Discussion paper on climate data for the Resilient EP Project

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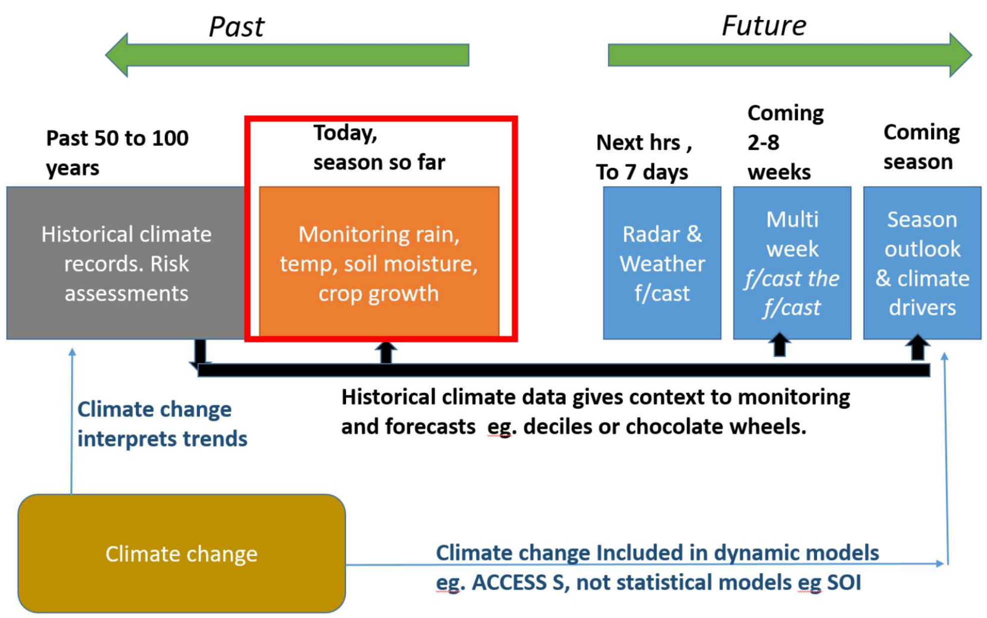
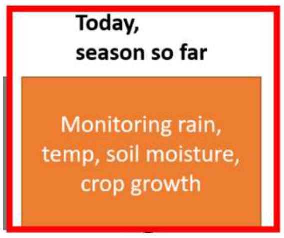
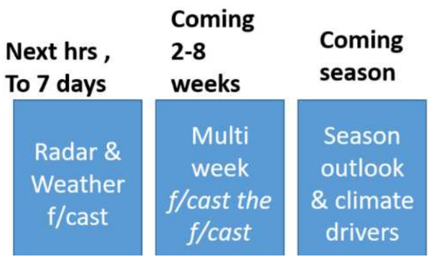
The Resilient EP project is about better use of data to improve on-farm decision making. Making decisions involves collating available data and information and using this to predict the future and make judgements about the best steps. The project is focussed on real time monitoring of soil moisture to assess the season to date and make decisions about the future. SARDI Climate Applications is interested in how farmers and agronomists are using other sources of information such as long term climate records, weather and seasonal climate forecasts. The Figure below is a schematic showing some of the main information components.



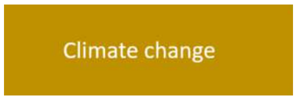


The main interest in this project (highlighted in the red box) is on data for monitoring with soil moisture probes. Additional information on the season to date is local weather stations and spatial measures of crop growth. Farmers and agronomists are interested in better measures of soil moisture not because they are soil scientists looking for another source of data but *because it helps to predict future crop growth.* Water that is stored in the root zone is like 'money in the bank'. Soil moisture is a relatively slow moving variable and skilled interpretation of the shape of the soil moisture probe can tell when the crop is running out of water. Other sources of monitoring the season to date come from local weather stations. In this project the information is being run through Yield Prophet to provide probability distributions of wheat yields based on simulations of the climate to date and all future finishes to the season.



The future forecasts start with the next hours (radar) and the coming 7 days (short term weather). Beyond that time period, it is probably best to consider the multi-week forecast as 'forecasting the forecast' in other words providing guidance on what the 1-7 day forecast is likely to show. Seasonal outlooks are based on dynamic modes such as ACCESS S (BoM) and other models and are available on BoM website.

The long term climate record helps place the current year in context. This is the value of deciles. The same historical data is valuable for forecasts, especially seasonal forecasts which are expressed as percent chance of being in a certain percentile. The seasonal outlooks are complemented by information on climate drivers (ENSO and IOD). The website Forecasts4Profit developed by Ag Vic and SARDI enables farmers to look at the impact of IOD and ENSO on rainfall at their site.



Although Climate change science won't influence season by season planning, it is useful to interpret trends and projections are important data for decision making, but more for strategic decisions.

What information to provide?

SARDI climate applications has prepared a series of graphs. These graphs are not proposed to be distributed as regular updates. Regular updates on season to date rainfall and the impact of temperature on crop development are available from the YieldProphet graphs and the CliMate app.

One exception is the decile tracking for rainfall (see 1a in the following document). We have combined the decile tracking with the climate driver. This has been requested by agronomists in the past and we are unaware that it is available at this time from other sources.

The rest of the information is more likely to be used for review and planning. Some grain enterprises do this as separate a post-harvest meeting and pre-season meeting, other conduct it as the same meeting. For these meetings it is useful to have information on the recent season and how it compared to long term historical records.

Cummins

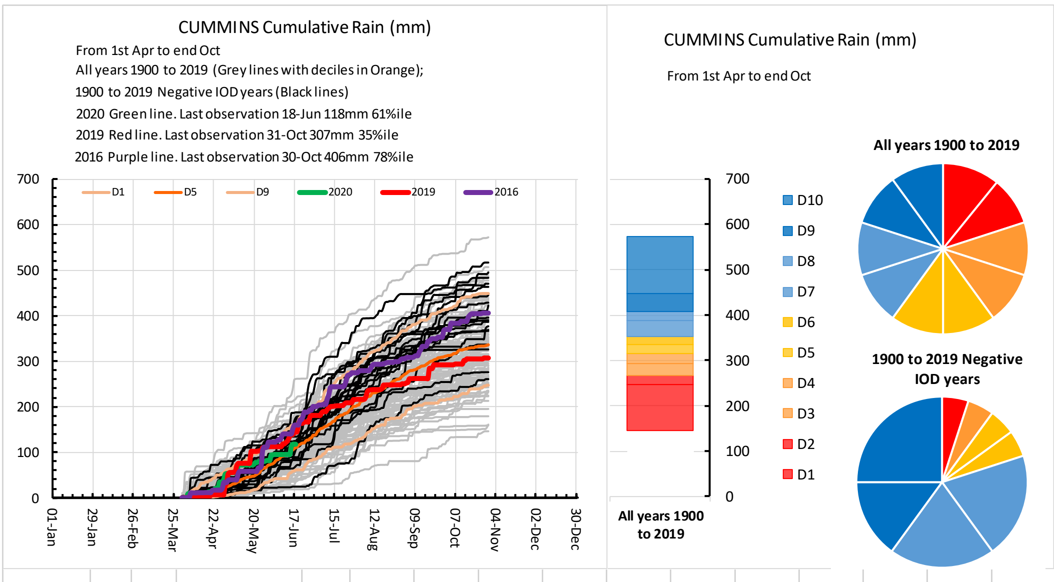
1a. Cumulative rainfall – How is the season tracking compared to all years, the last two years and for negative IOD years?

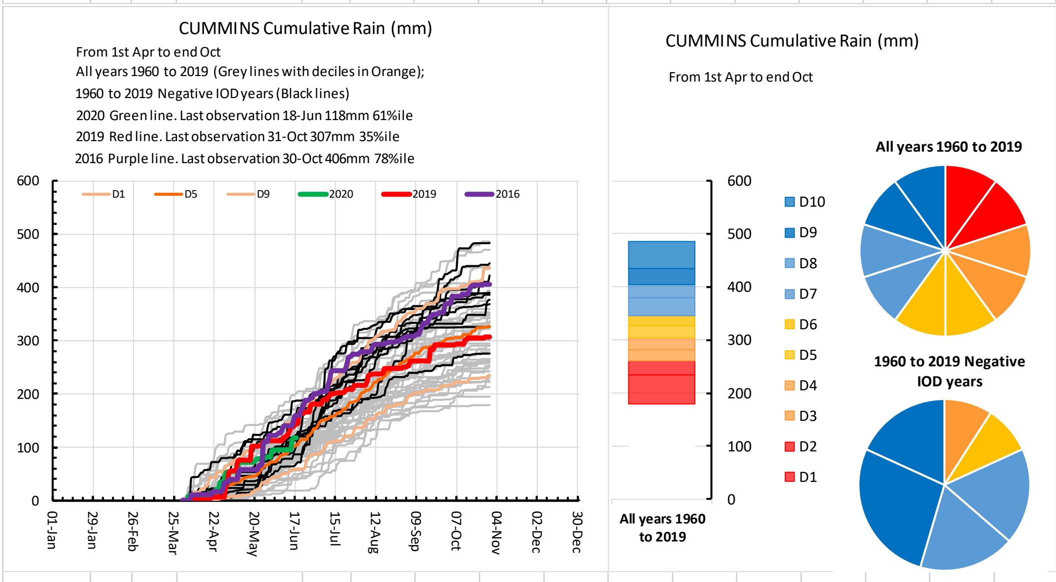
We have developed a spreadsheet that shows all years (grey) as a plume with deciles 1, 5 and 9 in orange. The Negative IOD years are shown as black lines. In the spreadsheet this can be changed for La Nina, El Nino or IOD positive. Three years of interest are shown as Green, Red and Purple lines. In this example green is the current year (2020), Red is 2019 (last year), Purple is 2016 (a recent Negative IOD year).

The stacked bar chart to the right of the plume shows the deciles in mm. Note that while the range from the wettest to driest year is 150mm to 580mm, the range between middle deciles of 3, 4, 5 and 6 is narrow.

The pie chart shows the chance of rainfall being in each decile. The upper pie chart shows that for all years there is equal chance of rainfall being in each decile. The lower pie chart shows the altered chance of being in each decile when we examine only the Negative IOD years. There is a shift away from the chance of lower decile (dry years) towards higher decile (wet years).

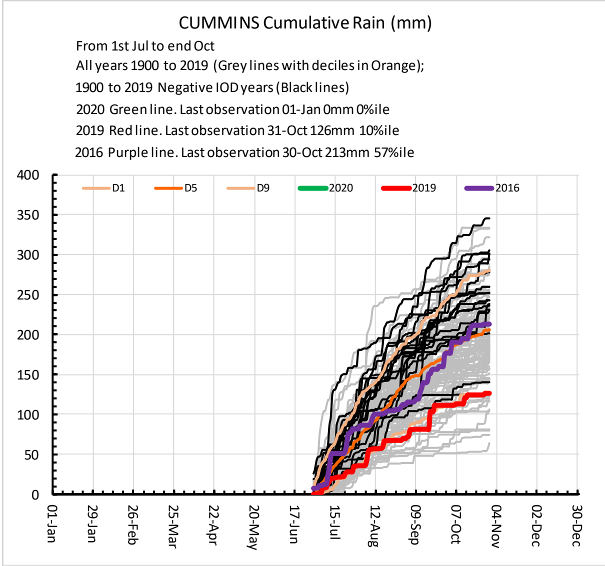
The same colour scheme of red for deciles 1&2, orange for 3&4, yellow 5&6, light blue 7&8 and dark blue 9&10 is used throughout this document. In later parts of the document the warm colours (red) are used for D 9&10 for temperature and cool colours for D 1&2.

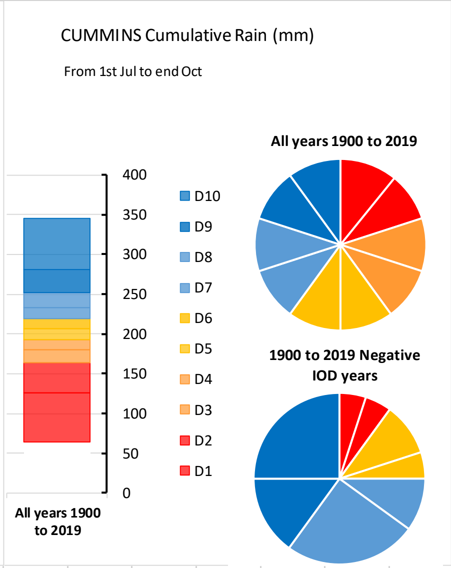




Impact of Negative IOD on cumulative rainfall from July to October

1900 to 2019





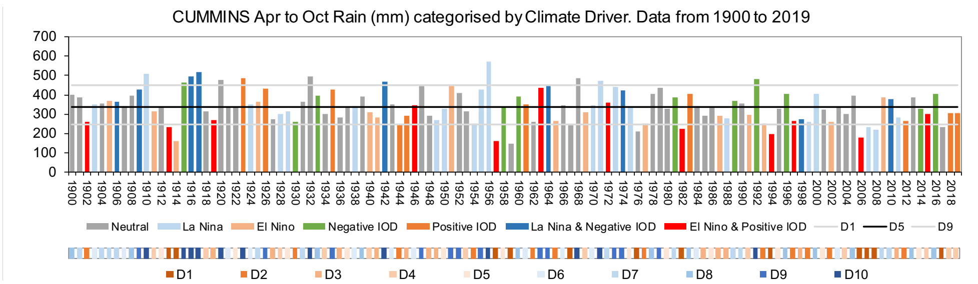
The number of Negative IOD years that have cumulative April to October rainfall in each decile of all historic years. Data used for analysis from 1900 to 2019 (left column) and from 1960 to 2019 (right column).

1900 to 2019 Negative IOD years	
There are a total of 20 years	
These correspond to 1900 to 2019	
Decile 1	0 years
Decile 2	1 years
Decile 3	1 years
Decile 4	0 years
Decile 5	1 years
Decile 6	1 years
Decile 7	4 years
Decile 8	4 years
Decile 9	3 years
Decile 10	5 years

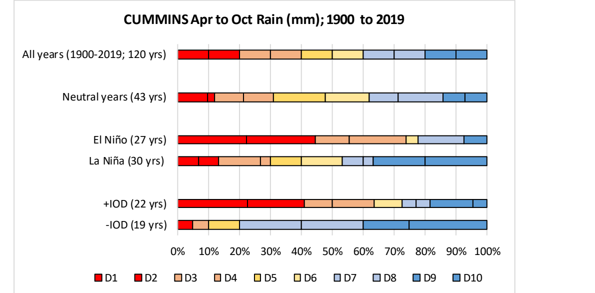
1960 to 2019 Negative IOD years	
There are a total of 11 years	
These correspond to 1960 to 2019	
Decile 1	0 years
Decile 2	0 years
Decile 3	1 years
Decile 4	0 years
Decile 5	1 years
Decile 6	0 years
Decile 7	2 years
Decile 8	2 years
Decile 9	3 years
Decile 10	2 years

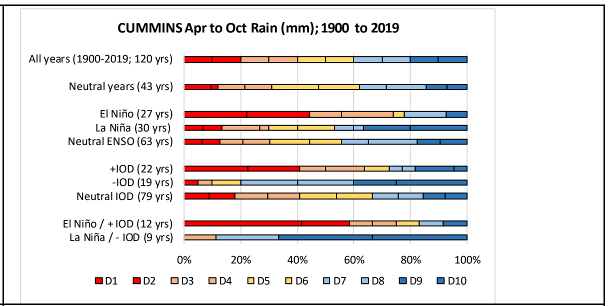
1b.What has been the impact of climate drivers on season rainfall?

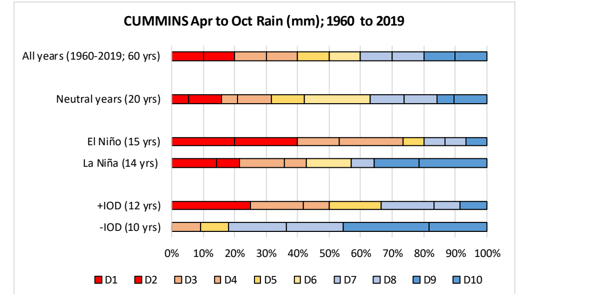
The next graph shows rain with the colours of the bars representing the categorization according to the phase of ENSO (La Nina or El Nino), IOD (Negative IOD or Positive IOD) or the combination of these Climate Drivers. Note not all combinations exist with only La Nina and Negative IOD; and El Nino and Positive IOD shown. Years categorised as Neutral are neutral for both ENSO and IOD. The horizontal lines showing decile 1 (D1), decile 5 (D5) and decile 9 (D9) are shown. The coloured boxes in the lower part of figure indicate the decile of each year.

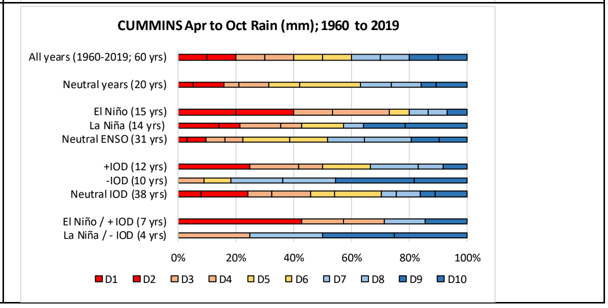


Breakdown of impact of ENSO and IOD (and interaction in Right hand graph) on April to October rainfall during the period 1900 to 2019 (left column) and 1960 to 2019 (right column). El Nino and Negative IOD increase the chance of below median and in particular decile 1 and 2 years, while La Nina and Positive IOD years the chance of above median and in particular decile 9 and 10 years. The column chart (see above) shows the rainfall (mm) corresponding to these deciles.









1c. How do recent seasons compare with the long term record?

The table of monthly and cumulative rainfall shows the amounts (mm) and uses the same colours as. This table shows data from 1957 to 2020 (1957 to 2019 used to calculate deciles). The accumulation of rainfall is calculated from January. The cumulative rainfall from April to October, and the accumulation from the five months of November of previous year to March are also shown. The number of years below median in 20 years from 2000 to 2019 is also shown (expect 10). Of note is that the decile values of monthly values are much more variable than those of accumulated rainfall. That is, while an individual month with a high decile (wet) or low decile (dry) affects accumulated rainfall it does not necessarily shift the decile of the accumulated rainfall.

Mean monthly rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1957	0	1	17	9	16	30	45	26	30	3	13	15
1958	1	1	28	7	65	13	108	47	63	34	12	16
1959	2	14	15	4	17	8	27	24	37	28	37	13
1960	16	57	16	50	97	42	58	49	84	11	27	12
1961	2	7	4	74	33	32	79	76	40	17	9	1
1962	2	15	17	10	60	49	28	50	19	46	10	23
1963	17	26	6	27	64	113	125	58	20	28	2	2
1964	4	11	0	40	39	87	154	34	50	42	75	10
1965	0	1	4	10	68	42	50	58	28	10	21	12
1966	5	2	40	4	32	80	93	23	72	45	21	101
1967	9	19	1	8	32	11	75	59	47	11	1	8
1968	24	4	62	66	61	64	101	98	44	52	34	27
1969	8	44	15	56	54	54	69	25	49	2	13	7
1970	13	1	2	32	42	65	53	98	48	7	9	9
1971	1	1	53	84	74	52	43	120	76	21	40	48
1972	59	18	0	18	16	41	104	145	16	22	4	15
1973	7	3	39	28	69	83	74	81	57	48	7	10
1974	35	0	1	31	80	10	131	63	34	74	7	4
1975	3	6	30	11	83	17	66	49	38	69	14	14
1976	20	38	1	10	29	55	24	37	35	23	26	3
1977	19	15	14	7	75	27	40	47	36	20	23	3
1978	11	1	1	15	34	82	114	60	91	10	17	12
1979	2	12	4	31	62	11	59	76	162	37	59	14
1980	2	0	1	45	42	67	70	34	15	54	17	13
1981	6	27	46	5	55	121	70	106	9	19	12	4
1982	5	15	39	24	45	81	28	23	11	11	2	5
1983	3	5	43	105	49	31	124	50	32	14	5	20
1984	4	1	25	21	26	16	100	101	64	15	13	12
1985	2	2	29	27	18	41	37	103	34	31	14	15
1986	8	0	0	41	25	39	82	67	43	38	12	35
1987	8	32	4	17	55	39	122	28	8	21	3	17
1988	19	13	10	3	58	53	87	27	43	8	33	20
1989	2	0	4	12	42	79	107	69	45	16	6	22
1990	18	14	0	12	10	78	105	87	37	26	1	87
1991	2	0	5	21	23	54	44	88	60	4	11	0
1992	3	3	37	80	48	57	41	107	92	59	47	113
1993	24	1	10	2	20	30	39	65	40	55	15	16
1994	6	7	0	1	43	70	29	19	12	21	13	7
1995	79	14	9	8	66	68	116	14	37	17	10	1
1996	3	9	17	23	21	103	98	84	59	19	11	9
1997	14	5	16	1	54	31	31	48	70	31	15	35
1998	14	3	5	54	27	55	52	44	22	22	5	18
1999	9	0	35	9	51	44	34	44	43	36	10	24
2000	7	40	16	48	52	69	88	65	39	45	6	2
2001	7	27	37	5	67	50	39	46	64	52	47	20
2002	10	0	3	8	51	43	66	31	24	37	18	7
2003	23	54	3	11	33	87	50	84	27	44	16	9
2004	6	9	15	23	25	63	68	84	38	1	32	10
2005	6	0	19	4	7	136	48	60	57	82	33	25
2006	29	44	54	28	26	45	46	25	7	2	12	17
2007	31	0	21	41	55	31	42	14	19	32	21	32
2008	5	5	6	18	49	20	65	54	16	0	54	35
2009	0	0	37	31	23	102	99	46	75	12	17	15
2010	26	10	22	29	38	71	41	82	70	45	16	46
2011	3	54	22	15	57	42	55	44	37	33	14	27
2012	6	9	12	31	34	80	35	47	30	8	9	2
2013	8	2	38	29	30	96	84	83	49	17	19	16
2014	8	68	3	23	73	104	98	9	17	1	8	18
2015	26	0	0	83	22	42	36	80	38	2	24	7
2016	1	74	8	33	89	78	74	31	64	36	4	24
2017	81	7	0	4	15	4	69	85	41	18	47	31
2018	4	15	1	14	33	43	52	134	11	20	26	10
2019	0	2	1	6	105	69	36	32	44	15	9	7
2020	10	22	6	52	30	36						
Number of years below median in 20 years from 2000 to 2019 (expect 10)												
	10	8	10	9	11	9	12	11	12	11	7	8

Accumulation of mean monthly rainfall (mm)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Apr-Oct	Nov-Mar
1957	0	1	18	26	42	72	118	144	173	177	189	204	204	159	41
1958	1	2	30	37	102	114	222	269	332	366	378	394	394	336	57
1959	2	17	32	35	52	60	87	112	149	177	215	228	228	146	59
1960	16	73	89	138	235	277	335	384	468	479	505	517	517	390	139
1961	2	9	13	87	120	152	231	308	347	365	374	375	375	352	51
1962	2	17	34	43	104	152	180	230	249	295	305	328	328	262	44
1963	17	43	50	77	141	254	379	437	457	485	487	489	489	435	82
1964	4	16	16	56	94	181	335	369	419	461	536	546	546	445	20
1965	0	1	5	14	82	123	173	231	259	269	291	303	303	265	90
1966	5	7	47	51	83	162	255	278	350	395	417	517	517	348	81
1967	9	28	29	37	68	80	155	214	260	271	272	280	280	242	151
1968	24	28	90	156	216	280	382	479	524	576	610	637	637	486	99
1969	8	52	67	123	176	230	299	324	373	375	387	394	394	308	128
1970	13	14	15	47	89	154	208	306	353	360	370	379	379	345	35
1971	1	2	55	139	213	265	308	428	504	525	565	614	614	471	74
1972	59	77	77	95	110	151	255	400	416	438	442	457	457	361	165
1973	7	10	49	77	145	229	303	384	440	488	495	504	504	439	68
1974	35	35	37	67	147	158	288	351	385	459	466	470	470	422	53
1975	3	9	39	50	134	150	217	265	303	372	387	401	401	333	50
1976	20	57	58	68	97	152	176	213	248	271	297	300	300	213	87
1977	19	34	47	55	129	156	197	243	280	300	323	326	326	252	77
1978	11	13	13	28	62	144	259	319	409	419	436	448	448	406	39
1979	2	14	18	49	110	121	181	256	418	455	514	528	528	438	47
1980	2	2	3	48	91	157	227	261	276	330	347	360	360	327	75
1981	6	33	79	84	139	261	330	437	446	466	477	481	481	386	109
1982	5	20	58	82	127	208	237	260	271	283	284	289	289	224	74
1983	3	8	51	156	205	235	360	410	442	455	460	480	480	405	57
1984	4	4	29	50	76	92	192	294	358	372	385	397	397	343	54
1985	2	4	34	61	78	120	156	259	292	324	338	353	353	290	58
1986	8	9	9	50	74	114	195	262	305	343	355	390	390	334	38
1987	8	40	43	60	115	154	276	305	312	334	336	353	353	291	91
1988	19	31	41	44	102	155	242	269	312	320	352	372	372	279	60
1989	2	2	7	18	60	139	246	315	359	375	382	403	403	369	59
1990	18	32	32	43	53	131	235	322	359	385	386	473	473	353	60
1991	2	2	7	29	52	106	149	238	298	302	313	313	313	295	95
1992	3	6	43	123	171	228	269	375	468	526	573	686	686	483	54
1993	24	25	35	38	58	88	127	193	233	287	302	318	318	252	195
1994	6	12	12	13	57	126	155	174	186	207	220	227	227	195	43
1995	79	93	102	110	176	244	360	374	411	428	438	439	439	326	122
1996	3	12	29	52	73	176	273	357	416	436	447	455	455	407	40
1997	14	19	34	35	89	120	151	199	269	300	314	349	349	266	54
1998	14	17	22	76	103	157	210	254	276	298	303	321	321	276	72
1999	9	9	44	53	104	148	182	226	269	305	315	338	338	261	67
2000	7	47	64	112	164	233	321	386	424	470	475	477	477	406	97
2001	7	34	71	76	143	193	232	278	342	394	440	460	460	323	78
2002	10	10	13	21	72	115	181	212	236	273	290	297	297	259	80
2003	23	77	80	91	124	211	261	345	372	416	432	441	441	337	104
2004	6	15	30	53	78	141	209	292	330	331	363	372	372	301	55
2005	6	6	25	28	36	172	220	280	336	419	452	477	477	394	66
2006	29	74	128	156	182	227	273	298	305	307	319	336	336	179	187
2007	31	31	51	92	147	178	220	233	253	284	305	338	338	233	80
2008	5	10	15	33	82	103	168	222	237	237	291	327	327	222	69
2009	0	0	37	68	91	192	291	337	411	423	439	454	454	386	127
2010	26	36	58	88	126	197	238	320	390	435	451	497	497	377	90
2011	3	57	79	94	151	193	248	292	330	363	377	403	403	283	141
2012	6	15	28	59	93	173	207	255	285	293	302	304	304	266	68
2013	8	10	48	77	107	202	287	370	419	436	455	470	470	388	59
2014	8	76	78	101	174	278	377	386	403	404	412	430	430	326	113
2015	26	26	26	109	131	173	210	290	327	329	353	360	360	303	52
2016	1	75	83	117	205	283	358	388	453	489	493	517	517	406	114
2017	81	89	89	92	107	111	180	265	305	324	371	402	402	235	116
2018	4	20	21	35	68	111	163	296	307	327	353	363	363	306	99
2019	0	2	3	9	114	183	219	251	295	310	319	326	326	307	39
2020	10	32	37	89	119	155									53
Number of years below median in 20 years from 2000 to 2019 (expect 10)															
	10	8	8	7	7	5	10	10	11	11	11	9	9	13	7

2a. How does the temperature for this season compare to long term records?

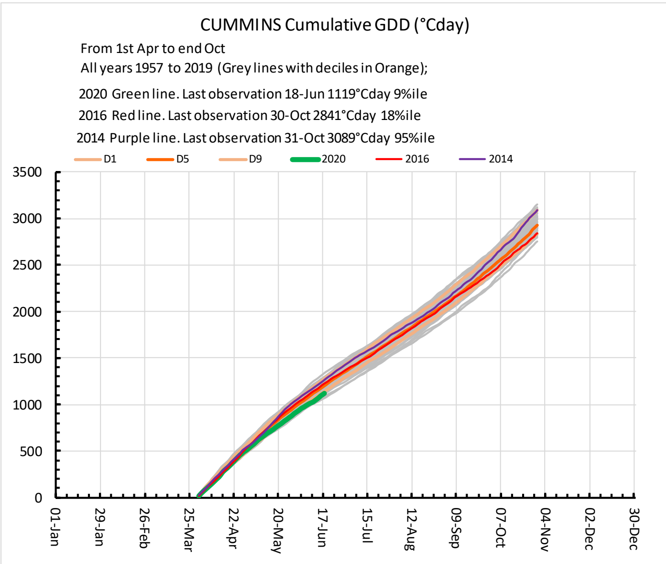
Table of mean monthly temperature is shown below. The mean temperature is the average of daily maximum and daily minimum temperature. These mean temperatures inform the accumulation of temperature which is measured as Growing degree days (GDD). A growing degree day is calculated as the mean daily temperature minus a base temperature (in this case 0°C, but other industries use different base temperatures – for example grape industry uses a base temperature of 10°C) with any negative values being given a corrected value of 0. As the base temperature used here is 0°C it is highly unlikely that the daily mean temperature will be below 0°C.

The table of monthly mean temperature, monthly mean GDD and cumulative GDD shows the amounts (°C, °Cday for GDD) and is coloured according to the decile of these values. The tables shows data from 1957 to 2020 (1957 to 2019 used to calculate deciles). The accumulation of GDD is calculated from January. The cumulative GDD from April to October is also shown.

Similar to the impact of individual monthly values on the accumulation over longer periods noted in the rainfall table, it can be seen that while an individual month may be warmer or colder than the median the value of the resulting accumulated amount (for example annual temperature, accumulation of GDD) is less effected. That is, these accumulated values have a slower moving 'memory' than the shorter individual monthly values.

Of interest is that in the period from 2000 to 2019 there have been many more warmer years, warmer months from late spring to early autumn, but this warming has had lesser effect on other months and on the April to October period.

The plume graph of accumulated GDD shows less year-to-year variation than that for accumulated rainfall. However these differences can affect plant development (phenology). All years from 1957 to 2019 are shown as grey lines with deciles in orange. Three years of interest are shown as Green, Red and Purple lines. In this example green is the current year (2020), Red is 2016 (recent Negative IOD year but mild April to October period), Purple is 2014 (recent Negative IOD year but warm April to October period).



Mean monthly temperature (°C), mean annual temperature (°C) and mean temperature during April to October (°C). The number of years above median in the 20 years from 2000 to 2019 is also shown (expect 10)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Apr-Oct
1957	20.3	20.6	18.8	17.2	14.6	16.0	10.8	11.8	13.4	16.2	17.8	20.1	16.4	14.3
1958	20.5	21.1	18.8	18.2	15.9	11.4	11.4	12.0	12.2	14.7	17.4	17.6	15.9	13.7
1959	21.7	20.5	20.0	18.2	14.7	13.2	11.7	13.8	13.7	16.1	19.9	17.4	16.7	14.5
1960	22.5	19.8	20.5	15.9	12.3	10.8	10.9	11.0	12.8	16.3	16.0	20.9	15.8	12.8
1961	23.3	22.3	20.6	18.1	15.2	13.6	11.5	11.9	15.8	17.0	17.9	20.8	17.3	14.7
1962	21.5	21.1	19.6	18.2	13.7	14.5	12.6	12.7	14.3	15.1	19.1	18.5	16.7	14.4
1963	20.5	20.5	18.9	16.4	14.5	12.7	11.5	11.9	14.2	16.7	18.5	19.5	16.3	14.0
1964	20.1	18.6	19.2	17.2	14.5	12.7	12.0	12.1	13.6	14.6	17.3	17.2	15.8	13.8
1965	19.8	21.8	20.0	15.8	15.1	12.1	11.4	12.1	14.2	17.2	17.8	21.1	16.5	14.0
1966	21.8	20.7	19.8	17.2	14.4	13.0	11.0	11.2	12.8	14.3	19.0	18.4	16.1	13.4
1967	19.9	21.1	19.1	18.7	15.3	13.2	12.0	11.6	14.0	16.9	18.2	19.0	16.6	14.5
1968	23.0	23.1	20.4	18.3	13.4	12.1	10.8	11.4	12.7	16.1	16.4	18.8	16.3	13.5
1969	22.6	20.4	19.3	17.6	13.8	12.2	12.0	12.4	11.7	16.1	17.3	17.8	16.1	13.7
1970	19.3	21.7	18.7	17.3	13.6	13.1	11.9	10.9	12.0	15.3	17.5	19.3	15.8	13.4
1971	20.7	21.6	21.8	18.6	13.8	12.2	11.1	11.3	13.2	15.0	16.3	18.3	16.1	13.6
1972	19.8	21.2	19.0	17.8	15.1	11.9	12.1	12.1	14.1	15.8	16.9	20.6	16.4	14.1
1973	22.8	20.7	19.4	18.3	15.7	11.4	11.5	12.2	13.6	15.8	17.5	20.0	16.6	14.1
1974	23.2	21.0	21.6	17.0	14.1	12.4	11.8	12.2	12.4	15.4	16.6	18.6	16.3	13.6
1975	19.6	22.9	18.4	17.2	15.9	11.4	12.8	11.6	13.6	14.5	18.2	20.4	16.3	13.9
1976	20.4	21.8	19.0	16.4	13.8	11.6	10.9	11.9	13.3	13.9	16.6	20.0	15.8	13.1
1977	21.4	22.0	18.8	15.6	14.2	11.7	11.2	13.5	12.7	16.9	18.1	21.1	16.4	13.7
1978	20.3	21.0	19.9	17.0	14.2	12.3	11.3	11.3	12.2	15.6	17.6	19.0	16.0	13.4
1979	23.1	22.1	19.9	15.9	13.1	12.9	11.3	11.5	13.5	15.0	18.5	20.0	16.3	13.3
1980	19.6	20.4	19.0	18.2	15.3	11.9	11.5	12.4	14.8	16.2	19.2	21.1	16.6	14.3
1981	23.3	21.7	17.3	18.7	14.4	11.9	11.2	12.0	14.6	15.3	17.5	19.1	16.4	14.0
1982	22.6	21.2	20.1	16.6	14.2	10.5	10.1	13.6	13.2	15.7	19.7	19.9	16.4	13.4
1983	20.5	23.3	19.3	15.8	14.1	11.6	10.5	11.9	14.0	15.6	17.8	20.2	16.2	13.4
1984	20.1	21.2	18.9	16.3	14.7	11.6	10.7	12.0	11.8	15.7	18.1	19.7	15.9	13.3
1985	21.3	20.8	20.4	17.1	14.1	12.0	12.0	11.8	12.5	15.3	17.8	18.6	16.1	13.5
1986	19.9	19.9	21.5	17.0	14.3	11.9	10.8	11.7	13.1	14.0	17.8	18.6	15.9	13.2
1987	19.2	20.8	18.9	17.5	14.1	12.4	11.2	11.4	13.9	15.5	18.2	19.9	16.0	13.7
1988	21.8	19.8	20.7	17.3	15.8	12.9	11.8	12.0	15.0	17.3	17.3	20.1	16.8	14.6
1989	21.3	21.8	21.1	17.4	14.7	10.9	10.3	10.5	13.5	14.9	18.5	21.1	16.3	13.2
1990	21.0	20.2	21.0	17.8	16.0	12.1	11.6	11.5	14.3	16.6	18.9	19.2	16.7	14.3
1991	21.6	21.8	19.0	17.4	14.5	14.0	11.8	12.2	14.2	16.6	18.4	18.6	16.6	14.4
1992	18.5	21.5	19.9	17.3	13.9	12.0	11.9	11.0	11.5	15.0	15.7	18.3	15.5	13.2
1993	21.3	21.1	19.1	17.8	14.9	11.9	12.0	13.2	13.6	15.8	18.8	19.2	16.5	14.1
1994	20.3	20.7	20.1	17.7	15.6	13.1	11.8	11.2	12.7	16.1	17.0	21.0	16.4	14.0
1995	21.0	22.1	17.7	15.6	13.7	12.5	11.6	12.3	13.3	16.0	17.6	18.6	16.0	13.6
1996	18.9	21.6	20.2	15.6	14.2	12.8	11.9	11.8	13.1	15.6	16.8	19.0	15.9	13.5
1997	21.7	24.5	17.8	17.4	14.1	12.1	9.8	11.1	13.7	15.4	19.0	19.2	16.3	13.4
1998	20.8	20.1	19.7	15.9	14.7	12.1	10.2	12.6	14.1	15.5	17.7	20.2	16.1	13.6
1999	22.5	22.2	19.3	15.5	14.9	12.0	12.4	12.1	15.1	16.6	16.7	20.0	16.6	14.1
2000	21.4	24.1	20.6	17.5	13.7	12.0	11.8	11.5	14.4	15.4	19.9	20.5	16.9	13.7
2001	24.2	23.5	19.3	16.7	14.0	12.9	11.7	12.7	14.7	14.2	16.8	17.1	16.4	13.8
2002	20.1	19.3	19.1	18.2	16.0	12.7	12.3	11.4	13.7	15.6	18.6	20.4	16.4	14.3
2003	22.3	21.0	18.1	17.0	14.8	12.5	11.8	11.5	12.9	13.3	19.1	21.1	16.3	13.4
2004	18.9	22.3	19.3	17.6	14.3	13.2	11.2	12.1	12.9	16.7	18.8	20.1	16.4	14.0
2005	20.8	20.4	19.6	19.0	15.8	13.3	11.6	12.5	13.4	15.5	18.1	20.5	16.7	14.4
2006	22.5	19.5	20.2	15.9	13.0	10.3	11.4	12.8	14.6	16.8	19.1	19.9	16.3	13.5
2007	22.1	23.0	20.3	18.6	15.4	10.7	10.8	12.0	14.5	16.2	20.0	21.3	17.0	14.0
2008	22.3	21.0	23.1	17.3	14.7	12.4	10.5	9.7	13.6	16.9	17.8	19.4	16.5	13.6
2009	23.2	23.6	19.7	16.9	13.7	12.0	11.6	12.4	13.0	15.1	22.5	21.2	17.0	13.5
2010	23.1	23.2	20.8	18.2	14.3	11.4	10.5	10.8	11.8	14.5	17.4	20.0	16.3	13.1
2011	22.9	21.9	19.1	17.3	13.8	12.1	11.2	12.1	13.8	15.6	19.3	21.1	16.7	13.7
2012	23.3	21.0	19.4	17.9	13.7	11.3	10.2	10.9	13.5	16.2	19.3	20.7	16.5	13.4
2013	22.1	22.9	21.7	18.1	16.3	11.8	11.3	12.6	15.3	16.2	17.6	20.7	17.2	14.5
2014	23.4	22.5	20.0	17.6	16.2	12.3	11.3	11.1	14.5	18.1	19.4	19.3	17.1	14.4
2015	21.5	23.0	18.9	15.5	13.7	11.2	10.1	10.9	12.8	18.1	19.1	22.8	16.4	13.2
2016	22.7	20.5	20.5	17.2	15.3	11.6	10.7	11.5	11.9	14.5	16.8	21.1	16.2	13.2
2017	22.4	21.0	21.7	17.4	14.4	11.2	11.9	11.7	13.6	16.7	20.2	19.7	16.8	13.8
2018	23.1	22.6	20.5	19.5	14.4	11.2	11.2	11.3	11.7	16.4	17.4	20.9	16.7	13.7
2019	23.3	21.8	19.9	18.4	13.5	11.3	11.3	10.6	13.3	17.3	17.0	22.3	16.7	13.7
2020	21.8	21.1	19.9	16.5	13.0	11.4								
Number of years above median in 20 years from 2000 to 2019 (expect 10)														
	15	12	11	12	9	7	7	8	10	11	13	15	16	10

Mean monthly GDD (°Cday)

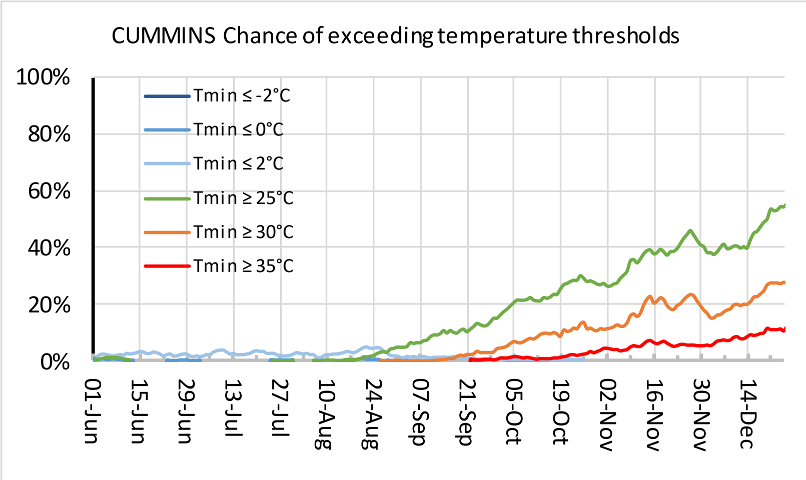
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1957	629	578	582	515	454	480	335	366	401	501	533	624
1958	635	590	582	545	493	343	352	371	367	455	521	545
1959	673	575	619	546	455	396	364	428	412	500	597	541
1960	697	574	636	477	381	325	338	340	384	504	479	648
1961	722	626	639	543	471	409	358	368	474	529	536	644
1962	667	592	607	546	423	434	391	394	430	470	573	575
1963	635	574	585	492	448	381	356	369	427	516	554	606
1964	624	541	594	515	448	381	374	375	409	453	520	534
1965	615	610	621	475	467	363	352	375	426	534	534	655
1966	675	579	614	517	447	389	342	347	384	444	571	571
1967	617	590	593	560	474	396	373	359	419	525	547	590
1968	713	671	632	548	415	362	335	353	381	499	493	582
1969	699	573	598	528	429	367	373	386	352	500	519	553
1970	599	608	579	519	423	392	370	337	361	475	525	599
1971	641	604	675	557	427	367	345	349	397	465	489	569
1972	615	615	588	535	469	356	377	374	424	490	506	639
1973	707	580	601	549	487	343	357	379	408	490	525	620
1974	719	587	670	509	437	372	364	378	371	477	499	578
1975	607	642	571	516	494	341	397	361	409	451	545	632
1976	632	633	588	491	427	347	337	368	400	430	499	620
1977	662	616	584	468	441	351	346	420	381	524	543	655
1978	629	587	618	511	442	370	352	349	367	484	527	589
1979	716	619	616	478	405	386	349	357	405	464	554	619
1980	607	592	588	547	475	358	358	385	443	502	577	655
1981	721	609	537	560	445	358	348	372	439	475	526	593
1982	699	595	622	497	440	316	313	421	397	487	590	618
1983	636	652	598	473	438	348	327	369	420	484	535	627
1984	624	615	586	490	454	349	332	373	354	487	542	610
1985	662	582	632	513	436	361	373	367	375	474	535	577
1986	616	559	667	509	442	358	336	363	392	435	533	577
1987	595	584	586	524	438	371	346	354	416	479	546	616
1988	676	573	643	520	489	386	365	372	450	536	518	623
1989	660	610	654	523	455	326	319	326	405	461	554	655
1990	651	566	651	533	496	363	359	358	430	515	568	595
1991	669	611	588	523	451	420	367	377	425	516	552	577
1992	575	625	618	519	431	360	370	341	344	464	472	567
1993	659	590	591	533	462	357	371	410	407	489	563	595
1994	630	580	623	531	485	393	367	348	382	499	511	652
1995	651	618	549	467	425	375	358	383	400	496	528	576
1996	585	626	627	469	440	383	368	365	393	483	505	588
1997	674	686	551	522	437	363	304	345	411	476	571	595
1998	644	562	611	478	455	363	316	390	422	480	531	625
1999	698	623	598	466	462	360	384	377	452	516	501	622
2000	664	698	638	524	426	359	366	358	432	479	597	637
2001	751	658	598	500	435	387	363	392	442	440	503	529
2002	623	542	591	547	495	382	382	354	412	484	558	633
2003	692	589	562	510	460	375	367	356	388	414	574	653
2004	586	646	599	527	442	396	349	374	386	518	565	624
2005	646	571	607	571	491	400	359	389	402	481	544	636
2006	699	545	628	476	404	308	352	396	439	520	574	617
2007	686	644	630	559	477	320	334	373	435	503	599	662
2008	693	610	715	519	457	372	326	300	407	523	534	601
2009	718	661	610	507	425	359	360	383	391	468	676	659
2010	717	649	644	547	444	343	324	336	353	449	521	621
2011	711	613	592	519	428	362	346	376	415	483	580	655
2012	723	608	601	538	426	340	316	339	406	503	580	642
2013	686	641	672	544	506	353	351	389	458	501	529	641
2014	724	631	621	528	503	369	349	343	436	562	582	597
2015	666	643	587	466	423	337	313	338	383	561	572	707
2016	704	594	636	516	473	349	332	358	358	449	505	655
2017	695	589	672	521	447	335	368	361	409	517	606	612
2018	717	632	635	586	447	336	346	350	351	509	523	649
2019	724	611	618	552	419	338	351	328	398	537	509	693
2020	677	613	617	494	404	206						
Number of years above median in 20 years from 2000 to 2019 (expect 10)												
	15	13	11	12	9	7	7	8	10	11	13	15

Accumulation of mean monthly GDD (°Cday)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Apr-Oct	Nov-Mar
1957	629	1207	1789	515	969	1448	1783	2149	2550	3051	3584	4207	5996	3051	2813
1958	635	1225	1807	545	1037	1380	1733	2103	2470	2926	3447	3992	5798	2926	2963
1959	673	1248	1867	546	1001	1397	1761	2189	2600	3101	3698	4238	6105	3101	2933
1960	697	1271	1907	477	858	1183	1521	1861	2244	2748	3227	3875	5782	2748	3044
1961	722	1348	1987	543	1014	1423	1780	2148	2622	3151	3686	4330	6317	3151	3114
1962	667	1259	1866	546	969	1403	1794	2188	2617	3087	3659	4234	6100	3087	3045
1963	635	1210	1795	492	940	1321	1677	2046	2473	2989	3543	4148	5943	2989	2942
1964	624	1165	1758	515	963	1344	1718	2092	2501	2954	3474	4008	5766	2954	2918
1965	615	1225	1845	475	942	1305	1657	2033	2459	2993	3527	4181	6026	2993	2899
1966	675	1254	1868	517	964	1352	1694	2041	2425	2869	3439	4010	5877	2869	3056
1967	617	1207	1800	560	1034	1430	1802	2161	2580	3105	3652	4243	6043	3105	2941
1968	713	1384	2015	548	963	1324	1659	2012	2393	2892	3384	3966	5981	2892	3153
1969	699	1272	1870	528	957	1324	1697	2083	2435	2935	3453	4006	5875	2935	2944
1970	599	1207	1785	519	942	1333	1703	2040	2401	2876	3401	4000	5785	2876	2856
1971	641	1245	1920	557	983	1350	1694	2043	2440	2905	3393	3962	5882	2905	3044
1972	615	1229	1817	535	1004	1360	1736	2110	2534	3024	3529	4169	5986	3024	2875
1973	707	1287	1887	549	1036	1379	1735	2114	2522	3011	3536	4156	6044	3011	3032
1974	719	1306	1976	509	946	1317	1682	2059	2431	2907	3406	3984	5960	2907	3121
1975	607	1248	1820	516	1010	1351	1748	2109	2518	2968	3513	4145	5964	2968	2896
1976	632	1265	1853	491	918	1264	1601	1969	2368	2799	3298	3918	5771	2799	3030
1977	662	1278	1862	468	908	1259	1605	2025	2406	2930	3473	4128	5990	2930	2981
1978	629	1216	1834	511	953	1323	1674	2023	2390	2874	3401	3990	5824	2874	3032
1979	716	1335	1952	478	883	1269	1618	1975	2379	2843	3397	4016	5968	2843	3068
1980	607	1199	1787	547	1022	1380	1738	2123	2566	3068	3645	4299	6086	3068	2959
1981	721	1330	1867	560	1006	1363	1711	2082	2522	2997	3523	4116	5983	2997	3099
1982	699	1294	1916	497	937	1253	1566	1987	2384	2871	3461	4078	5994	2871	3035
1983	636	1289	1886	473	911	1259	1586	1955	2375	2859	3394	4020	5906	2859	3094
1984	624	1239	1825	490	944	1293	1624	1997	2351	2838	3379	3989	5814	2838	2986
1985	662	1243	1875	513	949	1309	1682	2049	2423	2897	3432	4009	5884	2897	3027
1986	616	1175	1842	509	951	1309	1645	2007	2399	2834	3367	3944	5786	2834	2954
1987	595	1179	1765	524	962	1332	1678	2032	2448	2927	3473	4088	5853	2927	2875
1988	676	1249	1892	520	1009	1395	1760	2132	2582	3118	3636	4259	6151	3118	3054
1989	660	1270	1923	523	978	1304	1623	1949	2353	2814	3368	4023	5946	2814	3064
1990	651	1217	1867	533	1029	1391	1750	2108	2537	3052	3620	4214	6081	3052	3076
1991	669	1280	1868	523	973	1393	1760	2137	2562	3078	3630	4207	6074	3078	3030
1992	575	1199	1817	519	950	1310	1680	2021	2364	2828	3301	3867	5684	2828	2946
1993	659	1249	1840	533	995	1351	1722	2131	2539	3027	3590	4186	6026	3027	2879
1994	630	1210	1833	531	1016	1409	1776	2124	2506	3005	3517	4168	6001	3005	2991
1995	651	1269	1818	467	892	1267	1625	2008	2408	2903	3431	4007	5824	2903	2981
1996	585	1211	1838	469	909	1291	1659	2024	2416	2899	3404	3992	5829	2899	2941
1997	674	1360	1911	522	960	1322	1626	1971	2382	2858	3429	4023	5934	2858	3003
1998	644	1206	1817	478	932	1295	1611	2001	2423	2903	3434	4059	5876	2903	2982
1999	698	1320	1918	466	928	1288	1671	2048	2500	3016	3516	4138	6056	3016	3075
2000	664	1362	2000	524	949	1308	1674	2032	2464	2942	3540	4176	6176	2942	3122
2001	751	1409	2007	500	935	1322	1685	2077	2519	2959	3461	3990	5997	2959	3241
2002	623	1164	1755	547	1042	1424	1806	2160	2572	3055	3613	4246	6001	3055	2787
2003	692	1282	1844	510	969	1344	1711	2066	2454	2867	3442	4095	5939	2867	3035
2004	586	1232	1831	527	969	1364	1713	2087	2473	2990	3555	4179	6010	2990	3059
2005	646	1216	1823	571	1061	1461	1820	2209	2610	3091	3635	4271	6094	3091	3012
2006	699	1244	1872	476	879	1187	1539	1935	2374	2894	3468	4085	5957	2894	3052
2007	686	1330	1959	559	1036	1355	1690	2062	2497	3000	3599	4260	6220	3000	3150
2008	693	1303	2018	519	975	1347	1672	1972	2379	2902	3437	4037	6055	2902	3278
2009	718	1379	1989	507	931	1290	1651	2034	2425	2893	3569	4228	6216	2893	3124
2010	717	1366	2010	547	991	1334	1658	1994	2346	2795	3316	3937	5947	2795	3345
2011	711	1324	1916	519	947	1309	1654	2030	2445	2928	3507	4162	6078	2928	3059
2012	723	1331	1932	538	964	1304	1620	1959	2365	2868	3448	4089	6021	2868	3166
2013	686	1326	1998	544	1051	1403	1754	2144	2602	3103	3632	4273	6271	3103	3220
2014	724	1355	1976	528	1031	1400	1749	2092	2528	3089	3671	4268	6244	3089	3146
2015	666	1309	1896	466	889	1226	1539	1877	2260	2821	3393	4099	5995	2821	3075
2016	704	1298	1934	516	990	1338	1670	2028	2386	2835	3340	3995	5928	2835	3212
2017	695	1284	1956	521	968	1303	1671	2032	2441	2958	3563	4175	6131	2958	3116
2018	717	1349	1984	586	1032	1368	1713	2063	2414	2923	3446	4095	6078	2923	3201
2019	724	1335	1952	552	971	1309	1660	1988	2387	2924	3433	4126	6078	2924	3124
2020	677	1290	1907	2400	2804	3010									3109
Number of years below median in 20 years from 2000 to 2019 (expect 10)															
	15	16	16	12	13	11	9	9	10	10	10	12	16	10	17

2b. What is the long term risk of frost or spring heat events?

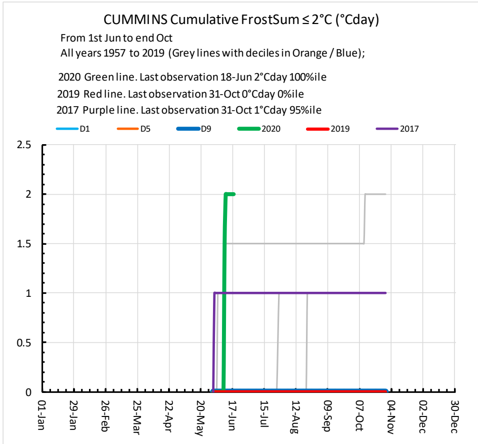
The graph shows the average chance of exceeding temperature thresholds in the 7 days surrounding the date (3 days before to 3 days after the date). The chance of cold night temperature decreases while the chance of hot day temperature increase from June.

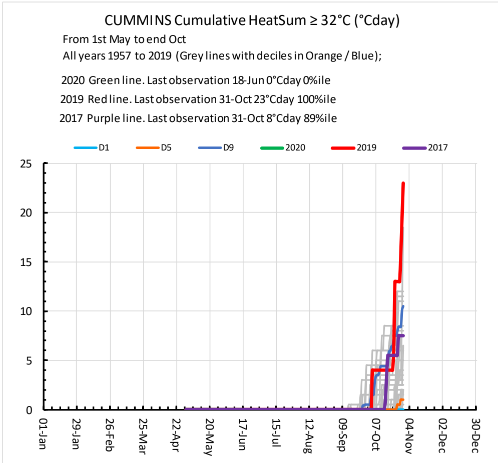


2c. How does accumulated spring frost and heat in recent years compare with long term record?

Extreme temperatures are also assessed using Frostsum and Heatsum. FrostSum is the sum of each days' difference in night minimum temperature below 0°C. For example, a night minimum temperature of 0°C counts as 0°Cday while a night minimum temperature of -1°C counts as 1°Cday. HeatSum is the sum of each days' difference in daily maximum temperature above 32°C. For example, a daily maximum temperature of 32°C counts as 0°Cday while a daily maximum temperature of 33°C counts as 1°Cday.

The plume chart shows the Frostsum less than or equal to 0°C and the Heatsum greater than or equal to 32°C in all years (grey) with deciles 1 and 9 shown in blue and decile 5 in Orange. For Frostsum it is likely that decile 9 is close to or equal to zero indicating that the chance of night temperature below 0°C are a rare event. Three years of interest are shown as Green, Red and Purple lines. In this example green is the current year (2020), Red is 2019 (last year and recent hot year), Purple is 2017 (recent year with frost and also a hot year).

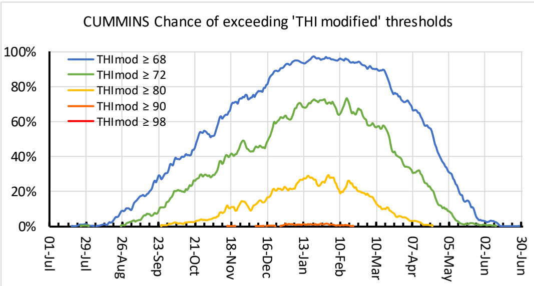




3. What is the risk of heat stress for sheep?

THI is a measure of animal comfort and productivity. Excessive THI can effect fertility and animal production. THI is calculated as = Maximum daily temperature (°C) + 0.36×Dew Point temperature (°C) + 41.2. We have shown the Modified THI value according to Mader et al., (2002). It is calculated as Modified THI = 4.51 + THI – 1.992 × Wind Speed (m/s) + 0.0068 × Solar Radiation (W/m^2).

The chance of extremes in daily THI are shown below. The graph shows the average chance of exceeding THI thresholds in the 7 days surrounding the date (3 days before to 3 days after the date). The chance increases in the warmer months.



The components of weather than contribute to THI are shown below. Temperature has a large effect on THI, and for any temperature more humid conditions (higher dew point) will have a larger effect than less humid conditions. Sheltering from radiation (shade) will reduce THI although the effect is relatively small (difference in radiation between a cloudy and a sunny day is roughly 20MJ/m2 so the 0.0068 × Solar Radiation equals roughly 0.0068×11.574 (conversion from W/m2 to MJ/m2) × 20 = 1.5.

Wind speed can have a large effect (see figure below). A light breeze (2m/s = 7.2km/h = wind felt on face) lowers THI by 4 while a moderate breeze (roughly 6m/s = 20 km/h = small branches can move) lowers THI by 12, and a fresh breeze (10m/s = 35km/h = small trees sway) lowers THI by 20.