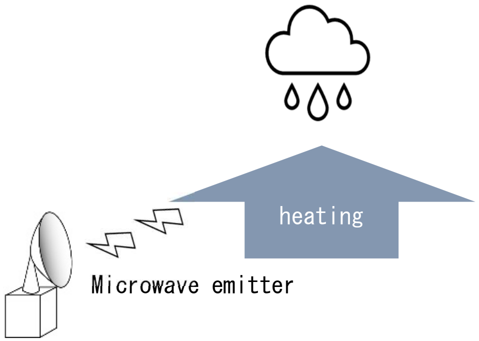
R&D item

6. Engineering

Progress until FY2023

1. Outline of the project

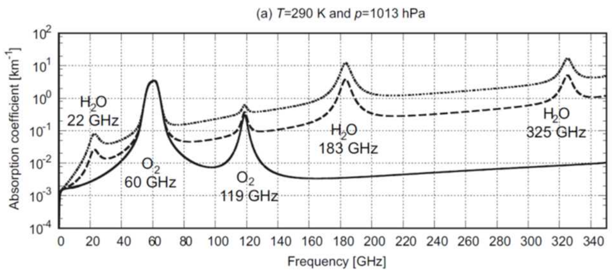
Weather intervention to prevent damage from heavy rainfall has never been tackled in human history, and is by no means an easy task, even with the cutting-edge technologies. Even if it is feasible, it requires careful consideration of safety and ethical issues. One method currently proposed is microwave atmospheric heating technology (see figure below), in which microwaves are irradiated to a certain point in the sky to promote atmospheric heating and induce the formation of raining clouds away from densely populated areas. It is essential to repeatedly run simulations on a computer prior to engineering indoor and outdoor experiments to fully confirm whether this technique is effective from meteorological and societal viewpoints.



The feasibility of microwave atmospheric heating will be verified through studies based on numerical simulations. In FY2023, we first examined the theoretical background essential for simulator program and derived a physical equation to quantify the atmospheric heating rate. From FY2024 onward, we plan to conduct studies using the simulator.

2. Outcome so far

Microwave atmospheric heating utilizes the physical processes of microwave absorption by water vapor and oxygen molecules in the atmosphere, as well as by cloud and rain water suspended in the atmosphere. By selecting appropriate microwave frequencies, the atmosphere can efficiently receive thermal energy from the electromagnetic waves. Selecting the desired frequency is the first subject to assess for our atmospheric heating simulations.



The figure above shows a microwave absorption spectrum of the Earth's atmosphere (gas component only) (from "Satellite Measurements of Clouds and Precipitation: Theoretical Basis" by H. Masunaga, Springer, 2022). In this study, we focus on the water vapor absorption line at 22 GHz and the oxygen absorption line at 60 GHz. Using the atmospheric absorption coefficient at these frequencies σ_{abs}, the equation for the heating rate in the atmosphere at a distance r from a microwave emitter with antenna gain G and power P_t is derived as follows.

$$\frac{dT}{dt} = \frac{P_t G}{4\pi\rho C_p r^2}\sigma_{\mathrm{abs}}(r)\exp\left[-\int_0^r \sigma_{\mathrm{ext}}(r')dr'\right]$$

Here, the exponential term on the right-hand side is responsible for the attenuation effect of microwaves propagating in the atmosphere along its path. In addition to this attenuation term, the effect of the microwave intensity weakens as the wave packet dilutes with distance (term inversely proportional to r^2). The atmospheric heating effect is hence expected to rapidly weaken as one moves further away from the radiator.

3. Future plans

From FY2024, numerical simulations of microwave atmospheric heating will be performed based on the physical equation derived, and a feasibility study on the heating effect will be started. Initially, we will assume a horizontally uniform idealized atmospheric model and conduct an overall analysis to determine whether sufficient heating effects can be achieved under the assumption of a technically feasible microwave emitter.

It is known that in raining clouds developing in the real atmosphere, a condensation latent heat heating of typically 1-100 degree/hour is released during condensation from water vapor into clouds. Our research direction at this point is to consider whether or not this level of heating rate can be achieved by microwave irradiation produced by a realistic emitter equipment.

In a humid environment around Japan from the rainy season to summer, air masses lifted from the sea surface begin to condense (i.e., form clouds) at an altitude of about 500 m to 1 km, and then rapidly grow into cumulonimbus clouds due to their own buoyancy as they rise higher. Therefore, a tentative goal of the numerical simulation assessment is to determine if it is possible to provide a microwave heating of sufficient intensity to target this altitude range.