Classification of atmospheric river events on the U.S. west coast using a trajectory model

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Introduction

- One of the challenging problems in understanding Atmospheric River (AR) events is in their apparent "randomness" and "variability". We characterize AR events into a small set of sensible types and obtaining common characteristics in terms of their water vapor origins and pathways to understanding these "random" events.
- We also investigate the role of upper level PV on AR events over the west coast of the U.S.

Data and Method

• **DATA:** Historical AR events (1997-2010) records, NASA Goddard trajectory model (*Schoeberl and Sparling* [1995], and later modified by *Wright et al.* [2011] and *Huang et al.* [2012]). Global Modeling Assimilation Office Modern Era Retrospective-analysis for Research and Applications (GMAO MERRA) [*Suarez et al.*, 2008; *Bosilovich et al.*, 2008, 2011; *Rienecker et al.*, 2011]. and observed Climate Prediction Center (CPC) hydrologic data [*Higgins et al.*, 2000].

• **Method:** *K-mean* clustering method in order to classify the trajectories. To remove the dry trajectories, we only select back-trajectories with specific humidity (q) larger than 1 g kg^{-1} along the trajectory at the target region and time.

Results

❑ Types of trajectories during AR events

1) Illustrative examples

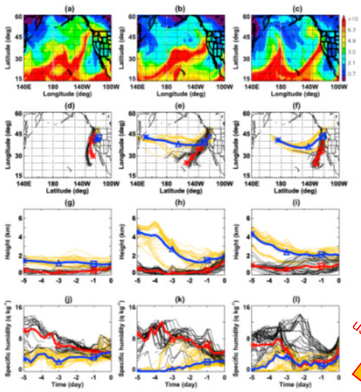
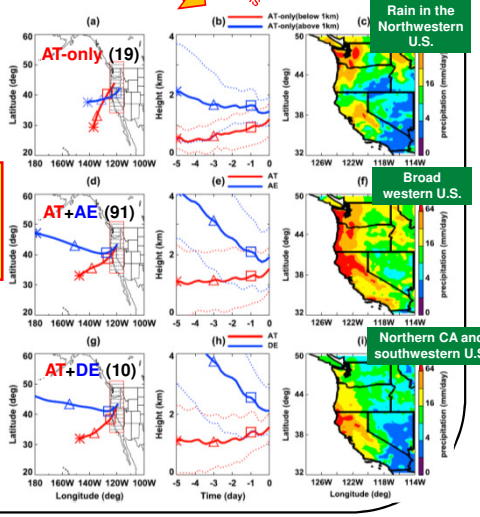


Figure 1. (top rows) *MERRA specific humidity (q) averaged from the surface up to 700 hPa, the* ***(second and third rows)*** *spatial and temporal evolution of 5-day backward trajectories, and* ***(bottom row)*** *q values (> 1 g kg^{-1}) along the trajectories obtained from the nearest location to MERRA q at each grid point for (a, d, g, j) January 19, 2005; (b, e, h, k) January 14, 1998; and (c, f, i, l) February 16, 2004.*

- We designate the first type as Ascending near landfall and of Tropical Origin (**AT**), the second type as Ascending near landfall and of Extratropical Origin (**AE**), and the third type as Descending or parallel near landfall and of Extratropical Origin (**DE**).

Classification using K-mean analysis

2) Classification



The majority of AR events (about 86%, 120 out of 140 AR events) over the west coast of the U.S. are associated with three trajectory types.

*•**Figure 2. (Left)** composite-mean horizontal maps, **(middle)** vertical evolutions of 5-day back trajectories on 290 K using MERRA reanalysis dataset, and **(right)** a map of daily precipitation intensity (unit in mm day^{-1}), for (a, b) AT-only, (d, e) AT+AE, and (g, h) AT+DE events.*

❑ Precipitation and AR Trajectories

There are different contributions of each trajectory type to precipitation.:

- **AT-only, AT + AE**: associated with high precipitation
- **AT + DE**: AT are strongly associated with high precipitation than DE
- Heavier precipitation are more associated with **AT+AE and AT+DE,** emphasizing the extratropical cyclone plays an important role in generating ARs.

- The descending or parallel trajectories (DE) are not typically associated with heavy precipitation, However, given that AT trajectories from AT+DE brings intense precipitation, DE trajectories appear to support in enhancing the updraft from the tropical lower altitude, and resulting in precipitation by AT trajectories.

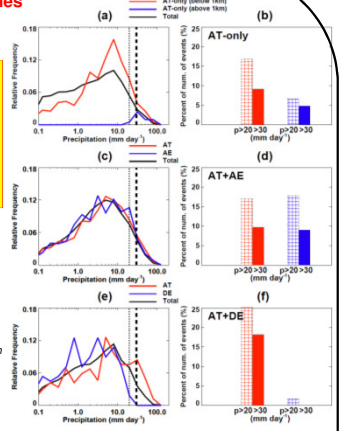
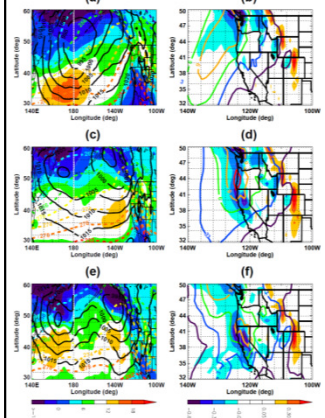


Figure 3. (a, c, e) *PDFs of precipitation corresponding to the mean trajectories, and* ***(b, d, f)*** *percentages of number of events when precipitation is larger than 20 (gridded fill), and 30 (solid fill) mm day^{-1} for AT-only (red), AE (blue), and DE (blue) trajectories. The red (blue) lines represent the PDF of precipitation for mean of AT (AT (above 1km for AT-only), AE, DE) trajectories.*

❑ Characteristics of meteorological fields



- For all events, the minimum surface pressure (less than 990 hPa) from the northern Pacific basin penetrates further southward. .

AT-only: **a single low pressure center,** strong vertical motion over the northwestern coast of the U.S.
AT+AE, AT+DE: **double low pressure centers**, making a strong trough-ridge structure, strong updraft overthe west coast of the U.S.

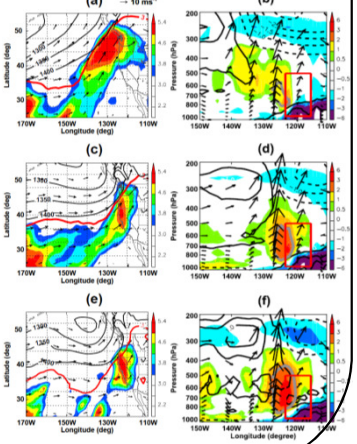
Figure 4*. Composite-mean* ***(a, c, e)*** *surface pressure (black solid line), zonal velocity (shading), overlaid by temperature (dashed line), and* ***(b, d, f)*** *Composite-mean vertical velocity (ω, Pa s^{-1}, shading, negative value means upward motion) overlaid by meridional velocity (contour), averaged over 700–1000 hPa for (top) AT-only, (middle) AT+AE, and (bottom) AT+DE events.*

- A plume of large tropospheric q and southwesterly flow (averaged over 850-700 hPa, left), RH (averaged over 1000-200 hPa, not shown) to the west coast of the U.S. are associated with the directions and locations of the upper level PV (ahead of PV).

- **The mid-level diabatic heating maximum promotes negative upper level PV anomalies** during cyclogenesis (Wernli and Davies, 1997).
- The location and intensity of **its influence varies with the size and shape of the cyclones** developed during ARs.

Figure 5. (left panels) *composite mean of 850 hPa horizontal wind (vectors), 850 hPa geopotential heights (black solid lines), and specific humidity (q) (g kg^{-1}) averaged over 850-700 hPa, PV of 3PVU (red line), and* ***(right panels)*** *composites of total diabatic heating anomalies (shading, [K day^{-1}]), and potential vorticity anomalies (PV, thick line [PVU], dashed line is negative) from the zonal mean, and wind vector (arrow [ms^{-1}]*10^{5}) at the target day for (a, b) AT-only, (c, d) AT+AE, and (e, f) AT+DE events.*

❑ Upper level PV and diabatic heating



❑ Rossby wave breakings (PV orientation)

Anticyclonic RWB types (79 events) are much more dominant types than the cyclonic RWB types (8 events) – 66% of AR events are associated with anticyclonic Rossby wave breakings

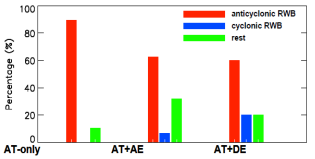


Figure 6. *The percentages of the PV orientation for each AR events*

- **AT-only**: 90% of AR events show a preference of anticyclonic RWB type orientation, but none of AT-only AR events has cyclonic RWB type orientation.
- **AT+AE and AT+DE**: preference of anticyclonic RWB type orientation with a slightly larger tendency toward cyclonic RWB and unclear type orientation.

❑ Vertically integrated water vapor fluxes

The vertically integrated water vapor fluxes are large for
•**AT-only**: in the **northwestern U.S.**
•(ranging from 42-50N).
•**AT+AE**: over the **broad region of the western U.S.**
•**AT+DE**: in the **southwestern U.S.** including California (ranging from 34-42N)

- These are all closely related to the direction of horizontal winds, and the shape of composite-mean upper level PV.

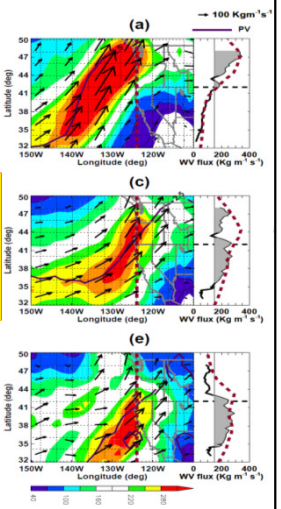


Figure 7. (a, c, e) (left) *The composite mean vertically integrated horizontal water vapor fluxes (color and arrows, unit in kg m^{-1} s^{-1}) overlaid by PV (2.5 PVU), and* ***(right)*** *the components orthogonal to the coastline for (top) AT-only, (middle) AT+AE, and (bottom) AT+DE events. Vector represents the magnitude of water vapor fluxes (unit in kg m^{-1} s^{-1}).*

Summary and Conclusions

- The majority of AR events (86%) in the western U.S. are related to one of the three trajectory types.
- The magnitude and the spatial distribution of precipitation of a given AR event are found to be strongly determined by the type of trajectories. For example,
  - i) AR events composed of both AT and AE trajectories (AT+AE) have more frequent precipitation over a broad region of the western U.S.
  - ii) AR events composed of both AT and DE trajectories (AT+DE) have intense precipitation over the southwestern U.S. due to AT trajectories.
  - iii) AR events of AT-only trajectories (AT-only) have intense precipitation, especially over the northwestern U.S., but are less frequent compared to those of AT + AE trajectories.
- Trajectory types are closely linked to diabatic heating and upper-level PV anomalies.
- About 70% of AR events are associated with anticyclonic Rossby wave breaking events.

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