

# Implications of Sea Breeze Circulations on Boundary Layer Aerosols in the Southern Coastal Texas Region

Tamanna Subba<sup>1</sup>, Michael P. Jensen<sup>1</sup>, Min Deng<sup>1</sup>, Scott E. Giangrande<sup>1</sup>, Mark C. Harvey<sup>2</sup>, Ashish Singh<sup>1</sup>, Die Wang<sup>1</sup>, Maria Zawadowicz<sup>1</sup>, Chongai Kuang<sup>1</sup>

<sup>1</sup>Environmental Science and Technologies, Brookhaven National Laboratory, Upton, NY, United States

<sup>2</sup>Department of Physics, Texas Southern University, Houston, TX, United States

Correspondence: Tamanna Subba (tsubba@bnl.gov)

## Abstract

The Sea Breeze Circulation (SBC) influences atmospheric processes at multiple scales in coastal regions. Understanding how SBCs impact the aerosol number budget and aerosol-cloud interaction processes is essential. This study investigates sea breeze-aerosol interactions (SAIs) during 46 summertime SBC events using data from the TRacking Aerosol Convection Interactions Experiment (TRACER) field campaign across urban (main) and rural (supplemental) coastal sites in southern Texas. Weather Research and Forecasting model coupled with Chemistry (WRF-Chem) simulations complement observations to explore spatio-temporal meteorological controls on boundary layer aerosols. During the summertime, Sea Breeze Fronts (SBF) penetrating inland transported cool, moist air over the land, introducing air masses with distinct properties compared to the preexisting continental air. These SAIs cause variability in number concentrations of up to a factor of two, with events typically lasting ~5 hours, before returning to background conditions. SAI impact on aerosols varies with site proximity to water and the preceding sea breeze (SB) history, primarily affecting the marine-influenced accumulation mode. The main site, influenced by both Galveston Bay and the Gulf of Mexico, reflects a stronger marine influence. In contrast, a supplemental site, at a similar shoreline distance but exposed to the Gulf of Mexico and typically upstream of the urban core, samples SB air that has traversed land and partially regained continental characteristics. Simulations show that the regional SAIs extend ~50 km inland and reach up to the boundary layer height. SAIs further decrease cloud condensation nuclei relevant aerosol number concentrations in ~20% of events during SBF passage.

- Formatted [1]
- Deleted: impact on aerosol
- Deleted: perturbation of incoming solar radiation
- Deleted: and urban
- Deleted: the campaign
- Formatted [2]
- Deleted: rs
- Deleted: 's
- Deleted: 's
- Deleted: the sea
- Deleted: coastal
- Deleted: TRACER
- Formatted [3]
- Deleted: ,
- Deleted: while
- Deleted: the
- Formatted [4]
- Formatted [5]
- Formatted [6]
- Formatted [7]
- Formatted [8]
- Deleted: primarily
- Deleted: located inland site from both Galveston Bay and
- Deleted: farther from
- Formatted [9]
- Deleted: reflects
- Deleted: masses
- Deleted: ve
- Formatted [10]
- Formatted [11]
- Formatted [12]
- Formatted [13]
- Deleted: Model output
- Deleted: In addition, this study finds that
- Deleted: modify
- Formatted [14]
- Formatted [15]
- Deleted: SBC further influences the local aerosol ra(
- Deleted: SAIs modify cloud condensation nuclei in
- Deleted: For the typical TRACER SBF passage, the
- Deleted: ¶
- Formatted [16]

64 **1 Introduction**

65 A significant portion of the global population resides in coastal cities, including several  
66 megacities (Brown et al., 2013). Nearly half of the U.S. population faces environmental  
67 challenges associated with complexities tied to urban coastal atmospheres (Crossett et al.,  
68 2004; Hudson et al., 2012). Houston, located along the Southern Texas coastline, is one of the  
69 United States' most populated cities, while also one of its most polluted, with high aerosol  
70 concentrations (Yoon et al., 1994; Kleinman et al., 2002; Banta et al., 2011). ~~Aerosol particles~~  
71 ~~can negatively impact human health~~ (Partanen et al 2018; Mack et al., 2020), ~~and influence~~  
72 ~~Earth's energy balance.~~ ~~They exert direct effects by~~ scattering and absorbing the incoming solar  
73 radiation, ~~altering net radiative fluxes~~ (Charlson et al., 1992; Bond et al., 2013; IPCC, 2021),  
74 ~~and indirect effects by acting as~~ cloud condensation nuclei (CCN) and ice nucleating particles  
75 (INP), ~~thereby modulating cloud microphysical properties and precipitation processes~~  
76 (Twomey, 1974; Albrecht et al., 1989; Ramanathan et al., 2001; Rosenfeld et al., 2008; Ariya  
77 et al., 2009; Burkart et al., 2021).

78 In particular, the Houston region experiences highly complex aerosol processes due to  
79 elevated local emissions, diverse aerosol sources, and intricate atmospheric chemistry. ~~One~~  
80 ~~such process is new particle formation (NPF), which is a common aerosol microphysical~~  
81 ~~process that impacts the overall aerosol number concentration (Kulmala et al., 2004; Kerminen~~  
82 ~~et al., 2005; Kuang et al., 2008; IPCC 2013). NPF events typically include a sudden burst of~~  
83 ~~aerosols, i.e., the nucleation of gas molecules and formation of stable clusters of diameters~~  
84 ~~'Dp' > 2 nm, followed by subsequent growth, firstly to a size range with Dp > 50 nm and~~  
85 ~~possibly growing to a size where the particles can act as a CCN (Dp > 100 nm) (Yu and Luo,~~  
86 ~~2009; Kerminen et al., 2012; Gordon et al., 2017). In addition, mesoscale meteorological~~  
87 ~~phenomenon around Houston, such as sea breeze circulations (SBCs), further modulate these~~  
88 ~~aerosol dynamics~~ (SBC, e.g., Miller et al., 2003; Wang et al., 2024; Deng et al., 2025;  
89 ~~Thompson et al., 2025). These SBCs develop regularly in the warm season along coastal~~  
90 regions (Miller et al., 2003). One key challenge for aerosol process studies common to coastal  
91 city environments is in determining the relative importance of aerosol microphysical versus  
92 mesoscale meteorological controls such as ~~SBCs, in~~ governing the aerosol number budget and  
93 aerosol impacts on that population center.

94 The summertime SBC is a thermally-driven feature tied to differential heating between  
95 the land and sea; this results in density gradients that cause the cooler marine air to propagate

**Deleted:** These a

**Deleted:** have regional adverse effects on human health

**Deleted:** while on the global scales impacting Earth's energy balance...

**Deleted:** These impacts

**Deleted:** may be felt directly through aerosol

**Deleted:** and/or

**Deleted:** ly

**Deleted:** through aerosol influence on clouds and precipitation as...

**Formatted:** Font color: Auto

**Deleted:** For eg.,

**Formatted:** Font color: Auto

**Deleted:**

**Deleted:** s

**Deleted:** the

**Deleted:** Understanding

**Deleted:** complex aerosol processes around Houston is further complicated as the regional meteorology may be influenced by sea breeze circulations

**Deleted:** s

**Deleted:** areis a mesoscale meteorological phenomenaon that ...

**Deleted:** s

**Deleted:** SBCs in

119 inland (Miller et al., 2003; di Bernardino et al., 2021). Daytime SBC formation can facilitate  
 120 convective cloud and precipitation onset (Comin et al., 2015), influence boundary layer  
 121 meteorology (Adaricheva et al., 2023), and has been associated with complex impacts on  
 122 overall air quality (Simpson, 1994; Masselink and Pattiaratchi, 1998; Moorthy et al., 2003;  
 123 Miller et al., 2003; Augustin, et al., 2020; Park et al., 2020; Parajuli et al., 2022; Wang et al.,  
 124 2023). These circulations also influence transport of atmospheric gases (Gangoiti et al., 2001;  
 125 Ahmadov et al., 2007; Hernández-Ceballos et al., 2015) and aerosol particles (Clappier et al.,  
 126 1999; Borge et al., 2008; Papanastasiou et al., 2010). A sea breeze front (SBF), which is the  
 127 boundary between that cooler, ~~more moist~~ marine air of the SBC flow and the warmer, ~~drier~~  
 128 air over the land, is often a focal point that facilitates the transport and dispersal of aerosols, as  
 129 well as aiding in the formation of cumulus clouds (Miller et al., 2003). ~~While low-level lapse~~  
 130 ~~rates are often more stable on the maritime side of the SBF, the conditional instability~~  
 131 ~~(Convective Available Potential Energy-CAPE) is often observed to be greater on the maritime~~  
 132 ~~side due to the higher moisture content in that air mass (Hanft and Houston, 2018; Sharma et~~  
 133 ~~al., 2024; Boyer et al., 2025).~~ Convergence along these SBFs often ~~results in enhanced~~ upward  
 134 air motion, allowing aerosols to ascend to higher altitudes ~2 km (Iwai et al., 2011). Stronger  
 135 wind shear along these SBFs also generates increased turbulence, as owing to Kelvin-  
 136 Helmholtz instability occurring just behind this front (Linden and Simpson, 1986; Plant and  
 137 Keith, 2007), while the aforementioned vertical air motions are important for convective cloud  
 138 initiation (Rao and Fuelberg, 2000; Arrillaga et al., 2020).

139 The common conceptual model for SBCs is one where the marine air mass propagates  
 140 inland, bringing with it different atmospheric and aerosol characteristics compared to the  
 141 ambient land air mass conditions. In this study, ~~the influence of these SBCs on regional aerosols~~  
 142 ~~is termed~~ as “sea breeze - aerosol interaction” (SAI). Previous studies have shown that SAIs  
 143 vary depending on complex interactions among emissions sources, boundary layer dynamics,  
 144 and the strength and/or direction of ~~the SBC (Miller et al., 2003; Boyouk et al., 2011; di~~  
 145 ~~Bernardino et al., 2021)~~. For example, SBF passage has been ~~found to trap aerosols at lower~~  
 146 ~~elevations within the boundary layer (Miller et al., 2003).~~ In SBC environments, competing  
 147 processes can yield opposite aerosol responses, ~~as the~~ formation of ~~a shallow thermal boundary~~  
 148 ~~layer can confine particles near the surface and raise aerosol concentrations, whereas inland~~  
 149 ~~buoyant (convective) lifting within the convective boundary layer, can lift aerosols aloft~~  
 150 ~~(Simpson, 1994; Boyouk et al., 2011; di Bernardino et al., 2021).~~ In addition, SBCs may

**Deleted:** stable  
**Deleted:** unstable

**Deleted:** often  
**Formatted:** Not Highlight  
**Formatted:** Not Highlight  
**Deleted:** Moreover, locations  
**Deleted:** exhibit an enhancement in  
**Formatted:** Font: Italic  
**Formatted:** Font color: Auto

**Formatted:** Indent: First line: 0.5"

**Deleted:** we term any  
**Deleted:** have  
**Formatted:** Font color: Auto  
**Formatted:** Font color: Auto

**Deleted:** previously  
**Deleted:** The competition between converging winds associated with the front, and the vertical air mixing over the land, controls this lifting of aerosols (Simpson, 1994; di Bernardino et al., 2021).

**Formatted:** Font color: Auto  
**Deleted:** the often-opposing winds along associated with the front, and the vertical air mixing over the land, drive controls this

**Deleted:** On the other hand,  
**Formatted:** Font color: Auto

167 replace the regional air mass with the cleaner marine air mass, leading to a decrease in surface  
168 aerosol concentration. This now-modified coastal environment can affect the generation and  
169 growth of aerosols, impacting the local aerosol number budget that further influences their  
170 direct and indirect effects.

171 Although several studies have investigated the overall change in the aerosol loading  
172 during SBC events, less is known about the role of SAI on the aerosol microphysical properties.  
173 Moorthy et al. (1993) observed that the passage of the SBF was associated with an increase in  
174 the concentration of smaller particles. Furthermore, since SBFs propagate inland, SBCs can  
175 have far-reaching impacts on aerosol properties (Iwai et al., 2011; Park and van den Heever,  
176 2022). As an example, previous studies conducted in the Southeastern United States indicated  
177 that inland propagating SBFs are followed by air masses that often contrasted with regional air,  
178 having potential influence on distances 220 km from the Gulf of Mexico (Viner et al., 2021;  
179 Bao et al., 2023). In a similar case of these farther-reaching influences, Parajuli et al. (2020)  
180 found that the SBC influences the aerosol vertical distribution over the eastern coast of the Red  
181 Sea while lifting dust aerosols along the western slope of the Sarawat mountains, with the  
182 elevated dust at a height of ~1.5 km over the mountains. Similarly, Talbot et al. (2007) observed  
183 that enhanced turbulent activity along the SBF facilitated vertical aerosol transport above the  
184 boundary layer top (~1.1 km a.s.l.) over a flat coastal area of the North Sea.

185 Finally, high aerosol concentrations in the Houston area are linked to strong surface  
186 emissions and meteorological conditions (Wert et al., 2003; Ryerson et al., 2003). This metro  
187 region is also home to numerous petrochemical factories that are one of the sources of  
188 anthropogenic emissions. Several studies have also shown that meteorological conditions  
189 around Houston are highly susceptible to the interaction between large-scale (background)  
190 geostrophic flows and mesoscale SBCs (Miller, 2003; Wang et al., 2024; Deng et al., 2025).  
191 Pinto et al., (2014) observed that wind direction reversals bring aged, aerosol laden plumes  
192 with high O<sub>3</sub> and NO<sub>x</sub> levels back to the Houston area. They found that easterly winds,  
193 originating from the Houston Ship Channel (HSC), are most strongly associated with elevated  
194 levels of photochemically produced species. Similar conditions that promote O<sub>3</sub> and NO<sub>x</sub> build-  
195 up also drive secondary particle formation, leading to increases in aerosol number  
196 concentrations. These particle-phase enhancements in total number concentration result in  
197 higher aerosol concentration in the air mass transported from the east. Occasional increases in  
198 aerosol concentrations around the greater Houston metropolitan area can also be associated

Deleted: also

Deleted: the

Deleted: during the passage of the SBF

Deleted: oriented parallel and traveling perpendicular to the coastline to

Formatted: Font color: Auto

Deleted: As previously mentioned, inland SBF propagation of SBF may can significantly alter also bring additional aerosol property implications throughout and properties within and above the boundary layer.

Deleted: For instance,

Formatted: Font color: Auto

Formatted: Font color: Auto

Formatted: Font color: Auto

Deleted: was associated with

Deleted: for a

Deleted: (Talbot et al., 2007).

Deleted: TAs introduced above, the Houston-Galveston-Brazoria region in Texas is the fourth largest metropolitan area in the United States with a population exceeding 6 million people (Li et al., 2020).

Deleted: H

Formatted: Font color: Auto, Strikethrough

Formatted: Font color: Auto

Deleted: W

Deleted: oaded

Deleted: (Pinto et al., 2014)

Formatted: Not Highlight

Deleted: ozone

Formatted: Subscript

Deleted: ¶

Deleted: (

Deleted: metropoletin

Deleted: ?)at M1 and S3 sites

Formatted: Font color: Auto

225 with long-range transported aerosols. At the synoptic scales, the circulation patterns modulate  
 226 regional meteorology over the Gulf coast. The Bermuda-Azores High helps trans-Atlantic  
 227 transport of North African dust to the southeast coast (Perry et al., 1997; Bozlaker et al., 2013).  
 228 Summertime conditions are notably influenced by episodic transboundary aerosol transport  
 229 (Mao et al., 2020; Das et al., 2023), including dust events from the Sahara Desert (Aldhaif et  
 230 al., 2020) and biomass burning events in Central America and its neighboring states. The  
 231 biomass burning includes prescribed agricultural fires in Central America (Wang et al., 2018)  
 232 and forest fires in surrounding states (Westenbarger and Morris, 2018). Central America  
 233 biomass burning contributes to half of the biomass burning particulate matter concentrations  
 234 in Houston (Das et al., 2023). The motivation of this study is to investigate the role of SAIs as  
 235 observed over a complex urban megacity region, and specifically document SBC influence on  
 236 aerosol microphysical properties. These efforts expand on previous air quality studies over  
 237 Houston, including Li et al. (2020) who employed a K-Means clustering algorithm to study the  
 238 relationship between Houston-region SBCs and the daily ozone variability during the  
 239 DISCOVER-AQ (Deriving Information on Surface Conditions from Column and Vertically  
 240 Resolved Observations Relevant to Air Quality) field campaign. While Li et al. (2020) focused  
 241 on gas-phase chemistry, the same emissions and meteorological processes that drive ozone  
 242 variability can also influence aerosol loading over the southern Texas region.

243 This study capitalizes on the TRacking Aerosol Convection Interactions ExpeRiment  
 244 (TRACER) field campaign conducted by the US Department of Energy (DOE) Atmospheric  
 245 Radiation Measurement (ARM) user facility (Mather and Voyles, 2013), which took place  
 246 from October 1, 2021, to September 30, 2022 (Jensen et al., 2022; 2025). The main TRACER  
 247 field site was placed at an urban coastal location in Houston. As in TRACER's overarching  
 248 motivations, the Houston region is frequented by isolated convective clouds that interact with  
 249 ambient aerosol conditions from the urban and industrial sources, potentially serving as a  
 250 natural contrast to clouds that form in surrounding areas that exhibit significantly lower  
 251 background aerosol concentrations (Banta et al., 2011; Parrish et al., 2009; Wang et al., 2024;  
 252 Thompson et al., 2025). Additional observations were made at a rural coastal site (supplemental  
 253 site) in southern Texas during an intensive observation period (IOP) from June 1 to September  
 254 30, 2022. Using these TRACER-IOP measurements, our study explores how these SBCs  
 255 influence the aerosol environment at multiple ground sites. In addition, the Weather Research  
 256 and Forecasting model coupled with Chemistry (WRF-Chem) is used to investigate the

Formatted: Font color: Text 1

Deleted: dust originating in the far west to

Formatted: Font color: Auto

Formatted: Font color: Blue

Formatted: Font color: Auto

Formatted: Font color: Blue

Deleted: both the

Deleted: The Bermuda-Azores High helps dust originates in the far west to transport to the southeast coast (Perry et al., 1997; Bozlaker et al., 2013). This synoptic system and the mesoscale atmospheric circulation combine to influence the aerosol transport (Mao et al., 2020).

Deleted: In addition, the large-scale circulation patterns modulate regional meteorology over the Gulf coast. The Bermuda-Azores High governs wind regimes and modulates the flux of moisture to the Gulf of Mexico coastal region during summer (Hill et al., 2010; Wang et al., 2022). This synoptic system and the mesoscale atmospheric circulation combine to influence the aerosol transport (Mao et al., 2020). The Bermuda-Azores High helps dust originateoriginates in the far west to transport to the southeast coast (Perry et al., 1997; Bozlaker et al., 2013).

Deleted: Our

Deleted: Houston

Deleted: such as

Deleted: ¶

Formatted: Font color: Auto

Deleted: recent

Formatted: Indent: First line: 0.5"

Deleted: The, and a

Formatted: Font color: Auto

Deleted: will

Deleted:

Deleted: explore

Formatted: Font color: Auto

Deleted: we will use targeted

Deleted: ing

288 regional impacts of SAI over Southern Texas. A detailed description of the TRACER sites,  
289 instruments, measurements, and methodology, followed by the WRF-Chem model  
290 configuration details, are presented in Section 2. Section 3 presents campaign observational  
291 and simulated results. Our efforts will characterize the composite meteorological (Section 3.1)  
292 and aerosol (Section 3.2) observations during the IOP at the TRACER main and supplemental  
293 sites. This is followed by a composite analysis of the observed effects of the sea breeze on  
294 aerosol properties at the two ARM sites (Section 3.3), as well as a detailed case study  
295 examination of SAI influence for these locations (Section 3.4). The regional influence of SAI  
296 is further explored using model simulations, as demonstrated for the horizontal (Section 3.5)  
297 and vertical propagation of SAIs (Section 3.6), and SAI impact on cloud condensation nuclei  
298 over the southern Texas region (Section 3.7). The study concludes with our key findings  
299 summarized in Section 4.

Deleted: our

Deleted: primary

Deleted: urban

Deleted: rural

Formatted: Font color: Auto

Formatted: Font color: Auto

Deleted: and local aerosol radiative forcing

Formatted: Font: (Default) Arial, 11 pt

300

## 301 2 Data and methods

### 302 2.1 Site description

303 The DOE ARM TRACER field campaign was centered on the deployment of the first ARM  
304 Mobile Facility (Miller et al., 2016, herein AMF1) at the main instrument site (M1) (Fig. 1).  
305 The M1 is an urban coastal site located at the La Porte, Texas (TX) airport, to the south east of  
306 Houston, TX. Given the high propensity for isolated convective cloud events during  
307 summertime months (Jensen et al., 2022; 2025), the TRACER IOP was conducted from June  
308 1 to September 30, 2022, with a goal towards sampling a range of aerosol-cloud interactions  
309 during these convective events. Additional ARM and guest instruments were deployed to a  
310 supplemental site (S3) during the IOP as documented in Jensen et al. (2022). The S3  
311 supplemental site is a rural coastal site in Guy, TX, located ~70 km west from M1, upstream  
312 and periphery to the highly populated and commercial sectors of the Houston-Galveston-  
313 Brazoria region.

Deleted: 's

Deleted: and its

Formatted: Font color: Auto

Deleted: n

Deleted: ancillary

Deleted: this

Deleted: TRACER

Deleted: also

Deleted: This

Formatted: Font color: Auto

Formatted: Font color: Auto

314 The southern Texas region is characterized by flat terrain with elevations < 50 m a.s.l and  
315 a diversity of land cover/use, including urban, rural, grassland, and forested coastal  
316 environments (see Fig. 2a). Although both the M1 and S3 sites are a similar distance from the  
317 Gulf of Mexico, the M1 site is located near the western shore of Galveston Bay. This urban

Deleted: e

Formatted: Font color: Auto

332 M1 site may experience different sea-breeze timing because of its location, the added influence  
 333 of the Galveston Bay breeze, and urban heating that alters local circulations. The M1 site is  
 334 expected to be strongly influenced by anthropogenic activities due to its proximity to the  
 335 Houston urban core, large-scale industrial complexes and the HSC. The HSC is lined with  
 336 dense clusters of industrial facilities, including major petrochemical complexes (Yoon et al.,  
 337 2021), which can contribute to aerosol populations beyond those typically associated with an  
 338 urban environment. Similarly, the Texas A&M University (TAMU) TRACER measurements  
 339 also showed that short-lived ship emissions contributed to high aerosol concentrations (up to  
 340 34,000 cm<sup>-3</sup>) (Rapp et al., 2024; Thompson et al., 2025). The S3 site, while relatively less  
 341 impacted by the emissions from the Greater Houston area, is not representative of a pristine  
 342 rural location in terms of aerosol loading. Under typical south-southeasterly wind, this S3 site  
 343 is located downstream of heavy industry along the southeast Texas coastline (Freeport, TX and  
 344 Lake Jackson, TX), and can be influenced by upstream anthropogenic sources (Fig. 2b).

## 346 2.2 Measurements of aerosols and meteorological properties

347 This study focuses on the enhanced aerosol and complementary observations available  
 348 during the TRACER summertime IOP period. The key aerosol datasets available during this  
 349 IOP include: (1) the aerosol number size distribution and total number concentration, (2) bulk  
 350 aerosol chemical composition, and (3) state meteorological properties (e.g., surface  
 351 temperature, humidity). Campaign availability of in-situ observations at two contrasting sites  
 352 provided an excellent opportunity to understand the regional aspects of SAI.

353 The aerosol number size distribution with diameter ranging from 10 to 500 nm was  
 354 measured at M1 and S3 sites using Scanning Mobility Particle Sizer (SMPS) (Singh and Kuang,  
 355 2024). The aerosol number size distributions (dN/dlogDp) (aerosol number concentrations in  
 356 different diameter bins) at different diameters (Dp) were added to calculate the total integrated  
 357 aerosol number concentrations. Bulk aerosol chemical compositions consisting of total  
 358 organics, sulfate, nitrate, ammonium, and chloride were measured at M1 and S3 sites using  
 359 Aerosol Chemical Speciation Monitor (ACSM) (Watson, 2017). Surface meteorological  
 360 variables: temperature, water vapor mixing ratio ( $w$ ), wind direction and wind speed at M1 and  
 361 S3 sites were taken from the meteorological instruments collocated with the aerosol  
 362 instruments. All of these instruments are part of the ARM Aerosol Observing Systems (AOS).

Deleted:

Deleted: The southern Texas region is characterized by flat terrain with elevations < 50 m a.s.l and a diversity of land cover/use, including urban, rural, grassland, and forested coastal environments (see Fig. 2a).

Deleted: the

Formatted: Not Highlight

Formatted: Not Highlight

Deleted: H

Deleted: during the

Formatted: Superscript

Deleted: e

Formatted: Not Highlight

Formatted: Font color: Auto

Deleted: still

Deleted: , particularly near

Deleted: ,

Deleted: ure

Deleted: As in TRACER's overarching motivations, the Houston region is frequented by isolated convective clouds that interact with ambient aerosol conditions from the urban and industrial sources, potentially serving as a natural contrast to clouds that form in surrounding areas that exhibit significantly lower background aerosol concentrations (Banta et al., 2005; Parrish et al., 2009; Wang et al., 2024).

Formatted: Font color: Auto

Formatted: Font color: Auto

Formatted: Not Highlight

Deleted: T

Deleted: operating

Deleted:

Formatted: Font color: Auto

Formatted: Font color: Auto

386 which is the platform for in situ aerosol measurements at Earth's surface (Uin et al., 2019).  
387 Missing data were excluded from this analysis. If more than 20% of the data were missing  
388 during the 5 hours before and after the passing of the SBF, the dataset was not used to study  
389 SAI processes. SMPS and ACSM sample data at 5-minute and ~30-minute intervals,  
390 respectively. State meteorological variables were observed at one second intervals. All  
391 datasets, except for the ACSM, were averaged over a 5-minute interval, centered on the time  
392 of the SMPS sample.

393 To supplement the ARM observations, we use particulate matter of 2.5 micrometers or less  
394 in diameter (PM<sub>2.5</sub>) mass concentrations from the Texas Commission on Environmental  
395 Quality (TCEQ) database (Shrestha et al., 2023; sfcmetradatq-tceq ARM PI product). Although  
396 TCEQ operates a broad network of air quality monitoring stations throughout Texas, the  
397 Seabrook Friendship Park site (C45, -95.02°E, 29.58°N) was selected because it is the nearest  
398 monitor to the M1 site (~6 km away) and provided continuous hourly PM<sub>2.5</sub> data during the  
399 study period. PM<sub>2.5</sub> was chosen as a representative aerosol to directly compare with the model  
400 simulations. For reference, this TCEQ C45 site location was added to the map displaying the  
401 TRACER sites (Fig. 1).

402 This study draws heavily from SBC synoptic-scale regime identification performed by  
403 Wang et al. (2024) to further inform on controls affecting SBC evolution and cloud formation  
404 at the two sites. Every SBC day identified by Wang et al. (2024) during the IOP period is  
405 considered to explore SAI during TRACER. A total of 46 SBC events at the M1 site, and 30  
406 SB events at the S3 site were identified by Wang et al. (2024) during TRACER's IOP (Table  
407 1). They explored Gulf breeze and bay breeze circulation characteristics using a suite of  
408 datasets, including ground-based measurements, satellite observations, and reanalysis datasets,  
409 using machine learning techniques, and Lagrangian cell tracking methods. Most IOP SBC  
410 events were classified as occurring during large-scale anticyclonic conditions, with the  
411 predominant occurrence of SBCs observed during southeasterly background surface wind  
412 directions. The SBF timing at both ARM sites was determined using surface wind and w mixing  
413 ratio time series.

414 Overall, Wang et al. (2024) found that the SBF typically arrived at the M1 site at 20:30  
415 UTC (i.e., 15:30 LT), and at the S3 site at 20:50 UTC (i.e., 15:50 LT). The M1 site, situated  
416 along the western shore of the Galveston Bay, was also influenced by bay breeze circulations,  
417 frequently resulting in an earlier shift in the local meteorological state, compared to that of the

- Formatted ... [20]
- Deleted: e
- Formatted ... [21]
- Deleted: provide
- Formatted ... [22]
- Deleted: M
- Formatted ... [23]
- Deleted: every
- Formatted ... [24]
- Deleted: at
- Deleted: resampled to
- Formatted ... [25]
- Deleted: All data were averaged to 5-minute intervals.
- Deleted: those ...he ARM observations, we use we ... [26]
- Deleted: ; sfcmetradatq-tceq ARM PI product.... The ... [28]
- Formatted ... [27]
- Deleted: we selected the
- Deleted: at ...he Seabrook Friendship Park site (C45 ... [29]
- Formatted ... [30]
- Deleted: , the
- Deleted:
- Deleted: location
- Deleted: ,
- Deleted: was used in the analysis
- Formatted ... [31]
- Deleted: .
- Formatted ... [32]
- Deleted: context
- Formatted ... [33]
- Deleted: e
- Formatted ... [34]
- Deleted: i
- Deleted: efforts
- Formatted ... [35]
- Deleted: studied synoptic-scale
- Formatted ... [36]
- Deleted: We consider e
- Formatted ... [37]
- Deleted: l
- Formatted ... [38]
- Deleted: the
- Formatted ... [39]
- Formatted ... [40]
- Deleted: of the
- Formatted ... [41]
- Deleted: se
- Formatted ... [42]
- Deleted: cases
- Formatted ... [43]
- Deleted: are
- Deleted: under the control of
- Deleted: systems
- Deleted:
- Deleted: (Wang et al., 20242)), with
- Formatted ... [44]
- Formatted ... [45]
- Deleted: is
- Deleted: identified
- Formatted ... [46]
- Formatted ... [47]

541 S3 site (only influenced by the Gulf SBC). The M1 site was shown to experience an additional  
542 bay breeze contribution during 22 out of 43 SBC events. Wang et al. (2024) also reported that  
543 M1 experienced higher intensity changes in the meteorological conditions associated with these  
544 SBFs as compared to S3, particularly when the background wind directions are southwesterly  
545 or westerly. At both the sites, these SBF passages were associated with a significant increase  
546 in  $w$  and wind speed, along with a decrease in surface temperature. The arrival of the fronts  
547 also typically increased the vertical wind speed within the boundary layer, with a mean speed  
548 of up to  $2 \text{ m s}^{-1}$  within the lowest 1 km. The enhanced updrafts associated with SBF low level  
549 convergence also was shown to promote short lived-isolated convective clouds, and likely  
550 associated with vertical mixing of aerosols by diluting near-surface concentrations and  
551 redistributing aerosols aloft.

### 553 2.3 Model simulation setup

554 The WRF-Chem model (Grell et al., 2005; Skamarock et al., 2008) was used to simulate  
555 the multiscale interactions between aerosols and meteorology over the coastal region of  
556 southeast Texas. Fig. 2 shows the model domain centered on the M1 site and extended from  
557 26 to 33 °N (~770 km) in latitude and from -98.5 to -91.5 °E (~770 km) in longitude. The model  
558 simulations were performed for the period from 1 July to 30 August 2022, using a 5x5 km  
559 horizontal grid spacing with 45 vertical layers. A model spin-up time of 3 days was used, and  
560 the restart files were used for the remainder of the simulations. Initial and boundary conditions  
561 for meteorology were provided by the North American Mesoscale (NAM) model every 6 hours.  
562 The model configuration was successfully set-up and is considered sufficient to resolve the key  
563 meteorological processes relevant to the aerosol chemistry examined in this study. To validate  
564 this assumption, simulated meteorological fields and aerosol variabilities are compared against  
565 observations. Similar model setups have been successfully applied in previous WRF-Chem  
566 studies over the continental US (e.g., Berg et al., 2015; Wang et al., 2021; Subba et al., 2023;  
567 Shrivastava et al., 2024), which demonstrate their suitability for representing aerosol-cloud  
568 interactions. The details of the configurations are shown in Table 2.

569 The model simulations were performed with (with aerosol-WA condition) and without (no  
570 aerosol-NA condition) full aerosol-gas chemistry, and land-atmosphere interactions enabled.  
571 Boundary conditions for gas-phase species and aerosols were provided by the Whole

Deleted: , which ...nlyis...influenced only ...by the Gulf SBCulf breeze (... [50])

Deleted: According to Wang et al. (2024), t

Deleted: uggested

Deleted: likely...experience an additionals...a ...ay breeze contribution during 22 out of 43 SBCsea breeze...eve (... [51])

Formatted: Font color: Auto

Formatted: Font color: Auto

Formatted: Font: Italic, Font color: Auto

Deleted: s ...higher intensity changes in the meteorological conditions associated with of ...hese SBFs as compared to S3fronts... particularly when the background wind directions are southwesterly or westerly. At both the sites, these SBFse events...passages were are...typically ...associated withfollowed by (... [52])

Formatted: Font: Italic

Deleted: s

Formatted: Superscript

Deleted: ...was shown to promote short lived-isolat (... [53])

Deleted: ¶

Deleted: ¶

Deleted: We use t

Deleted: is

Formatted: Font color: Auto

Formatted: Font color: Auto

Deleted: Houston... In (... [54])

Deleted: , we ...hows the implemented...model don (... [55])

Formatted: Font color: Auto

Deleted: 6...0 km) in longitude. The model simulati (... [56])

Deleted: d...waswere (... [57])

Deleted: The geogrid component of the WRF Proces (... [58])

Deleted: chosen grid spacing...and domain configur (... [59])

Deleted: assumed

Deleted: captur

Deleted: salient

Formatted: Font color: Auto

Formatted: Font color: Auto

Formatted: Font color: Auto

Deleted: factors...influencing y (... [60])

Deleted: suitable to

Deleted: considered

Formatted: Font color: Auto

Formatted

Deleted: 1... ¶ (... [62])

675 Atmosphere Community Climate Model (WACCM) (Gettelman et al., 2019). The WACCM  
 676 output datasets, available on a horizontal grid resolution of  $1^{\circ} \times 1^{\circ}$  were spatially interpolated  
 677 to our model domain every 6 hours. Biogenic emissions were generated online by WRF-Chem  
 678 model based on meteorology and land use data, using the Model of Emissions of Gases and  
 679 Aerosols from Nature version 2.1 (MEGAN2.1) by Guenther et al. (2012). The U.S.  
 680 Environmental Protection Agency National Emission Inventories (NEI, Ma and Tong, 2022)  
 681 was used to provide anthropogenic emissions of trace gases and aerosols from diverse sources,  
 682 including point, area, on-road mobile, non-road mobile, and other sectors. These emissions are  
 683 incorporated to WRF-Chem at hourly intervals. The area surrounding the M1 site is  
 684 characterized by urban infrastructure and cropland, whereas the S3 site is largely a mix of  
 685 cropland, natural mosaic, and barren or sparsely vegetated land type. Both sites have cropland  
 686 and grassland to the west and north, as well as evergreen, deciduous, and mixed forests from  
 687 the north to east directions. The selected domain included both anthropogenic and biogenic  
 688 aerosol sources, as indicated by NEI and MEGAN datasets (Fig. 2b). The M1 site is anticipated  
 689 to be more influenced by anthropogenic sources due to its proximity to the Houston urban core,  
 690 local industry and the HSC. The S3 site is expected to be more influenced by biogenic sources.

691 The role for these simulations is to provide a physically-reasonable spatial approximation  
 692 for the meteorological and aerosol environments across the southern Texas region that are not  
 693 captured by the point measurements during TRACER. Comparing the meteorological variables  
 694 between the two sites helps identify the underlying factors that may influence the aerosol  
 695 transport and transformation processes. The simulated meteorological time series show  
 696 adequate agreement for the purposes of this study, at both sites (Fig. S1). We assessed model  
 697 performance using metrics: mean bias (MBE), root mean square error (RMSE), and correlation  
 698 coefficient (R) for the quantities of temperature, wind speed, and wind direction. In addition,  
 699 we also considered Modern-Era Retrospective analysis for Research and Applications  
 700 (MERRA-2) reanalysis products to further evaluate the model performance (Geralo et al.,  
 701 2017). Our model reproduces the measured temperature diurnal cycle at both sites with high  
 702 correlation ( $r$  up to 0.87) and low MBE ( $< \pm 1^{\circ} \text{C}$ ). Wind speed and wind directions show  
 703 weaker correlation ( $r$  up to 0.65) and MBE of  $0.76 \text{ m s}^{-1}$  and  $12.5^{\circ}$ , respectively. Individual  
 704 SBF events are further analysed to compare the measured and modeled variables in later  
 705 sections.

Formatted: Font color: Auto

Deleted: °

Formatted: Font color: Auto

Deleted: °

Deleted: Simulations used meteorological boundary conditions from North America mesoscale (NAM), and anthropogenic emission inventory from National Emissions Inventory (NEI) (Ma and Tong, 2022), and biogenic emissions from the Model of Emissions of Gases and Aerosols from Nature version MEGAN v2.1 (Guenther et al., 2012). The model simulations were performed with full aerosol-gas chemistry, and land-atmosphere interactions enabled. The geogrid component of the WRF Processing System handles the land use data (Fig. 2a). The grid spacing and configuration is assumed sufficient to capture the salient meteorology suitable to the aerosol chemistry considered. The details of the configurations are shown in Table 1.

Deleted: ¶

Deleted: primarily

Deleted: are positioned with

Deleted: in directions

Deleted: conditions

Deleted: to

Deleted: shipping channel

Formatted: Font color: Auto

Deleted: When compared with the TRACER measurements, t...

Formatted: Font color: Auto

Deleted: feasible

Deleted: agreement

Deleted: the

Deleted: of

Deleted: implemented

Deleted: widely applied

Deleted: MERRA-2:

Deleted: performance compare these meteorological variables to assess the performance of the model simulations...

Deleted: The

Deleted: the

Deleted: days

743 We find a reasonable behavior in the heterogeneous spatial distribution of PM<sub>2.5</sub>, with  
 744 higher values in the urban areas around the M1 site and lower values in the rural areas around  
 745 the S3 site (Fig. 3b). The simulated hourly PM<sub>2.5</sub> has been compared with the TCEQ measured  
 746 values (Fig. 3a). The model reasonably captures the timings and magnitude of high and low  
 747 aerosol concentrations. The model (mean ~ 10.8 μg m<sup>-3</sup>, median ~8.5 μg m<sup>-3</sup>) overestimates the  
 748 observations (mean ~8.2 μg m<sup>-3</sup>, median ~7.0 μg m<sup>-3</sup>), with a correlation of r ~0.6,  
 749 corresponding to differences of ~30% in the mean and ~23% in the median. These model-  
 750 measurement discrepancies are consistent with previously reported WRF-Chem biases. For  
 751 example, Soni et al. (2022) reported that during dust storm events over the Indian sub-  
 752 continent, WRF-Chem captured spatial aerosol patterns but underestimated concentrations in  
 753 regions of high aerosol loading. Similarly, Tuccella et al. (2012) reported that WRF-Chem  
 754 underestimated peak aerosol concentrations by 7.3%. More recently, Georgiou et al. (2022)  
 755 reported underestimation of background PM<sub>2.5</sub> by 16% and of industrial by ~20%.

### 757 3 Results and discussion

#### 758 3.1 Composite IOP Meteorological Observations

759 Comparisons between the background summertime meteorology around the TRACER  
 760 sites help to identify the underlying factors that may influence the aerosol transport and  
 761 transformation processes. Fig. 4 shows composite averaged diurnal variations of  
 762 meteorological properties during the IOP period. When comparing meteorological variables  
 763 between M1 and S3 sites, paired t-test results calculated a very low p-value (<0.0001) and a  
 764 large negative or positive t-statistic, indicating a statistically significant difference. M1 exhibits  
 765 higher temperatures during the cooler parts of the day (early morning) and slightly lower  
 766 temperatures during the warmest parts of the day (early afternoon). W at M1 is lower during  
 767 the warmer periods and higher during the cooler periods of the day. At both sites the value  
 768 stays near 17-18 g kg<sup>-1</sup> for most of the day, with a common moistening pulse around 13:00-  
 769 15:00 UTC that coincides with increased wind speed. At similar hours, the wind directions are  
 770 similar at both the sites. Except in the morning, winds at M1 are typically 1-2 m s<sup>-1</sup> stronger  
 771 than at S3. The M1 site shows an increase in w near 20:00 UTC, likely tied to the SBC. S3  
 772 exhibits a larger shift in the wind directions compared to that of M1. The two sites have similar

- Formatted ... [63]
- Deleted: see
- Deleted: We also compare t
- Formatted ... [64]
- Deleted: Our ...he model (mean ~ 10.8 μg m<sup>-3</sup>, med... [65]
- Deleted: showed r
- Deleted: WRF-Chem simulations during dust storm ... [66]
- Formatted ... [67]
- Deleted: found
- Deleted: the ...RF-Chem underestimated model cap... [68]
- Formatted ... [69]
- Formatted ... [70]
- Deleted: The M1 site was uniquely situated for TRA... [71]
- Deleted: The meteorological variables between the t... [72]
- Deleted: ng
- Deleted: overall
- Formatted ... [73]
- Formatted ... [74]
- Formatted ... [75]
- Deleted: s
- Deleted: the ...urnal variations of meteorological ... [77]
- Formatted ... [76]
- Deleted: s
- Deleted: varies in relation to with temperature, with
- Deleted: The opposite trend is observed for RH, with... [79]
- Deleted: values
- Formatted ... [78]
- Deleted: cooler
- Deleted: values
- Deleted: warmer
- Formatted ... [80]
- Deleted: These
- Deleted: Both RH and temperature values are compa... [81]
- Deleted: W
- Deleted: speeds
- Deleted: approximately
- Deleted: higher
- Formatted ... [82]
- Formatted ... [83]
- Formatted ... [84]
- Formatted ... [85]
- Deleted: M1 throughout the day, except during the n... [87]
- Formatted ... [86]
- Formatted ... [88]

995 directions during the late night (00:00- 05:00 UTC) and early morning (13:00-15:00 UTC)  
996 hours. During the dominant afternoon SBC period (around 20:00 UTC), winds are  
997 predominantly from the southeast at M1 and from the southwest at S3.

998 Although these sites are geographically close, their different proximities to water bodies  
999 and varying land cover types may account for the observed meteorological variations, such as  
1000 differences in temperature modulation, humidity, and breeze development. M1 lies adjacent to  
1001 both Galveston Bay and Gulf of Mexico, thus nearby water moderates temperature and  
1002 promotes higher humidity, favoring sea- or bay- breeze circulations. In contrast, although S3  
1003 is at a similar distance from the Gulf as M1, it is more inland, separated from the shoreline by  
1004 an intervening expanse of land, so it experiences stronger daytime heating and a weaker, more  
1005 modified marine influence than M1. It has a land surface covered predominantly with  
1006 vegetation and soil that cools faster at night than urban landscapes. However, urban landscapes  
1007 retain heat, remaining warmer into the nighttime and potentially moderating temperatures  
1008 during the subsequent daytime (Maria et al., 2013). These behaviors are consistent with the  
1009 prior studies showing the coastal sites experienced moderate temperature and enhanced  
1010 humidity (Hu, 2021; Subramanian et al., 2023), and that land-use influenced local temperature  
1011 and boundary layer dynamics via evapotranspiration and surface heating (Fang et al., 2025).

### 1013 3.2 Composite IOP Aerosol Observations

1014 The southern Texas region is influenced by locally-generated (e.g., vehicular, industrial,  
1015 construction and road dust, and sea spray) and long range transported aerosols (e.g., biomass  
1016 burning, mineral dust, and sea spray) from anthropogenic and natural sources (Brown et al.,  
1017 2002; Barrett and Sheesley, 2014; Karnae and John, 2019; Song et al., 2021; Das et al., 2023;  
1018 Shrestha et al., 2023). In Fig. 5a, aerosol number concentration peaks around 17:00 UTC at M1,  
1019 and around 20:00 UTC at S3. Both sites exhibit a tri-modal aerosol size distribution (Fig. 5b).  
1020 Throughout the day, the aerosol concentrations are consistently higher at the M1 site when  
1021 compared to those observed at the S3 site. At the M1 site, we observe a distinct nucleation  
1022 mode that appears at diameter <20 nm, and two additional modes at larger diameters ~80 nm  
1023 and ~150 nm. This nucleation mode is less prominent at the S3 site, which more commonly  
1024 exhibits similar modes at diameters ~80 nm and ~150 nm.

**Deleted:** On the other hand, wind directions are comparable throughout the day, except during the late night to morning hours, when the average direction changes by about 45 degrees..

**Deleted:**

**Deleted:** M1 and S3

**Formatted:** Font color: Auto

**Formatted:** Indent: First line: 0.5", Space Before: 12 pt, Border: Top: (No border), Bottom: (No border), Left: (No border), Right: (No border), Between : (No border)

**Deleted:** Specifically,

**Deleted:** 's closer proximity to

**Formatted:** Font color: Auto

**Deleted:** water

**Deleted:** so

**Deleted:** results

**Deleted:** in reduced

**Formatted:** Font color: Auto

**Formatted:** Font color: Auto

**Formatted:** Font color: Auto

**Deleted:** raises

**Deleted:** higher

**Formatted:** Font color: Auto

**Deleted:** promoting

**Formatted:** Font color: Auto

**Deleted:** 's more...inland positioning ... [89]

**Deleted:** and land surroundings land, including from the shoreline of Galvestonbay yield higher...daytime hea... [90]

**Formatted:** Font color: Auto

**Deleted:** with

**Deleted:**

**Deleted:** , which

**Deleted:** .

**Deleted:** (lower T and higher RH)

**Deleted:** S3 being a rural site, has land surface cover... [91]

**Formatted:** Font color: Auto

**Formatted:** Font color: Auto

**Deleted:** retain heat, remaining warmer into the nigh... [92]

**Deleted:** which ...retain heat, remainingstaying...wa... [93]

**Deleted:** Although the M1 and S3 sites are located n... [94]

**Deleted:** Wang et al. (2024) studied synoptic-scale c... [95]

**Deleted:** The measured aerosol number concentratio... [96]

**Deleted:** we plot the diurnal distribution of ...erosol... [97]

1185 The ACSM observations suggest a similar percentage contribution from various species,  
 1186 with organics having the highest concentration (59.2% at M1 and 53.0% at S3), followed by  
 1187 sulfate (23.3% at M1 and 30.6% at S3), ammonium (11.4% at M1 and 10.8% at S3), nitrate  
 1188 (5.2% at M1 and 5.0% at S3) and chloride (less than 0.9% at M1, and less than 0.6% at S3).  
 1189 Higher percentages of organics and sulfate were also measured at other urban (Minguillón et  
 1190 al., 2015; Huang et al., 2010; Qi et al., 2020) and rural locations (Crippa et al., 2014; Atabakhsh  
 1191 et al., 2023).

1192 The NPF events are identified by analyzing the aerosol size distribution measured by the  
 1193 SMPS (Kuang et al., 2008; Dal Maso et al., 2002; Mikkonen et al., 2011). This is accomplished  
 1194 by designating characteristic features for NPF found in the size distribution behaviors in time,  
 1195 including the appearance of the nucleation mode at a diameter ( $D_p$ ) < 25 nm, followed by  
 1196 distinct growth pattern (where the particles increase in size over several hours), forming the  
 1197 characteristic “banana-shaped” pattern in the aerosol number size distribution. NPF events  
 1198 were common at both the M1 and S3 sites. During summertime, NPF events were identified at  
 1199 both the M1 and S3 sites, finding 23 and 17 events, respectively. In approximately 35% of  
 1200 cases, NPF events were observed simultaneously at the sites, implying a regional-scale  
 1201 behavior. These regional NPF nucleation modes appear at  $D_p$  < 25 nm and grow consistently  
 1202 across a broader region, covering a minimum radius of tens of kilometers. However, these  
 1203 simultaneously-occurring NPF events displayed different characteristics in terms of their  
 1204 duration and growth, hinting at the possible influence of mesoscale to larger-scale  
 1205 meteorological controls on these processes (such as SBCs), the background aerosol  
 1206 concentration and/or the availability of necessary precursors.

### 1208 3.3 Observed Sea Breeze aerosol interaction at the surface

1209 Coastal regions have a mixture of urban, terrestrial, and marine aerosol regimes. The  
 1210 inland-penetrating SBF can have a complex influence on the aerosol populations over Houston  
 1211 and its surroundings depending on several coexisting factors including: (i) the pre-existing  
 1212 aerosol regime over the location, (ii) the aerosol regime of the air mass preceded by the SBF,  
 1213 (iii) the local synoptic thermodynamic conditions resulting from convective boundary layer  
 1214 features such as horizontal convective rolls, and (iv) the characteristics of the SBF itself,  
 1215 including the lifting and mixing of the onshore flow with the ambient air, and wind anomalies

- Deleted: The aerosol bulk mass concentration range (... [98])
- Deleted: suggested ...bservations suggest a similar (... [99])
- Deleted: 36
- Deleted: 32
- Deleted: 15
- Deleted: 7
- Formatted (... [100])
- Formatted (... [101])
- Formatted (... [102])
- Formatted (... [103])
- Formatted (... [104])
- Deleted: 4
- Deleted: 5
- Formatted (... [105])
- Formatted (... [106])
- Deleted: are consistent with the measurements at both
- Deleted: On average, organics and ammonium are (... [107])
- Deleted: New particle formation (NPF), a microphy (... [108])
- Deleted: primarily ...dentified by analyzing the act (... [110])
- Formatted (... [109])
- Formatted (... [111])
- Deleted: es,...appearance of the nucleation mode a (... [112])
- Deleted: M1 (...3 events) and S3 (...nd 17 events, (... [113])
- Deleted: The majority of these NPF events exhibite (... [114])
- Deleted:
- Formatted (... [115])
- Deleted: NPF events
- Deleted: ,
- Deleted: we observed regional
- Formatted (... [116])
- Deleted: occurring
- Deleted: both
- Formatted (... [117])
- Deleted: M1 and S3
- Formatted (... [118])
- Deleted:
- Deleted: co-occurring...NPF events displayed differe (... [119])
- Deleted: One particular of those potential meteorolo (... [120])
- Deleted: Wang et al. (2024) showed that both M1 and (... [121])
- Deleted: s
- Formatted (... [122])
- Deleted: populaitons...over th (... [123])
- Formatted (... [124])
- Deleted: is location...and its surroundings dependi (... [125])
- Formatted (... [126])
- Deleted: and
- Deleted: to ...rom convective boundary layer featu (... [127])
- Deleted: (for example

1385 near the surface, Three scenarios for the influence of an inland-penetrating SBF on aerosols  
1386 within the region of influence are considered.

1387 First, we consider a potential “reduction influence” that may occur when an air mass with  
1388 higher aerosol concentration over a location is replaced by an air mass with lower aerosol  
1389 concentration. In contrast, an “enhancement influence” may occur when an air mass with lower  
1390 aerosol concentration over a location is replaced by an air mass with higher aerosol  
1391 concentration. Otherwise, a “neutral influence” implies minimal change associated with the  
1392 SBF, defined as a change in the aerosol concentration is less than 5% in the pre-existing aerosol  
1393 regime. This scenario indicates that the air mass following the SBF is similar to the existing  
1394 conditions.

1395 For example, these enhancement influence scenarios may be anticipated when long-range  
1396 transported aerosols are present in the air mass downwind of the SBF, or when the SBF first  
1397 advects over areas (marine or continental) with high local emissions. Similarly, neutral  
1398 influence scenarios are anticipated when the entire region has relatively homogeneous (i.e.,  
1399 similar aerosol concentrations also belonging to the same aerosol regime) distribution of  
1400 aerosols. Nevertheless, aerosol exchanges are complex, and TRACER also provided several  
1401 examples of marine aerosols carried by the SBF that were associated with negligible influences  
1402 on the ambient marine aerosol mode. Finally, TRACER site measurements may not always be  
1403 representative of a broader air mass or regional conditions (e.g., intermittent local source  
1404 interactions with smaller-scale SBC features), WRF-Chem modeling may help to bridge these  
1405 spatial representativeness gaps and provide reference for the regional context of the potential  
1406 impact of the SBC on aerosol distributions.

1407 To investigate the influence of SAI, one approach employed in this study is to normalize  
1408 the surface aerosol concentration at time  $T$ , by the value measured immediately before the  
1409 passing of the SBF ( $T_{\text{SBF}}=0$  hour). The timing of the SBF for each event is explicitly  
1410 considered, using the passage times provided in Table A1 on Wang et al. (2024). The SBF  
1411 passage at a site is defined as  $T_{\text{SBF}}=0$ . This approach allowed evaluation of aerosol number  
1412 concentrations before and after the SBF passage while retaining the diurnal cycle context. Here,  
1413 “just before” refers to the five minutes prior to the SBF passage, as previously identified by  
1414 Wang et al. (2024), Figs. S2 and S3, show the temporal variation of this normalized aerosol  
1415 number concentration for all the SB events. At both the M1 and S3 sites, before-SBF aerosol  
1416 concentrations can vary by up to a factor of two.

- Deleted: , and the extent of the SB lifecycle)
- Deleted: For any inland-penetrating SBF, the autho ... [128]
- Formatted ... [129]
- Deleted: possible
- Formatted ... [130]
- Deleted: there is
- Formatted ... [131]
- Deleted: , which...may occurs
- Formatted ... [133]
- Deleted: Next, there may beis
- Deleted: , which...occurs
- Formatted ... [134]
- Formatted ... [136]
- Deleted: Finally
- Formatted ... [137]
- Deleted: ,
- Deleted: ing
- Deleted: new
- Deleted: introduced by
- Formatted ... [138]
- Formatted ... [139]
- Formatted ... [140]
- Deleted: an
- Deleted: occur
- Formatted ... [141]
- Formatted ... [142]
- Deleted: is...SBF, or when the SBF first advects o ... [144]
- Formatted ... [143]
- Deleted: s
- Formatted ... [145]
- Formatted ... [146]
- Deleted: However... aerosol exchanges are comple ... [147]
- Formatted ... [148]
- Deleted: also exhibited
- Formatted ... [149]
- Deleted: It is also important to note that the M1 and S3
- Deleted:
- Deleted: . For e.g., small-scale wind shifts associat ... [150]
- Formatted ... [151]
- Deleted: As one approach t... investigate the influe ... [152]
- Formatted ... [153]
- Deleted: , we normalized the aerosol concentration ... [154]
- Formatted ... [155]
- Deleted: with the concentration of aerosols
- Formatted ... [156]
- Deleted: just
- Deleted: hr
- Formatted ... [157]
- Deleted: us to
- Deleted: e...aerosol number concentrations before ... [160]
- Formatted ... [158]
- Formatted ... [159]
- Deleted: the continental sites

1532 Example days with an “enhancement influence” in the aerosol concentration after  $T_{\text{SBF}}$  are  
 1533 shown in Fig. 6, highlighting the 18 July event at the M1 site, and a 10 August event at the S3  
 1534 site. In contrast, the 17 June (M1 site) and 10 July (S3 site) events in the same figure help  
 1535 illustrate a “reduction influence” in aerosol concentration after  $T_{\text{SBF}}$ . While these example  
 1536 events are instructive, there is not a **clear trend** for TRACER events given the high level of  
 1537 variability in the duration or influence of SAIs. For example, the sharp increase we observe in  
 1538 aerosol concentration on the 10 August “enhancement” event quickly **dissipates** within an hour  
 1539 after  $T_{\text{SBF}}$  at the S3 site. In contrast, the increase in the number concentration we observed on  
 1540 18 July persisted for over an hour after  $T_{\text{SBF}}$ . Considering all the SBF passages we collected  
 1541 (Figs. S2 and S3), we suggest  $\Delta T = T_{\text{SBF}} \pm 1$  hour often best represents the “before” ( $\Delta T = T_{\text{SBF}}$   
 1542 - 1 hour) and “after”- SBF ( $\Delta T = T_{\text{SBF}} + 1$  hour) times over a location. **The enhancement or**  
 1543 **reduction effects are most pronounced during the first hour following the passing of the SBF.**  
 1544 **Beyond this period, the observed changes may be influenced by additional factors, such as the**  
 1545 **secondary effects resulting from meteorological transitions induced by the SBF. Additionally,**  
 1546 **the intensity of the SBF’s impact may begin to weaken or become less pronounced after the**  
 1547 **first hour.** With that assumption, a percentage change of the aerosol number concentration  
 1548 [(after-before)/before x 100%] can be further calculated. ‘Neutral influence’ days with the  
 1549 change in aerosol concentration <10% are not considered in this analysis.

1550 **Table 1 summarizes the total number of SBC events, along with number and percentage of**  
 1551 **days showing enhancement, reduction, or neutral influence on the aerosol number**  
 1552 **concentration at the M1 and S3 sites. Neutral days were excluded from the overall averages to**  
 1553 **focus solely on the cases with a clear aerosol response. Out of 46 SBC events at the M1 site,**  
 1554 **29 events (~63%) showed an enhancement or reduction influence on total aerosol number**  
 1555 **concentration, while the remaining 17 events (~37%) were classified as having a neutral**  
 1556 **influence. In contrast to M1, at the S3 site, out of 30 SBC events, only 12 events (~40%)**  
 1557 **exhibited a detectable change in aerosol number concentration, with the remaining 19 days**  
 1558 **(~60%) considered neutral. At the M1 site, reduction events (16 events) slightly outnumbered**  
 1559 **enhancement events (13 events). In contrast, at S3, enhancements (8 events) were twice as**  
 1560 **common as reductions (4 events). This opposite pattern underscores the site-dependent nature**  
 1561 **of the sea-breeze influence.**

1562 **During enhancement days, the M1 site shows an average increase in aerosol number**  
 1563 **concentration of ~ 55%, rising from  $3.8 \times 10^3 \text{ cm}^{-3}$  during  $\Delta T^-$  to  $5.9 \times 10^3 \text{ cm}^{-3}$  during  $\Delta T^+$ . In**

- Deleted: a
- Deleted: clean conceptual model
- Deleted: disappears
- Deleted: r
- Formatted ... [161]
- Deleted: r
- Deleted: r
- Formatted ... [162]
- Formatted ... [163]
- Formatted ... [164]
- Formatted ... [165]
- Deleted: 5
- Formatted ... [166]
- Deleted: days
- Formatted ... [167]
- Deleted: days
- Formatted ... [168]
- Deleted: A
- Formatted ... [169]
- Formatted ... [170]
- Deleted: days
- Deleted: These results suggest that anthe influence ... [171]
- Formatted ... [172]
- Formatted ... [173]
- Deleted: 16 events at the M1 site and 4 events at th ... [174]
- Deleted: Neutral days were excluded from this ana ... [175]
- Deleted: The M1 site (60% of the SB days) experie ... [176]
- Deleted: , and 9 and 13 SB days showed neutral in ... [177]
- Formatted ... [178]
- Formatted ... [179]
- Formatted ... [180]
- Formatted ... [181]
- Formatted ... [182]
- Formatted ... [183]
- Formatted ... [184]
- Formatted ... [185]
- Formatted ... [186]
- Formatted ... [187]
- Formatted ... [188]
- Formatted ... [189]
- Formatted ... [190]

1615 contrast, during the reduction days, the concentration decreases by ~42%, dropping from  $13.2 \times 10^3 \text{ cm}^{-3}$   
1616  $10^3 \text{ cm}^{-3}$  during  $\Delta T^-$  to  $7.6 \times 10^3 \text{ cm}^{-3}$  during  $\Delta T^+$ . At the S3 site, the average changes are ~64%  
1617 (from  $2.4 \times 10^3 \text{ cm}^{-3}$  during  $\Delta T^-$  to  $3.9 \times 10^3 \text{ cm}^{-3}$  during  $\Delta T^+$ ) enhancement and ~45% (from  
1618  $4.9 \times 10^3 \text{ cm}^{-3}$  during  $\Delta T^-$  to  $2.7 \times 10^3 \text{ cm}^{-3}$  during  $\Delta T^+$ ) reduction. When averaged across all  
1619 events, the aerosol number concentration at M1 shows a net decrease of ~23%, from  $8.9 \times 10^3$   
1620  $\text{cm}^{-3}$  during  $\Delta T^-$  to  $6.8 \times 10^3 \text{ cm}^{-3}$  during  $\Delta T^+$ , while S3 exhibits a net increase of ~9%, from  
1621  $3.2 \times 10^3 \text{ cm}^{-3}$  during  $\Delta T^-$  to  $3.5 \times 10^3 \text{ cm}^{-3}$ . These contrasting trends underscore the regional  
1622 variability in aerosol responses associated with SAI events.

1623 As previously mentioned, the geographical positioning of M1 and S3 sites could be one of  
1624 the reasons for such variabilities. M1 is more influenced by the bay breeze coming from  
1625 Galveston Bay and S3 is more likely influenced by Gulf breeze from Gulf of Mexico. Even if  
1626 the air mass associated with the SBF contains lower aerosol concentration, the longer distance  
1627 the SBF travels to reach the S3 site allows the marine air mass to mix with the continental air  
1628 mass, potentially resulting in higher aerosol concentrations, and vice versa. The M1 site is  
1629 influenced by the air masses and SBCs from both sources, whereas the S3 site is affected  
1630 predominantly by those originating from the Gulf of Mexico. As discussed in detail by previous  
1631 studies (Sharma et al., 2024; Wang et al., 2024), the SBFs originating from Galveston Bay and  
1632 the Gulf of Mexico are often distinct at onset but tend to merge later in the afternoon or evening.  
1633 Due to the M1 site's proximity to Galveston Bay, it is more directly influenced by maritime air  
1634 masses that are heavily modified by Galveston Bay as the SBF originating from the Gulf of  
1635 Mexico traverses the Bay. On the other hand, the Gulf-originating SBF must cross land before  
1636 reaching S3. The difference in SBF pathways can lead to notable meteorological and aerosol  
1637 contrasts between the two sites. In addition, as observed by Thompson et al. (2025), the  
1638 maritime air masses near Galveston can deviate significantly from typical clean maritime  
1639 conditions. As a result, bay breeze passages may not always lead to cleaner air but can, in fact,  
1640 be more polluted. The consequences of this increased aerosol concentration in the modified  
1641 maritime air mass are reflected in the enhancement aerosol response observed at the M1 site.

1642 SAIs can also interfere with NPF events. On SB days, a total of 7 NPF events were observed  
1643 at the M1 site and 4 at the S3 site, with 3 occurring simultaneously at both sites. Among these,  
1644 45% (5 out of 11) events showed distinct changes in NPF characteristics during the SBF  
1645 passage. For example, on 16 July an NPF event was observed at M1 prior to the SBF (Fig. S4).  
1646 With the arrival of the SBF, particle growth abruptly ceased, and the elevated particle

Formatted [191]

Formatted: Font color: Auto

Deleted: B

Deleted:

Deleted: ¶

Formatted [192]

Deleted: make... it is more directly influenced by [193]

Formatted [194]

Deleted: is heavily

Formatted [195]

Deleted: nd...the SBF originating from the Gulf of Mexico traverses the Bay. On the other hand, the Gulf-originating SBF originates [196]

Formatted [197]

Deleted: We suggest that ...AIs can also potentially interfere with aerosol microphysical processes, inclu [198]

Deleted: A...total of 711 [200]

Formatted [199]

Deleted: occurred during SB events

Deleted: Out of those

Formatted: Font color: Auto

Formatted [201]

Deleted: -5

Deleted: days...showed a ...distinct changes in the ...PF characteristics during the passing of the ...BF passage. For example, an NPF event that occurred at the M1 site [202]

Formatted: Font color: Auto

Formatted: Font color: Auto

Deleted: during before-...BF hours [203]

Formatted: Font color: Auto

Deleted: Upon...the arrival of the SBF during this [204]

Formatted: Font color: Auto

1694 concentration ( $\sim 14 \text{ e}^3 \text{ particles cm}^{-3}$ ) rapidly decreased to  $\sim 5 \text{ e}^3 \text{ particles cm}^{-3}$  (Fig. S4). The  
1695 normalized aerosol size distribution further shows that the NPF activity evident in the hours  
1696 before the SBF period ( $\Delta T = T_{\text{SBF}} - 1 \text{ hour}$ ) disappeared in the hour following the SBF  
1697 ( $\Delta T = T_{\text{SBF}} + 1 \text{ hour}$ ). The low aerosol concentration air mass trailing the SBF passage thus led  
1698 to a sharp reduction in the aerosol number concentrations in the after-SBF period.

1699 The open-air polar plots summarize the relationship between aerosol number concentration,  
1700 wind speed and wind direction within  $\Delta T = T_{\text{SBF}} \pm 1 \text{ hour}$  during enhancement and reduction  
1701 events (Fig. 7). At M1, enhancement events reveal elevated aerosol concentrations when the  
1702 prevailing winds emanate from the east and southeast, where the air mass is influenced by  
1703 industry and shipping along Galveston Bay. During the reduction influence the pre-SBF aerosol  
1704 loading is higher compared to that of the reduction events. These high concentrations are  
1705 associated with the influence from the Houston urban core in the northwest and the other  
1706 influences from the east as mentioned above. These are also apparent in the monthly plots  
1707 shown in Fig. S5. After-SBF winds, particularly from the southeast and south, are associated  
1708 with markedly lower aerosol loads, indicative of cleaner marine air intrusion.

1709 Meanwhile, at S3, enhancement scenarios also manifest somewhat higher concentrations  
1710 when winds shift southeastward, though to a lesser extent, reflecting rural aerosol dynamics.  
1711 In reduction scenarios at S3, aerosol levels decrease most notably under southerly and  
1712 southwest flow, reinforcing the interpretation that sea breeze incursions generally replace  
1713 continental aerosol-laden air with cleaner marine air at both sites, albeit with stronger source  
1714 influence at M1. This wind-direction-dependent concentration pattern aligns with previous  
1715 findings: northwesterly to easterly winds bring continental aerosols, while southerly to  
1716 southwesterly flows usher in marine-influenced clean air that modulates aerosol number  
1717 concentrations (Levy et al., 2013; Pinto et al., 2014). However, as shown in Figs. S2 and S3,  
1718 each SB event is unique in terms of the change in the aerosol concentrations.

### 1719 3.4. Examples of sea breeze aerosol interaction at the TRACER sites

1720 In Fig. 8, we provide an example of an aerosol reduction influence of SAI. Since M1 and  
1721 S3 both experienced the passage of a SBF on 10 July, this day serves as a good example to  
1722 investigate how SAIs evolve when simultaneously viewed at multiple sites. The SBF reached  
1723 the M1 site in the afternoon at around 21:30 UTC, and the S3 site at around 23:45 UTC. In Fig.  
1724 S6, we supplement these discussions with displays for the temporal variation of measured and

Formatted: Font color: Auto

Deleted: observed during this NPF event simultaneously

Formatted: Font color: Auto

Deleted: During the days where there were ongoing

Formatted: Font color: Auto

Deleted: events, the aerosol concentrations were high during the

Deleted: -

Deleted: r

Formatted: Font color: Auto

Formatted: Not Highlight

Formatted: Font color: Auto

Deleted: r

Formatted: Font: (Default) Cambria Math, Font color: Auto

Formatted: Font color: Auto

Formatted: Font color: Auto, Subscript

Formatted: Font color: Auto

Deleted: .

Deleted: cleaner air mass

Deleted: er

Formatted: Font color: Auto, Subscript

Formatted: Font color: Auto

Formatted: Not Highlight

Formatted: Font color: Auto

Deleted: ( $\Delta T = T_{\text{SBF}} + 1 \text{ hr}$ )

Formatted: Subscript

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Not Highlight

Deleted: .

Deleted: The open-air polar plots summarize the relationship between aerosol number concentration, wind speed and wind direction within  $\Delta T = T_{\text{SBF}} \pm 1$  during all the SB events (Fig. 6b). Our supplemental Fig. S5 also indicates that overall aerosol concentrations at the M1 site are higher when the prevailing winds emanate from the east and north directions associated with the Houston urban core (specially in August and September). Overall, the passage of SBF at M1 is marked by an increase in wind speed and a shift in dominant wind direction toward the southeast and intermediate directions. This transition is consistently accompanied by a reduction in aerosol number concentrations relative to the before-SBF aerosol concentrations, confirming that SBFs transport mari (... [205]

Deleted: 7

1797 model-simulated meteorological properties for this event. Both sites suggest the typical  
1798 temperature decreases and surface wind speed increase associated with the SBF reaching the  
1799 site. The wind direction changes from east to south at the M1 site and from southwest to south  
1800 at the S3 site.

1801 The changes in aerosol size distribution, reduction in the bulk chemical composition, and  
1802 simulated PM<sub>2.5</sub> all suggest that the air mass following SBF passage contains lower aerosol  
1803 concentration (Fig. 8). This likely indicates that during the after-SBF period, the air mass is  
1804 arriving from directions less influenced by the aerosol sources. The SBF acts as a leading edge  
1805 of this cleaner marine air mass. The aerosol number concentration decreases by ~5% (5.2 e<sup>2</sup>  
1806 cm<sup>-3</sup>) at the M1 site. At the M1 site, there was no significant change in the mean Dp (~100 nm)  
1807 during the first 45 min after T<sub>SBF</sub>, which is followed by a sharp decrease in the mean Dp (~25  
1808 nm). This change in the aerosol number concentration is synchronous with the changes in wind  
1809 directions. During the after-SBF period, the winds shift predominantly from the southeast and  
1810 south, bringing in a more marine-influenced air mass.

1811 Immediately after the passing of the SBF at the S3 site, the SAI also indicates a  
1812 reduction of the aerosol number concentration by ~62% (3.3 e<sup>3</sup> cm<sup>-3</sup>) (Fig. 8b). However, the  
1813 background aerosol mode persists at diameters ~60 and 150 nm (aerosol size distribution plot  
1814 in Fig. 8b). Note, we did not observe a profound change in the wind directions after the passing  
1815 of the SBF at the S3 site. However, we suggest that the higher wind speed associated with the  
1816 SBF dilutes the existing air mass with marine air with lower aerosol concentration. Higher  
1817 wind speeds enhance near-surface shear, mechanically generate turbulence, deepen the  
1818 boundary layer, and strengthen vertical transport, thereby accelerating dispersion and diluting  
1819 aerosol and water-vapor concentrations (Kgabi and Mokgwetisi, 2009; Dueker et al., 2017; Liu  
1820 et al., 2025). Conversely, low winds with a shallow boundary layer and weak turbulence  
1821 promote accumulation and often worsen air quality due to limited dilution (Seinfeld and Pandis,  
1822 2006). The modified near-surface air mass at S3 persists overnight until convective mixing  
1823 begins the following day. Under stable stratification, buoyant turbulence is suppressed, and  
1824 shear-driven mixing becomes the primary dilution mechanism; although weaker than  
1825 convective mixing, it can still substantially mitigate concentration build-up (Rodier et al.,  
1826 2017).

1827 The aerosol bulk chemical mass concentration at the M1 site shows a steady buildup  
1828 through the day, peaking just before the passing of the SBF. Organics were the dominant

**Deleted:** 7

**Deleted:** The changes in aerosol size distribution, reduction in bulk chemical composition, and simulated PM<sub>2.5</sub> all suggest that the air mass following the SBF passage contains lower aerosol concentrations.

**Deleted:** from east to south (polar plots in Fig. 7a), consistent with a more marine aerosol environment.

**Deleted:** suggests

**Deleted:** ed

**Deleted:** influence of ~62% (3.3 e<sup>3</sup> cm<sup>-3</sup>) in terms

**Deleted:** ,

**Deleted:** 7

**Deleted:** 7

**Deleted:** that from the

**Deleted:**

**Deleted:** mass

**Deleted:** The modified near-surface air mass at S3 persists overnight until convective mixing begins the following day.

**Formatted:** Font color: Auto

**Formatted:** Font: Not Italic, Font color: Black

**Formatted:** Font: Not Italic, Font color: Auto

**Formatted:** Font: Not Italic, Font color: Black

1847 species throughout, with sulfate and nitrate also contributing. After the passage of the SBF,  
1848 concentrations dropped rapidly by about 1 to 3  $\mu\text{g m}^{-3}$ , with the drop being more apparent in  
1849 sulfate and ammonium. Within a few hours, concentrations returned to the background levels.  
1850 These concentrations remained higher than those at the rural S3 site. However, the more  
1851 pronounced changes in aerosol properties were observed at the S3 site. The concentrations of  
1852 all species, including organic, decreased by 2 to 3  $\mu\text{g m}^{-3}$ . This is consistent with the earlier  
1853 discussion that the maritime air mass near Galveston Bay exhibits higher aerosol  
1854 concentrations compared to the more pristine maritime air mass originating directly from the  
1855 Gulf of Mexico.

1856 In Figs. S7 and S8, we provide additional examples from TRACER SAI events. The first  
1857 example is from the 17 July event where we observed an increased influence in the aerosol  
1858 concentration that followed SBF passage. In Fig. S7, we present an example of an aerosol  
1859 enhancement case associated with an SAI event on 17 July. The SBF reached the M1 site in  
1860 the early afternoon (~18:12 UTC), and at around 21:42 UTC at the S3 site. The aerosol size  
1861 distribution displayed an enhancement of particles in the diameter range of 15-100 nm. Total  
1862 organics, sulfate, and simulated  $\text{PM}_{2.5}$  also increased, suggesting that the post-SBF air mass  
1863 contained higher aerosol concentrations, likely due to transport from more polluted source  
1864 regions. Similar to the 10 July case, the SBF acted as the leading edge, but here it marked a  
1865 more polluted marine-influenced air mass.

1866 At M1, the aerosol number concentration also doubled ( $\sim 2.2 \times 10^3 \text{ cm}^{-3}$ ), accompanied by a  
1867 significant shift in mean particle diameter (within 15-100 nm) during the first hour after SBF  
1868 passage, with weaker changes thereafter. These responses were synchronous with shifts in wind  
1869 direction from southwest to east. The easterly winds, influenced by emissions from the HSC,  
1870 contributed to the observed increase. In contrast, at S3 the SAI did not produce distinct changes  
1871 in aerosol size distribution or mass concentrations, and except for the increase in the wind  
1872 speed, no substantial wind direction change occurred after SBF passage. The modified near-  
1873 surface air mass at both sites persisted for only ~2 hours, after which background conditions  
1874 returned. Notably, background aerosol modes at ~60 nm and ~150 nm persisted throughout  
1875 (Fig. S7).

1876 Fig. S8 shows an example of a neutral SAI influence on 16 August. The SBF reached M1  
1877 at ~17:05 UTC and S3 at ~20:10 UTC. At M1, winds shifted from east to south, while no  
1878 distinct directional change was observed at S3. Unlike the 10 and 17 July cases, M1 was already

Deleted: the

Deleted: higher

Formatted: Font: Not Italic, Font color: Auto

Formatted: Font: Not Italic, Font color: Auto

Formatted: Font: Not Italic, Font color: Black

Formatted: Font color: Black

Formatted: Font: Not Italic, Font color: Black

Deleted: not as sharp as what we

Deleted: and Houston

Formatted: Font: Not Italic, Font color: Auto

Formatted: Font: Not Italic, Font color: Black

Formatted: Not Highlight

Formatted: Font: Not Italic, Font color: Black

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Superscript

Formatted: Superscript, Not Highlight

Formatted: Not Highlight

Deleted: ouston Ship Channel

Formatted: Font color: Auto

Formatted: Not Highlight

Formatted: Not Highlight

1884 under high aerosol conditions, with particle concentrations consistently elevated at diameters  
1885 <80 nm. In contrast, S3 remained under low aerosol conditions for most of the day, except for  
1886 a brief increase just prior to the SBF passage. The SAI did not produce notable changes in  
1887 aerosol size distribution, bulk chemical composition, or simulated PM<sub>2.5</sub>, indicating that pre-  
1888 and post-SBF aerosol concentrations were comparable at both sites. Although wind direction  
1889 changed at M1, the marine-influenced air mass was also burdened by high aerosol loading,  
1890 limiting its impact on conditions at the site. Similarly, S3 showed no discernible change, with  
1891 concentrations remaining low before and after the SBF passage. Detailed discussions on these  
1892 example events will be continued in the next section that expands this discussion to include  
1893 regional removal and transport influences on these SAI events.

1894

### 1895 3.5. Regional influence of sea-breeze aerosol interaction

1896 In Fig. 9, we provide the spatial distribution of modeled  $w$ , planetary boundary layer height  
1897 (PBLH), surface-level wind vectors, PM<sub>2.5</sub>, and integrated aerosol number concentration  
1898 (nucleation-nu0 + accumulation-ac0 mode) using WRF-Chem. Together, nu0 and ac0  
1899 concentrations reveal size-dependent aerosol changes that bulk PM<sub>2.5</sub> mass or total number  
1900 obscure, allowing SBF-driven redistribution to be attributed to specific aerosol modes and  
1901 clarifying implications for microphysics, CCN/INP, and radiative effects. On 10 July, the  
1902 observed SBF reached the M1 site at 21:30 UTC and reached the S3 site at 23:45 UTC. The  
1903 simulation for this event accurately represents this timing for the SBF passage. The output for  
1904 the time 20:00 UTC on 10 July corresponds to an example point in the simulation, and daytime  
1905 observations when the SBF had not reached either site. The 22:00 UTC examples correspond  
1906 to a time when the modeled and observed SBF has recently passed the M1 site but not reached  
1907 the S3 site. The 00:00 UTC examples (next day) correspond to a timing when the SBF has  
1908 passed both TRACER field sites.

1909 Behind the SBF in our simulations, south or southeast winds prevail, passing through from  
1910 the Gulf of Mexico and blowing onshore at an average speed of 5 m s<sup>-1</sup>. There is an increase in  
1911  $w$  associated with the SBF passage. This transition in the air mass is also observed around the  
1912 M1 site at timestep 22:00 UTC. A similar pattern in the  $w$  is observed at the S3 site at the  
1913 timestep 00:00 UTC. This change at S3 is also accompanied by a decrease in the modeled  
1914 PBLH.

**Deleted:** The increased influence continued for the next ~2 hours. The second example is from 16 August that illustrates a neutral influence event on the aerosol concentrations following the passing of the SBF.

**Deleted:** 8

**Formatted:** Not Highlight

**Deleted:** .

**Deleted:** 40

**Deleted:** model

**Deleted:** model

**Deleted:** model runs

**Formatted:** Font color: Auto

**Deleted:** model

**Formatted:** Not Highlight

**Formatted:** Not Highlight

**Deleted:** (Fig. 8)

1927 The 10 July simulations help illustrate that while changes in aerosol and meteorological  
1928 properties are more pronounced near the SBF, SBF influences may extend >50 km inland  
1929 associated with the path and extent of this feature. Along the convergence zone associated with  
1930 the SBF, particle concentrations are higher ahead of the SBF and lower behind it, due to  
1931 intrusion of cleaner marine air into the convergence zone. Consequently, SBF passage in the  
1932 model creates a swath of reduced aerosol concentration (up to 50%) parallel to the Galveston  
1933 Bay or Gulf of Mexico coastline. ~~Over time, a well-defined dipole pattern emerges,~~  
1934 ~~characterized by reduced concentrations over the coastal zone and enhanced concentrations~~  
1935 ~~farther inland, consistent with the inland penetration of the maritime air mass and displacement~~  
1936 ~~of pre-existing polluted air.~~

1937 ~~The additional example on 17 July (Fig. 10) is suggestive of an enhancement in aerosol~~  
1938 ~~concentration associated with the SBF event, while the 16 August event (Fig. 11) is indicative~~  
1939 ~~of a neutral influence from the SBF passage. Similar to 10 July, both days exhibit an increase~~  
1940 ~~in  $\mu$ , associated with passage of the SBF, relative to inland areas not influenced by the front~~  
1941 ~~(Figs. 10a, 11a). The SBF passage was also accompanied by a decrease in modeled PBLH~~  
1942 ~~(Figs. 10b, 11b). On 17 July, the SBF had reached M1 and S3 by ~19:00 and 21:00 UTC,~~  
1943 ~~respectively; winds were predominantly from southwest to east, with easterlies likely advecting~~  
1944 ~~emissions from the HSC and contributing to the observed enhancements.~~

1945 ~~Notably, the 17 July event occurred in a different ambient aerosol environment than the 10~~  
1946 ~~July event. MERRA-2 column dust mass concentrations (Fig. S9) indicate Saharan dust~~  
1947 ~~transport on this day, yielding elevated dust loading over the Gulf of Mexico and resulting in~~  
1948 ~~marine aerosol mass concentrations that exceeded those over land. The high concentrations are~~  
1949 ~~also observed to be more prominent to the southwest of the M1 site (Fig. 10c). Hence, as the~~  
1950 ~~SBF moves inland on 17 July, it transports this higher aerosol containing air mass, replacing~~  
1951 ~~the lower aerosol containing air over the site and causing an increased aerosol concentration at~~  
1952 ~~the M1 site. The onshore winds carry an air mass influenced by both local and long-range~~  
1953 ~~transport, originating from both land and sea. In contrast to the other two events, the 16 August~~  
1954 ~~event occurred under a transitional regime, and likely influenced by the bay breeze. The aerosol~~  
1955 ~~environment was notably uniform over the wider regional air masses, thus SBF passage~~  
1956 ~~resulted in minimal changes to the aerosol distribution (Fig. 11c, d, f).~~

1957 ~~Overall, one implication from these simulations is that the effect of the inland-~~  
1958 ~~penetrating SBF on the aerosol environment appears highly dependent on the pre-existing~~

**Deleted:** event

**Deleted:** also ...elp illustrate that while changes in aerosol and meteorological properties are more pronounced near the SBF, SBF influences may extend >50 km inland associated with the path and extent of this feature. Along the convergence zone associated with the SBF, particle (... [206])

**Deleted:** the

**Formatted:** Font color: Auto

**Deleted:** Over time, this lower concentration area it (... [207])

**Deleted:** Fig. 9 provides

**Deleted:** cases

**Deleted:** s from the remaining reference TRACER (... [208])

**Deleted:** , the ...7 July event (... [209])

**Formatted:** Font color: Auto

**Deleted:** event suggestive of an enhancement in ae (... [210])

**Deleted:** and

**Deleted:** case

**Formatted:** Font color: Auto

**Formatted:** Font color: Auto

**Deleted:** water-vapor mixing ratio

**Formatted** (... [211])

**Deleted:** -

**Formatted** (... [212])

**Deleted:** ouston Ship Channel

**Deleted:** First, it is noteworthy that

**Deleted:** exhibits a very...different ambient aerosol (... [213])

**Formatted:** Font color: Auto

**Formatted:** Font color: Auto

**Formatted:** Font color: Auto

**Deleted:** and the southern US

**Deleted:** The aerosol mass concentrations over the (... [214])

**Deleted:** (Fig. 9a)

**Formatted:** Font color: Auto

**Deleted:** (Fig. 9b)

**Deleted:** t simulations

**Formatted:** Font color: Auto

**Formatted** (... [215])

**Deleted:** features an...aerosol environment that (... [216])

**Deleted:** 9

**Formatted:** Font color: Auto

**Deleted:** From these simulated event examples, it i (... [217])

**Formatted:** Font color: Auto

**Formatted** (... [218])

2055 aerosol condition over the location, as well as the air mass characteristics trailing the SBF. The  
2056 wind anomaly associated with the Gulf breeze front can transport more (less) polluted, particle-  
2057 laden air mass, leading to increased (decreased) aerosol concentration as it passes the site  
2058 during the subsequent ~5 hours after the front passes. A study by Deng et al., (2025) using  
2059 scanning radar data collected during TRACER reported similar findings during one of the SB  
2060 events on 10 September 2022. They reported a reduced influence on the aerosol concentration  
2061 immediately after the passing of the bay breeze front for the next few hours, due to the  
2062 dominance of onshore flow consistent with the findings from this study (Fig. S2).

2063

### 2064 3.6 Sea breeze effects on the vertical distribution of aerosols

2065 Fig. 12 shows the modeled normalized  $PM_{2.5}$  at different elevations before and after the  
2066 passage of the SBF. On 10 July, the cleaner marine air mass that follows the SBF led to a  
2067 decrease in aerosol concentration below 1 km at the ARM sites. The model indicates surface  
2068 convergence along the SBF (Fig. S10.). The aerosol concentrations are redistributed  
2069 horizontally and vertically. Two hours later, the SBF reaches the S3 site where its passage  
2070 causes a similar change in the aerosol concentration. The varying extent of this air mass and its  
2071 inland propagation redistributes the vertical  $PM_{2.5}$  profiles from urban to suburban regions as  
2072 this SBF moves northwest from Houston. Similar to the changes in the aerosol mass  
2073 concentrations, the changes in the vertical distributions of  $nu_0$  (Fig. 12b) and  $ac_0$  number  
2074 concentration (Fig. 12c) are not homogeneous within these layers. The cleaner air mass  
2075 following the SBF replaces the more polluted continental air, lowering aerosol number  
2076 concentrations. The response is vertically inhomogeneous, reductions are most prominent  
2077 around M1 and are strongest below ~500 m. Within the 1.5 km,  $nu_0$  shows the largest negative  
2078 anomalies (often > 80%), immediately behind the SBF, consistent with marine air being  
2079 relatively depleted in the smallest particles. A thin narrow yellow/orange area (~+70%  
2080 normalized changes) behind the front (within 1 to 1.5 km) reflects lifting, which can  
2081 momentarily concentrate or mix in small particles. The  $ac_0$  exhibits a similar pattern but weaker  
2082 signal. This reflects that accumulation-mode particles are less sensitive to the front, so the  
2083 reductions are smaller and less uniform, with occasional localized decreases along the front.  
2084 Overall, the inland-propagating SBF drives an exchange between cleaner marine and more  
2085 polluted continental air masses, redistributing aerosols both horizontally and vertically.

Formatted: Font color: Auto

Deleted: /

Deleted: /

Deleted: For TRACER examples, the inland propagation of regional SBFs extends up to 50 km from the coastline, with wind speeds reaching up to ~7 m s<sup>-1</sup>.

Deleted: These behaviors are consistent with previ( ... [219]

Deleted: ArRecent

Deleted: observations

Deleted: reported that bBoundary layer wind field analysis

Deleted: using scanning radar data during TRACER

Deleted: supports our findings that there w

Deleted:

Deleted: is

Deleted: on 10 September 2022

Deleted: (Deng et al., 2025)

Deleted:

Deleted: However, t

Deleted: The wind anomaly associated with the gu( ... [222]

Formatted ... [220]

Formatted ... [221]

Deleted: 10a

Deleted: also shows

Formatted ... [223]

Formatted ... [224]

Deleted: The model indicates that cleaner air mass ... [225]

Deleted: 0

Deleted: 10c

Deleted: higher

Deleted: aerosol number concentrations

Deleted: However, the changes are not consistent ... [226]

Deleted: The

Deleted: in the concentrations is found over a large( ... [227]

Deleted: In addition, the changes in the number ... [228]

Deleted: T

Deleted: c

Deleted: normalized

Deleted: changes in  $nu_0$

Deleted: at the higher altitudes are >80% compared to  $ac_0$ .

Deleted: ¶

Deleted: there is an interchange of low and high

Deleted: aerosol-laden air

Deleted: masses influenced by the inland propagating SBF

2139 ~~These results compliment those shown~~ in SB simulations by Lu and Turco (1994),  
 2140 Verma et al.<sub>2</sub> (2006), Igel et al.<sub>2</sub> (2018), and Parajuli et al.<sub>2</sub> (2022). Parajuli et al.<sub>2</sub> (2022)  
 2141 observed that the SB pushes dust inland and upward along the mountain slopes, reaching  
 2142 heights of up to 1.5 km. During TRACER, the vertical influence of SAI extended up to ~1.5  
 2143 km (~~~PBLH~~). The region of SBC influence is shown to extend inland up to 50 km and vertically  
 2144 up to 2 km over a period of up to 5 hours following the passage of the SBF. The model  
 2145 simulations supplement the observations by filling observational gaps and enabling the  
 2146 extrapolation of findings across a broader regional scale, an endeavor that would be challenging  
 2147 to achieve with limited in-situ observational sites or standalone models.

### 2149 3.7 Impacts of sea breeze aerosol interaction on cloud condensation nuclei

2150 Fig. 13 shows the time series of the normalized aerosol number concentration with  $D_p >$   
 2151 100 nm,  $N_{100}$  for the 10 July event. ~~Due to the unavailability of measured CCN data at both M1~~  
 2152 ~~and S3~~,  $N_{100}$  serves as our proxy for the CCN ( $CCN_{proxy}$ ) concentration (Ahlm et al., 2013).  
 2153 ~~Hence, the current analysis is limited to observational evidence of  $N_{100}$  variability.~~ Similar to  
 2154 the changes in the overall aerosol number budget, the SBF passage and the air mass that follows  
 2155 induces simultaneous changes in the CCN budget. During this event, the  $CCN_{proxy}$   
 2156 concentration decreases by ~35% at the M1 site and ~60% at the S3 site, with these changes  
 2157 observed within an hour of the SBF passage.

2158 Simulations performed for this event also suggest similar changes in aerosol budget,  
 2159 indicating that the SBF brings in a cleaner air mass from directions consistent with a more  
 2160 marine environment. Model results suggest that the CCN concentration at the surface decreases  
 2161 by up to 60%, consistent with the observations. In our supplemental Figs. S11. and S12., we  
 2162 include the temporal variation of the normalized  $N_{100}$  during all the other SB events during the  
 2163 TRACER IOP. The preexisting  $N_{100}$  is less frequently impacted by the SAI than previous  
 2164 examples we provided for SBF changes to the total number concentration, and these events  
 2165 show a decrease in  $N_{100}$  for ~25% of the SB events at both M1 and S3 site. This suggests that  
 2166 the influence of SAI is lesser over the marine influenced regional background aerosol larger  
 2167 than 100 nm in diameter.

## 2169 4 Summary and conclusions

- Deleted: This
- Deleted: pattern
- Deleted: resembles
- Deleted: that
- Deleted: observed
- Formatted: Indent: First line: 0.5", Space After: 0 pt
- Deleted: within
- Deleted:
- Deleted: For TRACER, t
- Formatted: Font color: Auto
- Formatted: Font color: Auto
- Deleted: ARM TRACER
- Deleted: TRACER
- Formatted: Justified, Space After: 6 pt, Border: Top: (No border), Bottom: (No border), Left: (No border), Right: (No border), Between : (No border)
- Deleted: on aerosol direct and indirect effects
- Deleted: ¶
- 3.7.1 Changes in ...
- Formatted: Font color: Auto
- Deleted: 1a
- Deleted: the
- Formatted: Font color: Auto
- Deleted: For this case
- Formatted: Font color: Auto, Subscript
- Formatted: Font color: Auto
- Deleted: CCN
- Formatted: Font color: Auto
- Formatted: Font color: Auto, Subscript
- Deleted: ¶
- Deleted: s
- Deleted: ¶

6445 Sea breezes influence multi-scale processes across the land-ocean-atmosphere interface  
6446 within the region of influence of the SBC. The TRACER field campaign provided a unique  
6447 opportunity to understand how aerosol and meteorological processes impact weather and  
6448 climate in the urban and rural coastal environment of Houston, Texas. A total of 46 (M1) and  
6449 30 (S3) instances of SB passages were identified during the summertime TRACER IOP period.  
6450 Summertime measurements from the ARM sites coupled with WRF-Chem model simulations  
6451 (July and August 2022) help to quantify aerosol changes resulting from onshore transport of  
6452 marine boundary layer air masses due to SBF passage and the associated atmospheric SBC  
6453 impacts.

6454 Understanding the spatial extent and duration of SAIs is crucial for assessing their  
6455 environmental and meteorological impacts. For inland-penetrating SBFs, aerosol responses fall  
6456 into one of the three types: reduction (clean marine air replacing more polluted continental air);  
6457 enhancement (import of more polluted air), or neutral (similar air masses). The sign and  
6458 magnitude of changes depend on coastal proximity to the coast and the upwind air mass history  
6459 prior to SBF arrival.

6460 TRACER measurements indicate that the urban M1 site, closer to both Galveston Bay  
6461 and the Gulf of Mexico, experiences more frequent aerosol concentration changes (increase or  
6462 decrease during 63% of SB events) than the rural S3 site (increase or decrease during 40% of  
6463 SB days), which is primarily Gulf-breeze influenced and farther from urban/industrial sources.  
6464 During IOP events, surface aerosol number changed by up to a factor of two. On average, SBF  
6465 passages were associated with a decrease of ~23% at M1 and increase of ~4% at S3. SBF  
6466 passages produce distinct aerosol responses depending on the type of SAI event. At M1,  
6467 enhancement days (28% of SB events) are associated with an average increase of aerosol  
6468 concentration by ~55%, while reduction days (35% of SB events) show an average decrease of  
6469 ~42%. At S3, enhancement days (27% of SB events) exhibit an average increase of ~64%,  
6470 whereas reduction days (13% of SB events) show a decrease of ~45%.

6471 This study also provides support for how SAIs may interfere with aerosol microphysical  
6472 processes, including NPF events, a key driver of the overall aerosol number budget. These  
6473 changes occur with sharp meteorological shifts, including RH (+30%) and wind speed (+4 m  
6474 s<sup>-1</sup>) increases, and backing to southeasterly flow (Figs. 7. and 8.). The relationship between  
6475 wind and aerosol number concentrations showed that aerosol concentrations at the M1 site are  
6476 higher when prevailing winds originate from the direction of the Houston urban core

- Formatted [229]
- Deleted: l
- Deleted: any ...land-penetrating SBFs, its influen [230]
- Formatted [231]
- Deleted: where the SB replaces polluted aerosol air [232]
- Formatted [233]
- Deleted: , where no significant change occurs beca [234]
- Formatted [235]
- Deleted:
- Formatted [236]
- Deleted: site...proximity to the coast and the upwi [237]
- Deleted: passage... [239]
- Formatted [238]
- Formatted [240]
- Deleted: suggest
- Deleted: the
- Deleted: land-ocean interface
- Formatted [241]
- Deleted:
- Deleted: s
- Formatted [242]
- Formatted [243]
- Deleted: 57
- Deleted: in aerosol concentrations compared to
- Deleted: 34
- Formatted [244]
- Deleted: is f
- Deleted: urther downstream
- Deleted: and
- Deleted: influences in this SBC region
- Formatted [245]
- Formatted [246]
- Formatted [247]
- Deleted: Surface aerosol concentration d...ring IO [249]
- Formatted [248]
- Deleted: aerosol number concentrations that ... de [251]
- Deleted: by
- Deleted: 5... at M1 and increased [254]
- Deleted: by
- Deleted: 7... at S3. SBF passages produce distinct [257]
- Formatted [250]
- Formatted [252]
- Formatted [253]
- Formatted [255]
- Formatted [256]
- Deleted: It is important to note that ...his study als [258]
- Deleted: were accompanied by sudden shifts...in [260]
- Deleted: conditions
- Formatted [259]
- Formatted [261]
- Deleted: e...ncreasenhancement [262]
- Deleted: in...wind directions to the [264]
- Formatted [263]

6577 (northwest), to north, compared to the winds coming from the sea (south) (Fig. S5). Recently,  
6578 Rapp et al. (2024) emphasized using targeted mobile sampling that collecting measurements  
6579 on both sides of SB boundaries are critical for disentangling aerosol from meteorological  
6580 controls. These findings are complementary to the results in this study that boundary timing  
6581 and air mass origin drive the different responses at M1 and S3.

6582 WRF Chem simulations extend the site perspective regionally, indicating  
6583 heterogeneous SAI footprints (Figs. 9, 10, 11, and 12). Across 18 simulated events, near surface  
6584 PM<sub>2.5</sub> tends to decrease by ~15% around the M1 site and increase by ~3% near the S3 site (Fig.  
6585 S13). However, these responses vary with altitude (Fig. 12). The SBF may alter the vertical  
6586 aerosol distribution in the boundary layer up to 2 km. Beyond thermodynamics, SB fronts also  
6587 reshape convective environments (Wang et al., 2024). The storm characteristics across  
6588 maritime vs. continental sides of these fronts drive the air mass contrasts produced by SBCs  
6589 (Sharma et al., 2024), which can further influence the aerosol environment.

6590 With respect to cloud-relevant particles, both observations and simulations indicate that  
6591 the surface CCNproxy concentrations decrease by up to 60% following SBF passage (Fig. 13),  
6592 although such changes are infrequent (~25% of the SB events at both M1 and S3 site), implying  
6593 a weaker impact of SAI on marine influenced regional background accumulation mode. This  
6594 aligns with Thompson et al. (2025), which showed that aerosol cloud-forming properties differ  
6595 between polluted marine and continental air masses, with variability in size, hygroscopicity,  
6596 and CCN efficiency across sites. Given the complex mix of marine, terrestrial, and urban  
6597 sources, and the strong spatial heterogeneity revealed by both our analysis and prior TRACER  
6598 studies, future studies should include direct CCN and INP measurements and size-resolved  
6599 aerosol properties to better capture the role of SAI in aerosol–cloud interactions. It is important  
6600 to remember that these effects are localized, occurring only during shorter timescales (~5  
6601 hours) associated with daily SBC cycles over these locations. But these SAI timings align with  
6602 periods of peak solar radiation and elevated aerosol concentrations, potentially leading to  
6603 significant impacts on the radiation budget over the coastal regions. During times in close  
6604 proximity to SBF passage, changes in solar radiation and cloud formation may influence the  
6605 aerosol formation and distribution, modify atmospheric chemical reactions, and affect cloud  
6606 formation and properties, thereby impacting various atmospheric processes and interactions.  
6607 Because many coastal cities have high aerosol loading with frequent SBCs, accounting for SAI

- Deleted: east...to north) ... [265]
- Deleted: and intermediate directions
- Deleted: ...using targeted mobile sampling, ... [266]
- Deleted: simultaneously ...easurements on ing ... [268]
- Formatted ... [267]
- Deleted: is
- Formatted ... [269]
- Deleted: ...supporting the ... [270]
- Formatted ... [271]
- Formatted ... [272]
- Deleted: were performed to investigate the regiona ... [273]
- Deleted: 10 and 11
- Deleted: The...18 TRACER events ... [275]
- Deleted: indicate that
- Formatted ... [274]
- Formatted ... [276]
- Deleted: concentrations
- Formatted ... [277]
- Deleted: 10
- Deleted: For example, our efforts suggest t
- Formatted ... [278]
- Formatted ... [279]
- Deleted: Coastal SBCs are a global phenomenon. ... [280]
- Deleted: B...th observations and model ...imulatio ... [282]
- Formatted ... [281]
- Deleted: 11
- Formatted ... [283]
- Deleted: .
- Deleted: However, the ...changes in CCNproxy ... [285]
- Deleted: rare
- Deleted: suggesting
- Formatted ... [284]
- Formatted ... [286]
- Formatted ... [287]
- Deleted: aerosols
- Formatted ... [288]
- Formatted ... [289]
- Deleted: Model simulations suggest that changes in ... [290]
- Formatted ... [291]
- Deleted: Since many coastal cities have high aeros ... [292]
- Deleted: < 6...hoursours... associated with daily S ... [294]
- Formatted ... [293]
- Formatted ... [295]

6742 when estimating direct aerosol radiative forcing is crucial. However, quantifying these changes  
6743 is challenging, underscoring the need for detailed future studies across diverse coastal regions.

6744  
6745 **Code and data availability.** DOE-ARM datasets can be downloaded from the ARM data  
6746 discovery ([https://adc.arm.gov/discovery/#/results/instrument\\_class\\_code::#](https://adc.arm.gov/discovery/#/results/instrument_class_code::#)). The TCEQ  
6747 data can be downloaded from [https://www.tceq.texas.gov/agency/data and sfcmetradatq-tceq](https://www.tceq.texas.gov/agency/data_and_sfcmetradatq-tceq)  
6748 [ARM PI product \(https://doi.org/10.5439/2587278\)](https://doi.org/10.5439/2587278). The Weather Research and Forecasting  
6749 Model with Chemistry model code is available from  
6750 [www2.mmm.ucar.edu/wrf/users/download/](http://www2.mmm.ucar.edu/wrf/users/download/). WRF-Chem preprocessors are available on the  
6751 website ([www.acom.ucar.edu/wrf-chem](http://www.acom.ucar.edu/wrf-chem)). The model output data is made available upon  
6752 request. The primary tools to analyze the model output and generate figures are CDO  
6753 ([code.mpimet.mpg.de/projects/cdo/](http://code.mpimet.mpg.de/projects/cdo/)), MATLAB ([www.mathworks.com/products/](http://www.mathworks.com/products/)), and  
6754 Jupyter Notebook platform (<https://jupyter.org>).

6755  
6756 **Supplement.** The supplementary document contains supplementary figures referred to in the  
6757 main manuscript.

6758  
6759 **Author contribution.** TS and CK planned the study; TS conducted the analysis and wrote the  
6760 manuscript; MH provided the aerosol data; MJ, MD, SG, MH, AS, DW, MZ and CK reviewed  
6761 and edited the manuscript.

6762  
6763 **Competing interests.** The authors declare that they have no conflict of interest.

6764  
6765 **Acknowledgments.** We would like to acknowledge support from the Atmospheric System  
6766 Research (ASR) program, the Atmospheric Radiation Measurement (ARM) user facility, and  
6767 the ARM TRACER operation and science teams. This research was supported in part by  
6768 resources provided by the National Energy Research Scientific Computing Center (NERSC),  
6769 a DOE Office of Science User Facility under Contract No. DE-AC02-05CH11231, through  
6770 NERSC award BER-ERCAP0026649. Additionally, the NE Linux Cluster (nlc) at Brookhaven  
6771 National Laboratory was utilized for model simulations and output storage.

Deleted: estimating

Formatted: Font color: Auto

Deleted: in aerosol radiative forcing

Deleted: therefore, a

Deleted: y

Deleted: of these changes

Deleted: different

Deleted: is important

Formatted: Font color: Auto

Formatted: Font color: Auto

Formatted: Font color: Auto

Deleted: <https://www.tceq.texas.gov/agency/data>

Formatted: Font color: Auto

Deleted: [sfcmetradatq-tceq ARM data product \(](https://doi.org/10.5439/2587278)

Deleted: h

Deleted: .

Formatted: Font color: Auto

Formatted: Not Highlight

Deleted:

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Not Highlight

6784

6785 **Financial support.** This paper has been authored by employees of Brookhaven Science  
6786 Associates, LLC, under Contract DE-SC0012704 with the U.S. Department of Energy (DOE).

6787

6788

## 6789 **References**

6790 [Ackermann, I. J., Hass, H., Memmesheimer, M., Ebel, A., Binkowski, F. S., & Shankar, U.:](#)

6791 [Modal aerosol dynamics model for Europe: Development and first applications.](#)

6792 [Atmospheric Environment, 32\(17\), 2981–2999. <https://doi.org/10.1016/S1352->](#)

6793 [2310\(98\)00006-5, 1998.](#)

6794 [Adaricheva, K., Bernhardt, J. E., Liu, W., & Schmidt, B.: Importance of overnight parameters](#)

6795 [to predict Sea Breeze on Long Island. <http://arxiv.org/abs/2309.01803>, 2023.](#)

6796 [Ahlm, L., Junin, J., Fountoukis, C., Pandis, S. N., & Riipinen, I. \(2013\). Particle number](#)

6797 [concentrations over Europe in 2030: The role of emissions and new particle formation.](#)

6798 [Atmospheric Chemistry and Physics, 13\(20\), 10271–10283.](#)

6799 <https://doi.org/10.5194/acp-13-10271-2013>

6800 [Ahmadov, R., Gerbig, C., Kretschmer, R., Koerner, S., Neining, B., Dolman, A. J., & Sarrat,](#)

6801 [C.: Mesoscale covariance of transport and CO<sub>2</sub> fluxes: Evidence from observations and](#)

6802 [simulations using the WRF-VPRM coupled atmosphere-biosphere model. \*Journal of\*](#)

6803 [Geophysical Research Atmospheres, 112\(22\). <https://doi.org/10.1029/2007JD008552>,](#)

6804 [2007.](#)

6805 [Albrecht, B. A.: Aerosols, cloud microphysics, and fractional cloudiness. \*Science\*, 245, 1227–](#)

6806 [1230, 1989.](#)

6807 [Aldhaif, A. M., Lopez, D. H., Dadashazar, H., & Sorooshian, A.: Sources, frequency, and](#)

6808 [chemical nature of dust events impacting the United States East Coast. \*Atmospheric\*](#)

6809 [Environment, 231. <https://doi.org/10.1016/j.atmosenv.2020.117456>, 2020.](#)

6810 [Ariya, P., Sun, J., Eltouny, N., Hudson, E. D., Hayes, C. T., & Kos, G.: Physical and chemical](#)

6811 [characterization of bioaerosols—Implications for nucleation processes. \*International\*](#)

6812 [Reviews in Physical Chemistry, 28\(1\), 1–32.](#)  
6813 <https://doi.org/10.1080/01442350802597438>, 2009.

6814 [Arrillaga, J. A., Jiménez, P., de Arellano, J. V.-G., Jiménez, M. A., Román-Cascón, C., Sastre,](#)  
6815 [M., and Yagüe, C.: Analyzing the synoptic-, meso- and local-scale involved in sea](#)  
6816 [breeze formation and frontal characteristics. J. Geophys. Res. Atmos., 125,](#)  
6817 [e2019JD031302, https://doi.org/10.1029/2019JD031302, 2020.](#)

6818 [Atabakhsh, S., Poulain, L., Bigi, A., Coen, M. C., Pöhlker, M., & Herrmann, H.: Trends of](#)  
6819 [PM1 aerosol chemical composition, carbonaceous aerosol, and source over the last 10](#)  
6820 [years at Melpitz \(Germany\). Atmospheric Environment, 346,](#)  
6821 [https://doi.org/10.1016/j.atmosenv.2025.121075, 2025.](#)

6822 [Augustin, P., Billet, S., Crumeyrolle, S., Deboudt, K., Dieudonné, E., Flament, P., Fourmentin,](#)  
6823 [M., Guilbaud, S., Hanoune, B., Landkocz, Y., Méausoone, C., Roy, S., Schmitt, F. G.,](#)  
6824 [Sentchev, A., & Sokolov, A.: Impact of sea breeze dynamics on atmospheric pollutants](#)  
6825 [and their toxicity in industrial and urban coastal environments. Remote Sensing, 12\(4\),](#)  
6826 [https://doi.org/10.3390/rs12040648, 2020.](#)

6827 [Banta, R. M., Senff, C. J., Alvarez, R. J., Langford, A. O., Parrish, D. D., Trainer, M. K., Darby,](#)  
6828 [L. S., Michael Hardesty, R., Lambeth, B., Andrew Neuman, J., Angevine, W. M.,](#)  
6829 [Nielsen-Gammon, J., Sandberg, S. P., & White, A. B.: Dependence of daily peak O3](#)  
6830 [concentrations near Houston, Texas on environmental factors: Wind speed,](#)  
6831 [temperature, and boundary-layer depth. Atmospheric Environment, 45\(1\), 162–173.](#)  
6832 [https://doi.org/10.1016/j.atmosenv.2010.09.030, 2011.](#)

6833 [Bao, S., Pietrafesa, L., Gayes, P., Noble, S., Viner, B., Qian, J. H., Werth, D., Mitchell, G., &](#)  
6834 [Burdette, S.: Mapping the Spatial Footprint of Sea Breeze Winds in the Southeastern](#)  
6835 [United States. Journal of Geophysical Research: Atmospheres, 128\(7\),](#)  
6836 [https://doi.org/10.1029/2022JD037524, 2023.](#)

6837 [Barrett, T. E., & Sheesley, R. J.: Urban impacts on regional carbonaceous aerosols: Case study](#)  
6838 [in central Texas. Journal of the Air and Waste Management Association, 64\(8\), 917–](#)  
6839 [926. https://doi.org/10.1080/10962247.2014.904252, 2014.](#)

6840 [Bauman, W. H.: Verify MesoNAM Performance. NASA Contractor Report CR-2010-216-287,](#)  
6841 [Kennedy Space Center, FL, 31 pp. \[Available from ENSCO, Inc., 1980 N. Atlantic](#)

6842 [Ave., Suite 830, Cocoa Beach, FL, 32931 and online at](#)  
6843 <http://science.ksc.nasa.gov/amu/final-reports/mesoNAMverify.pdf.>], 2010.

6844 [Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., Deangelo, B. J., Flanner,](#)  
6845 [M. G., Ghan, S., Kärcher, B., Koch, D., Kinne, S., Kondo, Y., Quinn, P. K., Sarofim,](#)  
6846 [M. C., Schultz, M. G., Schulz, M., Venkataraman, C., Zhang, H., Zhang, S., ... Zender,](#)  
6847 [C. S.: Bounding the role of black carbon in the climate system: A scientific assessment.](#)  
6848 [Journal of Geophysical Research Atmospheres, 118\(11\), 5380–5552.](#)  
6849 <https://doi.org/10.1002/jgrd.50171>, 2013.

6850 [Borge, R., Alexandrov, V., José del Vas, J., Lumbreras, J., & Rodríguez, E.: A comprehensive](#)  
6851 [sensitivity analysis of the WRF model for air quality applications over the Iberian](#)  
6852 [Peninsula. Atmospheric Environment, 42\(37\), 8560–8574.](#)  
6853 <https://doi.org/10.1016/j.atmosenv.2008.08.032>, 2008.

6854 [Boyer, C. H., Keeler, J. M., & Rakoczy, B. C. \(2025\). An Idealized Parameter Study of](#)  
6855 [Destabilization and Convection Initiation in Coastal Regions. Part I: Calm or Offshore](#)  
6856 [Synoptic-Scale Flow. Journal of the Atmospheric Sciences, 82\(3\), 519–539.](#)  
6857 <https://doi.org/10.1175/JAS-D-23-0180.1>

6858 [Boyouk, N., Léon, J. F., Delbarre, H., Augustin, P., & Fourmentin, M.: Impact of sea breeze](#)  
6859 [on vertical structure of aerosol optical properties in Dunkerque, France. Atmospheric](#)  
6860 [Research, 101\(4\), 902–910. https://doi.org/10.1016/j.atmosres.2011.05.016](#), 2011.

6861 [Bozlaker, A., Prospero, J. M., Fraser, M. P., & Chellam, S.: Quantifying the contribution of](#)  
6862 [long-range saharan dust transport on particulate matter concentrations in Houston,](#)  
6863 [Texas, using detailed elemental analysis. Environmental Science and Technology,](#)  
6864 [47\(18\), 10179–10187. https://doi.org/10.1021/es4015663](#), 2013.

6865 [Brown, S., Nicholls, R. J., Woodroffe, C. D., Hanson, S., Hinkel, J., Kebede, A. S., Neumann,](#)  
6866 [B. and Vafeidis, A. T.: “Sea-Level Rise Impacts and Responses: A Global Perspective.”](#)  
6867 [In Coastal Hazards, edited by Charles W. Finkl, 117–49. Dordrecht: Springer](#)  
6868 [Netherlands. https://doi.org/10.1007/978-94-007-5234-4\\_5](#), 2013.

6869 [Burkart, J., Gratzl, J., Seifried, T. M., Bieber, P., & Grothe, H.: Subpollen particles \(SPP\) of](#)  
6870 [birch as carriers of ice nucleating macromolecules. Biogeosciences Discussions, 1–15,](#)  
6871 [2021.](#)

6872 [Charlson, R. J., Schwartz, S. E., Hales, J. M., Cess, R. D., Coakley, J. A. Jr, Hansen, J. E., and](#)  
6873 [Hofmann, D. J.: Climate forcing by anthropogenic aerosols. \*Science\* 255, 423–430,](#)  
6874 [1992.](#)

6875 [Chen, F., & Dudhia, J.: Coupling an advanced land surface-hydrology model with the Penn](#)  
6876 [State-NCAR MM5 modeling system. Part I: Model implementation and sensitivity.](#)  
6877 [\*Monthly Weather Review\*, 129\(4\), 569–585. \[https://doi.org/10.1175/1520-\]\(https://doi.org/10.1175/1520-0493\(2001\)129<0569:caalsh>2.0.co;2\)](#)  
6878 [0493\(2001\)129<0569:caalsh>2.0.co;2, 2001.](#)

6879 [Chou, M., Suarez, M. J., Ho, C., Yan, M. M., & Lee, K.: Parameterizations for cloud](#)  
6880 [overlapping and shortwave single-scattering properties for use in general circulation](#)  
6881 [and cloud ensemble models. \*Journal of Climate\*, 11\(2\), 202–214. \[https://doi.\]\(https://doi.org/10.1175/1520-0442\(1998\)011<0202:PFCOAS>2.0.CO;2\)](#)  
6882 [org/10.1175/1520-0442\(1998\)011<0202:PFCOAS>2.0.CO;2, 1998.](#)

6883 [Clappier, A., Martilli, A., Grossi, P., Thunis, P., Pasi, F., Krueger, B. C., Calpini, B., &](#)  
6884 [Graziani, G., Bergh, H.V.D.: Effect of Sea Breeze on Air Pollution in the Greater](#)  
6885 [Athens Area. Part I: Numerical Simulations and Field Observations. \*J. of Applied\*](#)  
6886 [meteorology,](#) (39). [https://doi.org/10.1175/1520-](https://doi.org/10.1175/1520-0450(2000)039<0546:EOSBOA>2.0.CO;2)  
6887 [0450\(2000\)039<0546:EOSBOA>2.0.CO;2, 1999.](#)

6888 [Comin, A. N., Miglietta, M. M., Rizza, U., Acevedo, O. C., & Degrazia, G. A.: Investigation](#)  
6889 [of sea-breeze convergence in Salento Peninsula \(southeastern Italy\). \*Atmospheric\*](#)  
6890 [Research, 160, 68–79. <https://doi.org/10.1016/j.atmosres.2015.03.010>, 2015.](#)

6891 [Crippa, M., Canonaco, F., Lanz, V. A., Äijälä, M., Allan, J. D., Carbone, S., Capes, G.,](#)  
6892 [Ceburnis, D., Dall’Osto, M., Day, D. A., DeCarlo, P. F., Ehn, M., Eriksson, A., Freney,](#)  
6893 [E., Hildebrandt Ruiz, L., Hillamo, R., Jimenez, J. L., Junninen, H., KiendlerScharr, A.,](#)  
6894 [Kortelainen, A. M., Kulmala, M., Laaksonen, A., Mensah, A. A., Mohr, C., Nemitz, E.,](#)  
6895 [O’Dowd, C., Ovadnevaite, J., Pandis, S. N., Petäjä, T., Poulain, L., Saarikoski, S.,](#)  
6896 [Sellegri, K., Swietlicki, E., Tiitta, P., Worsnop, D. R., Baltensperger, U., Prévôt, A. S.](#)  
6897 [H.: Organic aerosol components derived from 25 AMS data sets across Europe using a](#)  
6898 [consistent ME-2 based source apportionment approach. \*Atmos. Chem. Phys.\* 14 \(12\),](#)  
6899 [6159–6176. <https://doi.org/10.5194/acp-14-6159>, 2014.](#)

6900 [Crossett, K., Culliton, T., Wiley, P., & Goodspeed, T.: Population trends along the coastal](#)  
6901 [United States, 1980–2008. Silver Spring, National Oceanic and Atmospheric](#)  
6902 [Administration, 2004.](#)

Formatted: Not Highlight

Formatted: Not Highlight

Formatted: Not Highlight

6903 [Das, S., Prospero, J. M., & Chellam, S.: Quantifying international and interstate contributions](#)  
6904 [to primary ambient PM2.5 and PM10 in a complex metropolitan atmosphere.](#)  
6905 [Atmospheric Environment, 292. https://doi.org/10.1016/j.atmosenv.2022.119415,](#)  
6906 [2023.](#)

6907 [Deng, Min, et al.: A Closed Bay-Breeze Circulation and Its Lifecycle from TRACER with a](#)  
6908 [New Orienteering Tape Recorder Diagram, Journal of Geophysical Research:](#)  
6909 [Atmospheres \(under revision\), 2025.](#)

6910 [di Bernardino, A., Iannarelli, A. M., Casadio, S., Mevi, G., Campanelli, M., Casasanta, G.,](#)  
6911 [Cede, A., Tiefengraber, M., Siani, A. M., Spinei, E., & Cacciani, M.: On the effect of](#)  
6912 [sea breeze regime on aerosols and gases properties in the urban area of Rome, Italy.](#)  
6913 [Urban Climate, 37. https://doi.org/10.1016/j.uclim.2021.100842, 2021.](#)

6914 [Emmons, L. K., Walters, S., Hess, P. G., Lamarque, J. F., Pfister, G. G., Fillmore, D., et al.:](#)  
6915 [Description and evaluation of the model for ozone and related chemical tracers, version](#)  
6916 [4 \(MOZART-4\). Geoscientific Model Development, 3\(1\), 43–67.](#)  
6917 [https://doi.org/10.5194/gmd-3-43-2010, 2010.](#)

6918 [Dueker, M. E., O’Mullan, G. D., Martínez, J. M., Juhl, A. R., & Weathers, K. C.: Onshore](#)  
6919 [wind speed modulates microbial aerosols along an urban waterfront. Atmosphere,](#)  
6920 [8\(11\). https://doi.org/10.3390/atmos8110215, 2017.](#)

6921 [Fang, C., Li, X., Li, J., Tian, J., & Wang, J. \(2025\). Research on the impact of land use and](#)  
6922 [land cover changes on local meteorological conditions and surface ozone in the north](#)  
6923 [China plain from 2001 to 2020. Scientific Reports, 15\(1\).](#)  
6924 [https://doi.org/10.1038/s41598-025-85940-0](#)

6925 [Gangoiti, G., Millán, M. M., Salvador, R., & Mantilla, E.: Long-range transport and re-](#)  
6926 [circulation of pollutants in the western Mediterranean during the project Regional](#)  
6927 [Cycles of Air Pollution in the West-Central Mediterranean Area. Atmospheric](#)  
6928 [Environment, 35\(36\), 6267–6276. https://doi.org/10.1016/S1352-2310\(01\)00440-X,](#)  
6929 [2001.](#)

6930 [Gelaro, R., and Coauthors: The Modern-Era Retrospective Analysis for Research and](#)  
6931 [Applications, version 2 \(MERRA-2\). J. Climate, 30, 5419–5454,](#)  
6932 [https://doi.org/10.1175/JCLI-D-16-0758.1, 2017.](#)

6933 [Georgiou, G. K., Christoudias, T., Proestos, Y., Kushta, J., Pikridas, M., Sciare, J., Savvides,](#)  
6934 [C., & Lelieveld, J.: Evaluation of WRF-Chem model \(v3.9.1.1\) real-Time air quality](#)  
6935 [forecasts over the Eastern Mediterranean. \*Geoscientific Model Development\*, 15\(10\),](#)  
6936 [4129–4146. <https://doi.org/10.5194/gmd-15-4129-2022>, 2022.](#)

6937 [Gettelman, A., Mills, M. J., Kinnison, D. E., Garcia, R. R., Smith, A. K., Marsh, D. R., et al.:](#)  
6938 [The wholeatmosphere community climate modelversion 6 \(WACCM6\). \*Journal of\*](#)  
6939 [Geophysical Research: Atmospheres](#), 124, <https://doi.org/10.1029/2019JD030943>,  
6940 [2019.](#)

6941 [Glantz, P., Nilsson, D. E., & von Hoyningen-Huene, W. \(2006\). Estimating a relationship](#)  
6942 [between aerosol optical thickness and surface wind speed over the ocean. In \*Atmos.\*](#)  
6943 [Chem. Phys. Discuss \(Vol. 6\). \[www.atmos-chem-phys-discuss.net/6/11621/2006/\]\(http://www.atmos-chem-phys-discuss.net/6/11621/2006/\)](#)

6944 [Grell, G. A., & Devenyi, D.: A generalized approach to parameterizing convection combining](#)  
6945 [ensemble and data assimilation techniques. \*Geophysical Research Letters\*, 29\(4\), 38-1–](#)  
6946 [38-4. <https://doi.org/10.1029/2002GL015311>, 2002.](#)

6947 [Grell, G. A., Peckham, S. E., Schmitz, R., McKeen, S. A., Frost, G., Skamarock, W. C., &](#)  
6948 [Eder, B.: Fully coupled “online” chemistry within the WRF model. \*Atmospheric\*](#)  
6949 [Environment](#), 39(37), 6957–6975. <https://doi.org/10.1016/j.atmosenv.2005.04.027>,  
6950 [2005.](#)

6951 [Guenther, A. B., Jiang, X., Heald, C. L., Sakulyanontvittaya, T., Duhl, T., Emmons, L. K., &](#)  
6952 [Wang, X.: The model of emissions of gases and aerosols from nature version 2.1](#)  
6953 [\(MEGAN2.1\): An extended and updated framework for modeling biogenic emissions.](#)  
6954 [\*Geoscientific Model Development\*, 5\(6\), 1471–1492. \[https://doi.org/10.5194/gmd-5-\]\(https://doi.org/10.5194/gmd-5-1471-2012\)](#)  
6955 [1471-2012, 2012.](#)

6956 [Hanft, W., & Houston, A. L.: An Observational and Modeling Study of Mesoscale Air Masses](#)  
6957 [with High Theta-E. <https://doi.org/10.1175/MWR-D-17, 2018>.](#)

6958 [Hernández-Ceballos, M. A., Sorribas, M., San Miguel, E. G., Cinelli, G., Adame, J. A., &](#)  
6959 [Bolívar, J. P.: Impact of sea-land breezes on 210Pb in southern Iberian Peninsula–](#)  
6960 [Feasibility study on using submicron-sized aerosol particles to analyze 210Pb hourly](#)  
6961 [patterns. \*Atmospheric Pollution Research\*, 7\(1\), 1–8.](#)  
6962 [<https://doi.org/10.1016/j.apr.2015.06.011>, 2016.](#)

6963 [Hong, S. Y., Noh, Y., & Dudhia, J.: A new vertical diffusion package with an explicit treatment](#)  
6964 [of entrainment processes. Monthly Weather Review, 134\(9\), 2318–2341.](#)  
6965 <https://doi.org/10.1175/MWR3199.1>, 2006.

6966 [Hu, L. \(2021\). A Global Assessment of Coastal Marine Heatwaves and Their Relation With](#)  
6967 [Coastal Urban Thermal Changes. Geophysical Research Letters, 48\(9\).](#)  
6968 <https://doi.org/10.1029/2021GL093260>

6969 [Huang, X. F., He, L. Y., Hu, M., Canagaratna, M. R., Sun, Y., Zhang, Q., Zhu, T., Xue, L.,](#)  
6970 [Zeng, L. W., Liu, X. G., Zhang, Y. H., Jayne, J. T., Ng, N. L., Worsnop, D. R.: Highly](#)  
6971 [time-resolved chemical characterization of atmospheric submicron particles during](#)  
6972 [2008 Beijing Olympic Games using an Aerodyne High-Resolution Aerosol Mass](#)  
6973 [Spectrometer. Atmos. Chem. Phys. 2010, 10, 8933–8945, DOI: 10.5194/acp-10-8933-](#)  
6974 [2010.](#)

6975 [Hudson, B.: Coastal Land Loss and the Mitigation-Adaptation Dilemma: Between Scylla and](#)  
6976 [Charybdis Repository Citation Coastal Land Loss and the Mitigation-Adaptation](#)  
6977 [Dilemma: Between Scylla and Charybdis. In Louisiana Law Review \(Vol. 73\).](#)  
6978 <https://digitalcommons.law.lsu.edu/lalrev/vol73/iss1/3>, 2012.

6979 [Igel, A. L., van den Heever, S. C., & Johnson, J. S.: Meteorological and Land Surface](#)  
6980 [Properties Impacting Sea Breeze Extent and Aerosol Distribution in a Dry](#)  
6981 [Environment. Journal of Geophysical Research: Atmospheres, 123\(1\), 22–37.](#)  
6982 <https://doi.org/10.1002/2017JD027339>, 2018.

6983 [IPCC, Intergovernmental Panel on Climate Change: In V. Masson-Delmotte, P. Zhai, A.](#)  
6984 [Pirani, S. L. Connors, C. P.an, S. Berger, et al. \(Eds.\), The Physical Science Basis.](#)  
6985 [Contribution of Working Group I to the Sixth Assessment Report of the](#)  
6986 [Intergovernmental Panel on Climate Change. Cambridge University Press.](#)  
6987 <https://doi.org/10.1017/9781009157896>, 2021.

6988 [Iwai, H., Murayama, Y., Ishii, S., Mizutani, K., Ohno, Y., & Hashiguchi, T.: Strong Updraft at](#)  
6989 [a Sea-Breeze Front and Associated Vertical Transport of Near-Surface Dense Aerosol](#)  
6990 [Observed by Doppler Lidar and Ceilometer. Boundary-Layer Meteorology, 141\(1\),](#)  
6991 [117–142. https://doi.org/10.1007/s10546-011-9635-z](#), 2011.

6992 [Janjic, Z. I.: Nonsingular implementation of the Mellor–Yamada level 2.5 scheme in the NCEP](#)  
6993 [Meso model. NCEP Office Note, 437, 61, 2002.](#)

6994 [Jensen, M. P., and Coauthors. \(2022\): A Succession of Cloud, Precipitation, Aerosol, and Air](#)  
6995 [Quality Field Experiments in the Coastal Urban Environment. Bull. Amer. Meteor.](#)  
6996 [Soc., 103, 103–105, <https://doi.org/10.1175/BAMS-D-21-0104.1>, 2022.](#)

6997 [Jensen, M. P., Flynn, J. H., Gonzalez-Cruz, J. E., Judd, L. M., Kollias, P., Kuang, C.,](#)  
6998 [McFarquhar, G. M., Powers, H., Ramamurthy, P., Sullivan, J., Aiken, A. C., Alvarez,](#)  
6999 [S. L., Argay, P., Argrow, B., Bell, T. M., Boyer, D., Brooks, S. D., Bruning, E. C.,](#)  
7000 [Brunner, K., ... Zhu, Z. \(2025\). Studying Aerosol, Clouds, and Air Quality in the](#)  
7001 [Coastal Urban Environment of Southeastern Texas. Bulletin of the American](#)  
7002 [Meteorological Society. <https://doi.org/10.1175/bams-d-23-0331.1>](#)

7003 [Karnač, S., & John, K.: Source apportionment of PM<sub>2.5</sub> measured in South Texas near U.S.A.](#)  
7004 [– Mexico border. Atmospheric Pollution Research, 10\(5\), 1663–1676.](#)  
7005 [https://doi.org/10.1016/j.apr.2019.06.007](#)

7006 [Kerminen, V. M., Chen, X., Vakkari, V., Petäjä, T., Kulmala, M., & Bianchi, F. : Atmospheric](#)  
7007 [new particle formation and growth: Review of field observations. In Environmental](#)  
7008 [Research Letters \(Vol. 13, Issue 10\). Institute of Physics Publishing.](#)  
7009 [https://doi.org/10.1088/1748-9326/aadf3c, 2018.](#)

7010 [Kgabi, N. A., & Mokgwetsi, T. \(2009\). Dilution and dispersion of inhalable particulate matter.](#)  
7011 [WIT Transactions on Ecology and the Environment, 127, 229–238.](#)  
7012 [https://doi.org/10.2495/RAV090201](#)

7013 [Kleinman, L. I., Daum, P. H., Imre, D. G., Lee, Y.-N., Nunnermacker, L. J., Springston, S. R.,](#)  
7014 [Weinstein-Lloyd, J., and Rudolph, J.: Ozone production rate and hydrocarbon reactivity](#)  
7015 [in 5 urban areas: A cause of high ozone concentration in Houston, Geophys. Res. Lett.,](#)  
7016 [29\(10\), 1467, doi:10.1029/2001GL014569, 2002.](#)

7017 [Kuang, C., Chen, M., Zhao, J., Smith, J., McMurry, P. H., & Wang, J.: Size and time-resolved](#)  
7018 [growth rate measurements of 1 to 5 nm freshly formed atmospheric nuclei. Atmospheric](#)  
7019 [Chemistry and Physics, 12\(7\), 3573–3589. <https://doi.org/10.5194/acp-12-3573-2012>,](#)  
7020 [2012.](#)

7021 [Kuang, C., McMurry, P. H., and McCormick, A. V.: Determination of cloud condensation](#)  
7022 [nuclei production from measured new particle formation events, Geophys. Res. Lett.,](#)  
7023 [36, L09822, doi:10.1029/2009GL037584, 2009.](#)

7024 [Kulmala, M., Laakso, L., Lehtinen, K. E. J., Riipinen, I., Dal Maso, M., Anttila, T., Kerminen,](#)  
7025 [V.-M., Horrak, U., Vana, M., and Tammet, H.: Initial steps of aerosol growth, \*Atmos.\*](#)  
7026 [Chem. Phys., 4, 2553–2560, doi:10.5194/acp-4-2553-2004, 2004.](#)

7027 [Kulmala, M., Petäjä, T., Ehn, M., Thornton, J., Sipilä, M., Worsnop, D. R., & Kerminen, V.](#)  
7028 [M.: Chemistry of atmospheric nucleation: On the recent advances on precursor](#)  
7029 [characterization and atmospheric cluster composition in connection with atmospheric](#)  
7030 [new particle formation. \*Annual Review of Physical Chemistry\*, 65, 21–37.](#)  
7031 [https://doi.org/10.1146/annurev-physchem-040412-110014, 2014.](#)

7032 [Levy, M. E., Zhang, R., Khalizov, A. F., Zheng, J., Collins, D. R., Glen, C. R., Wang, Y., Yu,](#)  
7033 [X. Y., Luke, W., Jayne, J. T., & Olaguer, E.: Measurements of submicron aerosols in](#)  
7034 [Houston, Texas during the 2009 SHARP field campaign. \*Journal of Geophysical\*](#)  
7035 [Research Atmospheres](#), 118(18), 10,518-10,534. <https://doi.org/10.1002/jgrd.50785>,  
7036 [2013.](#)

7037 [Li, W., Wang, Y., Bernier, C., & Estes, M.: Identification of Sea Breeze Recirculation and Its](#)  
7038 [Effects on Ozone in Houston, TX, During DISCOVER-AQ 2013. \*Journal of\*](#)  
7039 [Geophysical Research: Atmospheres](#), 125(22). <https://doi.org/10.1029/2020JD033165>,  
7040 [2020.](#)

7041 [Linden, P.F., Simpson, J.E., Gravity-driven flows in a turbulent fluid. \*Journal of Fluid\*](#)  
7042 [Mechanics](#), 172, 481-497. doi:10.1017/S0022112086001829, 1986.

7043 [Liu, H., Zhang, B., Moore, R. H., Ziemba, L. D., Ferrare, R. A., Choi, H., Sorooshian, A.,](#)  
7044 [Painemal, D., Wang, H., Shook, M. A., Scarino, A. J., Hair, J. W., Crosbie, E. C., Fenn,](#)  
7045 [M. A., Shingler, T. J., Hostetler, C. A., Chen, G., Kleb, M. M., Luo, G., ... Johnson,](#)  
7046 [M. S.: Tropospheric aerosols over the western North Atlantic Ocean during the winter](#)  
7047 [and summer deployments of ACTIVATE 2020: Life cycle, transport, and distribution.](#)  
7048 [Atmospheric Chemistry and Physics](#), 25(4), 2087–2121. [https://doi.org/10.5194/acp-](https://doi.org/10.5194/acp-25-2087-2025)  
7049 [25-2087-2025, 2025.](#)

7050 [Lu, R., & Turco, R. P.: Air pollutant transport in a coastal environment.1. 2-dimensional](#)  
7051 [simulations of sea-breeze and mountain effects. \*Journal of the Atmospheric Sciences\*,](#)  
7052 [51\(15\), 2285–2308. https://doi.org/10.1175/1520-](#)  
7053 [0469\(1994\)051<2285:APTIAC>2.0.CO;2, 1994.](#)

7054 [Ma, S., & Tong, D. Q.: Neighborhood Emission Mapping Operation \(NEMO\): A 1-km](#)  
7055 [anthropogenic emission dataset in the United States. \*Scientific Data\*, 9\(1\).](#)  
7056 <https://doi.org/10.1038/s41597-022-01790-9>, 2022.

7057 [Mack, S. M., Madl, A. K., & Pinkerton, K. E.: Respiratory health effects of exposure to ambient](#)  
7058 [particulate matter and bioaerosols. \*Comprehensive Physiology\*, 10\(1\), 1–20.](#)  
7059 <https://doi.org/10.1002/cphy.c180040>, 2020.

7060 [Mao, F., Zang, L., Wang, Z., Pan, Z., Zhu, B., & Gong, W.: Dominant synoptic patterns during](#)  
7061 [wintertime and their impacts on aerosol pollution in Central China. \*Atmospheric\*](#)  
7062 [Research](#), 232. <https://doi.org/10.1016/j.atmosres.2019.104701>, 2020.

7063 [Maria, V. D., Rahman, M., Collins, P., Dondi, G., & Sangiorgi, C. \(2013\). Urban Heat Island](#)  
7064 [Effect: Thermal Response from Different Types of Exposed Paved Surfaces.](#)  
7065 [International Journal of Pavement Research and Technology](#), 6(4), 414-422.  
7066 [https://doi.org/10.6135/ijprt.org.tw/2013.6\(4\).414](https://doi.org/10.6135/ijprt.org.tw/2013.6(4).414)

7067 [Masselink, G., and Pattiaratchi, C. B.: The effect of sea breeze on beach morphology, surf zone](#)  
7068 [hydrodynamics and sediment resuspension, \*Mar. Geol.\*, 146, 115–135, 1998.](#)

7069 [Mather, J. H., and Voyles, J. W.: The Arm Climate Research Facility: A Review of Structure](#)  
7070 [and Capabilities. \*Bull. Amer. Meteor. Soc.\*, 94, 377–392,](#)  
7071 <https://doi.org/10.1175/BAMS-D-11-00218.1>, 2013.

7072 [Miller, S. T. K., Keim, B. D., Talbot, R. W., & Mao, H.: Sea breeze: Structure, forecasting,](#)  
7073 [and impacts. \*Reviews of Geophysics\*, 41\(3\). <https://doi.org/10.1029/2003RG000124>,](#)  
7074 [2003.](#)

7075 [Minguillón, M. C., Ripoll, A., Pérez, N., Prévôt, A. S. H., Canonaco, F., Querol, X., and](#)  
7076 [Alastuey, A.: Chemical characterization of submicron regional background aerosols in](#)  
7077 [the western Mediterranean using an Aerosol Chemical Speciation Monitor, \*Atmos.\*](#)  
7078 [Chem. Phys.](#), 15, 6379–6391, <https://doi.org/10.5194/acp-15-6379-2015>, 2015.

7079 [Mlawer, E. J., Taubman, S. J., Brown, P. D., Iacono, M., & Clough, S. A.: Radiative transfer](#)  
7080 [for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the](#)  
7081 [longwave. \*Journal of Geophysical Research\*, 102\(D14\), 16663–16682.](#)  
7082 <https://doi.org/10.1029/97JD00237>, 1997.

7083 [Monin, A. S., & Obukhov, A. M.: Basic laws of turbulent mixing in the surface layer of the](#)  
7084 [atmosphere. Contributions of the Geophysical Institute of the Slovak Academy of](#)  
7085 [Science, USSR, 151, 163–187, 1954.](#)

7086 [Moorthy, K. K., Murthy, B. V. K., and Nair, P. R.: Sea-breeze front effects on boundary layer](#)  
7087 [aerosols at a tropical station, J. Appl. Meteorol., 32, 1196–1205. 1993.](#)

7088 [Moorthy, K. K., Pillai, P. S., & Suresh Babu, S.: Influence of changes in the prevailing synoptic](#)  
7089 [conditions on the response of aerosol characteristics to land-and sea-breeze circulations](#)  
7090 [at a coastal station. In Boundary-Layer Meteorology \(Vol. 108\), 2003.](#)

7091 [Morrison, H., Curry, J. A., and Khvorostyanov, V. I.: A new double-moment microphysics](#)  
7092 [parameterization for application in cloud and climate models. Part I: Description.](#)  
7093 [Journal of the Atmospheric Sciences, 62\(6\), 1665–1677.](#)  
7094 [<https://doi.org/10.1175/jas3446.1>, 2005.](#)

7095 [Papanastasiou, D. K., Melas, D., Bartzanas, T., & Kittas, C.: Temperature, comfort and](#)  
7096 [pollution levels during heat waves and the role of sea breeze. International Journal of](#)  
7097 [Biometeorology, 54\(3\), 307–317. <https://doi.org/10.1007/s00484-009-0281-9>, 2010.](#)

7098 [Parajuli, S. P., Stenchikov, G. L., Ukhov, A., Mostamandi, S., Kucera, P. A., Axisa, D.,](#)  
7099 [Gustafson, W. I., & Zhu, Y.: Effect of dust on rainfall over the Red Sea coast based on](#)  
7100 [WRF-Chem model simulations. Atmospheric Chemistry and Physics, 22\(13\), 8659–](#)  
7101 [8682. <https://doi.org/10.5194/acp-22-8659-2022>, 2022.](#)

7102 [Parajuli, S., Stenchikov, G. G., Ukhov, A., Shevchenko, I., Dubovik, O., & Lopatin, A.:](#)  
7103 [Aerosol vertical distribution and interactions with land/sea breezes over the eastern](#)  
7104 [coast of the Red Sea from lidar data and high-resolution WRF-Chem simulations.](#)  
7105 [Atmospheric Chemistry and Physics, 20\(24\), 16089–16116.](#)  
7106 [<https://doi.org/10.5194/acp-20-16089-2020>, 2020.](#)

7107 [Park, J. M., van den Heever, S. C., Igel, A. L., Grant, L. D., Johnson, J. S., Saleeby, S. M.,](#)  
7108 [Miller, S. D., & Reid, J. S. \(2020\). Environmental Controls on Tropical Sea Breeze](#)  
7109 [Convection and Resulting Aerosol Redistribution. Journal of Geophysical Research:](#)  
7110 [Atmospheres, 125\(6\). <https://doi.org/10.1029/2019JD031699>, 2020.](#)

7111 [Park, M. J., and van den Heever, S. C.: Weakening of tropical sea breeze convective systems](#)  
7112 [through interactions of aerosol, radiation, and soil moisture. \*Atmospheric Chemistry\*](#)  
7113 [and Physics, 22\(16\), 10527–10549. <https://doi.org/10.5194/acp-22-10527-2022>, 2022.](#)

7114 [Parrish, D. D., Allen, D. T., Bates, T. S., Estes, M., Fehsenfeld, F. C., Feingold, G., Ferrare,](#)  
7115 [R., Hardesty, R. M., Meagher, J. F., Nielsen-Gammon, J. W., Pierce, R. B., Ryerson,](#)  
7116 [T. B., Seinfeld, J. H., & Williams, E. J.: Overview of the second texas air quality study](#)  
7117 [\(TexAQS II\) and the Gulf of Mexico atmospheric composition and climate study](#)  
7118 [\(GoMACCS\). \*Journal of Geophysical Research Atmospheres\*, 114\(13\).](#)  
7119 [https://doi.org/10.1029/2009JD011842, 2009.](#)

7120 [Partanen, A. I., Landry, J. S., and Matthews, H. D.: Climate and health implications of future](#)  
7121 [aerosol emission scenarios. \*Environmental Research Letters\*, 13\(2\).](#)  
7122 [https://doi.org/10.1088/1748-9326/aaa511, 2018.](#)

7123 [Perry, K. D., Cahill, T. A., Eldred, R. A., Dutcher, D. D., and Gill, T. E.: Long-range transport](#)  
7124 [of North African dust to the eastern United States. \*Journal of Geophysical Research\*](#)  
7125 [Atmospheres, 102\(10\), 11225–11238. <https://doi.org/10.1029/97jd00260>, 1997.](#)

7126 [Pinto, J. P., Dibb, J., Lee, B. H., Rappenglück, B., Wood, E. C., Levy, M., Zhang, R. Y., Lefer,](#)  
7127 [B., Ren, X. R., Stutz, J., Tsai, C., Ackermann, L., Golovko, J., Herndon, S. C., Oakes,](#)  
7128 [M., Meng, Q. Y., Munger, J. W., Zahniser, M., & Zheng, J.: Intercomparison of field](#)  
7129 [measurements of nitrous acid \(HONO\) during the SHARP campaign. \*Journal of\*](#)  
7130 [Geophysical Research, 119\(9\), 5583–5601. <https://doi.org/10.1002/2013JD020287>,](#)  
7131 [2014.](#)

7132 [Plant, R. S., & Keith, G. J.: Occurrence of Kelvin-Helmholtz billows in sea-breeze circulations.](#)  
7133 [Boundary-Layer Meteorology, 122\(1\), 1–15. \[https://doi.org/10.1007/s10546-006-\]\(https://doi.org/10.1007/s10546-006-9089-x\)](#)  
7134 [9089-x, 2007.](#)

7135 [Qi, L., Vogel, A. L., Esmailirad, S., Cao, L., Zheng, J., Jaffrezo, J. L., Fermo, P., Kasper-](#)  
7136 [Giebl, A., Daellenbach, K. R., Chen, M., Ge, X., Baltensperger, U., Prévôt, A. S. H., &](#)  
7137 [Slowik, J. G.: A 1-year characterization of organic aerosol composition and sources](#)  
7138 [using an extractive electrospray ionization time-of-flight mass spectrometer \(EESI-](#)  
7139 [TOF\). \*Atmospheric Chemistry and Physics\*, 20\(13\), 7875–7893.](#)  
7140 [https://doi.org/10.5194/acp-20-7875-2020, 2020.](#)

7141 [Ramanathan, V., Crutzen, P. J., Kiehl, J. T., & Rosenfeld, D.: Aerosols, Climate, and the](#)  
7142 [Hydrological Cycle. \*Science\*, 294, 5549, DOI: 10.1126/science.1064034, 2001.](#)

7143 [Rao, P. A., & Fuelberg, H. E.: An Investigation of Convection behind the Cape Canaveral Sea-](#)  
7144 [Breeze Front, 2000.](#)

7145 [Rapp, A. D., Brooks, S. D., Nowotarski, C. J., Sharma, M., Thompson, S. A., Chen, B., et al.](#)  
7146 [\(2024\). TAMU TRACER: Targeted mobile measurements to isolate the impacts of](#)  
7147 [aerosols and meteorology on deep convection. \*Bulletin of the American Meteorological\*](#)  
7148 [Society, 105\(9\), E1685–E1702. <https://doi.org/10.1175/BAMS-D-23-0218.1>](#)

7149 [Rodier, Q., Masson, V., Couvreur, F., & Paci, A. \(2017\). Evaluation of a buoyancy and shear](#)  
7150 [based mixing length for a turbulence scheme. \*Frontiers in Earth Science\*, 5.](#)  
7151 [https://doi.org/10.3389/feart.2017.00065](#)

7152 [Rosenfeld, D., et al.: Flood or drought: How do aerosols affect precipitation? \*Science\*, 321,](#)  
7153 [1309–1313, 2008.](#)

7154 [Ryerson, T. B., Trainer, M., Angevine, W. M., Brock, C. A., Dissly, R. W., Fehsenfeld, F. C.,](#)  
7155 [Frost, G. J., Goldan, P. D., Holloway, J. S., Hübler, G., Jakoubek, R. O., Kuster, W. C.,](#)  
7156 [Neuman, J. A., Nicks, D. K., Parrish, D. D., Roberts, J. M., Sueper, D. T., Atlas, E. L.,](#)  
7157 [Donnelly, S. G., et al.: Effect of petrochemical industrial emissions of reactive alkenes](#)  
7158 [and NO<sub>x</sub> on tropospheric ozone formation in Houston, Texas. \*Journal of Geophysical\*](#)  
7159 [Research: Atmospheres, 108\(8\). <https://doi.org/10.1029/2002jd003070>, 2003.](#)

7160 [Schell, B., Ackerman, I. J., Hass, H., Binkowski, F. S., & Ebel, A.: Modelling the formation](#)  
7161 [of secondary organic aerosol within a comprehensive air quality model system. \*Journal\*](#)  
7162 [of Geophysical Research, 106\(D22\), 28275–28293.](#)  
7163 [https://doi.org/10.1029/2001JD000384, 2001.](#)

7164 [Seinfeld, J.H.; Pandis, S.N. \*Atmospheric Chemistry and Physics: From Air Pollution to\*](#)  
7165 [Climate Change, 2nd ed.; Wiley: Hoboken, NJ, USA, 2006.](#)

7166 [Sharma, M., Rapp, A. D., Nowotarski, C. J., & Brooks, S. D. \(2024\). Observed Variability in](#)  
7167 [Convective Cell Characteristics and Near-Storm Environments across the Sea- and](#)  
7168 [Bay-Breeze Fronts in Southeast Texas. \*Monthly Weather Review\*, 152\(11\), 2419–2441.](#)  
7169 [https://doi.org/10.1175/MWR-D-23-0243.1](#)

7170 [Shrestha, S., Zhou, S., Mehra, M., Guagenti, M., Yoon, S., Alvarez, S. L., Guo, F., Chao, C.](#)  
7171 [Y., Flynn, J. H., Wang, Y., Griffin, R. J., Usenko, S., & Sheesley, R. J.: Evaluation of](#)  
7172 [aerosol- and gas-phase tracers for identification of transported biomass burning](#)  
7173 [emissions in an industrially influenced location in Texas, USA. Atmospheric Chemistry](#)  
7174 [and Physics, 23\(19\), 10845–10867. <https://doi.org/10.5194/acp-23-10845-2023>, 2023.](#)

7175 [Shrivastava, M., Zhang, J., Zaveri, R. A., Zhao, B., Pierce, J. R., O'Donnell, S. E., et al.:](#)  
7176 [Anthropogenic extremely low volatility organics \(ELVOCs\) govern the growth of](#)  
7177 [molecular clusters over the Southern Great Plains during the springtime. Journal of](#)  
7178 [Geophysical Research: Atmospheres, 129, e2024JD041212,](#)  
7179 <https://doi.org/10.1029/2024JD041212>, 2024.

7180 [Simpson, J. E.: Sea Breeze and Local Wind, 234 pp., Cambridge Univ. Press, New York, 1994.](#)

7181 [Singh, A. and Kuang, C.: Scanning Mobility Particle Sizer \(SMPS\) Instrument Handbook. U.S.](#)  
7182 [Department of Energy, Atmospheric Radiation Measurement user facility, Richland,](#)  
7183 [Washington. DOE/SC-ARM-TR-147, 2024.](#)

7184 [Skamarock, W. C., Klemp, J. B., Dudhia, J., Gill, D. O., Barker, D., Wang, W., Powers, J. G.:](#)  
7185 [A description of the Advanced Research WRF version 3. NCAR Tech. Note](#)  
7186 [NCAR/TN-475+STR, 113 pp., doi:10.5065/D68S4MVH, 2008.](#)

7187 [Song, S. K., Choi, Y. N., Choi, Y., Flynn, J., & Sadeghi, B.: Characteristics of aerosol chemical](#)  
7188 [components and their impacts on direct radiative forcing at urban and suburban](#)  
7189 [locations in Southeast Texas. Atmospheric Environment, 246,](#)  
7190 <https://doi.org/10.1016/j.atmosenv.2020.118151>, 2021. Maria, V. D., Rahman, M.,

7191 [Collins, P., Dondi, G., & Sangiorgi, C. \(2013\). Urban Heat Island Effect: Thermal](#)  
7192 [Response from Different Types of Exposed Paved Surfaces. International Journal of](#)  
7193 [Pavement Research and Technology, 6\(4\), 414-422.](#)  
7194 [https://doi.org/10.6135/ijprt.org.tw/2013.6\(4\).414](https://doi.org/10.6135/ijprt.org.tw/2013.6(4).414)

7195 [Soni, M., Verma, S., Mishra, M. K., Mall, R. K., and Payra, S.: Estimation of particulate matter](#)  
7196 [pollution using WRF-Chem during dust storm event over India. Urban Climate, 44,](#)  
7197 <https://doi.org/10.1016/j.uclim.2022.101202>, 2022.

7198 [Stockwell, W. R., Middleton, P., Chang, J. S., and Tang, X.: The second generation regional](#)  
7199 [acid deposition model chemical mechanism for regional air quality modeling. Journal](#)

7200 of Geophysical Research, 95(D10), 16343–16367.  
7201 <https://doi.org/10.1029/JD095iD10p16343>, 1990.

7202 Subba, T., Zhang, Y., & Steiner, A. L.: Simulating the transport and rupture of pollen in the  
7203 atmosphere. *Journal of Advances in Modeling Earth Systems*, 15, e2022MS003329.  
7204 <https://doi.org/10.1029/2022MS003329>, 2023.

7205 Subramanian, A., Nagarajan, A. M., Vinod, S., Chakraborty, S., Sivagami, K., Theodore, T.,  
7206 Sathyanarayanan, S. S., Tamizhdurai, P., & Mangesh, V. L. (2023). Long-term impacts  
7207 of climate change on coastal and transitional eco-systems in India: an overview of its  
7208 current status, future projections, solutions, and policies. In *RSC Advances* (Vol. 13,  
7209 Issue 18, pp. 12204–12228). Royal Society of Chemistry.  
7210 <https://doi.org/10.1039/d2ra07448f>

7211 Talbot, C., Augustin, P., Leroy, C., Willart, V., Delbarre, H., Khomenko, G.: Impact of a sea  
7212 breeze on the boundary-layer dynamics and the atmospheric stratification in a coastal  
7213 area of the North Sea. *Boundary Layer Meteorology*, 125, 133–154, 2007.

7214 Thompson, S. A., Chen, B., Matthews, B.H., Li, R., Nowotarski, C. J., Rapp, A. D., & Brooks,  
7215 S. D. (2025). Characterizing Greater Houston's aerosol by air mass during TRACER.  
7216 *Journal of Geophysical Research: Atmospheres*, 130, e2025JD043353.  
7217 <https://doi.org/10.1029/2025JD043353>.

7218 Tuccella, P., Curci, G., Visconti, G., Bessagnet, B., Menut, L., & Park, R. J.: Modeling of gas  
7219 and aerosol with WRF/Chem over Europe: Evaluation and sensitivity study. *Journal of*  
7220 *Geophysical Research Atmospheres*, 117(3). <https://doi.org/10.1029/2011JD016302>,  
7221 2012.

7222 Twomey, S.: Pollution and the planetary albedo. *Atmos. Environ.*, 8, 1251–1256, 1974.

7223 Uin, J., Aiken, A. C., Dubey, M. K., Kuang, C., Pekour, M., Salwen, C., Sedlacek, A. J.,  
7224 Senum, G., Smith, S., Wang, J., Watson, T. B., & Springston, S. R.: Atmospheric  
7225 radiation measurement (ARM) aerosol observing systems (AOS) for surface-based in  
7226 situ atmospheric aerosol and trace gas measurements. *Journal of Atmospheric and*  
7227 *Oceanic Technology*, 36(12), 2429–2447. [https://doi.org/10.1175/JTECH-D-19-](https://doi.org/10.1175/JTECH-D-19-0077.1)  
7228 [0077.1](https://doi.org/10.1175/JTECH-D-19-0077.1), 2019.

7229 [Verma, S., Boucher, O., Venkataraman, C., Reddy, M. S., Müller, D., Chazette, P., &](#)  
7230 [Crouzille, B.: Aerosol lofting from sea breeze during the Indian Ocean Experiment.](#)  
7231 [Journal of Geophysical Research, 111, 07208. https://doi.org/10.1029/2005JD005953,](#)  
7232 [2006.](#)

7233 [Viner, B., Noble, S., Qian, J. H., Werth, D., Gayes, P., Pietrafesa, L., and Bao, S.: Frequency](#)  
7234 [and characteristics of inland advecting sea breezes in the Southeast United States.](#)  
7235 [Atmosphere, 12\(8\). https://doi.org/10.3390/atmos12080950, 2021.](#)

7236 [Wang, B., Geddes, J. A., Adams, T. J., Lind, E. S., McDonald, B. C., He, J., Harkins, C., Li,](#)  
7237 [D., and Pfister, G. G.: Implications of Sea Breezes on Air Quality Monitoring in a](#)  
7238 [Coastal Urban Environment: Evidence From High Resolution Modeling of NO2 and](#)  
7239 [O3. Journal of Geophysical Research: Atmospheres, 128\(11\).](#)  
7240 [https://doi.org/10.1029/2022jd037860, 2023.](#)

7241 [Wang, D., Jensen, M. P., Taylor, D., Kowalski, G., Hogan, M., Wittmann, B. M.,](#)  
7242 [Rakotoarivony, A., Giangrande, S. E., & Park, J. M.: Linking Synoptic Patterns to](#)  
7243 [Cloud Properties and Local Circulations Over Southeastern Texas. Journal of](#)  
7244 [Geophysical Research: Atmospheres, 127\(5\). https://doi.org/10.1029/2021JD035920,](#)  
7245 [2022.](#)

7246 [Wang, D., Melvin, E. C., Smith, N., Jensen, M. P., Gupta, S., Abdullah-Smoot, A., Pszeniczny,](#)  
7247 [N., & Hahn, T.: TRACER Perspectives on Gulf-Breeze and Bay-Breeze Circulations](#)  
7248 [and Coastal Convection. Monthly Weather Review, 152\(10\), 2207–2228.](#)  
7249 [https://doi.org/10.1175/MWR-D-23-0292.1, 2024.](#)

7250 [Wang, K., Zhang, Y., Yahya, K.: Decadal application of WRF/Chem over the continental U.S.:](#)  
7251 [Simulation design, sensitivity simulations, and climatological model evaluation.](#)  
7252 [Atmospheric Environment, 253, 118331,](#)  
7253 [https://doi.org/10.1016/j.atmosenv.2021.118331, 2021.](#)

7254 [Wang, S. C., Wang, Y., Estes, M., Lei, R., Talbot, R., Zhu, L., & Hou, P.: Transport of Central](#)  
7255 [American Fire Emissions to the U.S. Gulf Coast: Climatological Pathways and Impacts](#)  
7256 [on Ozone and PM2.5. Journal of Geophysical Research: Atmospheres, 123\(15\), 8344–](#)  
7257 [8361. https://doi.org/10.1029/2018JD028684, 2018.](#)

7258 [Watson, T.B.: Aerosol Chemical Speciation Monitor \(ACSM\) Instrument Handbook. U.S.](#)  
7259 [Department of Energy, Atmospheric Radiation Measurement user facility, Richland,](#)  
7260 [Washington.DOE/SC-ARM-TR-196, 2024.](#)

7261 [Wert, B. P., Trainer, M., Fried, A., Ryerson, T. B., Henry, B., Potter, W., Angevine, W. M.,](#)  
7262 [Atlas, E., Donnelly, S. G., Fehsenfeld, F. C., Frost, G. J., Goldan, P. D., Hansel, A.,](#)  
7263 [Holloway, J. S., Hubler, G., Kuster, W. C., Nicks, D. K., Neuman, J. A., Parrish, D. D.,](#)  
7264 [... Wisthaler, A.: Signatures of terminal alkene oxidation in airborne formaldehyde](#)  
7265 [measurements during TexAQS 2000. Journal of Geophysical Research D:](#)  
7266 [Atmospheres, 108\(3\). <https://doi.org/10.1029/2002jd002502>, 2003.](#)

7267 [Westenbarger, D. A., & Morris, G. A.: Identifying biomass burning impacts on air quality in](#)  
7268 [Southeast Texas 26–29 August 2011 using satellites, models and surface data.](#)  
7269 <https://doi.org/10.5194/acp-2017-1234>, 2018.

7270 [Yoon, S., Ortiz, S. M., Clark, A. E., Barrett, T. E., Usenko, S., Duvall, R. M., Ruiz, L. H.,](#)  
7271 [Bean, J. K., Faxon, C. B., Flynn, J. H., Lefer, B. L., Leong, Y. J., Griffin, R. J., &](#)  
7272 [Sheesley, R. J.: Apportioned primary and secondary organic aerosol during pollution](#)  
7273 [events of DISCOVER-AQ Houston. Atmospheric Environment, 244.](#)  
7274 <https://doi.org/10.1016/j.atmosenv.2020.117954>, 2021.

7275 ▼

7276

7277

7278 ▼

**Deleted:** Ackermann, I. J., Hass, H., Memmesheimer, M., Ebel, A., Binkowski, F. S., & Shankar, U.: Modal aerosol dynamics model for Europe: Development and first applications. *Atmospheric Environment*, 32(17), 2981–2999. [https://doi.org/10.1016/S1352-2310\(98\)00006-5](https://doi.org/10.1016/S1352-2310(98)00006-5), 1998. ¶

Adaricheva, K., Bernhardt, J. E., Liu, W., & Schmidt, B.: Importance of overnight parameters to predict Sea Breeze on Long Island. <http://arxiv.org/abs/2309.01803>, 2023. ¶

Ahmadov, R., Gerbig, C., Kretschmer, R., Koerner, S., Neining, B., Dolman, A. J., & Sarrat, C.: Mesoscale covariance of transport and CO<sub>2</sub> fluxes: Evidence from observations and simulations using the WRF-VPRM coupled atmosphere-biosphere model. *Journal of Geophysical Research Atmospheres*, 112(22). <https://doi.org/10.1029/2007JD008552>, 2007. ¶

Albrecht, B. A.: Aerosols, cloud microphysics, and fractional cloudiness. *Science*, 245, 1227–1230, 1989. ¶

Aldhaif, A. M., Lopez, D. H., Dadashazar, H., & Soroshian, A.: Sources, frequency, and chemical nature of dust events impacting the United States East Coast. *Atmospheric Environment*, 231. <https://doi.org/10.1016/j.atmosenv.2020.117456>, 2020. ¶

Ariya, P., Sun, J., Eltouny, N., Hudson, E. D., Hayes, C. T., & Kos, G.: Physical and chemical characterization of bioaerosols—Implications for nucleation processes. *International Reviews in Physical Chemistry*, 28(1), 1–32. <https://doi.org/10.1080/01442350802597438>, 2009. ¶

Arrillaga, J. A., Jiménez, P., de Arellano, J. V.-G., Jiménez, M. A., Román-Cascón, C., Sastre, M., and Yagüe, C.: Analyzing the synoptic-, meso- and local-scale involved in sea breeze formation and frontal characteristics. *J. Geophys. Res. Atmos.*, 125, e2019JD031302, <https://doi.org/10.1029/2019JD031302>, 2020. ¶

Atabakhsh, S., Poulain, L., Bigi, A., Coen, M. C., Pöhlker, M., & Herrmann, H.: Trends of PM<sub>1</sub> aerosol chemical composition, carbonaceous aerosol, and source over the last 10 years at Melpitz (Germany). *Atmospheric Environment*, 346. <https://doi.org/10.1016/j.atmosenv.2025.121075>, 2025. ¶

Augustin, P., Billet, S., Crumeyrolle, S., Deboudt, K., Dieudonné, E., Flament, P., Fourmentin, M., Guilbaud, S., Hanoune, B., Landkocz, Y., Méausoone, C., Roy, S., Schmitt, F. G., Sentchev, A., & Sokolov, A.: Impact of sea breeze dynamics on atmospheric pollutants and their toxicity in industrial and urban coastal environments. *Remote Sensing*, 12(4). <https://doi.org/10.3390/rs12040648>, 2020. ¶

Banta, R. M., Senff, C. J., Alvarez, R. J., Langford, A. O., Parrish, D. D., Trainer, M. K., Darby, L. S., Michael Hardesty, R., Lambeth, B., Andrew Neuman, J., Angevine, W. M., Nielsen-Gammon, J., Sandberg, S. P., & White, A. B.: Dependence of daily peak O<sub>3</sub> concentrations near Houston, Texas on environmental factors: Wind speed, temperature, and boundary-layer depth. *Atmospheric Environment*, 45(1), 162–173. <https://doi.org/10.1016/j.atmosenv.2010.09.030>, 2011. ¶

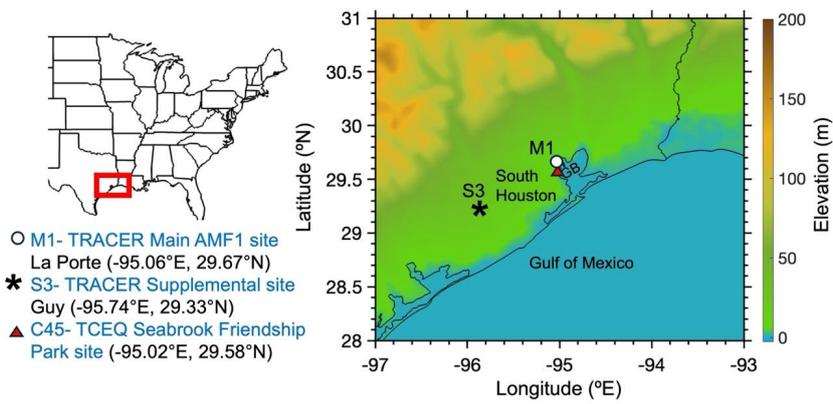
Bao, S., Pietrafesa, L., Gayes, P., Noble, S., Viner, B., Qian, J. H., Werth, D., Mitchell, G., & Burdette, S.: Mapping the Spatial Footprint of Sea Breeze Winds in the Southeastern United States. *Journal of Geophysical Research: Atmospheres*, 128(7). [296]

**Deleted:** [297]

7427

7428

7429



7430

7431 **Figure 1.** Map showing the TRACER field campaign main site (M1) and supplemental site  
 7432 (S3), **and the TCEQ Seabrook Friendship Park site (C45)**. Terrain elevation is shown in color.  
 7433 Here, “GB” corresponds to the Galveston Bay.

7434

7435

7436

7437

7438

7439

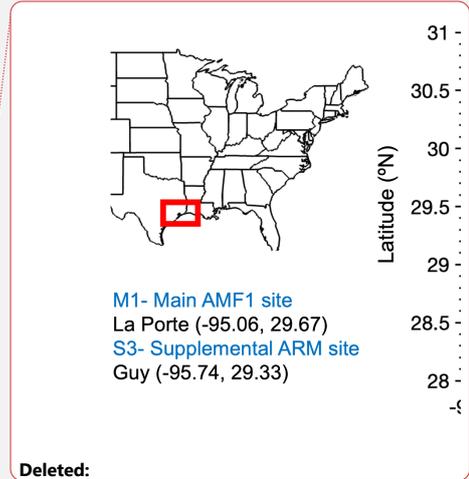
7440

7441

7442

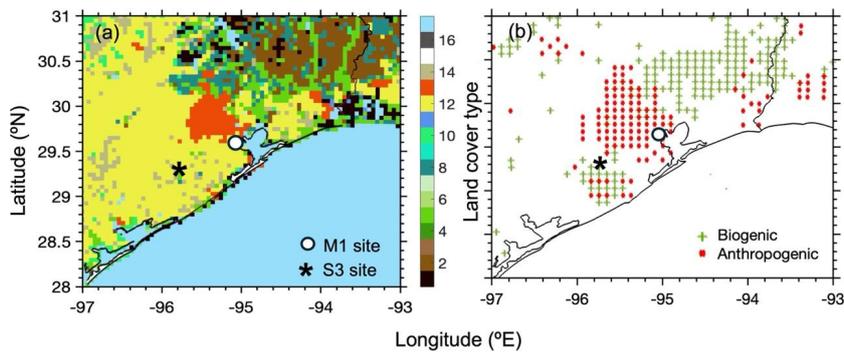
7443

7444



Deleted:

7446  
7447  
7448  
7449



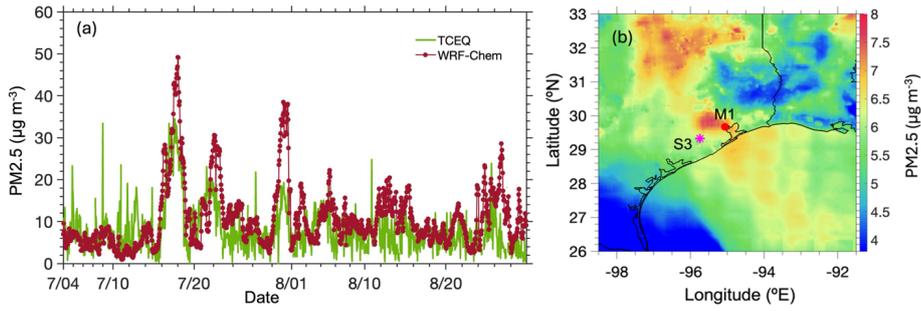
7450

7451 **Figure 2.** Weather Research and Forecasting model coupled with Chemistry (WRF-Chem)  
7452 simulation domain with (a) primary land cover types comprising of (1) Evergreen Needleleaf  
7453 Forest, (2) Evergreen Broadleaf Forest, (3) Deciduous Needleleaf Forest, (4) Deciduous  
7454 Broadleaf Forest, (5) Mixed Forest, (6) Closed Shrubland, (7) Open Shrubland, (8) Woody  
7455 Savanna, (9) Savanna, (10) Grassland, (11) Permanent Wetlands, (12) Cropland, (13) Urban  
7456 and Build-up, (14) Cropland/Natural Mosaic, (15) Snow and Ice, (16) Barren or Sparsely  
7457 Vegetated, and (17) Water; (b) Anthropogenic (red dots) and biogenic (green dots) aerosol  
7458 emission source points obtained using the National Emissions Inventory (NEI) data and Model  
7459 of Emissions of Gases and Aerosols from Nature (MEGAN) modeling system, respectively.

7460  
7461  
7462  
7463  
7464  
7465  
7466

7467

7468



7469

7470 **Figure 3.** (a) Comparison of daily averaged PM<sub>2.5</sub> observed (green) at the TCEQ site, and  
7471 WRF-Chem simulated (red) at the M1 site. (b) Spatial distribution of averaged PM<sub>2.5</sub> simulated  
7472 with WRF-chem (color-filled contour).

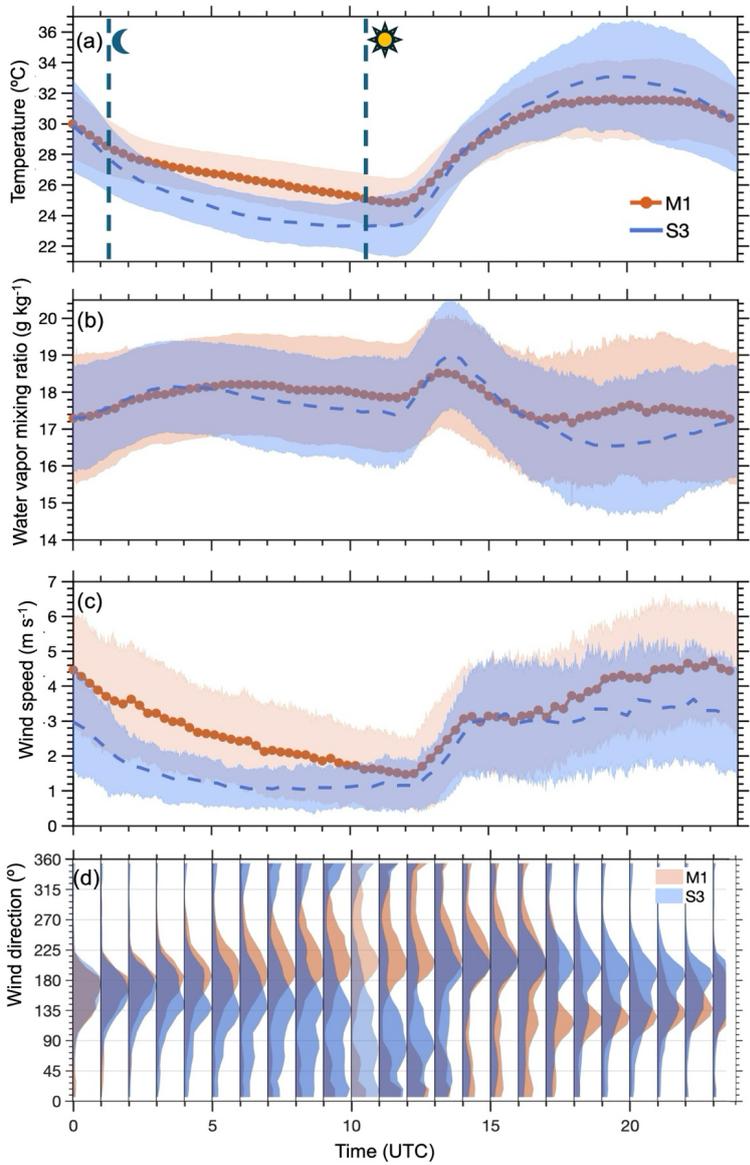
7473

7474

7475

7476

7477

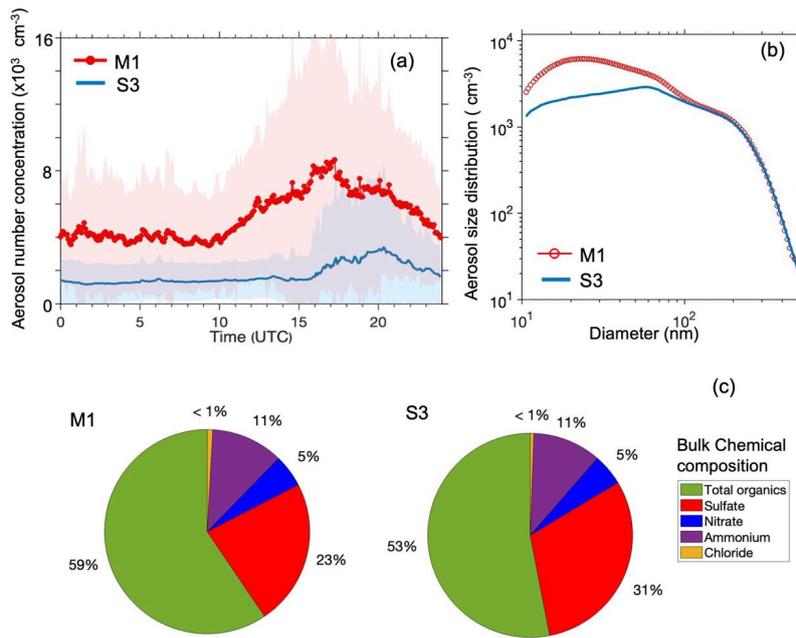


7478

7479 **Figure 4.** Diurnal variation of meteorological variables (a) Temperature at 2 m, (b) water vapor  
 7480 mixing ratio ( $w$ ) (c) wind speed at 10 m, and (d) wind direction [waterfall diagram](#) at 10 m  
 7481 measured at M1 (in [orange](#)) and S3 (in [blue](#)) sites averaged during IOP. The shaded color  
 7482 represents the standard deviation from the mean.

- Formatted: Not Highlight
- Formatted: Font color: Auto
- Deleted: blue
- Deleted: orange
- Formatted: Font color: Auto
- Formatted: Font color: Auto

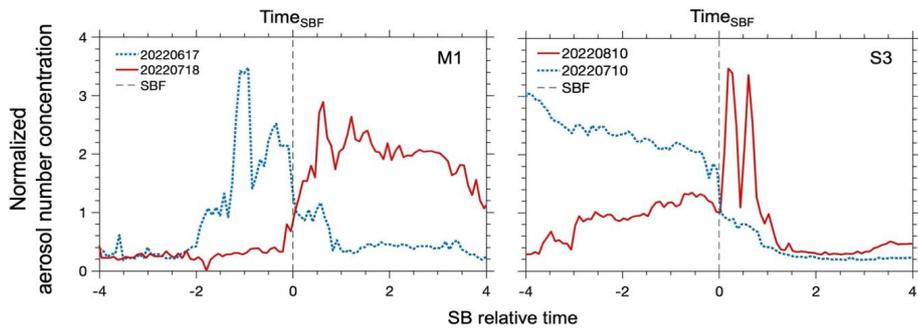
7485  
7486  
7487



7488  
7489  
7490  
7491  
7492  
7493  
7494  
7495  
7496  
7497

**Figure 5.** Measured (a) diurnal distribution of aerosol number concentration, (b) aerosol size distribution, and (c) percentage contribution of bulk chemical composition at M1 and S3 sites averaged from June to September 2022.

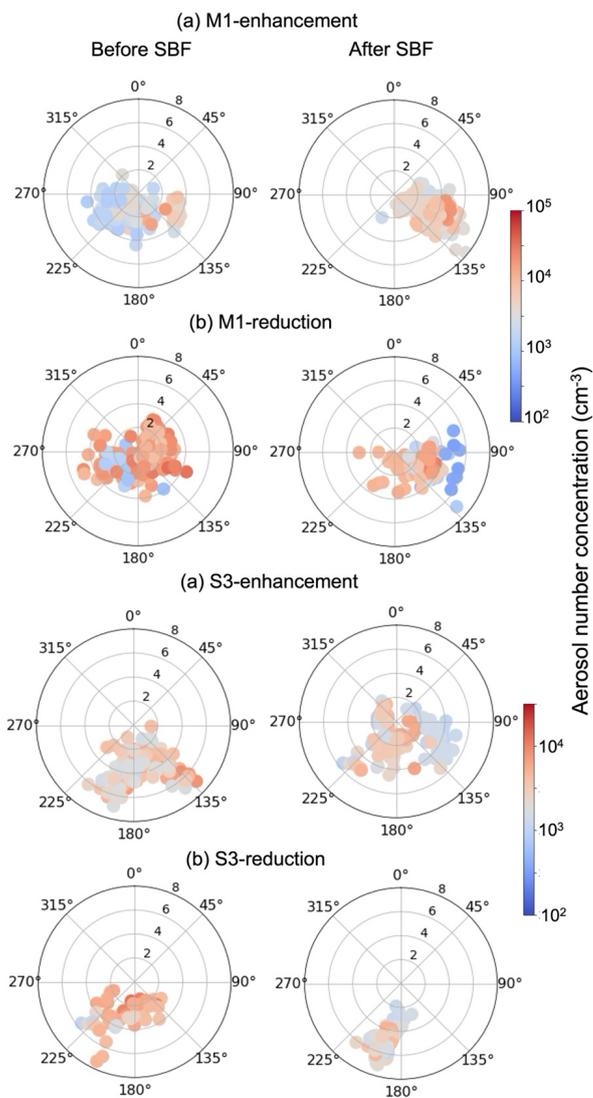
7498  
7499  
7500  
7501



7502  
7503  
7504  
7505  
7506

**Figure 6.** Time series of the normalized aerosol number concentration, with the time centered at the time of the passing of the SBF ( $T_{\text{SBF}}=0$ ) at the M1 site (1st column) and the S3 site (2nd column) during the individual SB event days.

- Deleted: (a)
- Deleted: first row
- Deleted: left panel
- Deleted: second row
- Formatted: Font color: Auto
- Formatted: Font color: Auto
- Deleted: right panel



7512

7513 **Figure 7.** Open-air polar plots for aerosol number concentration before and after the passing  
 7514 of the SBF ( $\Delta T = T_{\text{SBF}\pm 1}$ ) during (a) enhancement and (b) reduction events at M1 and S3 sites.  
 7515 The wind speed (in  $\text{m s}^{-1}$ ) grid lines are presented with black circles; the color scales represent  
 7516 the concentrations observed with each wind speed and direction combinations.

Formatted: Font color: Auto

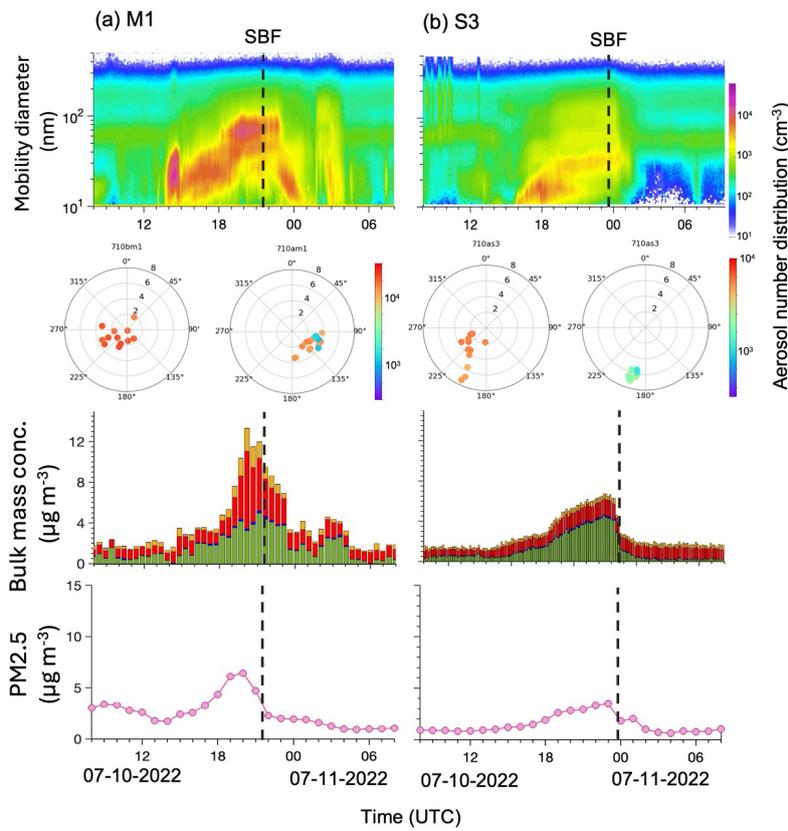
Formatted: Centered

Deleted: (b)

Formatted: Font: Bold

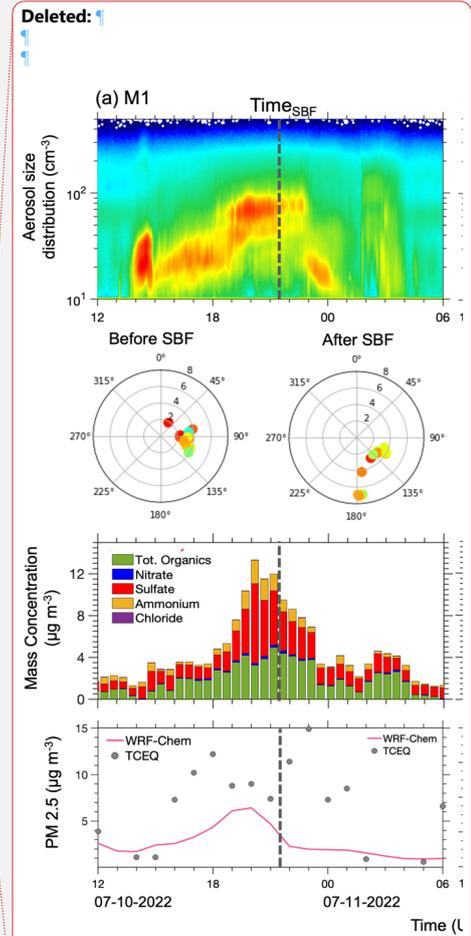
Deleted: during the SB event days in June-September 2022

7519  
7520  
7521  
7522



7523

7524 **Figure 8.** Time series of measured aerosol size distribution (1st row), measured bulk chemical  
7525 composition (3rd row), and modeled and TCEQ measured PM<sub>2.5</sub> mass concentration (4th row)  
7526 at (a) M1 and (b) S3 on 10 July 2022. Polar plot showing the measured integrated aerosol  
7527 number concentration during one hour before and after the passing of the SBF (2nd row). The  
7528 black dashed line represents the time of the passing of the SBF ( $T_{\text{SBF}}$ ) at the respective sites.



Formatted: Font color: Auto

Formatted: Space Before: 0 pt

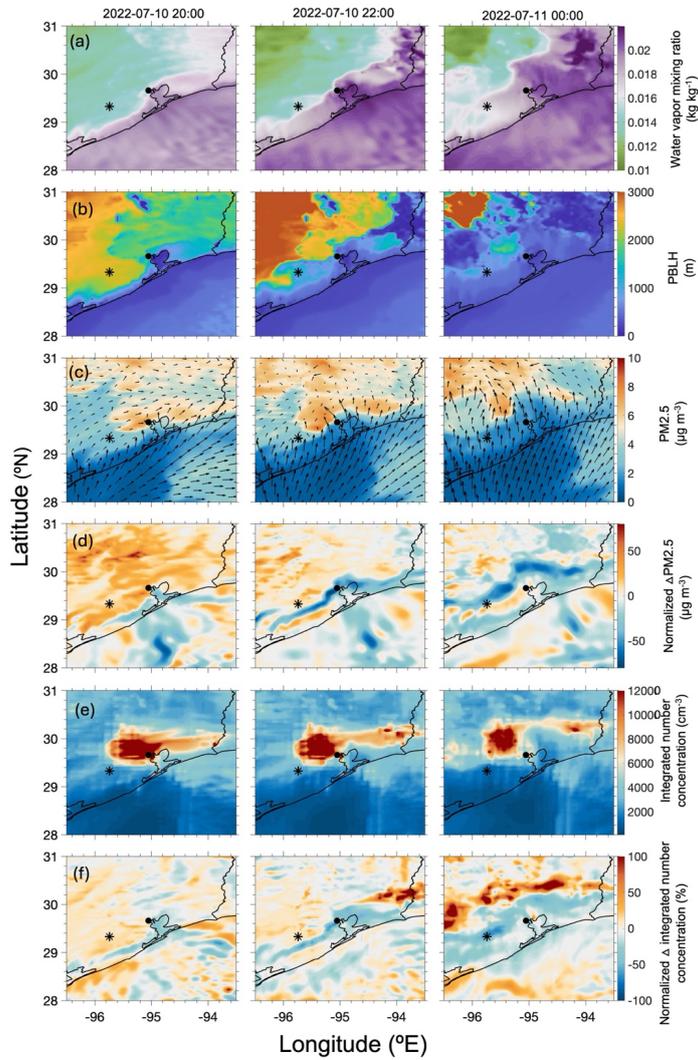
Deleted: 7

Deleted: 3rd

Formatted: Font color: Auto

Formatted: Font color: Auto

Formatted: Font color: Auto



7535

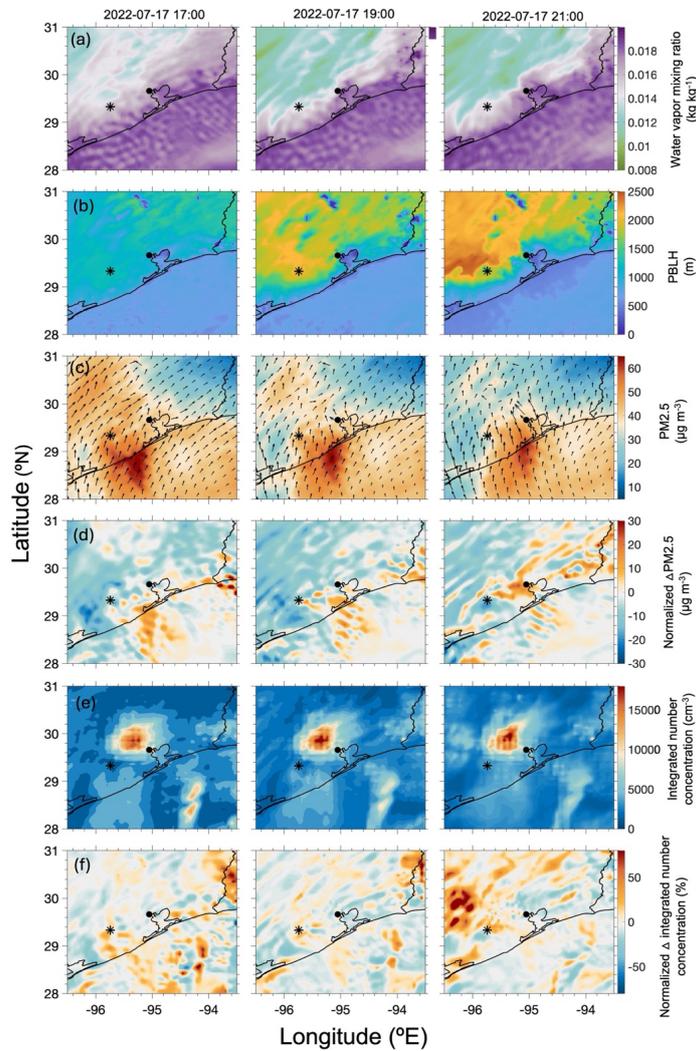
7536 **Figure 2.** Modeled surface distribution of (a) water vapor mixing ratio ( $w$ ), (b) PBLH, (c)  
 7537  $PM_{2.5}$ , and wind vector (black arrows, at the surface), and (e) integrated aerosol number  
 7538 concentration (nucleation + accumulation mode) at three-time steps: 20:00 and 22:00 UTC on  
 7539 10 July, and 00:00 UTC on 11 July. Sub-panels (d) and (f) show the normalized changes, where  
 7540  $\Delta$  is the change from the previous time step. The filled-circle marker in the panels represent the  
 7541 M1 site, while the star represents the S3 site.

Deleted: 8

Formatted: Not Highlight

Formatted: Justified

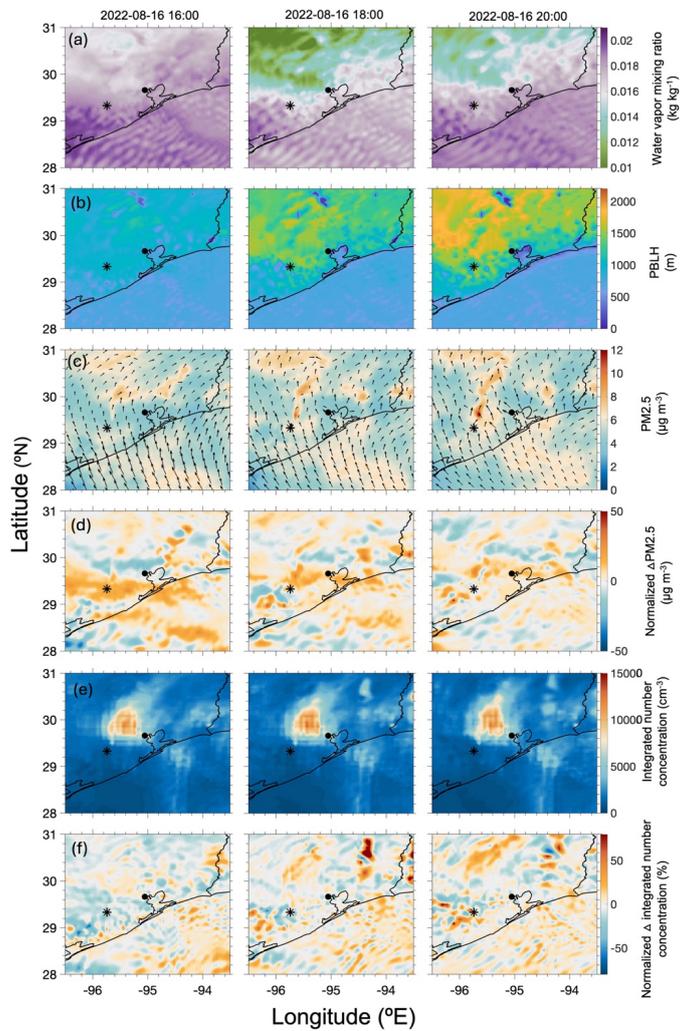
Deleted: ¶



7546

7547 **Figure 10.** Modeled surface distribution of (a) water vapor mixing ratio ( $w$ ), (b) PBLH, (c)  
 7548  $PM_{2.5}$ , and wind vector (black arrows, at the surface), and (e) integrated aerosol number  
 7549 concentration (nucleation + accumulation mode) at three-time steps: 17:00, 19:00 and 21:00  
 7550 UTC on 17 July. Sub-panels (d) and (f) show the normalized changes, where  $\Delta$  is the change  
 7551 from the previous time step. The filled-circle marker in the panels represent the M1 site, while  
 7552 the star represents the S3 site.

Formatted: Not Highlight  
 Formatted: Justified

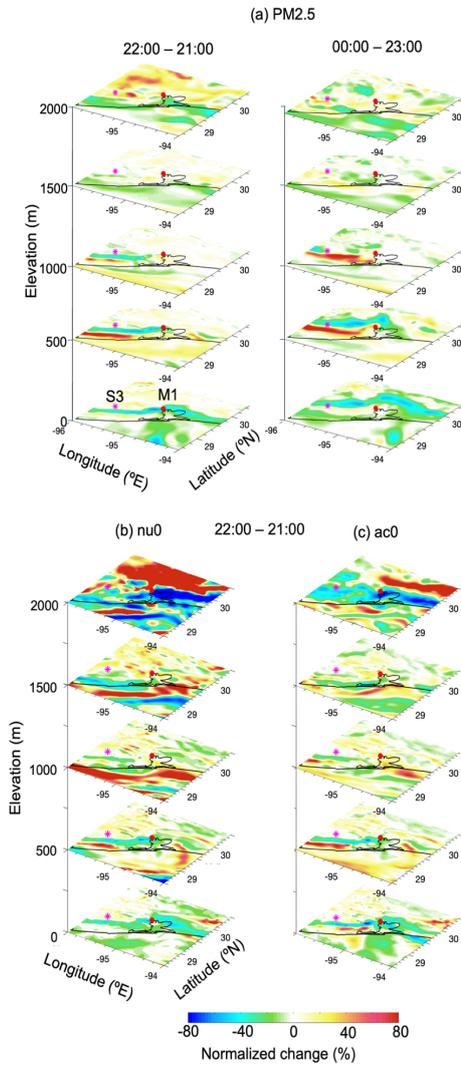


7553

7554 **Figure 11.** Modeled surface distribution of (a) water vapor mixing ratio ( $w$ ), (b) PBLH, (c)  
 7555  $PM_{2.5}$ , and wind vector (black arrows, at the surface), and (e) integrated aerosol number  
 7556 concentration (nucleation + accumulation mode) at three-time steps: 16:00, 18:00 and 20:00  
 7557 UTC on 16 August. Sub-panels (d) and (f) show the normalized changes, where  $\Delta$  is the change  
 7558 from the previous time step. The filled-circle marker in the panels represent the M1 site, while  
 7559 the star represents the S3 site.

Formatted: Not Highlight

Formatted: Justified



7562 **Figure 12.** First row: the spatial distribution of normalized  $\Delta PM_{2.5}$  at different elevations at  
 7563 timesteps (a) 21:00 and 22:00 UTC on 10 July, and 23:00 UTC on 10 July and 00:00 UTC on  
 7564 11 July. Second row: the spatial distribution of normalized (b)  $\Delta$ nucleation mode (nu0) and (c)  
 7565  $\Delta$ accumulation mode (ac0) aerosol number concentration at timesteps 21:00 and 22:00 UTC  
 7566 on 10 July.

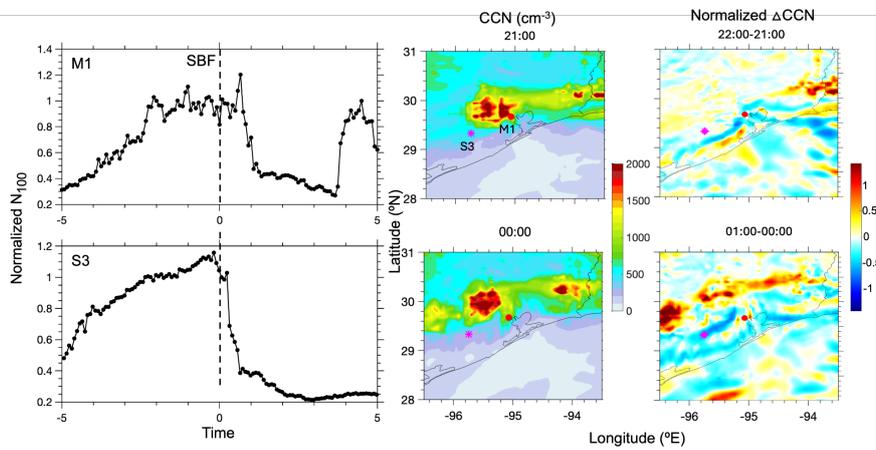
**Deleted:** Figure 9. Modeled surface distribution of (a)  $PM_{2.5}$  on 17 July and (c) 16 August at the respective hours as shown in the panels. Sub-panels (b) and (d) show the normalized changes, where  $\Delta$  is the change from the previous time step. The filled-circle marker in the panels represents the M1 site, while the star represents the S3 site.†

**Deleted:** 10

**Deleted:** normalised

**Deleted:** normalised

7576  
7577  
7578  
7579  
7580  
7581  
7582



7583

7584 **Figure 13.** Time series of the normalized measured  $N_{100}$  along the time of the SBF's passing  
7585 through the M1 site (first row) and the S3 site (second row) on 10 July 2022 (1<sup>st</sup> column).  
7586 Spatial distribution of the modeled hourly averaged (2<sup>nd</sup> column) and normalized  $\Delta\text{CCN}$  (3<sup>rd</sup>  
7587 column).

Deleted: 11  
Deleted: time normalised to the

7588  
7589  
7590  
7591  
7592  
7593

7596

7597

7598

7599

Table 1: Summary of SBC influence on aerosol number concentration at the M1 and S3 sites. Events are classified into enhancement, reduction, and neutral categories.

Site	Description	Combined	Enhancement	Reduction	Neutral
M1	Days (fraction of the total events %)	46 (total SB events)	13 (28 %)	16 (35 %)	17 (37 %)
	Concentration change (after - before) %	-23 (all enhancement + reduction events)	+55	-42	-11
		-7 (total number of events)			
S3	Days	30 (total SB events)	8 (27 %)	4 (13 %)	18 (60 %)
	Concentration change (after - before) %	+9 (all enhancement + reduction events)	+64	-45	-10
		+3 (total number of events)			

7600

7601

7602

7603

7604

7605

7606

7607

7608

7609

- Formatted (... [298])
- Formatted (... [299])
- Formatted (... [300])
- Formatted (... [301])
- Formatted (... [303])
- Formatted (... [304])
- Formatted (... [305])
- Formatted (... [306])
- Formatted (... [307])
- Formatted Table (... [302])
- Formatted (... [308])
- Formatted (... [309])
- Formatted (... [310])
- Formatted (... [311])
- Formatted (... [314])
- Formatted (... [312])
- Formatted (... [313])
- Formatted (... [315])
- Formatted (... [316])
- Formatted (... [317])
- Formatted (... [318])
- Formatted (... [319])
- Formatted (... [320])
- Formatted (... [321])
- Formatted (... [323])
- Formatted (... [324])
- Formatted (... [325])
- Formatted (... [322])
- Formatted (... [326])
- Formatted (... [327])
- Formatted (... [328])
- Formatted (... [329])
- Formatted (... [331])
- Formatted (... [333])
- Formatted (... [330])
- Formatted (... [332])
- Formatted (... [334])
- Formatted (... [335])
- Formatted (... [336])
- Formatted (... [337])
- Formatted (... [338])
- Formatted (... [340])
- Formatted (... [341])
- Formatted (... [342])
- Formatted (... [339])
- Formatted (... [343])

7610

7611 **Table 2.** Model configuration

Simulation period	1 July - 30 August 2022
Domain	26 to 33 °N and -98 to -92 °E
Horizontal resolution (dx)	5 x 5 km
Vertical resolution	45 layers from 1000-50 mb
Meteorological initial and boundary conditions	North America mesoscale (NAM) forecast output at T221 (32-km) resolution, 28 vertical levels (Bauman, 2010)
Shortwave radiation	Goddard shortwave radiation scheme (Chou et al., 1998)
Longwave radiation	The rapid radiative transfer mode (RRTM) (Mlawer et al., 1997)
Land surface	Community National Center for Environmental Prediction (NCEP), Oregon State University, Air Force, and Hydrologic Research Lab-NWS Land Surface Model (NOAH) (Chen and Dudhia, 2001)
Surface Layer	Monin-Obukhov (Monin and Obukhov, 1954; Janjic, 2002)
PBL	Yonsei University Scheme (YSU) (Hong et al., 2006)
Cumulus	The Grell scheme (Grell and Devenyi 2002)
Microphysics	Morrison 2-moment scheme (Morrison, 2005)
Chemical mechanism	RACM Chemistry with MADE/VBS aerosols using KPP library along with the volatility basis set (VBS) used for Secondary Organic Aerosols (Stockwell et al., 1990; Ackerman et al., 1998; Schell et al., 2001)
Chemical initial and boundary conditions	MOZBC from the Model for Ozone and Related chemical Tracers (MOZART) model (Emmons et al., 2010)
Anthropogenic emissions	National Emissions Inventory (NEI), U.S. Environmental Protection Agency (EPA)
Biogenic emissions	The Model of Emissions of Gases and Aerosols from Nature version MEGAN v2.1 biogenic emissions (Guenther et al., 2012)

7612

Deleted: 1

**Page 1: [1] Formatted**

**Subba, Tamanna**

**9/18/25 8:50:00 PM**

Justified

▲  
**Page 1: [2] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲  
**Page 1: [3] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲  
**Page 1: [4] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲  
**Page 1: [5] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲  
**Page 1: [6] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲  
**Page 1: [7] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲  
**Page 1: [8] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲  
**Page 1: [9] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲  
**Page 1: [10] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 1: [11] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 1: [12] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 1: [13] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 1: [14] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 1: [15] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 1: [16] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 1: [17] Deleted**                      **Tamanna Subba**                      **9/13/25 4:58:00 PM**

**Page 1: [18] Deleted**                      **Subba, Tamanna**                      **8/15/25 9:08:00 AM**

**Page 1: [19] Deleted**                      **Tamanna Subba**                      **9/13/25 4:58:00 PM**

**Page 8: [20] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black

**Page 8: [20] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [21] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [21] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [21] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [21] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [21] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [21] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [22] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [22] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [22] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [22] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [23] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Auto



**Page 8: [24] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [24] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [25] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [25] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [25] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [26] Deleted**

**Subba, Tamanna**

**8/18/25 9:55:00 AM**



**Page 8: [26] Deleted**

**Subba, Tamanna**

**8/18/25 9:55:00 AM**



**Page 8: [27] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



Page 8: [28] Deleted

Subba, Tamanna

9/19/25 8:32:00 PM

Page 8: [28] Deleted

Subba, Tamanna

9/19/25 8:32:00 PM

Page 8: [28] Deleted

Subba, Tamanna

9/19/25 8:32:00 PM

Page 8: [28] Deleted

Subba, Tamanna

9/19/25 8:32:00 PM

Page 8: [29] Deleted

Subba, Tamanna

8/24/25 1:43:00 PM

Page 8: [29] Deleted

Subba, Tamanna

8/24/25 1:43:00 PM

Page 8: [29] Deleted

Subba, Tamanna

8/24/25 1:43:00 PM

Page 8: [30] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font color: Auto

Page 8: [31] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Subscript

Page 8: [32] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font: Not Italic, Font color: Black

**Page 8: [32] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [32] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 8: [33] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [34] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [35] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [36] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [37] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [38] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [39] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [39] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [40] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [41] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [42] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [43] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [44] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [44] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [45] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Blue



**Page 8: [45] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Blue



**Page 8: [46] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 8: [47] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Italic



**Page 8: [48] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 8: [49] Deleted**                      **Scott Giangrande**                      **9/11/25 3:44:00 PM**

**Page 8: [49] Deleted**                      **Scott Giangrande**                      **9/11/25 3:44:00 PM**

**Page 8: [49] Deleted**                      **Scott Giangrande**                      **9/11/25 3:44:00 PM**

**Page 8: [49] Deleted**                      **Scott Giangrande**                      **9/11/25 3:44:00 PM**

**Page 8: [49] Deleted**                      **Scott Giangrande**                      **9/11/25 3:44:00 PM**

**Page 8: [49] Deleted**                      **Scott Giangrande**                      **9/11/25 3:44:00 PM**

**Page 8: [49] Deleted**                      **Scott Giangrande**                      **9/11/25 3:44:00 PM**

**Page 8: [49] Deleted**                      **Scott Giangrande**                      **9/11/25 3:44:00 PM**

**Page 9: [50] Deleted**                      **Scott Giangrande**                      **9/11/25 3:45:00 PM**

**Page 9: [50] Deleted**                      **Scott Giangrande**                      **9/11/25 3:45:00 PM**



**Page 9: [50] Deleted**                      **Scott Giangrande**                      **9/11/25 3:45:00 PM**



**Page 9: [50] Deleted**                      **Scott Giangrande**                      **9/11/25 3:45:00 PM**



**Page 9: [51] Deleted**                      **Scott Giangrande**                      **9/11/25 3:46:00 PM**



**Page 9: [51] Deleted**                      **Scott Giangrande**                      **9/11/25 3:46:00 PM**



**Page 9: [51] Deleted**                      **Scott Giangrande**                      **9/11/25 3:46:00 PM**



**Page 9: [51] Deleted**                      **Scott Giangrande**                      **9/11/25 3:46:00 PM**



**Page 9: [51] Deleted**                      **Scott Giangrande**                      **9/11/25 3:46:00 PM**



**Page 9: [52] Deleted**                      **Scott Giangrande**                      **9/11/25 3:47:00 PM**



**Page 9: [52] Deleted**                      **Scott Giangrande**                      **9/11/25 3:47:00 PM**



Page 9: [52] Deleted

Scott Giangrande

9/11/25 3:47:00 PM

Page 9: [52] Deleted

Scott Giangrande

9/11/25 3:47:00 PM

Page 9: [52] Deleted

Scott Giangrande

9/11/25 3:47:00 PM

Page 9: [52] Deleted

Scott Giangrande

9/11/25 3:47:00 PM

Page 9: [52] Deleted

Scott Giangrande

9/11/25 3:47:00 PM

Page 9: [53] Deleted

Scott Giangrande

9/11/25 3:51:00 PM

Page 9: [53] Deleted

Scott Giangrande

9/11/25 3:51:00 PM

Page 9: [54] Deleted

Tamanna Subba

9/15/25 6:44:00 PM

Page 9: [54] Deleted

Tamanna Subba

9/15/25 6:44:00 PM

Page 9: [55] Deleted

Tamanna Subba

9/13/25 7:57:00 PM

**Page 9: [55] Deleted** **Tamanna Subba** **9/13/25 7:57:00 PM**

▼  
▲

**Page 9: [55] Deleted** **Tamanna Subba** **9/13/25 7:57:00 PM**

▼  
▲

**Page 9: [56] Deleted** **Subba, Tamanna** **9/18/25 8:59:00 PM**

▼  
▲

**Page 9: [56] Deleted** **Subba, Tamanna** **9/18/25 8:59:00 PM**

▼  
▲

**Page 9: [56] Deleted** **Subba, Tamanna** **9/18/25 8:59:00 PM**

▼  
▲

**Page 9: [56] Deleted** **Subba, Tamanna** **9/18/25 8:59:00 PM**

▼  
▲

**Page 9: [56] Deleted** **Subba, Tamanna** **9/18/25 8:59:00 PM**

▼  
▲

**Page 9: [57] Deleted** **Tamanna Subba** **9/15/25 6:44:00 PM**

▼  
▲

**Page 9: [57] Deleted** **Tamanna Subba** **9/15/25 6:44:00 PM**

▼  
▲

**Page 9: [58] Deleted** **Subba, Tamanna** **8/15/25 2:01:00 PM**

▼  
▲

**Page 9: [59] Deleted** Tamanna Subba 9/16/25 6:58:00 PM

x.....  
▲.....

**Page 9: [59] Deleted** Tamanna Subba 9/16/25 6:58:00 PM

x.....  
▲.....

**Page 9: [60] Deleted** Tamanna Subba 9/15/25 6:49:00 PM

x.....  
▲.....

**Page 9: [60] Deleted** Tamanna Subba 9/15/25 6:49:00 PM

x.....  
▲.....

**Page 9: [61] Formatted** Subba, Tamanna 10/12/25 5:12:00 PM

Font color: Auto  
▲.....

**Page 9: [61] Formatted** Subba, Tamanna 10/12/25 5:12:00 PM

Font color: Auto  
▲.....

**Page 9: [62] Deleted** Subba, Tamanna 9/2/25 6:20:00 PM

▼.....  
▲.....

**Page 9: [62] Deleted** Subba, Tamanna 9/2/25 6:20:00 PM

▼.....  
▲.....

**Page 11: [63] Formatted** Subba, Tamanna 10/12/25 5:12:00 PM

Font color: Auto  
▲.....

**Page 11: [64] Formatted** Subba, Tamanna 10/12/25 5:12:00 PM

Not Superscript/ Subscript  
▲.....

Page 11: [65] Deleted

Subba, Tamanna

8/18/25 10:05:00 AM

Page 11: [65] Deleted

Subba, Tamanna

8/18/25 10:05:00 AM

Page 11: [65] Deleted

Subba, Tamanna

8/18/25 10:05:00 AM

Page 11: [65] Deleted

Subba, Tamanna

8/18/25 10:05:00 AM

Page 11: [65] Deleted

Subba, Tamanna

8/18/25 10:05:00 AM

Page 11: [65] Deleted

Subba, Tamanna

8/18/25 10:05:00 AM

Page 11: [65] Deleted

Subba, Tamanna

8/18/25 10:05:00 AM

Page 11: [65] Deleted

Subba, Tamanna

8/18/25 10:05:00 AM

Page 11: [65] Deleted

Subba, Tamanna

8/18/25 10:05:00 AM

Page 11: [65] Deleted

Subba, Tamanna

8/18/25 10:05:00 AM

**Page 11: [65] Deleted**

**Subba, Tamanna**

**8/18/25 10:05:00 AM**



**Page 11: [65] Deleted**

**Subba, Tamanna**

**8/18/25 10:05:00 AM**



**Page 11: [65] Deleted**

**Subba, Tamanna**

**8/18/25 10:05:00 AM**



**Page 11: [66] Deleted**

**Subba, Tamanna**

**8/20/25 8:58:00 PM**



**Page 11: [66] Deleted**

**Subba, Tamanna**

**8/20/25 8:58:00 PM**



**Page 11: [66] Deleted**

**Subba, Tamanna**

**8/20/25 8:58:00 PM**



**Page 11: [66] Deleted**

**Subba, Tamanna**

**8/20/25 8:58:00 PM**



**Page 11: [66] Deleted**

**Subba, Tamanna**

**8/20/25 8:58:00 PM**



**Page 11: [66] Deleted**

**Subba, Tamanna**

**8/20/25 8:58:00 PM**



**Page 11: [66] Deleted**

**Subba, Tamanna**

**8/20/25 8:58:00 PM**



**Page 11: [67] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 11: [68] Deleted**

**Subba, Tamanna**

**8/20/25 8:59:00 PM**

**Page 11: [68] Deleted**

**Subba, Tamanna**

**8/20/25 8:59:00 PM**

**Page 11: [68] Deleted**

**Subba, Tamanna**

**8/20/25 8:59:00 PM**

**Page 11: [68] Deleted**

**Subba, Tamanna**

**8/20/25 8:59:00 PM**

**Page 11: [68] Deleted**

**Subba, Tamanna**

**8/20/25 8:59:00 PM**

**Page 11: [68] Deleted**

**Subba, Tamanna**

**8/20/25 8:59:00 PM**

**Page 11: [68] Deleted**

**Subba, Tamanna**

**8/20/25 8:59:00 PM**

**Page 11: [68] Deleted**

**Subba, Tamanna**

**8/20/25 8:59:00 PM**

**Page 11: [68] Deleted**

**Subba, Tamanna**

**8/20/25 8:59:00 PM**

Page 11: [68] Deleted

Subba, Tamanna

8/20/25 8:59:00 PM

Page 11: [68] Deleted

Subba, Tamanna

8/20/25 8:59:00 PM

Page 11: [68] Deleted

Subba, Tamanna

8/20/25 8:59:00 PM

Page 11: [68] Deleted

Subba, Tamanna

8/20/25 8:59:00 PM

Page 11: [69] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font: 12 pt, Not Bold, Font color: Auto

Page 11: [70] Formatted

Subba, Tamanna

8/20/25 9:03:00 PM

Justified, Indent: First line: 0.25", Space Before: 6 pt, Border: Top: (No border), Bottom: (No border), Left: (No border), Right: (No border), Between : (No border)

Page 11: [71] Deleted

Tamanna Subba

9/6/25 10:55:00 PM

Page 11: [72] Deleted

Scott Giangrande

9/11/25 4:00:00 PM

Page 11: [73] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font: Not Italic, Font color: Auto

Page 11: [74] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font: Not Italic, Font color: Auto

**Page 11: [74] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Auto

**Page 11: [75] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font: Not Italic

**Page 11: [75] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font: Not Italic

**Page 11: [75] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font: Not Italic

**Page 11: [76] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Blue

**Page 11: [77] Deleted**                      **Scott Giangrande**                      **9/11/25 4:01:00 PM**

**Page 11: [77] Deleted**                      **Scott Giangrande**                      **9/11/25 4:01:00 PM**

**Page 11: [77] Deleted**                      **Scott Giangrande**                      **9/11/25 4:01:00 PM**

**Page 11: [77] Deleted**                      **Scott Giangrande**                      **9/11/25 4:01:00 PM**

**Page 11: [77] Deleted**                      **Scott Giangrande**                      **9/11/25 4:01:00 PM**

▲  
**Page 11: [77] Deleted**

**Scott Giangrande**

**9/11/25 4:01:00 PM**

✖  
▲  
**Page 11: [78] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight

▲  
**Page 11: [78] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight

▲  
**Page 11: [79] Deleted**

**Subba, Tamanna**

**8/15/25 3:57:00 PM**

▼  
▲  
**Page 11: [80] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲  
**Page 11: [80] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲  
**Page 11: [80] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲  
**Page 11: [80] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲  
**Page 11: [81] Deleted**

**Tamanna Subba**

**9/13/25 8:19:00 PM**

▼  
▲  
**Page 11: [82] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 11: [83] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 11: [84] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 11: [85] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 11: [86] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 11: [87] Deleted**                      **Tamanna Subba**                      **9/13/25 8:44:00 PM**

✘ .....

▲ .....  
**Page 11: [88] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 11: [88] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 11: [88] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 12: [89] Deleted**                      **Tamanna Subba**                      **9/13/25 9:13:00 PM**

✘ .....

▲ .....  
**Page 12: [89] Deleted**                      **Tamanna Subba**                      **9/13/25 9:13:00 PM**

✘ .....

▲  
**Page 12: [90] Deleted**

**Tamanna Subba**

**9/13/25 9:13:00 PM**

✖  
▲  
**Page 12: [90] Deleted**

**Tamanna Subba**

**9/13/25 9:13:00 PM**

▲  
**Page 12: [91] Deleted**

**Subba, Tamanna**

**8/24/25 2:57:00 PM**

▲  
**Page 12: [92] Deleted**

**Tamanna Subba**

**9/16/25 6:53:00 PM**

▲  
**Page 12: [93] Deleted**

**Scott Giangrande**

**9/11/25 4:11:00 PM**

▲  
**Page 12: [93] Deleted**

**Scott Giangrande**

**9/11/25 4:11:00 PM**

▲  
**Page 12: [93] Deleted**

**Scott Giangrande**

**9/11/25 4:11:00 PM**

▲  
**Page 12: [93] Deleted**

**Scott Giangrande**

**9/11/25 4:11:00 PM**

▲  
**Page 12: [93] Deleted**

**Scott Giangrande**

**9/11/25 4:11:00 PM**

▲

**Page 12: [94] Deleted**                      **Subba, Tamanna**                      **8/21/25 12:23:00 AM**

▼ ..... ▲

**Page 12: [95] Deleted**                      **Subba, Tamanna**                      **9/17/25 9:07:00 PM**

✖ ..... ▲

**Page 12: [96] Deleted**                      **Tamanna Subba**                      **9/6/25 11:01:00 PM**

▼ ..... ▲

**Page 12: [97] Deleted**                      **Subba, Tamanna**                      **8/18/25 10:10:00 AM**

▼ ..... ▲

**Page 12: [97] Deleted**                      **Subba, Tamanna**                      **8/18/25 10:10:00 AM**

▼ ..... ▲

**Page 12: [97] Deleted**                      **Subba, Tamanna**                      **8/18/25 10:10:00 AM**

▼ ..... ▲

**Page 12: [97] Deleted**                      **Subba, Tamanna**                      **8/18/25 10:10:00 AM**

▼ ..... ▲

**Page 12: [97] Deleted**                      **Subba, Tamanna**                      **8/18/25 10:10:00 AM**

▼ ..... ▲

**Page 12: [97] Deleted**                      **Subba, Tamanna**                      **8/18/25 10:10:00 AM**

▼ ..... ▲

**Page 12: [97] Deleted**                      **Subba, Tamanna**                      **8/18/25 10:10:00 AM**

▼ ..... ▲

**Page 12: [97] Deleted**                      **Subba, Tamanna**                      **8/18/25 10:10:00 AM**

▼  
▲  
**Page 13: [98] Deleted**

**Tamanna Subba**

**9/6/25 11:08:00 PM**

✖  
▼  
▲  
**Page 13: [99] Deleted**

**Subba, Tamanna**

**8/18/25 10:12:00 AM**

▼  
▲  
**Page 13: [99] Deleted**

**Subba, Tamanna**

**8/18/25 10:12:00 AM**

▼  
▲  
**Page 13: [99] Deleted**

**Subba, Tamanna**

**8/18/25 10:12:00 AM**

▼  
▲  
**Page 13: [100] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Red

▼  
▲  
**Page 13: [101] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Red

▼  
▲  
**Page 13: [102] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Red

▼  
▲  
**Page 13: [103] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Red

▼  
▲  
**Page 13: [104] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Red

▼  
▲  
**Page 13: [104] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Red

**Page 13: [105] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Red

**Page 13: [106] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Red

**Page 13: [107] Deleted**      **Subba, Tamanna**      **8/21/25 12:43:00 AM**

**Page 13: [108] Deleted**      **Tamanna Subba**      **9/6/25 11:12:00 PM**

**Page 13: [109] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 13: [110] Deleted**      **Scott Giangrande**      **9/11/25 4:30:00 PM**

**Page 13: [110] Deleted**      **Scott Giangrande**      **9/11/25 4:30:00 PM**

**Page 13: [111] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 13: [112] Deleted**      **Scott Giangrande**      **9/11/25 4:31:00 PM**

**Page 13: [112] Deleted**      **Scott Giangrande**      **9/11/25 4:31:00 PM**

**Page 13: [112] Deleted**                      **Scott Giangrande**                      **9/11/25 4:31:00 PM**

**Page 13: [112] Deleted**                      **Scott Giangrande**                      **9/11/25 4:31:00 PM**

**Page 13: [113] Deleted**                      **Subba, Tamanna**                      **8/18/25 10:14:00 AM**

**Page 13: [113] Deleted**                      **Subba, Tamanna**                      **8/18/25 10:14:00 AM**

**Page 13: [113] Deleted**                      **Subba, Tamanna**                      **8/18/25 10:14:00 AM**

**Page 13: [113] Deleted**                      **Subba, Tamanna**                      **8/18/25 10:14:00 AM**

**Page 13: [114] Deleted**                      **Tamanna Subba**                      **9/6/25 11:21:00 PM**

**Page 13: [115] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 13: [116] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 13: [117] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 13: [118] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 13: [118] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 13: [119] Deleted**      **Tamanna Subba**      **9/7/25 8:14:00 PM**

**Page 13: [119] Deleted**      **Tamanna Subba**      **9/7/25 8:14:00 PM**

**Page 13: [119] Deleted**      **Tamanna Subba**      **9/7/25 8:14:00 PM**

**Page 13: [120] Deleted**      **Scott Giangrande**      **9/16/25 2:50:00 PM**

**Page 13: [121] Deleted**      **Scott Giangrande**      **9/11/25 7:24:00 PM**

**Page 13: [122] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 13: [123] Deleted**      **Scott Giangrande**      **9/15/25 7:01:00 PM**

**Page 13: [123] Deleted**      **Scott Giangrande**      **9/15/25 7:01:00 PM**

**Page 13: [124] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 13: [125] Deleted**

**Scott Giangrande**

**9/11/25 7:24:00 PM**

**Page 13: [125] Deleted**

**Scott Giangrande**

**9/11/25 7:24:00 PM**

**Page 13: [126] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 13: [127] Deleted**

**Subba, Tamanna**

**8/15/25 9:11:00 AM**

**Page 13: [127] Deleted**

**Subba, Tamanna**

**8/15/25 9:11:00 AM**

**Page 14: [128] Deleted**

**Subba, Tamanna**

**8/18/25 10:22:00 AM**

**Page 14: [128] Deleted**

**Subba, Tamanna**

**8/18/25 10:22:00 AM**

**Page 14: [128] Deleted**

**Subba, Tamanna**

**8/18/25 10:22:00 AM**

**Page 14: [129] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [130] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [131] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [132] Deleted**

**Scott Giangrande**

**9/11/25 7:27:00 PM**

**Page 14: [132] Deleted**

**Scott Giangrande**

**9/11/25 7:27:00 PM**

**Page 14: [133] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [134] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [135] Deleted**

**Scott Giangrande**

**9/11/25 7:28:00 PM**

**Page 14: [135] Deleted**

**Scott Giangrande**

**9/11/25 7:28:00 PM**

**Page 14: [136] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [137] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [138] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 14: [139] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 14: [140] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 14: [141] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 14: [142] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 14: [143] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 14: [144] Deleted**

**Scott Giangrande**

**9/11/25 7:33:00 PM**



**Page 14: [144] Deleted**

**Scott Giangrande**

**9/11/25 7:33:00 PM**



**Page 14: [145] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 14: [146] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 14: [147] Deleted**                      **Scott Giangrande**                      **9/11/25 7:34:00 PM**



**Page 14: [147] Deleted**                      **Scott Giangrande**                      **9/11/25 7:34:00 PM**



**Page 14: [148] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto



**Page 14: [149] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto



**Page 14: [150] Deleted**                      **Scott Giangrande**                      **9/11/25 7:42:00 PM**



**Page 14: [150] Deleted**                      **Scott Giangrande**                      **9/11/25 7:42:00 PM**



**Page 14: [150] Deleted**                      **Scott Giangrande**                      **9/11/25 7:42:00 PM**



**Page 14: [150] Deleted**                      **Scott Giangrande**                      **9/11/25 7:42:00 PM**



**Page 14: [150] Deleted**                      **Scott Giangrande**                      **9/11/25 7:42:00 PM**



**Page 14: [150] Deleted**                      **Scott Giangrande**                      **9/11/25 7:42:00 PM**



**Page 14: [151] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [152] Deleted**      **Tamanna Subba**      **9/13/25 10:21:00 PM**

**Page 14: [152] Deleted**      **Tamanna Subba**      **9/13/25 10:21:00 PM**

**Page 14: [153] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [154] Deleted**      **Tamanna Subba**      **9/13/25 10:21:00 PM**

**Page 14: [154] Deleted**      **Tamanna Subba**      **9/13/25 10:21:00 PM**

**Page 14: [154] Deleted**      **Tamanna Subba**      **9/13/25 10:21:00 PM**

**Page 14: [155] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [156] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [157] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [158] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Subscript

**Page 14: [159] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 14: [160] Deleted**      **Tamanna Subba**      **9/13/25 10:26:00 PM**

**Page 14: [160] Deleted**      **Tamanna Subba**      **9/13/25 10:26:00 PM**

**Page 14: [160] Deleted**      **Tamanna Subba**      **9/13/25 10:26:00 PM**

**Page 14: [160] Deleted**      **Tamanna Subba**      **9/13/25 10:26:00 PM**

**Page 15: [161] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Not Highlight

**Page 15: [162] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Not Highlight

**Page 15: [163] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Not Highlight

**Page 15: [164] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font: Not Italic

**Page 15: [165] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font: Not Italic

**Page 15: [166] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 15: [167] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 15: [168] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 15: [169] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 15: [170] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 15: [171] Deleted**      **Tamanna Subba**      **9/15/25 7:51:00 PM**

**Page 15: [172] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 15: [173] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 15: [174] Deleted**      **Tamanna Subba**      **9/15/25 7:51:00 PM**

Page 15: [175] Deleted

Scott Giangrande

9/15/25 7:10:00 PM

Page 15: [176] Deleted

Subba, Tamanna

8/16/25 2:36:00 PM

Page 15: [177] Deleted

Subba, Tamanna

8/16/25 3:08:00 PM

Page 15: [178] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font color: Red

Page 15: [179] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Not Highlight

Page 15: [180] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font color: Red

Page 15: [181] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font color: Red, Superscript

Page 15: [182] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font color: Red

Page 15: [183] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font color: Red, Superscript

Page 15: [184] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font color: Red

**Page 15: [185] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 15: [186] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Red



**Page 15: [187] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Red, Superscript



**Page 15: [188] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Red



**Page 15: [189] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Red, Superscript



**Page 15: [190] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Red



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [191] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [192] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 16: [192] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 16: [192] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 16: [193] Deleted**

**Michael Jensen**

**9/14/25 11:09:00 PM**



**Page 16: [193] Deleted**

**Michael Jensen**

**9/14/25 11:09:00 PM**



**Page 16: [194] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [194] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [194] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Not Highlight



**Page 16: [195] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 16: [195] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic, Font color: Black



**Page 16: [196] Deleted** Michael Jensen 9/14/25 11:10:00 PM

x.....  
▲.....

**Page 16: [196] Deleted** Michael Jensen 9/14/25 11:10:00 PM

x.....  
▲.....

**Page 16: [197] Formatted** Subba, Tamanna 10/12/25 5:12:00 PM

Font color: Black  
▲.....

**Page 16: [197] Formatted** Subba, Tamanna 10/12/25 5:12:00 PM

Font color: Black  
▲.....

**Page 16: [197] Formatted** Subba, Tamanna 10/12/25 5:12:00 PM

Font color: Black  
▲.....

**Page 16: [198] Deleted** Tamanna Subba 9/7/25 8:28:00 PM

v.....  
▲.....

**Page 16: [198] Deleted** Tamanna Subba 9/7/25 8:28:00 PM

v.....  
▲.....

**Page 16: [198] Deleted** Tamanna Subba 9/7/25 8:28:00 PM

v.....  
▲.....

**Page 16: [199] Formatted** Subba, Tamanna 10/12/25 5:12:00 PM

Font color: Auto  
▲.....

**Page 16: [199] Formatted** Subba, Tamanna 10/12/25 5:12:00 PM

Font color: Auto  
▲.....

**Page 16: [199] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 16: [200] Deleted**      **Tamanna Subba**      **9/7/25 8:29:00 PM**

**Page 16: [200] Deleted**      **Tamanna Subba**      **9/7/25 8:29:00 PM**

**Page 16: [201] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 16: [201] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 16: [202] Deleted**      **Tamanna Subba**      **9/7/25 8:21:00 PM**

**Page 16: [202] Deleted**      **Tamanna Subba**      **9/7/25 8:21:00 PM**

**Page 16: [202] Deleted**      **Tamanna Subba**      **9/7/25 8:21:00 PM**

**Page 16: [202] Deleted**      **Tamanna Subba**      **9/7/25 8:21:00 PM**

**Page 16: [202] Deleted**      **Tamanna Subba**      **9/7/25 8:21:00 PM**

**Page 16: [203] Deleted**      **Tamanna Subba**      **9/7/25 8:31:00 PM**

▼ .....  
▲ .....

**Page 16: [203] Deleted**      **Tamanna Subba**      **9/7/25 8:31:00 PM**

▼ .....  
▲ .....

**Page 16: [204] Deleted**      **Tamanna Subba**      **9/7/25 8:32:00 PM**

✕ .....  
▲ .....

**Page 16: [204] Deleted**      **Tamanna Subba**      **9/7/25 8:32:00 PM**

✕ .....  
▲ .....

**Page 17: [205] Deleted**      **Subba, Tamanna**      **9/1/25 4:43:00 PM**

✕ .....  
▲ .....

**Page 21: [206] Deleted**      **Subba, Tamanna**      **8/18/25 10:52:00 AM**

▼ .....  
▲ .....

**Page 21: [206] Deleted**      **Subba, Tamanna**      **8/18/25 10:52:00 AM**

▼ .....  
▲ .....

**Page 21: [207] Deleted**      **Subba, Tamanna**      **8/17/25 9:46:00 AM**

▼ .....  
▲ .....

**Page 21: [208] Deleted**      **Subba, Tamanna**      **9/2/25 6:39:00 PM**

▼ .....  
▲ .....

**Page 21: [209] Deleted**      **Scott Giangrande**      **9/15/25 8:47:00 PM**

▼ .....  
▲ .....

**Page 21: [209] Deleted**      **Scott Giangrande**      **9/15/25 8:47:00 PM**

Page 21: [210] Deleted

Subba, Tamanna

9/2/25 6:39:00 PM

Page 21: [211] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font: Italic, Not Highlight

Page 21: [211] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Font: Italic, Not Highlight

Page 21: [212] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Not Highlight

Page 21: [212] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Not Highlight

Page 21: [212] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Not Highlight

Page 21: [212] Formatted

Subba, Tamanna

10/12/25 5:12:00 PM

Not Highlight

Page 21: [213] Deleted

Tamanna Subba

9/14/25 1:26:00 AM

Page 21: [213] Deleted

Tamanna Subba

9/14/25 1:26:00 AM

Page 21: [214] Deleted

Tamanna Subba

9/14/25 1:27:00 AM

▲ .....  
**Page 21: [215] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 21: [215] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 21: [215] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 21: [215] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 21: [215] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 21: [216] Deleted**                      **Tamanna Subba**                      **9/14/25 1:36:00 AM**

✖

▲ .....  
**Page 21: [216] Deleted**                      **Tamanna Subba**                      **9/14/25 1:36:00 AM**

✖

▲ .....  
**Page 21: [217] Deleted**                      **Scott Giangrande**                      **9/15/25 8:50:00 PM**

✖

▲ .....  
**Page 21: [218] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲ .....  
**Page 21: [218] Formatted**                      **Subba, Tamanna**                      **10/12/25 5:12:00 PM**

Font color: Auto

▲

**Page 22: [219] Deleted**      **Tamanna Subba**      **9/15/25 5:32:00 PM**

**Page 22: [220] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 22: [221] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 22: [222] Deleted**      **Tamanna Subba**      **9/15/25 5:35:00 PM**

**Page 22: [223] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 22: [224] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Not Highlight

**Page 22: [225] Deleted**      **Subba, Tamanna**      **8/25/25 3:28:00 PM**

**Page 22: [226] Deleted**      **Subba, Tamanna**      **9/18/25 12:43:00 PM**

**Page 22: [227] Deleted**      **Subba, Tamanna**      **9/18/25 12:44:00 PM**

**Page 22: [228] Deleted**      **Subba, Tamanna**      **9/18/25 12:44:00 PM**

**Page 24: [229] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [230] Deleted**      **Tamanna Subba**      **9/15/25 3:36:00 PM**

**Page 24: [230] Deleted**      **Tamanna Subba**      **9/15/25 3:36:00 PM**

**Page 24: [230] Deleted**      **Tamanna Subba**      **9/15/25 3:36:00 PM**

**Page 24: [231] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [232] Deleted**      **Tamanna Subba**      **9/15/25 3:37:00 PM**

**Page 24: [232] Deleted**      **Tamanna Subba**      **9/15/25 3:37:00 PM**

**Page 24: [232] Deleted**      **Tamanna Subba**      **9/15/25 3:37:00 PM**

**Page 24: [233] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [233] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [234] Deleted**      **Tamanna Subba**      **9/15/25 3:38:00 PM**

▼ ..... ▲ ..... ◀

**Page 24: [234] Deleted**      **Tamanna Subba**      **9/15/25 3:38:00 PM**

▼ ..... ▲ ..... ◀

**Page 24: [234] Deleted**      **Tamanna Subba**      **9/15/25 3:38:00 PM**

▼ ..... ▲ ..... ◀

**Page 24: [235] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [236] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [237] Deleted**      **Tamanna Subba**      **9/15/25 3:39:00 PM**

✖ ..... ▲ ..... ◀

**Page 24: [237] Deleted**      **Tamanna Subba**      **9/15/25 3:39:00 PM**

✖ ..... ▲ ..... ◀

**Page 24: [238] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [239] Deleted**      **Tamanna Subba**      **9/15/25 3:40:00 PM**

✖ ..... ▲ ..... ◀

**Page 24: [239] Deleted**      **Tamanna Subba**      **9/15/25 3:40:00 PM**

✖ ..... ▲ ..... ◀

**Page 24: [240] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [241] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [242] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [243] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [244] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [245] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [246] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [247] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [248] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [249] Deleted**

**Tamanna Subba**

**9/15/25 3:47:00 PM**

**Page 24: [249] Deleted**      **Tamanna Subba**      **9/15/25 3:47:00 PM**

**Page 24: [249] Deleted**      **Tamanna Subba**      **9/15/25 3:47:00 PM**

**Page 24: [250] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [251] Deleted**      **Tamanna Subba**      **9/15/25 3:48:00 PM**

**Page 24: [251] Deleted**      **Tamanna Subba**      **9/15/25 3:48:00 PM**

**Page 24: [252] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [253] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [254] Deleted**      **Tamanna Subba**      **9/14/25 1:49:00 AM**

**Page 24: [254] Deleted**      **Tamanna Subba**      **9/14/25 1:49:00 AM**

**Page 24: [255] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [256] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [257] Deleted**

**Tamanna Subba**

**9/14/25 1:49:00 AM**

**Page 24: [257] Deleted**

**Tamanna Subba**

**9/14/25 1:49:00 AM**

**Page 24: [258] Deleted**

**Scott Giangrande**

**9/15/25 9:02:00 PM**

**Page 24: [258] Deleted**

**Scott Giangrande**

**9/15/25 9:02:00 PM**

**Page 24: [259] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [260] Deleted**

**Tamanna Subba**

**9/15/25 3:50:00 PM**

**Page 24: [260] Deleted**

**Tamanna Subba**

**9/15/25 3:50:00 PM**

**Page 24: [261] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [262] Deleted**

**Subba, Tamanna**

**8/19/25 8:35:00 PM**

**Page 24: [262] Deleted**      **Subba, Tamanna**      **8/19/25 8:35:00 PM**

**Page 24: [263] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 24: [264] Deleted**      **Tamanna Subba**      **9/15/25 3:50:00 PM**

**Page 24: [264] Deleted**      **Tamanna Subba**      **9/15/25 3:50:00 PM**

**Page 25: [265] Deleted**      **Tamanna Subba**      **9/15/25 2:55:00 AM**

**Page 25: [265] Deleted**      **Tamanna Subba**      **9/15/25 2:55:00 AM**

**Page 25: [266] Deleted**      **Scott Giangrande**      **9/15/25 9:04:00 PM**

**Page 25: [266] Deleted**      **Scott Giangrande**      **9/15/25 9:04:00 PM**

**Page 25: [267] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 25: [268] Deleted**      **Michael Jensen**      **9/15/25 11:32:00 PM**

**Page 25: [268] Deleted**      **Michael Jensen**      **9/15/25 11:32:00 PM**

**Page 25: [269] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 25: [270] Deleted**      **Scott Giangrande**      **9/15/25 9:04:00 PM**

**Page 25: [270] Deleted**      **Scott Giangrande**      **9/15/25 9:04:00 PM**

**Page 25: [271] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 25: [272] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 25: [273] Deleted**      **Tamanna Subba**      **9/14/25 1:51:00 AM**

**Page 25: [274] Formatted**      **Subba, Tamanna**      **10/12/25 5:12:00 PM**

Font color: Auto

**Page 25: [275] Deleted**      **Tamanna Subba**      **9/15/25 3:55:00 PM**

**Page 25: [275] Deleted**      **Tamanna Subba**      **9/15/25 3:55:00 PM**

**Page 25: [276] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 25: [277] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto, Not Superscript/ Subscript



**Page 25: [278] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 25: [279] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 25: [280] Deleted**

**Tamanna Subba**

**9/15/25 5:03:00 PM**



**Page 25: [281] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 25: [282] Deleted**

**Tamanna Subba**

**9/15/25 5:03:00 PM**



**Page 25: [282] Deleted**

**Tamanna Subba**

**9/15/25 5:03:00 PM**



**Page 25: [282] Deleted**

**Tamanna Subba**

**9/15/25 5:03:00 PM**



**Page 25: [283] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto



**Page 25: [284] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 25: [285] Deleted**

**Tamanna Subba**

**9/15/25 5:05:00 PM**

**Page 25: [285] Deleted**

**Tamanna Subba**

**9/15/25 5:05:00 PM**

**Page 25: [286] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 25: [287] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 25: [288] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 25: [289] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 25: [290] Deleted**

**Tamanna Subba**

**9/14/25 1:53:00 AM**

**Page 25: [291] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

**Page 25: [292] Deleted**

**Tamanna Subba**

**9/7/25 11:43:00 PM**

**Page 25: [293] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font color: Auto

Page 25: [294] Deleted Tamanna Subba 9/14/25 1:59:00 AM

Page 25: [294] Deleted Tamanna Subba 9/14/25 1:59:00 AM

Page 25: [294] Deleted Tamanna Subba 9/14/25 1:59:00 AM

Page 25: [295] Formatted Subba, Tamanna 10/12/25 5:12:00 PM

Font color: Auto

Page 43: [296] Deleted Subba, Tamanna 9/16/25 11:11:00 PM

Page 43: [297] Deleted Subba, Tamanna 9/18/25 12:27:00 PM

Page 50: [298] Formatted Subba, Tamanna 10/12/25 5:12:00 PM

Font: Not Italic, Font color: Black

Page 50: [299] Formatted Subba, Tamanna 10/12/25 5:12:00 PM

Font color: Black

Page 50: [300] Formatted Subba, Tamanna 10/12/25 5:12:00 PM

Font: Italic, Font color: Black

Page 50: [301] Formatted Subba, Tamanna 10/12/25 5:12:00 PM

Font: Not Italic

**Page 50: [302] Formatted Table**

**Subba, Tamanna**

**9/2/25 6:21:00 PM**

Formatted Table



**Page 50: [303] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [304] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [305] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [306] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [307] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [308] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [309] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [310] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [311] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [312] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [313] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [314] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [315] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [316] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [317] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [318] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [319] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [320] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [321] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [322] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [323] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [324] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [325] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [326] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [327] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [328] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [329] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [330] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [331] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [332] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [333] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [334] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [335] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [336] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [337] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [338] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [339] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [340] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



**Page 50: [341] Formatted**

**Subba, Tamanna**

**10/12/25 5:12:00 PM**

Font: Not Italic



Font: Not Italic



Font color: Black

