FOSTERING A COLLABORATIVE ATMOSPHERIC CHEMISTRY RESEARCH COMMUNITY IN THE LATIN AMERICA AND CARIBBEAN REGION

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A more cohesive and sustained community of atmospheric scientists is needed in the Latin America–Caribbean region to address the pressing issues of air quality and climate change.

The Latin America–Caribbean (LAC) region is defined as the countries south of the Rio Grande along the U.S.–Mexico border and includes Mexico, Central America, the islands of the Caribbean, and South America. Oftentimes, the LAC region is referred to as a homogeneous entity because of a common history, culture, and socioeconomic issues. However, to understand atmospheric chemistry in the region and its impacts on human health, ecosystems, and climate, it is of the utmost importance to address the heterogeneity of the LAC region's physical and human geography (Fig. 1, left). For example, the climate of northern Mexico is hot and dry, while the climates of many Central America and Caribbean countries consist of a prolonged wet summer season that includes many tropical storms and hurricanes. Within South America the topography and climate vary greatly from the Andean regions to Amazonia and from Atlantic forests to Patagonia.

The LAC region is also unique in the fact that ~80% of the population lives in urban areas, resulting in high-density hot spots of urbanization and vast rural, sparsely populated areas (Heilig 2012; United Nations 2012) (Fig. 1, right). As a result of the high percentage of people living in urban areas and the coinciding emissions resulting from rapid development, urban air pollution has become a ubiquitous problem throughout the LAC region. Socioeconomic gradients among countries and inequities within them act as amplifiers of environmental problems, leading to differentiated emission patterns, exposure to air pollution, and vulnerability to climate change in urban areas (Bell et al. 2011; Gallardo et al. 2012; Mena-Carrasco et al. 2012; Romero-Lankao et al. 2013). Despite continuous growth in the number of stations monitoring air pollutants throughout the region and the development of policies to meet air quality standards, urban areas continue to exceed the World Health Organization's (WHO) Air Quality Guidelines (WHO 2005; see Fig. 2). In addition, long-range transport of air pollutants can hinder local or national-level strategies to meet air quality

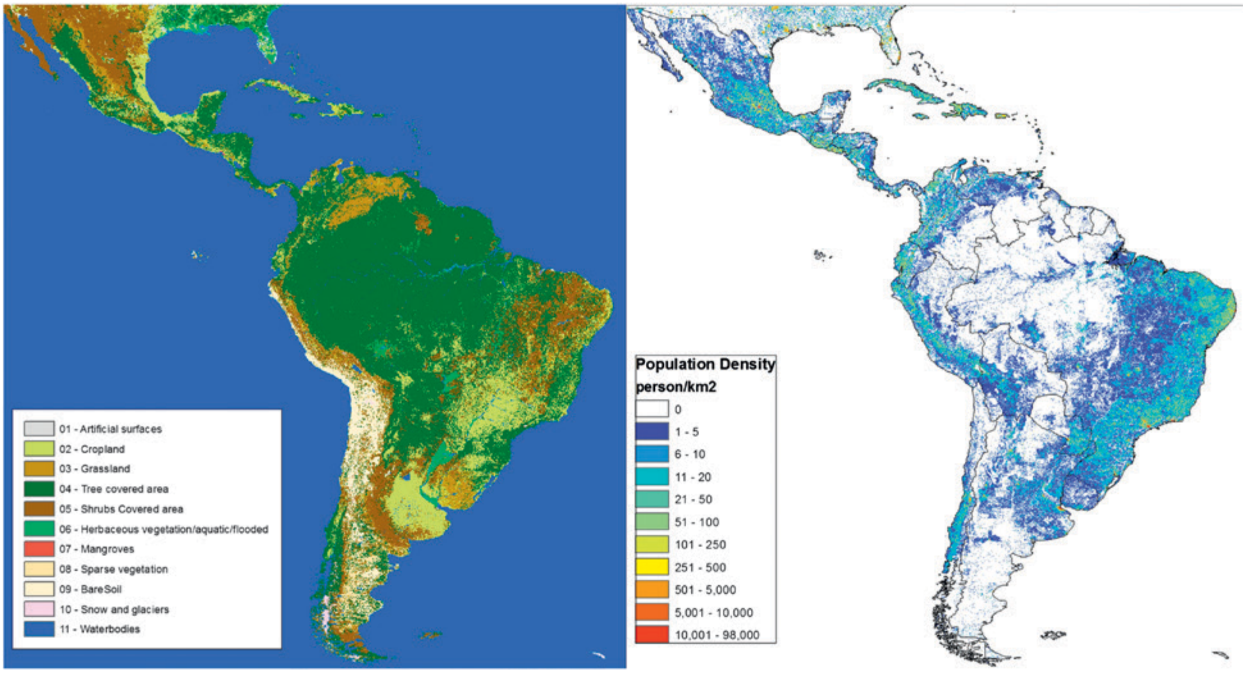

Fig. 1. (left) Land cover map and (right) population density of the LAC region.

standards in urban areas and can also decrease air quality in rural areas (CEC 1997; Galanter et al. 2000; Longo et al. 2009; NRC 2009; Zhu et al. 2012; Prospero et al. 2014).

Although atmospheric chemistry research has been conducted throughout the LAC region for decades, the amount and quality of the research vary greatly, as does the participation of local scientists. U.S. and European scientists often collaborate with local scientists where the research is being conducted, but very rarely is the invitation to work on such joint projects extended to other researchers in the LAC region. However, the uniqueness of the LAC region and the scientific questions that need to be addressed would greatly benefit from a cohesive community of scientists in the LAC region working together, and with international partners, to address atmospheric composition, its temporal evolution, and its impacts on human health, climate, and ecosystems.

In response to this need, members of the international Commission on Atmospheric Chemistry and Global Pollution (iCACGP) and the International Global Atmospheric Chemistry (IGAC) Project from the LAC region came together in 2013 to form the iCACGP/IGAC Americas Working Groups (AWG). The AWG aims to build a strong cohesive community and foster the next generation of atmospheric scientists within the region with the goal of contributing to the development of a scientific community focused on building collective knowledge for the Americas. The AWG aims to achieve this goal by focusing on four areas:

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- improving the collaboration and communication among scientists in the LAC region,
- connecting scientists within the LAC region to the international community,
- training and fostering the next generation of scientists in the LAC region, and
- enhancing the visibility and credibility of scientists in the LAC region.

Currently, the AWG consists of 12 members, including two cochairs, with the following composition: two scientists from Central America, two scientists from the Caribbean, three scientists from "Andean" countries (Bolivia, Ecuador, Venezuela, Peru, and Colombia), two scientists from "South American" countries (Argentina, Chile, Uruguay, and Paraguay), one scientist from Mexico, one scientist from Brazil, and one scientist from the United States or Canada. Each member serves a four-year term on the AWG and is to represent his/her country/subregion during their membership. The representation on the AWG was determined by the current scientific capacity of the different countries/subregions and is subject to change as scientific capacity grows in the LAC region.

The AWG has already been successful during its short two years of existence in achieving its goals by focusing on the four areas listed above. For example, in 2015 two short courses have been developed to train and foster the next generation of scientists. The first of these courses took place in La Paz, Bolivia, in July 2015 and was focused on aerosol measurements. The second course was focused on remote sensing techniques and took place in Mexico City, Mexico, in December 2015. These courses were organized by LAC region scientists, in collaboration with European and U.S. scientists as instructors. In an effort to connect LAC scientists to the international community and to enhance the visibility and credibility of scientists in the region, the AWG connected the Coalition for Clean Air and Climate (CCAC) with local scientists to have them lead and be contributing authors on a soon to be released assessment on short-lived climate pollutants (SLCPs) in the LAC region. Collaborations and communication between scientists in the LAC region have also been fostered by the AWG through the development of the Global Emissions Initiative (GEIA) Americas Working Group; coordinated efforts to install a World Meteorological Organization (WMO) Global Atmosphere Watch (GAW) station, along with remote sensing instruments at the Smithsonian Tropical Research Institute in Panama; and an effort to create an Aerosol Robotic Network (AeroNet) observation network in the LAC region as well as the Caribbean Aerosol Network.

The iCACGP/IGAC AWG will continue to build upon current efforts in the LAC region to address research questions on atmospheric chemistry that impact human health, ecosystems, and climate. Here, we discuss current examples of research in the LAC region and identify remaining main scientific questions to be addressed and the key steps forward to address these questions through a collaborative atmospheric chemistry research community.

EXAMPLES OF ATMOSPHERIC RESEARCH IN LAC. Atmospheric chemistry research capabilities and achievements vary greatly among and even within LAC countries owing to the inherent characteristics of the research systems and the criticality of the issues related to atmospheric chemistry in every country. Urban air pollution in Mexico City, for instance, triggered the cultivation of scientists, research groups, institutes, and large projects that have increased the level of knowledge and helped decision-makers to address air pollution. In Brazil research policies have produced a robust scientific system that has increased

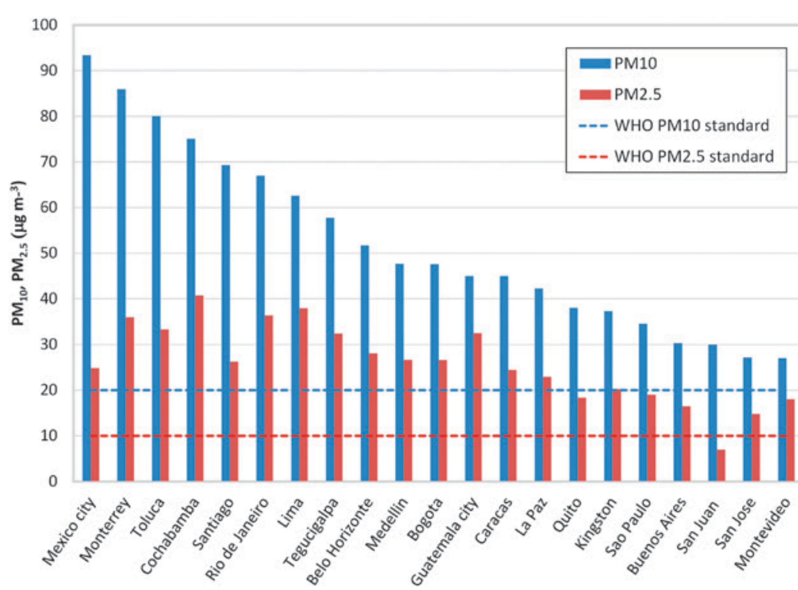

Fig. 2. The PM_{10} and $PM_{2.5}$ annual average levels in some LAC cities, based on official 2010–13 data, according to availability for each city (WHO 2014b).

scientific capacity in the region, allowing scientists to become leaders in developing new technologies and climate models on the regional level. We have selected a number of cases that can be considered as indicative examples of the type and level of atmospheric chemistry research that has been conducted in the region around two major issues, namely urban air quality and the long-range transport of air pollutants.

Urban air quality research. Air quality is a public health issue throughout the world with an estimated seven million premature deaths caused by indoor and outdoor air pollution in 2012 (Lim et al. 2012; WHO 2014b). The LAC region is not an exception and urban air pollution remains a significant public health issue. During the last few decades there has been a large increase in the number of vehicles in most urban and semiurban areas in the region (Romero-Lankao 2007; CEPAL 2010; Gallego et al. 2013) and countries are industrializing (West and Schandl 2013). This has resulted in poor air quality and many LAC governments view this as a major public health problem. Some air pollution events are enhanced as a result of particular geographic and atmospheric conditions. For example, in Santiago, Chile, the combination of thermal inversions and complex terrain results in acute air pollution episodes (Saide et al. 2011b). Complex topography, especially near the Andes, creates ideal conditions for having high levels of air pollution. As a result, even relatively small cities report poor air quality, especially during winter when wood burning is still used for heating (Toro et al. 2006; Diaz-Robles et al. 2008).

Monitoring networks have been established by and for local and national governments in many cities throughout the LAC region to monitor air quality and establish air pollution control strategies. Although these networks were not built for scientific research purposes, they have greatly contributed to a better understanding of the local and regional atmosphere. An example of local efforts addressing measurements of air quality can be found in Bogota, Colombia. Since 1997, 13 automatic air quality stations (12 stationary and 1 mobile) measure common air pollutants. Datasets are available to the public on the city's Secretary of the Environment website (http://oab.ambientebogota.gov.co/es/indicadores?id=1&v=l) (Gaitán et al. 2007). Even though this monitoring network has suffered operational problems at times, something relatively common in LAC cities, this information has been very valuable for designing air pollution abatement measures, estimating health benefits from these measures, and prioritizing air quality research needs (Ortiz and Rojas 2013). In general, the air pollution monitoring networks in the LAC region could benefit from common data quality assurance and control protocols. This is particularly important regarding speciation of hydrocarbons and the characterization of particulate matter (Vargas et al. 2012).

In other cases large field campaigns, such as the Mexico City Metropolitan Area (MCMA) field campaign in 2003 and the Megacity Initiative: Local and Global Research Observations (MILAGRO) field campaign in 2006, have played an important role in understanding atmospheric chemistry in the region and creating scientific capacity in Mexico (Molina et al. 2010 and references therein). More recently, researchers from Buenos Aires, Argentina; São Paulo, Brazil; Santiago de Chile; Bogota; Medellin, Colombia; and Lima, Peru, developed the South American Emissions, Megacities and Climate (SAEMC) project, sponsored by the Inter-American Institute for Global Change Research (IAI). SAEMC improved emission inventories, developed chemical weather forecasting tools at the continental and city scales and optimized the design of monitoring networks (Martins et al. 2006; Martins and Andrade 2008; Saide et al. 2009; Alonso et al. 2010; D'Angiola et al. 2010; Longo et al. 2010; Freitas et al. 2011; Saide et al. 2011a,b; Gallardo et al. 2012; Longo et al. 2013; Osses et al. 2013).

Remote sensing techniques have been applied for atmospheric chemistry research in the LAC region in order to retrieve ground-level and vertical profiles of air pollutants and other relevant atmospheric gases. For instance, the temporal variability of NO_2 has been studied in Mexico, El Salvador, and Argentina by using differential optical absorption spectroscopy (DOAS; Alberti et al. 2012, p. 165; Raponi et al. 2012; Rivera et al. 2013). The DOAS technique has also been used to study industrial and volcanic emissions, for example, the Network for Observation of Volcanic and Atmospheric Change (NOVAC), a European Union funded project (Grutter et al. 2008; Rivera et al. 2009). In addition, greenhouse gases and other pollutants have been measured in the region using Fourier transform infrared spectroscopy (FTIR) methods (Bezanilla et al. 2014; Grutter et al. 2014). There are also significant lidar capabilities in the LAC region for the study of tropospheric aerosols, industrial pollution, and biomass burning (Antuña et al. 2012; Ristori et al. 2012; Lopes et al. 2014). Existing lidar teams in the LAC region are collaborating through the Latin American Lidar Network (www.lalinet.org), which is a contributing network to the WMO GAW Aerosols Lidar Network (GALION). There are also many sun photometers located in the LAC region that are used to characterize aerosols, for example, to study the maritime mixed aerosols in Camagüey, Cuba, and the intraseasonal variability of smoke during a biomass burning season in South America (Estevan et al. 2011; Rosário et al. 2013).

In spite of expanding economies, research spending, and scientific output over the past two decades, research communities in general and atmospheric chemistry communities in particular are still small in most of the LAC countries (Van Noorden 2014). According to a systematic search using the Scopus database, Brazil, specifically the University of São Paulo, leads by far in research and scientific publications on atmospheric science subjects in the LAC region. Many studies are also related to the health effects of air pollution (Brito et al. 2013). Therefore, scientific capacity building remains a foremost requirement to addressing the issues associated with growing cities such as air quality and climate change. Material and human resources for atmospheric research in the LAC region, possibly with the exception of large cities/states in Brazil, are insufficient. This makes it difficult to conduct high-level research, contribute to international programs, and influence sustained impacts in local development. That is why air quality and climate researchers critically need regional collaborating networks and significant investments in capacity building at various levels. Within this framework, it is important to acknowledge the contribution of large international campaigns and projects like MCMA, MILAGRO, and SAEMC not only in increasing the scientific understanding of atmospheric processes in LAC cities but also in building scientific capacity within the region through training, participation, and coauthoring scientific publications with local and international scientists. Local research initiatives have produced a number of interesting results in relation to urban air quality and small groups have been increasing their capabilities both in infrastructure and scientific/technical expertise. As a result, they are addressing broader and deeper research questions emerging from the rapid changes in the region.

Long-range transport of pollutants. Urban and rural air quality in LAC countries is often impacted by the long-range transport of air pollutants that are produced within and outside the region and transported under the right meteorological conditions. Examples of long-range transport are dust from Africa, specifically the Sahara/Sahel region, and smoke produced by biomass burning from central Africa. Examples of regional transport are smoke from agricultural fires and anthropogenic pollutants within the continent (i.e., smoke from the Amazon reaching the Andes).

Dust transported from North Africa across the Atlantic to the Caribbean basin and the central United States occurs mostly from June to August (Husar et al. 1997; Perry et al. 1997; Prospero 1999; Nowottnick et al. 2011; Prospero and Mayol-Bracero 2013). A southward displacement of the dust cloud in the winter months transports dust into South America, as seen in satellite products and characterized by measurements over the Amazon (Swap et al. 1992; Husar et al. 1997; Prospero 1999; Martin et al. 2010; Huneeus et al. 2011). The transport of African dust causes severe impacts on the air quality of receptor countries (e.g., reduction in visibility, poor air quality) (Prospero et al. 2008; Bozlaker et al. 2013; Prospero and Mayol-Bracero 2013; Prospero et al. 2014; Ortiz-Martínez et al. 2015). African dust has also been shown to have an impact on hurricanes, precipitation, clouds, climate, and ecosystem health (Swap et al. 1996; Dunion and Velden 2004; Koren et al. 2006; Bristow et al. 2010; Okin et al. 2004; Prospero and Mayol-Bracero 2013; Spiegel et al. 2014; Raga et al. 2016; Valle-Diaz et al. 2015). This happens mostly during the Northern Hemisphere wintertime when African dust reaches northeastern South America. This African dust has been shown to have a positive impact on the Amazon forest as a result of the input of nutrients (Artaxo et al. 1990; Swap et al. 1996; Husar et al. 2004; Koren et al. 2006; Ansmann et al. 2009; Ben-Ami et al. 2010; Bristow et al. 2010; Martin et al. 2010). Many important questions still remain regarding the importance of the long-range transport of dust and its impacts on the Earth's biogeochemistry cycle (Okin et al. 2004).

Biomass burning smoke within the Amazon basin occurs in the austral winter/spring primarily because of land clearing. Fires generated in Brazil, Bolivia, Paraguay, and Argentina emit smoke that is then transported locally and regionally (Fig. 3) (Freitas et al. 2005; Evangelista et al. 2007; Longo et al. 2009; Pereira et al. 2011). Amazonian biomass burning plumes have been observed in LAC countries such as Suriname and Venezuela (Andreae et al. 2001; Hamburger et al. 2013). In addition, smoke produced by biomass burning in the Bolivian lowlands and, possibly, Brazil, Argentina, and Paraguay, has been measured high in the central Andes, suggesting that the convective transport of biomass burning plumes is of importance to the region (Andrade et al. 2011; M. Andrade et al. 2016, in preparation). Heavy smoke from forest fires in the Amazon basin has been observed to shift precipitation formation in convective clouds to greater heights and thereby

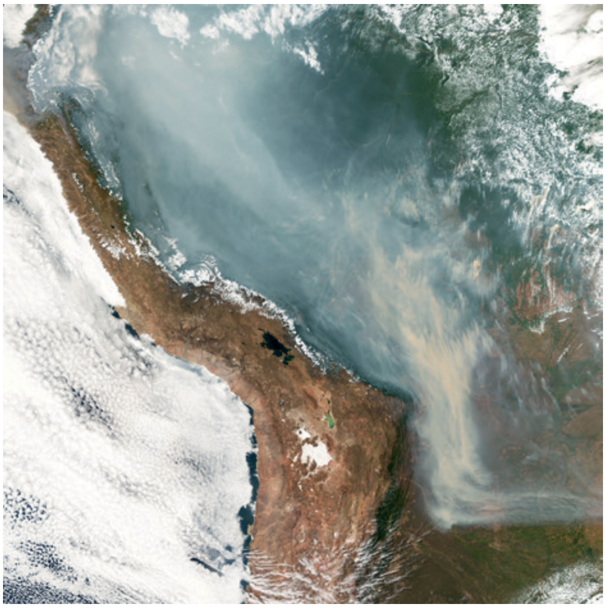

Fig. 3. Smoke from the Amazon basin being transported to the Andes on 14 Sep 2004. [NASA image created by J. Allen, Earth Observatory, using data obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) Rapid Response Team.]

impact the water cycle, the pollution burden of the atmosphere, and the dynamics of atmospheric circulation (Andreae et al. 2004). Studies performed by Lau et al. (2010) over the Himalayas suggest that black carbon (BC) from biomass burning in South America, transported to the Andean glaciers, cannot only decrease the albedo of ice/snow, but can warm the local atmosphere, further contributing to the melting of glaciers in the Andean region. This suggests that both the ice/snow albedo effect and the warming of the atmosphere resulting from BC likely have contributed to the rapid observed rate of glacial melting, which impacts freshwater security in the Andean region. As a result, an area of current research is the impact of biomass burning smoke from the Amazon basin on freshwater via changes in precipitation patterns and the enhanced melting of glaciers (Molina et al. 2015). It is important to note that besides biomass burning there are multiple sources of BC in the LAC region: diesel vehicles, industrial sources, residential burning of wood and waste for heating and cooking, and informal burning kilns for brick production, etc. Several studies have addressed the long- and short-range transport of urban and wood burning aerosol over the Andes (Longo et al. 2009; Pereira et al. 2011; Cereceda-Balic et al. 2012; Rosário et al. 2013; Mena-Carrasco et al. 2014; Schmitt et al. 2015).

MAIN SCIENTIFIC QUESTIONS AND KEY STEPS FORWARD. The foci of scientific questions may differ significantly depending on the specific needs within the LAC region, but it is nevertheless possible to generalize some main questions that have, and can, be commonly addressed. First, it is important to examine the link between air pollution and climate in more depth, which is crucial for understanding the feedback mechanisms involving short- and long-lived species. For example, the forcing and impacts of short-lived climate pollutants (SLCPs) on air quality and climate, the changes in boundary layer processes including the heat island effect and stratification over complex terrain, and the effect of increasing temperatures on photochemistry are not well understood in the LAC region. The aforementioned links between air pollution and climate govern how air pollutant emissions result in ambient concentrations, which have direct impacts on human health and ecosystems. The development of local, national, and regional emission inventories is a critical scientific need in the LAC region in order to address air quality and climate considerations. Long-range transport is another main theme among the remaining scientific questions regarding the fate of African dust and biomass burning plumes and their impacts on cloud formation, urban air pollution, and freshwater security. In addition, the transport of particulate matter and gases from the near surface to the free troposphere over complex terrain is another area of scientific interest in the Andean region. The evolution of urban and industrial plumes, on the other hand, may affect atmospheric composition, cloud processes, and pristine environments (glaciers, biomes, protected areas, oceans, etc.). There is still more to learn about how the intercontinental transport of dust impacts the biogeochemical cycles of the oceans and in the ecosystems in the LAC region and how it impacts air quality, clouds, and storm formation. The extent of how natural (volcanic, biogenic, and oceanic) emissions contribute to the overall loading of aerosols and gases and how they are involved in various atmospheric processes is not fully understood. Finally, the impacts of future changes on the composition of the atmosphere associated with climate change and rapid land-use change in the LAC region have not been fully studied. Many of these issues are not exclusive to the LAC region but are global in nature and will require international collaboration to be fully understood.

To address the issues mentioned above, there is an urgent need to increase the number of qualified scientists and specialized technicians in the LAC region. Some countries have shown significant advances in establishing research groups and high-level educational programs, but the growth in the number of experts has been slow and geographically uneven. Most LAC scientists are educated in developed countries but often cannot find adequate research positions in their home countries. There is a need to lure these scientists back to the region by developing an adequate infrastructure from the level of local institutions to national governments. Moreover, there is an appalling need to improve the observational, analytical, and modeling capacities, which in turn requires sustained, prioritized, and oriented funding. Convincing governmental agencies about the socioeconomic benefits of investing in research in environmental problems is a challenge to the community. Finally, since alliances with the United States and Europe have been favored over regional collaborations, even in cases when regional expertise is available, a key component to overcome is the current limitations to fostering stronger collaborations among LAC research groups.

The iCACGP/IGAC AWG is stepping forward to address these and other questions that may arise as the LAC region faces new and more complex environmental problems. Addressing these issues requires a strong cohesive community of atmospheric scientists within the region and the coordination of activities among the research community to foster collaborative projects by means of specialized courses, thematic workshops, and exchange programs. We therefore invite these scientists to join the iCACGP/IGAC AWG to help create a more collaborative atmospheric chemistry community in the LAC region (sign up for the iCACGP/IGAC AWG e-mail list at http://eepurl.com/-dSCr).

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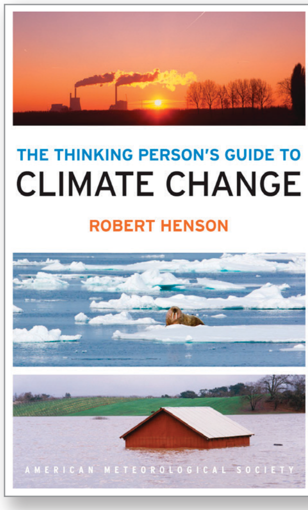

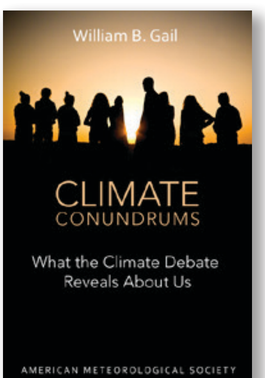

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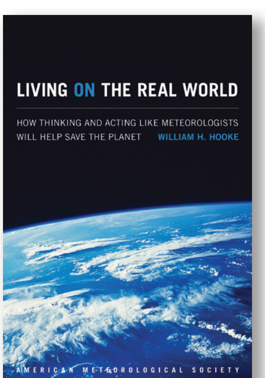

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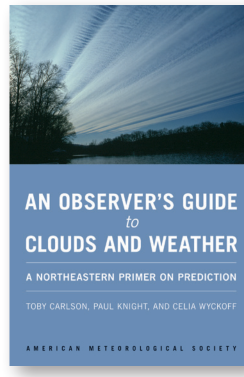

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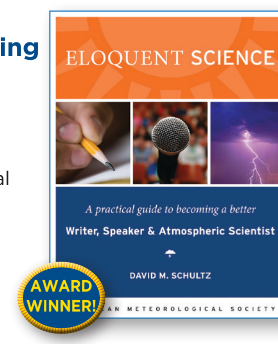

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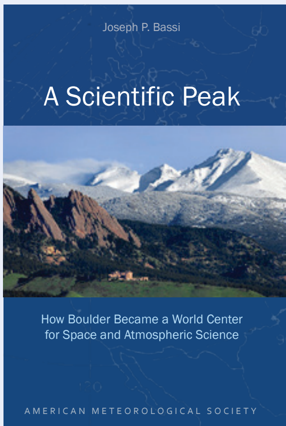

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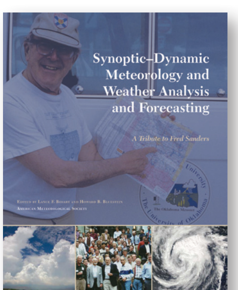

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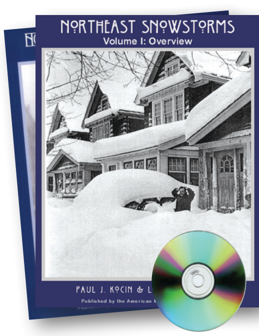

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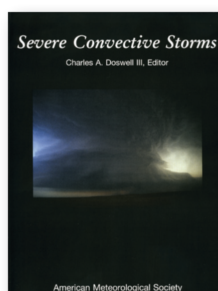

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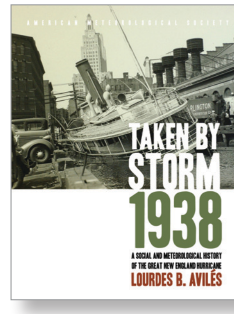

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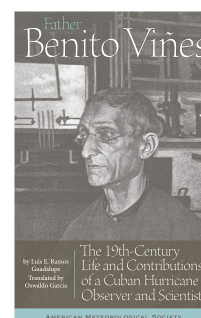

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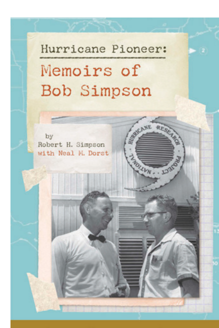

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