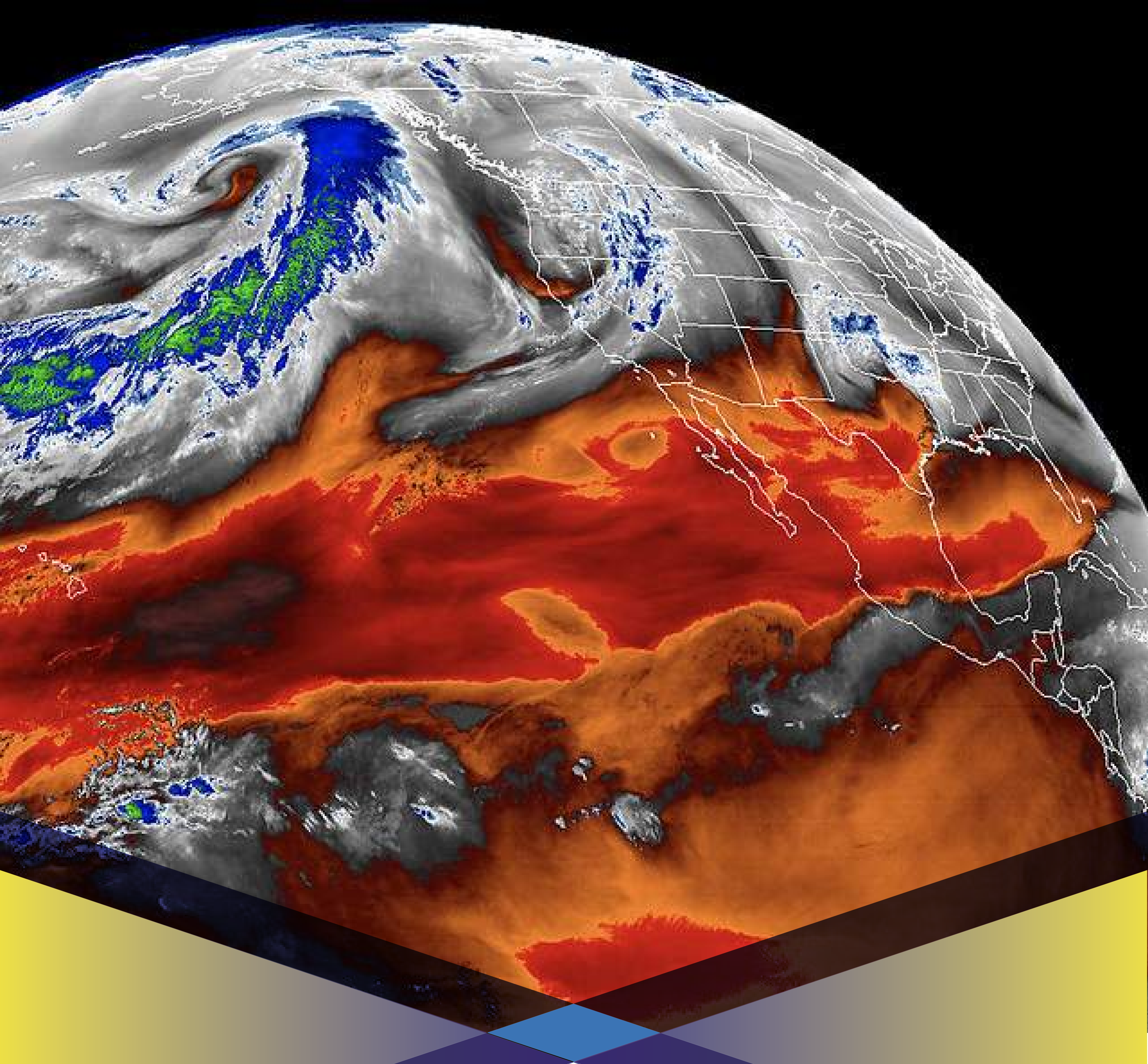

ATMOSPHERIC RIVERS AND BOMB CYCLONES

STUART BROWNING

BRIEFING NOTE 475

JANUARY 23, 2023

After three consecutive years of La Niña, the term "Atmospheric River" has become all-too-common in Australian vernacular, and is now regularly used to describe weather conditions responsible for widespread and frequent flooding.

The term was initially coined in the early 1990's by Zhu and Newell (1994) to describe long (about 2000 km), narrow (about 300–500 km wide) bands of enhanced water vapour flux, transporting volumes comparable to those of the world's largest rivers.

Atmospheric Rivers are a key mechanism for poleward water vapour transport (Gimeno et al 2014), and there are typically five or six on the globe at any one time. In the Australian region, atmospheric rivers are most often found to the south of the continent ahead of cold fronts in the mid-latitude storm tracks (Figure 1; Lora et al 2020), but they also form in the tropics off the northwest and northeast coasts of Australia. The most distinct are those associated with northwest cloud bands, which can stretch over 3000 km and transport moisture from the tropical Indian Ocean into Victoria (Figure 2).

IMPACTS OF ATMOSPHERIC RIVERS IN AUSTRALIA

Atmospheric Rivers can bring beneficial drought-busting rain to Australia's interior—Figure 3a shows that a large portion of heavy rainfall days in the Murray Darling Basin can be attributed to Atmospheric Rivers. However, they are also responsible for some of the most severe flood events including the March 2021 floods (Figure 3b; Reid et al 2022), and during winter can decimate alpine snowpacks with warm rain (McGowan et al 2021). Risk Frontier's Briefing Note 472 illustrates the confluence of Atmospheric Rivers from the Indian Ocean and Tasman Sea which drove the October 2022 flooding in Victoria.

The frequency of Atmospheric River events is closely linked to regional sea surface temperatures and the tropical climate drivers of the El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD). When SST around Australia are warmer than usual (during IOD negative and La Niña) Atmospheric Rivers tend to be more frequent and are able to transport more water vapour. Figure 2 illustrates the warm SST anomalies in the tropical Indian Ocean during 2016 which are typical of IOD negative and were associated with multiple Atmospheric River events (McGowan et al 2021).

As La Niña's influence wanes into late summer, and our seasonal forecast promises a welcome return to neutral ENSO for autumn, we will likely see a decrease in Atmospheric River activity impacting Australia. But on the other side of the Pacific, where it is currently winter, recent Atmospheric Rivers have been a blessing and a curse for California.

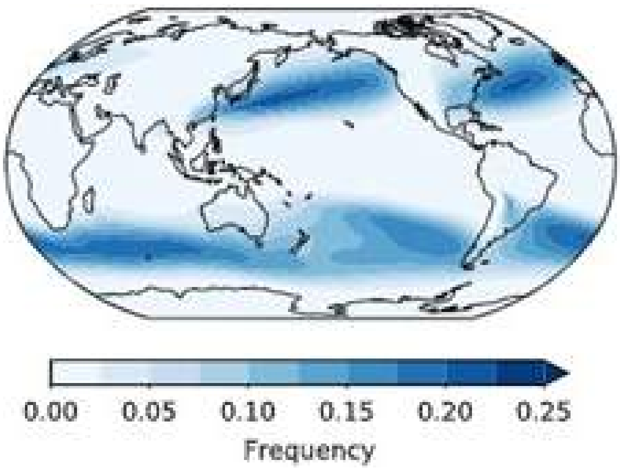

Figure 1. Global atmospheric river frequency (fraction of time with an atmospheric river present). Darker areas indicate regions where atmospheric rivers are more common. A value of 0.1 indicates atmospheric rivers are present 10% of the time. Source: Lora et al. 2020

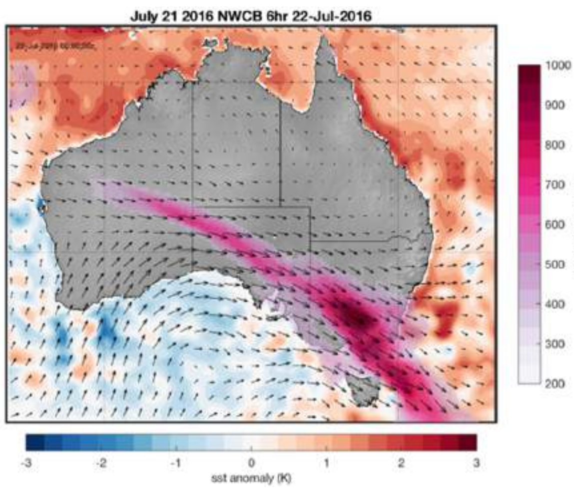

Figure 2 Australia's longest Atmospheric Rivers can stretch >3000km from the Indian Ocean into Victoria. This example from July 2016 brought heavy rainfall to the Southern Alps (McGowan et al 2016). The Atmospheric River is represented by integrated water vapour transport in in Kg/m/s. Sea surface temperature anomalies highlight the warm ocean conditions at the origin of the Atmospheric River.

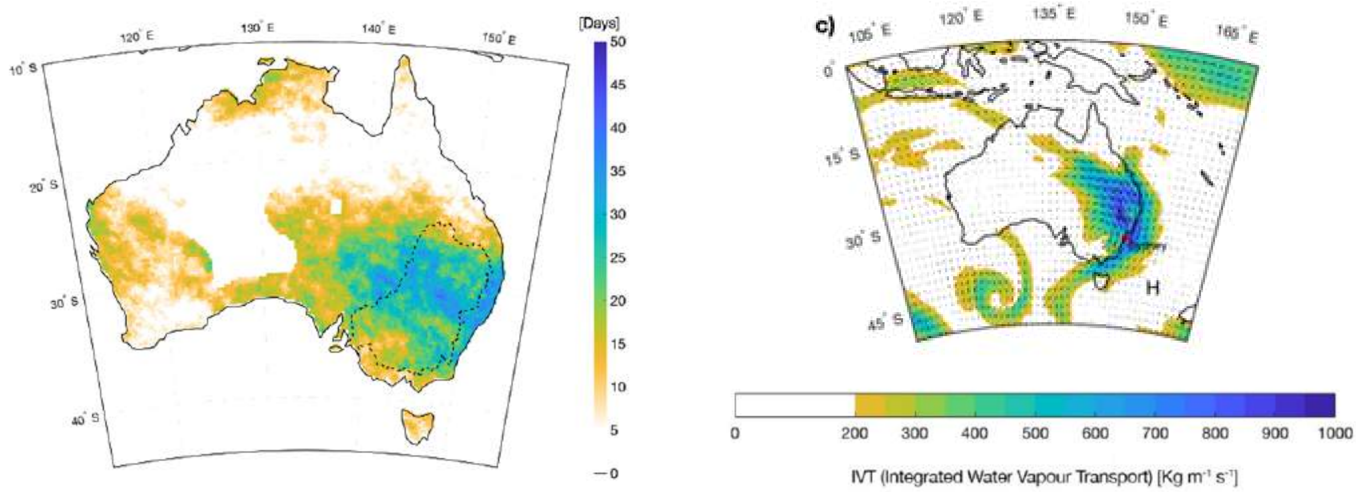

Figure 3. Left: Number of the top 100 rainfall days (ranked by amount) at each grid box that occurred during an atmospheric river during 1980-2019. Dashed outline indicates the boundary of the Murray-Darling Basin. Right: Atmospheric water vapour transport (Kg/m/s) between 0-9km high, transported from the tropics to eastern Australia, that led to the March 2021 floods. Areas of blue indicate regions of very high water vapour transport. Source: Reid (2022).

CURRENT ATMOSPHERIC RIVERS AND BOMB CYCLONES IMPACTING CALIFORNIA

Since New Year's eve, California has been subjected to intense winds and rainfall that have been caused by atmospheric rivers and "bomb cyclones" (Cassidy, 2023).

Just four days after heavy rain fell in California, the state was drenched with another atmospheric river on January 4 and 5, 2023. A plume of moisture from the tropical Pacific interacted with a low-pressure system that rapidly strengthened over the northeast Pacific, producing a storm that caused flooding, toppled trees, and downed power lines.

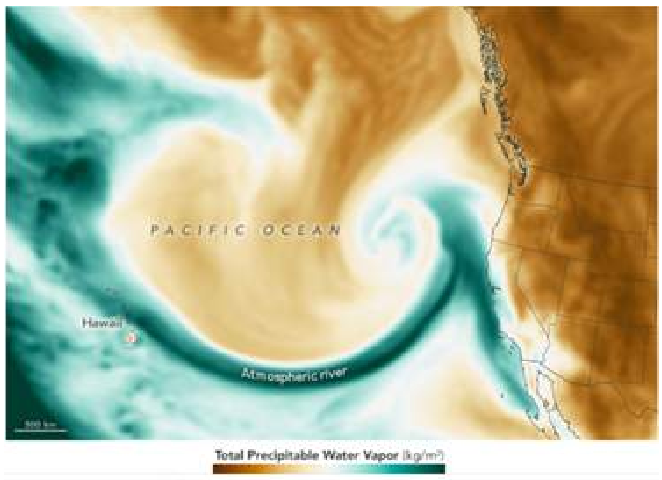

Figure 4 Total precipitable water vapour in the atmosphere at 5:30 a.m. Pacific Standard Time on January 4, 2023, derived from NASA's Goddard Earth Observing System, GEOS ADAS. Source: Cassidy, 2023

Coastal areas of California were subjected to wind speeds of 40 to 80 miles per hour, and exceeded 100 miles per hour near Lake Tahoe. Figure 4 shows the total precipitable water vapour in the atmosphere at 5:30 a.m. Pacific Standard Time on January 4, 2023. Precipitable water vapour is the amount of water in a column of the atmosphere if all of the water vapour were condensed into liquid. Dark green areas on the map indicate a narrow band of moisture flowing from the tropical Pacific toward the West Coast, making this atmospheric river an example of a "Pineapple Express" that can be seen over the north Pacific Ocean in Figure 1.

As Californians cleaned up from this latest storm system, the National Weather Service's Weather Prediction Center expected more atmospheric rivers to reach the state on January 7 and 9, 2023.

The image shown in Figure 5 was acquired on January 4, 2023, at 1:20 p.m. PST by the Visible Infrared Imaging Radiometer Suite (VIIRS) on the NOAA-20 satellite. It shows the storm as it was intensifying, which contributed to the high wind speeds.

When air pressure in a mid-latitude cyclone rapidly drops and winds intensify, these storms can undergo a process meteorologists call bombogenesis. Storms with central pressures that fall an average of least 1 millibar per hour for 24 hours are called "bomb cyclones" (Zhu and Newell, 1994).

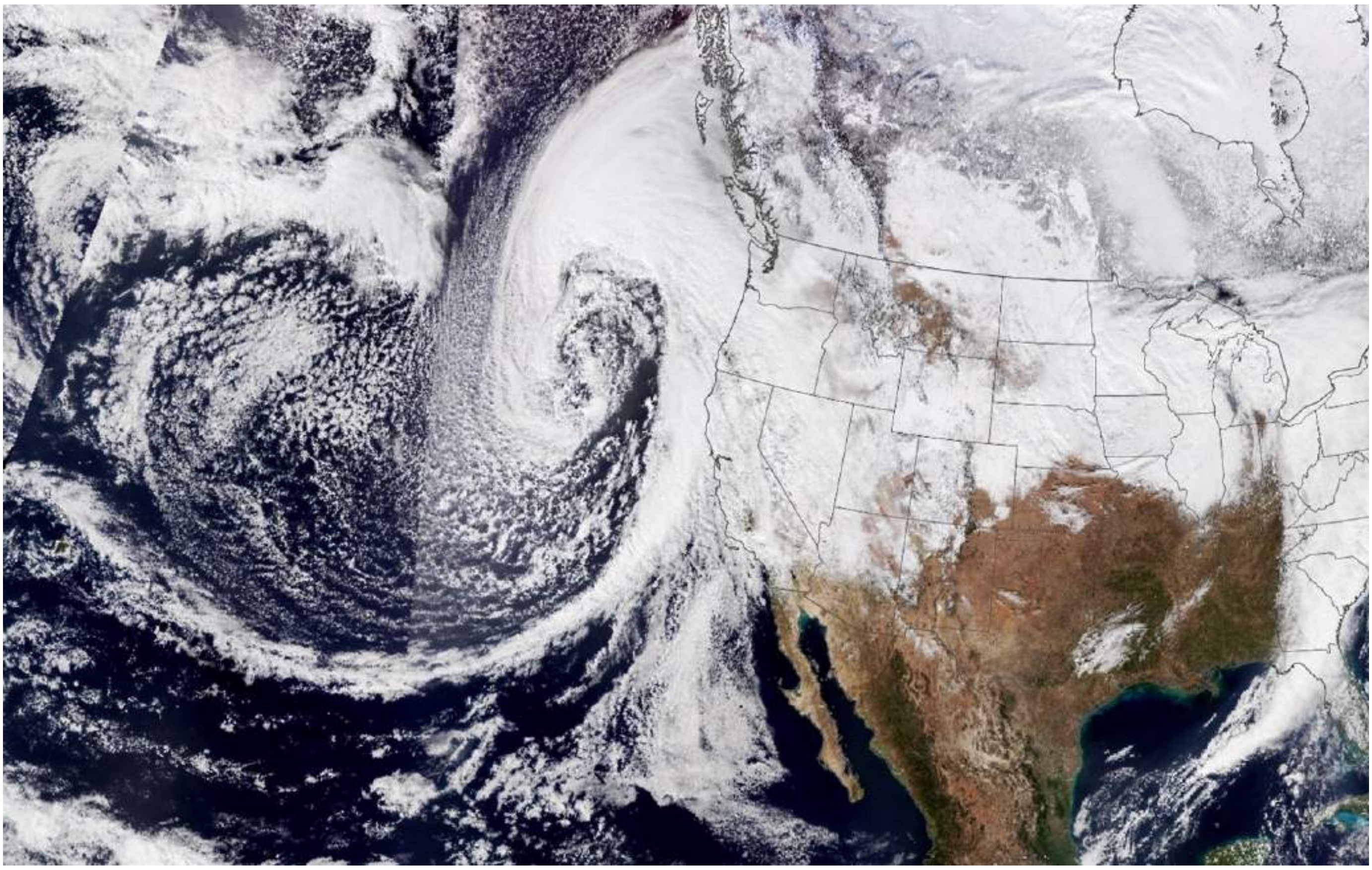

Figure 5 Himawari-8 satellite image of an Atmospheric River ahead of a cold front in June 2021. Source: NASA Earth Observatory images by Lauren Dauphin, using GEOS-5 data from the Global Modeling and Assimilation Office at NASA GSFC and VIIRS data from NASA EOSDIS LANCE, GIBS/Worldview, and the Joint Polar Satellite System (JPSS).

Atmospheric rivers occur regularly in the northern wintertime, and they account for up to 50 percent of all rain and snow that falls in the western United States. The current events are providing welcome relief from the State's persistent drought. Snowpack depths across California are the deepest on record (since 1976) and more than double the long-term average (California Department of Water Resources 2023), providing a bumper ski season for resorts, such as in the Lake Tahoe area, but also creating dangerous avalanche conditions. Atmospheric Rivers are among the most damaging storm types in the middle latitudes, especially in the hazardous winds that they produce. According to the Washington Post on January 10th, the rapid succession of events this winter has left much of the state in disarray, with thousands evacuated, power outages, collapsed roadways, mud and landslides, treacherous floodwaters and at least 17 deaths.

It is expected that under a warming climate the frequency of Atmospheric Rivers will increase, and they will be transporting more moisture, leading to greater impacts (Reid et al 2022). However, the NOAA seasonal forecast from October 2022 provided no warning of the impending Atmospheric River onslaught, instead they predicted a worsening of drought conditions—clearly the large scale drivers of these events are still not well understood.

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Stuart is Risk Frontiers' Climate Risk Scientist, with extensive experience studying the weather and climate in Australian and the Asia-Pacific region. His focus is to understand the large-scale climatic drivers of extreme weather events to better quantify risk over seasonal to multi-decadal timescales, using reanalysis data, model simulations, and paleoclimate records.