ACLIM2 CMIP6 ROMSNPZ Indices quick start guide

K. Holsman

Contents

Download the ACLIM2 repo & data

Clone the ACLIM2 repo

To run this tutorial first clone the ACLIM2 repository to your local drive:

Option 1: Use R

This set of commands, run within R, downloads the ACLIM2 repository and unpacks it, with the ACLIM2 directory structrue being located in the specified `download_path`. This also performs the folder renaming mentioned in Option 2.

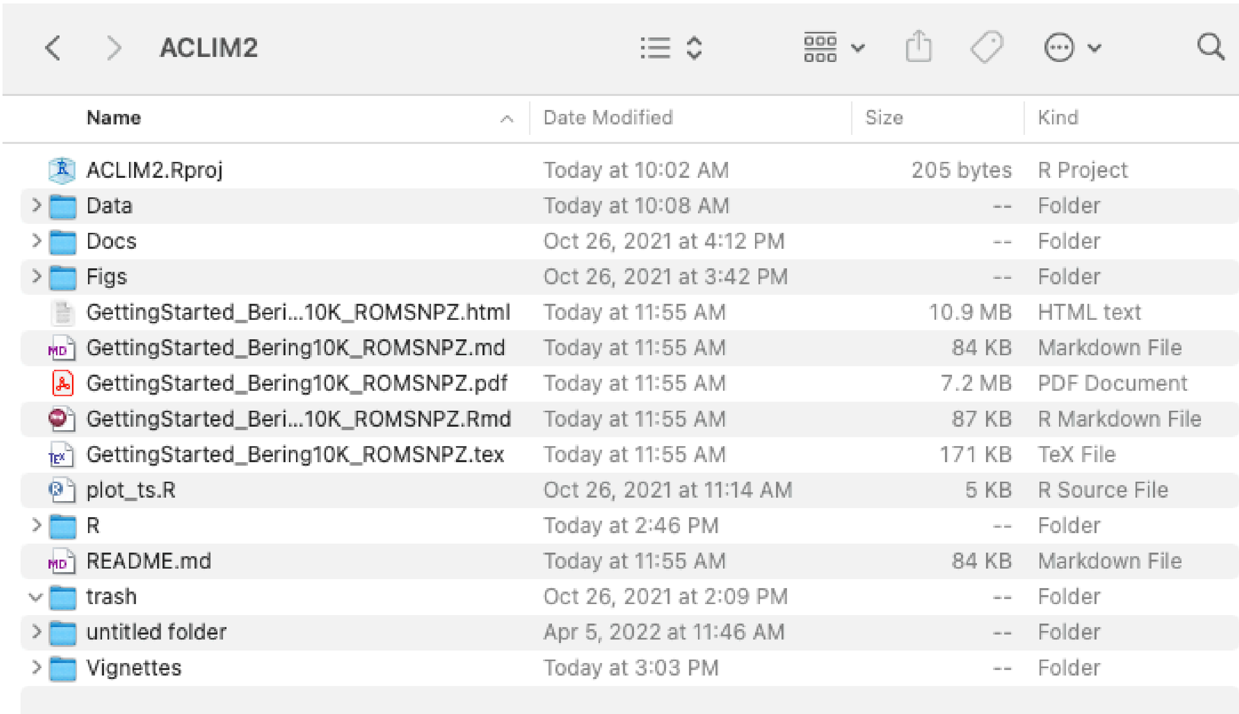
```
# Specify the download directory
main_nm       <- "ACLIM2"

# Note: Edit download_path for preference
download_path <-  path.expand("~")
dest_fldr     <- file.path(download_path,main_nm)

url           <- "https://github.com/kholsman/ACLIM2/archive/main.zip"
dest_file     <- file.path(download_path,paste0(main_nm,".zip"))
download.file(url=url, destfile=dest_file)

# unzip the .zip file (manually unzip if this doesn't work)
setwd(download_path)
unzip (dest_file, exdir = download_path,overwrite = T)

#rename the unzipped folder from ACLIM2-main to ACLIM2
file.rename(paste0(main_nm,"-main"), main_nm)
setwd(main_nm)


# Caption: Timeseries of season Aug East Bering Sea bottom temp or 400m temp (which ever is shallower)
```

Option 2: Download the zipped repo

Download the full zip archive directly from the **ACLIM2 Repo** using this link: **https://github.com/kholsman/ACLIM2**
and unzip its contents while preserving directory structure.

Important! If downloading from zip, please **rename the root folder** from `ACLIM2-main` (in the zipfile) to `ACLIM2` (name used in cloned copies) after unzipping, for consistency in the following examples.

Your final folder structure should look like this:



Option 3: Use git commandline

If you have git installed and can work with it, this is the preferred method as it preserves all directory structure and can aid in future updating. Use this from a **terminal command line, not in R**, to clone the full ACLIM2 directory and sub-directories:

```
git clone https://github.com/kholsman/ACLIM2.git
```

Get the data

–>

- Go to the google drive and download the zipped file with the R ACLIM2 indices `ACLIM2_indices.zip`:
- 00_ACLIM_shared > 02_Data > Newest_Data(use this) > unzip_and_put_in_dat_out_folder_CMIP6
  00_ACLIM_shared > 02_Data > Newest_Data(use this) > unzip_and_put_in_dat_out_folder_CMIP5
- Unzip `K29P19_CMIP5.zip` or `K29P19_CMIP6.zip` files move the `K29P19_CMIP5` or `K29P19_CMIP6` folders to your local folder `ACLIM2/Data/out`. The result should be the following folder structure on your local computer:

- `ACLIM2/Data/out/K29P19_CMIP6/allEBSmeans`: main folder with annual, monthly, seasonal, and survey replicated level 4 ACLIM indices

- `ACLIM2/Data/out/K29P19_CMIP6/BC_ACLIMregion`: Weekly x Strata based indices, including delta and bias corrected values (these are "rolled up" to become strata AREA weighted mean vals in the allEBSmeans folder).
- `ACLIM2/Data/out/K29P19_CMIP6/BC_ACLIMsurveyrep`: Survey replicated indices at each station, including delta and bias corrected values (these are "rolled up" to become average across station mean vals in the allEBSmeans folder).
- `ACLIM2/Data/out/K29P19_CMIP6/allEBSmeans`: as above but for CMIP5
- `ACLIM2/Data/out/K29P19_CMIP6/allEBSmeans`: as above but for CMIP5
- `ACLIM2/Data/out/K29P19_CMIP6/allEBSmeans`: as above but for CMIP5

Set up the Workspace

Open R() and used 'setwd()' to navigate to the root ACLIM2 folder (.e.g, ~/mydocuments/ACLIM2)

```
# set the workspace to your local ACLIM2 folder
# e.g., "/Users/kholsman/Documents/GitHub/ACLIM2"
# setwd( path.expand("~/Documents/GitHub/ACLIM2") )

# --------------------------------------
# SETUP WORKSPACE
tmstp  <- format(Sys.time(), "%Y_%m_%d")
main   <- getwd()  #"~/GitHub_new/ACLIM2"

# loads packages, data, setup, etc.
suppressWarnings(source("R/make.R"))
```

```
## ------------------------------
## ALIM2/R/setup.R settings
## ------------------------------
## data_path            : D:/romsnpz/roms_for_public
## Rdata_path           : D:/romsnpz/2022_10_17_Rdata/roms_for_public
## redownload_level3_mox: FALSE
## update.figs          : FALSE
## load_gis             : FALSE
## update.outputs       : TRUE
## update.figs          : FALSE
## dpiIN                : 150
## update.figs          : FALSE
## ------------------------------
## ------------------------------
##
## The following datasets are public, please cite as Hermann et al. 2019 (v.H16) and Kearney et al. 202
## B10K-H16_CMIP5_CESM_BIO_rcp85
## B10K-H16_CMIP5_CESM_rcp45
## B10K-H16_CMIP5_CESM_rcp85
## B10K-H16_CMIP5_GFDL_BIO_rcp85
## B10K-H16_CMIP5_GFDL_rcp45
## B10K-H16_CMIP5_GFDL_rcp85
## B10K-H16_CMIP5_MIROC_rcp45
## B10K-H16_CMIP5_MIROC_rcp85
```

```
## B10K-H16_CORECFS
## B10K-K20_CORECFS
##
## The following datasets are still under embargo, please do not share outside of ACLIM:
## B10K-K20P19_CMIP6_cesm_historical
## B10K-K20P19_CMIP6_cesm_ssp126
## B10K-K20P19_CMIP6_cesm_ssp585
## B10K-K20P19_CMIP6_gfdl_historical
## B10K-K20P19_CMIP6_gfdl_ssp126
## B10K-K20P19_CMIP6_gfdl_ssp585
## B10K-K20P19_CMIP6_miroc_historical
## B10K-K20P19_CMIP6_miroc_ssp126
## B10K-K20P19_CMIP6_miroc_ssp585
```

Read this before you start

Overview

The **ACLIM2 github repository** contains R code and Rdata files for working with netcdf-format data generated from the **downscaled ROMSNPZ modeling** of the ROMSNPZ Bering Sea Ocean Modeling team; Drs. Hermann, Cheng, Kearney, Pilcher,Ortiz, and Aydin. The code and R resources described in this tutorial are maintained by Kirstin Holsman as part of NOAA's **ACLIM project** for the Bering Sea. *See Hollowed et al. 2020 for more information about the ACLIM project.*

This document provides an overview of accessing, plotting, and creating bias corrected indices for ACLIM2 based on CMIP6 (embargoed for ACLIM2 users until 2023) and CMIP5 (publicly available) simulations. This guide assumes analyses will take place in R() and that users have access to the data folder within the ACLIM2 shared drive. For more information also see the full tutorial ("GettingStarted_Bering10K_ROMSNPZ" available at the bottom of **this repo page**.

Important! A few key things to know before getting started are detailed below. Please review this information before getting started.

ROMSNPZ versions

Important! ACLIM1 CMIP5 and ACLIM2 CMIP5 and CMIP6 datasets use different base models.

There are two versions of the ROMSNPZ model:

1. ACLIM1 an older 10-depth layer model used for CMIP5 ("H-16")
2. ACLIM2 a new 30-depth layer model used for CMIP6 ("K20" or "K20P19")

The models are not directly comparable, therefore the projections should be bias corrected and recentered to baselines of hindcasts of each model (forced by "observed" climate conditions). i.e. CMIP5 and CMIP6 have corresponding hindcasts:

1. Hindcast for CMIP5 "H19" –> H16_CORECFS

2. Hindcast for CMIP5 "K20P19" –> H16_CORECFS
3. Hindcast for CMIP6 "K20P19" –> K20_CORECFS

In addition for CMIP6 "historical" runs are available for bias correcting. We will use those below.

For a list of the available simulations for ACLIM enter the following in R():

```r
# list of the climate scenarios
data.frame(sim_list)
```

```
##                                sim_list
## 1                      B10K-K20_CORECFS
## 2        B10K-H16_CMIP5_CESM_BIO_rcp85
## 3            B10K-H16_CMIP5_CESM_rcp45
## 4            B10K-H16_CMIP5_CESM_rcp85
## 5        B10K-H16_CMIP5_GFDL_BIO_rcp85
## 6            B10K-H16_CMIP5_GFDL_rcp45
## 7            B10K-H16_CMIP5_GFDL_rcp85
## 8           B10K-H16_CMIP5_MIROC_rcp45
## 9           B10K-H16_CMIP5_MIROC_rcp85
## 10                     B10K-H16_CORECFS
## 11        B10K-K20P19_CMIP5_CESM_rcp45
## 12        B10K-K20P19_CMIP5_CESM_rcp85
## 13        B10K-K20P19_CMIP5_GFDL_rcp45
## 14        B10K-K20P19_CMIP5_GFDL_rcp85
## 15       B10K-K20P19_CMIP5_MIROC_rcp45
## 16       B10K-K20P19_CMIP5_MIROC_rcp85
## 17  B10K-K20P19_CMIP6_cesm_historical
## 18       B10K-K20P19_CMIP6_cesm_ssp126
## 19       B10K-K20P19_CMIP6_cesm_ssp585
## 20  B10K-K20P19_CMIP6_gfdl_historical
## 21       B10K-K20P19_CMIP6_gfdl_ssp126
## 22       B10K-K20P19_CMIP6_gfdl_ssp585
## 23 B10K-K20P19_CMIP6_miroc_historical
## 24      B10K-K20P19_CMIP6_miroc_ssp126
## 25      B10K-K20P19_CMIP6_miroc_ssp585
```

ROMSNPZ variables

For a list of the available variables from the ROMSNPZ:

```r
# Metadata for variables
(srvy_var_def[-(1:5),])
```

```
##                    name                            units
## 6                   Ben                        mg C m^-2
## 7                DetBen                        mg C m^-2
## 8                  Hsbl                            meter
## 9                IceNH4                      mmol N m^-3
## 10               IceNO3                      mmol N m^-3
## 11               IcePhL                        mg C m^-3
## 12                 aice
```

```
## 13                hice                              meter
## 14              shflux                       watt meter-2
## 15              ssflux                     meter second-1
## 16      Cop_integrated                      (mg C m^-3)*m
## 17       Cop_surface5m                          mg C m^-3
## 18     EupO_integrated                      (mg C m^-3)*m
## 19      EupO_surface5m                          mg C m^-3
## 20     EupS_integrated                      (mg C m^-3)*m
## 21      EupS_surface5m                          mg C m^-3
## 22      Iron_bottom5m                   micromol Fe m-3
## 23     Iron_integrated             (micromol Fe m-3)*m
## 24      Iron_surface5m                  micromol Fe m-3
## 25      Jel_integrated                      (mg C m^-3)*m
## 26       Jel_surface5m                          mg C m^-3
## 27      MZL_integrated                      (mg C m^-3)*m
## 28       MZL_surface5m                          mg C m^-3
## 29     NCaO_integrated                      (mg C m^-3)*m
## 30      NCaO_surface5m                          mg C m^-3
## 31     NCaS_integrated                      (mg C m^-3)*m
## 32      NCaS_surface5m                          mg C m^-3
## 33        NH4_bottom5m                      mmol N m^-3
## 34      NH4_integrated                  (mmol N m^-3)*m
## 35       NH4_surface5m                      mmol N m^-3
## 36        NO3_bottom5m                      mmol N m^-3
## 37      NO3_integrated                  (mmol N m^-3)*m
## 38       NO3_surface5m                      mmol N m^-3
## 39      PhL_integrated                      (mg C m^-3)*m
## 40       PhL_surface5m                          mg C m^-3
## 41      PhS_integrated                      (mg C m^-3)*m
## 42       PhS_surface5m                          mg C m^-3
## 43  prod_Cop_integrated                   mg C m^-2 d^-1
## 44 prod_EupO_integrated                   mg C m^-2 d^-1
## 45 prod_EupS_integrated                   mg C m^-2 d^-1
## 46  prod_Eup_integrated (milligram carbon meter-3 d-1)*m
## 47  prod_Jel_integrated                   mg C m^-2 d^-1
## 48  prod_MZL_integrated                   mg C m^-2 d^-1
## 49 prod_NCaO_integrated                   mg C m^-2 d^-1
## 50 prod_NCaS_integrated                   mg C m^-2 d^-1
## 51  prod_NCa_integrated (milligram carbon meter-3 d-1)*m
## 52  prod_PhL_integrated                   mg C m^-2 d^-1
## 53  prod_PhS_integrated                   mg C m^-2 d^-1
## 54      salt_surface5m
## 55       temp_bottom5m                          Celsius
## 56     temp_integrated                      (Celsius)*m
## 57      temp_surface5m                          Celsius
## 58      uEast_bottom5m                   meter second-1
## 59     uEast_surface5m                   meter second-1
## 60     vNorth_bottom5m                   meter second-1
## 61    vNorth_surface5m                   meter second-1
##                                                      longname
## 6                                 Benthic infauna concentration
## 7                                Benthic detritus concentration
## 8                          depth of oceanic surface boundary layer
## 9                                    Ice ammonium concentration
```

```
## 10                                   Ice nitrate concentration
## 11                                     Ice algae concentration
## 12                             fraction of cell covered by ice
## 13                               average ice thickness in cell
## 14                                       surface net heat flux
## 15                           surface net salt flux, (E-P)*SALT
## 16         Small copepod concentration, integrated over depth
## 17               Small copepod concentration, surface 5m mean
## 18   Offshore euphausiid concentration, integrated over depth
## 19         Offshore euphausiid concentration, surface 5m mean
## 20   On-shelf euphausiid concentration, integrated over depth
## 21         On-shelf euphausiid concentration, surface 5m mean
## 22                         iron concentration, bottom 5m mean
## 23                  iron concentration, integrated over depth
## 24                        iron concentration, surface 5m mean
## 25             Jellyfish concentration, integrated over depth
## 26                   Jellyfish concentration, surface 5m mean
## 27      Microzooplankton concentration, integrated over depth
## 28            Microzooplankton concentration, surface 5m mean
## 29 Offshore large copepod concentration, integrated over depth
## 30       Offshore large copepod concentration, surface 5m mean
## 31 On-shelf large copepod concentration, integrated over depth
## 32       On-shelf large copepod concentration, surface 5m mean
## 33                     Ammonium concentration, bottom 5m mean
## 34              Ammonium concentration, integrated over depth
## 35                    Ammonium concentration, surface 5m mean
## 36                      Nitrate concentration, bottom 5m mean
## 37               Nitrate concentration, integrated over depth
## 38                     Nitrate concentration, surface 5m mean
## 39   Large phytoplankton concentration, integrated over depth
## 40         Large phytoplankton concentration, surface 5m mean
## 41   Small phytoplankton concentration, integrated over depth
## 42         Small phytoplankton concentration, surface 5m mean
## 43                Cop net production rate, summed over depth
## 44               EupO net production rate, summed over depth
## 45               EupS net production rate, summed over depth
## 46    secondary production Euphausiids, integrated over depth
## 47                Jel net production rate, summed over depth
## 48                MZL net production rate, summed over depth
## 49               NCaO net production rate, summed over depth
## 50               NCaS net production rate, summed over depth
## 51     secondary production Neocalanus, integrated over depth
## 52                PhL net production rate, summed over depth
## 53                PhS net production rate, summed over depth
## 54                                  salinity, surface 5m mean
## 55                   potential temperature, bottom 5m mean
## 56            potential temperature, integrated over depth
## 57                  potential temperature, surface 5m mean
## 58        u-momentum component, geo-rotated, bottom 5m mean
## 59       u-momentum component, geo-rotated, surface 5m mean
## 60        v-momentum component, geo-rotated, bottom 5m mean
## 61       v-momentum component, geo-rotated, surface 5m mean
```

Data outputs

Important! There are 2 types of post-processed data available for use in ACLIM.

The ROMSNPZ team has developed a process to provide standardized post-processed outputs from the large (and non-intuitive) ROMSNPZ grid. These have been characterized as:

1. Level 1 (original ROMSNPZ U,V, grid, not rotated or corrected)

2. Level 2 (lat long bi-weekly high res versions, shouldn't be needed and are difficult to work with)

3. **Level 3 indices (depth corrected and area weighted means for each model variable; i.e., what we will mostly use)**

    a. "ACLIMsurveyrep_": groundifsh survey replicated (replicated in space and time)
    b. "ACLIMregion_": weekly strata based averages

To get more information about each of these level 3 datasets enter this in R:

```
# Metadata for Weekly ("ACLIMregion_...") indices
head(all_info1)
```

```
##                              name                   Type B10KVersion  CMIP  GCM
## 1 B10K-H16_CMIP5_CESM_BIO_rcp85 Weekly regional indices         H16 CMIP5 CESM
## 2     B10K-H16_CMIP5_CESM_rcp45 Weekly regional indices         H16 CMIP5 CESM
## 3     B10K-H16_CMIP5_CESM_rcp85 Weekly regional indices         H16 CMIP5 CESM
## 4 B10K-H16_CMIP5_GFDL_BIO_rcp85 Weekly regional indices         H16 CMIP5 GFDL
## 5     B10K-H16_CMIP5_GFDL_rcp45 Weekly regional indices         H16 CMIP5 GFDL
## 6     B10K-H16_CMIP5_GFDL_rcp85 Weekly regional indices         H16 CMIP5 GFDL
##     BIO Carbon_scenario               Start                 End nvars
## 1  TRUE           rcp85 2006-01-22 12:00:00 2099-12-27 12:00:00    59
## 2 FALSE           rcp45 2006-01-22 12:00:00 2081-02-16 12:00:00    59
## 3 FALSE           rcp85 2006-01-22 12:00:00 2099-12-27 12:00:00    59
## 4  TRUE           rcp85 2006-01-22 12:00:00 2099-12-27 12:00:00    59
## 5 FALSE           rcp45 2006-01-22 12:00:00 2099-12-27 12:00:00    59
## 6 FALSE           rcp85 2006-01-22 12:00:00 2099-12-27 12:00:00    59
```

```
# Metadata for Weekly ("ACLIMsurveyrep_...") indices
head(all_info2)
```

```
##                              name              Type B10KVersion  CMIP  GCM   BIO
## 1 B10K-H16_CMIP5_CESM_BIO_rcp85 Survey replicated         H16 CMIP5 CESM  TRUE
## 2     B10K-H16_CMIP5_CESM_rcp45 Survey replicated         H16 CMIP5 CESM FALSE
## 3     B10K-H16_CMIP5_CESM_rcp85 Survey replicated         H16 CMIP5 CESM FALSE
## 4 B10K-H16_CMIP5_GFDL_BIO_rcp85 Survey replicated         H16 CMIP5 GFDL  TRUE
## 5     B10K-H16_CMIP5_GFDL_rcp45 Survey replicated         H16 CMIP5 GFDL FALSE
## 6     B10K-H16_CMIP5_GFDL_rcp85 Survey replicated         H16 CMIP5 GFDL FALSE
##   Carbon_scenario Start  End nvars
## 1           rcp85  1970 2100    60
## 2           rcp45  1970 2100    60
## 3           rcp85  1970 2100    60
## 4           rcp85  1970 2100    60
## 5           rcp45  1970 2100    60
## 6           rcp85  1970 2100    60
```

#Indices & bias correction UPDATED{.tabset}

Summary

We recommend using the 'mn_val' column in the hindcast and either the 'val_biascorrected' or 'val_delta' column for projections.

use val_biascorrected' or 'val_delta'?

This will depend in part on the index and scale you are working at. For fine scale (weekly strata, or station specific, or finer) we recommend using the 'val_delta', i.e., the delta method. For the ACLIM2 spring sprint we are recommending the 'val_biascorrected' in order to align modeling output.

However,at the larger pooled scales there is very little difference between the two but a sensitivity analysis may be needed to determine if the choice makes a profound difference in projections. Following an in depth analysis of the effects of bias correction at the finer scales of model output we found that bias correction via the Ho et al. method can result in artifacts that impact final indices in unsatisfactory ways. The effects do not emerge as frequently when data are pooled at the annual or basin-wide scale but do occur at finer scales, especially when areas or time-period have values in the hindcast but the corresponding historical runs have only small values, resulting in amplification that is not found in the raw projection to historical time-series comparison. However the Ho et al. approach is better at re-scaling variance between projections and the hindcast, and preserves a more parsimonious variance structure in projections. Whereas, the delta method assumes equal variance between the hindcast and projection models (during the overlapping reference years 1980:2013 when overall variance should match) and does do not adjust projections if the corresponding historical variance is larger or smaller than the hindcast sigma. Applying the delta method adjustment at the smallest possible resolution of the indices (weekly or by station) minimizes the effects of superimposing the variance structure of the historical time-series on the projection.

The average weekly strata value per or the average station value (for survey replicated indices) across the reference years 1980-2013 were calculated for the hindcast and corresponding historical runs to determine the mean hindcast and mean historical values for bias correction; 'mn_hind' and 'mn_hist', respectively. We used the mgcv package to smooth weekly values 'mgcv::gam(…bs="cc")') across all reference years to remove artifacts (e.g. divide by 0) in the average ($\bar{Y}^{hind}_{w,k}$ and $\bar{Y}^{hist}_{w,k}$) and variance ($\sigma^{hist}_{w,k}$ and $\sigma^{hind}_{w,k}$) terms were predicted from the gam (without error; example for $\bar{Y}^{hind}_{w,k}$):

$$\bar{Y}^{hind}_{w,k} = \mu + s(w, k = .8n) + \epsilon \;\; and \;\; \epsilon \sim N(0, \sigma)$$

Important! Note: the delta adjustment and the bias corrections were done on "raw" values which in some cases results in negative values (or <0 or >1 for proportion variables like 'aice'). For these variables, values <0 were set to 0, >1 set to 1 as needed after (delta) bias correction.

ACLIM2 Indices correction methods

###Delta method The next step creates ACLIM2 indices (i.e., Level4) based on the Level3 output for each hindcast, historical run, and CMIP6 projection. The script below delta adjusts or bias corrects each projected index using the corresponding historical run. (such that projections are Δ from historical mean values for the reference period `deltayrs      <- 1980:2013`).

Important! Note that for projections the 'mn_val' represents raw mean values, while 'val_delta' and 'val_biascorrected' are the adjusted values using scaling factor of 1 or SD_hind/SD_hist on a weekly basis (respectively).

Delta method correction was done on "raw" values which in some cases results in negative values (or <0 or >1 for proportion variables like 'aice'). For these variables, values <0 were set to 0, >1 set to 1 as needed after the delta adjustment. Delta method adjustments were conducted at the weekly level for strata specific data and at the station level for survey replicated indices:

Such that (Y):

$$Y^{fut'}_{t,k} = \bar{Y}^{hind}_{k,\bar{T}} + (Y^{fut}_{t,k} - \bar{Y}^{hist}_{k,\bar{T}})$$

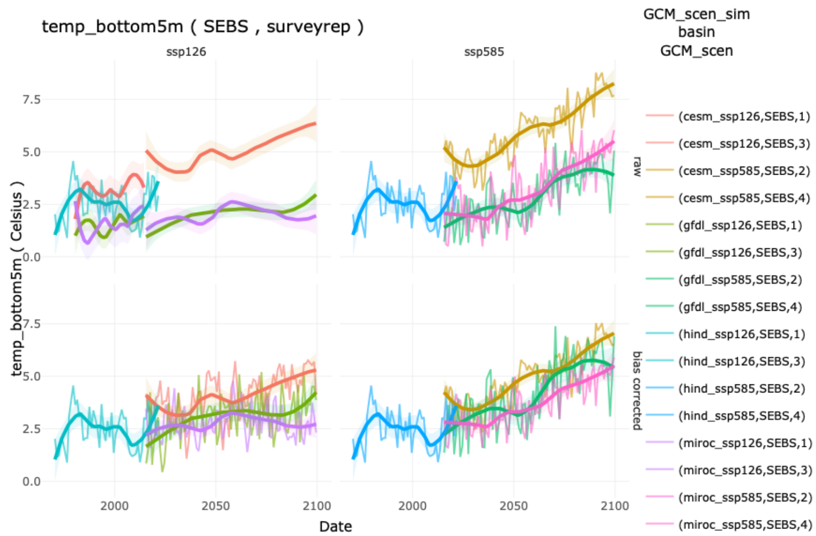


Figure 1: **Raw (top row) and bias corrected (bottom row)bottom temperature indices based on survey replicated Level3 outputs for the SEBS**

where $\bar{Y}^{fut'}_{y,k}$ is the bias corrected variable k value for time-step t (e.g., year, month, or season), $\bar{Y}^{hind}_{k,\bar{T}}$ is the mean value of the variable k during the reference period $\bar{T} = [1980, 2013]$ from the hindcast model, $\sigma^{hind}_{k,\bar{T}}$ is the standard deviation of the hindcast during the reference period $\bar{T}$, $\sigma^{hist}_{k,\bar{T}}$ is the standard deviation of the historical run during tje reference period, $Y^{fut}_{t,k}$ is the value of the variable from the projection at time-step t and $\bar{Y}^{hist}_{k,\bar{T}}$ is the average value from the historical run during reference period $\bar{T}$.

###Bias correction

Bias correction was done on "raw" values which in some cases results in negative values (or <0 or >1 for proportion variables like 'aice'). For these variables, values <0 were set to 0, >1 set to 1 as needed after bias correction. Bias correction adjustments were conducted at the weekly level for strata specific data and at the station level for survey replicated indices:

Such that (Y):

$$Y^{fut'}_{t,k} = \bar{Y}^{hind}_{k,\bar{T}} + \left(\frac{\sigma^{hind}_{k,\bar{T}}}{\sigma^{hist}_{k,\bar{T}}} * (Y^{fut}_{t,k} - \bar{Y}^{hist}_{k,\bar{T}}) \right)$$

where $\bar{Y}^{fut'}_{y,k}$ is the bias corrected variable k value for time-step t (e.g., year, month, or season), $\bar{Y}^{hind}_{k,\bar{T}}$ is the mean value of the variable k during the reference period $\bar{T} = [1980, 2013]$ from the hindcast model, $\sigma^{hind}_{k,\bar{T}}$ is the standard deviation of the hindcast during the reference period $\bar{T}$, $\sigma^{hist}_{k,\bar{T}}$ is the standard deviation of the historical run during tje reference period, $Y^{fut}_{t,k}$ is the value of the variable from the projection at time-step t and $\bar{Y}^{hist}_{k,\bar{T}}$ is the average value from the historical run during reference period $\bar{T}$.

For log-normally distributed variables(Y):

$$Y^{fut'}_{y,k} = e^{\ln \bar{Y}^{hind}_{k,\bar{T}} + \left(\frac{\hat{\sigma}^{hind}_{k,\bar{T}}}{\hat{\sigma}^{hist}_{k,\bar{T}}} * (\ln Y^{fut}_{t,k} - \ln \bar{Y}^{hist}_{k,\bar{T}}) \right)}$$

, where $\hat{\sigma}^{hist}_{k,\bar{T}}$ and $\hat{\sigma}^{hind}_{k,\bar{T}}$ are the standard deviation of the $\ln \bar{Y}^{hist}_{k,t}$ and $\ln \bar{Y}^{hind}_{k,t}$ during the reference period $\hat{T}$ (respectively).