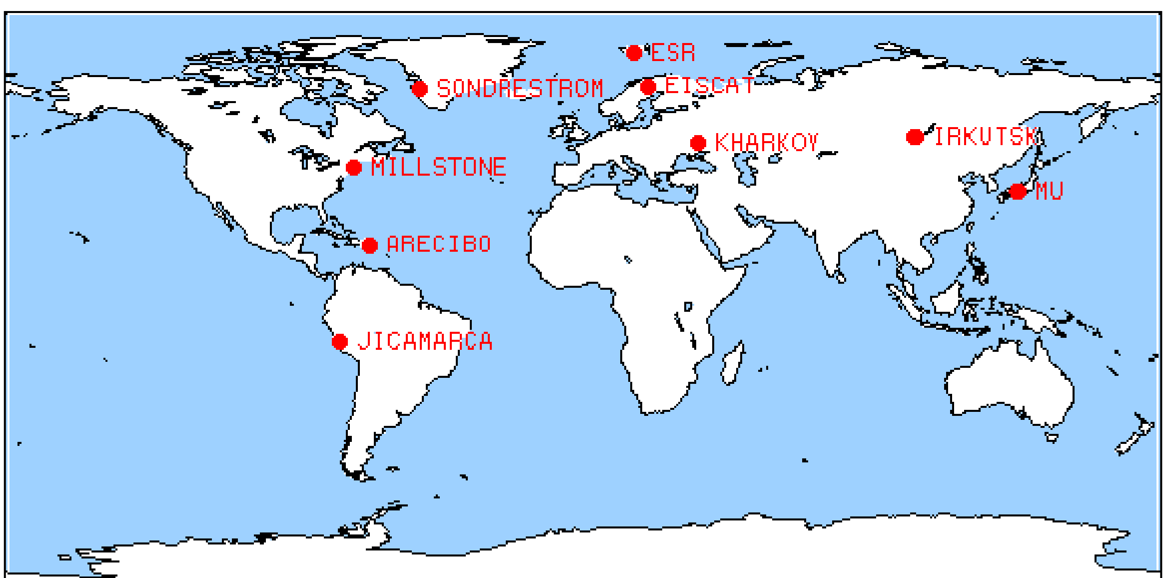
Studying Space Weather – The Incoherent Scatter Radar

Millstone IS Radar, Westford, MA

Incoherent Scatter (IS) Radar is the most powerful ground-based system for examining the ionosphere and its interactions with the upper atmosphere, the magnetosphere and the solar plasma (the solar wind). ISR systems provide a wealth of data that is complemented by observations from balloons, rockets and satellites as well as a wide range of ground-based instruments such as magnetometers, all-sky cameras, and coherent backscatter radars.

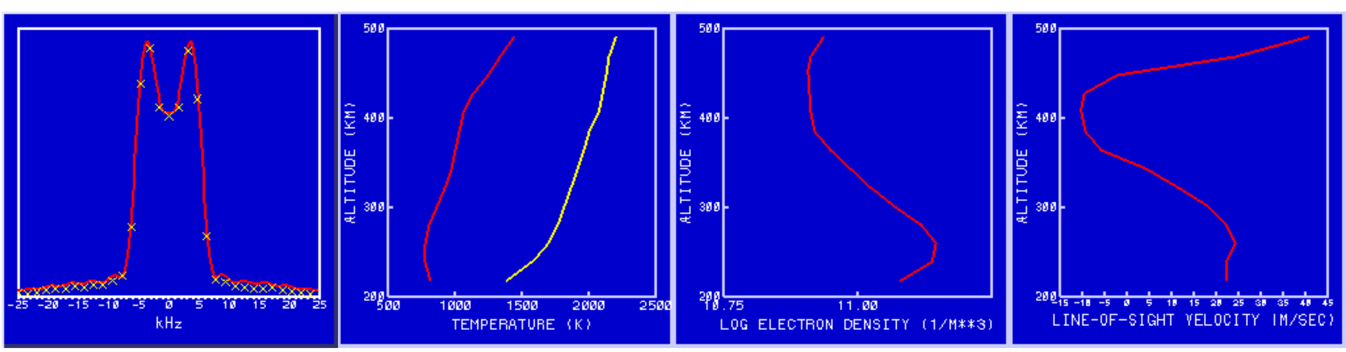
We normally think of a radar as working by sending out a microwave beam and receiving and analyzing its reflected echo. For example, the direction and distance (or range) of the radar from its target is done by sending transmitting short pulses, and measuring the time between the transmission and the reception of the echo. Echo strength will vary with the distance of the target, its size, its shape and its composition. Larger aircraft are distinguished from smaller aircraft.

Millstone's IS Radar works differently from conventional radar, sending out gigawatt beams, but receiving only picowatt signals! All IS radar systems have powerful gigawatt transmitters, large high-gain antennas, sensitive receivers, sophisticated radar control and data acquisition systems to detect and evaluate weak ionospheric incoherent scatter echoes. The map shows the current nine systems worldwide that track space weather.



The Millstone Hill IS Radar, as well as all IS radar systems, targets the electrons in the ionosphere. The ionosphere extends from about 100 km (60 miles) to 1000 km (600 miles) above the Earth's surface. High-energy ultraviolet radiation from the Sun knocks off electrons from atoms and molecules and ionizes them. It is these electrons that scatter radio waves. The electron densities range from about 10^4 to 10^6 electrons/cm^3. Since the amount of scattered energy from each electron is known, the strength of the echo from the ionosphere is a measure of the number of electrons in a scattering volume, which is the electron density or pressure.

Obviously an incoherent scatter echo comes from a very large number of electrons in random thermal motion. Consequently the echo will not be at a single frequency, but a spectrum, a range of frequencies near the transmitted frequency. As the temperature increases, the average velocity of the electrons increases, and the range of velocities increases, and so the spectrum's width increases; the incoherent scatter radar acts as a thermometer, measuring the ionosphere's temperature. In fact, two temperatures are obtained. When electrons are ionized from atoms, together the positive ions and electrons form a plasma. The ions may have a different temperature **(T_i)** from the electrons **(T_e)**. Because of the electrical interactions between the ions and electrons, the width of the spectrum measures the **ion temperature.** The spectrum usually has two peaks, and the height of these peaks measures the **electron temperature**. In addition to the electron and ion thermal motions, the entire plasma is usually in motion forming a plasma wind which will shift the entire spectrum away from the transmitted frequency, making the IS Radar a **wind speed meter.** An example of a spectrum and their interpretation are shown in the following figures.



In summary, IS Radars send out a powerful beam and its echo is the result of the electron scattering in the ionosphere's plasma, which is strongly affected by the much slower, heavier positive ions, causing power fluctuations in the electron density scattering. The analysis of the typically double-peaked IS spectrum, the total returned power, the spectrum's width and shift tells us:

- The electron and ion temperature, composition and velocity in the plasma,
- The electron temperature as well as scattering processes,
- The number of electrons and an estimate of the ionosphere's electron density.
- The ratio of the ion temperature to ion mass, and
- The bulk ionic motion.

With suitable assumptions on the ionosphere's ionic concentrations, IS Radars give the basic parameters of electron density, electron temperature, ion temperature, and ion velocity. At altitudes below about 120 km, collisions between the ions and the neutral atmosphere affect the incoherent scattering process and result in a single-humped spectrum from which the frequency of ion collisions with the neutral molecules of the upper atmosphere can also be deduced.

Using incoherent scatter radar to get many of the ionosphere and upper atmospheric parameters sounds great but in actual practice the method is very complex and altitude dependent. As a result, not all parameters can be obtained at once. Finally, because of the complicated processes going on in the ionosphere, interpretation of the data is often difficult and problematic.

About Millstone

Millstone Hill is a broad-based observatory for a wide range of atmospheric science investigations. The **incoherent scatter radar** has been supported by the National Science Foundation since 1974 for studies of the earth's upper atmosphere and ionosphere. The facility has evolved from part-time research, sharing its radar with the M.I.T. Lincoln Laboratory satellite tracking radar, to a separately funded, independent system dedicated to upper atmospheric research.

The scientific capability was greatly expanded in 1978 with the installation of a fully-steerable 46 meter antenna to complement the 67 meter fixed zenith pointing dish. The favorable location combined with the great operational range of its steerable antenna permits observations over a latitude span encompassing the region between the polar cap and the near-equatorial ionosphere.

Summarized from:
http://www.haystack.mit.edu/atm/mho/instruments/isr/isTutorial.html and
http://www.naic.edu/~isradar/is/aboutis/radar.html

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The Incoherent Scatter Radar and Space Weather

Answer the following questions:

1. What is the "most powerful" ground-based system for examining space weather?

2. Describe how a conventional radar unit in an airport works.

3. How is incoherent scatter radar different from conventional radar?

4. List several parameters an IS radar can measure, and describe how the system provides those parameters.

5. Give at least three advantages for the Millstone Hill facility.