An evaluation of Climate Forecast System Reanalysis (CFSR) data for use in models that require meteorological weather station data in New Zealand

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Abstract

Pre-processed, weather station data provides necessary inputs to numerous biophysical, process-based enviro-agronomic models, such as the SWAT model. Long-term Climate Forecast System Reanalysis (CFSR) data from The National Centers for Environmental Prediction (NCEP), was compared with data from the New Zealand National Climate Database. This reanalysis data is available as pre-processed daily Global Weather Data for the SWAT model and covers a 36-year period from 1979 through to mid-2014. CFSR data has the potential to be used in numerous simulation models in New Zealand where meteorological data is needed. The data is freely available. Data from nearby CFSR stations were compared with meteorological station data in the Rotorua region. The analysis shows that mean daily temperatures (minimum and maximum), precipitation, and solar radiation from observation data at the Rotorua airport, including combined data was within the range of means from nearby CFSR stations and approximately equal to overall means. Q-Q plots showed similar rainfall probability distributions. There was insufficient long-term relative humidity data in the National Climate Database at this station to make a valid comparison. The analysis shows that CFSR data can be very useful for wider use but needs to be quality assured using a greater number of monitoring stations from the New Zealand National Climate Database.

Additional keywords: Climate Forecast System Reanalysis (CFSR) data, mean daily temperatures, New Zealand National Climate Database, precipitation, solar radiation.

Introduction

Crop-growth models are used extensively in the analysis, evaluation and prediction of crop growth and production, on in-field scale up to regional or country levels.

These models usually use daily evapotranspiration and soil moisture availability calculations from daily meteorological station data (e.g. temperature, solar radiation, rainfall and wind speed). It is not unusual for models of crop growth to use precipitation data from the nearest meteorological station which could be tens of kilometres away and solar radiation data from stations which could be almost a hundred kilometres away. Basic factors such as topography (e.g. mountain ranges) should be considered when choosing representative weather-monitoring stations in the region.

Crop models are found within physically-based hydrological, transport models, such as the Soil and Water Assessment Tool (SWAT) model (www.swat.tamu.edu). This model requires a considerable amount of input data which must be accurate, consistent, continuous, and cover the entire region of interest. This model and others require spatial data such as land use, soils, and topography as well as climate data including (at a minimum) daily precipitation, minimum, and maximum temperature, wind speed and solar radiation. Deriving climate data and pre-processing it to be used in models, can be a laborious and time-consuming task.

Many countries have pre-processed climate data, derived from their climate databases and these are made publicly available. The selection and pre-processing of climate data for use in models such as SWAT is more complex than it may seem and guidelines exist for assessing the suitability of spatial climate data sets (Daly 2006). Although full coverage of a country may be needed, the required quality and density of data varies depending on where it is to be used. If the models focus on agriculture, observation density and accuracy are key in heavily cultivated areas. Topographic climatic effects are less critical in agricultural regions, tending to be more prominent in mountainous areas where there is little or no agriculture. Accurate average annual total precipitation, and the distributional frequency and intensity of rainfall events are critical for hydrology in a catchment. Satellite data and various statistical methods, relating to the scale of interest have been used to improve the quality of conventional meteorological data.

Climate data, as needed by models can either be 1) point observations at discrete weather stations; or 2) maps derived from interpolations, remotely sensed, or simulations averaged over some spatial scale, usually a grid. The climate data derived using the latter is dependent on the spatial scale required (field and small sub-catchments or larger regional catchments). If models apply a single set of weather observations to an entire sub-catchment, then it is important that these data are representative of the entire sub-catchment. Differing data sources and methods may be evaluated and used to synthesize a seamless daily climate dataset for application in models such as SWAT. These processed climate data have been publicly released via the web to support other SWAT modelling projects (e.g. White *et al*. 2017 for SWAT assessments in the United States). The various comprehensive climate station datasets for deriving pre-processed climate data in the United States, each with their own limitations are discussed by White *et al*. (2017), including the various gridded climatic databases which employ some interpolation or modelling methods between ground stations, and which utilize topography or remote sensing data. Direct comparisons between various datasets are reported by White *et al.* (2017) to be limited.

In New Zealand, relevant point climate station data may be obtained from the National Climate Database, through CliFlo, the web system that provides access to New Zealand's National Climate Database (www.cliflo.niwa.co.nz). Climate database for a wider catchment or region requires 1) extracting a lot of station data from the national climate database, or 2) acquiring the complete National Climate Database from NIWA, which continues to receive data from about 600 stations that are currently operating. There are licensing issues with how much data can be downloaded. Also, the data is difficult to download, and difficult to amalgamate from different stations since there are gaps in data, some stations have moved slightly, or there is equipment changed over time. Acquiring the complete database is not an option unless there is a very strong commercial case, and to date this has never been done. If available, this will allow database queries to be performed, and this includes smarter ways of gap filling.

In the absence of station data one may use spatially interpolated station data purchased from the NIWA VCSN (Virtual Climate Station Network data) through the NIWA data service (https://www.niwa.co.nz/climate/our-services/virtual-climate-stations). This data is quality assured data from over 300 NIWA monitoring stations and includes over 11000 'virtual' data points (on a regular (~5km) grid) nationwide developed by interpolation using ANUSPLIN (Hutchinson 2012) and used for climate analysis (Tait *et al*. 2006). There could be step changes in the time series when new stations have either been removed or added and this is noticed in modelling projects.

A comparison between meteorological data from NIWA and data from independent meteorological stations was reported by Mason *et al*. (2017). Monthly mean global radiation, and suitably adjusted estimates of mean daily maximum and minimum termperature from the VCSN were found to estimate these properties for points in the landscape with reasonable precision and small bias. Rainfall, however, was imprecisely estimated.

The lack of easily accessible climate station data across New Zealand was reported to be a big hindrance in developing a pre-processed national climate database for New Zealand for use in models such as SWAT (Parshotam 2018) and workarounds relied on using freely available gridded Global Weather data for SWAT (See https://globalweather.tamu.edu/). The quality of this data in projects requiring weather station monitoring data still needs to be addressed before it can be widely used with confidence.

Global Weather Data for SWAT is obtained from The National Centers for Environmental Prediction (NCEP), Climate Forecast System Reanalysis (CFSR) (See https://globalweather.tamu.edu/#pubs). The CFSR (https://rda.ucar.edu/pub/cfsr.html) was designed and executed as a global, high-resolution, coupled atmosphere-ocean-land-surface-sea ice system to provide the best estimate of the state over a 36-year period of 1979 through to mid-2014. A climate reanalysis gives a numerical description of the recent climate, produced by combining models with observations. It contains estimates of atmospheric parameters such as air temperature, pressure, and wind at different altitudes and surface parameters such as rainfall, soil moisture content, and sea-surface temperature. It uses observations made by meteorological observations, ranging from early in-situ surface observations made by meteorological observers to modern high-resolution satellite data sets (see details in Vidal *et al*. 2010). For New Zealand, the CFSR uses all available observation and satellite data in its analysis, including all New Zealand observations sent on the GTS-land-based stations, upper air soundings, aircraft, ships and drifting buoys. In that respect it may be a good match but this needs to be confirmed by examining the methodology followed by NOAA/NCAR to create these datasets. The observed data used for New Zealand are 40 surface synoptic stations sent by the New Zealand MetService to the global modelling centres via the World Meteorological Organisation (WMO) Global Telecommunication System (GTS). Many of these stations are at airports with the full list being Cape Reinga, Purerua, Bay of Islands, Mokohinau Island, Auckland Airport, Tauranga Airport, Hicks Bay, Taharoa, Taupo Airport, Gisborne Airport, New Plymouth Airport, Waiouru, Napier Airport, Palmerston North Airport, Paraparaumu Airport, Wellington Airport, Castlepoint, Westport Airport, Farewell Spit, Nelson Airport, Cape Campbell, Hokitika Airport, Kaikoura, Haast, Tara Hills - Omarama, Timaru Airport, Christchurch Airport, Secretary Island, Puysegur Point, Queenstown Airport, Invercargill Airport, Dunedin airport, Southwest Cape, Stewart Island, Enderby Island, Campbell Island, Chatham Island Airport and Raoul Island.

New Zealand Weather Data for SWAT and in SWAT file format is available through the Global Weather Data for SWAT website (See https://globalweather.tamu.edu/). Here, one may download daily Climate Forecast System Reanalysis (CFSR) data (precipitation, wind, relative humidity, and solar) for a given location and time period. The CFSR data is produced at ~38km resolution (Saha *et al*. 2010). File names of individual grid stations are derived from its station location unique identifiers (latitude and longitude data). There are 619 'stations' available across New Zealand with long-term data and because of the range of coordinate constraints, these need to be downloaded separately for the North and South Islands. A complete database of climate reanalysis data for New Zealand for performing basic queries may be created by "joining" relevant data files.

Numerous models may also use data from stochastic weather generators. This is a synthetic time series of weather data for a location based on the statistical characteristics of observed weather at that location. Weather geneators (WGs) are usually used for climate change simulations, and to fill missing data. There is an option to use the weather generator algorithm within the SWAT model, where there are no climate stations with measurement data in the modelled location. Three methods may be used to derive a set of national weather generators (WG's):

i) Creating a nationwide WG using downloaded CFSR station data using the WGEN Parameters Estimation Tool, which uses MS-Access (See https://swat.tamu.edu/media/116061/swat-weatherdatabase-v01803.7z).

This needs at least 10 years of downloaded data for every station and output data is in SWAT format.

ii) Downloading the CFSR_World weather database from https://swat.tamu.edu/media/99082/cfsr_world.zip,

which includes CFSR stations, including New Zealand ones. The SWAT model chooses the nearest and relevant weather station, WG's when necessary.

iii) An excel macro for creating WG in SWAT format is available from https://swat.tamu.edu/media/41583/wgen-excel.zip.

This requires extracting data from the national climate database to create a nationwide weather generator. Data from stochastic weather generators are not evaluated in this work.

The objective for this work is to evaluate different data sources in New Zealand suitable for application with models that require daily climate station data, such as SWAT. This is done by taking a 'spot check' of gridded CFSR data and comparing it with nearby local Meteorological Station data in the Rotorua region. The strengths and weaknesses of these two data sources are discussed. The climate area of interest in this study comes within the Eastern North Island climate zone. A similar analysis in the future may be performed for other NZ climate zones (Northern NZ, Central North Island, South-West North Island, Northern South Island, Western South Island, Eastern South Island, Inland South Island and Southern NZ).

Materials and Methods

Meteorological station data files in the Rotorua region are downloaded and analysed for completeness and a representative station is chosen. Data files from four CFSR stations are downloaded, analysed for completeness and compared with local meteorological station data.

A basic evaluation with means and standard deviations is performed using all station data, i.e. weather station data and gridded CFSR data. It is known that both datasets contain gaps. For the rainfall analysis, only data that was present in both datasets were used. Probablity plots or quantile-quantile (*Q*-*Q*) plots are used to compare the probability distributions of one rainfall dataset against each other. If the distributions are exactly the same, then we expect the plot to fall roughly on the straight line $y=x$. If the distributions are linearly related the points in the *Q*-*Q* plot will approximately lie on a line, but not necessarily on the line $y=x$. A regression analysis between ranked daily rainfall from rainfall gauges at various stations is performed. This allows one to construct a synthetic record if needed (see Semadeni Davies & Parshotam 2009).

Note that timing of wind speed measurement and relative humidity is unspecified in CFSR and in the national climate database, windspeed is given at 9am and relative humidity is an hourly average, throughout the day.

Meteorological station data

Station data in the Rotorua area are extracted through CliFlo (https://cliflo.niwa.co.nz/).

Open stations are favoured in the analysis and joining spliced datasets from different stations is avoided. The location of weather stations is given in Figure 1 and this includes start and end dates. The two climate stations chosen are stations with agent numbers 1770 and 1768, located at the Rotorua airport and data from these may be joined whereas the others are for other locations and may not be joined. These are all reported to have 100% complete data but on closer examination, this is not the case, and there are numerous gaps (Table 1).

The observing authority for 1770 AWS station, an open station is New Zealand Meteorological Services. Also of interest, is station with Agent number 41077, with observing authority being NIWA, which has a 100% complete dataset. Station with agent number 41077 also has mean temperature data.

Select	Agent Number	Network Number	Start Date	End Date	Percent Complete	Name	Lat (dec deg)	Long (dec deg)
☐	41077	B86128	25-Sep-2015	21-Aug-2019	100	Rotorua Ews	-38.14635	176.2578
☐	1770	B86133	31-Dec-1981	20-Aug-2019	100	Rotorua Aero Aws	-38.10595	176.31485
☐	1768	B86131	11-Nov-1963	31-Dec-1991	100	Rotorua Aero 2	-38.11065	176.31756
☐	1762	B86121	01-Apr-1923	31-Mar-1952	100	Rotorua,Sophia St	-38.15	176.25
☐	1763	B86122	01-May-1940	31-Jan-1952	100	Rotorua,Golf Links	-38.15	176.25

Figure 1: Screen Image of all Rotorua Stations in the national climate database obtained through CliFlo. Coordinates use the NZGD49 coordinate system.

Table 1: Time period of available data in the national climate database for stations with agent numbers 1768, 1770 and 41077. This does not include missing data. Current is September, 2019.

Agent number	Precipitation (mm)	Temperature (min/max °C)	Wind (m/s)	Relative Humidity (%)	Solar radiation (MJ/m^2)
1768	12/11/1963–1/1/1992	1/1/1972–1/1/1992	1/4/1964–1/1/2013	N/A	1/1/1972–current
1770	1/1/1982–current	20/12/91–current	29/6/2009–1/1/2013	29/6/2009–1/1/2013	17/11/91–current
41077	26/9/15–current	25/9/15–current	25/9/15–current	25/9/15–current	25/09/15–current

Table 1 gives the time period of available measurement data in the national climate database for individual datasets. Agent 1770 has the longest record for precipitation (1/1/1982 to current) and is favoured for daily rainfall analysis.

Station with agent number 1768 is a closed station. Station with agent number 1770 has the longest record. Solar radiation from stations with agent numbers 1768 and 1770 may be combined. Relative humidity only exists from mid-2009. Where there is overlap of data, Agent 1770 data is given precedence. There are only four years of recent data from station with Agent number 41077 and this station is not used for the analysis. The station with the longest record for rainfall (i.e. Agent 1770) is taken for the purposes of rainfall analysis, and is not combined with data from other stations.

For convenience, CliFlo-1768, CliFlo-1770 and CliFlo-41077 denotes weather data with Agent numbers 1768, 1770, and 41077, respectively.

Global weather data for SWAT

Figure 2 presents a screen image of four CFSR stations selected within a 'square' region near the Rotorua airport with data available to download. The downloaded data may be generated as SWAT TXT files or CSV files. SWAT TXT files are individual files for each gridded station for precipitation, wind, temperature, solar radiation and relative humidity. There is a header start date and missing values are assigned '-99'. In addition, there are SWAT station coordinate files generated for all stations. SWAT CSV files are individual files for a gridded station with separate columns containing date, latitude, longitude, elevation, precipitation, wind, temperature (minimum and maximum), solar radiation and relative humidity. File-name identifiers are derived from location coordinates.

Note that there are discrepancies over the two sources of data even though they should contain the same information. In all CSV files, the following dates are missing: 2-Sept-1983 to 30 Sept 1983 (incl); 1-Jan-1985 to 31-Jan-1985 (incl); 31-May-1986; 25-Dec-1986 to 31-Dec-1986 (incl); 2-Jun-1996 to 30-June-1996 (incl) and 1-Jan-1999 to 31-Jan-1999 (incl). This amounts to 1% of dates (and corresponding data) which are missing. In the TXT files (used for SWAT modelling), where there are missing dates, data has have nominal values of '-99' every day or every second day. There are missing data (given nominal values of '-99' in corresponding TXT files which corresponds to about the same number of days (or 1% of all data), that are missing.

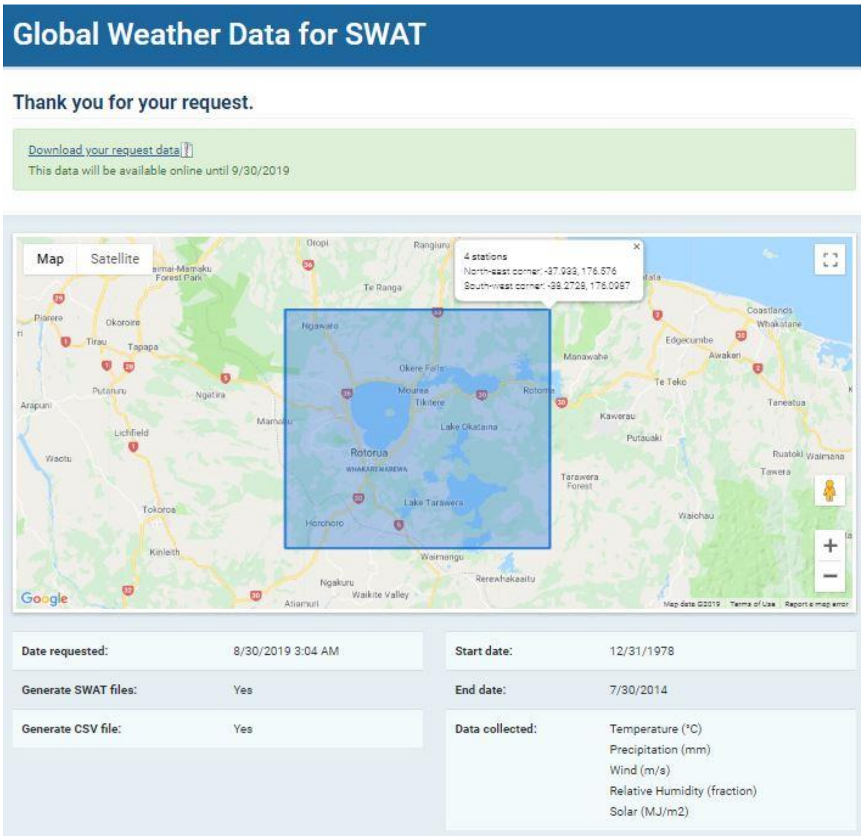

Figure 2: Screen Image of Four CFSR stations in the Rotorua area and the data available to download from https://globalweather.tamu.edu/. Gridded stations are not pin-pointed. These may be downloadable in CSV format or SWAT file TXT format. The CFSR stations 3791763, 3791766, 3821763 and 3821763 have (longitude, latitude) coordinates (176.25, -37.9358), (176.562, -37.9358), (176.25, -38.248), and (176.562, -38.248), respectively.

For convenience, a CFSR station with station number X is referred to as a CFSR-X. Note that CFSR-3791763 and CFSR-3821763 stations are closest to climate stations with Agent numbers, 1768 and 1770.

Results

Table 2 gives a summary of means and standard deviations (SDs) of data from Agent numbers 1768 and 1770, and combined (1768&1770) data. There is a slight variation in means and standard deviations of data at all stations.

Table 3 presents the means and standard deviations (SDs) at all four gridded stations from 1979 to mid-2014 from downloaded CSV files.

Table 2: Means of station data from all data available over their respective measurement periods.

Agent number	Precipitation (mm)	Temp min (°C)	Temp max (°C)	Wind speed (m/s)	Relative humidity (%)	Solar radiation (MJ/m^2)
1768	3.95 (10.56)	8.14 (4.78)	17.4 (4.35)	3.13 (2.52)	N/A	14.60 (7.90)
1770	3.72 (10.20)	8.15 (4.91)	17.32 (4.35)	3.06 (2.37)	83.18 (12.67)	14.37 (7.98)
1768 & 1770	3.83 (10.44)	8.14 (4.85)	17.35 (4.35)	3.13 (2.52)	83.18 (12.67)	14.60 (7.90)

Table 3: Means and standard deviations (SDs) of CFSR gridded station data from 1979 to mid-2014.

CFSR	Precipitation (mm)	Temp min (°C)	Temp max (°C)	Wind speed (m/s)	Relative humidity (%)	Solar radiation (MJ/m^2)
3791763	4.32 (9.44)	8.60 (3.97)	17.20 (4.49)	3.81 (1.62)	81.9 (9.3)	13.71 (8.88)
3791766	3.63 (8.58)	9.64 (3.82)	17.65 (4.31)	4.03 (1.70)	78.7 (9.5)	14.67 (8.94)
3821763	3.99 (8.77)	7.15 (4.09)	16.65 (4.88)	3.5 (1.48)	82.4 (10.1)	13.78 (9.08)
3821766	3.61 (8.22)	7.46 (4.02)	16.7 (4.83)	3.64 (1.55)	81.5 (10.0)	14.17 (9.07)
Means	3.89	8.21	17.05	3.75	81.1	14.08
Range of stn means	3.61 –4.32	7.15 –9.64	16.65 –17.65	3.5 –4.03	78.7 –82.4	13.78 –14.67

There is a noticeable range in means of CFSR data estimates at the gridded stations.

The analysis shows that mean daily temperatures (minimum and maximum), precipitation, and solar radiation from observation data at the Rotorua airport, including their combined data was within the range of means from nearby CFSR stations and approximately equal to the overall means. There was insufficient long-term relative humidity data in the national climate database in order to make a valid comparison. Mean windspeeds in the CFSR are higher than windspeeds from observation data. For precipitation data, the time period common to datasources (CliFlo-1770 and CFSR-X) is the period 1/1/1982 to mid-2014. The number of rows removed during this time period is 3.5% with most removed during this time period being from 2.7% rows of missing data in the national climate database.

Table 4: Daily means and standard deviations (SDs) of gridded CFSR data from 1/1/1982 to mid-2014 with rows with missing data removed.

Station	CliFlo-1770	Weatherdata--3791763	Weatherdata--3791766	Weatherdata--3821763	Weatherdata--3821766
Daily Rainfall (mm)	3.71 (10.2)	4.21 (9.26)	3.57 (8.48)	3.93 (8.68)	3.56 (8.16)

The Quantile-Quantile plots show that the distributions of precipitation data from the two datasources (Figure 3) are linearly related.

Daily rainfall data from these climate stations are not well correlated to each other (results not shown), unless ranked, in which case CliFlo-1770 data is correlated to CFSR-3791763, CFSR-3791766, CFSR-3821763, and CFSR-3821766 data with R^2 values of 0.9773, 0.9901, 0.9788, and 0.983, respectively. The closest gridded stations to CliFlo-1770 stations are CFSR-3791763 and CFSR-3821763 and these do not have the highest R^2, as expected (details not shown). The slope is always less than one and this shows that the rainfall was always underestimated, particularly the large values.

Discussion

Meteorological reanalysis data such as CFSR data has the potential to be used in numerous simulation models in New Zealand, where meteorological station data is required. Although this current work is only a ‘spot check’, it would be advisable to take multi-spot checks to verify that the tool is appropriate to any point, and not only those locations where data was used. Including more points and more data types is recommended. A comparison of the complete CFSR database with the national climate database is not possible without the complete national climate database. CFSR data is probably reasonable around any low-lying areas (where airports are more common) but is likely to be significantly in error near any mountains. This has to be verified.

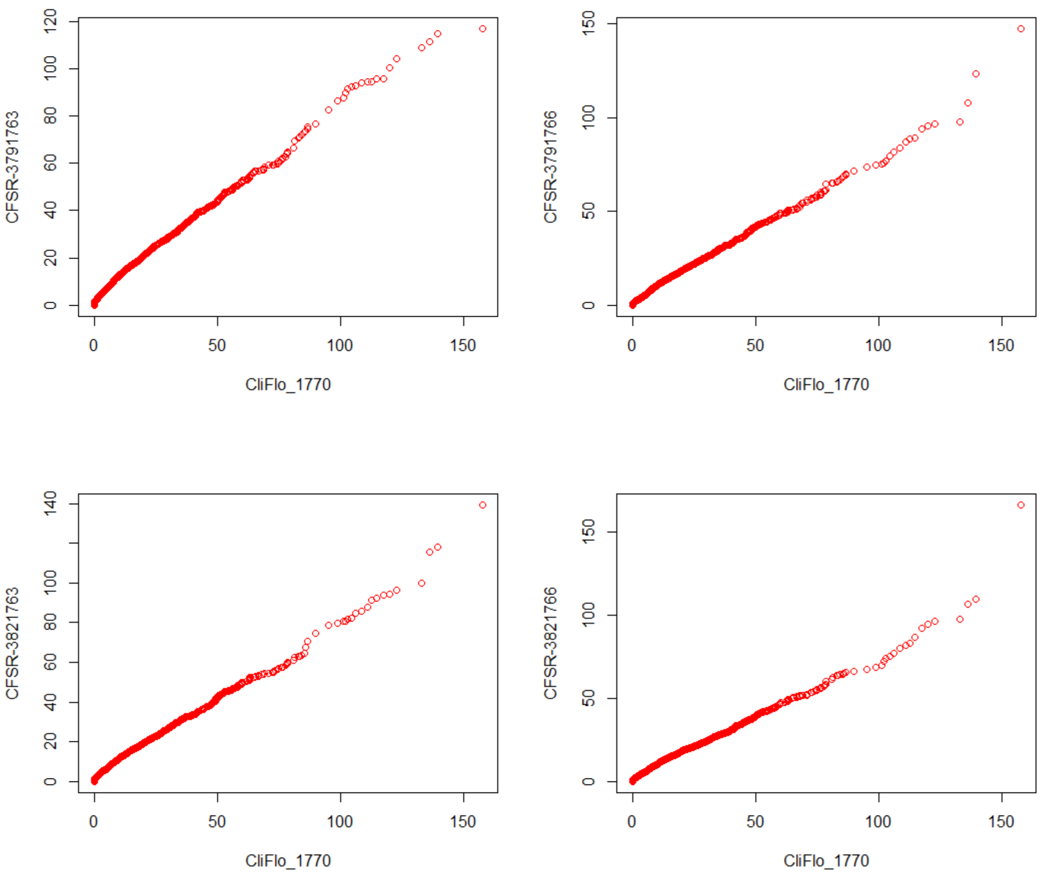

Figure 3: Probability plots or Quantile-quantile plots of CliFlo_1770 and CFSR-X precipitation data during the same time periods. 1/1/1982 to mid-2014.

A rough analysis of CFSR data around New Zealand shows that the grid point locations provided in the files do not match any known reporting stations in New Zealand. The northern most observation site is Cape Reinga, at 35.430^0 South, 172.682^0 East. None of the data in the downloaded files downloaded match this location. The data files show the three northern-most grid points lying to the east of the North Island. Another gridpoint in the data files is 32km offshore from Whanganui, and there has been no long-term observing platform there according to New Zealand Meteorological Services records. Since it is gridded data, it is not unusual for there to be a station in the water. This is true also of VCSN although to a smaller extent as the grid sizes are smaller.

A fully spatially-referenced, climate database is useful for performing simple database queries such as identifying regional climate-change trends, and to fill missing data using correlated data from nearby stations. The fully spatially-referenced CFSR database may be used for these purposes.

Downloaded CFSR data file names are based on a convenient identification system and visual selection process. From the file names one can easily determine the nearest station of interest. CFSR data is not seamless and may have some missing data. In contrast, the National Climate database is archaic and cumbersome to work with. There is a standard limit of 40 000 rows, and pop-ups that need to be enabled in the web browser. There is no easy way of identifying missing rows.

Use of meteorological reanalysis data must be taken with caution (Trenberth, 2001). Evaluation of CFSR data for hydrological modelling using SWAT has been evaluated by Dile and Srinivasan (2014) using climate forecast system reanalysis as weather input data for SWAT adapted models is discussed by Fuka *et al*. (2013). For these studies, it is assumed that the weather data that best correlates with catchment streamflow is the best representation of the weather occurring over the entire catchment. Dile and Srinivasan showed that simulations with conventional weather performed better than CFSR weather data. Fuka *et al*. (2013) showed that utilizing precipitation and temperature data to force the SWAT model provides stream discharge simulations that are as good as or better than models forced using traditional weather gauging stations, especially when stations are more than 10km from the catchment. It is recognised that CFSR weather data could be a valuable option for hydrological predictions where conventional streamflow gauges are not available.

The analysis uses downloaded CFSR CSV files and not TXT files, which are used for SWAT modelling. There are discrepancies over the two sources of data even though they should contain the same information. This will have to be considered if CFSR data is used as SWAT model inputs.

Alternative global reanalysis data sets are also available and these cover New Zealand. For example, the Japanese 55-year **Reanalysis** (**JRA-55**, S. Kobayashi *et al*. 2015) and the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis datasets (https://www.ecmwf.int/en/forecasts/datasets/browse-reanalysis-datasets). Climate reanalysis data developed within New Zealand using the national climate database is not available, to date.

CFSR meteorological reanalysis data provides an alternative to VCSN data. Its derivation is well-referenced in the international literature. The VCSN was not used in this comparison because of cost and licensing issues.

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