Climatology of low-level inversions within first 3 meters

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Introduction

Low-level temperature inversions are atmospheric events where the cool air stays under the warm air, having a stable air mass with no convection currents flowing in the atmosphere. Indiana has almost a years' worth of data at 9 mesonet sites throughout the state, so it could be possible to develop an hourly-by-month climatology of low-level inversions for any given site. Having this climatology would be helpful for farmers to better understand the timing when certain volatile chemicals are most likely to drift and damage certain crops if an inversion is present as it is a phenomenon with uncertain climatology.

Rationale

Usually, atmospheric temperature decreases with height. This phenomenon occurs because radiation from the sun warms surface and air it tends to rise over the cool air in the atmosphere. This promotes vertical mixing in the lower atmosphere. Low-level inversions disrupt the natural air cycle. By its very nature, low-level inversions occur more commonly in absence of the sun: at night. Where the sun is not constantly heating up the surface which generates hot air that then rises.

The problem that low-level inversions that cause is that, due to the air's stability, any pollutants, chemicals, or particles in the air can travel long horizontal distances as limited vertical circulation occurs. In other words, during an inversion, these chemicals stay in the warm air until the surface heats enough to generate convection currents where they fall.

A few indicators of low-level inversions mentioned and studied in detail by University of Minnesota (Mizzou Weed Science, 2017) are: the lack of wind, low level fog, dew or frost at the surface, and a clear sky with no cumulus clouds. Specifically, <3 mph winds speeds were shown to be greatly correlated with low-level inversions. However, no clear climatology has been conducted over the behavior low-level inversions in Indiana, which poses a serious problem for farmers who plan to spread chemicals on their crops. Information on what times-of-year and times-of-day likely to be free from low-level inversions would be helpful for crop management.

Methods

Summary

The study analyzed data stored in the Mesonet Data Hub (2022). I downloaded data from Feldun PAC - Bedford (FPAC) at 38.88°N, 86.55°W, July 2021, and 30-Minute Data. I rearranged the raw data in RStudio to create a useful new table that would be used to generate the plots for the analysis. The inversion strength calculations done in the database is the maximum value difference between the temperature calculation at 3m – 1.5m, or 3m – 0.5m, or 1.5m – 0.5m from the surface. Negative values are set to an inversion strength of zero. We know the equipment has a 2°C uncertainty in its measurements, meaning that inversions less than 2 degrees can be due to instrumentation error. There is a chance of 4 degrees of uncertainty, but for the purposes of the study, we do not wish to dismiss potential inversions. There is also a 2m sensor but given the possibility that is calibrated differently from the other three, no conclusions wish to be drawn from it.

Code Method

The R script developed defined a series of functions that would help generalize and automize the calculations and plot generations without copy pasting the same process repeatedly. The first function defined was Get All Data Points(). In it, we access the raw data and isolate the columns we are interested in. Then, Generate Plot Inversion Hour() which is an automation of a summary plot of inversion strengths by hour for a given month. Create Histogram Density() is a function that automates the plotting of how often was a given inversion strength occurred throughout the month as a whole. Create Histogram Frequency(), this function is similar to the one before but the y-axis is the number of occurrences when a given inversion strength occurred. Create Histogram Frequency Positive() was a very similar function to the previous one with the exception of removing all the zero valued inversions, Plot Inversion All Data() is a helper function that generates a table with all the inversion strengths to better facilitate the other functions and readability for the user. Main Method() is an excerpt as an example of how the previous defined functions were accessed to generate the tables and plots.

Results

All these plots are generated by the local time at the FPAC station. In July 2021, in other words, -04:00 UTC/GMT. From the coordinates of the station, we can calculate the sunrise to be around 6:30AM and sunset around 9:30PM (Sunrise Sunset Calculator). View 'Figure 5 - Sunrise Sunset Calculations for July 2021' for further details. In 'Figure 2 - Inversion Strength Plot throughout July 2021 Summarized by Hour' the time is represented in 24-hour format, treating each half hour as 0.5 more for that hour. For example, 12AM is 0, 12:30PM is 12.5, and 8PM is 20. Also, inversion strength is calculated as above in Celsius.

There were five plots generated by the code shown.

Figure 1 - Inversion Strength Plot throughout July 2021

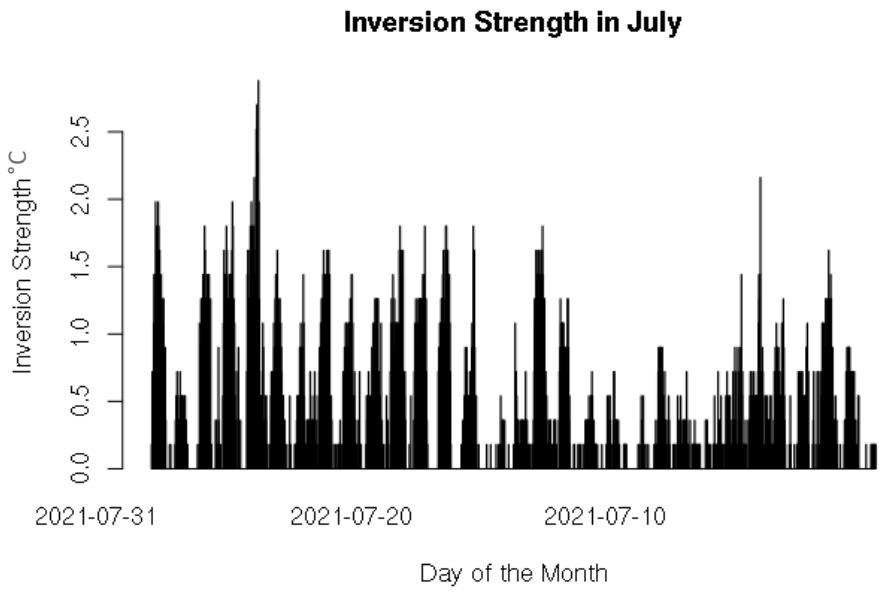


Figure 2 - Inversion Strength Plot throughout July 2021 Summarized by Hour

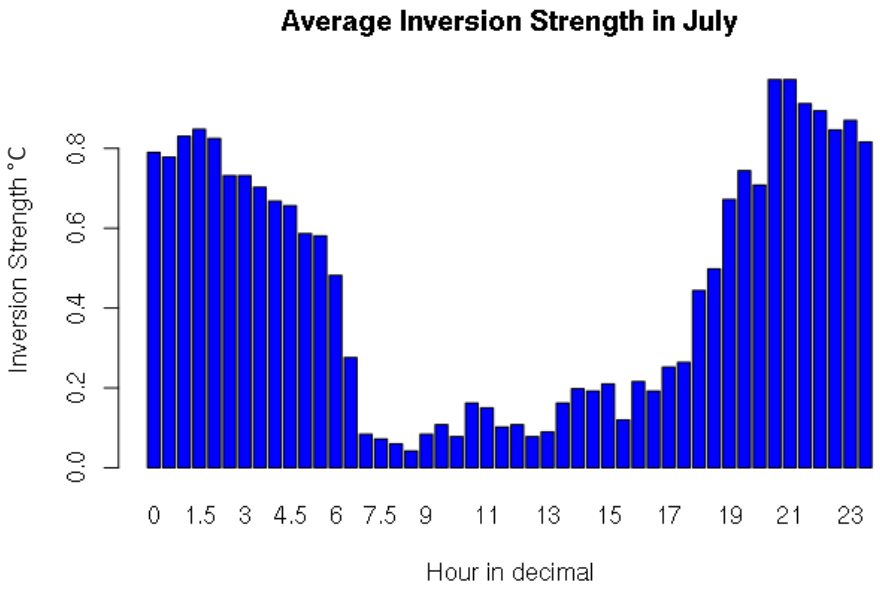


Figure 3 - Inversion Strength Frequency Plot throughout July 2021

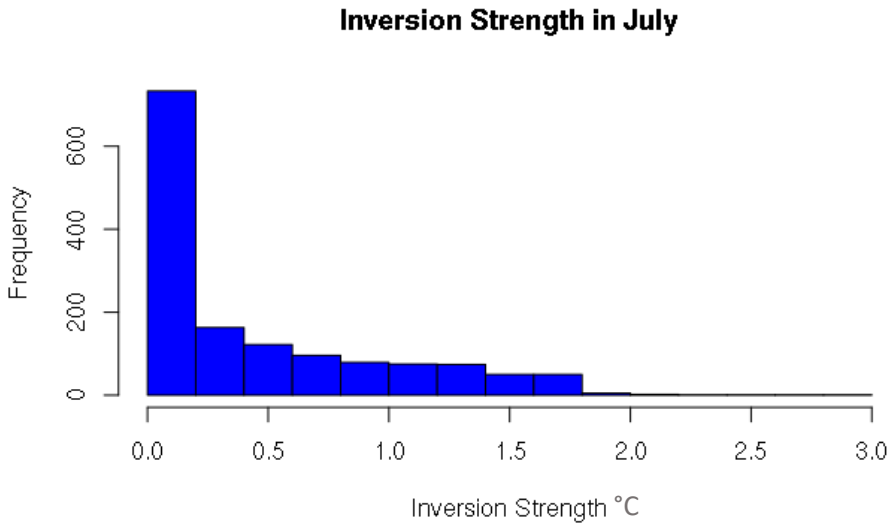
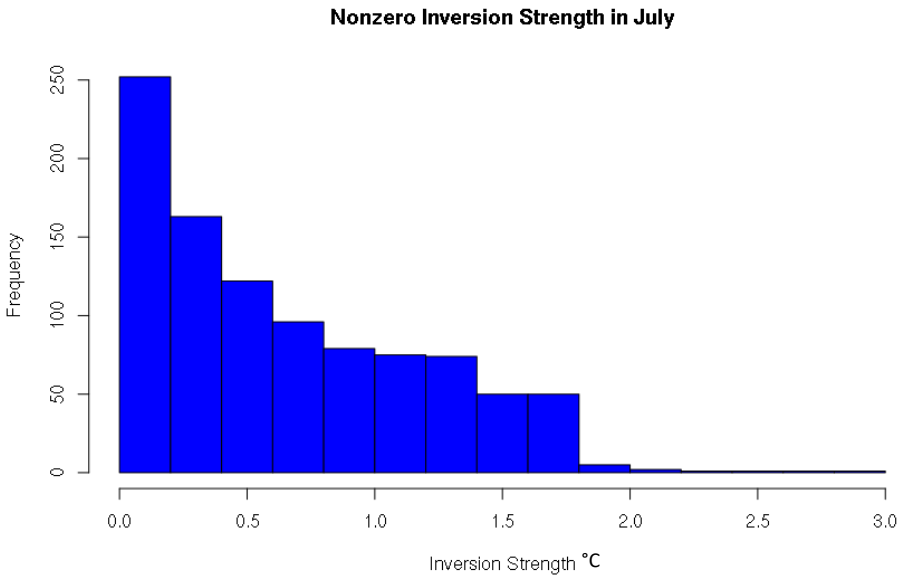


Figure 4 - Nonzero Inversion Strength Frequency in July 2021



Conclusion

From ‘Figure 1 - Inversion Strength Plot throughout July 2021’ we can visualize the cycling nature of low-level temperature inversions and that only one inversion event stronger than 2°C occurred in July (the fifth peak from left to right). ‘Figure 2 - Inversion Strength Plot throughout July 2021 Summarized by Hour’, shows the average calculations per hour throughout the month of July to be lower 1°C, which can be slightly deviated due to instrumentation errors.

From we can see temperature inversion are highly unlikely. Most of the measurements consider no inversions to be occurring, and from ‘Figure 4 - Nonzero Inversion Strength Frequency in July 2021’, we can visualize that even among inversion events, strong inversions are highly unlikely. Even so, some possibility that many of the measured temperature inversions are due to instrumentation error reinforcing the impossibility of low-level temperature inversions.

Taking all figures into consideration, we can conclude it is unlikely to have temperature inversions during the month of July, with lowest likelihood from 6:30AM-6:30PM as inversion strengths are on average smaller or equal than 0.2°C. While the diurnal pattern ranges from 6:30AM-9:30PM. Thus. the average inversion strength is larger at night, as expected; but overall,

the magnitude of the inversions is weak and could be within error of the instruments. Although further research is still required to understand the strength at which the phenomenon may occur. More specifically, that although some inversion events may occur, they are not strong enough to overcome the possibility of instrumentation error. Leaving the current investigation unable to generate further conclusions into the specific climatology of these inversions. Taking into consideration the big limitation in the amount of data, as not many years have been measured and recorded, we cannot generalize the calculations to all the months of July to be quite of this behavior.

Related Products

R Code

Function Definitions

Get All Data Points()

```
> getAllDataPoints <- function(time, monthfile, monthnum) {
+     timetable <- data.frame()
+     if (time > 11.5) {
+         halfday <- sprintf("PM")
+     } else {
+         halfday <- sprintf("AM")
+     }
+     if (time < 1) {
+         time <- 12 + time
+     }
+     if (time > 12.5) {
+         time <- time - 12
+     }
+     if (as.integer(time) != time) {
+         halfhour <- sprintf("30")
+     } else {
+         halfhour <- sprintf("00")
+     }
+     if (monthnum < 10) {
+         monthnumstr <- sprintf("0%d", as.integer(monthnum))
+     } else {
+         monthnumstr <- sprintf("%d", as.integer(monthnum))
```

```
+     }
+     if (time < 10) {
+       timestr <- sprintf("0%d", as.integer(time))
+     } else {
+       timestr <- sprintf("%d", as.integer(time))
+     }
       # for a given month the number of days may change
+     for (day in 1:31) {
+       if (day < 10) {
+         daystr <- sprintf("0%d", day)
+       } else {
+         daystr <- day
+       }
+       for (row in 1:nrow(monthfile)) {
+         if (monthfile[row, ]$Time..LST. == sprintf("2021-%s-%s %s:%s %s", monthnumstr, daystr, timestr, halfhour, halfday)) {
+           timetable <- rbind(timetable, monthfile[row, ])
+         }
+       }
+     }
+     return(timetable)
+ }
```

Generate Plot Inversion Hour()

```
> generatePlotInversionHour <- function(monthfile, month) {
+     time <- 0.0
+     momentaneous = data.frame()
+     while (time < 24) {
+       timetable <- getAllDataPoints(time, monthfile, month)
+       avg <- mean(timetable$Inversion.Strength)
+       momentaneous <- rbind(momentaneous, c(time, avg))
+       time <- 0.5 + time
+     }
+     colnames(momentaneous) <- c("Hour", "Average")
+     barplot(momentaneous$Average,names.arg=momentaneous$Hour,xlab="Hour in decimal",ylab="Inversion Strength",col="blue", main=sprintf("Average Inversion Strength in %s", monthfile))
+     return(momentaneous)
+ }
```

Create Histogram Density()

```
> createHistogramDensity <- function(monthfile) {
+     hist(monthfile$Inversion.Strength, main="Inversion Strength in July",
+          xlab="Inversion Strength",
+          col="blue",
```

```
+         freq = FALSE)
+ }
```

Create Histogram Frequency()

```
> createHistogramFrequency <- function(monthfile) {
+     hist(monthfile$Inversion.Strength, main="Inversion Strength in July",
+         xlab="Inversion Strength",
+         col="blue")
+ }
```

Create Histogram Frequency Positive()

```
> createHistogramFrequencyPositive <- function(monthfile) {
+ plot = data.frame()
+ for (row in 1:nrow(monthfile)) {
+     if (monthfile[row, ]$Inversion.Strength > 0) {
+         plot <- rbind(plot, c(monthfile[row, ]$Inversion.Strength))
+     }
+ }
+ colnames(plot) <- c("Inversion.Strength")
+ hist(plot$Inversion.Strength, main="Nonzero Inversion Strength in July", xlab="Inversion
Strength",col="blue")
+ }
```

Plot Inversion All Data()

```
> PlotInversionAllData <- function(monthfile, monthnum) {
+     row <- nrow(monthfile)
+     plot <- data.frame()
        # for a given month the number of days may change
+     for (day in 1:31) {
+         time1 <- 0.0
+         if (day < 10) {
+             daystr <- sprintf("0%d", day)
+         } else {
+             daystr <- sprintf("%d", day)
+         }
+         while (time1 < 24) {
+             if (row == 0) {
+                 break
+             }
+             time <- time1
+             if (time > 11.5) {
+                 halfday <- sprintf("PM")
+             } else {
+                 halfday <- sprintf("AM")
+             }
```

```
+            if (time < 1) {
+               time <- 12 + time
+            }
+            if (time > 12.5) {
+               time <- time - 12
+            }
+            if (as.integer(time) != time) {
+               halfhour <- sprintf("30")
+            } else {
+               halfhour <- sprintf("00")
+            }
+            if (monthnum < 10) {
+               monthnumstr <- sprintf("0%d", as.integer(monthnum))
+            } else {
+               monthnumstr <- sprintf("%d", as.integer(monthnum))
+            }
+            if (time < 10) {
+               timestr <- sprintf("0%d", as.integer(time))
+            } else {
+               timestr <- sprintf("%d", as.integer(time))
+            }
+            if (monthfile[row, ]$Time..LST. == sprintf("2021-%s-%s %s:%s %s", monthnumstr, daystr, timestr, halfhour, halfday)) {
+               plot <- rbind(plot, c(monthnum, day, sprintf("%s:%s %s", timestr, halfhour, halfday), monthfile[row, ]$Inversion.Strength))
+               row <- row - 1
+            }
+            time1 <- time1 + 0.5
+         }
+      }
+      colnames(plot) <- c("Month", "Day", "Hour", "Inversion.Strength")
+      return(plot)
+ }
```

Main Method()

```
> july <- read.csv("July FPAC.csv", header = TRUE)
> all <- PlotInversionAllData(july, 7)
> barplot(july$Inversion.Strength,names.arg=july$Time..LST.,xlab="Day of the Month",ylab="Inversion Strength",col="blue", main=sprintf("Inversion Strength in %s", "July"))
> plot <- createHistogramFrequencyPositive(july)
```

Additional Data

Figure 5 - Sunrise Sunset Calculations for July 2021

Day	Date	Civil Dawn	Sunrise	Sunset	Civil Dusk
Thu	7/1	5:53 am	6:24 am	9:15 pm	9:47 pm
Fri	7/2	5:53 am	6:25 am	9:15 pm	9:47 pm
Sat	7/3	5:54 am	6:25 am	9:15 pm	9:46 pm
Sun	7/4	5:54 am	6:26 am	9:15 pm	9:46 pm
Mon	7/5	5:55 am	6:27 am	9:14 pm	9:46 pm
Tue	7/6	5:56 am	6:27 am	9:14 pm	9:46 pm
Wed	7/7	5:56 am	6:28 am	9:14 pm	9:45 pm
Thu	7/8	5:57 am	6:28 am	9:13 pm	9:45 pm
Fri	7/9	5:58 am	6:29 am	9:13 pm	9:45 pm
Sat	7/10	5:58 am	6:30 am	9:13 pm	9:44 pm
Sun	7/11	5:59 am	6:30 am	9:12 pm	9:44 pm
Mon	7/12	6:00 am	6:31 am	9:12 pm	9:43 pm
Tue	7/13	6:01 am	6:32 am	9:11 pm	9:43 pm
Wed	7/14	6:01 am	6:32 am	9:11 pm	9:42 pm
Thu	7/15	6:02 am	6:33 am	9:10 pm	9:41 pm
Fri	7/16	6:03 am	6:34 am	9:10 pm	9:41 pm
Sat	7/17	6:04 am	6:35 am	9:09 pm	9:40 pm
Sun	7/18	6:05 am	6:35 am	9:09 pm	9:39 pm
Mon	7/19	6:06 am	6:36 am	9:08 pm	9:39 pm
Tue	7/20	6:06 am	6:37 am	9:07 pm	9:38 pm
Wed	7/21	6:07 am	6:38 am	9:07 pm	9:37 pm
Thu	7/22	6:08 am	6:39 am	9:06 pm	9:36 pm
Fri	7/23	6:09 am	6:39 am	9:05 pm	9:35 pm
Sat	7/24	6:10 am	6:40 am	9:04 pm	9:34 pm
Sun	7/25	6:11 am	6:41 am	9:03 pm	9:34 pm
Mon	7/26	6:12 am	6:42 am	9:03 pm	9:33 pm
Tue	7/27	6:13 am	6:43 am	9:02 pm	9:32 pm
Wed	7/28	6:14 am	6:44 am	9:01 pm	9:31 pm
Thu	7/29	6:15 am	6:45 am	9:00 pm	9:30 pm
Fri	7/30	6:16 am	6:45 am	8:59 pm	9:29 pm

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