CUSTAR
(The Canterbury University Stratosphere Troposphere Radar)

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Abstract

The University of Canterbury has just completed the first phase of the development of a new ST radar. This radar operates at 42.5MHz, has an array area of 3000m^2 and the peak transmitted power is 100kW. This radar measures returns from clear air echoes and examines the returned signal power and Doppler shift from ranges between 3 and approximately 14km. At this stage in the radar's development only the returns from a single vertically pointed beam are made. Therefore, only vertical signal power and vertical velocity measurements can be examined at this time. Initial results and details of the current system are discussed. The addition of six spaced antennas in the near future will allow the system to measure the horizontal velocity between 3 and 14km and the design of these extra components is also detailed.

Figure 1: The CUSTAR antenna aray.

Introduction

CUSTAR is a clear air radar (radars of this class are also often called wind profilers since they are most often used to measure the vertical and horizontal wind speed) which means that it primarily observes clear air echoes which are produced by fluctuations in the atmospheric radio refractive index. It is important to note that these radar are also sensitive to Rayliegh scatter from hydrometeors, but that the signal from this source is significantly smaller than that from radio refractive index fluctuations at the operating frequency of the radar (42.5MHz). The radio refractive index is a function of absolute temperature, atmospheric pressure and the partial pressure of water vapour and while the variations of atmospheric temperature, pressure and humidity only give rise to variations of refractive index with magnitudes of the order of $<10^{-6}$, these are sufficient to cause detectable radar signals to be observed up to 14 km.

In general these small perturbations in the radio refractive index are produced by turbulence caused by dynamic and convective instabilities. Turbulent mixing across a region gives rise to refractive index gradients across a wide range of scale sizes which produce returned signals. Fresnel reflection also occurs from sharp vertical changes in the refractive index which are horizontally coherent over a large spatial scale (the first Fresnel zone). Theoretical analysis of both these return mechanisms indicates that the returned signal power observed is directly related to the vertical gradient of the radio refractive index. Thus examination of the returned signal allows us to determine –

- information about humidity
- information about temperature
- information about clear air turbulence and other scattering mechanisms

Current CUSTAR system

The first phase of the development of the CUSTAR system has now been completed and a single near-vertically directed antenna has been in continuous operation since August 2002. This radar operates at 42.5MHz and has a large antenna formed from an array of dipoles (Figure 1), the area of the array being approximately 3000m^2 (7.5λ by 7.5 λ). The transmitter utilized produces pulses with a peak transmitted power of 100kW and can produce pulses with a maximum duty cycle of 1.4% with a pulse repetition frequency of nearly 2000Hz.. The returned signals are at present processed using a simple Doppler spectral processing scheme. The first three moments of the derived Doppler spectra allow the returned signal power, Doppler shift and spectral width to be derived. The spectra can also be examined to determine the noise level and the signal to noise ratio of the returns. It should be noted that at this stage in the radar's development because only the returns from a single vertically pointed beam are measured only vertical signal power and vertical velocity measurements can be examined.

The antenna array has been designed to maximize gain and directivity while minimizing sidelobes and the overall cost. To achieve these aims, in the diagonal direction, the dipoles are spaced by 0.707λ, and in the N-S and E-W directions the rows are spaced by half a wavelength. Thus, when looking either North-South or East-West the power polar diagram is that of a half-wavelength spaced array (with no ground lobe) and when looking along either diagonal the pattern is that of a 0.707λ array. Figure 2 shows the theoretical antenna power polar diagrams for the array along the North-South axis, the NW-SE axis and the NE-SW axis. In all of the polar disagrams the ground lobe is more than 20dB below the value at the mainlobe. To ensure that the theoretical polar diagram and the antennas actual polar diagram are consistent reverse radio astronomy has been used. Reverse radio astronomy usually uses a reference sky temperature map to determine radar reflectivity calibrations and allow system performance monitoring. However, the presence of strong radio stars and the galactic centre can also be used to verify the beam diagram, beam width and beam pointing direction of the antenna array. A comparison of the noise level measured by the antenna array with a reference sky temperature map for the Southern hemisphere is displayed in Figure 3. Examination of the two curves shows that they follow each other very closely. However, it can be observed that the peaks occur at slightly different right ascensions which suggests that the beam is not pointing vertically, this difference being less than three minutes which corresponds to approximately half a degree.

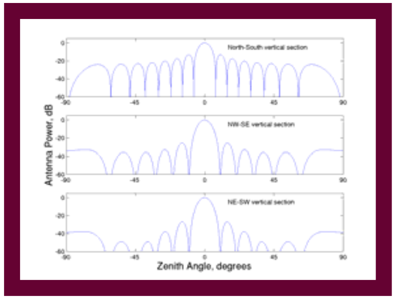

Figure 2: Power polar diagrams which display the tapering effect of the antennas diamond configuration.

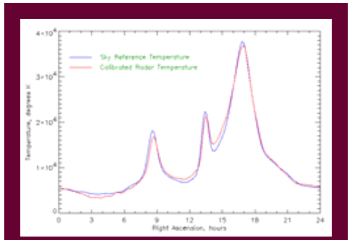

Figure 3: Comparison between a Southern hemisphere reference sky temperature map and the calibrated radar temperature.

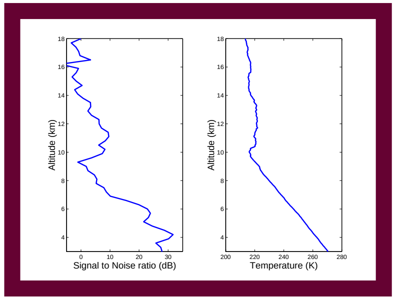

Figure 4: A profile of the average signal to noise ratio (left diagram) observed above the Birdlings Flat field site is compared with a temperature profile measured over Paraparaumu by a MetService radiosonde.

Phase 2 system development

Several developments are to be made in the near future which will allow horizontal wind speed to be determined. A set of five (possibly six) extra spaced array antennas are to be built, the area of each of these antennas being 3λ by 3λ. The returns from each of these antennas will be received by a new receiver design. This design will reduce the saturation effect observed at low altitudes at present so that measurements can be made to 1km. The inphase and quadrature components from each of the six receivers is then passed to a new state-of-the-art data acquisition system which can sample the twelve channels simultaneously at a rate greater than one million samples per second. It should be noted that the throughput of this system is expected to be in the region of several GigaBytes per hour and thus data reduction and signal processing schemes will be of great importance. By examining the returns from each of these antenna using a scheme known as Full Correlation Analysis the horizontal wind speed can be determined. Full Correlation Analysis estimates the atmospheric wind velocity from the ground diffraction pattern resulting from the backscatter of a transmitted signal by atmospheric refractive index irregularities. The analysis assumes that contours of equal spatiotemporal correlation of the ground diffraction pattern can be approximated by a family of ellipsoids. The pattern is then generally sampled at three antennas, and the magnitudes of the temporal autocorrelation function and cross correlation functions calculated from the complex signals recorded at the antennas are used to parameterize the spatiotemporal correlation function and thereby the wind speed.

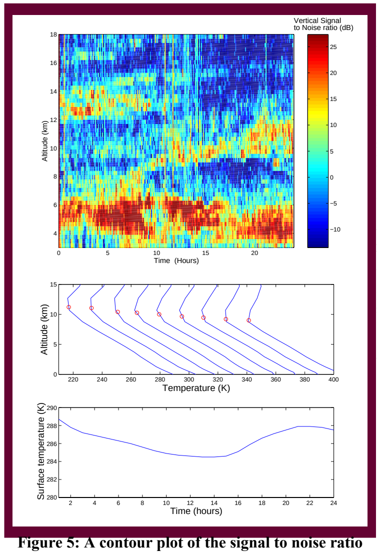

Figure 5: A contour plot of the signal to noise ratio (top diagram) observed above the Birdlings Flat field site is compared with a series of temperature profiles (middle diagram) simulated using a mesoscale model, each profile relates to a 3 hour period later profiles being offset by 10K for clarity. The red dot on each profile defines the tropopause altitude. The surface temperature from the mesoscale model is shown in the bottom diagram, the mesoscale model data being produced by Richard Turner of NIWA.

Initial results

As indicated in the introduction the returned signal includes information on the temperature and humidity gradients observed in the atmosphere. At altitudes above approximately 8km the humidity signal becomes small and the returned signal power (or alternatively the signal to noise ratio) is then dependent on the static stability. The large change in static stability between the troposphere and the stratosphere is therefore a clear feature in the radar returns. Figure 4 displays a profile of the signal to noise ratio observed above the Birdlings Flat field site averaged over a one hour period and a temperature profile measured over Paraparaumu by a MetService radiosonde. A clear increase in the signal to noise ratio is observed at the same altitude as the tropopause level. Figure 5 displays a contour plot of the signal to noise ratio for the 10th September 2002. Enhancements in the signal to noise ratio are observed at altitudes just above the tropopause level and a diagonal line between 05:00 NZST at 6km and 15:00NZST at 10km is observed, this feature corresponds to a cold front passing over the radar site. Comparison of the radar contour plots structure with temperature profiles simulated using a mesoscale model and the surface temperature also obtained from the model data (also shown in Figure 5) show good correspondence and indicate how the tropopause is at a high level before the cold front passage and at a lower level after the passage of the frontal zone.

Figure 6 displays a contour plot of the vertical velocity observed by the CUSTAR system on the 17th October 2001. It should be noted that to allow only good estimates of the vertical velocity to be displayed only regions with signal to noise ratios greater than 10dB are shown. This diagram shows that the coverage of the radar data is approximately from 3 to 7km and at a higher altitude of 9 to 12km (the enhancement being associated with the tropopause level and an increase in the returned signal). This coverage is based on using a lower peak transmitted power and a lower pulse repetition frequency than the transmitter is capable of and thus can be improved. However, the smaller area of the spaced antennas means that this diagram probably represents the horizontal wind speed coverage that can be achieved with the system once these new components are in place.

Examination of Figure 6 shows a region of large velocities after approximately 10NZST in the height range 3 to 7km and a region of relatively small vertical velocities before this period. Many other clear air radars have observed similar signatures and these are generally considered to be associated with high frequency gravity wave motions related to a frontal zone or to Mountain Lee waves. In the near future a surface weather station will be installed at the Birdlings Flat field site and this will allow the occurrence of these enhanced vertical velocity events to be examined relative to the surface wind direction. It is thought that this will allow these events to be identified as Mountain Lee waves launched from Banks peninsula and the Southern Alps.

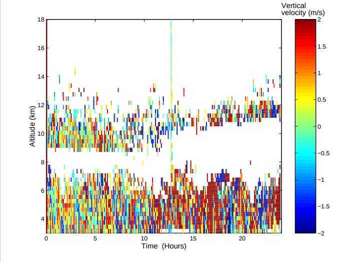

Figure 6: A contour plot of the vertical velocity observed above the Birdlings Flat field site. Only regions in which the signal to noise ratio was above 10dB are shown for accuracy.

Conclusions and Further work

A brief description of the CUSTAR system has been detailed and initial results indicating the current ability of the radar to determine tropopause height and examine the structure of atmospheric phenomena have been discussed. In the second phase of the CUSTAR development a set of six spaced antennas and a new receiver will be developed, the resultant data can then be processed using the full correlation analysis method to determine profiles of the horizontal wind speed from approximately 1 to 14km. While these components are being developed work will be carried out on automated tropopause height algorithms and an examination of the strong vertical velocity events observed relative to the surface wind direction measured using a surface weather station to be installed in the near future. It has been suggested that these events are likely to be associated with Mountain Lee waves launched from Banks peninsula and the Southern Alps.

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