TEAM 1007

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

Summary

In this report, we aimed to discover the number of extreme adverse weather events with a ~100 year average historical return period that New Zealand could potentially experience over the next decade (2021 through 2031). By considering the potential effects of climate change, we were able to anticipate a sustained temperature increase of between 0.269°C and 0.385°C over the stated time period, resulting in a ~2% increase in rainfall. Subsequently, using a probabilistic simulation in combination with a machine learning model, we receive a **final answer of between 0 and 4 weather events, with an average of ~2.28 extreme weather events** within the next decade.

1.0 Introduction

With the accelerating rate of climate change and rising temperatures over the past several decades, largely fostered by rapid increases in greenhouse gas emissions (henceforth referred to as simply "emissions"), the number of adverse weather events encountered globally has increased in turn. In June of this year, for example, the Canterbury region experienced severe flooding as a result of rainfall significantly above the historical average; this event was commonly labelled as a "1 in 100 year flood".

These events appear to have become far more commonplace in recent years, unbefitting of their name, and herald a dangerous shift in weather conditions that can have serious consequences. In New Zealand, extreme weather events can result in major damage to critical infrastructure (water, electricity, transport) in addition to risking lives and property - this especially threatens farming communities and tourism, which are crucial to the country's economy. These impacts are reflected elsewhere too; in July, flooding in the Chinese city of Zhengzhou killed hundreds.

To better prepare for such impacts over the next decade, it is valuable to model and estimate the potential for further adverse 1 in 100 year weather events over the next decade (2021 - 2031). This is the objective of our report.

1.1 Defining the Question

We define a **1 in 100 year weather event** as a severe natural atmospheric event (e.g. severe rain or severe wind) that results in major damage, such as flooding, on the surrounding environment and civilization. Per the name, these events must be uncommon enough to have historically had an average return period of approximately 100 years.[1] This gives it an approximate 1% chance of occurring in any given year.

To narrow the scope of this investigation, we immediately excluded all natural disasters with non-atmospheric *origins*, including but not limited to earthquakes, volcanoes, and tsunamis, regardless of their atmospheric impact.

In the context of rainfall, we assume a 1 in 100 year weather event refers to a 48-hour precipitation total of approximately 400mm in 48 hours (or equivalent), considering that a 526mm rainfall event is estimated to occur every 1 in 200 years.[2]

For the purposes of this report, **New Zealand** will refer to the territory encompassed by New Zealand's 16 regional councils (which cover all of mainland New Zealand: the North and South Islands, plus Stewart Island), in addition to the Chatham

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[1] Retrieved August 7, 2021 from: https://niwa.co.nz/natural-hazards/faq/what-is-a-return-period
[2] Retrieved August 7, 2021 from:
https://www.stuff.co.nz/national/weather-news/125435034/some-of-canterburys-floods-labelled-a-onein200year-event

Islands.[3] Importantly, this excludes New Zealand dependencies and associated states, including Tokelau, Niue, the Cook Islands, and the Ross Dependency.[4] We make this exclusion due to the availability of data, which is often limited to mainland New Zealand (with the knowledge that distant territories have completely different and unique weather conditions).

1.2 Assumptions

This report uses a number of reasonable assumptions to reduce complexity.

1. We assume that all weather events are 48 hours long. As the definition of a 1 in 100 year event changes depending on the timeframe, we are unable to effectively consider all different variations.

2. Our calculations for weather events are applied in a blanket fashion over New Zealand as a whole. We acknowledge that average rates of rainfall or other weather events may vary by region, however given the incredibly complex nature of New Zealand's terrain and location, considering all such factors would be impractical and absurd within our constraints. We also believe that the core of the question surrounds general weather conditions as a consequence of climate change for the country and not, for example, the impact of the Southern Alps on rainfall in Christchurch.

3. We also assume that all weather events are independent, meaning a severe rain event in one place does not lead to a separate rain event in another.

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[3] Retrieved August 7, 2021 from:
https://datafinder.stats.govt.nz/layer/104254-regional-council-2020-generalised/
[4] Retrieved August 7, 2021 from:
https://gg.govt.nz/office-governor-general/roles-and-functions-governor-general/constitutional-role/constitution/constitution

2.0 Analysis of Question

To approach this question, we need to consider two key areas. Firstly, the extent of worsening climate conditions, and secondly, those worsening conditions' impact on local weather events.

Upon investigation, it was discovered that the vast majority of weather events that used a "1 in 100 year" definition were rainfall related; it is the consequences of rainfall related events that have the most significant impact on New Zealanders (i.e. flooding), so we chose to focus on these events only.

2.1 Impacts of Climate Change

NIWA, the National Institute of Water and Atmospheric Research, works with the Ministry of Environment to consider potential future climate outcomes for New Zealand. By considering these potential outcomes, we can estimate the potential changes in weather conditions as a result.

2.1.1 Increase in Temperature

NIWA estimates, from climate modelling, that *"By 2040 (2031–50, relative to 1986–2005), temperatures are projected to increase by between 0.7°C (RCP2.6) and 1.0°C (RCP8.5) nationally."*[5]. The lower bound model, RCP2.6, refers to a state of maximum mitigation where significant measures are taken to reduce temperature growth. The upper bound, RCP8.5, assumes a worst-case scenario of rapid population growth and little addressing of climate issues.[6]

With the understanding that national temperatures in the period commencing in 2031 will represent a 0.7°C to 1.0°C increase over a period ending in 2005, we can estimate the extent of temperature changes within our 2021-2031 time frame as follows:

Lower bound:

$$\frac{0.7}{2031 - 2005} \times (2031 - 2021)$$

$$\frac{0.7}{26} \times (10) = 0.269 \, (3 \, sf)$$

[5] Retrieved August 7, 2021 from:
https://environment.govt.nz/assets/Publications/Files/Climate-change-projections-2nd-edition-final.pdf
[6] Retrieved August 7, 2021 from:
https://www.carbonbrief.org/explainer-what-climate-models-tell-us-about-future-rainfall

Upper bound:

$$\frac{1}{2031 - 2005} \times (2031 - 2021)$$

$$\frac{1}{26} \times (10) = 0.385 \ (3 \ sf)$$

Thus, we approximate that the **mean temperature increase nationwide in the period 2021 to 2031 will be between 0.269°C to 0.385°C**.

2.1.2 Increase in Rainfall

These increased temperatures directly affect the possibility for extreme weather conditions such as torrential rain.
While the exact nature of the relationship between temperature and precipitation varies (given the vast number of factors typically at play in the atmosphere, not just temperature) by source, existing research by NIWA gives one such percentage increase in precipitation per degree of temperature increase.

ARI: Duration	2 yr	5 yr	10 yr	20 yr	30 yr	50 yr	100 yr
1 hour	12.2	12.8	13.1	13.3	13.4	13.5	13.6
	9.8 – 17.5	10.6 – 18.1	10.7 – 18.5	10.7 – 18.8	10.7 – 18.9	10.7 – 19.1	10.7 – 19.4
2 hours	11.7	12.3	12.6	12.8	12.9	13.0	13.1
	9.2 – 18.0	9.9 – 18.4	10.0 – 18.7	10.1 – 19.0	10.1 – 19.1	10.1 – 19.3	10.1 – 19.6
6 hours	9.8	10.5	10.8	11.1	11.2	11.3	11.5
	7.5 – 14.9	8.0 – 15.4	8.3 – 15.9	8.4 – 16.4	8.5 – 16.6	8.5 – 17.0	8.5 – 17.4
12 hours	8.5	9.2	9.5	9.7	9.8	9.9	10.1
	5.7 – 13.5	6.5 – 13.9	6.8 – 14.2	7.1 – 14.5	7.2 – 14.8	7.3 – 15.1	7.3 – 15.4
24 hours	7.2	7.8	8.1	8.2	8.3	8.4	8.6
	4.0 – 11.9	4.6 – 12.0	4.8 – 12.1	4.9 – 12.2	5.0 – 12.3	5.1 – 12.5	5.2 – 12.8
48 hours	6.1	6.7	7.0	7.2	7.3	7.4	7.5
	2.6 – 11.0	3.1 – 11.1	3.3 – 11.2	3.4 – 11.3	3.4 – 11.3	3.4 – 11.4	3.5 – 11.5
72 hours	5.5	6.2	6.5	6.6	6.7	6.8	6.9
	2.1 – 10.5	2.6 – 10.6	2.7 – 10.8	2.8 – 10.9	2.9 – 11.0	2.9 – 11.1	2.9 – 11.2
96 hours	5.1	5.7	6.0	6.2	6.3	6.4	6.5
	1.7 – 10.0	2.2 – 10.2	2.4 – 10.5	2.5 – 10.7	2.6 – 10.9	2.6 – 11.0	2.7 – 11.2
120 hours	4.8	5.4	5.7	5.8	5.9	6.0	6.1
	1.3 – 9.6	1.9 – 9.7	2.1 – 10.0	2.3 – 10.2	2.3 – 10.4	2.4 – 10.5	2.4 – 10.7

Percentage increase in precipitation for rainfall events of various durations and return periods per degree of temperature change, sourced from a NIWA report.[7]

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[7] Retrieved August 7, 2021 from:
https://environment.govt.nz/assets/Publications/Files/Climate-change-projections-2nd-edition-final.pdf
(pg 100)

This table describes the increase in rainfall level required for different durations of severe rainfall events with different return periods (ARI). For our purposes, we are only looking at the increases themselves, not how the ARI changes.

By taking into account the average increase in precipitation across all rainfall events of 48 hours, and accounting for how common they are we can approximate the general impact on rainfall.

$$\left(6.1 \times \frac{1}{2}\right) + \left(6.7 \times \frac{1}{5}\right) + \left(7.0 \times \frac{1}{10}\right) + \left(7.2 \times \frac{1}{20}\right) + \left(7.3 \times \frac{1}{30}\right) + \left(7.4 \times \frac{1}{50}\right) + \left(7.5 \times \frac{1}{100}\right)$$
$$= 5.916 \approx 6$$

From this, we conclude that per degree of temperature increase, we can expect an approximately 6% increase in total rainfall for a severe weather event with a 48 hour duration.

By multiplying this answer by our temperature increase estimates of 0.269°C to 0.385°C, we estimate that, over the following decade in severe rainfall events, **rainfall will increase by between 1.61% to 2.31%.**

2.2 Probabilistic Model

We know that a 1 in 100 year event will have, historically, demonstrated a probability of occurring in any given year of 1/100, or 1%.
As determined in section 2.1, there will be an increase in rainfall over the next decade as a result of climate change. Subsequently, we can use those increases to determine the increased rate at which extreme weather events will occur, and the probability of them happening.

This will be performed through a Java program, note the code comments which detail individual steps. We first create our variables:

```java
//Adjustable variables
double temperatureIncreaseDeg = 0.269;

//Fixed variables
double primaryProbability = 0.01;
double rainfallIncreasePctPerDegree = 0.06;

//Output variables
double rainfallIncreasePct;
double rainEventProbability;

int lowerBound = 999; //Unrealistically high number
int higherBound = 0;
```

The following depicts the real program code, which simulates (100,000 times) a 10 year scenario, where each year is tested for a chance of a 1 in 100 year event occurring. Each occurrence results in an addition to the number of events, and we save the number of events per simulation. The lowest outcome and highest outcome are recorded, giving us a lower and upper bound.

```java
System.out.println("Temperature increase 10yrs: " + temperatureIncreaseDeg);

//Calculates the percentage increase in rainfall given increase in temperature.
rainfallIncreasePct = temperatureIncreaseDeg * rainfallIncreasePctPerDegree;

//Calculates the updated probability of a 1/100 year rain event for each year in the 2021-2031 period.
rainEventProbability = (rainfallIncreasePct * primaryProbability) + primaryProbability;

//Loops through 100,000 iterations of 10 years
for (int i = 0; i < 100000; i++) {
    int events = 0;

    //Creates a random number between 0 and 1.
    //If the number falls within the probability of an event, we add an event to the total.
    //Runs 10 times, for 10 years.
    for (int j = 0; j < 10; j++) {
        double random = Math.random();
        if(random < rainEventProbability) events++;
    }

    //Creates a lower bound and higher bound out of the lowest and highest results.
    if(events > higherBound) higherBound = events;
    else if(events < lowerBound) lowerBound = events;

}

System.out.println("Higher bound: " + higherBound);
System.out.println("Lower bound: " + lowerBound);
```

We ran this against our lower and upper bound temperature change outcomes from section 2.1.

```
Temperature increase 10yrs: 0.269
Higher bound: 3
Lower bound: 0
```

```
Temperature increase 10yrs: 0.385
Higher bound: 4
Lower bound: 0
```

Ultimately, from our probabilistic model we calculate, in an optimistic situation of minimal climate involvement, between 0 and 3 1 in 100 year weather events in the next decade. In contrast, with a temperature increase of 0.385 degrees, the upper bound becomes 4.

2.3 Statistical Regression Model

The probabilistic model, however, assumes a genuine 1% chance historically of these events occurring. In practice this is not the case, as in our research we discovered far more instances of a "1 in 100 year event" (>400mm rainfall) in the past century than 1.

With this in mind, the conclusions made in 2.2 can be checked again, then, through a statistical model.

To do this, we implemented a self learning regression model. The framework this is based on is Google's TensorFlow, a library for machine learning infrastructure, and Keras, a Python API. This model, a many-to-one model, was trained on 2 parameters to be able to predict the number of events that happened that year.

Features	Label
Year	Number of 1 in 100 events
Average temperature increase in NZ in a given year.	

Tabel 1, Features and labels for predictive model

The design of this model is shown below:

```python
# Set random for reproducibility
tf.random.set_seed(12)

# Defining model
model = tf.keras.Sequential(name='Regresion_model_1')
model.add(tf.keras.layers.Dense(10, activation='relu', name='Hiddin_Layer_1', input_shape=(3,)))
model.add(tf.keras.layers.Dense(10, activation='relu', name='Hiddin_Layer_2'))
model.add(tf.keras.layers.Dense(10, activation='relu', name='Hiddin_Layer_3'))
model.add(tf.keras.layers.Dense(1, activation='relu', name='Output_Layer'))

# Build model
model.build()
```

Model Creation

```python
# Model Compiler
model.compile(optimizer=tf.keras.optimizers.Adam(),
              loss=tf.keras.losses.mae,
              metrics=['accuracy'])
```

Model Compiler

The following is the data that the model has been trained on. Through our research, we discovered the amount of 1 in 100 (i.e. >400mm rainfall) weather events that occurred in the past century, in addition to average temperatures over the past year.

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# of 1 in 100 Events	
Year	Amount[9]
2021	1
1998	1
1966	1
1938	1
1927	1

Temperature yearly average each Year
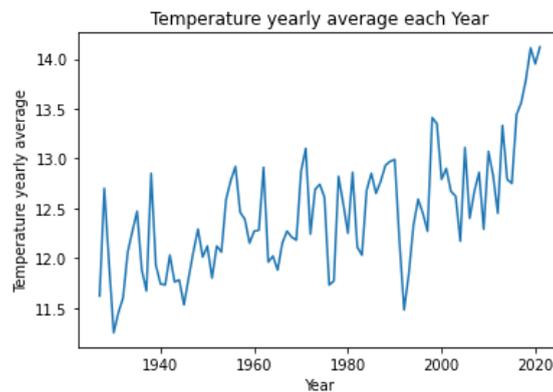
By adding the temperature increases that were deduced in section 2.1 to our dataset on the right, we are left with only one missing variable for the 2021-2031 time frame: the number of 1 in 100 events.

This gives us a variable that we can ask the model to provide a prediction for.

```
model.fit(X_dataSet, y_dataSet, epochs=10)

Epoch 1/10
3/3 [==============================] - 3s 4ms/step - loss: 25.3767 -
Epoch 2/10
3/3 [==============================] - 0s 4ms/step - loss: 12.3720 -
Epoch 3/10
3/3 [==============================] - 0s 4ms/step - loss: 11.8307 -
Epoch 4/10
3/3 [==============================] - 0s 4ms/step - loss: 9.0997 - 
Epoch 5/10
3/3 [==============================] - 0s 4ms/step - loss: 8.2489 - 
Epoch 6/10
3/3 [==============================] - 0s 4ms/step - loss: 8.6591 - 
Epoch 7/10
3/3 [==============================] - 0s 5ms/step - loss: 8.2725 - 
Epoch 8/10
3/3 [==============================] - 0s 4ms/step - loss: 8.2265 - 
Epoch 9/10
3/3 [==============================] - 0s 4ms/step - loss: 8.0233 - 
Epoch 10/10
3/3 [==============================] - 0s 4ms/step - loss: 8.0629 - 
<tensorflow.python.keras.callbacks.History at 0x7f939d69a050>


model.predict([15.21])

array([[0.22776632]], dtype=float32)

[ ]
```

By running this machine learning model, we are given a 0.228 chance for 1 in 100 year events happening each year. By applying this result over 10 years, this gives us, on average, **2.28 1-in-100 year events**, to happen in the next 10 years.

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[8] Retrieved August 7, 2021 from:
https://data.mfe.govt.nz/table/89453-new-zealands-national-temperature-19092016/
[9] Retrieved August 7, 2021 from:
https://data.mfe.govt.nz/table/52586-number-of-extreme-weather-events-identified-by-icnz-19752014/

The model made this prediction based on the fact that there is a decrease in time between each 1-in-100 event historically. Given that the last 2 1-in-100 events happened within the last 20 years, coupled with the increasing impacts of climate change and the fact it falls within the ranges given in our probabilistic model, we believe that this is a reasonable prediction.

3.0 Limitations

This investigation included several limitations where elements were omitted, uncertain, or unable to be considered.
- The values of temperature increase resulting from climate change referred to throughout this report are approximated (in section 2.1) by, effectively, dividing a 25-year estimated change by 2.5 to get the change over 10 years. This assumes that the rate of temperature change is linear. In reality, human development and therefore emissions have been exponential, which our figures do not account for and therefore harbour some inaccuracy. However, given the (relatively) short timeframe covered by this report, we believe the impact of this is not as significant as it could otherwise be.
- Our modelling does not account for more uncommon types of weather events, including hail storms and snowstorms. However, when looking at previous 1 in 100 year weather events in New Zealand, the vast majority are rain or wind related, thus, we do not believe the odds of an extreme outlier event are of significant impact.

Limitations of the statistical model:
- The statistical machine learning model, which our final average is based on, draws its prediction on only four data points for 1 in 100 year events. This is an unavoidable issue, given the rarity of such events, but will reduce the accuracy of our conclusion
- As the machine learning model learned by relating to previous temperatures, it may have drawn unrealistic conclusions from the volatility of pre-2000s temperature data (i.e. a spike in temperature equaling a severe weather event). This means that, given the rapid increase in temperatures in the 2020s, it may significantly overestimate the odds of events occurring, which would mean our predicted average could be significantly higher than reality.

4.0 Conclusion

After confirming that our statistical model falls within the boundaries set out by our probabilistic model, we determine that the number of 1 in 100 year weather events experienced by New Zealand in the next decade most likely **falls between 0 and 4, with an average of 2.28.** This represents a significant departure from existing weather norms, which either heralds a significant risk for New Zealand and our future weather sustainability, or highlights a consequence of a previously stated limitation.