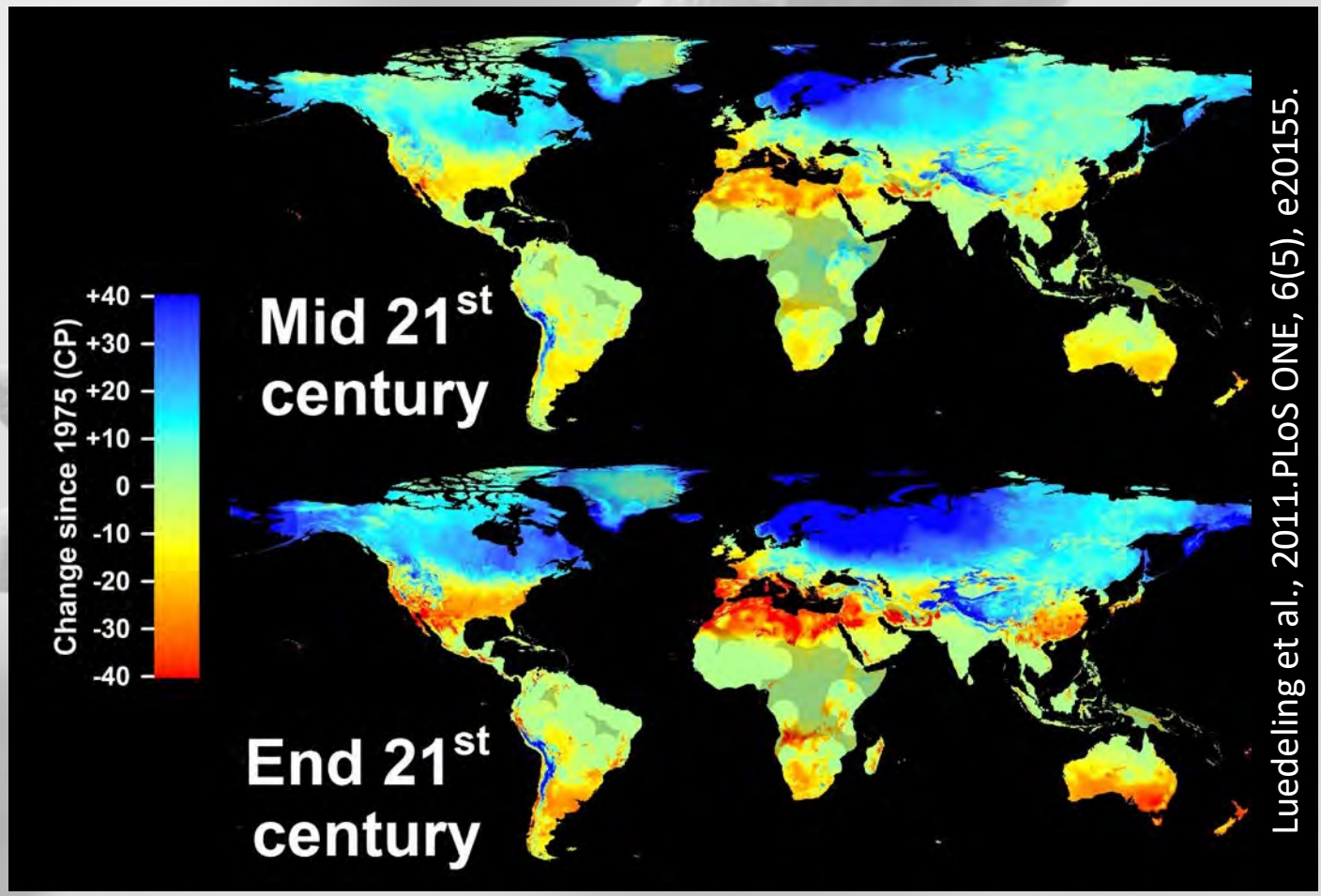
# Future chill risk assessment using chillR

Eike Luedeling

# Winter chill

- Critical requirement for temperate tree crops to break dormancy
- Important criterion for selecting tree species and cultivars
- May be severely impacted by climate change

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# State-of-the-art chill risk assessment

| | | |
|---|---|---|
| • Needs hourly temperature records | ➡ | • No (hourly) temperature data |
| • Use a credible chill model (i.e. currently the Dynamic Model) | ➡ | • Dynamic Model is quite complicated |
| • Evaluate historic trends | ➡ | • No long-term data |
| • Consider many future scenarios | ➡ | • Data processing challenges |
| • Realistic weather projections | ➡ | • Hard to produce |
| • Assess risk of chill shortfall, not just means | ➡ | • Statistical appraisal difficult |

**Major challenges**

**Very rarely achieved**

**Most assessments have severe deficiencies (or aren‘t even done)**

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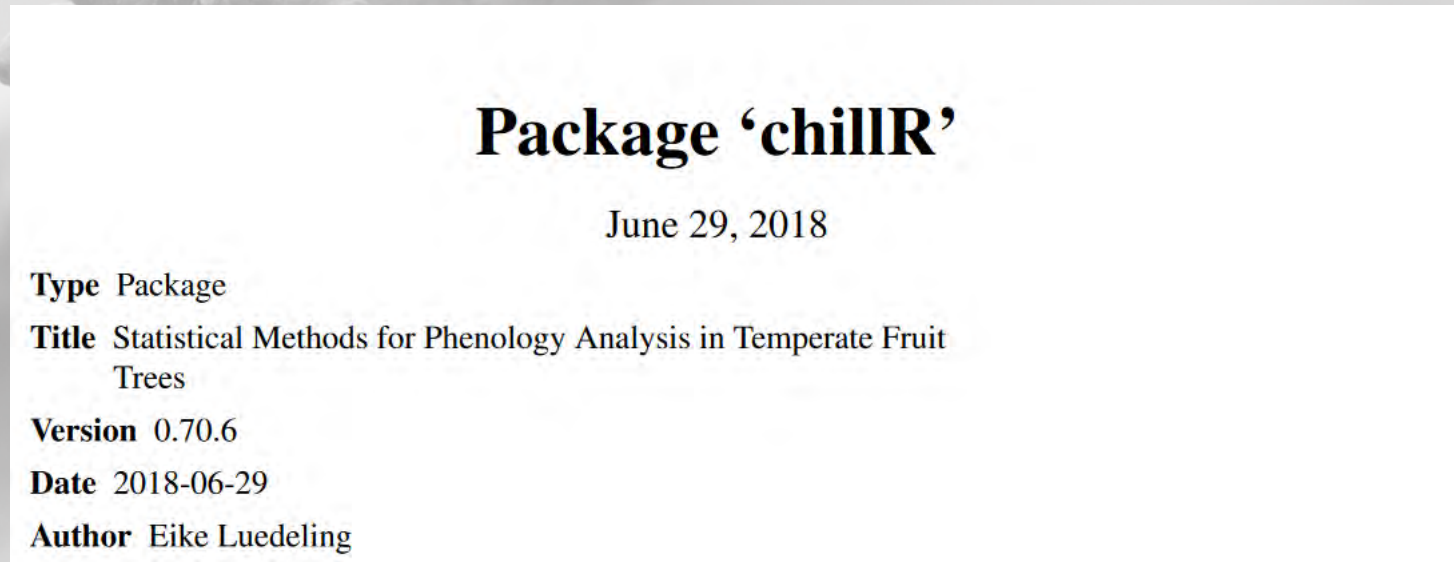
# chillR – a tool for chill risk assessment

- The chillR package for R aims to facilitate chill assessments
- Open-source contributed package (on CRAN, R‘s official server)
- Successively added functions since 2013
- Automates many data processing and analysis steps in phenology analysis



**Package ‘chillR’**

June 29, 2018

**Type** Package

**Title** Statistical Methods for Phenology Analysis in Temperate Fruit Trees

**Version** 0.70.6

**Date** 2018-06-29

**Author** Eike Luedeling

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# Get historic temperature records

- Function to access NOAA's Global Summary of the Day database

```
lat=41;long=29 #geographic coordinates of Istanbul
stat_list<-handle_gsod(action="list_stations",
                       location=c(x=long,y=lat),
                       time_interval=c(1945,2018))
```

```
gw<-handle_gsod(action="download_weather",
                location=stat_list$chillR_code[1],
                time_interval=c(1945,2018),
                station_list = stat_list)
weather<-fix_weather(handle_gsod(gw)$weather)
```

| chillR_code | STATION.NAME | CTRY | Lat | Long | BEGIN | END | distance | Overlap_years | Perc_interval_covered |
|---|---|---|---|---|---|---|---|---|---|
| 170600_99999 | ATATURK | TU | 40.977 | 28.821 | 19450613 | 20180807 | 15.28 | 73.15 | 99.38 |
| 170610_99999 | SARIYER | TU | 41.133 | 29.067 | 19510101 | 20180807 | 15.81 | 67.60 | 91.84 |
| 170620_99999 | ISTANBUL/GOZTEPE | TU | 40.900 | 29.150 | 19990603 | 20070509 | 16.82 | 7.93 | 10.78 |
| 170640_99999 | ISTANBUL BOLGE (KARTAL) | TU | 40.900 | 29.150 | 20140218 | 20180807 | 16.82 | 4.47 | 6.07 |
| 170223_99999 | SAMANDIRA | TU | 41.000 | 29.217 | 20111212 | 20180807 | 18.26 | 6.66 | 9.04 |
| 170590_99999 | KUMKOY | TU | 41.250 | 29.033 | 19730101 | 20180807 | 27.90 | 45.60 | 61.95 |
| 170630_99999 | SABIHA GOKCEN | TU | 40.899 | 29.309 | 20031118 | 20180807 | 28.33 | 14.72 | 20.00 |
| 171190_99999 | YALOVA | TU | 40.667 | 29.283 | 20080808 | 20180807 | 44.01 | 10.00 | 13.58 |
| 170680_99999 | CENGIZTOPEL | TU | 40.850 | 29.900 | 19990315 | 20180807 | 77.62 | 19.40 | 26.36 |
| 170670_99999 | GOLCUK/DUMLUPINAR | TU | 40.667 | 29.833 | 19630101 | 20161214 | 79.40 | 53.96 | 73.30 |
| 170661_99999 | IZMIT | TU | 40.767 | 29.900 | 20150817 | 20180807 | 80.15 | 2.98 | 4.04 |
| 171160_99999 | BURSA | TU | 40.183 | 29.067 | 19730101 | 20180807 | 90.90 | 45.60 | 61.95 |
| 170540_99999 | CORLU | TU | 41.138 | 27.919 | 20070127 | 20180807 | 92.14 | 11.53 | 15.66 |
| 170575_99999 | CORLU | TU | 41.133 | 27.917 | 19921223 | 20180522 | 92.22 | 25.41 | 34.52 |
| 170672_99999 | YENISEHIR | TU | 40.250 | 29.550 | 20040510 | 20180528 | 95.40 | 14.05 | 19.09 |
| 171180_99999 | YENISEHIR | TU | 40.255 | 29.563 | 20070419 | 20180807 | 95.46 | 11.30 | 15.36 |
| 172005_99999 | TOPEL | TU | 40.735 | 30.083 | 19770323 | 20180807 | 95.93 | 41.38 | 56.21 |
| 171150_99999 | BANDIRMA | TU | 40.318 | 27.978 | 19500101 | 20180807 | 114.91 | 68.60 | 93.20 |
| 170690_99999 | ADAPAZARI | TU | 40.783 | 30.417 | 20030606 | 20180807 | 121.82 | 15.17 | 20.61 |
| 170560_99999 | TEKIRDAG | TU | 40.983 | 27.550 | 19630101 | 20180807 | 122.02 | 55.60 | 75.54 |
| 171200_99999 | BILECIK | TU | 40.150 | 29.967 | 19950901 | 20180807 | 124.95 | 22.94 | 31.16 |
| 156610_99999 | ACHTOPOL | BU | 42.100 | 27.850 | 19730305 | 20180430 | 155.34 | 45.16 | 61.35 |
| 170520_99999 | KIRKLARELI | TU | 41.733 | 27.233 | 19910202 | 20180807 | 168.77 | 27.51 | 37.38 |
| 156620_99999 | PRIMORSKO | BU | 42.283 | 27.750 | 19890604 | 20020922 | 176.49 | 13.30 | 18.07 |
| 171500_99999 | BALIKESIR | TU | 39.619 | 27.926 | 19500101 | 20180807 | 178.46 | 68.60 | 93.20 |

| | DATE | Year | Month | Day | Tmin | Tmax | Tmean | Prec | no_Tmin | no_Tmax |
|---|---|---|---|---|---|---|---|---|---|---|
| 1972-05-18 | 12:00:00 | 1972 | 5 | 18 | 0.9530324 | 10.60648 | NA | NA | TRUE | TRUE |
| 1972-05-19 | 12:00:00 | 1972 | 5 | 19 | 0.9488524 | 10.60382 | NA | NA | TRUE | TRUE |
| 1972-05-20 | 12:00:00 | 1972 | 5 | 20 | 0.9446724 | 10.60116 | NA | NA | TRUE | TRUE |
| 1972-05-21 | 12:00:00 | 1972 | 5 | 21 | 0.9404925 | 10.59850 | NA | NA | TRUE | TRUE |
| 1972-05-22 | 12:00:00 | 1972 | 5 | 22 | 0.9363125 | 10.59584 | NA | NA | TRUE | TRUE |
| 1972-05-23 | 12:00:00 | 1972 | 5 | 23 | 0.9321325 | 10.59318 | NA | NA | TRUE | TRUE |
| 1972-05-24 | 12:00:00 | 1972 | 5 | 24 | 0.9279526 | 10.59052 | NA | NA | TRUE | TRUE |
| 1972-05-25 | 12:00:00 | 1972 | 5 | 25 | 0.9237726 | 10.58786 | NA | NA | TRUE | TRUE |
| 1972-05-26 | 12:00:00 | 1972 | 5 | 26 | 0.9195926 | 10.58520 | NA | NA | TRUE | TRUE |
| 1972-05-27 | 12:00:00 | 1972 | 5 | 27 | 0.9154127 | 10.58254 | NA | NA | TRUE | TRUE |
| 1972-05-28 | 12:00:00 | 1972 | 5 | 28 | 0.9112327 | 10.57988 | NA | NA | TRUE | TRUE |
| 1972-05-29 | 12:00:00 | 1972 | 5 | 29 | 0.9070527 | 10.57722 | NA | NA | TRUE | TRUE |
| 1972-05-30 | 12:00:00 | 1972 | 5 | 30 | 0.9028728 | 10.57456 | NA | NA | TRUE | TRUE |
| 1972-05-31 | 12:00:00 | 1972 | 5 | 31 | 0.8986928 | 10.57190 | NA | NA | TRUE | TRUE |
| 1972-06-01 | 12:00:00 | 1972 | 6 | 1 | 0.8945128 | 10.56924 | NA | NA | TRUE | TRUE |
| 1972-06-02 | 12:00:00 | 1972 | 6 | 2 | 0.8903329 | 10.56658 | NA | NA | TRUE | TRUE |
| 1972-06-03 | 12:00:00 | 1972 | 6 | 3 | 0.8861529 | 10.56392 | NA | NA | TRUE | TRUE |
| 1972-06-04 | 12:00:00 | 1972 | 6 | 4 | 0.8819729 | 10.56126 | NA | NA | TRUE | TRUE |
| 1972-06-05 | 12:00:00 | 1972 | 6 | 5 | 0.8777930 | 10.55860 | NA | NA | TRUE | TRUE |
| 1972-06-06 | 12:00:00 | 1972 | 6 | 6 | 0.8736130 | 10.55594 | NA | NA | TRUE | TRUE |
| 1972-06-07 | 12:00:00 | 1972 | 6 | 7 | 0.8694330 | 10.55328 | NA | NA | TRUE | TRUE |

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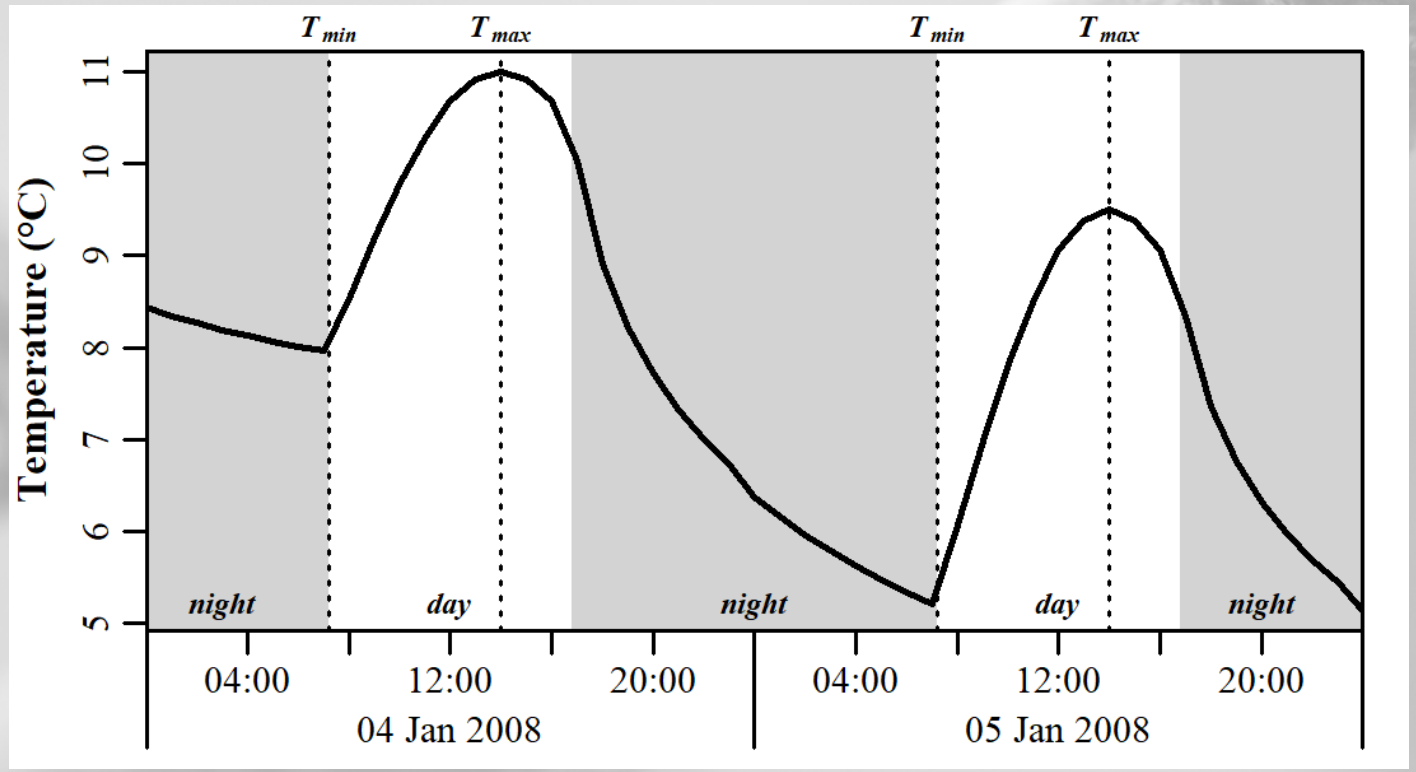
# Prepare temperature data for chill assessment

- Patch gaps with records from other stations
- Produce hourly data based on idealized temperature curves

```
Temps<-stack_hourly_temps(weather,latitude=lat)
```




**Recent addition:**

Function to interpolate gaps in hourly temperature records

Luedeling, 2018. International Journal of Biometeorology, in press.

# Compute chill and heat metrics

- Simple one-line code for computing common chill and heat metrics
- Separate functions for several metrics
- Capability for implementing additional temperature-based models

```
start_day=300
end_day=31
chill_results<-chilling(HourTemps,Start_JDay=start_day,End_JDay=end_day)
```

| Season | End_year | Season_days | Data_days | Interpolated_days | Perc_complete | Chilling_Hours | Utah_Model | Chill_portions | GDH |
|---|---|---|---|---|---|---|---|---|---|
| 1945/1946 | 1946 | 97 | 97 | 0 | 100.00000 | 910 | 1222.0 | 60.00751 | 9783.477 |
| 1950/1951 | 1951 | 97 | 97 | 0 | 100.00000 | 493 | 1045.5 | 57.17759 | 12875.208 |
| 1951/1952 | 1952 | 97 | 97 | 4 | 95.87629 | 837 | 1240.5 | 62.10163 | 9625.305 |
| 1952/1953 | 1953 | 98 | 98 | 0 | 100.00000 | 474 | 816.5 | 47.66997 | 15053.048 |
| 1953/1954 | 1954 | 97 | 97 | 0 | 100.00000 | 1158 | 1152.0 | 60.15309 | 4743.945 |
| 1954/1955 | 1955 | 97 | 97 | 31 | 68.04124 | 771 | 1351.0 | 60.82417 | 10546.561 |
| 1963/1964 | 1964 | 97 | 97 | 0 | 100.00000 | 952 | 1002.5 | 55.06393 | 9598.316 |
| 1964/1965 | 1965 | 98 | 98 | 0 | 100.00000 | 851 | 1226.0 | 58.59804 | 10536.622 |
| 1965/1966 | 1966 | 97 | 97 | 2 | 97.93814 | 678 | 1156.0 | 60.42672 | 10472.925 |
| 1966/1967 | 1967 | 97 | 97 | 0 | 100.00000 | 701 | 596.5 | 45.69500 | 13916.746 |
| 1967/1968 | 1968 | 97 | 97 | 19 | 80.41237 | 615 | 827.0 | 51.32018 | 11441.830 |
| 1968/1969 | 1969 | 98 | 98 | 31 | 68.36735 | 693 | 1306.5 | 61.50517 | 10772.180 |
| 1973/1974 | 1974 | 97 | 97 | 0 | 100.00000 | 1279 | 1481.0 | 68.23749 | 5419.767 |
| 1974/1975 | 1975 | 97 | 97 | 0 | 100.00000 | 1000 | 1442.0 | 65.01356 | 8222.298 |
| 1975/1976 | 1976 | 97 | 97 | 0 | 100.00000 | 991 | 1353.0 | 66.31119 | 6838.810 |
| 1976/1977 | 1977 | 98 | 98 | 0 | 100.00000 | 1009 | 1244.5 | 57.82485 | 9696.700 |

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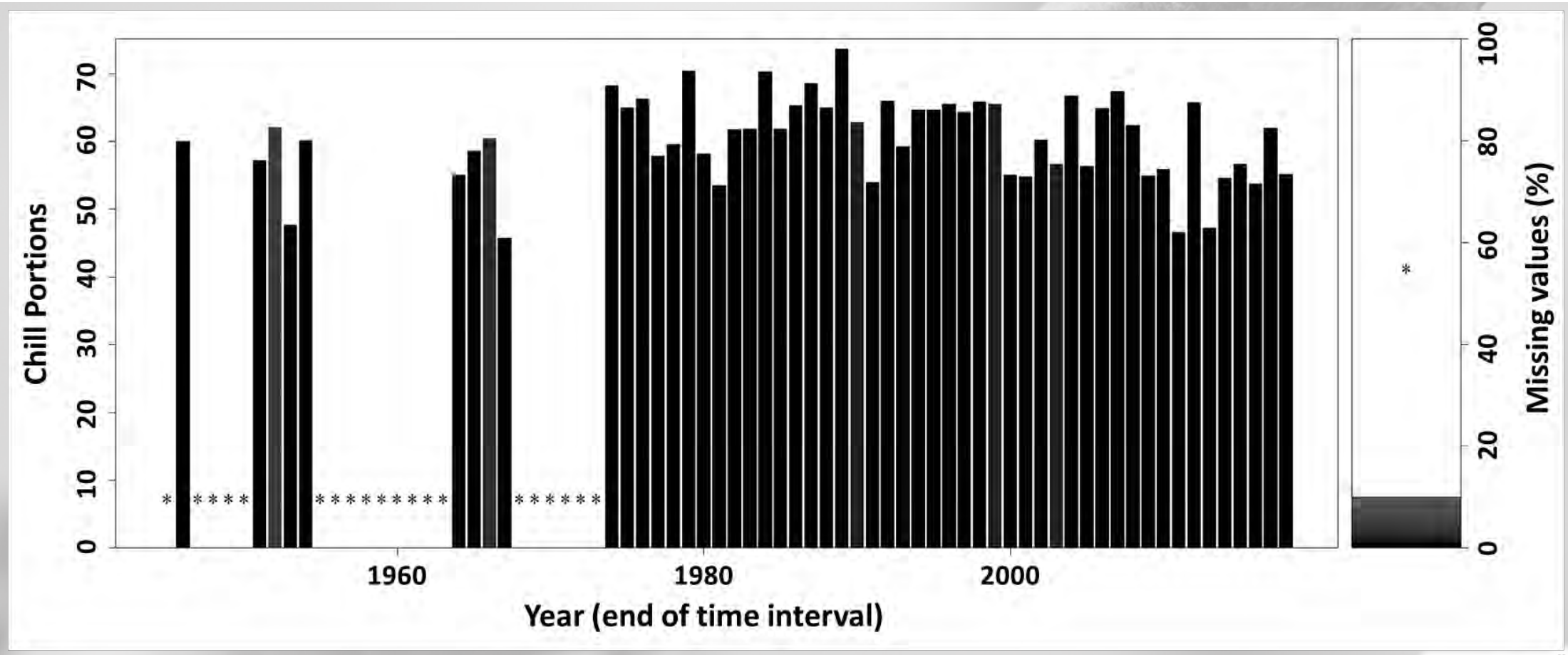
# Evaluate past data

- Simple functions to produce summary plots for historic data

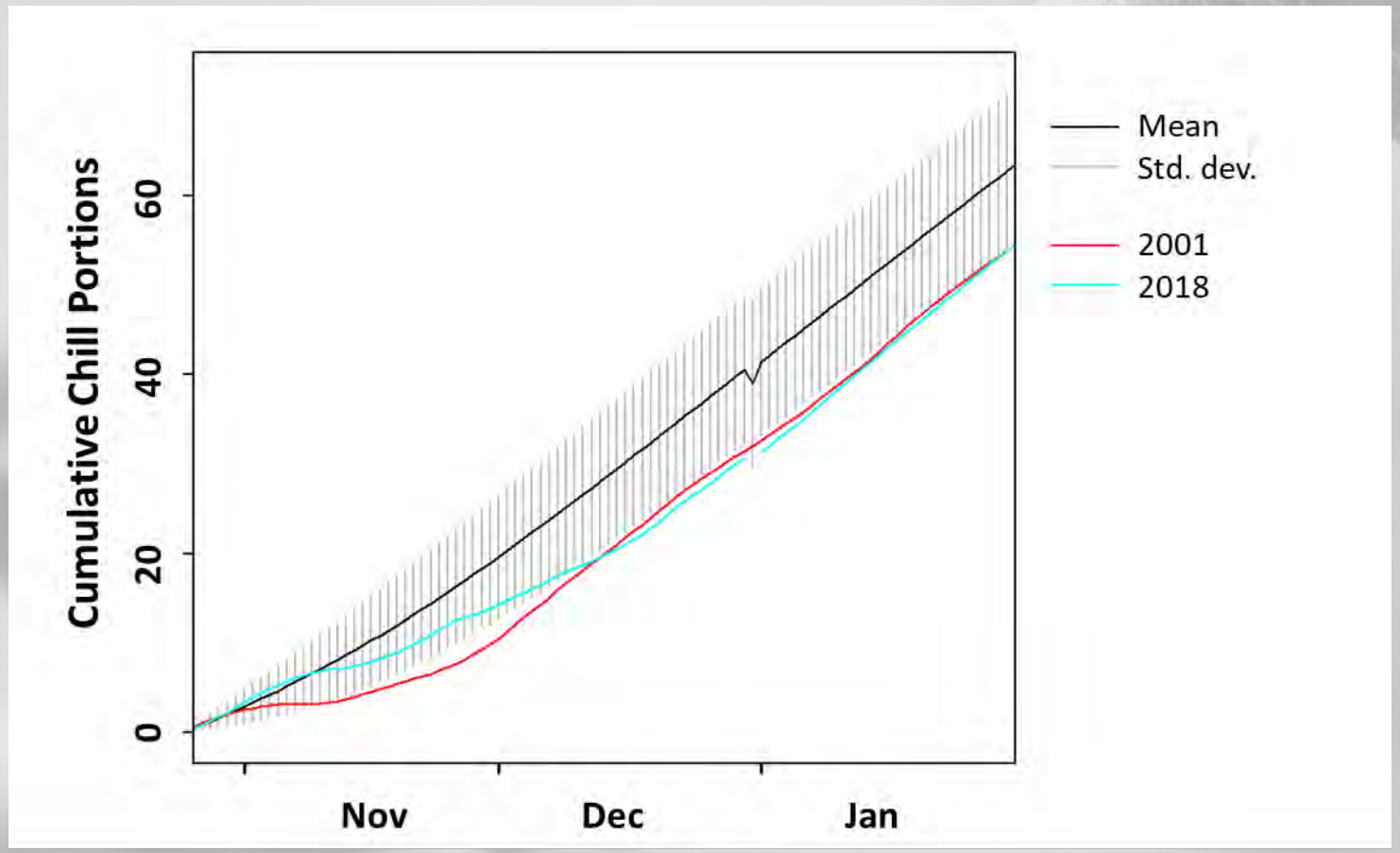
```
make_chill_plot(chill_results,model="Chill_portions",start_year=1945,end_year=2018,metriclabel="Chill Portions")
```



# Evaluate past data

- Illustrate typical chill accumulation and highlight particular years

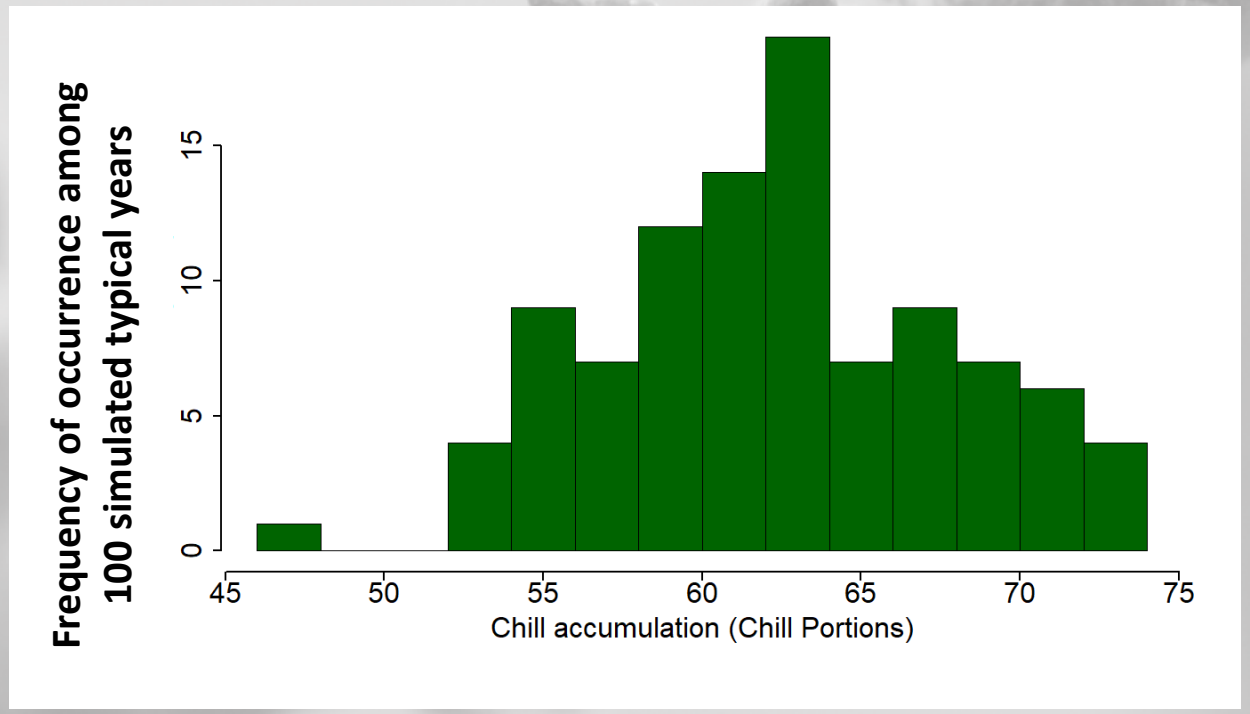
```
day_chill<-make_daily_chill_plot(daily_chill(HourTemps,running_mean=11),focusyears=c(2001,2018),cumulative=TRUE,startdate=start_day,enddate=end_day)
```



# Temperature scenarios

- Inclusion of a weather generator to produce synthetic weather ‚replicates' that can be stochastically evaluated
- Allows probabilistic risk assessment

```
Temp<-temperature_generation(weather,years=c(1970,2010),sim_years = c(2001,2100))
Istanbul_chill_distribution<-chilling(stack_hourly_temps(Temp[[1]],latitude=29),Start_JDay=start_day,End_JDay=end_day)[1:99,]
hist(Istanbul_chill_distribution$Chill_portions,breaks=10,col="dark green",lwd=2,cex.axis=2,cex.lab=2,xlab="Chill accumulation (Chill Portions)")
```

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# Access future temperature datasets

- Function to download climate metrics from ClimateWizard database, which contains site-specific climate change ensemble data

```
ClimWiz<-getClimateWizardData(coordinates=c(x=long,y=lat),scenario="rcp45",start_year=2035,end_year=2065)
```

| | GCM | tasmin1 | tasmin2 | tasmin3 | tasmin4 | tasmin5 | tasmin6 | tasmin7 | tasmin8 | tasmin9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | bcc-csm1-1 | 1.28 | 1.08 | 1.11 | 1.74 | 1.66 | 2.14 | 2.54 | 2.88 | 2.27 |
| 2 | BNU-ESM | 1.69 | 1.07 | 0.67 | 1.04 | 1.34 | 1.49 | 3.73 | 4.95 | 2.50 |
| 3 | CanESM2 | 2.12 | 1.58 | 2.42 | 3.06 | 2.24 | 2.93 | 4.09 | 4.13 | 3.43 |
| 4 | CESM1-BGC | 1.17 | 1.37 | 1.50 | 1.34 | 1.04 | 1.23 | 1.49 | 2.20 | 1.86 |
| 5 | MIROC-ESM | 1.52 | 2.06 | 2.16 | 2.22 | 2.76 | 3.28 | 3.84 | 4.49 | 3.80 |
| 6 | CNRM-CM5 | 1.89 | 2.16 | 1.68 | 1.37 | 1.33 | 1.71 | 2.08 | 2.04 | 2.05 |
| 7 | ACCESS1-0 | 2.28 | 2.03 | 2.53 | 1.72 | 1.70 | 2.33 | 2.52 | 1.91 | 2.08 |
| 8 | CSIRO-Mk3-6-0 | 1.05 | 0.56 | 0.75 | 1.15 | 1.44 | 1.87 | 1.53 | 1.86 | 1.32 |
| 9 | GFDL-CM3 | 1.34 | 1.69 | 1.82 | 1.99 | 1.57 | 2.29 | 3.16 | 4.16 | 3.78 |
| 10 | GFDL-ESM2G | 1.55 | 1.62 | 1.14 | 0.28 | 0.38 | -0.09 | 0.29 | 0.89 | 1.26 |
| 11 | GFDL-ESM2M | 0.89 | 1.54 | 1.62 | 1.54 | 0.62 | 0.54 | 0.70 | 1.37 | 1.41 |
| 12 | inmcm4 | 0.31 | 0.21 | 0.75 | 0.59 | 1.28 | 1.12 | 1.81 | 1.44 | 1.00 |
| 13 | IPSL-CM5A-LR | 2.51 | 1.49 | 2.00 | 2.16 | 2.13 | 2.59 | 2.44 | 3.04 | 2.98 |
| 14 | IPSL-CM5A-MR | 1.76 | 2.76 | 2.10 | 1.77 | 1.55 | 2.50 | 2.68 | 2.51 | 2.51 |
| 15 | CCSM4 | 1.50 | 1.07 | 1.09 | 1.09 | 1.07 | 0.96 | 1.85 | 2.07 | 1.74 |

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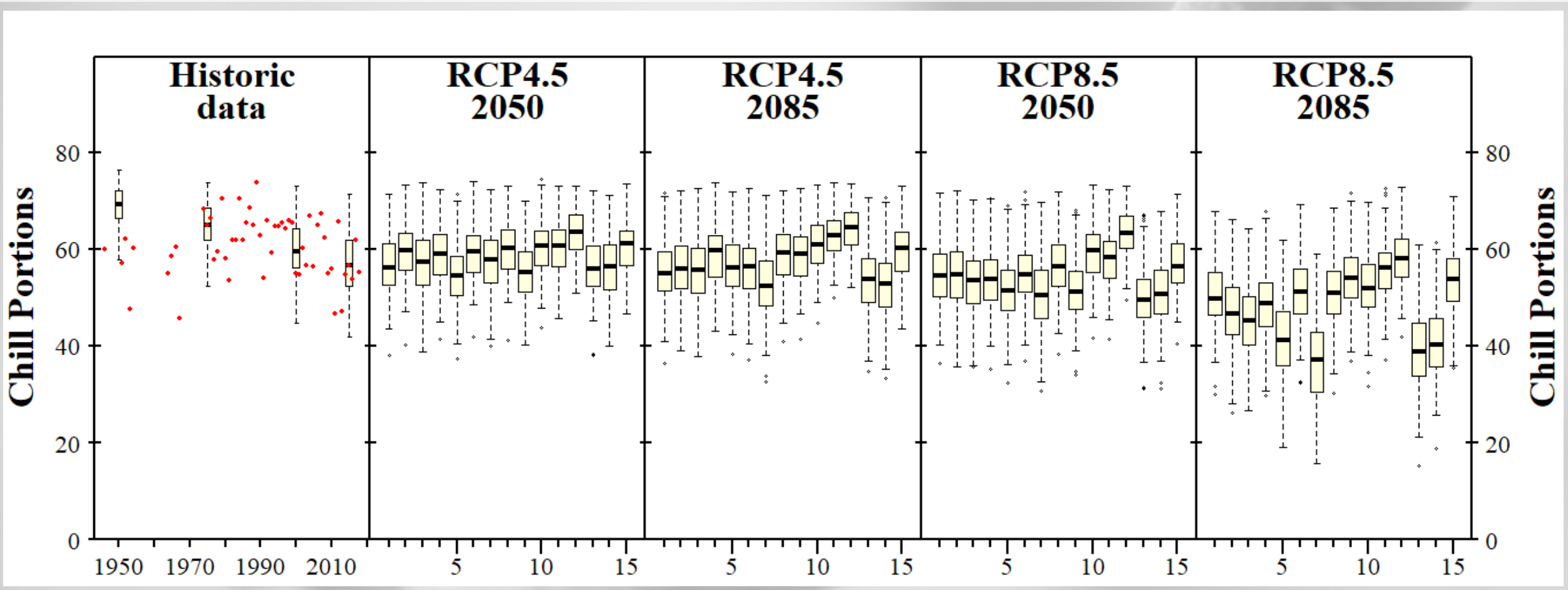
# Climate impact projection

- Combination of functions to produce state-of-the-art climate impact projections, including
  - bias-correction
  - calibration with local data
  - an ensemble of future scenarios
  - probabilistic risk assessment

```
scenarios<-list(c("rcp45",2035,2065,"RCP4.5"),c("rcp45",2070,2100,"RCP4.5"),c("rcp85",2035,2065,"RCP8.5"),c("rcp85",2070,2100,"RCP8.5"))

for(years in c(1950,1975,2000,2015))
  {yearscen<-temperature_scenario_from_records(weather=weather,year=c(years))
   if(years==1950) year_scens<-yearscen else year_scens[[as.character(years)]]<-yearscen[[as.character(years)]]}

hist_temps<-temperature_generation(weather,years=c(1970,2010),sim_years = c(2001,2100),temperature_scenario=year_scens)
chill_hist<-tempResponse_daily_list(hist_temps,latitude=lat,Start_JDay = start_day,End_JDay = end_day,misstolerance = 5)
chills<-make_climate_scenario(chill_hist,caption=c("Historic","data"),
                              historic_data=tempResponse_daily_list(weather,latitude=lat,Start_JDay = start_day,End_JDay = end_day,misstolerance = 5),time_series=TRUE)

climate_wizard_baseline_scen<-temperature_scenario_from_records(weather=weather,year=c(1977.5))
weather_baseline_scen<-temperature_scenario_from_records(weather=weather,year=c(1990))
baseline_adjustment<-temperature_scenario_baseline_adjustment(weather_baseline_scen,climate_wizard_baseline_scen)

for(scen in 1:length(scenarios))
  {sce<-scenarios[[scen]]
   ClimWiz<-getClimateWizardData(coordinates=c(x=long,y=lat),scenario=sce[1],start_year=sce[2],end_year=sce[3],
                         temperature_generation_scenarios=TRUE)
   temps<-temperature_generation(weather,years=c(1970,2010),sim_years = c(2001,2100),
                         temperature_scenario=temperature_scenario_baseline_adjustment(baseline_adjustment,ClimWiz))
   chill<-tempResponse_daily_list(temps,latitude=lat,Start_JDay = start_day,End_JDay = end_day,misstolerance = 5)
   chills<-make_climate_scenario(chill,caption=c(sce[4],mean(as.numeric(c(sce[2],sce[3])))),add_to=chills)}

plot_climate_scenarios(chills,metric="Chill_Portions",metric_label="Chill Portions")
```

# Climate impact projection




**Climate models**

| | | | |
|---|---|---|---|
| 1 | bcc-csm1-1 | 9 | GFDL-CM3 |
| 2 | BNU-ESM | 10 | GFDL-ESM2G |
| 3 | CanESM2 | 11 | GFDL-ESM2M |
| 4 | CESM1-BGC | 12 | inmcm4 |
| 5 | MIROC-ESM | 13 | IPSL-CM5A-LR |
| 6 | CNRM-CM5 | 14 | IPSL-CM5A-MR |
| 7 | ACCESS1-0 | 15 | CCSM4 |
| 8 | CSIRO-Mk3-6-0 | | |

**Past and future chill in Istanbul**

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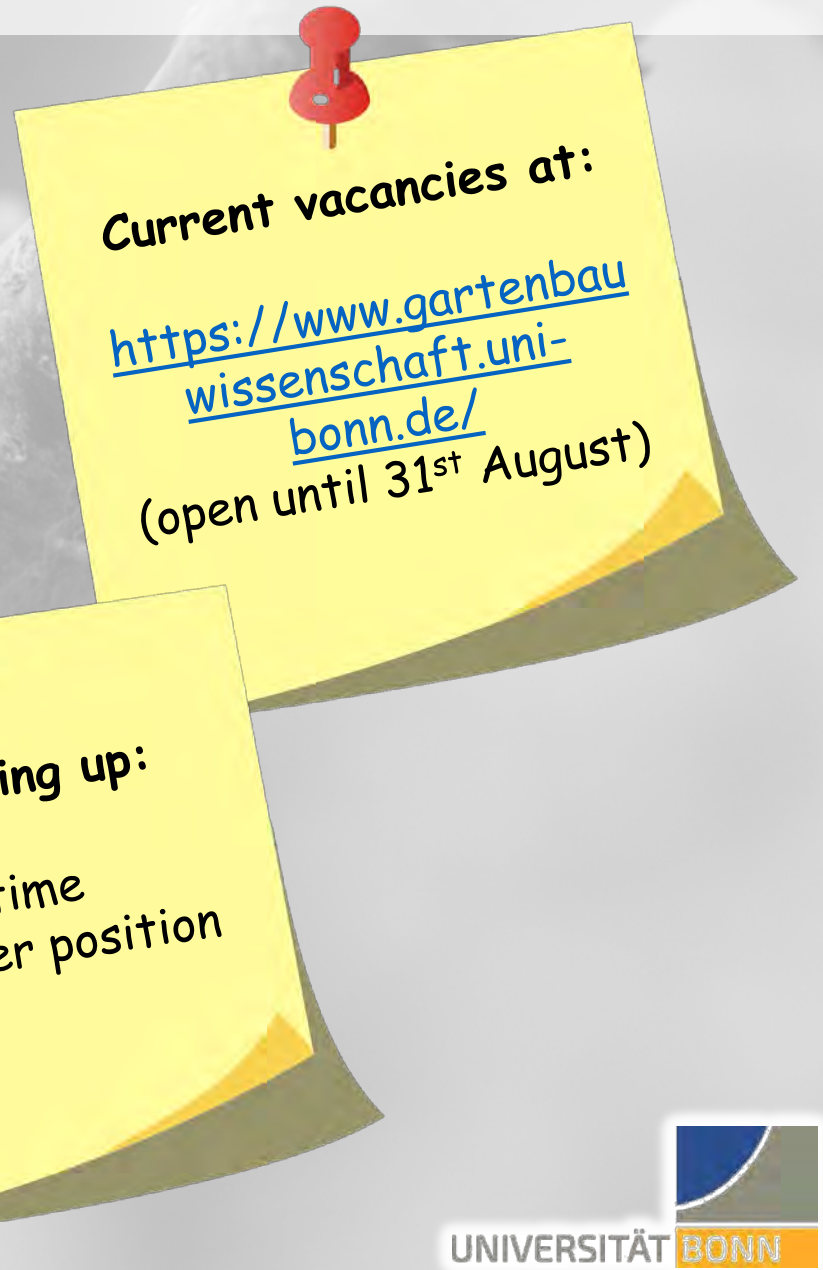
# Making phenology analysis easier

- chillR aims to facilitate the use of advanced temperature and phenology analysis methods by people who are not technical experts
- Still room for expansion and improvement
- Intensified efforts to start soon at the University of Bonn

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# Thanks for your attention!

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