored supply of large data samples can

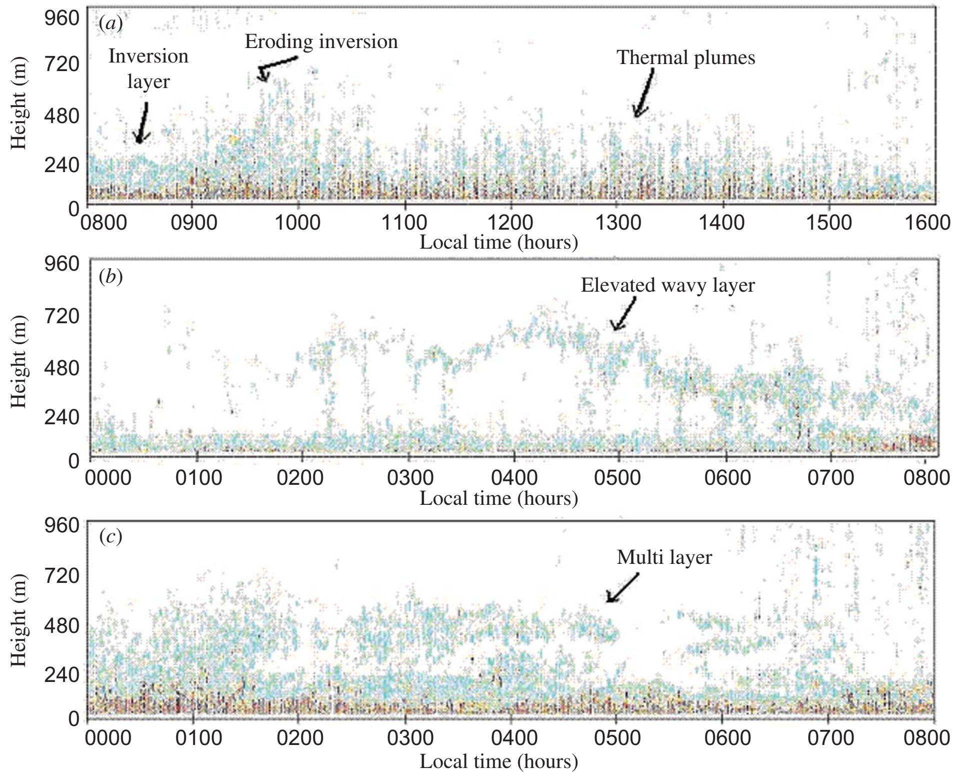

Figure 3. Sodar echograms of various thermal structures.

be manipulated through, for example, periodic sampling or data averaging, to achieve the desired sampling rate for required facsimile/or frequency data processing.

3. Outlook of data structure and data processing

Each acquired data point is read with 8-bit resolution and stored in the data file with a pre-assigned file name depending upon the date and time at the start of data acquisition. The data points are assigned different colour codes depending upon the signal intensity. The dynamic range of received signal (0–5 V) is subdivided into eight steps and each step is pre-assigned a particular colour code. Depending upon the time lapsed after transmission of tone burst and digitalization of individual data points, the acquired data point is assigned a height value, $h = ct/2$, where c is velocity of sound in air (340 m s^{-1}) and t is time lapsed in seconds.

Each data point with assigned colour is displayed as a 3D image in time versus height graphics, on the computer monitor in real time. Depending on the chosen data sampling rate and the repetition rate of tone burst, the number of data points acquired per scan are displayed as marking one horizontal line of coloured dots on the monitor. Line by line integration of different scans produces a pictorial view of the sodar echograms shown in figure 3. The digital data are stored in a binary data file with a prefix header file which gives the start time of each scan and relevant operational parameters. The data file keeps updating with each progressive scan until the end of data acquisition is reached, either through user interruption or on reaching at the pre-selected end time. The size of the data file continues to increase with the passage of time, and data from several days are accommodated in the same file. An offline program developed on the .net platform in C# can read the stored data file and reproduce separate fascimile records on a 24-hour time scale for each day. The facsimile data can be printed on standard A4 size pages using a standard printer.

4. Noise treatment

Sodar works on acoustic waves, so heavy ambient acoustic noise due to traffic, birds, etc., may mask the weak sodar signals and pose serious problems in data processing. Conventionally an acoustic shield is used to surround the antenna to protect it from ambient noise. Additionally a narrowband filter is used in the hardware electronics to avoid noise at unwanted frequencies. However, noise at the operating frequency and that entering the antenna from the vertical axis cannot be avoided, and has to be managed through data processing techniques.

Noise can be sampled in parallel and subtracted from the signal plus noise in real time. However, it requires an additional identical microphone for noise sampling. The wavelet technique has been used to distinguish sodar signals from heavy air craft noise and fixed reflections (Jordan *et al*. 1998). However, we have used each alternate scan for sampling noise and data respectively. The noise is sampled prior to each scan of data sampling. Stepwise, the first receiver is switched on for the receive period, which equals the scan duration. Only noise is received. The noise data, with samples pertaining to different intensity values, are analysed for weighted mean value. In a second step, a pulse is transmitted and the backscattered sodar signal is received and sampled at the desired sampling rate. The weighted mean noise level determined in the first step is subtracted from each actual data point sample (which constitutes signal plus noise). Subsequently, the subtracted signal depending upon its intensity value is assigned a colour code and displayed as 3-dimensional data point on the monitor to generate an online plot of the facsimile echogram. Depending upon the desired spatial range resolution, the sampling period may be appropriately adjusted so as to account for comparatively better data quality.

The weighted mean noise is used because the noise character is random and it includes short lived high noise values due to birds, vehicles, etc. The few high noise values may significantly increase the simple average value of background noise. The increased noise, in turn, will reduce the true signal value, which is taken as above the noise.

We also analysed each dataset pertaining to the range resolution (17 m) offered through the transmit burst period (100 ms), since actual sampling is at 1-m intervals and therefore the amplitude of samples pertaining to the pulse volume (or within range resolution of 17 m) must be close to each other. Therefore, the amplitude variation of a dataset of 17 samples is analysed to count the good data (wherein signal > noise) and their standard deviation (SD). Only a good dataset with a data count of more than 60% (i.e. 10 points) and SD within 10% of the mean value is considered to plot fascimile records. The schematic representation of the technique is illustrated in figure 4. The technique has worked well and it has enabled us to retrieve the signal buried in heavy rain noise, to improve signal-to-noise ratio of online facsimile plots, and to detect weaker signals from higher heights and thereby offer increased operational range.

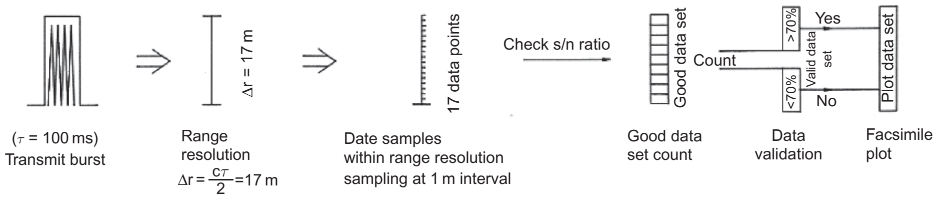

Figure 4. Schematic diagram of noise filtering, producing good data for facsimile records.

5. Results

The virtual instrumentation software of National Instruments (National Instrument Corporation 2008) has been developed to works on the Windows XP platform and can transform any standard computer to a stand-alone sodar data acquisition system. Such a computer-based mono-static sodar, developed at NPL, has been successfully operating for the last couple of years. The user-friendly system runs without problems and provides continuous real-time data on the dynamics of ABL thermal structures. The various sodar echograms are shown in figure 3. These echograms are manifestations of the prevailing meteorological conditions and portray a qualitative measure of the diurnal variation of atmospheric dispersion capabilities.

The thermal plumes shown in figure 3, representing convectively mixed atmospheric conditions, indicate the occurrence of favourable dispersion conditions. Ground-based nocturnal inversion represents stable atmospheric conditions, which restrict the dispersion of pollutants as shown in figure 3.

A detailed discussion of the meteorological relevance of each structure with reference to air quality consideration is beyond the scope of present work. Interested readers can refer to Singal *et al*. (1994).

An illustration of a noise management technique for improved facsimile records is shown in figure 5(*a*). The technique shows encouraging results for extracting a signal buried under heavy rain noise (figure 5(*b*)). This new concept of noise filtration technique has enabled detection of eroding inversion reaching beyond 2 km, which previously could not be detected beyond 700 m, with the earlier data processing techniques of NPL sodar. A comparative record of eroding inversion detected by old and new techniques, shown in figure 6, demonstrates the significant increase in the operational range of the present sodar.

6. Conclusion

The soundcard capabilities of new-generation Pentium IV series computers have been successfully exploited for developing a sodar data acquisition system. The technology offers economical sodar development and trouble-free operation using any standard computer, including laptops. Technology overcomes the limitations of using electronic hardware circuits in their physical forms and expensive add-on data acquisition cards which are becoming obsolete with the emerging new technologies. The merits of minimizing hardware include producing transportable mobile sodar applications for field experiments. The new concept of pulse volume data analysis for noise filtration not only enables signals to be extracted from heavy noise, but also improves signal-to-noise ratio of facsimile plots and achieves increased operational range. The technique has enabled the present sodar to clearly map eroding inversion over more than 2 km, which was not detected beyond 700 m with the previous NPL sodar design.

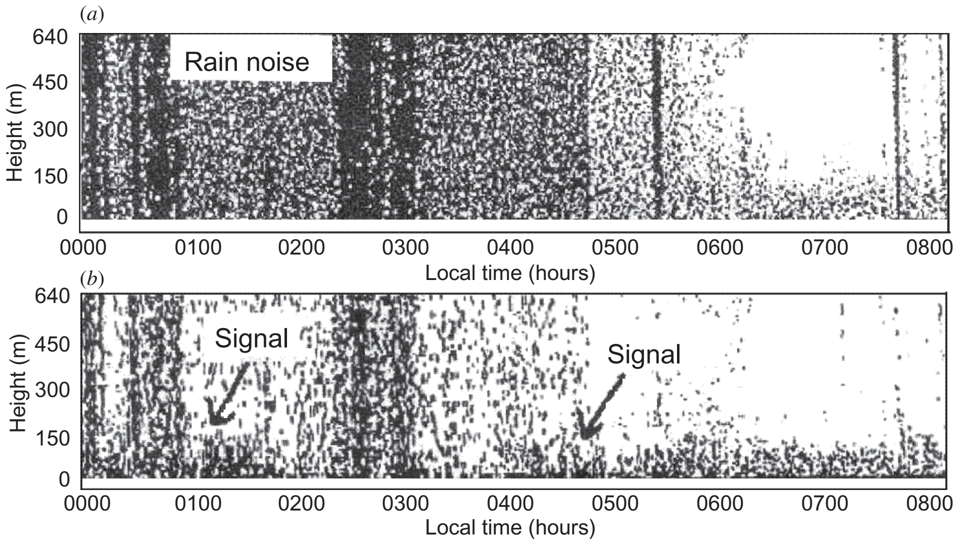

Figure 5. Illustration of noise filtration showing sodar facsimiles (*a*) before and (*b*) after noise filtration.

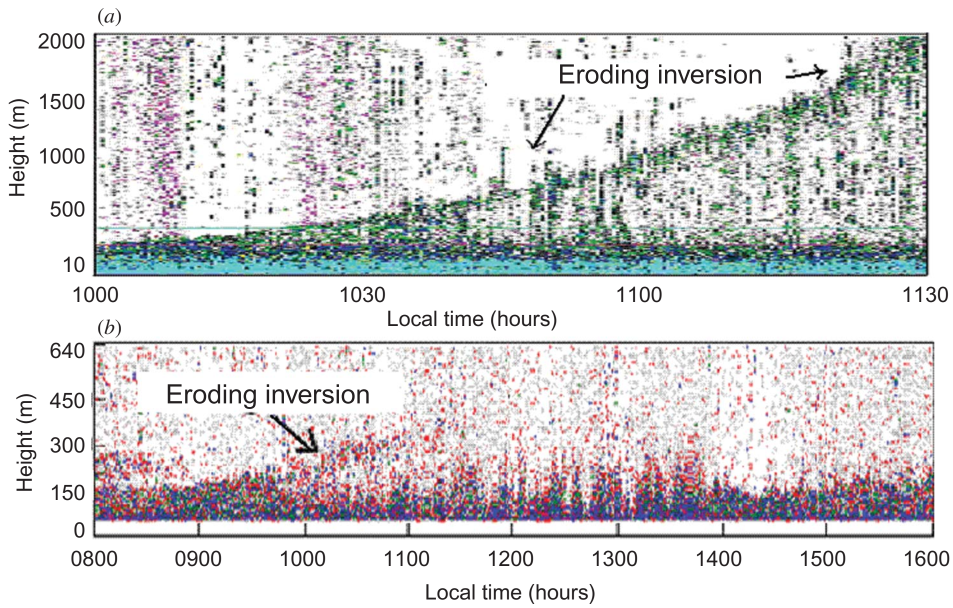

Figure 6. Comparative record of eroding inversion obtained with (*a*) present and (*b*) old sodar data acquisition techniques.

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