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Unlocking Potential: Analyzing the Content, Style, Structure, and Interactivity of Mesonets as Operational Dashboards

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ABSTRACT

Emergency managers need data and information to make life-saving decisions on behalf of the public. Operational dashboards, if designed appropriately, can provide this information in a central location and reduce cognitive demands during decision-making. Mesonet websites can serve as a type of operational dashboard that has the potential to provide the meteorological data necessary for emergency managers to make decisions. In this study, we use quantitative content analysis to examine the content, style, structure, and interactivity of 18 Mesonet websites from across the contiguous U.S. We find that Mesonet websites vary in the type and amount of content they include. For website style, we find that Mesonet websites primarily present their content with maps and data filters. We find that the structure of the website content was consistent across websites. Finally, we find that most Mesonet websites lacked interactivity, or visual feedback, which inhibits ease of use. We discuss extensions for future work.

SIGNIFICANCE STATEMENT

This study captures the content, style, structure, and interactivity of Mesonet websites when they are used as operational dashboards to support weather-related decision-making. Weather dashboards have the potential to support decision-makers of all types during severe weather events by providing all critical information in one place. With this streamlined approach, decision-making is made more efficient, as gathering information from multiple sources is no longer necessary. Mesonet dashboards provide a valuable context to analyze the content, style, and structure of webpages that can be useful for users. Through this work, we hope to identify the design principles and trends present in these dashboards, providing a basis for future research and efforts to improve design, user experience, and accessibility.

1. Introduction

Imagine an emergency manager who must prepare for an incoming snowstorm. They require access to maps, forecasts, and data to determine the impacts for their region. If the amount of information they need is extensive, this emergency manager may spend considerable time and effort switching between websites, datasets, etc. However, if a dashboard exists that includes all pertinent information in a central location, the amount of

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time spent shifting between information sources can be reduced. This conserves time and energy for the decision-making process itself (Sweller 1998).

Dashboards are an increasingly popular avenue for decision-makers like emergency managers to monitor and analyze data in one place (Rahman 2017). A data dashboard visualizes essential information needed to achieve one or more organization-specific objectives (Few 2006). Vague or misleading information about threats can confuse the user about timing or severity (Demuth et al. 2012). This compounds when emergency managers navigate multiple websites for data sources (Galluppi et al. 2012) that may be inconsistent or conflict. By incorporating dashboards, emergency managers can consolidate critical data and information in one place, making their decision-making process more efficient and straightforward.

Ideally, dashboard displays are concise, clear, and intuitive, without requiring expertise to interpret them (Few 2006)**.** Effective dashboard design will include content relevant to decision-making tasks, as well as aesthetic visual elements and good use of space (Few 2006). Other factors include visible navigation and interactivity features (Few 2006). These factors constitute a well-designed (i.e., highly usable) dashboard, which allows decision-makers to quickly retrieve information that supports their decision-making (Nadj et al. 2020).

Mesonet websites may provide the key types of data needed for public safety decision making. Mesoscale networks (or Mesonets) are comprised of equipment that monitors the weather, drawing from individual stations across a geographical area or territory. Mesonet coverage can vary from regional to statewide to nationwide. Network data of surface weather observations from these stations are reported in real-time or near-real-time to a central web repository, which posts data to a website for use. State-funded Mesonet data are publicly available to decision-makers like wildland firefighters, transportation departments, outdoor recreation, emergency management and public safety, and agricultural entities. Other Mesonets are privately operated, such as networks built and maintained by utility companies for their own purposes. Mesonets were originally developed in the 1980s, stemming from the idea that states could utilize automated weather data collection for near-real time decision-making (Mahmood et al. 2017; Hubbard et al. 1983). This motivation lends itself well to being visualized by a dashboard.

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The data Mesonet stations collect is displayed similarly to an operational dashboard: graphics like maps and tables with varying levels of interactivity are used to visualize real-time and archived information. These are useful for populations who rely on weather information to make decisions. Because Mesonet websites visualize measurements and observations for decision-making, they can inform decision-makers about current conditions during high-impact weather events (National Mesonet US, 2018). We argue that Mesonet dashboards are a type of operational dashboard— a dashboard that helps one make actionable decisions (Sarikaya et al. 2018). For this reason, we use the term dashboard, rather than website, to describe the focus of our analysis, described below.

In this study, we use quantitative content analysis to identify how 18 Mesonet dashboards present their data: the types of content, style, structure, navigability, and interactivity that are present on their websites. This type of systematic examination can reveal the current design practices and visual and functional features of Mesonet dashboards. Future efforts can draw from these findings to adapt individual dashboards to meet the needs of decision makers. We begin by reviewing the literature on how dashboard design can facilitate efficient decision-making.

2. Literature Review

Emergency managers and other decision makers require a range of data and information on past, current, and future conditions to make informed decisions. Information-seeking is driven by the need to close the gap of information insufficiency a person believes they have (Dunwoody & Griffin 2015). However, having to dig through too many sources of information (especially in an unorganized fashion) can reduce their ability to process the information, stemming from phenomena described as “cognitive overload” (Fisher & Weber 2020; Hwang & Lin 1999). Cognitive overload can reduce a decision-maker’s ability to (a) understand the current situation and (b) select the proper course of action (Javed et al. 2012; Chan 2001). Although other factors can lead to cognitive overload, such as time constraints (Edwards et al. 2012; Chu & Spires 2001; Hahn 1992), the presence of too much information is a commonly cited reason it occurs (Schulz et al. 2012).

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The need for a speedy decision at the risk of timeliness and accuracy often becomes a trade-off in the decision-making process (Laker et al. 2018; Murphy 1993). Making time-critical decisions based on past experiences can catalyze a change in circumstances and may allow for more time for further decision-making (Klein, 1986). However, when a person is overwhelmed with an unusual situation or a surplus of new information, decision-makers may be unable to rely on past experiences. To overcome cognitive overload, decision makers can "satisfice" when they seek out information. Satisficing occurs when a decision maker attempts to produce the most acceptable solution efficiently, as opposed to the best decision (Simon 1955). For example, an overwhelming amount of information to sort through may lead to decision-makers picking the solution that is "good enough" or satisfactory, rather than ideal. By accepting an easier answer, the decision-maker does not have to do as much work (Caplin 2011). However, satisficing while making decisions for high-impact weather may lead to suboptimal decisions (Artinger 2022), rather than the best decision for the context.

A dashboard has the potential to alleviate some cognitive overload. A well-designed dashboard will facilitate quick and easy decision-making by presenting relevant data in a digestible format by consolidating information (Few 2006) or visualizing complex data with a simple graphical presentation (Huang et al. 2009). Dashboards can also eliminate the need to satisfice. By displaying essential information all in one place, dashboards can reduce the cognitive effort one needs when searching for information (Drury 2012; Norman 2013) or the time taken for extensive information-seeking (Ley et al. 2013, Rosati 2013). However, the existence of a dashboard alone does not guarantee effectiveness: poorly designed dashboards that are visually disorienting, cluttered, or contain insufficient information negate the advantages of a having access to all the information that is needed in one place. A good balance is required (Yigitbasioglu & Velcu, 2012).

As a form of communication about data, we can evaluate dashboards by their composition, which determines how individual components are combined and presented (Bach et al. 2022). These components include content, presentation style, interactivity, and structure (Few 2006; Shen & Bigsby 2013; Sarikaya et al. 2018). We describe each of these features in detail next.

Content

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Content refers to what the dashboard is about and/or the data it contains, typically communicated via numbers, text, or images. For example, operational dashboards have been created for decision-makers in public health using epidemiological data (e.g., confirmed COVID-19 cases; Dong et al. 2020), higher education administration using educational data (e.g., student retention; Muntean et al. 2010), and business using financial data (e.g., a company's stock market value over time; Nica et al. 2021). Mesonet data is meteorological in nature, with variables such as temperature, dewpoint, and humidity for a location.

Style

Presentation style refers to the way the content is presented—or *how it appears* to the viewer. Data can be visualized with graphs, charts, maps, or other formats that convey the content in meaningful ways to the viewer (Bostrom et al. 2016). The way these data visualizations are designed also has implications for the overall usability of the dashboard. For example, bar graphs should be sorted from highest to lowest to allow for easier comparison between categories (Camm et al. 2017). Varying colors or fonts can call a viewer's attention to specific data or create continuity between categories (Sutton & Fischer 2021). A consistent presentation style also strengthens visual aesthetics, which can enhance usability (Moshagen et al. 2009).

Interactivity

Dashboard interactivity refers to tools that allow a user to *engage and interact* with its content. These include mouse-over effects (e.g., feedback and hover-over information), scrolling and panning (e.g., dragging content vertically or horizontally), zooming in or out, and pointing and clicking on objects. Interactive tools can be utilized through various modalities which affords users greater participation (Sundar et al. 2010). Some interactive tools are active (or direct), facilitating and initiating changes in the dashboard through clicking, selecting, or typing. Interactivity can also be passive: indicators such as changing mouse shapes or changing colors when the user guides or hovers their mouse over objects. Passive interactivity does not directly change content but can affect how the user perceives information on the website.

Structure

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Structure refers to where the content, presented as shapes and objects, is *physically placed* on the page through hierarchy, proximity, and continuation. Structure helps to create a visual hierarchy of content (Shen & Bigsby 2013), such as placing the most important content at the top. Dashboards that are structured using a visual hierarchy are easier to read, facilitating easier information seeking and processing. Hierarchies are created by structuring content proximally and in cohesive or continuous patterns (Djamasbi 2011). Proximity suggests a relationship between different content by measures of how close or far each object is from each other (Wertheimer 1938). Items close in proximity are perceived as related to each other. However, if items are too close, the dashboard can appear cluttered. Conversely, items too far apart can create considerable whitespace, which can create an "empty" look (Chaparro et al. 2000). For objects to achieve a sense of continuation, balance can be found by placing them close to each other, cohesively. Continuation allows the viewer to observe content quickly because their eyes take a natural path between elements, rather than having to jump between elements (Wertheimer 1938). Operational dashboards that are designed following these principles may enable end users to make quicker decisions with optimal information access due to their navigability and ease on visual attention.

With all of these components in mind, we pose the following research questions:

RQ1: What type of content is included in Mesonet dashboards?

RQ2: What is the style in which content is presented in Mesonet dashboards?

RQ3: To what extent are Mesonet dashboards interactive?

RQ4: How are Mesonet dashboards structured?

3. Method

Sample

To determine our sample of Mesonet websites to analyze, the research team began by examining the list of Mesonets from the "Mesonet" Wikipedia page, which hosts a master list of all Mesonet stations past and presently operating. Out of these, 36 Mesonets were found to have websites. We excluded ten Mesonet websites because they did not operate in the United States, leaving 26 sites for further investigation. From there, we selected websites that display

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real-time observational data, removing two additional websites that only contained archival observation data. We also excluded three more websites because two provided content only in a non-interactive, static format, and one dashboard contained only live radar imagery. Additionally, one website was under construction, and one dashboard was no longer operating. Of the original 26 pages selected, 18 Mesonet websites remained: six in the Northeast, three in the Southeast, five in the Midwest, two in the South (two within the same state), and two in the Southwest (see Table 1).

Name	**State**	**Scope**
New York	NY	Statewide
Kentucky	KY	Statewide
Texas	TX	Statewide
Keystone Mesonet	PA	Statewide
Nebraska Mesonet	NE	Statewide
North Dakota Agricultural Weather Network (NDAWN)	ND	Statewide
Mesonet	OK	Statewide
Kansas Mesonet	KS	Statewide
Florida Automated Weather Network (FAWN)	FL	Statewide
West Texas Mesonet	TX	State (portion)
New Jersey Weather & Climate Network (NJWxNet)	NJ	Statewide
Mt. Washington Regional Mesonet	NH	Statewide

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Delaware Environmental Observing System (DEOS)	DE	Statewide
North Carolina ECONet	NC	Statewide
Arizona Meteorological Network	AZ	Statewide
Georgia Automated Weather Network (AEMN)	GA	Statewide
Mesowest	UT	Nationwide
Ohio Agricultural Research and Development Center (OARDC) Weather System	OH	State (portions)

Table 1. List of Mesonets.

c. Coding

We focused on the landing page (or homepage) of each Mesonet website as the unit of analysis. For each homepage, we coded for the presence or absence of each feature described below (see Table 2). The codes were developed inductively, that is, they emerged from the data, by a coding team comprised of the first author and an undergraduate student in atmospheric science. This team collaborated over multiple sessions, identifying three distinct aspects of Mesonet dashboard design: content, style, and interactivity.

Code	Definition	Example
Content	Atmospheric variables measured at Mesonet station sites	Temperature, humidity
Style	How data is presented on the dashboard	Maps, tables, graphs

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Interactivity	Features that enable dynamic interaction of each dashboard	Mouse over effects, scrolling, and panning

Table 2. Coding scheme for content, style, and interactivity

Coding was performed independently by both members of the coding team for each Mesonet dashboard, identifying the presence or absence of content and style elements. Codes were recorded using Excel spreadsheets. The team then jointly discussed their coding results until they reached 100% agreement.

To determine interactivity, coders used the computer mouse to interact with each dashboard on a desktop computer. Interactivity characteristics include mouse-over effects (including 'feedback' and 'hover-over information'), scrolling and panning (dragging content, usually a map, vertically or horizontally, respectively), zoom, and point-and-click data filters, and map overlays. While they may have been present, available datasets were not downloaded.

The first author independently assessed the *structure* of each dashboard, by identifying where physical contents are placed on the screen. First, the common dashboard elements visible on the homepage (e.g., logo, header, map, legend, filer toggle, station information, social media, and banners) were identified as key areas of interest (AoIs; Sutton & Fischer 2021). Next, we drew boxes around each AoI to measure the area in pixels (px^2). Sectioning off content in boxes illustrates the approximate space they take on the dashboard. To draw direct comparisons of placement across dashboards, these boxes were organized by color.

Each entire screen was calculated to be 1920x1080 px, the standard size of a desktop computer screen (Fig. 1). Then, each Mesonet homepage was divided into nine equal grids to determine where each content feature was located within each section of the grid. The ratio of nine equal grids stems from the Rule of Thirds, a composition-framing tool from the discipline of photography (Krages 2005).

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Fig 1a. Mesonet standardization

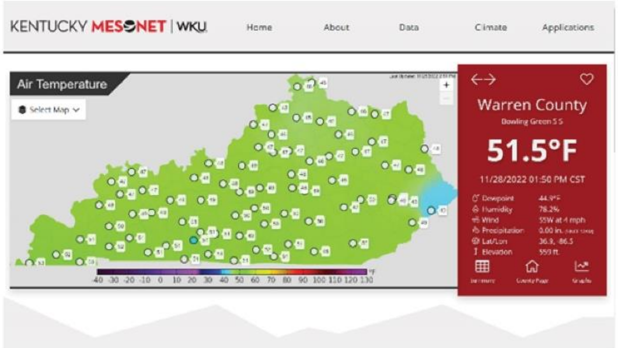

Fig 1b. Areas of Interest (AoIs)

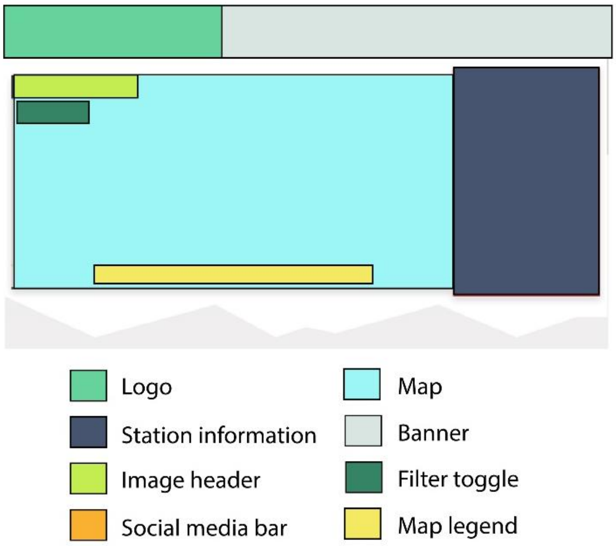

Fig 1c. Rule of Thirds

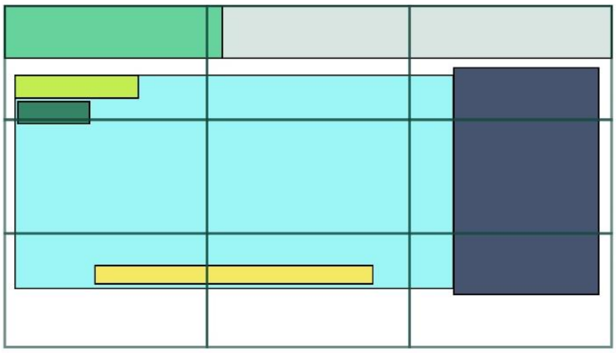

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Fig. 1. The process of structure analysis: (a) An example of a dashboard (here, from the Kentucky Mesonet) resized to a fit a standard computer screen. (b) The dashboard in (a) is decomposed into areas of interest (AoI) that reflect the placement of content and interactive controls. (c) The generalized representation of AoI from (b) are further divided using the Rule of Thirds to explore and analyze the visual alignment of information in each dashboard.

Handwritten notes were taken throughout the coding process to provide further insight into notable elements within each category (Saldana 2015).

4. Results

a. Content

15 Mesonet dashboards contain data that covers the entirety of the state in which they were located and often have multiple purposes, two Mesonet dashboards span portions of their states, and one Mesonet dashboard is nationwide. Most included historical data (77.7%; *n* = 14) and provided real-time observations (83.3%; *n* = 15). A subset of Mesonet dashboards focused on agriculture (27.7%; *n* = 5), which provide additional measurements such as soil temperature or index tools for crop management.

Mesonet dashboards included variations on five types of meteorological measurements: temperature, moisture variables, precipitation, wind speed, and barometric pressure (see Table 3). All 18 Mesonet dashboards displayed the current temperature (100%), and five (27.8%) included the minimum/maximum predicted temperatures for that day. Mesonet dashboards also frequently included measurements of moisture such as precipitation (94.4%; *n* = 17), relative humidity (83.3%; *n* = 15), and current dewpoint (72.2%; *n* = 13). In addition, all 18 (100%) Mesonet dashboards included measurements of wind speed, and 11 (61.1%) had measurements of barometric pressure.

Variable	(AMS Glossary of Meteorology definition)	n	% found on dashboards
Air Temperature	The temperature indicated by a thermometer exposed to the air in a place sheltered from direct solar radiation.	18	100

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Maximum Temperature	The highest temperature reported for a given location during a given period.	5	27.8
Minimum Temperature	The lowest temperature reported at a given location during a given period.	5	27.8
Dewpoint	The temperature to which a given air parcel must be cooled at constant pressure and constant water vapor content in order for saturation to occur.	13	72.2
Relative Humidity	The ratio of the vapor pressure to the saturation vapor pressure with respect to water.	15	83.3
Precipitation	Hydrometeors formed in the atmosphere that are large enough to fall as a result of gravity: here, measured in liquid-equivalent amount regardless of type.	17	94.4
Wind Speed	Ratio of the distance covered by the air to the time taken to cover it.	18	100
Atmospheric or Barometric Pressure	The pressure exerted by the atmosphere as a consequence of gravitational attraction exerted upon the "column" of air lying directly above the point in question	11	61.1

Table 3. Atmospheric content identified in each Mesonet dashboard.

c. Style

Mesonet dashboards display content in three ways: maps (to show the geographical location of data), sidebars (boxes found along the side of content it is emphasizing), and graphs (plots or other presentations of data) (see Table 4). Approximately 89% of Mesonet dashboards (*n* = 16) employed maps to depict state-wide observations from geographically placed data points. Mesonets without maps communicated data using tables with location names or presented data as a collection of graphs on one page. All maps made use of filters that allow users to visually overlay meteorological variables. Map filters featured

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measurements of temperature, humidity, dewpoint, accumulated precipitation, pressure, and wind speed. All Mesonet dashboards with maps contained coordinate points of stations across the state, often signified with a dot or data point. Mousing over or clicking on these station points provides a detailed view of observations from individual stations. Less than half of the Mesonet dashboards (44.4%; *n* = 8) included radar loops (that is, reflectivity maps from which precipitation intensities can be inferred by trained readers). Radar loops are presented as animations overlaid on maps to visualize the motion of current precipitation.

Approximately 55% of dashboards (*n* = 10) include sidebars. Sidebars are comprised of boxes located beside a map containing detailed information about a local Mesonet station when selected by the user. Sidebars typically display the data for one station at a time and are separated from the map rather than located as a box on top of it. Like map filters, sidebars included tables with temperature, precipitation, humidity, dewpoint, pressure and wind speed content. However, sidebars represent point-in-time measures for an individual location, whereas state-wide map filters show a gradient across multiple stations.

Only two Mesonet dashboards (11%) displayed content as a series of graphs to show changes over time (line graphs), accumulation (bar graphs), or outlook forecasts (Table 5). Dashboards that presented content in graph form did not contain maps.

Variable	n	% found on dashboards
Filter (static colors)	16	100
Radar Loop	8	50
Sidebar	10	62.5

Table 4. Style of map dashboards (n = 16)

Variable	n	% found on dashboards
Tables	2	100

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Graphs (line and bar)	2	100

Table 5. Style of non-map dashboards (n = 2)

d. Interactivity

Overall, 16 Mesonet dashboards (88.8%) use passive, hover-over interactivity to display pop-up text boxes when the user drags the mouse cursor over an interactable feature (see Table 6). These text boxes can contain more information about the individual data point, the region the data point is in, or other meteorological measurements from the station.

Other forms of passive indication were less common. Only five Mesonet dashboards (27.8%) used visual feedback to highlight areas of interest. Feedback distinguishes what can be interacted with from the rest of the page via a visible prompt. Visual prompts include the mouse cursor changing from an arrow to a hand or the interactable item changing color. The two pages that did not include hover-over or pop-up boxes (11.2%) lacked an indication of interactive elements unless the user manually clicked on one of the items.

Maps also had active interaction features. Mesonet dashboards with maps on the homepage have a default map layer activated (e.g., current temperature). For example, 14 Mesonet dashboards (77.7%) allowed users to stack multiple datasets and switch between them through filter toggling. Filter toggling allows the user to replace the default observation measurement with other content (e.g., dewpoint, humidity, wind speed) through options in a dropdown menu. Filter toggling eases the effort required for user interaction, whereby the user only takes one click to change a static image to a different one. However, most dashboards only allowed for one additional layer of information. No Mesonet map dashboards had more than three filters on a map at a time (e.g., default map layer, one extra layer, radar loop).

Variable		Definition	n	% found on dashboards
Passive indication	Feedback	A visual transformation of the mouse cursor that indicates the interactive	5	27.8

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		potential of the object/item that is hovered over		
	Hover-over information	A pop-up box that provides additional text information when hovering the mouse cursor over an object.	16	88.8
Direct user action	Scroll/Pan	The user's ability to change the map perspective by clicking and dragging with the mouse. Scrolling drags the map vertically. Panning drags the map horizontally.	11	61.1
	Zoom	The user's ability to enlarge or minimize the map by using the mouse wheel or zoom buttons (+/-).	11	61.1
	Filter Toggles	The ability to cycle through different filters on the map while remaining on the same dashboard	14	77.7

Table 6. Interactivity was commonly divided between passive indicators and direct user action.

Furthermore, 11 Mesonet dashboards (61.1%) with maps included scrolling, panning, and zooming features. Scrolling and panning allow the user to move the map horizontally and vertically. The zoom feature allows the user to magnify and minimize areas on the map. Mesonet dashboards that did not have these features contain static maps with fixed

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granularity. Compared to dynamic maps, users cannot adjust the map beyond the scope of what the Mesonet dashboard provides.

e. Structure

We show Mesonet structure using a heatmap in Figure 2. Each percentage represents a fraction of the total pixels used across all Mesonet dashboards. Here, the darker color represents the highest concentration of content. Across all Mesonet dashboards, the center of the page contained the greatest concentration of content (15.8% of total pixels used), followed by the top-center of the page (14.7%). Mesonet dashboards also frequently placed content along the top, using the top-left (12.6%), top-right (11.9%), and bottom-center (11.8%) areas.

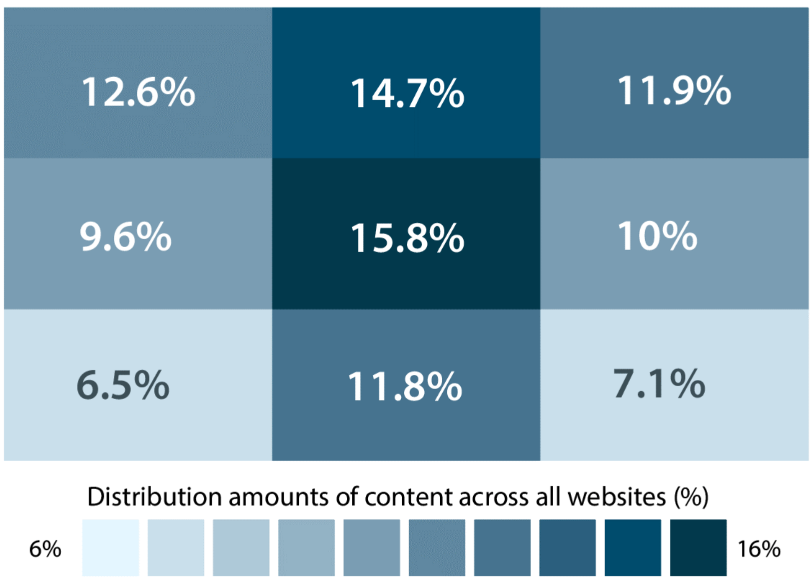

Fig. 2. Total percentage of content placement across all dashboards (in %)

The location of some content was standard across all dashboards (Fig. 3). Logos, included in 83.3% (n = 15) of dashboards, were consistently placed in the top left. These logos were frequently placed within banners of the dashboard (94.4%; n = 17), which spanned the top of

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the dashboard. Banners are long stretches of space that contain logos, whitespace, or tabs for navigating to different pages within the dashboard.

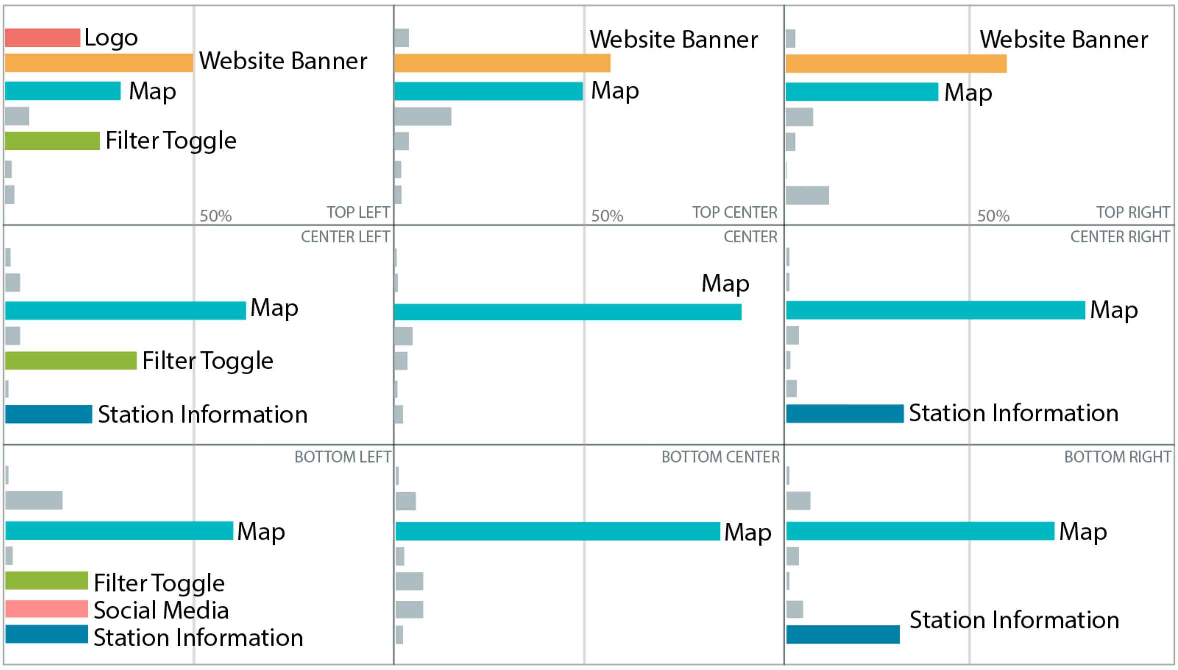

Fig. 3. AOI placement and distribution across dashboards (n=18) in %

Maps, included in 88.9% (*n* = 16) of dashboards, occupy the most space and are generally centered in orientation. Maps could range in size from three grids to all nine grids and were oriented both horizontally and vertically. Map filter toggles (88.9%; *n* = 16) tended to be on the left column beside the associated maps. In fewer dashboards (*n* = 2), we found filter toggles along the top or to the right of the map. Map legends, present in 55.6% of dashboards (*n* = 10), were usually in the bottom left grid, below the map, or within the map. Map legends are important for facilitating the interpretation of colors used within maps.

Other contents could vary in location. Station information, found in 61.1% of dashboards (*n* = 11) provides meteorological observation content and was equally likely to be located on the left or right side of the map. Station information was generally placed within sidebars (55.6% *n* = 10), which displayed station information distinctively through the use of color or size. Only one dashboard (5.55%) provided station information alongside the map as a table without a distinctive design.

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5. Discussion

We conducted a quantitative content analysis of 18 Mesonet dashboards to identify the type of meteorological content included in each dashboard, the style, the structure of the dashboard, and dashboard interactivity. By taking inventory of their visual and functional aspects, we can understand what is currently being done to communicate data about meteorological conditions.

a. Content

First, we find that there is consistency of content across most dashboards. Mesonet content most frequently includes temperature, humidity, dewpoint, precipitation, and wind speed data. However, we also find that the inclusion of some content is inconsistent between dashboards. For example, dewpoint and relative humidity are reasonable proxy measures for fog or mist. Including dewpoint in a dashboard can aid decision-making regarding weather conditions like dangerous fog or heat amplified by both high temperatures and moisture. However, dewpoint was not present in 28% of dashboards. Barometric pressure, a common metric used by meteorologists for determining large-scale weather patterns, was not included in around 39% of Mesonet dashboards.

Some Mesonet dashboards delivered specific content to specific audiences: when they did, those designs differed. For example, Mesonet dashboards that are agriculturally based include index tools for livestock and crops that non-agricultural Mesonet dashboards do not. These indices were typically presented as static tables. It remains unclear how sector-specific dashboards were designed to specifically address the needs of the end user. However, the possibility exists that the dashboard designer chose to present data as static tables due to demand from individuals within the agriculture sector.

b. Style

We find that Mesonet dashboards typically allow users to observe at a broad geographical scale as well as point measurements via maps. For example, most landing pages feature statewide maps displaying individual station measurements. This presentation style offers an overview of the meteorological conditions across the state, allowing conditions between different stations to be compared. By using map filters to monitor environmental changes

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over time, decision-makers can infer changes in their area like the geographical direction of temperature and precipitation moving in. This can assist in anticipating the timing of incoming events, and deployment of key resources in response.

Mesonet dashboards also present information narrowly. By clicking a point on the map, individuals can see more detailed station information displayed within sidebars. Because sidebars are visually placed alongside the map, the user can view both wide and narrow observations simultaneously and make comparisons of the narrower local conditions with statewide observations. Sidebars reduce the need to toggle between different content on different pages, thus reducing the cognitive effort necessary to hold information in working memory as a new page is viewed.

Mesonet dashboards also display station information in table format. These tables are usually static, whereby users can pull up station information for viewing but cannot manipulate the data any further. Mesonet dashboards also used time-series plots like line graphs and bar graphs. Line graphs commonly represent trends and changes in temperature, humidity, and dewpoint. Bar graphs commonly represent precipitation accumulation measurements. Using time-series plots has advantages and drawbacks. Designers who do not wish to include maps may find these plots as a suitable alternative if they wish to represent change over time. However, those dashboards would be limited to individual station points and would lack broad coverage of changing weather conditions.

Mesonet dashboards did not use charts other than line and bar graphs. Also missing from all dashboards was the use of dials or other dynamic indicators, such as severity indices (i.e., a diagram visualizing stoplight colors for risk). Dials can be useful for visualizing intensity of individual variables. Their applicability on a Mesonet dashboard is not known and is a point for future research.

c. Interactivity

Page interactivity can amplify the effects of visual displays (Bostrom et al. 2008). Map toggles, map filters, and station information selection are all interactive features that allow users to stay on the homepage while viewing additional content. The user can choose different content to overlay on the map and switch between them on one screen. Toggles

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simplify dashboard layout by allowing data to remain visible without the user losing their place. Toggles also eliminate user multitasking since they do not need to browse multiple pages. In other words, the decision-maker can record and compare different observations simultaneously. Mesonet dashboards with map layers also use less visual space on the screen by tucking several data sets into a small library until the user needs it.

Equally important to page interactivity is functionality. In this study, we found that more than 72% of Mesonet dashboards lacked noticeable visual feedback. When users do not have obvious visual cues to indicate what they can interact with, they cannot utilize the dashboard to its fullest potential. If a user cannot find the toggle to change map filter layers because its design is less noticeable than other features, the advantages gained from layering data will be lost. For the Mesonet dashboards that displayed station information as graphs instead of maps, these tables were static. They do not provide any functionality for calculating or manipulating the data beyond hovering over it for more information. Adding dynamic functionality may improve the use of the dashboard by allowing the user more interaction.

d. Structure

We found that page structure was consistent in that most Mesonet dashboards started with a map of their respective state placed in the center of the grid. Station information was to the left and right of maps, filter toggles were on the left, map legends were at the bottom, and logos were on the top left. Logos are a general feature of dashboard branding: dashboards that do not have logos filled space with full-sized maps that take up the whole page. Also notable is that approximately one-third of the Mesonet dashboards that included a map did not have legends.

And finally, the design consistency of Mesonet dashboards follows standard web design standards. Eye-tracking research has found that F-shaped scanning is a pattern for viewers reading content on computer screens (Pernice et al. 2018; Djamasbi 2011). F-shaped scanning occurs in areas where people skim for relevant information from top to bottom, and then across from left to right, typical of western languages. Dashboard design does not need to be F-shaped to be successful: F-shaped scanning is the default pattern when there are no obvious design cues towards important information (Pernice et al. 2018). However, content that is structured along natural scanning patterns may relieve the cognitive load of the user, which

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helps users make quicker decisions (Oviatt, 2006). Across Mesonet dashboards the distribution of pixels used across the nine grid boxes followed a similar pattern (T-shaped, instead of F)- the top three grids and center grids contained the most content. It is not known how T-shaped structure affects visual search and decision-making.

It may not be a surprise to see that on average, content is accumulated at the center of the screen for Mesonet dashboards, while the left and right sides of the screen are used interchangeably for station information. Unequally balancing content to one side or the other is a typical design practice for visual variety. What is notable is the lower left and right corners are often left with more whitespace than the other portions. Designers may consider utilizing this empty space to place content (while being mindful that unnecessary clutter should be avoided).

6. Limitations & Future Research

This paper analyzes the content, style, structure, and interactivity of 18 Mesonet dashboards to characterize their existing design and usability. With additional research, these analyses can serve as a starting point to adapt these dashboards to the needs of decision-makers, such as emergency managers, working in contexts of high-impact weather. In this study, we quantify what data are presented and how it is presented; we do not yet know who accesses those data and why. Future research should include investigations with Mesonet users to determine what Mesonet data are used, how they are useful, and under what conditions. For example, to design for emergency management decision makers, user testing can include task-specific activities based on decision-making scenarios to uncover decision-maker needs. These activities can prompt decision-makers to explain their goals, demonstrate their use of existing sources and websites, and describe how decisions are made while accessing disparate data tools. By anchoring future dashboard design with end-user needs, decision-making dashboards will be informed directly by the user. This work makes the design process more efficient and effective.

In addition to determining what content should be included, user interaction research can determine what should not be included. For example, some researchers have found that not all emergency managers understand (Sutton et al. 2023) or rely on meteorological data for

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their work (Hoss & Fishbeck 2018). In this study, we found that meteorological variables like dewpoint or pressure were not consistently included. Dashboards that present surface pressure data can be useful for decision-making about extreme heat, winter weather, and severe storm threats; dewpoint can provide evidence of fog; rising dewpoint levels offer clues to imminent heat risks. However, they are only meaningful if end users have received the necessary meteorological training to read, interpret, and apply these raw data for decision-making. To analyze the usefulness of meteorological parameters (and by extension, the exclusion of unnecessary data), both the designer's intent and the characteristics and needs of the intended user should be accounted for.

Finally, the style and interactivity of data presentation, such as the use of filters and toggles, should provide easy access to data layers and may also be visually appealing. However, its usefulness will be limited if a decision-maker prefers data presented as simple, static, tabular station information. The relationship between aesthetic and usability is not strictly linear (Lindgaard & Dudek, 2002). We don't yet know if the colorful and interactive designs of some sites serve end-user purposes or what those specific purposes may be.

7. Conclusions

Prior research on dashboard design has indicated that the design of a dashboard for decision-making should consider the end user's goals and objectives while also presenting content in a style that is intuitive and uncluttered. Good design can reduce cognitive load and facilitate easy access to data that allows side-by-side evaluation of trends, patterns, and individual data points of meteorological observations for high-impact events. In this study, we have identified the key features that are included in 18 Mesonet dashboards across the contiguous U.S., to assess consistency in content, style, interactivity, and structure. From this assessment, we have identified the anatomy of a Mesonet dashboard, which could lead to strategies to improve information organization, create focal points, and facilitate data access for decision-making.

Ideally, the results of this study should inform future designers of what currently exists and how it is structured, as well as inspire existing Mesonet designers to take another look at their dashboards. Whether or not every aspect of these dashboards (content, style, structure

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and interaction) were intentionally and precisely designed cannot be determined by this paper. However, one avenue to attaining “good design” of a Mesonet dashboard is dictated by how well the average user can navigate and use it—“good design” being the act of making the product (the dashboard) useful. For designers looking to improve upon their product, this is where the implementation of user feedback provides benefit.

While user feedback is crucial for determining the necessary contents and data presentation style in a dashboard, one element remains consistent regardless of domain expertise: all users should be able to efficiently navigate dashboards. This means making key content easily identifiable, creating obvious cues to interactivity, offering a legend and labeling maps, and organizing content using a visual hierarchy by shaping the most important content with noticeable size and color contrasts compared to other data. Discussing the existing contrast levels between areas of interest or the color-blind friendliness of current palettes is beyond the scope of this paper. However, these design concepts are extremely relevant to dashboard designers. Whether a Mesonet dashboard user has domain expertise in the field of meteorology or not, their ability to navigate a dashboard and identify key content should be intuitive and simple, and the factors listed above are vital to that.

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Data Availability Statement.

All data is provided in full in the results section of this paper.

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