A Global Perspective of Major Atmosphere and Ionosphere Radar Research

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In the second part of the past century giant radar systems have been designed and efficiently used for scientific research of the Earth's upper, middle and lower atmosphere. There are basically two different branches of radar methods. These are the weather radars, which operate in frequency bands above one gigahertz providing azimuth scans of precipitation and atmospheric turbulence, and so-called incoherent scatter and coherent scatter radars, which make use of electromagnetic wave scattering from free electrons in the ionospheric plasma and from irregularities in the electron density, temperature and humidity, respectively. This talk will mainly concentrate on the latter kind of radars, describe their instrumentation and present a few most impressive results.

The incoherent scatter radars, mostly operating in frequency bands below one gigahertz, require very high transmitter powers and large antenna apertures. The most prominent and original examples of these systems are the radars at the Jicamarca Radio Observatory (JRO) in Peru and at the Arecibo Observatory (AO) in Puerto Rico. Both have transmitter powers of more than one megawatt and antennas of 300 meters diameter. They can observe the Earth's near space atmosphere up to almost 2000 kilometers altitude. The JRO is located at the magnetic equator, where strong bubbles of ionization depletions convect upwards from a few hundred to more than 1000 kilometers altitude. The AO radar observes for instance the loss of atomic hydrogen from the Earth's atmosphere into space. At very high polar latitudes the incoherent scatter radar systems of EISCAT (a scientific association formed by six European countries and Japan) are used to observe the coupling of the solar wind to the Earth's magnetosphere, ionosphere and upper atmosphere. Very impressive visual phenomena of this coupling are the northern lights, also known as aurora. The EISCAT radars, operating with large steerable dish antennas, are intensively used for investigations of the aurora and the complex plasma processes related to them. Also coherent scatter radars are employed for studies of the corresponding plasma irregularites. This allows also the measurements of upper atmosphere plasma drift and wind velocities, which can exceed 1000 meters per second. Networks of these radars exist, which cover most of the polar cap regions of the Arctic and Antarctic. These are also operated by an international scientific consortium including Japan.

The radar at JRO was the prototype of the new class of systems for studies of the middle and lower atmosphere (i.e. the height region below 100 kilometers). Several radars of this kind, operating in the 50 megahertz-band, were constructed thereafter, such as the SOUSY (sounding system) radar, operated by the Max-Planck-Institute in Germany (and which has been relocated to JRO in the past years), and the MU (middle and upper atmosphere) radar, operated by the Research Institute of Sustainable Humanosphere (formerly Radio Science Center for Space and Atmosphere) of the Kyoto University in Japan. Such huge radars, using power levels up to one megawatt and antennas with diameters of about 100 meters diameter, were also installed in Alaska, India, Svalbard/Spitzbergen and recently the Equatorial Atmosphere Radar EAR in Sumatra as a Japanese-Indonesian collaboration. They allow observations of the mesosphere, stratosphere and troposphere and are therefore also called MST radars. They measure continuously winds, waves, turbulence and atmospheric stability.

Smaller versions of this kind of radars are also used in meteorological operations, when they are called wind profilers. Two networks of this kind are outstanding, such as the transpacific equatorial profiler network, was operated by NOAA/USA, which is for instance used for climatological studies in context to El Nino. The more recently installed network of 25 wind profilers, covering Japan, is mainly used for weather forecasting.

Mesosphere observations are of particular importance as well, since this is the region of the atmosphere, which is most unexplored and cannot be sensed by radiosonde balloons or satellites. Very impressive phenomena occur in the polar summer mesosphere, which is the coldest region of the Earth's atmosphere. Small ice particles are formed there between 80 and 90 kilometers, which can be seen as the Earth's highest clouds. These ice particles interact with the ionosphere and cause noticeable radar echoes. It is assumed that this has a relation to global atmosphere change.

The MST radars and wind profilers are intensively used for studies of meteorological phenomena, such as synoptic-scale disturbances, their fronts and tropopause foldings, resulting in troposphere-stratosphere exchange of minor constituents. Atmospheric gravity waves, generated in jet streams or by air flow over mountains, transport energy and momentum horizontally and vertically. They can break into turbulence, which results in vertical turbulent diffusion. Passages of typhoons (hurricanes) are also observed by MST radars. Convection processes penetrate into the lower stratosphere, where they generate waves and transport moist air into that region, affecting the global circulation system. Examples of these processes will be presented and briefly interpreted as well as their relation to the INTAR project highlighted. More discussions of the latter are to be presented in the companion talk "**INTAR – Networking of radars for small-, meso-, and large-scale atmosphere observation**".