Atmospheric Rivers: An overlooked threat to the Australian snowpack in a warming World

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Abstract

The Australian seasonal snowpack can be classified as a marginal maritime snowpack with a temperature near 0 °C throughout the snow season. Subtle changes in atmosphere – snow energetics therefore result in rapid change in snowpack properties, which occur against a background of a warming climate. This has been attributed to a 40% decline in spring snow depths in the past 40 yrs. and geologic records suggest the seasonal snowpack is now near a 2000 yr. minimum. Modelled future snow cover predicts further decline by 57 % to 78 % of current maximum snow depth by the 2040s. Such research primarily attributes this decline in snow cover to global warming. However, the past decline in Australian snow cover can also be attributed to change in synoptic wintertime precipitation patterns that have resulted in a dramatic increase in proportional winter and spring precipitation of tropical origin since the 1950s. Tropical moisture is predominantly transported into southeast Australia during negative phases of the Indian Ocean Dipole (IOD) by northwest cloud bands – visible expressions of atmospheric rivers coupling tropical moisture sources northwest of Australia to the Australian Alps. Here we present a case study of one such event that occurred from the 21 to 23 July 2016 when 118 mm of rain-on-snow over a 12 hr period led to near complete ablation of the snowpack. While predictions of future variability of the IOD due to global warming remain uncertain, we suggest that warming atmospheric temperatures increase the risk of such extreme rain–on-snow events during negative IOD events. Combined with reduced snow cover in response to warmer ambient wintertime temperatures, such rain-on-snow events may further accelerate the reduction in seasonal snow cover in the Australian Alps, possibly on occasions after which the snowpack does not recover before spring. These conditions would present significant challenges to the Australian snow sports industry which is worth $2 billion annually and lead to change in snow dependent ecosystems and alpine hydrology.

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1. INTRODUCTION

Atmospheric Rivers transport large volumes of water vapour from areas of high sea-surface temperatures (STTs) like the tropics providing the potential for very significant rainfall events in the mid-latitudes. They have increasingly been a focus of research into extreme precipitation events, notably along the west coast of North America. While more than sixty scientific papers have been published on these phenomenon in the past 5 years, none have investigated their impact on Australian hydroclimate.

Australian Northwest Cloud Bands (NWCB) (Figure 1) are baroclinic systems that transport moisture along > 3,500 km path (Atmospheric River) from the tropical northeast Indian Ocean to southeast Australia. In winter these systems can trigger warm rain-on-snow events in the Australian Alps that cause flash flooding and disruption to snow sports – an industry worth $2 billion annually, and the Snowy Mountains Hydroelectric Scheme that supports 1/3 of renewable energy supply to the Eastern Australia electricity grid.

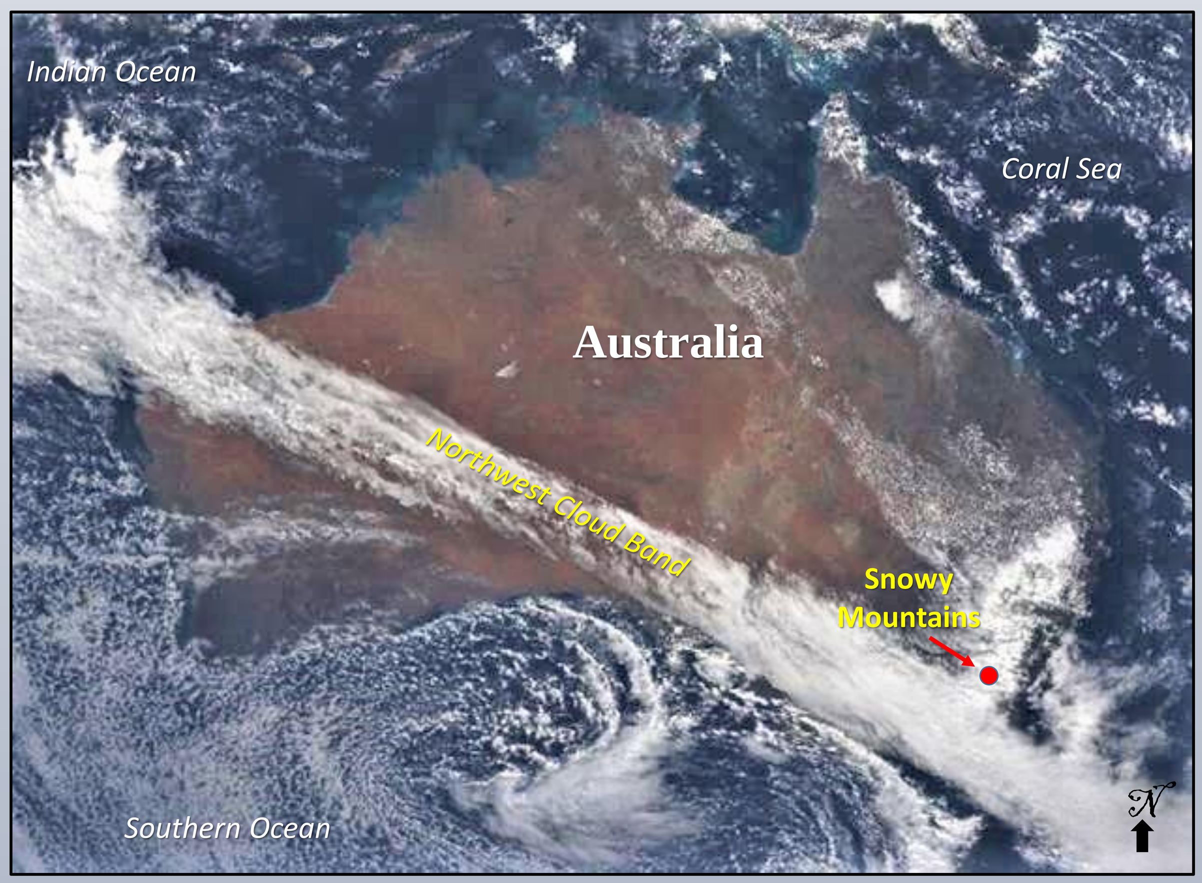


Figure 1. Northwest Cloud Band 1200 EST (0200 UTC) 22 July 2016 (*Himawari-8*).

2. BACKGROUND

An increased sea surface temperature (SST) gradient during winter (JJA) between the Indonesian Archipelago and central Indian Ocean favours development of NWCB as a result of strong trans-equatorial flow. This flow feeds warm moist air into the region northwest of Australia which if concurrent with a more equatorward path of the mid-latitudinal short-wave trough leads to the formation of a strong baroclinic zone along the northwest – southeast orientated convergence. North-westerly flow then develops along the leading edge of the convergence zone over Australia transporting a stream of warm moist air toward southeast Australia – forming an Atmospheric River (Figure 2).

Frequency minima of NWCBs occur in the austral winter with a median of 1 event during July (1984 - 2014) (Reid et al 2019). However, anomalously warm SSTs in the northeast Indian Ocean during negative phases of the Indian Ocean Dipole (IOD) cause more frequent winter NWCB with 27 days affected in the –IOD winter of 2014. Here we report on the 22 July 2016 (-IOD) NWCB event which caused rapid snow melt and flash flooding in the Snowy Mountains of the Australian Alps.

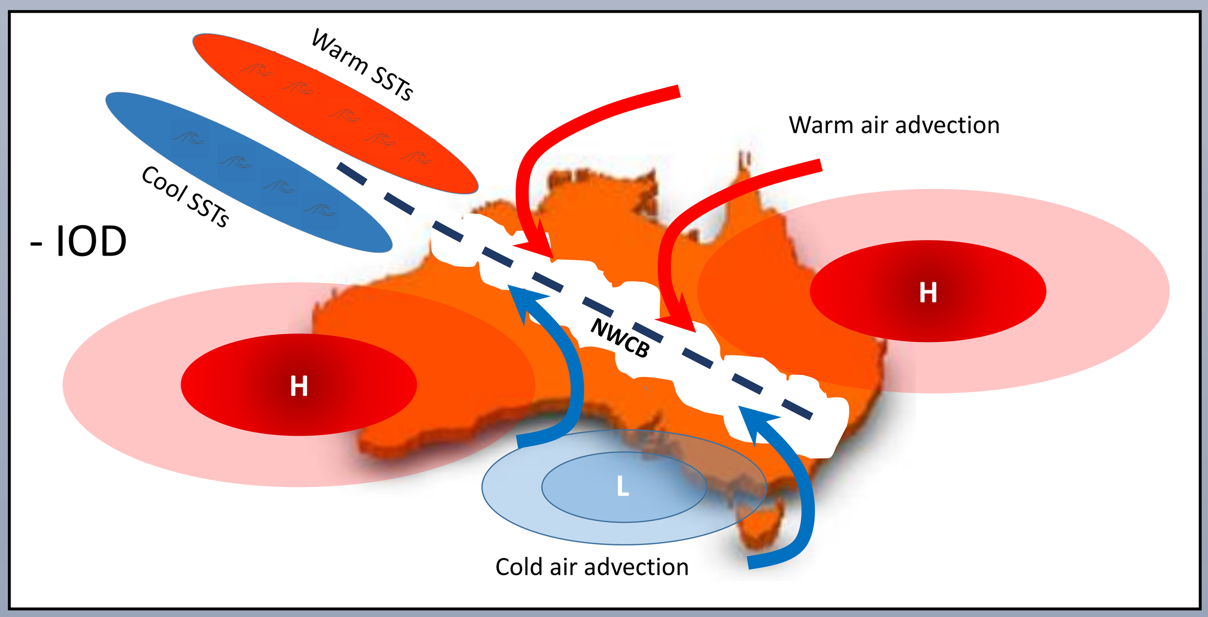


Figure 2. Conceptual model of Northwest Cloud band formation (modified after Reid et al 2019).

3. EVENT METEOROLOGY

Mean sea level analyses for the 22 July 2016 show a complex low pressure system south of Australia with two cold fronts and a trough over central Australia (Figure 3). This baroclinic system extended through to the 400 hPa level with flow at 700 hPa (~ 800 m above Snowy Mountains) transporting warm humid air from central Indonesia to the Australian Alps – a distance of ~5500 km (Figure 4). Approximately 130 mm of warm rainfall was recorded in the Snowy Mountains between 1PM 21 July to 6PM 22 July with mean maximum intensities of 20 mm/hr. Air temperature at 1850 m asl. peaked at 8 °C at midday on the 22 July before onset of the cold southerly post frontal flow (Figure 4).

4. IMPACT ON SNOWPACK AND HYDROLOGY

Rapid snow melt triggered by the warm rain-on-snow on the 22 July 2016 ablated most of the snowpack below 1900 m als. causing flash flooding. Discharge from the Snowy River increased from the winter base flow of 8 m^3s^{-1} to 300 m^3s^{-1} over the period of 5 hrs in response to warm rain-on-snow (Figure 5a,b), while extensive flooding of ski field facilities occurred with disruption to infrastructure services (Figure 6a,b).

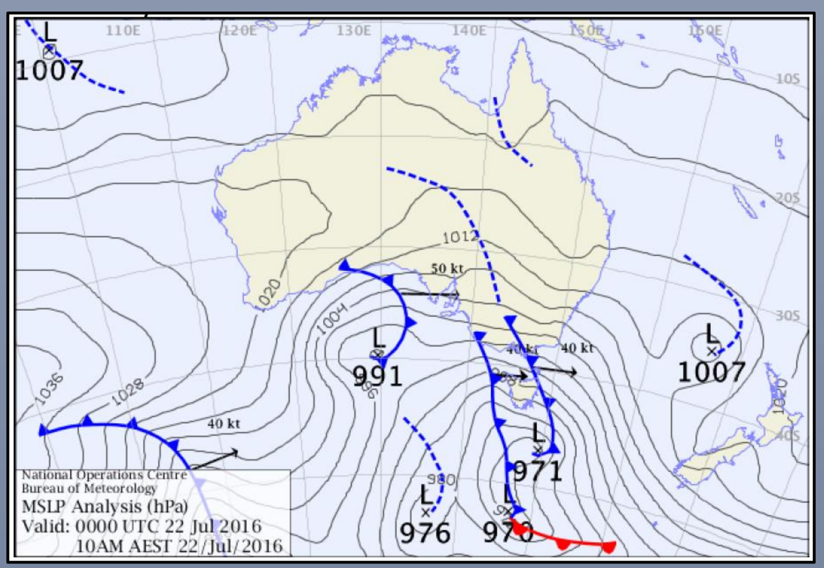


Figure 3. MSLP analysis 1000 EST 22 July 2019

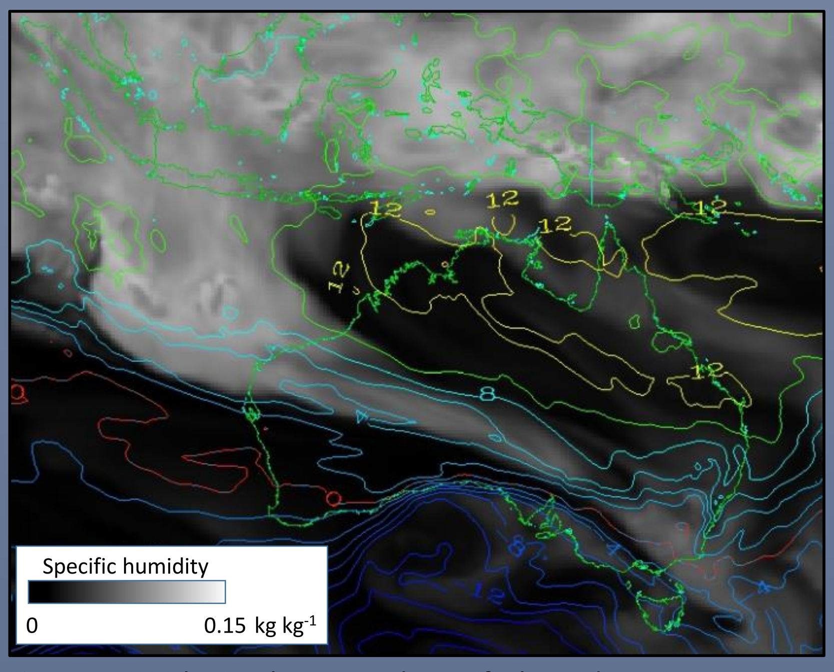
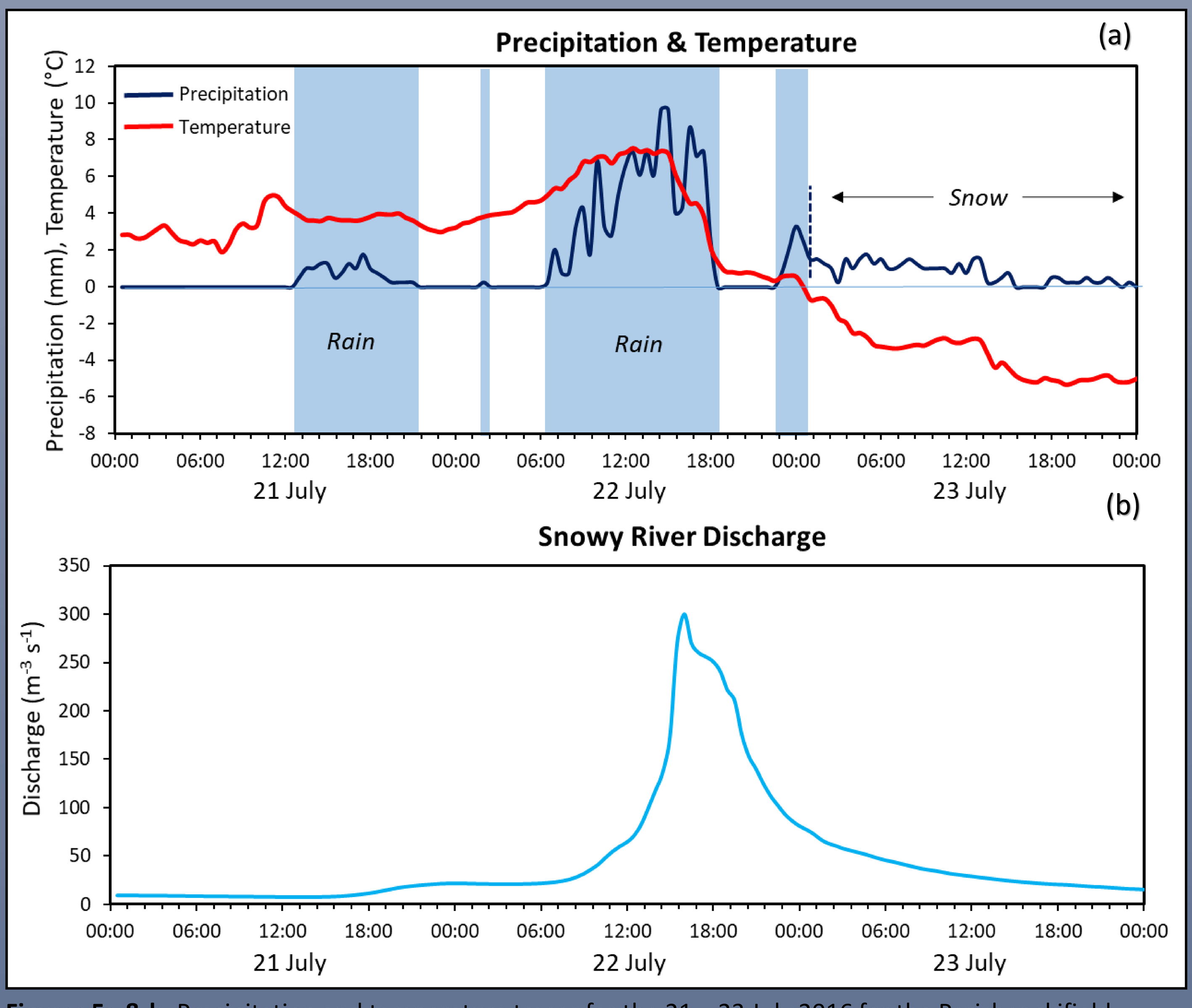


Figure 4. 700 ha isotherms and specific humidity 1200 EST (0200 UTC) 22 July 2019 (source ERA5).



Figures 5a & b. Precipitation and temperature traces for the 21 – 23 July 2016 for the Perisher skifield base ~1760 m asl., Snowy Mountains, showing peak warm rain-on-snow on the 22 July with the transition to snow and colder temperatures early on the 23 July (a). Discharge for the Snowy River above 1630 m asl. peaked late afternoon on 22 July at 300 m^{-3} s^{-1} (37 times pre event base flow).

Figures 6a & b. Flash flooding of skifield (Perisher) facilities 22 July 2016.

5. CONCLUSION

NWCBs are Atmospheric Rivers which transport moisture from the Indian Ocean to southeast Australia. Negative phases of the Indian Ocean Dipole (IOD) increase the frequency of NWCB which during winter cause warm rain-on-snow events such as the 22 July 2016. These result in rapid ablation of the seasonal snow pack, trigger flash flooding and widespread disruption to the winter snow sport industry. While the impact of global warming on the IOD remains uncertain (Hui and Zheng 2018), higher temperatures as a direct result of global warming will cause future NWCB rain-on-snow events to further accelerate the loss of the already highly marginal Australian winter snowpack.

References

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Reid, K.J., Simmonds, I., Vincent, C.L. and King, A.D 2019: The Australian Northwest Cloudband: Climatology, Mechanisms, and Association with Precipitation. *Journal of Climate,* 32, 6665-6684