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WORKSHOP ON PHYSICS OF MESOSPHERE-STRATOSPHERE-TROPOSPHERE INTERACTIONS WITH SPECIAL EMPHASIS ON MST RADAR TECHNIQUES

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INTRODUCTION TO PROBING THE LOWER ATMOSPHERE WITH THE MST RADAR TECHNIQUE

Prof. K. S. Gage

National Oceanic and Atmospheric Administration (Noaa)
Aeronomy Laboratory
Boulder, Colorado
United States of America

strada costiera, 11 - 34014 trieste italy - tel. +39 40 2240111 fax +39 40 224163 - sci_info@ictp.trieste.it - www.ictp.trieste.it

Introduction to Probing the Lower Atmosphere with the MST radar technique.

Lecture Notes:
This lecture is intended to provide an overview of the use of the MST Radar technique in observational studies of lower atmosphere dynamics. To place the developments of the past 20 years into context the structure of the atmosphere is introduced first along with the conventional methods to observe the atmosphere. This is followed by a brief discussion of the origins of the radar techniques from a lower atmospheric perspective. Early MST radar research facilities are introduced first followed by a brief introduction to the development of UHF profilers. The lecture ends with an overview of the scattering mechanisms responsible for the observed radar echoes.

1. **Structure of the Atmosphere:**
The layer of the atmosphere nearest the surface is fairly well mixed and contains the systems that give us our weather. The troposphere extends typically up to 10 - 18 km depending on latitude and season. The troposphere is bounded above by the tropopause. The lowest 1-2 km of the troposphere are often referred to as the planetary boundary layer and the lowest 100 m as the surface boundary layer. Above the planetary boundary layer is the free troposphere. The stratosphere extends above the tropopause to about 50 km and is bounded above by the stratopause. The mesosphere extends above the stratopause to about 85 km and is bounded above by the mesopause. Above the mesopause lies the thermosphere.

The regions of the atmosphere are distinguished by their temperature lapse rate. An atmosphere which is neutrally stable to a vertical displacement has a temperature lapse rate of 9.8 degrees per km which is known as the adiabatic lapse rate. The potential temperature is the temperature that a parcel of air would have if it were brought adiabatically to surface pressure. A parcel resists vertical displacement if its environment is hydrostatically stable (the potential temperature increases with height and is unstable if the potential temperature decreases with height). Convection occurs when the potential temperature decreases with height and buoyancy waves (or internal gravity waves) can occur when the potential temperature increases with height. Temperature decreases with height due to the decrease in atmospheric pressure.

In the troposphere temperature typically decreases 5-6 degrees per km and potential temperature nominally increases with height. Temperature decreases up to the tropopause where typically there is an abrupt change of lapse rate. In the stratosphere the temperature is nearly isothermal or increases and the potential temperature increases with height by 10 - 15 degrees per km. Consequently the stratosphere is hydrostatically stable and tropospheric vertical motions only rarely penetrate into the lower stratosphere.

2. **Observing the atmosphere:**

The most conventional observing techniques are *in situ*. Temperature, pressure or wind measurements are made near the surface by thermometers, anemometers and barometers, respectively. These provide essentially Eulerian point measurements. Remote sensing is relatively new and can be done by ground-based, air-borne or satellite-borne insruments. Most satellite sensors are passive. Sensors that emit energy and receive energy back are said to be active devices. Examples of active devices are radars, sodars and lidars. Balloons that float at a constant pressure level provide Lagrangian measurements.

3. **History of Radio and Radar Probing of the lower neutral atmosphere:**

Radio and radar meteorology has its historical roots in the 1930's. Early radar studies were conducted using instruments that transmitted at a few to 50 MHz. These were long wavelength radar. During world war II a dramatic leap forward in technology occurred and radars were developed with cm wavelengths. The longer wavelength radars are not very sensitive to hydrometeors and consequently are not much affected by the weather whereas the shorter wavelength radars are very sensitive to hydrometeors and have been utilized for weather radars.

While meter wavelength radars are relatively insensitive to precipitation they are influenced by turbulence and stable atmospheric structure. The hydrostatically stable atmosphere tends to be layered with thin layers of turbulence of varying thicknesses bounded by more stable regions. Clear air turbulence leads to turbulent echoes from regions of high refractivity turbulence and very stable regions give rise to specular or quasi-specular partial reflections that are referred to as Fresnel reflections or Fresnel scatter.

Radio propagation by UHF radio signals is subject to the same scattering and reflection influences from a layered atmosphere as are radars. Turbulence and stable layer structure can be responsible for radio propagation of UHF signals over the horizon. Many of the theories for turbulent scatter and partial reflections originated with radio propagation studies in the 1950's. In the 1960's scanning radars were utilized to probe atmospheric structure of the optically clear atmosphere. In the 1970's techniques from the lower atmosphere and ionosphere were combined to show the feasibility of measuring vertical profiles of atmospheric wind and turbulence.

In the 1980's the operational profilers were constructed and operated in networks for the first time. This work continued in the 1990's with an increased emphasis on profiling the lower troposphere with UHF profilers and use of the profilers for precipitation research.

4. Early MST and ST Radar facilities:

The first MST radar was the Jicamarca radar located near Lima Peru. Several pioneering experiments were conducted in the early 1970's that led to ST radars constructed at Sunset Colorado and the SOUSY radar constructed in the Harz mountains near Lindau, Germany. After the feasibility of profiling the lower atmosphere was demonstrated at Sunset and Platteville, Colorado and with the SOUSY system in Germany, the Poker Flat MST radar was constructed near Fairbanks, Alaska and the MU Radar was constructed at Shigaraki, Japan. The Indian MST radar was constructed near Gadanki in the late 1980's. MST radars typically operate near 50 MHz and can observe into the mesosphere. Many other less powerful VHF radars have been constructed near 50 MHz and these are generally referred to as ST radars or profilers since they observe primarily in the troposphere and lower stratosphere. UHF radars and profilers that observe in the troposphere and lower stratosphere are also referred to as ST radars.

5. Overview of scattering Mechanisms:

Atmospheric echoes observed by MST/ST radars from the optically clear atmosphere are typically due to turbulence or stable layered structure. The turbulent echoes can be either isotropic or anisotropic although they are often assumed to be homogeneous and isotropic. Reflection or scattering from stable layered structure is highly anisotropic and is typically referred to as specular of quasi-specular. Much can be learned about the stability of the atmosphere and its turbulent characteristics by comparing backscattering over a range of zenith angles. To complicate matters atmospheric layers that give rise to partial reflections can be tilted and tilted layers will spread the zenith angles at which specular echoes are observed. These mechanisms may also influence the precision of wind measurement.

At UHF frequencies it does not appear that there is any evidence of specular echoes as backscattering appears to be isotropic at UHF. Thus it appears that echoes from the optically clear atmosphere are largely due to turbulence although at the shorter wavelengths returns from biological targets (birds and insects) are increasingly likely. Turbulent echoes are commonly referred to as Bragg scatter and are from the half-wavelength Fourier component of the refractivity turbulence. Rayleigh scatter from particulates such as hydrometeors has a strong wavelength dependence while the turbulence scatter has only a weak dependence on wavelength. While it is sometimes difficult to judge whether backscatter is due to turbulence or particulates with a single radar it is possible to make this distinction unambiguously with two radar operating at different frequencies. An example of observations from McTEX in Australia are shown to illustrate this.