Mid-Latitude Dynamics and Atmospheric Rivers

Session: Theory, Structure, Processes 1
Wednesday, 10 August 2016

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2016 International Atmospheric Rivers Conference
8–11 August 2016
Scripps Institution of Oceanography

Objective and Outline

Objective

- What components of midlatitude circulation support formation and structure of atmospheric rivers?

Outline

- Part 1: ARs, midlatitude storm track, and cyclogenesis
- Part 2: ARs, tropical moisture exports, and warm conveyor belt

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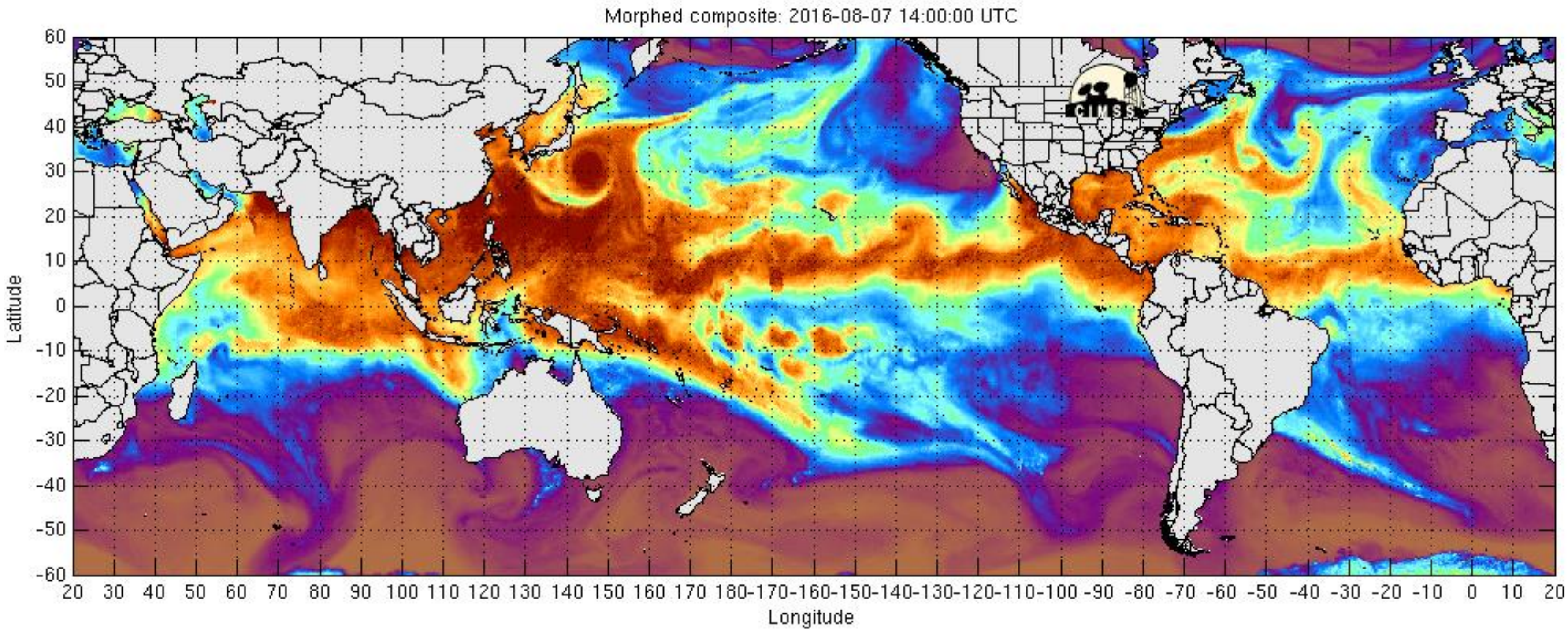
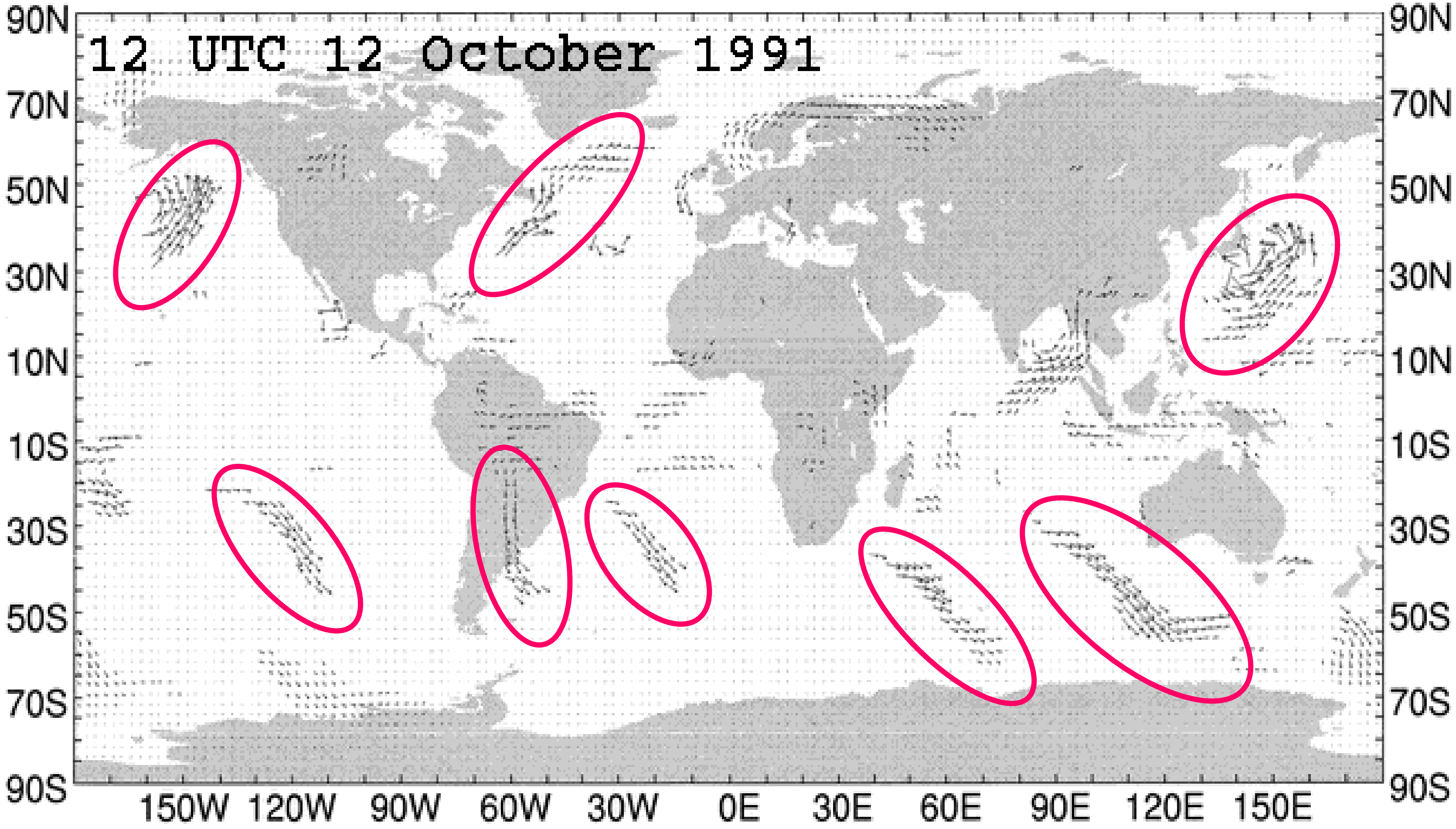
Mimic TPW (SSEC/Wisconsin)



- Global water vapor distribution is concentrated at lower latitudes owing to warmer temperatures
- Observations illustrate poleward extrusions of water vapor along “tropospheric rivers” or “atmospheric rivers”

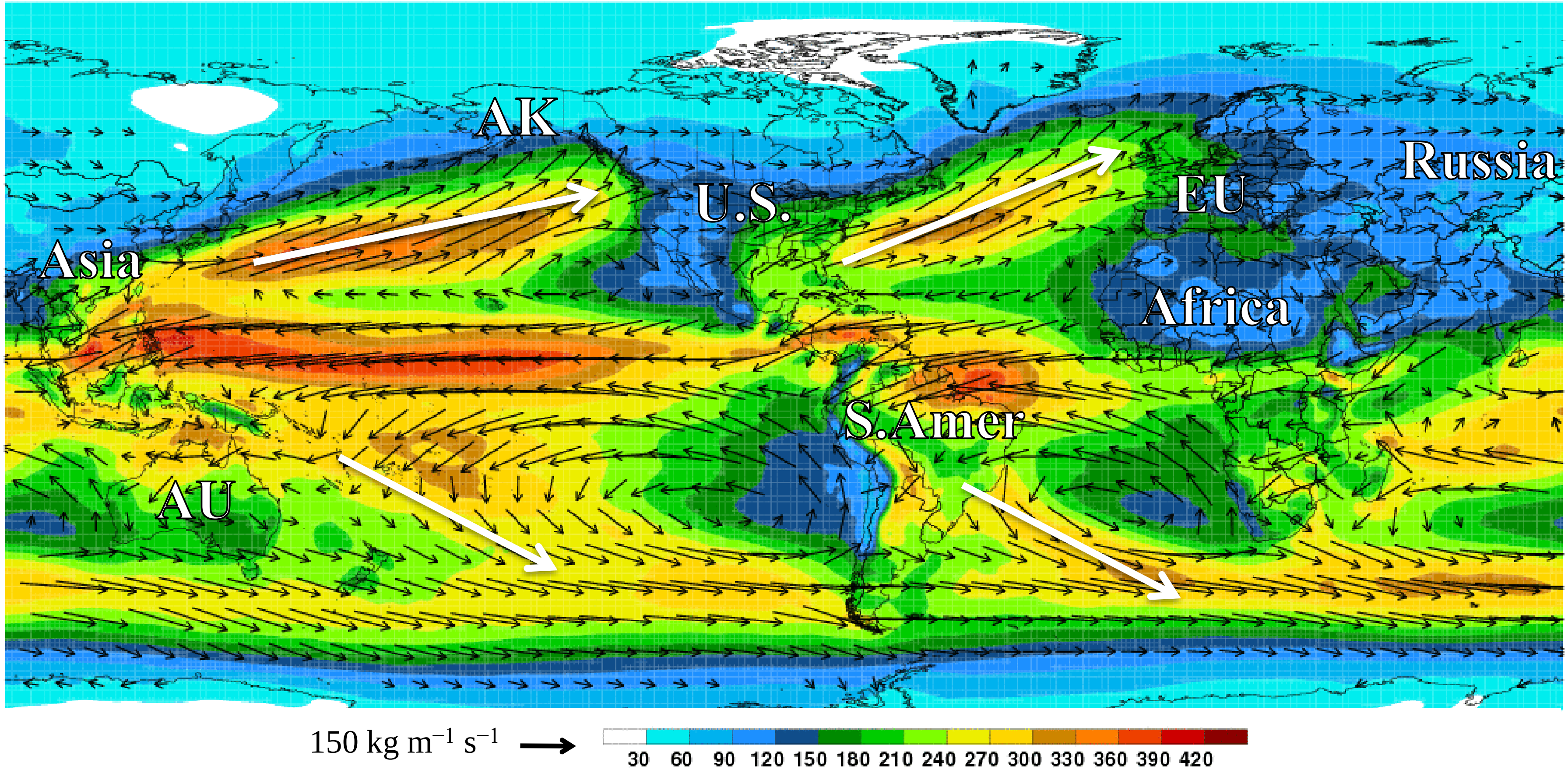
Zhu and Newell (MWR-1998)



- >90% of meridional water vapor transports occurs along ARs
- ARs part of midlatitude cyclones and move with storm track

Climatology of Water Vapor Transport

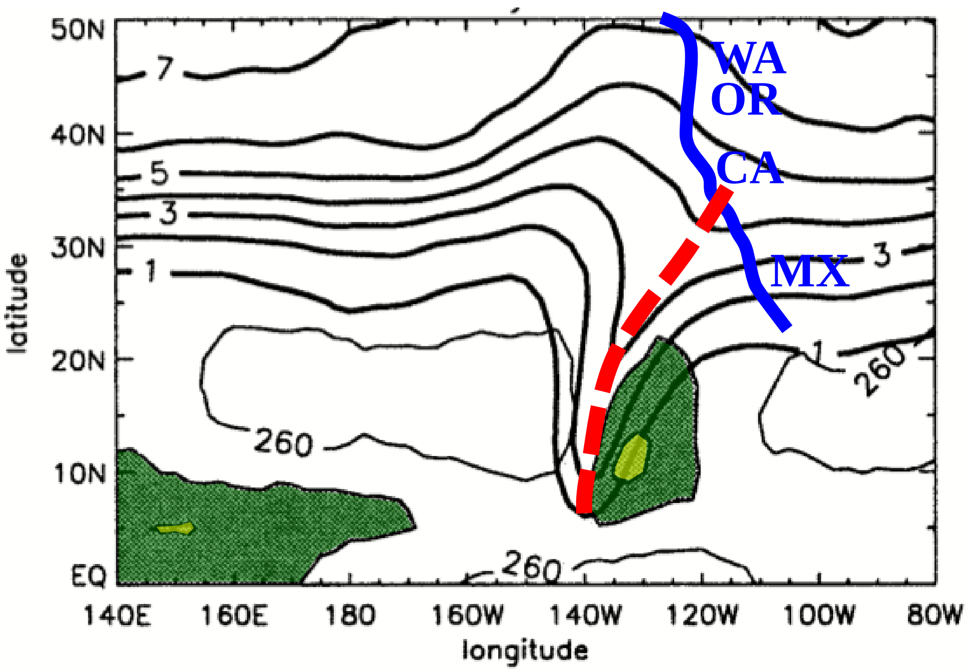
Global mean IVT



- ECMWF ERA Interim Reanalysis
- Oct–Mar 99/00 to 08/09 (i.e., ten winters)
- IVT calculated for isobaric layers between 1000 and 100 hPa

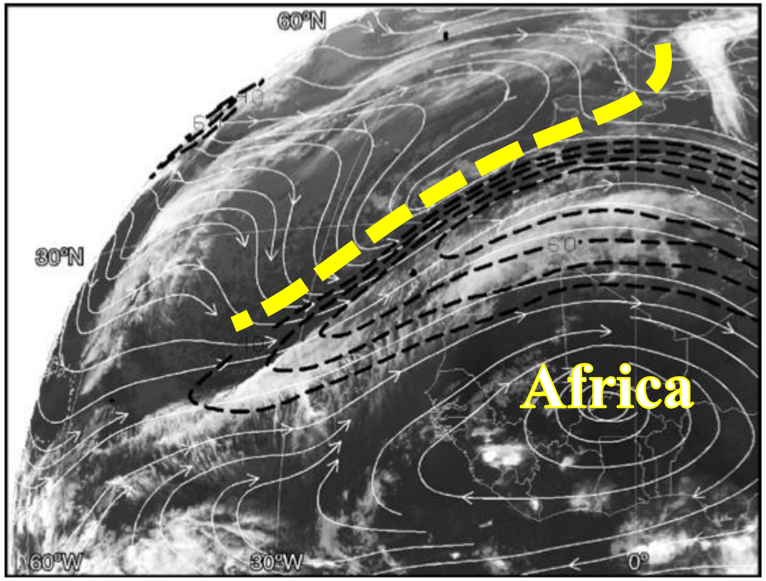
Tropical–Extratropical Interactions

Waugh and Fanutso (2003-JAS)



Composite 350-K PV and negative OLR anomalies for "trough intrusions" at low latitudes

Knippertz (2005-MWR)

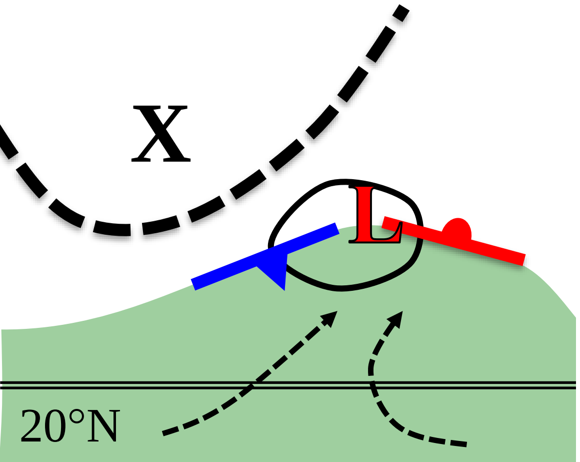


Case study 345-k streamlines and isotachs for low-latitude trough over eastern North Atlantic

- Initiation of water vapor transport along ARs linked to occurrences of upper-tropospheric troughs at lower latitudes, changes in static stability, and downstream southerly flow
- TCs may also contribute to poleward heat/moisture flux

Midlatitude cyclogenesis

- Upper-level disturbance (X) embedded within a Rossby wave initiates cyclogenesis → southerly flow aids in development of poleward water vapor transport



Midlatitude cyclogenesis

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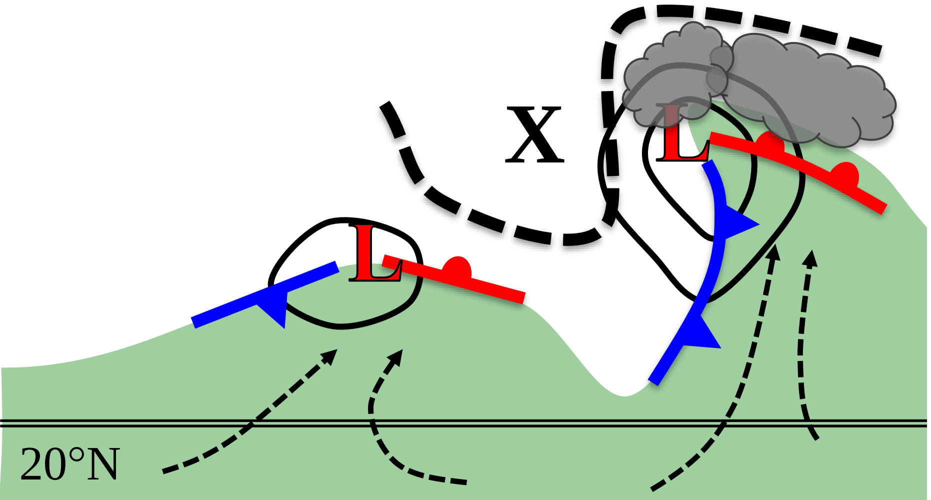
- Diabatic processes contribute to modification of Rossby wave structure that favors further cyclogenesis, stronger cyclone, additional poleward water vapor transport



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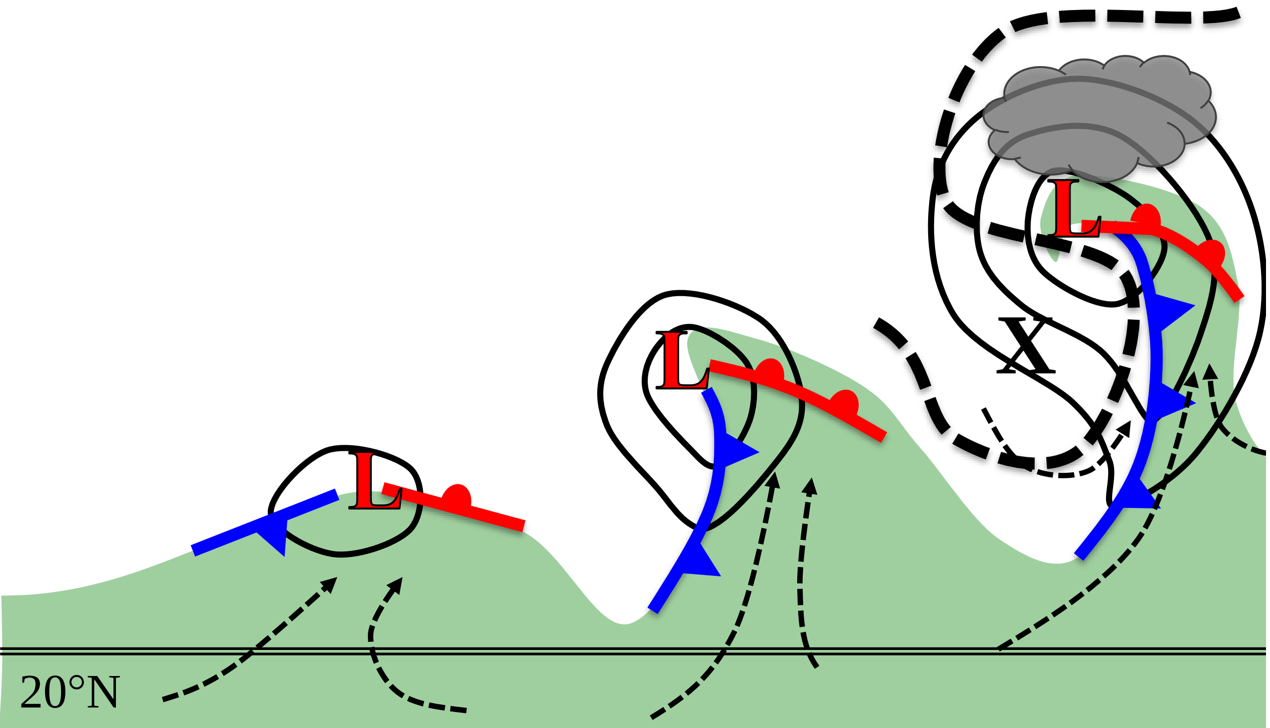
- Frontogenesis along frontal features favors aggregation of water vapor



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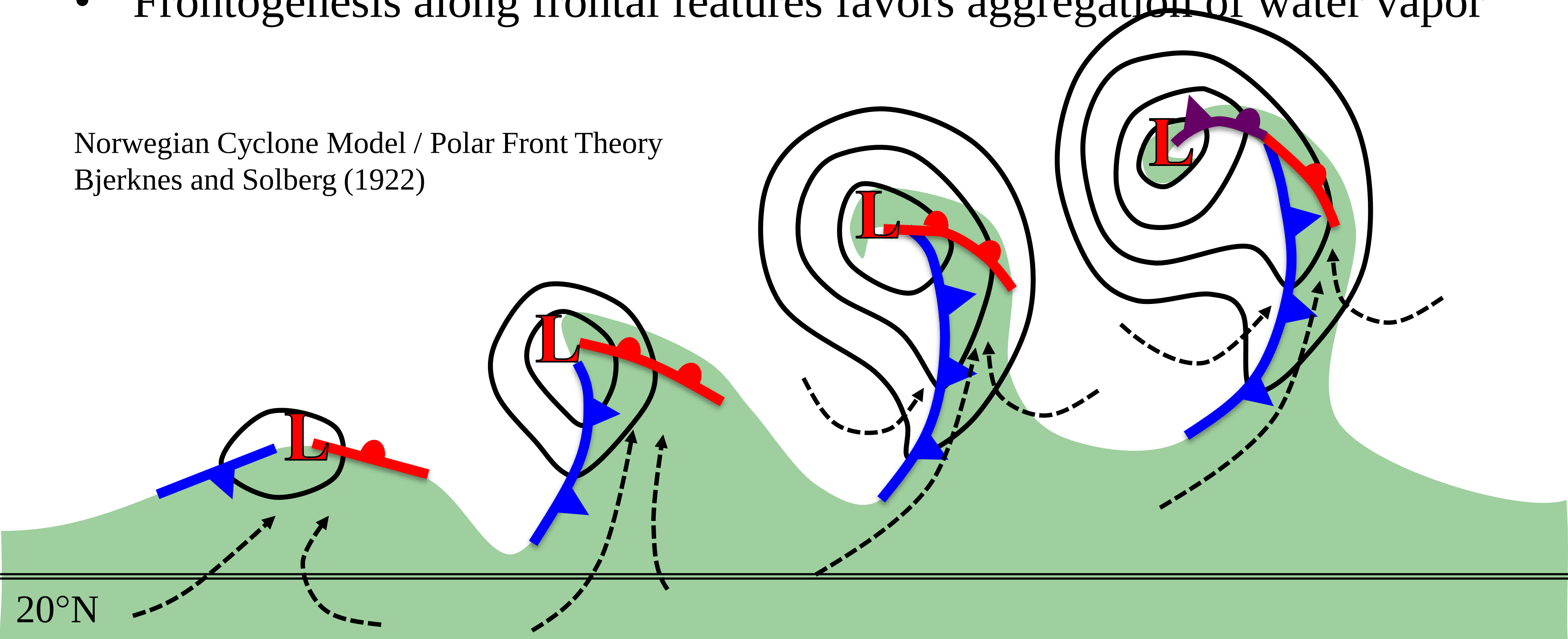
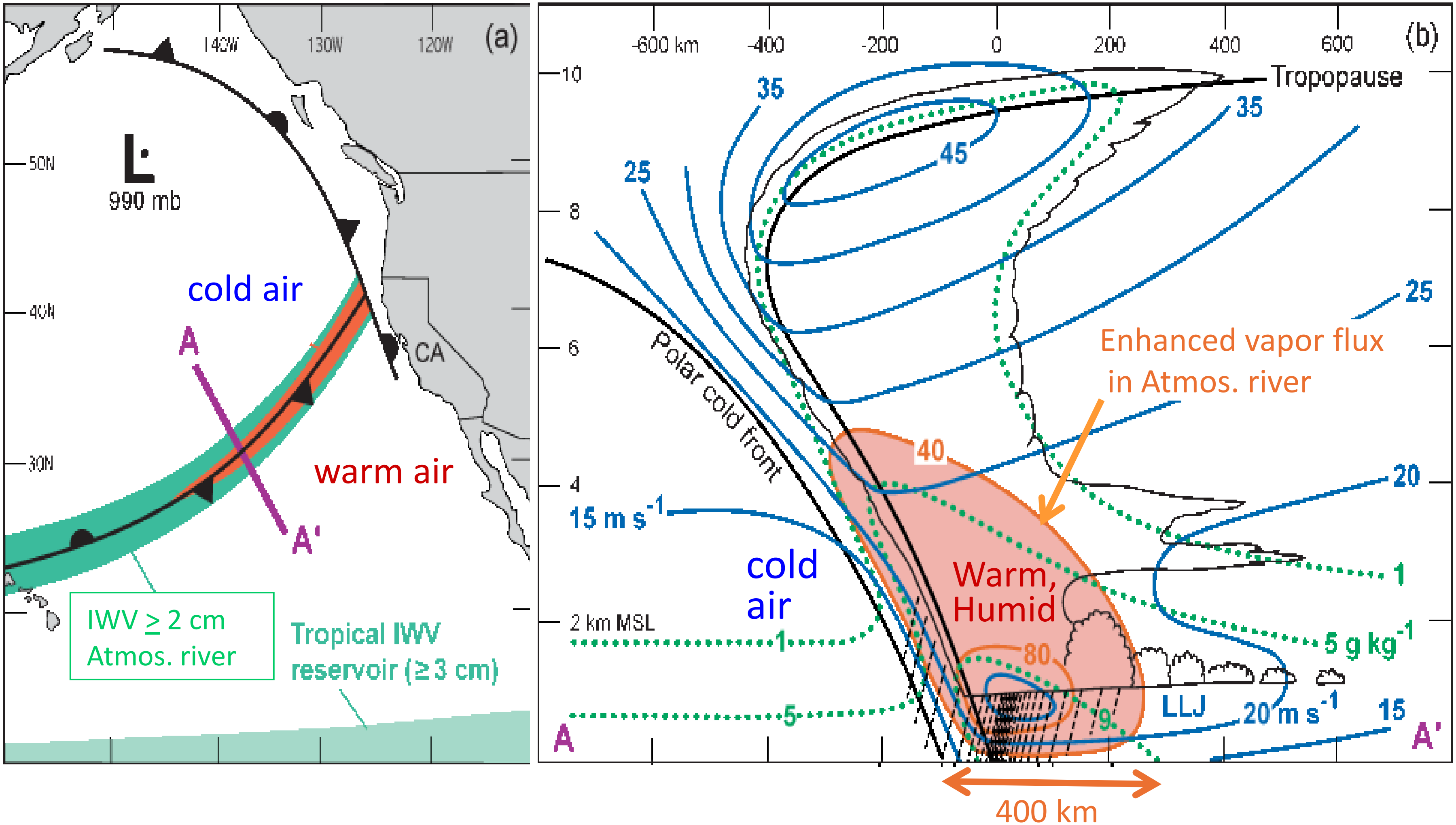
Norwegian Cyclone Model / Polar Front Theory
Bjerknes and Solberg (1922)



Ralph et al. (2004-MWR, 2005-MWR, 2006-GRL)



- ARs situated near leading edge of cyclone cold front
- 75% of water vapor flux occurs below 2.25 km near LLJ

ARs and the midlatitude cyclone

- AR resembles tropical moisture export (TME)
- Located in region of warm conveyor belt (WCB)
- 3D kinematic and thermodynamic processes involved in simultaneously maintaining/removing IWV

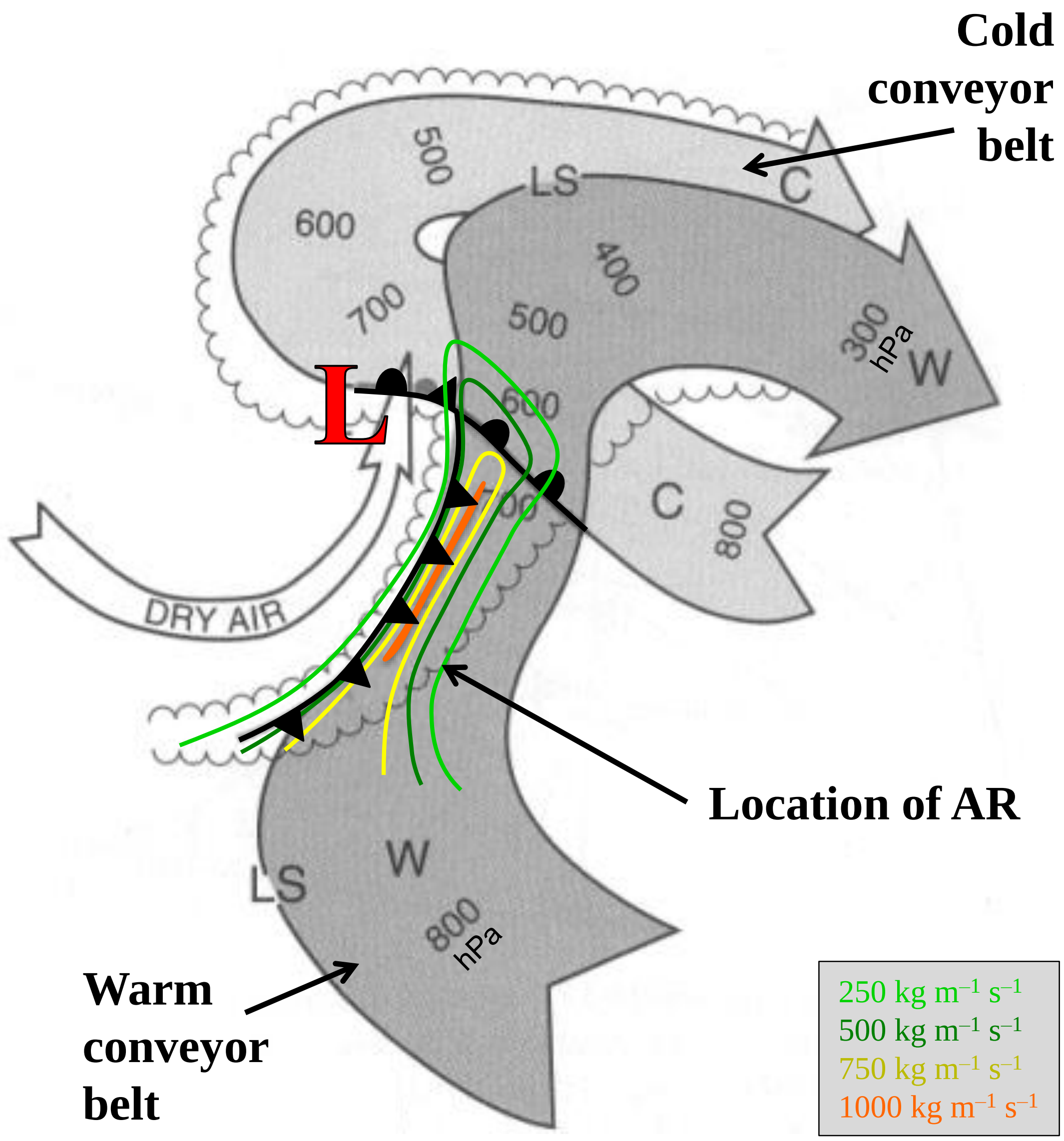
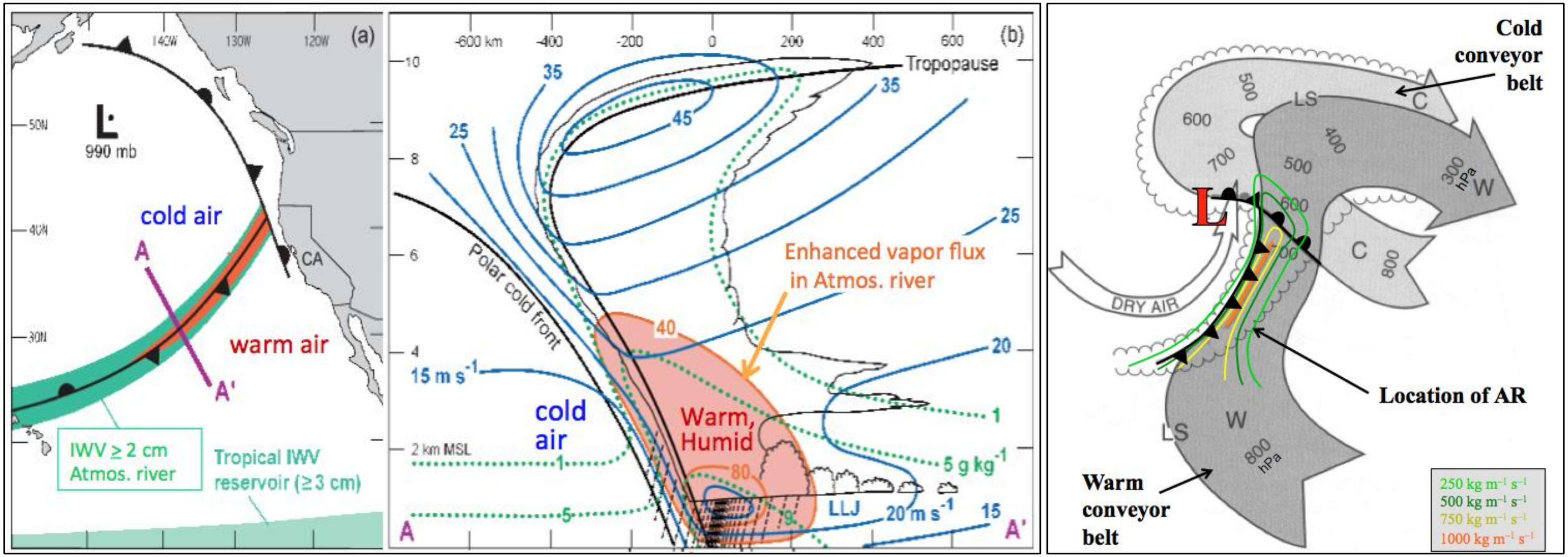


Image adapted from Carlson (1980)

ARs and the midlatitude cyclone

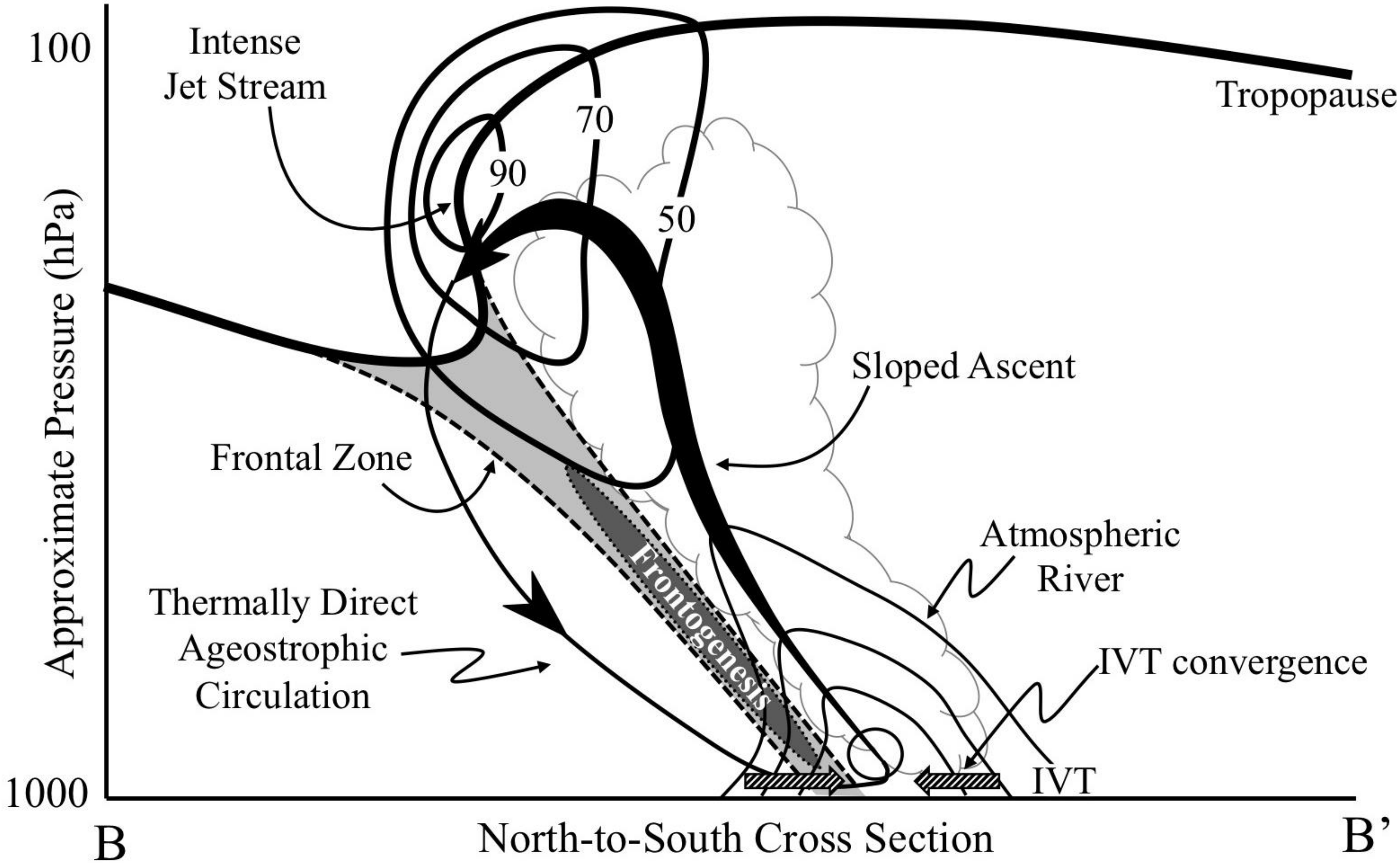


- **Negative contribution (IWV removal):**
  Frontal circulations and isentropic ascent are regions of vertical motion that favor removal of IWV

- **Positive contribution (IWV maintenance):**
  Kinematic frontogenesis may lead to water vapor flux convergence, evaporation into dry air on back edge

Can offset

ARs and the midlatitude cyclone



Cordeira et al. (2013-MWR)

ARs and the midlatitude cyclone

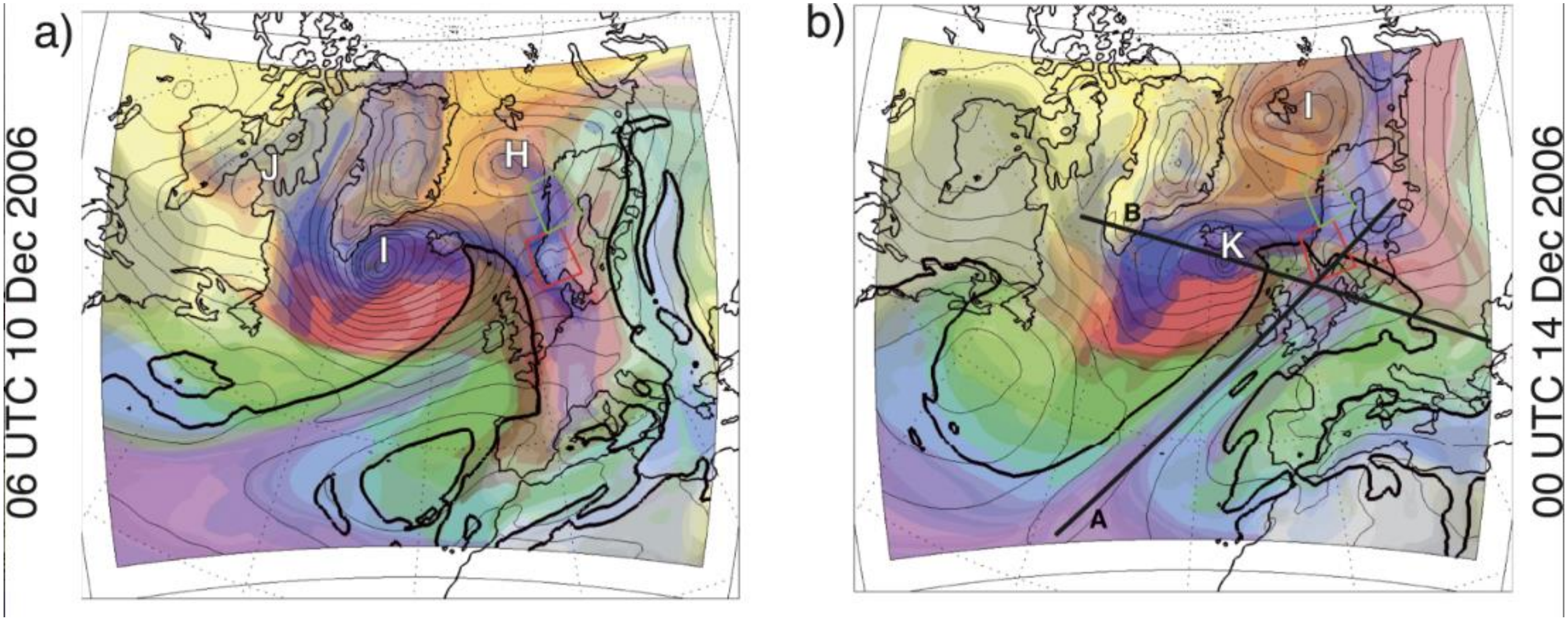


Fig. 6a,b from Sodemann and Stohl (2013, MWR): Moisture origin and meridional transport in atmospheric rivers and their association with multiple cyclones

Summary provided by Sodemann and Stohl (2013-MWR)

1. *Formation of ARs tightly coupled to circulation at tropopause level*
2. *Individual cyclones contribute to formation and maintenance of ARs at trailing end by adding moisture accumulated at their cold fronts*
3. *Cyclones use a part of ARs as a reservoir to feed their WCB*
4. *Individual ARs maintained or depleted by several cyclones in sequence*

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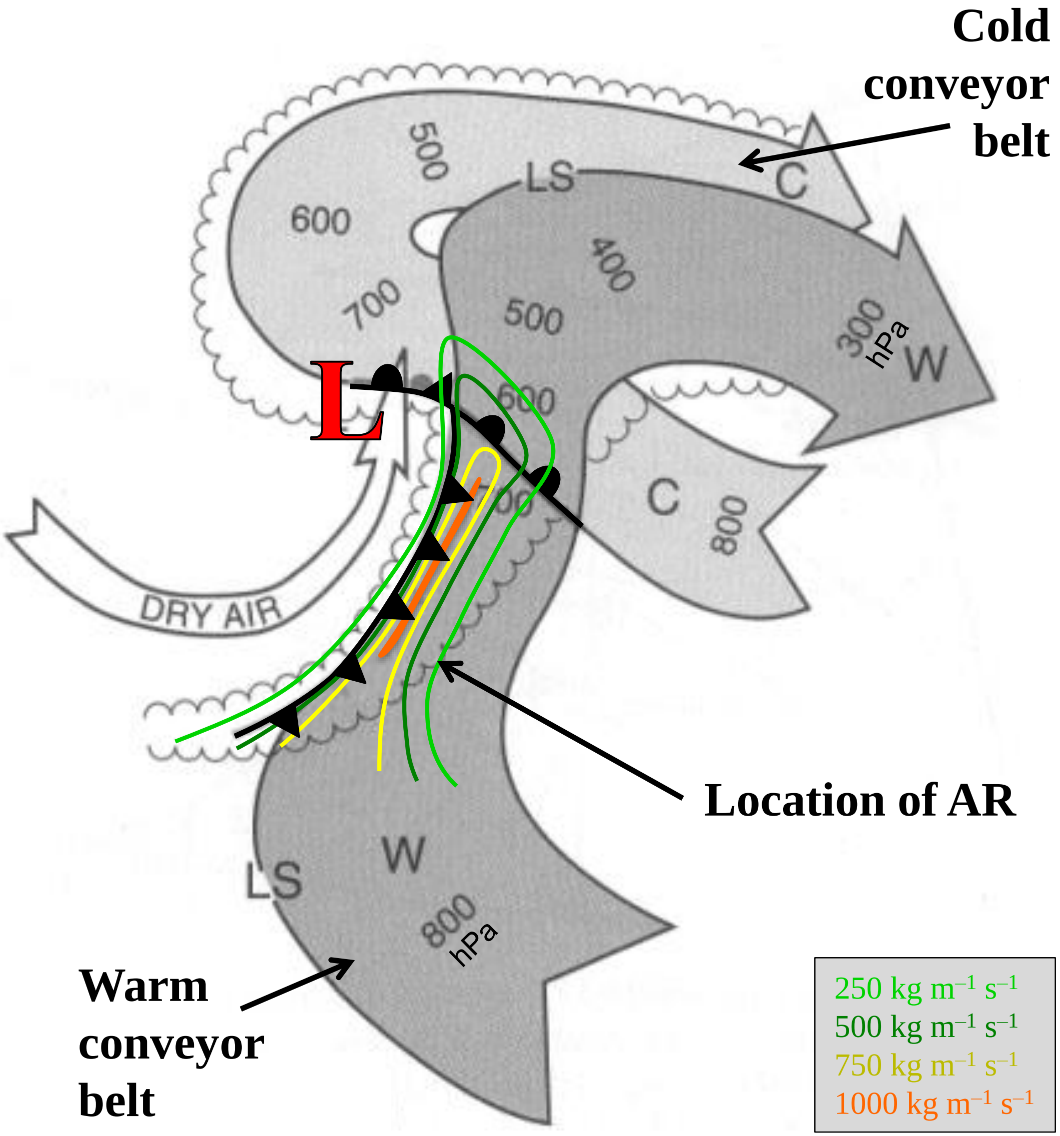
Part 2 - ARs, TMEs, and WCBs

- Can we quantitatively identify spatial correspondence between ARs, TMEs, and WCB?
- How are these three processes related?
- How can we rectify the difference between Lagrangian and Eulerian perspectives?



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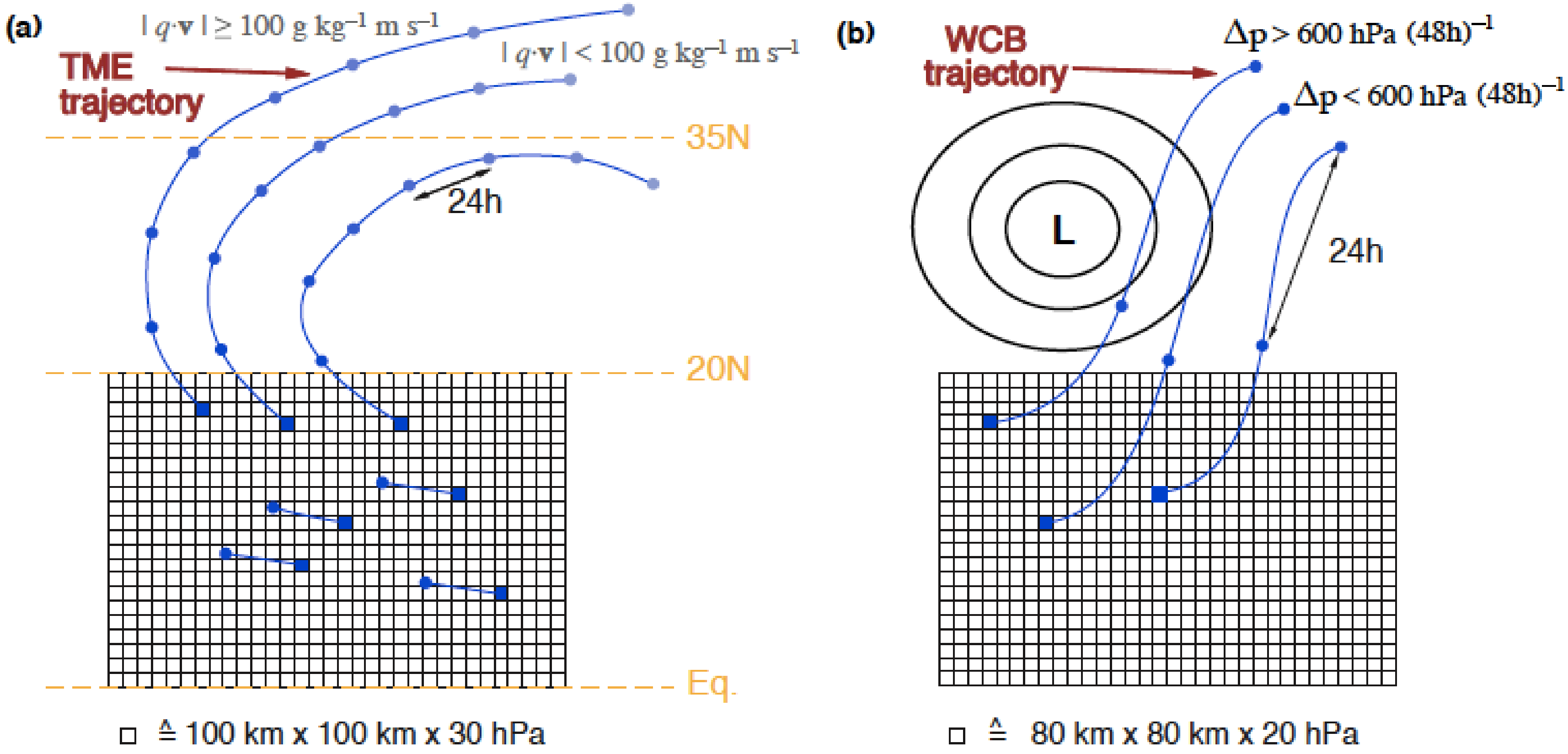
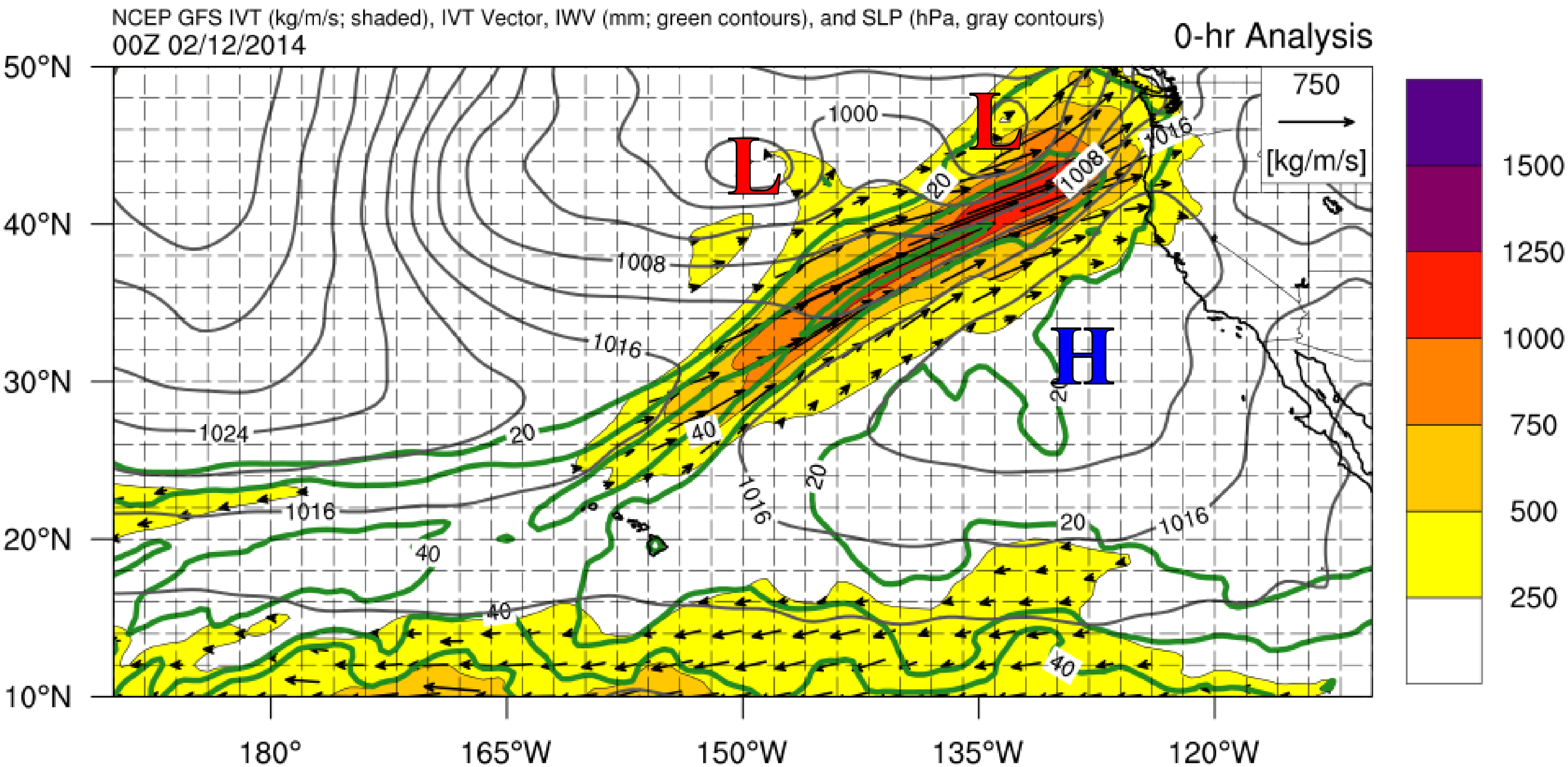
Part 2 - ARs, TMEs, and WCBs



Lagrangian definitions of air parcel characteristics

- TMEs related to water vapor transport out of tropics
- WCBs related to ascent of air parcels in cyclone warm sector

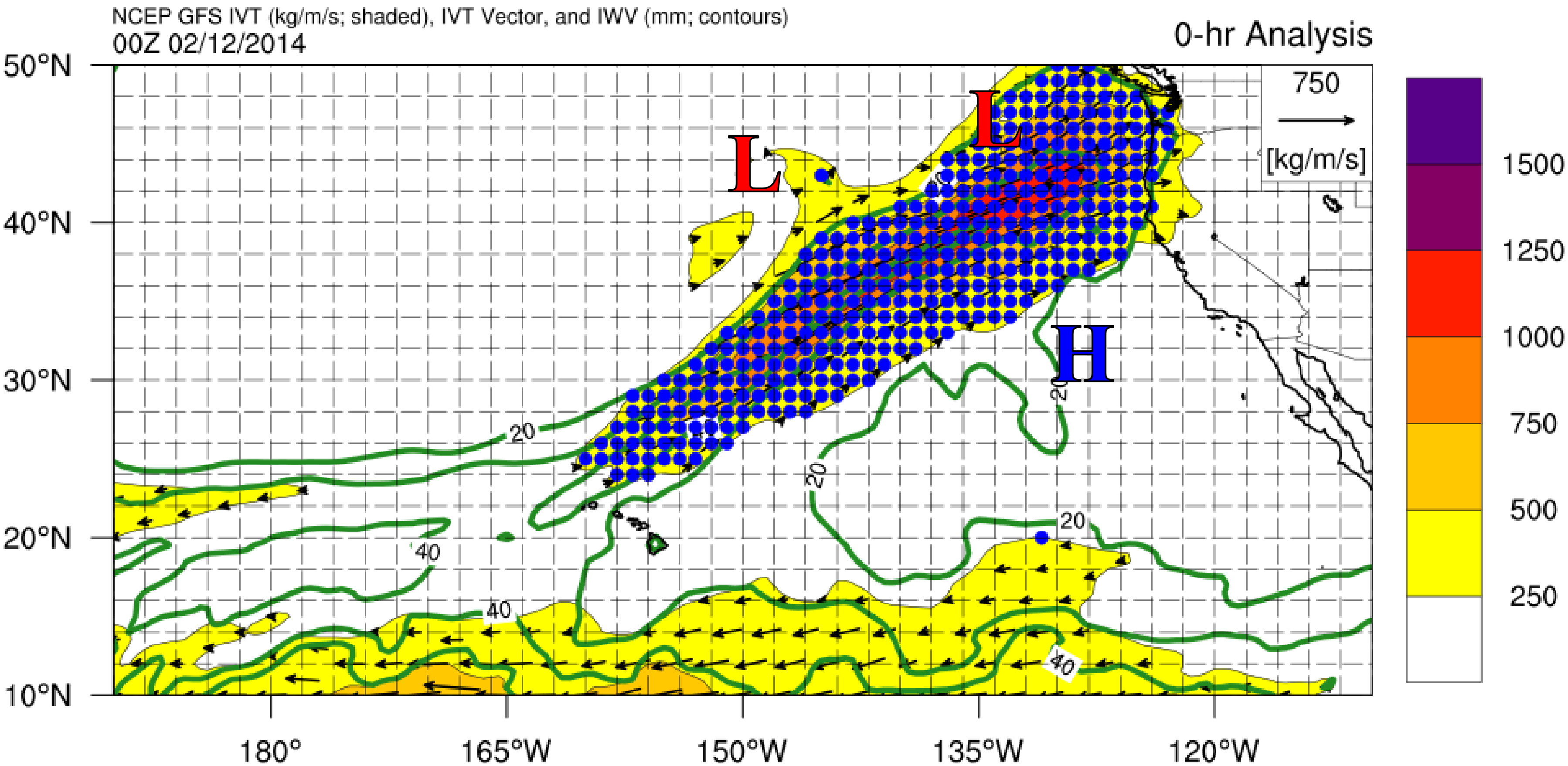
Part 2 - ARs, TMEs, and WCBs



Methodology

- Define an AR based on threshold values of IVT and IWV

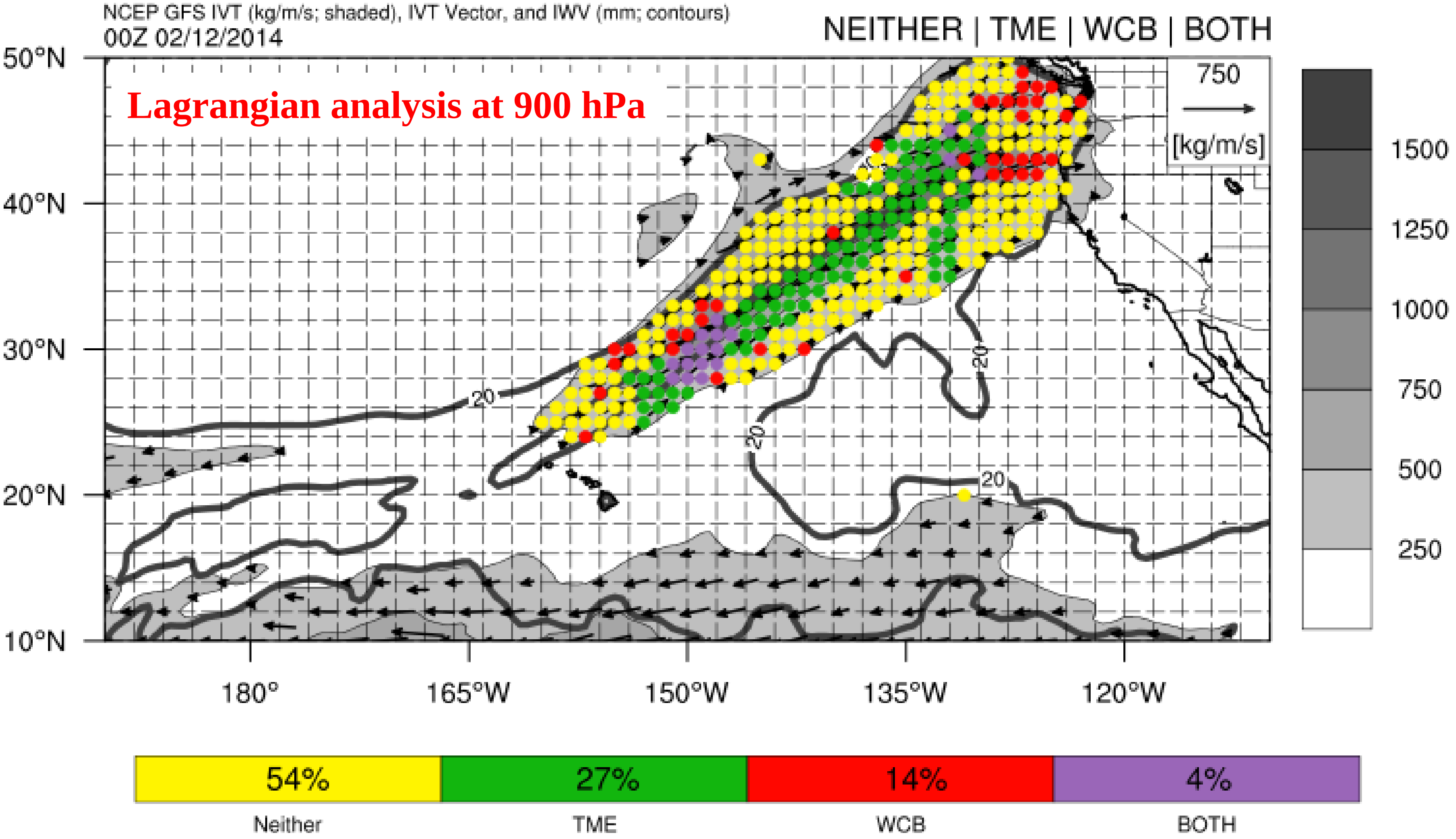
Part 2 - ARs, TMEs, and WCBs



Methodology

- 357 points identified on grid in AR conditions with IVT>250 kg m^{-1} s^{-1} and IWV>20 mm

Part 2 - ARs, TMEs, and WCBs



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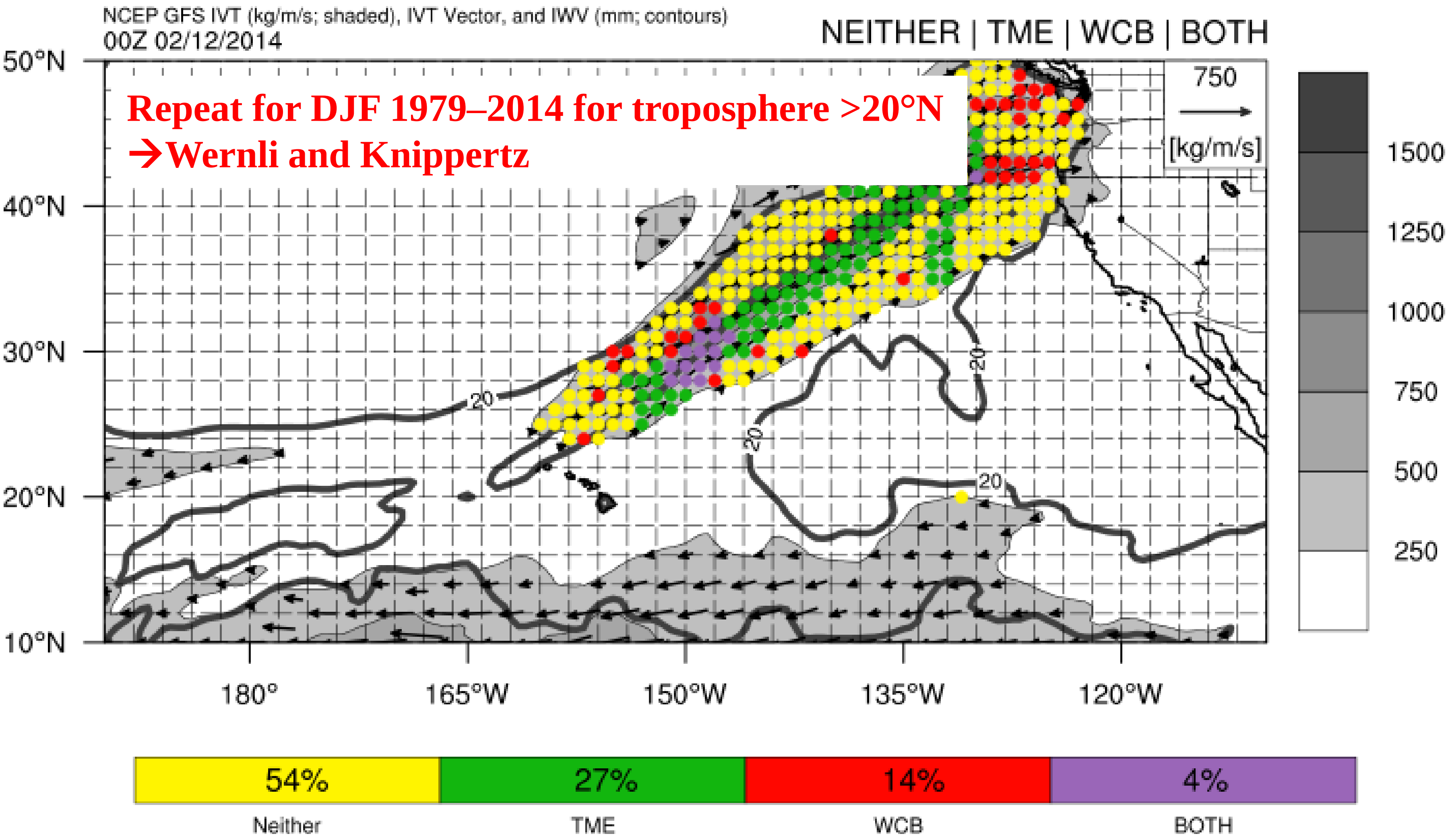

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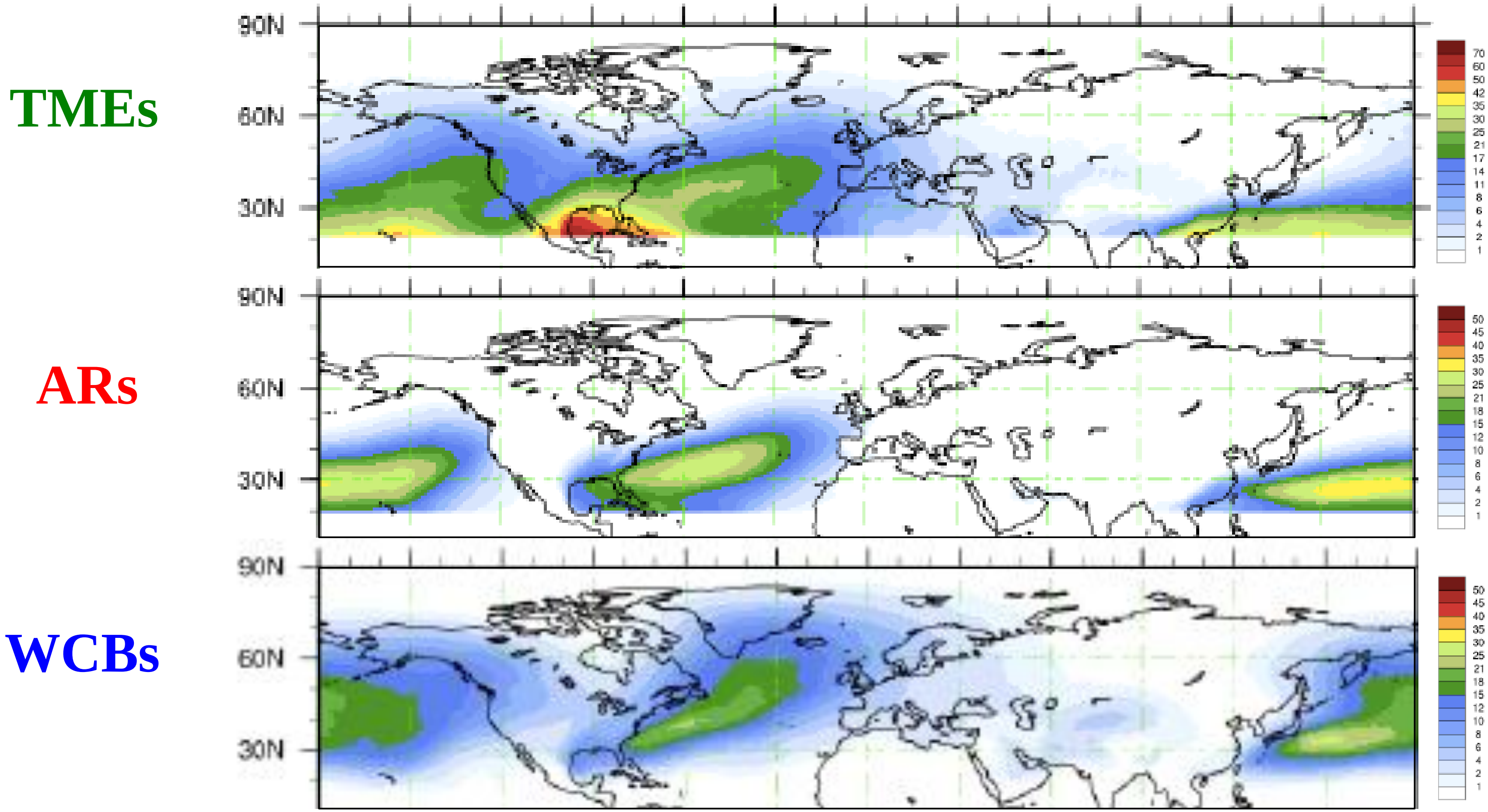
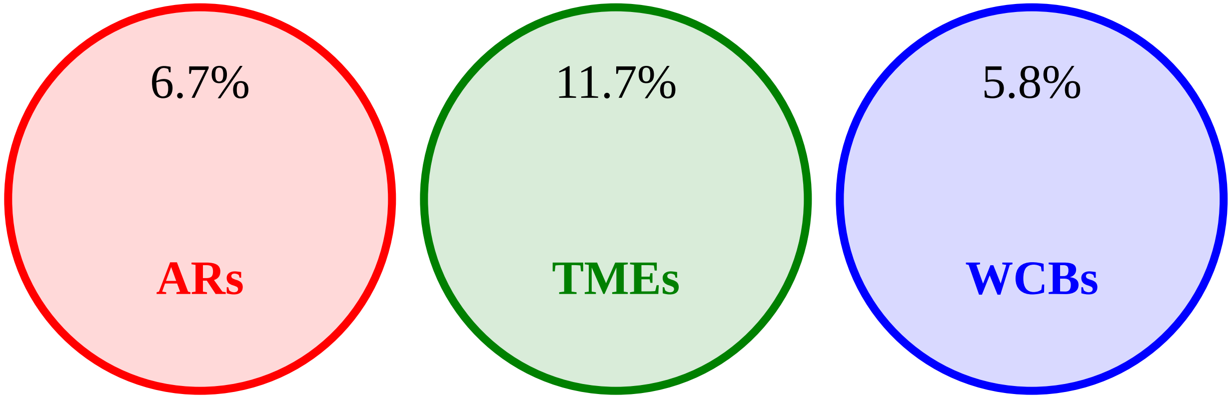


Average DJF Frequency

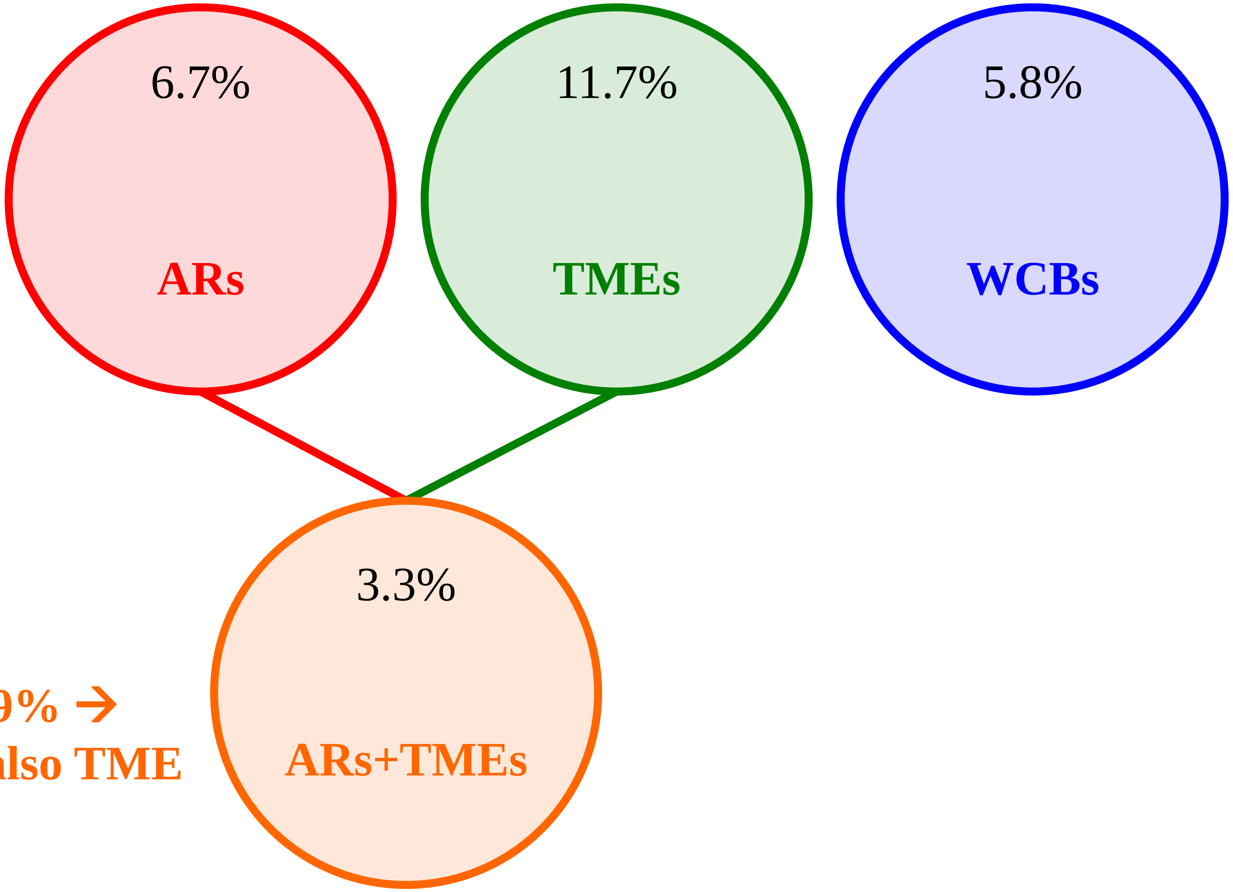
- Next step: Identify geographic coverage and spatial overlap of AR, TMEs, and WCBs

Part 2 - ARs, TMEs, and WCBs



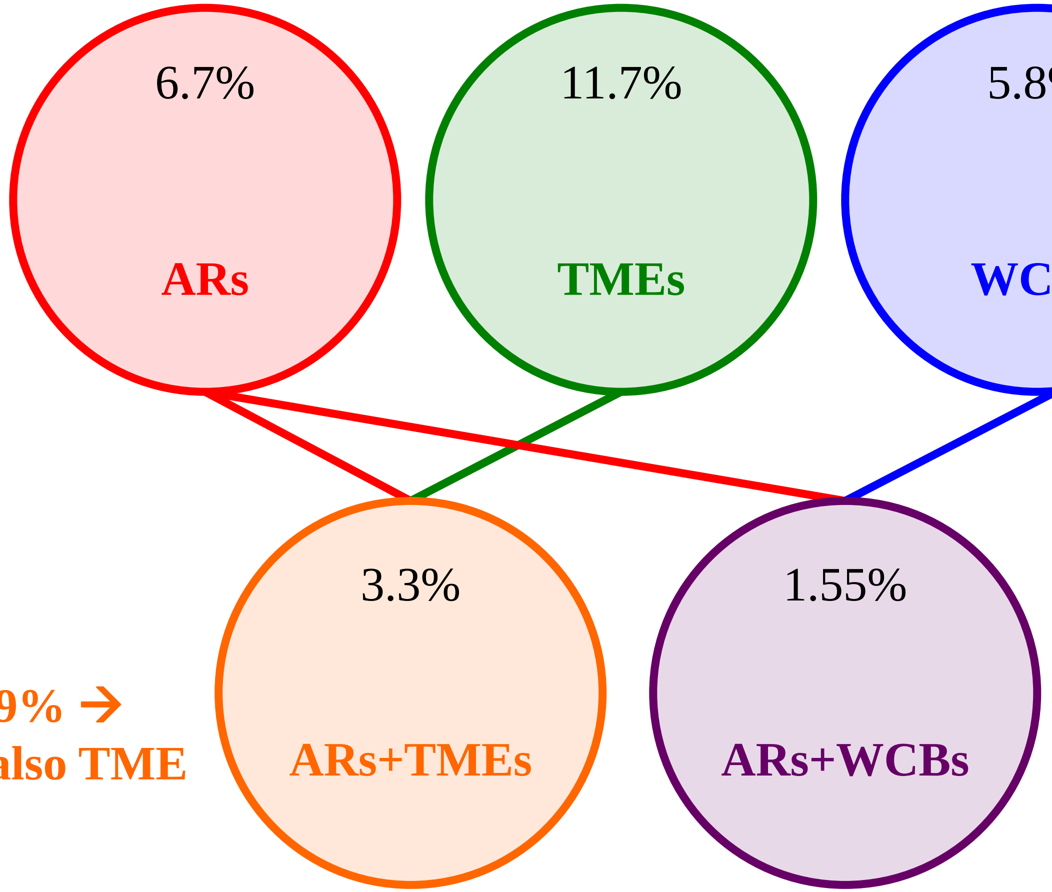
- Percentage of area poleward of 20ºN that is on average covered by ARs, TMEs, and WCBs only

Part 2 - ARs, TMEs, and WCBs



3.3÷6.7=49% →
% AR grids also TME

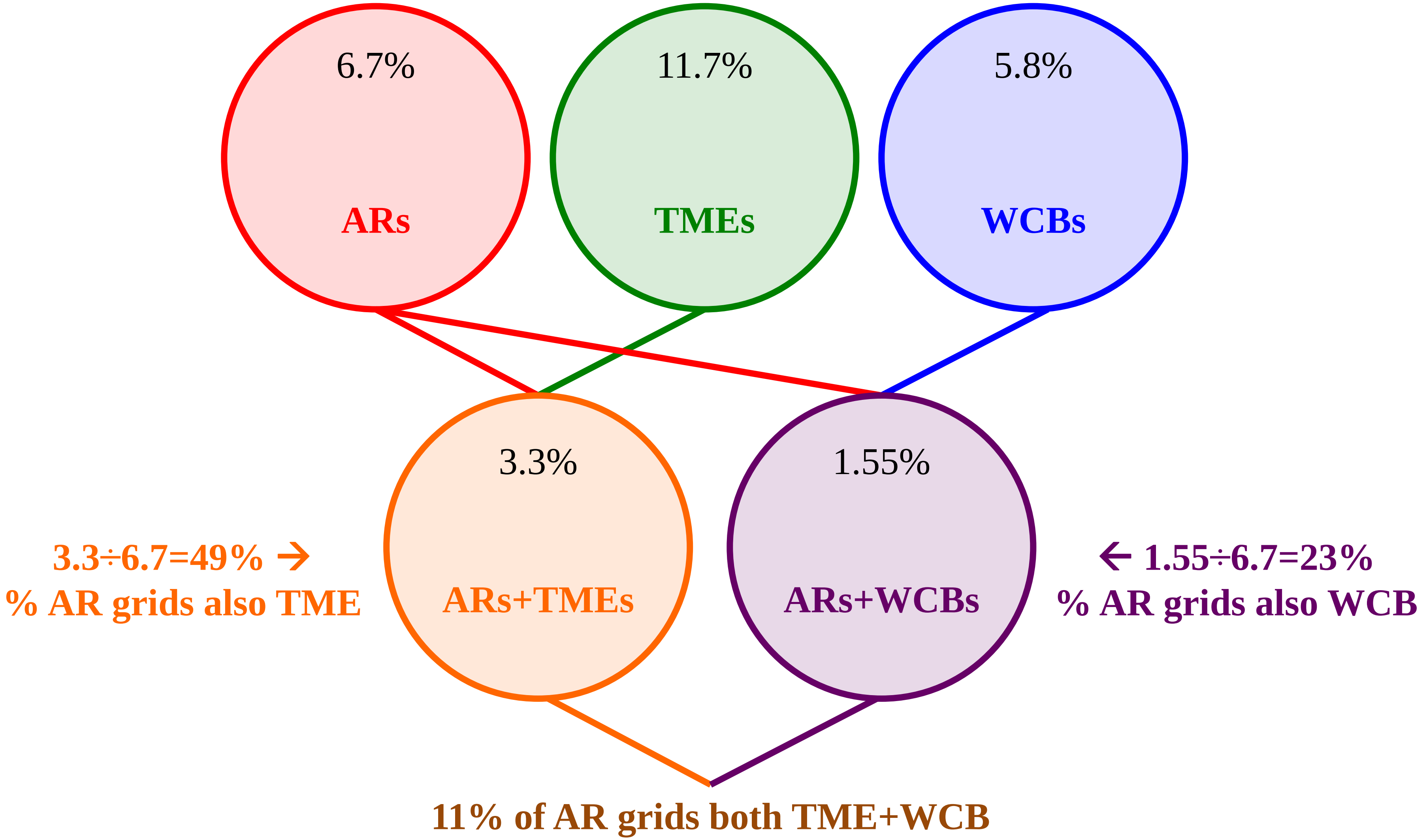
Part 2 - ARs, TMEs, and WCBs



3.3÷6.7=49% →
% AR grids also TME

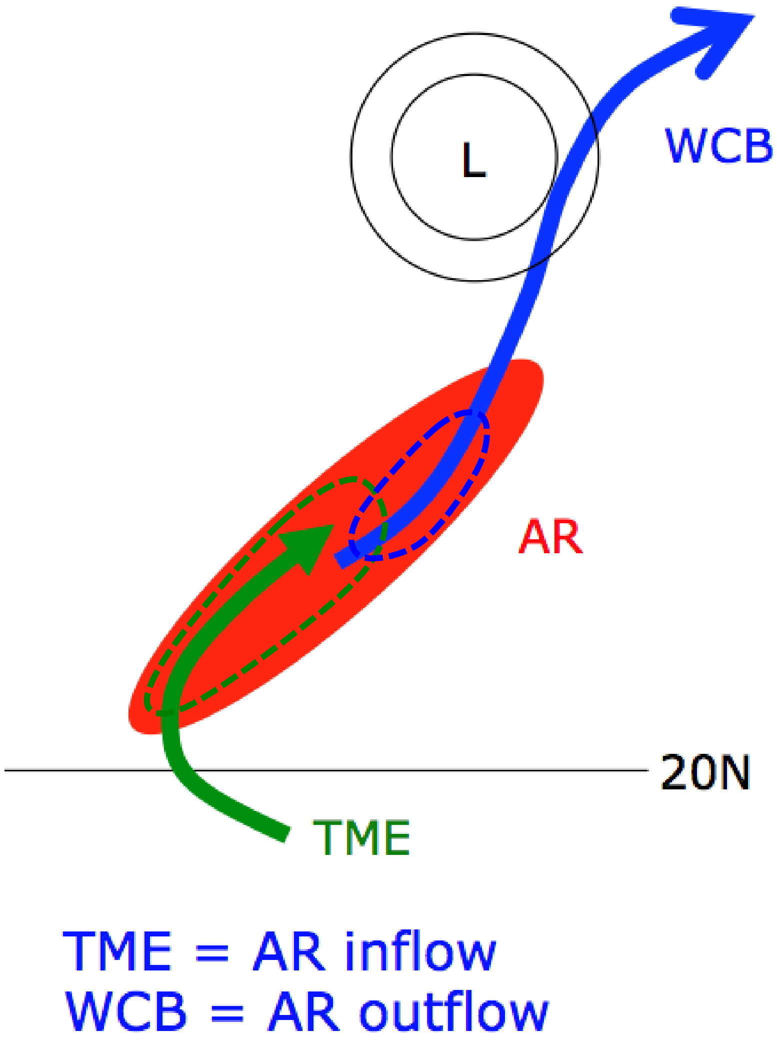
← 1.55÷6.7=23%
% AR grids also WCB

Part 2 - ARs, TMEs, and WCBs



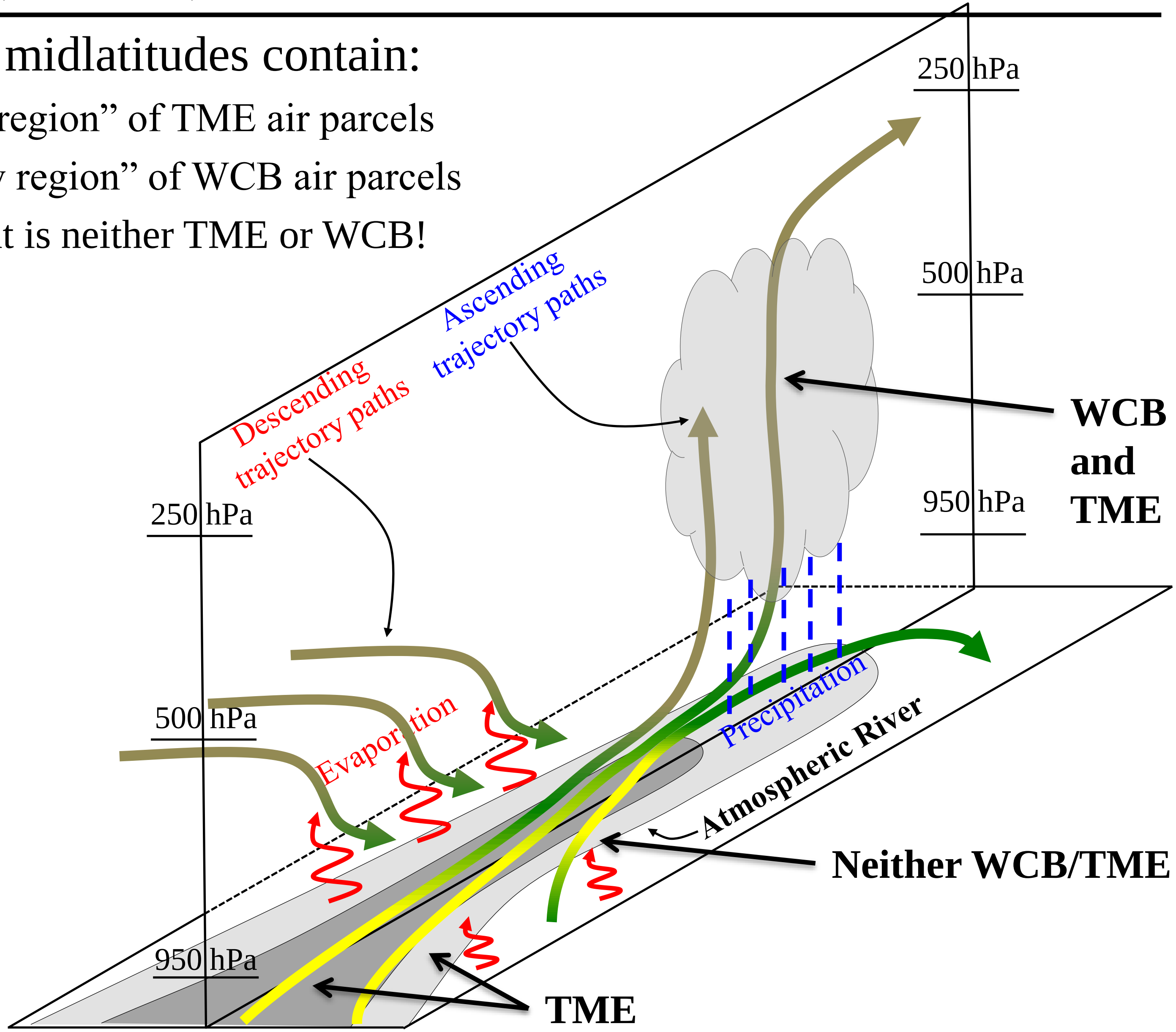
Part 2 - ARs, TMEs, and WCBs

- ARs are relatively “small” spatial features on a global scale (~6%)
- ~50% of spatial area defined as an AR also TME
- ~25% of spatial area defined as AR also part of WCB
- Note that using thresholds of IVT=250 kg m^{-1} s^{-1} and IWV=20 mm resulted in a null overlap of 40%



Part 2 - ARs, TMEs, and WCBs

- Some ARs in midlatitudes contain:
  - An "inflow region" of TME air parcels
  - An "outflow region" of WCB air parcels
  - A region that is neither TME or WCB!



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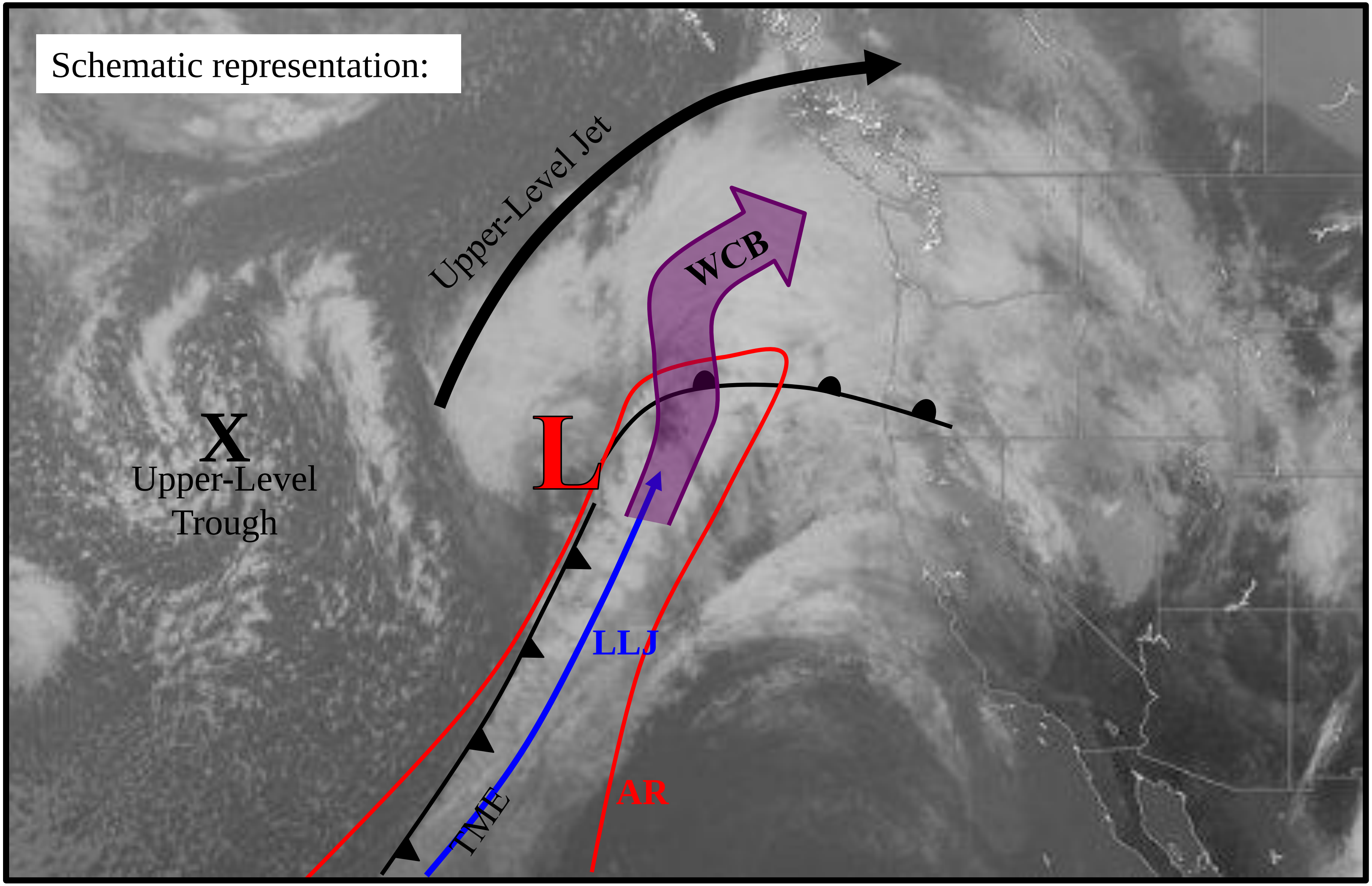

Summary

- ARs result from poleward water vapor transport that may develop in concert with changes in midlatitude storm track and cyclogenesis
- ARs propagate as storm track and cyclones evolve, contributing water vapor to dynamical processes
- ARs are terminated in presence of moist ascent/precipitation, but may be sustained in presence water vapor flux convergence and evaporation
- TMEs comprise a large portion of some ARs, whereas WCBs comprise a small portion of some ARs
- TMEs may give rise to [some] ARs, whereas WCBs lead to their demise