DEFINING "ATMOSPHERIC RIVER"
How the *Glossary of Meteorology* Helped Resolve a Debate

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Since the term "atmospheric river" (AR) first appeared in modern scientific literature in the early 1990s, it has generated debate about the meaning of the concept. A common popular definition is something along the lines of a "river in the sky," albeit as a river of water vapor rather than of liquid. This general concept has come into regular use in the western United States and in some other regions affected by ARs, partly due to its use by media, and due to the intuitive nature of the concept. However, over the last 20 years there have been varying perspectives on the term in the technical community. These perspectives range roughly from considering it duplicative of preexisting concepts, such as the warm conveyor belt (WCB), to arguments that the analogy to terrestrial rivers is inappropriate, to being a primary topic of focused research, applications, and usage by water managers.

Despite this debate, or possibly because of it, requests for the creation of a formal definition were submitted to the *Glossary of Meteorology* (*GoM*). After decades of debate regarding the term "atmospheric river," it was an opportune time to develop a formal definition for the *GoM*. The purpose of this short report is to describe a development process with deep roots in community-wide feedback resulting in the newly minted definition as it now appears in the *GoM*. Because of the national and international interests in ARs, the typical review process for *GoM* terms was modified to include broader interests and greater expertise than is typically found in the Scientific and Technological Activities Commission (STAC) committee experts. The chief editor has the capability to form unique review teams and other methods determined on an individual term basis. It is this process that we describe that was unique for the AR term development.

The process originated from two key events in 2015: the *GoM* received requests to include a definition of AR, and a workshop (briefly summarized by Dettinger et al. 2015) brought together experts on ARs, WCBs, and tropical moisture exports (TMEs) to openly discuss the relationships between these concepts. The workshop was held in June 2015 at the Scripps Institution of Oceanography and was organized by the recently created Center for Western Weather and Water Extremes. Three scientific leaders, one for each subject (Heini Wernli on WCB, Harold Sodemann on TME, and Jason Cordeira on AR), were asked to provide their independent perspectives on the relationship. Roughly 25 people participated in the workshop, which included three seminar presentations by these topic leaders, as well as other presentations and in-depth discussions. The three topic leaders each took a different approach to address the problem, and yet each came to roughly the same conclusion. They found that the AR, WCB, and TME concepts are interrelated, but distinct from one another in important ways. For example, ARs can form and exist without a TME or a WCB, but in other cases a TME can feed tropical moisture into an AR and a WCB can be the downwind terminus of an AR through rainout. The initial request for the AR term was submitted to the *GoM* as a result of this first workshop.

Partly spurred on by the interest in a *GoM* definition and by the success of the AR workshop in 2015, a panel discussion was held on the definition of the term at the First International Atmospheric Rivers Conference (IARC) in August 2016 (Ralph et al. 2017). The IARC brought together more than 100 interested individuals from across the globe for

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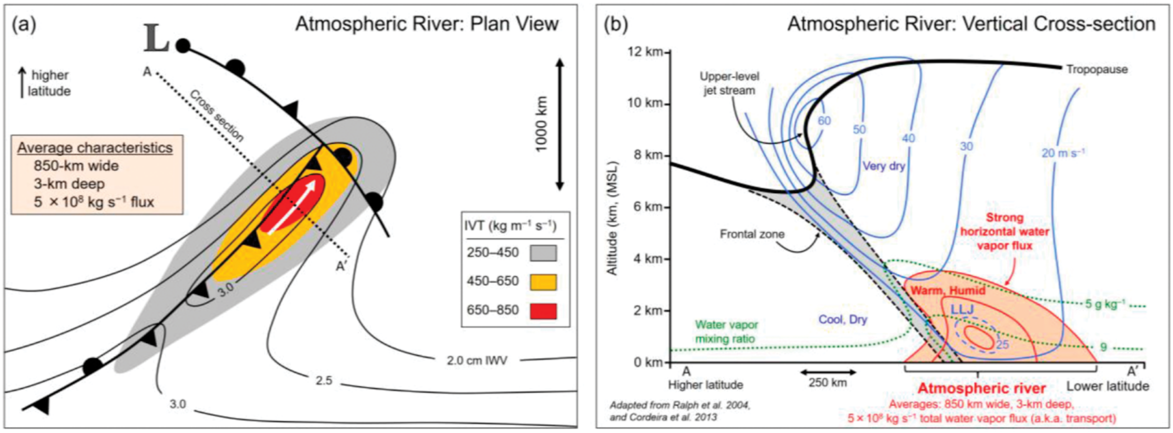
DOI:10.1175/BAMS-D-17-0157.1



Schematic summary of the structure and strength of an atmospheric river based on dropsonde measurements deployed from research aircraft across many atmospheric rivers and on corresponding reanalyses that provide the plan-view context. Magnitudes of variables represent an average midlatitude atmospheric river. Average width is based on atmospheric river boundaries defined by vertically integrated water vapor transport (IVT; from surface to 300 hPa) lateral boundary threshold of 250 kg m^{-1} s^{-1}. Depth corresponds to the altitude below which 75% of IVT occurs. The total water vapor transport (a.k.a. flux) corresponds to the transport along an atmospheric river, bounded laterally by the positions of IVT = 250 kg m^{-1} s^{-1} and vertically by the surface and 300 hPa. (a) Plan view including parent low pressure system and associated cold, warm, and warm-occluded surface fronts. IVT is shown by color fill (magnitude; kg m^{-1} s^{-1}) and direction in the core (white arrow). Vertically integrated water vapor (IWV; cm) is contoured. A representative length scale is shown. The position of the cross section shown in (b) is denoted by the dashed line A–A′. (b) Vertical cross-section perspective, including the core of the water vapor transport in the atmospheric river (orange contours and color fill) and the pre-cold-frontal low-level jet (LLJ), in the context of the jet–front system and tropopause. Water vapor mixing ratio (green dotted lines; g kg^{-1}) and cross-section-normal isotachs (blue contours; m s^{-1}) are shown. [Figure reproduced from Ralph et al. (2017b). Schematic prepared by F. M. Ralph, J. M. Cordeira, and P. J. Neiman and adapted from Ralph et al. (2004), Cordeira et al. (2013), and others.]

four days to discuss AR dynamics, observations, impacts, climate change implications, and applications. The international organizing committee provided the AR definition panel with a draft definition and a question about whether to retain the connection to extratropical cyclone–related dynamics, which had dominated the subject, or to broaden it to include tropical and other conditions. The panelists presented diverse perspectives, and there was robust discussion (Ralph et al. 2017).

Shortly after IARC, the chief editor of *GoM* worked with AR experts to adopt a strategy to develop the definition that included opportunities for meteorological and hydrological community engagement. The strategy included the chairs of the AMS Mesoscale (Thomas Galarneau), Hydrology (John Eylander), and Water Resources (Mike Dettinger) STAC committees and was led by F. Martin Ralph. This committee used input from the 2016 IARC, the AR workshop in 2015, and individual perspectives to create a draft AR definition.

To provide opportunities for community engagement, the committee then organized two town hall meetings at prominent conferences to present the draft definition and solicit feedback and input. The first of these town hall meetings was at the AGU Fall Meeting in San Francisco in December 2016, and the second was at the AMS Annual Meeting in Seattle in January 2017. Each town hall included several panelists who offered their comments on the draft definition, and allowed roughly half the time for questions and open discussion. The panelists (including at IARC) were M. Anderson, L. Bosart, J. Cordeira, M. Dettinger, R. Leung, G. Magnusdottir, A. Ramos, L. Schick, R. Schumacher, D. Waliser, and R. Webb. From 70 to 100 people attended each town hall, and open discussion took place. One outcome of these town halls was the clear preference to retain the extratropical dynamics connection in the definition. Other recommendations were to keep the definition as short as possible and to leave specifications of how the boundaries of an AR are to be quantified open for future and specialized developments.

The committee then refined the definition and added schematic summaries, including plan-view and vertical cross-sectional perspectives based on previously published research and on a combination of airborne dropsonde observations of ARs and reanalyses to provide synoptic-scale context. The final version of this, agreed upon by the four committee members (representing atmospheric science and hydrology), informed by roughly a dozen panelists, and considering input from more than 250 attendees of IARC and the town hall meetings, has now been included in the *GoM*.

THE DEFINITION AS IT APPEARS IN THE *GLOSSARY OF METEOROLOGY*

Atmospheric river–A long, narrow, and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone. The water vapor in atmospheric rivers is supplied by tropical and/or extratropical moisture sources. Atmospheric rivers frequently lead to heavy precipitation where they are forced upward—for example, by mountains or by ascent in the warm conveyor belt. Horizontal water vapor transport in the midlatitudes occurs primarily in atmospheric rivers and is focused in the lower troposphere. Atmospheric rivers are the largest "rivers" of fresh water on Earth, transporting on average more than double the flow of the Amazon River.

While the process in the development of the *GoM* AR definition lasted more than a year and a half, the *GoM* review allowed for flexibility in order to provide the best term definition. The process was unique, as most *GoM* term reviews are not nearly as extensive as what was undertaken in this case. The *GoM* process will continue to follow the normal review procedures using the STAC committees while retaining the flexibility for special review in the future.

FOR FURTHER READING

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