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Oceanic Sources of Continental Precipitation

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Oceanic sources of continental precipitation

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Abstract In this special section, the authors have tried to address some of the many unanswered questions related to the transport of moisture from oceanic sources to the continents, including among others that of whether or not the moisture source regions have remained stationary over time, how the many changes in the intensity and position of the sources have affected the distribution of continental precipitation, and also the question of the role of the main modes of climate variability in the variability of the moisture regions.

From the perspective of climate change, obtaining a proper understanding of the intensity of the hydrological cycle and its development over time is one of the most important challenges for research in Geoscience for the century ahead. Of particular importance are our understanding of the processes that govern the evaporation of water from the oceans (in the domain of oceanography) [*Yu and Weller*, 2007], the transport of moisture in the atmosphere (meteorology) [*Trenberth et al*., 2003], and the effects of these processes on the hydrological cycle (hydrology) [*Bales*, 2003], all within the context of the current paradigm of global climate change [*Stocker et al*., 2013].

The transport of moisture from oceanic sources to the continents forms the connection between evaporation from the ocean and precipitation over the continents, and a detailed study of this topic can provide both a better understanding of the observed changes and some physical evidence to support the results of projections of future climates [*Gimeno et al*., 2012]. Other motivations for understanding the transport of moisture include a firmer grasp of the monsoonal precipitation that greatly influences both local continental evaporation and the transport of vapor from adjacent oceanic regions [e.g., *Dominguez et al*., 2008], and the role of anomalies in the transport of moisture observed during natural hazards (i.e., extremes of drought or precipitation). Most studies of moisture transport make use of Eulerian approaches, which can be used to estimate the ratio of advected to recycled moisture and to calculate moisture transport from predetermined source and sink regions, although they are unable to identify the moisture source regions directly; this is achieved using more complicated Lagrangian computational techniques. Several such methods have recently been developed by *Stohl and James* [2004, 2005], *Sodemann et al*. [2008], and *Dirmeyer and Brubaker* [2007], in order to diagnose the net changes in water vapor along a large number of back trajectories and thereby infer the sources of the precipitation that falls in a target region. These methods have recently been used to identify those continental regions affected by precipitation originating from specific oceanic regions [*Gimeno et al*., 2010, *Gimeno et al*., 2013]; in these studies it was found that the supply of oceanic moisture to the continents is highly asymmetric.

A review of the conceptual models of moisture transport is necessary in order to study the origins of continental precipitation. Two meteorological structures are primarily responsible, namely Low-Level Jet (LLJ) systems and Atmospheric Rivers (ARs). The former are particularly important in tropical and subtropical regions; the wide range of characteristics of LLJs was discussed by *Stensrud* [1996]. To date, the transport of moisture in LLJs and their characteristics have been studied using Eulerian approaches [*Marengo et al*., 2004]. However, Lagrangian approaches allow a more detailed characterization of the jets by identifying them as beams with coherent trajectories. ARs are another structure important in the transport of moisture in extratropical regions (see *Gimeno et al*. [2014] for a review). Analysis at shorter time scales reveals that there are 3–5 ARs per hemisphere in the atmospheric circulation system and that these are responsible for the transport of large amounts of water along relatively narrow streams from the tropics through the midlatitudes and toward higher latitudes. The term "atmospheric river" was in fact first used by *Newell et al*.

[1992], because the volumes of water involved are comparable with those transported by large terrestrial rivers. Similar to LLJs, Lagrangian approaches can be used to identify ARs as coherent-trajectory beams.

Special mention should be made of the transport of moisture for monsoonal regimes and during natural hazards (i.e., extreme drought or precipitation). Several authors have identified the presence of low levels of moisture transport during the active phases of monsoon regimes [e.g., *Thorncroft et al*., 2011]. However, the few Lagrangian studies of the sources of moisture for monsoon systems were limited to just a few years, so there is still some way to go in terms of our understanding of the interannual variability of the sources linked to precipitation in these regions, the role of the main modes of climate variability, and the effects of any changes in the position and intensity of the sources. There have been very few studies of natural hazards focusing on the anomalous transport of moisture. It is well known that transport from regions of large amounts of water vapor and its associated convergence may trigger extreme rainfall and cause flooding [*Stohl et al*., 2008]; the persistence of drought could be due in part to the absence of moisture transport to the continents [*Seneviratne et al*., 2006].

Our best estimates, such as those derived from the OAFlux data [*Yu and Weller*, 2007], have revealed strong increasing trends in evaporation from the oceans since 1978, with the trend being most pronounced during the 1990s. The scenarios of climate change suggest that the high sensitivity of the saturation vapor pressure to temperature will result in a more intense hydrological cycle, with increased rates of evaporation and precipitation in a world that is warmer than it is today [e.g., *Stocker et al*., 2013]. It is essential to analyze the changes in intensity and position of the sources under different Global Climate Models (GCMs) and climate change scenarios, and to study the potential influence of these changes on continental precipitation. The identification of regions particularly vulnerable to changes in the hydrological cycle requires all the oceanic moisture sources to be located; additionally, the exact target areas, where the water evaporating from these sources precipitates over land, must be identified. The sources of continental precipitation—and the changes in these—must be determined, allowing us (1) to identify and analyze the main meteorological structures transporting moisture at the planetary scale, (2) to determine the contribution of the anomalous transport of moisture during drought periods and extreme precipitation events, (3) to explore the possible variations in the sources of continental precipitation, and (4) to assess how these are linked to climate change.

It is these diverse questions that make this topic one of the main challenges in atmospheric research over the next few decades [*Gimeno*, 2013]. We must address the many questions that remain unanswered, including whether the moisture source regions have remained stationary over time, how any changes in the intensity and position of the sources affect the distribution of continental precipitation, and the role of the main modes of climate variability in the variability of the moisture regions. We must also quantify the moisture being transported by LLJs and ARs, and assess both the role of warm pools in the supply of moisture, and how the source regions may alter in a changing climate.

The authors of the papers in this special section have tried to answer some of these key research questions. *Sato and Sugimoto* [2013] analyzed the role of the sea surface temperature (SST) anomaly in modulating winter precipitation by means of a numerical experiment with a regional atmospheric model, concluding that the trends in precipitation in some of the regions they analyzed are influenced by trends in SST, whereas in other regions significant trends in precipitation can occur even in the absence of these trends. *Jouzel et al*. [2013] reviewed the link between the isotopic composition of precipitation and its oceanic sources, and discussed the value of oxygen-17 measurements as used in studies of this type. *Zahn and Allan* [2013] used the high spatial and temporal resolution provided by the ECHAM5-model data to quantify the projected atmospheric moisture transport to the continents in future climate scenarios. *Gómez-Hernández et al*. [2013] analyzed the seasonal and interannual variability of the main atmospheric moisture sources in one target hydrological region, the Mediterranean. *Guan et al*. [2013] linked the anomalously high frequency of AR occurrence with the massive Sierra Nevada snowpack during the winter of 2010/2011 and analyzed the role of major climate modes such as the Arctic Oscillation (AO) and the Pacific North American Pattern (PNA) in favoring the anomalously high incidence of ARs. *Ordoñez et al*. [2013] investigated how the Madden-Julian Oscillation affects the transport of moisture by the Somali LLJ and assessed its effects on the Indian summer monsoonal rainfall. *Risi et al*. [2013] focused on the possible use of water isotopes to quantify the role of continental recycling in the intraseasonal variability of continental moisture. *Van der Ent and Savenije* [2013] identified oceanic sources of continental precipitation, finding that those nearest the continents had the strongest influence on precipitation, and testing whether changes in SST for the moisture sources influence the related precipitation. *Farlin et al*. [2013] found a link between synoptic weather events and the isotopic composition of precipitation in continental areas. *Castillo et al*. [2014] analyzed the role of the El Niño southern oscillation influence (ENSO) in modifying transport from the major oceanic moisture sources, and R. Nieto et al. (A catalogue of moisture sources for continental climatic regions, submitted to *Water Resources Research*, 2014) built a catalogue of the moisture sources associated with continental climatic regions based on their similarities in terms both of their mean climates and their projected changes in precipitation in future climates.

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