THOMPSON RIVERS UNIVERSITY

TRENDS IN HOURLY WEATHER AND FIRE WEATHER INDICES ACROSS BIOGEOCLIMATIC ZONES IN BRITISH COLUMBIA UNDER A CHANGING CLIMATE

by

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ABSTRACT

The increased occurrence of hot, dry, and windy weather is resulting in worsening fire conditions with five of the worst fire seasons on record in British Columbia occurring since 2017. Two critical daily periods have implications for fire growth: peak burn and overnight conditions. This study aims to provide insights into changing conditions during peak burn and overnight weather by investigating trends in hourly weather variables (temperature, relative humidity, and windspeed) and associated fire weather indices (Fine Fuel Moisture Code, Initial Spread Index, and Fire Weather Index) across different Biogeoclimatic Ecosystem Classification (BEC) zones in British Columbia. Historical weather data from June, July, August, and September spanning two periods, 1990-2005 and 2006-2021 was analyzed at an hourly scale. The analysis revealed the greatest magnitude of change occurred in the afternoon hours for all zones and months in the study. Spread event conditions are occurring more frequently and BEC zones affected by the rain shadow effect are seeing more significant results indicating warming and drying. This analysis of hourly weather highlights the implications of observed trends on expected changes in fire behaviour with a spatial and temporal lens and can be used to inform wildfire management practices across British Columbia.

Key words: hourly weather, BEC zones, climate change, wildfire management

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"Our greatest weakness lies in giving up. The most certain way to succeed is always to try just one more time." —Attributed to Thomas Edison

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AT – Alpine Tundra
BEC -Biogeoclimatic Ecosystem Classification
BCWS – British Columbia Wildfire Service
BG - Bunchgrass
BUI – Build-up Index
BWBS – Black and White Boreal Spruce
CDF – Coastal Douglas Fir
CWH – Coastal Western Hemlock
DC – Drought Code
DMC – Duff Moisture Code
ESSF – Englemann Spruce Subalpine Fir
FFMC – Fine Fuel Moisture Content
FTS – Forest Technology Systems
FWI – Fire Weather Index
ICH – Interior Cedar Hemlock
IDF – Interior Douglas Fir
IPCC – Intergovernmental Panel on Climate Change
ISI – Initial Spread Index
MAP – Mean Annual Precipitation
MAT – Mean Annual Temperature
MCMT – Mean Coldest Month Temperature
MH – Mountain Hemlock
MODIS – Moderate Resolution Imaging Spectroradiometer
MS – Montane Spruce
MSP – Mean Summer Precipitation
MWMT – Mean Warmest Month Temperature
PP – Ponderosa Pine
RH – Relative Humidity
SBPS – Sub-boreal Pine-Spruce
SBS – Sub-boreal Spruce
SWB – Spruce Willow Birch
TD – Differential between MWMT and MCMT
TEMP - Temperature
WS – Wind Speed

CHAPTER 1 - INTRODUCTION

Climate change & fire

Human-caused greenhouse gas emissions have resulted in global surface temperatures increasing by 1.1 °C as of 2020 (Intergovernmental Panel on Climate Change, 2023). All regions, globally, have experienced climate extremes and are expected to see increased occurrence and adverse effects associated with natural disasters as global warming intensifies hazards (Intergovernmental Panel on Climate Change, 2023). Climate change is leading to longer, hotter, and drier fire seasons with increasing area burned (Flannigan et al. 2009).

A notable amount of research has been conducted on the implications of climate change on wildland fires. Flannigan et al. (2009) conducted a meta-analysis examining the effects of changing climate on global wildland fire across 47 studies published between 1991 and 2009. They found that fire activity, including fire weather, area burned, fire occurrence, fire season, fire intensity, and fire severity were associated with future climate change emission scenarios (Flannigan et al. 2009). Their synthesis highlighted a consistent pattern of results suggesting an overwhelmingly positive relationship between climate change and wildland fire globally, with only one study finding a negative relationship (specific to Brandenburg, Germany) and 10 studies with trends showing mixed results, with both positive and negative trends. Further research into future climate change scenarios has continued to show agreement on a trend toward extreme fire weather and aggressive fire behaviour (Abatzoglou et al., 2019; Ellis et al., 2021; Flannigan et al., 2009; Guindon et al., 2021; Jain et al., 2021; Jolly et al., 2015; Meyn et al., 2010; Parisien et al., 2023; Wang et al., 2015; Wotton et al., 2017).

Wildfire fundamentals

The physical process by which combustion occurs is a well-understood phenomenon; however, the behaviour of fire varies depending on the characteristics of the fire environment. The fire environment is comprised of fuel, weather, and topography (Countryman, 1972). The interactions among these three components create a dynamic environment for fire by either accelerating or dampening the process of heat transfer (Van

Wagner, 1983; Agee, 1996; Sullivan, 2017), which results in a mosaic of potential fire intensities across the landscape (Van Wagner, 1983).

Weather has a dominant influence on fire behaviour due to a complex series of processes that both directly and indirectly affect fire (Flannigan et al. 2009). Temperature, relative humidity, wind and precipitation affect fuel moisture (Van Wagner, 1983; Sullivan, 2017) and fuel moisture determines whether wildfires can ignite and sustain combustion. Temperature has a strong influence on the capacity of air to hold moisture. For every 1°C increase in temperature, precipitation needs to increase by over 15% to counteract the fuel moisture loss in fine fuels, 10% in medium fuels, and 5% for deep or heavy fuels (Flannigan et al., 2016). Winds affect the drying rate of fine fuels and precipitation directly adds moisture, with increasing thresholds required to impact deeper fuel layers (Van Wagner, 1987). Relative humidity influences the moisture content of dead fuels. Low relative humidity has been linked with the development of extreme fire behaviour (Werth et al., 2016).

In addition to fuel moisture impacts, wind is also key factor in determining the rate and direction of fire spread. Winds supply oxygen to the fire which increases combustion. Winds also tilt the angle of flame closer to fuels ahead of the flaming front, accelerating fire spread through pre-heating and winds facilitate lofting and transfer of embers ahead of the flaming front into available fuels. Ember loft is increased in areas of atmospheric instability, which is associated with strong updrafts, gusty surface winds, dust devils, fire whirls, pyrocumulonimbus development, strong downdrafts, and extreme fire behaviour (Werth et al., 2016). When hot, dry, windy weather conditions coincide with continuous dry fuels across the landscape, fires experience rapid growth, expelling substantial quantities of heat energy (Sullivan, 2017) and challenging suppression efforts.

FWI System Overview

The influence of weather on fire growth and spread is of critical importance to understand and forecast fire behaviour potential. Thus, the Fire Weather Index (FWI) System was developed by federal government fire researchers and has been in use since the 1970s (Van Wagner, 1987; Wotton, 2009). The FWI System uses measurements of the key weather variables: temperature, 10-wind speed, relative humidity, and 24-h precipitation recorded daily at noon LST (Lawson & Armitage, 2008). The weather variables are used to calculate six fire weather indices representative of peak burning conditions at 1600 h (Figure 1) (Forestry Canada Fire Danger Group, 1992; Taylor & Alexander, 2003; Lawson & Armitage, 2008). There are three primary indices of fuel moisture content, the Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC), and Drought Code (DC).

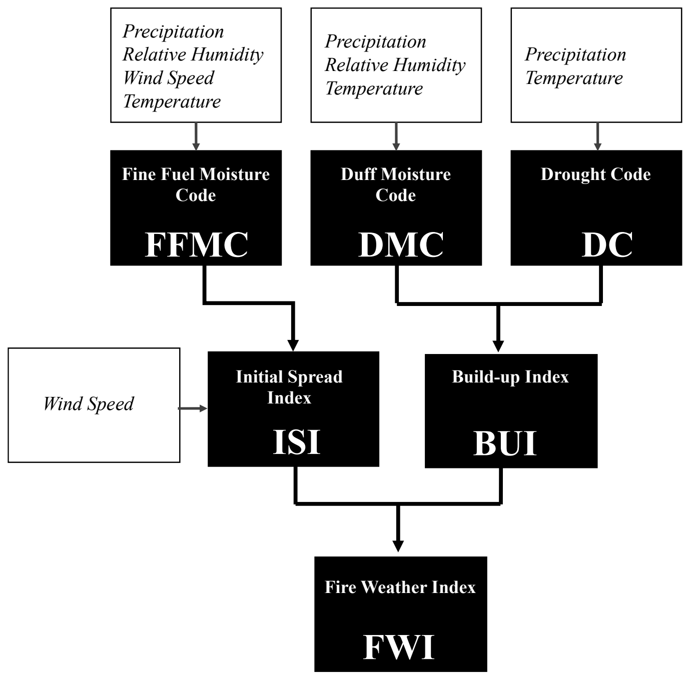

Figure 1:Weather parameter inputs and components of the Fire Weather Index System (Van Wagner, 1987).

The fuel moisture codes are differentiated by fuel size class and quantity, water holding capacity, and the time it takes for fuels to dry or wet to meet equilibrium moisture content with the environment (Van Wagner, 1987). The Fine Fuel Moisture Code (FFMC) represents fuel moisture in litter, small twigs, and other fine fuels. Precipitation (>0.5mm in the last 24 hours), increased relative humidity and cooler temperatures can cause these fuels to draw in moisture from the environment. The drying or wetting rate will increase or decrease depending on the atmospheric conditions, but drying in this layer is approximately 12 hours at 25°C, 30% relative humidity and 10km/h wind speeds (Wotton, 2009). The FFMC value indicates fuel receptivity to ignition and fire spread, which is dependent on the availability of fine dry fuels. The Duff Moisture Code (DMC) represents the layer of fuels beneath litter, up to 7cm, which is comprised of decomposing organic material, and has a drying time of approximately 10 days at 25°C and 30% relative humidity. Cumulative 24-hour precipitation exceeding 1.5mm is required to effectively add moisture back to this fuel layer (Van Wagner, 1987). Finally, the third moisture index, the Drought Code (DC) represents fuel moisture in the deep organic layer and large-diameter fuels on the forest floor. These fuels take approximately 50 days to dry under 25°C conditions and require cumulative 24-hour precipitation to exceed 2.8mm to effectively increase moisture content (Van Wagner, 1987).

The fuel moisture codes, FFMC, DMC and DC, are then used to derive two intermediate indices, which represent the potential rate of fire spread, the Initial Spread Index (ISI) which considers the FFMC and wind speed, and the potential fuel consumption, represented by the Build-Up Index (BUI) and derived from a combination of the DMC and DC. Finally, an overall index, the Fire Weather Index (FWI), is calculated from the ISI and BUI to represent the overall potential level of fire intensity calculated from the indicators of possible fuel consumption and rate of spread.

Fire Growth Thresholds

Thresholds of the FWI system can be used by management agencies to understand potential fire danger due to current and forecast conditions. Most area burned occurs during periods of extreme fire weather (Rothermel et al., 1994). A ‘spread event’ is defined as an event where a wildfire exhibits substantial growth in a relatively short amount of time (Podur & Wotton, 2011). FWI system values associated with extreme fire weather can be used to understand conditions where fires are likely to exhibit ease of ignition, high intensity, and rapid growth rates (Table 1). An FFMC of 91 and above is associated with vigorous fire spread (Taylor & Alexander, 2006; Wotton, 2009). An ISI threshold of 8.7 has been shown as a key indicator of spread event potential (Podur & Wotton, 2011; Wang et al., 2014). Although there is no threshold for BUI, which is less effective as a spread event indicator (Wang et al., 2023), the overall FWI takes into consideration the ISI and BUI and a threshold value of 19 has been linked to active fire spread (Podur & Wotton, 2011). Wang et al. (2023) found FFMC was the most robust measure of spread events across large geographic areas but also recommend ISI and FWI as the top three indicators of choice. Their study addressed spread events by season spring (March, April, May), summer (June, July, August) and fall (September, October, November) across Canada and used ecozones as the geographic study area, providing a more nuanced approach to spread event thresholds regionally across the country.

Table 1: Threshold values from the literature for Fine Fuel Moisture Code (FFMC), Initial Spread Index (ISI) and Fire Weather Index (FWI)

FWI System Indices	Spread Day Threshold	Reference
FFMC	91	Taylor and Alexander (2006); Wotton (2009)
ISI	8.7	Podur and Wotton (2011); Wang et al. (2014)
FWI	19	Podur and Wotton (2011)

Fire Management and the Diurnal Cycle

A typical operational firefighting period is between 1000h and 1900h. This ensures resources (crews, equipment, aircraft) are available during the peak burning conditions of a day to respond to new fire starts and work to prevent wildfire escapes. The diurnal weather patterns of temperature and relative humidity lead to peak fire activity occurring between 1600h and 1800h when fuel moisture is at its lowest point. The increased occurrence of hot, dry, and windy weather is resulting in worsening fire conditions. Five of the worst fire seasons on record in British Columbia have occurred since 2017 (Government of British Columbia, 2025). Extreme fire weather results in fire behaviour that exceeds the capacity and effectiveness of suppression personnel and equipment. Under periods of extreme fire growth, resources are removed from active duty due to safety concerns.

Conversely, the least active time for fire activity is overnight and early morning when relative humidity is at its highest leading to fuel moisture recovery. However, in recent years, more observations of overnight fire growth have occurred (Balch et al., 2022; Luo et al., 2024). These studies have shown the number of flammable overnight burning hours has increased globally from 1979-2020 (Balch et al., 2022), overnight wildfire intensity has increased from 2003-2020 (Balch et al., 2022) and that overnight burning events were associated with large fires from 2017-2020 (Luo et al., 2024) Globally, daily minimum temperatures were found to rise at a faster rate than daily max temperatures, leading to a narrowing of the diurnal temperature range (Easterling et al. 1997).

Many of the assumptions operational personnel have on daily fire behaviour are being challenged due to recent extreme fire weather conditions. Many studies agree that fire weather and fire behaviour are expected to become more extreme under a changing climate (Abatzoglou et al., 2019; Flannigan et al., 2009; Jain et al., 2021; Jolly et al., 2015; Meyn et al., 2010; Parisien et al., 2023; Wang et al., 2015; Wotton et al., 2017). However, the nuances of changing weather haven't yet been explored at the diurnal scale.   This study aims to understand how changing weather patterns are impacting regions in British Columbia by analyzing trends in hourly weather across the full 24 hours of observed historical weather data and hourly fire weather indices.

Research question:

This thesis investigates the following research question:

What trends (geographically, and diurnally) in hourly weather (temperature, relative humidity, and wind speed), fire weather indices (FFMC, ISI, and FWI), and spread event thresholds can be detected from a historical weather dataset spanning two periods (1990-2005 and 2006-2021) across biogeoclimatic ecosystem classification (BEC) zones in British Columbia?

CHAPTER 2 - METHODS

Study Area

This study focuses on understanding weather and fire weather variation across the province of British Columbia. The province is geographically diverse leading to variable climatic conditions across the land base. Orographic influences of the coastal and rocky mountain ranges affect moisture patterns from West to East off the Pacific Ocean. Latitudes ranging from 48°N to 60°N span a variety of ecosystems from semi-arid deserts along the southern border of British Columbia to boreal forests in the north and altitudes spanning sea level to alpine tundra.

Due to the diversity of ecosystems within British Columbia, it is important to take a detailed approach to analysis and avoid aggregating data from complex geographical areas (Meyn et al., 2010). British Columbia's unique ecosystems are classified into 14 zones, with each zone representing generally homogenous patterns of vegetation and climate. These zones are characterized by the Biogeoclimatic Ecosystem Classification system (BEC; Meidinger & Pojar, 1991). This study uses BEC zones as analysis units. BEC zones accurately reflect unique groupings of homogenous macroclimate characteristics, thus they are an effective unit for examining the implications of climate change (DeLong et al., 2010). However, because BEC zones are ecologically different, the fire effects experienced under a changing climate will be realized differently depending on regional conditions. Furthermore, BEC zones are classified into subzones and variants to further identify unique ecosystems within the broad classes. Fire behaviour and ecological impacts will further vary within these subzones and with localized physiographic features like slope and aspect.

Of the 14 BEC zones, eight zones were omitted from analysis due to insufficient data (<20 weather stations) and included the Alpine Tundra zone (AT: 0 stations), Spruce-Willow-Birch (SWB: 0 stations), Sub-Boreal Pine Spruce (SBPS: 3 stations), Mountain Hemlock (MH: 4 stations), Englemann Spruce Subalpine Fir (ESSF: 13 stations), Bunchgrass (BG: 2 stations), Ponderosa Pine (PP: 4 stations), and Coastal Douglas Fir (CDF: 4 stations).

BEC zones with sufficient weather stations for analysis (Figure 2) included the Boreal White and Black Spruce Zone (BWBS: 29 stations), Coastal Western Hemlock (CWH: 49

stations), Interior Cedar Hemlock (ICH: 53 stations), Interior-Douglas Fir (IDF:33 stations), Montane Spruce (MS: 23 stations), and Sub Boreal Spruce (SBS: 44 stations) BEC zones. Mean climate characteristics for each zone are summarized in Table 2, and a summary of weather station elevation data (mean, minimum, maximum) are in Table 3.

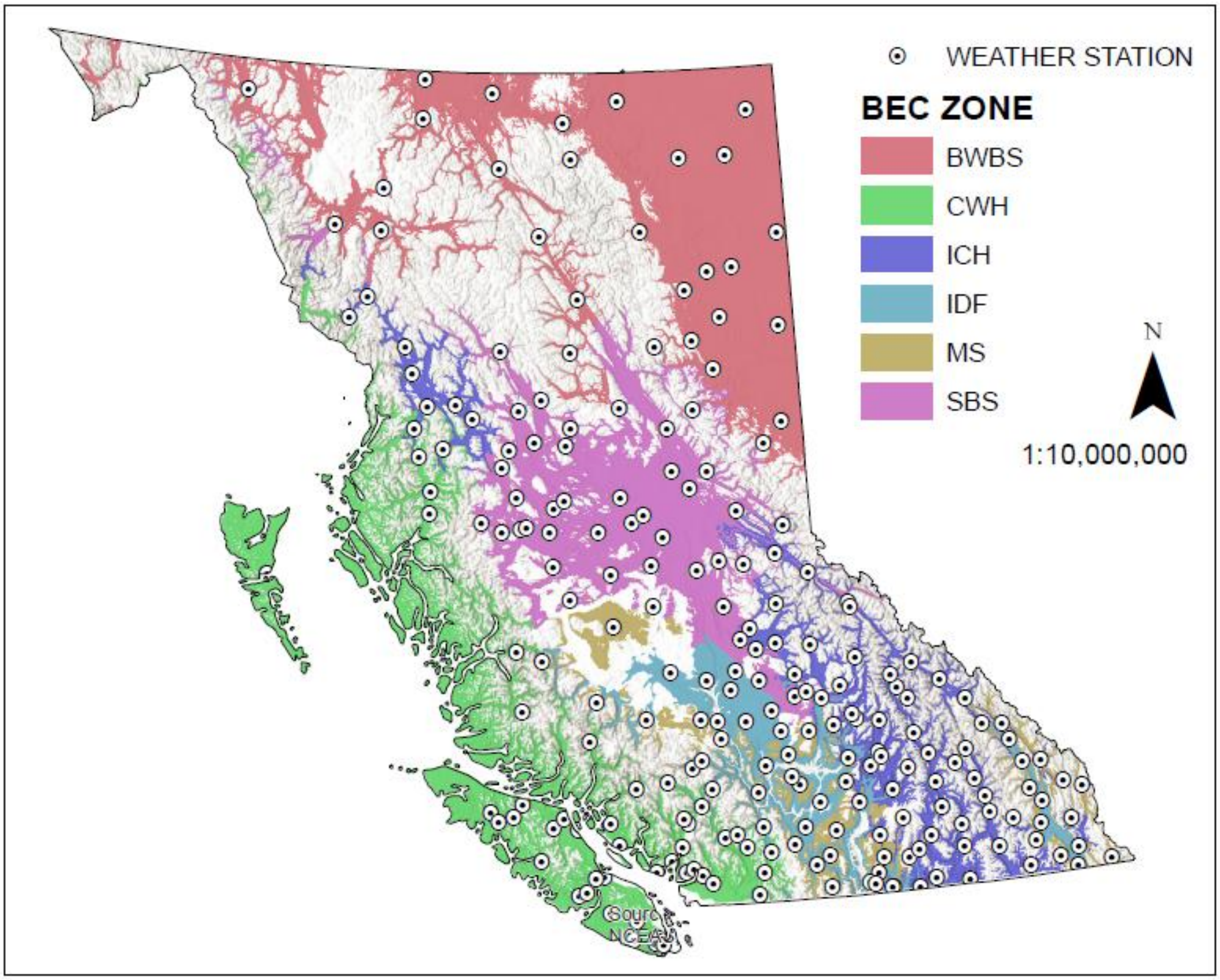

Figure 2: Map of British Columbia showing the Biogeoclimatic Ecosystem Classification (BEC) zones used in this analysis: Boreal White and Black Spruce Zone (BWBS), Coastal Western Hemlock (CWH), Interior Cedar Hemlock (ICH), Interior Douglas-Fir (IDF) Montane Spruce (MS), and Sub Boreal Spruce (SBS). Locations of weather stations are indicated by the circles.

Table 2: Mean climate characteristics for the Biogeoclimatic Ecosystem Classification (BEC) zones used in the study from 1961-1990. Characteristics shown include area (millions of ha), mean annual temperature (°C, MAT), mean warmest month temperature (°C, MWMT), mean coldest month temperature (°C, MCMT), differential between MWMT and MCMT (°C, TD), mean annual precipitation (mm, MAP), mean summer precipitation (mm, MSP, May to September)(Centre for Forest Conservation Genetics, *n.d.*).

Zone	Area	MAT	MWMT	MCMT	TD	MAP	MSP
BWBS	15.8	0.4	14.0	-14.0	27.9	638	333
CWH	11	6.5	14.6	-1.0	15.7	2256	494
ICH	5.24	3.3	14.6	-8.6	23.1	779	302
IDF	4.14	4.2	15.4	-7.5	22.9	503	203
MS	2.74	1.5	12.1	-9.3	21.4	692	239
SBS	10.31	2.3	13.7	-10.2	23.9	652	286

Table 3: Summary of weather station elevation data grouped by BEC zones.

Zone	Number of Stations	Elevation (m) Minimum	Maximum	Mean
BWBS	29	382	1126	774
CWH	49	21	869	310
ICH	53	191	1608	907
IDF	33	330	1220	890
MS	23	861	1683	1408
SBS	44	600	1580	897

Weather data

Historical records of hourly weather data, including temperature, relative humidity, wind speed, and calculated FWI indices (FFMC, ISI, and FWI) from a total of 231 stations were downloaded from the British Columbia Wildfire Service DataMart and compiled into .csv files. Weather records were grouped by BEC zone, and month (June, July, August, September), and separated into two time periods for analysis (1990-2005 and 2006-2021), with each period grouping observations by hour for direct hour-to-hour comparisons between the two periods.

Precipitation was not included in this study of hourly weather due to the spatial variability across the landscape. Unlike observations of temperature, relative humidity and windspeed which are measurable across the landscape at any given time, precipitation can be very patchy across geographic areas. Indirectly, precipitation is accounted for in the study through the calculated FWI indices, but as a stand-alone variable it was excluded from analysis.

The weather stations used by the British Columbia Wildfire Service are made by Forest Technology Systems (FTS) and transmit station data to satellites at hourly intervals. Temperature records represent the temperature (°C) at hourly intervals, whereas recordings of relative humidity (%) and windspeed (km/h) represent the 10-minute average before the hourly transmission (FTS Inc. 2015). In the event of a station failure producing a missing value, the data is interpolated from nearby stations using an inverse distance weighting methodology. Interpolated temperature is corrected using a lapse rate of -6.5°C/km to account for elevation differences and relative humidity values are adjusted using an elevation-adjusted temperature grid in combination with the gridded mixing ratio of water vapour to dry air. The completed and continuous record of hourly weather observations are then used to calculate the FWI indices following the methodology outlined in Van Wagner and Pickett (1985).

Data Cleaning

The dataset generated for this study consisted of hourly weather observations from 231 weather stations across British Columbia from 1990-2021. The raw weather observations were reviewed for outliers using the z-score method for data quality control. The z-score method is a standardized assessment to identify observations that are unusually far from the mean. Typically, studies using the z-score method will classify outliers when there is a z-score of ±2 or ±3. Because this study is particularly interested in capturing observations at the extreme ends, it was found that a z-score of ±4 was more appropriate to exclude what appeared to be true outliers from the observations, without excessively trimming true extremes (Table 4). Data trimmed using a z-score ±3 overly constrained the range of data, likely excluding true observations. The FFMC scale ranges from 0-101, a few values in the original dataset exceeded this, likely due to minor calculation or rounding errors, cleaning the data reduced the number of occurrences leaving only one value above 101 in the final dataset.

Table 4: Data ranges for each variable used in the study from the raw dataset compared to data cleaned to both ±3 z, and ±4 z

Variable	**Data Range (min-max)**		
	Raw	**Cleaned (±3 z)**	**Cleaned (±4 z)**
Temperature	-50-60	-8-34	-12-42
Relative Humidity	0-100	0-100	0-100
Wind Speed	0-65	0-21	0-26
FWI	0-160	0-38	0-48
FFMC	0-105	0-102	0-102
ISI	0-115	0-12	0-15

Analysis

Mean, Median, and 95th percentile hourly comparison

Hourly weather variables (temperature, relative humidity, windspeed) and Fire Weather Index variables (FFMC, ISI, FWI) were compared between two time periods (1990-2005, 2006-2021) by month (June, July, August, and September) and by BEC zone (BWBS, CWH, ICH, IDF, MS, SBS). Comparisons were conducted at an hour-by-hour scale, where data from each time period (1990-2005, 2006-2021) was pooled to represent overall conditions occurring at each hourly timestep through the diurnal cycle. Therefore, statistical tests looked directly at how weather at X hour of the day during period 1, compared to the same X hour during period 2.

Weather data from individual stations was aggregated and summarized at the BEC zone level to understand changes across each region, rather than at each station location. Hourly mean, median, and 95th percentiles of each of the three weather variables and three FWI variables from the two time periods were compared. All analysis was completed using R Studio (R Core Team, 2022). Base R was used to conduct the Welch 2-sample t-test to compare means, and the WRS2 statistical analysis package (Mair and Wilcox, 2020) was used to conduct a quantile analysis of variance (Qanova) on the median and 95th percentile values. The WRS2 package is more robust to outliers compared to a traditional ANOVA. All tests used a significance value of $\alpha<0.05$.

Interpretation of mean, median and 95th percentile results

This study has a focus on informing decisions made at an operational wildfire level. Several studies have confirmed climate change is showing trends towards hotter, drier and windier conditions (Abatzoglou et al., 2019; Ellis et al., 2021; Flannigan et al., 2009; Guindon et al., 2021; Jain et al., 2021; Jolly et al., 2015; Meyn et al., 2010; Parisien et al., 2023; Wang et al., 2015; Wotton et al., 2017). This study looked across six variables to detect a change between two time periods at the hourly level. Results were interpreted to broadly infer a trend in the fire environment towards conditions reflecting an environment with either higher fuel moisture or lower fuel moisture between the two time periods.

Each variable was assessed independently for the direction of change (positive or negative) between the 1990-2005 and 2006-2021 datasets for each of the three tests run (mean, median and 95th percentile). The six variables chosen for analysis in the study all relate to fuel moisture. If conditions are showing an increase in temperature and wind speed, or a decrease to relative humidity, fuels will dry more quickly and the fire environment would be more hazardous, as indicated by the fire weather indices (FFMC, ISI and FWI) where higher values indicate drier fuels and greater potential for wildfire behaviour (Van Wagner, 1987).

Therefore, this study considers a ‘warming, drying trend’ where significant findings of the variables assessed were in the direction of a drier fire environment, or more hazardous conditions, and a ‘cooling, wetting’ trend where significant findings were in the direction of a less hazardous fire environment, as indicated by a decrease in temperature, wind speed, fire weather indices, or an increase to relative humidity.

Due to the use of longer time periods (16 years) which mask short term variability, and comparison of multiple variables, the results can be used to infer a broader trend occurring due to climate change and inform operational decisions in wildfire management.

Spread Day Thresholds

Examining the differences in how often Fire Weather Index thresholds associated with spread events were exceeded was challenging due to varying completeness in records and the number of observation points in each daily period. To address this, data were pooled into four daily periods: 1) 0000h-0500h, 2) 0600h-1100h, 3) 1200h-1700h and 4) 1800h-

2300h and the total percentage of records exceeding a threshold (FFMC ≥91, ISI ≥8.7, FWI ≥ 19) was calculated and compared between the 1990-2005 dataset, and the 2006-2021 dataset, by month and BEC zone. The percentage of recorded observations was selected to avoid skewing results due to a greater number of observations in the 2006-2021 dataset. Percent change of each daily period was then calculated to compare between the 1990-2005 and 2006-2021 time periods by month and BEC zone.

CHAPTER 3 - RESULTS

Mean, Median, and 95th percentile hourly comparison

Each of the six BEC zone in this study had 1728 statistical tests (24 hours x 4 months x 6 weather variables x 3 measures - mean, median, and 95th percentile) run on hourly data comparisons from the 1990-2005 dataset and the 2006-2021 dataset for a total number of 10,368 statistical tests. Of all the significant results generated in this study, the majority were associated with a warming and drying trend (Table 5). The SBS zone had the greatest number of significant results with 59.6%, followed by the IDF at 54.4% and the ICH at 47.6%. Less than 1% of results were significant with a cooling trend for CWH, ICH, IDF, and SBS. The MS had the greatest amount of cooling with 2.1% followed by the BWBS at 1.2%.

The number of hours with a significant difference ($\alpha<0.05$) in the mean, median, and 95th percentile was totaled and summarized by variable, month, and BEC zone. Significant shifts with a cooling and wetting trend are summarized in

Table 6, and significant shifts with a warming, and drying trend are summarized in Table 7. Overall, very few hours showed a cooling trend. The MS zone had the most cooling compared to the other zones. Cooling trends occurred most often in June or September, and least often in July and August.

Warming trends were seen most often in July for all zones. August had the second most warming trends for BWBS, CWH, MS, and SBS whereas June had the second most warming in both ICH and IDF. The SBS zone had the most significant warming hours overall, followed by the IDF and ICH. Most significant warming trends were associated with changes in the mean value, followed by the median (Temperature, RH, FFMC, ISI, and FWI). Wind speed had the most significant shifts in the median, followed closely by the mean, and the least significant shifts in the 95th percentile compared to the other variables. Significant changes in the 95th percentile was most prevalent for FWI, with the SBS zone having the greatest number of significant hours at the 95th percentile weather with a warming trend.

Table 5: Summary of significant findings of the 1728 statistical tests by BEC zone of the total number, and percentage of significant findings for both a cooling and warming trend. Bold values indicate the zone with the highest percentage in each category.

Zone	Cooling, Wetting		Warming, Drying	
	Number of significant results	Percentage with significant results	Number of significant results	Percentage with significant results
BWBS	20	1.2%	422	24.4%
CWH	11	0.6%	675	39.1%
ICH	7	0.4%	823	47.6%
IDF	6	0.3%	940	54.4%
MS	**36**	**2.1%**	412	23.8%
SBS	10	0.6%	**1030**	**59.6%**

The figures in Appendix A visually represent the diurnal data curves for mean, median, and 95th percentile hourly values with significant results shown and the magnitude of change visualized between the 1990-2005 and 2006-2021 datasets shown in Appendix B. Significant findings were summarized by month (June: Table 8, July: Table 9, August: Table 10, September: Table 11) with the maximum significant difference of mean, median, and 95th percentile between the 1990-2005 and 2005-2021 datasets shown for each variable by zone. The associated hour when the max difference was found is specified, and the overall mean of the significant differences is shown. Negative RH values, or positive temperature, wind speed, FFMC, ISI, and FWI values indicate a warming trend over time.

In June, the MS and IDF had the largest differences compared to the other zones (Table 8). The 95th percentile temperature in the MS increased an average of 3.5°C across all significant hours, with a maximum of 5.1°C at 1400h. MS had the greatest change in FFMC, with a max median difference of 40.9 occurring at 0400h. The IDF zone had the highest mean and 95th percentile shifts in relative humidity, with the 95th percentile decreasing 12.5% at 0500h. The windspeed also showed the greatest shift in the IDF zone with the mean 0800h winds increasing by 4.4 km/h and the median increasing by 4.8km/h.

The same trend is evident in reviewing the July data (Table 9). The IDF and MS show the greatest changes compared to the other BEC zones. Mean FFMC, ISI, and FWI were all greatest in the IDF zone, with the biggest peaks occurring throughout the day (0700h, 1400h, and 2300h, for FFMC, ISI, and FWI respectively).

In August, the MS zone had the greatest mean (2.9 °C increase at 1300h) and median (2.8 °C increase at 1300h) temperature change compared to the other BEC zones (Table 10). The maximum decrease in hourly RH occurred in the SBS where the mean decreased by a maximum of 9.8% and the median decreased by a maximum of 15%. The IDF zone saw the greatest increased wind speed across the mean, median, and 95th percentile values with maximums occurring at 1400h, 2100h, and 0700h respectively. The CWH zone had the greatest increases in 95th percentile FFMC, ISI, and FWI, all occurring at 1200h and the median FFMC increased by a maximum of 16.4 at 1600h. Mean FFMC, ISI, and FWI were greatest in the IDF all occurring at 1200h, and median ISI and FWI were also highest in the IDF at 1200h.

The data for September shows greater warming in the BWBS zone, which has the highest mean and median temperature increases (2.7 °C maximum mean change and 3.3 °C maximum median change, both occurring at 1000h) (Table 11). The 95th percentile temperature increases were second highest in BWBS, surpassed by the MS zone with a 4.5 °C maximum change occurring at 1300h. The IDF had the greatest change in WS, ISI, and the mean and median FWI. The MS zone had the highest increase in mean FFMC at 0100h, but the overall trend in the median across all significant hours showed a marginal decline. The SBS had the highest overall change in the median across all significant hours.

The greatest September RH changes were seen across different zones. The maximum mean change occurred in the BWBS, but the overall greatest mean change was in the IDF. The IDF also had the greatest maximum median and overall median change. However, the 95th percentile changes decreased the highest amount in the CWH zone (26% decrease at 0500h, and 18% overall). Of interest, the CWH zone also had the greatest change in 95th percentile relative humidity in July and August with a reduction in July of 18.7% at 2200h and an average decline of 13.6% across all significant hours. In August, the maximum decrease was 21% at 2200h, with a mean of 11.6% and in September the 0500h relative humidity decreased by 26%, with an 18% overall decrease.

The frequency of significant findings per hour are summarized in Figure 3 to Figure 5. These figures provide a visual representation of how often each hour was associated with a significant finding in the comparisons of the six variables (temperature, relative humidity, wind speed, FFMC, ISI, and FWI) across the four months tested in this study (June, July, August, September). The significant findings are shown for the comparisons of mean (Figure 3), median (Figure 4), and 95th percentile (Figure 5). The hours associated with the maximum significant difference in Table 8 to Table 11 were summarized in Figure 6. Generally, the maximum significant differences occurred throughout all hours in the day, however, there was a slight increase during daytime hours from 0700h to 1800h. The ICH and BWBS zones had the highest count of maximum significant differences at 1400h. The IDF, MS, SBS, and CWH had the highest count of maximum significant differences at 1200h.

The significant findings were further summarized by periods in Figure 7 to better detect trends in the diurnal cycle. The SBS, IDF, and ICH zones have the greatest number of significant results. The IDF and SBS had the greatest mean warming trends during the second period (0600-1100h). The BWBS zone had fewer significant findings in the mean comparison in the fourth period (1800h-2300h) compared to the other periods, and the CWH had greater significant findings in the mean comparison in the fourth period (1800h-2300h) compared to the other three time periods.

There were fewer significant changes in the median compared to the mean, or 95th percentile analyses. Unlike the mean comparison, the third period (1200h-1700h) had the most frequent significant results for the ICH and SBS zones. The MS had the fewest significant median results, with most occurring during the third period (1200h-1700h). The IDF followed a similar trend as the mean comparison, with the second period (0600h-1100h) having the greatest number of significant findings.

The SBS zone had the greatest number of significant findings in the 95th percentile comparison, with slightly more findings occurring in the third period (1200h-1700h). The CWH and ICH had similar results with the most significant results landing in the third and fourth periods (spanning 1200h-2300h) compared to the earlier hours. The maximum significant differences of mean, median, and 95th percentile occurred in the third period (1200h-1700h) across all BEC zones but were most evident in the BWBS, CWH, ICH, and IDF.

Table 6: Number of hours with significant change (Mean, Median, and 95th percentile) towards a cooling and wetting trend between 1990-2005 and 2006-2021 by BEC zone, month, and weather variable (Temperature, Relative Humidity, Wind Speed, Fine Fuel Moisture Code, Initial Spread Index, and Fire Weather Index). The number of hours are colour coded on a gradient from light grey to dark blue from 0 to 24 hours to highlight fields with a higher count of significant findings with a cooling trend.

	Cooling and wetting trend																	
	Temp Decrease			**RH Increase**			**WS Decrease**			**FFMC Decrease**			**ISI Decrease**			**FWI Decrease**		
	M	Mdn	95	M	Mdn	95	M	Mdn	95	M	Mdn	95	M	Mdn	95	M	Mdn	95
BWBS																		
JUNE	0	1	0	1	1	2	0	0	0	0	0	2	0	0	0	0	0	0
JULY	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
AUGUST	0	0	0	0	0	1	0	0	2	0	0	0	0	0	0	0	0	0
SEPTEMBER	0	0	0	2	1	2	0	0	2	0	0	0	0	0	0	0	1	1
CWH																		
JUNE	0	1	0	0	0	1	0	0	1	0	0	2	0	1	0	0	1	0
JULY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AUGUST	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
SEPTEMBER	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	0	0	0
ICH																		
JUNE	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AUGUST	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SEPTEMBER	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	1	0	0
IDF																		
JUNE	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
JULY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AUGUST	0	0	2	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
SEPTEMBER	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
MS																		
JUNE	0	0	0	0	0	2	0	0	5	0	0	0	0	0	0	0	0	0
JULY	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
AUGUST	1	1	0	0	0	2	0	0	1	0	0	3	0	0	1	0	0	0
SEPTEMBER	0	1	0	2	2	1	0	0	1	0	3	0	1	3	0	0	2	0
SBS																		
JUNE	1	1	1	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
JULY	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AUGUST	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
SEPTEMBER	1	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0

Table 7: Number of hours with significant change (Mean, Median, and 95th percentile) towards a warming and drying trend between 1990-2005 and 2006-2021 by BEC zone, month, and weather variable (Temperature, Relative Humidity, Wind Speed, Fine Fuel Moisture Code, Initial Spread Index, and Fire Weather Index). The number of hours are colour coded on a gradient from green to red from 0 to 24 hours to highlight fields with a higher count of significant findings with a warming trend.

	Warming and drying trend																	
	Temp Increase			**RH Decrease**			**WS Increase**			**FFMC Increase**			**ISI Increase**			**FWI Increase**		
	M	Mdn	95	M	Mdn	95	M	Mdn	95	M	Mdn	95	M	Mdn	95	M	Mdn	95
BWBS																		
JUNE	2	1	4	5	4	2	7	6	2	5	1	4	4	3	4	4	2	2
JULY	12	8	8	12	10	6	6	10	0	14	10	10	12	10	8	19	9	12
AUGUST	4	3	4	5	3	5	10	14	1	7	2	5	6	4	5	12	5	9
SEPTEMBER	5	3	6	5	6	2	3	5	0	9	5	2	5	7	3	6	6	2
CWH																		
JUNE	4	0	6	6	7	3	14	12	3	3	0	2	3	1	3	8	2	9
JULY	12	11	5	18	16	6	16	16	3	11	4	9	16	20	9	21	18	12
AUGUST	10	6	8	14	16	6	20	21	1	15	4	9	14	15	12	16	14	14
SEPTEMBER	13	9	9	12	13	7	12	15	1	0	0	11	8	0	12	15	0	14
ICH																		
JUNE	3	0	5	14	13	9	24	24	3	18	8	11	18	10	14	15	6	19
JULY	15	15	10	17	17	11	24	24	3	23	12	11	24	20	15	24	23	17
AUGUST	4	6	3	9	8	1	24	24	3	17	5	3	16	12	9	14	13	10
SEPTEMBER	7	4	7	8	8	2	24	23	2	9	3	1	5	4	2	8	2	4
IDF																		
JUNE	4	4	5	11	13	7	24	24	9	19	9	10	21	18	11	21	14	14
JULY	15	16	6	18	18	9	24	23	10	22	24	5	24	24	16	24	24	14
AUGUST	5	3	2	14	14	1	24	24	8	18	13	2	22	22	5	21	19	8
SEPTEMBER	5	3	2	6	7	2	24	24	10	11	2	1	12	14	7	13	11	7
MS																		
JUNE	4	3	6	5	3	1	5	8	0	13	5	6	7	5	3	7	8	4
JULY	11	8	1	10	8	6	12	10	0	17	3	5	17	11	7	18	15	7
AUGUST	3	3	2	4	2	3	8	12	1	14	4	3	10	6	3	11	8	5
SEPTEMBER	1	1	3	1	1	3	8	10	2	5	1	1	1	1	2	5	2	3
SBS																		
JUNE	4	2	1	16	17	5	24	23	1	22	11	7	21	15	9	19	13	13
JULY	17	15	12	22	22	14	22	24	0	20	9	21	24	18	23	24	19	24
AUGUST	12	8	4	20	19	8	23	24	3	21	12	16	23	16	20	20	16	19
SEPTEMBER	10	7	10	12	13	6	22	21	0	15	6	9	12	6	9	16	9	10

Table 8: Maximum difference between 1990-2005 and 2006-2021 for the Mean, Median, and 95th percentile values for each variable (Temperature, Relative Humidity, Wind Speed, Fine Fuel Moisture Code, Initial Spread Index, and Fire Weather Index) by BEC zone in June. The associated hour where the max occurs is shown, and the mean difference across all significant findings. The top 10% of each difference is in bold. NA indicates no significant findings.

	JUNE								
	MEAN			MEDIAN			95th PERCENTILE		
	Max Diff	Hour of Max	Mean Diff	Max Diff	Hour of Max	Mean Diff	Max Diff	Hour of Max	Mean Diff
TEMP									
BWBS	1.7	9	1.4	1.5	9	0.2	3.4	9	2.2
CWH	1.9	16	1.2	-1.6	18	-1.6	4.3	16	2.7
ICH	1.3	18	1.2	-0.8	16	-1.0	3.0	15	2.4
IDF	1.9	15	1.4	1.8	15	0.6	3.5	17	2.3
MS	**3.0**	12	**1.9**	**2.5**	10	**1.8**	**5.1**	14	**3.5**
SBS	1.1	13	0.6	1.2	14	0.4	1.5	6	0.1
RH									
BWBS	-7.7	9	-4.2	-11.0	2	-5.0	-7.4	9	0.9
CWH	-8.1	8	-5.6	-10.0	6	-6.2	-9.6	3	-3.3
ICH	-7.7	7	-5.5	-11.0	2	-6.7	-7.6	6	-5.7
IDF	**-10.8**	9	-7.1	-11.0	2	-7.7	**-12.5**	5	**-6.6**
MS	-10.3	10	**-8.4**	**-12.0**	10	**-9.3**	-6.8	12	5.3
SBS	-8.1	11	-5.4	-10.0	6	-6.7	-7.6	6	-5.6
WS									
BWBS	2.0	17	1.8	2.5	9	1.9	3.2	2	2.8
CWH	2.4	15	1.2	2.7	4	1.9	3.5	21	1.3
ICH	2.8	20	2.0	3.7	2	2.5	3.8	23	3.0
IDF	**4.4**	8	**3.0**	**4.8**	8	**3.6**	**6.9**	11	**4.3**
MS	2.3	12	2.0	3.2	8	2.1	-3.0	16	-4.5
SBS	2.7	12	1.7	3.3	10	2.2	3.5	22	-0.1
FFMC									
BWBS	10.4	14	8.8	7.5	14	7.5	1.3	12	0.3
CWH	10.4	12	9.4	NA	NA	NA	2.7	21	0.2
ICH	16.2	12	9.3	21.7	6	14.5	3.3	12	2.0
IDF	21.7	14	11.4	21.2	14	8.3	2.3	13	1.8
MS	**27.6**	4	**15.8**	**40.9**	4	**27.4**	**6.2**	12	**3.3**
SBS	15.9	9	9.4	17.0	1	9.6	2.7	21	1.8
ISI									
BWBS	1.2	14	0.7	1.9	14	1.2	2.4	14	1.9
CWH	1.0	12	0.8	0.7	3	0.0	3.7	12	2.5
ICH	1.1	12	0.7	0.8	14	0.5	3.6	12	2.4
IDF	1.8	14	1.1	**2.5**	20	**1.4**	4.5	11	2.6
MS	**2.1**	12	**1.1**	1.6	12	1.3	**5.9**	12	**3.2**
SBS	1.1	12	0.7	1.2	1	0.8	2.8	21	2.0
FWI									
BWBS	3.1	14	2.1	4.7	14	3.6	6.9	22	5.7
CWH	2.5	20	1.7	2.7	12	1.0	9.8	21	6.3
ICH	2.6	12	1.7	1.7	18	1.2	8.9	12	5.3
IDF	**5.1**	21	**3.2**	**7.0**	14	**4.1**	10.6	16	6.9
MS	4.8	12	3.0	5.6	12	3.2	**11.5**	19	**10.1**
SBS	2.5	1	1.7	2.9	1	2.0	7.6	23	5.3

Table 9: Maximum difference between 1990-2005 and 2006-2021 for the Mean, Median, and 95th percentile values for each variable (Temperature, Relative Humidity, Wind Speed, Fine Fuel Moisture Code, Initial Spread Index, and Fire Weather Index) by BEC zone in July. The associated hour where the max occurs is shown, and the mean difference across all significant findings. The top 10% of each difference is in bold. NA indicates no significant findings.

	JULY								
	MEAN			MEDIAN			95th PERCENTILE		
	Max Diff	Hour of Max	Mean Diff	Max Diff	Hour of Max	Mean Diff	Max Diff	Hour of Max	Mean Diff
TEMP									
BWBS	3.1	16	1.6	3.1	16	1.8	3.2	10	2.4
CWH	2.1	14	1.5	2.6	12	1.9	**3.6**	13	2.7
ICH	2.8	14	1.5	3.4	14	1.8	3.0	22	2.1
IDF	2.9	15	1.5	**4.4**	1	1.9	3.1	1	1.9
MS	**3.2**	13	**2.0**	3.7	13	**2.6**	3.4	16	**3.4**
SBS	2.1	15	1.4	2.6	8	1.4	2.8	18	2.0
RH									
BWBS	-11.0	10	-6.4	-12.0	10	-6.9	-11.0	14	-7.3
CWH	-10.6	17	-6.2	-17.5	17	-8.0	**-18.7**	22	**-13.6**
ICH	-10.5	14	-7.1	-13.0	4	-9.2	-15.9	2	-8.1
IDF	**-14.1**	7	-7.8	**-21.0**	7	**-9.6**	-7.0	7	-5.1
MS	-12.4	18	**-8.8**	-12.5	8	-9.4	-17.3	5	-7.5
SBS	-10.1	12	-6.1	-11.5	15	-7.1	-12.9	8	-8.4
WS									
BWBS	1.9	8	1.5	2.8	13	1.6	-3.2	18	-3.2
CWH	2.2	18	1.4	2.6	8	1.8	3.9	14	3.6
ICH	2.4	2	1.9	3.7	2	2.6	3.2	19	2.9
IDF	**4.5**	15	**2.9**	**5.1**	23	**3.5**	**5.8**	13	**3.9**
MS	2.6	9	1.9	3.8	10	2.3	-3.0	12	-4.4
SBS	2.2	21	1.5	3.3	10	1.9	NA	NA	NA
FFMC									
BWBS	15.6	12	9.2	10.9	13	6.8	3.6	12	2.3
CWH	11.7	2	9.4	6.4	14	4.5	3.8	12	**3.0**
ICH	16.9	14	10.8	13.8	13	7.9	3.5	6	1.9
IDF	**24.3**	7	11.8	10.7	7	3.7	2.5	12	1.5
MS	19.6	13	**12.8**	5.6	21	4.1	3.0	12	2.3
SBS	16.8	12	9.4	**14.9**	11	**8.5**	**4.7**	12	2.4
ISI									
BWBS	1.5	16	0.8	1.6	16	0.9	**4.7**	16	2.4
CWH	1.5	14	0.8	1.6	17	0.8	3.7	13	2.4
ICH	2.4	14	1.1	2.8	14	1.2	4.3	22	2.8
IDF	**2.7**	14	**1.6**	**3.4**	15	**2.1**	3.8	12	2.4
MS	2.1	18	1.2	2.8	21	1.5	4.5	5	**3.1**
SBS	1.7	12	0.9	1.9	18	0.9	4.3	12	2.4
FWI									
BWBS	4.3	12	2.2	3.9	20	2.4	11.6	12	7.4
CWH	4.9	22	3.0	4.6	14	3.1	16.5	15	8.6
ICH	6.6	14	3.9	8.0	14	4.3	15.3	2	**9.8**
IDF	**10.0**	23	**6.0**	**13.3**	23	**8.6**	11.9	7	6.5
MS	8.0	21	4.5	12.1	21	6.0	**17.3**	5	8.8
SBS	5.2	18	3.2	5.0	12	3.0	13.3	18	8.7

Table 10: Maximum difference between 1990-2005 and 2006-2021 for the Mean, Median, and 95th percentile values for each variable (Temperature, Relative Humidity, Wind Speed, Fine Fuel Moisture Code, Initial Spread Index, and Fire Weather Index) by BEC zone in August. The associated hour where the max occurs is shown, and the mean difference across all significant findings. The top 10% of each difference is in bold.

	AUGUST								
	MEAN			MEDIAN			95th PERCENTILE		
	Max Diff	Hour of Max	Mean Diff	Max Diff	Hour of Max	Mean Diff	Max Diff	Hour of Max	Mean Diff
TEMP									
BWBS	1.3	17	1.1	1.9	8	1.5	**3.1**	17	2.1
CWH	1.4	7	1.2	1.9	8	1.3	2.9	11	**2.5**
ICH	1.9	14	1.2	2.2	6	1.4	1.8	0	1.4
IDF	1.5	2	**1.3**	2.2	15	**1.6**	2.1	18	0.2
MS	**2.9**	13	**1.3**	**2.8**	13	1.5	2.7	17	2.1
SBS	1.5	13	0.9	1.9	8	1.1	2.0	13	1.6
RH									
BWBS	-6.6	10	-4.9	-10.0	6	-9.3	-6.1	2	-2.6
CWH	-8.1	10	-6.0	-12.0	10	-6.7	**-21.0**	22	**-11.6**
ICH	-7.1	14	-5.0	-9.0	22	-7.3	-5.1	12	-5.1
IDF	-9.6	9	-5.8	-14.5	7	-7.2	-6.3	12	-6.3
MS	-8.8	15	**-7.8**	-12.0	10	**-10.5**	-6.9	10	1.6
SBS	**-9.8**	11	-5.5	**-15.0**	8	-6.7	-14.0	8	-7.8
WS									
BWBS	2.4	14	1.5	2.7	12	1.9	4.9	9	-1.0
CWH	2.3	10	1.4	2.8	13	1.9	2.6	11	-0.3
ICH	2.7	12	1.9	3.5	20	2.6	3.3	3	2.7
IDF	**3.8**	14	**2.8**	**4.1**	21	**3.4**	**5.8**	7	**3.6**
MS	2.7	10	1.9	2.9	21	2.2	5.0	10	0.6
SBS	2.6	6	1.5	3.4	1	2.0	4.3	6	1.8
FFMC									
BWBS	11.9	10	9.5	7.0	10	6.9	3.2	12	1.9
CWH	16.2	7	10.5	**16.4**	16	**8.1**	**6.1**	12	**3.2**
ICH	16.2	14	9.6	12.0	11	6.9	2.1	12	1.4
IDF	**22.4**	12	10.6	5.4	9	2.8	2.4	12	0.7
MS	16.4	3	**11.5**	3.3	19	2.7	2.0	11	0.0
SBS	18.7	8	9.6	14.0	8	6.9	3.5	12	1.9
ISI									
BWBS	0.9	12	0.7	1.0	14	0.7	2.7	12	2.0
CWH	1.7	12	0.9	1.8	15	0.8	**5.6**	12	2.4
ICH	1.7	14	0.8	2.1	14	1.0	3.3	14	2.4
IDF	**2.6**	12	**1.2**	**3.1**	12	**1.6**	2.9	10	**2.4**
MS	1.4	19	1.1	1.8	19	1.2	3.8	11	1.4
SBS	1.5	12	0.7	1.6	19	0.9	3.2	12	1.9
FWI									
BWBS	3.0	21	2.0	3.3	14	2.2	10.5	21	6.7
CWH	5.9	12	3.4	6.6	16	4.1	**17.0**	12	8.6
ICH	4.9	19	3.1	6.0	14	3.6	11.1	19	6.9
IDF	**8.9**	12	**4.7**	**12.4**	12	**6.5**	7.9	12	5.7
MS	6.0	22	4.2	9.4	22	5.5	9.6	6	**9.2**
SBS	4.9	0	3.0	6.7	19	3.3	11.7	0	7.4

Table 11: Maximum difference between 1990-2005 and 2006-2021 for the Mean, Median, and 95th percentile values for each variable (Temperature, Relative Humidity, Wind Speed, Fine Fuel Moisture Code, Initial Spread Index, and Fire Weather Index) by BEC zone in September. The associated hour where the max occurs is shown, and the mean difference across all significant findings. The top 10% of each difference is in bold. NA indicates no significant findings.

	SEPTEMBER								
	MEAN			MEDIAN			95th PERCENTILE		
	Max Diff	Hour of Max	Mean Diff	Max Diff	Hour of Max	Mean Diff	Max Diff	Hour of Max	Mean Diff
TEMP									
BWBS	**2.7**	10	**1.9**	**3.3**	10	**2.4**	4.3	18	3.0
CWH	2.0	4	1.2	1.8	16	1.4	3.8	18	2.8
ICH	1.6	13	1.0	1.9	9	1.2	3.1	17	1.9
IDF	1.7	3	1.4	2.2	15	1.7	3.3	15	3.1
MS	1.7	12	1.7	2.5	9	0.5	**4.5**	13	**3.3**
SBS	1.5	10	0.9	1.4	15	0.8	2.9	14	2.0
RH									
BWBS	**-9.3**	10	-3.7	-12.0	10	-4.6	-8.4	10	2.1
CWH	-6.2	11	-4.6	-7.0	23	-3.2	**-26.0**	5	**-18.0**
ICH	-7.5	13	-3.5	-7.5	11	-4.7	-8.4	8	-0.8
IDF	-9.1	8	**-6.1**	**-13.5**	22	**-8.3**	-11.0	7	-0.8
MS	-8.2	12	2.0	-6.0	22	5.2	-7.5	13	-1.9
SBS	-7.9	11	-4.9	-10.0	6	-5.0	-14.9	14	-7.1
WS									
BWBS	1.9	1	1.6	2.9	13	1.9	-3.3	5	-3.8
CWH	1.8	22	1.2	2.7	4	1.9	3.6	8	-1.9
ICH	2.6	20	1.8	3.5	20	2.5	3.1	8	2.8
IDF	**4.3**	15	**2.9**	**4.7**	13	**3.7**	**6.1**	20	**4.3**
MS	2.7	4	2.0	4.6	22	2.3	4.7	18	0.9
SBS	2.2	23	1.5	3.3	6	2.0	-3.5	16	-3.5
FFMC									
BWBS	13.6	14	9.0	14.1	14	8.4	2.6	18	2.6
CWH	NA	NA	NA	-16.4	9	-16.4	**6.5**	3	**4.5**
ICH	13.9	13	7.9	17.3	9	12.5	1.9	12	0.2
IDF	11.8	13	8.5	6.2	7	4.5	2.9	12	2.9
MS	**15.6**	1	**11.1**	**18.1**	1	-0.1	1.9	5	1.9
SBS	11.9	6	8.3	17.6	10	**13.3**	3.3	12	2.1
ISI									
BWBS	0.8	18	0.6	1.0	14	0.6	3.1	18	**2.5**
CWH	0.6	19	0.4	-0.4	9	-0.4	3.3	12	2.0
ICH	0.6	13	0.4	0.5	13	0.4	1.7	12	1.5
IDF	**1.4**	12	**0.9**	**1.3**	16	**0.9**	**3.5**	12	2.0
MS	0.7	1	-0.1	1.1	1	-0.6	2.5	23	2.3
SBS	0.5	22	0.4	0.6	13	0.4	2.1	17	1.5
FWI									
BWBS	2.9	18	1.9	2.5	2	1.4	10.5	18	3.7
CWH	3.3	19	1.7	NA	NA	NA	**14.0**	19	**8.6**
ICH	2.6	23	1.3	1.4	0	1.3	7.7	23	6.0
IDF	**4.6**	0	**3.4**	**5.9**	4	**4.2**	9.2	12	6.9
MS	3.4	20	2.8	3.4	20	-0.5	9.2	2	7.8
SBS	2.8	22	1.3	1.8	23	0.9	9.8	22	5.0

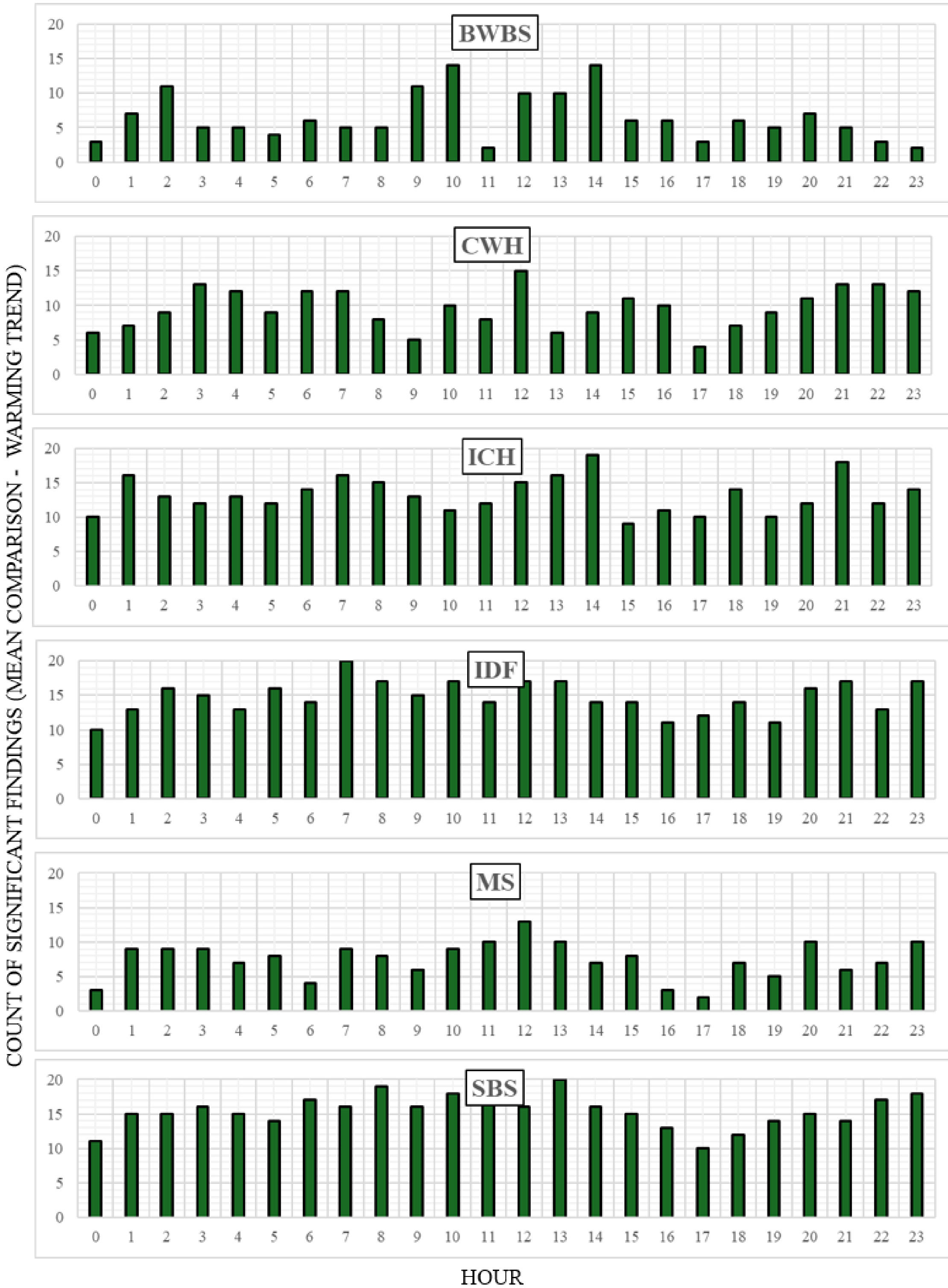

Figure 3: The count of significant findings (α<0.05) with a warming trend per hour for a 24-hour period analyzed by BEC zone between 1990-2005 and 2006-2021. Variables in the analysis were the means of temperature, relative humidity, wind speed, FFMC, ISI, and FWI. Monthly data (June, July, August, and September) was analyzed individually and is being presented in aggregate.

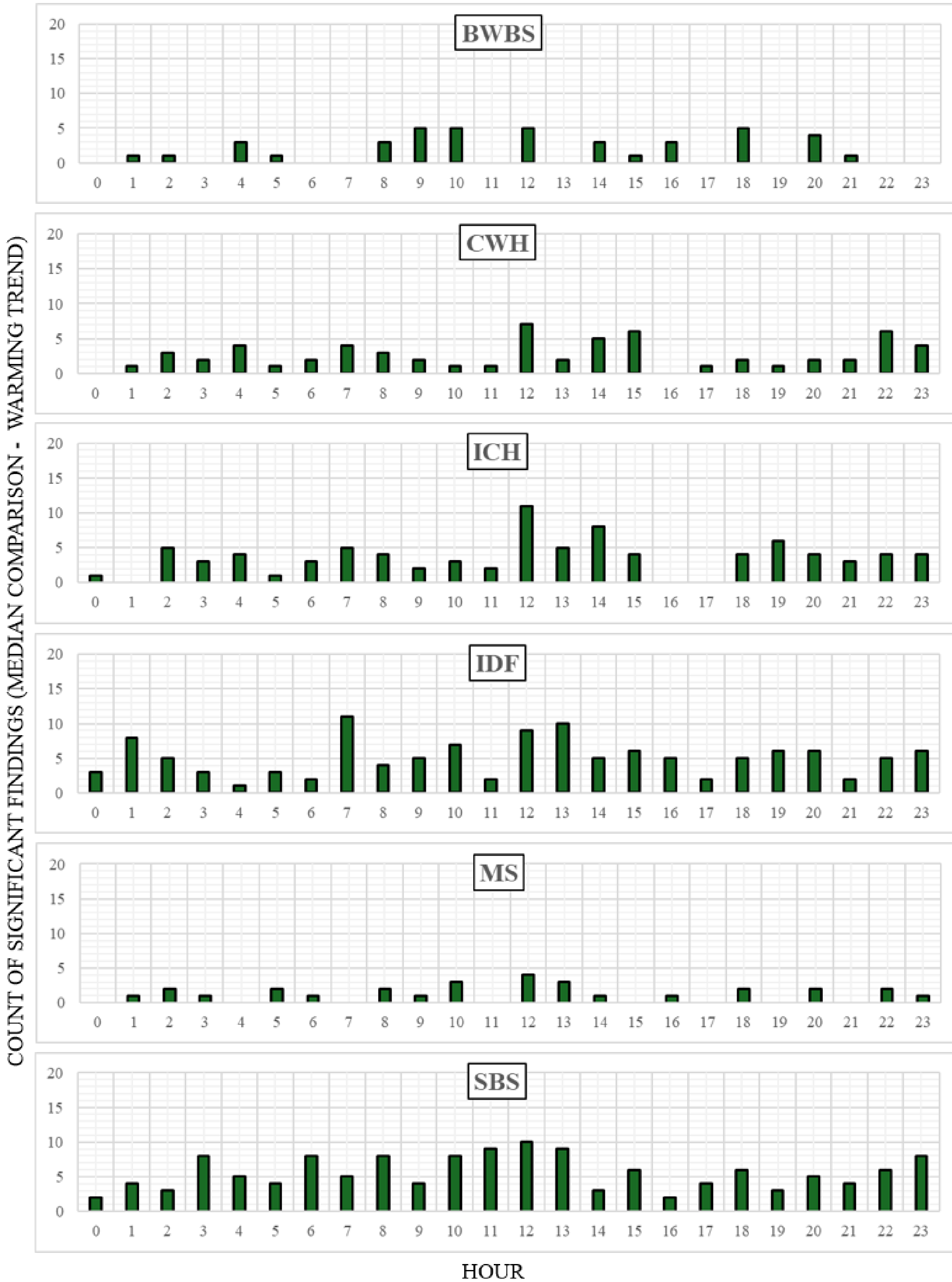

Figure 4: The count of significant findings (α<0.05) with a warming trend per hour for a 24-hour period analyzed by BEC zone between 1990-2005 and 2006-2021. Variables in the analysis were the medians of temperature, relative humidity, wind speed, FFMC, ISI, and FWI. Monthly data (June, July, August, and September) was analyzed individually and is being presented in aggregate.

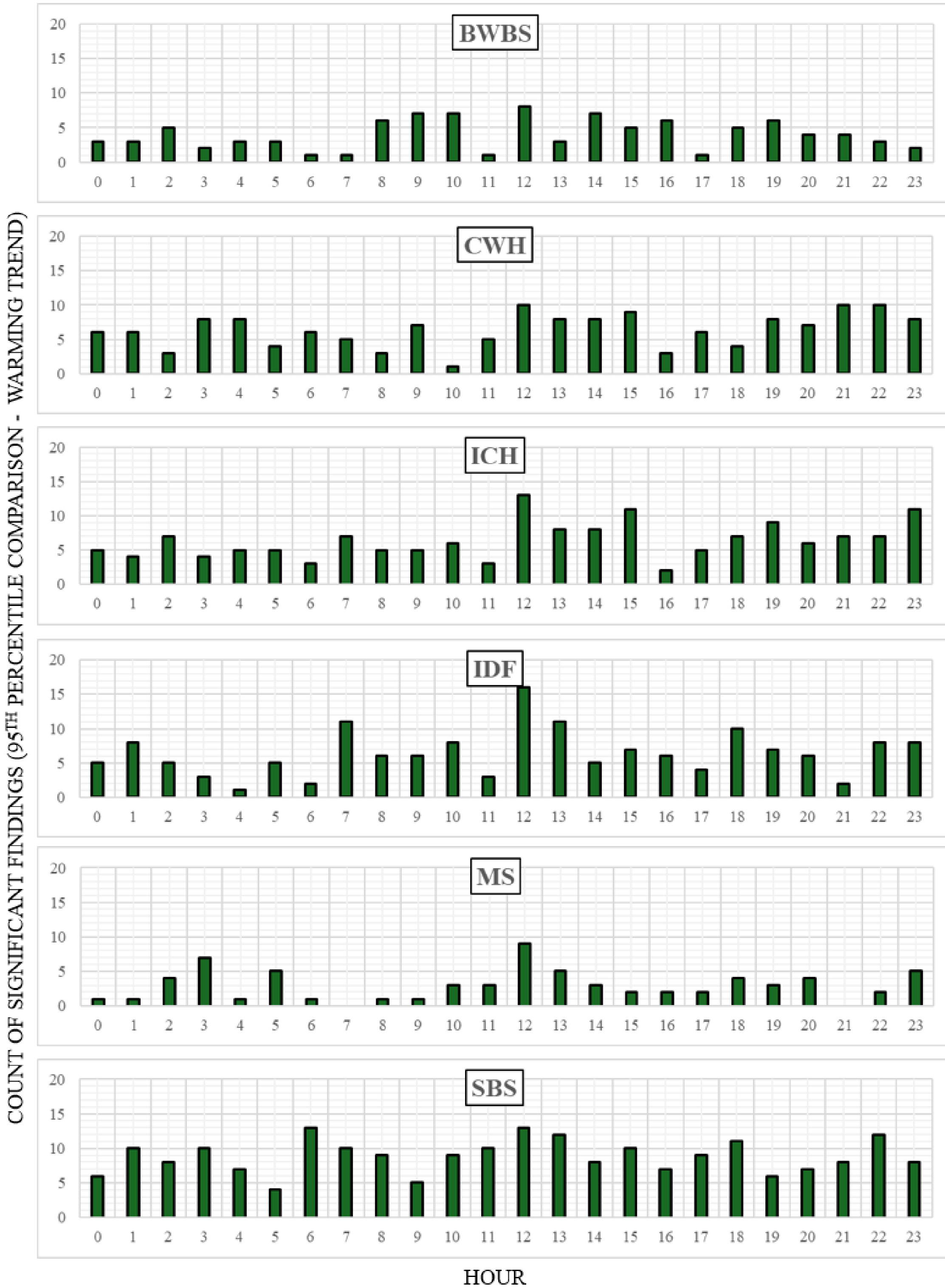

Figure 5: The count of significant findings (α<0.05) with a warming trend per hour for a 24-hour period analyzed by BEC zone between 1990-2005 and 2006-2021. Variables in the analysis were the 95th percentiles of temperature, relative humidity, wind speed, FFMC, ISI, and FWI. Monthly data (June, July, August, and September) was analyzed individually and is being presented in aggregate.

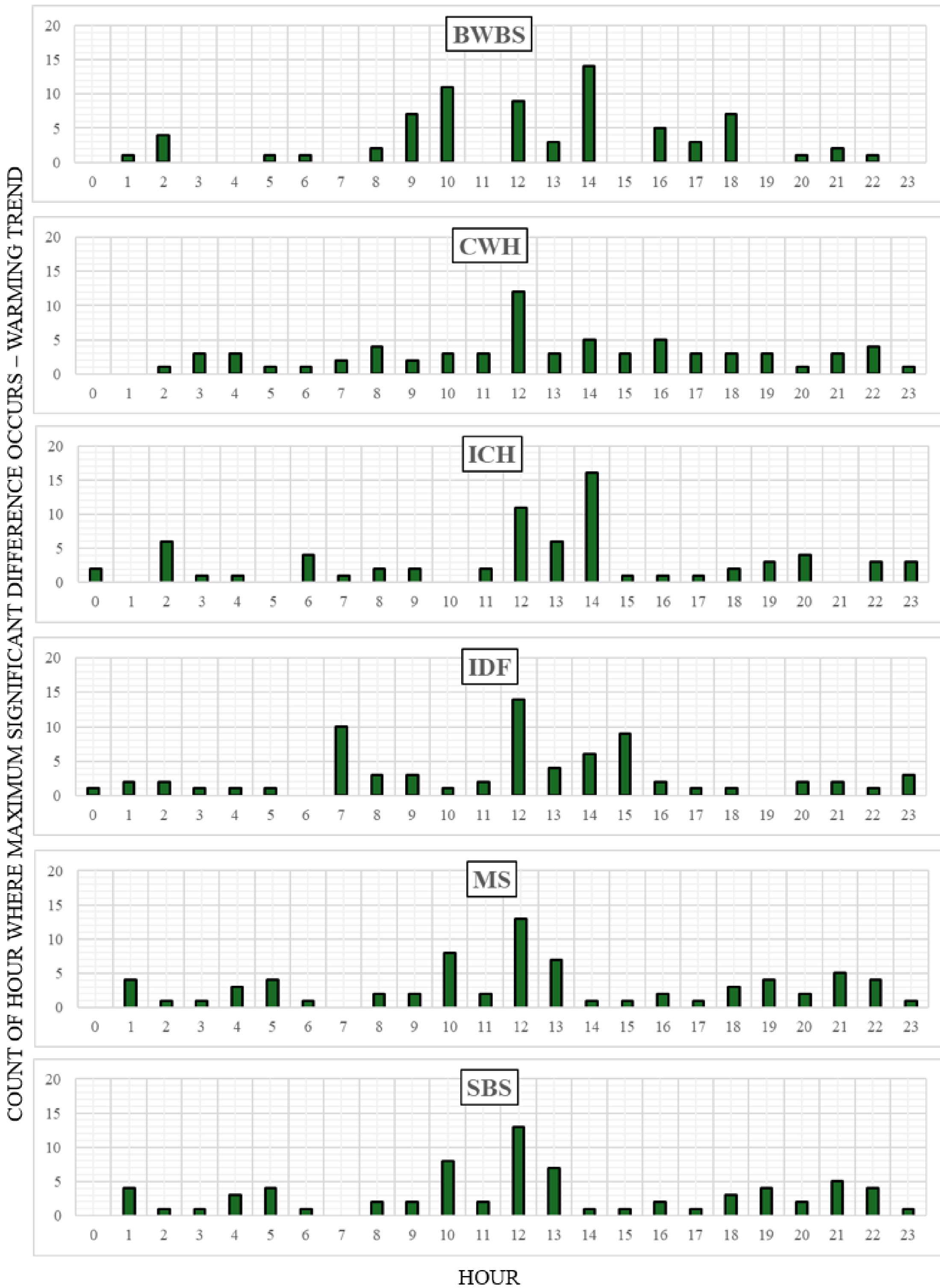

Figure 6: The aggregated count per hour of significant findings (α<0.05) with a warming trend when the maximum difference occurred by BEC zone. Analyses included a comparison of mean, median, and 95th percentile temperature for six variables (relative humidity, wind speed, FFMC, ISI, and FWI) for each month (June, July, August, September) over two time periods (1990-2005 and 2006-2021) for a total of 72 comparisons completed for each hourly timestep.

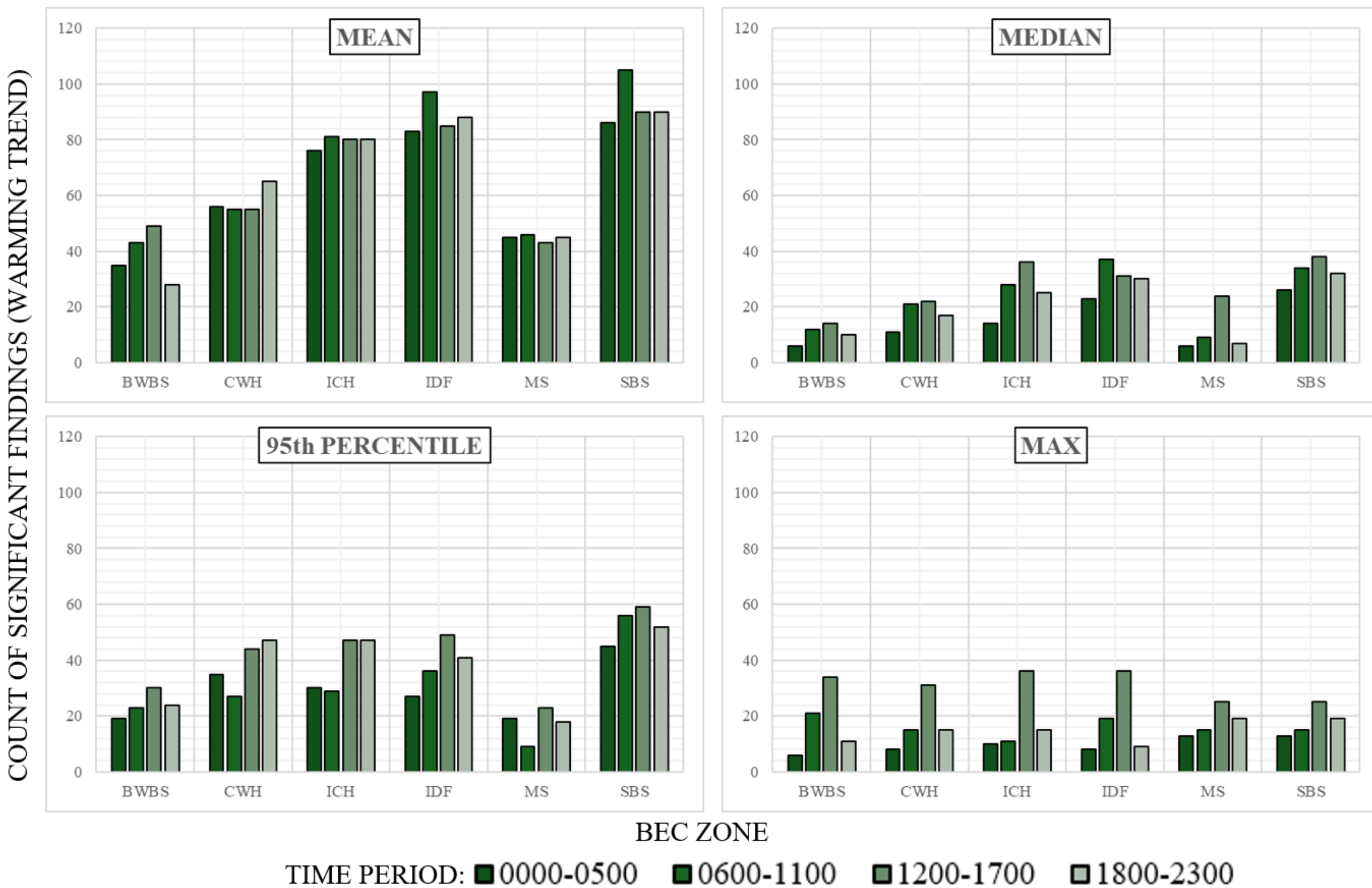

Figure 7: The count of significant findings (α<0.05) with a warming trend, grouped by periods, for each BEC ZONE. Analyses included comparisons of hourly temperature, relative humidity, wind speed, FFMC, ISI, and FWI for each month (June, July, August, and September) over two time periods (1990-2005 and 2006-2021). Counts are summarized by mean, median, 95^{th} percentile, and hour of maximum difference.

Spread Day Thresholds

A comparison between the 1990-2005 dataset and the 2006-2021 dataset of the percentage of observations exceeding known thresholds for fire spread events was summarized by zone for FFMC (Figure 8 to Figure 13), ISI (Figure 14 to Figure 19) and FWI (Figure 20 to Figure 25).

The ICH and IDF zones had the greatest percentage of values that exceeded the threshold for FFMC (≥91). The greatest number of thresholds were exceeded during period 4 (1800h-2300h), followed by period 3 (1200h-1700h) with the lowest amount of FFMC thresholds exceeded in period 2 (0600h-1100h). There was an observed trend of more thresholds being exceeded in 2006-2021 compared to 1990-2005. When reviewing the percentage change, the BWBS had the greatest percent change compared to all other zones, and it was highest in period 2 (0600h-1100h) for July, August, and September. Overall, in the BWBS, there was a small percentage of values exceeding, but it had the greatest change compared to the other zones.

For the ISI threshold of ≥8.7, most thresholds were exceeded during the third period (1200-1700h), followed by fourth (1800-2300h), and the least in the second (0600-1100h). The zones with the highest percentage of thresholds exceeded were the IDF, then ICH, and finally MS. Overall, higher percentages of thresholds were observed in 2006-2021 compared to 1990-2005 except a decreased ISI threshold observations most common in September for the CWH, ICH and SBS. The IDF zone had the greatest percent change in ISI during the June 0600h-1100h period and the second greatest change occurred in the third June period (1200-1700h) in the ICH zone.

The FWI threshold of ≥19 was exceeded most often in the IDF zone. The MS zone had the second highest percentage followed by the ICH. Period 3 (1200h-1700h) had the highest number of values over the threshold, followed by period 4 (1800-2300h), period 1 (0000h-0500h), and the least observed thresholds occurring during period 2 (0600-1100h). The greatest percent change occurred in the BWBS and SBS in July. The BWBS had the greatest change in FWI threshold exceedance in the first period (0000h-0500h))in July, and SBS in the fourth period (1800-2300h) in July and first (0000h-0500h) in August. Cooling trends occurred in CWH in June and September but had a higher change to warmer conditions exceeding thresholds in the third (1200h- 1700h) period in July.

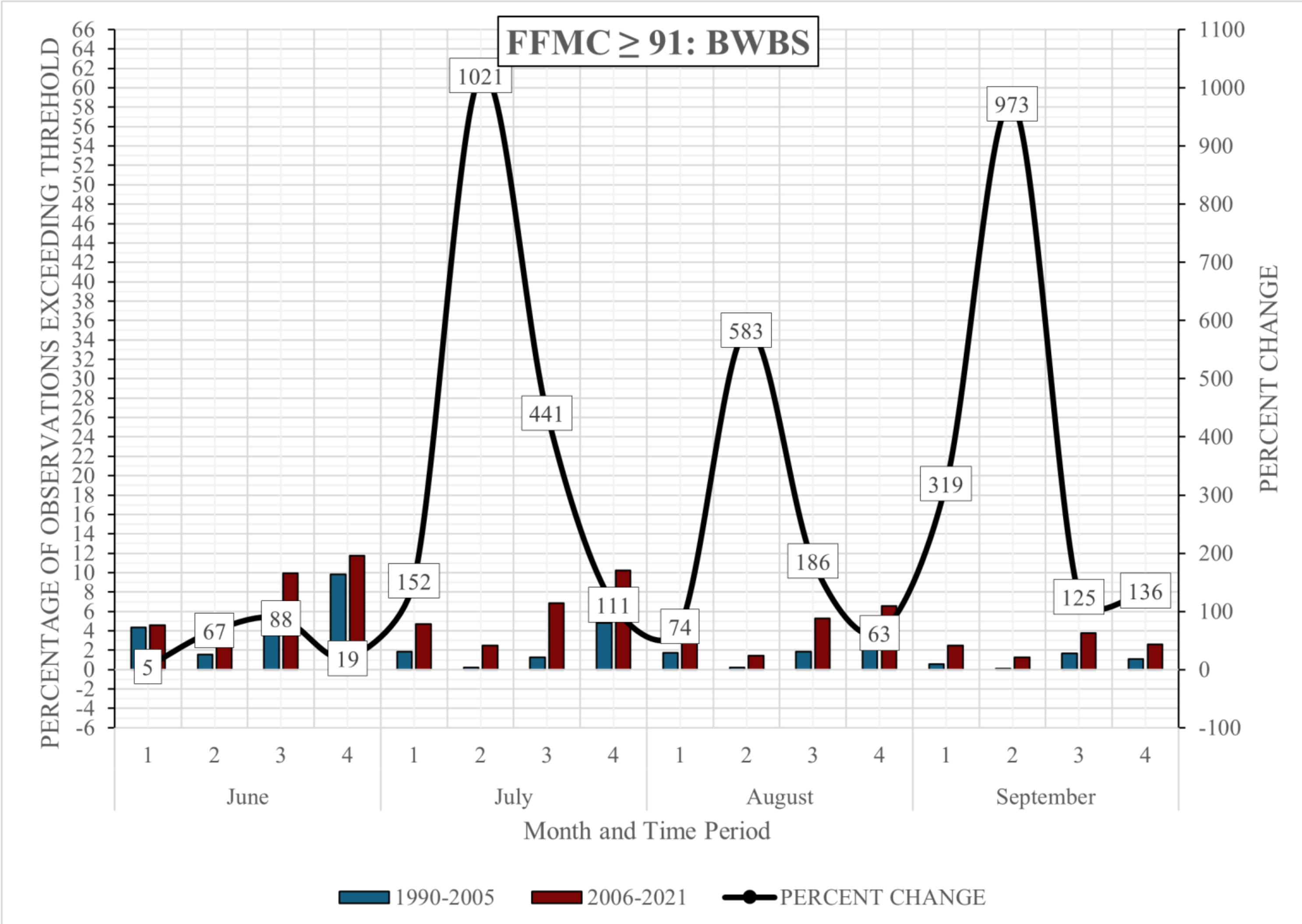

Figure 8: BWBS BEC Zone: Percentage of observed FFMC values exceeding a threshold of ≥91 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

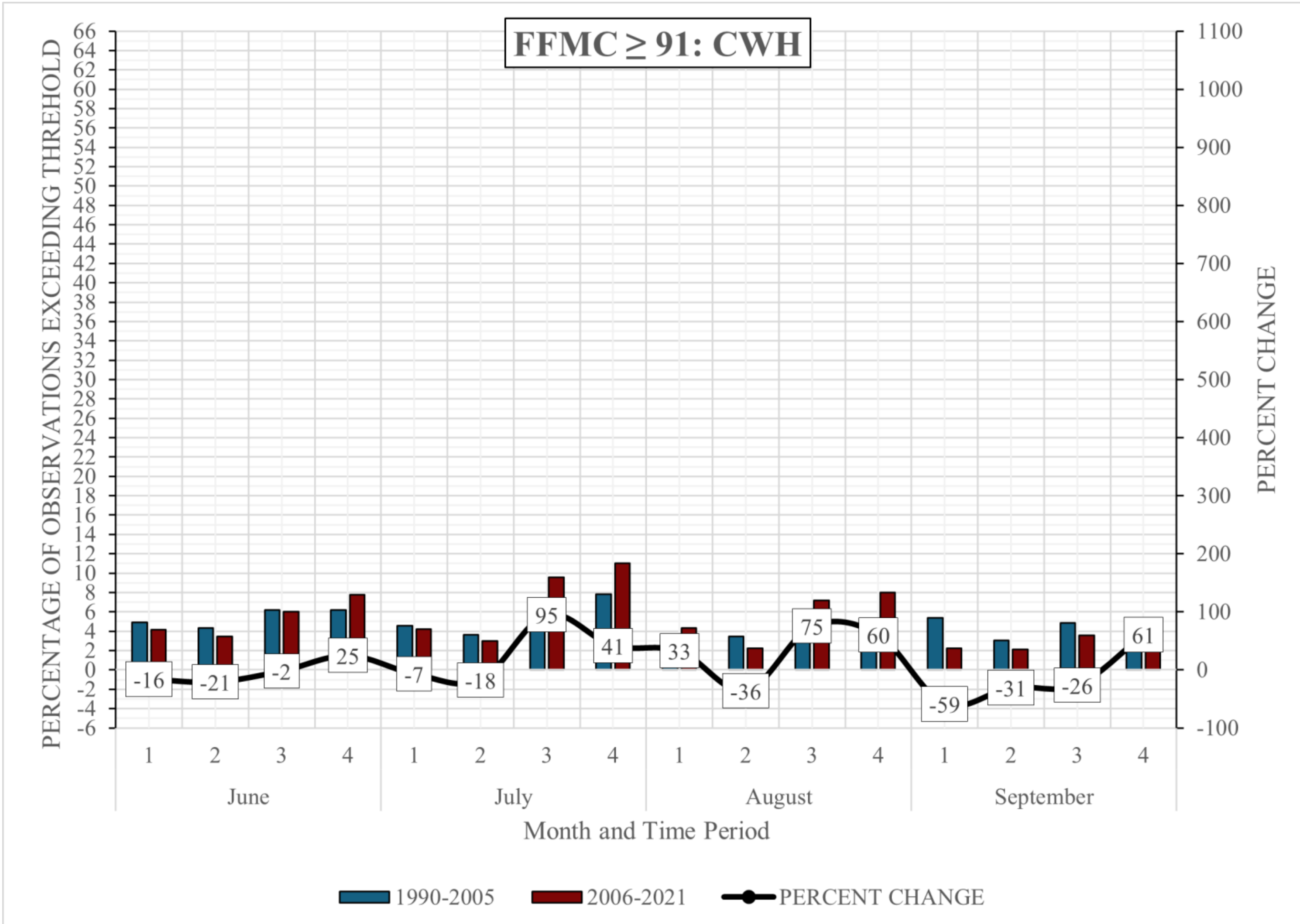

Figure 9: CWH BEC Zone: Percentage of observed FFMC values exceeding a threshold of ≥91 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

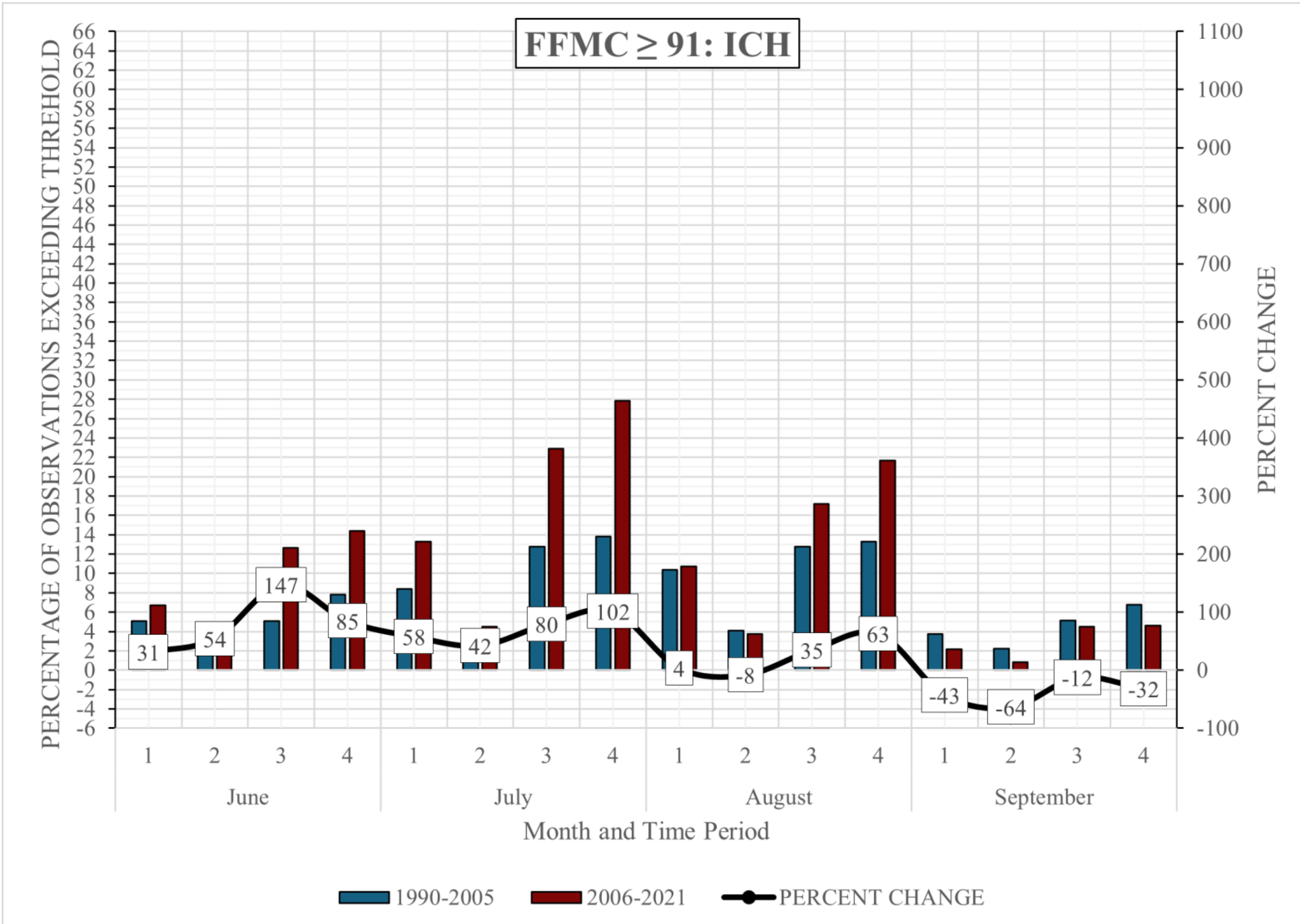

Figure 10: ICH BEC Zone: Percentage of observed FFMC values exceeding a threshold of ≥91 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

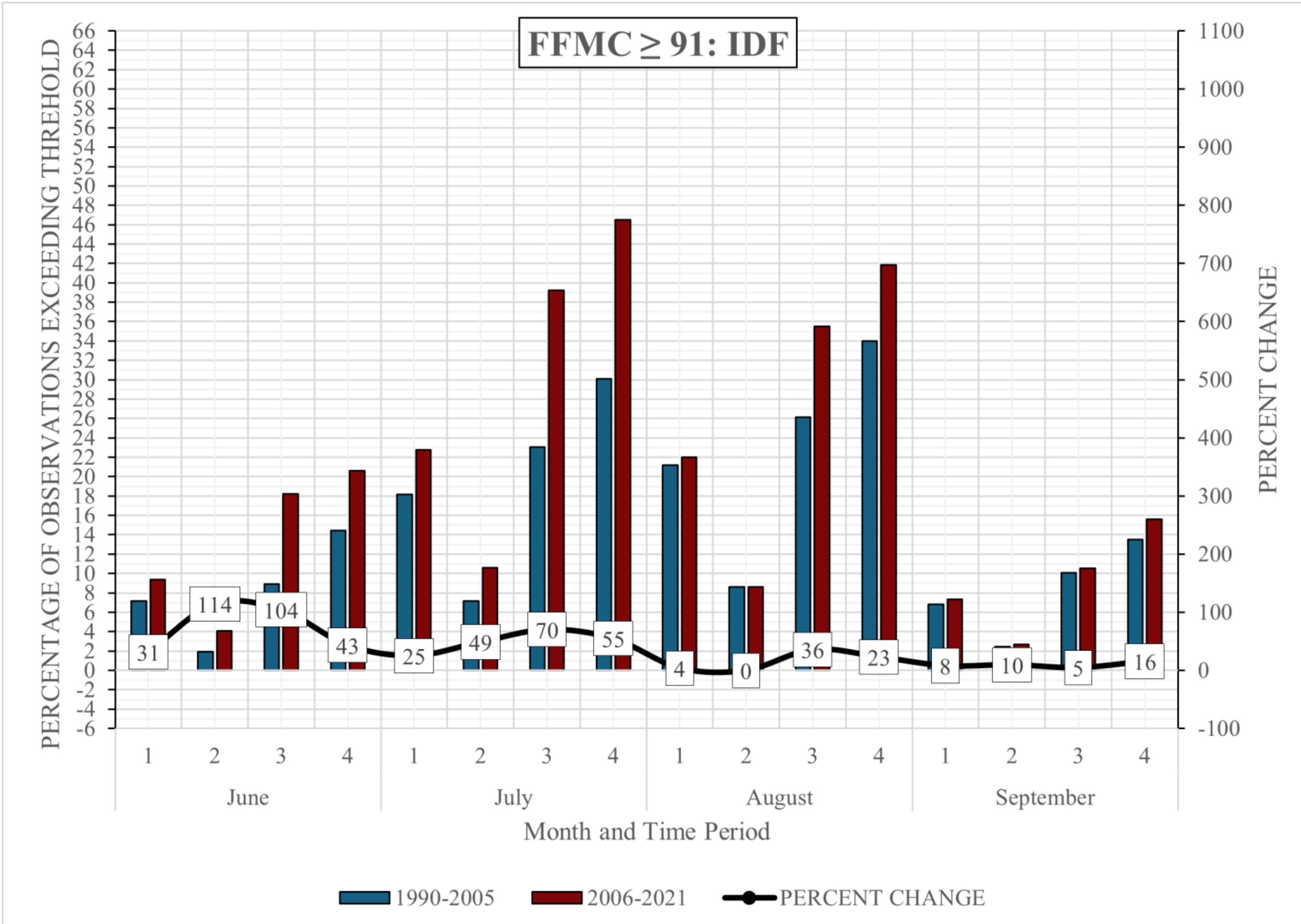

Figure 11: IDF BEC Zone: Percentage of observed FFMC values exceeding a threshold of ≥91 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

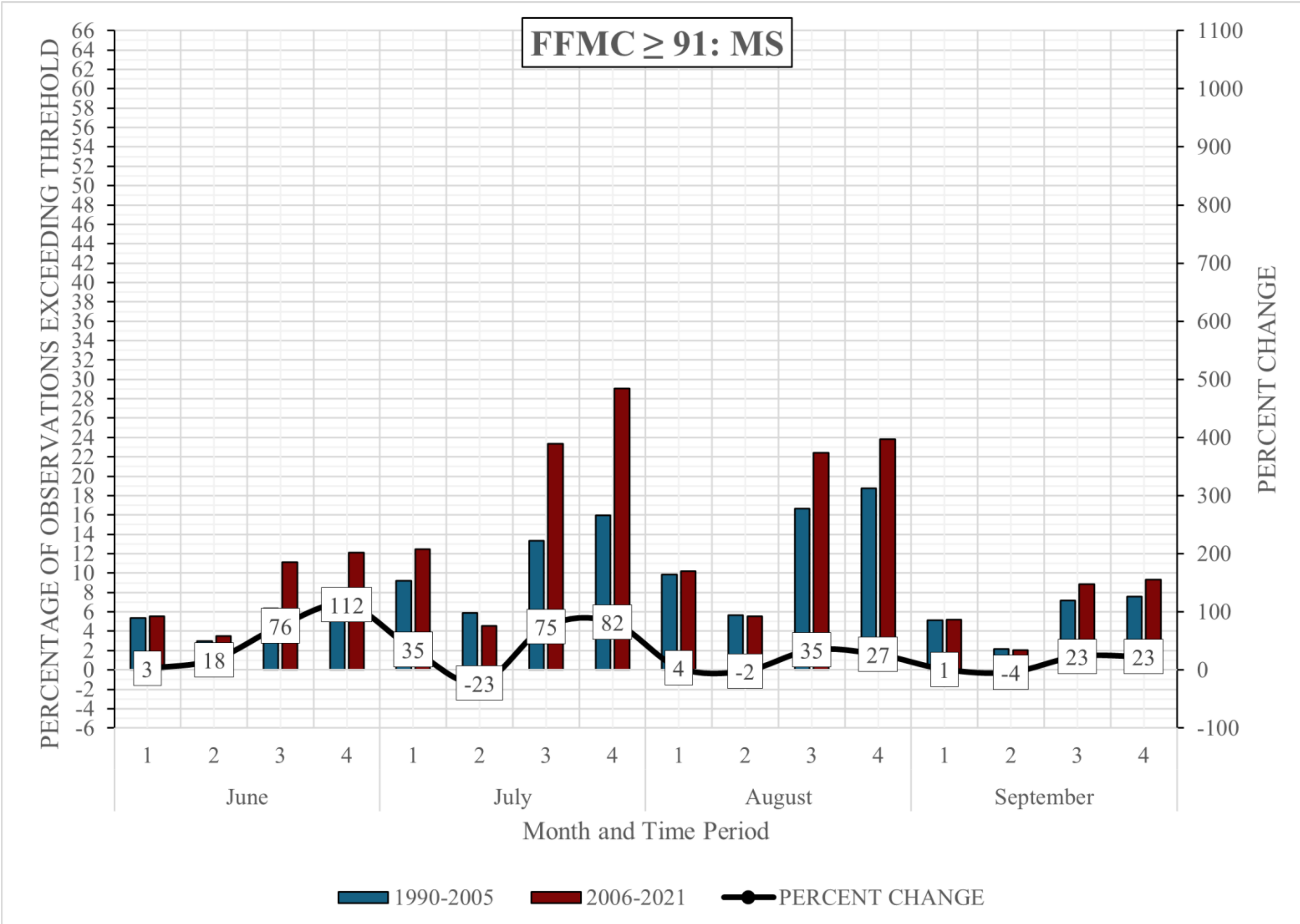

Figure 12: MS BEC Zone: Percentage of observed FFMC values exceeding a threshold of ≥91 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

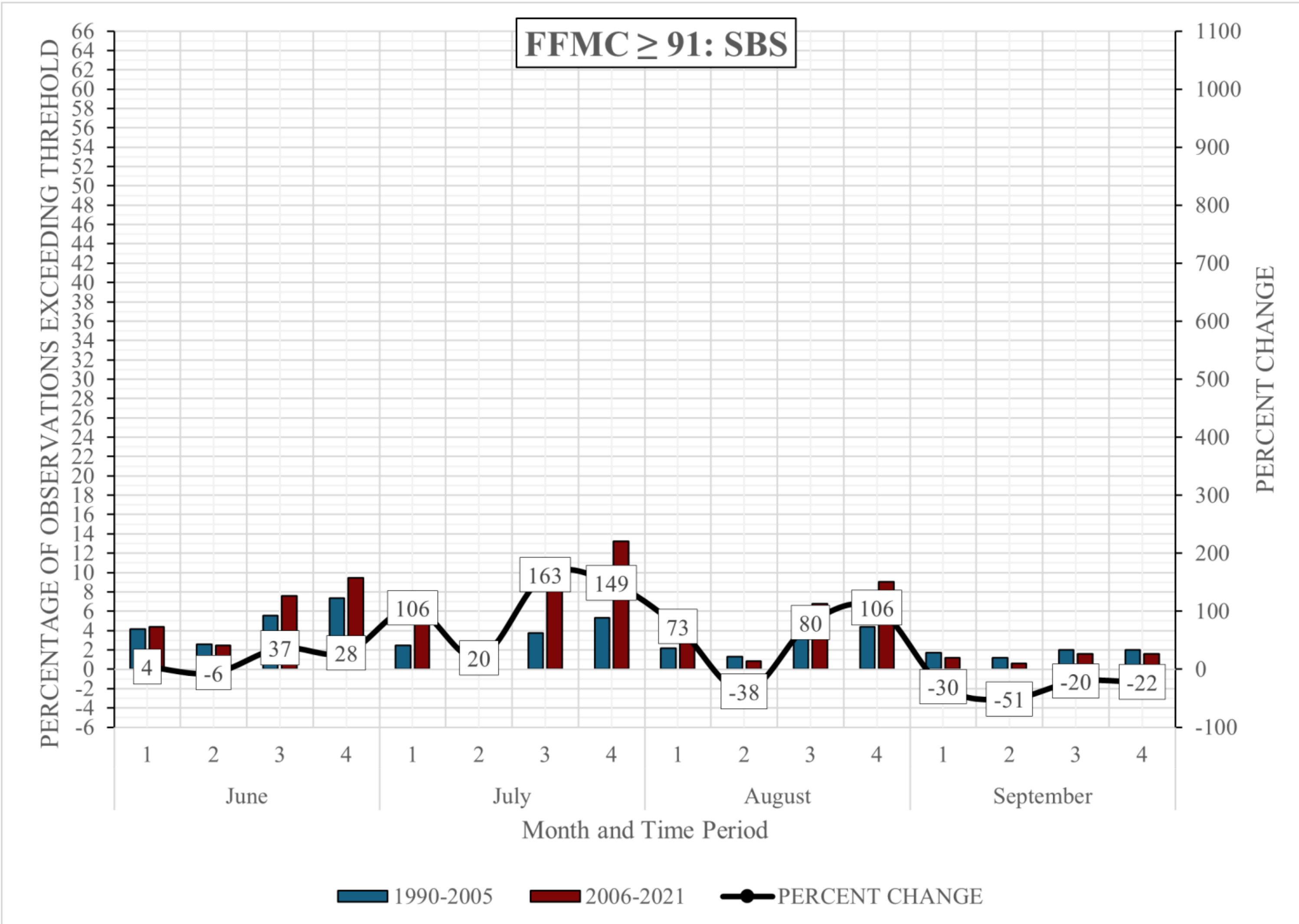

Figure 13: SBS BEC Zone: Percentage of observed FFMC values exceeding a threshold of ≥91 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

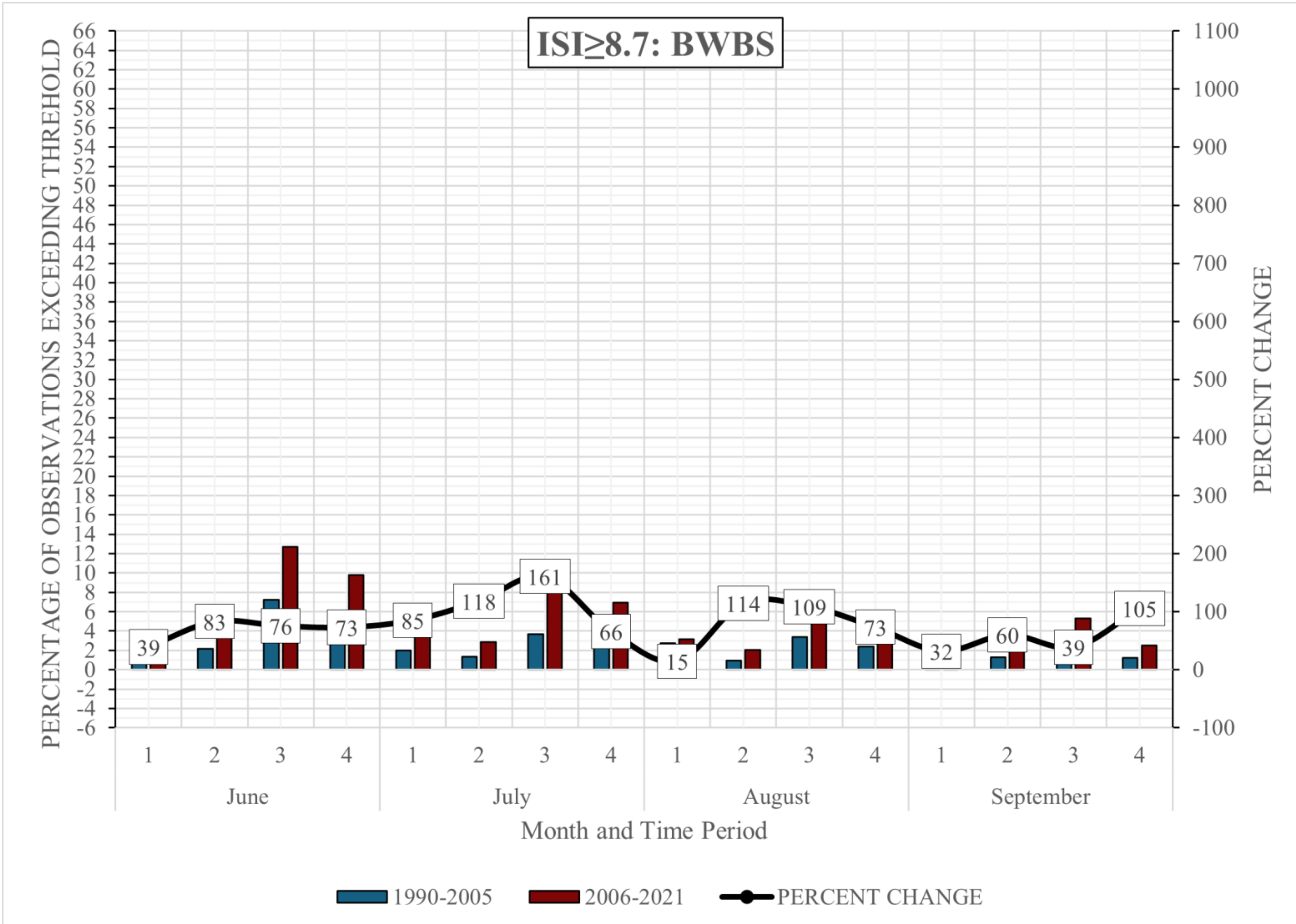

Figure 14: BWBS BEC Zone: Percentage of observed ISI values exceeding a threshold of ≥8.7 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

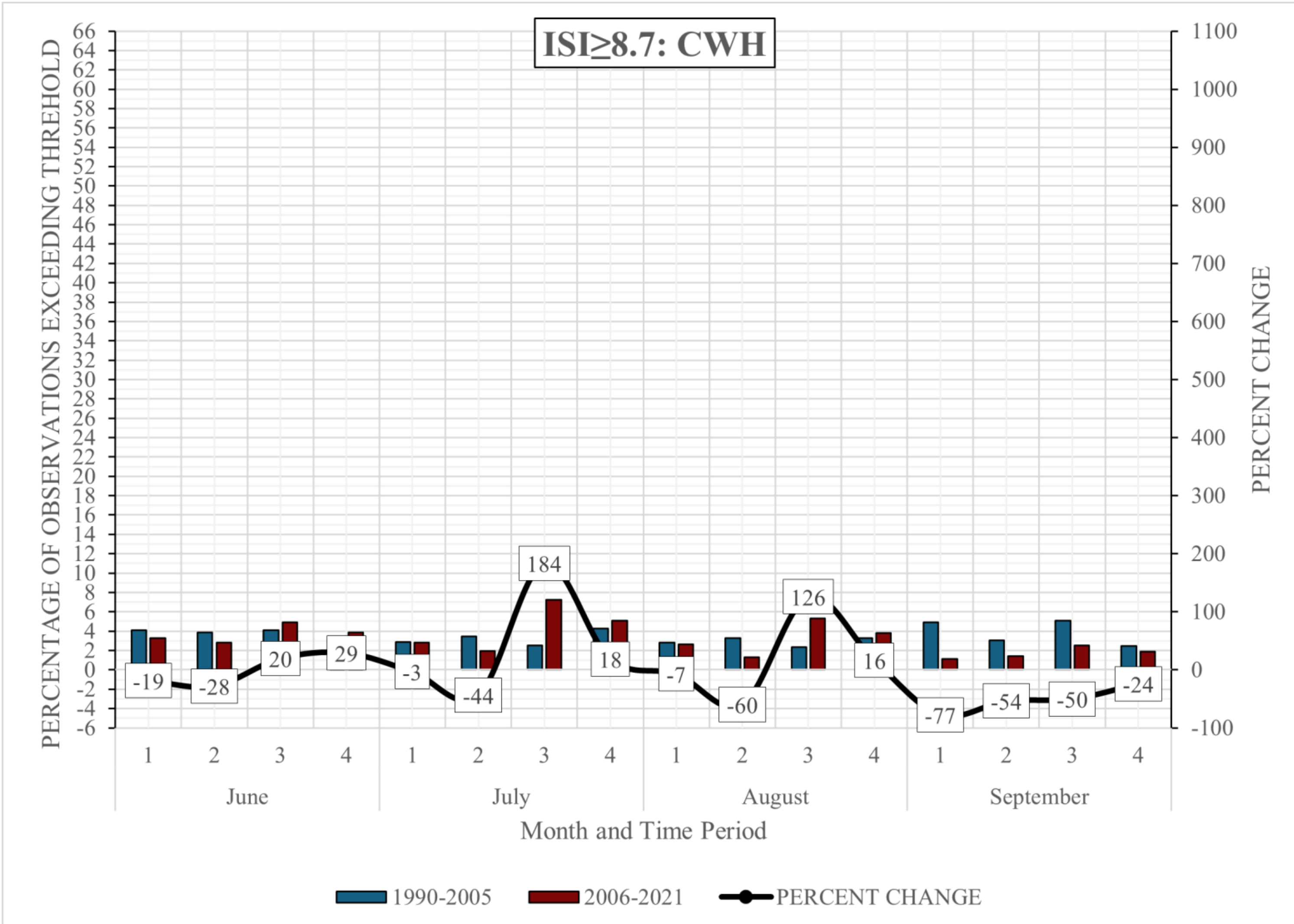

Figure 15: CWH BEC Zone: Percentage of observed ISI values exceeding a threshold of ≥8.7 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

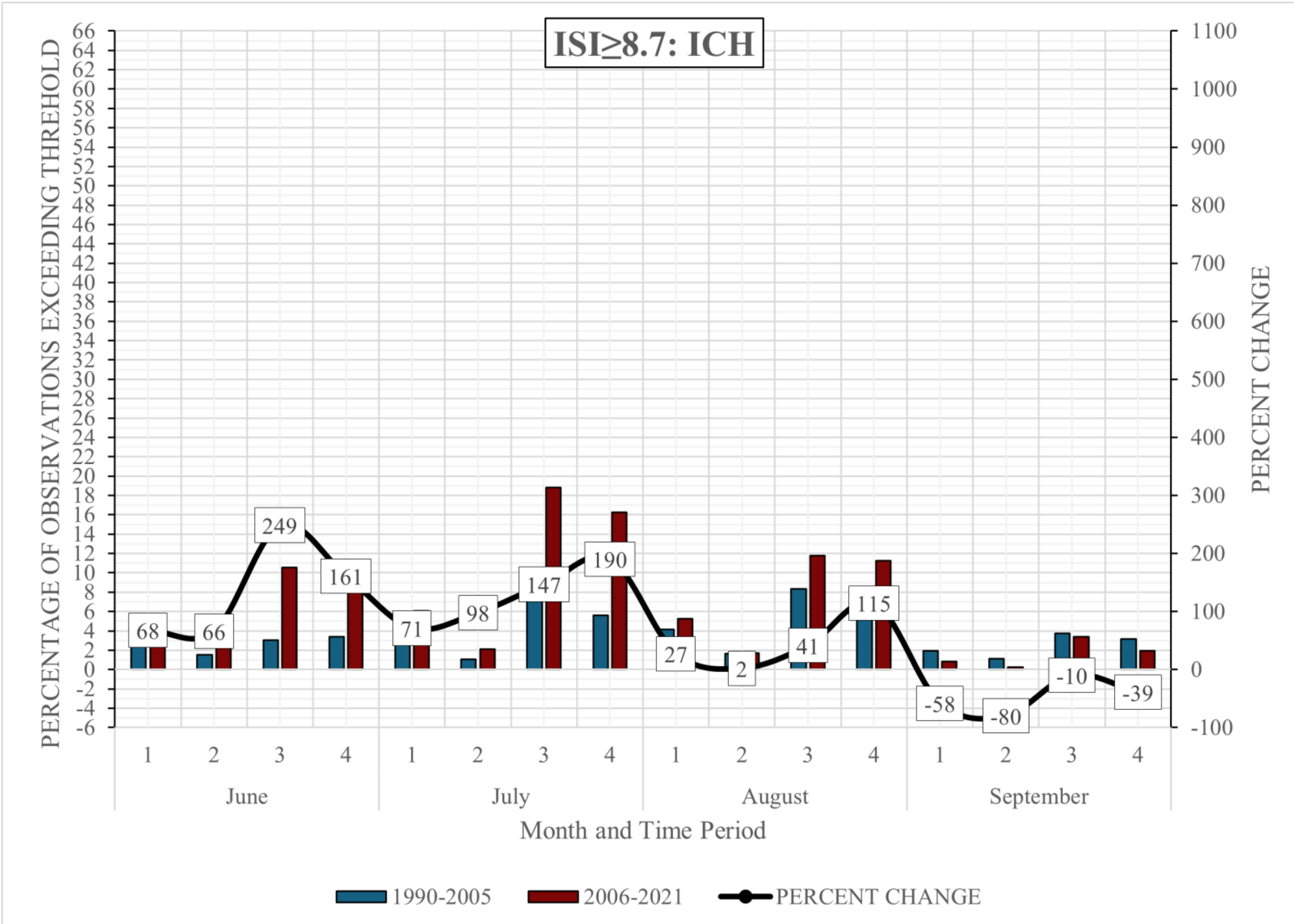

Figure 16: ICH BEC Zone: Percentage of observed ISI values exceeding a threshold of ≥8.7 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

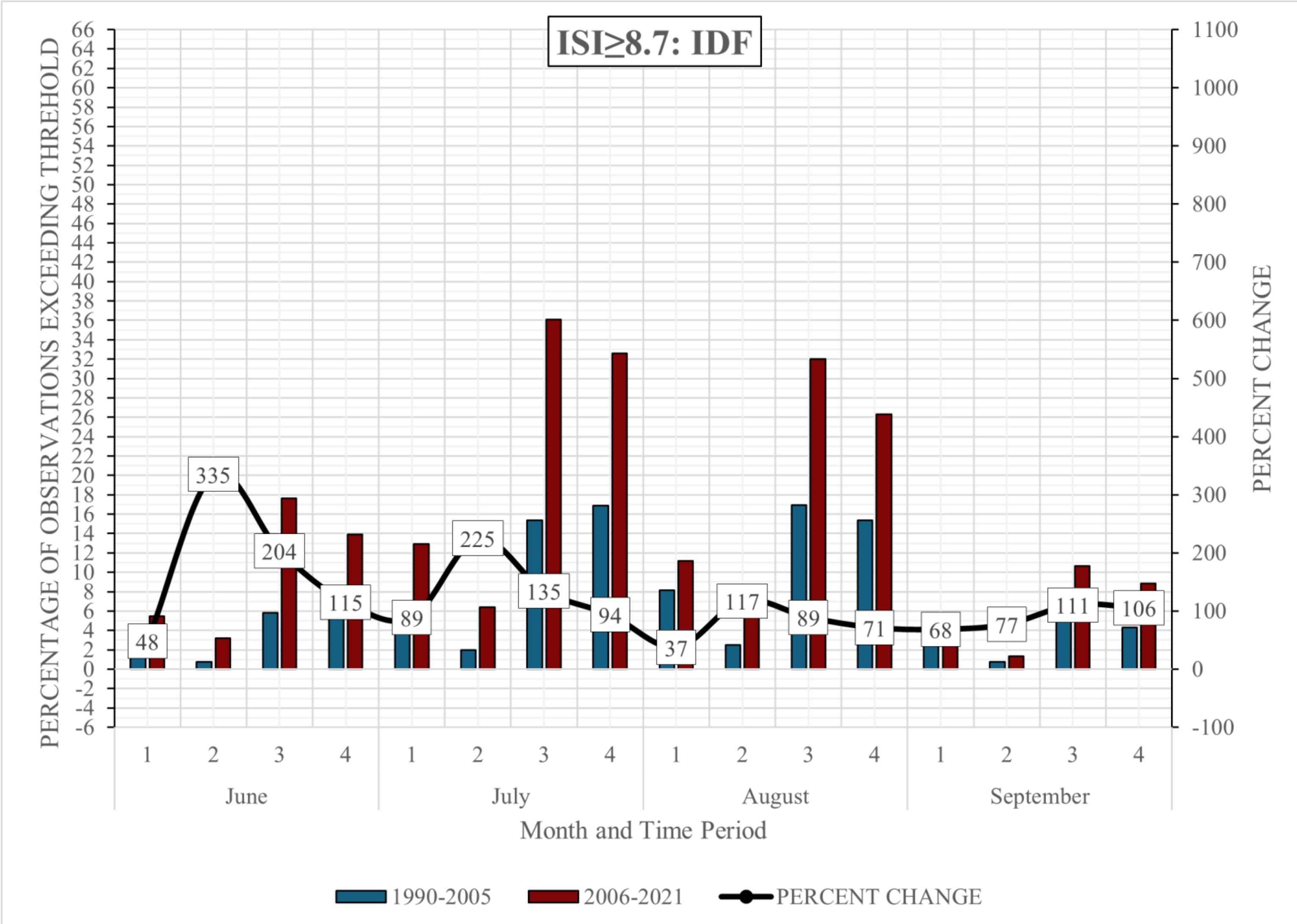

Figure 17: IDF BEC Zone: Percentage of observed ISI values exceeding a threshold of ≥8.7 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

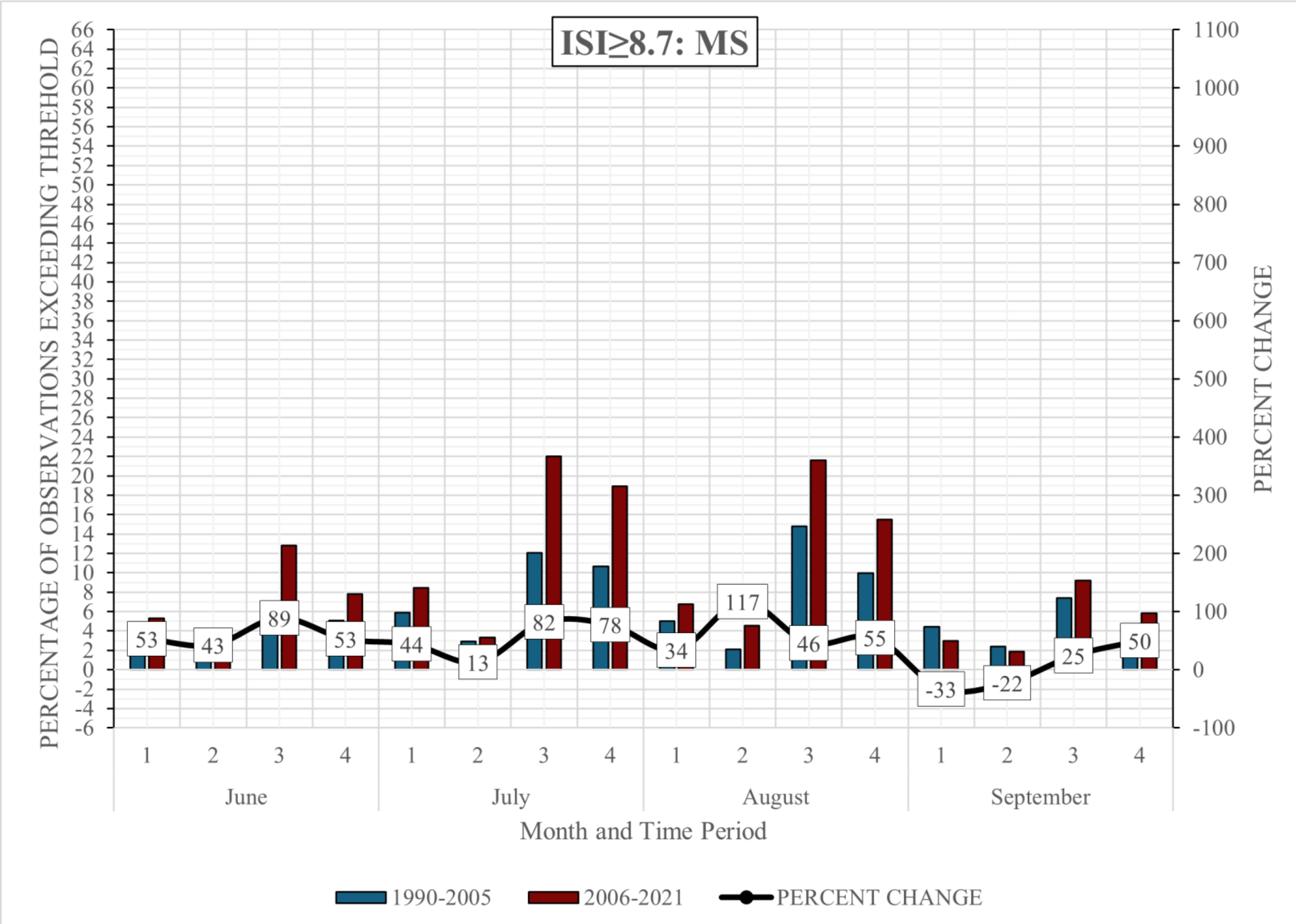

Figure 18: MS BEC Zone: Percentage of observed ISI values exceeding a threshold of ≥8.7 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

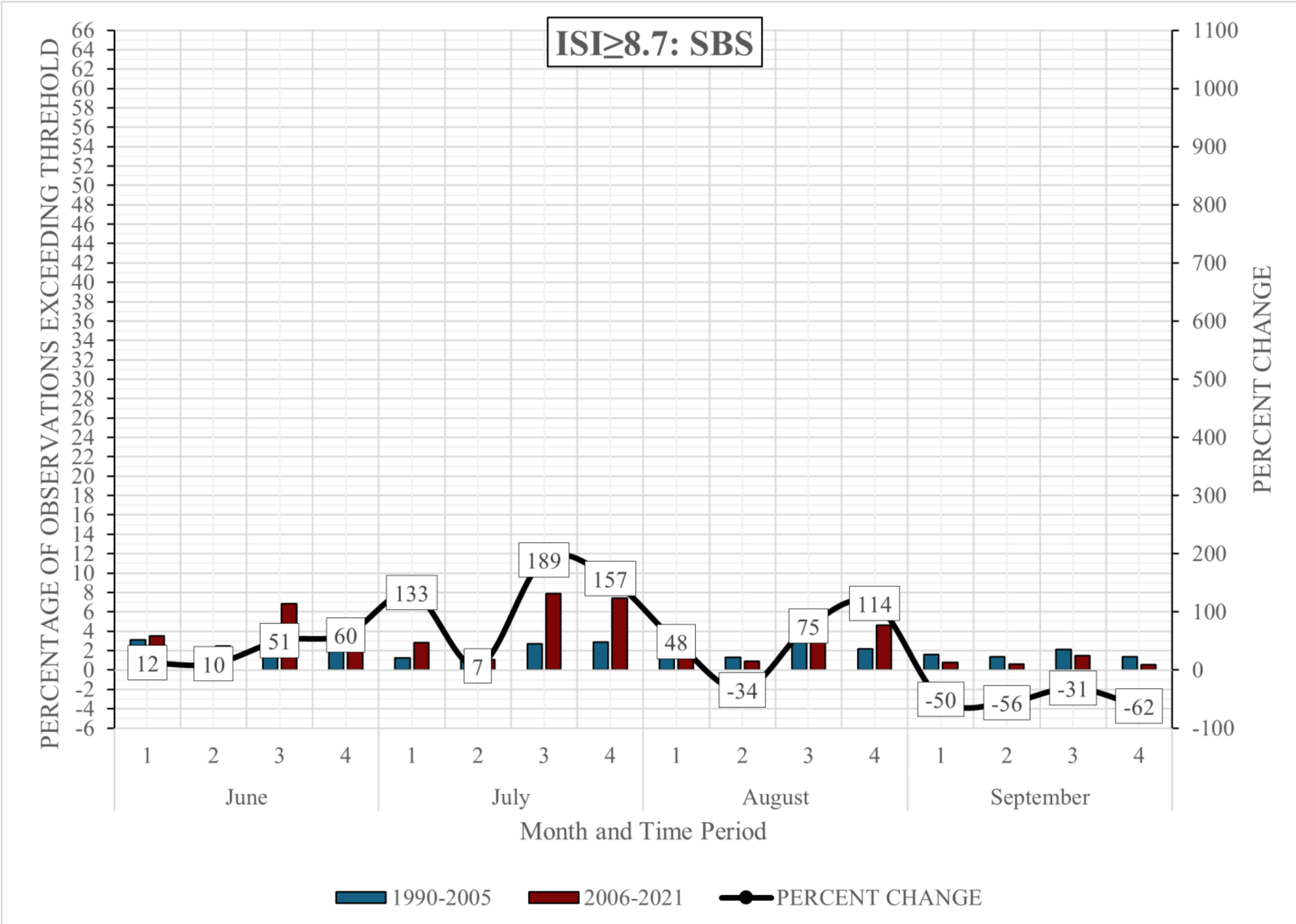

Figure 19: SBS BEC Zone: Percentage of observed ISI values exceeding a threshold of ≥8.7 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

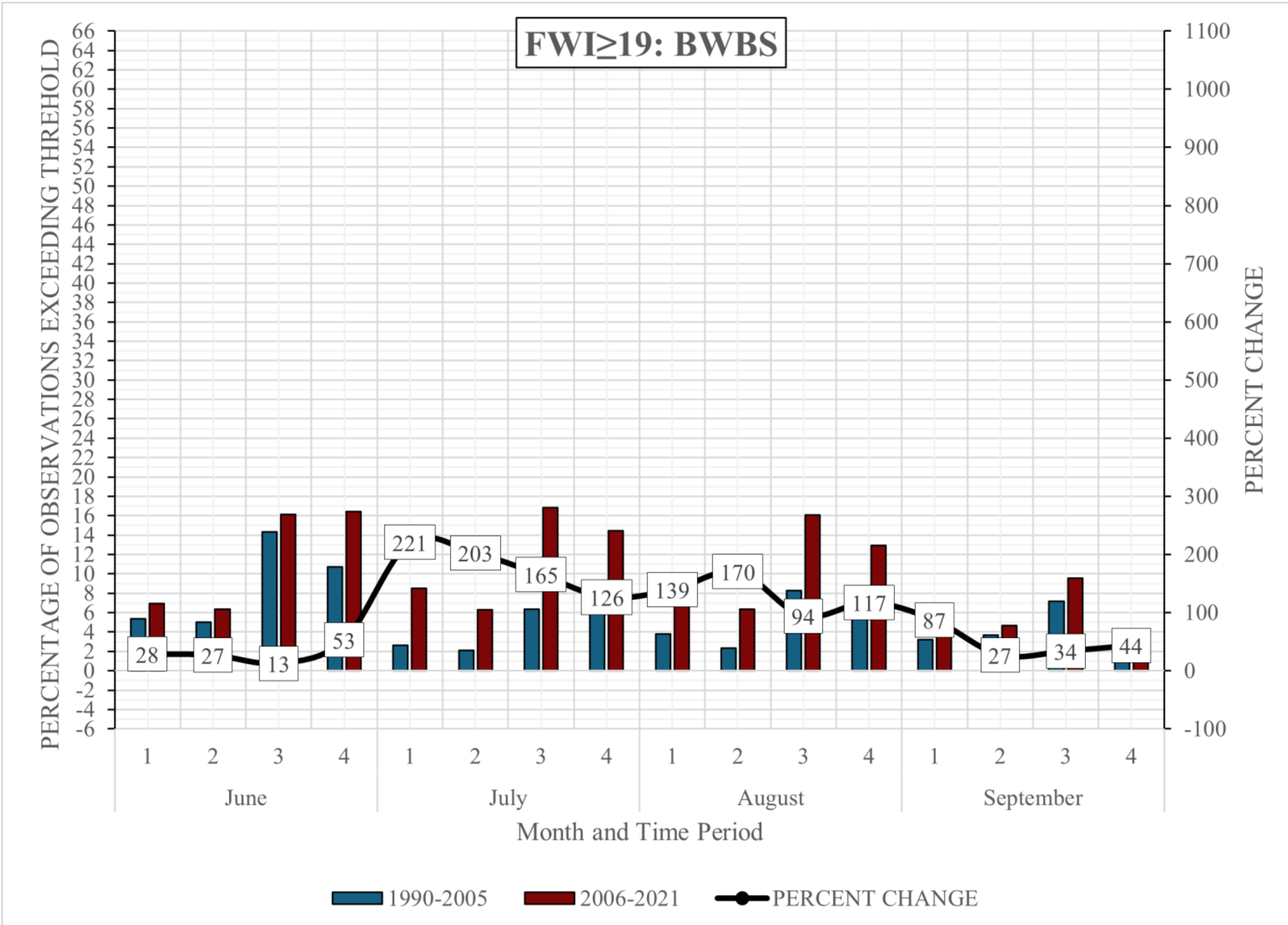

Figure 20: BWBS BEC Zone: Percentage of observed FWI values exceeding a threshold of ≥19 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

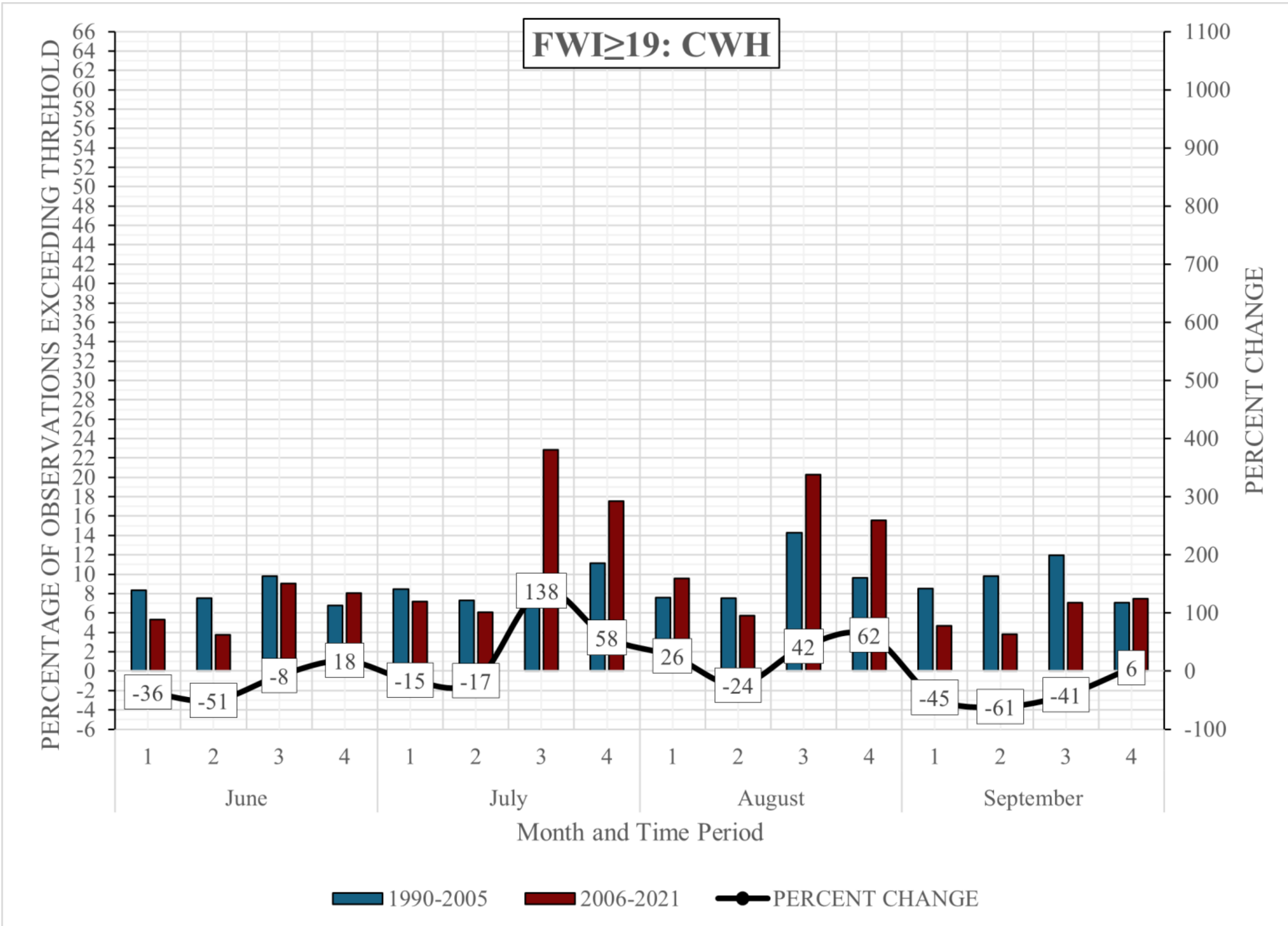

Figure 21: CWH BEC Zone: Percentage of observed FWI values exceeding a threshold of ≥19 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

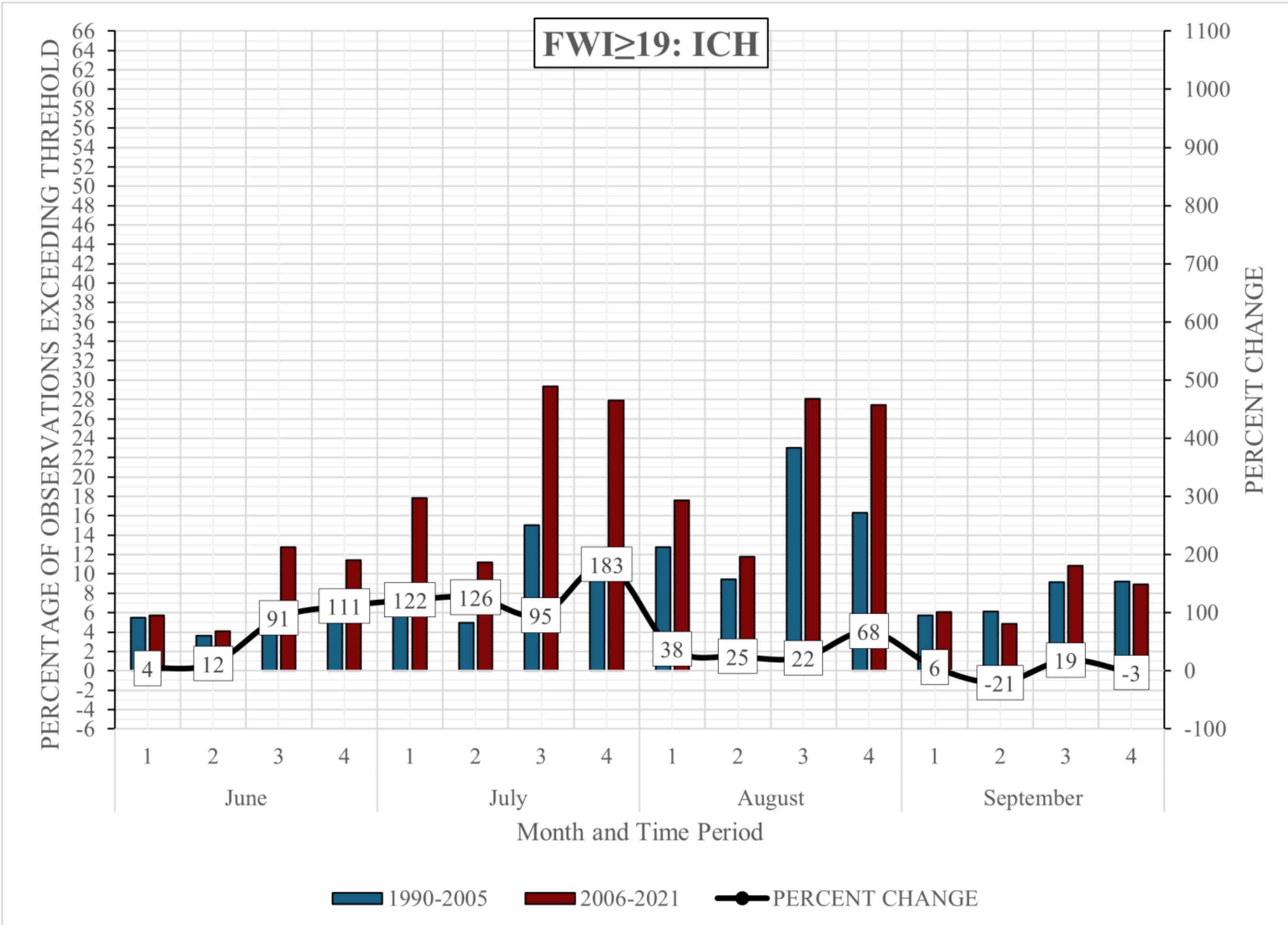

Figure 22: ICH BEC Zone: Percentage of observed FWI values exceeding a threshold of ≥19 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

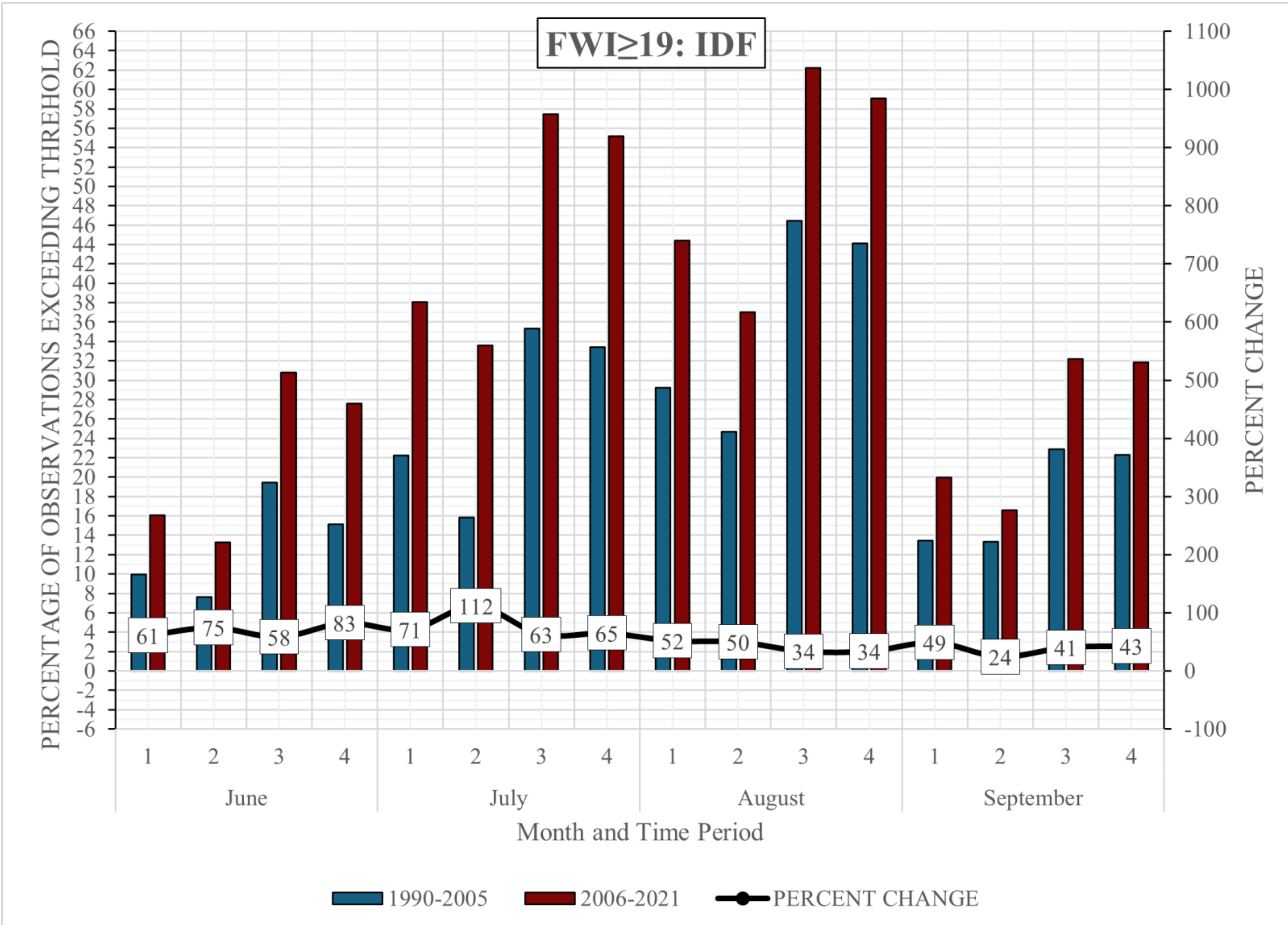

Figure 23: IDF BEC Zone: Percentage of observed FWI values exceeding a threshold of ≥19 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

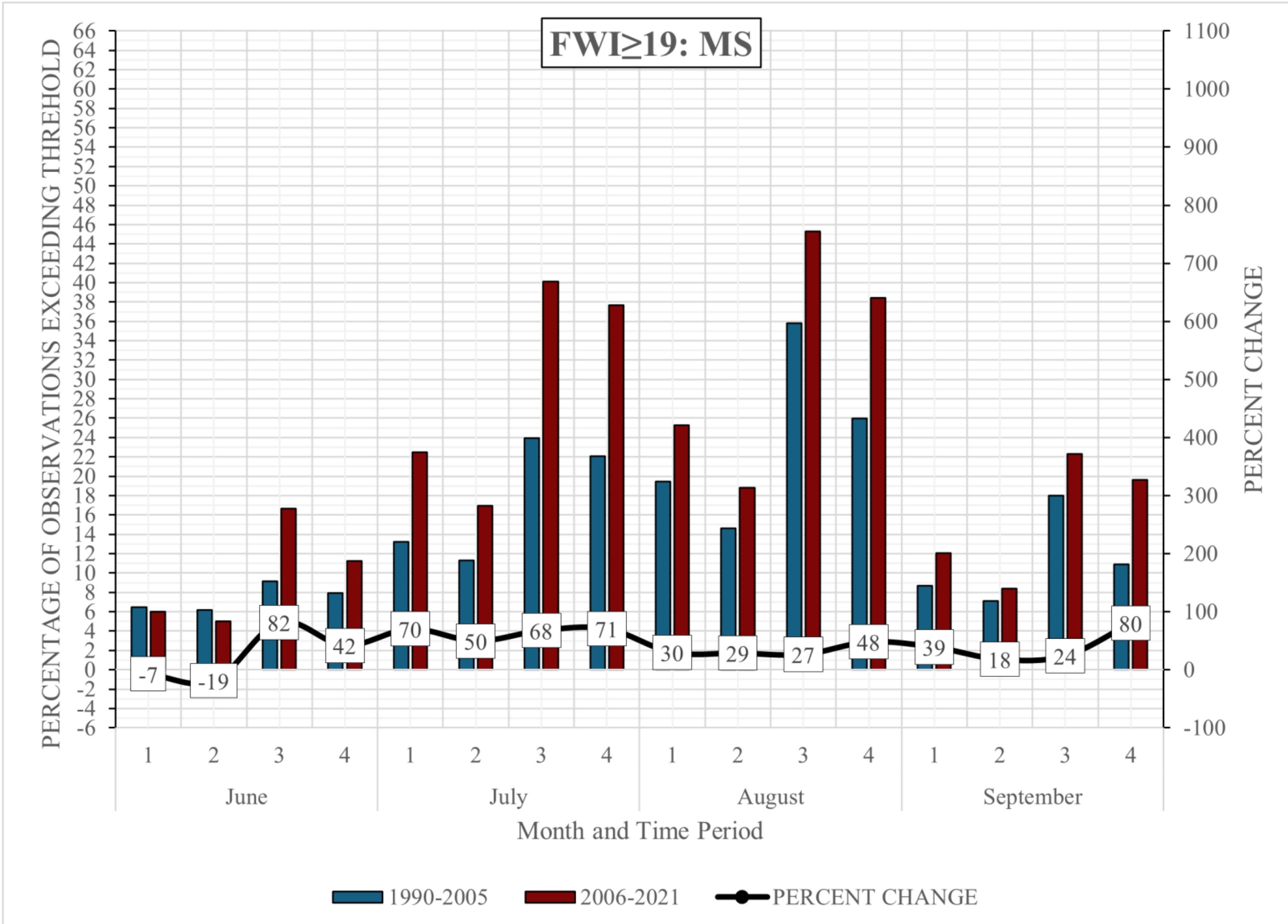

Figure 24: MS BEC Zone: Percentage of observed FWI values exceeding a threshold of ≥19 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

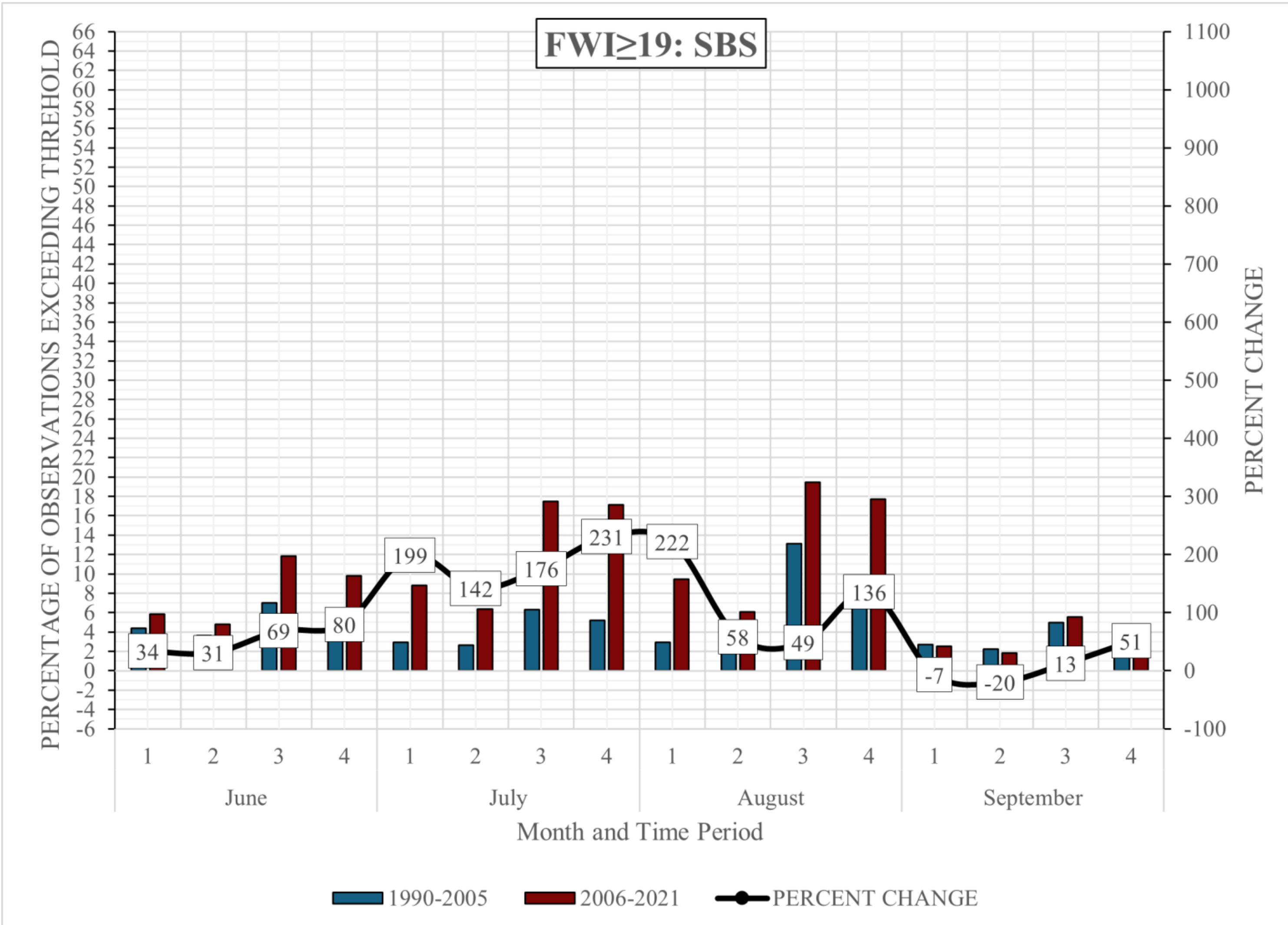

Figure 25: SBS BEC Zone: Percentage of observed FWI values exceeding a threshold of ≥19 across four daily periods: 1) 0000h-0500h, 2) 0600-1100h, 3) 1200h-1700h and 4) 1800-2300h by month for data grouped from 1990-2005 and 2006-2021. The secondary Y-axis shows the percentage change of the FFMC values from the earlier dataset (1990-2005) to the more recent dataset (2006-2021).

CHAPTER 4 – DISCUSSION

Overall Findings

The first Intergovernmental Panel on Climate Change (IPCC) report was released in 1990 and confirmed the link between human activities and global climate change leading to an increase in average temperatures. This analysis confirms significant changes towards a broader warming trend associated with climate change has occurred across many BEC zones in British Columbia from weather observations recorded between 2006-2021 compared to observations from 1990-2005. Following the period used in this analysis, the global average surface temperature in 2023 was the warmest on record (NOAA, 2024). British Columbia broke records for the warmest summer with 84% of the province experiencing abnormally dry conditions, with exceptional drought recorded across some regions. The Upper Fraser West, Nechako, and Skagit basin all recorded their lowest annual precipitation since 1950. As a result, the province had low streamflow, low soil moisture, and record-breaking wildfires.

Using annual suppression costs as one indicator of wildfire season severity, it is evident that fire seasons are worsening. Annual wildfire suppression costs in British Columbia have shown increasing variability and higher total costs in recent periods compared to historical records (1970-2000 compared to 2001-2013; Stocks & Martell, 2016). Wildfire costs are expected to continue increasing under climate change, with extreme seasons predicted to occur every 1-2 years compared to every 10 years historically (Hope et al., 2016). Kirchmeier-Young et al. (2019) attributed the extreme wildfire season of 2017 to anthropogenic climate change noting extremes in warm and dry temperatures lead to extremes in fire behaviour. A study by Jain et al. (2021) also found a trend of increasing global mean 95th percentile FWI and ISI in a study spanning 1979-2020. Their study showed eight of the most extreme years on record occurred between 2011-2020 which aligns with the trends shown in this study for British Columbia.

Regional Findings

This study suggests that the SBS, IDF, and ICH zones are seeing more significant changes compared to the other zones, however, a warming trend was detected across all zones in the study with few findings showing a cooling trend. Differences between the zones show the importance of not aggregating data for large areas with complex topography (Meyn et al., 2010).

BEC zones are the recommended climate unit for assessing climate change at a provincial scale (DeLong et al., 2010). Although fire effects will vary based on localized variations in the fire environment and vegetative community, these results can be applied to management from a broad lens by providing a better understanding of regional climate shifts. Fire management personnel working in different fire zones across the province can use these findings to understand the changes occurring in their regions. Effectively adapting to climate change requires an understanding of conditions, and this study provides insights on climate change impacts across different regions of the province allowing for localized adaptation.

Meyn et al. 2010 found a decreasing trend in fire frequency and area burned in the ICH, IDF, CWH, and SBS for a period spanning 1920-2000. They attributed this decrease to wetter summers during this period. The significant warming trends found in this study may suggest a shift away from wetter summers detected in the second period used for comparison (2006-2021 dataset). Findings from Parisien et al. (2023) found climate change to be a primary factor in increased wildfire activity in British Columbia following a shift occurring around 2005 towards increased evaporative demand and warming temperatures. These climatological changes were found to be a factor in the extreme severity of four recent wildfire seasons (2017, 2018, 2021, and 2023). The results of this study confirm a shift towards a warmer, drier climate across British Columbia.

By comparing the results of shifts across the mean, median, and 95th percentile, it is possible to understand different patterns over time. The mean is more sensitive to outliers and extreme values and may be more likely to show changes based on short-term variations. The median values are less sensitive to extremes and better reflect a shift towards more frequently changed values which can indicate a change in the typical conditions over some time. Across the mean, median, and 95th percentile, the SBS, IDF, and ICH all had the greatest number of significant findings compared to the other zones. This shows these zones are exhibiting both greater extremes, and an overall increase towards more frequent warm and dry conditions.

This study detected significant changes across both mean and median wind speeds across almost all hours (>21 hours) tested in the ICH, IDF, and SBS zones. Comparisons in the 95th percentile winds were rarely significant in all zones (<3 hours), except in the IDF (<10 hours). This finding is contrary to expectations. Shaw and Miyawaki (2023) found fast winds increase

2.5 times more than average winds whereby fast winds get faster. Their study projects an increase in upper-level jet stream winds with climate change. Increases in strong dry, surface winds can have critical implications for wildfire growth and spread, exceeding suppression capacity (Beverly et al. 2011, Potter and McEvoy 2021). The weather stations used in this study rely on a 10-minute average wind speed recorded in the last 10 minutes of each hour. True extreme values of gusty or erratic winds may have been missed or had their effect diluted due to the nature of data collection.

Jain et al. (2021) found the strongest drivers of extreme FWI and ISI included relative humidity, temperature, and vapour pressure deficit. Wind speed and precipitation were responsible for fewer significant results in their study, ranging from only 11-13% of the global area. In British Columbia, their results showed an increasing trend in extreme fire weather in the south of the province due to increases in temperature outpacing changes in moisture.

The Chiodi et al. (2021) study spanned 1980-2019 and found the greatest overnight vapour pressure deficits in foothill regions near arid plateaus across the western United States. This study had the greatest number of significant findings in the SBS, IDF, and ICH zone, and the largest magnitude of changes in the MS and IDF during June and July. The MS is on the leeward side of the coast mountains with the SBS and IDF zones comprising the interior plateau. The impacts of climate change may be exacerbated by the rain shadow effect leading to a greater number of significant results in these BEC zones, and greater magnitude of changes. Simpson et al. (2024) found the discrepancy between climate model predictions and observed near-surface humidity was also greatest in arid and semi-arid regions. The models assume that the warmer air will carry more moisture, however, observations show vapour remaining constant despite warming temperatures. The resulting increase in vapour pressure deficit has implications for wildland fire management. For every 1°C increase in temperature, a 15% increase in seasonal precipitation is required to offset fuel drying (Flannigan et al. 2016).

Historical Fire Context

British Columbia has a history of notable fire events (Government of British Columbia, 2025). During the first time period used in this study, 1990-2005, a series of significant wildfire events occurred in the interior. In 1994, the Penticton wildfire burned 5,500 hectares and damaged 18 structures. The Salmon Arm Wildfire of 1998 burned 6,000 hectares and damaged

40 buildings. During 2003, two extreme interface fires occurred: the Okanagan Mountain Park Wildfire, and the McClure Wildfire. Both of these fires resulted in mass evacuations, significant loss of infrastructure (homes, businesses and trestle bridges) and grew to final sizes exceeding 25,000 hectares.

During the second time period, 2006-2021, the historical fire records in British Columbia demonstrate substantially more challenging conditions (Government of British Columbia, 2025). Reviewing season summaries from recent years shows far greater area burned, financial impact through suppression costs and social impact of structure loss and evacuations. Several notable events are mentioned across the years 2009-present compared to relatively few recorded fires of note in the historical records. In 2017, the area burned broke records, exceeding 1.2 million hectares. Notable fires included the Elephant Hill Wildfire in the Kamloops Fire Zone, which grew to a over 1,000 hectares within the first 24 hours of ignition, and a final size of 191,865 hectares. In the Cariboo Fire Zone, the plateau complex which resulted from 20 separate lightning fires growing together, ended at a final combined area of 545,131 hectares across the Chilcotin Plateau. In 2018, area burned records were exceeded once again across the province with a total area of 1,345,284 hectares. The greatest area burned occurred in the Northwest, Coastal and Prince George fire centers. In 2021 the fire season was exacerbated by below-average fall and winter precipitation and an extended and historic record-breaking heat wave spanning from mid-June to mid-July. Multiple lightning storms resulted in new fire starts and hot, dry, windy weather facilitated substantial fire growth into August. The Kamloops, Cariboo and Prince George Fire centers had the greatest area burned.

Findings from this study showed an increase in the frequency of spread event thresholds being exceeded. All zones had an increase in the percentage of observations exceeding thresholds in July and August between the hours of 1200h-2300h. Although fire effects and fire behaviour will vary within and between each zone, this increased frequency of values above threshold shows conditions are changing towards more volatile conditions. Fire history recorded during the second period shows a reality with increasing area burned and more challenging suppression conditions requiring substantial resources.

This research is focused on historical data spanning 1990-2021. Since then, British Columbia recorded the most destructive wildfire season in history. In 2023, 2.84 million hectares burned across the province (Government of British Columbia, 2025). The area burned was 10 times greater than the 20-year average annual area burned and was twice as high as the previous record-breaking season which occurred in 2018 with a total of 1.35 million hectares. Notable fire events included the Donnie Creek Wildfire which became the largest wildfire ever recorded in British Columbia's history (Government of British Columbia, 2023), and the Newcastle Creek Wildfire on Vancouver Island which was observed to be burning as deep as 1 meter below ground (Government of British Columbia, 2025). The Donnie Creek fire burnt primarily in the BWBS zone. In this study, the BWBS zone showed less warming compared to other zones, but had the greatest percent change in the FFMC spread event thresholds between time periods, particularly between 0600h and 1100h in July, August, and September. This zone, which previously had very few hours above thresholds, is showing a large shift. This means areas that previously experienced a long fire return interval with infrequent fires, may be more susceptible to burning in future climates.

The Newcastle Creek fire was another fire of note in 2023 which occurred within the CWH zone. Although this fire did not exhibit large growth, the fire effects were severe due to the extent of deep burning. Deeply burning fires are ecologically damaging and require exceptional time and expense to extinguish. This BEC zone had several significant results across June, July, and August with increasing temperature and windspeed and a decrease in RH. These sustained periods of warmer, drier weather are unusual in a coastal environment, but likely to occur more frequently in a future climate.

Timing

This study is the first to review changes across space and time in British Columbia with the intent of informing operational wildfire management decisions. The analysis is highly detailed providing results for each BEC zone by each month through the primary summer fire season in British Columbia, and by each hour during that month. This detailed approach can be used to determine what areas of the province may require greater resourcing on a monthly scale, and inform the most beneficial operational shift schedule for resources working on active fires. Typical scheduling overlaps with peak burn period, where resources often need to be stood down from action due to safety concerns. With the increasing fire intensity and severity associated with climate change, fire behaviour during peak burn often cannot be controlled. At wildfire intensity class 4 (4,000-10,000 kW/m) fire are extremely difficult to control and often have prolific spot fires 500-1000m ahead of the fire front (Tedim et al. 2018). At higher intensity classes (>10,000kW/m), control becomes impossible, and spot fires can start several kilometers ahead of the main fire front (Tedim et al. 2018). Prioritizing sustained action suppression resources during time periods where fires are easier to control could result in better outcomes on large, challenging wildfires.

Monthly

This study showed differences in the strength of warming relationships across June, July, August, and September. The most significant warming trends appeared during July, followed by August. Other studies typically take a seasonal approach to understanding fire weather, for example, June-August (Meyn, 2010), May-August (Xiao and Zhuang, 2007) and Spring (March, April, May), Summer (June, July, August) and Fall (September, October, November) (Wang et al. 2023). Understanding changes seasonally is important, however, the approach used in this study provides further detail to fire management agencies and can be used to understand when resources may be challenged and where and when to prepare for additional personnel or equipment needs. The challenging 2023 fire season in British Columbia was exacerbated by heatwaves and record-breaking warm and dry temperatures across May through September (Government of British Columbia, 2024).

Hourly

The largest significant changes were detected during the third period (1200h-1700h) across all six BEC zones in this study. This suggests the magnitude of changes caused by climate change is greatest during the afternoon hours for the zones and months analyzed. However, the zones differed with the BWBS and IDF having the second highest magnitude in the second period (0600-1100), whereas the MS and SBS had the second highest magnitude in the fourth period (1800h-2300h). These differences show how climate change is affecting areas across British Columbia differently. The implications may result in fires exhibiting greater growth during the peak burn period across BWBS and IDF due to antecedent warming of fuels earlier in the day. In the MS and SBS, the peak burn period could extend later into the evening. The results could be applied regionally to inform and schedule suppression resources during periods where they are likely to make the greatest impact.

The understanding that fire behaviour reduces overnight has been challenged in recent years (Luo et al. 2024). Following reports from wildland personnel on observations of overnight fire spread, Chiodi et al. (2021) conducted a study that found prominent increases in overnight vapor pressure deficits (VPD), driven by increased temperature and decreased vapour pressure where the observed overnight VPD exceeded climate change model predictions. The change in nighttime fire activity has been outpacing daytime fire activity when analyzed through MODIS observations across the conterminous United States (Freeborn et al., 2022). Luo et al. (2024) also found an increase in fire behaviour associated with overnight burning attributed to drought conditions allowing fires to burn over a greater period and result in larger fire sizes. This study showed spread event thresholds were more likely to be exceeded in the later dataset (2006-2021) compared to the past conditions (1990-2005). A study in India reviewing hourly weather data has also shown warming trends during night and early mornings and an overall increase in warming hours leading to increased duration of heatwaves (Rohini et al., 2022).

Limitations & Future Research

This study relied on data from a network of weather stations maintained by the British Columbia Wildfire Service. Between the dates used in this study (1990-2021), many stations would have undergone routine maintenance and instrumentation changes which may have impacted the accuracy of observations. Instrument upgrades and maintenance are unlikely to have had a significant influence on the results. A second limitation of the dataset was the required cleaning for quality control which is important when working with a large dataset. It is possible that some true extremes were eliminated from the dataset and erroneously classified as outliers, however, the conservative approach to using a z-score of 4 makes it unlikely that the results were impacted. Finally, eight BEC zones were omitted from the analysis due to insufficient weather station data. Future research could examine the ERA5 reanalysis dataset which includes hourly climate data across the entire globe at a resolution of 0.25° x 0.25° from 1940 to the present (Hersbach et al. 2023). This dataset relies on the physical modeling of climate variables to fill gaps where observations are lacking to create a comprehensive dataset across the earth's surface.

A notable exclusion from this study was data from stations in the Ponderosa Pine BEC zone. The PP zone includes weather stations which had record breaking temperatures during the

2021 heat dome which heavily impacted British Columbia. Lytton, British Columbia recorded a temperature of 49.6°C on June 29, 2021 and broke records for the highest temperature ever recorded in Canada. Other stations in the PP BEC zone with record breaking highs include Kamloops which recorded 47.3°C, Kelowna with 45.7°C, and Osoyoos with 46.9°C. The maximum temperature value used in this study was 42°C. This shows the importance of expanding this assessment across all BEC zones in British Columbia. This study showed significant warming trends across the province, but the situation may be more severe in zones which were unable to be assessed through station data alone.

Variables not included in this study include hourly rainfall, the Duff Moisture Code (DMC), Drought Code (DC), and Build-up Index (BUI). Hourly rainfall is accounted for through calculations of the FFMC, ISI, and FWI so it was indirectly assessed through focusing on those variables. As a stand-alone variable for analysis at the hourly scale in this study it was omitted due to the spatial variation in weather systems bringing precipitation. The DC, DMC, and BUI are not significantly associated with spread events (Wang et al. 2023). Drought is a critical fire weather element associated with extreme fire behaviour, especially when paired with strong, unstable winds and low relative humidity (Werth et al., 2016); however, droughts are a consequence of weather patterns occurring over relatively long durations which would be inappropriate to study at the hourly scale used in this study.

Thresholds in this study were applied equally across all BEC zones. Wang et al. 2023 found spread events can occur under less severe conditions both as latitude increases and throughout coastal areas. Their study, which used Canadian ecozones as analysis units found differences across the spread event thresholds between coastal areas (Pacific Maritime), interior British Columbia (Montane Cordillera), and Northern British Columbia (Boreal Ecozones). For all three spread event indices (FFMC, ISI, and FWI), the greatest values were needed in the Montane Cordillera zone and included an FFMC $\geq$ 92, ISI $\geq$ 11, and FWI $\geq$ 26. The Pacific maritime ecozone exceeded spread event thresholds at FFMC of 90-90.9, ISI 5-5.9, and FWI range of 9-13.9. The boreal regions had FFMC of 88-88.9, ISI range of 6-9.9, and FWI of 16-23.9. There is a large variation in these spread event thresholds applied to Canadian Ecozones. Future work could consider an approach similar to the Wang et al. (2023) Canada-wide study to better inform spread event thresholds by BEC zone throughout British Columbia. A study conducted in Alberta found an ISI ≥ 9 to be an important factor in late spring fires (Tymstra et al., 2021). Understanding regionally specific thresholds can help fire managers make more informed decisions. When assessing all three indices (FFMC, ISI, and FWI) the single best indicator of spread events appears to be FFMC (Wang et al. 2023). Results from this study are valuable to show the trends and magnitude of change in the variables analyzed.

CHAPTER 5 – CONCLUSION

This study examined differences in weather at an hourly scale across British Columbia and confirmed that climate change has already led to significant warming between two historical periods (1990-2005 and 2006-2021) with subsequent spread event thresholds being more likely to be exceeded. Geographically, the BEC zones with the most significant findings included the SBS, IDF and ICH. The varying results between zones highlights the nuanced effect of climate change and the regional implications with differences in daily impacts, magnitude and rate of change. The results can be used at a finer management scale to understand what climate change impacts have already been identified and inform future management decisions. For example, these results could inform personnel and suppression equipment needs throughout a fire season by month and guide changes to the standard daily firefighting operational periods for greater safety and effectiveness in wildfire management. A changing climate is resulting in spread event thresholds being surpassed throughout more hours in a day, meaning the conventional understanding of peak burn will not be the only challenging operational period, and fires will be less likely to slow or stop spread overnight.

Compared to other climate-based studies, this research was unique in analyzing weather data at an hourly scale to understand how a changing climate may be impacting the fire environment through the diurnal cycle using BEC zones as analysis units. The comparison of these two sixteen-year periods provides an understanding of how climate change impacts are materializing across the province of British Columbia and can provide fire management agencies with information on how anticipated fire behaviour and growth may be impacted with the nuance of time and space taken into consideration. Future research could identify spread event thresholds for each unique BEC zone and use the gridded ERA-5 dataset to fill gaps in the BEC zones which were excluded from this study due to insufficient station observations. Similar studies could be expanded to other provinces and territories across Canada, using regionally appropriate analysis units.

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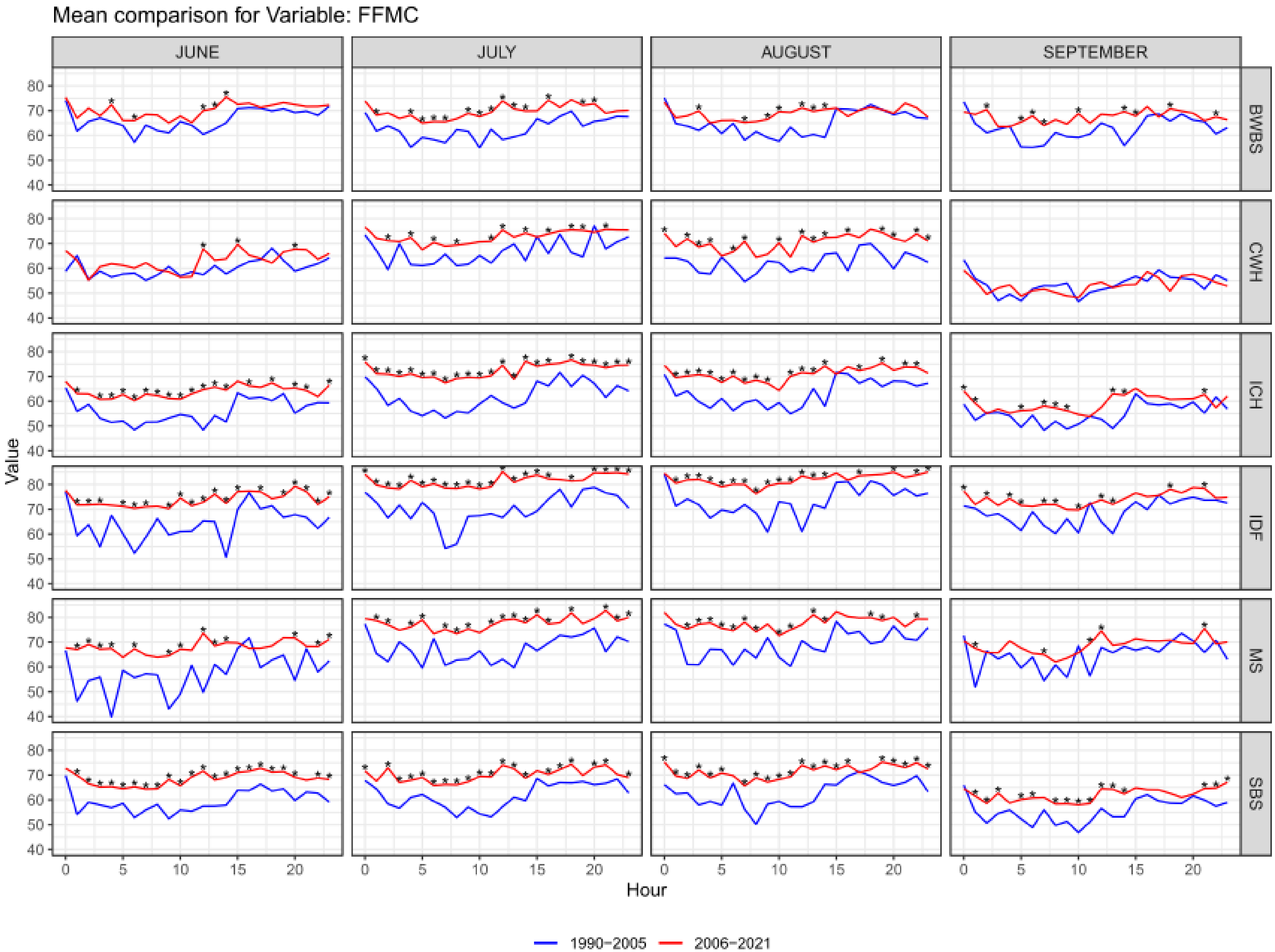
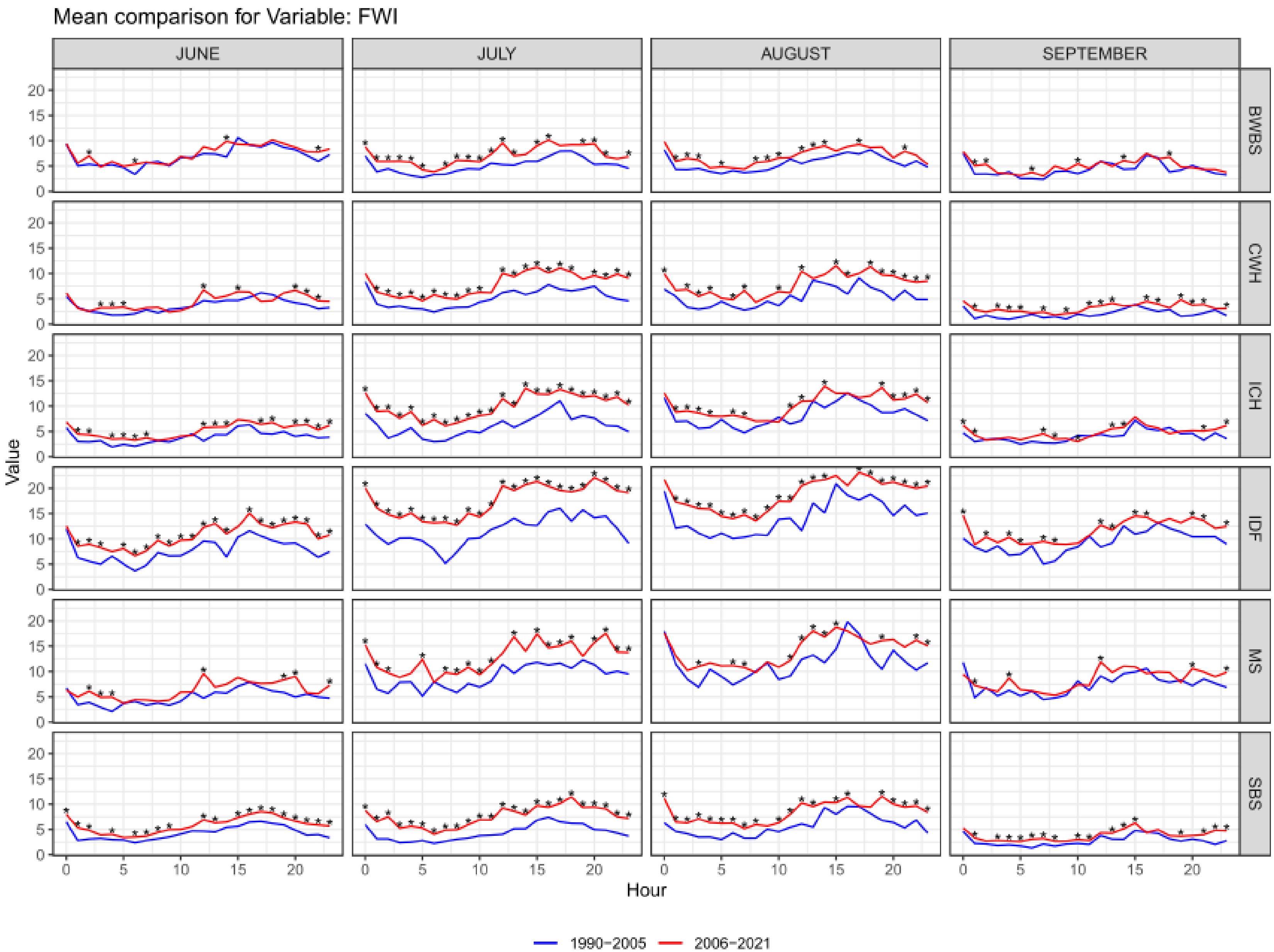
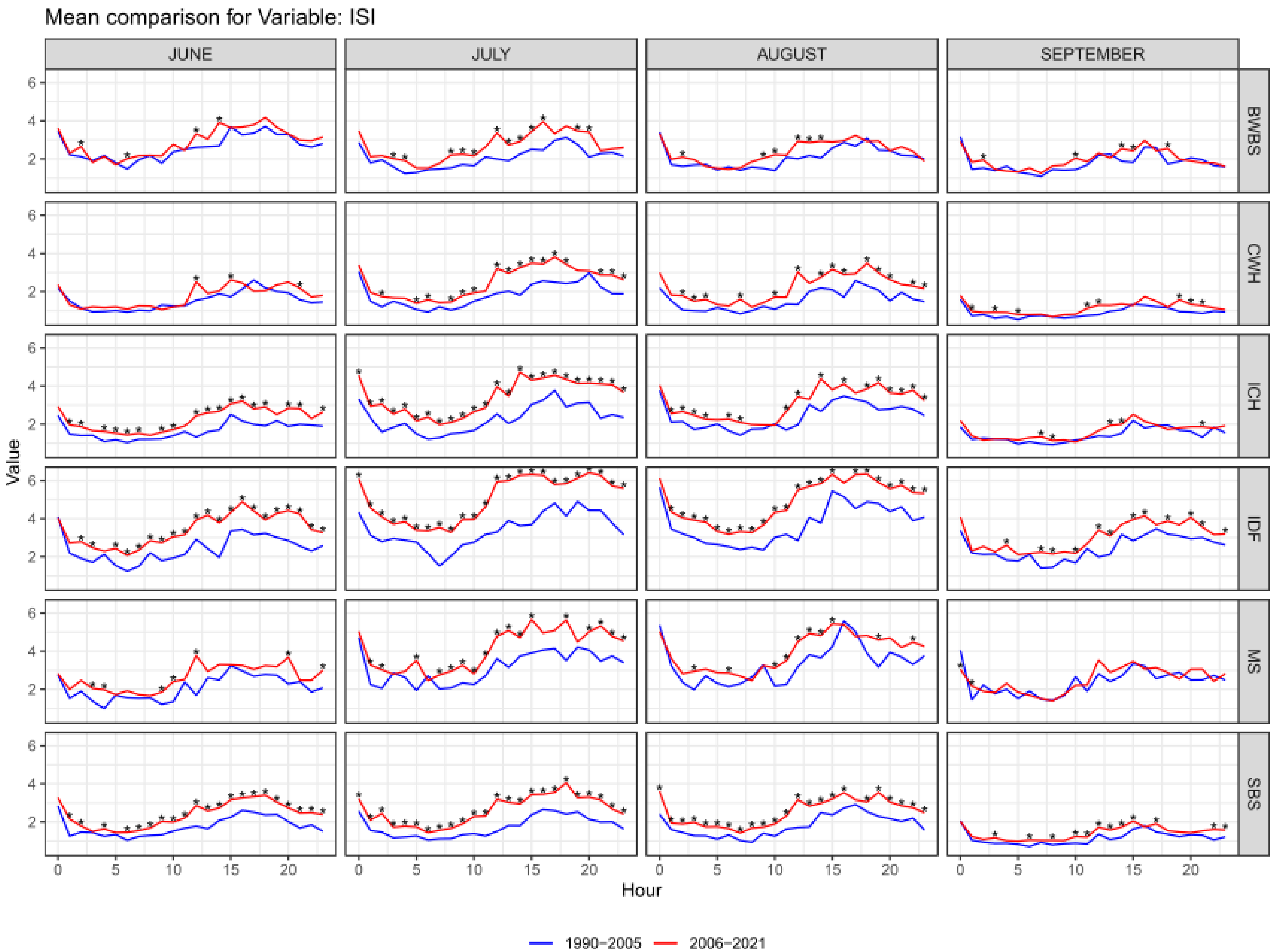
APPENDIX A – RESULTS OF MEAN, MEDIAN AND 95th PERCENTILE ANALYSIS – 1990-2005 COMPARED TO 2006-2021

The following figures visually represent the diurnal data curves for mean, median, and 95th percentile hourly values with significant results shown by an asterisk.

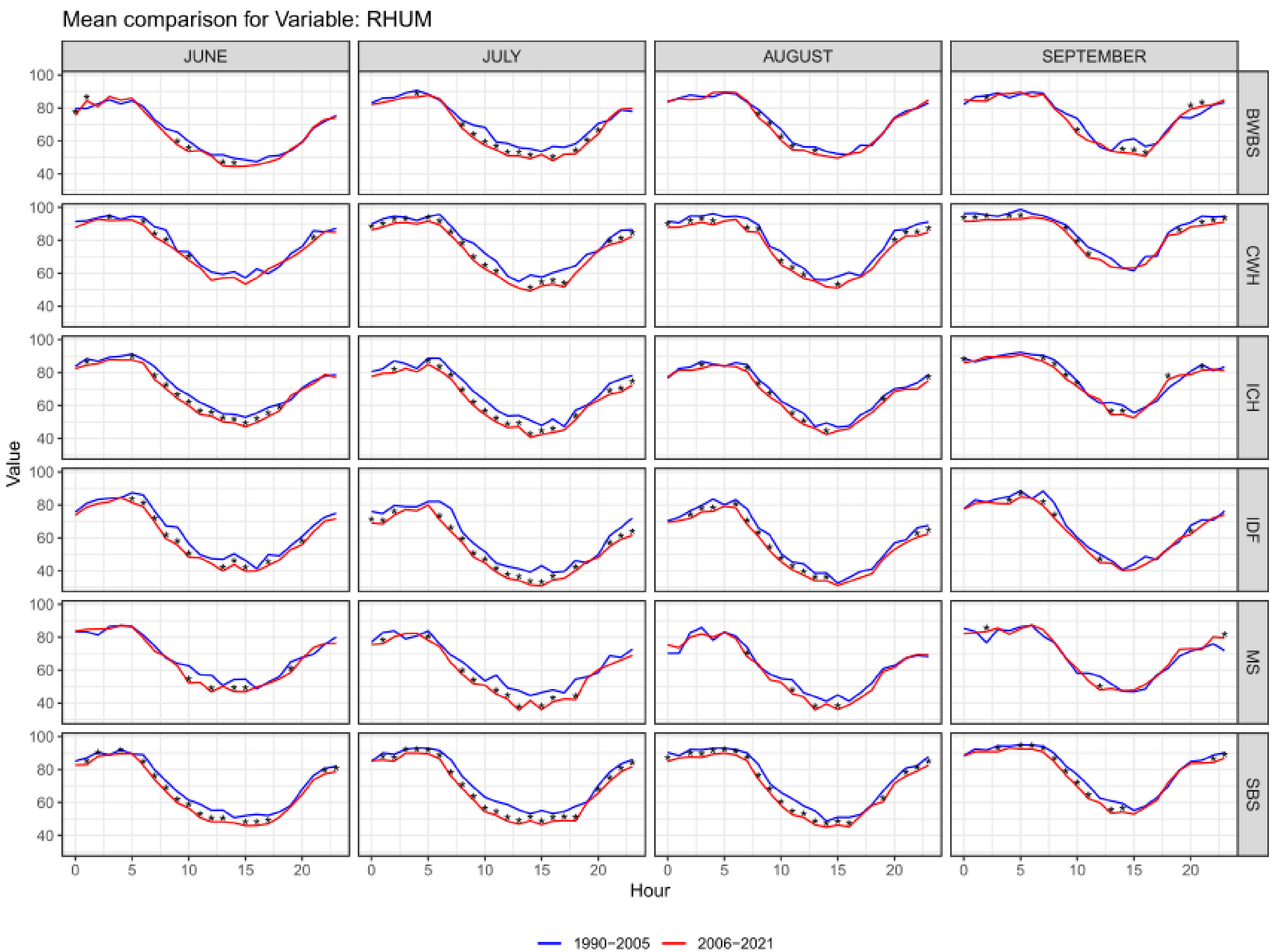


Mean comparison for Variable: FFMC
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021

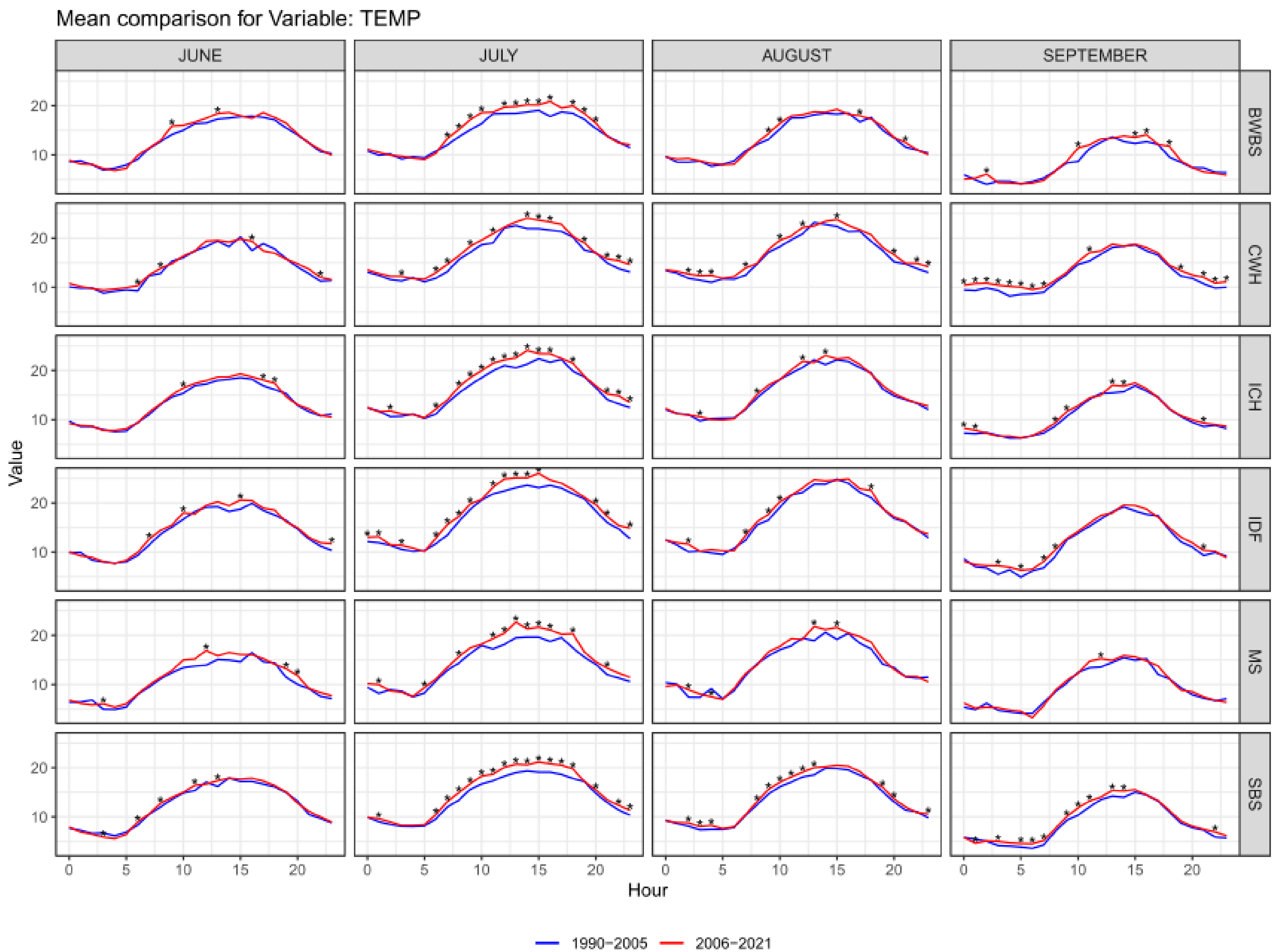

Mean comparison for Variable: FWI
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021



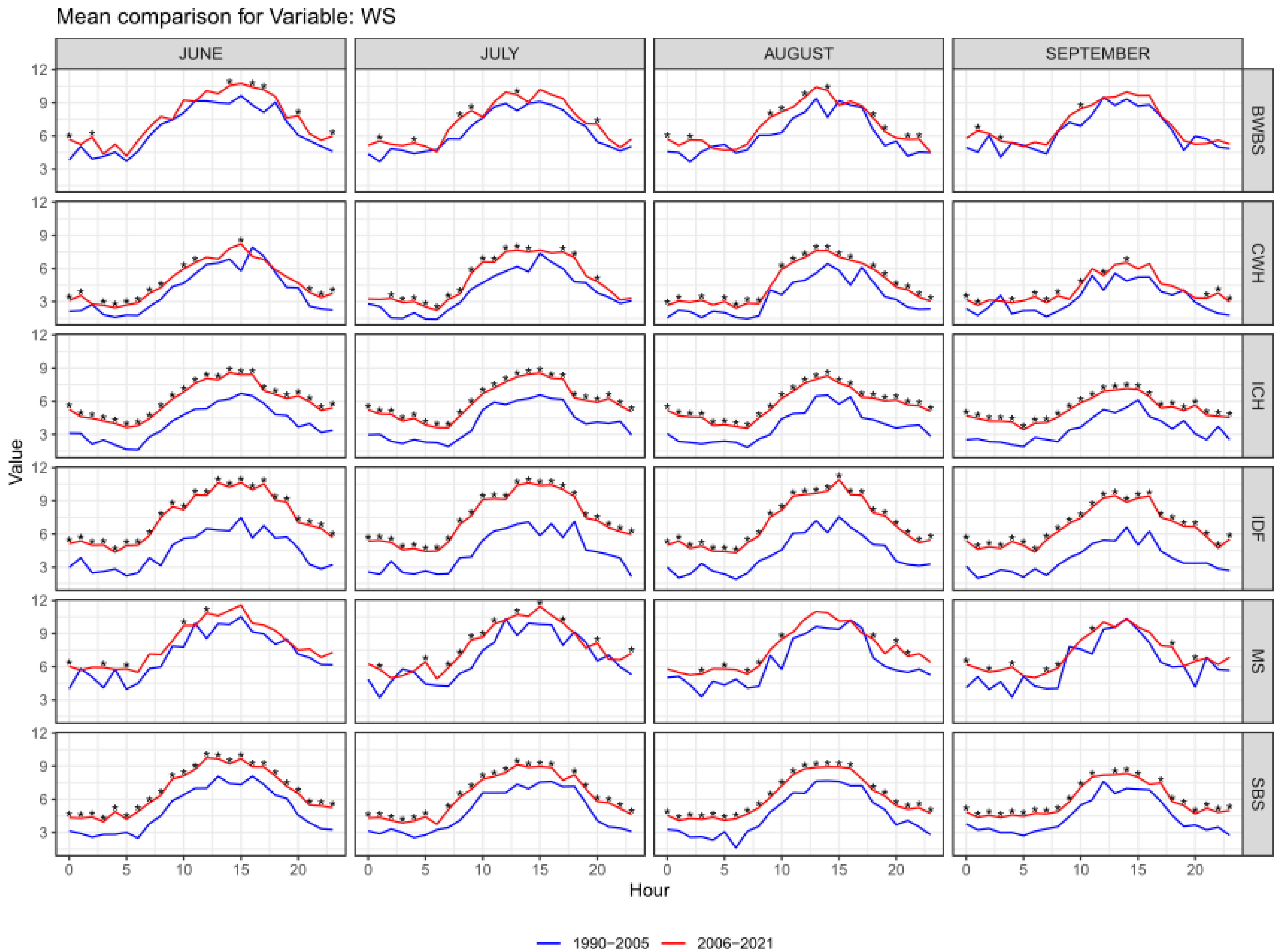
Mean comparison for Variable: ISI
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021

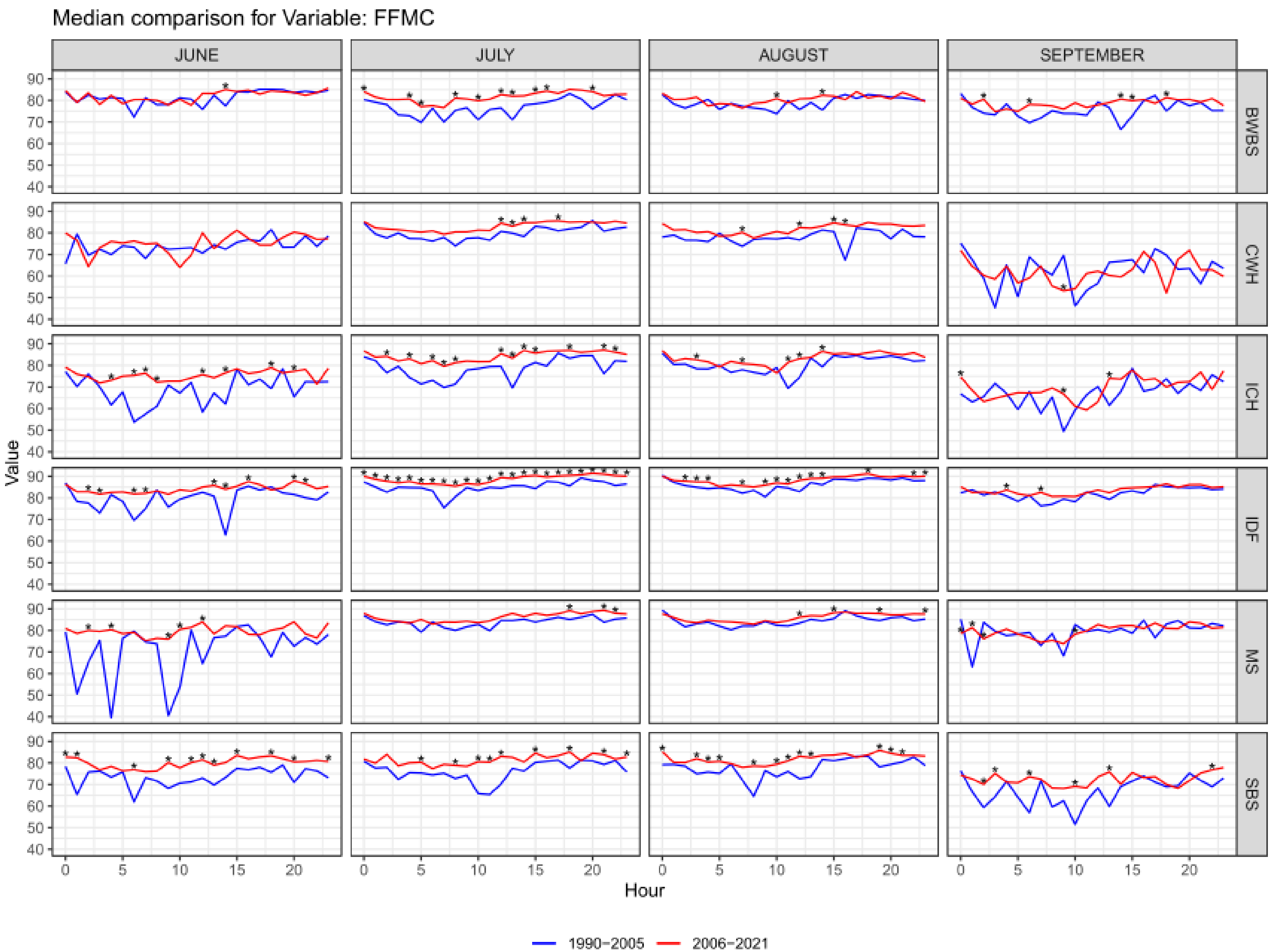


Mean comparison for Variable: RHUM
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021

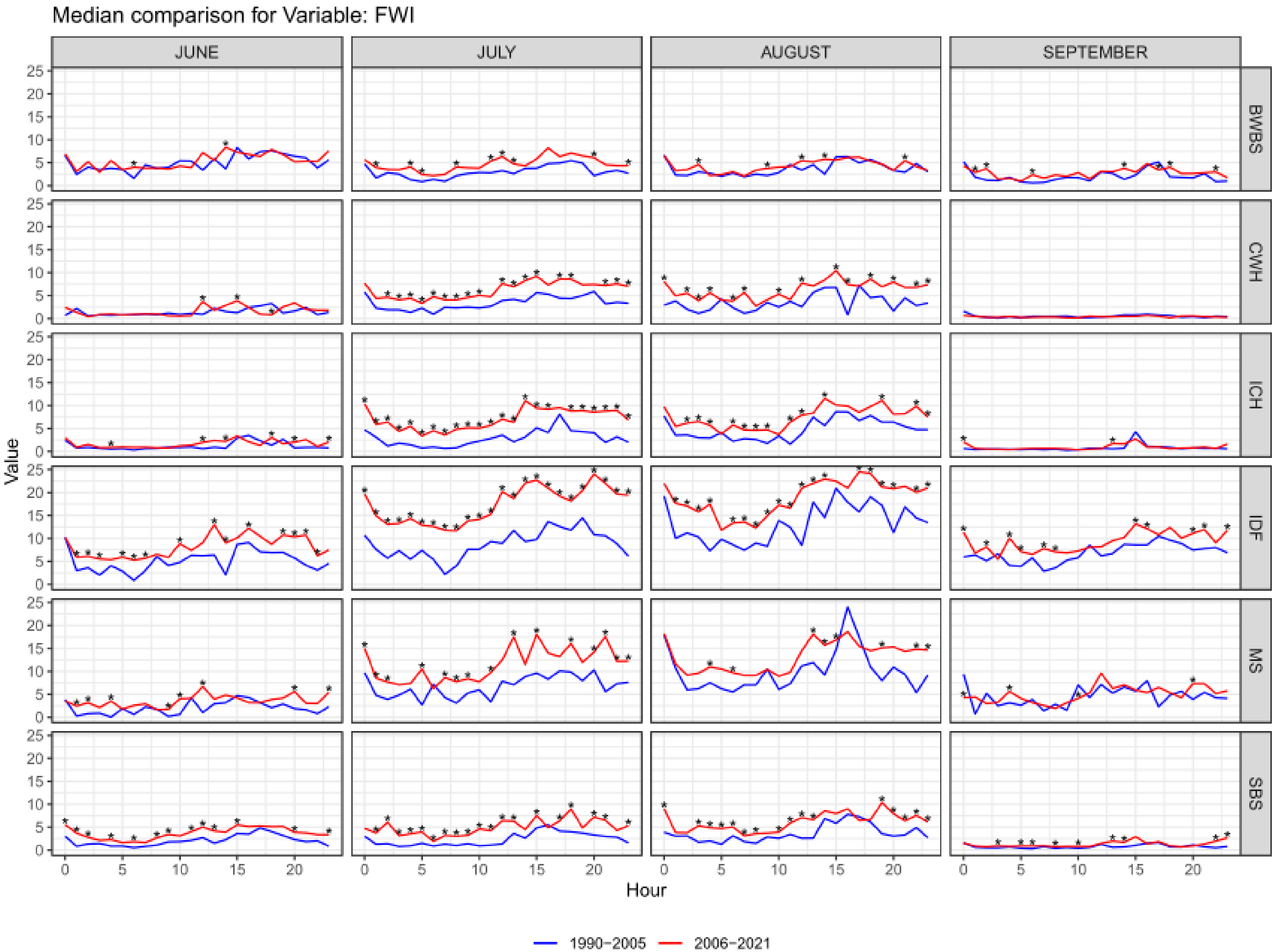


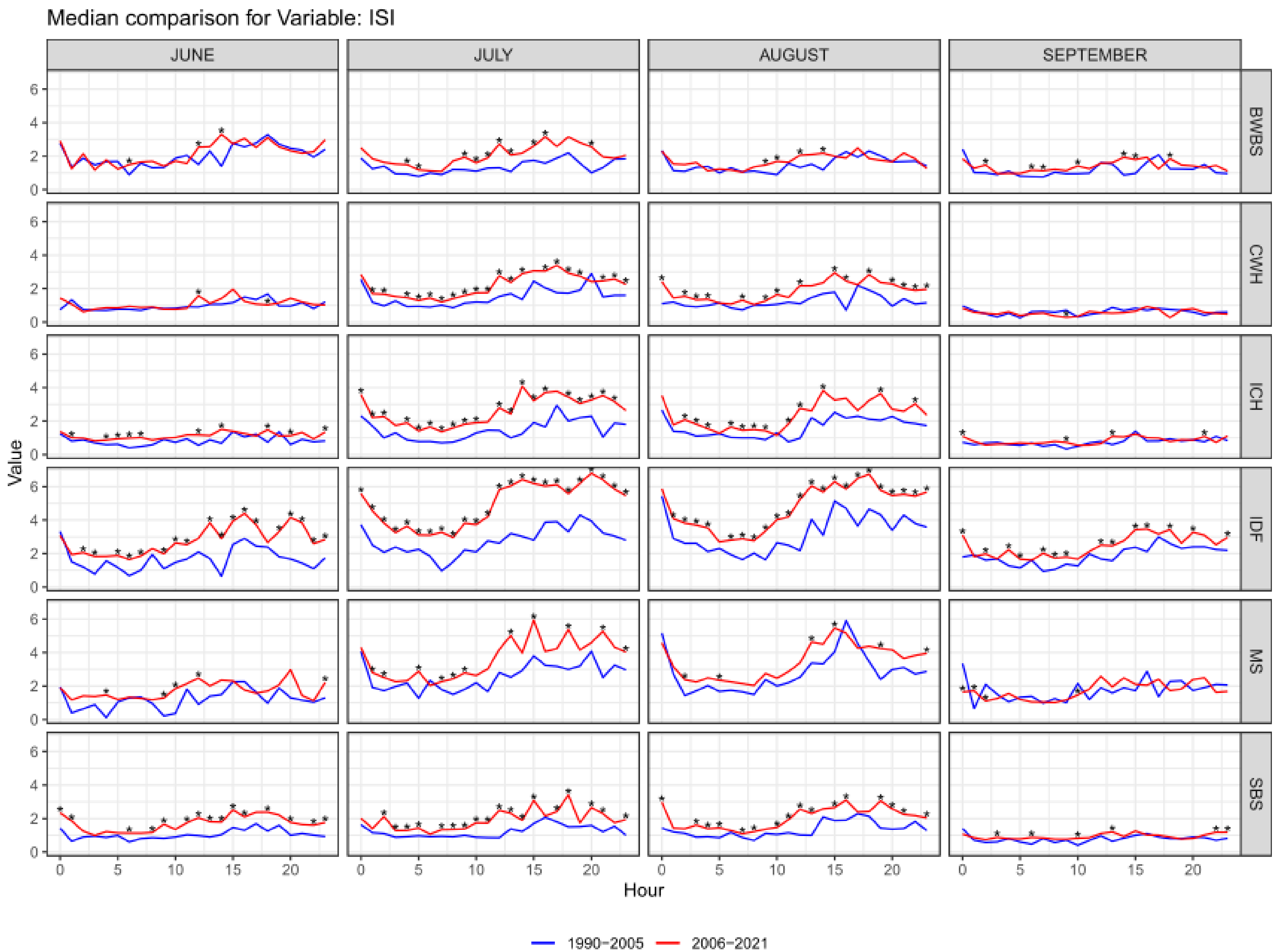
Mean comparison for Variable: TEMP
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021

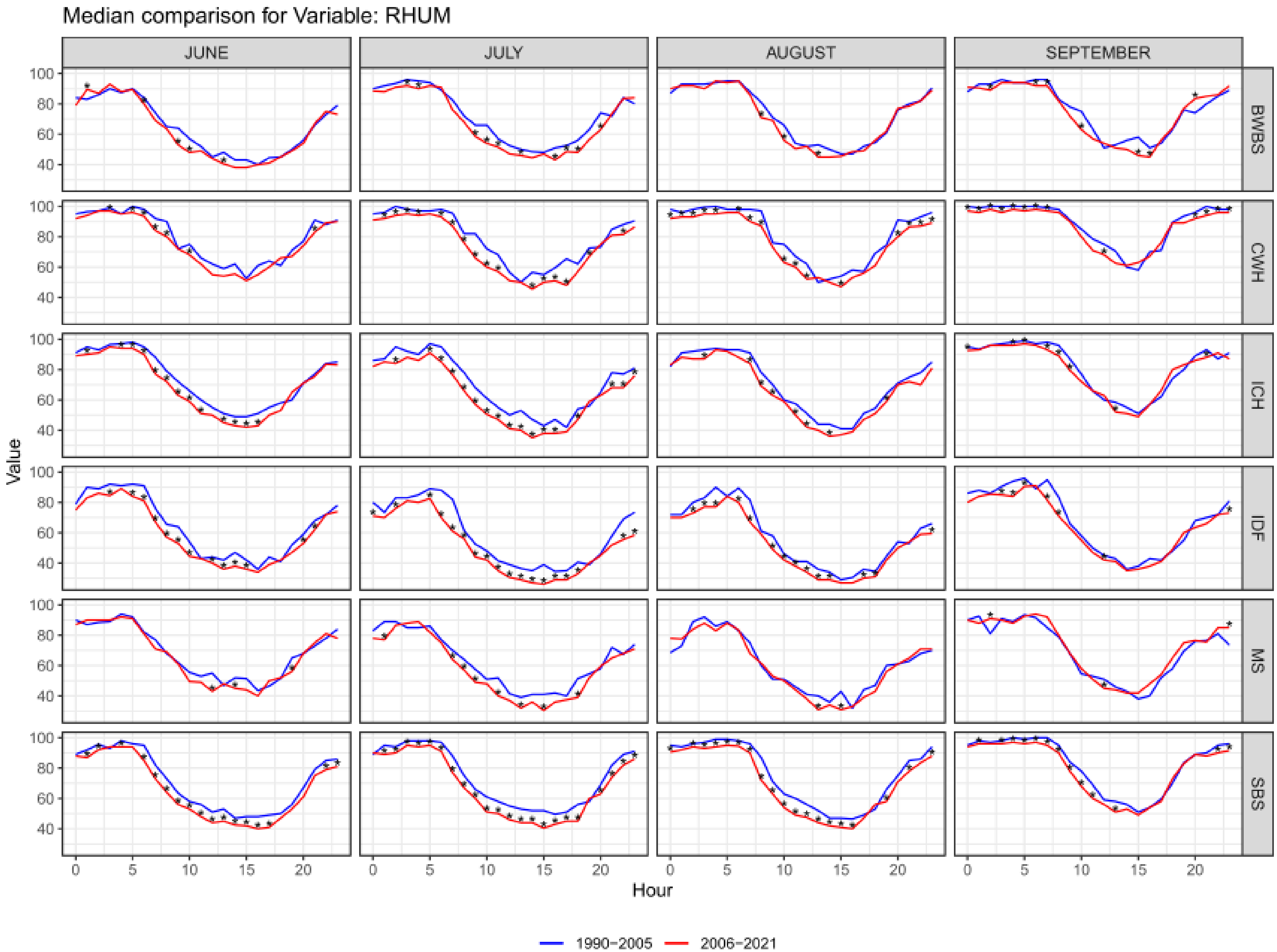

Mean comparison for Variable: WS
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021



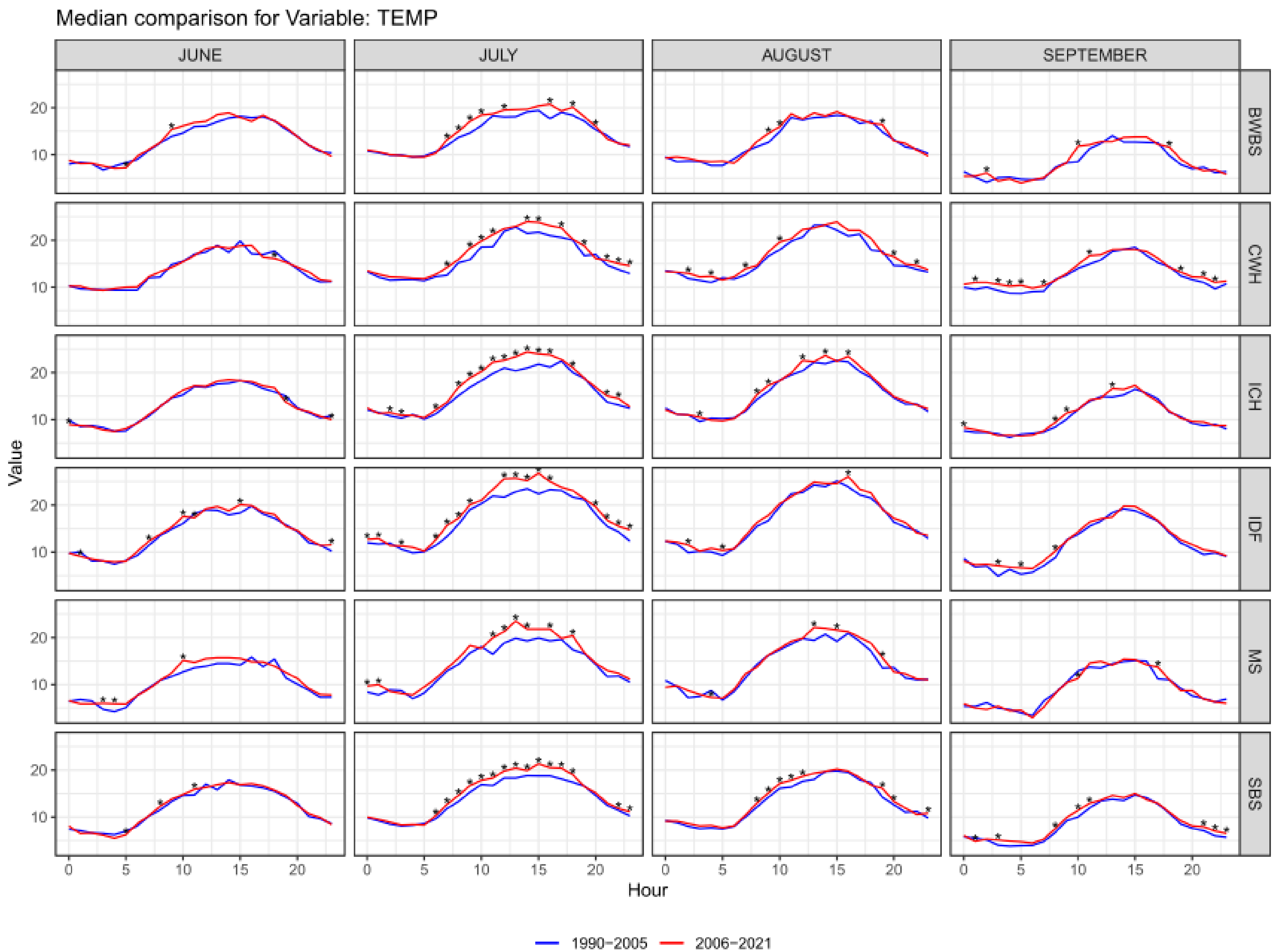
Median comparison for Variable: FFMC
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021

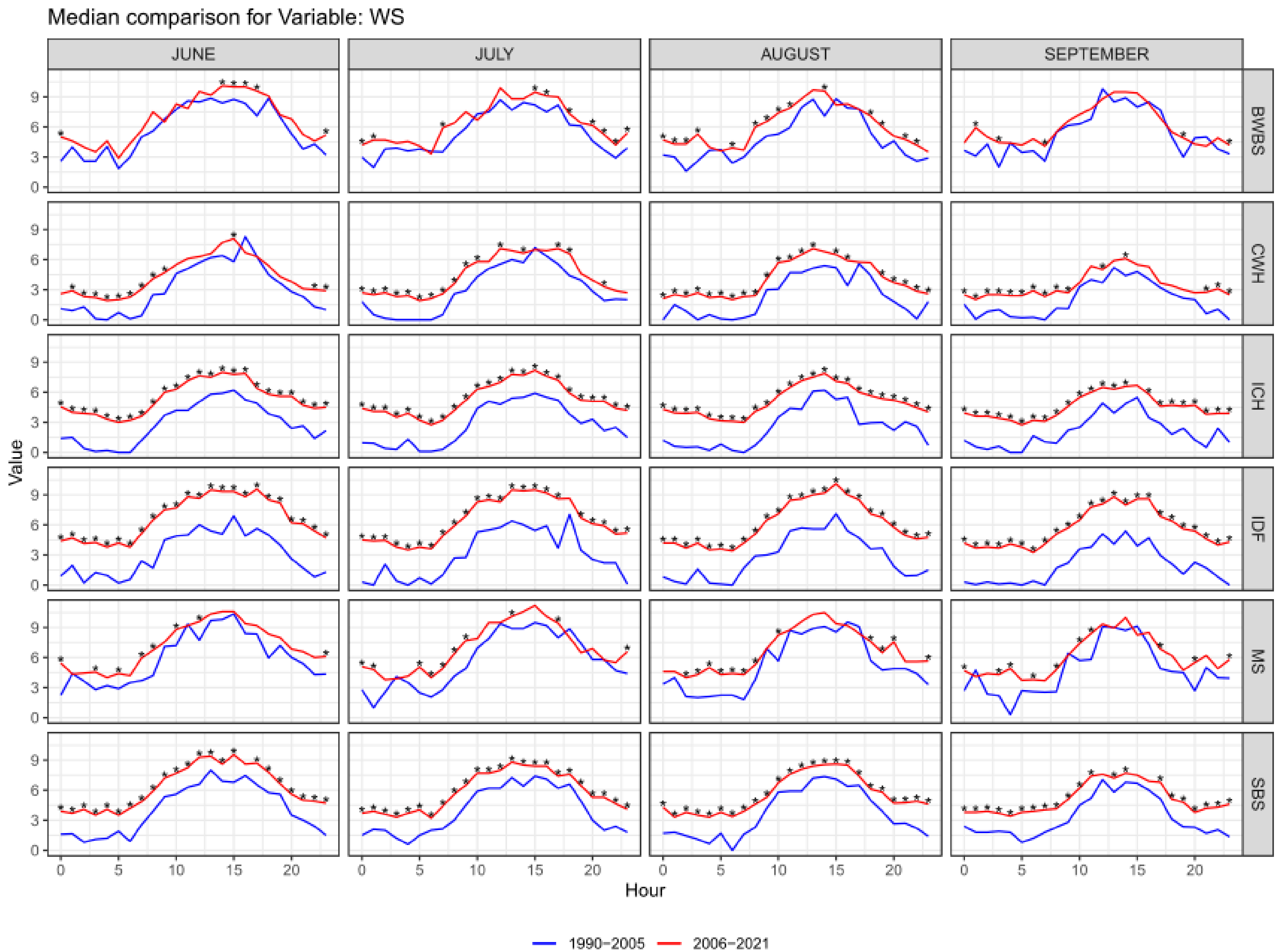

Median comparison for Variable: FWI
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021

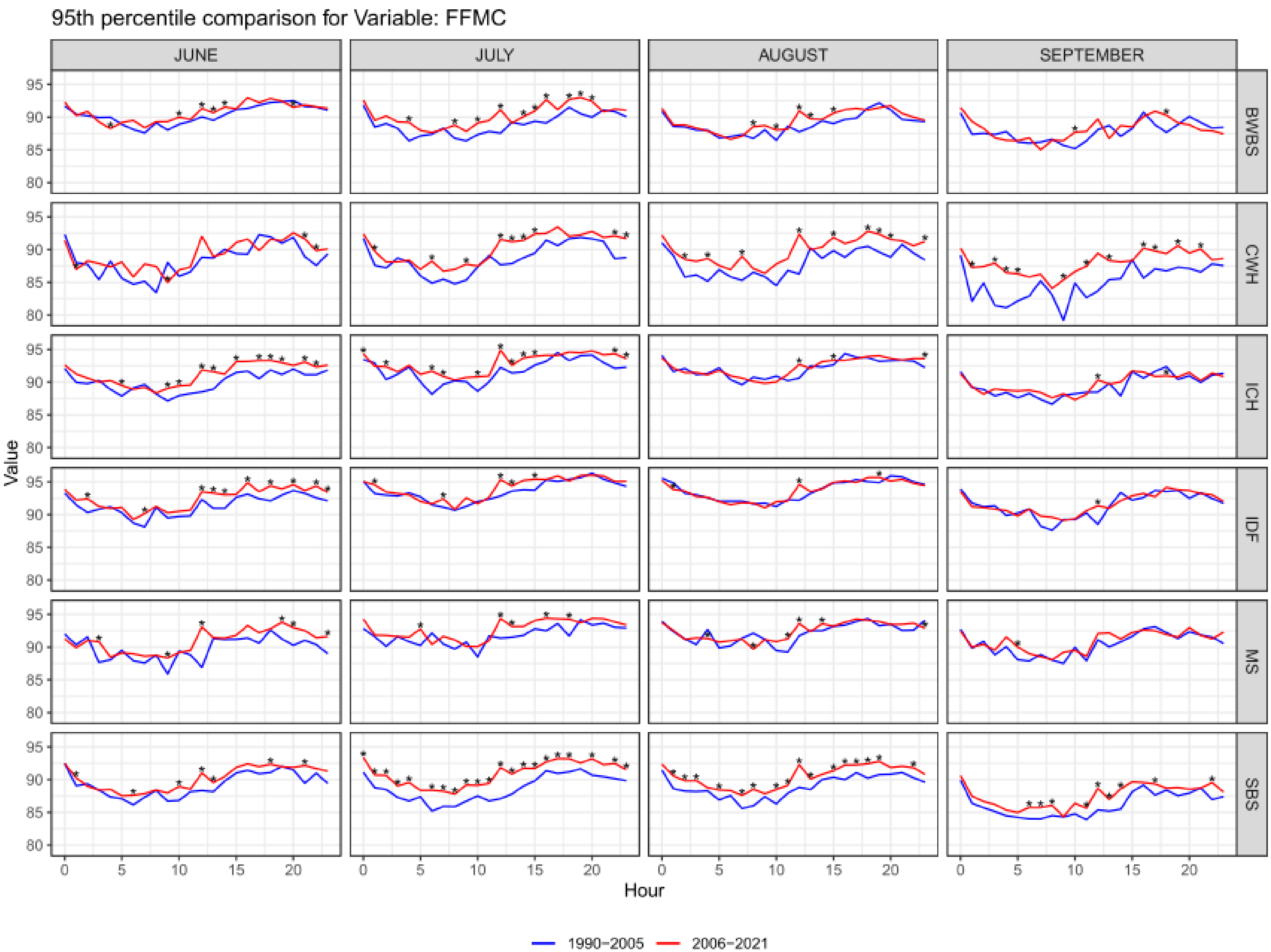

Median comparison for Variable: ISI
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021

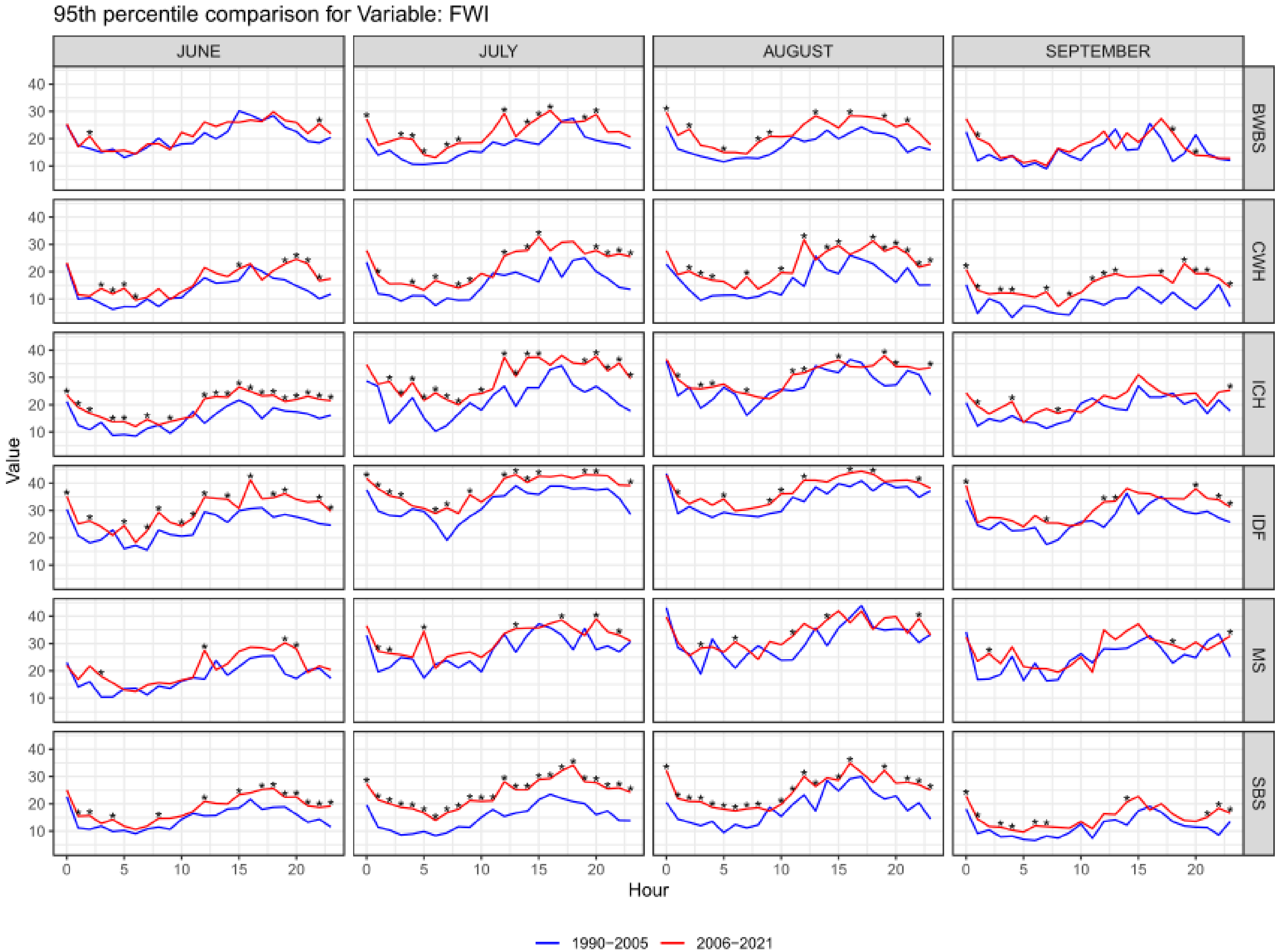


Median comparison for Variable: RHUM
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021

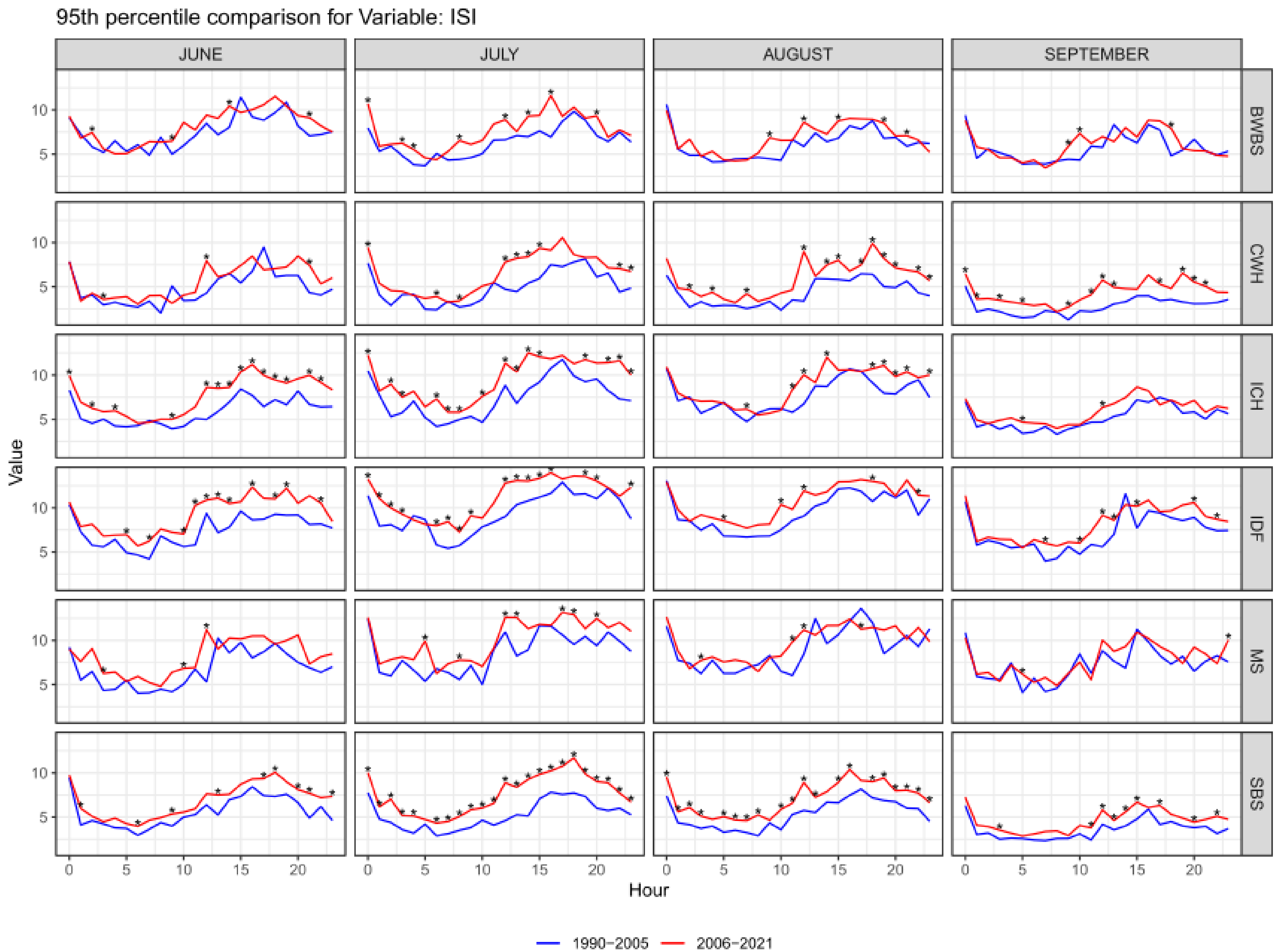

Median comparison for Variable: TEMP
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021

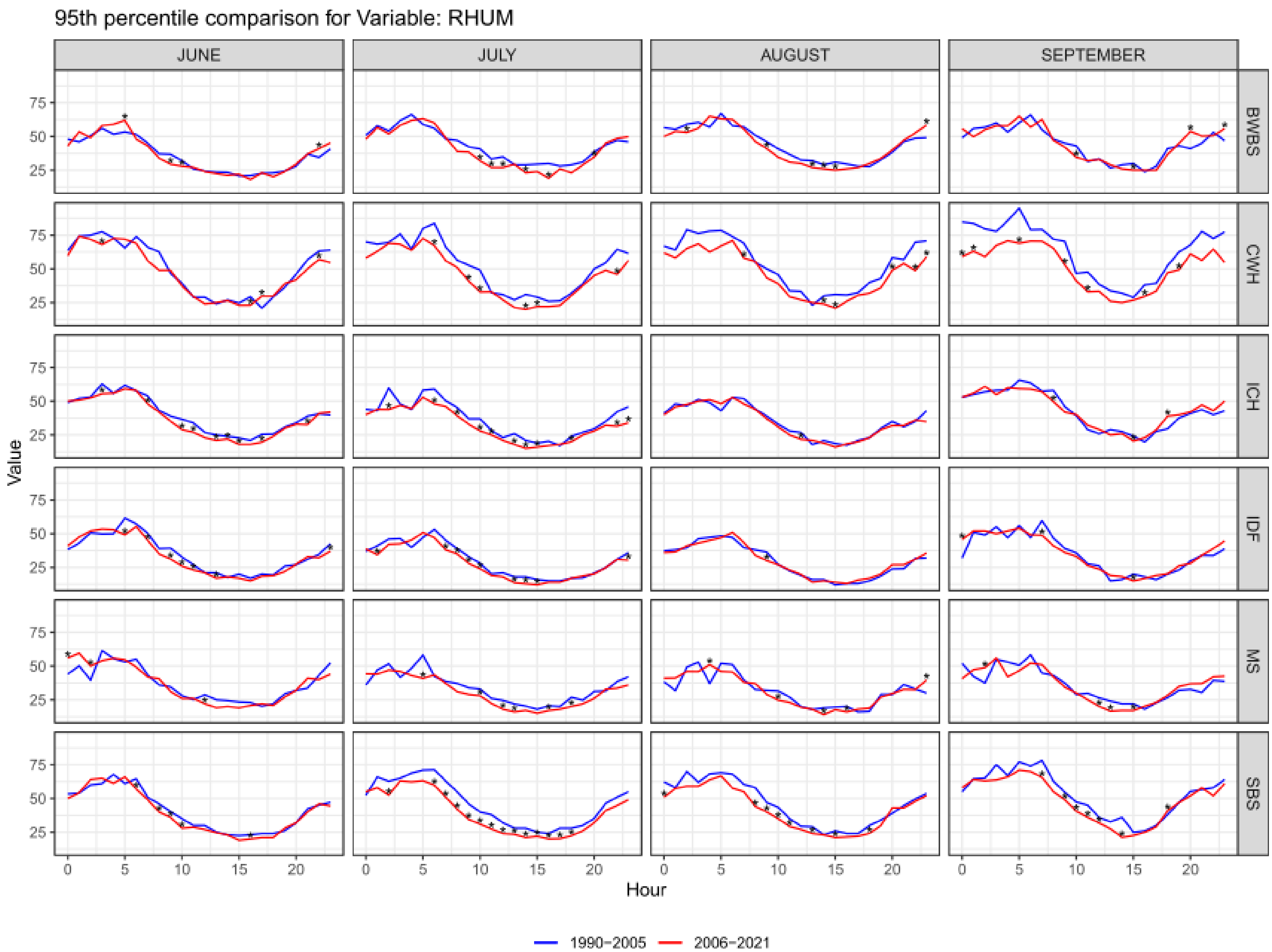

Median comparison for Variable: WS
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990−2005
2006−2021

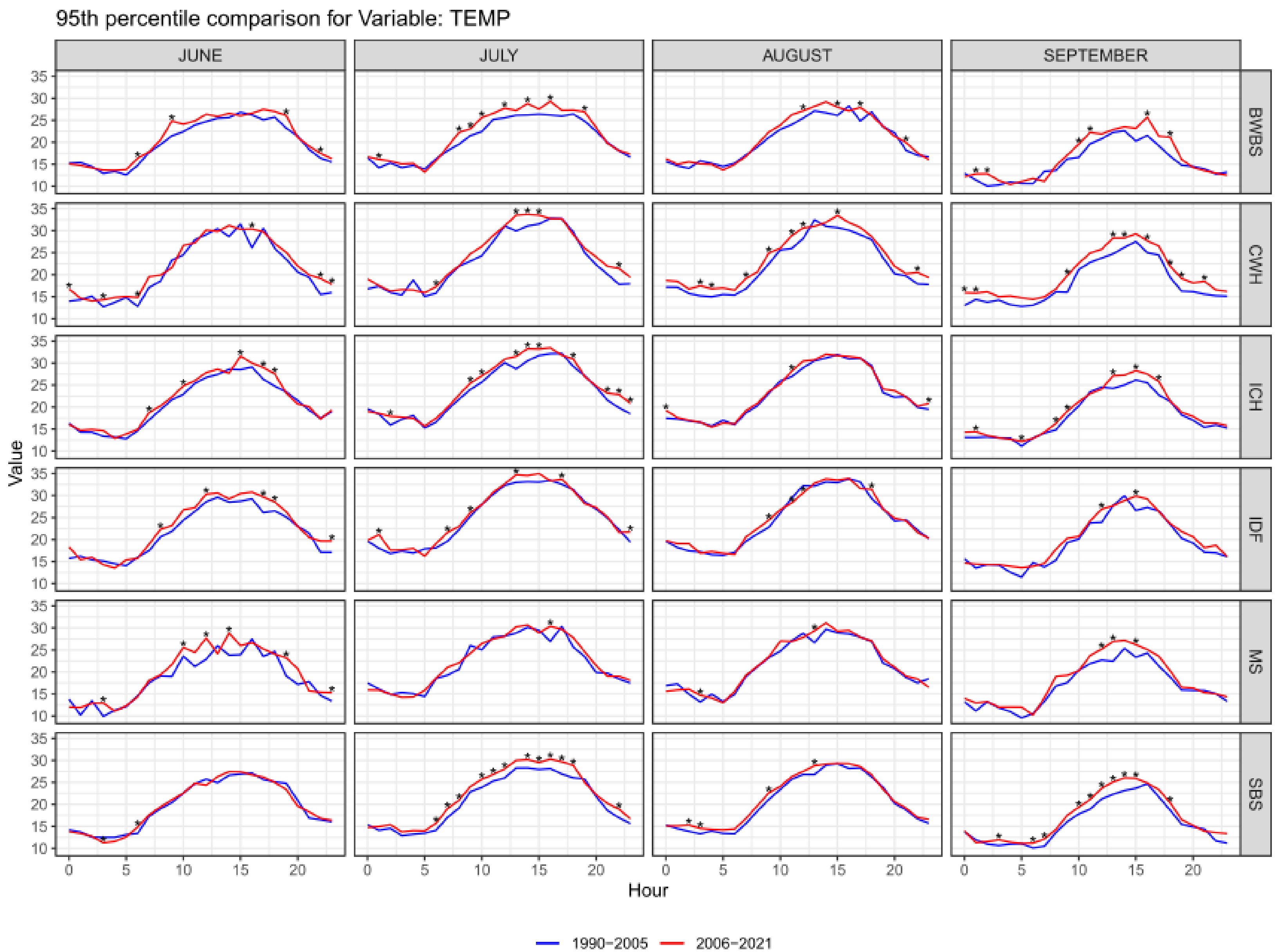

95th percentile comparison for Variable: FFMC
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990–2005
2006–2021



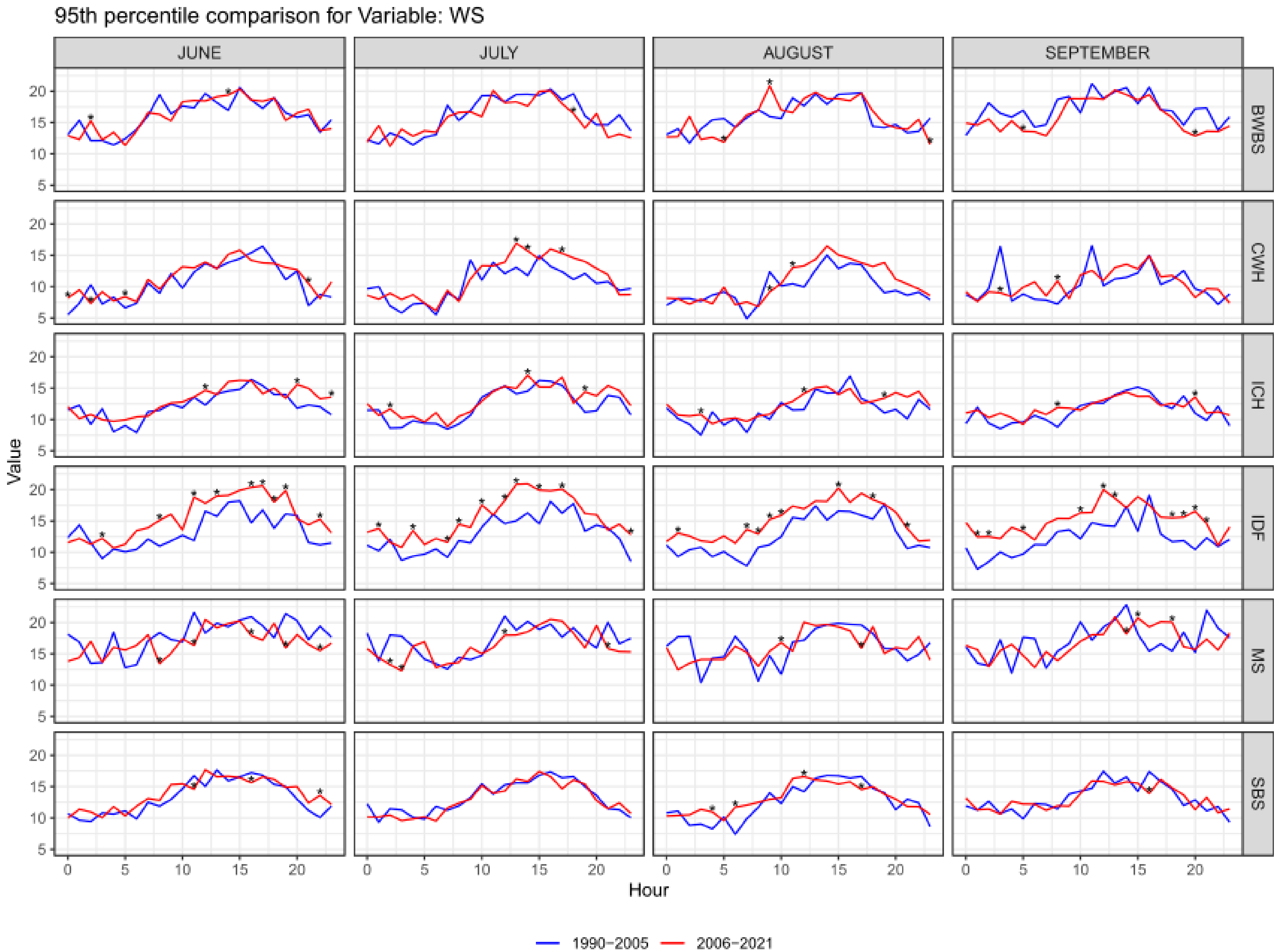
95th percentile comparison for Variable: FWI
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990–2005
2006–2021


95th percentile comparison for Variable: ISI
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021


95th percentile comparison for Variable: RHUM
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021

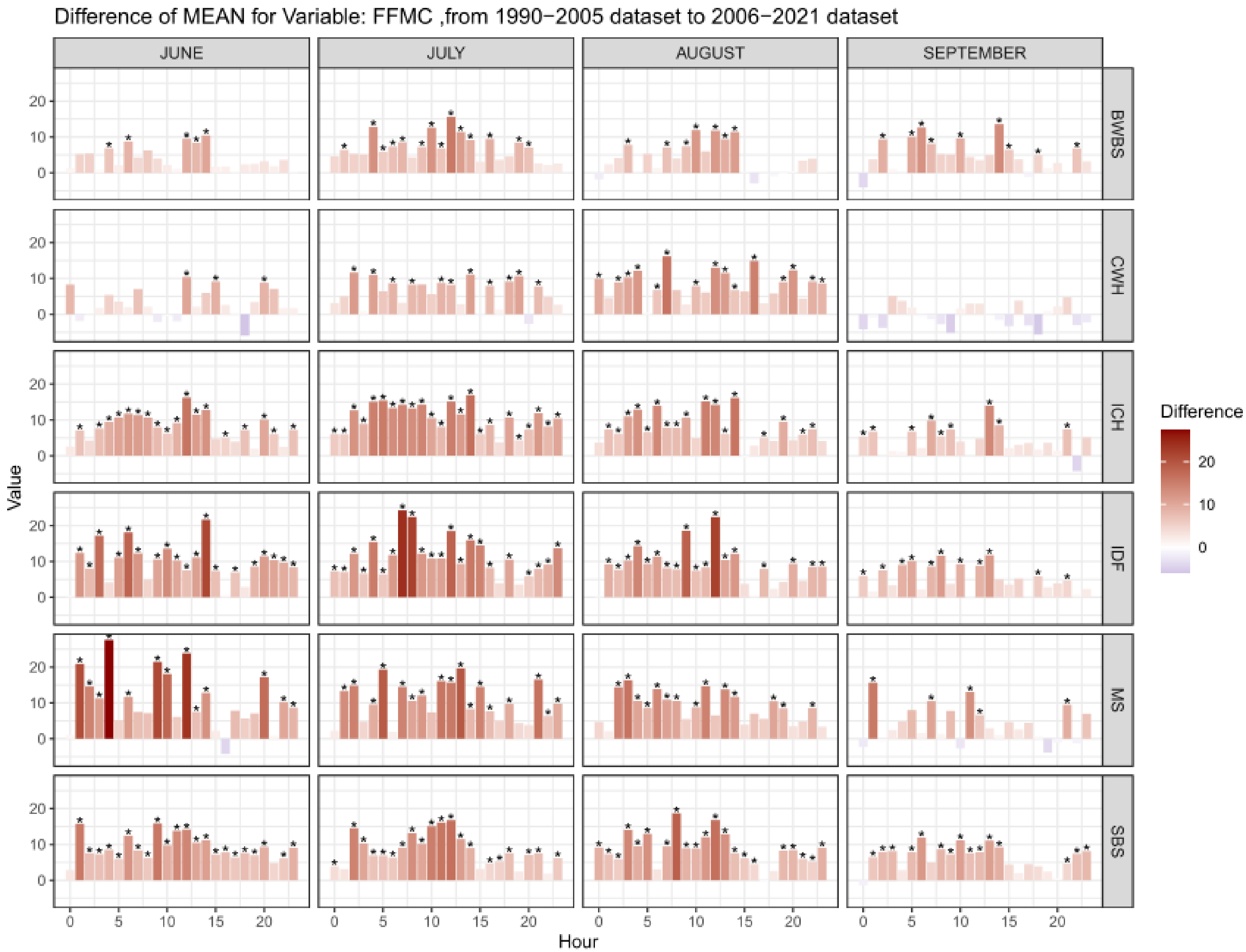


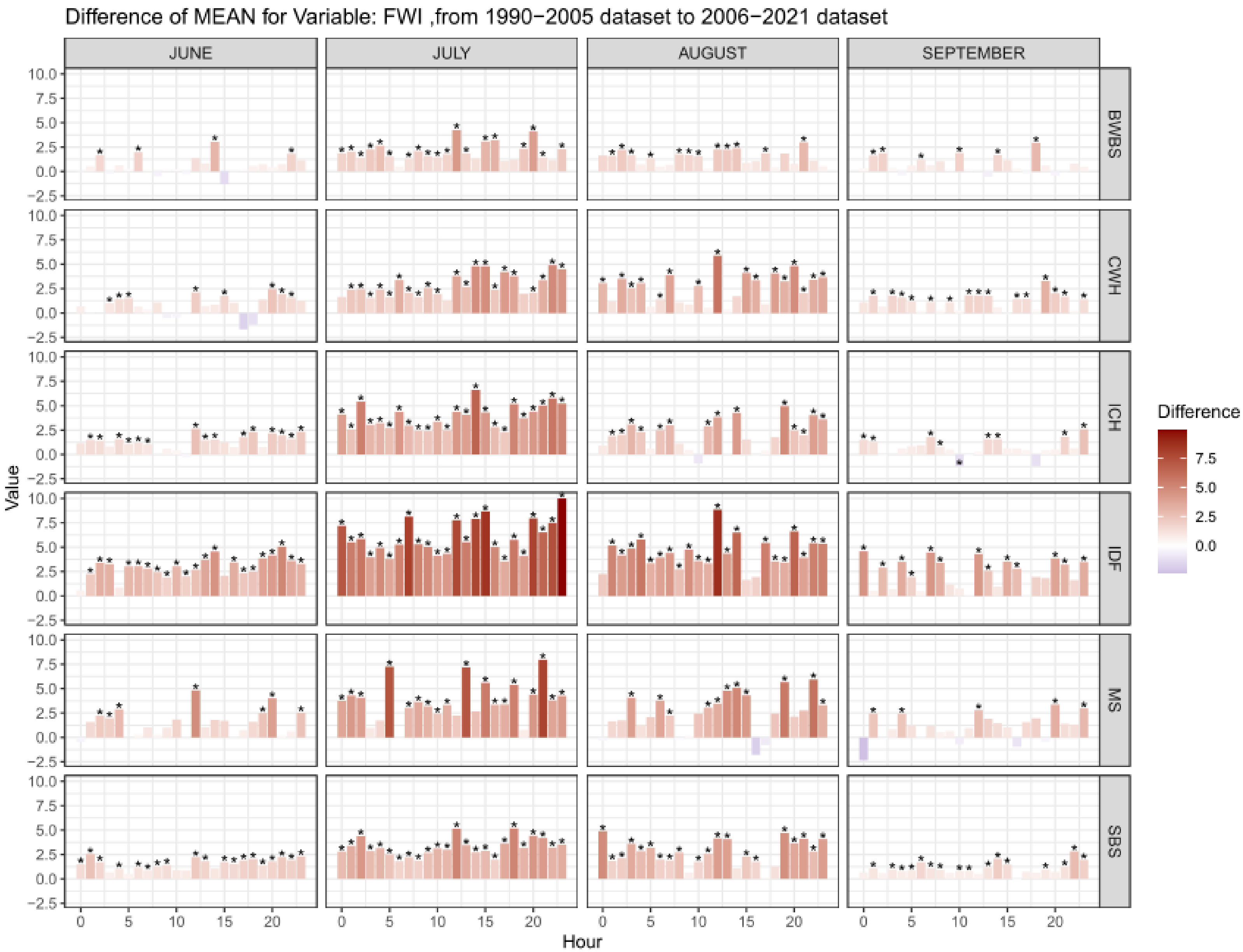
95th percentile comparison for Variable: TEMP
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021

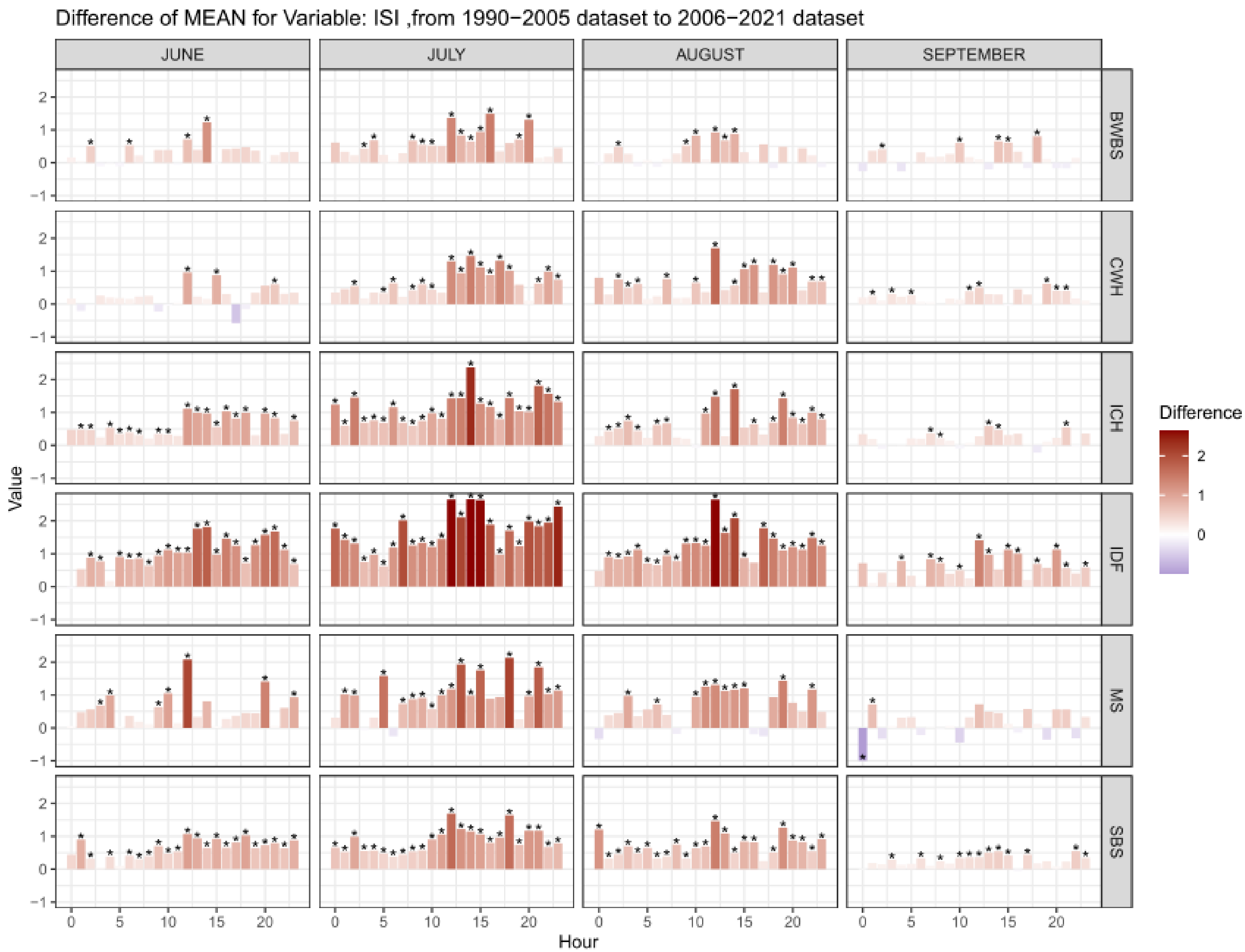

95th percentile comparison for Variable: WS
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
1990-2005
2006-2021

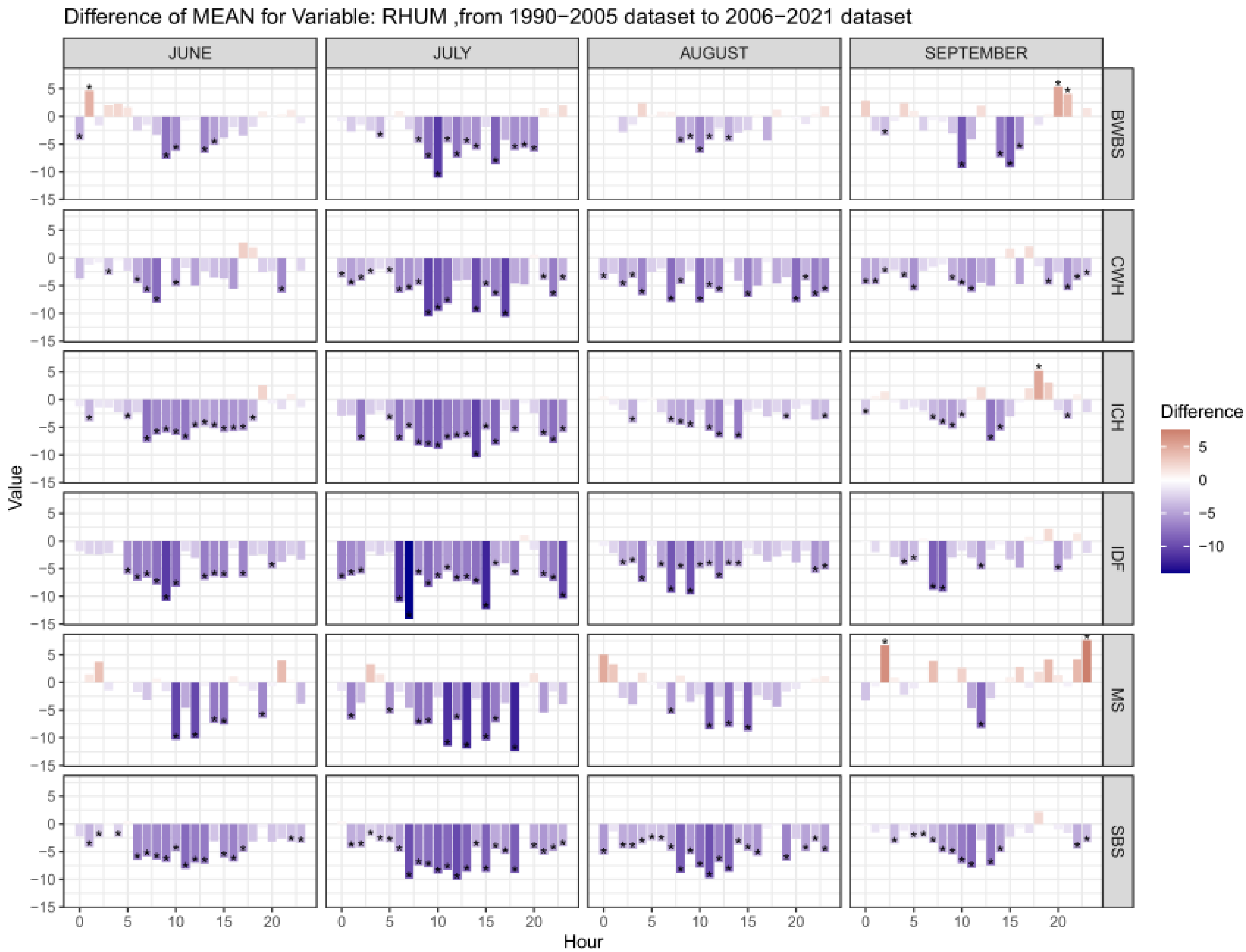
APPENDIX B – MAGNITUDE OF CHANGE IN RESULTS OF MEAN, MEDIAN AND 95th PERCENTILE ANALYSIS – 1990-2005 COMPARED TO 2006-2021

The following figures visually represent the change between the mean, median, and 95th percentile hourly values with significant results shown by an asterisk.

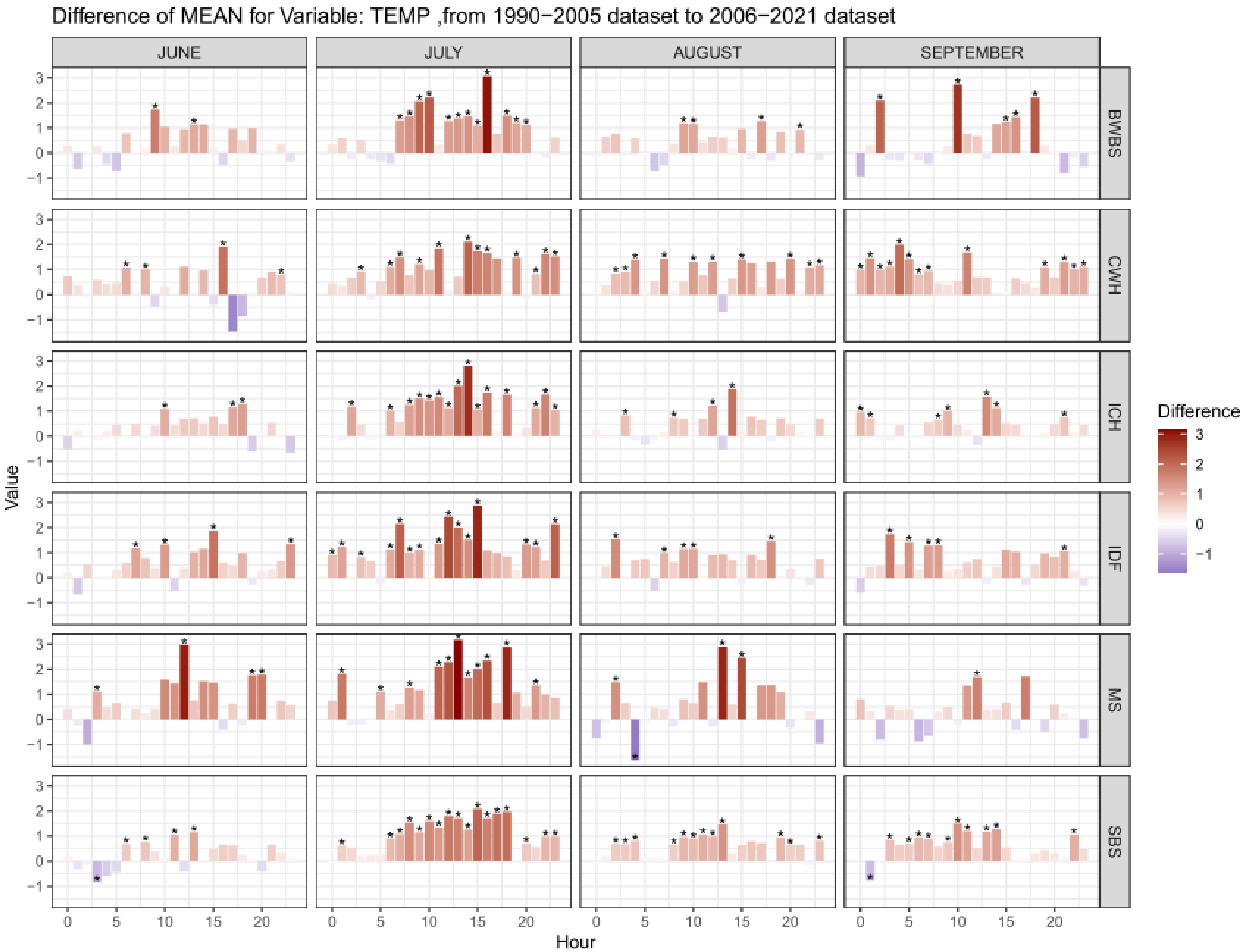

Difference of MEAN for Variable: FFMC ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
20
10
0

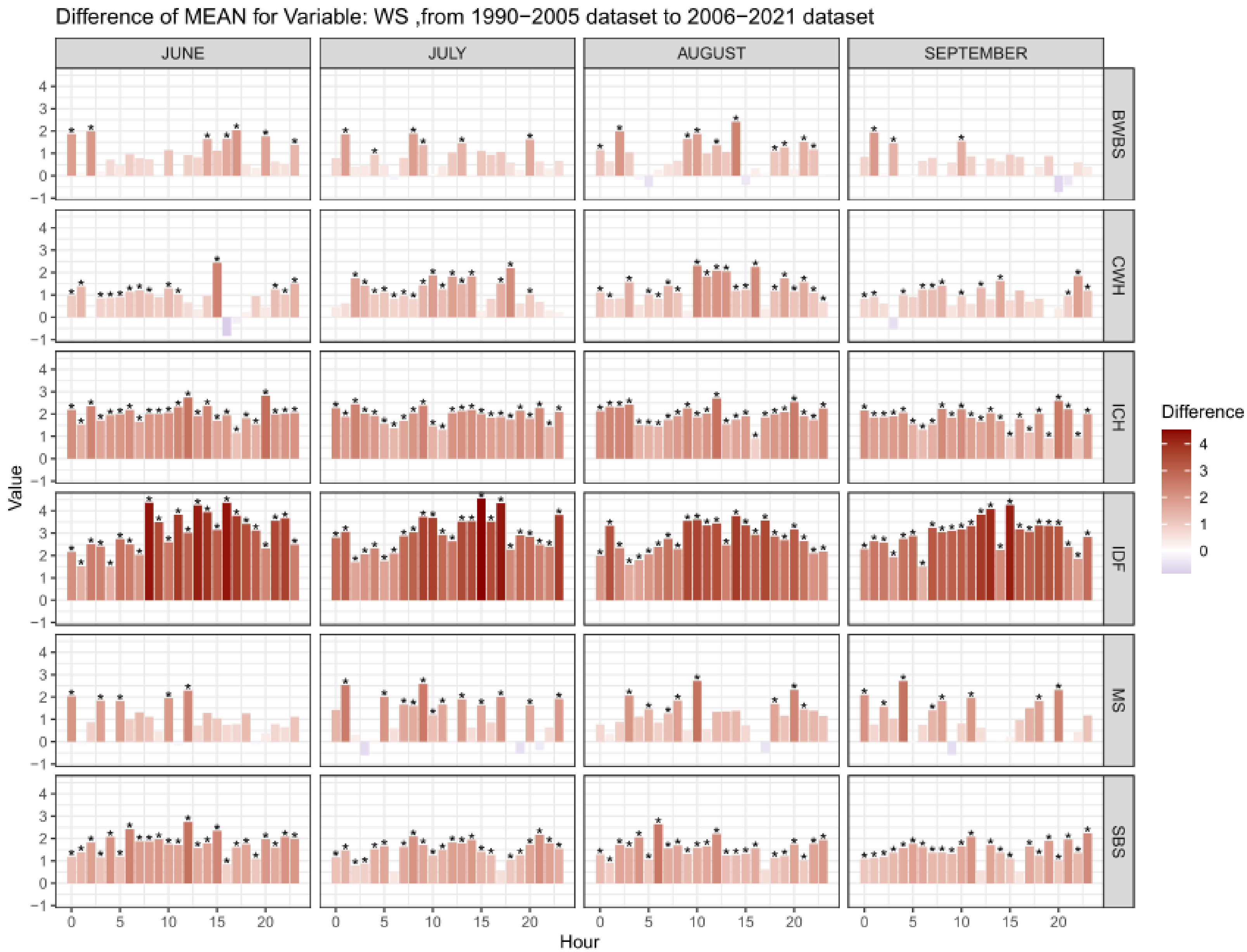

Difference of MEAN for Variable: FWI ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference


Difference of MEAN for Variable: ISI ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
2
1
0
−1
0
5
10
15
20

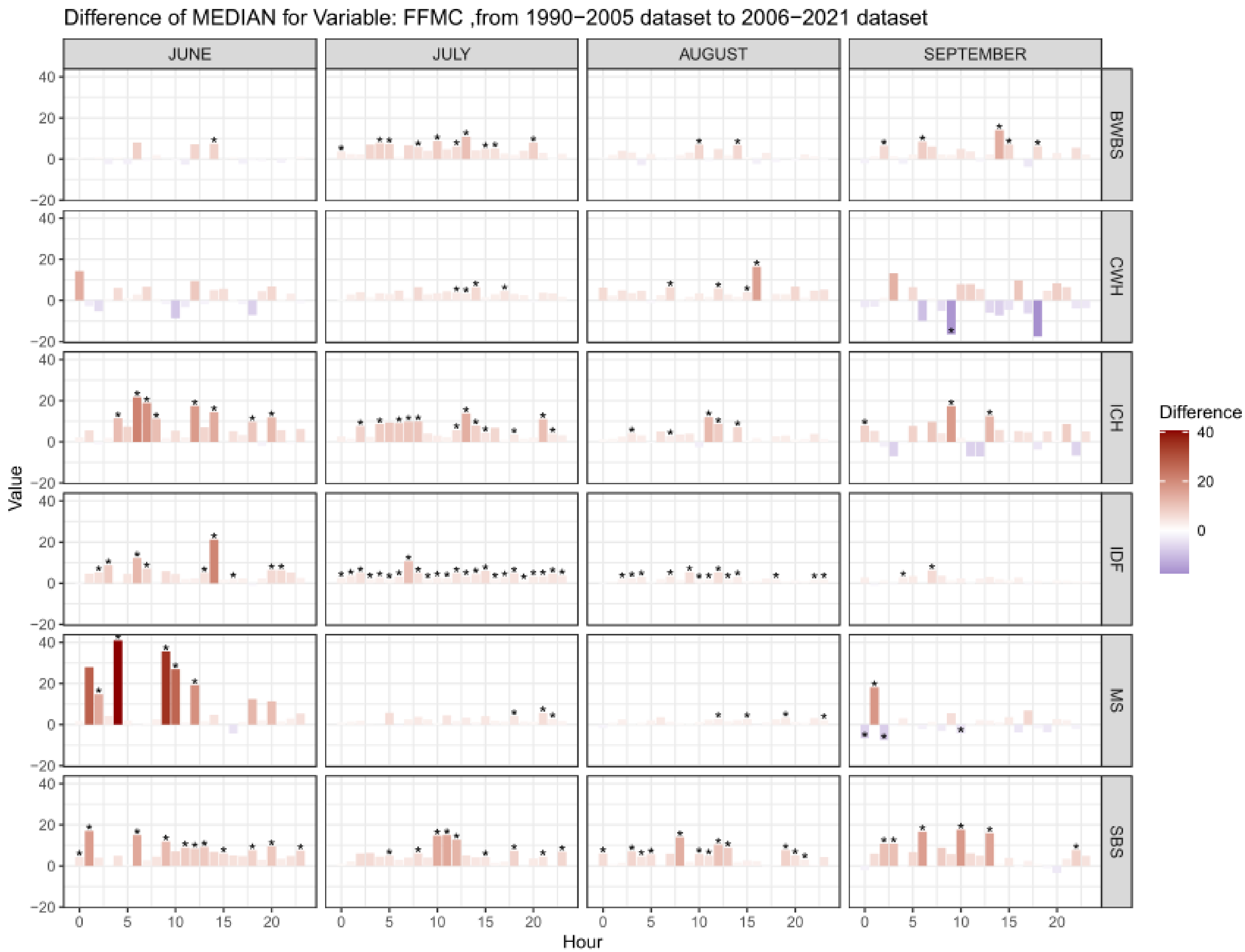


Difference of MEAN for Variable: RHUM ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
5
0
−5
−10
−15
10
15
20

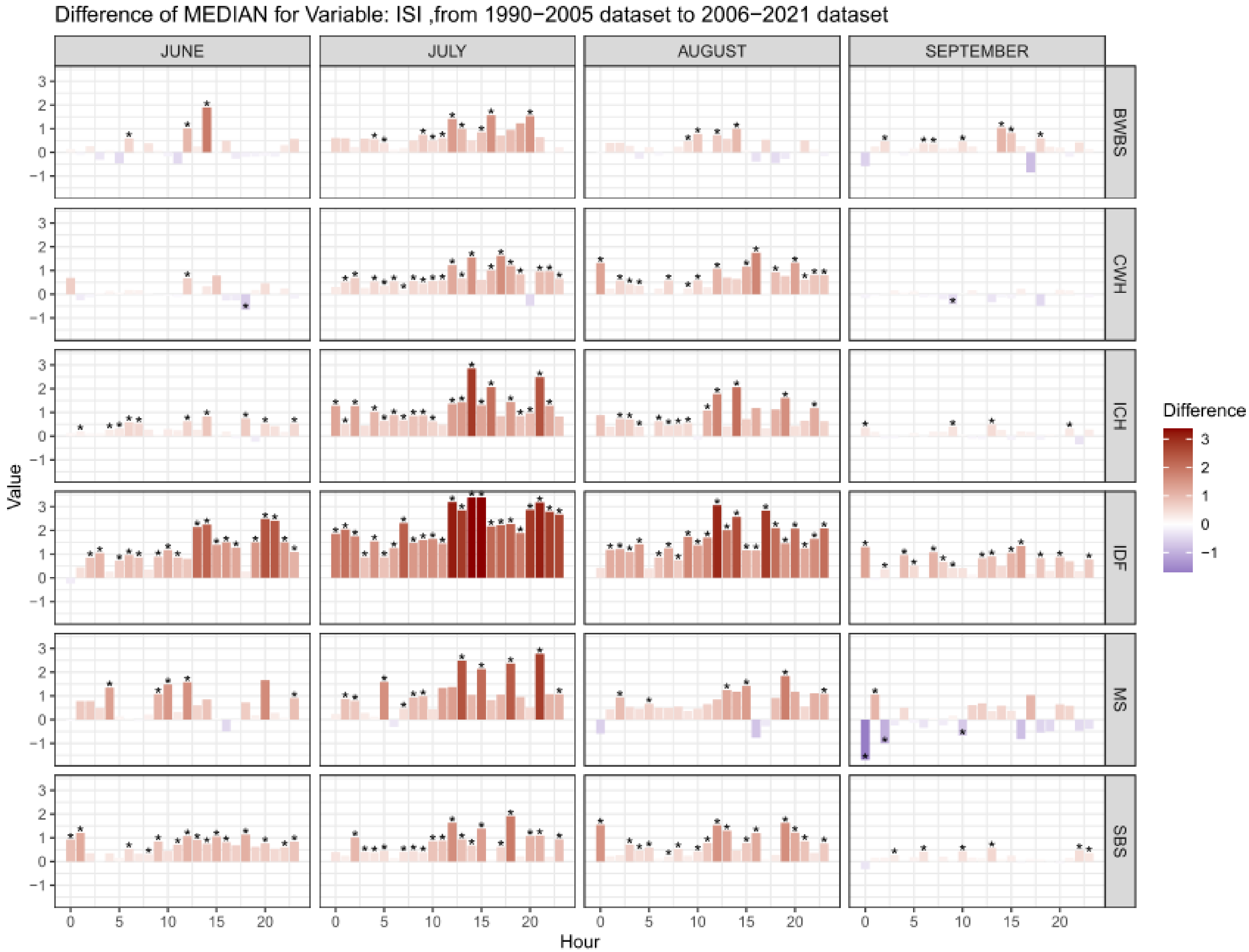

Difference of MEAN for Variable: TEMP ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference

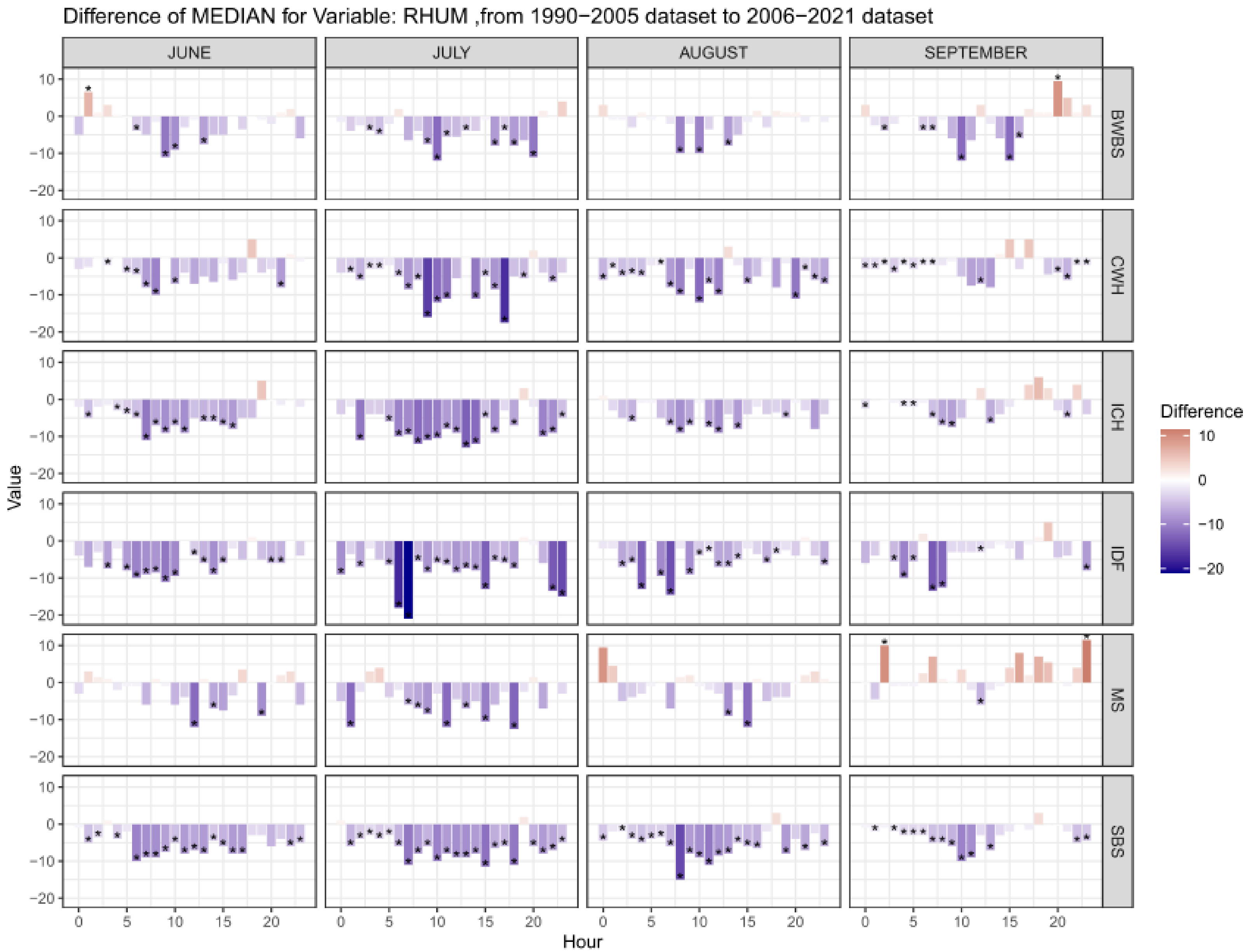


Difference of MEAN for Variable: WS ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference

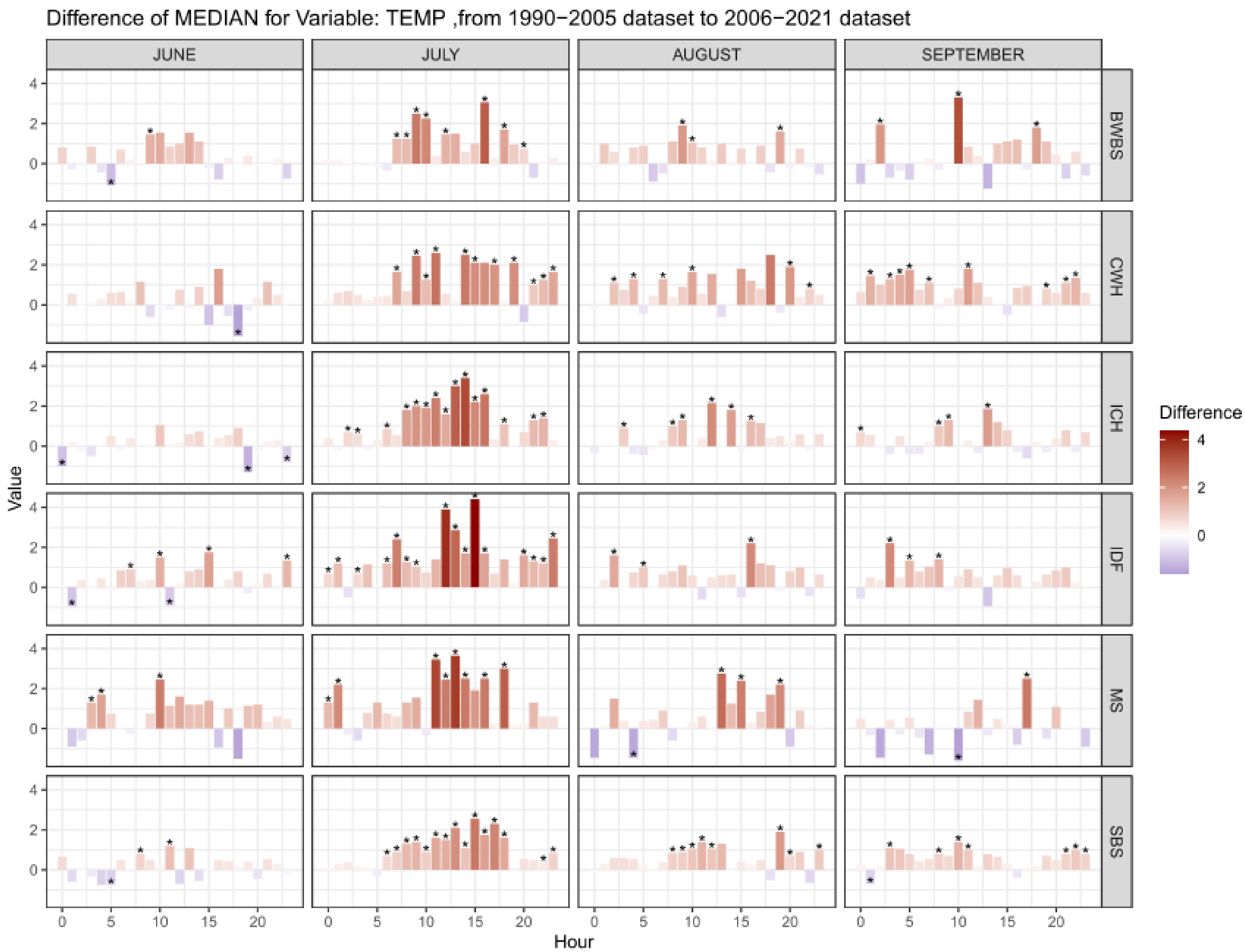

Difference of MEDIAN for Variable: FFMC ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
40
20
0

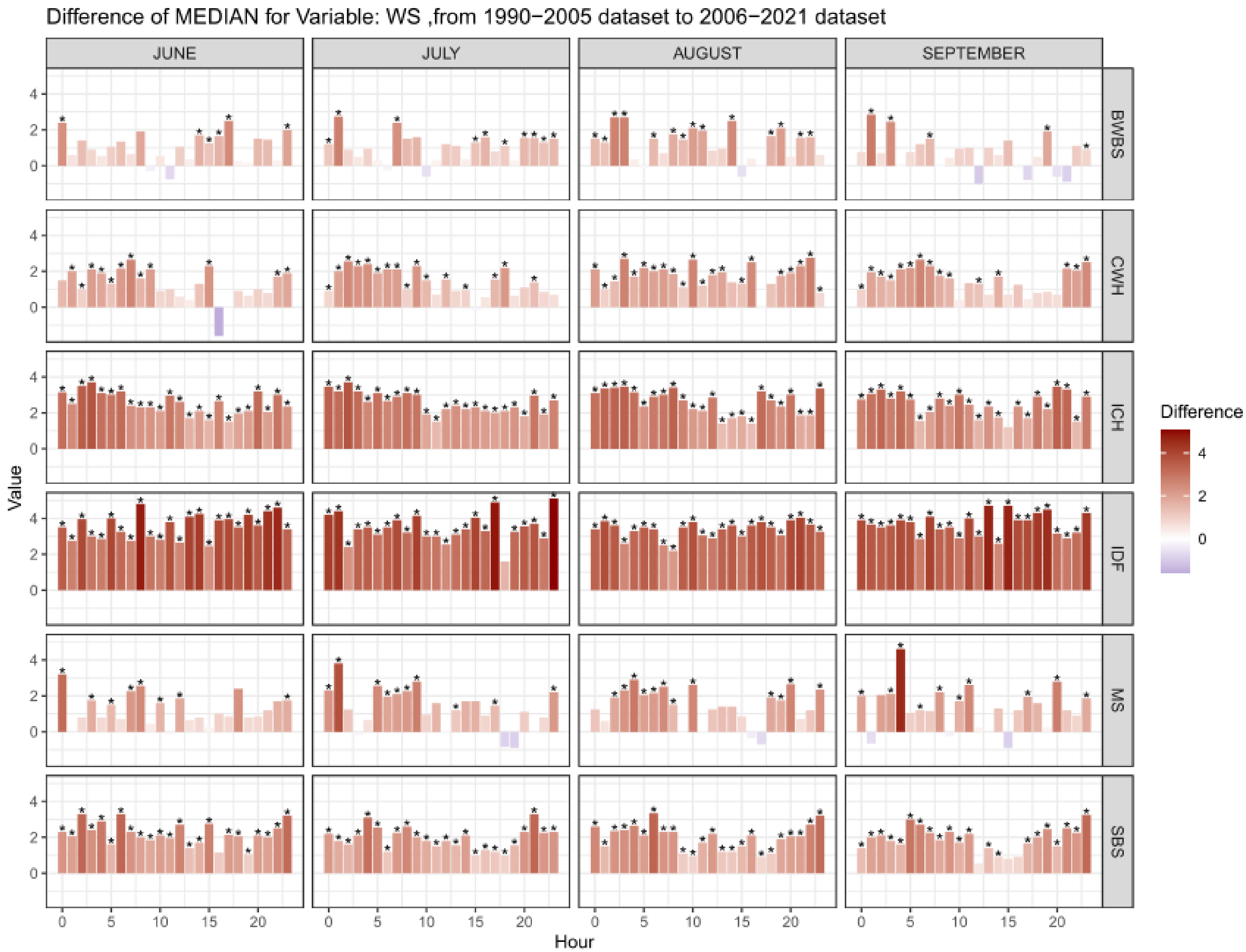
Difference of MEDIAN for Variable: FWI ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
10
5
0
−5

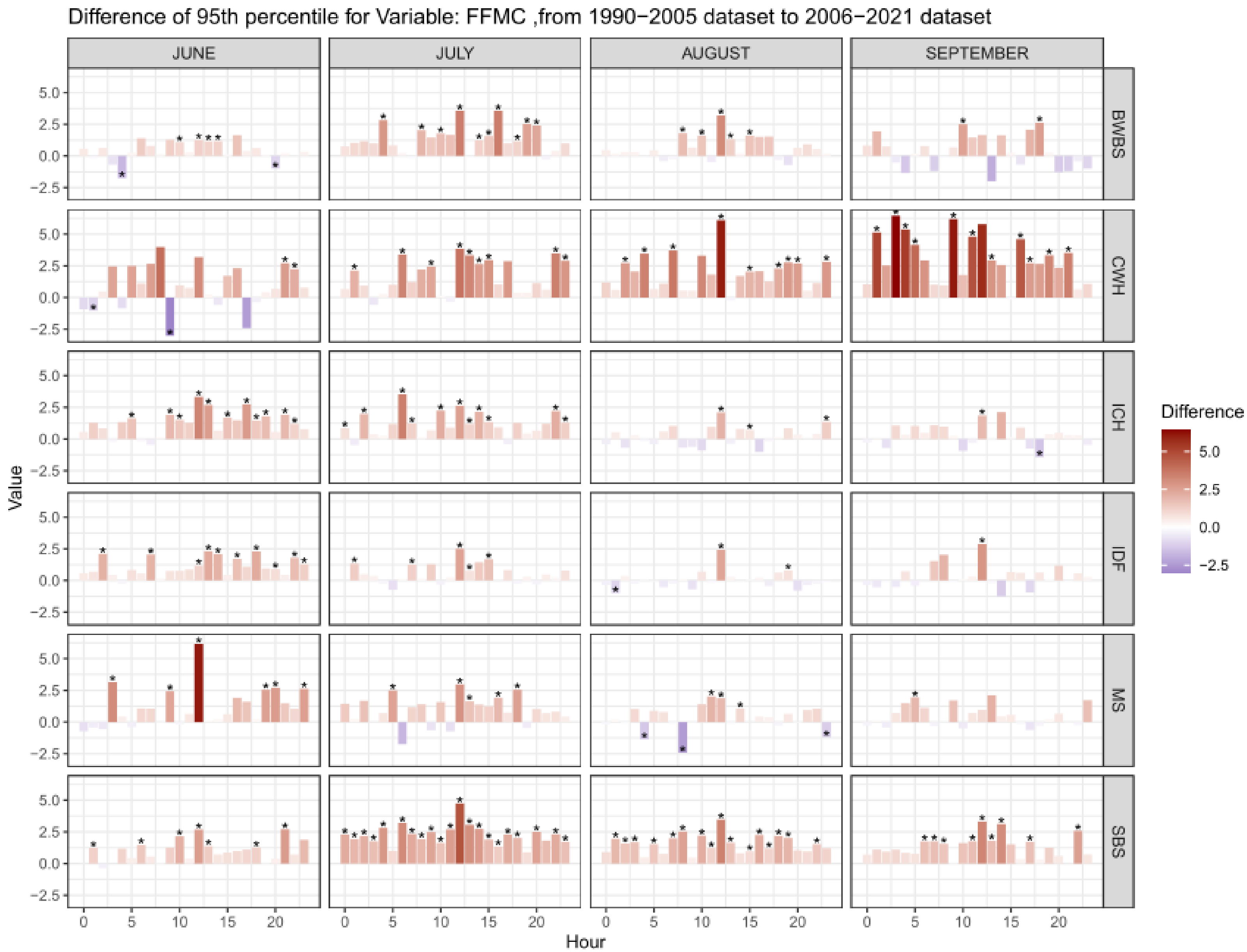

Difference of MEDIAN for Variable: ISI ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
3
2
1
0
−1

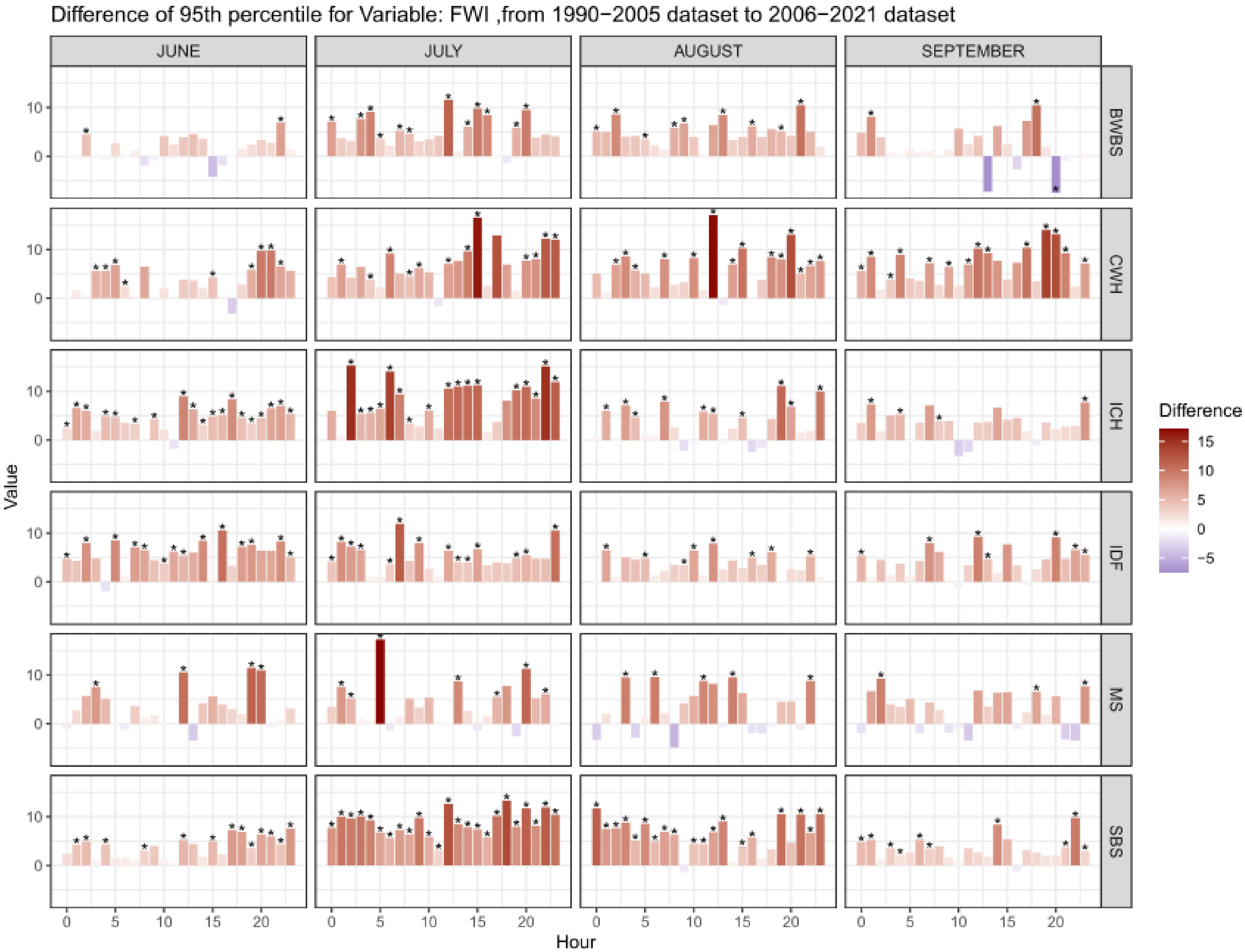


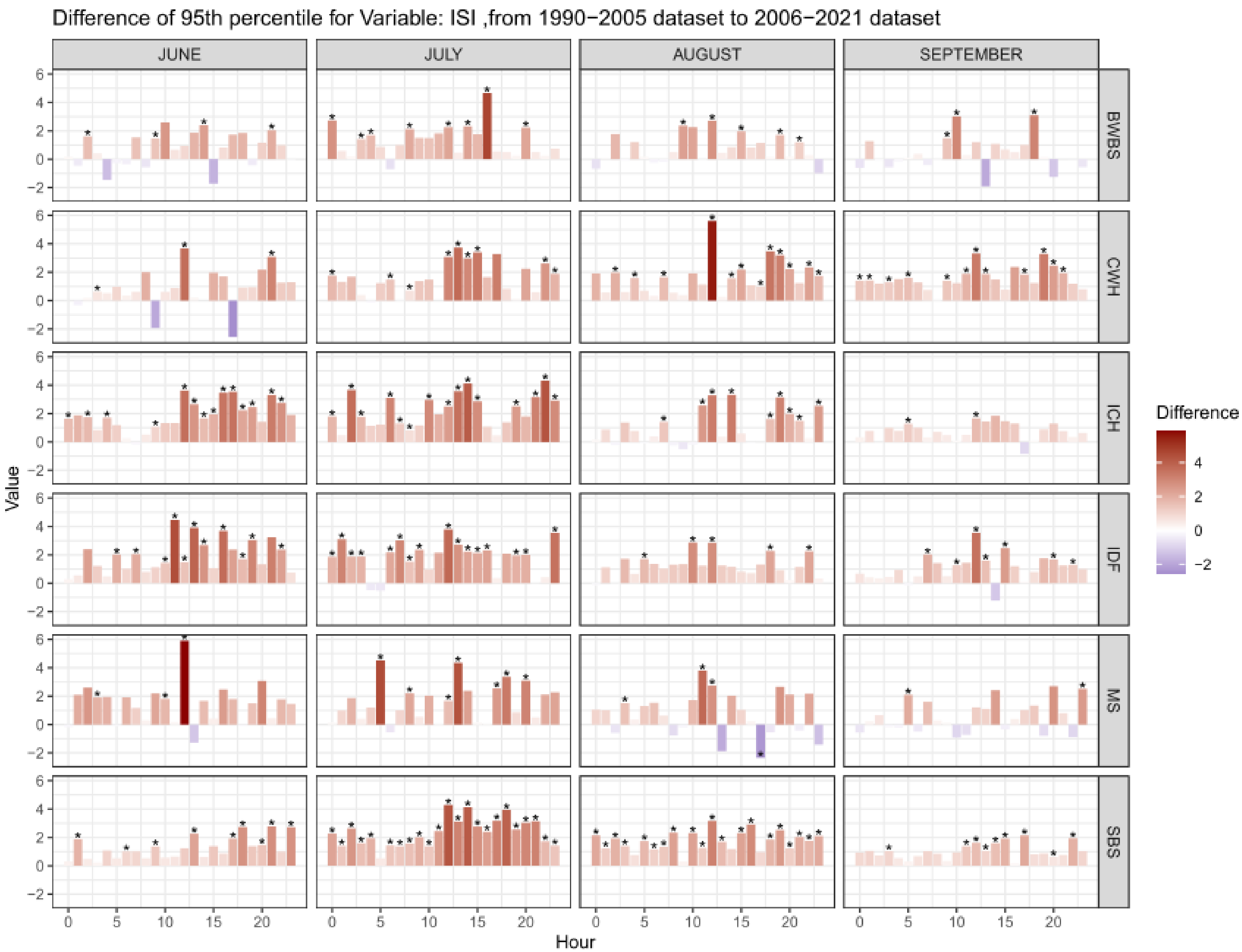
Difference of MEDIAN for Variable: RHUM ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
10
0
−10
−20


Difference of MEDIAN for Variable: TEMP ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
4
2
0
0
5
10
15
20

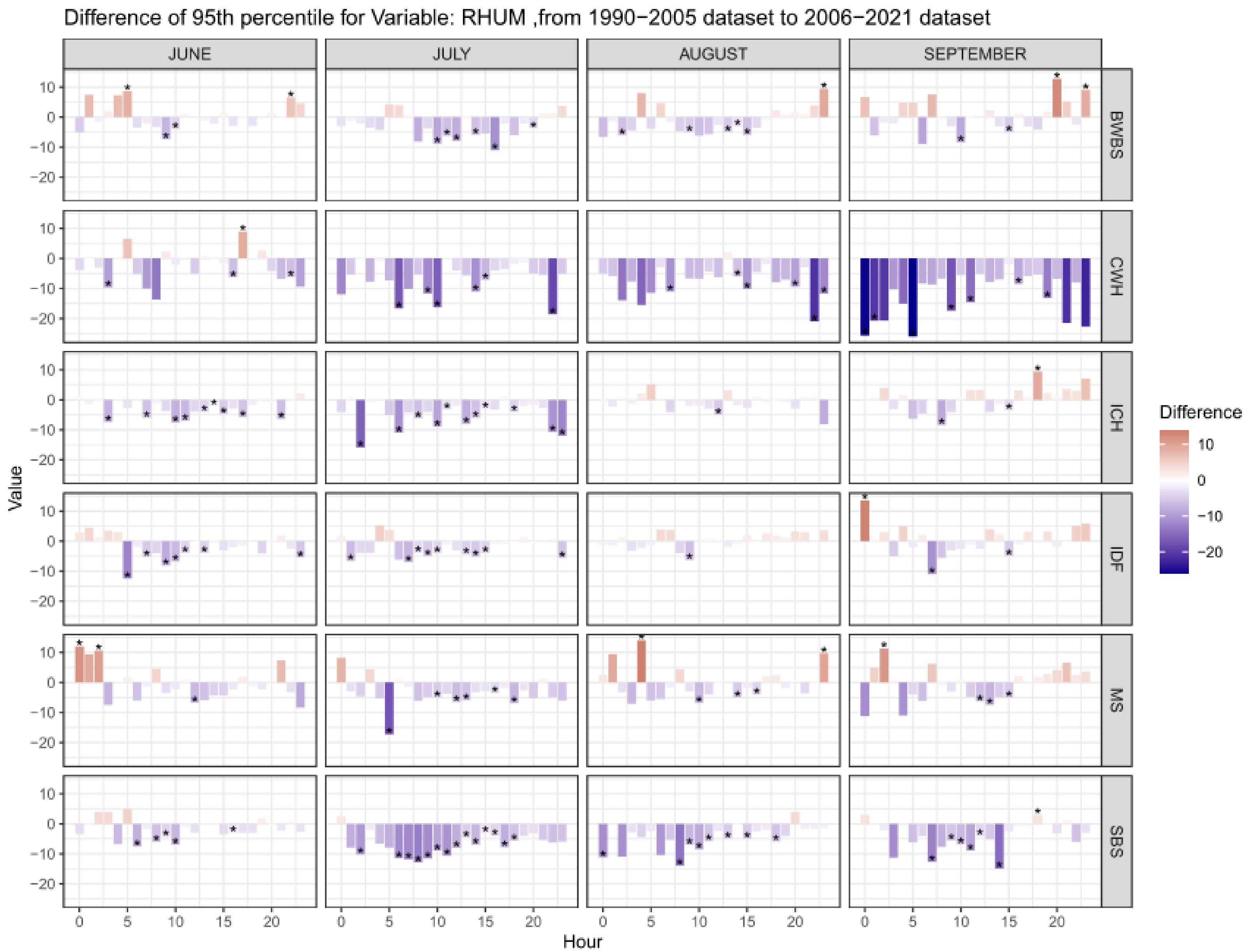

Difference of MEDIAN for Variable: WS ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
4
2
0
0
5
10
15
20

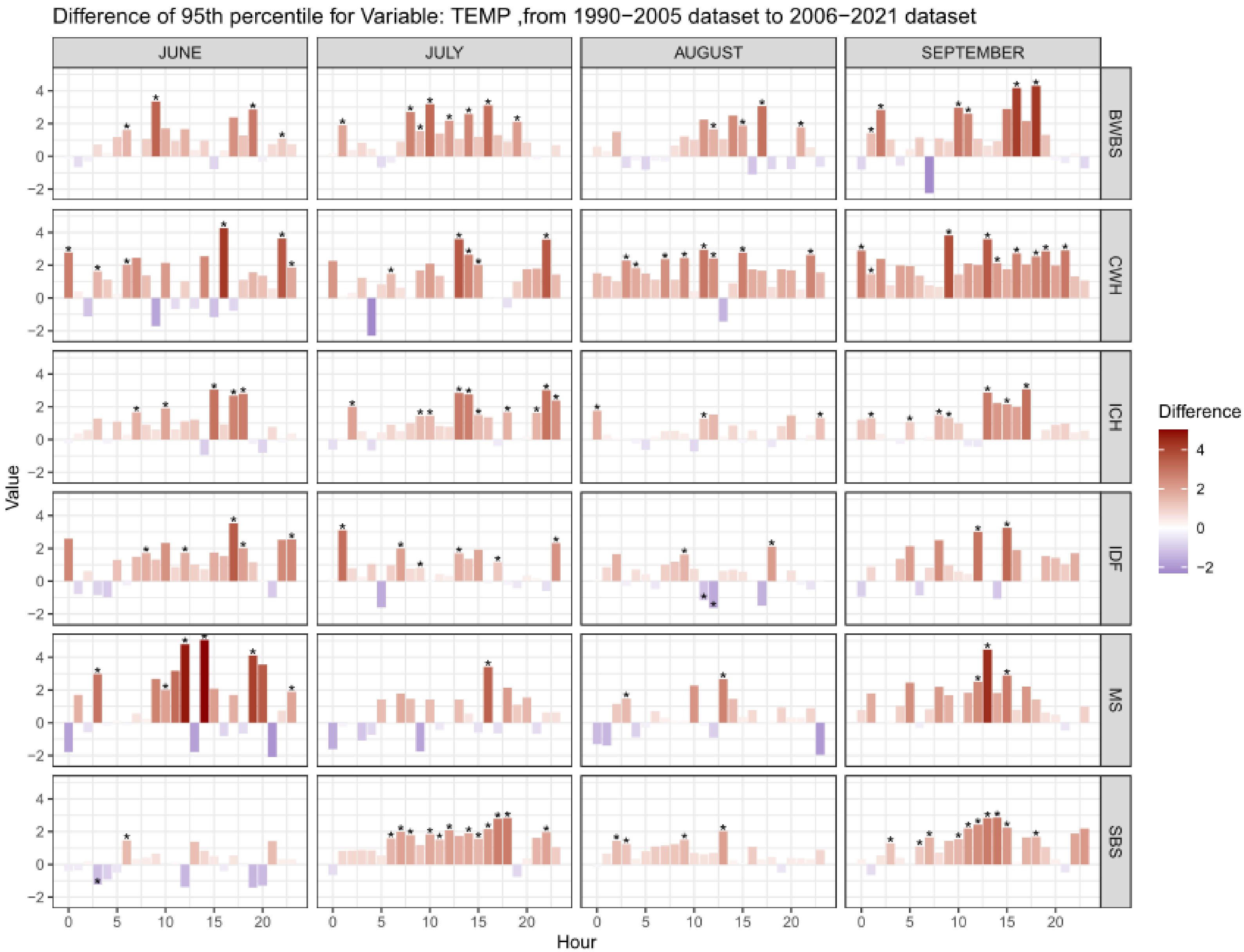

Difference of 95th percentile for Variable: FFMC ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
5.0
2.5
0.0
−2.5


Difference of 95th percentile for Variable: FWI ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
15
10
5
0
-5

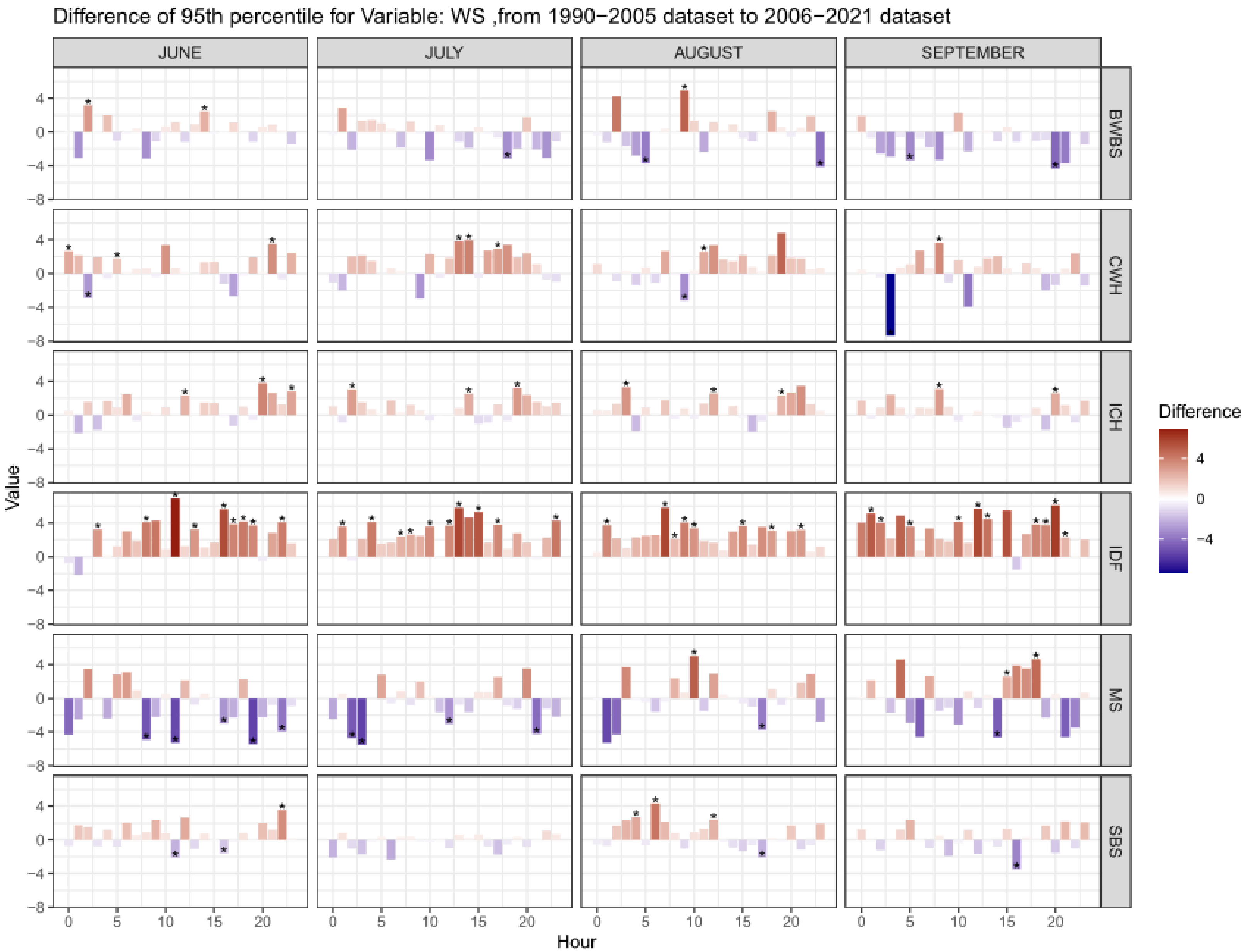


Difference of 95th percentile for Variable: ISI ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference


Difference of 95th percentile for Variable: RHUM ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
10
0
−10
−20



Difference of 95th percentile for Variable: TEMP ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
4
2
0
−2


Difference of 95th percentile for Variable: WS ,from 1990−2005 dataset to 2006−2021 dataset
JUNE
JULY
AUGUST
SEPTEMBER
BWBS
CWH
ICH
IDF
MS
SBS
Value
Hour
Difference
4
0
−4
−8
5
10
15
20