An analysis of 40+ years of intermittent cloud seeing cover central Tasmania

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MONASH University Science

International Symposium on Weather Modification

Current Weather Modification Research in Australia

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TIFF (Uncompressed) decompressor
are needed to see this picture.

South Eastern Queensland

2007-2010

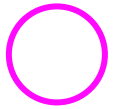
Snowy Mountains

2004-2009

Central Tasmania

Ongoing (1964 - present)

South Eastern Queensland



QuickTime™ and a
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are needed to see this picture.

- Announced December 2006
- Science plan still being finalized
- Hygroscopic seeding planned for spring and summer convective clouds
- Funded by the state government of Queensland

Snowy Mountains, New South Wales

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

- Snowy Precipitation Enhancement Research Project (SPERP) 2004-2009
- Glagiogenic seeding to winter orographic clouds
- Privately funded by Snowy Hydro
- Received an Federal grant for Renewable Energy (December 2006)

Central Tasmania

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

- Operational cloud seeding
- Glaciogenic seeding to primarily frontal systems, Winter and late Spring
- Funded privately through Hydro Tasmania
- Australian Research Council Industry Linkage Grant awarded from 2005-2008.

Outline

- Historical background
- Observations available
- Science questions
- Analysis of target area precipitation
  - Analysis of variance (ANOVA)
  - Monte Carlo
  - Sampling Error
- Analysis of control areas
- Outstanding Issues

Historical Background

Australia, through the CSIRO, conducted cloud seeding experiments in Australia from 1947-1994 (see Ryan and King, BAMS, 1997)

The vast majority of these experiments have proven to be inconclusive, and as a consequence CSIRO no longer undertakes any cloud seeding activities.

The catchment area of Central Tasmania is unique in that it has been the target of three separate experimental seeding programs, as well as two operational seeding programs.

Historical Background

Seeding period	*Mode*	*Seeding agent*	*Number of winters seeded*
*1964-1971**	Research	Silver Iodide	4
1979-1983	Research	Silver Iodide	5
*1988-1991***	Operational	Silver Iodide	4
1992-1994	Research	Dry Ice	3
*1998-2005****	Operational	Silver Iodide	7

* no seeding at all during the winters of 1965, 1967 and 1969

** seeding period from May through November only

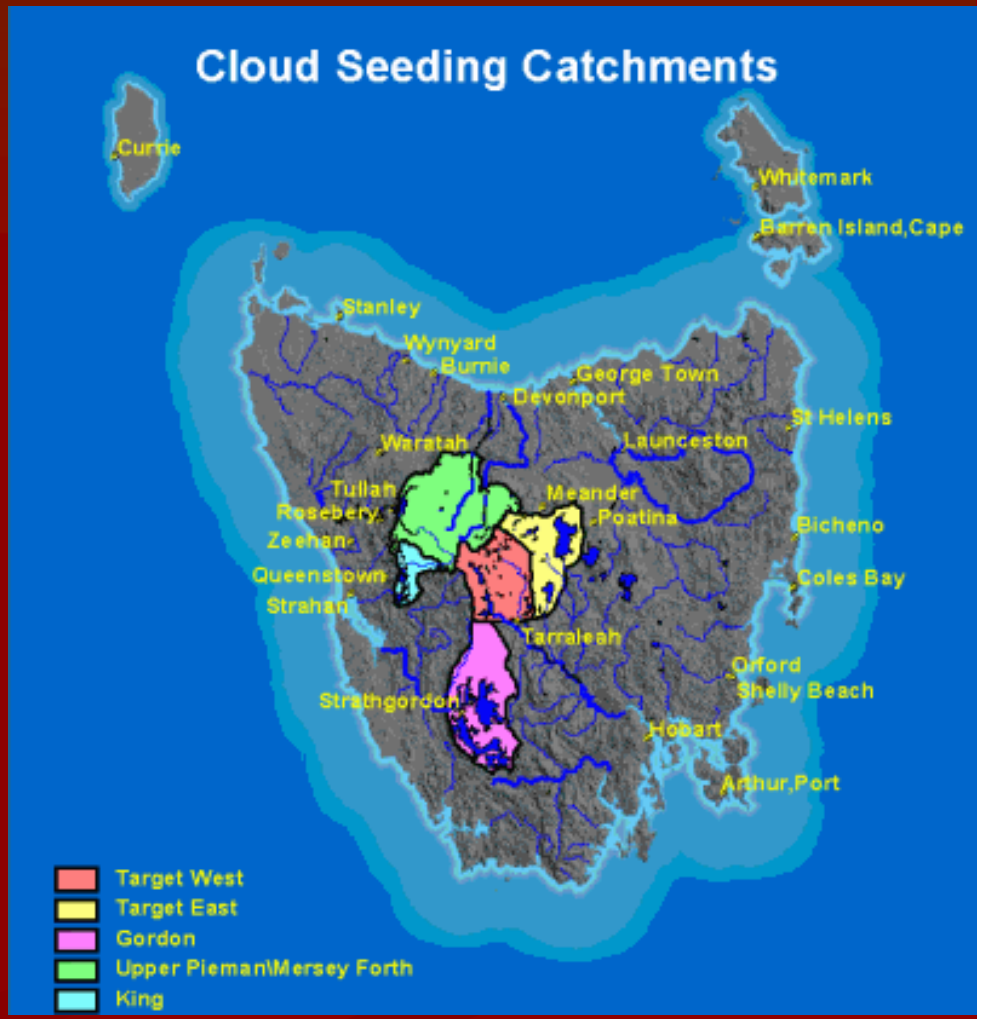
*** winter seeding began in 1999

Historical Background

Why is Tasmania so special?

It was reported by the CSIRO that precipitation was enhanced by **30%** in the Autumn of the first experimental period and **37%** in the second experimental period.

It isn't clear that these results were ever published in peer-reviewed literature.



Historical Background

In the words of the Committee on the Status of and Future Directions in U.S. Weather Modification Research and Operations of the U.S. National Academy of Sciences (2003), **“there still is no convincing scientific proof of the efficacy of intentional weather modification efforts.”**

In short, the great natural variability of precipitation makes it very difficult to obtain conclusive statistical results.

Science Questions

Have the five interspersed cloud seeding operations over the last 40^{+} years over central Tasmania left a detectable signal in the precipitation records?

Can we somehow combine these separate cloud seeding operations into a single experiment?

Data Preparation

What is an appropriate unit of time for this analysis?

The five different seeding periods have employed various seeding strategies. The first experimental period, seeding was undertaken in 12 day blocks. The second experiment looked at individual precipitation events. The operational periods have seeded whenever the meteorology is appropriate.

We have chosen to prepare the data as monthly totals

This has a number of advantages

There is greater confidence in the records on this timescale

Rainfall variability is much more manageable

The definition of the seeding mask is concise

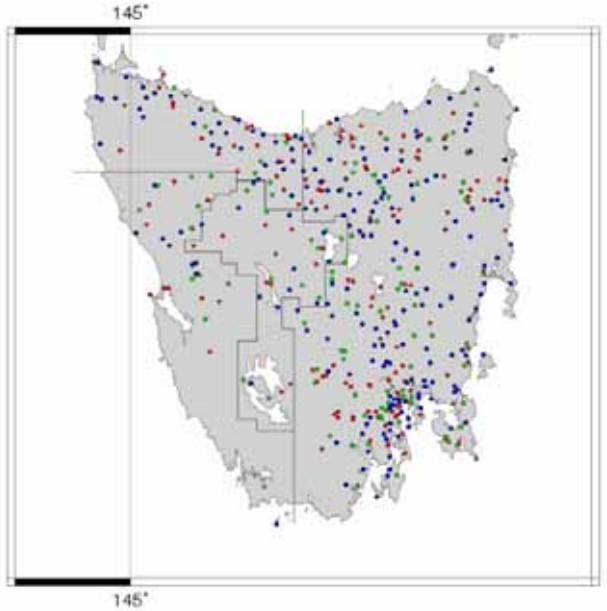
The obvious disadvantage is that rarely has an entire month been seeded even during the operational periods. Any signal is likely to be that much weaker.

Data Preparation

We have chosen not to use synthesized or processed rainfall for this analysis to avoid hidden biases, instead we have employed the original rain gauge observations.

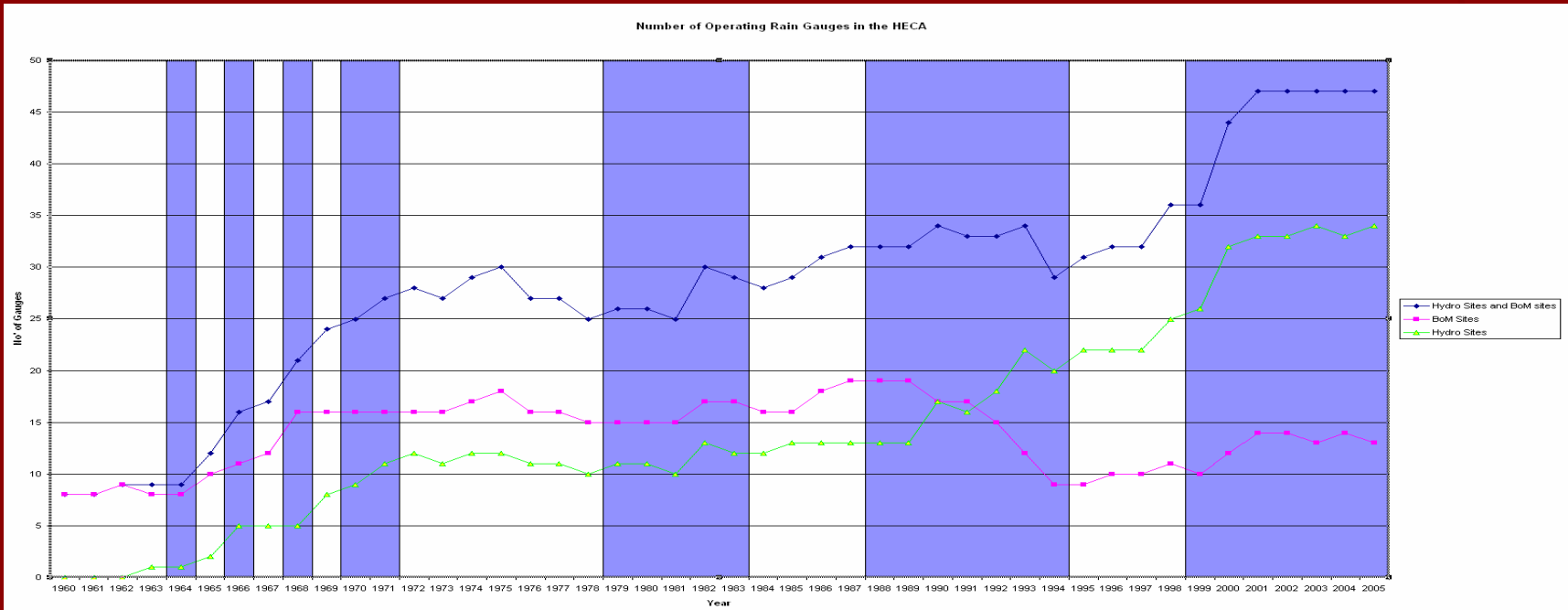
The Bureau of Meteorology maintains a historical record of over 1000 rain gauge sites in Tasmania that date back to before 1900. Over this time, there have been 53 sites located in the catchment area.

Hydro Tasmania independently records a network of 89 stations that date back to the late 1950's. 39 of these sites are in the target area, and a handful are shared with the Bureau of Meteorology.



Data Preparation

Unfortunately the vast majority of these sites have not operated continuously from 1960-2005. Indeed the is only ONE site in the target region that has operated the entire duration.



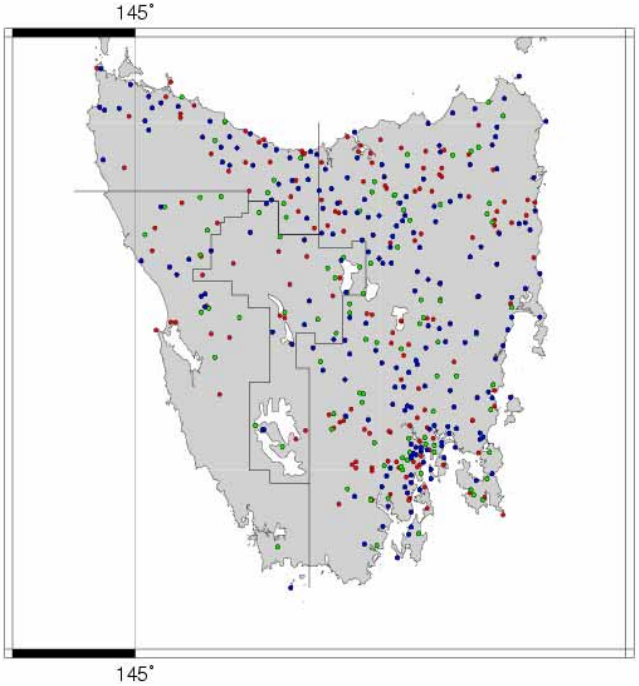
Data Preparation

Roughly a dozen of these rain gauges in the central catchment area have only been installed in the past 8 years. These observations can offer no insight into unseeded periods.

As a means of filtering the data we consider those rain gauges that have operated for a minimum of **75, 50 or 25%** of the time from 1960-2005.

As additional tests to the sensitivity to the data, we have also extended the analysis to run from 1950-2005. We have also considered using only Bureau of Meteorology data.

Perhaps surprisingly, we have found the results to be relatively insensitive to these various filters.



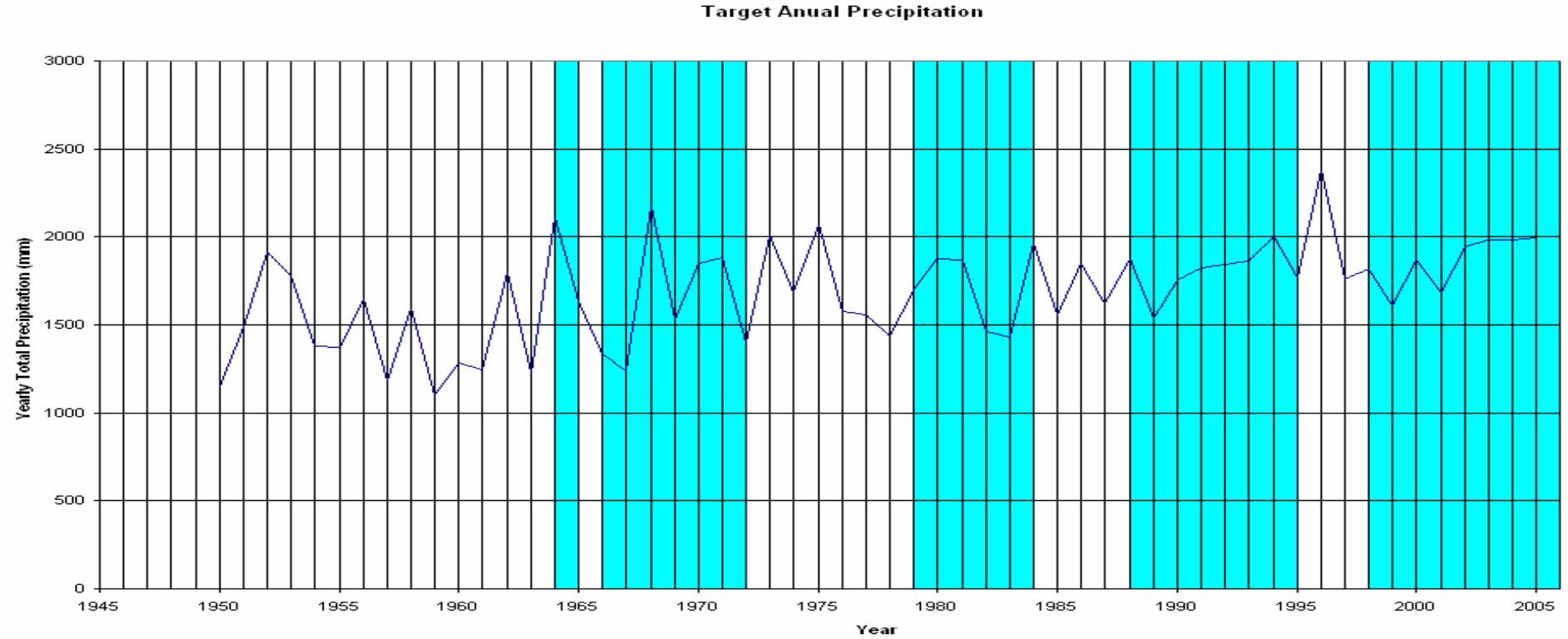
Data Preparation

There are advantages and disadvantages to this approach.

- The most notable disadvantage is that we have built in a sampling bias. If, for example, more sites were operating in wet locations for limited periods of time, this will color the results. (We will attempt to address this bias later on.)
- Another caveat is that the boundaries of the target region have steadily been increasing over the last two seeding operations.

Data Preparation

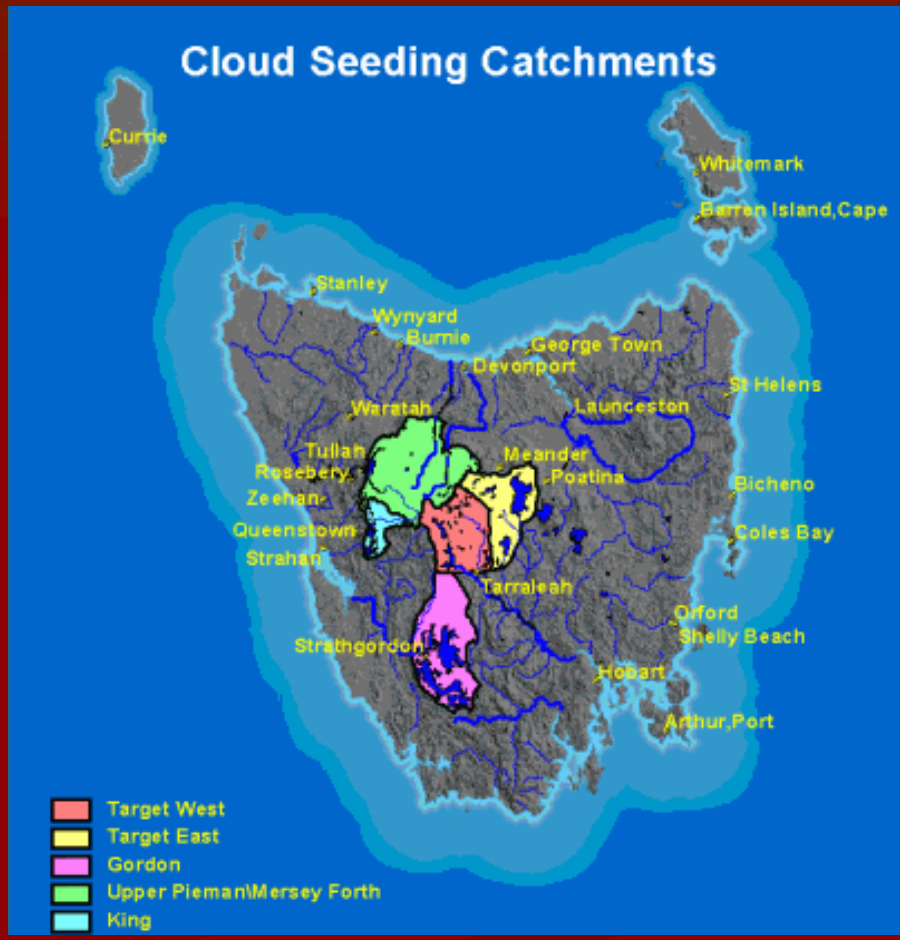
For example, the precipitation for the minimum 50% duration, 1950-2005 for the Bureau of Meteorology sites only is shown below. Note this is the annual total only, not the monthly values actually used in the analysis.



Data Preparation

The target site for the first of the experiment period (1964-1971) was much smaller. The original analysis also split the target region up into an east and a west zone.

We average over all selected sites for the entire target region. This should serve to further weaken any signal.

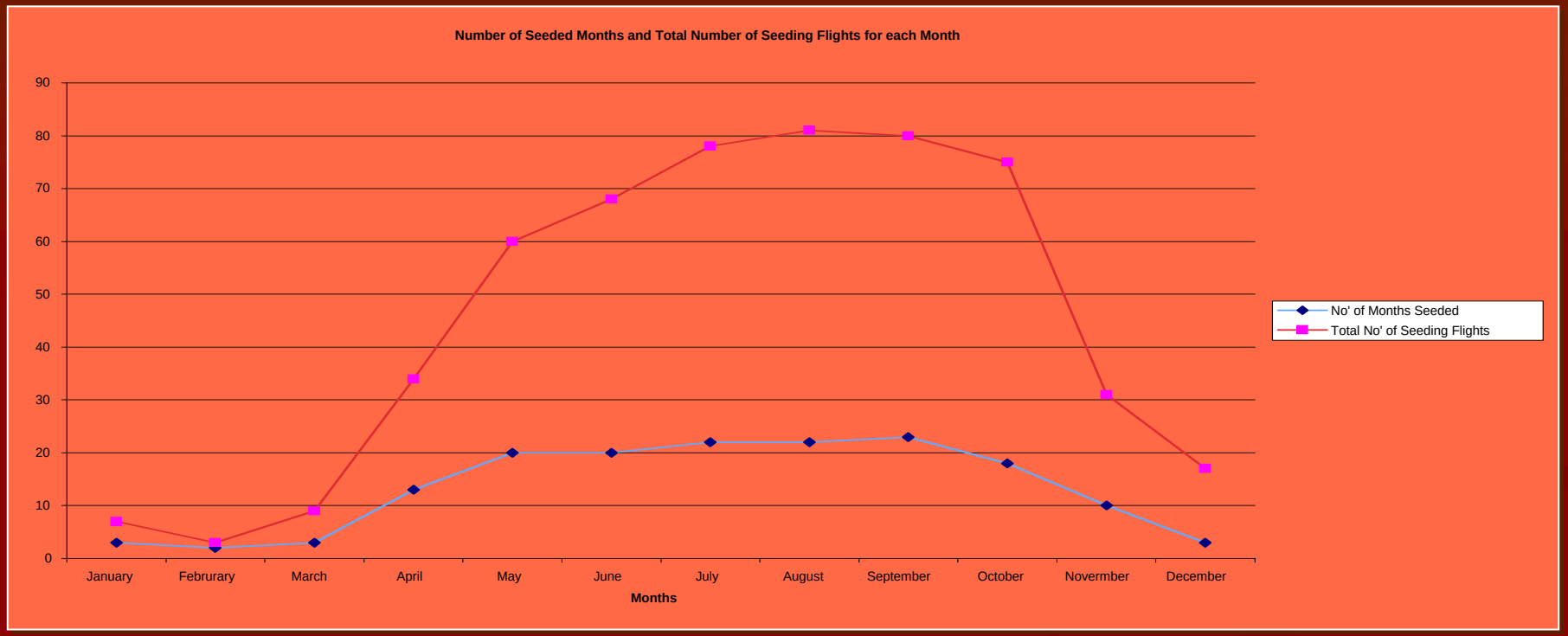


Analysis

- We are left with a 12 x 46 array of area-averaged monthly precipitation values for each of the 12 different site selection groupings.
- We also have defined a corresponding seeding mask array which has either a one or a zero for an entry, depending on whether any cloud seeding was undertaken.
- Even one single cloud seeding operation in a given month will define the month as have been "seeded."

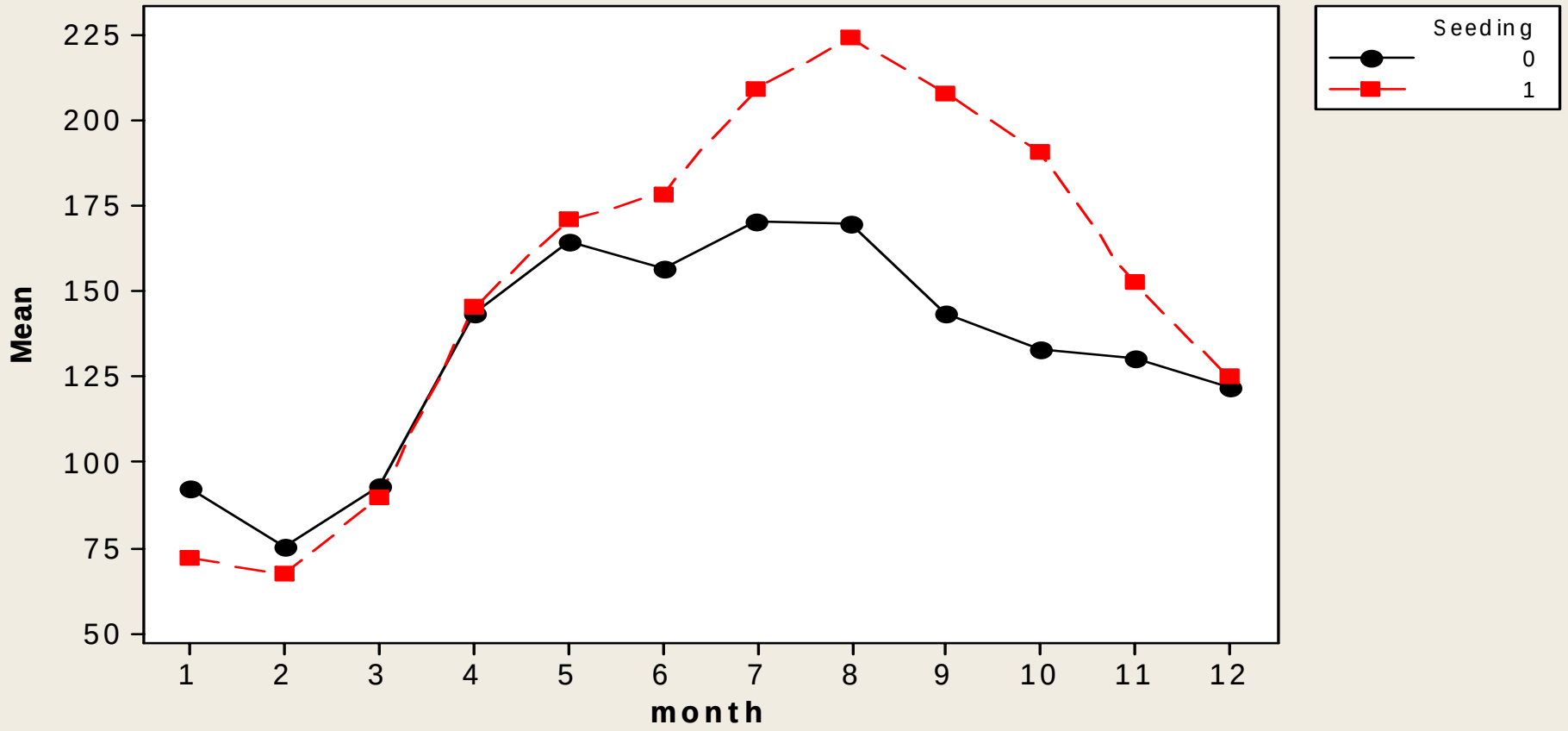
	1	2	3	4	5	6	7	8	9	10	11	12
1963												
1964					1	1			3	2		3
1965												
1966	3	1	4	4	2	3	1	1	2		2	4
1967										8	8	9
1968	3	2	4	7	11	7	5	7	6	13	8	1
1969	1											
1970			1	4	1	4	12	5	7	2		
1971					6	2	2	3	1	3		
1972												
1973												
1974												
1975												

Analysis



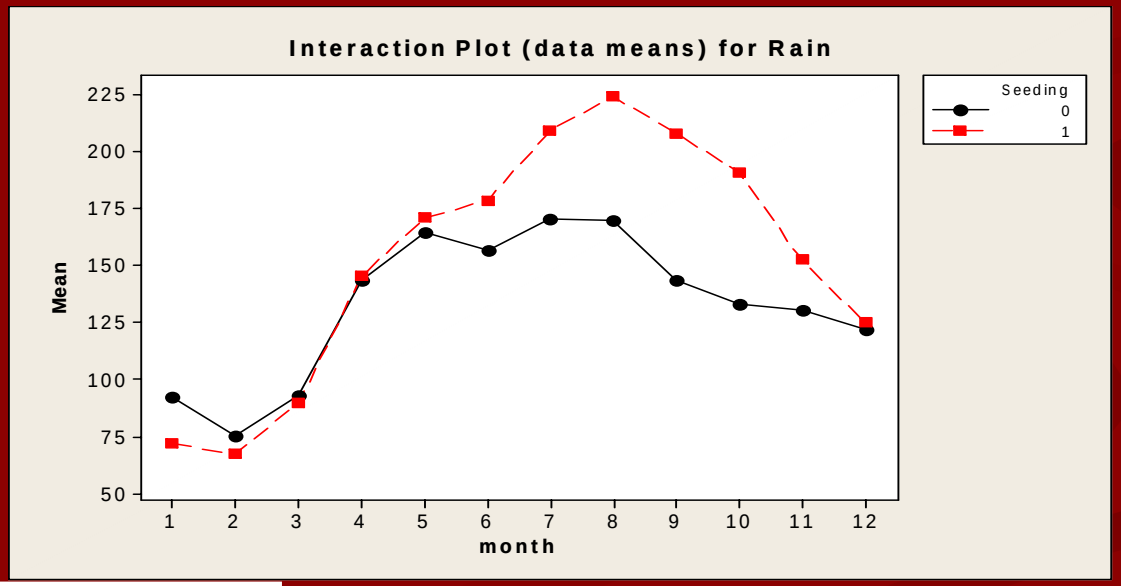
Seeding has primarily taken place from May to October. On average, Hydro Tasmania will seed four times a month.

Analysis


Interaction Plot (data means) for Rain
Mean
225
200
175
150
125
100
75
50
1
2
3
4
5
6
7
8
9
10
11
12
month
Seeding
0
1

Analysis

Incredibly, the monthly averages show a 30-40% increase in rainfall during the late winter and spring when seeding was applied. Again, seeding was only applied approximately 4 times per month.



Analysis of Variance Test

An ANOVA was performed with the 3 factors:
Month, Year and Seeding
All were found highly significant

Source	DF	Seq SS	Adj SS	Adj MS	F	P
month	11	914832	552283	50208	13.40	0.000
year	55	361204	323164	5876	1.57	0.007
Seeding	1	65024	65024	65024	17.35	0.000
Error	600	2248791	2248791	3748		
Total	667	3589851				

S = 61.2208 R-Sq = 37.36% R-Sq(adj) = 30.36%

Least Squares Means for Rain

Seeding	Mean	SE Mean
0	132.1	3.159
1	167.4	6.811

Restricting the analysis to months 12-5 we find that seeding is not significant for Summer or Autumn.

Monte Carlo Analysis

A more crude, but more compelling test is to undertake a Monte Carlo upon the seeding mask. ***Effectively we are asking whether the seeding mask makes any difference to the outcome.***

10,000 randomizations of the seeding mask were undertaken. Our Monte Carlo approach preserves the number of times seeded for each month.

Two methods of randomisations were considered: a permutation of the mask, and a random draw. The permutation method returns greater values for the standard deviation.

	January	February	March	April	May	June	July	August	September	October	November	December
1957	18.347	47.988	11.37	39.151	32.182	42.846	41.757	56.652	43.63	42.19	47.96	21.896
1958	41.629	46.601	52.822	46.309	47.165	43.402	38.192	33.53	57.853	33.484	22.794	23.093
1959	43.74	62.002	33.258	32.259	25.702	55.775	24.876	25.457	42.338	30.834	31.4	32.135
1960	25.096	47.687	44.256	38.054	41.118	36.429	55.388	50.499	32.954	46.606	38.101	20.649
1961	55.482	31.633	43.043	34.348	13.941	38.269	39.799	40.536	61.244	34.528	43.225	47.261
1962	55.459	44.944	40.279	38.969	33.59	23.483	46.971	30.169	50.728	42.979	39.004	36.394
1963	39.511	26.881	26.949	59.957	46.007	18.373	30.686	38.841	43	27.527	62.596	23.182
1964	44.255	39.746	27.687	32.116	35.827	30.854	31.478	13.885	48.731	38.101	61.086	28.45
1965	42.27	39.373	35.132	22.484	56.075	43.651	44.087	54.091	33.395	49.679	48.144	27.175
1966	37.573	40.001	24.583	46.102	31.793	32.964	41.389	27.245	51.133	28.424	41.194	39.069
1967	49.435	35.868	26.273	28.254	9.7723	22.664	64.027	31.05	43.491	41.808	29.501	8.6103
1968	32.352	54.235	59.142	40.466	23.989	53.945	36.424	57.413	48.125	36.93	34.003	30.973
1969	68.381	15.638	40.725	31.842	53.723	30.743	68.763	28.18	26.385	39.019	21.722	21.912
1970	38.227	45.566	24.175	46.96	38.528	39.853	59.611	34.633	59.964	35.339	35.131	44.285
1971	41.481	51.643	39.464	47.187	44.93	39.989	14.714	33.42	45.648	12.991	33.878	47.781
1972	53.868	49.502	25.332	37.352	52.275	36.757	18.153	61.057	15.077	38.134	62.767	41.913
1973	40.771	47.512	22.459	13.294	12.434	45.155	32.544	41.052	46.109	58.113	49.792	38.681
1974	38.757	40.524	36.606	41.723	31.619	36.568	37.584	25.946	56.567	48.473	40.845	5.7452
1975	29.179	48.802	52.395	60.708	30.844	18.368	40.116	25.381	48.301	35.097	36.194	40.365
1976	43.827	47.396	41.672	53.239	26.764	26.623	50.88	62.564	57.95	31.401	41.077	28.608

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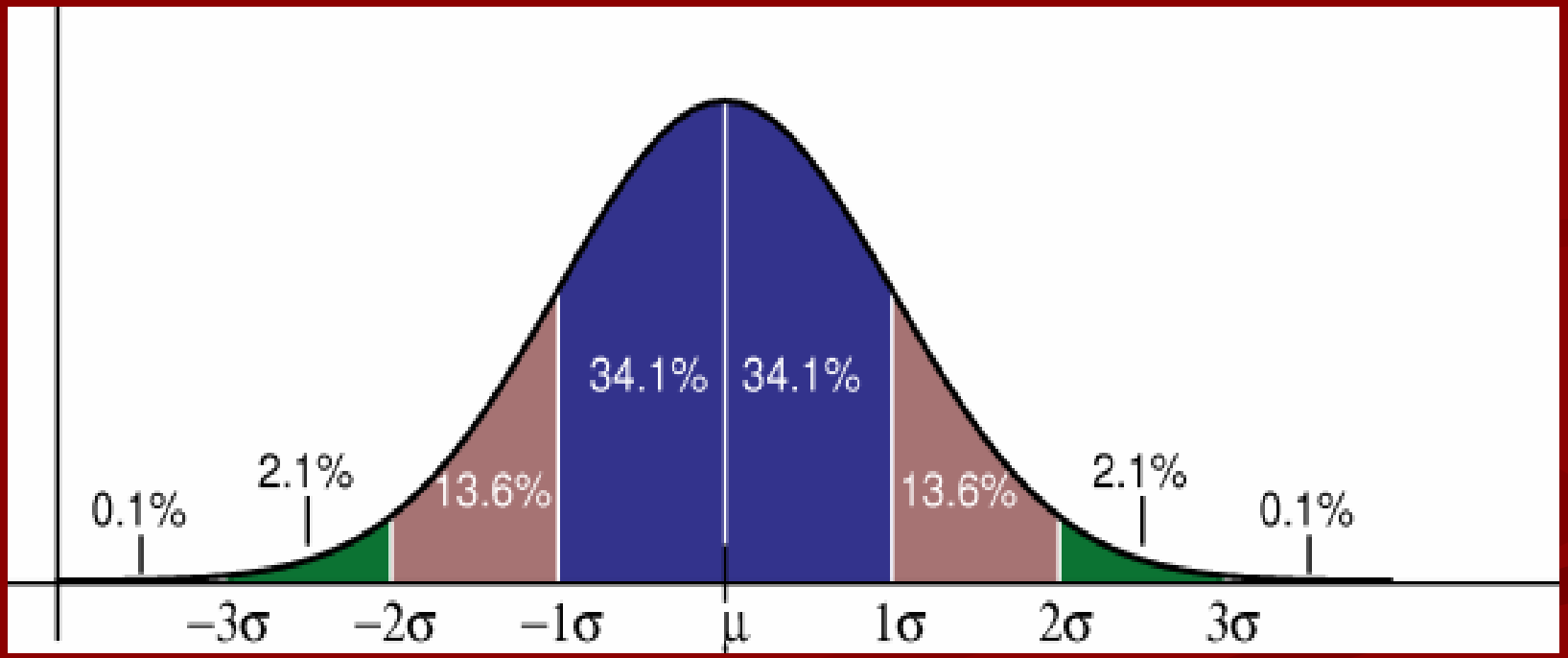
1976	43.827	47.396	41.672	53.239	26.764	26.623	50.88	62.564	57.95	31.401	41.077	28.608

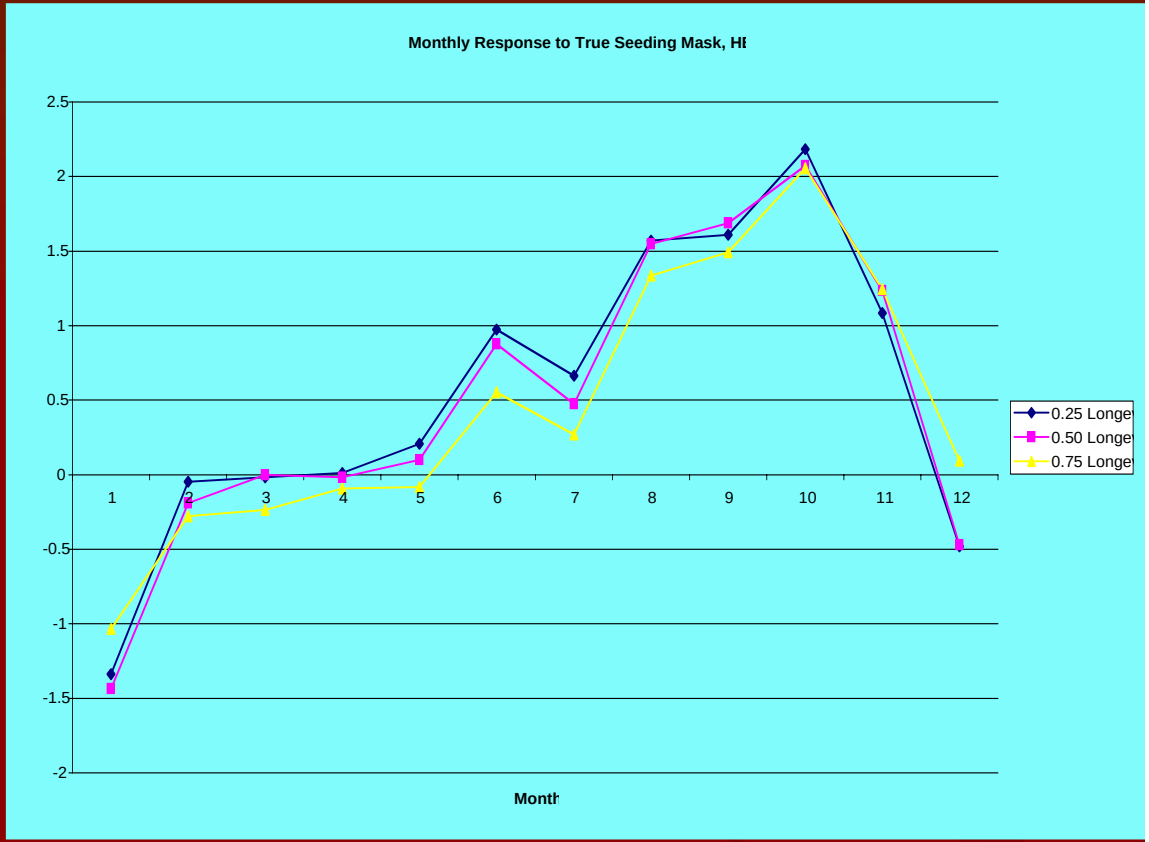
Monte Carlo Analysis

A 2-3 standard deviation increase in the precipitation from the overall average suggests that the cloud seeding has been highly effective.



Monte Carlo Analysis

- A 2-3 standard deviation increase in the precipitation from the overall average suggests that the cloud seeding has been highly effective.
- Note that if the “permutation” method of Monte Carlo rearrangement was employed, the standard deviation would be nearly 3 for October.



Outstanding Caveats

Sampling Bias

What is the potential bias/error brought about by the limited period of operation of the various rain gauge sites over the duration of the experiment?

Long-term climatological trends

The application of the seeding agent has not been random over the years. Indeed, there is a clear bias towards seeding in more recent years. What if these years are wetter than average?

Sampling Bias

To test for potential sampling bias we re ran the analysis with idealized, unbiased data for each site. For each site and month, we calculate the mean and standard deviation. We then created normally distributed monthly rainfalls and returned these quantities to the records and redid the analysis. This exercise was repeated 100 times.

Note, that this exercise is completely independent of the actual seeding mask.

The sampling bias was found to be primarily between -1.0 and 1.0 standard deviations. In general, the sampling bias was stronger (and positive) for the time period of 1950-2005 than for 1960-2005.

Long Term Climate Trends

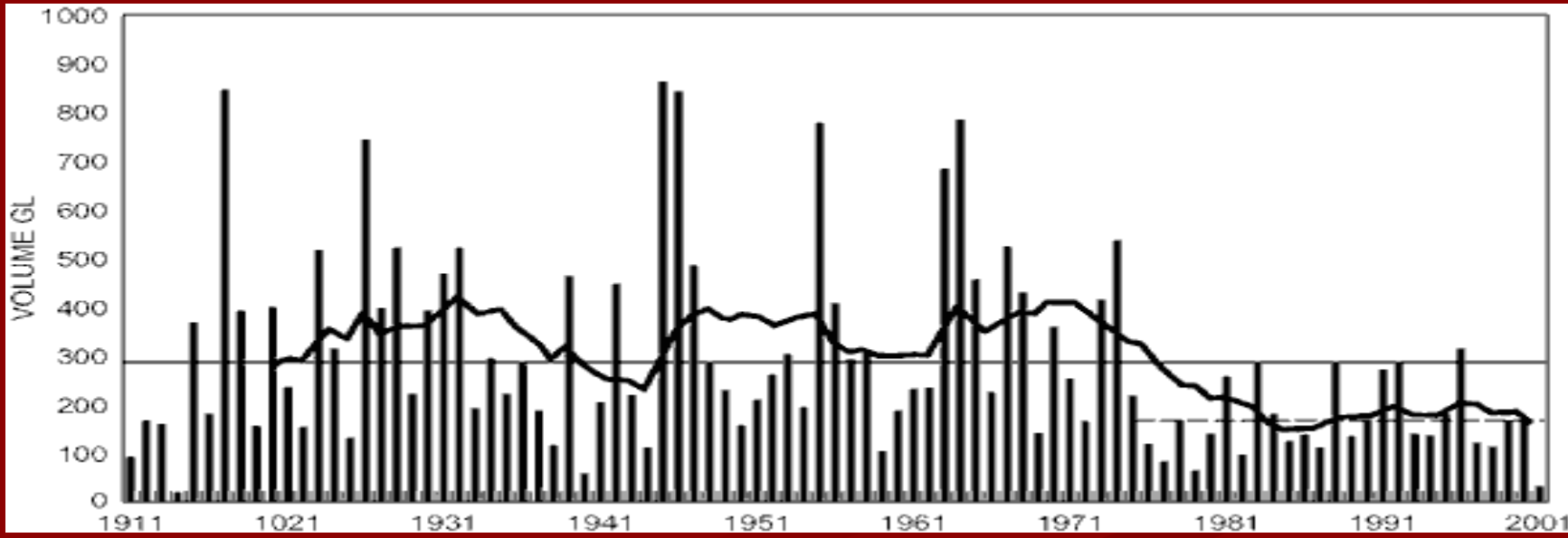
While the decision to seed was made with no consideration of things like ENSO, the Antarctic Circumpolar Wave (ACW) or the Indian Ocean Dipole (IOD), it doesn't mean that there isn't any correlation. For example, it is reported in the literature that rainfall in Tasmania is sensitive to ENSO.

Early calculations have found no significant correlation with these climate indices.

Long Term Climate Trends

It is also very possible for long-term climate trends to occur in the precipitation records.

The rainfall in southwestern Australia is a prime example where annual precipitation amounts appear to have decreased 15-20% rather suddenly in the early 1970s.



Long Term Climate Trends

We were also urged by both the Hobart office of the Bureau of Meteorology and a number of climate scientists familiar with Tasmania to investigate whether this signal can be found outside of the central plateau. In particular, some earlier work by Pook and Budd suggested that a signal was evident outside of the target region to the west of the catchment.

Cloud-seeding puts dampener on towns
Matthew Denholm
23 September 2006

THE AUSTRALIAN

WHILE much of drought-stricken Australia debates whether cloud-seeding is effective, Tasmania's west coast community complains it works too well.
West Coast Mayor Darryl Gerrity said cloud-seeding - the use of chemicals to make rain - by power and water utility Hydro Tasmania was damaging tourism and making life wetter than nature intended.
"We've got children at our schools who get cabin fever because they can't get out to play because it's raining so much," Mr Gerrity said.

Analysis of Control Areas

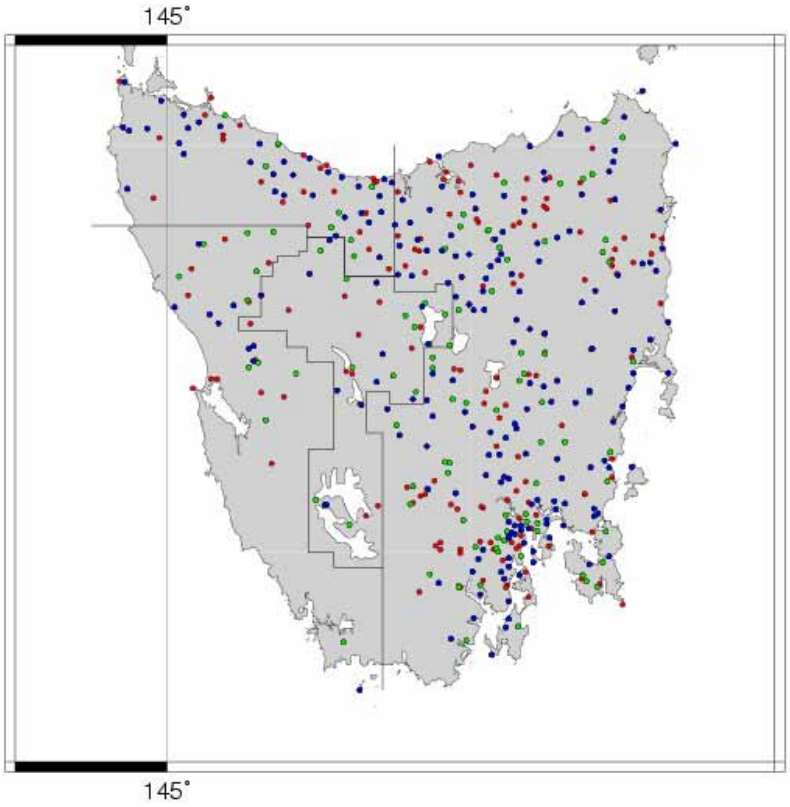
Four “control” areas have been considered.

A west control

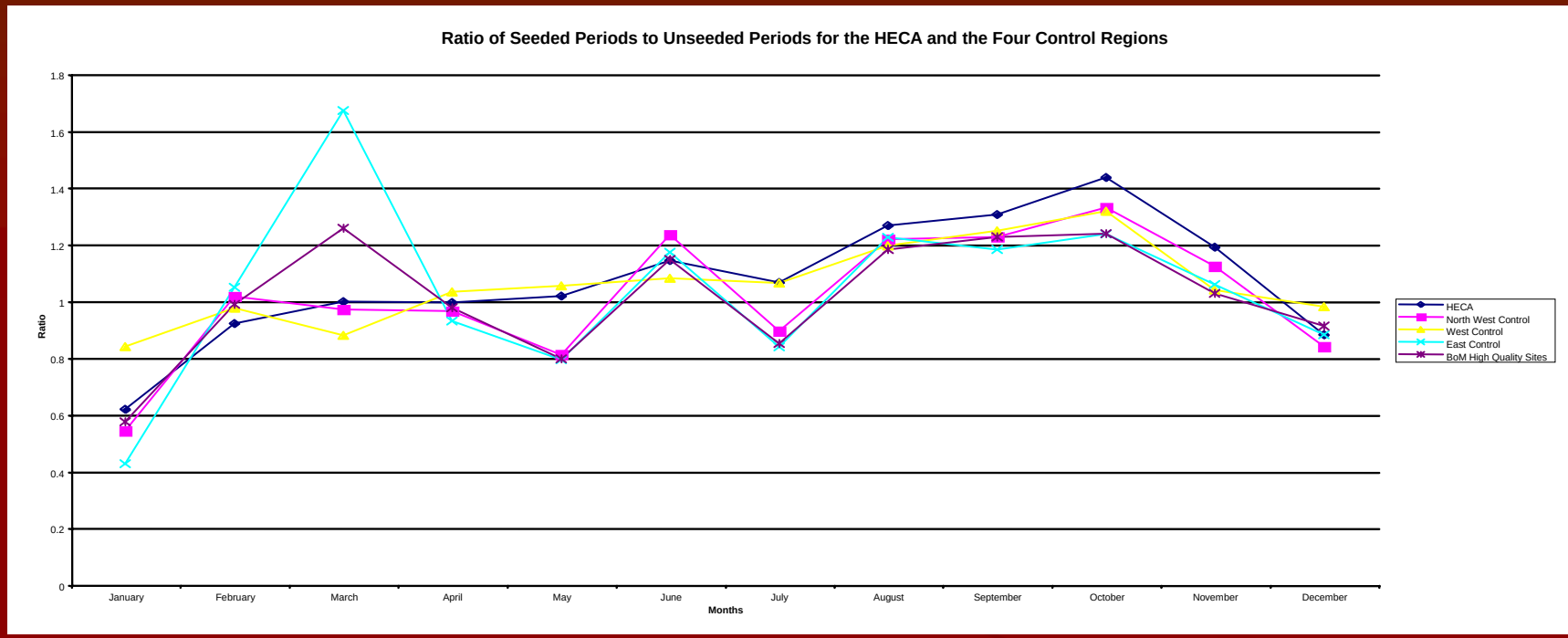
A northwest control

An east control

A “high quality” data control



Analysis of Control Areas



The analysis suggests that the signal is readily apparent in the west and northwest control, and even in the east control.

Analysis of Control Areas

Is the signal in response to weather modification or some long-term, wide spread forcing (e.g. climate change?)

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Analysis of Control Area

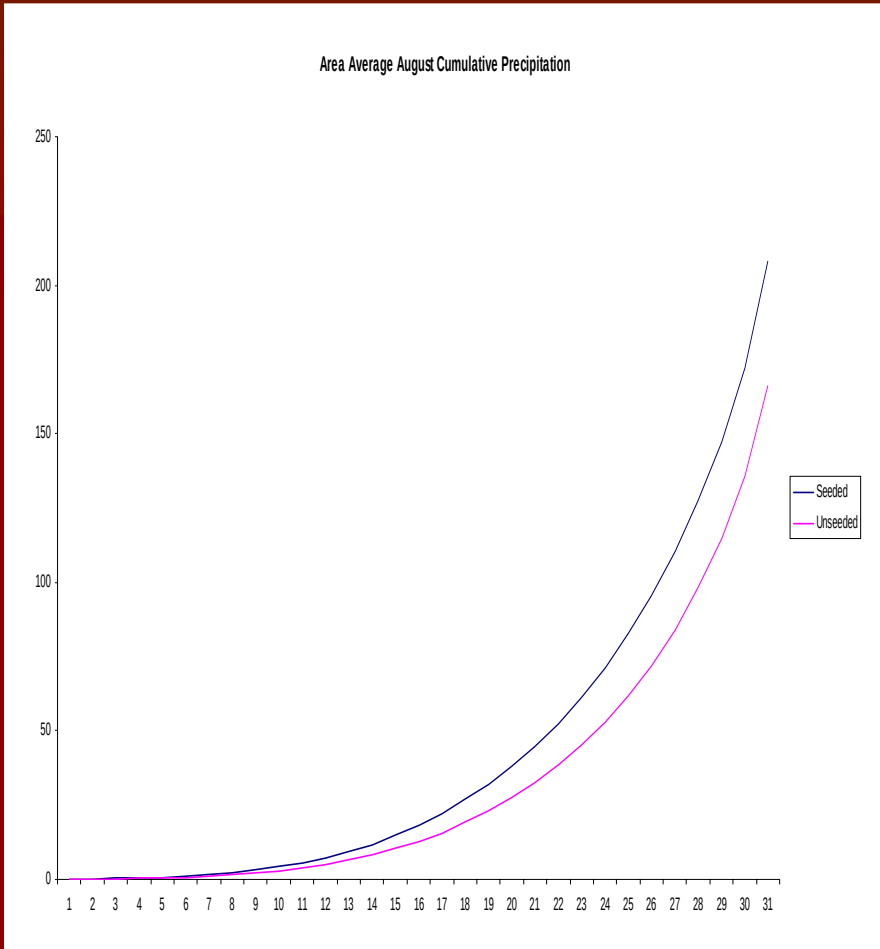
We do note that it is plausible for the cloud seeding to be having a wide-spread effect across Tasmania. Hydro Tasmania is NOT seeding simply orographic clouds.

Cloud seeding is located “30 minutes” upwind of the target area based on the 10,000 ft aviation forecasts. This regularly puts the aircraft over the west and northwest controls.

Seeding then happens near the -5 C altitude, which places the aircraft above 2 or even 3 km altitude, well above the boundary layer.

Other Outstanding Questions

- Can anything be learned from looking at the daily rainfall records? Is it reasonable to expect that a handful of seeding events can affect a monthly rainfall record?
- Early results are diffiicult to explain.



Conclusions

The cloud seeding records over Central Tasmania are quite unique given their longevity.

While there was no attempt to design a decades long experiment, the results may be used to this effect, although with a number of concerns.

- variable number of rain gauges
- changing definition of target area
- changing seeding operation

When the data is prepared in a relatively crude, conservative matter, a relatively strong signal is still visible. This signal is, however, also evident outside of the target area.

The wide spread nature of the signal is not consistent with our theoretical framework.

Ultimately it is difficult to attribute this signal to cloud seeding, given the potential for some unseen forcing such as climate change.