Atmospheric River Formation and Behavior over the North Pacific Basin

Ashley E. Payne and Gudrun Magnusdottir
Department of Earth System Science, University of California Irvine, Irvine, CA, 92697-3100

Goal: What are the dynamical controls behind atmospheric rivers and how active are the tropics?

Atmospheric rivers

- Narrow plumes of moisture, stretch over thousands of kilometers in the lower troposphere
- Not simply trajectories of moisture → constantly evolving pathways of moisture, transporting and recycling
- Connected to extratropical cyclones and to WCBs, not tied to a single WCB (Sodemann and Stohl, 2013)
- Connected to heavy precipitation and flooding events globally
- Always present, globally occurring
- Variable behavior - not all have the same intensity, the same hydrological effects or even make landfall

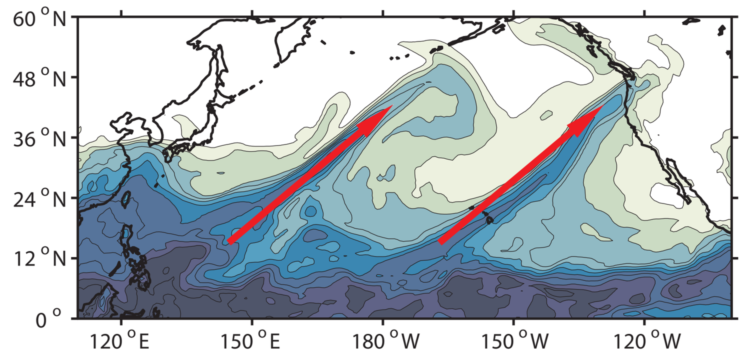


Figure 1: Instantaneous image of two atmospheric rivers that formed in late March of 2005 captured on the 26 March 2005 at 21:00. The atmospheric rivers are depicted in Total Precipitable Water (TPW) from the MERRA dataset, contoured in intervals of 0.5cm from 1cm to 6cm. Appear to connect the extratropics and the tropics in unbroken 'rivers', but are in reality constantly evolving pathways of moisture transport. Because they occur with such frequency and over synoptic timescales, large-scale analysis is difficult; a method employed to address this difficultly is shown in Figure 2.

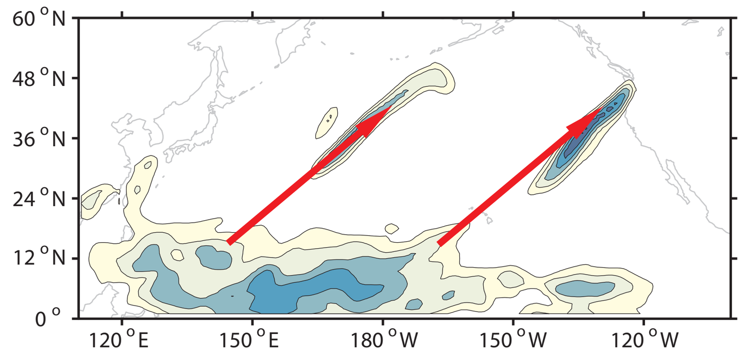


Figure 2: Instantaneous image of the same two atmospheric rivers that formed in late March of 2005 captured on the 26 March 2005 at 21:00 shown in Figure 1. The atmospheric rivers are this time depicted as the magnitude of integrated vapor transport (IVT), shown with a static threshold of 250 $kgm^{-1}s^{-1}$.

Data and Methodology

Modern Era Retrospective Reanalysis (MERRA) dataset

Multivariate MJO (RMM) index

Visualizing ARs:

- TPW (Figure 1) commonly used as a proxy due to limitations on lower level winds in observations
- Use dynamically consistent reanalysis dataset to calculate integrated vapor transport (IVT) within a Eulerian framework (AR: IVT ≥ 250 $kg{\cdot}m^{-1}s^{-1}$):

$$IVT_\lambda = g^{-1}\int_{1000}^{700} qu\, dp \qquad IVT_\phi = g^{-1}\int_{1000}^{700} qv\, dp$$

Case Selection

- Landfalling climatologies from Neiman et al. (2008) and Dettinger et al. (2011)
- 30 dates with highest IVT and more than 15 days separation retained
- Image analysis used to track the 30 chosen ARs over the course of their lifetime → formation, landfall, termination
- Strength of the 30 chosen ARs measured by the lifetime averaged IVT

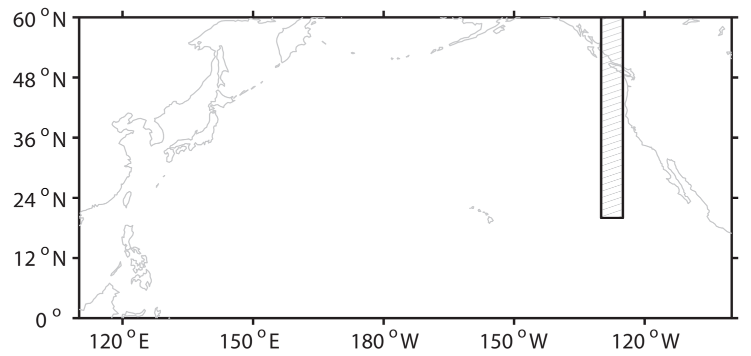
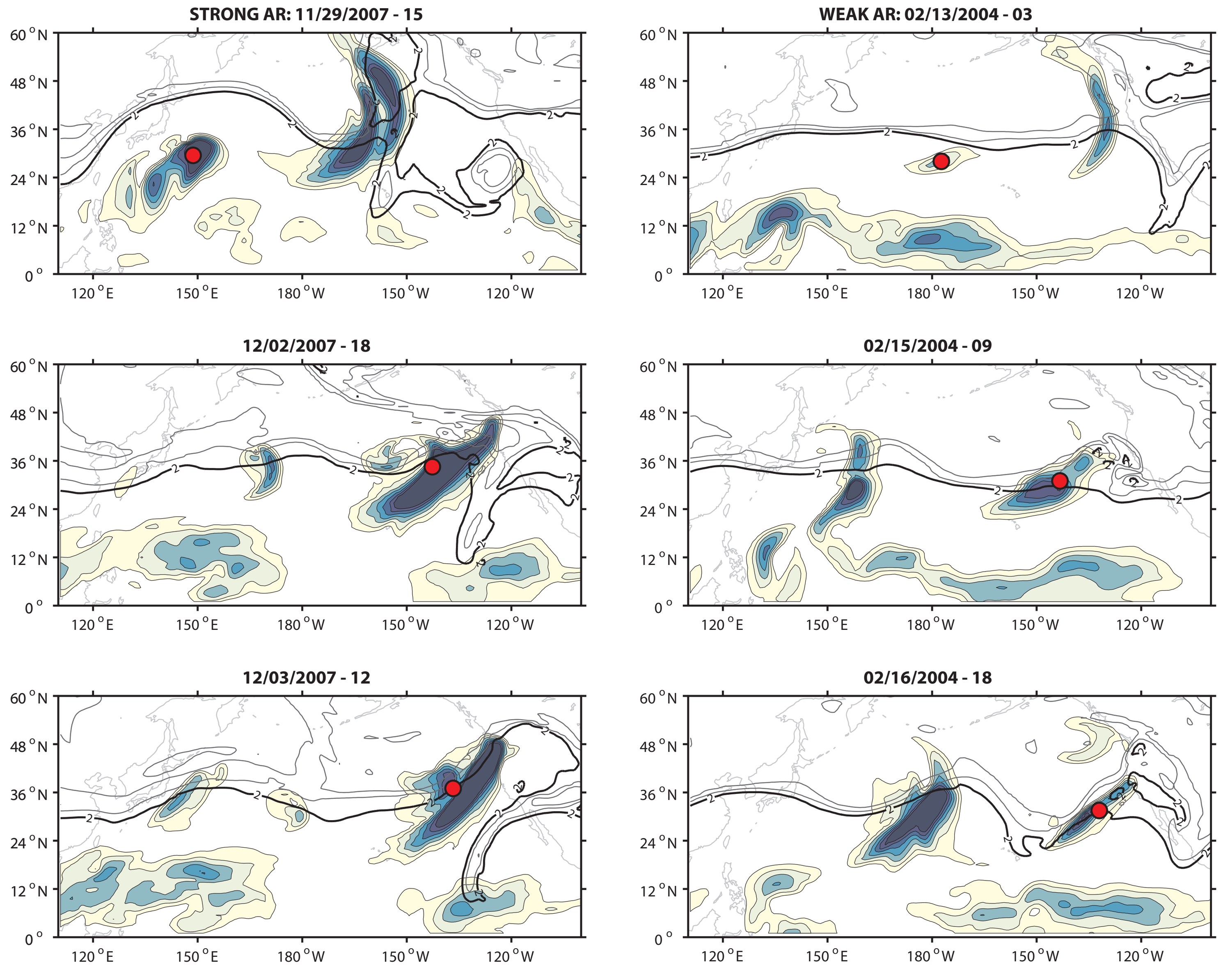


Figure 3: Map showing the study area. The highest 30 ARs were chosen based on the daily averaged IVT of each land-falling date, averaged over the hatched region in the eastern Pacific.

Relationship between RWB and ARs



Comparison between upper level PV (200hPa) and lower level IVT show a close relationship

The same general relationship was found for all 30 cases:

- Formation of AR in association with Rossby wave propagation or breaking
- Formation of anticyclonic (most often) RWB in the eastern Pacific
- Movement of the AR along the western edge of the bay
- Termination of AR prior to complete overturning of PV contours

Figure 4: Figures depict IVT calculated, shaded, and PV at 200hPa, contours starting at 2PVU in black and increasing in intervals of 2 in grey. The columns show the time evolution of two example cases to demonstrate the general relationship found for most of the cases between moisture transport low in the troposphere and Rossby waves at 200hPa. The left column shows the time evolution of a strong AR (mean IVT: 935 $kg{\cdot}m^{-1}s^{-1}$ and max IVT: 1276 $kg{\cdot}m^{-1}s^{-1}$), which made landfall on the 3rd of December 2007. The right column shows the time evolution of a relatively weak AR (mean IVT: 607.5 $kg{\cdot}m^{-1}s^{-1}$ and max IVT: 781.4 $kg{\cdot}m^{-1}s^{-1}$), which made landfall on the 15th of February 2004. In each panel, the AR of interest is marked by a filled red circle. For both cases, some perturbation of the PV field is apparent preceding the appearance of the AR, however, for the December 2007 event, deformation of the PV contours is associated with the appearance of the AR and the resulting bay in the east Pacific is much larger and more well developed than that in the February 2004 event.

Vertical comparison in PV

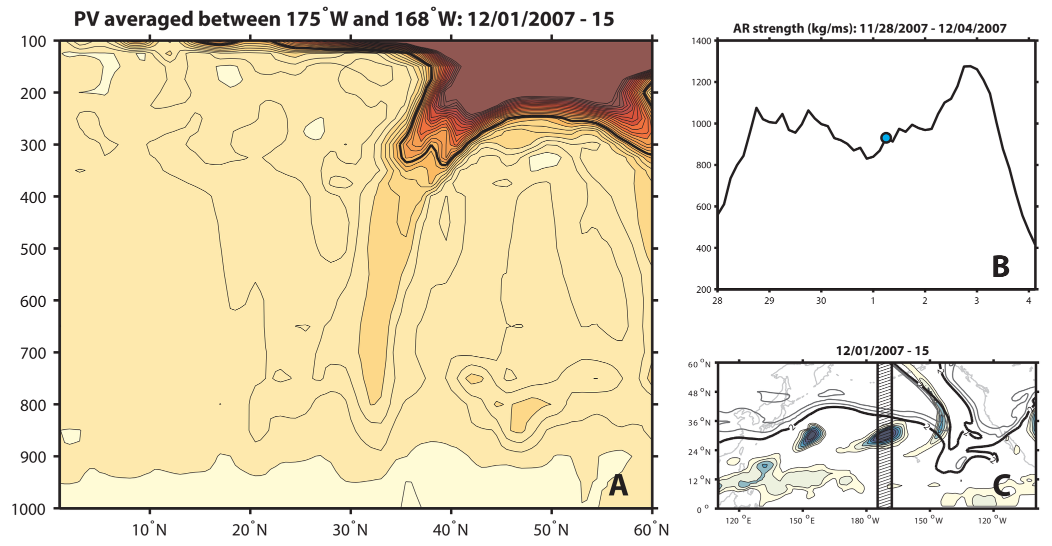


Figure 5: Analysis of the relationship between PV and AR intensity for the strong case shown in Figure 4 (left column). The latitudinal vertical profile of PV, averaged around the AR centroid shown by the highlighted region in Figure 5c, is shown in 5a and reveals high PV reaching deep into the troposphere from upper levels. Figure 5b shows the lifetime strength of the AR as calculated from the averaged IVT for each timestep of the AR's lifetime.

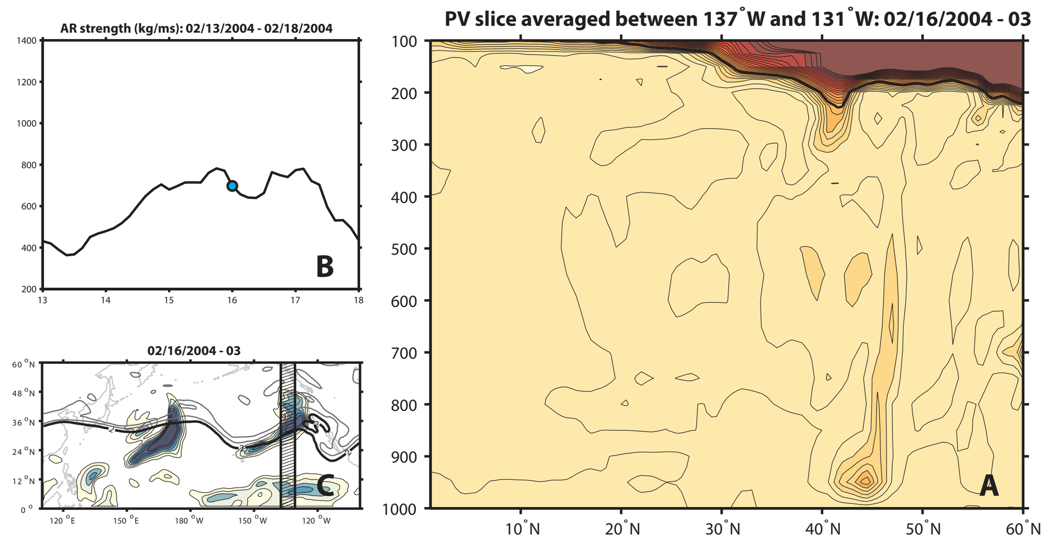


Figure 6: Analysis of the relationship between PV and AR intensity for the weak case shown in Figure 4 (right column). The latitudinal vertical profile of PV, averaged around the AR centroid shown by the highlighted region in Figure 6c, is shown in 6a and reveals little high PV penetration from the upper troposphere, but high PV also reaching from the surface upwards. Figure 6c shows the band averaged over, shown in 6a.

Role of the MJO on AR behavior

- Previous work has found statistical connections between precipitation patterns along the West Coast and the MJO
- Ralph et al. (2011): AR case study describing a mechanistic relationship between the ability of an AR to tap tropical moisture and the MJO
- There does not appear to be a clear connection to either phase or amplitude of the MJO and strength of the ARs
  - Inferred → tropical tap of AR increases its intensity through influence on moisture component of IVT calculation
  - Some other mechanism influences AR intensity
  - The interaction between upper and lower PV generation

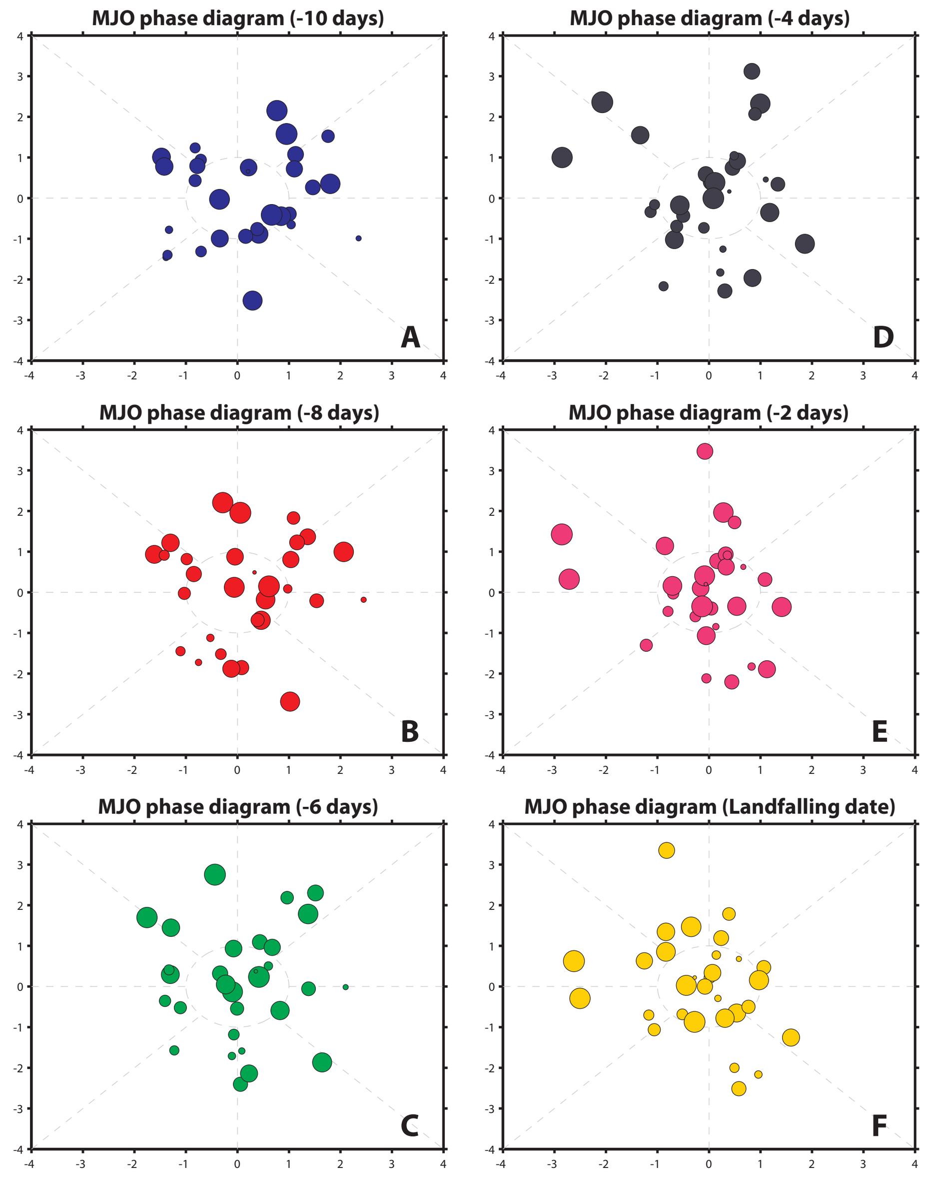


Figure 7: MJO phase diagrams illustrating the location and amplitude of the MJO 10 days prior to (a), 8 days prior to (b), 6 days prior to (c), 4 days prior to (d), and 2 days prior to (e) to the land-falling date (f) for all 30 of the atmospheric rivers investigated. The points on the phase diagrams are scaled according to the strength of the AR, the larger points indicate the most intense ARs in the dataset. The high amplitude points found in the five phase diagrams correspond to 7 different ARs (all with amplitudes above 2). These 7 ARs include three that are within strongest five ARs studied and two within the weakest five ARs studied.

Conclusions

- ARs, which form and move at lower levels in the troposphere, are dynamically linked to Rossby wave propagation and breaking at upper levels in the troposphere
- The majority of ARs studied formed in association with anticyclonic RWB
- RWB is generally present prior to the formation of ARs and may play a role in preconditioning the atmosphere for a series of land-falling ARs back to back (AR families)
- PV structures are present for both strong and weak ARs → two sources: (1) deep reaching PV from upper levels and (2) generation of high PV from the surface
- The ARs studied do not show any systematic correlation to the phase or amplitude of the MJO

Dettinger, M. D., F. M. Ralph, T. Das, P. J. Neiman, and D. R. Cayan (2011), Atmospheric rivers, floods and the water resources of California, Water, 3(2), 445–478.
Neiman, P. J., F. M. Ralph, G. A. Wick, J. D. Lundquist, and M. D. Dettinger (2008b), Meteorological characteristics and overland precipitation impacts of atmospheric rivers affecting the west coast of North America based on eight years of SSM/I satellite observations, Journal of Hydrometeorology, 9(1), 22–47.
Ralph, F.M., P.J. Neiman, G.N. Kiladis, K. Weickmann, and D.W. Reynolds (2011), A multi-scale observational case study of a Pacific atmospheric river exhibiting tropical-extratropical connections and a meso-scale frontal wave, Monthly Weather Review, 139, 1169 - 1189.
Sodemann, H., and A. Stohl (2013), Moisture origi n and meridional transport in atmospheric rivers and their association with multiple cyclones, Monthly Weather Review, in press.