

EPIDEMIA Malaria Forecasting System: Detailed Walk-through Guide

For epidemic-demo v.1.0.0 using epidemiar v1.1.1

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1 Introduction

This detailed walk-through will explain each section of the `run_epidemiar_demo.R` script in the `epidemiar-demo` R project.

All surveillance data in this demo is *simulated* and for *demo use only*. The environmental data, from Google Earth Engine, is real. This walkthrough is adapted from documentation given to our colleagues in Ethiopia.

For more details on the `epidemiar` package, see the vignettes:

- Overview: `vignette("overview-epidemiar", package = "epidemiar")`, and
- Input data and modeling parameters: `vignette("data-modeling", package = "epidemiar")`.

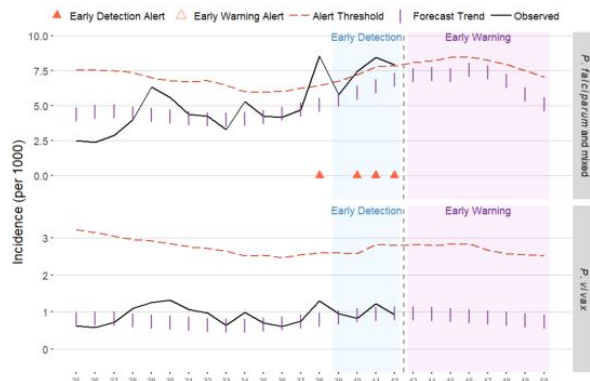
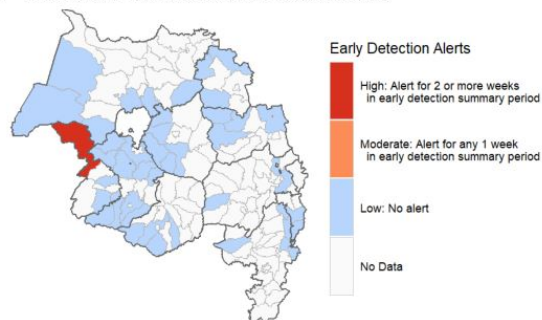
This demo is an example of how you might organize your data and settings to feed into `epidemiar::run_epidemia()`.

Goal & end product: The final report presents a malaria forecasting report for 47 woredas in the Amhara region for the past 18 weeks through 8 weeks forecasted into the future (26 total weeks). Malaria is broken out by species: *Plasmodium falciparum* and mixed species, and also *P. vivax*. The report includes environmental and epidemiological surveillance data.

Example sections of the final report:

1 Alert Summaries

1.1 Alert Map: *P. falciparum* and mixed malaria



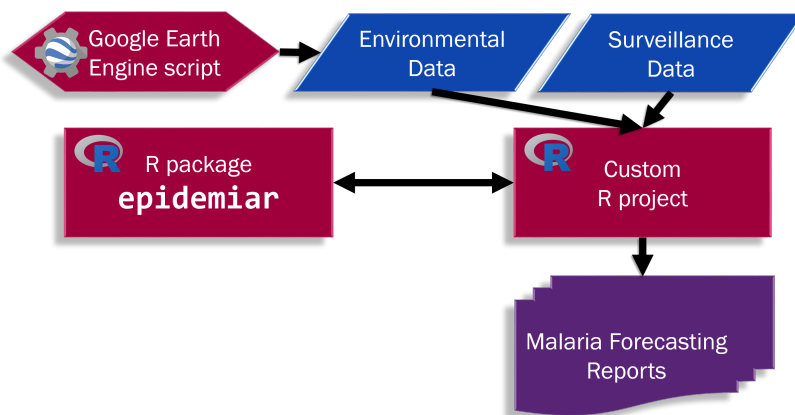
We are going to use an R script to:

- bring in malaria surveillance and remotely-sensed environmental data
- set some model and event detection parameters
- call the `epidemiR` functions to run the model, forecast, event detection, produce & save the report data output
- send the results to a formatting script (`report/epidemia_report_demo.Rnw`, a Sweave file) to create the final pdf report.

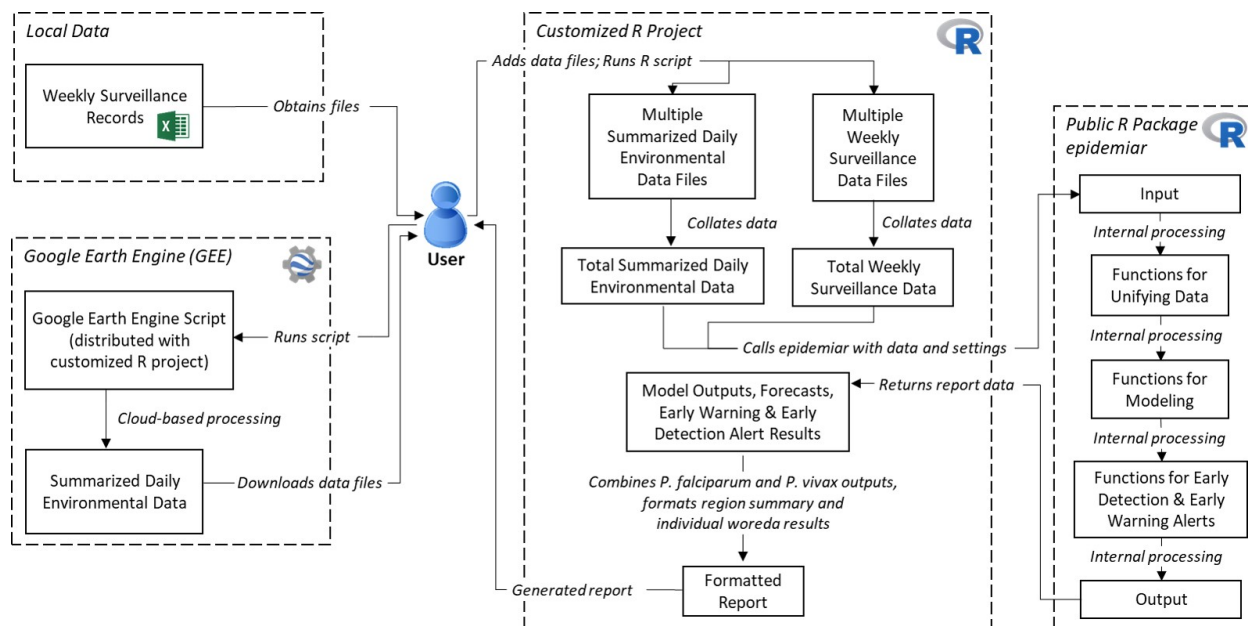
If you have not installed `epidemiR`, or MikTeX (“Install missing packages on-the-fly” = Yes; and restart the computer) yet, please see the Install & Update Guide (“documentation/install_update.pdf”) for details on those steps.

Video tutorials were made for our colleagues for a previous version of the software. Some of the details have since changed, but you can view them here: <https://www.youtube.com/channel/UC-NKR1cer4wkg8hHHP7K9Vw>.

Overview diagram of how `epidemiR-demo` (custom R project) fits into the EPIDEMIA Forecasting System:



A more detailed look at the system:



2 R script

Open the `epidemiator_demo.Rproj`, and open the `run_epidemiator_demo.R` script in RStudio. This script is divided into sections:

1. Loading packages & functions
2. Reading in the data
3. Setting up the Forecasting controls
4. Setting up the Early Detection controls
5. Run epidemic & create report data
6. Merge species data, save, and create pdf report

2.1 Loading packages & functions

First, we need to load the R packages and functions we will use in this R script.

```
## Load packages necessary for script
```

```
#make sure pacman is installed
if (!require("pacman")) install.packages("pacman")
```

```
## Loading required package: pacman
```

```
#load packages
#note: data corrals use dplyr, tidyr, lubridate, readr, readxl, epidemiator
#note: pdf creation requires knitr, tinytex
pacman::p_load(dplyr,
               knitr,
               lubridate,
               parallel,
               readr,
               readxl,
               tidyr,
               tinytex,
               tools)
```

```
#load specialized package (https://github.com/EcoGRAPH/epidemi-ar)
library(epidemi-ar)
```

Using `pacman` is a convenient way of loading libraries (`library(package-name)`). If a package is missing, it will install it before continuing and prevent the script from stopping with an error.

We use `library()` for the `epidemi-ar` package, because this is our project-specific package and does not exist on the R package repository (CRAN), so `pacman` would fail trying to install `epidemi-ar`. See the Install & Update Guide ("[documentation/install_update.pdf](#)") for how to install `epidemi-ar`, if you have not done so already.

There are also some local R functions, which are local user-defined functions but not part of any package. The functions are in separate R script files that we `source()` so we can use the function. The `date_functions` offer a function for creating a full date (year, month, day) from ISO year and ISO week. The `data_corrals` functions are how the epidemiological and environmental data are each read in and merged together to create datasets to be given to the `epidemi-ar` function for modeling. The `report_save_create_helpers` offer two functions, one to merge the results from *P. falciparum* & mixed species, and *P. vivax* model data, and another function to send the result data to the formatting script to produce the pdf.

```
## Locally-defined Functions
source("R/data_corrals.R")
source("R/report_save_create_helpers.R")
```

2.2 Reading in the data

The `epidemi-ar` modeling and code requires 3 main sets of data:

- 1) epidemiological data,
- 2) daily environmental data, and
- 3) historical environmental reference/climatology data.

A few look-up tables (metadata or informational reference sets) are needed as well.

2.2.1 Woreda metadata

First, we read in some information about the woredas in the Amhara region. We are going to create a subset of woredas that are going to be included in the report. A column named `report` in the Excel metadata file "`data/woredas.xlsx`" indicates if the woreda should be in the report. Currently, these are the 47 pilot woredas. To be included in the report, the woreda would need sufficient epidemiological data, environmental data, and model cluster ID. (Note: See documentation inside the `epidemi-ar` package regarding cluster information. Options are available for clustering, or not, of various geographic areas.) The list of report woredas is going to be used to filter the epidemiological and environmental data into a smaller dataset to reduce processing time.

```
# read in woreda metadata
report_woredas <- readxl::read_xlsx("data/woredas.xlsx", na = "NA") %>%
  dplyr::filter(report == 1)
```

2.2.2 Epidemiological data

For the epidemiology data, we will need weekly case counts per woreda of confirmed *P. falciparum* & mixed, and *P. vivax* malaria. To merge data from multiple files, we will use a "data corral" subfolder `data_epidemiological` in the `epidemi-demo` folder.

The `corral_epidemiological()` function will merge all `xlsx` files in this directory, so you can have multiple files, e.g. one for each year, month, or even by week. No special file names are expected, so you are free to use your standard naming convention. The script is expecting the file to be in your standard format. Specifically,

it is looking for the fields: Woreda/Hospital, Budget Year, Epi- Week, Blood film P. falciparum, RDT P. falciparum, Blood film P. vivax, RDT P. vivax.

There should be a line for each week and woreda, even for missing data. Any missing (NA) values in the data will be filled in by linear interpolation inside of the epidemic modeling functions. Gaps in the data, like missing weeks for a woreda, will trigger an error and stop the script. A log file of missing dates will be written, `log_missing_report_epidemiology.csv`, which can be opened with Excel.

No other files should be in this folder. An Excel file that is not epidemiological data will cause the script to fail.

The `corral_epidemiological()` function will loop through all of your `xlsx` files and combine them. Next, the function will remove any duplicates, choosing data from the file that was most recently modified. The `corral_epidemiological()` function is flexible enough to handle overlapping or partial year files, as long as there are no gaps in dates.

In regards to dates: Conversion from Ethiopian date to Gregorian date was done by adding 7 (ISO week \geq 28) or 8 (ISO week $<$ 28) years, e.g. budget year 2011 is in year 2018 for weeks 28 - 52, and 2019 for weeks 1 - 27. Currently, no R function exists for converting full Ethiopian dates to full Gregorian calendar dates. The `obs_date` field is the last day of ISO-8601 week.

The epidemic package needs total malaria case counts per species. To create this variable, we will add the count of positive blood tests and the count of positive rapid diagnostic tests, for each species. `test_pf_tot` = 'Blood film P. falciparum' + 'RDT P. falciparum' and `test_pv_only` = 'Blood film P. vivax' + 'RDT P. vivax'.

The `corral_epidemiological()` function also needs three additional metadata files:

- Spelling crosswalk: `data/woreda_spellings.xlsx`: This is a crosswalk between the spellings found in the shapefile and the ones found in the epidemiological `xlsx` file. Additional alternative spellings can be added into this metafile as needed: `woreda_name` is the shapefile spelling, and `to_replace` is the alternative spelling, and a woreda may have multiple entries. (Note: This is not needed in the demo dataset, but kept for reference.)
- Split woreda information: `"data/woredas_split.xlsx"`: This is a list of woredas that have split since the model was fitted and produced. Separate environmental data does not yet exist for the split woredas. A new shapefile will need to be added to GEE first and historical information gathered. Model fitting with cluster identification was done on the pre-split woreda and until the model has been updated, the report can only be generated on the combined woreda. The split woredas will be added back together, to match the original woreda before the split. More splits can be added: `woreda_name` is the original woreda, and `split_1` and `split_2` are the two woredas that it was split into. (Note: This is not needed in the demo dataset, but kept for reference.)
- Population data: `"data/population_weekly_2012_2030.csv"`: This population data is from the EPIDEMIA project: population living in malarious areas, called population at risk, and total population numbers. The population numbers were estimated out into the past and future, using an estimated population growth factor of 1.018.

The script will use the most recent week of data as the malaria report date, i.e. it will produce a report with forecasting starting the following future week.

```
# read & process case data needed for report
am_epi_data <- corral_epidemiological(report_woreda_names = report_woredas$woreda_name)
```

```
## Reading epidemiological data...
```

```
## Processing epidemiological data...
```

```
## Epidemiological data date range is 2012-07-15 to 2018-12-30 (YYYY-MM-DD).
```

2.2.3 Environmental data

For the environmental data, daily data is expected for each environmental variable for each worded.

We are using the previous 181 days of environmental data in modeling the effects of the environmental variables to the case numbers, and so we must have environmental data at least that number of days *before* the first epidemiology data date. The included EPIDEMIA project environmental dataset has environmental data starting 2012 W1. We will set the lag length to 181 days (`lag_length`) in the Forecasting section below.

Updated environmental data will be obtained from Google Earth Engine (GEE), which is a repository for many different types of satellite imagery and will process and summarize this data for us, so that we only have to download a small text-based file.

The script can run with more recent epidemiological data than environmental data. Missing environmental data, up to the date of the last epidemiological data date, will be filled in using a persistence scheme. This scheme uses the last known value of the environmental variable and copies it forward in time for each missing week. If there are many values being estimated, the accuracy of the results may be reduced. We highly recommend getting the latest environmental data available before running the report.

The `corral_environment()` function works similarly. All environmental data files are stored in subfolder `data_environmental/`. The `corral_environment()` function will loop through all csv (GEE) files and combine them. Next, the function will remove any duplicates, choosing data from the file that was most recently modified. Finally, it will check for any gaps in data. Missing days for any environmental variable will cause an error and stop the script. A log file of the missing days will be written, `log_missing_environmental.csv` which can be opened in Excel. To fix the error, run the GEE script for the missing dates and copy the files into the `data_environmental` subfolder.

Only GEE downloaded data in csv format should be added to the `data_environmental/` folder. An csv file that is not GEE-formated environmental data will cause the script to fail.

The `corral_environment()` function takes a single argument, a tibble of worded that will be included in the report. This list of worded is used to filter the environmental data into a smaller subset of data. The smaller dataset will take less time to process and the script will run faster.

```
# read & process environmental data for worded in report
am_env_data <- corral_environment(report_worded = report_worded)
```

```
## Reading environmental data...
## Processing environmental data...
## Environmental data date range (YYYY-MM-DD):
## # A tibble: 9 x 3
##   environ_var_code start_dt   end_dt
##   <chr>           <date>   <date>
## 1 evi            2012-01-01 2018-12-30
## 2 lst_day        2012-01-01 2018-12-30
## 3 lst_mean       2012-01-01 2018-12-30
## 4 lst_night      2012-01-01 2018-12-30
## 5 ndvi           2012-01-01 2018-12-30
## 6 ndwi5          2012-01-01 2018-12-30
## 7 ndwi6          2012-01-01 2018-12-30
## 8 savi           2012-01-01 2018-12-30
## 9 totprec        2012-01-01 2018-12-30
```

2.2.4 Optional: Date Filtering

By default, the report will be generated for the last week of available epidemiological data in the `data_epidemiological/` corral folder. If you wish to run a report for a particular previous week, you can

quickly filter the data after the corrals. Environmental data does not need to be filtered as it will run with whatever environmental data is or is not available.

```
# ## Optional: Date Filtering for running certain week's report
# # week is always end of the week, 7th day
# req_date <- epidemiar::make_date_yw(year = 2018, week = 52, weekday = 7)
# am_epi_data <- am_epi_data %>%
#   filter(obs_date <= req_date)
# am_env_data <- am_env_data %>%
#   filter(obs_date <= req_date)
```

2.2.5 Environmental reference/climatology data

The environmental reference / climate data file "data/env_ref_data.csv" contains a average value for each the environmental variable for each woreda for each week of the year. These data are used with the most recently known daily environmental values to estimate future values of the environmental variables for forecasting. These data are also used to calculate anomalies. Anomalies are the difference between the current value and the historical average value. The anomalies are used in the modelling. The current reference file is a 17 year average (2001 - 2018).

```
# read in climatology / environmental reference data
am_env_ref_data <- read_csv("data/env_ref_data.csv", col_types = cols())
```

2.2.6 Environmental variable information

The environmental variable information file "data/envIRON_info.xlsx" lists the environmental variables and important information about the variable.

```
# read in environmental info file
am_env_info <- read_xlsx("data/envIRON_info.xlsx", na = "NA")
```

- **environ_var_code**: Short name for the environmental variable, using the GEE variable names
- **reference_method**: 'sum' or 'mean' for how to aggregate daily values into weekly values. For example, rainfall would be the 'sum' of the daily values, while LST would be the 'mean' value during that week
- **report_label**: The axis label to be used in creating the formatted report graphs

2.3 Set up Forecast controls

In this section, we first set the number of weeks in the report and set up for modeling and forecasting.

The malaria forecasting report will show a total of 26 weeks. We want to forecast eight (8) weeks out into the future from the last known epidemiological data date. The total 26 weeks is therefore 18 weeks of known data and 8 weeks of future forecasts. (Note: These week lengths were not arbitrary, but a consensus agreement from discussions with our Ethiopian colleagues.)

```
#total number of weeks in report (including forecast period)
am_report_period <- 26

# forecast 8 weeks into the future
am_forecast_future <- 8
```

Next, we are going to read in two files that contain which environmental variables to use, and the woreda clustering information. The model is based on a general additive model (GAM) regression of multiple factors, including the woreda cluster, lagged environmental drivers (anomalies of the environmental variables), long terms trends, and seasonality.


```
#read in model environmental variables to use
am_pfm_model_env <- read_csv("data/falciparum_model_envvars.csv", col_types = cols())
am_pv_model_env <- read_csv("data/vivax_model_envvars.csv", col_types = cols())
```

- These files just have a list of which `environ_var_code` variables to use in the modeling.

For the *P. falciparum* and mixed malaria model, the environmental variables are rainfall, daytime Land Surface Temperature (LST), and Normalized Difference Water Index (NDWI6; a satellite- derived index for vegetation water content). For the *P. vivax* model, the environmental variables are rainfall, the mean of daytime and nighttime LST, and NDWI6.

Woredas were clustered by the pattern of how the malaria incidence responds to the environmental variables. Woredas where these *interactions* between malaria incidence and environment variables were similar were placed in the same cluster. This gives us greater power for the forecast modeling because we have more datapoints in that cluster than in a single woreda alone.

```
#read in model cluster information
am_pfm_clusters <- read_csv("data/falciparum_model_clusters.csv", col_types = cols())
am_pv_clusters <- read_csv("data/vivax_model_clusters.csv", col_types = cols())
```

- The field `cluster_id` gives the cluster value for each woreda, by `woreda_name`.

(Note: Clustering is not necessary, you may also run with a global or individual model. See the vignette in `epidemiR` on modeling data inputs `vignette("data-modeling", package = "epidemiR")` for more details.)

We want to use the previous 181 days, the “lag length”, of environmental data in modeling the effects of the environmental variables on malaria case numbers.

Each woreda and week is associated with environmental data on the day the week began, up to 180 days in the past, so that each woreda-week has a 181-day history of weather data. A distributed lag basis is created with the natural cubic splines function, including intercept, with knots at 25%, 50%, and 75% of the lag length. The 5 basis functions that result are multiplied by each woreda’s history, so that there are just 5 summary statistics, instead of 181, for every combination of woreda, week, and environmental covariate.

```
#set maximum environmental lag length (in days)
am_lag_length <- 181
```

Next are a few technical settings for how the modeling itself is run. There is an option to fit the model week by week, but this is very slow, and is not noticeably different from fitting the model once in our data. We are also taking advantage of parallel processing. We are splitting the modeling into pieces that run *at the same time* on different processors on the computer. (Note: BAM can only efficiently use a number of cores. If you are working on a computer with a large number, e.g. 24, you may wish to experiment with a set value around six or so.)

```
#model fit frequency: fit once ("once"), or fit every week ("week")
am_fit_freq <- "once"

#set number of cores to use on computer for parallel processing
#default value is the number of physical cores minus 1, minimum 1 core.
am_cores <- max(detectCores(logical=FALSE) - 1, 1)
```

Finally, we just put the forecasting controls into a list, so that we have one list object per species with all the controls for the forecasting.

```
#make control lists
am_pfm_fc_control <- list(env_vars = am_pfm_model_env,
                          clusters = am_pfm_clusters,
                          lag_length = am_lag_length,
```



```

fit_freq = am_fit_freq,
ncores = am_cores)

am_pv_fc_control <- list(env_vars = am_pv_model_env,
clusters = am_pv_clusters,
lag_length = am_lag_length,
fit_freq = am_fit_freq,
ncores = am_cores)

```

2.4 Set up Early Detection controls

In this section, we set up the parameters for the early detection algorithm.

The malaria forecasting report shows a total of 26 weeks. This will be 18 weeks of known data, and 8 weeks of forecasted values. Within the 18 weeks of known data, the most recent four (4) weeks are designated as the ‘early detection period’. (Note: These lengths were not arbitrary, but a consensus agreement from discussions with our Ethiopian colleagues.)

```

#number of weeks in early detection period
# (last n weeks of known epidemiological data to summarize alerts)
am_ed_summary_period <- 4

```

Next, we are going to set up the parameters used in the Farrington improved event detection algorithm. We will be using the `farringtonFlexible()` function as implemented in the `surveillance` package.

The central idea of event detection is to identify when the number of cases exceeds a baseline threshold, and this detection happens as close to real-time as possible. Event detection is done in a prospective manner, where the algorithm knows past data up to the present. This is different from retrospective methods, where events are identified from historical data. There are many different prospective event detection algorithms. Each algorithm calculates baseline thresholds differently and have different assumptions about the pattern of disease transmission, speed of outbreak development, seasonality, and trends.

The Farrington Original method was developed in 1996 and an improved version was released in 2013. The original method is used at Statens Serum Institut in Denmark, Centre for Infections of the Health Protection Agency (HPA) UK, National Institute for Public Health and the Environment (RIVM) the Netherlands (as of 2010). The Farrington methods are based on quasi-Poisson regression, and allows for long-term trend adjustments, seasonality, and re-weighting of past event case numbers.

The parameters below are the Farrington improved versions we tested that had the highest percent of events caught and the lowest rate of false alarms. The Farrington method performed better than the other methods we compared: Center for Disease Control and Prevention (CDC) Early Aberration Reporting System (EARS) and the first EPIDEMIA system using dynamic linear modeling. We tested each species separately, so there are different settings for *P. falciparum* (and mixed) and *P. vivax*. The parameters are all added to a list so that we have one object that has all the controls for Farrington event detection.

```

#settings for Farrington event detection algorithm
am_pfm_ed_control <- list(
  w = 3, reweight = TRUE, weightsThreshold = 2.58,
  trend = TRUE, pThresholdTrend = 0,
  populationOffset = TRUE,
  noPeriods = 12, pastWeeksNotIncluded = 4,
  thresholdMethod = "nbPlugin")

am_pv_ed_control <- list(
  w = 4, reweight = TRUE, weightsThreshold = 2.58,
  trend = TRUE, pThresholdTrend = 0,
  populationOffset = TRUE,

```

```
noPeriods = 10, pastWeeksNotIncluded = 4,
thresholdMethod = "nbPlugin")
```

Farrington flexible settings:

- w: the number of timepoints in the window
- reweight: if identified past events are reweighted lower (so past events don't raise the new thresholds too high)
- weightsThreshold: the default value 2.58 in the Farrington revised algorithm that was found to be best performing by the authors who updated the algorithm
- trend: Use trend weighting over the past years
- pThresholdTrend: 0 value means always use trend adjustment
- populationOffset: Use population to adjust case numbers
- noPeriods: break up the year into 10 periods for modeling
- pastWeeksNotIncluded: Discount the first 4 weeks when testing for events to avoid incorrect results when an event is occurring right at the beginning of the period
- thresholdMethod: Use the recommended statistical method for calculating thresholds.

For more details, please run `?surveillance::farringtonFlexible` in the RStudio console to get the help file for this function.

2.5 Run epidemiar & create report data

Now to actually run the model and generate the report data! Basically, we gather up all the data and settings, and feed it to the `run_epidemia()` function in our `epidemiar` package. We are also setting that we want incidence reported as per 1000 persons.

Each malaria species is run on its own, with their respective settings. The main epidemiological dataset contains both species in different columns, and therefore the `casefield` changes between “test_pf_tot” for *P. falciparum* and mixed species, and “test_pv_only” for *P. vivax*. Similarly, the controls for event detection (`ed_control`) and forecasting (`am_pfm_fc_control`) also change.

(Note: Since this is a long script, and early error messages may have been missed, we've added a simple check to make sure the epidemiological and environmental datasets have been generated, and if not, it'll produce an informative message towards this end of the script.)

```
#Run modeling to get report data
# with check on current epidemiology and environmental data sets

if (exists("am_epi_data") & exists("am_env_data")){

  # P. falciparum & mixed
  message("Running P. falciparum & mixed")
  pfm_reportdata <- run_epidemia(epi_data = am_epi_data,
                                casefield = test_pf_tot,
                                populationfield = pop_at_risk,
                                #incidence rates per 1000
                                inc_per = 1000,
                                groupfield = woreda_name,
                                week_type = "ISO",
                                report_period = am_report_period,
                                ed_summary_period = am_ed_summary_period,
                                ed_method = "Farrington",
                                ed_control = am_pfm_ed_control,
                                env_data = am_env_data,
                                obsfield = environ_var_code,
```

```

                                valuefield = obs_value,
                                forecast_future = am_forecast_future,
                                fc_control = am_pfm_fc_control,
                                env_ref_data = am_env_ref_data,
                                env_info = am_env_info)

# P. vivax
message("Running P. vivax")
pv_reportdata <- run_epidemia(emi_data = am_emi_data,
                             casefield = test_pv_only,
                             populationfield = pop_at_risk,
                             #incidence rates per 1000
                             inc_per = 1000,
                             groupfield = woreda_name,
                             week_type = "ISO",
                             report_period = am_report_period,
                             ed_summary_period = am_ed_summary_period,
                             ed_method = "Farrington",
                             ed_control = am_pfm_ed_control,
                             env_data = am_env_data,
                             obsfield = environ_var_code,
                             valuefield = obs_value,
                             forecast_future = am_forecast_future,
                             fc_control = am_pv_fc_control,
                             env_ref_data = am_env_ref_data,
                             env_info = am_env_info)

} else {
  message("Error: Epidemiological and/or environmental datasets are missing.
          Check Section 2 for data error messages.")
}

```

```

## Running P. falciparum & mixed
## Preparing for forecasting
## Generating forecasts
## Running early detection
## Running P. vivax
## Preparing for forecasting
## Generating forecasts
## Running early detection

```

Depending how powerful your computer is, this could take anywhere from 3 to 15 minutes or so for each species.

The `run_epidemia()` function returns one object. For *P. falciparum* we called this object `pfm_reportdata`, and `pv_reportdata` for *P. vivax*. The reportdata object is a list of tibbles of the outputs from the modeling, early detection and early warning algorithms, and other results. (Note: In the Amhara implementation, we have two species that we then combine the results before sending it to the formatting script. You could have multiple diseases you are working with, or you could have only one. Your situation will then drive how you code your report formatting script/Rnw file.)

2.5.1 Report data output

The `run_epidemia()` function returns one object. For *P. falciparum* we called this object `pfm_reportdata`. This object is a list of tibbles, or dataframes. These tibbles are the outputs from the modeling, early detection and early warning algorithms, and other results.

1. `summary_data`
2. `epi_summary`
3. `modeling_results_data`
4. `environ_timeseries`
5. `environ_anomalies`
6. `params_meta`
7. `regression_object`

(Note: For a more generic description of the `reportdata` object, including per column definitions, see the output data vignette in the `epidemiarn` package: `vignette("output-report=data", package = "epidemiarn")`. The following description is specific to the malaria demo data.)

2.5.1.1 summary_data

```
pfm_reportdata$summary_data
```

```
## # A tibble: 47 x 5
##   worda_name      ed_alert_count ed_sum_level ew_alert_count ew_level
##   <chr>          <dbl> <ord>          <dbl> <ord>
## 1 Abargelie            0 Low            0 Low
## 2 Alefa                0 Low            0 Low
## 3 Andabiet             0 Low            0 Low
## 4 Ankesha              0 Low            0 Low
## 5 Antsokiya Gemza      0 Low            0 Low
## 6 Artuma Fursi         0 Low            0 Low
## 7 Awabel               0 Low            0 Low
## 8 Bahir Dar Zuria      0 Low            0 Low
## 9 Baso Liben           0 Low            0 Low
## 10 Borena              0 Low            0 Low
## # ... with 37 more rows
```

This tibble contains the early detection and early warning alert levels for each worda.

Early detection alerts (`ed_alert_count`) are alerts that are triggered during the early detection period, which is defined as the 4 most recent weeks of known epidemiology data. Similarly, early warning alerts (`ew_alert_count`) are alerts in the future forecast estimates. “High” level indicates two or more weeks in this period had incidences greater than the alert threshold, “Medium” means that one week was in alert status, and “Low” means no weeks had alerts (`ed_sum_level` and `ew_level`, respectively).

2.5.1.2 epi_summary

```
pfm_reportdata$epi_summary
```

```
## # A tibble: 47 x 2
##   worda_name      mean_inc
##   <chr>          <dbl>
## 1 Abargelie      1.77
## 2 Alefa          0.533
## 3 Andabiet       0.115
## 4 Ankesha        0.258
## 5 Antsokiya Gemza 0.0151
## 6 Artuma Fursi    0.0220
```

```
## 7 Awabel 0.0463
## 8 Bahir Dar Zuria 0.135
## 9 Baso Liben 0.684
## 10 Borena 0.0606
## # ... with 37 more rows
```

This tibble holds the mean incidence of malaria in the early detection period per woreda, and is used to generate maps in the third section of the pdf report.

2.5.1.3 modeling_results_data

```
pfm_reportdata$modeling_results_data
```

```
## # A tibble: 4,512 x 9
##   woreda_name obs_date series value lab upper lower week_epidemiariar
##   <chr> <date> <chr> <dbl> <chr> <dbl> <dbl> <dbl>
## 1 Abargelie 2018-09-02 obs 0.900 Obse~ NA NA 35
## 2 Abargelie 2018-09-09 obs 0.919 Obse~ NA NA 36
## 3 Abargelie 2018-09-16 obs 0.937 Obse~ NA NA 37
## 4 Abargelie 2018-09-23 obs 1.07 Obse~ NA NA 38
## 5 Abargelie 2018-09-30 obs 1.14 Obse~ NA NA 39
## 6 Abargelie 2018-10-07 obs 1.41 Obse~ NA NA 40
## 7 Abargelie 2018-10-14 obs 1.56 Obse~ NA NA 41
## 8 Abargelie 2018-10-21 obs 1.80 Obse~ NA NA 42
## 9 Abargelie 2018-10-28 obs 2.10 Obse~ NA NA 43
## 10 Abargelie 2018-11-04 obs 2.40 Obse~ NA NA 44
## # ... with 4,502 more rows, and 1 more variable: year_epidemiariar <dbl>
```

This tibble dataset contains multiple timeseries values for observed, forecast, and alert thresholds of malaria incidence, for each woreda. These data are used in creating the individual woreda control charts in the pdf report.

- **series:** “obs” = observed disease incidence, “fc” = modeled/forecast incidence values, “thresh” = event detection threshold values, “ed” = early detection alert (binary), “ew” = early warning alert (binary)
- **value:** Value of the **series** for that woreda for that week
- **lab:** Labels for the series (“Observed”, “Forecast Trend”, “Alert Threshold”, “Early Detection Alert”, “Early Warning Alert”)

2.5.1.4 environ_timeseries

```
pfm_reportdata$environ_timeseries
```

```
## # A tibble: 3,666 x 16
##   woreda_name environ_var_code year_epidemiariar week_epidemiariar obs_date
##   <chr> <chr> <dbl> <dbl> <date>
## 1 Abargelie lst_day 2018 35 2018-09-02
## 2 Abargelie ndwi6 2018 35 2018-09-02
## 3 Abargelie totprec 2018 35 2018-09-02
## 4 Abargelie lst_day 2018 36 2018-09-09
## 5 Abargelie ndwi6 2018 36 2018-09-09
## 6 Abargelie totprec 2018 36 2018-09-09
## 7 Abargelie lst_day 2018 37 2018-09-16
## 8 Abargelie ndwi6 2018 37 2018-09-16
## 9 Abargelie totprec 2018 37 2018-09-16
## 10 Abargelie lst_day 2018 38 2018-09-23
## # ... with 3,656 more rows, and 11 more variables: val_epidemiariar <dbl>,
## # reference_method <chr>, data_source <chr>, ref_value <dbl>,
```

```
## #   ref_sd <dbl>, ref_n <dbl>, ref_max <dbl>, ref_uq <dbl>,
## #   ref_median <dbl>, ref_lq <dbl>, ref_min <dbl>
```

This tibble dataset contains multiple timeseries for the environmental variables for each woreda, and are used to generate the environmental timeseries graphs on the individual woreda report pages.

- **val_epidemiari**: Value of the environmental variable for that geographic group for that week. Values are a combination of observed, or interpolated (for missing) or extended (future estimated) values.
- **data_source**: “Observed”, “Interpolated”, or “Extended”. Missing environmental data is handled in three different ways, depending on time period. For missing values in the middle of series, the value is a linear approximation of surrounding values (“Interpolated”). For missing values at the end of the series, up to the future forecast portion, values are carried forward in a persistence approach (also marked “Interpolated” at the moment). For the forecast future portion, values are a blending of the last known values and the climatic historical mean, with a gradual weighting scheme shifting from more weight from last known to historical mean (“Extended”).

2.5.1.5 environ_anomalies

```
pfm_reportdata$environ_anomalies
```

```
## # A tibble: 141 x 3
##   woreda_name environ_var_code anom_ed_mean
##   <chr>      <chr>              <dbl>
## 1 Abargelie  lst_day                -0.275
## 2 Abargelie  ndwi6                  0.0000490
## 3 Abargelie  totprec               -12.2
## 4 Alefa     lst_day                -0.170
## 5 Alefa     ndwi6                  0.0142
## 6 Alefa     totprec               -8.49
## 7 Andabiet  lst_day                -1.06
## 8 Andabiet  ndwi6                  0.00520
## 9 Andabiet  totprec               -9.11
## 10 Ankesha  lst_day                -0.447
## # ... with 131 more rows
```

This tibble dataset contains the differences of the environmental variable values from the climatology/reference average during the early detection period. These data are used to make anomaly maps in the third section of the pdf report.

- **anom_ed_mean**: The mean of the anomalies per environmental variable per geographic group summarized during the early detection period. The anomalies are calculated as the difference from the observed value to the historical mean for that week of the year.

2.5.1.6 params_meta

This lists all the dates, settings, and parameters that were used in the `run_epidemiari()` function. This keeps a record of all the settings so you can view them later.

2.5.1.7 regression_object

This is the regression object from the general additive model (GAM, parallelized with BAM) regression. This is only for statistical investigation of the model, and is usually not saved because it very large object.

2.6 Merge species data, save, and create pdf report

The Amhara malaria demo data has two different reportdata objects (*P. falciparum* and mixed species, and *P. vivax*), which need to be merged together into one object to save and to create the single pdf report.

(Note: Since this is a long script, and early error messages may have been missed, we've added a simple check to make sure the report data for each species have been generated, and if not, it'll produce an informative message towards this end of the script.)

```
if (exists("pfm_reportdata") & exists("pv_reportdata")){

  #merging pfm & pv data, save out, and create pdf
  merge_save_report(rpt_data_main = pfm_reportdata,
    rpt_data_secd = pv_reportdata,
    #mark sections as P. falciparum and mixed (pfm) or P. vivax (pv)
    # used in the epidemia_report_am.Rnw file for the formatted report
    var_labs = c("pfm","pv"),
    #save out the report data in the file that the formatting file reads
    save_file = "report/report_data.RData",
    #save out a second copy of the report data
    # with year and week numbers in the name file
    second_save = TRUE,
    #create the pdf
    create_report = TRUE,
    #which Rnw file to use to create pdf
    formatting_file = "epidemia_report_demo.Rnw",
    #show the pdf immediately after creating
    show_report = TRUE)

} else {
  message("Error: Report data for P. falciparum and/or
    P. vivax have not been generated and are missing.")
}
```

Saved results to /report/report_data.RData

Saved results to /report/report_data_2018W52.RData

Saved report to /report/epidemia_report_demo_2018W52.pdf

This function will save out the merged report_data object in two places:

- `save_file = "report/report_data.RData"`: this file is the *input* file of the Rnw/formatting script (`epidemia_report_demo.Rnw`). The input file of the rnw cannot be particularly changed except by editing the rnw file directly. Therefore this is a 'generic' named file, which is overwritten each time to be used as input to the rnw file.
- `second_save = TRUE`: this saves out a more permanent version of the merged report_data object with an autogenerated year and week numbers in the file name (e.g. "report_data_2018W52.RData" for the report generated with last known epidemiological data of week 2018 Week 52: 2019-12-24 through 2018-12-30.)

(Note: This function also takes in the location/name of the rnw formatting script as well, so there is the possibility of having multiple different report formatting that uses the same input data. The `save_file` and `input file of the formatting_file` will need to match up correctly.)

This function calls a subfunction `create_pdf()` which calls the Sweave formatting script, `report/epidemia_report_demo.Rnw`, to read in the report data (`report/report_data.RData`, as specified in the rnw file) we just created, and to create the formatted pdf report. This Rnw Sweave file has been written specifically for the malaria forecasting report in Amhara. The Rnw file also uses some additional data: shapefiles (processed into R data files as `data/am.rda` and `data/am_simpl.rda`), and the woreda reference list (`data/woredas.xlsx`).

This subfunction will save two copies of the pdf formatted report:

- `epidemia_report_demo.pdf`: default output of an rnw file - name of the rnw file as a pdf

- `epidemia_report_demo{YYYY"W"WW}.pdf`: a renamed version of the file with autogenerated year and week numbers in the file, same scheme as the `second_save` of the `report_data` object, above.

(Note: there is a `show_report` argument that can be turned off, which is especially useful if you are writing loops to generate many reports sequentially.)

2.7 Alternative: Create pdf report

You can also call the `create_pdf()` function directly if you want to generate a formatted pdf report from a previously saved `report_data` object. The `new_data` file will overwrite `report_data_file`, which needs to be the input file that is coded inside the `formatting_file` (rnw script).

*# If you want to later recreate a pdf from a saved report_data file:
Change the input report_data_file to the previously saved version
And add a file/name for the saved output.*

```
create_pdf(new_data = "report/report_data_2018W52.RData",
  #file that is loaded in the formatting file
  report_data_file = "report/report_data.RData",
  formatting_file = "epidemia_report_demo.Rnw",
  #specific output file name
  report_save_file = "report/report_data_2018W52.pdf",
  show = TRUE)
```

2.8 Alternative: Rnw compile pdf

If you have not set MiKTeX to install missing packages on the fly without asking, the pdf creation will fail. You can compile the pdf once from the Rnw itself, and answer yes to the missing packages installation prompts. Then you can return to using the functions above. In RStudio, open `epidemia_report_demo.Rnw`, and click on Compile PDF.

2.9 Woreda names

For reference, here is a list of report woreda names:

```
readxl::read_xlsx("data/woredas.xlsx", na = "NA") %>%
  filter(report == 1) %>% pull(woreda_name)
```

## [1]	"Abargelie"	"Alefa"	"Andabiet"
## [4]	"Ankesha"	"Antsokiya Gemza"	"Artuma Fursi"
## [7]	"Awabel"	"Bahir Dar Zuria"	"Baso Liben"
## [10]	"Borena"	"Bugna"	"Burie Zuria"
## [13]	"Debre Elias"	"Dehena"	"Dembecha"
## [16]	"Denbia"	"Dera"	"Efratana Gidim"
## [19]	"Estea"	"Fagita Lekoma"	"Fogera"
## [22]	"Gondar Zuria"	"Gonji Kolela"	"Gozamin"
## [25]	"Guagusa Shekudad"	"Jabi Tehnan"	"Jawi"
## [28]	"Jilie Timuga"	"Kalu"	"Kewet"
## [31]	"Kobo Town"	"Lasta"	"Libokemkem"
## [34]	"Mecha"	"Mekit"	"Merehabete"
## [37]	"Metema"	"Misrak Belesa"	"North Achefer"
## [40]	"Quara"	"Raya Kobo"	"Sehela"
## [43]	"Shewa Robit"	"South Achefer"	"Tehulederie"
## [46]	"Womberma"	"Yilmana Densa"	