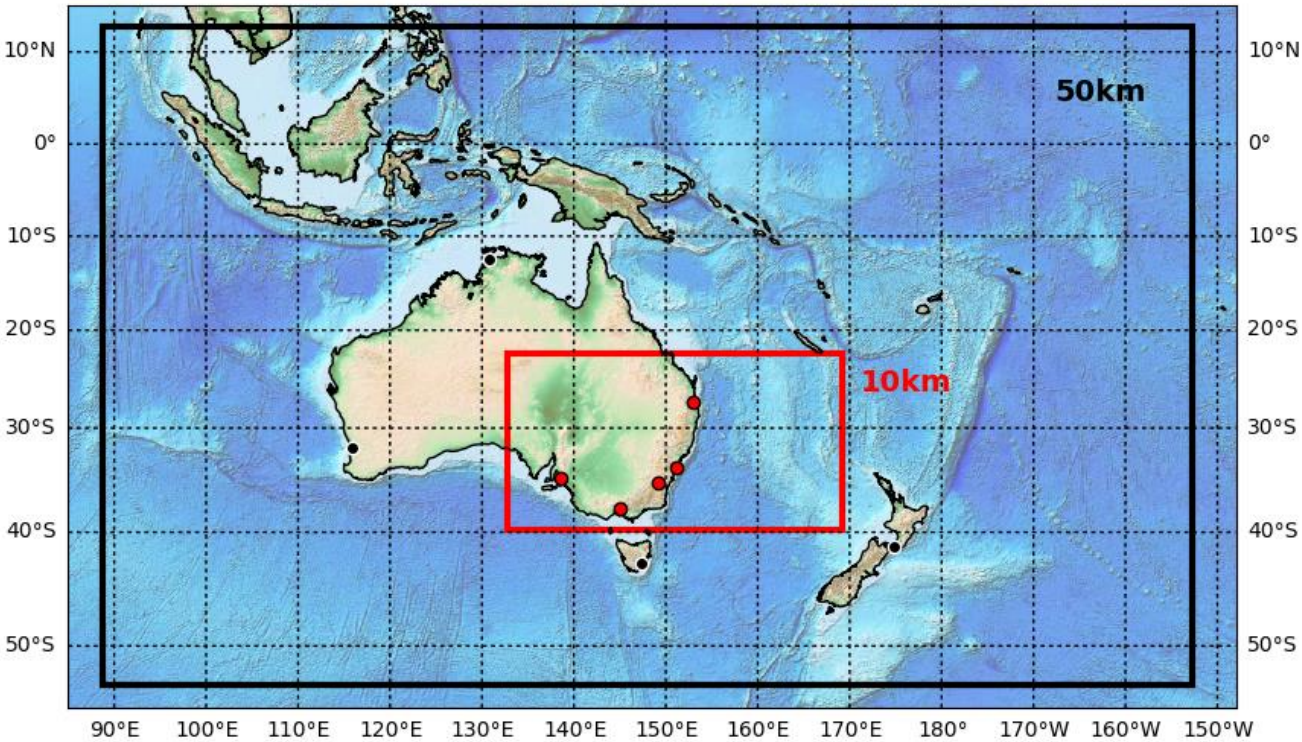
DEPARTMENT OF PLANNING, INDUSTRY & ENVIRONMENT

The NSW and ACT Regional Climate Modelling Project: Climate Projections Version 1.5

NARCliM1.5 Quality Assurance Report



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Abbreviations and acronyms

Abbreviation	Meaning
ACT	Australian Capital Territory
CORDEX	Coordinated Regional Climate Downscaling Experiment
CSV	Comma-separated values
DPIE	Department of Planning, Industry and Environment
GCM	Global climate models
NARCliM	NSW and ACT Regional Climate Modelling
NCI	National Computational Infrastructure
NSW	New South Wales
QA	Quality assurance
QAQC	Quality assurance and quality control
RCM	Regional climate model
SDC	Science Data Compute
UNSW	University of New South Wales
WRF	Weather research and forecasting

Introduction

Through the Climate Change Fund 2018–2022 program, the Science, Economics and Insights Division of the Department of Planning, Industry and Environment (the Department) is focusing on enhancing and updating high quality regional climate projections for New South Wales (NSW), determining climate change impacts on natural hazards, and assessing climate impacts on critical infrastructure.

The NSW Government's major regional climate projections dataset is the NSW and ACT Regional Climate Modelling (NARCliM) which was first released in 2014 (now named 'NARCliM1.0'). This original dataset has been enhanced and the next iteration of regional climate projections, 'NARCliM1.5' is now available (DPIE & UNSW 2020).

Under the Quality Management Framework discussed in World Meteorological Organization (2011) and World Climate Programme (2019), quality assurance and quality control (QAQC) are important aspects of data validation. In keeping with quality assurance requirements, quality assessments and data integrity checks were undertaken on the NARCliM1.5 datasets and are presented in this report.

The NARCliM1.5 quality assurance (QA) process ensures the modelling outputs are complete. In addition, the QA process ensures the data at various levels of post-processing are correct in terms of plausible values, and demonstrates for the NARCliM domain that ~99.9997% of the data passed our initial data tests and the remaining ~0.00003% of the data were manually checked and confirmed to be still plausible under acceptable conditions. All files passed data integrity checks. The variables that were quality assured were calculated and derived from the NARCliM1.5 modelling outputs (raw data).

This report, together with the NARCliM1.5 Technical Methods Report (DPIE & UNSW 2020), are intended to present process and procedural details for developing NARCliM1.5 and assuring its quality.

Technical quality assurance for each variable

The following QA tests are implemented primarily in an automated way and were performed on the raw model output files, the post-processed files and bias-corrected data. These represent standard, fundamental assurance tests that enable the data to be organised and accessed reliably, and address anomalies and artefacts in the data.

File external appearance

The following were tested for consistency: file size, file check-sum, file name (for automated access) and file extension.

Metadata

Within each post-processed file, the metadata were evaluated to ensure it conforms to the Coordinated Regional Climate Downscaling Experiment (CORDEX) standard NetCDF-CF (climate and forecast) conventions version 1.4 as appropriate.

Data

Various data variables were checked to ensure they have the right dimensions (e.g. time, latitude, longitude, vertical levels) and data type (integer, float and double). The data were checked to ensure they lie within specified thresholds (see Scientific quality assurance section below). For the time variable, the calendar type and the temporal resolution were checked.

Other checks

Other checks that were undertaken were checking that the:

- file is readable
- file format is recognised, consistent and correct
- file size is larger than zero
- file size is similar for different time periods
- number of data files is correct.

Scientific quality assurance

Part of the standard scientific rigour applied by the Department is the assurance of established scientific evidence. The following assurance checks were performed to assure the scientific methods were performed correctly and results are consistent with those practices.

Basic scientific quality assurance for post-processed variables

Initial evaluation for output of the NARCliM1.5 archive ensures that all post-processed variable values fall within a realistic range (WMO 2019, Table 2). For example, values of precipitation rates are checked to make sure they fall within the range, for example [0, 1200] mm/day.

Intermediate scientific quality assurance for key variables

The intermediate QA consists of the evaluation of the performance of the NARCliM1.5 ensemble compared with observations of the key variables such as rainfall, temperature, wind, mean sea level pressure. Several aspects of the climate are evaluated, including means, variability and extreme indices. Different metrics test the skill of the ensemble, such as mean biases, spatial correlations and spatial variances in errors.

Consistency between the different timescales (hourly, daily, monthly, yearly and decadal) were also checked. For example, accumulated hourly rainfall over 24 hours should match the daily rainfall.

Advanced scientific quality assurance for some special systems

Advanced scientific QA refers to the evaluation of the NARCliM1.5 ensemble performance when considering more sophisticated and complex diagnostics; such as when testing the ability of the models to represent monsoon systems and/or cyclonic activity (similar to the so-called type-2 assessment in WCRP 2015). If these diagnostics are successfully applied, it can be concluded that the data are of production grade quality. Such an application for these diagnostics will be developed progressively by experienced researchers in future.

User feedback process (registered users only)

In addition to formalised and automated scripted testing procedures, the Department relies on engagements with partners and collaborators to ensure quality from a user perspective. Quality assurance for NARCliM1.5 data is an ongoing process, particularly during early use by project partners and NARCliM1.5 technical working group members. The process for providing and acting on QA feedback is as follows:

- Registered users provide a description of the identified issue(s) to the Department's Climate Research Team via email (climate.research@environment.nsw.gov.au), including a description of the issue(s), the variable, location, model time of the problem and the name of the file containing the problem.
- The Climate Research Team investigates whether they can replicate the same issue. On confirmation, the Climate Research Team locates the data processing level at which the issue appears, that is, raw model output, post-process, bias correction or data extraction.
- If possible, the Climate Research Team will rectify the issue, and create and perform a process to identify and rectify throughout the dataset. If this is not possible, the Climate Research Team will escalate the problem to the University of New South Wales (UNSW) team.
- The UNSW team will investigate the issue and create and perform a process to identify and rectify the issue throughout the dataset where possible.
- The user will be notified of the availability of the corrected data and the new dataset will be available for all users.

All QA modifications to the data are recorded, including the identified problem, what was done to address the problem and by whom. Where issues are found, the original files are archived, except for the post-processed variables.

Technical quality assurance for each variable

Methodology

Data checks were performed for all outputs.

The first step of downscaling global climate models (GCMs) was to produce initial and boundary conditions from the parent GCMs. The outputs were checked manually by plotting time series of the minimum, maximum and mean of their values for each boundary and all initial conditions.

Whilst it was not initially performed for this iteration of NARCliM, future iteration will also involve checking the completeness of the parent GCM. In this particular case, GCM completeness was performed as a result of the detection of large abnormalities in the downstream product. Where data were found to be incomplete, efforts were made to extrapolate the missing data as faithfully as possible. In future, incomplete GCMs will be rejected outright from the selection of GCMs.

Prior to post-processing, a script was used to check for missing raw files and compare the sizes of files of the same domain and type (e.g., CORDEX-Australasia and NARCliM domains, daily and hourly timesteps and climate extreme indices). It was assumed that files from the same domain and type should all form a normal distribution in size after compression (before compression, sizes can be determined exactly before writing the file).The script flags files that are more than four standard deviations less than the mean size of all files of a given type (e.g. daily), and all the flagged files are manually checked.

Missing files can occur due to temporary network issues at the National Computational Infrastructure (NCI) facility or faulty compression of files. For simulations where missing or incomplete files were identified, the months in question with defective files were re-run and the simulation was checked again to ensure correct data.

Time series of the domain minimum, maximum and mean for each variable in the raw outputs were generated for every decade to monitor the integrity of results as they were being produced. Where abnormalities were identified, contour plots of target variables over suspect time periods were examined to ensure the data presented are plausible.

After post-processing, daily data was again checked for completeness in time. Daily data and their spatial gradients must fall within specified thresholds. The script flagged the time and space indices of data points which lay outside their specified thresholds. The plausibility of the data points was then examined. If the data were not plausible, and depending on the cause of the issue, remedial actions have included:

- re-running weather research and forecasting (WRF) simulations
- masking problematic values (e.g. negative humidity values, or replacing incorrect mask values)
- taking values from a donor dataset which should be identical (e.g. sea surface temperature is independent of the regional climate model (RCM) used, thus ensembles with the same parent GCM should have identical sea surface temperatures).

In all cases where we generated the data, new files were check-summed using SHA256 for versioning and ensuring data integrity during movement from NCI back to the Science Data Compute (SDC) data facility.

Example outputs for quality assurance of raw outputs

Example QA outputs are shown below in Figures 1 and 2. Raw and boundary QA outputs were not kept as these were primarily used to monitor simulation progress. Issues which can be captured by the QA scripts used on the raw and boundary outputs will also be captured by the QA scripts used to check the post-processed outputs. The raw data check results are summarised in the Supplemental Material 1. The final outputs are several csv text files (two for each variable, GCM, RCM, experiment and domain combination) which would be impractical to actually include within this document.

```
A1-3_R2_rcp85/decade05/logs/wrf_completeness.log

2020-08-06 11:36:43,175 *** __main__ *** INFO *** File size mix max ratio
wrfhrly_d01_*: 0.6739634817240133

2020-08-06 11:36:43,175 *** __main__ *** INFO *** File size mix max
difference/std ratio wrfhrly_d01_*: 3.3209985568946387

2020-08-06 11:36:43,178 *** __main__ *** INFO *** File size mix max ratio
wrfhrly_d02_*: 0.8462757875713949

2020-08-06 11:36:43,178 *** __main__ *** INFO *** File size mix max
difference/std ratio wrfhrly_d02_*: 5.0605461141087655

2020-08-06 11:36:43,182 *** __main__ *** INFO *** File size mix max ratio
wrfdly_d01_*: 0.14009991457545184

2020-08-06 11:36:43,182 *** __main__ *** INFO *** File size mix max
difference/std ratio wrfdly_d01_*: 3.9025262922317436

2020-08-06 11:36:43,186 *** __main__ *** INFO *** File size mix max ratio
wrfdly_d02_*: 0.40849634305886895

2020-08-06 11:36:43,186 *** __main__ *** INFO *** File size mix max
difference/std ratio wrfdly_d02_*: 7.272926809509154

2020-08-06 11:36:43,193 *** __main__ *** ERROR *** Following files have sizes
more than 4 std smaller than the mean

 file size

46 wrfdly_d02_2053-11-01_00:00:00 43679708

96 wrfdly_d02_2058-01-01_00:00:00 47656136
```

Figure 1 **Example output from weather research and forecasting (WRF) completeness check script**

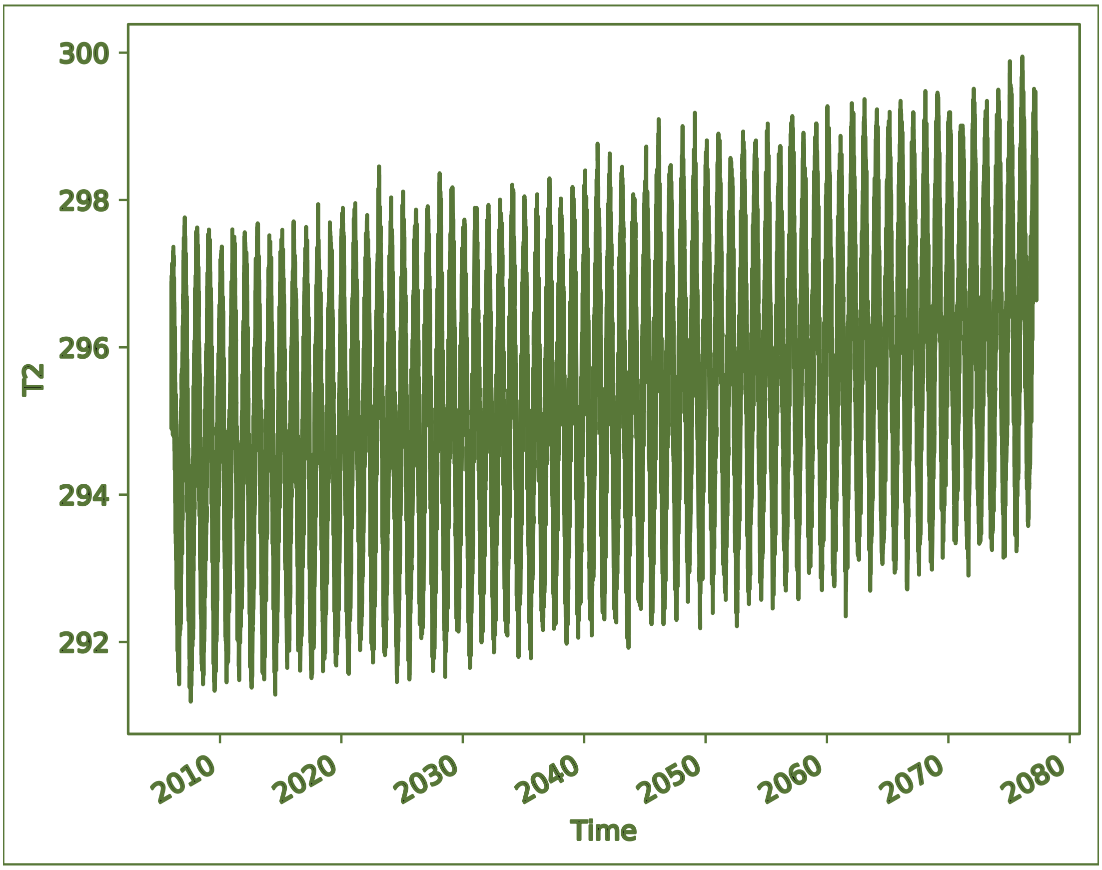


Figure 2 **Example output of time series of raw variable**

In this instance, the domain mean of 2 meter above surface hourly temperature is plotted to ensure there are no implausible jumps; and here, results are as expected.

Basic scientific quality assurance for post-processed variables

Variables

A QA process was applied to 44 post-processed variables (see Table 1).

Table 1 Variables checked in the data quality assurance process

No	Variable description	Code name	Units
1	Surface albedo	alb	no unit
2	Total cloud fraction	clt	percent (%)
3	Surface emissivity	emiss	no unit
4	Surface evaporation	evspsbl	kg m^{-2} s^{-1}
5	Surface upward latent heat flux	hfls	W m^{-2}
6	Surface upward sensible heat flux	hfss	W m^{-2}
7	Near surface relative humidity	hurs	percent (%)
8	Specific humidity at 850 hpa	hus850	kg/kg
9	Specific humidity at 2 m above surface	huss	kg/kg
10	Soil frozen water content	mrfso	kg m^{-2}
11	Surface runoff flux	mrros	kg m^{-2} s^{-1}
12	Total soil moisture content	mrso	kg m^{-2}
13	Accumulated daily precipitation	pr	kg m^{-2} s^{-1}
14	Convective precipitation flux	prc	kg m^{-2} s^{-1}
15	Surface air pressure	ps	Pa
16	Mean sea level pressure	psl	Pa
17	Downward longwave surface radiation	rlds	W m^{-2}
18	Upward longwave surface radiation	rlus	W m^{-2}
19	Top-of-atmosphere outgoing longwave radiation	rlut	W m^{-2}
20	Downward shortwave surface radiation	rsds	W m^{-2}
21	Upward shortwave surface radiation	rsus	W m^{-2}
22	Mean surface wind speed	sfcWind	m s^{-1}
23	Daily maximum surface wind speed	sfcWindmax	m s^{-1}
24	Snow depth	snd	m
25	Snow amount	snw	kg m^{-2}
26	Sea surface temperature	sst	K

No	Variable description	Code name	Units
27	Duration of sunshine	sund	s
28	Air temperature at 200 hpa	ta200	K
29	Air temperature at 500 hpa	ta500	K
30	Air temperature at 850 hpa	ta850	K
31	Temperature at 2 m above surface	tas	K
32	Daily maximum 2 m temperature	tasmax	K
33	Daily minimum 2 m temperature	tasmin	K
34	Northward wind at 200 hpa	ua200	m s^{-1}
35	Northward wind at 500 hpa	ua500	m s^{-1}
36	Northward wind at 850 hpa	ua850	m s^{-1}
37	10 m northward wind	uas	m s^{-1}
38	Eastward wind at 200 hpa	va200	m s^{-1}
39	Eastward wind at 500 hpa	va500	m s^{-1}
40	Eastward wind at 850 hpa	va850	m s^{-1}
41	10 m eastward wind	vas	m s^{-1}
42	Geopotential height at 200 hpa	zg200	m
43	Geopotential height at 500 hpa	zg500	m
44	Atmospheric boundary layer thickness	zmla	m

Methodology

The range and gradient of each variable for each grid cell within the NARCliM1.5 domains (CORDEX and NARCliM) for the historical period (1951 to 2005) and the future period (2006 to 2100) for six GCM/RCM simulations under two representative concentration pathways emissions scenarios (i.e. RCP4.5 and RCP8.5) were checked against pre-set thresholds. Checks were conducted for cases of whether:

- a variable was outside a given threshold which was selected based on historical records and/or educated guess
- two adjacent cells differed by more than a defined threshold (e.g. rainfall differed by more than 200 mm between two cells)
- a zero value cell was neighboured by a cell with a high value.

For temperature, a check was conducted to ensure that daily maximum temperature was higher than daily minimum temperature. For evaporation, a check was conducted to ensure that potential evaporation was larger than actual evaporation. For the purpose of this report, values that did not pass QA checks are considered as defects.

Thresholds

As there are no observations available for most post-processed variables, a first pass estimate of the thresholds was used, based on values from the NARCliM1.0 data QA. These thresholds were examined as follows to ensure reasonable values were used:

- The lower and higher thresholds (minimum and maximum values of the range in question) were adjusted by different methods (i.e. multiplied by 1.5 or add/minus a specific value).
- In most cases, the gradient threshold is estimated by multiplying a factor to the ranges of each variable. However, for temperature and precipitation, a different approach was used because historical precipitation and temperature observations are available for estimating their gradients, i.e. 10°C was defined for the temperature gradient threshold and 0.004 mm/s was defined for precipitation.

Thresholds for variables for the NARCliM domain are summarised in Table 2.

Table 2 Thresholds for different variables for the NARCliM domain

Variable	Variable description	Low threshold	High threshold	Gradient between neighbour cells
alb	Surface albedo	0	1	1
clt	Total cloud fraction	0	100	100
emiss	Surface emissivity	0.5	1	0.5
evspsbl	Surface evaporation	–0.01	0.01	0.004
hfls	Surface upward latent heat flux	–180	4,700	1,200
hfss	Surface upward sensible heat flux	–530	1,100	750
hurs	Near surface relative humidity	0	100	60
hus850	Specific humidity at 850 hpa	0	0.025	0.005
huss	Specific humidity at 2 m above surface	0.0002	0.135	0.05
mrfso	Soil frozen water content	0	50	30
mrros	Surface runoff flux	0	0.02	0.01
mrso	Total soil moisture content	0	1,390	700
pr	Accumulated daily precipitation	0	0.017	0.04
prc	Convective precipitation flux	0	0.016667	0.002894
ps	Surface air pressure	75,000	106,400	10,000
psl	Mean sea level pressure	95,000	105,000	800
rlds	Downward longwave surface radiation	116	712	148
rlus	Upward longwave surface radiation	160	830	130
rlut	Top-of-atmosphere outgoing longwave radiation	90	360	100
rsds	Downward shortwave surface radiation	0	630	370
rsus	Upward shortwave surface radiation	0	400	300
sfcWind	Mean surface wind speed	0	48	12

Variable	Variable description	Low threshold	High threshold	Gradient between neighbour cells
sfcWindmax	Daily maximum surface wind speed	0	70	18
snd	Snow depth	0	4	2
snw	Snow amount	0	1000	500
sst	Sea surface temperature	270	310	6
sund	Duration of sunshine	0	54,000	32,400
ta200	Air temperature at 200 hpa	200	250	4
ta500	Air temperature at 500 hpa	230	280	4
ta850	Air temperature at 850 hpa	260	310	10
tas	Temperature at 2 m above surface	260	320	25
tasmax	Daily maximum 2 m temperature	262	328	25
tasmin	Daily minimum 2 m temperature	255	313	25
ua200	Northward wind at 200 hpa	–120	120	20
ua500	Northward wind at 500 hpa	–80	80	18
ua850	Northward wind at 850 hpa	–45	45	16
uas	10 m northward wind	–48	48	18
va200	Eastward wind at 200 hpa	–110	110	20
va500	Eastward wind at 500 hpa	–70	70	18
va850	Eastward wind at 850 hpa	–45	45	16
vas	10 m eastward wind	–40	40	16
zg200	Geopotential height at 200 hpa	10,000	13,000	60
zg500	Geopotential height at 500 hpa	4,900	6,100	40
zmla	Height of boundary layer	0	5,000	3,000

Quality assurance and data validation checking software

Scripts were developed using the Python programming language to apply data validation checks of the climate data against the thresholds outlined in Table 2. These scripts are available on our Bitbucket repository. Full outputs can be provided as Supplemental Material to this document (see Supplemental Material).

Results

Updated versions of the results from this QAQC report as well as new QAQC checks and errata will be available on the NSW Climate Data Portal.

Results from different QA processes are documented on an ongoing basis. This section summarises the results from performing the basic scientific QA process.

1. Raw data completeness check

Two rounds of checks are undertaken:

a. The completeness of each simulation is checked immediately after the simulation is completed.

b. Post-processing scripts check the completeness of a specific simulation before they start to run. The post-processing scripts stop working if **any** input file is missing or corrupted/too small.

The two rounds of raw data completeness checks identified some months with corrupted files. These simulations were re-run and completeness checks were re-done. Subsequently, no corrupted files were detected in the simulations, and file naming, data format and head, and dates within files are correct.

2. Post-processed variables check

Multiple rounds of checks were undertaken on post-processed variables for the NARCliM and CORDEX domains. Some major issues were identified and corrected. These were as follows (see Table 1 for variable descriptions):

a. ACCESS1.0 simulations
   i. sst over land was zero for R1, RCP4.5 in 1958, and ua200, ua500, ua850 and va200, va500, va850 were wrong (extreme values) for R1 in 1958. The 12 monthly simulations for 1958 were re-run and these issues were resolved.
   ii. mrros was wrong on 31/03/2006 in R1 simulation. User warned on download page of timestamp of erroneous data.
   iii. sst, and ua200, ua500, ua850, and va200, va500, va850 were wrong for R2 (i.e. RCP8.5) in 1963. The 12 monthly simulations for 1963 were re-run and issues were resolved.

b. ACCESS1.3 simulations
   i. psl was wrong on 12/02/1956. The simulation for February 1956 was re-run and the issue was fixed.
   ii. mrros was wrong on 28/2/2006. User warned on download page of timestamp of erroneous data.
   iii. ua850 was wrong on 26/06/2076 in the R2 simulation. The simulation for June 2076 was re-run and the issue was fixed.
   iv. sst was wrong for R1 simulation on 1/11/2082. The simulation was re-run to fix the incorrect sst.

c. CanESM2 simulations

   i. sst was wrong on 6/01/1986 in R2 simulation. The simulation was re-run and the issue was resolved.

   ii. mrros was wrong on 30/04/1993 in R1 simulation. User warned on download page of timestamp of erroneous data.

   iii. ua850 and va850 were not corrected for a few specific periods in the historical, RCP8.5 and RCP4.5 simulations. The raw data for these periods were checked and no errors were identified. The post-processing for these variables was re-run to resolve the issues.

Some common issues across different simulations included:

- Small negative values for hus850 near boundaries. These were set as zero.
- Near ground relative humidity (hurs) for some grid cells was above 100%. These cells were set to 100%.
- sst values in ACCESS1.3 historical simulations were interpolated from the driving GCMs, however, the interpolation method was not used properly. As a result, there are inconsistencies in sst values for the historical simulations, which cannot be fixed. A one-year test with correct sst was done to assess this impact. The results show differences between the two one-year simulations are minor (comparisons of simulations are included in Supplemental Material 2 and 3), therefore the decision was made not to take a further intervention.

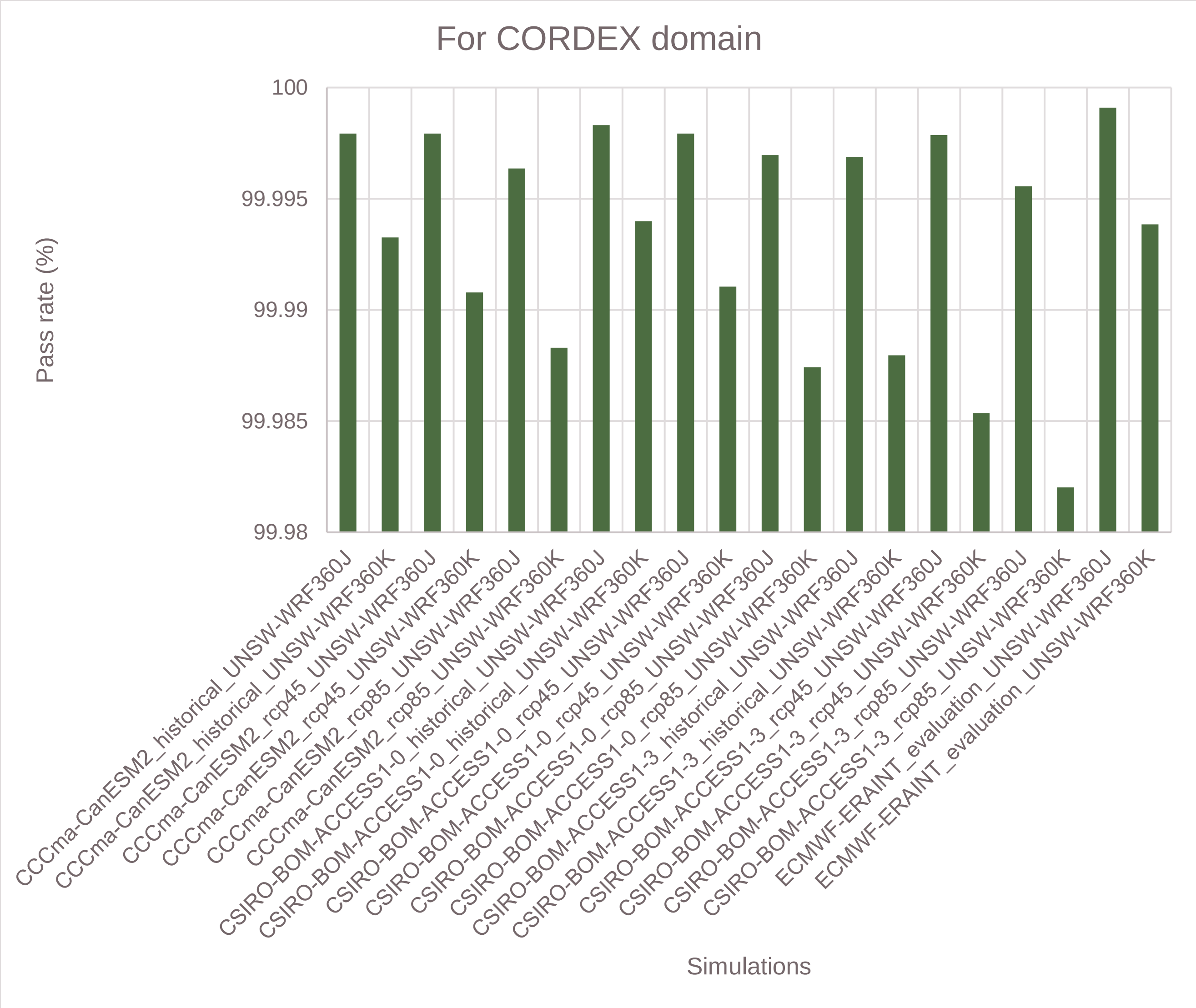
As RCP8.5 was used in NARCliM1.5, which entails a more aggressive set of assumptions than the A2 scenario used in NARCliM1.0, threshold values for some variables were adjusted for NARCliM1.5 simulations. All potential issues identified by the original threshold were manually checked.

The final data status

The new data checks using the latest version of thresholds is complete. Please see Supplemental Material 4 and 5 for details.

In general, there are no major data issues with the majority of variables. However, some variables for some simulations still have some grid cells with values outside their prescribed thresholds. These issues may exist across regions and different time slices. These are summarised in Supplemental Material 6 and 7. A manual check of those specific simulations did not reveal any critical errors.

The total pass rates (in %) of data QA for the CORDEX and NARCliM domains are shown in Figures 3 and 4.


For CORDEX domain
Pass rate (%)
100
99.995
99.99
99.985
99.98
CCCma-CanESM2_historical_UNSW-WRF360J
CCCma-CanESM2_historical_UNSW-WRF360K
CCCma-CanESM2_rcp45_UNSW-WRF360J
CCCma-CanESM2_rcp45_UNSW-WRF360K
CCCma-CanESM2_rcp85_UNSW-WRF360J
CCCma-CanESM2_rcp85_UNSW-WRF360K
CSIRO-BOM-ACCESS1-0_historical_UNSW-WRF360J
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CSIRO-BOM-ACCESS1-3_rcp85_UNSW-WRF360J
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ECMWF-ERAINT_evaluation_UNSW-WRF360J
ECMWF-ERAINT_evaluation_UNSW-WRF360K
Simulations

Figure 3 **Pass rate (%) of data quality assurance for the CORDEX domain**

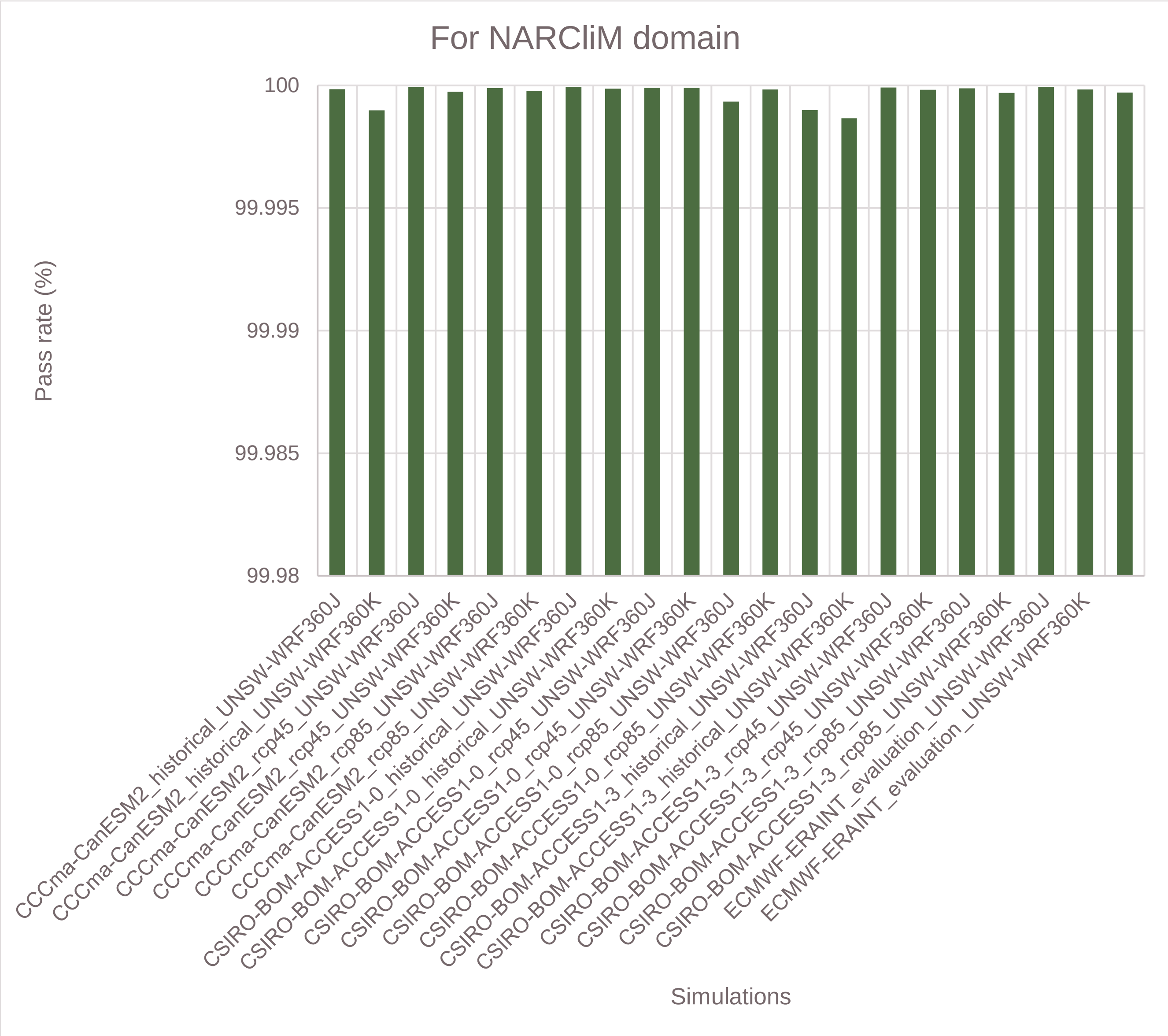

Figure 4 **Pass rate (%) of data quality assurance for the NARCliM domain**

Conclusion

After multiple rounds of data QA processes, some data issues were identified, with defects in data being recorded and resolved where possible. There remain issues associated with some variables that cannot be resolved due to model limitations. Accordingly, such variables (e.g. tasmaxtstep, tasmintstep) were excluded in the final delivery of NARCliM1.5. In summary, NARCliM1.5 dataset meets QA standards (with pass rate above 99.98% for the CORDEX domain and 99.99% for the NARCliM domain).

As the NARCliM1.5 modelling outputs are large, we have only applied a small subset of tests on the datasets (thresholds on values and gradients on the data) and this should not be considered comprehensive. This results in different levels of quality control and access for different variables. For example, we use the same surface pressure thresholds across the entire domain, however it is known that there is a strong relationship between altitude and pressure which was taken into account. As such, QA will be an ongoing process incorporating feedback from users and project partners as well as NARCliM1.5 technical working group members.

Supplemental Material

These Supplemental Materials can be provided as separate documents.

Supplemental Material 1	Raw data check outputs for simulations
Supplemental Material 2	Sea surface temperature (sst) issue description
Supplemental Material 3	One-year sea surface temperature (sst) test results
Supplemental Material 4	Details of grids with values outside of range and gradient thresholds for the CORDEX domain
Supplemental Material 5	Details of grids with values outside of range and gradient thresholds for the NARCliM domain
Supplemental Material 6	Summary of data quality across simulations and variables for the CORDEX domain
Supplemental Material 7	Summary of data quality across simulations and variables for the NARCliM domain

To request Supplemental Material, please contact us at narclim@environment.nsw.gov.au

References

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