Research Experiences
for Undergraduates
National Science Foundation

Flight Rules Category (FRC) Prediction Using CPC 6-10 Day Forecasts

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SMAG REU Program

Outline

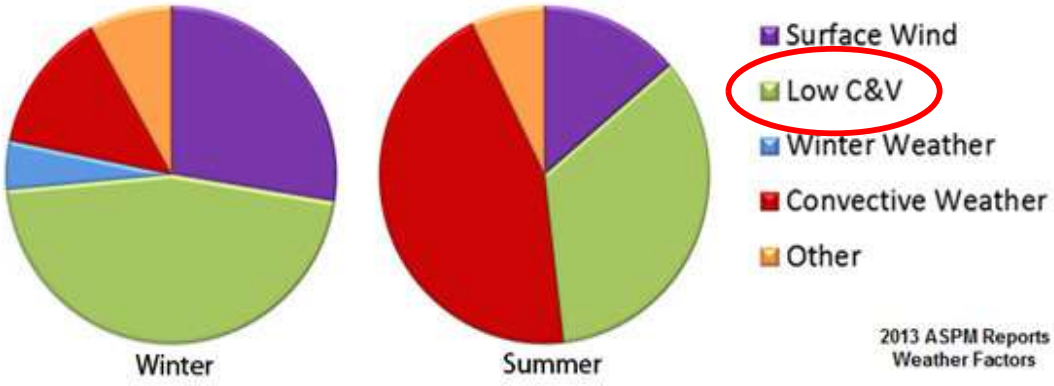
- Introduction & Relevant Work
- Datasets & Methods
- Results & Modeling
- Conclusion & Discussion

https://blueskypit.com/2019/02/07/flying-in-fog/

Why is weather important to aviation?

- Weather causes **70%** of delays
- In 2019, delays cost as much as **$33 billion** (FAA)
- Burning fuel releases an additional **7.1 million metric tons of CO_2 each year** (Committee, U., 2008).

These types of weather contributed to delays at Newark, LaGuardia and JFK in winter versus summer in 2013.



https://www.faa.gov/nextgen/programs/weather/faq/

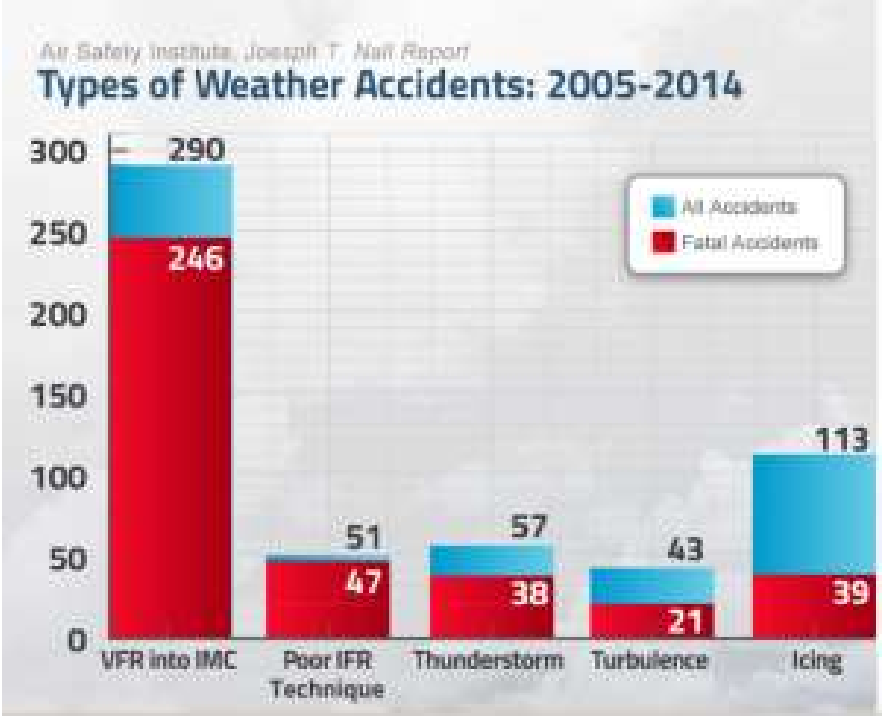
Defining Flight Rules Categories (FRCs)

Flight Rules Category (FRC)	Ceiling (ft AGL)	Visibility
Visual (VFR)	Greater than 3,000	Greater than 5 miles
Marginal Visual (MVFR)	1,000 to 3,000	3 to 5 miles
Instrument (IFR)	500 to 1,000	1 to 3 miles
Low Instrument (LIFR)	Less than 500	Less than 1 mile

- FRC is determined by **Ceiling** and **Visibility** (C&V)
- Low C&V → IFR & LIFR
  - Further separation, reduced efficiency
  - SFO arrival rate – 54 vs 36 per hour (Stevens, 2019)

Safety

- 27% of weather-related aviation accidents and 71% of fatalities are due to poor C&V (Fultz & Walker, 2016)
- “VFR into IMC” (good into bad)



https://safeblog.org/2018/09/08/vfr-into-imc-execute-your-parachute-option/

Relevant Work

Using the Second-Generation GEFS Reforecasts to Predict Ceiling, Visibility, and Aviation Flight Category (Verlinden & Bright 2017)

- Used the Global Ensemble Forecast System to predict ceiling and visibility out to 30 hours
- Yielded skillful predictions
- Short-term forecasting has been done

Predicting the Predominant Winter Flight Category in Central Ohio Using ENSO Indices (Frederick, 2012)

- Used El Niño Southern Oscillation indices to predict winter FRC.
- Found possible links
- Seasonal or long-term forecasting has been done

Using Climate Forecasts for Drought Management (Steinemann, 2006)

- Used Climate Prediction Center (CPC) forecasts for precipitation for drought management in Georgia
- Benefits of using their forecast precipitation index ranges from $30-$350 million dollars per year
- Demonstrates utility of CPC forecasts

Relevant Work

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- Yielded skillful predictions of C&V out to 30 h

Predicting the Predominant Winter Flight Category in Central Ohio Using ENSO Indices (Frederick, 2012)

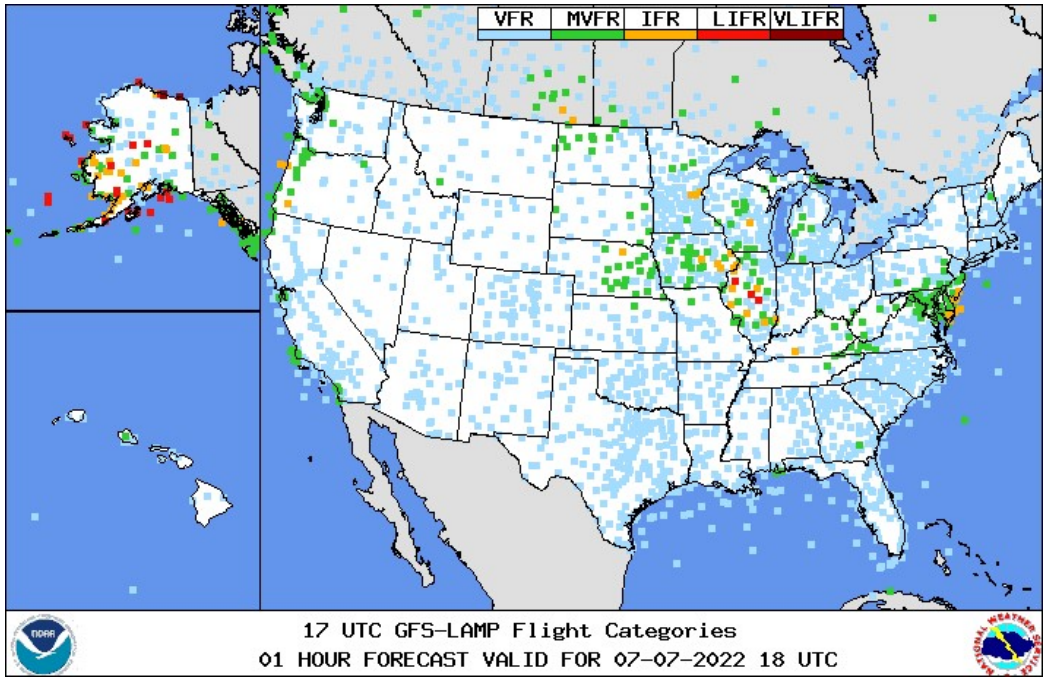
- Found links between ENSO indices and winter FRC rates

Using Climate Forecasts for Drought Management (Steinemann, 2006)

- Applied Climate Prediction Center precipitation outlooks to drought management

Summary of Literature Review

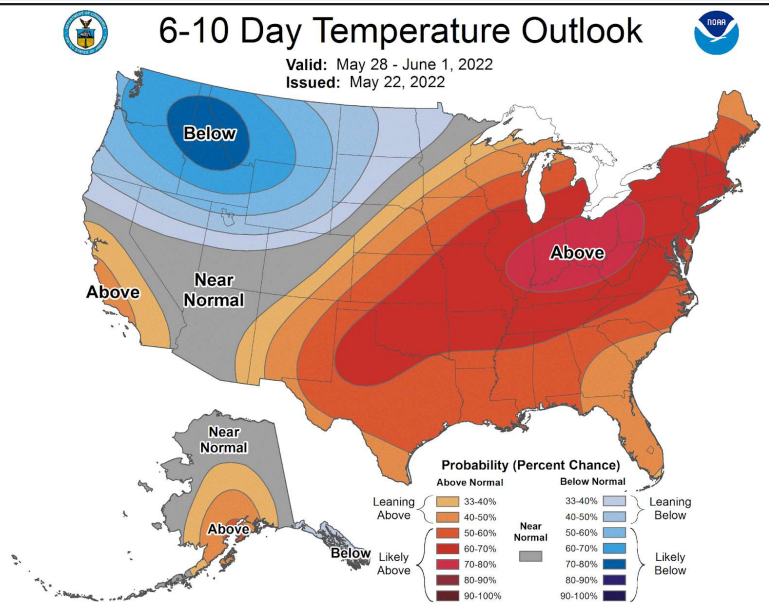
- Climate parameters have been used to predict FRCs
- Current work is mainly focused on short-term (up to 48 h) or seasonal forecasts.
- Intermediate term forecasting has not yet been done for FRCs
- Utility of CPC forecasts

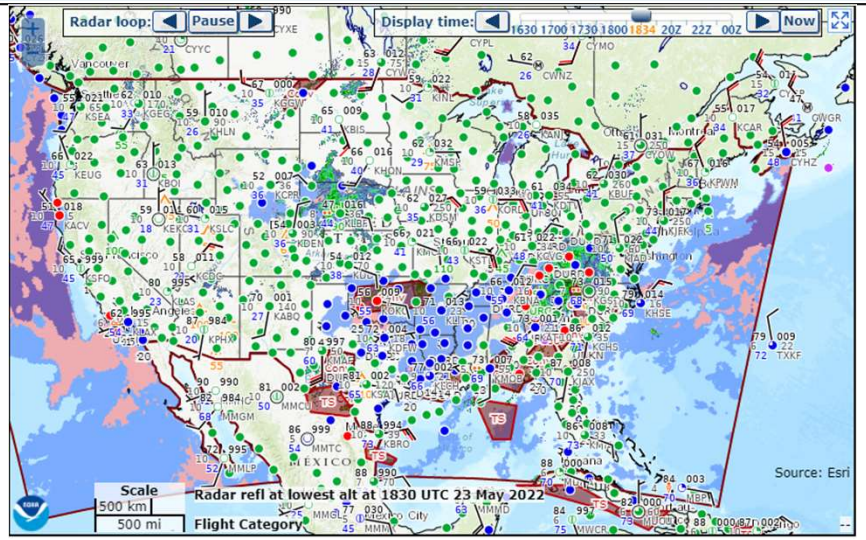


https://www.nws.noaa.gov/mdl/gfslamp/stnplots.php

Datasets & Methods

Goal: Can we use CPC 6-10 day outlooks to predict observed FRCs?





Climate Prediction Center (CPC):

- 6-10 day temp. & precip. outlooks
- Probabilities & Categories:

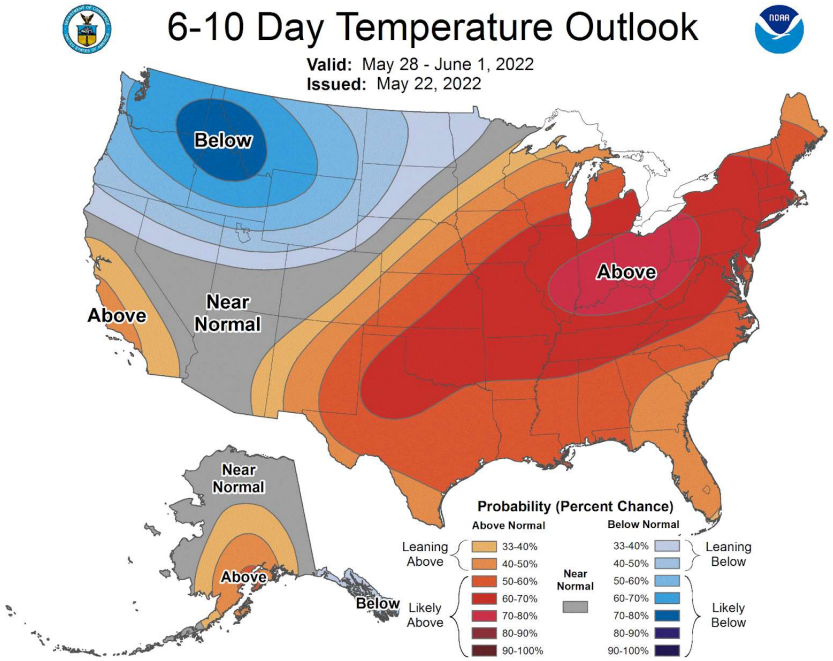
below-normal, normal, above-normal

Meteorological Terminal Air Reports (METARs):

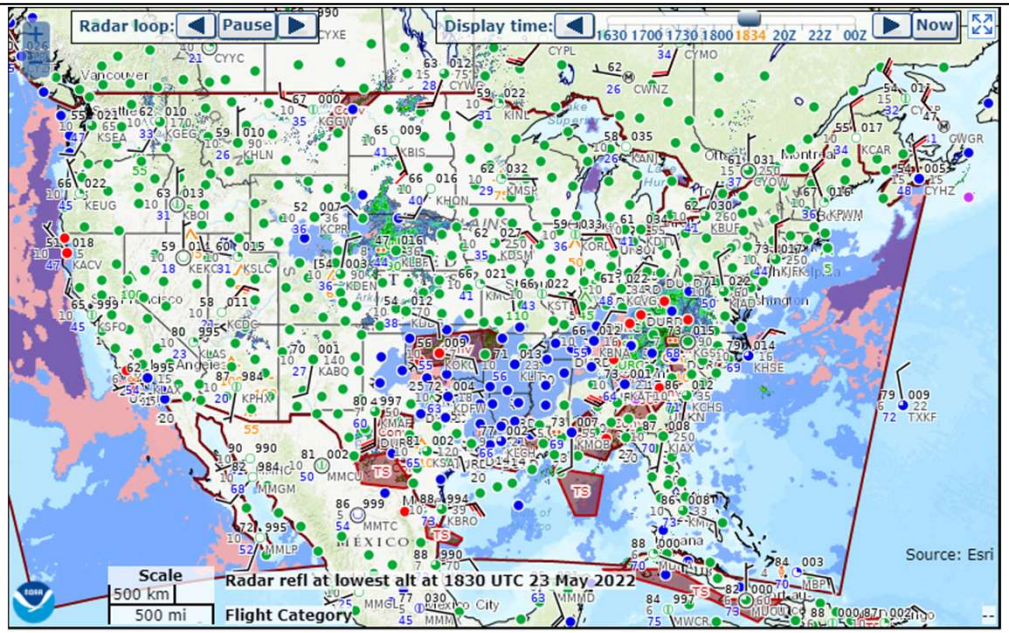
- Observed C&V (5-min & hourly)
  - Derived FRCs

Datasets

CPC 6-10 Day Outlooks



METARs



Climate Prediction Center (CPC):

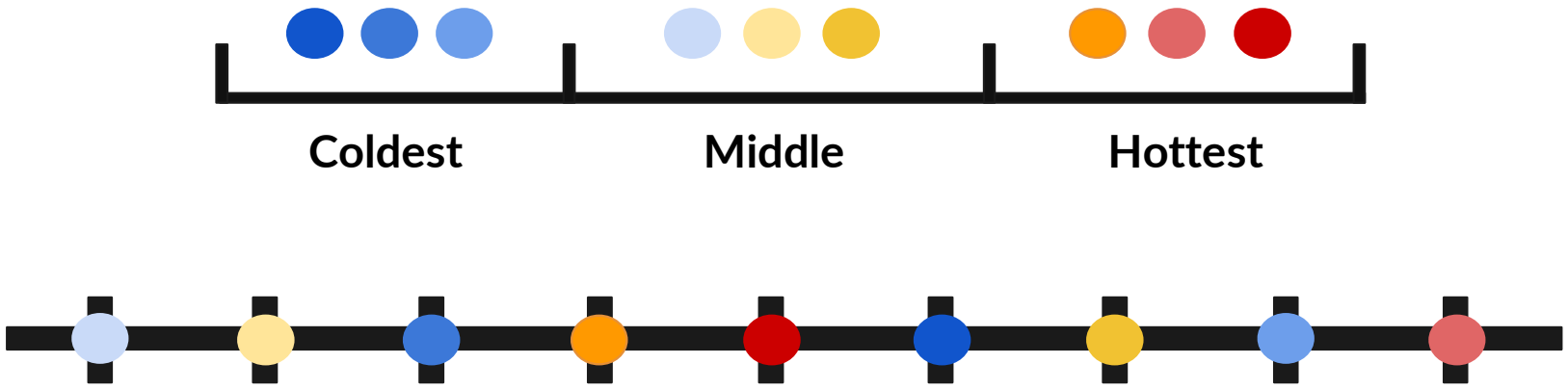
- 6-10 day outlooks for temperature and precipitation

Meteorological Terminal Air Reports (METARs):

- Observed Flight Rules Categories (FRCs) 5 min. & hourly reports

How does the CPC determine the “normal”

- 30 years of daily temperature records
  - Groups each 5-day span of recorded temperatures throughout the 30 years into three categories

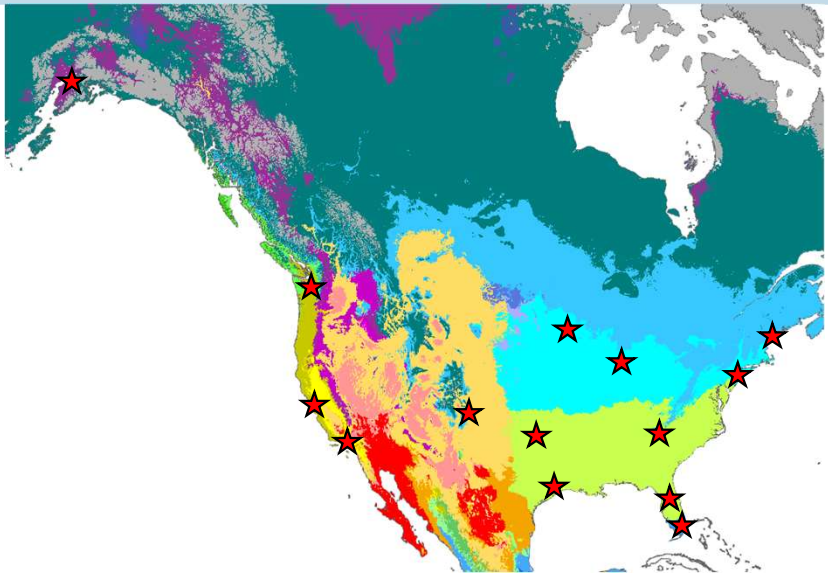


Same 5-day window, different years

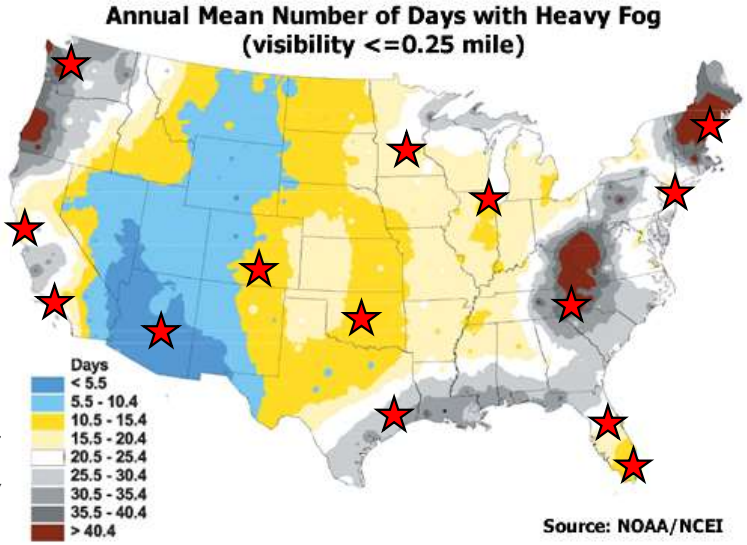
CPC 6-10 Day Outlooks

- Using this **Climatology**, the CPC forecasts the probabilities of Temp. being below-normal, normal, and above-normal then generates an outlook for the most likely

Choosing Airports



Köppen–Geiger climate classifications



Annual fog frequency

- Los Angeles (KLAX)
- San Francisco (KSFO)
- Seattle (KSEA)
- Orlando (KMCO)
- Phoenix (KPHX)
- Colorado Springs (KCOS)
- Houston (KIAH)
- Minneapolis (KMSP)
- Miami (KMIA)
- Asheville (KAVL)
- Portland ME (KPWM)
- Newark (KEWR)
- Anchorage (PANC)
- Oklahoma City (KOKC)
- Chicago (KORD)

Airports in red are among the 10 busiest in the nation

Data Issues

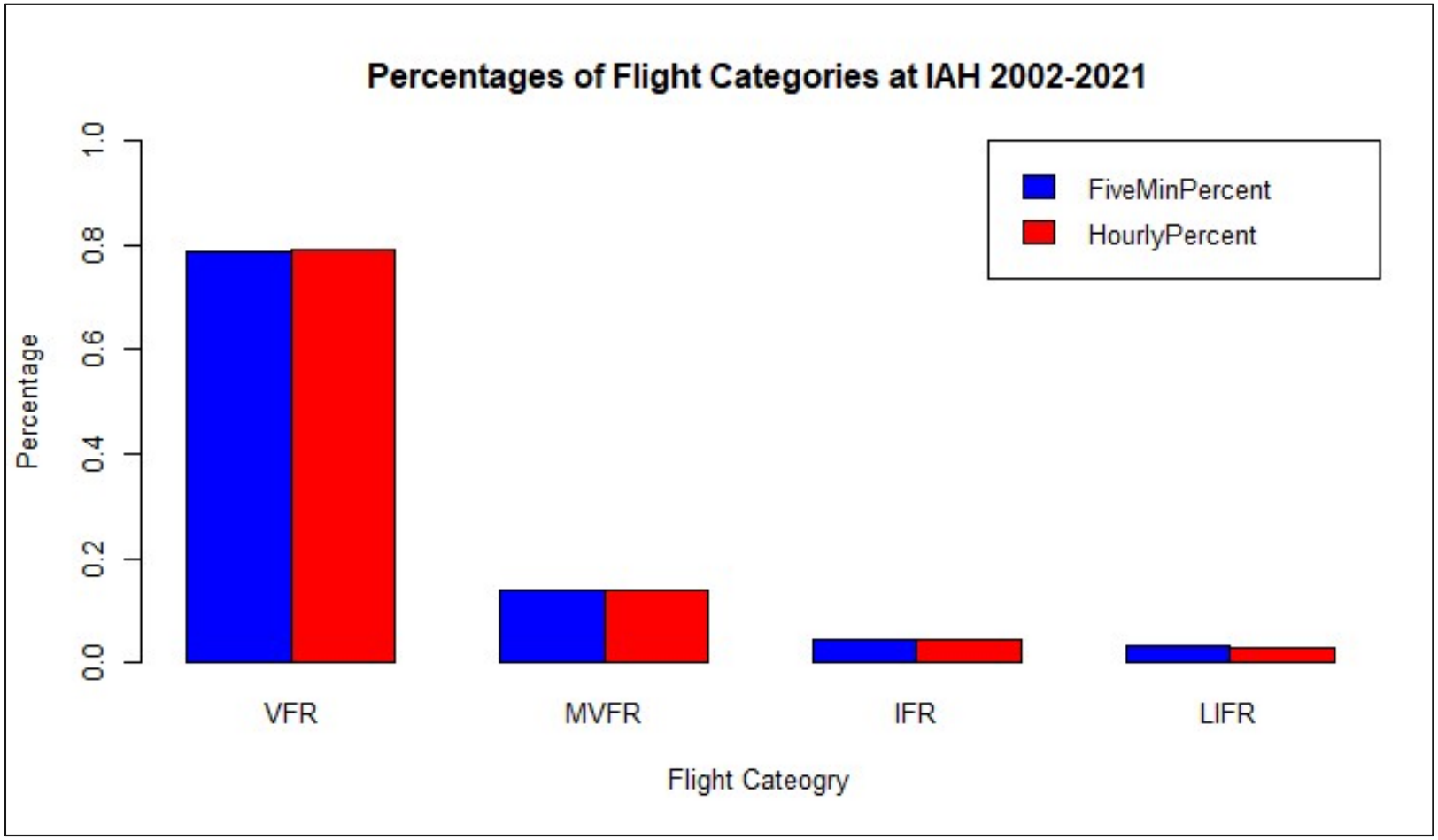
CPC

- **Incorrect dates (early data)**
- **Missing data**
  - Random
  - Weekends

METAR

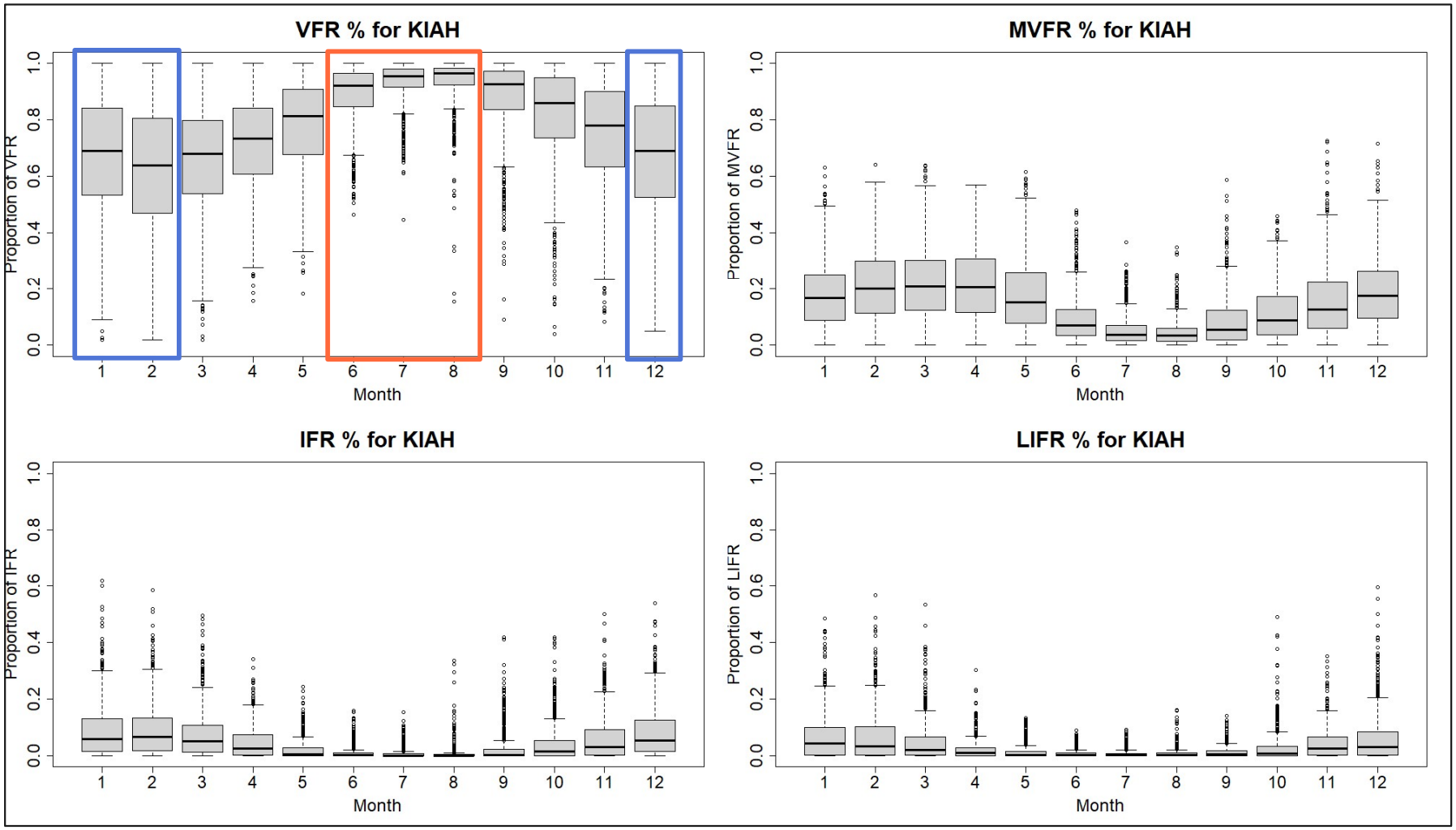
- **Missing data (5-min)**
  - Random
  - Inconsistent counts
- **Dallas & Denver replaced**
  - Oklahoma City
  - Colorado Springs

Combining 5 minute and Hourly data

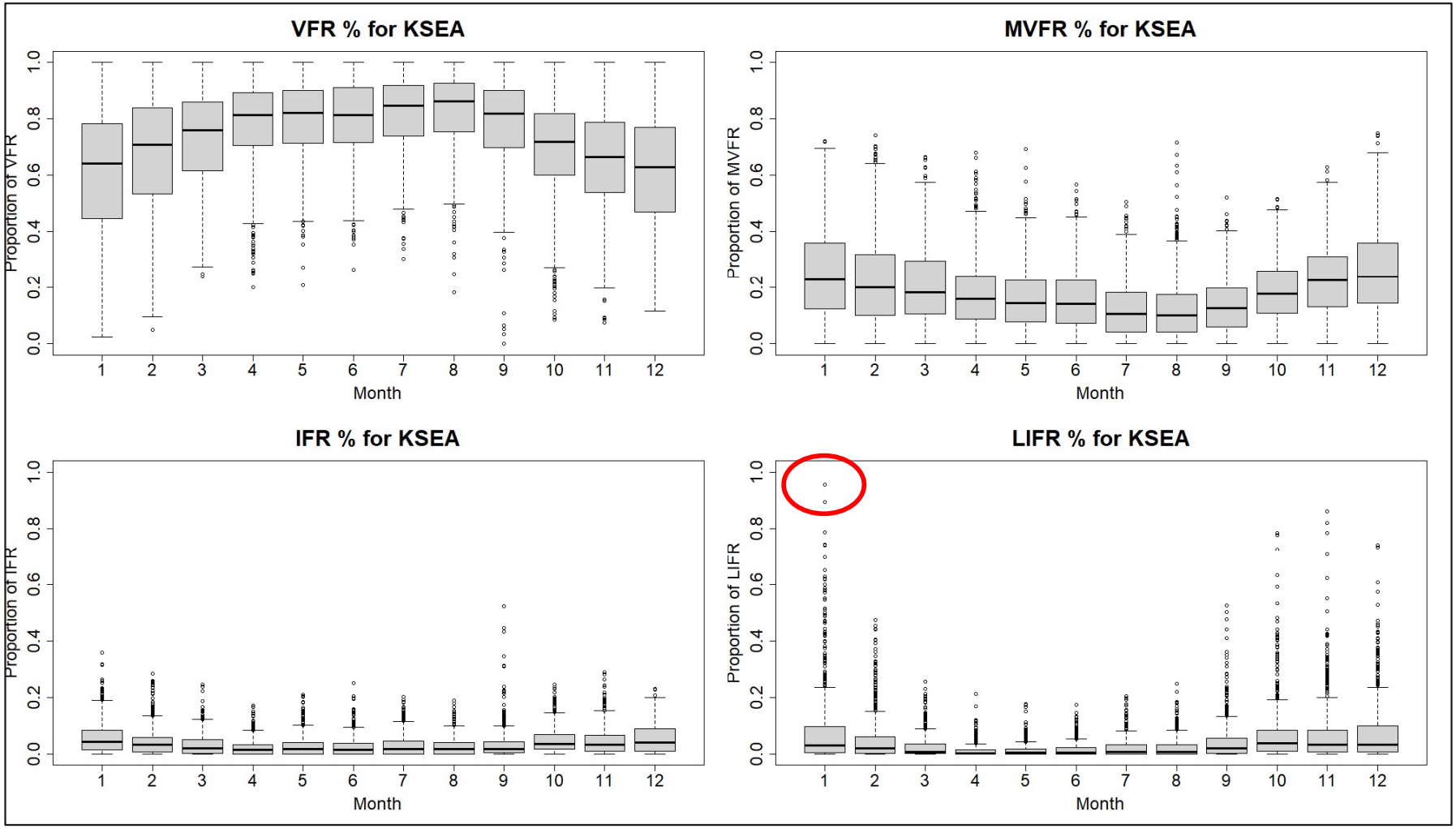


Results & Modeling

KIAH 30-year Observed FRC Climatology (monthly)

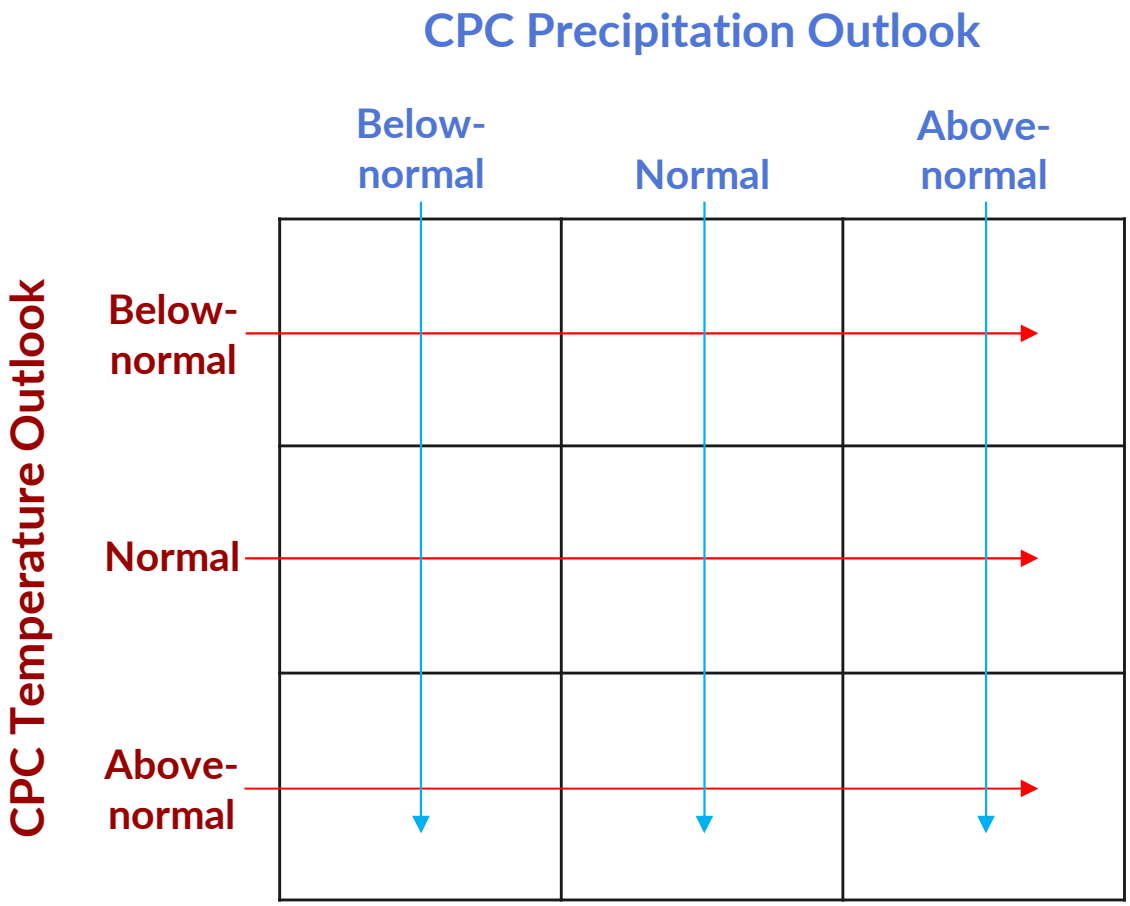


KSEA 30-year Observed FRC Climatology (monthly)



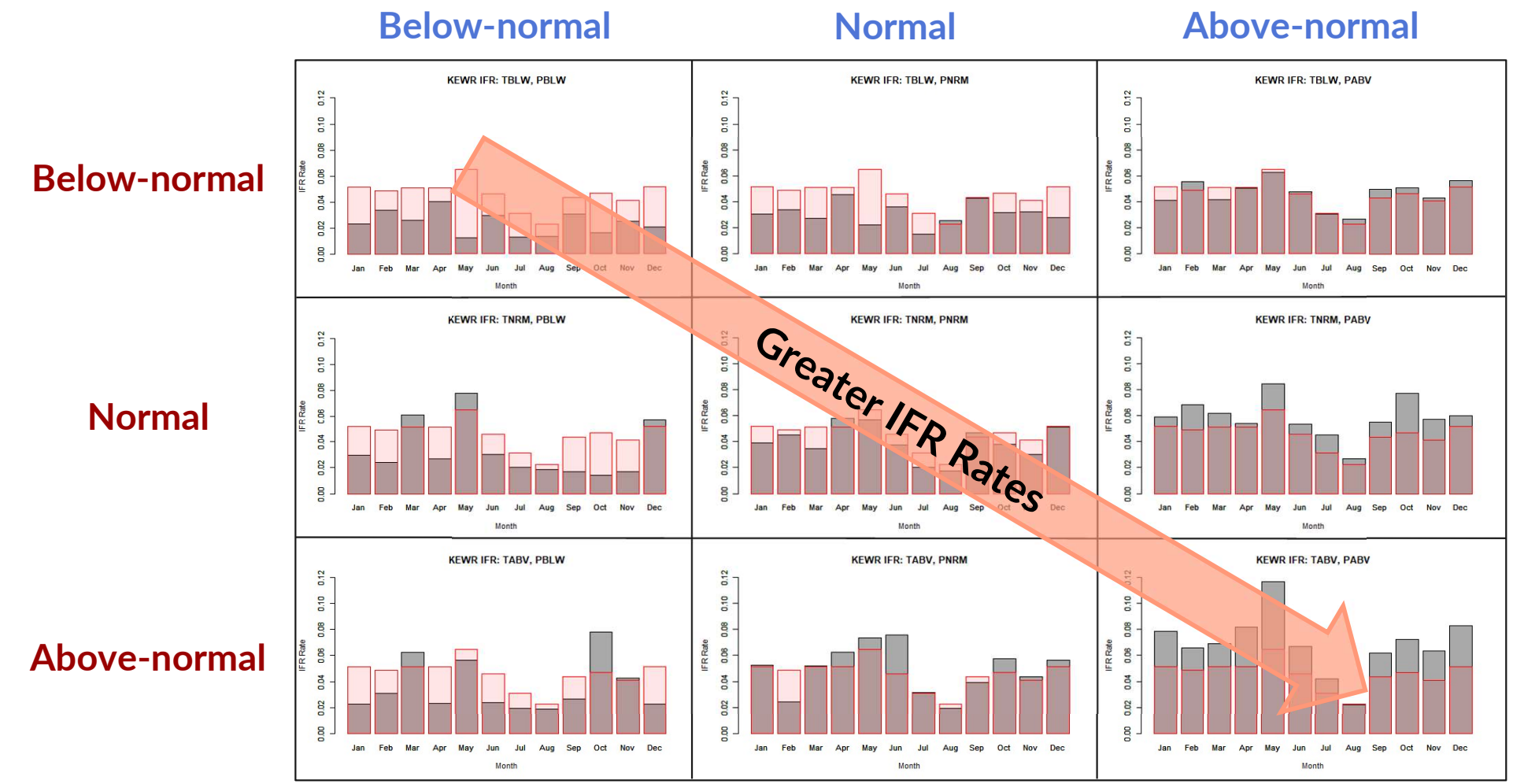
Combining FRC Rates and Climatology with CPC Outlooks

- Compare CPC forecasts to METAR FRC rates
- 9 combinations of CPC categories
- Account for seasonal variability
- Compare to climatology
- Complement statistical modeling



KIAH Observed IFR Rates vs. CPC Categorical Outlooks

KEWR Observed IFR Rates vs. CPC Categorical Outlooks



Modeling

CPC – Predictors

- **Terciles**
  - Probabilities: BLW, NRM, ABV
  - Categories: (1, 2, and 3)
- **Combined metric**
  - $\frac{1*\text{BLW} + 2*\text{NRM} + 3*\text{ABV}}{100}$
- **Month**
- **Interactions**

METAR - Predictands

- **Observed FRCs**
  - 5-day averaged rates for each FRC

Which type of model is best suited for our data?

- Beta Regression

How will we determine which combination of predictors is best?

- Performance on training data (AIC & Pseudo-R^2)

Sample of Modeling Results

- 30 variations of the model for each station, for each FRC
- Sample of the best models for 5 stations (IFR rates)
- Most of the best models had month and interactions as their predictors

Airport	AIC	Pseudo-R^2	Predictors	MSE (Test)
ANC	-37597.0	0.252	Month, Combined metrics, Interactions	0.0022
IAH	-31244.6	0.306	Month, Combined metrics, Interactions	0.0051
MCO	-36991.5	0.172	Month, CPC %s (log), Interactions	0.0168
ORD	-30179.8	0.204	Month, Combined metrics, Interactions	0.0010
SEA	-26069.0	0.106	Month, CPC %s (log), Interactions	0.0022

Table 2: Top performing beta regression models (AIC based) for IFR rates at each selected station. (MSE was only calculated for January 2022)

Conclusion & Discussion

- **Encouraging results**
  - CPC outlooks can be useful in predicting FRC rates
    - Categorical bar plots
    - Modeling based on probabilities

https://stormwater.wef.org/2019/03/passing-planes-pull-added-precipitation-from-clouds-finds-new-study/

Future Work

- **Final model can be improved with additional predictors and methods**
  - Soil moisture/drought index
  - CPC outlooks from multiple stations
  - Predict C&V rather than FRC
  - Inclusion of other climate factors
- **Test the model on a larger independent dataset**

References

- Andrew J. Fultz & Walker S. Ashley (2016) Fatal weather-related general aviation accidents in the United States, Physical Geography, 37:5, 291-312, DOI: 10.1080/02723646.2016.1211854
- Committee, U., 2008. *Your Flight Has Been Delayed Again - Your Flight Has Been Delayed Again - United States Joint Economic Committee*. [online] Jec.senate.gov. Available at: <https:/s/www.jec.senate.gov/public/index.cfm/democrats/2008/5/your-flight-has-been-delayed-again_1539>.
- FAA, 2019: Cost of Delay Estimates. [Available online at https://www.jec.senate.gov/public/_cache/files/47e8d8a7-661d-4e6bae72-0f1831dd1207/yourflighthasbeendelayed0.pdf]
- Frederick, M. A. (2012). *Predicting the Predominant Winter Flight Category in Central Ohio Using ENSO* Indices. OhioLINK ETD: https://etd.ohiolink.edu/apexprod/rws_olink/r/1501/10?clear=10&p10_accession_num=osu1354301630
- Steinemann, A. C. (2006). Using Climate Forecasts for Drought Management. *Journal of Applied Meteorology and Climatology*, *45*(10), 1353–1361. https://doi.org/10.1175/jam2401.1
- Stevens, S. E. (2019). Trends in Instrument Flight Rules (IFR) Conditions at Major Airports in the United States. *Journal of Applied Meteorology and Climatology*, *58*(3), 615–620. https://doi.org/10.1175/jamc-d-18-0301.1
- Verlinden, K. L., & Bright, D. R. (2017). Using the Second-Generation GEFS Reforecasts to Predict Ceiling, Visibility, and Aviation Flight Category. *Weather and Forecasting*, *32*(5), 1765–1780. https://doi.org/10.1175/waf-d-16-0211.1

Questions?

Thank you!

Beautiful Seattle, Washington
https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.portseattle.org%2Fsea-tac%2Fflight-status&psig=AOvVaw1u2tM2M62NdvU2z-oO9_JL&ust=1654705433843000&source=images&cd=vfe&ved=0CA0QjhxqFwoTCNDEh5_gm_gCFQAAAAAdAAAAABAD

Relevant Work

Using the Second-Generation GEFS Reforecasts to Predict Ceiling, Visibility, and Aviation Flight Category (Verlinden & Bright 2017)

- Postprocessing of NOAA Global Ensemble Forecast System (GEFS) Reforecasts
  - Yielded skillful predictions discerning IFR and VFR flight conditions out to 30 h for the majority of airports

Relevant Work

Predicting the Predominant Winter Flight Category in Central Ohio Using ENSO Indices (Frederick, 2012)

- Can El Niño Southern Oscillation (ENSO) indices be used to predict the predominant winter flight category?
- Tested El Niño/La Niña winter conditions against FRCs over 30 years at 3 airports (two in Ohio, one in Florida).
  - Found strong correlations, especially at Tampa Airport
- Forecasting on a seasonal timescale

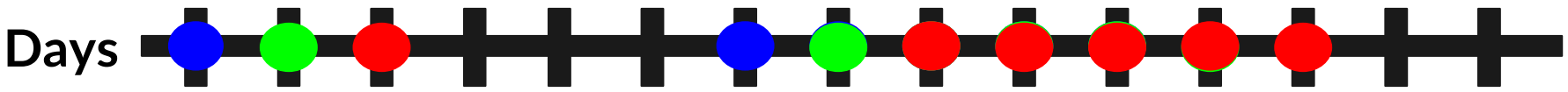
Relevant Work

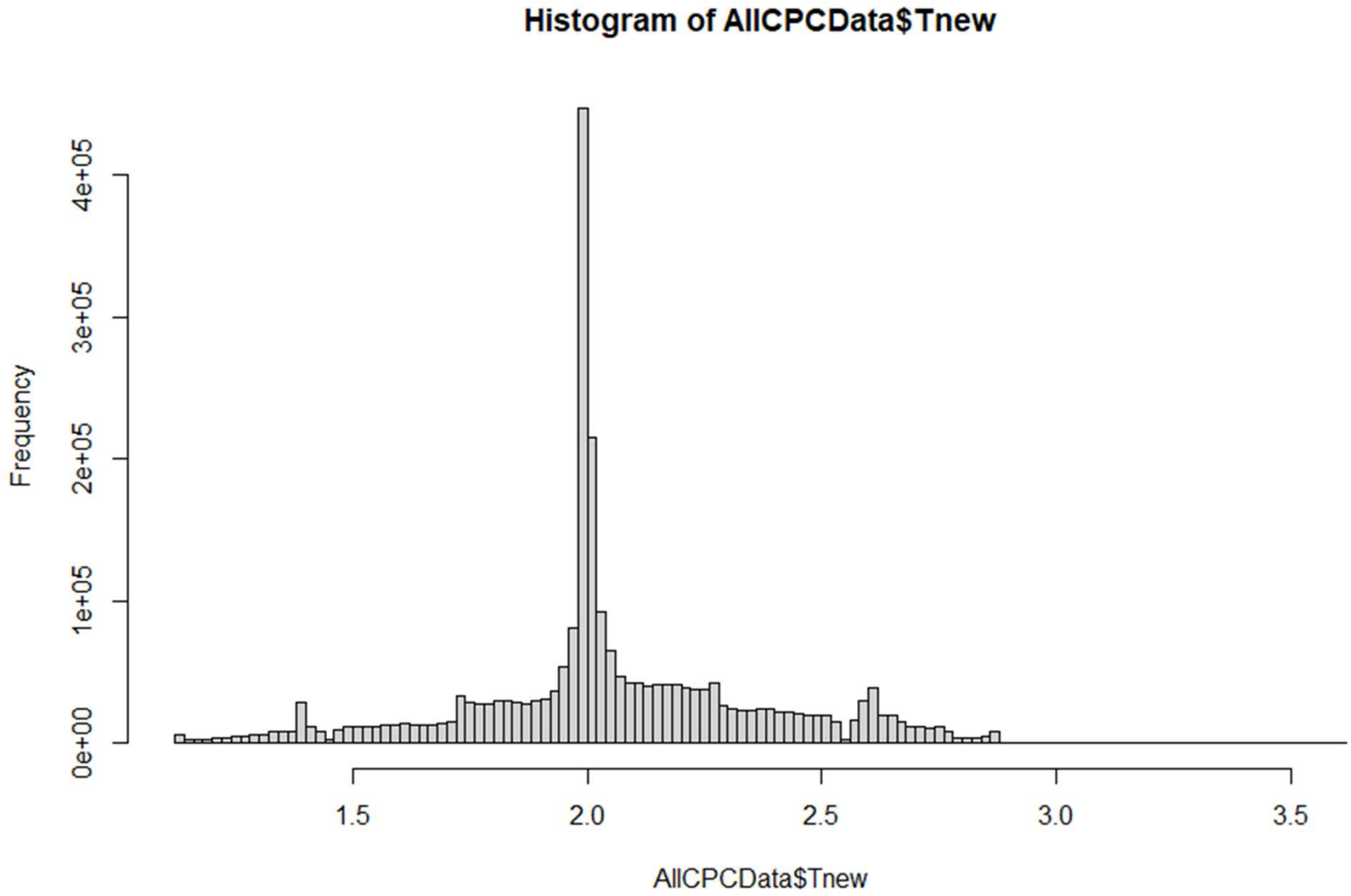
Using Climate Forecasts for Drought Management (Steinemann, 2006)

- Using Climate Prediction Center (CPC) seasonal outlooks for precipitation to aid drought managers
- Benefits of using the forecasts ranged from $30 million to $350 million per year to the state of Georgia
- In drought seasons, 88% of forecasts would have invoked correct response
- Application of CPC outlooks on a seasonal timescale

Data: CPC 6-10 day Outlooks

- Three Categories: above, normal, and below (Based on 30 year terciles)
  - Probabilities that the forecast falls into each category




Histogram of AllCPCData$Tnew
Frequency
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3e+05
4e+05
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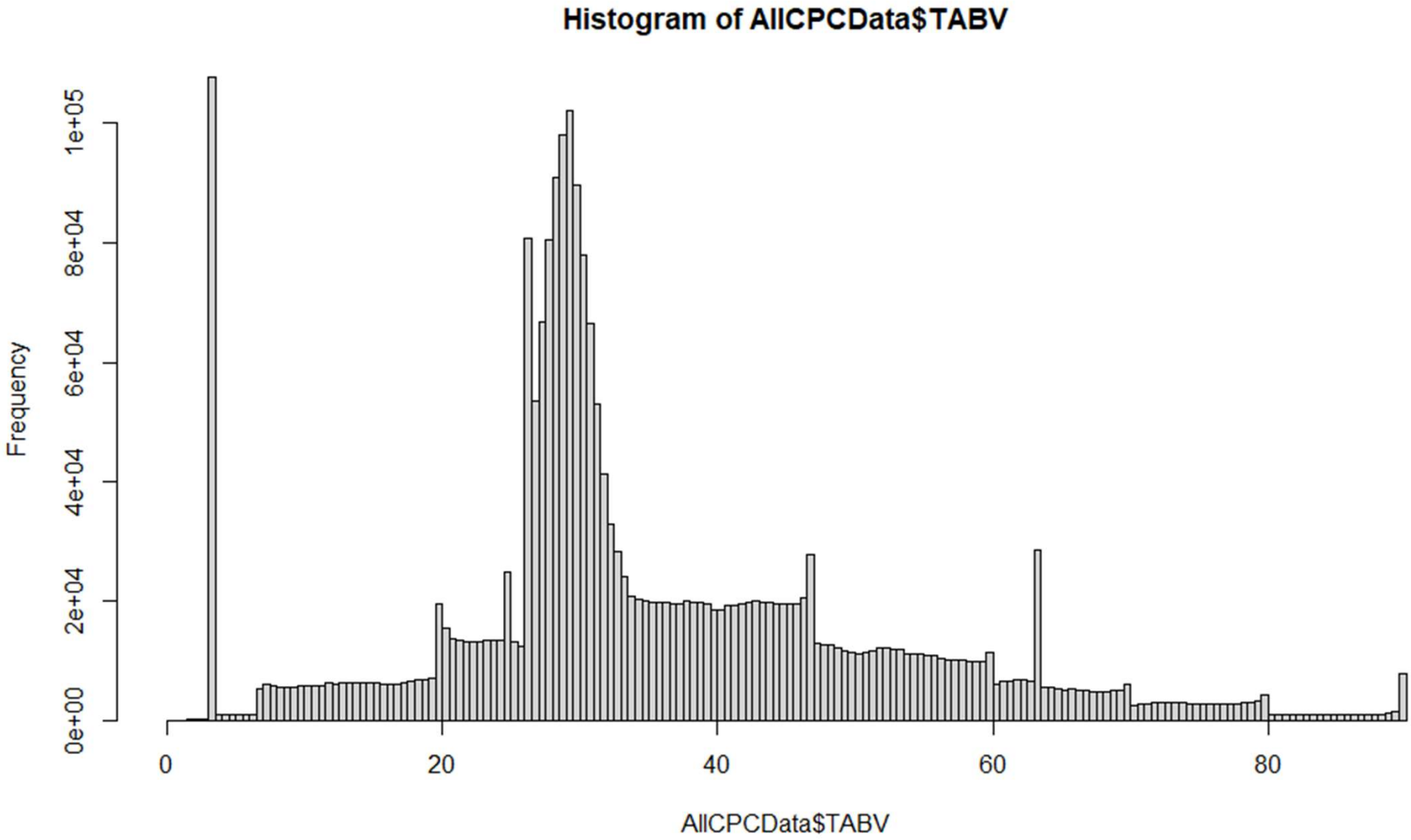
2.5
3.0
3.5
AllCPCData$Tnew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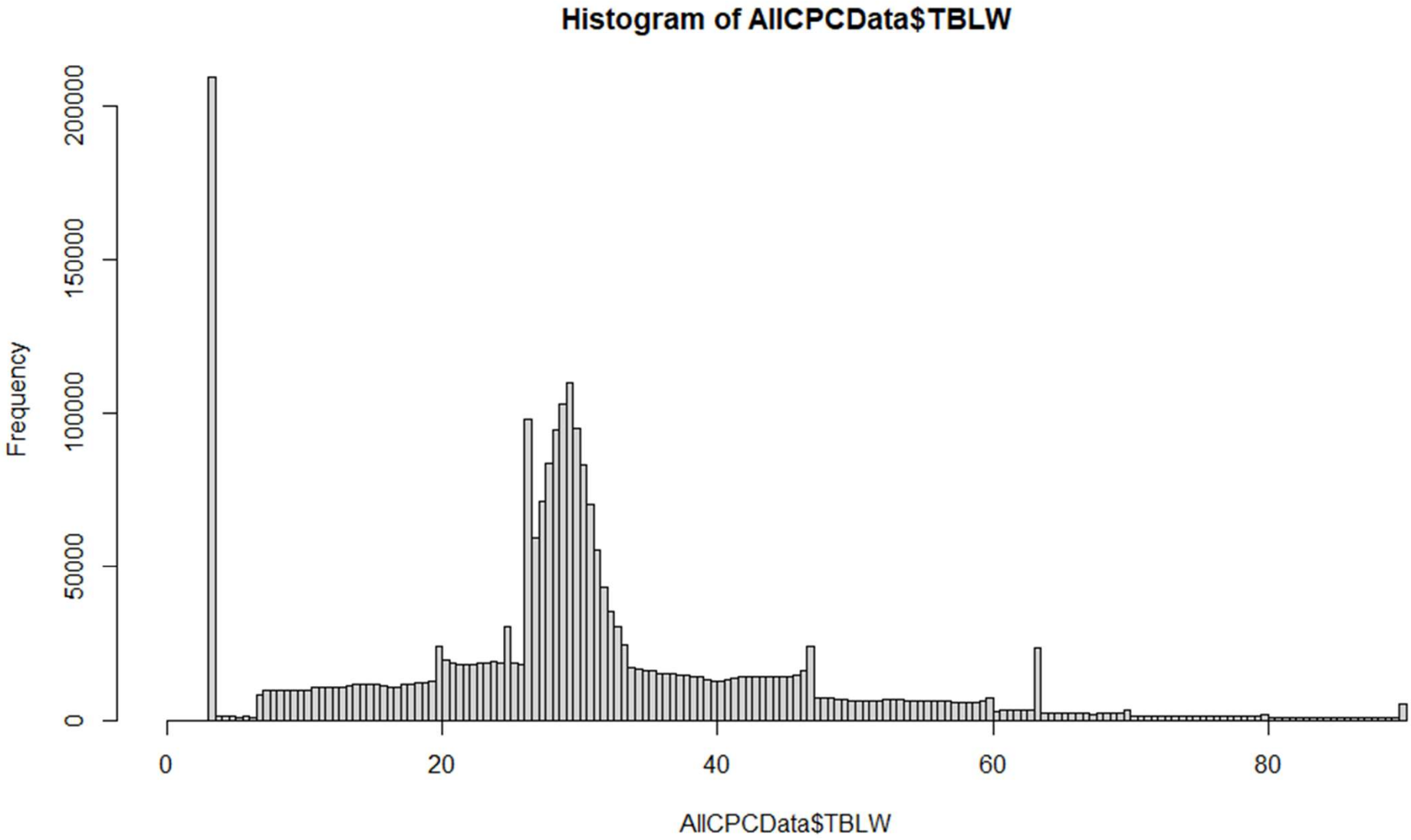
AllCPCData$TABV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20
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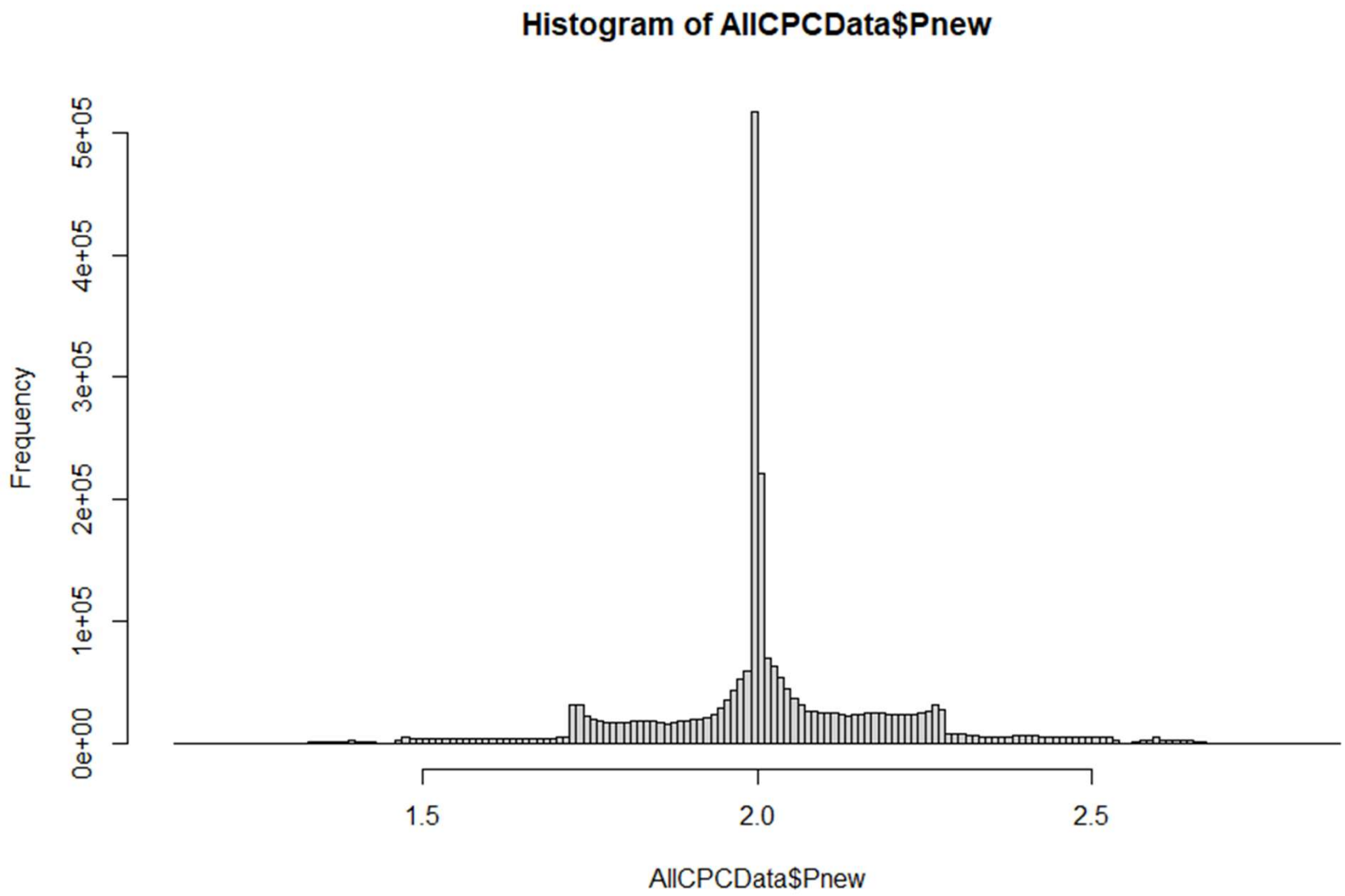
AllCPCData$TBLW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2.5
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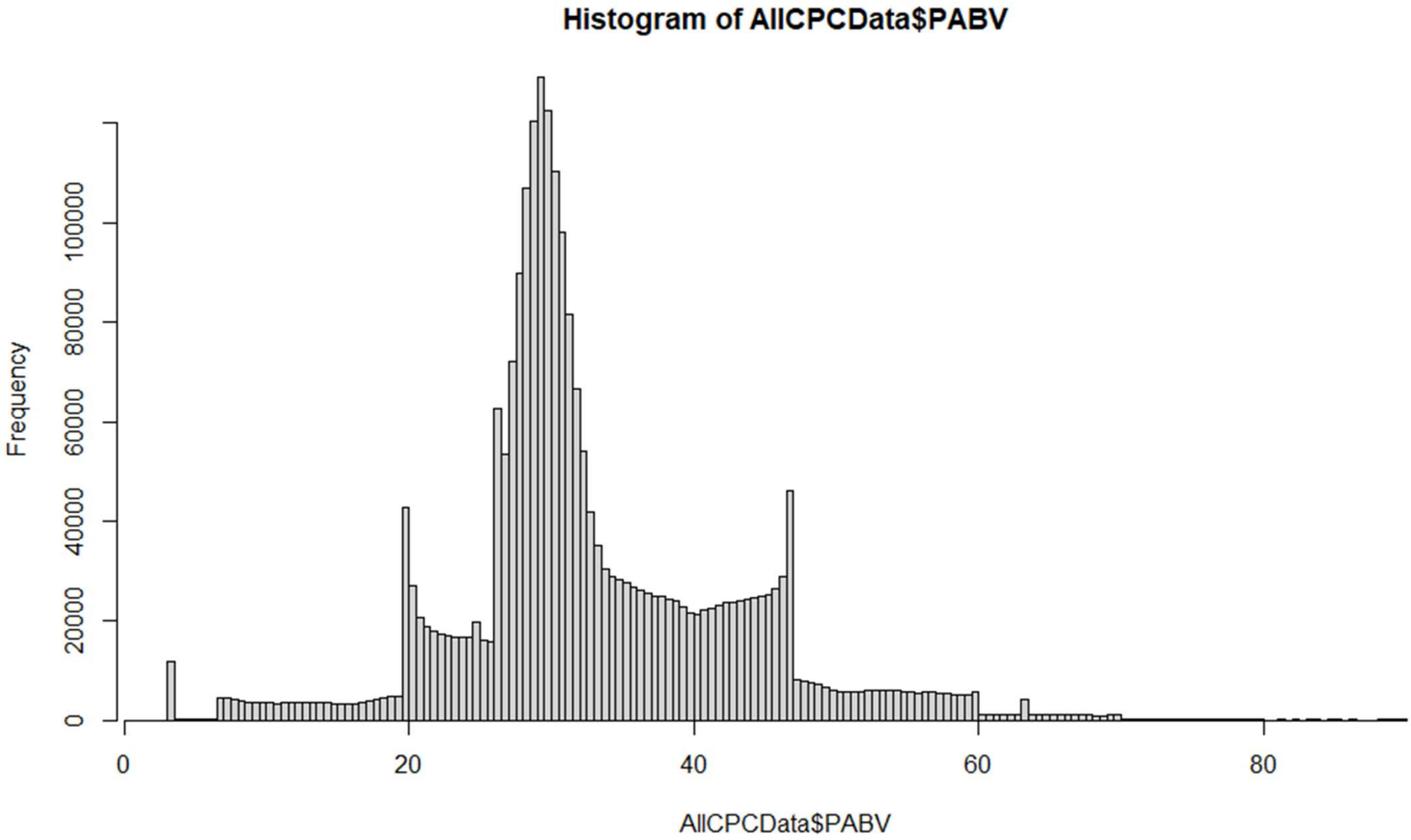
Histogram of AllCPCData$PABV
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0
20
40
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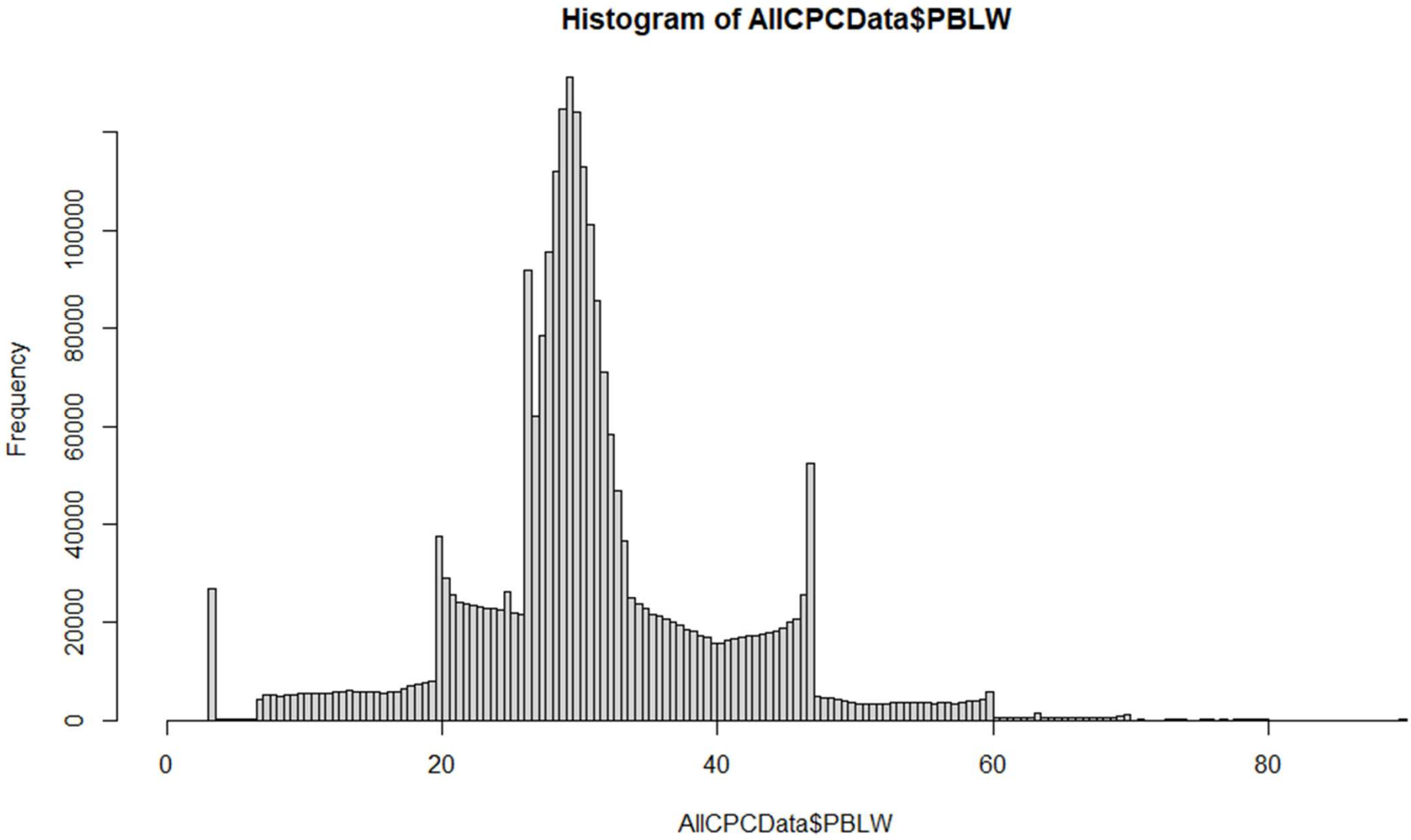
Histogram of AllCPCData$PBLW
Frequency
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20000
40000
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80000
100000
0
20
40
60
80
AllCPCData$PBLW

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