User Guide and Computing Infrastructure Requirements for DDRP

Len Coop, coopl@science.oregonstate.edu 541-737-5523
Brittany Barker, brittany.barker@oregonstate.edu
Oregon IPM Center (OIPMC), Oregon State University (formerly the Integrated Plant Protection Center)

Last updated on 10/28/20

Introduction

DDRP (Degree-Days, Risk mapping, and Phenological event mapping) is a population modeling platform that integrates mapping of phenology and climatic suitability in real-time to provide guidance on both where and when invasive insect species could potentially invade the 48-state conterminous United States (Barker et al. 2020). The platform is in development by OSU OIPMC in collaboration with APHIS PPQ, and it is currently being used to model 15 high-priority invasive insects as specified by the APHIS Cooperative Agricultural Pest Survey (CAPS) pest detection program. DDRP may also be used to monitor and manage populations of IPM pests and classical biological control agents, and it could be modified to model other temperature-dependent organisms such as non-insect invertebrates and plants. The platform uses a process-based modeling approach in which degree-days and temperature stress are calculated daily and accumulate over time to model phenology and climatic suitability, respectively. We refer users to Barker et al. (2020) for a more thorough description of DDRP and its products, the process of model parameterization, and its potential applications. Knowledge of the R programming language, and experience with systems administration and spatial weather database management, are recommended for using DDRP.

Program features

Some of the major features of DDRP currently include:

1) Degree-day parameters including durations and lower and upper developmental thresholds for four separate life stages (these are the egg, the larva or nymph, the pupa or pre-oviposition, and the adult), plus a separately parameterized overwintering stage.
2) The ability to spread the population using cohorts. Typically seven cohorts are specified but any number can be used. While cohorts offer the ability to spread the population in a Gaussian or other distribution, there is currently no distributed-delay function, meaning that the spread does not increase over multiple generations.
3) Phenological event maps (PEMs, also known as pest event maps), which depict estimated calendar dates of seasonal activities or population events. PEM parameters are specified as degree-days within each of the four (plus overwintering) stages. For example, DDRP can be parameterized to make first egg-hatch PEMs by setting a degree-day value near the completion of the egg stage, or at the beginning of the larval stage. If the former is used, then a second PEM, say for mid-larval development, could be parameterized using a value such as one-half of the degree-day total for larval development.
4) Climatic suitability maps, which show two levels of climatic suitability (moderate and severe stress exclusions). These are intended to indicate risk likelihood of short vs. long-term establishment but could also indicate migration zones, and uncertainties such as in species parameterization, model structure, and in the sources of climate data.

Description and requirements

DDRP is an R program/script (“`DDRP_v2.R`,” currently *ca.* 2,400 lines) that processes daily minimum (Tmin) and maximum (Tmax) data to produce predictions of phenology and climatic suitability in raster and image file formats. The use of precipitation or types of moisture data is pending further development of DDRP. The program requires an auxiliary R script ("`DDRP_v2_funcs.R`," currently *ca.* 2,100 lines) that contains 21 functions needed for modeling.

Operating system and hardware

DDRP can be run in a UNIX/Linux environment (we recommend Scientific Linux or CentOS, but other distributions should work as well) and in Microsoft Windows. We have run the program on a Windows 10 PC with eight cores, but have not yet attempted to run it on a Windows server. The computer/server should have multicore functionality because many DDRP processes are run in parallel to increase speed and efficiency. The program may crash if there are insufficient cores available to complete an operation, particularly for memory intensive processes such as the daily time step ("DailyLoop" function) and certain post-processing operations. For running DDRP on a server, we recommend an HP (or equivalent) rack mount server such as DL380, dual processors (8 or more cores per processor), ≥128GB memory, ≥4TB SAS RAID (5 or 50 or similar configuration) hard (or solid state) drives. Connectivity to the server via HTTPS, SSH, SCP is required.

Software

The latest version of R should be installed with the following libraries: `"doParallel", "dplyr", "foreach", "ggplot2", "ggthemes", "lubridate", "mapdata", "mgsub", "optparse", "parallel", "purrr", "RColorBrewer", "rgdal", "raster", "readr", "R.utils", "sp", "stringr", "tidyr", "tictoc", "tools,"` and `"toOrdinal"`. Additionally, the Geospatial Data Abstraction Library (`GDAL`) software must be installed. The `"sp"` library in R automatically links to GDAL and depends on it for reading and writing raster and vector geospatial data formats.

Input files

Species parameter file

Each species modeled by DDRP requires a parameter file, which may be stored in a subdirectory under the DDRP code directory (e.g. `/home/DDRP/spp_params/ALB.params`). Each parameter file has comment lines beginning with "#" and parameter lines such as:

```
larvaeLDT <- 10    # IPPC modeling
```

Here, the lower developmental threshold for larvae (`larvaeLDT`) is set to 10°C. A description of each species parameter and an example parameter file are provided in Appendix 1 and 2 of this document, respectively.

Temperature (Tmin and Tmax) data

<u>Real-time temperature data (PRISM)</u>

For real-time modeling, we have been using daily Tmin and Tmax data at a 4 km spatial resolution from the PRISM (Parameter-elevation Relationships on Independent Slopes Model) database (available at http://www.prism.oregonstate.edu). Tmax and Tmin data are read from a local directory directly into the DDRP platform. We use a 50 line BASH script that controls a 230 line R script to download these data on a daily basis. The PRISM data should not be modified (i.e., retain the cartographic projection, file name, and other conventions of each PRISM file). Users of PRISM data should become familiar with their file naming conventions including the increasing data quality (and lag time) of their data types classified as "early", "provisional", and "stable". We also place forecast data (next section) in the PRISM-containing directories. Past year data directories can be purged of forecast data and "early" and "provisional" PRISM data, leaving only "stable" PRISM data if storage is limited. DDRP can be readily modified to ingest 800 m PRISM data (available for a price), or 2.5 km DAYMET data for past years (DAYMET is not available in real-time during the current year). Users may also wish to consider using downscaled global climate model (GCM) data such as MACAv2-METDATA, available from the University of Idaho.

Forecast temperature data

For forecast models, we currently use NMME (North American Multi-Model Ensemble) daily temporal-downscaled 7-month forecast data, followed by 10-year recent average PRISM data as the primary forecast regime. The 10-year recent average data can be readily calculated either monthly or yearly using R. Other options include using 30-year (1981–2010) NORMALS (e.g., available from the PRISM group and DAYMET), NDFD 7-day forecasts, and CFSv2 (NCEP Coupled Forecast System model version) forecasts that, like NMME, extend to 7 months. We use a Perl+GRASS GIS program to temporally downscale monthly NMME forecast data (Tmax, Tmin and Precip) to a daily resolution each month but a similar program could also be written in R. Both 10-year average PRISM data and NMME forecasts can be freely obtained from the OSU OIPMC/USPEST.ORG server if users need a product that does not require Perl+GRASS GIS (to run our code) or require reprogramming from Perl+GRASS GIS to R. Contact us if this is your preference.

Temperature data organization, naming, and quality

We keep temperature data for each year in its own folder. For example, all data for 2020 are located in /data/PRISM/2020/. PRISM file names are not changed from the naming conventions used by the PRISM group, but we rename other file types (e.g., 10-year averages and NMME) to mimic the PRISM naming conventions. A full explanation for naming of PRISM files is available from the PRISM website. Below is a description of each part of a file name using the example file “PRISM_tmin_early_4kmD2_20200222_bil.bil.”

File name part	Description
PRISM_	Data source (this is ignored by DDRP so it may be edited if desired)
tmin_	Data type (tmin is daily minimum temperature in °C at a nominal 2 m from ground)
early_	PRISM data type (see below), others include “NMME_”, “10yr1019”, etc.
4kmD2_	Spatial resolution and data version; we use PRISM 4K data
20200222_	Date that the data represents; in this case Feb 22, 2020
bil.bil	File format (bil = band interleaved by line; a common raster data format)

DDRP chooses the highest quality file available for each date (“stable” > “provisional” > “early” > nmme > 10yr1019 or 30yrAVG). We compute 10-year average PRISM data and include the years represented in the file name: 10yr1019 is an average of data from 2010 to 2019. We repeat this computation every two months so that the final year includes an increasing amount of final, “stable” PRISM data. At the time of writing this document, the final year would be 2019 since the entire year has passed and data are therefore available for all dates. If the date falls in the future, users may specify if they prefer to use a 10-year average or NMME predictions. For example, available Tmin files for Feb 22, 2020 in order of quality may include:

```
PRISM_tmin_early_4kmD2_20200222_bil.bil
PRISM_tmin_provisional_4kmD2_20200222_bil.bil
PRISM_tmin_stable_4kmD2_20200222_bil.bil
PRISM_tmin_nmme_4kmD1_20200222_bil.bil
PRISM_tmin_10yr1019_4kmD1_20200222_bil.bil
```

To calibrate the climatic suitability model in accordance with CLIMEX outputs (see Barker et al. 2020), we use PRISM data for 1961–1990 to match the time-schedule of CLIMEX's climate data (CliMond CM10). These PRISM 30-year NORMALS have been scaled from a monthly to a daily temporal resolution because DDRP requires daily data, and PRISM lacks daily data for years prior to 1980. Currently these files are located in /data/PRISM/1990_daily_30yr/ and have file names such as:

```
PRISM_tmin_30yr6190_4kmM2_19750222.bil.bil
```

Input options

There are 17 command-line input options that must be specified to run DDRP, as summarized below.

Option	Description
spp	Species to model
forecast_data	Forecast data to use (PRISM 10yrAVG, NMME, etc.)
start_year	Year
start_doy	Start day of year
end_doy	End day of year
keep_leap	Should leap day be kept? (0 = no, 1 = yes)
region_param	Region [CONUS, EAST, WEST, or state (2-letter abbr.)]
exclusions_stressunits	Turn on/off climatic suitability modeling (0 = off, 1 = on)
pems	Turn on/off pest event maps (0 = off, 1 = on)
mapA	Make PEMs for adult stage (0 = no, 1 = yes)
mapE	Make PEMs for egg stage (0 = no, 1 = yes)
mapL	Make PEMs for larval stage (0 = no, 1 = yes)
mapP	Make PEMs for pupal stage (0 = no, 1 = yes)
out_dir	Output directory name
out_option	Sampling frequency (1 = 30 days, 2 = 14 days, 3 = 10 days, 4 = seven days, 5 = two days, 6 = one day)
ncohort	Number of cohorts to approximate end of overwintering stage
odd_gen_map	Create summary maps for odd generations only (0 = no, 1 = yes)

The `start_doy` and `end_doy` must range between 1 and 365 (or 366 for a leap year). The `keep_leap` parameter specifies whether leap day (Feb 29) should be included in the model if `start_year` is a leap year. Regardless of which `out_option` is specified, DDRP will sample the last day (`end_doy`), and the current date if the model is produced for the current year *and* the current date falls within the range of modeled days (i.e. between `start_doy` and `end_doy`). For example, let's say a DDRP model were run today (Oct 28, 2020) for each day of the year in 2020 (days 1 to 366), and a sampling frequency of 1 (every 30 days) was specified. DDRP would generate 14 maps: 12 for the every-30 day sampling period (i.e. 12 months), one for Oct 28, and one for the last day of the year (Dec 31).

Running DDRP

The "`DDRP_v2.R`" script must be edited to specify the locations of the "`DDRP_v2_funcs.R`" file, the species model parameter file ("`params_dir`"), the temperature data ("`base_dir`"), and the output directory ("`output_dir`").

On a Linux OS, the "`DDRP_v2.R`" script can be made into an executable file by using the `chmod` command ("`chmod +x DDRP_v2.R`"). We run DDRP from the command line within an automated scheduling program (cron) on our server, since we want real-time updates on species phenology and climatic suitability. Below is an example command that would run a DDRP model (phenology and climatic suitability model) for ALB for the entire year of 2020.

```
./DDRP_v2.R --spp ALB --forecast_data PRISM --start_year 2020 --start_doy 1 --
end_doy 366 --keep_leap 1 --region_param CONUS --exclusions_stressunits 1 --pems
1 --mapA 1 --mapE 1 --mapL 0 --mapP 0 --out_dir ALB_cohorts --out_option 1 --
ncohort 7 --odd_gen_map 0
```

On a Windows OS, it may be easiest to run DDRP via a Windows batch (BAT) file that has the command line argument (note that the location of Rscript needs to be specified).

```
"C:\Program Files\R\R-4.0.2\bin\Rscript.exe"
C:\Users\barkebri\Documents\DDRP\DDRP_v2.R --spp ALB --forecast_data PRISM --
start_year 2020 --start_doy 1 --end_doy 366 --keep_leap 1 --region_param CONUS -
-exclusions_stressunits 1 --pems 1 --mapA 1 --mapE 1 --mapL 0 --mapP 0 --out_dir
ALB_2020_new --out_option 1 --ncohort 7 --odd_gen_map 0
```

Running DDRP within RStudio is an ideal option for troubleshooting issues, optimizing settings for a particular server/computer (e.g., specifying a different number of cores for parallel processing), and customizing code. In this case, the input options are specified within the "`DDRP_v2.R`" script (see the first 200 lines of code under "`# Read in commands`").

Output files

Model outputs are generated in raster and image file formats (GeoTIFF and PNG files, respectively) at a user-specified sampling frequency (--out_option). The exception are PEMs, which are produced only on the last sampled day. Additionally, outputs are generated for the current day if it occurs within the specified time period, and for the last day of the time period. Rasters for each output file type have multiple layers (known as a raster stack/brick), with each layer representing the output for a sampled date. For example, if there are 14 sampled dates then the raster stack will have 14 layers. The GeoTIFF files can be readily ingested by most GIS programs including ArcGIS. The summary map (PNG) files are complete with color tables, legends, etc. and provide an example of how results may be conveyed.

<u>Output file types</u>

The types of model outputs generated by DDRP are only summarized here; we refer users to Barker et al. (2020) for a more thorough description of the methods involved in the modeling process. Phenology model outputs are generated by analyzing results across all cohorts, except for life stage by generation (`StageCount`), which is currently based on results for the middle cohort only due to computational complications (most of the population will belong to a middle cohort, e.g., cohort 4 if there seven cohorts). Additionally, outputs for degree-day accumulation (`DDtotal`) and for all climatic suitability model products (`Cold_Stress_Units`, `Heat_Stress_Units`, `Cold_Stress_Excl`, `Heat_Stress_Excl`, `All_Stress_Excl`) are generated only for a single cohort (cohort) because they will be representative for all cohorts.

All output file names will contain a prefix followed by the sampled date. The table below summarizes attributes of each output file type.

File name prefix(es)	Description	Value range
`DDtotal`	Accumulated degree-days	0 to max number of accumulated degree-days
`Egg, Larvae, Pupae, Adult, OWstage`	Relative size of population represented by each life stage including the overwintering stage (`OWegg, OWlarvae, OWpupae, OWadult`)	0 to 100
`StageCount`	Life stage by generation (middle cohort only). Life stage value (eggs = 1, larvae = 2, pupae = 3, adults = 4) for each generation are separated by a decimal (e.g. 1.0 and 1.2 is eggs of the overwintered and first generation, respectively)	0.1, 0.2, 0.3, 0.4, 1.1, etc.
`NumGen`	Relative size of population in each generation	0 to 100
`Avg_PEM`	Average calendar day of phenological event across cohorts	0 to 366
`Earliest_PEM`	Earliest calendar day of phenological event across cohorts	0 to 366
`Cold_Stress_Units`	Cold stress unit accumulation	0 to max number of units
`Heat_Stress_Units`	Heat stress unit accumulation	0 to max number of units
`Cold_Stress_Excl`	Cold stress exclusion	0, −1, −2
`Heat_Stress_Excl`	Heat stress exclusion	0, −1, −2
`All_Stress_Excl`	All stress exclusion	0, −1, −2

For PEMs, output files will be named according to the stage and generation. For example, if PEMs for Asian longhorned beetle (ALB) are produced for adults for overwintering (PEMa0) and up to two additional (PEMa1 and PEMa2) generations, then the output files would include:

```
ALB_Avg_PEMa0_20201231.tif
ALB_Avg_PEMa1_20201231.png
ALB_Avg_PEMa2_20201231.tif
ALB_Earliest_PEMa0_20201231.tif
ALB_Earliest_PEMa1_20201231.png
ALB_Earliest_PEMa2_20201231.tif
```

Additionally, DDRP integrates phenology and climatic suitability model outputs (with the exception of total accumulated degree-days) to create two additional files associated with each sampled date. The first file includes severe climate stress exclusions only, whereas the second file includes both severe and moderate stress exclusions. Thus, outputs for the average date of the overwintering adult event (first row of above example) would now include two additional files:

```
ALB_Avg_PEMa0_20201231.tif
ALB_Avg_PEMa0_Excl1_20201231.tif
ALB_Avg_PEMa0_Excl2_20201231.tif
```

Output file organization

The main output directory (`out_dir`) will contain select output PNG files that were generated for the last sampled day of the specified time period (e.g., Dec. 31, 2020 if the entire year was modeled). Files for life stage by generation (`StageCount`), however, will be for the current day. `StageCount` maps are the nearest equivalent to the "Degree-day lookup table maps" that are in current production by collaborators including the APHIS PPQ SAFARIS group "Weekly Degree Day Phenology Maps" (website at https://safaris.cipm.info/safarispestmodel/StartupServlet?fieldops), and the USA National Phenology Network (NPN) group "Pheno Forecast" maps (example at https://www.usanpn.org/data/forecasts/EAB). All files in the main output directory will have names that begin with the species abbreviation.

The "`Misc_files`" subdirectory will contain all other model output files, including raster bricks. Additional PNG files in this folder are considered to be less important than those in the main output directory, at least not for pest monitoring purposes.

The "`Logs_metadata`" subdirectory will contain three text files:

1. `metadata.txt`: metadata including model run date and time, species parameter information, and command-line input options.
2. `model_rlogging.txt`: reports model run progress and certain errors and warnings (e.g., inappropriate input options).
3. `rmessages.txt`: may contain error messages from R resulting from an unsuccessful model run.

Model run times

The following four factors are the major determinants of model run times:

1) The number of cores available on the server or PC. For example, a model for ALB for CONUS with seven cohorts took 27 minutes on a Linux server with 36 cores, whereas it took ~3× longer to run on a Windows 10 PC with 8 cores (76 minutes).
2) The generation time of the species being modeled. Species such as ALB that are primarily univoltine (one generation per year) will run faster than multivoltine species. For example, a model run for tomato leafminer (TABS) that applied the same command-line input options as a run for ALB for 2020 took 2× longer to run (53 vs. 27 minutes) because TABS could potentially complete up to 14 generations for that year.
3) The number of cohorts. Increasing the number of cohorts will positively correlate with model run times because the daily time step is run for each cohort, and additional computational resources are needed for processing daily time step results. Typically we apply seven cohorts to approximate a normal distribution of emergence times.
4) Region size. Model runs for CONUS will take the longest, while runs for small states will complete relatively quickly.

Species with parameterized models

We have configured DDRP to output files to OSU OIPMC's server at USPEST.ORG: https://uspest.org/CAPS/xxx... where "xxx..." represents the abbreviation of any species for which DDRP phenology and climatic suitability models have been developed:

1. ALB_cohorts - Asian longhorned beetle, *Anoplophora glabripennis*
2. ASRB_cohorts – Asiatic rice borer, *Chilo suppressalis*
3. CGN_cohorts – Honeydew moth, *Cryptoblabes gnidiella*
4. EAB_cohorts – Emerald ash borer, *Agrilus planipennis* (IPM species)

5. FCM_cohorts - False codling moth, *Thaumatotibia leucotreta*
6. JPSB_cohorts - Japanese pine sawyer beetle, *Monochamus alternatus*
7. LBAM_cohorts - Light brown apple moth, *Epiphyas postvittana*
8. OAB_cohorts - Oak ambrosia beetle, *Platypus quercivorus*
9. OWBW_cohorts - Old world bollworm, *Helicoverpa armigera*
10. PTLM_cohorts - Pine tree lappet moth, *Dendrolimus pini*
11. SLI_cohorts – Common or cotton cutworm, *Spodoptera litura*
12. STB_cohorts – Small tomato borer, *Neoleucinodes elegantalis*
13. SLYM_cohorts – Silver Y moth, *Autographa gamma*
14. SUNP_cohorts – Sunn pest, *Eurygaster integriceps*
15. TABS_cohorts – Tomato leafminer, *Tuta absoluta*

The climatic suitability model is still in the process of being parameterized for:

16. ECW_cohorts – Egyptian cottonworm, *Spodoptera littoralis*

References

Barker, B.S., Coop, L., Wepprich, T., Grevstad, F., and Cook, G. 2020. DDRP: real-time phenology and climatic suitability modeling of invasive insects. bioRxiv. https://doi.org/10.1101/2020.05.18.102681

Appendix 1. Description of parameters in a species parameter file. The "owstage" parameter may be overwintering (OW) egg, larvae, pupae, or adult (OE, OL, OP, or OA) and the "stgorder" parameter is the owstage stage plus the four remaining stages (E = egg, L = larvae, P = pupae, and A = adult).

Parameter	**Description**
fullname	Full name of species
pestof	Host plants
stgorder	Stage order beginning with the OW stage
owstage	Overwintering (OW) stage
Thresholds	
eggLDT	egg lower developmental threshold
eggUDT	egg upper developmental threshold
larvaeLDT	larvae lower developmental threshold
larvaeUDT	larvae upper developmental threshold
pupaeLDT	pupae lower developmental threshold
pupaeUDT	pupae upper developmental threshold
adultLDT	adult lower developmental threshold
adultUDT	adult upper developmental threshold
Degree-day req.	
eggDD	duration of egg stage in DDs
larvaeDD	duration of larvae stage in DDs
pupaeDD	duration of pupae stage in DDs
adultDD	duration of adult stage in DDs
eggEventDD	DDs into egg stage when event occurs
larvaeEventDD	DDs into larval stage when event occurs
pupaeEventDD	DDs into pupal stage when event occurs
adultEventDD	DDs into adult stage when event occurs
OWstageDD	DDs until OW stage emerges (only used if ncohort = 1)
calctype	Degree-day calculation method
Phenological event maps	
PEMnumgens	Create PEMs for up this many generations (max is 4)
eggEventDD	DDs of egg stage event
eggEventLabel	Label for egg PEM
larvaeEventDD	DDs of larval stage event
larvaeEventLabel	Label for larval PEM
pupaeEventDD	DDs of pupal stage event
pupaeEventLabel	Label for pupal stage event
adultEventDD	DDs of adult stage event
adultEventLabel	Label for adult stage PEM
OWEventP	Prop. of OW stage completed when OW event occurs (0 - 1)
OWEventLabel	Label for OW stage PEM
Climatic suitability	
coldstress_threshold	cold stress threshold
coldstress_units_max1	cold degree day limit when most individuals die
coldstress_units_max2	cold degree day limit when all individuals die
heatstress_threshold	heat stress threshold
heatstress_units_max1	heat stress degree day limit when most individuals die
heatstress_units_max2	heat stress degree day limit when all individuals die
Cohorts	
distro_mean	average DDs to emergence
distro_var	variation in DDs to emergence
xdist1	minimum DDs to emergence
xdist2	maximum DDs to emergence
distro_shape	shape of the distribution

Appendix 2. Example species parameter file (ALB.params).

```
# these are OSU IPPC/APHIS PPQ DDRP model params and values for
# ALB, asian longhorned beetle, Anoplophora glabripennis (Motschulsky) - in Celsius (C)
# Last udpated in June 2019 for DDRP v2 (cohorts)
  fullname   <- "Asian longhorned beetle"
  pestof     <- "ash, birch, elm, maple, buckeye, mimosa, poplar, willow, sev. other trees"
  stgorder   <- c("OL","P","A","E","L”) # stgorder changed to 1, 2, 3, 4, 5
  owstage    <- "OL"  # OL means ow as larvae
  eggLDT     <- 10    # IPPC modeling http://uspest.org/wea/ALB_model_v1.pdf
  eggUDT     <- 35    # IPPC modeling
  larvaeLDT  <- 10    # IPPC modeling
  larvaeUDT  <- 35    # IPPC modeling
  pupaeLDT   <- 10    # IPPC modeling
  pupaeUDT   <- 35    # IPPC modeling
  adultLDT   <- 10    # IPPC modeling
  adultUDT   <- 35    # IPPC modeling
  eggDD      <- 240   # IPPC modeling
  larvaeDD   <- 2160  # IPPC modeling
  pupDD      <- 260
  adultDD    <- 256   # IPPC modeling approx time to 30% oviposition
  OWlarvaeDD <- 40   # OW stage 296 DD to begin pupation
  calctype   <- "average"
  # Pest Event Maps (PEMs) must be turned on for these to get used:
  PEMnumgens       <- 1  # create PEMS for up to this many generations (max is 4)
  eggEventDD       <- 220 # PEMs for egg stage hatch is ca 220 DDs into stage (egg devel
nearly complete)
  eggEventLabel    <- "egg hatch" # Label for PEM egg stage
  larvaeEventDD    <- 1080 # PEMs for larvae stage is 2250 DDs (midway) into stage
  larvaeEventLabel <- "larval development" # Label for PEM larvae stage
  pupaeEventDD     <- 255 # PEMs for pupal stage is at end to signal adults
  pupaeEventLabel  <- "adult emergence" # Label for PEM pupal stage
  adultEventDD     <- 210 # PEMs for adult stage (ca. 25% flight) is 16 DDs into stage
  adultEventLabel  <- "25% adult flight" # Label for PEM adult stage
  OWEventP         <- 0.5  # PEMs for OWlarvae stage is half-way (50%) into stage
  OWEventLabel     <- "larval development"  # Label for PEM OWlarvae stage
# coldstress params using data from Stotter and Terblanche 2009 J. Thermal Biol.
  coldstress_threshold  <- -20   # threshold using daily Tlow
  coldstress_units_max1 <- 300  # 300 ColdDD excl1; so "most" all die once reached
  coldstress_units_max2 <- 600  # 600 ColdDD excl2; so all die once reached
  heatstress_threshold   <- 40   # estimated from UDT=35
  heatstress_units_max1  <- 75   # HeatDD excl1; so "most" all die once reached
  heatstress_units_max2  <- 150  # HeatDD excl2; so all die once reached
 # OW stage emergence parameters (DDRP v2 only)
  distro_mean <- 250
  distro_var <- 35000
  xdist1 <- 30
  xdist2 <- 1250
  distro_shape <- "normal"
```