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Preferred atmospheric circulations associated with favorable prescribed burns in the Gulf of Mexico coast, USA

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Abstract

Background Application of prescribed fire in natural plant communities is an important wildlife habitat management tool. Prescribed fire managers have suggested anecdotally that changing weather patterns may be influencing the frequency of days that have optimal conditions to conduct coastal marsh burns along the US Gulf of Mexico coast. Our study objectives were to (1) determine whether the frequency of atmospheric circulation patterns associated with prescribed fire prescriptions has changed from 1979 to 2018 for the Gulf Coast and (2) identify circulation patterns preferred by land managers for implementing prescribed fire.

Results While coastal marsh habitat is threatened by climate change and human-associated degradation, weather type frequency was not identified as an important factor related to the application of prescribed fire, as the frequency of weather circulation types has not changed significantly over time ($p > 0.05$). However, some weather circulation patterns seem more advantageous (e.g., offshore winds) or disadvantageous (e.g., wet cold fronts and high winds) for consideration by prescribed fire applicators across the Gulf.

Conclusions Further insight into the weather conditions preferred and avoided by land managers along the Gulf of Mexico will improve prediction-based methods for identifying burn windows from weather forecasts. Land managers face many challenges in protecting coastal systems, while also reducing management conflicts (i.e., smoke transport) with local communities. Understanding how constraints such as urbanization, climate change, and sea-level rise interact to affect prescribed fire application will be an increasingly important aspect for developing successful adaptive management plans.

Keywords Coastal Plain, Gulf of Mexico, High marsh, Planning, Prescribed fire, Weather, Wildland fire management

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Resumen

Antecedentes La aplicación de quemas prescriptas en comunidades vegetales naturales es una herramienta importante para el manejo de la fauna silvestre. Los gestores de quemas prescriptas han sugerido de manera anecdótica que el cambio en los patrones del tiempo atmosférico puede influenciar la frecuencia de días que tienen condiciones óptimas para conducir esas quemas en las marismas costeras a lo largo de la costa del Golfo de México en los EEUU. Los objetivos de nuestro estudio fueron: 1) determinar si la frecuencia de circulación de los patrones atmosféricos asociados a quemas prescriptas han cambiado desde 1979 hasta 2018 para la costa de este golfo, y 2) identificar los patrones de circulación preferidos por los gestores de tierras para implementar las quemas prescriptas.

Resultados Aunque el hábitat de las marismas de esta costa está amenazado por el cambio climático y la degradación asociada al uso humano, la frecuencia en el tipo del tiempo meteorológico no fue identificado como un factor importante relacionado con la aplicación de quemas prescriptas, dado que la frecuencia de los tipos de circulación atmosférica no ha cambiado significativamente en el tiempo (p>0,05). De todas maneras, algunos patrones de circulación aparecen como ventajosos (e. g. brisas marinas) o desventajosos (e. g. frentes húmedos-fríos y vientos fuertes) para ser considerados por los aplicadores de quemas a lo largo del golfo.

Conclusiones Dado que el tiempo atmosférico es solo uno de los componentes de la ventana de prescripción, una visión sobre las condiciones preferidas y evitables por los manejadores de tierras a lo largo del golfo podría mejorar los métodos basados en predicciones para identificar ventanas de quema basadas en pronósticos meteorológicos. Los manejadores de tierras enfrentan varios desafíos en la tarea de proteger los ecosistemas costeros y en entender que condicionantes como las urbanizaciones y el aumento del nivel del mar interactúan con las condiciones preferidas para realizar aplicaciones de quemas, lo que será un aspecto cada vez más importante para desarrollar planes de manejo adaptativos exitosos.

Background

Fire is an important form of ecological disturbance in coastal ecosystems. Prescribed fire is widely used for managing succession and habitat availability, nutrient cycling, promoting plant production, suppressing woody vegetation, and reducing wildfire risk (Wright and Bailey 1982, Nyman and Chabrek 1995, Grace et al. 2005, Feher et al. 2021). Coastal prairies and marshes of the northern Gulf of Mexico coast (hereafter Gulf Coast) contain 58% of all US coastal wetlands and are particularly sensitive to many ecological stressors in the area (Field et al. 1988, Nyman and Chabrek 1995). Like all coastal wetlands, these areas serve valuable and often unique ecological, economic, recreational, and esthetic functions as they support biological productivity (Engle 2011; Mendelssohn et al. 2017; Purcell et al. 2020). For example, the coastal wetlands of the northern Gulf Coast provide vital habitats for fisheries and migratory bird species while also protecting coastlines and people from storm surge (Shabman and Batie 1978; Boesch and Turner 1984; Farber 1987; Michener et al. 1997; Costanza et al. 2008; Engle 2011; Baldera et al. 2018). Fire promotes primary plant growth and potentially slows the alarming rate of erosion caused by a combination of human development and sea-level rise (Osland et al. 2016, 2017; Spencer et al. 2016; Jankowski et al. 2017; Borchert et al. 2018). A fire-assisted reduction of coastal wetland loss in turn could allow for the continuation of ecosystem services in a positive feedback loop (Frost 1995; Mitsch and Gosselink 2000).

Fire practitioners in the US Gulf Coast region have shared concerns that coastal marsh management using prescribed fire is becoming more difficult (Black et al. 2020), and areas often fall short of meeting agency-prescribed burn targets. Failure to meet conservation targets regarding coastal wetlands in this area can have a host of implications that range from failure to meet other management objectives such as those for annual wildlife food production to more severe implications such as wetland loss and build-up of hazardous fuels that promote conditions for wildfire, to potential curtailment of funding or resources (Florida Forest Service 2013, EGCPJV 2014). Identifying weather patterns that are preferred by prescribed fire applicators could improve managers' abilities to better predict potential burn windows based on weather forecasts to better meet agency burn targets.

Climate and weather often determine the degree to which prescribed fire may be applied to the landscape. Many weather variables including temperature, relative humidity, rainfall, wind speed and direction, cloud cover, transport winds aloft, and probability of fog play an important role in applying fire along the Gulf Coast (National Wildfire Coordination Group (NWCG) 2021). These factors are critical in predicting fire behavior and achieving goals and objectives for a given prescribed burn application (Scott and Burgan 2005; Andrews 2009). Other factors such as herbaceous live fuel moisture, tides, water depth, and potential air quality and smoke impacts can play a critical role either independently or in combination with weather factors (Scott and Burgan 2005, NWCG 2020). As a result, burning policy and practice change over time and vary by state, agency, and specific management goals (e.g., Quinn-Davidson and Varner 2012, Florida Forest Service 2014, Shaw et al. 2015, Kupfer et al. 2020). Generally, prescribed burns along the Gulf Coast occur during late fall and winter in coastal marsh habitats when water levels are at or near the marsh surface, also known as a cover burn, because the recovery time is quick (e.g., less than 2 years) (Nyman and Chabreck 1995, Gabrey and Afton 2001). During the 1980s, managers preferred to burn prior to cold front passage when southerly (i.e., from the south) winds prevailed, so that the marsh surface was flooded by several inches of water during the burn (Cao et al. 2021). By contrast, many managers today prefer to wait until after the onset of winds with a northerly component, which typically occurs following the passage of a cold front, to ensure that smoke moves offshore (e.g., Florida Forest Service 2014), away from populated areas. Studies that evaluate weather and prescribed fire do not often include actual prescribed fire application data (e.g., Yurkonis et al. 2019, Kupfer et al. 2020), which can limit the utility of the results for identifying management patterns.

There is a need to determine the amount of annual variation in atmospheric conditions that allow for prescribed fire (Hiers et al. 2020). Kupfer et al. (2020) defined a suite of prescribed fire weather variables considered by prescribed fire managers in the southeastern USA, including temperature, relative humidity, wind speed, atmospheric mixing height, Keetch-Byram Drought Index, and other dispersion indices. Each variable is an individual component that responds to atmospheric circulation patterns; as a result, prescribed fire application as a management tool is heavily influenced by atmospheric circulation conditions (Chiodi et al. 2019). Cao et al. (2021) used an eigenvalue-based synoptic climatological approach to identify eight surface atmospheric circulation patterns, providing average value ranges of variables that influence prescribed fire application. The patterns described in Cao et al. (2021) minimize bias and subjectivity for predicting potential burn windows throughout the southeastern USA, a region where prescribed fire application is increasingly constrained (Kupfer et al. 2020). Determining the extent to which changing weather conditions across the northern Gulf Coast might influence prescribed fire application would provide some insight on potential management challenges in these increasingly threatened coastal areas.

Our study objectives were to (1) determine whether the frequency of weather conditions associated with prescribed fire prescriptions has changed over time for the Gulf Coast and (2) identify weather conditions that are preferred by land managers for implementing prescribed fire. Here, we integrate historic circulation data (1979–2018) and real prescribed fire data (1985–2018) to examine relationships among short-term weather patterns, when prescribed fire was applied, and management preferences throughout the US Gulf Coast. Following our results, we discuss other factors that may be limiting prescribed fire actions along the Gulf Coast.

Methods

Study area

The study area includes high marsh and other marsh habitats spanning the northern Gulf Coast (coastlines of Texas, Louisiana, Mississippi, Alabama, and Florida; Fig. 1). High marsh, one of the most vulnerable coastal habitats, is often characterized by high-salinity soils, periodic tidal inundation, and a unique suite of wetland plant species (Eddleman et al. 1994, NatureServe 2009, Enwright et al. 2022). Fire is the primary natural disturbance factor in many tidal, non-saline marshes. We used the five Gulf Coast Joint Venture (GCJV) Initiative Areas (IAs; i.e., Laguna Madre, Texas Mid-Coast, Chenier Plain, Mississippi River Coastal Wetlands, and Coastal Mississippi-Alabama) and two US Geological Survey (USGS) Biological Planning Units (BPUs; USGS Florida Big Bend and Tampa Bay) to compare prescribed fire application across the study area (Fig. 1). The IAs divide the Gulf Coast into five sections along the Texas, Louisiana, Mississippi, and Alabama coastlines. We also included the USGS Florida Big Bend and Tampa Bay BPUs to cover the Florida Gulf Coast. These IAs and BPUs were delineated to meet habitat conservation objectives along the Gulf. We did not incorporate BPUs along the southern Florida Gulf Coast, due to the transition from marsh to mangrove habitats in that region.

Data description

Weather data

The twice-daily calendar of near-surface (i.e., 1000-hPa level) synoptic weather types identified by Cao et al. (2021) is used here to represent the modes of variability in major atmospheric circulation in the study area. The Cao et al. (2021) system is an objective procedure for evaluating weather changes over time, while removing much of the human-introduced bias that can affect other weather classification systems. Weather data used by Cao et al. (2021) to classify the surface types were the geopotential height fields (which correspond to pressure patterns) at the 1000-hPa level, acquired from the fifth-generation

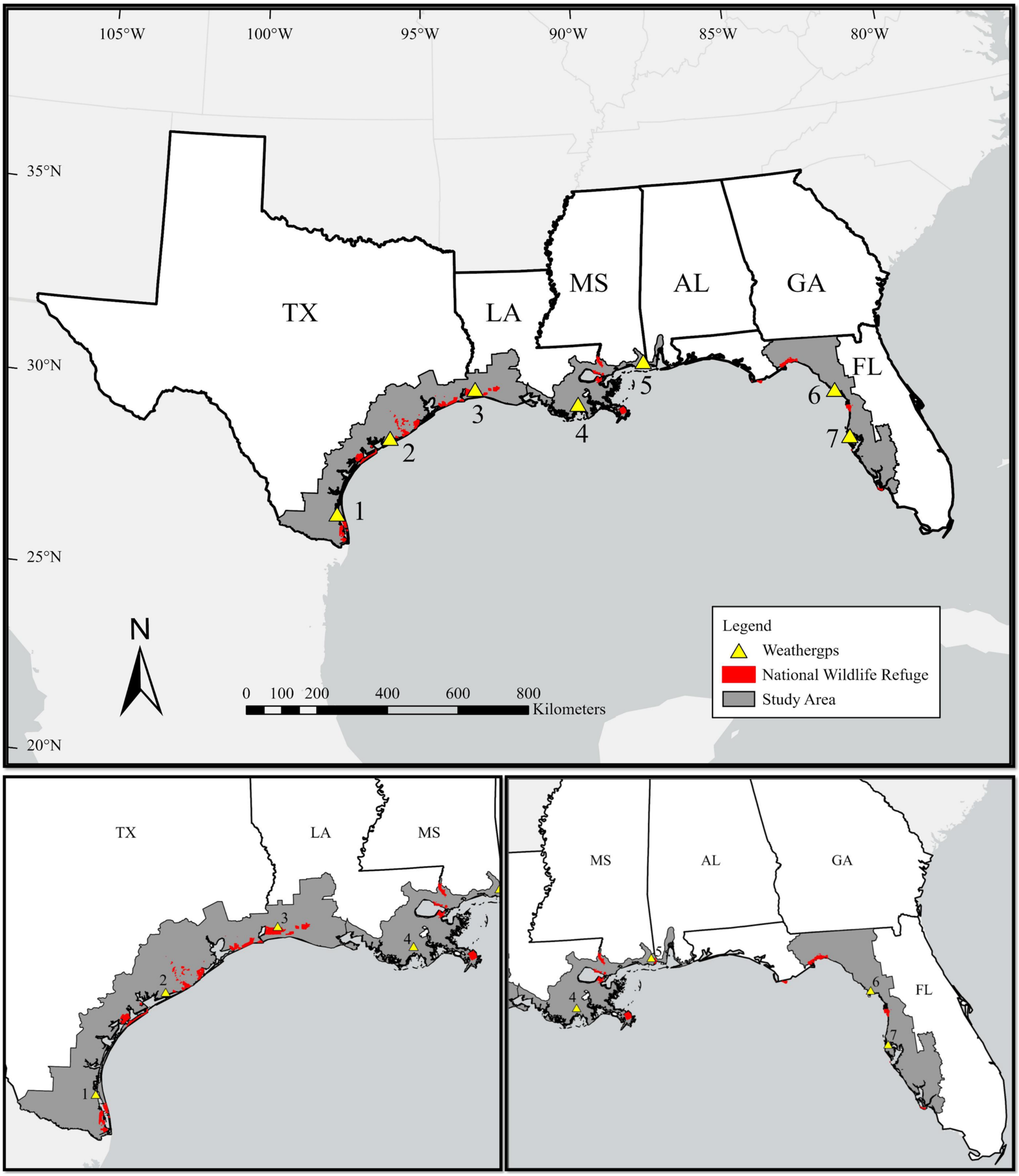

Fig. 1 Locations of the 23 National Wildlife Refuges (NWRs) included along the Gulf of Mexico (USA). Gray areas represent the study area, red areas represent NWRs with fire histories that were included in the study, and yellow triangles indicate the center of the Gulf Coast Joint Venture Initiative Area or center of the US Geological Survey Biological Planning Unit, where weather data were collected across the study area (1 = Laguna Madre Initiative Area; 2 = Texas Mid-Coast Initiative Area; 3 = Chenier Plain Initiative Area; 4 = Mississippi River Coastal Wetlands Initiative Area; 5 = Coastal Mississippi-Alabama Initiative Area; 6 = Florida Big Bend BPU; 7 = Tampa Bay BPU). For specific NWR names, see the "Methods" section

European Center for Medium-Range Weather Forecasts (ECMWF) Reanalysis version 5 (ERA5; Copernicus Climate Change Service (C3S), 2017) at 0.25° × 0.25° resolution, for the region bounded by 100°W, 40°N, 75°W, and 20°N, for 1200 UTC and 1800 UTC from January 1, 1979, to December 31, 2018. The ERA5 dataset is among the most highly respected reanalysis products, as it provides a uniform methodology for the spatial interpolation and the amalgamation of many different types of data that go into the model output. Then, temperature, dew point, *u*- and *v*-components of the wind vector, relative humidity, and cloud cover were collected in the present research and averaged for each classification type (Table S1).

The Cao et al. (2021) system is ideal for the present research because the types were developed specifically for prescribed fire in the US Gulf of Mexico. In the Cao et al. (2021) system, eight near-surface circulation regimes, represented by atmospheric geopotential height (which in turn represent pressure) patterns, are identified (Fig. 2), with higher geopotential height values (in m) corresponding to higher pressure. Because near-surface air in the Northern Hemisphere flows clockwise and outward away from enclosed areas of higher pressure (i.e., anticyclones), and counter-clockwise and inward into enclosed areas of lower pressure (i.e., cyclones), the generalized airflow can be inferred by the pattern of isohypses (i.e., lines of equal geopotential height) in Fig. 2. Moreover, wind speed is proportional to the isohypse gradients shown in Fig. 2; closely packed isohypses suggest faster winds, and widely spaced isohypses imply slower winds. The advantages of such a methodology involve the replicability and elimination of some, but not all, subjective biases that are inherent in manual classification methods.

Type a (Fig. 2a) in the Cao et al. (2021) system suggests high pressure over Oklahoma and northern Texas, which would produce offshore flow in Louisiana and Texas. *Type b* (Fig. 2b) contains an elongated zone of lower pressure over the east-central Gulf of Mexico, indicative of a cold frontal passage. *Type c* (Fig. 2c) resembles *type a*, but with stronger northerly flow across the US Gulf Coast west of Florida. *Type d* (Fig. 2d) suggests relatively high pressure in the Appalachians, with east-to-west flow across most of the US Gulf Coast. *Type e* (Fig. 2e) is similar, but with the higher pressure off the Atlantic Coast, generating southeasterly, onshore flow for the northern Gulf Coast and offshore flow over the Florida peninsular Gulf Coast. *Type f* (Fig. 2f) suggests relatively strong southerly airflow over most of the US Gulf Coast due to high pressure near the Bahamas. *Type g* (Fig. 2g) depicts weaker flow overall but relatively high pressure to the north of the Gulf Coast, producing very weak airflow over the study region. Finally, *type h* (Fig. 2h) suggests a cold front as indicated by the elongated orientation of relatively low 1000-hPa heights (i.e., low pressure) from the upper Mississippi Valley to the Louisiana-Texas border. Average weather conditions for each weather type in each region are provided in the supplementary material (Table S1).

Prescribed fire application data

We gathered prescribed fire histories representing 33 prescribed fire seasons (1985–2018) for 23 sites available from the US Fish and Wildlife Service Fire Management Information System. These include Anahuac, Aransas, Bayou Sauvage, Big Boggy, Big Branch, Bogue Chitto, Bon Secour, Brazoria, Cameron Prairie, Chassahowitzka, Delta, Egmont Key, Grand Bay, J.N. Ding Darling, Lacassine, Laguna Atascosa, Mandalay, McFaddin, Sabine, San Bernard, St. Marks, St. Vincent, and Texas Point National Wildlife Refuges. The range of prescription fire values for the different areas incorporated into our analyses can be found in the supplementary material (Table S2). We used location, date, and burn type information to identify the total number of prescribed fires attempted within our study area and to identify what circulation pattern was associated with each burn date during our period of interest (October–March of 1979–2018). We constrained our period of interest to October–March because most marsh prescribed fire management occurs during the late fall–winter; prescribed fire outside of this window is often used in upland habitat or for very specific habitat management (Nyman and Chabreck 1995, USFWS 2008). There were a total of 4006 marsh-associated prescribed fire records from 1985 to 2018, and 65% of records ($n=2616$) were associated with a single weather type and used for analysis.

Data analysis

We performed a simple linear regression analysis to determine whether the frequency of each weather type changed over time. We gathered weather data (Table S1) from 1979 to 2018 and classified daily weather patterns at 1200 h and 1800 h into one of the eight weather types following Cao et al. (2021) for each IA and BPU in our study ($n=7108$ weather days). Following the removal of days with more than one weather type classification ($n=1590$ days), we calculated the frequency of each weather type within each burn year from 1979 to 2017 (39 prescribed fire seasons), with the burn year corresponding to the typically prescribed fire season for the Gulf Coast of October through March and the "year" defined as the calendar year of October. We did not include changing weather days in our analysis due to the number of each possible weather type combination ($n=56$) and associated low sample sizes of prescribed fire records.

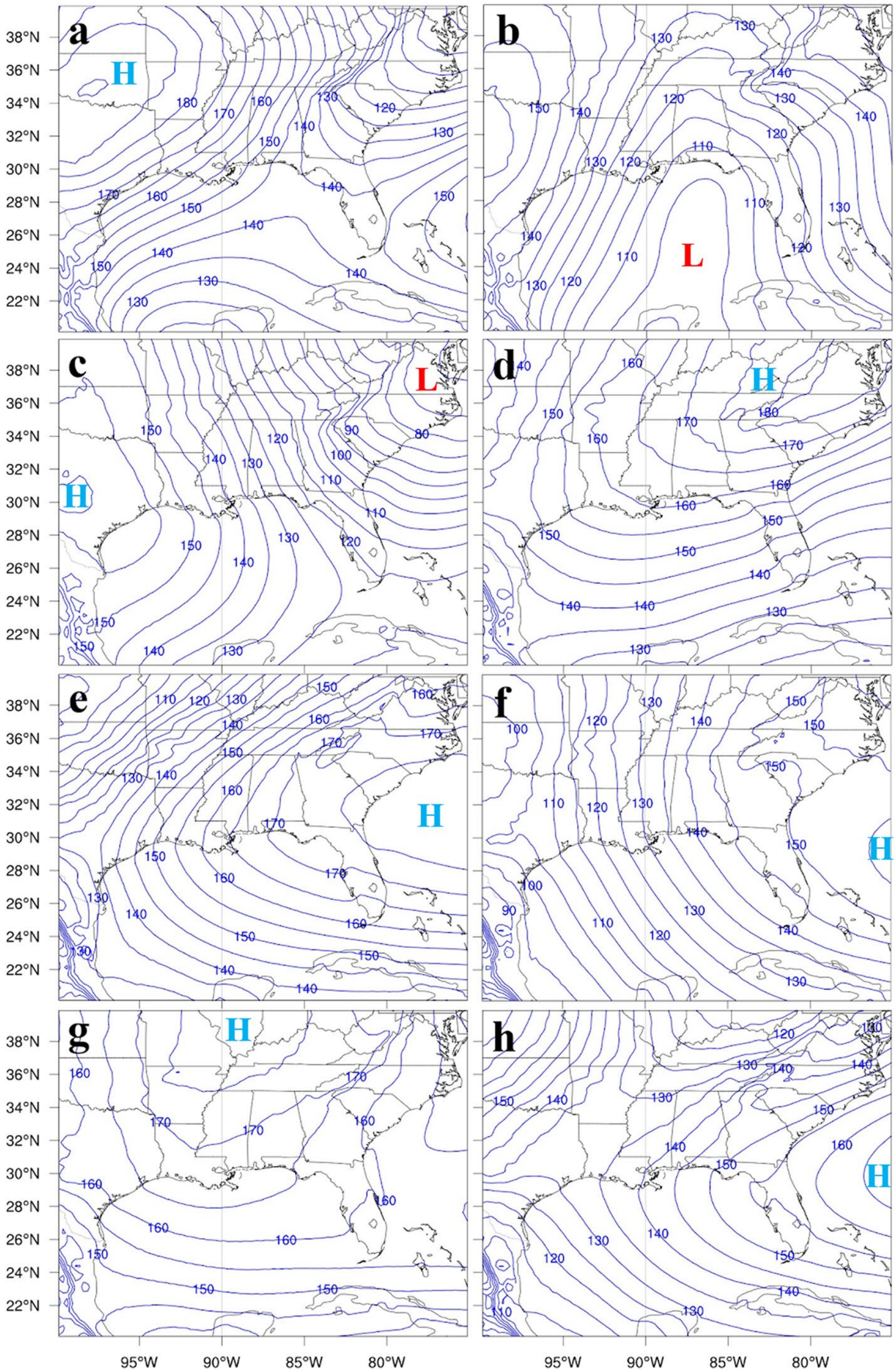

Fig. 2 Composite 1000-hPa geopotential height maps, by circulation type. In these kinds of maps, air flows clockwise and approximately parallel but slightly outward from the highest values, and counter-clockwise and approximately parallel but slightly inward into the lowest values (in the Northern Hemisphere); higher values are always to the right side of the flow, with the distance between adjacent isohypses approximately proportional to wind speed [modified from Cao et al. (2021)]. *H* and *L* indicate high and low pressure centers, respectively. See the "Methods" section for thorough descriptions of wind and weather movement

Overall, the frequency of changing system days did not change over the study period ($p = 0.43$, $R^2 = -0.009$). To address the question of whether fire managers prefer certain weather types for burns, we used a chi-square test and rank-choice analysis to examine differences between the expected proportion of each weather type and the proportion of each weather type when fire was applied. Data were pooled across the 33 prescribed fire seasons (1985-2017) present in both the weather and prescribed fire datasets. All analyses were performed in R v. 4.1.0 (R Core Team 2021), with the "epiDisplay" package (Chongsuvivatwong 2018) used to calculate frequencies.

Results

Weather type frequency over time

The most frequent weather type in the northern Gulf over the 39-year period was *type g* (19%), while the least common was weather *type a* (4%). Overall, we saw no significant change in weather type frequency over time for any of the eight weather types (Fig. 3). All R^2 values were < 0.1.

Table 1 Chi-square results comparing the proportion of weather type represented in actual prescribed fire burn data to weather type frequency across years (1985–2018) and regions. Bold indicates significance

Region	RX fire days	χ2	*p*-value
Laguna Madre	89	14.01	0.08
Texas Mid Coast	641	145.81	**< 0.0001**
Chenier Plain	565	124.29	**< 0.0001**
MS River Coastal Wetlands	111	81.07	**< 0.0001**
Coastal MS AL	28	13.94	0.08
Florida Big Bend	1127	249.29	**< 0.0001**
Tampa Bay	55	84.83	**< 0.0001**

Prescribed fire application and manager preference

Prescribed fire was applied most frequently in the Florida Big Bend BPU ($n = 1189$) and least frequently in the Coastal Mississippi-Alabama IA ($n = 28$) over the 33 prescribed burn seasons (Table 1). Prescribed burns in some regions were strongly tied to weather types (Table 1, Fig. 4). For example, the Texas Mid-Coast and Chenier Plain IAs and the Florida Big Bend and Tampa Bay BPUs all showed a significant difference between the expected proportion and observed proportion of weather types when fire was applied ($p < 0.05$, Table 1). Although not all regional data supported a statistically significant preference, all regions showed some preference and avoidance of certain weather types (Fig. 4, Table S3). The western Gulf Coast regions (Texas Coast and Chenier Plain Region of LA) preferred *types b* and *c* (Fig. 4B, C) and avoided *types f* and *h* (Fig. 4F, H). The central and eastern Gulf Coast regions showed more subtle preference and avoidance of weather types. In the Coastal Mississippi-Alabama IA, *type c* was the preferred burn weather and burns were avoided in *type e* (Fig. 4C, E) conditions. The Mississippi River Coastal Wetlands IA managers showed

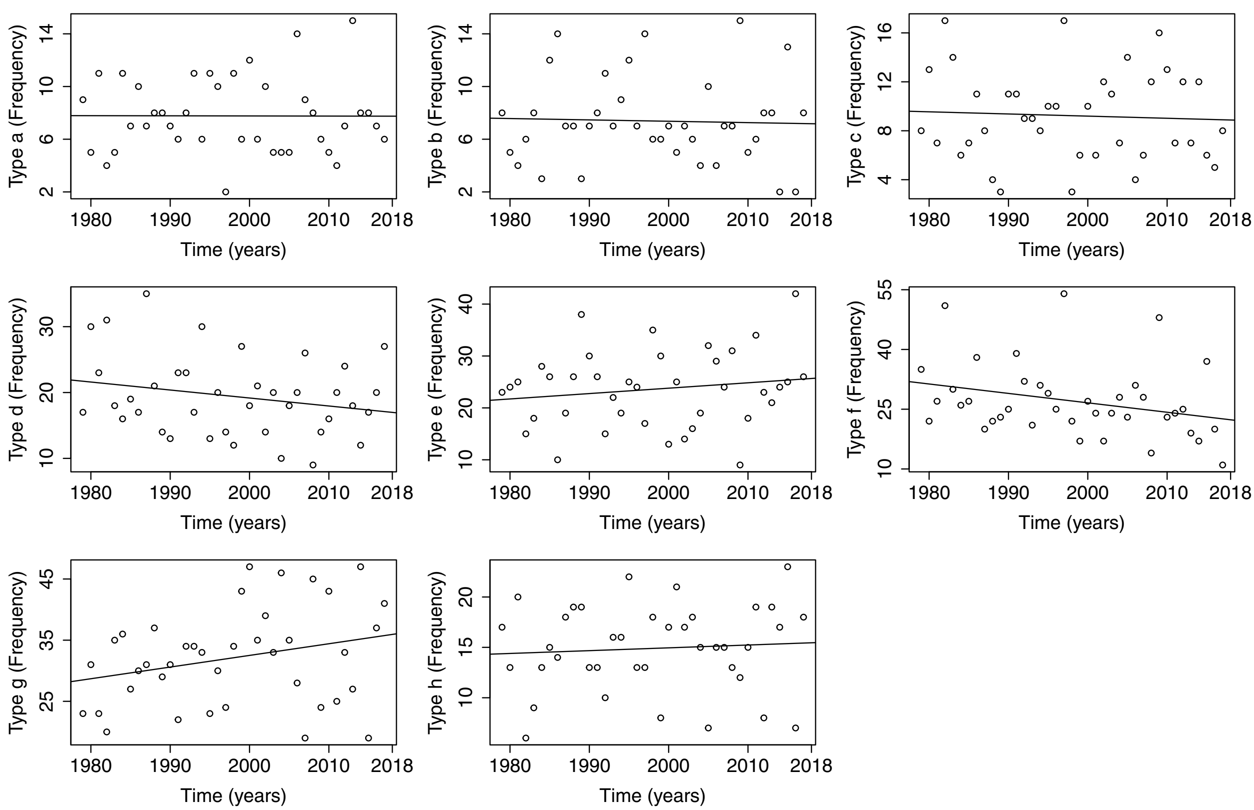

Fig. 3 Weather type frequency during the burn season (October–March) from 1979 to 2017

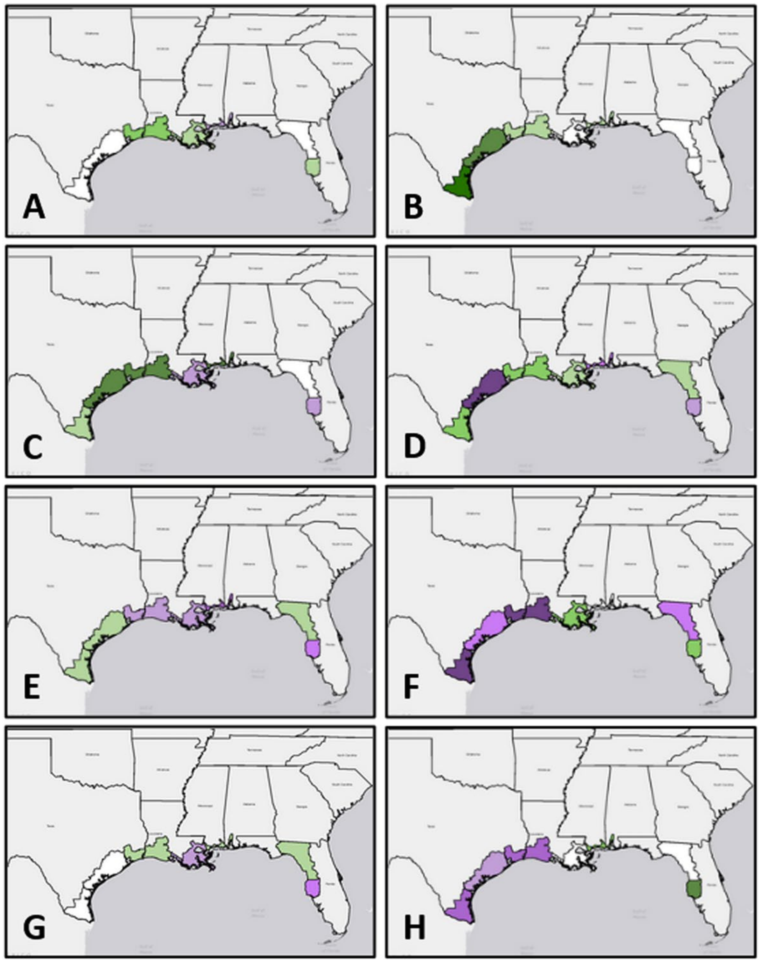

Fig. 4 Strength of preference or avoidance in each region for each weather type. Green indicates preference with darker shades indicating stronger preference. Purple indicates avoidance with darker shades indicating stronger avoidance. White indicates no preference or avoidance

a slight avoidance for applying prescribed fire under *type f* weather conditions (Fig. 4F), while the Florida Big Bend BPU fires were less frequent in *type e* weather conditions, with slightly weaker avoidance in *types d* and *g* (Fig. 4D–G) weather conditions. In contrast, Tampa Bay BPU managers preferred to apply prescribed fire during *types f* and *h* weather conditions and less frequently during *type g* conditions (Fig. 4F–H).

Discussion

Weather types and prescribed burns

We compared how weather type and frequency changed over time across the Gulf of Mexico to address a growing concern among land managers that weather patterns might be limiting prescribed fire application. Furthermore, Hiers et al. (2020) identified the need to determine the amount of annual variation in atmospheric conditions that allow for prescribed fire as a research priority. We observed no significant change in weather type frequency during the burn season (Oct–March) from 1979 to 2017, suggesting that other factors might be limiting prescribed fire application along the Gulf Coast. Of the seven regions included in our study, five showed a significant difference between the expected and observed proportion of weather types when fire was applied based on the federal prescribed fire dataset analyzed, reflecting preference and avoidance of weather types by land managers. In general, preference or avoidance of weather types is stronger along the western Gulf Coast (Texas) compared to the eastern Gulf Coast (Florida). This difference in application between the western and eastern Gulf Coast might reflect differences in social, economic, or environmental constraints. Regardless, across the Gulf Coast, there was a preference for the application of prescribed fire during weather types associated with strong offshore wind flows and avoidance of weather types with wind flowing inland. Our results highlight the need for evaluating other potential constraints on prescribed fire application, such as smoke abatement and management, human health and safety risk management, other factors related to climate change such as sea-level rise and extreme weather events, as well as fine-scale analysis of actual burn window length associated with the eight weather types (see Rohli and Henderson 1997).

Relationship between weather conditions and preferences by practitioners

Our results support the hypotheses that practitioners show a preference for certain weather conditions (e.g., offshore winds) and that the Cao et al. (2021) system captures regional differences well. Generally, prescribed fire practitioners apply fire when winds are likely to push smoke away from urban areas (Miller et al. 2019), which is likely why our results show a preference for offshore wind flow. The regional differences in preference and avoidance align well with Cao et al. (2021; Fig. 2). For example, *type c* is strongly preferred by Texas and the Louisiana Chenier Plain managers likely because wind is pushing smoke offshore, but is avoided in the MS River Coastal Wetlands region of Louisiana likely because wind is pushing into urban areas (e.g., New Orleans; Figs. 2c and 4C). Understanding preferred weather patterns associated with prescribed fire application will help in building prediction-based methods for identifying burn windows from weather forecasts.

Future conditions

Climate is changing and may include changes in long-term means, variability, and extremes of weather variables (Kupfer et al. 2020). Our results show that suitable weather condition frequency has not changed during the non-growing season (October–March) for the US Gulf of Mexico. Similar studies investigating the effects of climate change on potential prescribed fire application have suggested that non-growing season burn window conditions are less likely to change in the southeastern USA (Kupfer et al. 2020). In contrast, growing season (e.g., summer) weather conditions in the southeastern USA are predicted to become less suitable for prescribed fire, due to fewer suitable weather days (Chiodi et al. 2018; Kupfer et al. 2020) and increased wildfire frequency (Gao et al. 2021). Additionally, while we did not detect a significant increase in the frequency of weather *type e* as reported in Cao et al. (2021), our analysis only included days within the burning period (Oct 1–Mar 30) rather than all days within a year. Managers may experience fewer weather-related constraints if prescribed fire is applied during the non-growing season.

Sea-level rise and urbanization pose some of the most significant threats to the application of prescribed fire in a meaningful way along the Gulf of Mexico. Sea level has risen by an average of 10–20 cm in the past 60 years for our study area, with western portions of the study area having the highest documented rates of sea-level rise (National Oceanic and Atmospheric Administration [NOAA] 2021). Rising sea levels equate to more water on the landscape for longer periods of time, shifts in wetland vegetation, and increased potential for conversion to open water (Ravens et al. 2009; Twilley et al. 2016; Stagg et al. 2020; Törnqvist et al. 2020). Additionally, the Gulf of Mexico was the fastest growing coastal area of the USA between 2000 and 2017, with a rate of population change more than 10% higher than the national average during the same time period (United States Census Bureau 2019). As urban areas continue to expand ever closer to conservation areas included in this study, we expect increased socio-political constraints to further protect the human environment (Yoder 2008). Managers applying fire prescriptively at the wildland–urban interface often face additional weather and regulatory constraints in an effort to preserve human health and mitigate other potential short-term impacts to the human environment, such as road and waterway closures due to heavy smoke (Kupfer et al. 2020). Thus, high water levels and increased fragmentation inherently make applying a management tool such as prescribed fire more difficult.

As sea levels rise and urban areas expand, there is the potential for landward migration of coastal marsh habitats and coastal squeeze to occur across much of our study area. Borchert et al. (2018) recently modeled these phenomena for our study area and found that portions of our study area near Tampa Bay (FL), Galveston Bay (TX), and Atchafalaya/Vermilion Bays (LA) are projected to experience the highest levels of coastal squeeze, an inability for marshes to migrate inland due to urban barriers, and potential for future and more restrictive fire regulations. Coastal squeeze, increased water levels, rising human population levels in proximity to lands managed with fire, and factors associated with these changes have likely made applying fire more difficult for local and regional land managers over our study period and likely will continue this trend into the future. As a result, studies projecting changes in potential burn windows must incorporate multiple components associated with a burn window and not just suitable individual weather variables.

Other factors

If weather condition frequency has not changed over the last four decades, other factors associated with a burn window must play a more significant role in when a prescribed burn can be done. Indeed, some of the obstacles practitioners must navigate when trying to apply prescribed fire on coastal lands include liability (Yoder et al. 2004), and social (e.g., human perception and health considerations; Winter and Fried 2000) and operational constraints (e.g., staffing and budget; Quinn-Davidson and Varner 2012). Public sentiment in opposition to the use of prescribed fire due to perceived lack of control, negative wildfire experiences (e.g., Winter and Fried 2000), and concerns about health effects of smoke-related air pollution (Yoder 2008; Miller et al. 2019), particularly at the wildland–urban interface, may represent a more substantial impact on reduced burn windows. State and federal regulations on air quality can also narrow available burn windows and create competition between land managers and private businesses due to daily air pollution limits in some areas (Quinn-Davidson and Varner 2012). Based on our results, we suggest that an evaluation of the role non-weather factors have on prescribed fire planning in combination with favorable weather conditions is necessary to improve coastal marsh management.

Conclusions

Our study objective was to address land manager concerns that weather circulation patterns are limiting prescribed fire practices in the US Gulf Coast. While we found no change in long-term weather circulation patterns in the northern Gulf, we did identify land manager weather preferences for applying prescribed fire. Application of fire when wind conditions push smoke offshore helps increase fire management and likely reduces stakeholder complaints. The identification of land manager preferences using the Cao et al. (2021) weather classification system provides a framework for creating a prediction-based model for prescribed fire application. However, as we discussed, other factors in combination with weather circulation patterns could severely limit prescribed fire application. Further research and mapping products would be useful for identifying the areas of the northern Gulf of Mexico that are predicted to be the most affected by increased urbanization, sea-level rise, and coastal squeeze. As such, more collaboration is needed among all stakeholders (e.g., non-profit agencies, prescribed fire managers, members of coastal communities), to create an acceptable management plan if we are to maintain these important coastal habitats.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s42408-023-00169-4.

Additional file 1: Supplemental Table 1. Mean weather conditions by weather type and Gulf of Mexico region.

Additional file 2: Supplemental Table 2. Range of fire prescription values for the area along the Gulf of Mexico evaluated.

Additional file 3: Supplemental Table 3. Preference and avoidance values of prescribed fire application in each region. Increasingly positive numbers represent avoidance strength and increasingly negative numbers indicate preference strength (e.g., 4 = strongest avoidance | –4 = strongest preference). Zero indicates no preference or avoidance.

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Authors' contributions

PIs AMV and MSW and co-PIs JAN and RVR obtained funding. AMV, JAN, MSW, and RVR designed the study and developed the analysis approach. JAM and RVR gathered data used in the analysis. CSK organized and analyzed the data and drafted the manuscript. AMV, JAN, JAM, MSW, and RVR contributed to the drafting of the manuscript. The authors read and approved the final manuscript.

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Availability of data and materials

Data used and/or analyzed are available from the corresponding author upon reasonable request. Also, check noaafirebird.home.blog/datasets-and-publications for access.

Declarations

Ethics approval and consent to participate

Not applicable.

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The authors declare that they have no competing interests.

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