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Investing in Rainfall Enhancement: An Innovative Plan for Arid Regions

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Abstract: Water security in arid regions like Qatar is a very important concern due to the limited availability of fresh water. While desalination can provide fresh water by removing minerals from saline water, the process is very costly and involves significant security issues. Desalination plants are a focus point of failure which provide most of the drinking water to cities like Riyadh and Aba Dubai. While drinking water in these modern cities in the Gulf Cooperation Council (GCC) comes from desalination, agriculture in many arid countries consumes a majority of groundwater. Groundwater in GCC deteriorated significantly due to over-abstraction. A more economical method of replenishing groundwater than desalination is enhancing natural precipitation using cloud seeding techniques, also known as weather modification. Many countries worldwide, including the United Arab Emirates (UAE) and Saudi Arabia, have conducted recent weather modification projects on rainfall enhancement. Glaciogenic and hygroscopic cloud seeding are two techniques based on solid scientific understanding used to enhance rainfall and thereby increase available water resources. Glaciogenic cloud seeding involves releasing ice nuclei (particles that cause formation of ice crystals) into clouds with super-cooled liquid droplets, while hygroscopic cloud seeding involves introducing large-sized hygroscopic particles at cloud base. To enable effective targeting of specific cloud regions, aircraft are typically used to deploy seeding particles. Seeded clouds have the efficiency of the precipitation process increased since the seeding particles are typically not naturally abundant.

Atmospheric conditions important for precipitation development vary widely. For example, Mali in West Africa has cloud condensation nuclei condensations of 100-200 #/cm^3, while in an arid region such as Saudi Arabia the concentration is 1200-1800 #/cm^3. Therefore, a rain enhancement program should start with assessing the region's unique environment. The assessment should include measurements of the aerosol, cloud condensation nuclei, and cloud droplet concentrations; distribution of cloud base height and temperature; occurrence of super cooled liquid water; storm cell frequency, duration, and diurnal/seasonal variations. Obtaining these types of details on cloud properties requires a research aircraft such as the University of North Dakota's Citation Research Aircraft. The Citation Research Aircraft is a modified Cessna jet designed for conducting atmospheric research. The aircraft's basic instrument package includes measurements of speed, position, and atmospheric state parameters, such as temperature, relative humidity and winds. The Citation Research Aircraft also has very advanced instruments to conduct measurements of hydrometeor concentration, size and mass. The detailed measurements provided by a research aircraft should be supplemented with remote sensing observations made by radar and satellite platforms. Atmospheric observations provide knowledge of how variations in cloud condensation nuclei affect precipitation formation and how effective seeding particle are on increase precipitation amounts.

A well-planned program assesses the region's conditions during Phase I before developing an

operational plan to start cloud seeding. The operational plan's effectiveness would be assessed during a Phase II of the project. Scientists determine cloud seeding effectiveness by fully understanding the physical processes involved and/or by conducting a statistical analysis. Measurements that enable the region's important precipitation process to be accurately model provide a method for understanding the effectiveness of the seeding program. To statistically assess a program's effectiveness requires controls to compare with seeded clouds. If a program seeds all clouds which is typically done in a fully implemented weather modification project, then controls are not available to enable an assessment.

An effective rainfall enhancement program requires a great deal of infrastructure and highly skilled personnel, which requires time to implement. Hence, it is best to plan a program over several years and understand that a successful program will required a continuous commitment over a 5-10 year period. Ideally, a long-term program would be cyclic, repeating the regional environment assessment, cloud seeding effectiveness evaluation, and operational program design phases approximately every 10 years to allow for implementation of the latest methodology and technology. Ideally, a rainfall enhancement program would include an ongoing research component to develop new weather modification methods and optimize existing methods for specific regions. For example, researcher should optimize hygroscopic flares for arid regions. Analyzing existing measurements and conducting new measurements with state-of-the-art instruments enables incorporation of cloud condensation nuclei measurements into models operated at cloud-allowing scales and designed for arid regions. The latest version of the Weather Research and Forecast (WRF) model includes the necessary micro-physical processes to account for precipitation changes due to different aerosol concentrations and land surfaces. Changes in cloud condensation nuclei concentration affect the cloud droplet size distribution and hence precipitation formation. Different land surface have different latent and sensible heat fluxes which affects cloud formation. Models that incorporate aerosol and land surface affects should provide accurate precipitation simulations. Simulations of arid region for several seasons allow the model to be validated. The validated model can then be used to access how different types of seeding material affect the region's precipitation. Once the optimized type of seeding particle is determined, new flares for arid regions can be designed. The new flares should be tested using aerosol and cloud chambers. To determine how newly developed flares can enhance precipitation formation, WRF model sensitivity studies should investigate how changes in the cloud droplet distribution seen in chamber research affect precipitation amount.

The research component results is knowledge on how optimize seeding flares enhances the precipitation formation processes in an arid environment. Combining the increase in precipitation from the validated model simulation with the cost of conducting an operational program allows for a cost-benefit study to be conducted. Such a cost-benefit study would have to involve determining how much of the precipitation increase is available for near-term use and how much water is lost due to run-off and evaporation. Until the necessary atmospheric measurements are made and the precipitation model validated, it is not possible to know the exact price for fresh water created using weather modification methods in arid regions. However, studies indicate an increase of 5-10% with a relatively low-cost. Therefore, weather modification projects produce water at a cost far below other methods such as desalination. In conclusion, cloud seeding is a promising technique to augmentation precipitation to recharge depleted groundwater in countries such as Qatar; however, weather modification projects should considering the points highlighted above and plan to evaluate applied technique using a scientific assessment.

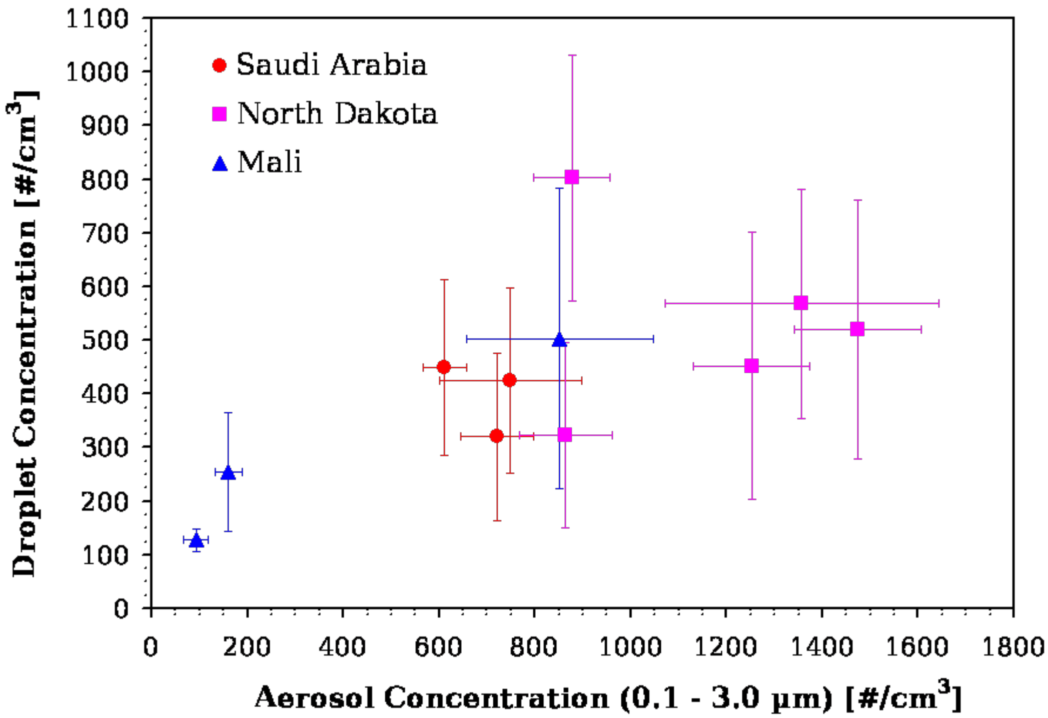

Figure 1: The aerosol and cloud droplet concentration obtain on different days during weather modification assessment programs using a research aircraft.