Rainfall Enhancement in the Hajar Mountains, Oman

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Introduction

Oman is one of most water-stressed countries in the world and is highly dependent on declining groundwater resources, and facing decreases in rainfall in the coming decades. Consequently, any technology that has the potential to increase natural rainfall and thereby increase groundwater recharge and water supplies, is of considerable interest. Australian Rain Technologies (ART) partnered with local company Trading and Investment Establishment (TIE) in the operation of a rainfall enhancement trial using a ground-based ionisation technology known as Atlant, in the Hajar Mountains in western Oman from May to October in 2013. This period was chosen to capture the high incidence of convective storms with suitable conditions for rainfall enhancement in this area[1].

Two ionising arrays were installed in the Batinah/Dakhliyah Region of Oman (Figure 1). Independent assessment of the effect of the Atlant technology based on rainfall and meteorological measurements recorded during the trial was conducted by the National Institute for Applied Statistics Research Australia (NIASRA) at the University of Wollongong. The 2013 Oman Rainfall Enhancement Trial builds on the series of Atlant trials undertaken in Australia 2007-2010.[2,3,4]

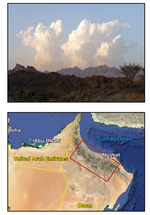


Figure 1. Trial location

Rain Enhancement by Ionization

Ground-based ionisation has a history of investigation, including field experiments into the electrification of clouds via the releases of ions into the sub-cloud air using a high-voltage power supply that generates corona discharges from an extensive array of small diameter wires exposed to local winds and updrafts.[5] Several mechanisms exist by which ions might influence the microphysical processes of precipitation formation at multiple stages through the process.[6] In particular, there is evidence consistent with ions enhancing the coalescence efficiency of charged cloud droplets compared to the neutral case.[7] However while previous studies provide at least semi-plausible "chain of events", mechanisms by which generated ions may influence precipitation, they are yet to be verified observationally.

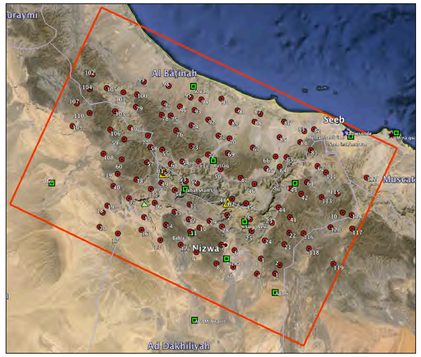
Atlant Ion Emitter

Each Atlant ion-emitting device consists of a high-voltage generator connected to a large network of thin metal wires supported on a frame with a series of pyramids on top (Figure 2). It generates voltages of 70-100 kV.

Figure 2. Atlant H2 (Hajar Mountains, Oman)

Trial Design

Two Atlant systems were located on the north side of the Hajar Mountains, H1 (2670 m) and H2 (2157 m) (Figure 3). Data was collected from 11 Automatic Weather Stations (AWS) operated by Oman Directorate General of Meteorology and Air Navigation (DGMAN). Due to the localised and short-lived nature of rainfall throughout the trial area, 120 rain gauges were also installed by TIE on an approximate 10 km regular grid. TIE also installed two AWS at the Atlant sites. All AWS and rain gauge data was provided hourly. Vertical profile data from Seeb International Airport radiosonde was also used. The launches occurred at 00z daily (4am local time). The trial employed a randomised crossover design, with the two Atlant sites operated on a randomly predetermined alternating schedule throughout the trial with no breaks (170 days from 15 May to 31 October).



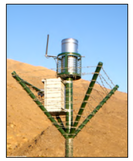


Figure 3. Trial Area. Instrument array. (Rain gauges - red circles. Surface weather stations- green squares. Radiosonde – blue star. ATLANT™s - yellow triangles).

The fundamental aspect of the evaluation methodology used in this trial is the use of a spatio-temporal statistical models to capture natural rainfall variation, enabling prediction of the level of unobserved rainfall (natural rainfall) that would have occurred in the target area if the ionisation emitters had not been operated. The potential effect is then the difference between observed rainfall and the estimated natural rainfall. The statistical model adopted for this purpose is itself rather complex, being a mixture of fixed effects, based on meteorological and topographic covariates, plus random spatial and temporal affects to account for correlations in the data due to systematic but unmeasured influences that might be inadvertently attributed to the operating status of the system. In particular, this methodology follows that employed previously, using dynamically defined target and control areas.[4]

Analysis

Model Specification

A key assumption the evaluation approach is that exposure of rainfall gauges to the Atlant depends on wind direction and speed at and above the ion generator on any particular day, with a rainfall gauge classified as being a target (exposed) gauge or a control (unexposed) gauge on the basis of its distance from the Atlant sites and its relative orientation to the steering wind direction vectors at these sites.

Given the variability of surface winds, the local orography, and day to day variation of steering winds, we present modelling results based on a 'corridor' model (Figure 4), where target and control gauges are designated on a daily basis as being those gauges located in two 30km wide and 75km long rectangular corridors oriented in the direction of the steering wind and extending downwind of the operational Atlant (target gauges) and the non-operational Atlant (control gauges). Steering wind defined daily from Seeb soundings at 750hPa/500hPa as advised by DGMAN.

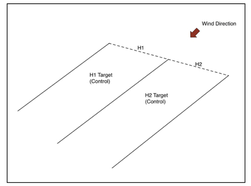


Figure 4. A stylised corridor model for designating target and control gauges

Rainfall Modeling Analysis

The objective of the statistical modelling is to allow estimation of the potential attribution, of the Atlant systems to rainfall over the trial area, measured as the estimated percentage increase in observed rainfall compared with natural rainfall. This estimation is carried out in three stages. The first stage involves construction of the instrumental variable that correlates with the expected amount of natural rainfall at a gauge on a day. This variable is defined by the values generated by a model for the rainfall recorded by gauges in the upwind part of the 30km corridors for the target and control areas. The second modelling stage involves fitting a model to the rainfall data in the downwind (i.e. target and control) area using a range of meteorological and topographic covariates including the instrumental variable. The third stage uses this downwind model to estimate how much of an increase (or decrease) in observed rainfall at a gauge should be attributed to the operation of the Atlant system. These gauge by day attribution estimates are finally summed over the gauges reporting rainfall over the trial to provide an overall estimate of the change in the amount of downwind rainfall observed over this period due to operation of the Atlant system.

The estimated Atlant attribution is a complex nonlinear statistic, and its sampling distribution cannot be calculated directly from the fitted model for LogRain (modelling is based on the logarithm of rainfall). In the final modelling stage, we resolve this issue by using a spatio-temporal implementation of a block bootstrap method[8], with the spatio-temporal blocks defined by the control and target downwind corridors on the day. This allows us to generate a robust estimate of the sampling distribution for the estimated attribution that is consistent with the rainfall and other meteorological and orographic information obtained during the trial.

Results

Operation of the Atlant systems was estimated to have led to a positive and significant rainfall enhancement effect. Overall total attribution (enhancement effect) in the trial area defined by the corridor model, as a percentage of estimated natural rainfall, was estimated to be 18 per cent with a bootstrap standard error of 8.4 per cent. The bootstrap analysis indicates that this attribution is significantly greater than zero at a 99 per cent level of confidence, with a lower bound of 1.1 per cent for the bootstrap 90 per cent confidence interval for this attribution (Table 1).

Model	Mean level Rainfall Enhancement Effect	Standard Error	Confidence Level Enhancement Effect > 0
30Km Corridor	18.0 %	8.4 %	99 %

Table 1. Summary of results

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While there was a positive Atlant attribution at the two Atlant sites, the attribution was substantially higher at H1 as opposed to H2 and the local attribution at H2 was not statistically significant. Detecting a significant enhancement effect at the individual sites is more difficult than for the trial area as whole. The question of whether the lower attribution downwind of H2 can be explained by other factors remains open. One possibility is this is due to the complex orographic effects that can occur in mountain ranges. Gaining a better understating of the orographic effects would require the deployment of vertical wind profiling at the Atlant sites, additional rain gauges and Atlant sites with operating schedules that ensure adequate separation between target and control gauges. Such deployment in the existing and a possible expanded trial creates the opportunity to investigate the broader processes that generate Oman summer rainfall directly in the environment of interest.

2014 Trial

The Oman rainfall enhancement trial was conducted over the same period in 2014 with the addition of two more Atlant installations, two SODAR wind profilers (Figure 5), and 40 extra rain gauges. Preliminary analysis of the SOADR data clearly showed that the orographic features gave rise to quite different vertical wind profiles at H1 and H2.

Figure 5. SODAR wind profiler installed at H1 in 2014

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