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Analysis of Hawk Mountain Wind Speed to Raptor Count Trends from 1976 through 2021

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1. Introduction

This analysis of summer 2023 is a sequel to the summer 2022 *Analysis of Hawk Mountain Sanctuary Observation Data from 1976 through 2021*, also available as a web page through end of 2024 here. A presentation of that and subsequent analysis presented at Kutztown University in November 2022 and to Hawk Mountain researchers in January 2023 is available as PDF slides here and also on the web through 2024 here. This work was funded by a Kutztown University Research Grant for spring 2022 through summer 2023.

Analytical use of these data proceeded through a subset of projects in three courses in the 2022-2023 academic year: *CSC 458 - Data Mining & Predictive Analytics I* in fall, *CSC 523 - Scripting for Data Science* in fall, and *CSC 558 - Data Mining and Predictive Analytics II* in spring. These courses include iterative exploration of data relationships that often result in new discoveries and consolidation of previous discoveries.

The current document focuses on one significant data relationship, that of consistent decrease of wind speed measures at Hawk Mountain's North Lookout, called *regional stilling* [1], to declining counts in certain raptor species from September through November in the later years of 1976 through 2021.

> "According to a recent study in Nature, the Arctic has, since 1979, been warming four times faster than the rest of the world. That's much quicker than scientists had previously thought, and this warming could presage an even steeper decline in wind than anticipated. Another factor possibly contributing to stilling is an increase in "surface roughness" — an uptick in the number and size of urban buildings, which act as a drag on winds.
>
> Wind has been an overlooked element of climate change studies, which helps explain why the debate over these trends continues. The field is young, with only 70 years of data — temperature data, by contrast, goes back thousands of years — and wind systems are notoriously difficult to study and analyze. Substantial annual fluctuations make long-term trends difficult to detect, and conclusions are rarely firm." [1]

Course work has uncovered the fact that certain weeks during the autumn observation period have seen more pronounced decreases in average wind speed, raptor counts, and corresponding increases in air temperature than other weeks. This analysis is based only on observations made at North Lookout. The summer 2022 study includes NOAA weather data from the Allentown, PA Airport. However, the urban climate at that site differs significantly from North Lookout, largely because of Heat Island Effect [2] and excessive truck pollution [3] in the Lehigh Valley.

Figure 1 shows the location of Hawk Mountain's North Lookout on the Kittatinny Ridge that runs southwest from northern New Jersey to central Pennsylvania. Figure 2 shows a zoomed-out view.

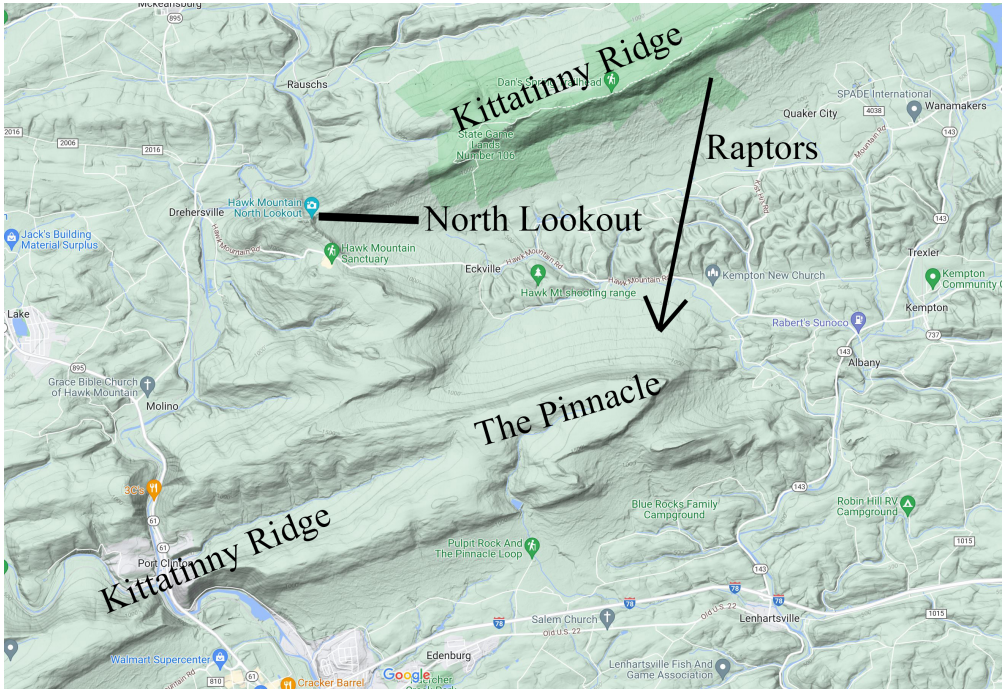

Figure 1: Kittatinny Ridge in the Hawk Mountain Area, from https://www.google.com/maps Search for "Hawk Mountain North Lookout" in the terrain view.

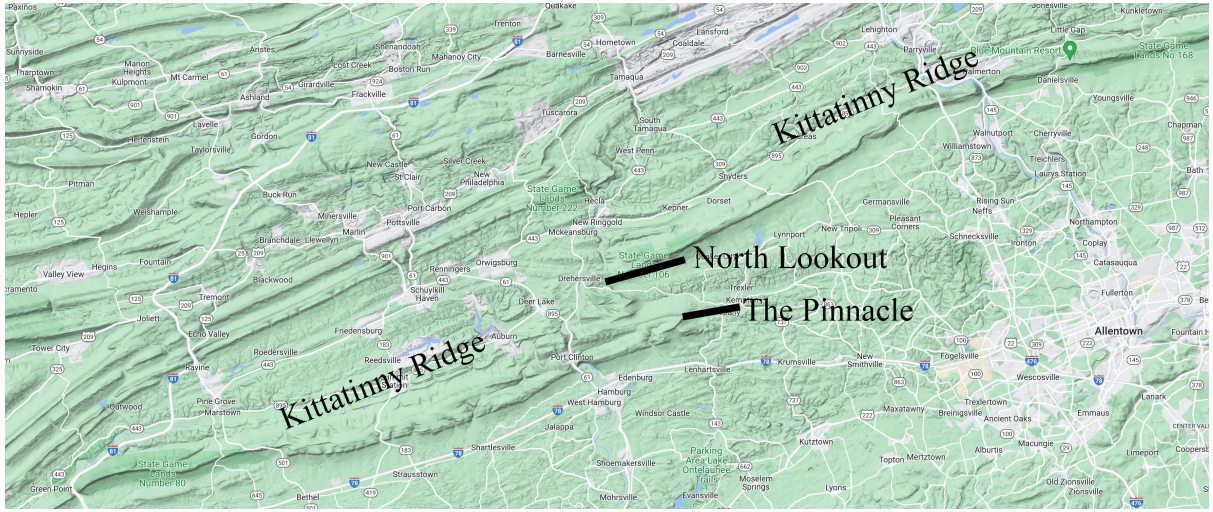

Figure 2: Zoomed out Kittatinny Ridge

Certain raptor species partially coast on updrafts along the north side of the ridge when predominately northwest winds are present [4]. The physical discontinuity in the ridge at the Eckville Fault makes it necessary for raptors to cross in the area of North Lookout in order to use updrafts at the Pinnacle and to the southwest, since the North Lookout's ridge drops to the valley directly to the southwest. This discontinuity acts as a funnel for steering raptors utilizing updrafts.

The next sections discuss raptor species whose seasonal counts correlate highly with declining winds that cause updrafts along the north side of Kittatinny Ridge.

2. Red-Tailed Hawks (RT)

This section displays graphs and models for wind speed, wind direction, air temperature, and red-tailed hawk count trends. Subsequent sections cover other species with substantial correlations to these attributes.

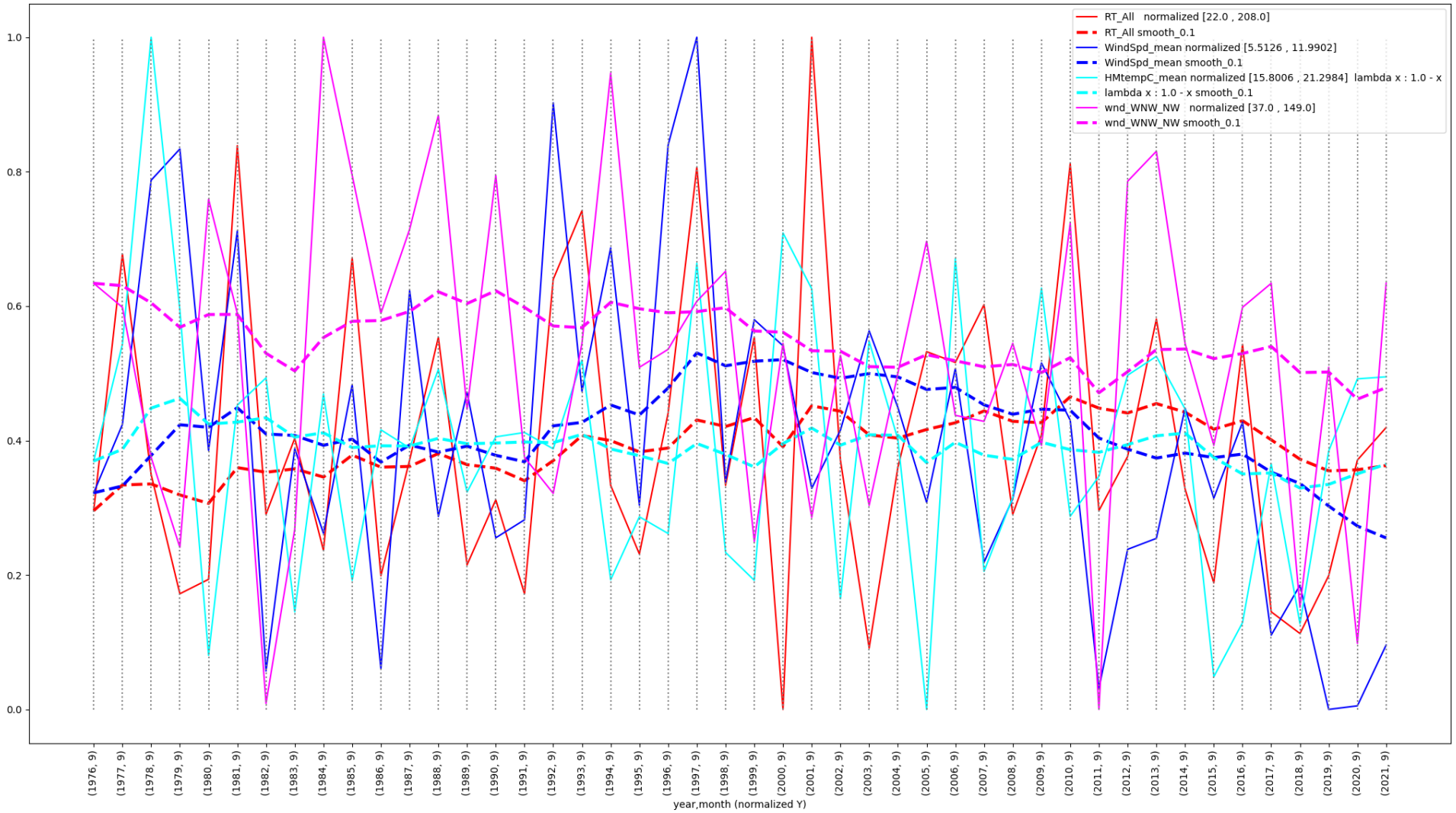

Figure 3: Normalized Red-tailed Hawk Counts and their Exponentially Smoothed Trends for September 1976 through 2021

Figure 3 and the graphs that follow show two sets of values across the years. The thin solid lines show normalized counts, where normalization maps a given year's monthly value into the range [0.0, 1.0] via the formula **NormalizedValue = ((Value - MinValue) / (MaxValue - MinValue))**. A normalized value is that fraction of the way from the minimum value to the maximum value for that attribute within the time frame September 1976 through 2021. If we know the MinValue and MaxValue we can find the original **Value = NormalizedValue * (MaxValue - MinValue) + MinValue**. The legend for these values in Figure 3 gives the MinValue and MaxValue for each data attribute, e.g., MinValue is 22 and MaxValue is 208 for the red-tailed count tally (**RT_All**) in September for these years. **WindSpd_mean** is the normalized mean wind speed for September in the range [5.5126, 11.9902] kilometers/hour. **HMTempC_mean** in these graphs is the inverted normalized average temperature Celsius at North Lookout in the range [15.8006, 21.2984] degrees. *Inverting* the normalized mean temperature value means subtracting the normalized value in the range [0.0, 1.0] from 1.0 so that an upward slope becomes a downward slope and vice versa. Inverting the slope

aligns it with the decrease in wind speed. Finally, **wnd_WNW_NW** is the normalized sum of west-northwest and northwest wind counts for that month, accounting for the fact that observers began using three-letter direction designations such as WNW in 1995 [5]. Northwesterly winds are significant because they drive the updrafts on the north side of the ridge [4].

The heavy dashed lines in these graphs are the exponentially smoothed values for their corresponding attributes. A smoothed value in these graphs is $\mathbf{SmoothedValue_{timeT} = (alpha\ X\ NormalizedValue_{timeT}) + ((1.0 - alpha)\ X\ NormalizedValue_{timeT-1})}$, with fractional multiplier **alpha** in the range [0.0, 1.0]. The graphs in this discussion use alpha = 0.1 to smooth the peaks and valleys in the normalized values in order to show long-term trends and slopes. [6]

Following these graphs are Linear Regression models and the Pearson Correlation Coefficient (CC) [9] of each linear model for the smoothed data of the figures, where a CC of 0.0 means no correlation of the model to the data, a CC of 1.0 is perfect correlation, and -1.0 is perfect negative correlation. Other error measures would be harder to interpret because of the normalization and smoothing of the original data. Models were extracted using the Weka machine learning toolkit [7]. Only the four attributes **RT_All_smooth**, **WindSpd_mean_smooth**, **HMtempC_mean_smooth**, and **wnd_WNW_NW_smooth** that appear in the graphs contribute to these models unless otherwise noted.

Smoothed Linear Regression Model for September 1976 through 2021

```
RT_All_smooth =
     0.388  * HMtempC_mean_smooth +
     0.398  * WindSpd_mean_smooth +
    -0.4227 * wnd_WNW_NW_smooth +
     0.2228
Correlation coefficient                  0.6638
```

Modeling 2008 through 2021 when the smoothed attribute slopes of Figure 3 roughly converge increases the CC about 29%:

Smoothed Linear Regression Model for September 2008 through 2021

```
RT_All_smooth =
    -0.6499 * HMtempC_mean_smooth +
     0.3825 * WindSpd_mean_smooth +
     0.6818
Correlation coefficient                  0.8565
```

Unlike the graphs, the HMtempC_mean_smooth trends and HMtempC_mean temperature values in the models are not inverted. Inversion in the graphs is for visual comparison of trend slopes. The models do not need this inversion. A negative multiplier such as -0.6499 indicates a substantial decrease in RT_All_smooth as HMtempC_mean_smooth increases and vice versa.

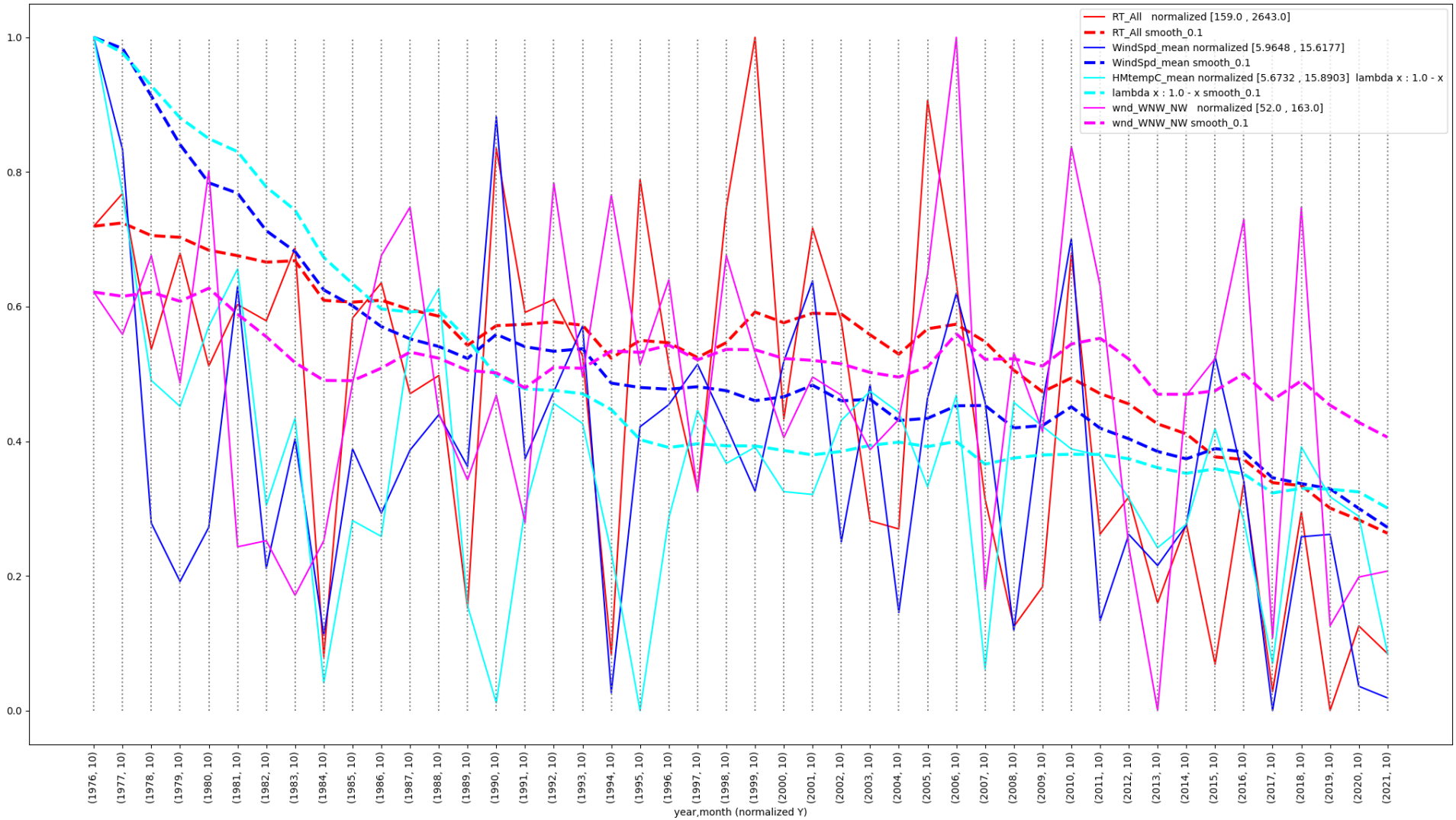

Figure 4: Normalized Red-tailed Hawk Counts and their Smoothed Trends Parallel other trends for October 1976 through 2021

The range of red-tailed hawk counts in Figure 4 for October, [159, 2643], is much higher than [22, 208] for Figure 3 of September, a more statistically significant sample size.

Smoothed Linear Regression Model for <u>October 1976 through 2021</u>

RT_All_smooth =
0.5387 * HMtempC_mean_smooth +
1.1919 * WindSpd_mean_smooth +
-0.3542

Correlation coefficient 0.8431

Modeling 1990 through 2021 when the smoothed attribute slopes of Figure 4 roughly converge increases the CC about 9%. **WindSpd_mean_smooth** is the strongest contributing attribute in terms of its multiplier in the linear expression, with **HMtempC_mean_smooth** coming in second. Normalization puts all attributes on the same scale so that the multipliers are comparable.

Smoothed Linear Regression Model for <u>October 1990 through 2021</u>

RT_All_smooth =
0.8032 * HMtempC_mean_smooth +
1.6502 * WindSpd_mean_smooth +
0.5137 * wnd_WNW_NW_smooth +
-0.9813

Correlation coefficient 0.9211

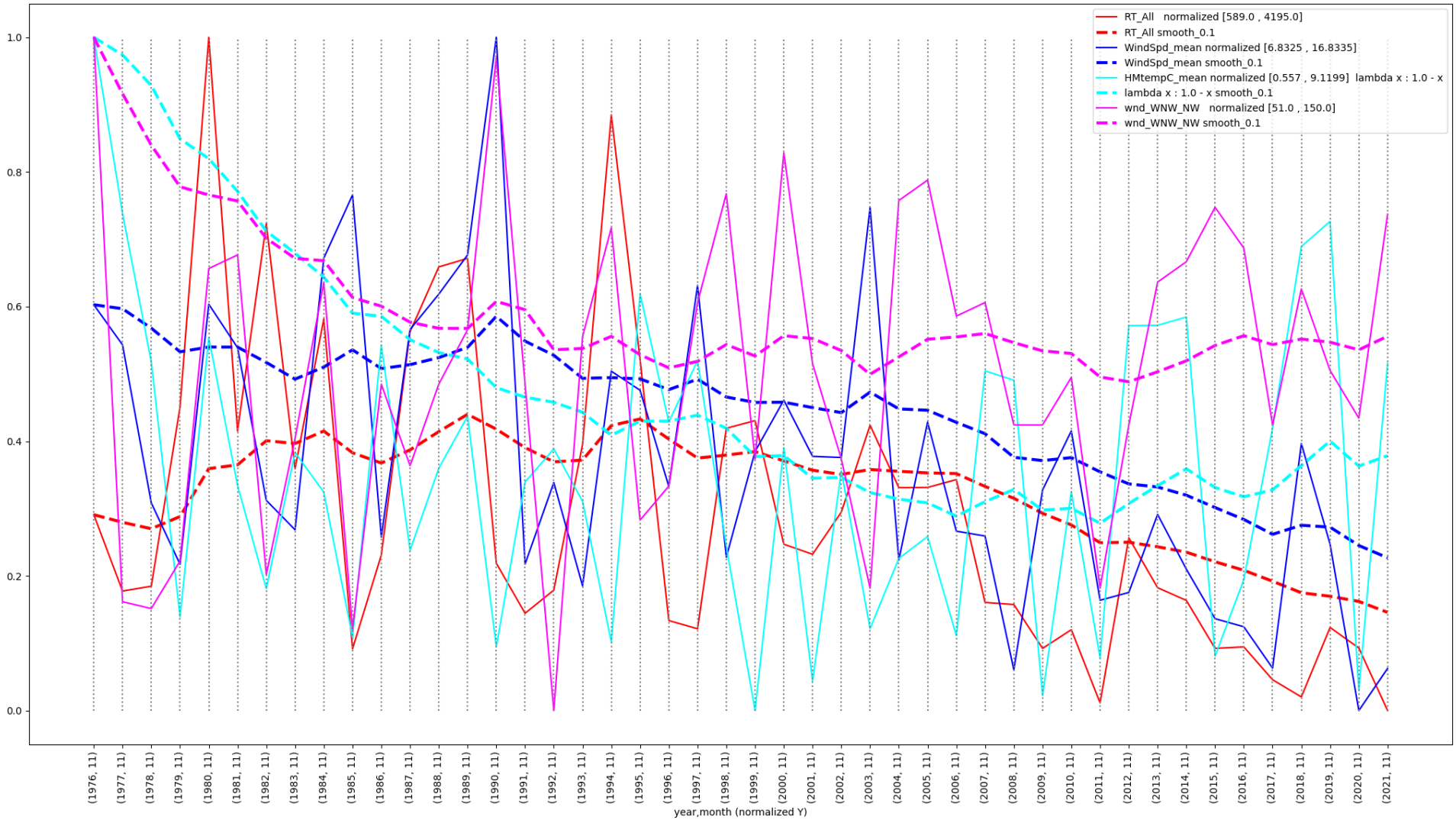

Figure 5: Normalized Red-tailed Hawk Counts and their Smoothed Trends Parallel Wind trends for November 1976 through 2021

The range of red-tailed hawk counts in Figure 5 for November, [589, 4185], is much higher than [159, 2643] for Figure 4 of October, again a more statistically significant sample size.

Smoothed Linear Regression Model for <u>November 1976 through 2021</u>

RT_All_smooth =
0.9035 * WindSpd_mean_smooth +
-0.4434 * wnd_WNW_NW_smooth +
0.1867

Correlation coefficient 0.9327

Modeling 1985 through 2021 when the smoothed attribute slopes of Figure 5 roughly converge increases the CC about 3% over an already-high CC. **WindSpd_mean_smooth** is the strongest contributing attribute in terms of its multiplier in the linear expression, with **HMtempC_mean_smooth** again coming in second. As always, normalization puts all attributes on the same scale so that the multipliers are comparable.

Smoothed Linear Regression Model for November 1985 through 2021

RT_All_smooth =
0.148 * HMtempC_mean_smooth +
0.9239 * WindSpd_mean_smooth +
-0.1567
Correlation coefficient 0.9604

A final model to consider uses the normalized values of the four attributes of Figure 5 without smoothing for long-term trends, i.e., the thin solid lines of Figure 5. While the CC is only about a third of the preceding, smoothed model, and an average error of 532 raptors in the range [589, 4185] of Figure 5, it is significant in identifying as the main attribute of influence .**WindSpd_mean**

Un-smoothed, Normalized Linear Regression Model for November 1985 through 2021

RT_All =
1425.1292 * WindSpd_mean +
1012.5687
Correlation coefficient 0.3208
Mean absolute error 531.9956

A non-linear Decision Stump tree gives a 26% improvement in CC over Linear Regression while identifying un-normalized, un-smoothed WindSpd_mean as the primary attribute of influence. The un-normalized nature of this model allows us to locate the decision point of WindSpd_mean = 11.5 km/hour in the range [6.8325, 16.8335] of Figure 5. These un-smoothed values take into account the peaks, valleys, and year-to-year slopes of the un-smoothed values in Figure 5.

Un-smoothed, Un-normalized Decision Stump Model for November 1985 through 2021

RT_All = WindSpd_mean <= 11.5169615 : 1275.0
WindSpd_mean > 11.5169615 : 2254.0
WindSpd_mean is missing : 1513.1351351351352
Correlation coefficient 0.4032 Mean absolute error 541.1215

Other studies have shown that arrival times for various raptor species are changing as a result of climate change [8]. Such changes perturb annual week-based raptor counts by moving peak count weeks. This study investigated year-to-year weekly data but did not use it because of shifting arrival and peak raptor weeks across the years. Also, small variations in weekly climate aspects are averaged out in monthly explorations of the data. Subsequently, this study examines only annual per-month data. Annual per-week data is available for the autumn observation weeks, but it only adds variability without highlighting long-term trends that are the current focus.

The slopes of Figures 4 and 5 and their smoothed monthly models show high correlation among red-tailed hawk counts and wind speed, inverted temperature, and westerly wind direction for October and November. Based on climate analysis [1], it is essentially established that there is a cause-and-effect relationship between increasing temperature homogenization and wind stilling. Based on the high correlation between decreasing smoothed wind speed and decreasing smoothed red-tailed hawk counts, it is reasonable to infer cause-and-effect, especially given the placement of North Lookout at the Eckville Fault of the Kittatinny Ridge. The next sections investigate whether there are similar correlations for other raptor species.

3. Sharp-Shinned Hawks (SS)

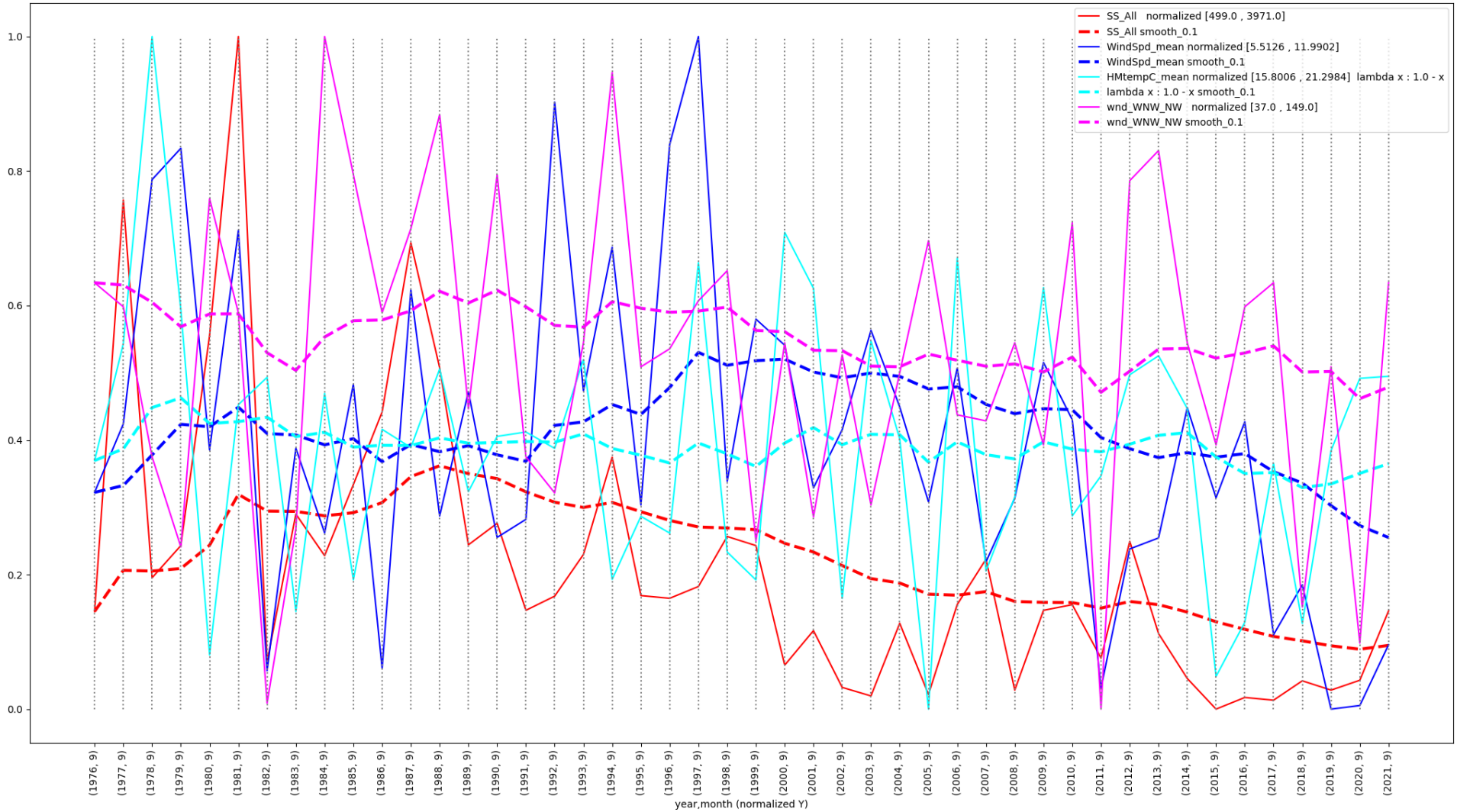

Figure 6: Normalized Sharp-shinned Hawk Counts and their Smoothed Trends for September 1976 through 2021

Smoothed Linear Regression Model for September 1976 through 2021

SS_All_smooth =
-0.6472 * HMtempC_mean_smooth +
0.2628 * WindSpd_mean_smooth +
1.0818 * wnd_WNW_NW_smooth +
-0.0895
Correlation coefficient 0.6623

Smoothed Linear Regression Model for <u>September 1997 through 2021</u>
SS_All_smooth =
0.4976 * WindSpd_mean_smooth +
0.506 * wnd_WNW_NW_smooth +
-0.3073
Correlation coefficient 0.9037

The sharp-shinned hawk count trend in the latter model starting in 1997 gives comparable weight for wind speed and northwesterly wind trends for the range of [499, 3971] raptors.

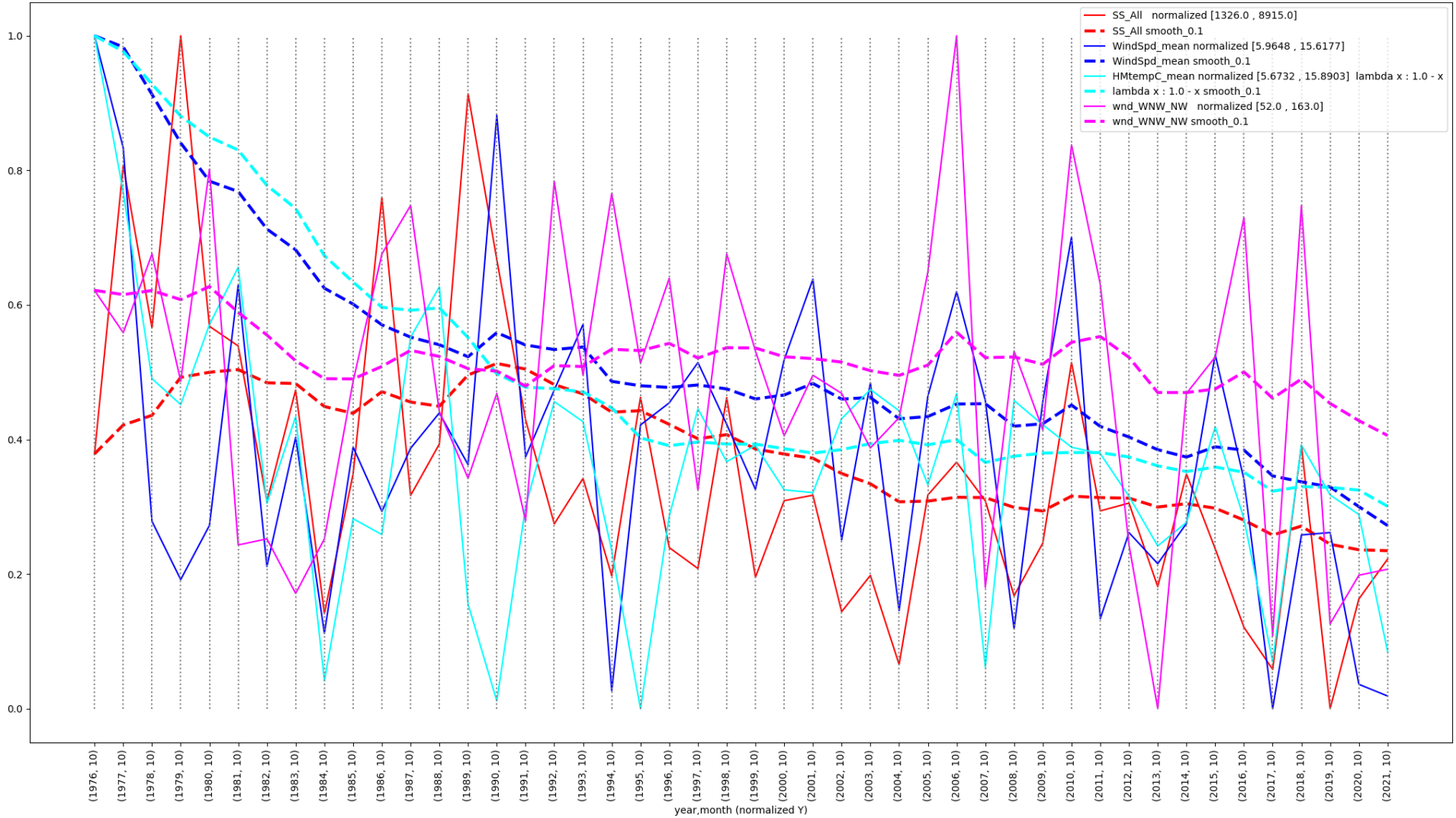

Figure 7: Normalized Sharp-shinned Hawk Counts and their Smoothed Trends for October 1976 through 2021

Smoothed Linear Regression Model for <u>October 1976 through 2021</u>

SS_All_smooth =
0.3389 * WindSpd_mean_smooth +
0.205

Correlation coefficient 0.565

Smoothed Linear Regression Model for <u>October 1997 through 2021</u>

SS_All_smooth =

0.7249 * WindSpd_mean_smooth +
0.0149
Correlation coefficient 0.8518

Note how the slopes converge around 1997 onward, with a 80.8% improvement in CC and identification of wind speed slope as the main correlate.

Sharp-shin counts for November are in the range [26, 321] which is much smaller and less significant for analysis than September and October numbers.

Smoothed trends in wind speed, temperature, and northwesterly winds are highly correlated factors in sharp-shinned count trends in September and October for the years 1997 through 2021.

4. American Kestrel (AK)

Only 8 kestrels appear in the November graph, so this section models only September and October, with secondary models starting in 1993 where the attribute slopes converge.

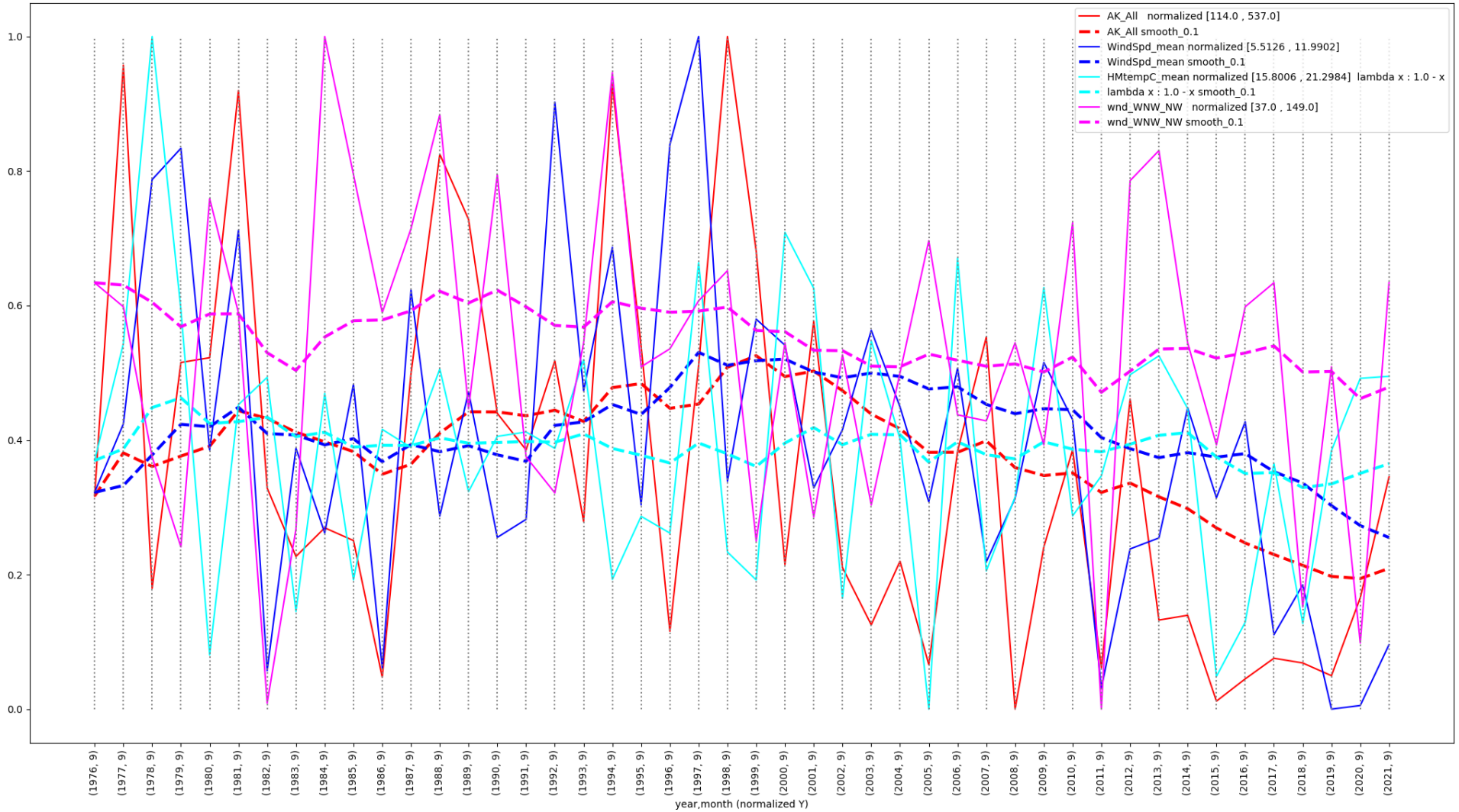

Figure 8: Normalized American Kestrel Counts and their Smoothed Trends for September 1976 through 2021

Smoothed Linear Regression Model for <u>September 1976 through 2021</u>

AK_All_smooth =
-0.4676 * HMtempC_mean_smooth +
0.9308 * WindSpd_mean_smooth +
0.7475 * wnd_WNW_NW_smooth +
-0.1336

Correlation coefficient 0.8737

Smoothed Linear Regression Model for <u>September 1993 through 2021</u>

AK_All_smooth =
-0.5722 * HMtempC_mean_smooth +
0.9547 * WindSpd_mean_smooth +
0.7225 * wnd_WNW_NW_smooth +
-0.0702

Correlation coefficient 0.9061

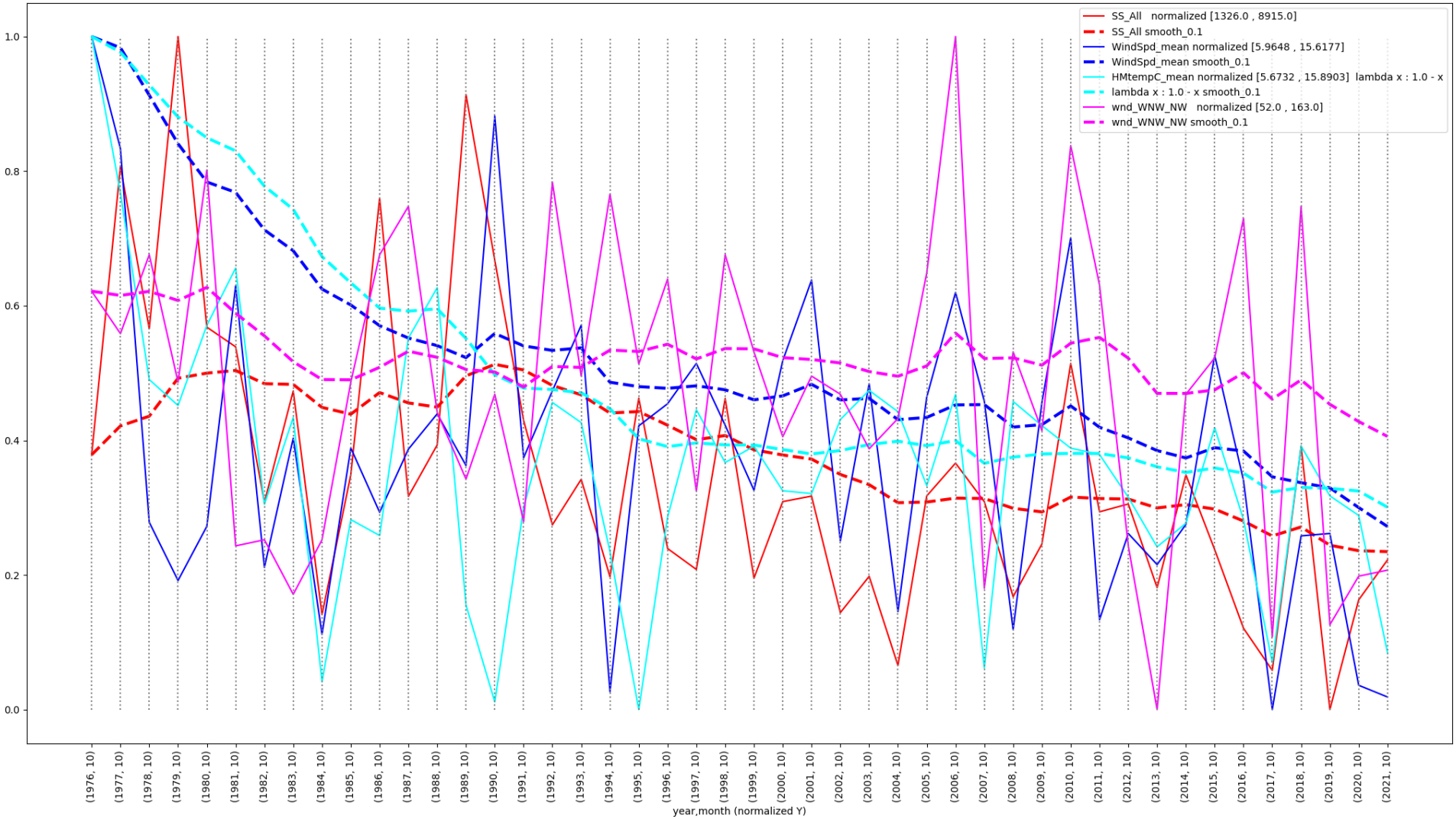

Figure 9: Normalized American Kestrel Counts and their Smoothed Trends for October 1976 through 2021

Smoothed Linear Regression Model for October 1976 through 2021

AK_All_smooth =
-0.5467 * WindSpd_mean_smooth +
1.2578 * wnd_WNW_NW_smooth +
-0.0172

Correlation coefficient 0.6207

Smoothed Linear Regression Model for October 1993 through 2021

AK_All_smooth =
0.8748 * WindSpd_mean_smooth +
0.0268

Correlation coefficient 0.8882

The high CC values for smoothed AK values in September and October for 1993 through 2021 in Figures 8 and 9 and their linear models demonstrate that declining wind speed trends are highly correlated with declining AK counts.

5. Broad-Winged Hawks.

Considering the essentially horizontal smoothed slope in BW across the years 1976-2021, Weka extracts a good (not excellent) Linear model. The overwhelming majority of BWs cross North Lookout in September, so that is the only BW graph appearing.

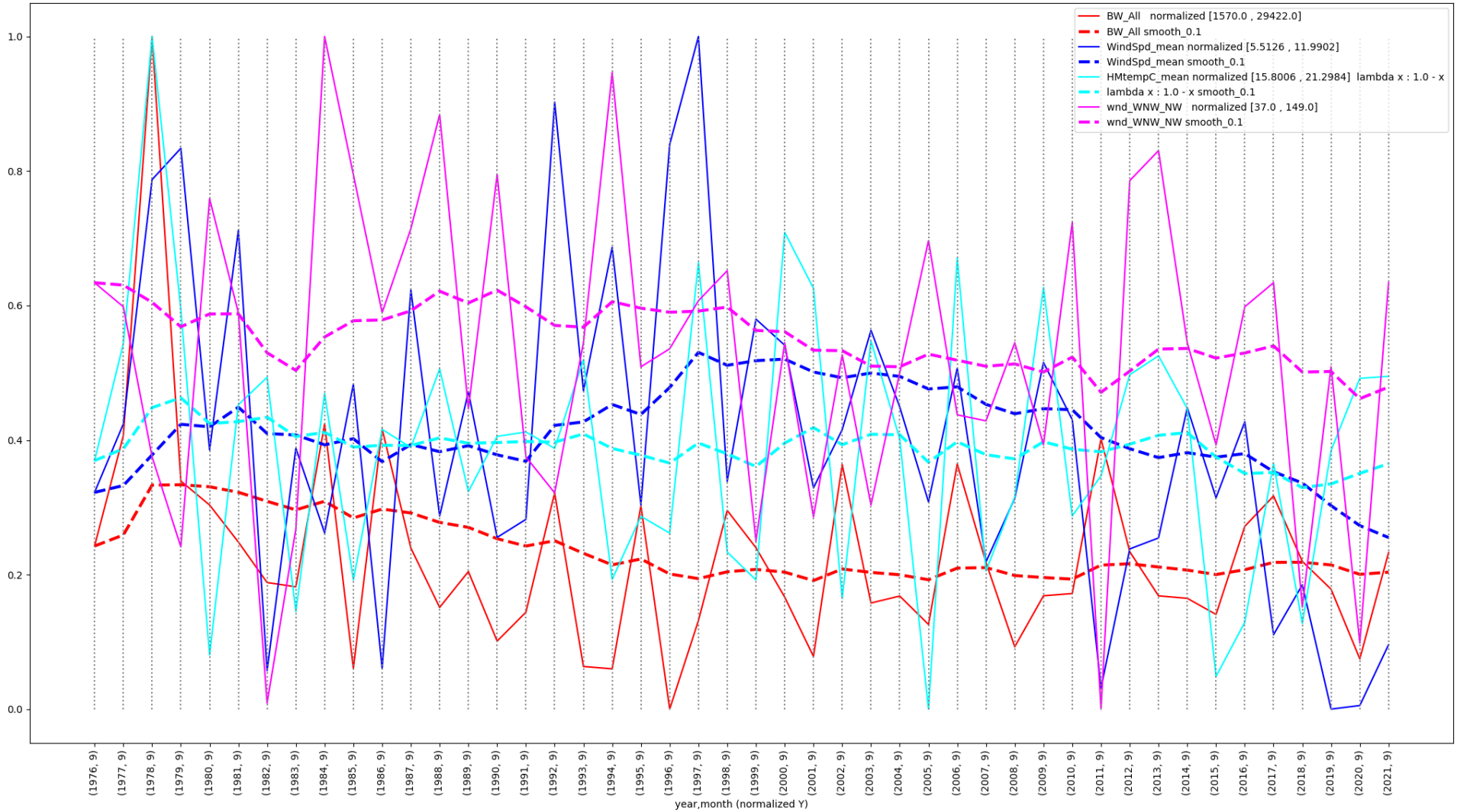

Figure 10: Normalized Broad-winged Hawk Counts and their Smoothed Trends for September 1976 through 2021

Smoothed Linear Regression Model for <u>September 1976 through 2021</u>

BW_All_smooth =
-1.0755 * HMtempC_mean_smooth +
-0.3081 * WindSpd_mean_smooth +
0.3085 * wnd_WNW_NW_smooth +
0.8493

Correlation coefficient 0.7395

This model shows that smoothed wind speed slope is the least important for BW of the three climate attributes modeled, both in magnitude and in direction. Negatively correlated temperature tracks BW the most closely.

6. Cooper's Hawk

October is the large-count month for CH, [79, 922] compared to [23, 290] for September and [2, 91] for November.

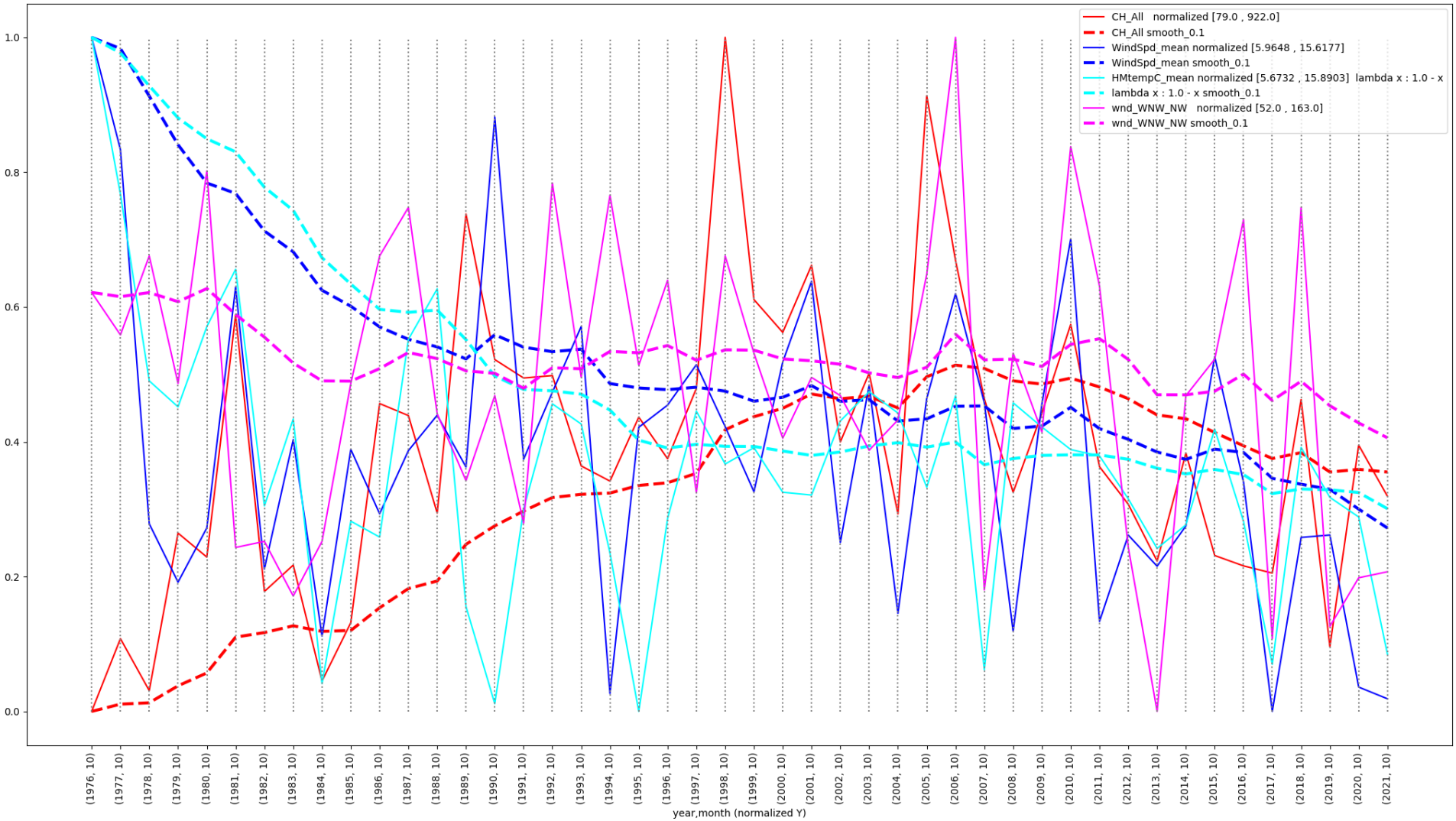

Figure 11: Normalized Cooper's Hawk Counts and their Smoothed Trends for October 1976 through 2021

Smoothed Linear Regression Model for October 1976 through 2021

CH_All_smooth =
0.9705 * HMtempC_mean_smooth +
1.2619 * wnd_WNW_NW_smooth +
-0.8241
Correlation coefficient 0.9529

In the earlier years, when CH and wind speed trends head in opposite directions, temperature and westerly wind directions in the above model yield a high CC. CH and wind speed trend slopes converge around 2001.

Smoothed Linear Regression Model for October 2001 through 2021

CH_All_smooth =
-1.0191 * HMtempC_mean_smooth +
0.5729 * wnd_WNW_NW_smooth +
0.8067
Correlation coefficient 0.8226

Eliminating all attributes other than WindSpd_mean_smooth and CH_All_smooth yields this model:

Smoothed Linear Regression Model for October 2001 through 2021 using only smoothed wind speed

CH_All_smooth =
0.8285 * WindSpd_mean_smooth +
0.1109
Correlation coefficient 0.8659

Finally, Weka's attribute ranker gives these CCs for individual attribute correlations to smoothed CH:

Ranked attributes:
0.892 2 WindSpd_mean_smooth
0.866 3 wnd_WNW_NW_smooth
-0.887 1 HMtempC_mean_smooth

All attributes have high correlations and very similar Figure 11 slopes to CH starting in 2001.

7. Osprey (OS)

Osprey have significant numbers in September and October. November has the range [0, 15] and does not appear here.

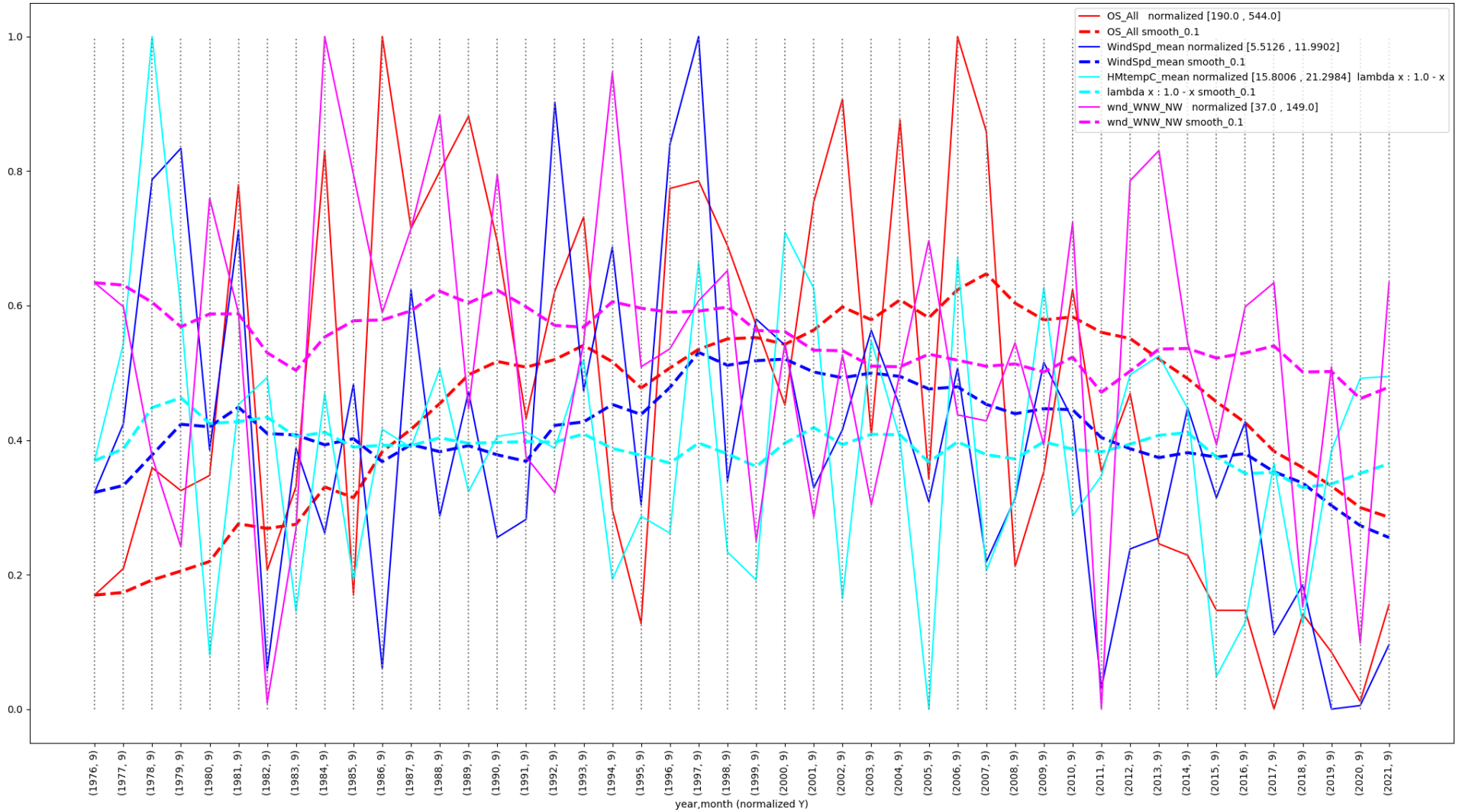

Figure 12: Normalized Osprey Counts and their Smoothed Trends for September 1976 through 2021

Smoothed Linear Regression Model for September 1976 through 2021

OS_All_smooth =
1.5448 * HMtempC_mean_smooth +
1.5469 * WindSpd_mean_smooth +
-0.7351 * wnd_WNW_NW_smooth +
-0.7289
Correlation coefficient 0.6745

Smoothed Linear Regression Model for September 2007 through 2021

OS_All_smooth =
-1.122 * HMtempC_mean_smooth +
1.6867 * WindSpd_mean_smooth +
-0.6937 * wnd_WNW_NW_smooth +
0.8986
Correlation coefficient 0.9687

Smoothed Linear Regression Model for September 2007 through 2021 with only smoothed wind speed and OS raptor counts

OS_All_smooth =
1.8261 * WindSpd_mean_smooth +
-0.2104
Correlation coefficient 0.9409

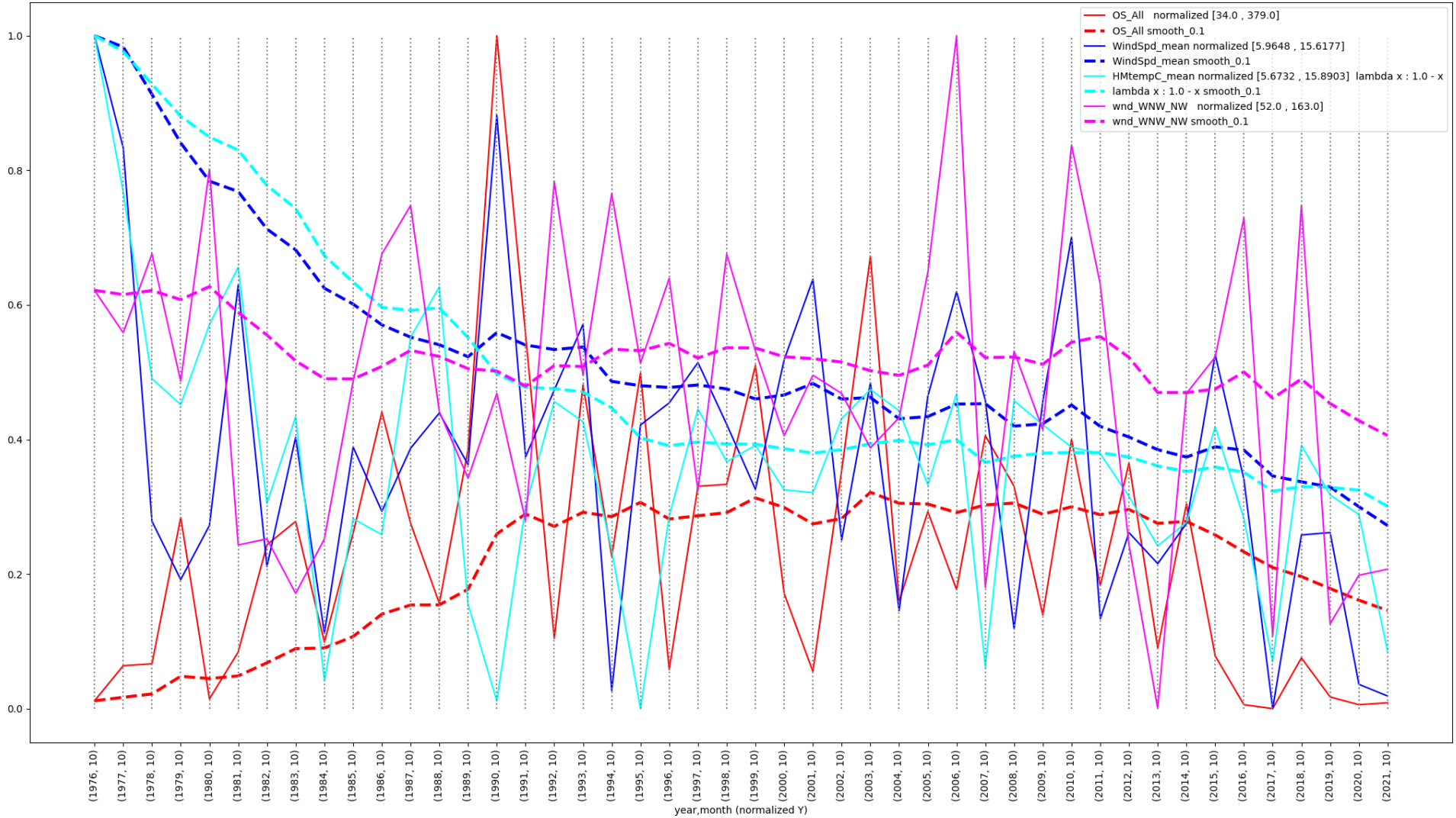

Figure 13: Normalized Osprey Counts and their Smoothed Trends for October 1976 through 2021

Smoothed Linear Regression Model for October 1976 through 2021

OS_All_smooth =
-0.6971 * WindSpd_mean_smooth +
1.1454 * wnd_WNW_NW_smooth +
-0.0188

Correlation coefficient 0.7781

Smoothed Linear Regression Model for October 2003 through 2021

OS_All_smooth =
0.9544 * WindSpd_mean_smooth +
-0.1151

Correlation coefficient 0.9284

Wind speed trends are important for Osprey trends in September and October, but the other attributes considered can play important roles in September for later years when included in the data.

8. Northern Harrier

Northern Harrier counts are consistent across all three months.

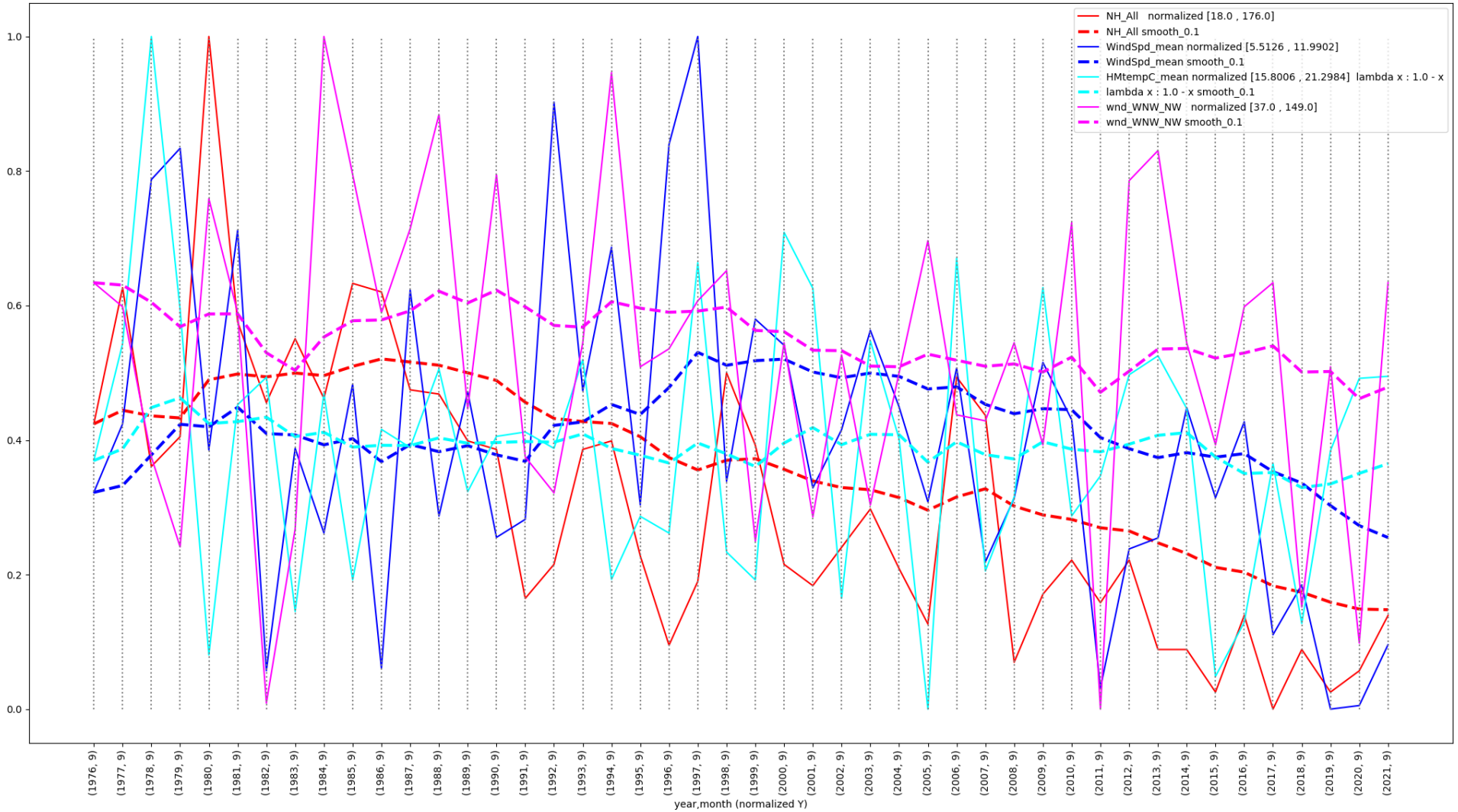

Figure 14: Normalized Northern Harrier Counts and their Smoothed Trends for September 1976 through 2021

Smoothed Linear Regression Model for September 1976 through 2021

NH_All_smooth =
-1.7604 * HMtempC_mean_smooth +
1.5325 * wnd_WNW_NW_smooth +
0.5869

Correlation coefficient 0.8034

Smoothed Linear Regression Model for September 1999 through 2021

NH_All_smooth =
0.8599 * WindSpd_mean_smooth +
-0.0936
Correlation coefficient 0.9456

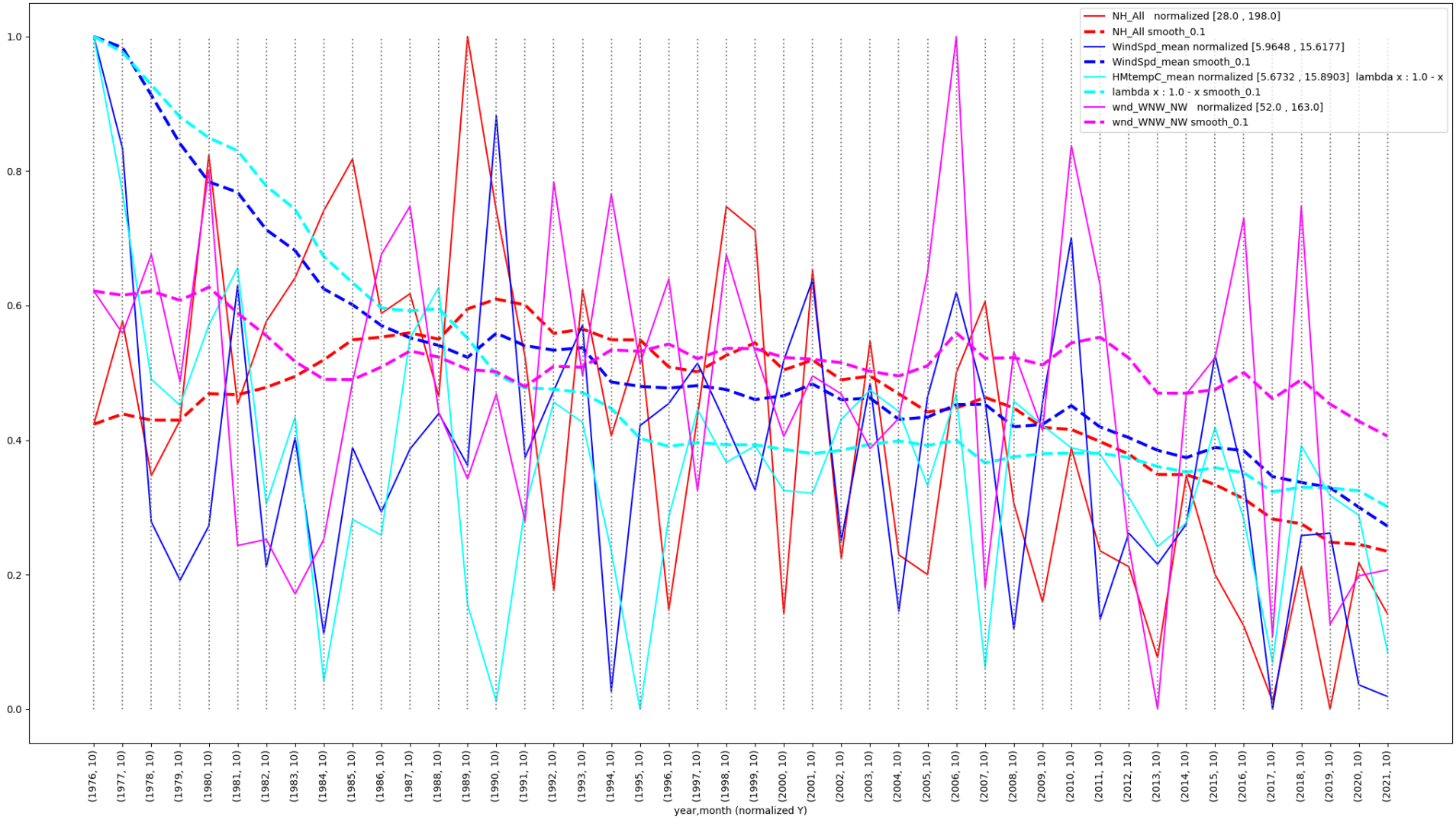

Figure 15: Normalized Northern Harrier Counts and their Smoothed Trends for October 1976 through 2021

Smoothed Linear Regression Model for October 1976 through 2021

NH_All_smooth =
0.6909 * wnd_WNW_NW_smooth +

0.0964
Correlation coefficient 0.0441

Smoothed Linear Regression Model for October 1999 through 2021
NH_All_smooth =
1.8739 * WindSpd_mean_smooth +
-0.5135 * wnd_WNW_NW_smooth +
-0.1101
Correlation coefficient 0.9441

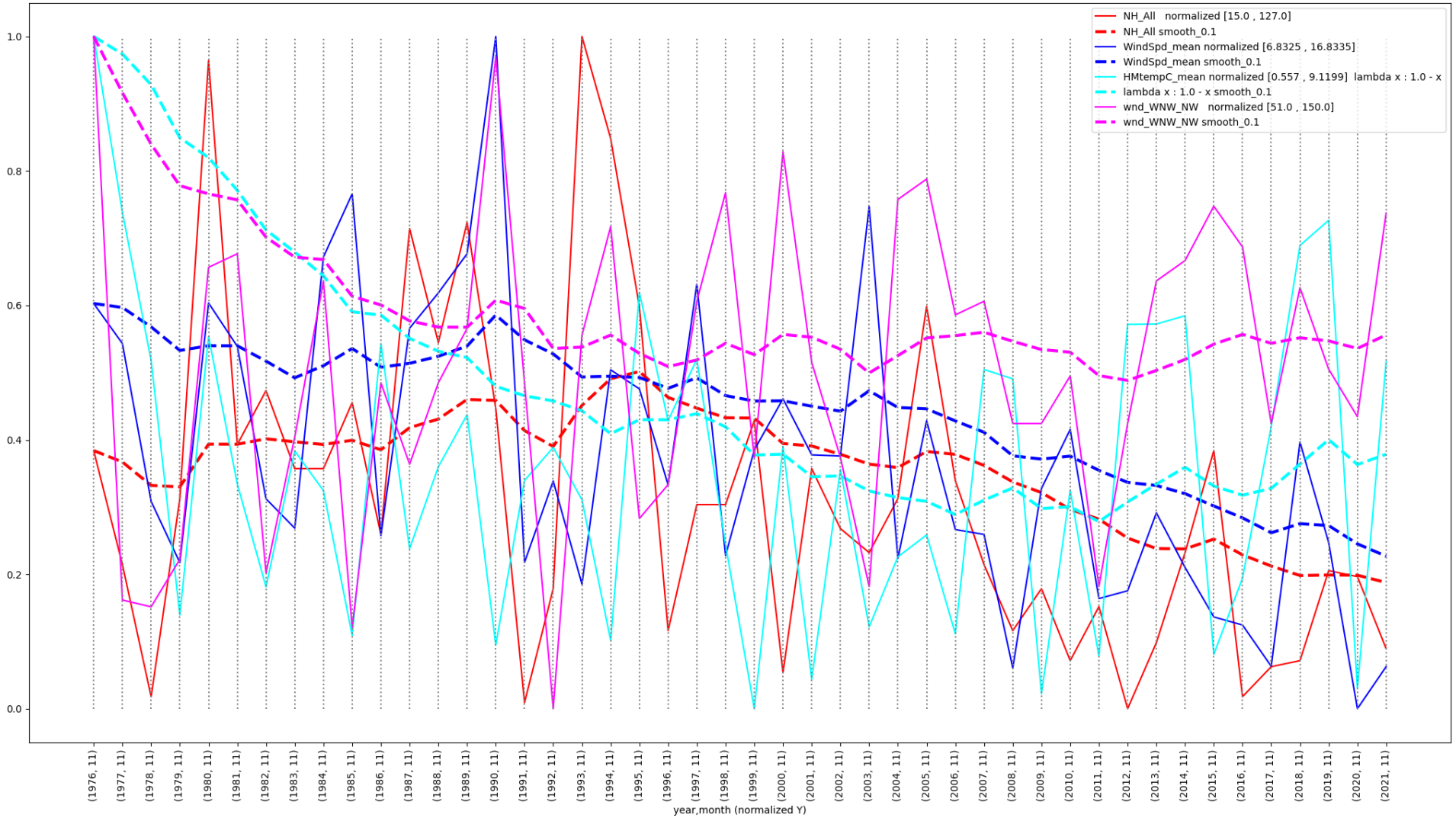

Figure 16: Normalized Northern Harrier Counts and their Smoothed Trends for November 1976 through 2021

Smoothed Linear Regression Model for November 1976 through 2021

NH_All_smooth =
0.936 * WindSpd_mean_smooth +
-0.38 * wnd_WNW_NW_smooth +
0.1661
Correlation coefficient 0.9166

Smoothed Linear Regression Model for November 1999 through 2021

NH_All_smooth =
0.9751 * WindSpd_mean_smooth +
0.555 * wnd_WNW_NW_smooth +
-0.3517
Correlation coefficient 0.97

Northern Harrier trends consistently track wind speed trends with high CC values starting in 1999 when their slope trends align with the other climate attributes.

9. Northern Goshawk (NG)

Northern Goshawk is the final species considered in this summer 2023 study. September's counts are in the low range [0, 4], so we examine only October and November. Rough-legged Hawk counts peak at [0, 17] in November, so they do not appear in this study.

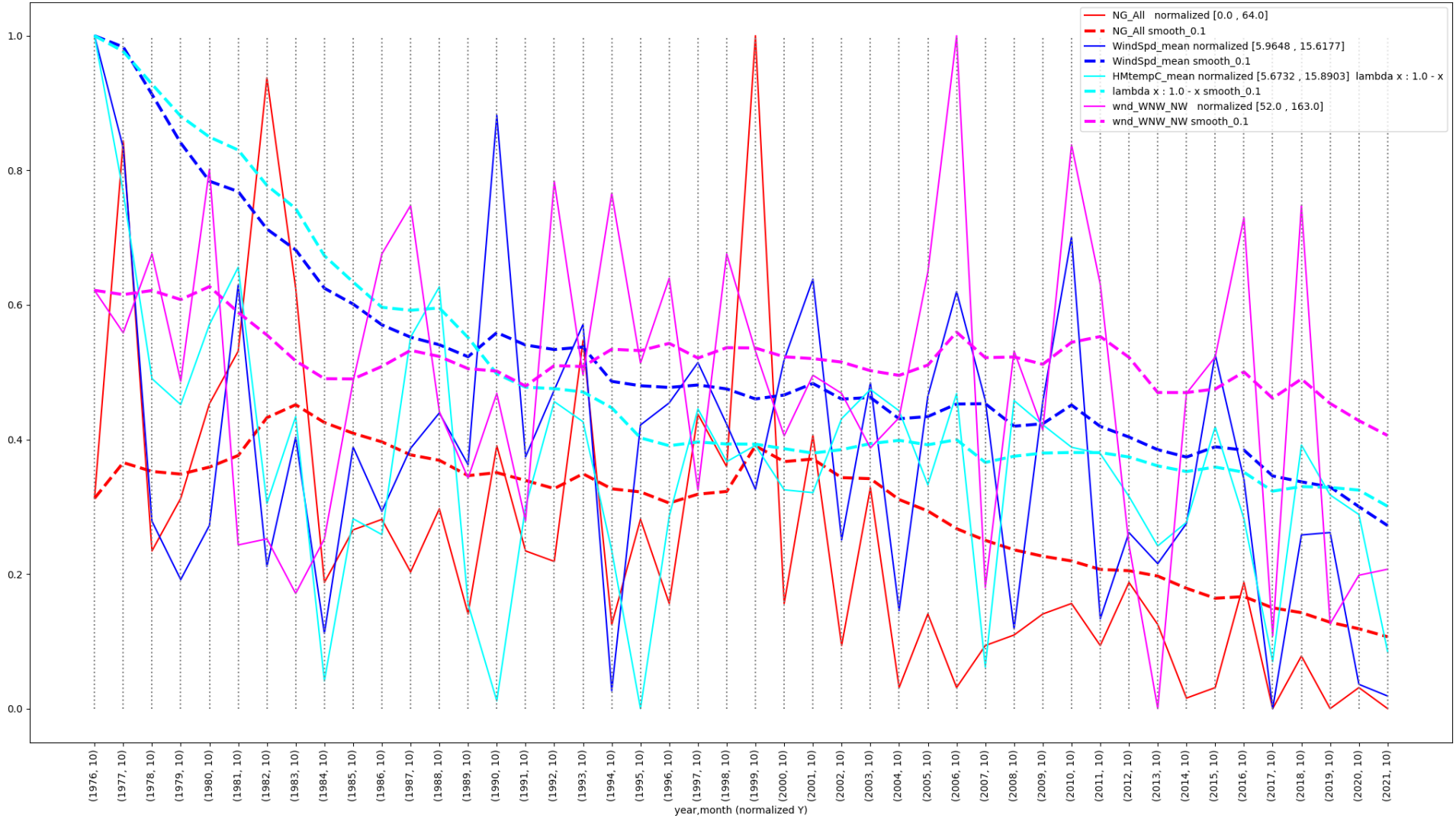

Figure 17: Normalized Northern Goshawk Counts and their Smoothed Trends for October 1976 through 2021

Smoothed Linear Regression Model for <u>October 1976 through 2021</u>

NG_All_smooth =
0.3532 * WindSpd_mean_smooth +
0.1128

Correlation coefficient 0.5648

Smoothed Linear Regression Model for <u>October 1999 through 2021</u>

NG_All_smooth =
1.9465 * WindSpd_mean_smooth +
-1.0484 * wnd_WNW_NW_smooth +
-0.0324
Correlation coefficient 0.8953

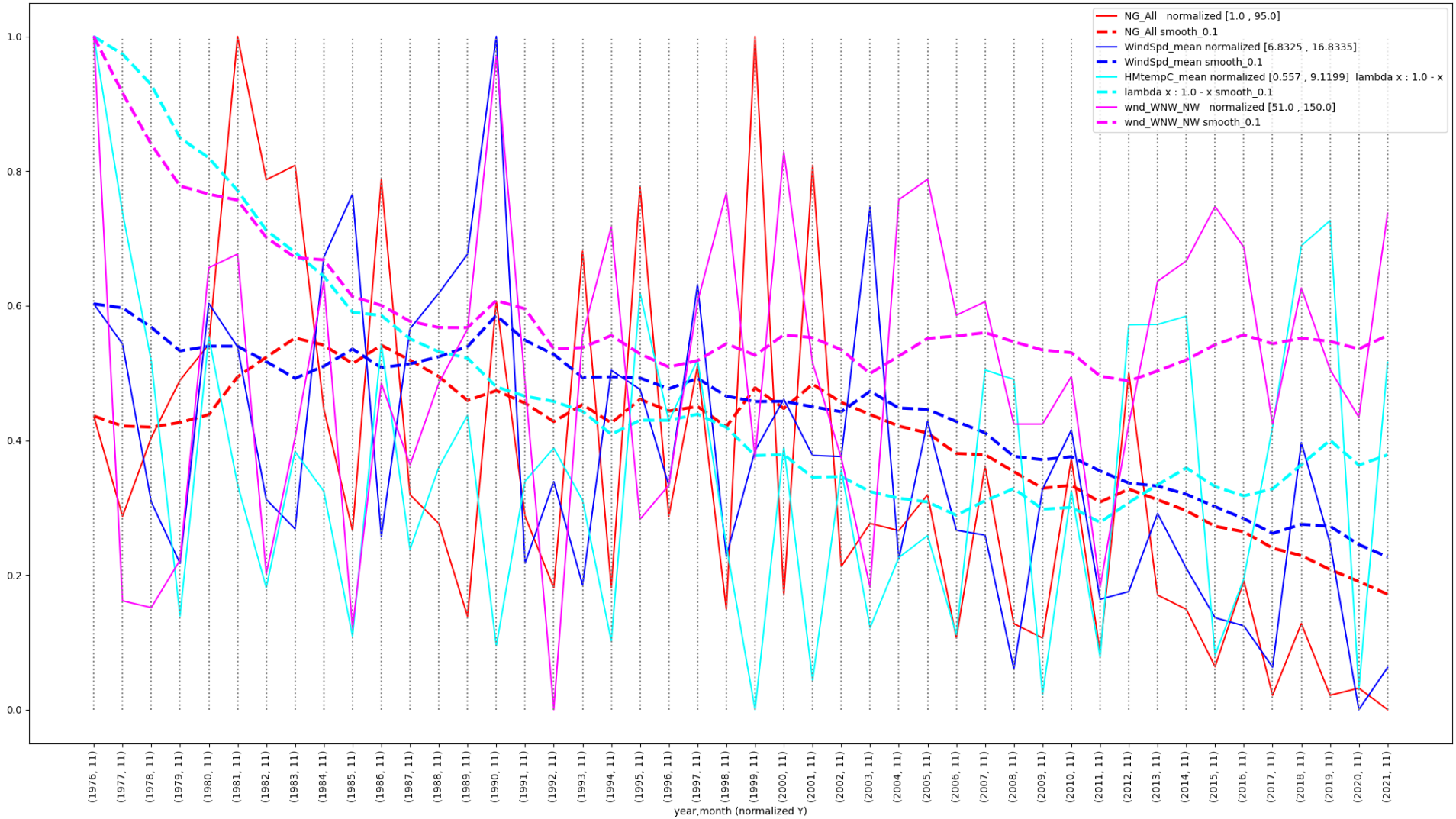

Figure 18: Normalized Northern Goshawk Counts and their Smoothed Trends for November 1976 through 2021

Smoothed Linear Regression Model for <u>November 1976 through 2021</u>
NG_All_smooth =

1.0091 * WindSpd_mean_smooth +
-0.2583 * wnd_WNW_NW_smooth +
0.1072
Correlation coefficient 0.8896

Smoothed Linear Regression Model for November 1999 through 2021
NG_All_smooth =
1.1591 * WindSpd_mean_smooth +
-0.0847
Correlation coefficient 0.9634

Models for all three months show the highest correlation of smoothed NG counts with smoothed wind speed averages from 1999 through 2021.

10. Correlation Table and Conclusions

Table 1 below shows the smoothed monthly climate attributes with the highest individual correlation coefficient magnitudes (positive and negative) [9] to the smoothed named-raptor count in the first column, which also gives the raptor count range for that month in 1976 through 2021. The Start and End years are the same as those for the Linear Expression models above for trailing years in which the smoothed raptor count slopes converge with HMtempC_mean_smooth, WindSpd_mean_smooth, and wnd_WNW_NW_smooth. The second-to-last column shows the smoothed attribute-to-raptor CC in the range [-1.0, 1.0] as before, the integer index in the data set (ignore it), and the climate attribute name. Recall that all attributes are normalized into the range [0.0, 1.0] using the formula **NormalizedValue = ((Value - MinValue) / (MaxValue - MinValue))**, in order to get values into the same range, before smoothing using the formula $\mathbf{SmoothedValue_{timeT} = (alpha\ X\ NormalizedValue_{timeT}) + ((1.0 - alpha)\ X\ NormalizedValue_{timeT-1})}$ [6], with alpha = 0.1 in this analysis for substantial smoothing of peaks and valleys. The last column shows the equivalent CC values for the un-smoothed attributes, taking into account peak, valley, and year-to-year slopes for the data graphed in the above figures. Wind directions and raptor attributes are counters and others are standard statistical measures. HMtempC is NOT inverted after normalization via the formula **1.0 - NormalizedHMtempC** in order to invert the slope; that inversion applies only in the graphs. The following list gives all of the climate attributes that Weka correlates in CC values in Table 1. The year and month are removed from the data before extracting CC values since they allow trivial mapping to raptor counts via memorization without considering patterns in climate change. The "pstdev" naming convention in attribute names indicates population standard deviation for that attribute; "wndUNK" is wind unknown for an observation in which no wind or mixed-direction breezes were present.

year, month, HMtempC_mean_smooth, WindSpd_mean_smooth, HMtempC_median_smooth,
WindSpd_median_smooth, HMtempC_pstdv_smooth, WindSpd_pstdv_smooth,
HMtempC_min_smooth, WindSpd_min_smooth, HMtempC_max_smooth, WindSpd_max_smooth,
wndN_smooth, wndNNE_smooth, wndNE_smooth, wndENE_smooth, wndE_smooth,
wndESE_smooth, wndSE_smooth, wndSSE_smooth, wndS_smooth, wndSSW_smooth,
wndSW_smooth, wndWSW_smooth, wndW_smooth, wndNNW_smooth, wndUNK_smooth,
wnd_WNW_NW_smooth

List 1: Attributes considered in the CC extraction of Table 1 below except year and month.

Raptor	Month	Start	End	Smoothed Attribute CC weights	Un-smoothed Attribute CC weights

RT [22, 208]	September	2008	2021	0.855 24 wndNNW_smooth **0.848 2 WindSpd_mean_smooth** 0.832 10 WindSpd_max_smooth 0.814 6 WindSpd_pstdv_smooth **0.801 4 WindSpd_median_smooth** -0.861 13 wndNE_smooth -0.874 22 wndWSW_smooth	0.4738 26 wnd_WNW_NW **0.452 2 WindSpd_mean** 0.4467 6 WindSpd_pstdv 0.4003 20 wndSSW **0.3696 10 WindSpd_max** -0.4082 22 wndWSW
RT [159, 2643]	October	1990	2021	**0.9659 4 WindSpd_median_smooth** **0.9093 2 WindSpd_mean_smooth** 0.7524 11 wndN_smooth 0.7511 26 wnd_WNW_NW_smooth -0.7581 1 HMtempC_mean_smooth -0.8048 22 wndWSW_smooth -0.8073 9 HMtempC_max_smooth -0.8223 15 wndE_smooth -0.8569 20 wndSSW_smooth -0.8591 25 wndUNK_smooth -0.888 12 wndNNE_smooth	**0.62381 2 WindSpd_mean** **0.57893 4 WindSpd_median** 0.45581 26 wnd_WNW_NW 0.35943 6 WindSpd_pstdv -0.28665 15 wndE -0.32198 20 wndSSW -0.34612 13 wndNE
RT [589, 4195]	November	1985	2021	**0.963 2 WindSpd_mean_smooth** 0.958 6 WindSpd_pstdv_smooth 0.937 10 WindSpd_max_smooth **0.932 4 WindSpd_median_smooth** 0.836 11 wndN_smooth -0.864 12 wndNNE_smooth -0.885 14 wndENE_smooth -0.925 25 wndUNK_smooth -0.926 16 wndESE_smooth	0.5319 10 WindSpd_max 0.5014 6 WindSpd_pstdv **0.4317 2 WindSpd_mean** 0.3088 8 WindSpd_min -0.2046 12 wndNNE -0.2164 16 wndESE -0.2256 14 wndENE -0.229 13 wndNE -0.4659 25 wndUNK
SS [499, 3971]	September	1997	2021	0.9395 6 WindSpd_pstdv_smooth **0.908 2 WindSpd_mean_smooth** 0.8532 10 WindSpd_max_smooth **0.8152 4 WindSpd_median_smooth** -0.8198 12 wndNNE_smooth -0.8433 25 wndUNK_smooth -0.9061 15 wndE_smooth -0.9081 14 wndENE_smooth -0.9499 13 wndNE_smooth	0.402 8 WindSpd_min 0.3279 21 wndSW 0.2938 17 wndSE 0.2628 23 wndW **0.2611 2 WindSpd_mean** 0.244 10 WindSpd_max **0.2329 4 WindSpd_median** -0.2161 1 HMtempC_mean -0.2301 15 wndE -0.3431 14 wndENE -0.6651 13 wndNE
SS [1326, 8915]	October	1997	2021	0.919 6 WindSpd_pstdv_smooth **0.885 2 WindSpd_mean_smooth** 0.863 11 wndN_smooth **0.814 4 WindSpd_median_smooth** 0.7 26 wnd_WNW_NW_smooth -0.72 13 wndNE_smooth -0.728 15 wndE_smooth -0.772 9 HMtempC_max_smooth -0.789 25 wndUNK_smooth -0.795 1 HMtempC_mean_smooth -0.817 20 wndSSW_smooth -0.825 14 wndENE_smooth -0.857 12 wndNNE_smooth -0.862 16 wndESE_smooth -0.888 22 wndWSW_smooth	0.576668 26 wnd_WNW_NW **0.566421 2 WindSpd_mean** **0.499188 4 WindSpd_median** 0.307796 8 WindSpd_min -0.365702 20 wndSSW -0.376211 9 HMtempC_max -0.457445 16 wndESE
AK [114, 537]	September	1993	2021	0.9227 8 WindSpd_pstdv_smooth **0.9109 4 WindSpd_mean_smooth** **0.855 6 WindSpd_median_smooth** 0.781 12 WindSpd_max_smooth 0.7325 7 HMtempC_pstdv_smooth 0.7186 13 wndN_smooth 0.6846 28 wnd_WNW_NW_smooth	0.35081 23 wndSW **0.295112 4 WindSpd_mean** **0.294594 6 WindSpd_median** 0.274253 28 wnd_WNW_NW -0.30252 25 wndUNK -0.306995 14 wndENE -0.356796 15 wndE

				-0.7984 7 HMtempC_min_smooth -0.8366 15 wndE_smooth -0.854 22 wndWSW_smooth -0.8587 25 wndUNK_smooth -0.8638 14 wndENE_smooth -0.9365 13 wndNE_smooth	-0.366446 13 wndNE
AK [53, 388]	October	1993	2021	**0.93644 4 WindSpd_median_smooth** **0.90761 2 WindSpd_mean_smooth** 0.7955 11 wndN_smooth 0.72848 26 wnd_WNW_NW_smooth 0.67275 6 WindSpd_pstdv_smooth -0.8099 1 HMtempC_mean_smooth -0.81811 20 wndSSW_smooth -0.84077 22 wndWSW_smooth -0.84955 15 wndE_smooth -0.87603 25 wndUNK_smooth -0.9006 12 wndNNE_smooth	**0.4437 2 WindSpd_mean** **0.43089 4 WindSpd_median** -0.29625 7 HMtempC_min -0.30318 14 wndENE -0.38468 25 wndUNK -0.40377 15 wndE
BW [1570, 29422]	September	1976	2021	0.7984 7 HMtempC_min_smooth 0.4819 8 WindSpd_min_smooth 0.4484 26 wnd_WNW_NW_smooth -0.7539 20 wndSSW_smooth -0.7893 5 HMtempC_pstdv_smooth -0.82 19 wndS_smooth -0.8242 17 wndSE_smooth -0.8327 23 wndW_smooth -0.8532 9 HMtempC_max_smooth	0.23428 8 WindSpd_min 0.23204 21 wndSW 0.21894 11 wndN -0.23942 3 HMtempC_median -0.27075 5 HMtempC_pstdv -0.28997 23 wndW -0.36532 1 HMtempC_mean -0.45654 9 HMtempC_max
CH [79, 922]	October	1976	2021	0.9296 7 HMtempC_min_smooth 0.9205 1 HMtempC_mean_smooth 0.9096 3 HMtempC_median_smooth 0.8954 9 HMtempC_max_smooth 0.8925 23 wndW_smooth -0.9035 10 WindSpd_max_smooth -0.9071 6 WindSpd_pstdv_smooth -0.9107 13 wndNE_smooth	0.47849 24 wndNNW 0.3112 18 wndSSE **0.29261 4 WindSpd_median** 0.24865 26 wnd_WNW_NW -0.30688 13 wndNE
CH [79, 922]	October	2001	2021	**0.8922 2 WindSpd_mean_smooth** **0.8825 4 WindSpd_median_smooth** 0.8662 26 wnd_WNW_NW_smooth 0.7318 11 wndN_smooth -0.7645 9 HMtempC_max_smooth -0.77 13 wndNE_smooth -0.8127 7 HMtempC_min_smooth -0.813 12 wndNNE_smooth -0.8226 20 wndSSW_smooth -0.8282 3 HMtempC_median_smooth -0.8867 1 HMtempC_mean_smooth	**0.64254 4 WindSpd_median** **0.58915 2 WindSpd_mean** 0.53846 26 wnd_WNW_NW 0.42592 24 wndNNW -0.32187 9 HMtempC_max -0.35703 15 wndE
OS [190, 544]	September	2007	2021	**0.9648 4 WindSpd_median_smooth** **0.9534 2 WindSpd_mean_smooth** 0.9026 10 WindSpd_max_smooth 0.891 6 WindSpd_pstdv_smooth 0.8206 24 wndNNW_smooth -0.6809 1 HMtempC_mean_smooth -0.7742 12 wndNNE_smooth -0.8209 19 wndS_smooth -0.9084 22 wndWSW_smooth -0.9661 13 wndNE_smooth	0.3912 10 WindSpd_max 0.3269 17 wndSE **0.3231 2 WindSpd_mean** 0.3136 23 wndW -0.3702 11 wndN -0.624 13 wndNE
OS [34, 379]	October	2003	2021	**0.9509 2 WindSpd_mean_smooth** **0.9277 4 WindSpd_median_smooth** 0.7998 6 WindSpd_pstdv_smooth 0.7912 26 wnd_WNW_NW_smooth	**0.4813 2 WindSpd_mean** 0.4483 6 WindSpd_pstdv 0.4327 8 WindSpd_min **0.3554 4 WindSpd_median**

				-0.8723 12 wndNNE_smooth -0.8731 7 HMtempC_min_smooth -0.8903 13 wndNE_smooth -0.9286 20 wndSSW_smooth -0.9289 1 HMtempC_mean_smooth	0.343 10 WindSpd_max -0.298 1 HMtempC_mean -0.3048 16 wndESE -0.344 9 HMtempC_max
NH [18, 176]	September	1999	2021	**0.9674 2 WindSpd_mean_smooth** **0.9624 4 WindSpd_median_smooth** 0.9393 6 WindSpd_pstdv_smooth 0.9151 10 WindSpd_max_smooth -0.7716 25 wndUNK_smooth -0.7787 7 HMtempC_min_smooth -0.8578 19 wndS_smooth -0.9099 22 wndWSW_smooth -0.965 13 wndNE_smooth	**0.56432 4 WindSpd_median** **0.53422 2 WindSpd_mean** 0.44983 10 WindSpd_max 0.35369 6 WindSpd_pstdv 0.32457 8 WindSpd_min -0.3944 22 wndWSW -0.55946 13 wndNE
NH [28, 198]	October	1999	2021	**0.9541 2 WindSpd_mean_smooth** **0.9467 4 WindSpd_median_smooth** 0.9227 11 wndN_smooth 0.8335 6 WindSpd_pstdv_smooth 0.8253 17 wndSE_smooth 0.7615 26 wnd_WNW_NW_smooth -0.8386 20 wndSSW_smooth -0.8852 25 wndUNK_smooth -0.904 1 HMtempC_mean_smooth -0.9102 12 wndNNE_smooth -0.9168 22 wndWSW_smooth	**0.50048 2 WindSpd_mean** 0.46024 8 WindSpd_min **0.432 4 WindSpd_median** 0.3601 6 WindSpd_pstdv 0.33506 26 wnd_WNW_NW -0.35149 9 HMtempC_max -0.35361 16 wndESE
NH [15, 127]	November	1999	2021	**0.9675 4 WindSpd_median_smooth** **0.967 2 WindSpd_mean_smooth** 0.9595 6 WindSpd_pstdv_smooth 0.9447 10 WindSpd_max_smooth 0.8708 11 wndN_smooth -0.8487 14 wndENE_smooth -0.9112 23 wndW_smooth -0.9251 19 wndS_smooth -0.9313 16 wndESE_smooth -0.9486 25 wndUNK_smooth	0.4868 3 HMtempC_median 0.4684 1 HMtempC_mean 0.4442 17 wndSE 0.4188 22 wndWSW 0.3846 18 wndSSE 0.2843 21 wndSW **0.2705 2 WindSpd_mean** -0.2238 25 wndUNK -0.3121 15 wndE -0.3461 11 wndN -0.5411 23 wndW
NG [0, 64]	October	1999	2021	0.94086 11 wndN_smooth **0.8868 2 WindSpd_mean_smooth** **0.88609 4 WindSpd_median_smooth** 0.84481 6 WindSpd_pstdv_smooth 0.80955 17 wndSE_smooth 0.63558 26 wnd_WNW_NW_smooth -0.81627 15 wndE_smooth -0.83264 1 HMtempC_mean_smooth -0.86919 12 wndNNE_smooth -0.90072 25 wndUNK_smooth -0.96956 22 wndWSW_smooth	0.29448 8 WindSpd_pstdv 0.28114 20 wndSSE **0.2533 4 WindSpd_mean** 0.23943 10 WindSpd_min -0.18266 3 HMtempC_median -0.19856 24 wndNNW -0.21504 1 HMtempC_mean -0.29409 13 wndNE -0.34472 9 HMtempC_max
NG [1, 95]	November	1999	2021	**0.9748 2 WindSpd_mean_smooth** **0.9668 4 WindSpd_median_smooth** 0.9543 6 WindSpd_pstdv_smooth 0.9233 10 WindSpd_max_smooth 0.9152 11 wndN_smooth -0.8053 14 wndENE_smooth -0.867 23 wndW_smooth -0.8889 16 wndESE_smooth -0.9098 19 wndS_smooth -0.9141 25 wndUNK_smooth	0.60903 24 wndNNW 0.44453 22 wndWSW **0.39398 2 WindSpd_mean** -0.25998 8 WindSpd_min -0.27292 19 wndS

Table 1: Strongest correlation coefficients of smoothed & un-smoothed monthly climate properties to raptor counts

In the smoothed column of Table 1, **WindSpd_mean_smooth** or **WindSpd_median_smooth**, **highlighted in bold**, appears within the top two most positively correlated attributes for raptor-month pairings, constrained by trailing years corresponding to aligned smoothed slopes in the graphs, except for Broad-winged Hawks (BW) in September across all years 1976 through 2021 and Cooper's Hawks (CH) in October across all years. CH in October for 2001 through 2021 shows WindSpd_mean_smooth and WindSpd_median_smooth as the two most highly-correlated attributes.

In the un-smoothed column of Table 1, **WindSpd_mean** or **WindSpd_median**, **highlighted in bold**, appears within most of the top three most positively correlated attributes for raptor-month pairings, constrained by trailing years. The exceptions are Sharp-shinned Hawks in September (these wind speed measures are in fifth and seventh places), Broad-winged Hawks as in the smoothed column, and Northern Harriers in November, where WindSpd_mean's CC is in seventh place. This un-smoothed column shows generally lower CC values because of temporal misalignment of peaks, valleys, and month-to-month slopes among the attributes. As noted before, the un-smoothed view of these data is not intended to show long-term trends. The smoothed and un-smoothed variants of , , appear as strong correlates for some of these raptor species, but not as generally strong as WindSpd_mean and WindSpd_median, which dominate the correlates. Wind speed correlates highly with raptor counts. Previous graphs show the decline in mean wind speed for more recent years. A few graphs showing trends in all wind speed and temperature parameters at North Lookout sets up completion of this discussion.

wnd_WNW_NWunderlined in Table 1 for emphasis

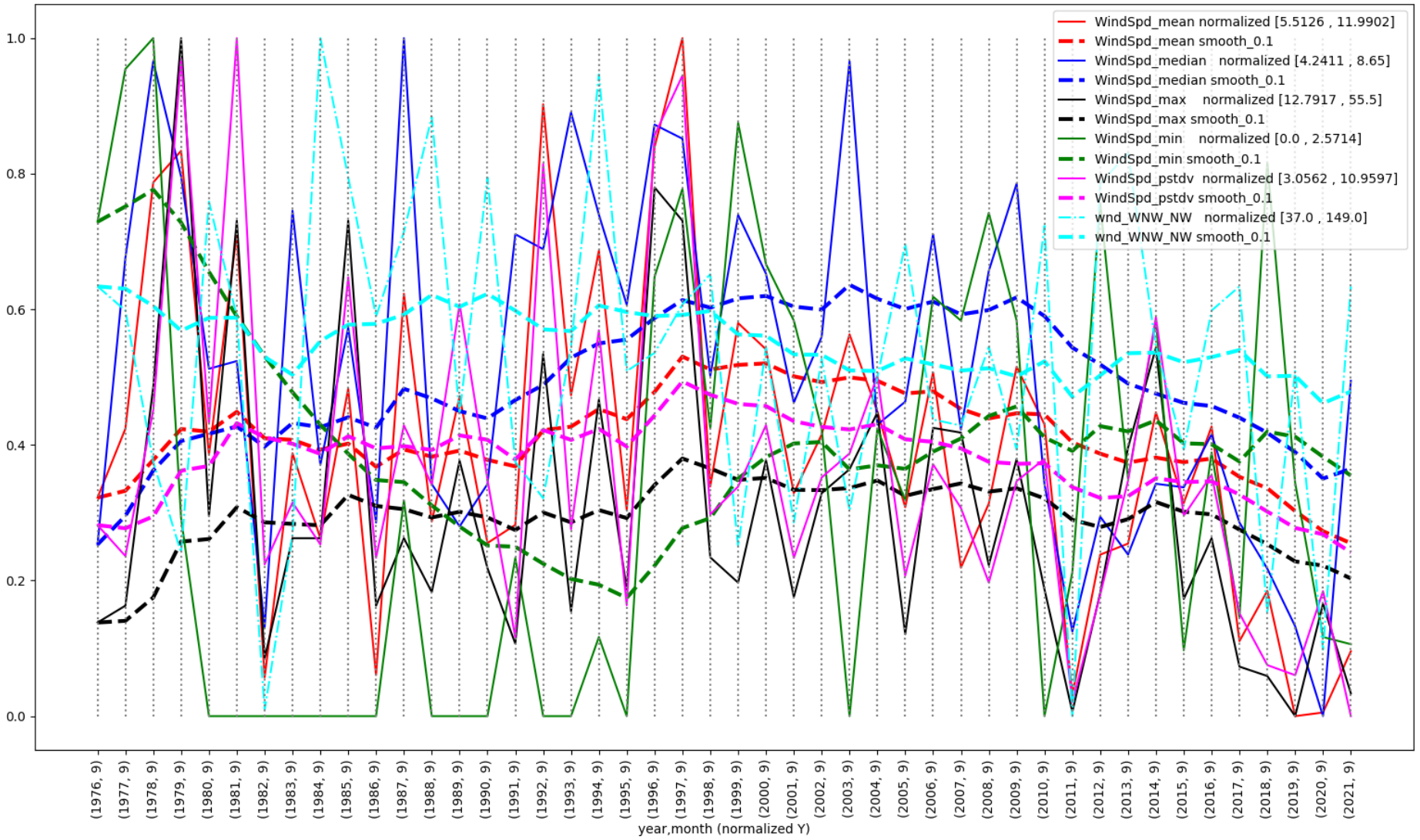

Figure 19: Wind Speed Un-smoothed and Smoothed Trends in September

September slopes show a gradual decline since 2009 with a rounded mean wind speed range of [5.5, 12.0] km/hour.

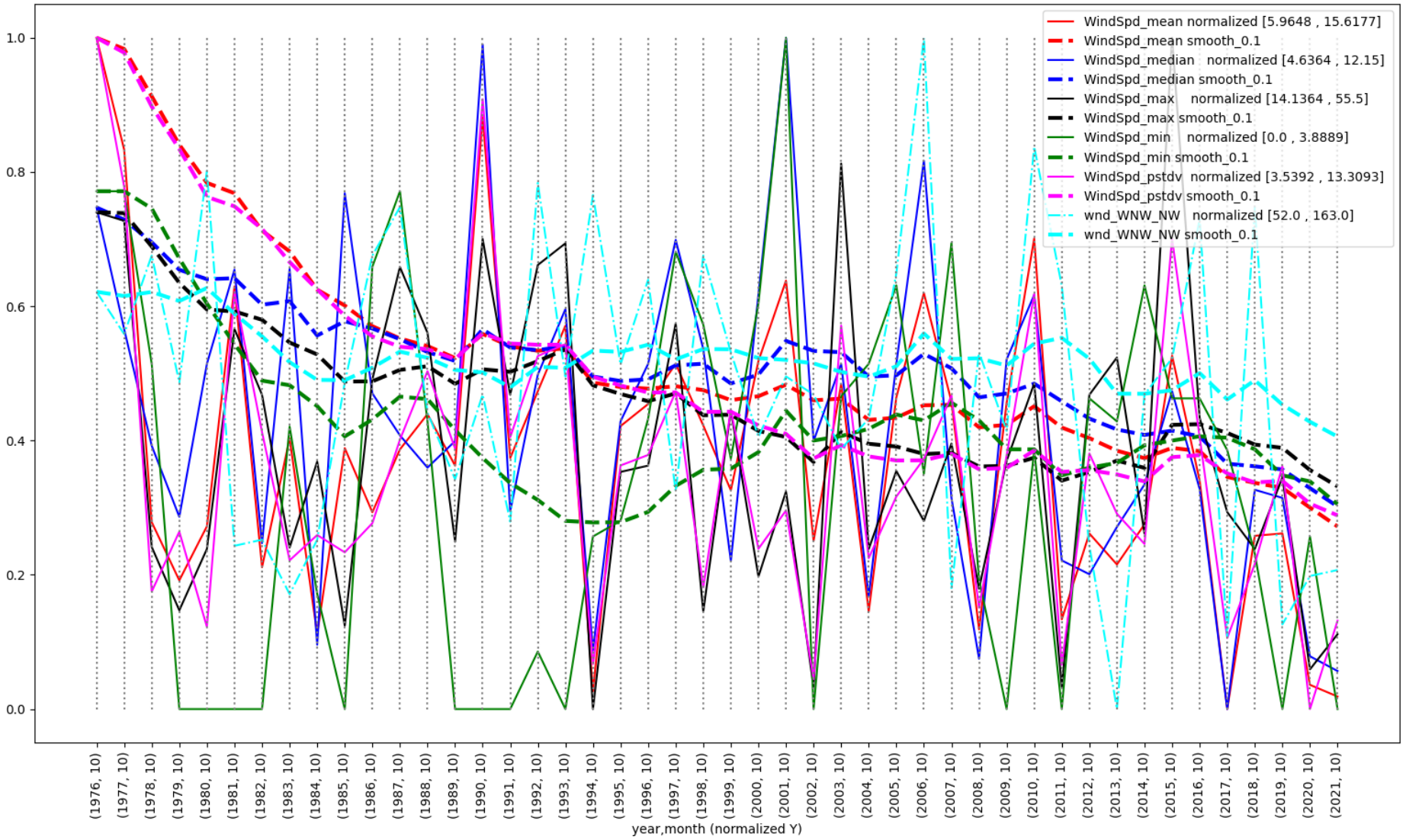

Figure 20: Wind Speed Un-smoothed and Smoothed Trends in October

October slopes show a steeper, consistent decline since 1976 with a rounded mean wind speed range of [6.0, 15.6] km/hour. While September's range of [5.5, 12.0] has a max-min distance of , October's [6.0, 15.6] has a max-min distance of , a 47.7% greater downslope from highest to lowest measure than in September. Notably, October and November are the prime raptor migration and observation months for many species. November's mean wind speed range in the next graph is [6.8. 16.8] km/hours, a slightly greater max-min distance of . The peaks in October are mostly missing in November of recent years.

6.5 km/hour9.6 km/hour10 km/hour

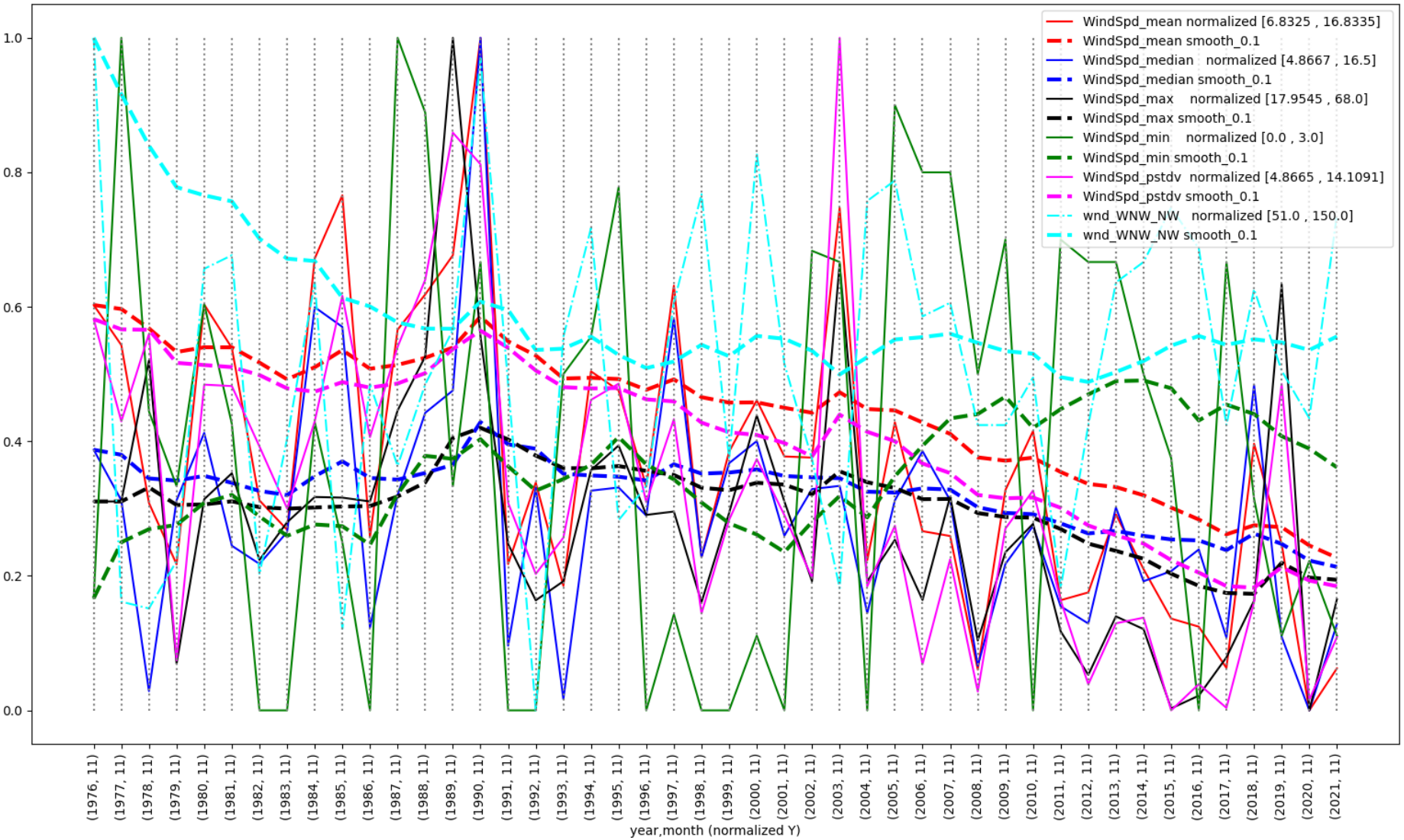

Figure 21: Wind Speed Un-smoothed and Smoothed Trends in November

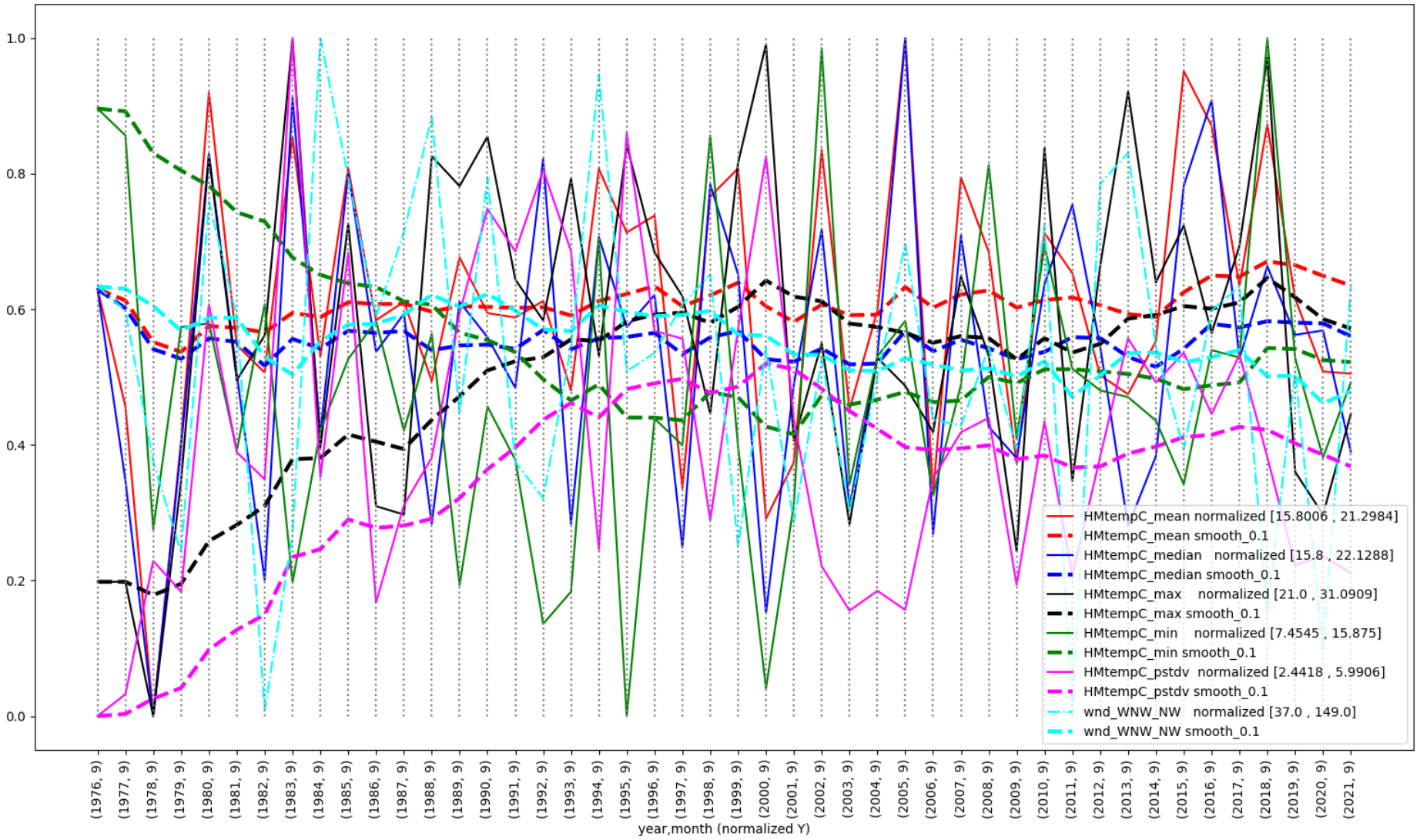

Figure 22: Temperature Celsius Un-smoothed and Smoothed Trends in September

Smoothed September monthly temperatures are roughly level in recent years.

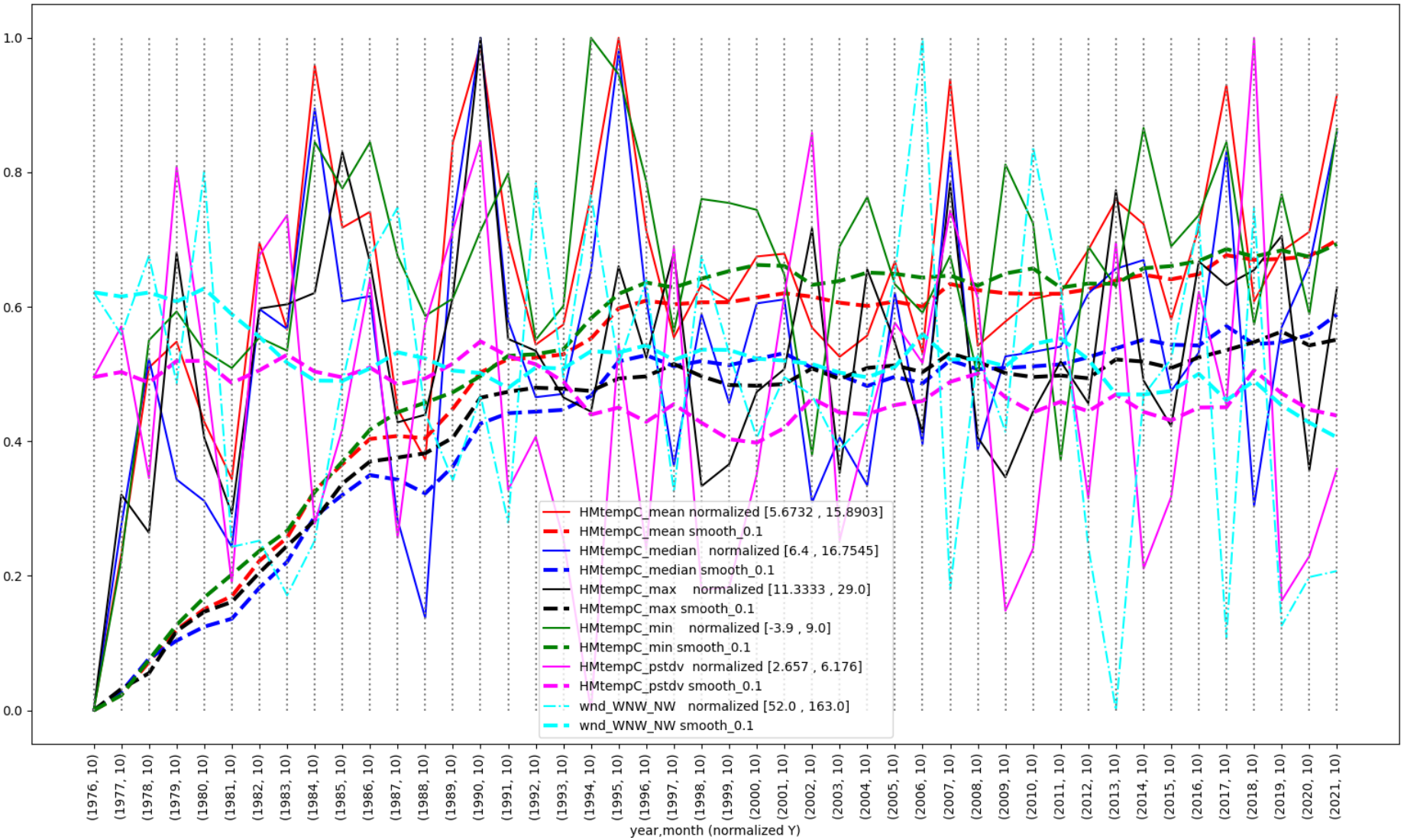

Figure 23: Temperature Celsius Un-smoothed and Smoothed Trends in October

October's and November's mean and median temperature have continued to grow at a gradual rate after rapid growth early in this span of years.

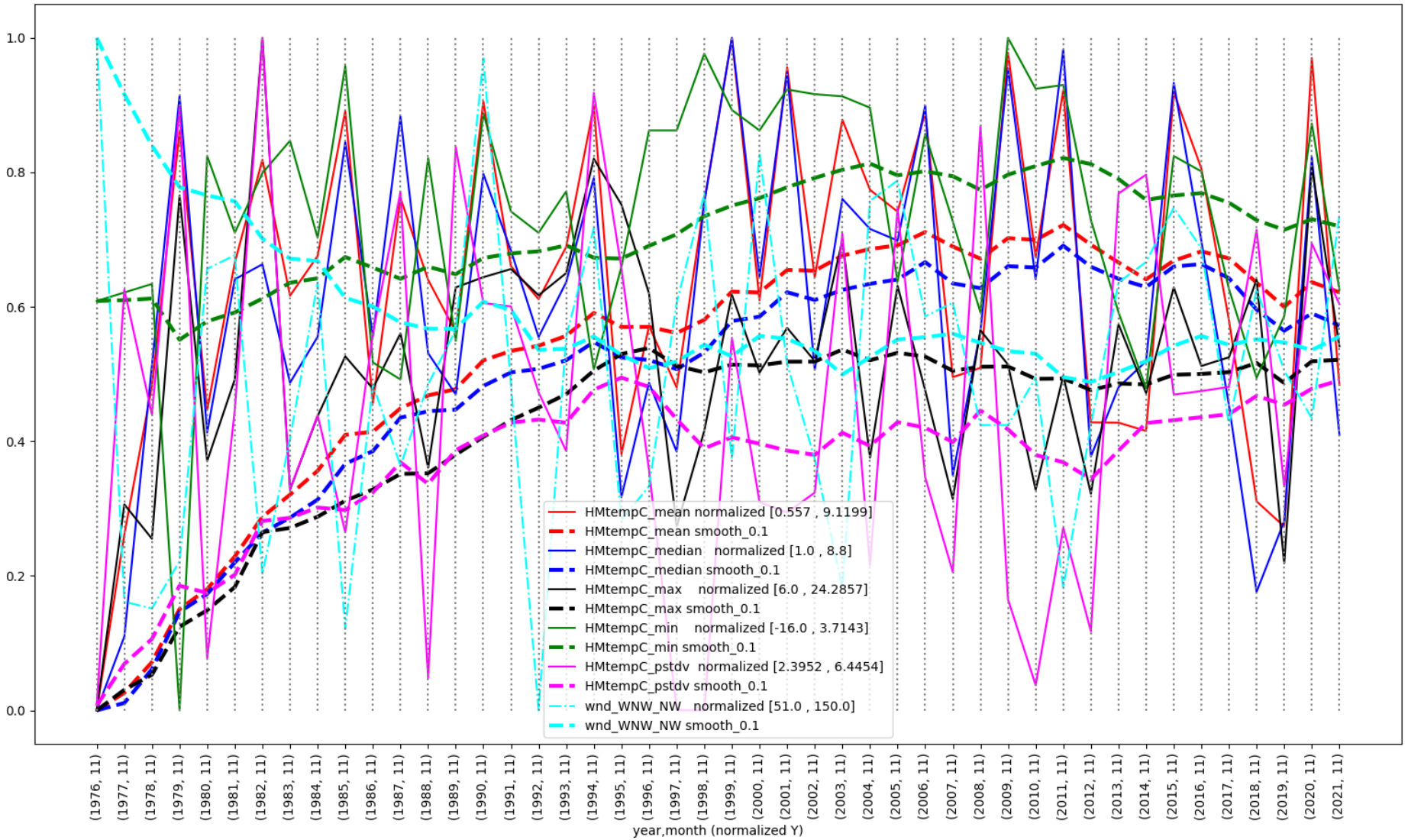

Figure 24: Temperature Celsius Un-smoothed and Smoothed Trends in November

As seen from Table 1 and Figures 19 through 21, especially for the prime observation months of October and November in Figures 20 and 21, wind speed measures that correlate strongly with most raptor species counts are consistently declining during observation periods. There are three potential hypothesis about the declining raptor counts. A) Diminishing updrafts on the north-northwest side of the Kittatinny Ridge are leading the raptors to cross the mountain at more widespread locations instead of funneling them past North Lookout and across the Eckville Fault. B) Raptors are wintering further north, perhaps due to increasing temperatures. C) Raptor populations are declining in numbers. The next step in this investigation would be to look for trends in the raptor counts during the spring, northerly migration. If there has been no significant change in the last quarter century, that would indicate alternative (A). This concludes this stage of the study.

References

1. *Global 'Stilling': Is Climate Change Slowing Down the Wind?* Jim Robbins, Yale School of the Environment, September 13, 2022. https://e360.yale.edu/features/global-stilling-is-climate-change-slowing-the-worlds-wind

2. *Learn About Heat Islands*, United States Environmental Protection Agency, https://www.epa.gov/heatislands/learn-about-heat-islands, URL tested June 24, 2023.

3. "The tipping point: The Lehigh Valley faces environmental and public health crises", *The Brown and White* newsletter, Nik Malhotra, January 20, 2021. https://thebrownandwhite.com/2021/01/20/the-tipping-point-the-lehigh-valley-faces-environmental-and-public-health-crises/

4. *Why do migrating raptors concentrate at Hawk Mountain*? Hawk Mountain Sanctuary. Raptorpedia. https://www.hawkmountain.org/conservation-science/resources/raptorpedia

5. Discussion with Dr. Laurie Goodrich concerning three-letter wind direction observations at North Lookout, January 2023.

6. A. Pal and P. Prakash, *Practical Time Series Analysis*, "Chapter 3: Exponential Smoothing based Methods". Packt Publishing, 2017.

7. *Weka 3: Machine Learning Software in Java*. https://www.cs.waikato.ac.nz/ml/weka/

8. Therrien, et. al, "Long-term phenological shifts in migration and breeding-area residency in eastern North American raptors". *The Auk, Ornithological Advances*, Volume 134, 2017, pp 871-881.

9. Pearson Correlation Coefficient, scipy.stats.pearsonr, https://docs.scipy.org/doc/scipy/reference/generated/scipy.stats.pearsonr.html