The Relationship between Atmospheric Rivers and the MJO

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Abstract

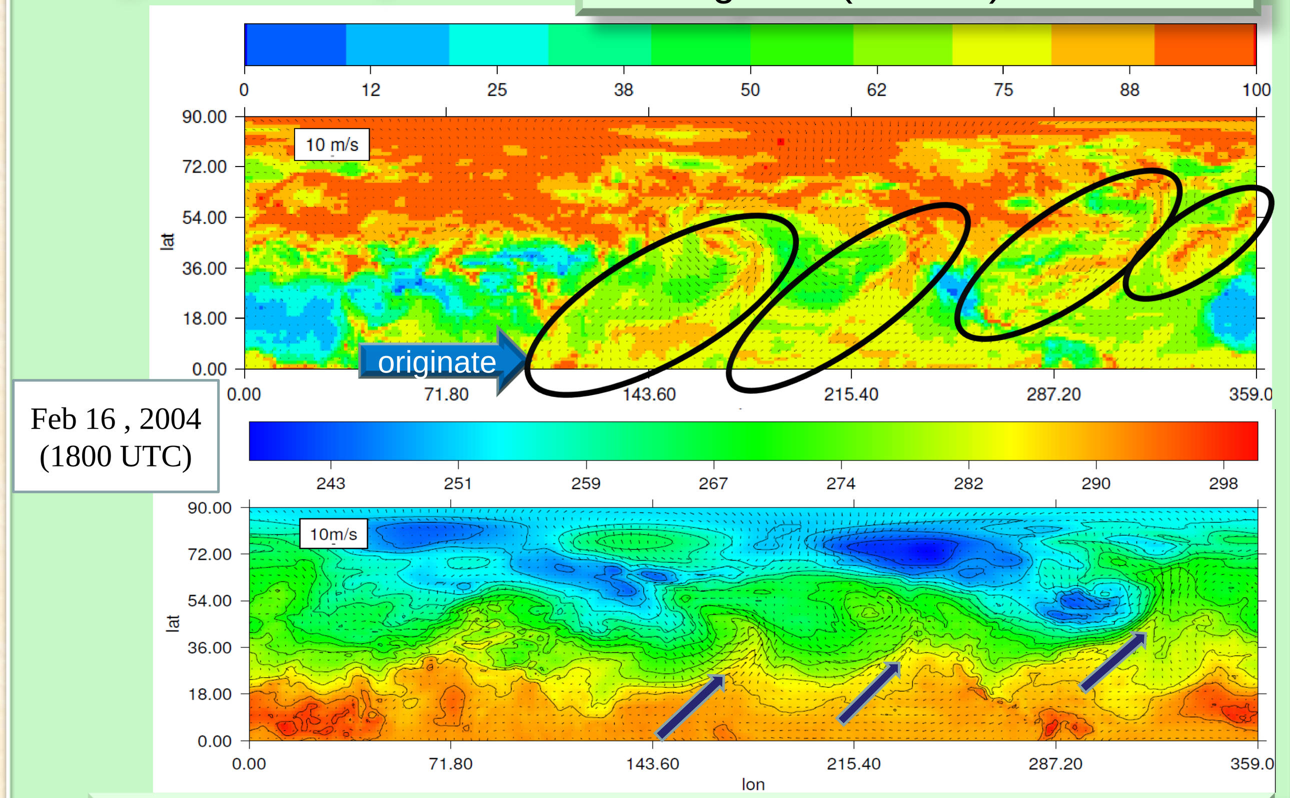
The goal of this study is to better understand the dynamics of atmospheric rivers (ARs) impinging on the west coast of North America. ARs have important roles in both local weather and global climate. The NCEP reanalysis data sets were used to diagnose several cases of ARs in recent decades. Diagnostic analyses indicate that strong meridional transport of moisture from tropical region to the mid-latitudes occurs through AR events causing remarkable precipitation. ARs are high frequency transient eddies with time-scales of around 5 days which lead to significant cores of eddy kinetic energy (EKE) in the downstream of storm track. Analyzing tropical low frequency phenomena and their feedback to the mid-latitudes gives us further insight into the mechanism of ARs. A strong correlation exists between west coast ARs and the phase of the Madden-Julian Oscillation (MJO). In particular, these atmospheric rivers tend to occur when the active phase of the MJO is in the central to western Pacific. From energetic and momentum perspectives, remarkable meridional moisture transport of ARs occurs in the regions where ageostrophic fluxes converge, and dissipates where eddy energy diverges. ARs amplifying downstream of storm tracks are associated with Rossby wave breaking.

Data and Methodology

In this study, 13 remarkable AR cases with heavy precipitation in cold seasons (October- March) were analyzed. Diagnostic and energetic analysis were based on National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis data-sets with spatial resolution of 2.5° x 2.5 ° and temporal resolution of 6 hours. Long-term averages are from 1948 to 2005. Extended momentum flux (E-vector) calculations at each pressure level (10-1000 mb) were based on the reanalysis Global Forecast System (GFS) data-set with a spatial resolution of 1°x1° and a temporal resolution of 6 hours. Filtering tools are Lanczos filters with a cut off of 5 and 10 days.

Diagnostic analysis

Mixing ratio (shaded) at 1000 mb

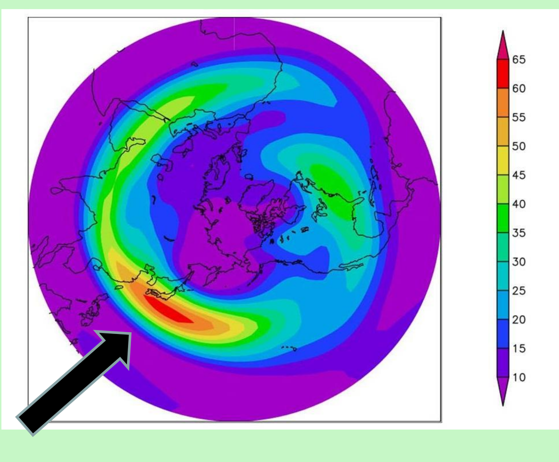


Temperature (shaded) and wind speed (vectors) at 850 mb

Pacific/ Atlantic ARs originate from tropical/ subtropical regions, accompanied with the position of jet streams.

ARs merge along the frontal zones in the warm advection sector of the mid-latitude cyclones.

ARs occur downstream of jet streams. On average, Pacific jet stream (compare with the position of Atlantic jet stream) elongates over lower latitudes corresponded to the subtropical jet.



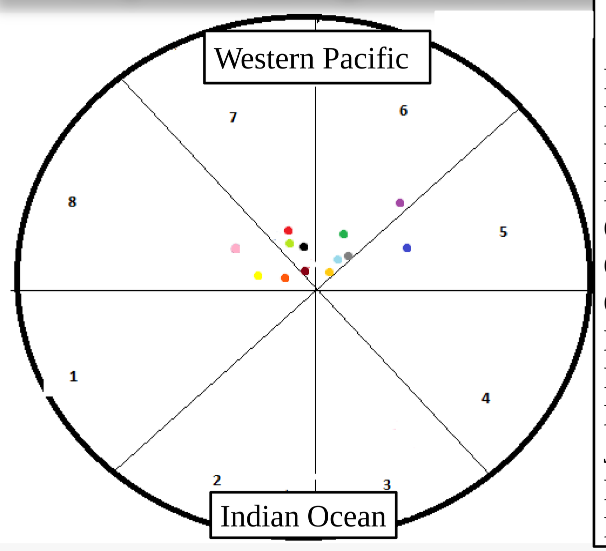
Long –term mean of wind speed at 300 mb for Feb 1998-2005

MJO

MJO is active in phases 6, 7 and 8 with low amplitude during remarkable Pacific AR events.

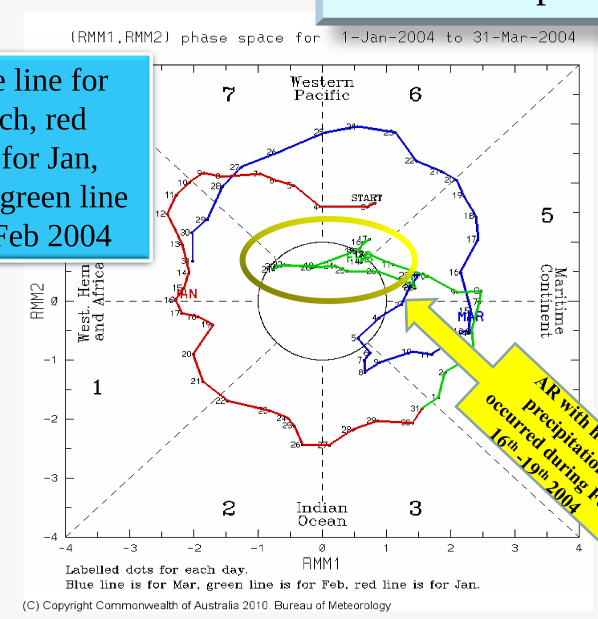
Strong correlation exists between ARs and the phase of the MJO.

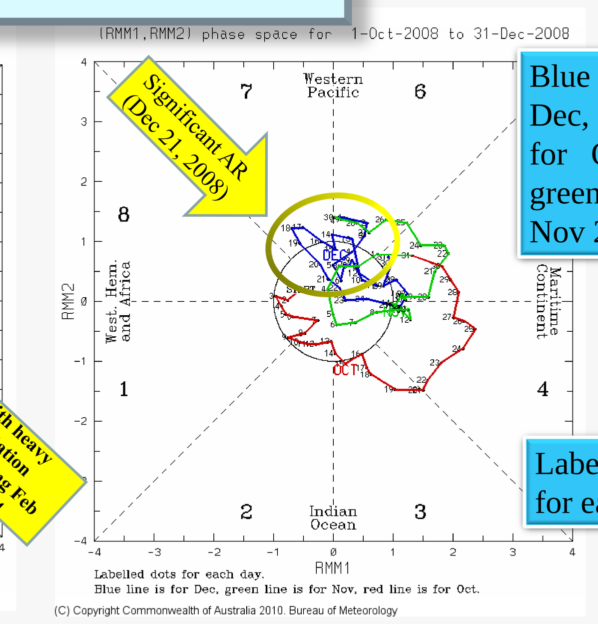
Active phase of the MJO and its amplitude during AR cases



AR cases with heavy precipitation
Feb 25, 2011
Feb 17, 2011
Dec 11, 2010
Dec 22, 2010
Oct 29, 2010
Oct 3, 2008
Oct 13, 2009
Dec 22, 2008
Feb 6, 2007
Dec 3, 2007
Jan 9, 2005
Feb 16, 2004
Feb 22, 2004

Active phase of the MJO





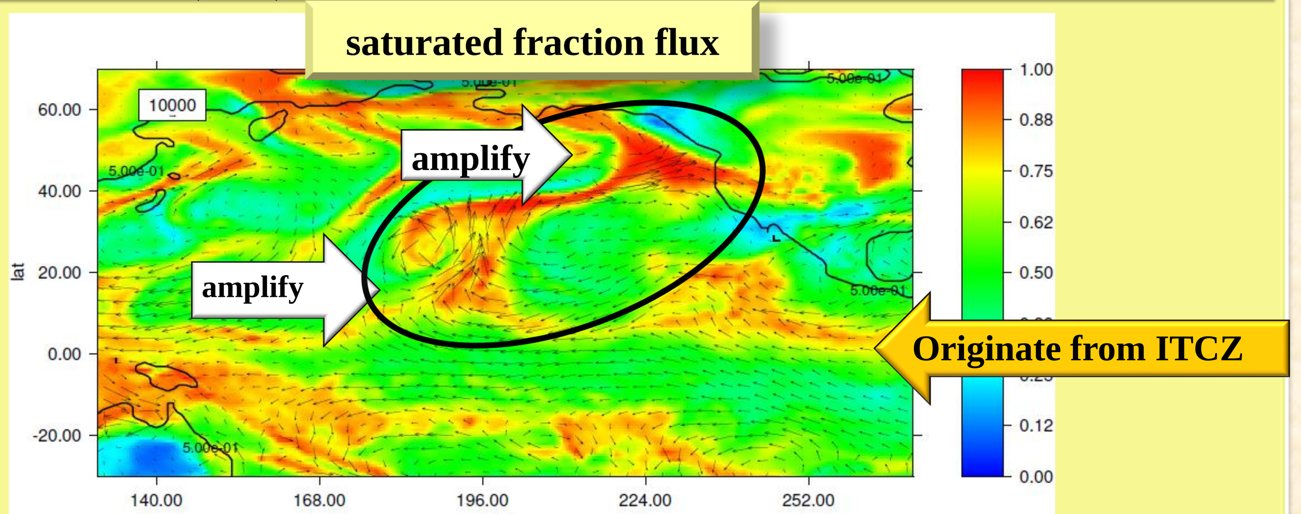
Energy perspective

The governing equation for the evolution of the eddy kinetic energy:

$$\frac{\partial K}{\partial t} = -\nabla\cdot(\mathbf{v}K) - \nabla\cdot(\mathbf{v}_a\phi') - \omega'\alpha' - \mathbf{v}'\cdot(\mathbf{v}_3'\cdot\nabla_3)\bar{\mathbf{v}} + \mathbf{v}'\cdot\overline{(\mathbf{v}_3'\cdot\nabla_3)\mathbf{v}'} - \frac{\partial}{\partial p}\omega K - \frac{\partial}{\partial p}\omega'\phi' + \text{Res.}$$

Convergence of total flux; Convergence of ageostrophic flux (CAF); Baroclinic conversion; Barotropic conversion

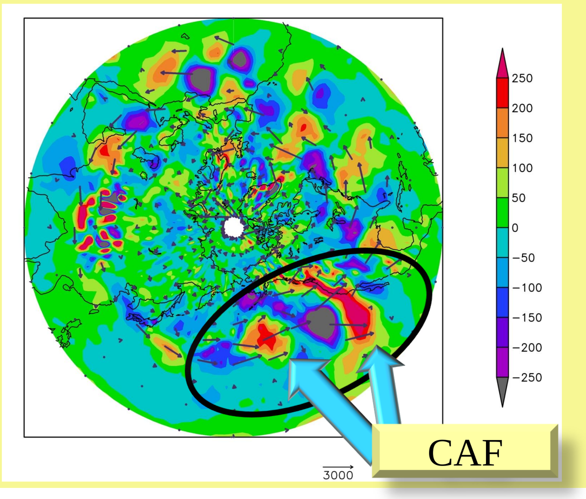
saturated fraction flux

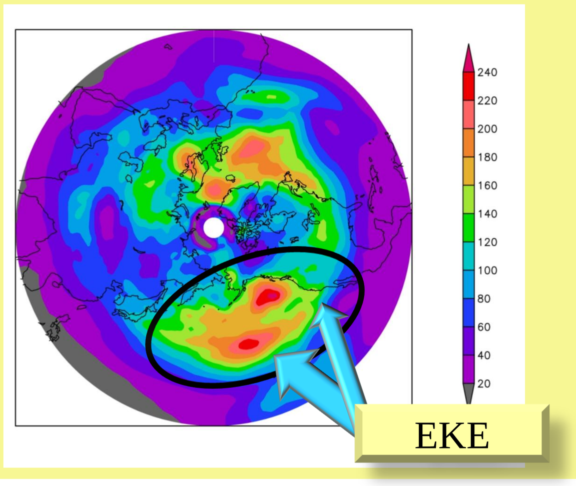


Saturated fraction (shaded) and saturated fraction flux (vector) for Dec 21, 2008 (12:00 UTC)

Strong meridional component of wind is a common feature of AR events which is responsible for transporting the large quantities of moisture from tropics to the mid-latitudes.

Although ARs originate from the Inter-tropical convergence zone (ITCZ), feeding and amplifying of ARs occur in the mid-latitudes. Amplifying of ARs is associated with significant cores of EKE downstream of storm track.





Vertical average for CAF and EKE from 100 to 1000 mb. (Time averaged during Dec 2008)

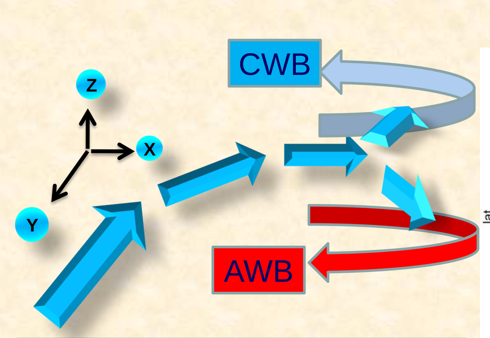
ARs propagate eastward along with the wave packets. In addition, strong divergence of eddy energy flux through wave packets radiates energy downstream of storm tracks.

Temporarily failing and recovering after a short period of time is another feature of ARs in the mid-latitudes. Remarkable moisture transport in ARs occur where ageostrophic flux converges, and dissipate where eddy energy diverges.

Significant cores of eddy kinetic energy due to cyclonic and anti-cyclonic wave breaking are accompanied with remarkable ARs over the central to eastern Pacific (downstream of Pacific storm track).

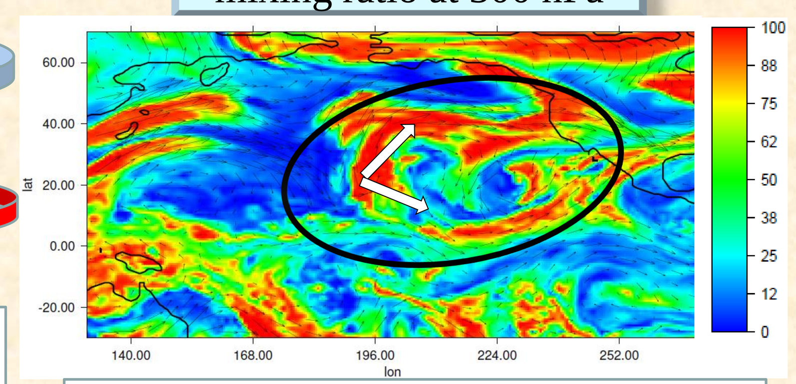
The number of Pacific and Atlantic ARs occurring simultaneously correspond to the number of wave packets downstream of storm tracks.

Momentum perspective



Schematic of E distribution for high frequency eddies.

mixing ratio at 300 hPa

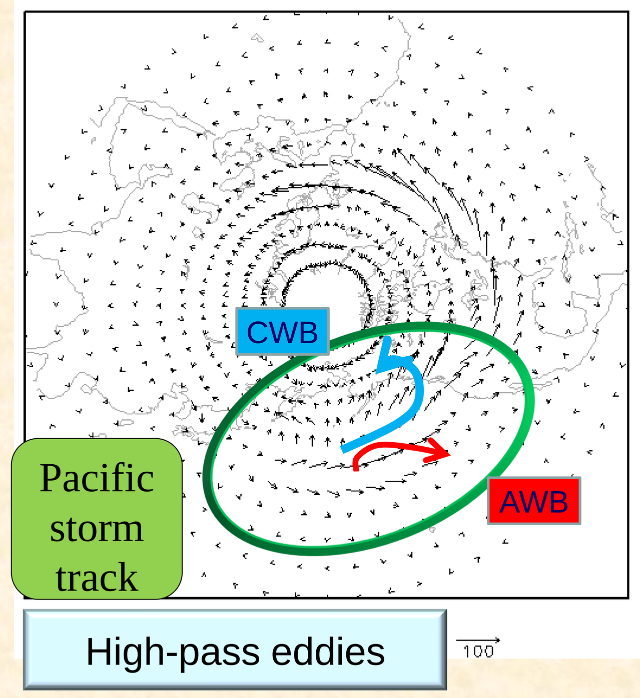


Horizontal mixing ratio (shaded) and wind speed (vector) at 300mb(Dec 21, 2008)

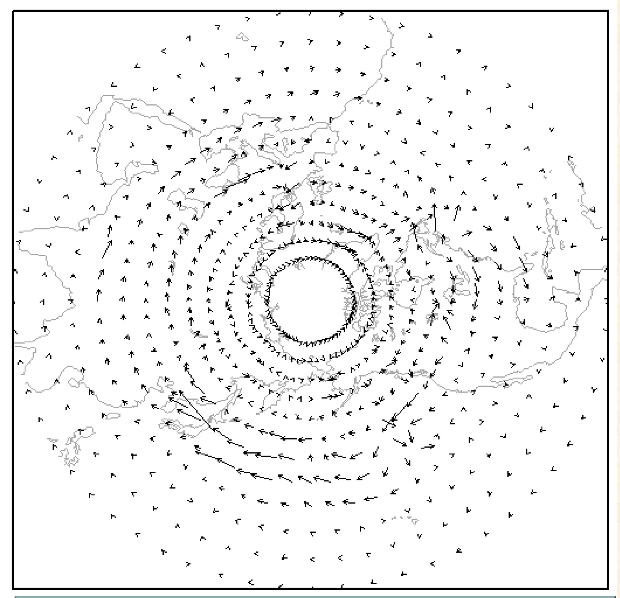
In most cases, significant moisture flux in the upper level is another feature of ARs which could be due to convective systems.

Although heavy precipitation corresponded to ARs over the coastal regions is less than a day, diagnostic analysis indicates that the time-scale for formation to dissipation of ARs is around 5 days. This feature is in agreement with high frequency eddy time-scale.

Time averaged E-vector for high frequency and low frequency transients eddies at 300 mb (December 2008).



High-pass eddies



Low-pass eddies

Meridional divergence and zonal convergence of E-vectors for high-pass transient eddies over the downstream of the Pacific storm track indicate the strong eastward propagation with SE-NW tilting of momentum flux for high frequency eddies (time-scale less than 5 days). All these features show that ARs are high frequency eddies.

Momentum analysis indicates amplifying of ARs over the downstream of Pacific storm track related to cyclonic (CWB) and anti-cyclonic (AWB) Rossby wave breaking at upper level troposphere.

Conclusion

- Strong correlation exists between ARs and the phase of the MJO. In most cases of ARs the MJO is active in phases 6, 7 and 8 with low amplitude.
- The MJO is active in other phases, when Pacific ARs dissipate before reaching west coasts. It seems that enhanced phase of the MJO supplies energy against dissipating of ARs.
- ARs propagate eastward along with the eddy wave packs.
- Remarkable meridional moisture transport of ARs occurs in the regions where ageostrophic fluxes converge, and dissipates where eddy energy diverges.
- Pacific (Atlantic) moisture flux in AR plumes originates from tropical (subtropical) regions due to the ITCZ, and propagates pole-ward downstream of jet streams.
- ARs amplifying downstream of the mid-latitude storm tracks are associated with Rossby wave breaking at the upper troposphere.
- ARs are high frequency transient eddies with time-scales of around 5 days which lead to significant cores of EKE in the downstream of storm track.

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