Heatwave and drought indices recommended by the ET-SCI

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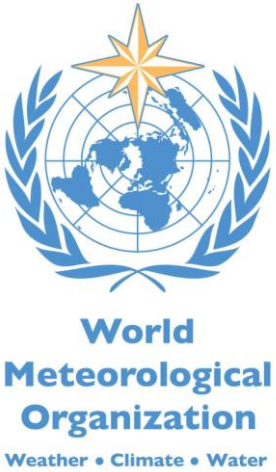
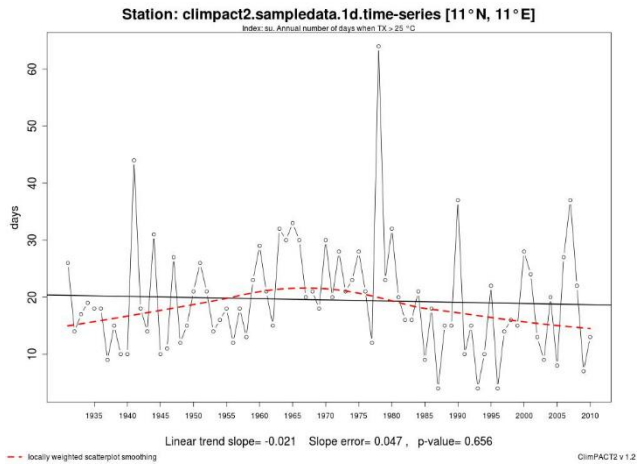
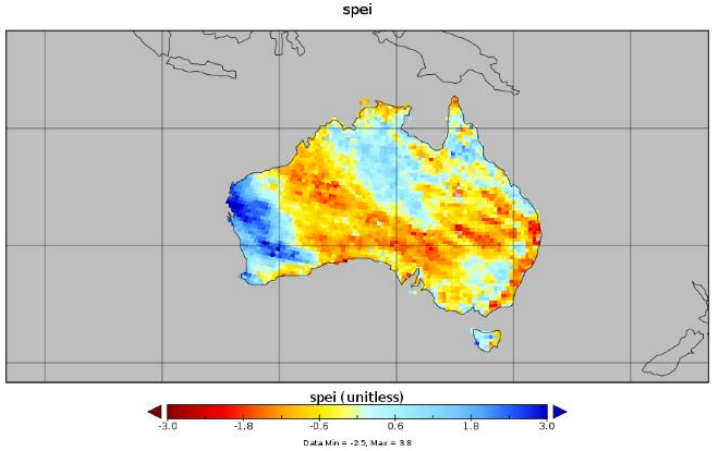


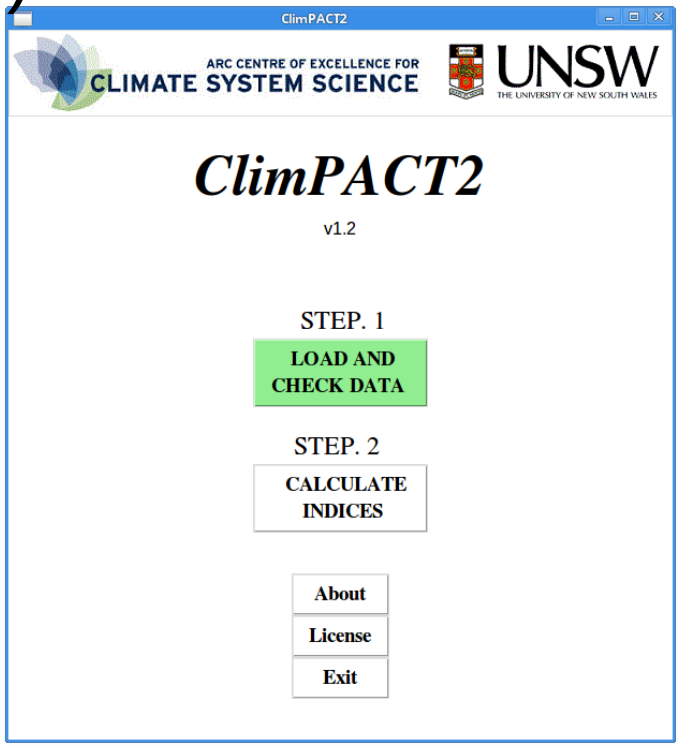
Reminder: what ClimPACT does

https://github.com/ARCCSS-extremes/climpact2 HTML USER GUIDE

- Reads in daily minimum temperature, maximum temperature and precipitation. In text or netCDF format.
- Calculates the ET-SCI indices (plus some others)
- Simple GUI and quality control for text file input.
- Command line for processing netCDF files.







Complex indices

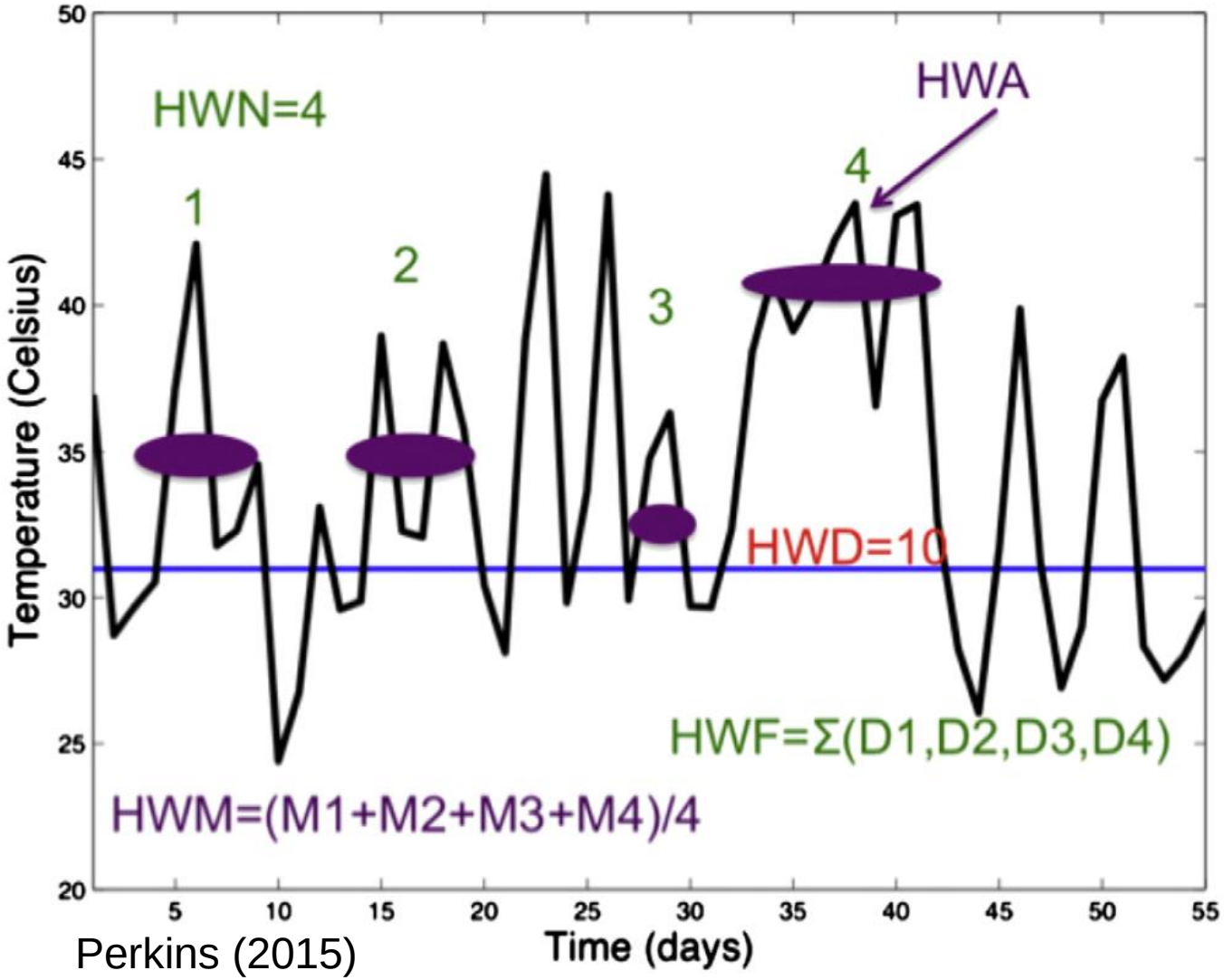
- Over 60 indices in ClimPACT. Most are very simple. (e.g. TXX = hottest day each year)
- A few are more complicated, namely the heatwave and SPEI/SPI indices*.

* There are some relatively simple heatwave indices also, such as the Warm Spell Duration Index (WSDI) = *no. days contributing to events where >= 6 days have TX warmer than the 90th percentile*

Heatwave indices

- ClimPACT calculates heatwaves (HWs) following Perkins and Alexander (2013) – with a few adjustments.
- There are 3 definitions and 5 ‘aspects’ - so 15 HW variables in total are calculated by CliMPACT.
- 3 definitions of heatwaves:
  - **TX90:** >= 3 days where TX >= 90th percentile. **REQUIRES TX**
  - **TN90:** >= 3 days where TN >= 90th percentile. **REQUIRES TN**
  - **EHF (Excess Heat Factor):** >= 3 days where the EHF is positive. **REQUIRES TX AND TN**
- 5 heatwave aspects:
  - **Heatwave Number (HWN):** The number of HW’s that begin in the period of interest (e.g. a particular month) as well as those that start prior to but continue into the period of interest.
  - **Heatwave Frequency (HWF):** The number of days that contribute to heatwaves defined by HWN. For HW’s that begin prior to the period of interest, only the HW days within the period of interest are counted. Similarly, for HW’s that continue beyond the period of interest, only HW days within the period of interest are counted. For HW’s that extend beyond the period of interest, a maximum of 14 days beyond the period of interest is counted in HWF.
  - **Heatwave Duration (HWD):** Length in days of the longest heatwave defined by HWN.
  - **Heatwave Magnitude (HWM):** The mean of the mean HW temperatures of all HWs defined by HWN.
  - **Heatwave Amplitude (HWA):** The peak daily temperature in the hottest heatwave (defined as the heatwave with highest HWM).

Heatwave aspects: frequency, duration, amplitude, magnitude and number



Perkins (2015)

Heatwave Number (HWN): The number of HW's that begin in the period of interest
Heatwave Frequency (HWF): The number of days that contribute to heatwaves defined by HWN.
Heatwave Duration (HWD): Length in days of the longest heatwave defined by HWN.
Heatwave Magnitude (HWM): The mean of the mean HW temperatures of all HWs defined by HWN.
Heatwave Amplitude (HWA): The peak daily temperature in the hottest heatwave (defined as the heatwave with highest HWM).

- Heatwave aspects are calculated annually considering the whole year or the local extended summer (depending on the heatwave definition)

The Excess Heat Factor (EHF)

- Developed by Nairn and Fawcett (2013), Bureau of Meteorology Australia.
- Designed to take into account the intensity of a heatwave plus a measure of potential acclimatisation that has occurred over the preceding 30 days.
- This is done through two excess heat indices (EHI) of significance (sig) and acclimatisation (acc), respectively.

$$EHI_{sig} = (T_i + T_{i-1} + T_{i-2})/3 - T_{95}$$

$$EHI_{acc} = (T_i + T_{i-1} + T_{i-2})/3 - (T_{i-1} + \ldots + T_{i-30})/30$$

- Where T_i represents the mean daily temperature, $(TX_i + TN_i)/2$, of day i and T_{95} represents the 95^{th} percentile of T over the base period 1961 – 1990.
- The Excess Heat Factor is a combination of the above two excess heat indices.

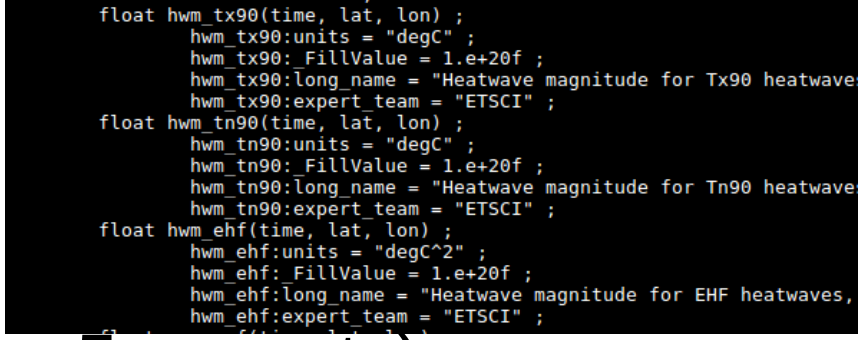
$$EHF = EHI_{sig} \times \max(1, EHI_{acc})$$

- The EHF has units of $^oC^2$

The Excess Cold Factor (ECF)

- Also developed by Nairn and Fawcett (2013). Basically the inverse of the Excess Heat Factor.
- 5 heatwave aspects also calculated for ECF.
- These are stored in the same file as the heatwave indices!
- Details in the ClimPACT user guide.

How are heatwave indices stored?



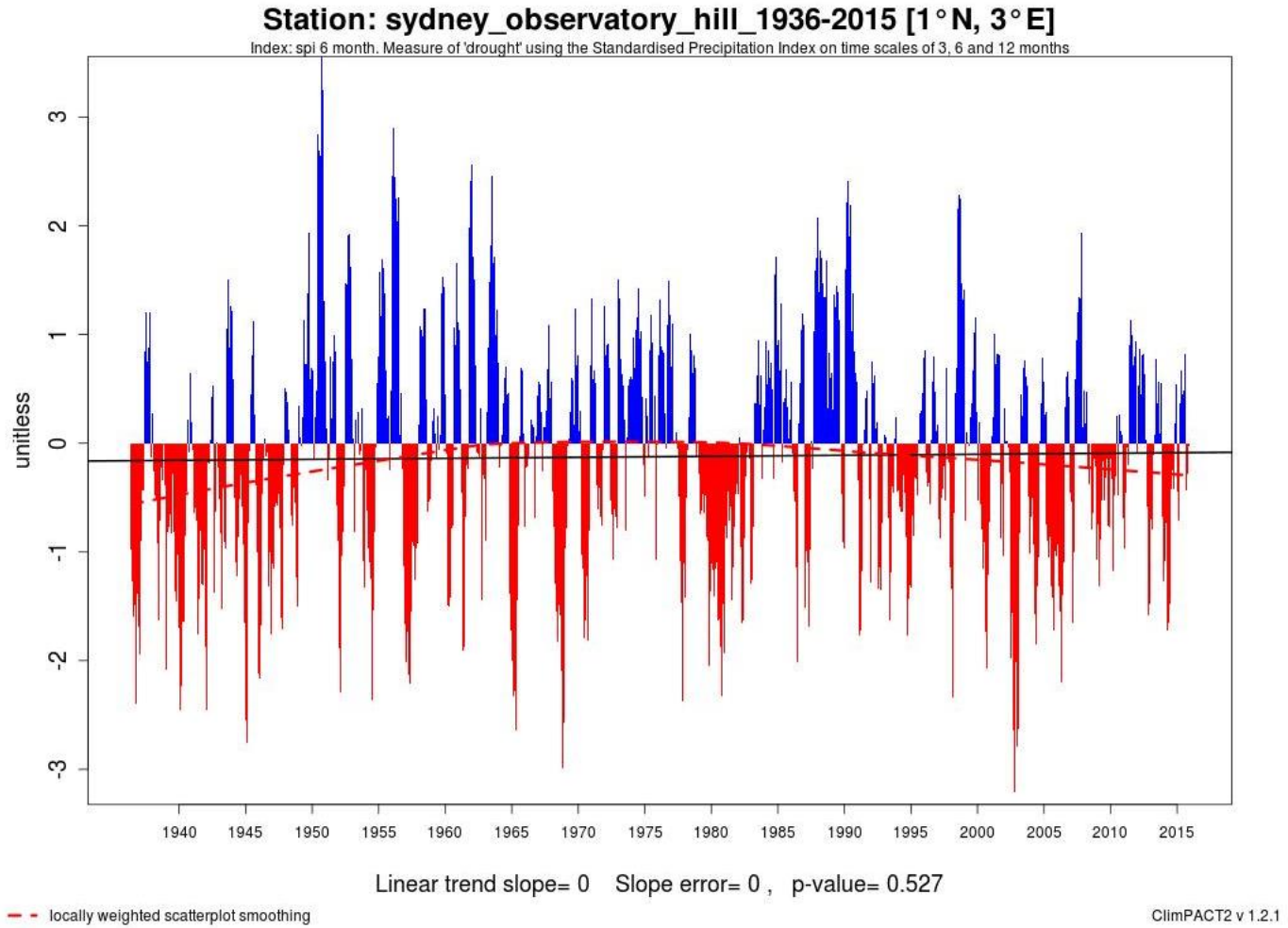
- Currently all 15 heatwave outputs (3 definitions x 5 aspects) are stored in one netCDF file by ClimPACT, as separate variables.
- Coldwave data also stored in the heatwave file!
  - Should each heatwave/coldwave definition (TX90, TN90, EHF, ECF) have it's own file?
  - Or should all aspects of a definition be stored in the one variable i.e. TX90(aspect,time,lat,lon)?
- Like other ClimPACT indices, important info is stored in the files global attributes. Including which version of EHF has been used.

```
// global attributes:
                :EHF_definition = "PA13" ;
                :history = "Fri Feb 26 10:25:00 2016: ncatted -a units,precip,o,c,kg m-2 d-1 climpact2.sampledata.gridded.1991-2010.nc" ;
                :index_calculation_frequency = "yr" ;
                :base_period = "1991-2010" ;
                :author_institution = "My University" ;
                :author_institution_id = "MU" ;
                :file_created = "2016-10-20T00:03:21Z" ;
                :file_created_by_userid = "z3506872" ;
                :R_version = "3.0.3" ;
                :climdex.pcic_version = "1.1.6" ;
                :ClimPACT2_version = "1.2.1" ;
                :ClimPACT2_github = "https://github.com/ARCCSS-extremes/climpact2" ;
}
```

Drought indices: The SPI

- Standardised Precipitation Index (SPI) developed by Mckee et al. (1993)
- The SPI is the WMO's recommended drought index (WMO user guide on SPI here).
- Calculated in ClimPACT by the R package "SPEI".
- Benefits;
  - Easy to calculate
  - Requires only one input (monthly precipitation)
  - Is completely flexible in time-scale (e.g. can calculate 1 month meteorological drought or 6 month agricultural drought!)
  - It's value can also indicate uncharacteristically wet periods.

What do SPI values mean?



> 0 Wetter than average

< 0 Drier than average

- E.g. The 3 month SPI for April 1996 compares the February-March-April precipitation total for 1996 to all other February-March-April totals in the time-series (or within the specified base period).

SPI continued

- The value of the SPI is the number of standard deviations from the mean. Thus negative values indicate drought and positive indicate excessive wet.
- 1 month SPI for meteorological drought, 6 month SPI for agricultural drought, 12 – 24 month SPI for hydrological drought.
- ClimPACT calculates the 3, 6 and 12 month SPI/SPEI.
- An explanation of the calculation

Table 1. SPI values

2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

Drought indices: The SPEI

- Standardised Precipitation-Evapotranspiration Index (SPEI) is an extension to SPI developed by Vicente-Serrano et al. (2010). Includes the effect of evapotranspiration.
- Calculated similarly to SPI but includes evapotranspiration. i.e. performs comparison of monthly (PRECIP-EVAPOT), not just (PRECIP).
- Evapotranspiration is not an input in ClimPACT, so is estimated from latitude, prec_monthly, TX_monthly and TN_monthly using the Hargreaves method!

How is SPI/SPEI stored by ClimPACT?

```
 > ncdump -h spi_MON_climpact.sample_historical_NA_1991-2010.nc
netcdf spi_MON_climpact.sample_historical_NA_1991-2010 {
dimensions:
        bnds = 2 ;
        time = UNLIMITED ; // (1080 currently)
        longitude = 118 ;
        latitude = 110 ;
        scale = 3 ;
variables:
        double time(time) ;
                time:units = "days since 2005-1-1" ;
                time:standard_name = "time" ;
                time:calendar = "360_day" ;
                time:axis = "T" ;
        double time_bnds(time, bnds) ;
        double longitude(longitude) ;
                longitude:units = "degrees_east" ;
                longitude:standard_name = "longitude" ;
                longitude:long_name = "longitude" ;
                longitude:axis = "X" ;
        double latitude(latitude) ;
                latitude:units = "degrees_north" ;
                latitude:standard_name = "latitude" ;
                latitude:long_name = "latitude" ;
                latitude:axis = "Y" ;
        int scale(scale) ;
                scale:units = "3,6,12 months" ;
                scale:long_name = "scale" ;
        float spi(scale, time, latitude, longitude) ;
                spi:units = "unitless" ;
                spi:_FillValue = 1.e+20f ;
                spi:long_name = "Standardised Precipitation Index" ;
                spi:cell_methods = "time: mean" ;
                spi:definition = "Measure of \'drought\' using the Standardised Precipitation Index on t
                spi:expert_team = "ETSCI" ;

// global attributes:
                :CDI = "Climate Data Interface version 1.7.2 (http://mpimet.mpg.de/cdi)" ;
                :Conventions = "CF-1.5" ;
                :history = "Wed Feb 22 15:25:10 2017: ncatted -O -a calendar,time,o,c,360_day precip_3.n
 precip_2.nc\nFri Feb 17 16:25:26 2017: ncrename -v precipitation_flux,precipit.nc precip_2.nc\nFri Feb
,time_bounds imnaea.pa.2005_2100.05216.nc historico_precip.nc\nConverted from UM by cf-python v1.1.7" ;
                :source = "UM" ;
                :runid = "imnae" ;
```

All ClimPACT indices

```
> l output/
cdd_ANN_climpact.sample_historical_NA_1991-2010.nc
cddcold18_ANN_climpact.sample_historical_NA_1991-2010.nc
cdd_MON_climpact.sample_historical_NA_1991-2010.nc
csdi5_ANN_climpact.sample_historical_NA_1991-2010.nc
csdi_ANN_climpact.sample_historical_NA_1991-2010.nc
cwd_ANN_climpact.sample_historical_NA_1991-2010.nc
cwd_MON_climpact.sample_historical_NA_1991-2010.nc
dtr_ANN_climpact.sample_historical_NA_1991-2010.nc
dtr_MON_climpact.sample_historical_NA_1991-2010.nc
fd_ANN_climpact.sample_historical_NA_1991-2010.nc
fd_MON_climpact.sample_historical_NA_1991-2010.nc
gddgrow10_ANN_climpact.sample_historical_NA_1991-2010.nc
gsl_ANN_climpact.sample_historical_NA_1991-2010.nc
hddheat18_ANN_climpact.sample_historical_NA_1991-2010.nc
hw_ANN_climpact.sample_historical_NA_1991-2010.nc
id_ANN_climpact.sample_historical_NA_1991-2010.nc
id_MON_climpact.sample_historical_NA_1991-2010.nc
prcptot_ANN_climpact.sample_historical_NA_1991-2010.nc
prcptot_MON_climpact.sample_historical_NA_1991-2010.nc
r10mm_ANN_climpact.sample_historical_NA_1991-2010.nc
r10mm_MON_climpact.sample_historical_NA_1991-2010.nc
r20mm_ANN_climpact.sample_historical_NA_1991-2010.nc
r20mm_MON_climpact.sample_historical_NA_1991-2010.nc
r30mm_ANN_climpact.sample_historical_NA_1991-2010.nc
r30mm_MON_climpact.sample_historical_NA_1991-2010.nc
r95p_ANN_climpact.sample_historical_NA_1991-2010.nc
r95ptot_ANN_climpact.sample_historical_NA_1991-2010.nc
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tmlt5_ANN_climpact.sample_historical_NA_1991-2010.nc
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tmm_MON_climpact.sample_historical_NA_1991-2010.nc
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tn10p_MON_climpact.sample_historical_NA_1991-2010.nc
tn90p_ANN_climpact.sample_historical_NA_1991-2010.nc
tn90p_MON_climpact.sample_historical_NA_1991-2010.nc
tnlt2_ANN_climpact.sample_historical_NA_1991-2010.nc
tnlt2_MON_climpact.sample_historical_NA_1991-2010.nc
tnltm20_ANN_climpact.sample_historical_NA_1991-2010.nc
tnltm20_MON_climpact.sample_historical_NA_1991-2010.nc
tnltm2_ANN_climpact.sample_historical_NA_1991-2010.nc
tnltm2_MON_climpact.sample_historical_NA_1991-2010.nc
tnm_ANN_climpact.sample_historical_NA_1991-2010.nc
tnm_MON_climpact.sample_historical_NA_1991-2010.nc
tnn_ANN_climpact.sample_historical_NA_1991-2010.nc
tnn_MON_climpact.sample_historical_NA_1991-2010.nc
tnx_ANN_climpact.sample_historical_NA_1991-2010.nc
tnx_MON_climpact.sample_historical_NA_1991-2010.nc
tr_ANN_climpact.sample_historical_NA_1991-2010.nc
tr_MON_climpact.sample_historical_NA_1991-2010.nc
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tx10p_MON_climpact.sample_historical_NA_1991-2010.nc
tx3tn3_ANN_climpact.sample_historical_NA_1991-2010.nc
tx90p_ANN_climpact.sample_historical_NA_1991-2010.nc
tx90p_MON_climpact.sample_historical_NA_1991-2010.nc
tx95t_DAY_climpact.sample_historical_NA_1991-2010.nc
txb3tnb3_ANN_climpact.sample_historical_NA_1991-2010.nc
txge30_ANN_climpact.sample_historical_NA_1991-2010.nc
txge30_MON_climpact.sample_historical_NA_1991-2010.nc
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txge35_MON_climpact.sample_historical_NA_1991-2010.nc
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txgt50p_MON_climpact.sample_historical_NA_1991-2010.nc
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txm_MON_climpact.sample_historical_NA_1991-2010.nc
txn_ANN_climpact.sample_historical_NA_1991-2010.nc
txn_MON_climpact.sample_historical_NA_1991-2010.nc
txx_ANN_climpact.sample_historical_NA_1991-2010.nc
txx_MON_climpact.sample_historical_NA_1991-2010.nc
wsdi5_ANN_climpact.sample_historical_NA_1991-2010.nc
wsdi_ANN_climpact.sample_historical_NA_1991-2010.nc
```

Custom interval indices

- We have plans to include in ClimPACT indices that count the number of days which satisfy user-specified conditions.
  - E.g. Number of days where TX > 35 && TN < 20 && PREC > 3. Or any combination of variables and conditions.
- No idea how this would/could be named.

References

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- Nairn J R and Fawcett R G 2013 *Defining heatwaves: heatwave defined as a heat-impact event servicing all community and business sectors in Australia* (Centre for Australian Weather and Climate Research)
- Perkins S E and Alexander L V 2013 On the Measurement of Heat Waves *J. Clim.* **26** 4500–17 Online: http://dx.doi.org/10.1175/JCLI-D-12-00383.1
- Vicente-Serrano S M, Beguería S and López-Moreno J I 2010 A Multiscalar Drought Index Sensitive to Global Warming: The Standardized Precipitation Evapotranspiration Index *J. Clim.* **23** 1696–718 Online: http://dx.doi.org/10.1175/2009JCLI2909.1
- WMO 2012 *Standardized Precipitation Index User Guide* (7 bis, avenue de la Paix – P.O. Box 2300 – CH 1211 Geneva 2 – Switzerland) Online: http://www.wamis.org/agm/pubs/SPI/WMO_1090_EN.pdf