Team 1004

"How many 1 in 100 year extreme weather events can NZ expect to experience over the course of the next decade?"

ABSTRACT

In this report, we considered the impact of climate change on New Zealand's climate, and the effect this would have on the frequency of "1 in 100 year" weather events in New Zealand. By mathematically modelling the shift caused by climate change on the probability density function of the main extreme weather events in New Zealand, and then using a MATLAB program to simulate 100 iterations of extreme weather events over 10 years, we determined that in the next decade we can expect to experience **0.554 $\pm$6.5%** extreme weather events on average over the course of the next decade.

INTRODUCTION

Extreme weather events can cause significant destruction throughout New Zealand, especially rare "1 in 100 year" events. With the recent acceleration of climate change due to our increasing greenhouse gas emissions, we are beginning to witness an increase of the frequency of these extreme weather events.

The extreme weather events New Zealand typically experiences consists of floods, tornadoes, cyclones/storms, and heat waves; the frequency of each of these events is mainly controlled by a different climatic factor (rainfall, wind speed, humidity, & temperature) which are uniquely affected by climate change. This means that extreme weather events, which are considered 1 in 100 year events today, will likely become more common over the next decade.

It would be useful to create a model to measure this change so we can forecast how many (currently) "1 in 100 year" weather events we can expect to see in the coming decade.

DEFINITIONS

The 4 primary extreme weather events that apply to NZ and their factors are:

Event	Floods	Cyclones/Storms	Tornadoes	Heatwaves
Factor	Rainfall	Humidity	Wind speeds	Temperature

We define a "1 in 100 year extreme weather event" as an event that we expect to occur once on average every 100 years (i.e it has a 0.01 chance of occurring each year or a $\frac{0.01}{12}$ chance per month). We consider each event in the table above individually.
In other words, for each of the above weather events, an 'extreme weather event' only occurs when the climatic factor is above a certain threshold boundary, the value of which we set to ensure the event only has a $\frac{0.01}{12}$ chance of occurring per month currently (in 2021).

For an extreme weather event to occur in New Zealand, it must occur on the mainland in New Zealand (either the North or South island, not offshore islands).

We define the next decade as the 10 years after August 7, 2021 (08/08/2021 to 08/08/2031).

ASSUMPTIONS

To ensure our computer simulation is tractable, we will check for the probability of an extreme weather event occurring ‘per month’. This requires us to assume that two of the same events cannot happen in the same month which is valid since most events that close together would be classified as stemming from the same event (e.g low pressure system) rather than independent event.

We will also be assuming that the occurrence of extreme weather events happens completely independently of each other. One extreme weather event occurring in New Zealand will not impact another extreme weather event happening. Because events are so rare, each event will have negligible impact on other events far into the future, so this is valid.

We assume that minor factors (i.e. wind direction for cyclones) have insignificant influence on the formation of these weather events. In other words only the factors mentioned above have a notable impact on the development of the extreme weather event.

We assume that climatic conditions follow a normal distribution on average due to the central limit theorem, which states that a distribution of averages (such as our average climatic conditions) will tend towards a normal distribution for large sample sizes.

We assume the frequency of each event scales linearly with changes in the affecting factor.

THEORETICAL APPROACH

Although we’d expect ‘once in 100 year’ extreme weather events to occur on average 0.1 times in 10 years (so 0.4 events total), due to the destabilising effects of climate change, we’d expect the frequency of extreme weather events to increase above $\frac{0.01}{12}$ over the course of the next decade. To be able to quantify the impact of climate change on the frequency of individual extreme weather events, we must be able to clearly know the causes of those events and how much they are affected by climate change. Climate change has an impact on temperature, rainfall, wind speed, and humidity, which each contribute to one of the listed extreme weather events.

Each factor impacting extreme weather events changes differently with the effects of climate change. Therefore, we created independent normal distributions for each weather event (we can assume these are approximately normal due to the CLT as outlined in our assumptions). We collated online data on the minimum, mean, and maximum results of weather events in New Zealand and also created an estimate of the standard deviation.

$$\sigma = \frac{range}{6}$$

This is a valid approximation since 99.7% of the data theoretically falls within 3σ either side of the mean in a normal distribution, which we assume incorporates all of the data.

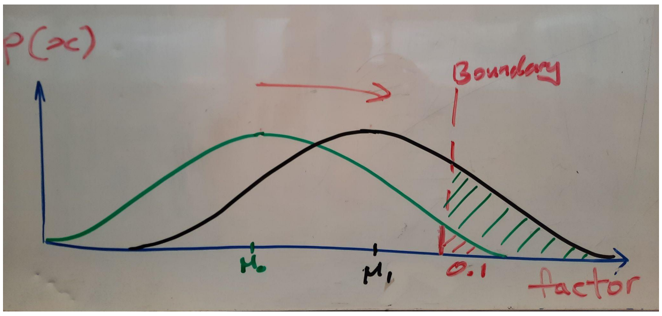
Event	**Unit**	**Min**	**Mean**	**Max**	**SD**
Floods	mm $month^{-1}$	1141	1287	1494	58.83
Cyclones	% $month^{-1}$	65.01	81.08	94.24	4.872

Tornadoes	kmph	19.80	22.50	25.20	0.9000
Heat waves	°C	11.04	12.19	13.33	0.3817

All the data we collected was converted to monthly averages across all of NZ where necessary.
Data sources and the graphs we produced to calculate these parameters are attached in the appendix.

Using the present-day mean and standard deviation, we can find the threshold boundary in the climatic factor that would produce an “extreme weather event” once in every hundred years (at present-day climatic conditions) by using an inverse normal distribution, where the probability for an extreme weather event occurring in one month is $\frac{0.01}{12}$, independent of other extreme weather events.

Over the course of the coming decade, the mean value of the factors for each event type will increase, shifting the probability distribution graph rightwards, accounting for the effects of climate change on the probabilities of each event occurring per month.



The forecast equation allows us to predict how the mean value of the factor (e.g rainfall for floods) will change in the next 10 years by using a time series model based on results from the past 10 years. As the mean shifts, the boundary value stays the same, and therefore, as the mean shifts, there is more area to the right of the boundary, and thus a higher probability of the event occurring. By inputting these values into a MATLAB simulation, we can anticipate the number of “1 in 100 extreme weather events” we can expect in the coming decade given their changing frequency due to climate change.

Event	**Unit**	**Min**	**Mean**	**Max**	**SD**	**Boundary**	**Forecast Equation**
Floods	mm $month^{-1}$	1141	1287	1494	58.83	1472	$0.0694t + 1287$
Cyclones	% $month^{-1}$	65.01	81.08	94.24	4.872	96.40	$0.005616t + 81.0$
Tornadoes	kmph	19.80	22.50	25.20	0.9000	25.33	$22.5(1.0000540)^t$
Heat waves	°C	11.04	12.19	13.33	0.3817	13.39	$0.0003924t + 12.$

Where t is measured in months from AUG 2021
(Link, Graphs, Equations, and Calculation are also included the appendix)

MODELLING

MATLAB will be used to create both our models. Our initial model does not account for the changes caused by climate change, and therefore assumes that the probability of each of the 4 extreme weather events will be 1% per year, or (1/12)% per month. This is assuming the probability will not change over the next 10 years, which is the next 120 months.

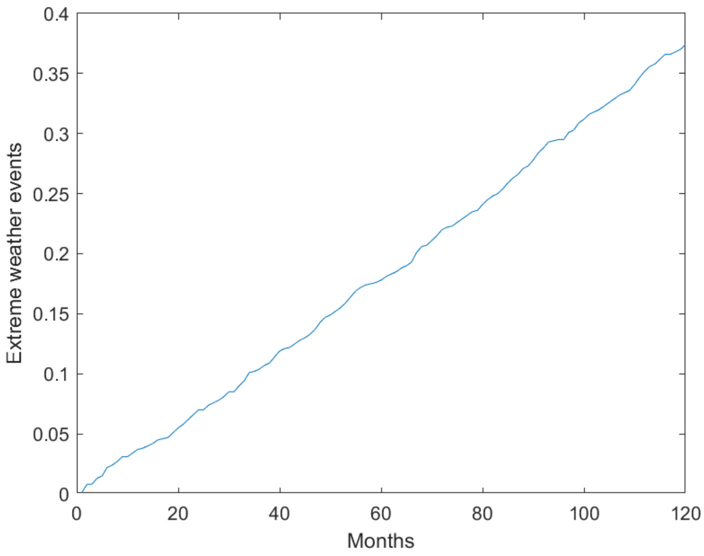
The script for MatLab is as follows:

```
%Model for estimating expected number of extreme weather events over 10
%years.
%probability of an extreme weather event occuring in a month
probability=1/1200
eventtypes = 4;
years=10;
months=years*12;
repeats=1000;
matrixA=[];
matrixsum=zeros(2,months);
%repeatedly use the model and find the average number of extreme weather
%events over the timespan of 10 years.
for repeat=1:repeats
    for i=1:(months)
    totalevents=0;
    matrixA(1,i)=i;
        for j=1:eventtypes
            totalevents=totalevents+event(probability);
        end
    matrixA(2,i)=totalevents;
       if i > 1
            matrixA(2,i)= matrixA(2,i)+ matrixA(2, (i-1));
       end
    end
    matrixsum = matrixsum + matrixA;
end
matrixsum=matrixsum./repeats %find the average of all the data
plot(matrixsum(1,:),matrixsum(2,:));
xlabel('Months')
ylabel('Extreme weather events')
```

The function below is what determines the probability that an extreme weather event will happen in a month.

```
%The following function determines whether or not an extreme weather event
%occurs in a given month for our model.
function weatherevent = event(monthlyprobability)
    a=rand;
    weatherevent=0;
    if a<(monthlyprobability)
        weatherevent=1;
    end
end
```

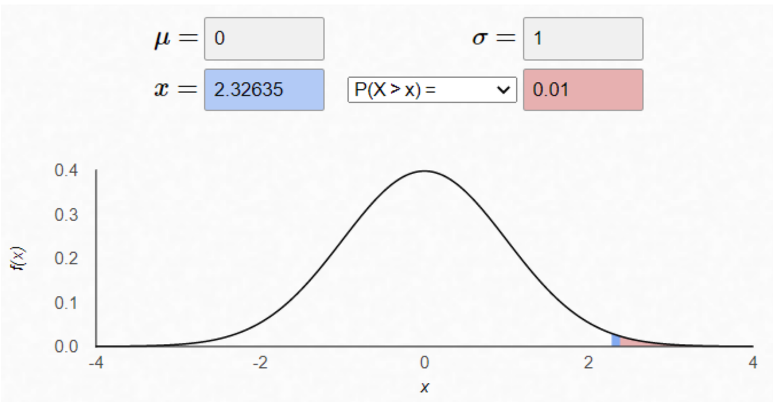
Our results can be seen in the following graph:



Our results over 1000 repetitions of our model shows that 0.374 extreme weather events can be expected to occur over the next 10 years (the next 120 months).

To improve the accuracy of our model, we understand climate change in the next 10 years will affect the probability of an extreme weather event occurring. Therefore, we modified the monthly probability function to adapt to the changing climate as time progresses.

Because rainfall, humidity, droughts, and other environmental extremes are continuous data, the probability of extreme weather events can be considered using the normal distribution model where x is the threshold for an event to be classified as extreme. Initially, the expected value for an extreme weather event occurring in a year is 1% so on the normal distribution, the shaded area should be equivalent to 0.01. This can be seen in the general normal distribution curve below with mean of zero, standard deviation of 1 and x value of 2.32635.

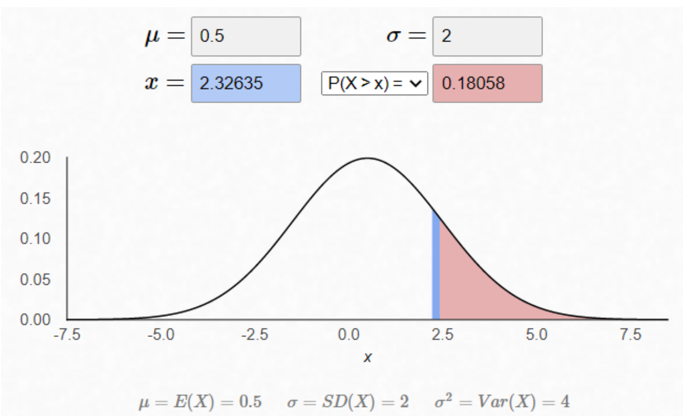


https://homepage.divms.uiowa.edu/~mbognar/applets/normal.html

Only the events above a certain x value will be considered to be considered an extreme weather event. For example, if the x variable was rainfall, it must cross a certain threshold to be considered an extreme weather event.

For climate change in the next 10 years, the x variable will remain the same, but the distribution will change which means that the probability that an extreme weather event will occur will also change. So considering the above general graph, if the x value remains the same but the average or standard deviation that has changed, the probability will also change. For example, if the average increases from 0 to 0.5, the standard deviation increases from 1 to 2, and x stays the same, then the probability will increase as seen in the graph below.

The probability density function for the normal distribution is:



$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$$

We will construct 4 new functions in MATLAB for each of the different types of extreme weather events to make a more realistic and accurate model.

We will consider our four events using the normal distribution. The probability now changes with respect to time and the general equation for probability of an extreme weather event occurring in a month will be the probability density function. So our probability function now changes to become:

```
function extremeweather = extremeweather(month)
    a=rand;
    fun = @(x, sigma, mu) (1./((sigma.*sqrt(2.*pi))).*exp((-1/2).*((x-mu)./sigma).^2))
    q = integral(@(x) fun(x,0.3817,mu),threshold,Inf)
    heatwave=0;
    if a<(q)
        extremeweather=1;
    end
end
```

If $extremeweather = 1$, then an extreme weather event will occur in that month. Now we use the previously discussed factors that are proportional to the extreme weather events to modify the function. The functions are as follows:

```
%The following function determines whether or not an extreme weather event
%occurs in a given month for our model.
function flood = flood(month)
    year = month/12;
    a=rand;
    mu = (0.0694*month+1287);
    fun = @(x, sigma, mu) (1./((sigma.*sqrt(2.*pi))).*exp((-1/2).*((x-mu)./sigma).^2))
    q = integral(@(x) fun(x,58.83,mu),1472,Inf)
    flood=0;
    if a<(q)
        flood=1;
    end
end
function cyclone = cyclone(month)
    a=rand;
    mu = (81.08+(0.005616*month));
    fun = @(x, sigma, mu) (1./((sigma.*sqrt(2.*pi))).*exp((-1/2).*((x-mu)./sigma).^2))
    q = integral(@(x) fun(x,4.872,mu),96.4,Inf)
    cyclone=0;
    if a<(q)
        cyclone=1;
    end
end
```

```matlab
function tornado = tornado(month)
    a=rand;
    mu = (22.5*(1.0000525)^month);
    fun = @(x, sigma, mu) (1./((sigma.*sqrt(2.*pi))).*exp((-1/2).*((x-mu)./sigma).^2))
    q = integral(@(x) fun(x,0.9,mu),25.33,Inf)
    tornado=0;
    if a<(q)
        tornado=1;
    end
end
function heatwave = heatwave(month)
    a=rand;
    mu = (0.0003924*month+12.19);
    fun = @(x, sigma, mu) (1./((sigma.*sqrt(2.*pi))).*exp((-1/2).*((x-mu)./sigma).^2))
    q = integral(@(x) fun(x,0.3817,mu),13.39,Inf)
    heatwave=0;
    if a<(q)
        heatwave=1;
    end
end
```

To implement this code, we will replace the lines in our initial MATLAB script from:

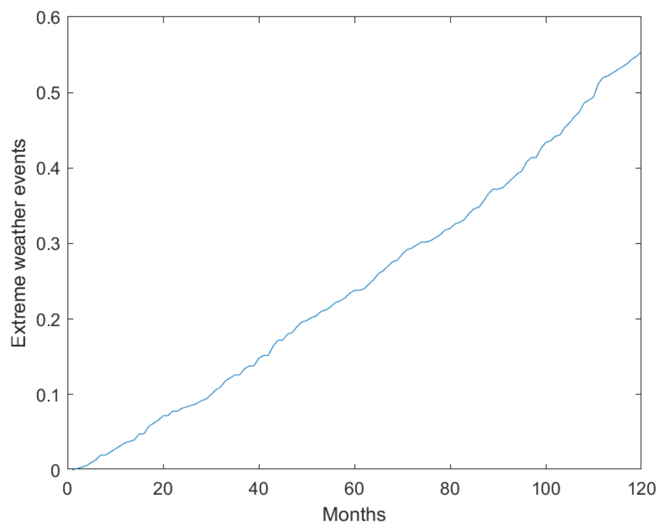
```matlab
for i=1:(months)
totalevents=0;
matrixA(1,i)=i;
    for j=1:eventtypes
        totalevents=totalevents+event(probability);
    end
matrixA(2,i)=totalevents;
   if i > 1
        matrixA(2,i)= matrixA(2,i)+ matrixA(2, (i-1));
   end
```

To the new version that is:

```matlab
for i=1:(months)
totalevents=0;
matrixA(1,i)=i;

totalevents=totalevents+flood(i);
totalevents=totalevents+cyclone(i);
totalevents=totalevents+tornado(i);
totalevents=totalevents+heatwave(i);

matrixA(2,i)=totalevents;
```



Our results from this modified model over 500 repetitions show that 0.554 extreme weather events can be expected to occur over the next 10 years (the next 120 months).

This is 0.554/0.374=1.48 times more than our previous model. This is understandable as climate change may result in extreme weather events becoming more frequent.

CONCLUSION

Using data from climate change and by analysing its relationship with the frequency of extreme weather events, the MATLAB model predicts how many extreme weather events can be expected over the next 10 years. From running the model on MATLAB for 500 repetitions, we have determined that we can expect 0.554 extreme weather events in the next 10 years on average. Comparatively, if we disregard climate change, New Zealand would only expect 0.4 extreme weather events over the next 10 years (0.1 * 4 event types). This shows that due to climate change, New Zealand is 1.385 times more likely to experience an extreme weather event in the next 10 years.

By comparing the theoretical value of 0.4 expected extreme weather events in the next 10 years (disregarding climate change) and 0.374 expected extreme weather events from simulation, it is clear that there would be a small margin of error. For this trial it was 6.5% error. Therefore, we expect the number of extreme weather events including the effects of climate change to include a similar error.

E(number of extreme weather events) = 0.554 $\pm$6.5%

DISCUSSION and LIMITATIONS

We assumed climate change will go up at a constant rate, and that the subsequent increases in rainfall, humidity, wind speed, and temperature are directly proportional to the likelihood of extreme weather events (floods, cyclones, tornadoes, and heatwaves) occurring. This is not the case, there are other factors that can influence the occurrence of these events, meaning that our estimates could be improved upon by considering these factors.

In our report, we excluded events with less than a “1 in 100 year” likelihood, such as blizzards and dust storms. Although they can occur, they do not occur enough in New Zealand for there to be reliable data about them. Our exclusion of these events does limit the broadness of our research, however, it is logical because of their lack of occurrence in New Zealand’s records.

We used a monthly interval for our predictions, meaning that we sumated the probabilities for each extreme weather event occurring for each month from 08/08/2021 to 08/08/2031 to find the probability of each extreme event occurring in the next decade. This could be improved upon by using a continuous integral to find the probability of each extreme weather event occurring, meaning that the effects climate change would have would be captured in the calculations, and give us a better estimate of the probability of an extreme weather event occurring in the next decade.

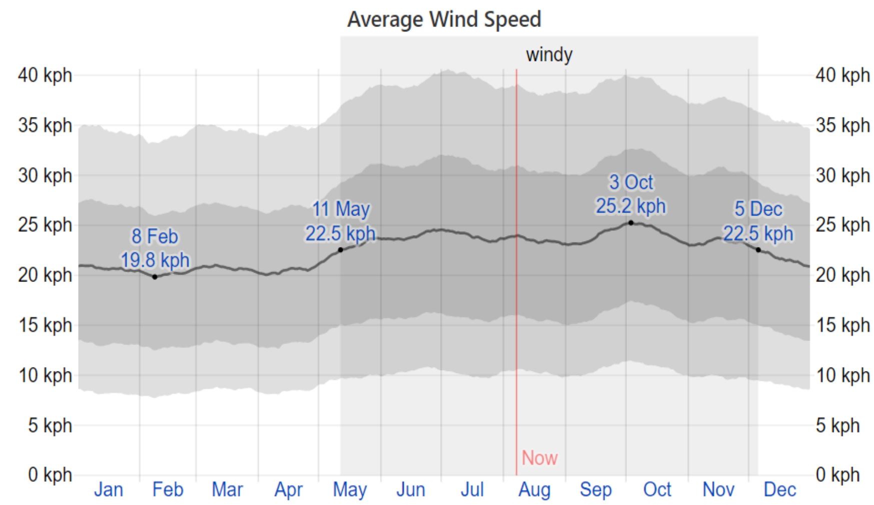
While we attempted to minimise the margin of error by retailing our predictions 500 times each on a normal laptop, the margin of error could still have been improved by retrialing 1000 or 10000 times. However, time limitations meant that we were unable to do so.

APPENDIX

A: Average wind speed graph
Sourced from

https://weatherspark.com/y/144891/Average-Weather-in-Auckland-New-Zealand-Year-Round#:~:text=The%20windier%20part%20of%20the,of%2015.7%20miles%20per%20hour average wind speed

https://www.climateaction.org/news/rise-in-global-wind-speeds-to-boost-renewable-energy-power Rate of change of wind speed



The average of mean hourly wind speeds (dark gray line), with 25th to 75th and 10th to 90th percentile bands.

Average wind speed of auckland. Increase in wind speed globally for the past decade was around 0.65%.

Per month that is ->

$1.0065 = (1.00 + X)^{10*12}$

$X = 0.0000540 = 0.00540\%$ increase per year

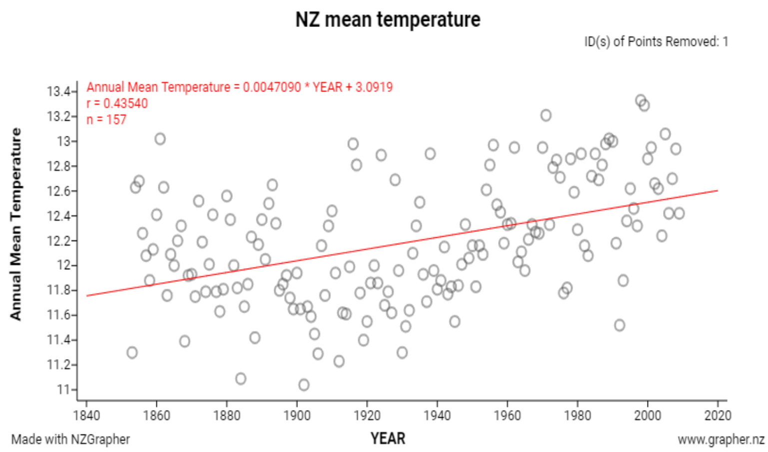
So the overall model is: $22.5(1.0000540)^{t}$

B: Average Temperature Graph

Data sourced from NIWA: "'Seven-station' series temperature data (archive)"
https://niwa.co.nz/our-science/climate/information-and-resources/nz-temp-record/review/changes/seven-station-series-temperature-data
Graph created in NZGrapher

Temperature at 2021: 0.0047090*(2021) + 3.0919= 12.609

Overall model: mX + C = 12.609 + 0.0047090*(y/12), where 'y' is number of years from 2021



C: Average Rainfall Graph

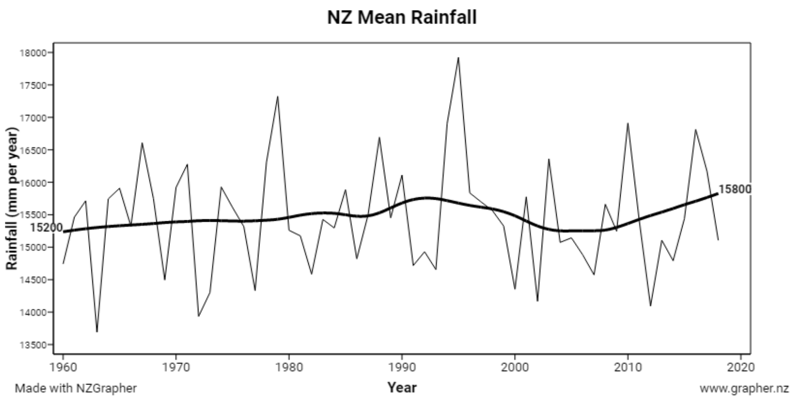
Data source from: https://www.stats.govt.nz/indicators/rainfall

For the past six decade, the change in rainfall per month was:

(15200-15800)/(60*12*12) =0.0694 mmpm-1

Mean rainfall: 1287 mmpm

Overall model: $0.8333t + 1287$



D: Humidity

https://niwa.co.nz/education-and-training/schools/resources/climate/humidity
https://www.gw.govt.nz/assets/Uploads/GWRC-2020-extremes-appendix-FINAL.pdf

From gw.govt (pg 35), the gradient of the increase in humidity from 2020 to 1928 can be calculated:
(0.4 + 2.1 + 3.6 + 0.1)/(2020 - 1928) = 6.2/92 = 0.06739 % year^{-1} or 0.005616 % month^{-1}

From NIWA, the mean humidity across NZ over all months in 2010 can be calculated, giving 79.27%.
Using the gradient from gw.govt, the mean humidity in 2021 is:
79.27 + 0.005616*11*12 = 81.01 %

Overall model: $0.005616t + 81.08$