annual_trends

```
library(tidyverse)
```

```
-- Attaching packages --------------------------------------- tidyverse 1.3.2 --
v ggplot2 3.4.0      v purrr   1.0.0
v tibble  3.1.8      v dplyr   1.0.10
v tidyr   1.2.1      v stringr 1.5.0
v readr   2.1.3      v forcats 0.5.2
-- Conflicts ------------------------------------------ tidyverse_conflicts() --
x dplyr::filter() masks stats::filter()
x dplyr::lag()    masks stats::lag()
```

```
library(zen4R)
library(here)
```

```
here() starts at G:/My Drive/research/thermal_phys
```

```
library(ggpmisc)
```

```
Loading required package: ggpp

Attaching package: 'ggpp'

The following object is masked from 'package:ggplot2':

    annotate
```

```
library(viridis)
```

```
Loading required package: viridisLite
```

Data: Annual indices of heat and humidity, U.S. Army installations, 1990-2018 Stephen Lewandowski

R data files for annual indices of heat of 25 Continental U.S. (CONUS) U.S. Army installations from 1990-2018 in list and long formats.

Annual indices were derived from hourly meteorological estimates from the North American Land Data Assimilation System 2 (NLDAS-2) forcing dataset served as the primary source of weather and atmospheric data. We selected NLDAS grid cells containing the centroid of each installation based on shapefiles from the Department of Defense (DoD) Military Installations, Ranges, and Training Areas (MIRTA) Dataset. We calculated relative humidity from specific humidity, temperature, and atmospheric pressure; heat index (HI) from temperature and relative humidity based on a US National Weather Service algorithm; and outdoor WBGT from air temperature, relative humidity, solar irradiance, barometric pressure, and wind speed using the method of Liljegren et al.

Download 1990-2018 NLDAS data

```
# download_zenodo("10.5281/zenodo.6893120", path = here::here("data"), files = list("annua
```

Load 1990-2018 NLDAS data

```
annual_indices <-
  read_rds("data/annual_indices.rds")

index_long <-
  read_rds("data/index_long.rds") %>%
  mutate(index = dplyr::recode(index, mean_tmp = "Mean Tmp",
                               mean_hi = "Mean HI",
                               mean_wbgt = "Mean WBGT",
                               max_tmp = "Max Tmp",
                               max_hi = "Max HI",
                               max_wbgt = "Max WBGT",
                               mean_tmp_may_sep = "Mean Tmp HS",
                               mean_hi_may_sep = "Mean HI HS",
                               mean_wbgt_may_sep = "Mean WBGT HS",
                               max_tmp_may_sep = "Max Tmp HS",
                               max_hi_may_sep = "Max HI HS",
```

```
                            max_wbgt_may_sep = "Max WBGT HS",
                            hours_tmp_gt90 = "Hrs Tmp > 90",
                            hours_tmp_gt100 = "Hrs Tmp > 100",
                            hours_hi_gt90 = "Hrs HI > 90",
                            hours_hi_gt105 = "Hrs HI > 105",
                            hours_wbgt_gt85 = "Hrs WBGT > 85",
                            hours_wbgt_gt90 = "Hrs WBGT > 90",
                            tmp_anomaly = "Tmp Anomaly",
                            hi_anomaly = "HI Anomaly",
                            wbgt_anomaly = "WBGT Anomaly",
                            days_tmp_gt1sd = "Days Tmp > 1 SD",
                            days_hi_gt1sd = "Days HI > 1 SD",
                            days_wbgt_gt1sd = " Days WBGT > 1 SD",
                            tmp_anomaly_may_sep = "Tmp Anomaly HS",
                            hi_anomaly_may_sep = "HI Anomaly HS",
                            wbgt_anomaly_may_sep = "WBGT Anomaly HS",
                            days_tmp_gt1sd_may_sep = "Days Tmp > 1 SD HS",
                            days_hi_gt1sd_may_sep = "Days HI > 1 SD HS",
                            days_wbgt_gt1sd_may_sep = "Days WBGT > 1 SD HS"),
          cat = case_when(str_detect(index, "Hrs")  ~ "Hours",
                          str_detect(index, "Day")  ~ "Days",
                          str_detect(index, "Anom")  ~ "Anomaly",
                          str_detect(index, "Mean")  ~ "Mean",
                          str_detect(index, "Max")  ~ "Maximum"),
          season = case_when(str_detect(index, "HS")  ~ "Heat Season",
                             TRUE ~ "Full Year"),
          index_scale = case_when(str_detect(index, "Tmp")  ~ "Temperature",
                                  str_detect(index, "HI")  ~ "Heat Index",
                                  str_detect(index, "WBGT")  ~ "WBGT"))
```

Site List

```
index_long %>%
  count(site_name)
```

```
# A tibble: 11 x 2
# Groups:   site_name [11]
   site_name             n
   <chr>             <int>
 1 Fort Benning        900
```

```
 2 Fort Bliss          900
 3 Fort Bragg          900
 4 Fort Campbell       900
 5 Fort Hood           900
 6 Fort Irwin          900
 7 Fort Jackson        900
 8 Fort Leonard Wood   900
 9 Fort Polk           900
10 Fort Riley          900
11 Fort Stewart        900
```

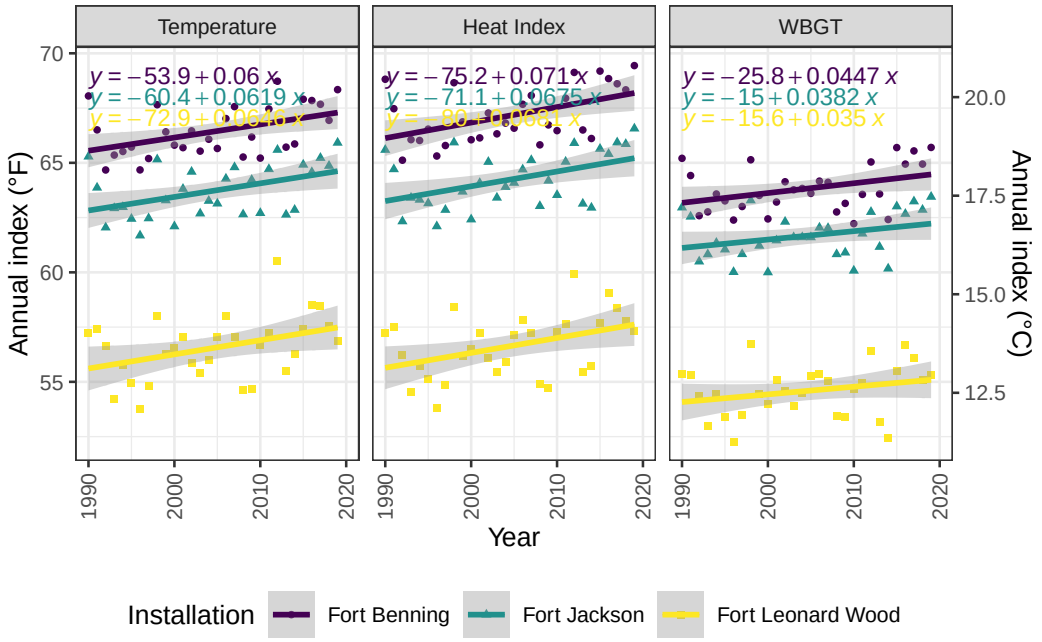
Plot IET Sites

IET - Full Calendar Year (Mean Annual)

```
mean_plot_iet_fullyear <-
    index_long %>%
     filter(site_name %in% c("Fort Benning", "Fort Jackson", "Fort Leonard Wood"),
            cat %in% "Mean",
            season %in% "Full Year") %>%
     mutate(index_scale = fct_relevel(index_scale, c("Temperature", "Heat Index", "WBGT"))
    ggplot(aes(x = year, y = value, color = site_name, shape = site_name)) +
      geom_point(size = 1) +
      geom_smooth(aes(group = site_name), method = lm, se = FALSE, linewidth = 0.25, alpha
  stat_poly_line() +
  stat_poly_eq(aes(label = after_stat(eq.label)), size = rel(3)) +
    facet_grid(~ index_scale, scales = "free") +
    theme_bw(base_size = 10) +
    theme(strip.text = element_text(
      size = 8)) +
    labs(x = "Year",
         y = "Annual index (°F)") +
    xlim(1990, 2020) +
    theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1)) +
    scale_y_continuous("Annual index (°F)", sec.axis = sec_axis(trans = ~ (5/9) * (. - 32)
  theme(legend.position="bottom") +
  labs(shape = "Installation", color = "Installation") +
  scale_color_viridis(discrete = TRUE)


mean_plot_iet_fullyear
```

```
`geom_smooth()` using formula = 'y ~ x'
```



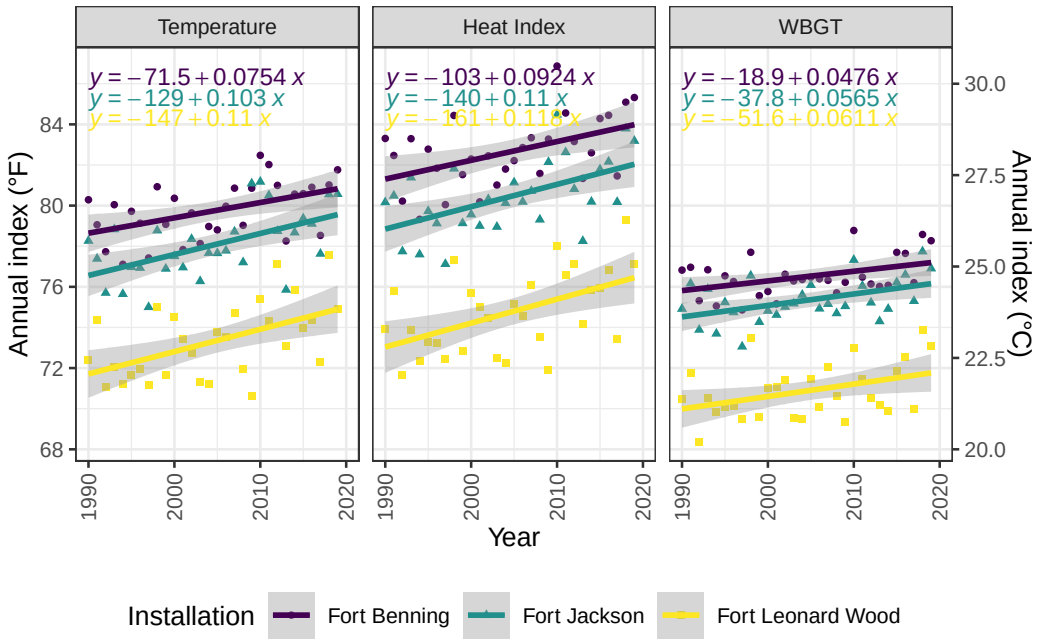
IET - Heat Season (Mean of Daily Means from May to Sep)

```
mean_plot_iet_maytosep <-
    index_long %>%
     filter(site_name %in% c("Fort Benning", "Fort Jackson", "Fort Leonard Wood"),
            cat %in% "Mean",
            season %in% "Heat Season") %>%
     mutate(index_scale = fct_relevel(index_scale, c("Temperature", "Heat Index", "WBGT"))
    ggplot(aes(x = year, y = value, color = site_name, shape = site_name)) +
      geom_point(size = 1) +
      geom_smooth(aes(group = site_name), method = lm, se = FALSE, linewidth = 0.25, alpha
  stat_poly_line() +
  stat_poly_eq(aes(label = after_stat(eq.label)), size = rel(3)) +
    facet_grid(~ index_scale, scales = "free") +
    theme_bw(base_size = 10) +
   # theme(strip.text = element_text(size = 8)) +
    labs(x = "Year",
         y = "Annual index (°F)") +
    xlim(1990, 2020) +
```

```
    theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1)) +
    scale_y_continuous("Annual index (°F)", sec.axis = sec_axis(trans = ~ (5/9) * (. - 32)
  theme(legend.position="bottom") +
  labs(shape = "Installation", color = "Installation") +
  scale_color_viridis(discrete = TRUE)

mean_plot_iet_maytosep
```

```
`geom_smooth()` using formula = 'y ~ x'
```



Plot All Sites

Mean Plot - All

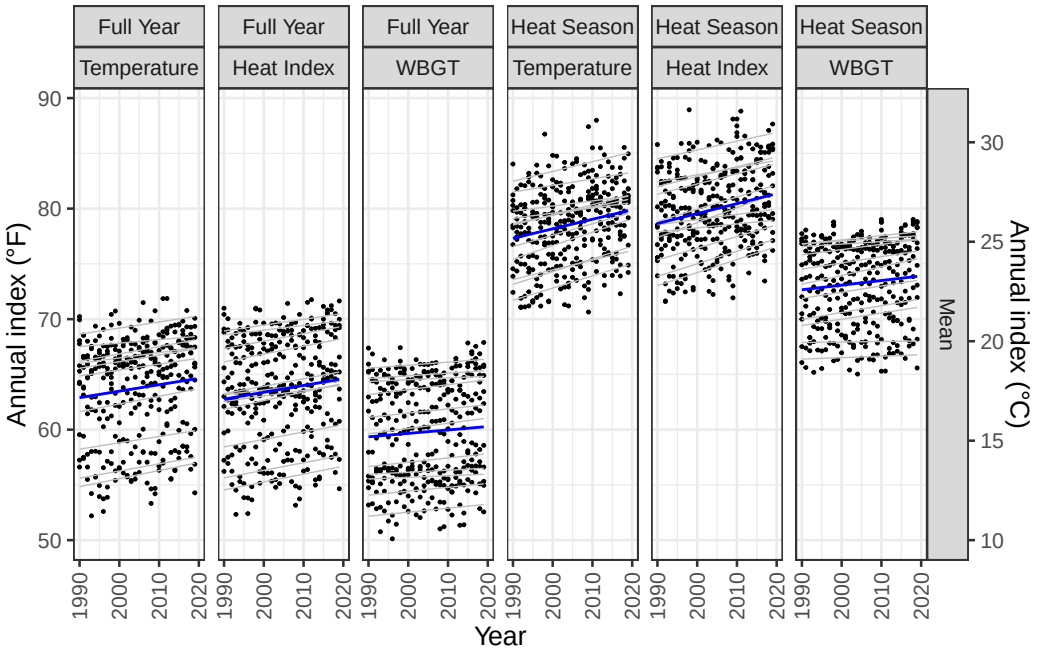
```
## Degree-based indices: Mean / Max

mean_plot_all <-
  index_long %>%
    filter(cat %in% "Mean") %>%
    mutate(index_scale = fct_relevel(index_scale, c("Temperature", "Heat Index", "WBGT"))
```

```
    ggplot(aes(x = year, y = value)) +
      geom_point(size = 0.2) +
      geom_smooth(aes(group = site_name), method = lm, se = FALSE, linewidth = 0.25, color
      geom_smooth(method = lm, se = FALSE, linewidth = 0.5, color = "blue") +
      #facet_grid(season + index_scale ~ cat, scales = "free") +
      facet_grid(cat ~ season + index_scale, scales = "free") +
    theme_bw(base_size = 10) +
    theme(strip.text = element_text(
      size = 8)) +
    labs(x = "Year",
         y = "Annual index (°F)") +
    xlim(1990, 2020) +
    theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1)) +
    scale_y_continuous("Annual index (°F)", sec.axis = sec_axis(trans = ~ (5/9) * (. - 32)


mean_plot_all
```

```
`geom_smooth()` using formula = 'y ~ x'
`geom_smooth()` using formula = 'y ~ x'
```

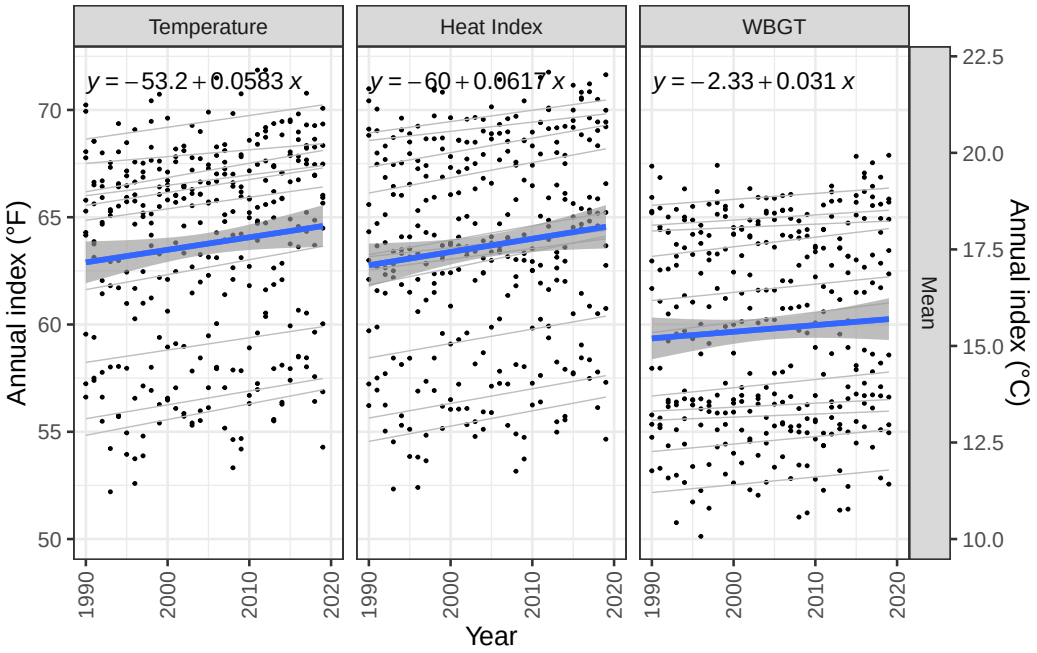


All - Full Calendar Year, Annual mean

```
mean_plot_all_fullyear <-
  index_long %>%
     filter(cat %in% "Mean",
            season %in% "Full Year") %>%
     mutate(index_scale = fct_relevel(index_scale, c("Temperature", "Heat Index", "WBGT"))
    ggplot(aes(x = year, y = value)) +
      geom_point(size = 0.2) +
      geom_smooth(aes(group = site_name), method = lm, se = FALSE, linewidth = 0.25, color
      # geom_smooth(method = lm, se = FALSE, linewidth = 0.5, color = "blue") +
      #facet_grid(season + index_scale ~ cat, scales = "free") +
      stat_poly_line() +
  stat_poly_line() +
  stat_poly_eq(aes(label = after_stat(eq.label)), size = rel(3)) +
    facet_grid(cat ~ index_scale, scales = "free") +
    theme_bw(base_size = 10) +
    theme(strip.text = element_text(
      size = 8)) +
    labs(x = "Year",
         y = "Annual index (°F)") +
    xlim(1990, 2020) +
    theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1)) +
    scale_y_continuous("Annual index (°F)", sec.axis = sec_axis(trans = ~ (5/9) * (. - 32)

mean_plot_all_fullyear
```

```
`geom_smooth()` using formula = 'y ~ x'
```



All - Heat Season, Annual mean

```
mean_plot_all_maytosep <-
  index_long %>%
     filter(cat %in% "Mean",
            season %in% "Full Year") %>%
     mutate(index_scale = fct_relevel(index_scale, c("Temperature", "Heat Index", "WBGT"))
    ggplot(aes(x = year, y = value)) +
      geom_point(size = 0.2) +
      geom_smooth(aes(group = site_name), method = lm, se = FALSE, linewidth = 0.25, alpha
      # geom_smooth(method = lm, se = FALSE, linewidth = 0.5, color = "blue") +
      #facet_grid(season + index_scale ~ cat, scales = "free") +
      stat_poly_line() +
  stat_poly_line() +
  stat_poly_eq(aes(label = after_stat(eq.label)), size = rel(3)) +
    facet_grid(cat ~ index_scale, scales = "free") +
    theme_bw(base_size = 10) +
    theme(strip.text = element_text(
      size = 8)) +
    labs(x = "Year",
         y = "Annual index (°F)") +
```

```
    xlim(1990, 2020) +
    theme(axis.text.x = element_text(angle = 90, vjust = 0.5, hjust = 1)) +
    scale_y_continuous("Annual index (°F)", sec.axis = sec_axis(trans = ~ (5/9) * (. - 32)

mean_plot_all_maytosep
```

```
`geom_smooth()` using formula = 'y ~ x'
```