Analysis of precipitation trends

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Contents

```
library(tidyverse)
library(tidyselect)
library(reshape2)
library(sf)
library(raster)
library(ggthemes)
library(rnaturalearth)
library(ggspatial)
```

Get precipitation data from Worldclim and coastline from Natural Earth.

```
world <- ne_coastline(scale = "medium", returnclass = "sf")

res <- "2.5"; rcp <- "8.5"
webres <- "2_5"; webrcp <- "85"

bio2000_file <- paste0("../data/wc2.0_", res, "m_bio_1970-2000.zip")
if(!file.exists(bio2000_file))
  download.file(
    paste0(
      "http://biogeo.ucdavis.edu/data/worldclim/v2.0/tif/base/wc2.0_",
      res, "m_bio.zip"),
    destfile = bio2000_file)
unzip(bio2000_file, files = paste0("wc2.0_bio_", res, "m_12.tif"),
      overwrite = FALSE, exdir = "../data" )

prec_2000 <- raster(paste0("../data/wc2.0_bio_", res, "m_12.tif"))

gcms <- list("ac", "bc", "cc", "cn", "gf", "gs", "hd", "he", "hg",
             "in", "ip", "mc","mg", "mi", "mp", "mr", "no")
length(gcms)
```

```
## [1] 17
```

```
sapply(gcms, function(g){
  bio2070_file <- paste0("../data/cmip5/", res, "m/rcp", rcp, "/",
                         g, rcp, "bi7012.zip")
  if(!file.exists(bio2070_file))
    download.file(
      paste0("http://biogeo.ucdavis.edu/data/climate/cmip5/", webres, "m/",
             g, webrcp,"bi70.zip"),
```

```
      destfile = bio2070_file)
  unzip(bio2070_file, files = paste0(g, webrcp, "bi70", "12.tif"),
        overwrite = FALSE,
        exdir = paste0("../data/cmip5/", res, "m/rcp", rcp))
})
```

```
##  [1] "../data/cmip5/2.5m/rcp8.5/ac85bi7012.tif"
##  [2] "../data/cmip5/2.5m/rcp8.5/bc85bi7012.tif"
##  [3] "../data/cmip5/2.5m/rcp8.5/cc85bi7012.tif"
##  [4] "../data/cmip5/2.5m/rcp8.5/cn85bi7012.tif"
##  [5] "../data/cmip5/2.5m/rcp8.5/gf85bi7012.tif"
##  [6] "../data/cmip5/2.5m/rcp8.5/gs85bi7012.tif"
##  [7] "../data/cmip5/2.5m/rcp8.5/hd85bi7012.tif"
##  [8] "../data/cmip5/2.5m/rcp8.5/he85bi7012.tif"
##  [9] "../data/cmip5/2.5m/rcp8.5/hg85bi7012.tif"
## [10] "../data/cmip5/2.5m/rcp8.5/in85bi7012.tif"
## [11] "../data/cmip5/2.5m/rcp8.5/ip85bi7012.tif"
## [12] "../data/cmip5/2.5m/rcp8.5/mc85bi7012.tif"
## [13] "../data/cmip5/2.5m/rcp8.5/mg85bi7012.tif"
## [14] "../data/cmip5/2.5m/rcp8.5/mi85bi7012.tif"
## [15] "../data/cmip5/2.5m/rcp8.5/mp85bi7012.tif"
## [16] "../data/cmip5/2.5m/rcp8.5/mr85bi7012.tif"
## [17] "../data/cmip5/2.5m/rcp8.5/no85bi7012.tif"
```

```
lapply(gcms,  function(gcm)
  paste0("../data/cmip5/", res, "m/rcp", rcp, "/", gcm, webrcp,"bi7012.tif"))
```

```
## [[1]]
## [1] "../data/cmip5/2.5m/rcp8.5/ac85bi7012.tif"
##
## [[2]]
## [1] "../data/cmip5/2.5m/rcp8.5/bc85bi7012.tif"
##
## [[3]]
## [1] "../data/cmip5/2.5m/rcp8.5/cc85bi7012.tif"
##
## [[4]]
## [1] "../data/cmip5/2.5m/rcp8.5/cn85bi7012.tif"
##
## [[5]]
## [1] "../data/cmip5/2.5m/rcp8.5/gf85bi7012.tif"
##
## [[6]]
## [1] "../data/cmip5/2.5m/rcp8.5/gs85bi7012.tif"
##
## [[7]]
## [1] "../data/cmip5/2.5m/rcp8.5/hd85bi7012.tif"
##
## [[8]]
## [1] "../data/cmip5/2.5m/rcp8.5/he85bi7012.tif"
##
## [[9]]
## [1] "../data/cmip5/2.5m/rcp8.5/hg85bi7012.tif"
##
```

```
## [[10]]
## [1] "../data/cmip5/2.5m/rcp8.5/in85bi7012.tif"
##
## [[11]]
## [1] "../data/cmip5/2.5m/rcp8.5/ip85bi7012.tif"
##
## [[12]]
## [1] "../data/cmip5/2.5m/rcp8.5/mc85bi7012.tif"
##
## [[13]]
## [1] "../data/cmip5/2.5m/rcp8.5/mg85bi7012.tif"
##
## [[14]]
## [1] "../data/cmip5/2.5m/rcp8.5/mi85bi7012.tif"
##
## [[15]]
## [1] "../data/cmip5/2.5m/rcp8.5/mp85bi7012.tif"
##
## [[16]]
## [1] "../data/cmip5/2.5m/rcp8.5/mr85bi7012.tif"
##
## [[17]]
## [1] "../data/cmip5/2.5m/rcp8.5/no85bi7012.tif"
```

Organise the data as raster layers.

```
prec_2070 <- stack(lapply(gcms,  function(gcm)
  raster(paste0("../data/cmip5/", res, "m/rcp", rcp, "/",
                gcm, webrcp,"bi7012.tif"))))

prec_2000 <- crop(prec_2000, extent(prec_2070[[1]]))
prec_2070 <-  stack(stack(prec_2000), prec_2070)
names(prec_2070) <- paste0("pr_", c("pres", paste0("fut_", unlist(gcms))))
```

Convert to data frames and then calculate metrics. For the paper, we only present a simple metric from Malhi et al 2008, Science. However, also estimate some other metrics here - the overall patterns are very similar.

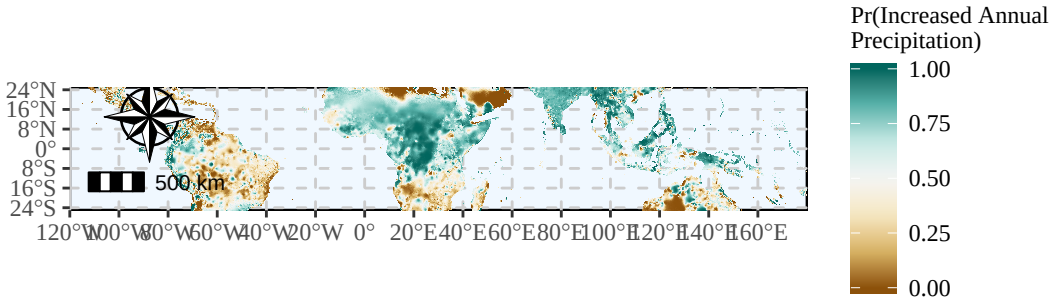
```
tropbounds <- list(x=c(-120, 180), y=c(-25, 25))
## get data from with each GCM in a column
tropprec_df <- prec_2070 %>% crop(extent(tropbounds)) %>%
  as.data.frame(xy=TRUE) %>%
  melt(id.vars=c("x", "y")) %>%  filter(!is.na(value)) %>%
  spread(key = variable, value = value)

## future columns
futcols <- vars_select(names(tropprec_df), starts_with("pr_fut"))

tropprec_df$pr_fut <- apply(tropprec_df[,futcols], 1, mean) # mean future
tropprec_df$pr_fut_sd <- apply(tropprec_df[,futcols], 1, sd) # sd future

tropprec_df <- tropprec_df %>% mutate(r_pr_fut = pr_fut/pr_pres) ## ratio fut/pres

## get some locations with 0/0, which are no change, so 1
tropprec_df$r_pr_fut[tropprec_df$pr_pres == 0 & tropprec_df$pr_fut==0] <- 1

## z score of change, converted to a probability (experimental).
```

```
tropprec_df <- tropprec_df %>% mutate(t_pr_fut = pnorm((pr_fut - pr_pres)/pr_fut_sd))

## set to 0.5 (i.e. no difference) when there is no difference between
## present and future and no variation among future projections.
tropprec_df$t_pr_fut[apply(tropprec_df[, c("pr_pres", futcols)],
                           1, function(x) var(x)==0)] <- 0.5

## rank of present precip in grid squre compared to projections of
## future precip in grid squre
## This is the metric used in the paper
tropprec_df$rank_pr_fut <- apply(tropprec_df[,c("pr_pres", futcols)], 1,
                                 function(x) mean(x[1] < x[-1]))
```

Plotting the projected change in precipitation on a map of the tropics.

```
precip_change <-  ggplot() +
  geom_tile(data=filter(tropprec_df, !is.na(t_pr_fut)),
                        aes(x=x, y=y, fill=t_pr_fut)) +
  geom_sf(data=world, col=NA, fill=NA, size=0.7) +
  coord_sf(xlim = tropbounds$x, ylim = tropbounds$y, expand = FALSE) +
  annotation_scale(location = "bl", width_hint = 0.08) +
  annotation_north_arrow(location = "bl", which_north = "true",
                         pad_x = unit(0.12, "in"), pad_y = unit(0.25, "in"),
                         style = north_arrow_nautical) +
  scale_fill_distiller(type="div", direction = 1, limit=c(0, 1)) +
  scale_x_continuous(breaks=seq(-180, 180,20)) +
  scale_y_continuous(breaks=seq(-24, 24, 8)) +
  labs(x="", y="", fill="Pr(Increased Annual \nPrecipitation)") +
  theme_tufte() +  theme(
    panel.grid.major = element_line(color = gray(0.8), linetype = "dashed",
                                    size = 0.5),
    panel.background = element_rect(fill = "aliceblue"),
    plot.margin = unit(c(0.5, 1, 0, 1), "cm"),
    legend.title=element_text(size=9))

precip_change
```

```
## Scale on map varies by more than 10%, scale bar may be inaccurate
```




```
ggsave("../figures/world_precip_change_pz2_rcp8.5.png", precip_change,
                dpi=600, height =4, width=10, units="in")
```

```
## Scale on map varies by more than 10%, scale bar may be inaccurate
```