

*XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia*

ATMOSPHERIC REMOTE SENSING: TEMPERATURE DATA ACCURACY EVALUATION OF RASS-WIND PROFILER SYSTEM

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Abstract – The aim of this paper is to show the usefulness of a combined apparatus of RASS (Radio Acoustic Sounding System) and radiometer as an integrated sensor system in Remote Sensing field, especially in recovering atmosphere temperatures. Since these two systems work at different frequencies and conditions, it is interesting to see how they can be integrated according to data calibration instead of processing. A supervising unit that describes signal state in some of its conditions has been implemented [1], for a particular instant of time measured in clock pulse. It is useful to calibrate RASS-Wind Profiler data with radiometer and radiosonde ones. That is, to increase the accuracy of recovered temperatures by RASS. Simulations and comparison with actual data have demonstrated that this kind of approach is necessary to fill limitations of one apparatus with respect to another.

Keywords: Atmospheric temperature measurement, Remote sensing, Radio Acoustic Sounding System

1. INTRODUCTION

RASS (Radio Acoustic Sounding System) uses acoustic wave emissions to measure atmospheric virtual temperature profiles [2]. Virtual temperature is that one must have dry air to equal humid air density at the same pressure.

This variable is very used because it is possible to study variations of virtual temperature instead of density ones. Thus we define [3]:

$$T_v = T(1 + 0.61Q) \tag{1}$$

where T is absolute temperature and Q is specific humidity defined as the ratio between water vapor mass and humid air mass containing water vapor:

$$Q = \frac{M_w}{(M_w + M_d)} \tag{2}$$

RASS is generally composed of four acoustic sources placed on profiler side that transmit an acoustic wave in vertical direction [3]. The Profiler uses this wave as target: it receives and processes the backscattered signal, and measures acoustic wave propagation speed.

The sound speed is linked to temperature by an important and basic relationship used in Remote Sensing and temperature recovery:

$$T = \frac{V_s^2}{\gamma R} \tag{3}$$

(where V_s is the sound speed, γ is the ratio between specific heat at constant pressure and specific heat at constant volume, and R perfect gas constant), then the Profiler can compute virtual temperature.

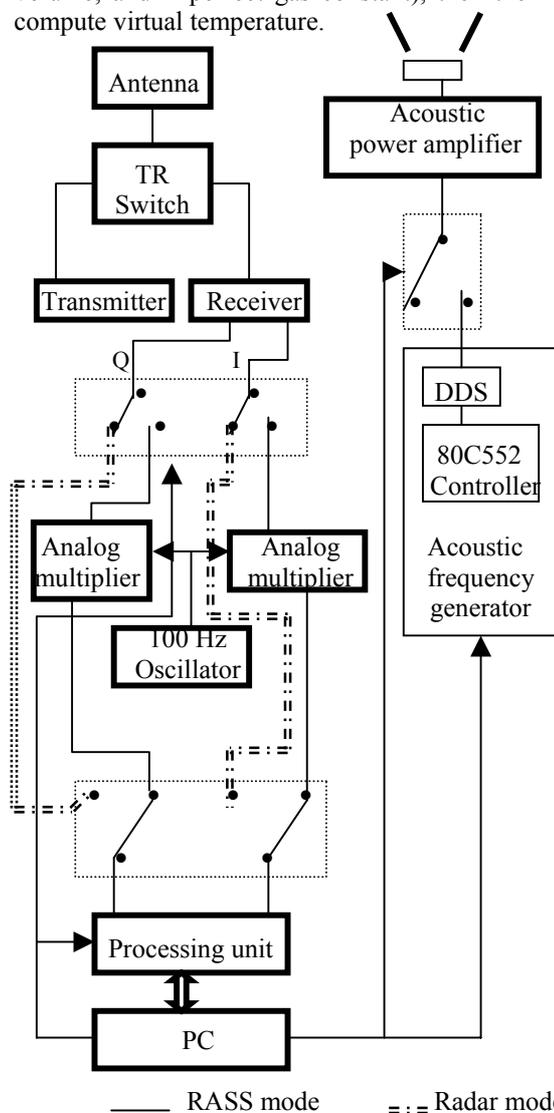


Fig.1. RASS – Wind Profiler scheme

RASS has almost the same resolution of Wind profiler, it means 2 km of height. We can say that the basic principle of RASS operation is the Bragg condition according to which

the radar wavelength is the half of acoustic wavelength [4]. Fig.1 shows a block scheme of RASS whose work frequency is more than 2 kHz. A typical commercial with the following commercial performance characteristics [5]: beamwidth 9°, sound pressure level 140 dB at 1 meter above transducer. RASS source has an aperture of 1.23 meter, with a parabolic reflector and zenith direction[6].

2. RASS-WIND PROFILER OPERATING MODE

A RASS-Wind Profiler is a fundamentally a pulse Doppler RADIo Detection And Ranging instrument, commonly called a radar. It transmits a pulse of electromagnetic energy in a chosen direction. When the pulse encounters a “target”, electromagnetic energy is scattered. A small portion of this scattered energy, called backscattered, will return to the radar, which can then compute the distance to the target from the time delay between the transmission and reception of the echo. The generic name “profiler” comes from the radar’s ability to show data for many heights of the atmosphere at the same time, thus giving a profile of the atmosphere. The profile from equally-spaced heights is created by sampling backscatter at equally-spaced time intervals. The sequential intervals during which backscatter is sampled are called range gates.

The considered RASS-Wind Profiler makes measurements in as many as five directions in order to compute wind measurements (speed and direction). The transmitted pulse is directed to an antenna that has a beam width of less than ten degrees. One beam is directed vertically. The four oblique beams are titled about 23.5°(915 MHz) or 15.5° (1290 MHz) from vertical and directed in four orthogonal directions as illustrated in Fig.2a and Fig.2b.

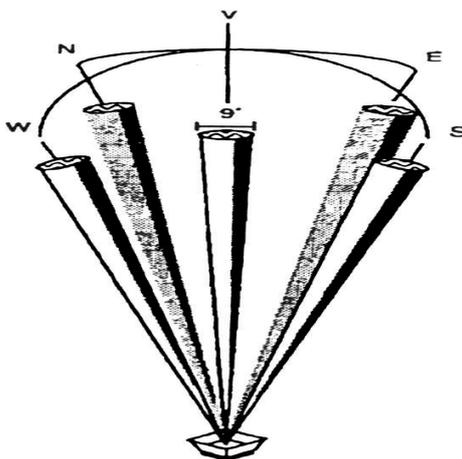


Fig. 2a. RASS-Wind Profiler Antenna positions

The phased transmission of the electromagnetic pulse from the radiating elements built into the antenna panels tilts the orthogonal beams, which is why it is called a phased-array antenna. In Fig.--- we have considered a vertical beam and two oblique beams in north direction and east one respectively; that is, by indicating with

v_1, v_2 e v_3 radial components of wind along the three beams (east, north and vertical, respectively), determined by shift Doppler effect, and with u, v e w the wind components wanted (perpendicular to relative beams), we get:

$$u = v_1 \cos \theta - v_3 \cot \theta$$

$$v = v_2 \cos \theta - v_3 \cot \theta$$

$$w = v_3$$

where θ stands for the angle between oblique beam and vertical direction. The beam sequence, including the number of beams and the order in which they are transmitted, is operator-controlled but normally should include the vertical beam and at least two tilted orthogonal beams for the Doppler shift computations to work. A complete rotation through the beam sequence is called a sample.

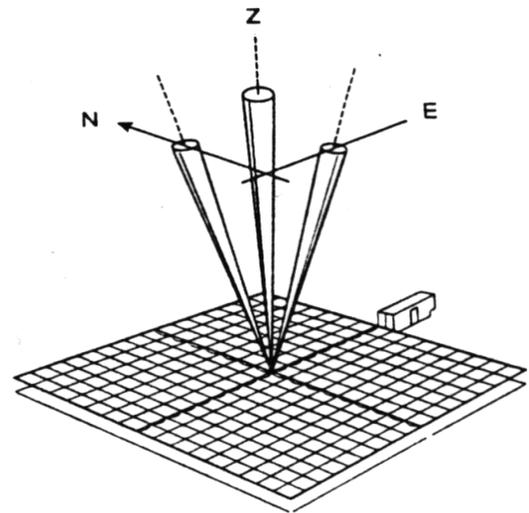


Fig. 2b. RASS-Wind Profiler Antenna positions

3. SIGNAL PROCESSING

The signal processing that the samples undergo is divided into two stages: the time-domain stage and the frequency-domain stage. In the time-domain stage, the samples are averaged. Time-domain averaging is also called coherent averaging because the samples come from targets that are more less fixed in relation to each other during the time the sample was taken and because the sample is taken a coherent measurement system. Four quantities are calculated for each set of spectrally averaged data (see Fig.3) during the frequency-domain stage:

- the doppler shift of the peak;
- the spectral width;
- the noise power; and
- the signal-to-noise ratio.

The result from these calculations is called moment data or just moments. The moments and spectra are considered “raw” data. The profiler creates a third type of data file, the consensus file. The data in this file have been processed with a wind consensus averaging algorithm. The algorithm

uses two values to determine whether data are valid. One value is a range in which the samples must fit. The second value is a percentage number of samples taken during the consensus period that must fit within that range before the consensus is accepted as valid.

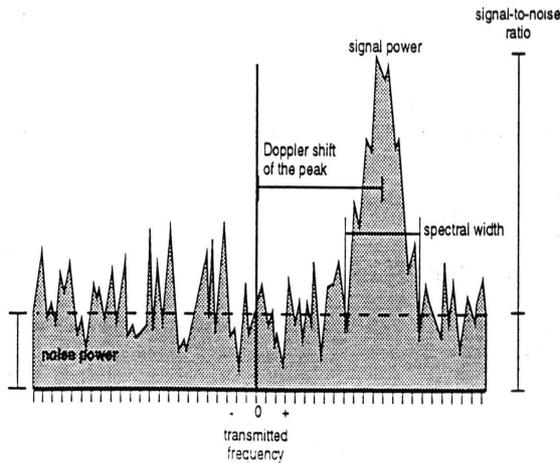


Fig. 3. Diagram of a spectrum showing the four measurements

4. RECIPROCAL CALIBRATION

Radiometer data [7] [8] have been used to implement a reciprocal calibration between the systems:

- a) both systems are based on two different operating modes;
- b) radiometer has a high resolution above 2 km as height; in the range 0.450÷2 km, RASS reveals a good and acceptable resolution than radiometer. The time resolution for both systems is about a few minutes in the usual operating mode. They are considered remote sensing instrumentations.

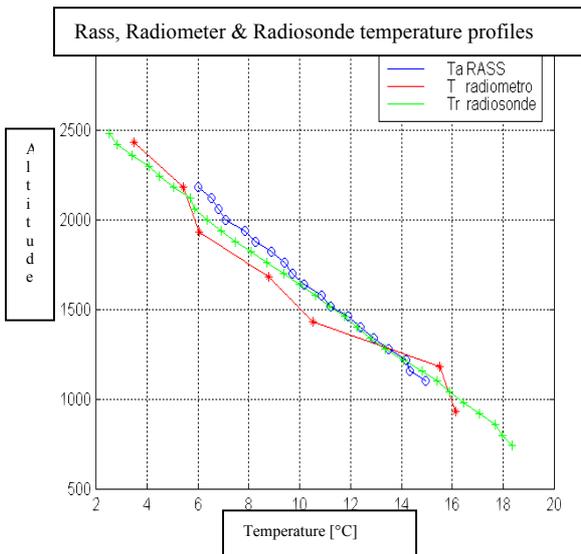


Fig. 4. Comparison between radiometer and RASS profiles

The radar software directly produces three kinds of file: .cns, .mom, .spc. Cns data that allow to get atmospheric temperature profiles; they are ascii ones. We have used data of year 1997 and

day 20 of may. They have been acquired each 30 minutes. Through a different Matlab procedure, developed by us, it permits to evaluate atmospheric temperature, showing its trend versus altitude. To improve the accuracy of RASS-Wind profiler, a combined virtual appliance has been implemented by using radiometer data in the same location. Further comparison between RASS-Wind Profiler and radiometer can help us to understand the accuracy improvement of the first instrumentation:

- c) in presence of precipitation, radiometer shows limitations and difficulties to operate, while RASS has no problems although there is a degradation of the temperature recovered value, because of influence on wind vertical component evaluation;
- d) as said above, the main aspect, certainly the basic one, is the work frequency. RASS uses as an acoustic source a radio frequency signal in UHF or VHF band, and an acoustic source with frequency of kHz; in the RASS – Wind Profiler system considered in this work, we operate with a radar at 1290 MHz and an acoustic frequency of about 2 kHz. This is the output frequency signal;
- e) radiometer uses in the input section, frequencies of GHz order, that are higher than those used in RASS. The output signal to be measured can be about 1 MHz. Consequently it is difficult to face on the point of view hardware, the signal coming from the two systems.

In this context, Fig. 4 illustrates a result of simulations involving RASS (Ta), radiometer (T) and radiosonde (Tr). Instead, Fig.5 represents the acquired RASS temperatures vs time; it shows the application of relationships (1) and (2).

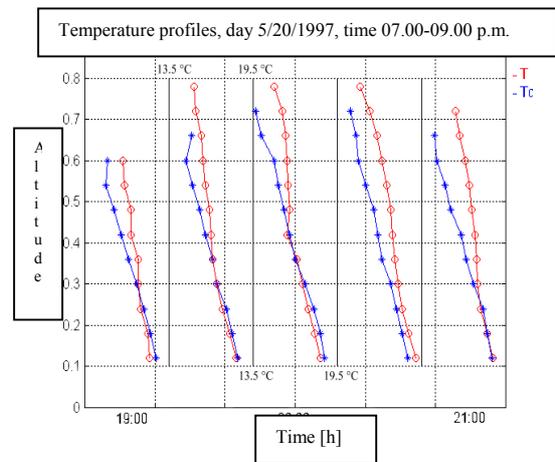


Fig. 5. Temperature profiles vs time

Now to demonstrate the goodness in terms of accuracy, data used in Fig. 4 have been computed in order to produce an improvement of RASS-Wind Profiler system. Thanks to data coming from radiometer and radiosonde, it was possible to enlarge RASS-Wind Profiler data validity, that is from 0 to 2.5 km. The more interesting aspect of the integrated system is to exploit information acquired by each appliance, without decreasing accuracy, so that we can obtain a system capable of supplying real-time atmospheric profiles. In fact, in Fig.6 we remark a smaller difference of error of the integrated system at the first kilometers. Since RASS-Wind Profiler presents a lack of accuracy, in the first kilometer, the integrated system improves it.

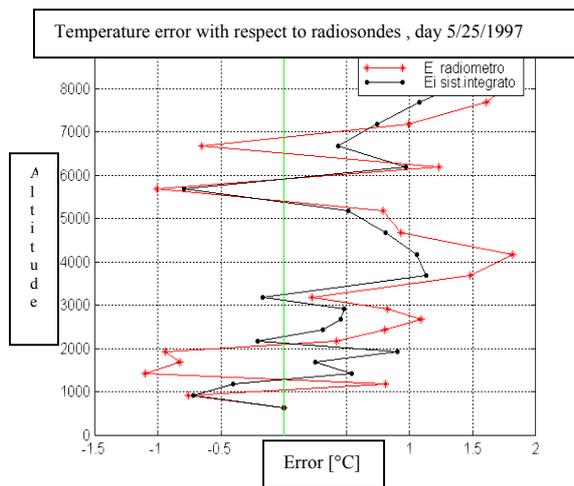


Fig. 6. Temperature errors due to radiometer and to integrated system

In this combined technique an acoustic source, placed beside a wind-profiling radar, transmits an acoustic wave into the volume of air sensed by radar, and simultaneously a passive apparatus like a microwave radiometer (that uses the *heterodyne* principle), receives a signal [9] [10] at some frequency incident on the antenna from the sky. Thus a portion of a profile can be determined by RASS and blended [11] with other sources of information [12] [13], like radiometer, to provide an entire profile. As it is obvious from the Fig. 4 and Fig. 6, the range of accurate profiling from the combined technique is considerably higher than 2 km. However according to experimental results and the Winter Statistics, there is a sharp increase in error in the pressure difference region 100 to 150 mbars.

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