Taking a chance on the weather

When it comes to long-term weather forecasting, chaos is a constant – as Brett Mullan, Principal Scientist Climate, NIWA, explains.

NIWA released its seasonal outlook for February-April 2016 at the beginning of February. The forecast indicated that the seasonal rainfall in the east of the North Island was equally likely to be near normal or below normal for that region. So, why might you be experiencing a downpour in Gisborne today?

Weather chaos

Small changes make a big difference to our weather, climate and atmospheric circulation.

It's "chaotic" which means tiny changes can result in completely different behaviour. This is sometimes known as the "butterfly effect".

Numerical weather prediction is based on a set of coupled differential equations – known as the dynamical equations of motion – that encapsulate basic physical properties such as conservation of energy, conservation of angular momentum and conservation of water (which can be evaporated from the ocean, moved about by the winds and then possibly deposited on the slopes of the Southern Alps).

While in theory this set of equations may suggest the weather is predictable, in practice the forecasts quickly become random due to the growth of small errors in the initial observations or in the numerical solutions.

The growth of small errors is a fundamental property of the type of mathematical equation that describes atmospheric motion, and would apply even if all the terms like evaporation, rainfall or friction could be formulated exactly. Numerical round-off is all that is needed to kick a forecast off-track, a result discovered serendipitously by Professor Edward Lorenz of the Massachusetts Institute of Technology in the early 1960s. Some years later, the very computer that Lorenz used, the size of a metal desk, was still quietly rusting away in the corner of an MIT office shared by a young soon-to-be-Dr Mullan.

Such randomness limits everyday weather prediction to about 10 to 14 days at most, before the predicted intensity, location and timing of weather systems bear no relation to what is subsequently observed. Smaller scale weather events, like afternoon convective showers, have much shorter predictability times. Conversely, the enormous thermal inertia of the ocean increases the predictability of fluctuations involving the ocean such as the El Niño-Southern Oscillation (ENSO).

Anomalies in ocean surface temperature can persist for several months, and influence the uptake of moisture and trajectories of air masses passing over them. ENSO temperature anomalies have two additional advantages: the persistence is longer because of feedbacks between the ocean and atmosphere changes that drive the Oscillation to one of its two extremes (El Niño versus La Niña) and 'hold' it there for up to six months and more.

The other advantage is that the tropics is a special place of the Earth for influencing weather elsewhere. Tropical circulation changes generate long-range wavelike fluctuations in the atmosphere that can influence weather at remote locations – what are termed "teleconnections".

One of the consequences of warmer than normal sea surface temperatures in the tropical Pacific under El Niño is to export some of the atmosphere's angular momentum to higher latitudes and strengthen the jet streams in both hemispheres. The jet stream locations can also shift from their normal position to some degree. For New Zealand, El Niño periods lead to more frequent or stronger westerlies, and this in turn has the obvious effect on the country's west-east rainfall gradient.

Unfortunately, superimposed on this ENSO signal, there is always chaos to contend with. It is like trying to predict the path of a large beach ball bouncing down a rocky hillside, while it is intermittently nudged to the left or right. The slope of the hill, and the direction of the nudging, provides a predictable component, with the random noise dependent on which rocks are hit on the way down the hill.

How do we forecast?

Seasonal outlooks are prepared using both statistical and dynamical approaches. The statistics route takes advantage of observed relationships in past weather and climate: how does New Zealand rainfall vary with the state of El Niño or with the temperature anomaly or gradients in the Tasman Sea?

One problem with this approach is that past relationships may no longer hold true as the climate changes under global warming. The dynamical equations remain valid regardless of the mean state of the climate, and, as computer technology improves, dynamical seasonal forecasts are becoming the standard approach.

At NIWA, each month the forecast team gets together by teleconference (climate scientists and weather forecasters from Auckland and Wellington, and hydrologists from Christchurch), and mull over the latest guidance from about a dozen different models, a mix of statistical and dynamical. This gives the forecasters

Dr Brett Mullan is a Principal Scientist at NIWA, and is manager of the Climate Variability Group on the Wellington campus, with more than 25 years' experience in the areas of seasonal climate forecasting and climate change science. He is a former member of the Royal Society of New Zealand Climate Committee, a former President of the Meteorological Society of New Zealand, and the lead author of the 2008 and 2016 climate change guidance manuals for local government prepared by NIWA for the Ministry for the Environment.

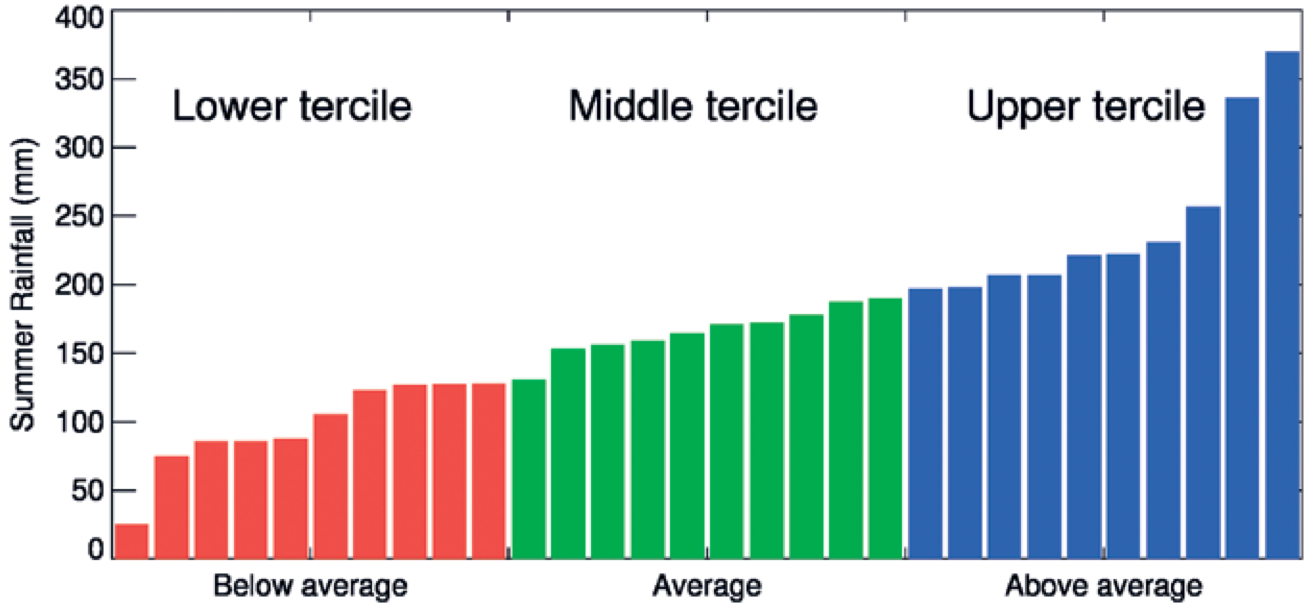
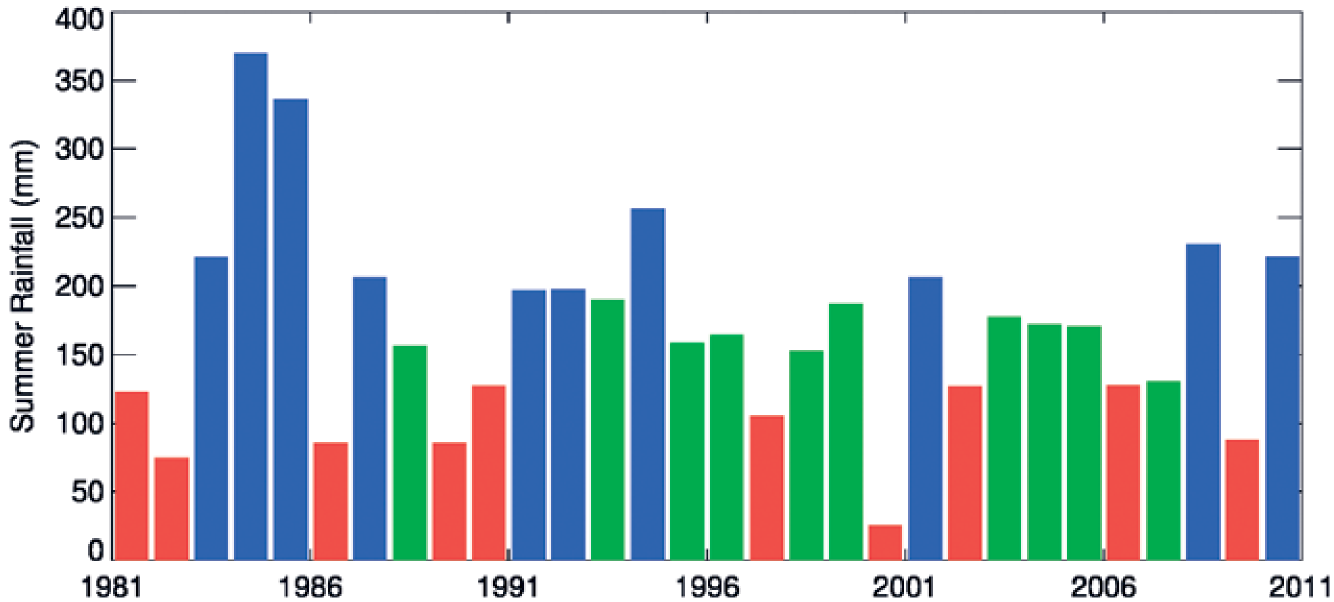


Figure: Summer rainfall total (mm) at Sevenoaks climate site in Marlborough. The top panel shows the seasons ranked from driest to wettest, with colour-coding for the three terciles. The bottom panel shows the observed sequence of dry (red), normal (green) and wet (blue) summers at this location.



a sample of predictions, known in the trade as an "ensemble", which can take some account of the chaotic evolution of the weather over the coming three months ahead.

Some of the individual models, of the dozen or so, are themselves explicit ensembles. For example, at the European Centre for Medium-Range Weather Forecasts (ECMWF) in England, every month an ensemble of 51 global forecasts are made for the following seven months. Each forecast starts from a very slightly different initial analysis of the global weather patterns, all of them consistent with the observations and their associated uncertainties.

Current research at NIWA is aimed at assessing how well the different forecast models do, and how best to combine the different results. If one model is forecasting an outcome quite different from the majority of models, then the outlier will be given less credibility. If one model has been performing much better than the other, then it is reasonable to give its forecast greater weight. Of course, deciding how well a model is performing, when the forecasts are expressed as probabilities, is not trivial.

The power of three

At NIWA, the climate forecasts are expressed as the probabilities of terciles – that is, one of three possible outcomes: below normal, near normal, and above normal. The Figure shows an example of how this works in the case of a rainfall forecast.

We take a climatological 30-year period, and rank the seasonal rainfall totals from lowest to highest. The 10 lowest rainfalls form the lower tercile of "below normal", the next 10 the middle tercile of "near normal", and the highest 10 the upper tercile of "above normal". Corresponding rainfall forecasts from a model ensemble are then collated, and the hit rate within each tercile is accumulated. The NIWA teleconference discussion will then modify this tercile distribution; at present, this is done qualitatively while a statistical scheme is worked on for weighting the various forecast models in an optimal fashion.

We might end up with a forecast rainfall distribution, for example, of 40:40:20, for the below normal: near normal: above normal terciles respectively. Here are some bullet points on interpreting the terciles; the NIWA website provides more.

- Remember that terciles are being used, so all terciles have a climatological expectation of approximately 33 percent. Compare the forecast probabilities against climatology.
- Because the climate outlooks are based on probabilities, it is best to plan for a range of possible outcomes.
- Any management decision should not be based solely on the climate outlook, as there will be a range of other relevant factors. Ideally, a cost-benefit analysis will weigh up the losses or gains of alternative options.
- The outlooks do not always indicate a high probability of dry or wet conditions. A 'flat' distribution (eg, 30:40:30) suggests the forecasters are not very confident in the outcome.
- It may be helpful to look at the least likely outcome. Using the 40:40:20 example above, the forecasters are most confident that rainfall will not be in the above normal range (20 percent versus 33 percent).

Long-term outlook

What is the long-term outlook for the rest of 2016? At present a very strong El Niño event dominates the tropical Pacific. The forecast models predict the tropical forcing (and other factors) to lead to a more persistent westerly weather pattern over New Zealand, and thus an increased chance of drier than normal conditions on the east coasts.

The current event is past its peak, and conditions in the Pacific are expected to return to normal by early winter. So a winter 2016 forecast will not be able to rely on ENSO relationships, but closer to the beginning of June, there may be other anomalies in the climate patterns to give us some guidance.

In the latter half of 2016, some of the ENSO forecast models (NIWA monitors 14 of them) are predicting a transition to La Niña conditions in the Pacific. If this happens, and there is about a 50:50 split between models predicting La Niña versus neutral (neither La Niña nor El Niño), then a warmer than normal spring is likely for New Zealand, with increased rainfall in north-eastern parts of the country. **WNZ**