Extreme precipitation events in the central and eastern U.S.

Benjamin J. Moore

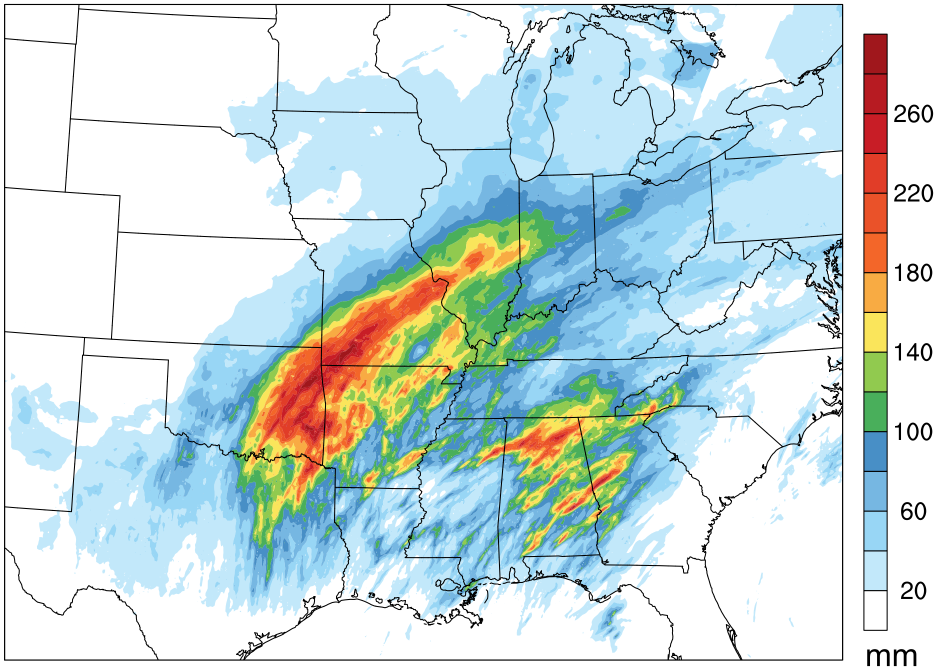
Atm 409/509 lecture

15 Sep 2015

Overview

- Extreme precipitation events (EPEs) the U.S. can result in high-impact flooding
- Thus there is a need to understand the dynamics and predictability of these events
- This lecture will discuss key multi-scale factors that contribute to extreme precipitation
- EPEs directly associated with tropical cyclones will be excluded from this discussion; sorry tropical people.

total precipitation, 25–30 Dec 2015



Data source: NCEP Stage IV

flooding near Tulsa, Oklahoma

Image source: Tulsa World

The simple yet profound formulae for precipitation from Doswell et al. (1996)

Total amount of precipitation produced at a given location

$$P = \underbrace{\overline{R}}_{\text{avg rate}} \times \underbrace{D}_{\text{duration}}$$

where $\overline{R} = Ewq$; w is vertical velocity, q is specific humidity, and E is precipitation efficiency

Total amount of precipitation produced by a system

$$P_{total} = \iint_A P\,dxdy$$

Key insight

It rains the most where the rainfall rate is highest for the longest duration.

Basic ingredients for extreme precipitation

high precipitation rates

strong vertical moisture flux into precipitating clouds

large portion of condensate falls out as precipitation

persistence in time and space

persistent flow patterns

motion and structural characteristics of precipitation systems

Basic ingredients for extreme precipitation

high precipitation rates

strong vertical moisture flux into precipitating clouds

Basic ingredients for extreme precipitation

high precipitation rates

strong vertical moisture flux into precipitating clouds

↓

strong lifting + abundant moisture (e.g., deep moist convection)

Basic ingredients for extreme precipitation

high precipitation rates

strong vertical moisture flux into precipitating clouds

↓

strong lifting + abundant moisture (e.g., deep moist convection)

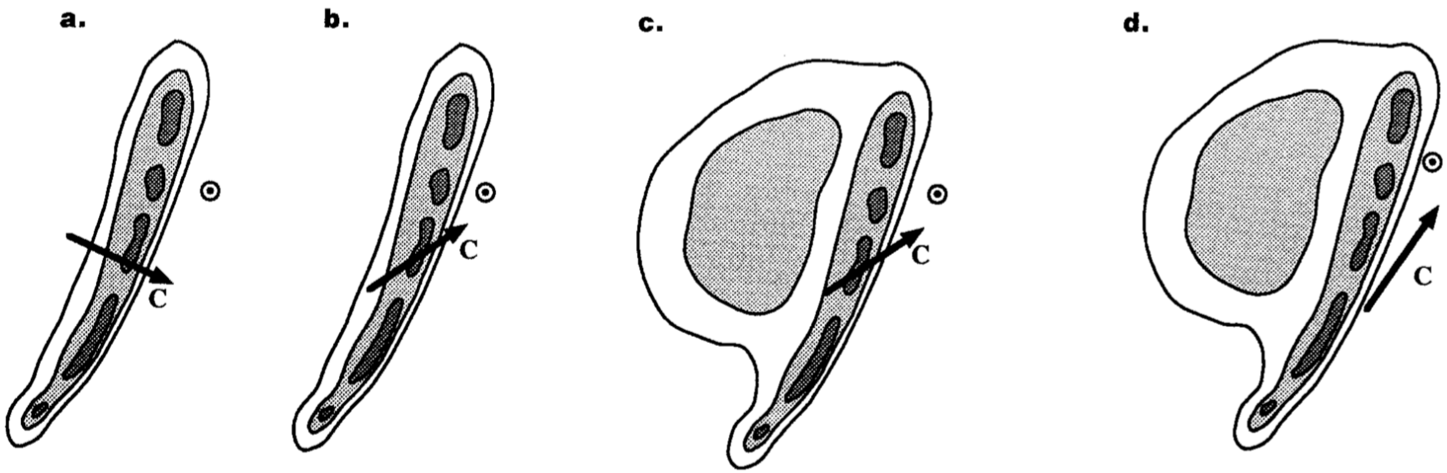
forcing for ascent
+
weak stability

moisture source region
+
transport of moisture into precipitation region

Implications for predictability

To accurately predict extreme precipitation, one must accurately predict all of the ingredients for extreme precipitation.

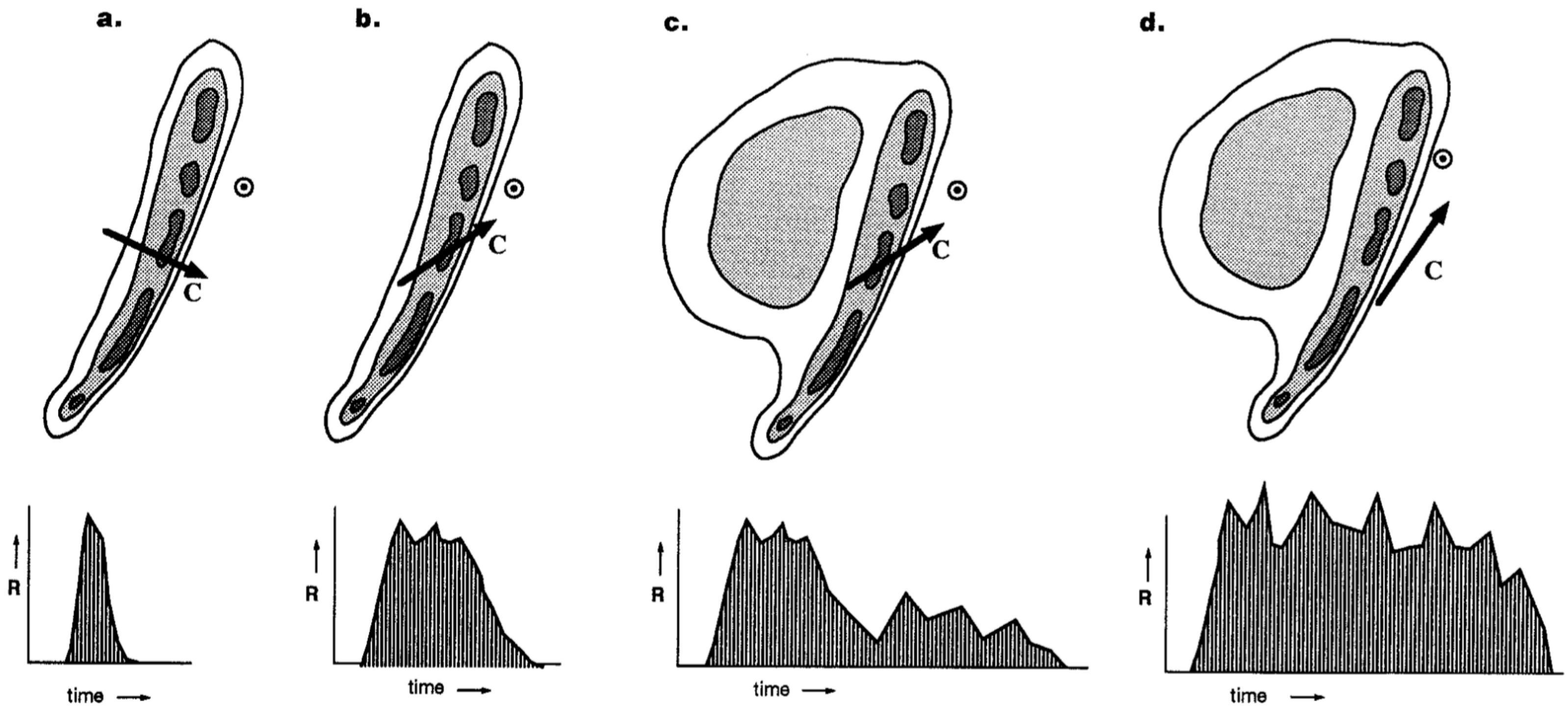
Mesoscale structure and evolution favoring extreme precipitation



Which will produce more rain?

Fig. 3 from Doswell et al. (1996)

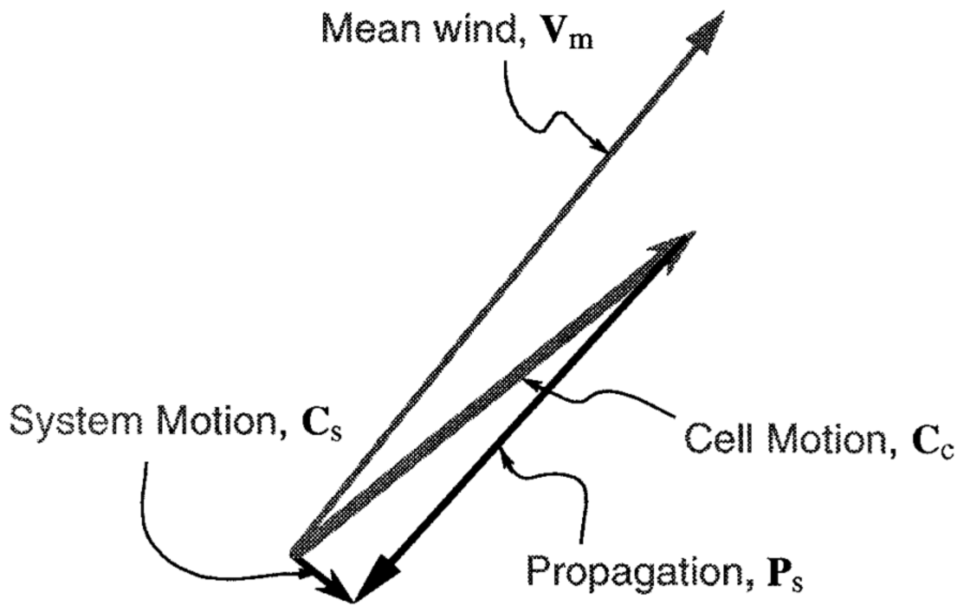
Mesoscale structure and evolution favoring extreme precipitation



precipitation time series for quasi-linear MCSs with different motion/structure characteristics

Fig. 3 from Doswell et al. (1996)

Mesoscale structure and evolution favoring extreme precipitation



- Precipitation systems are not *things*; rather, they are *processes* comprising numerous subprocesses
- Individual cells develop, move downstream, and decay
- New cell development (i.e., propagation) must occur upstream relative to motion of old cells to sustain quasi-stationary precipitation system
- Ingredients for heavy precipitation must be focused on upstream flank of system

Fig. 4 from Doswell et al. (1996)

Mesoscale structure and evolution favoring extreme precipitation

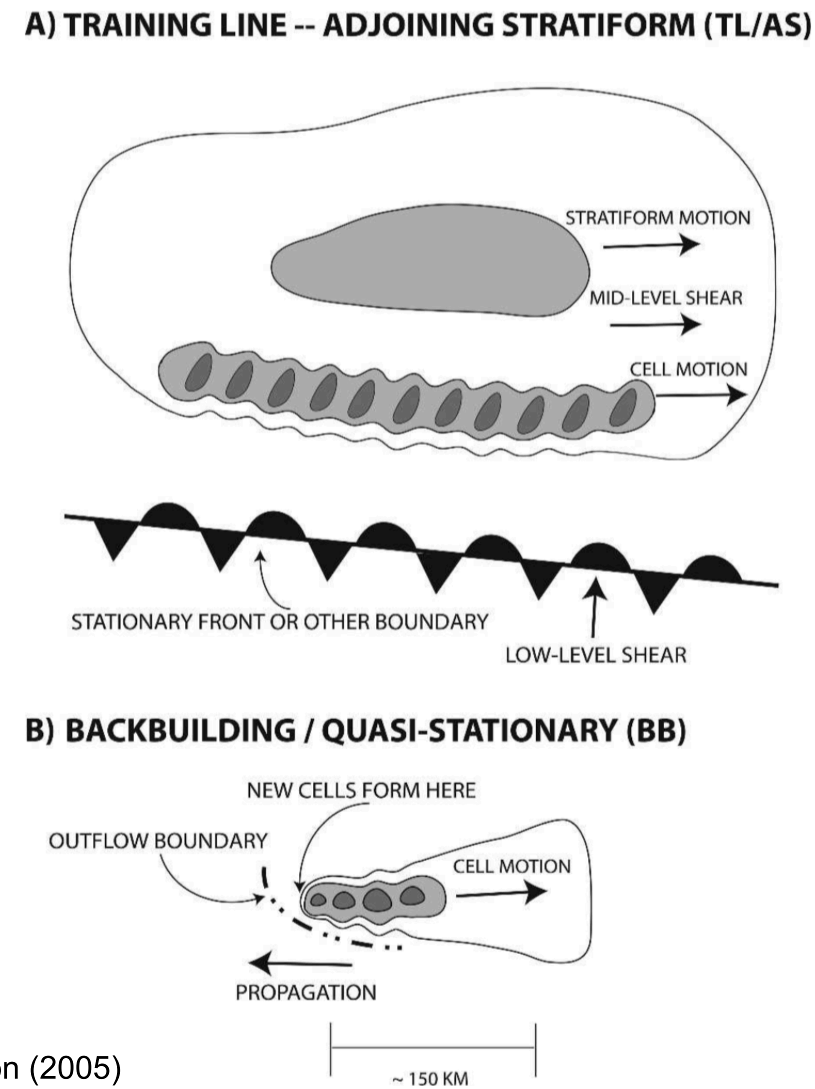
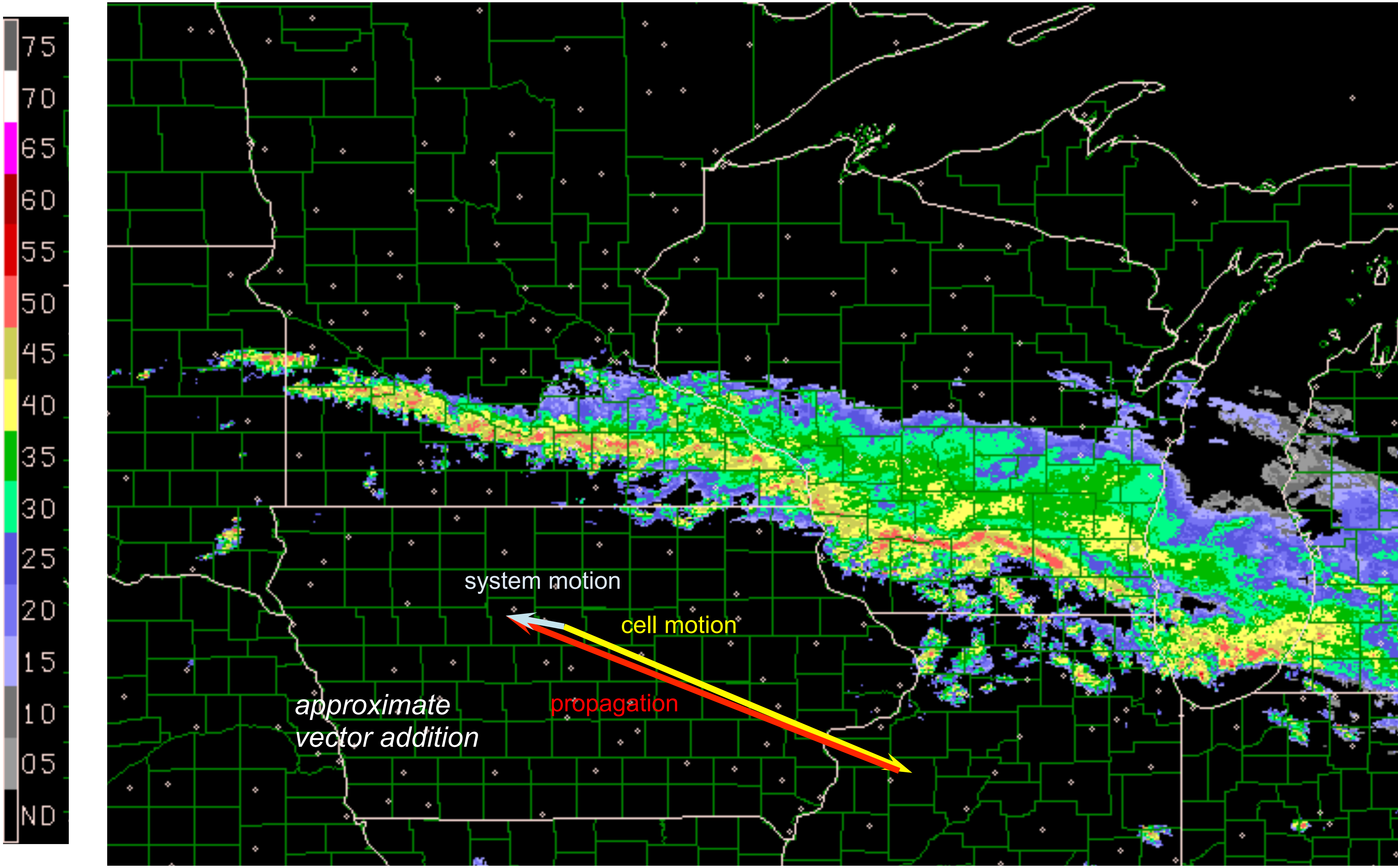


Fig. 3 from Schumacher and Johnson (2005)

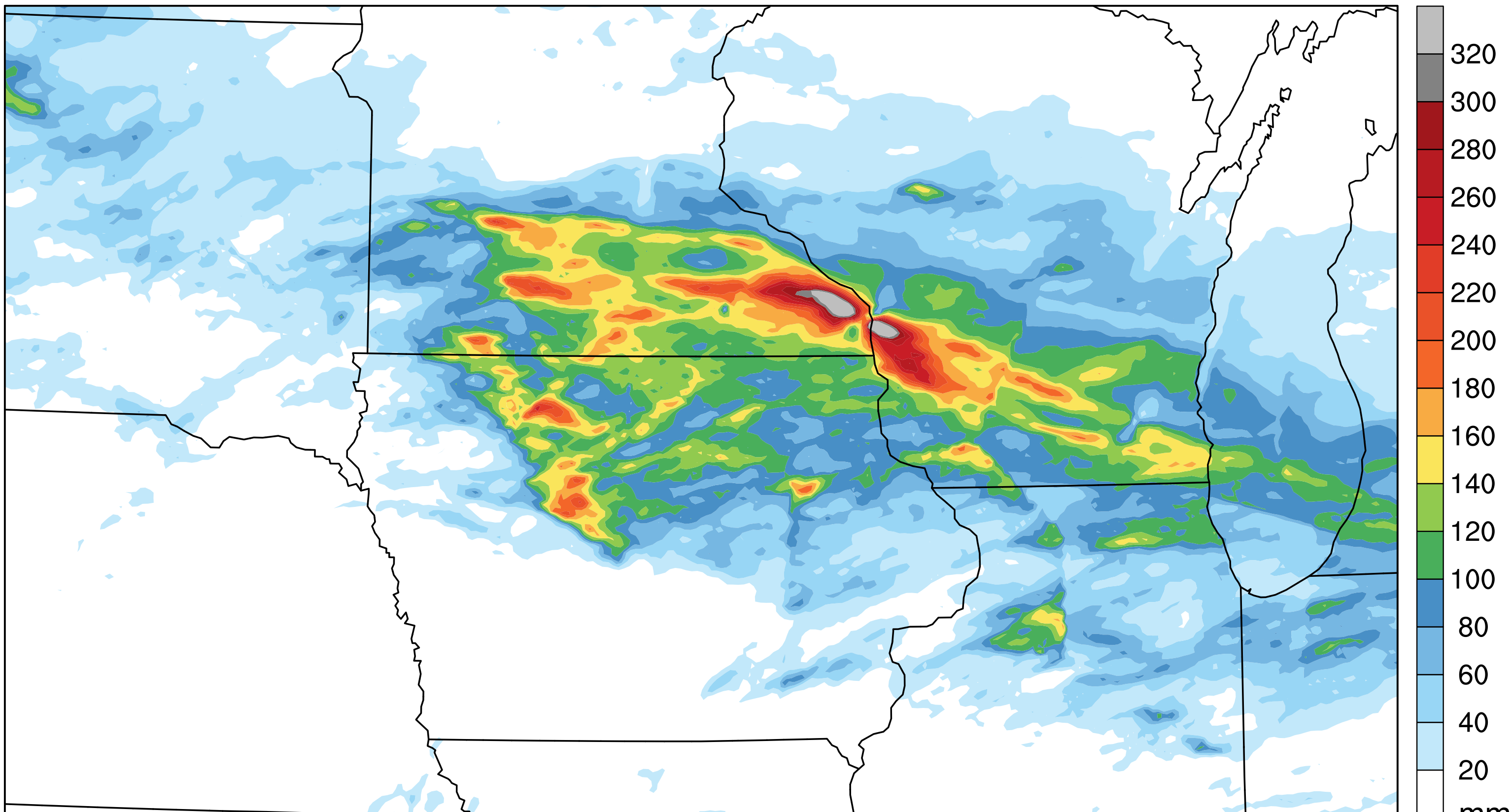
Example of mesoscale training and backbuilding

0600 UTC 19 Aug 2007



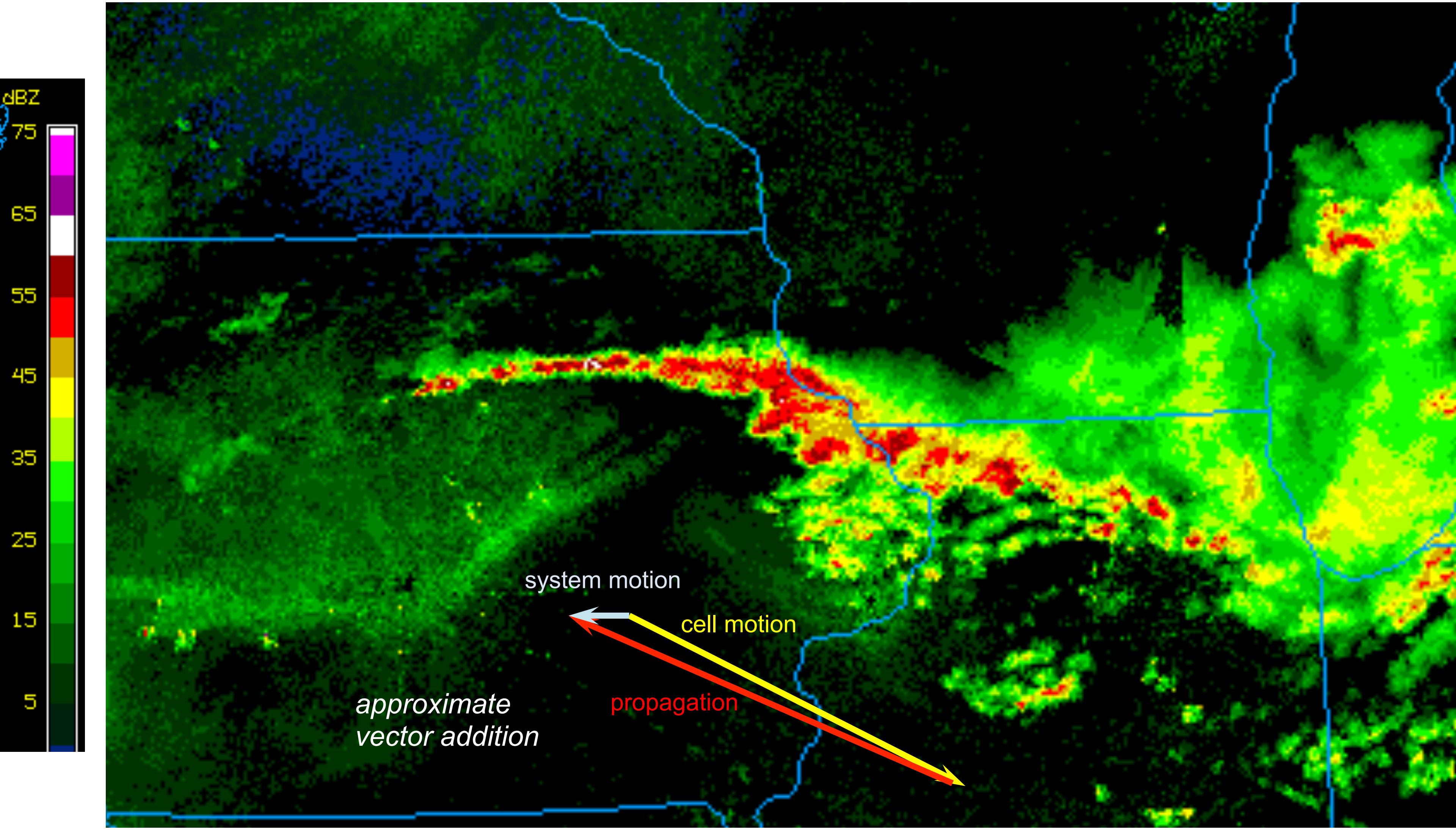
*animation in web browser

total precipitation, 18–19 Aug 2007



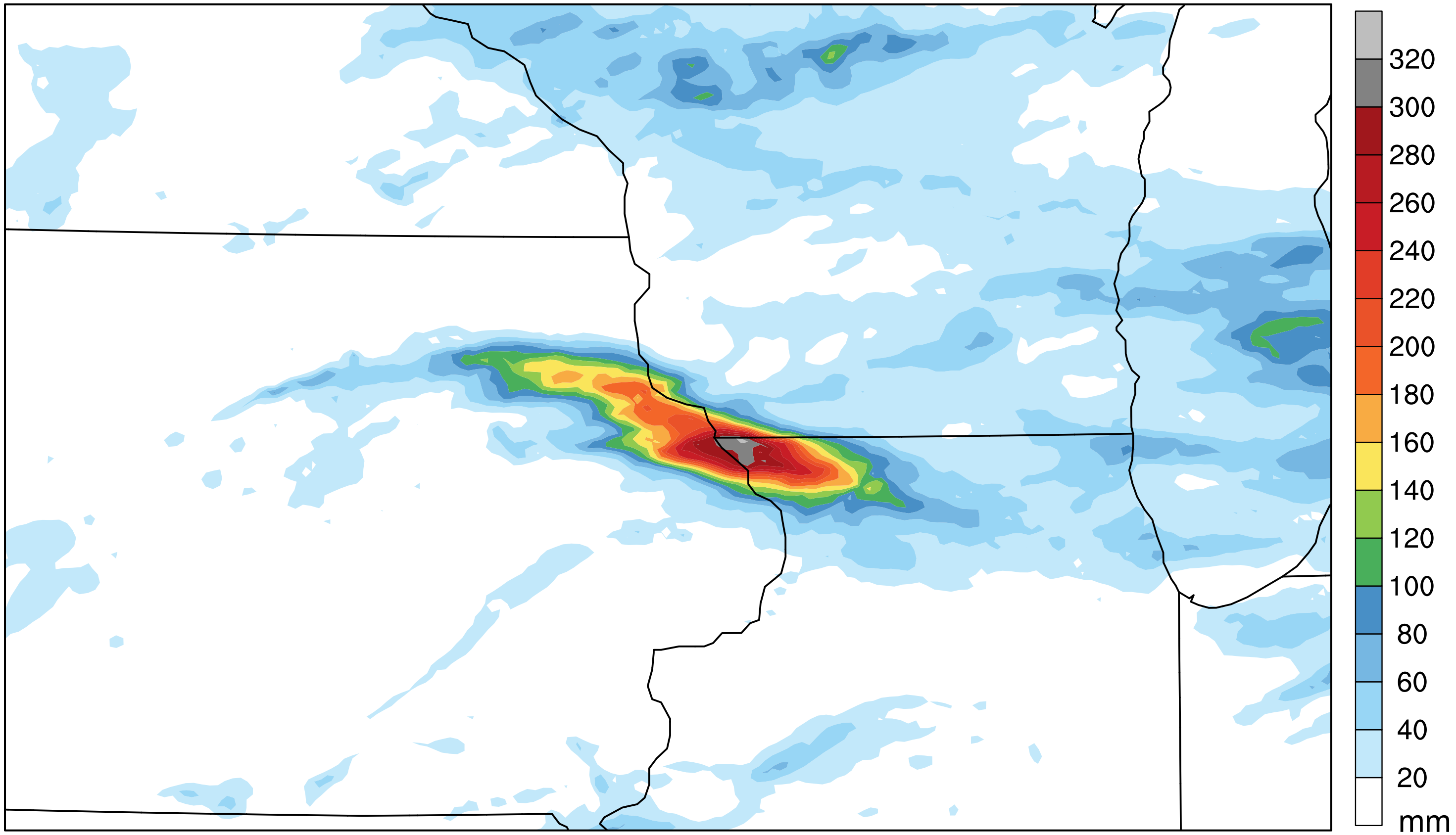
Example of mesoscale training and backbuilding

0700 UTC 28 Jul 2011



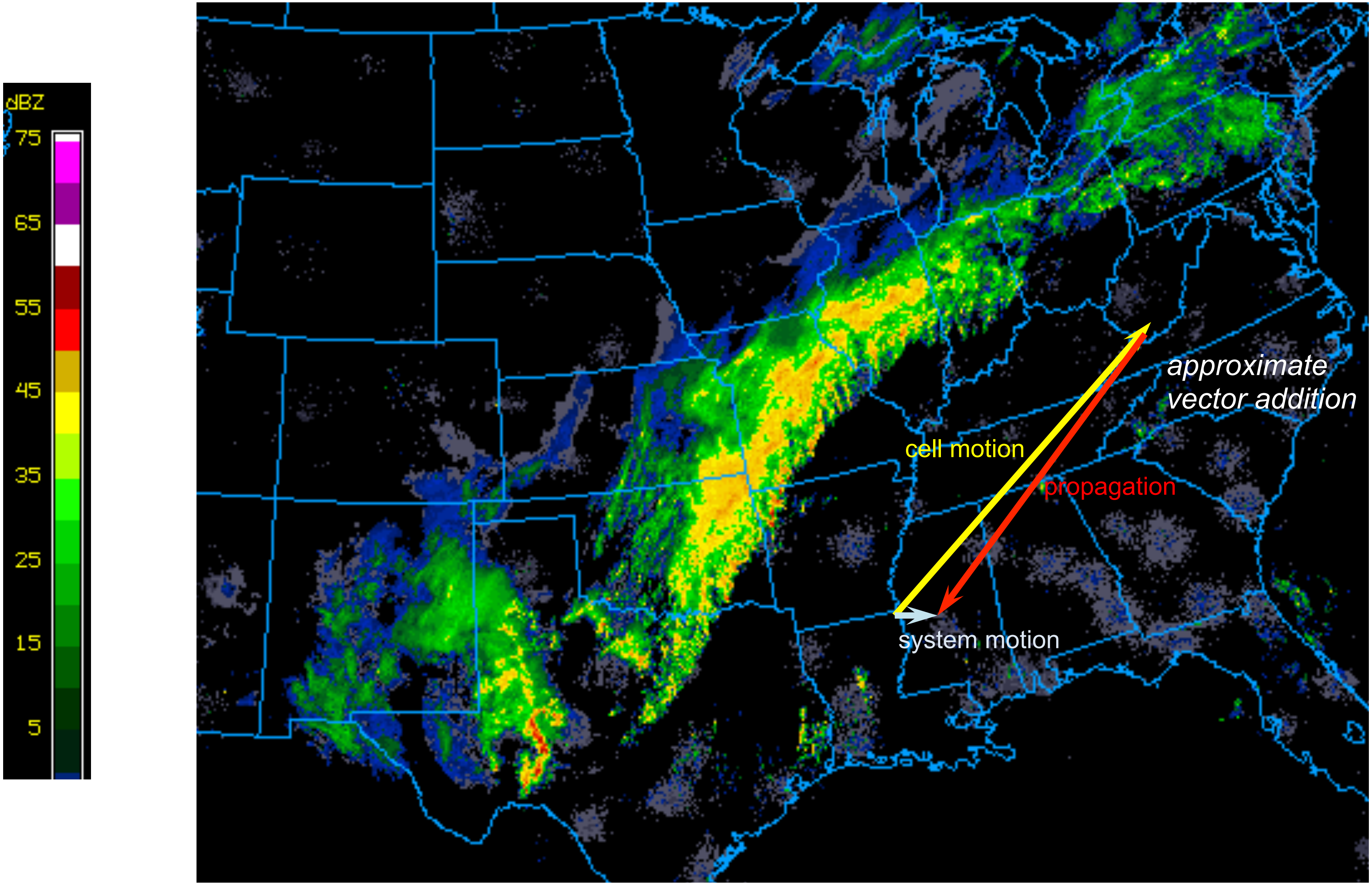
**animation in web browser*

total precipitation, 27–28 Jul 2011



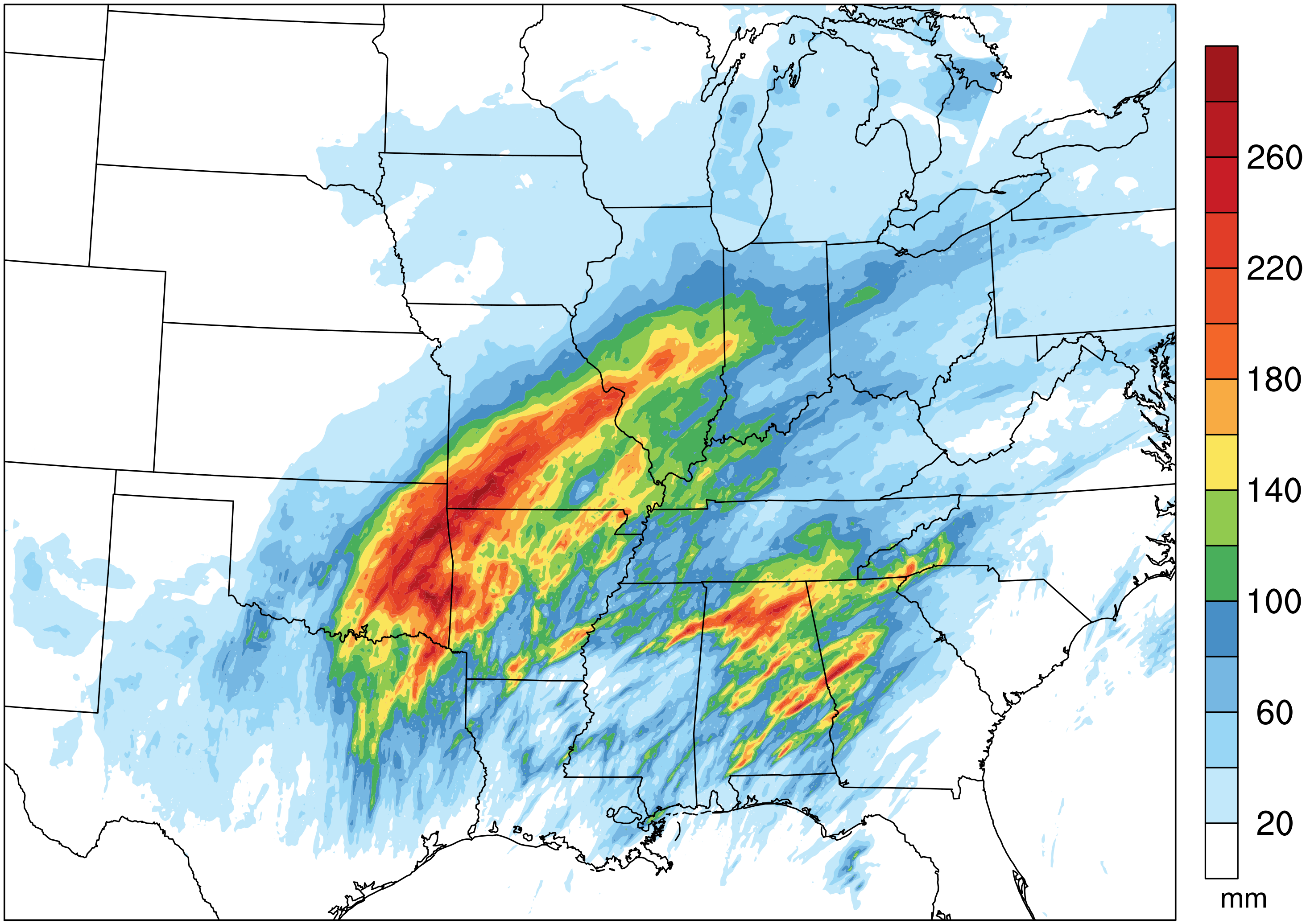
Example of training and backbuilding at larger scales

0400 UTC 27 Dec 2015



**animation in web browser*

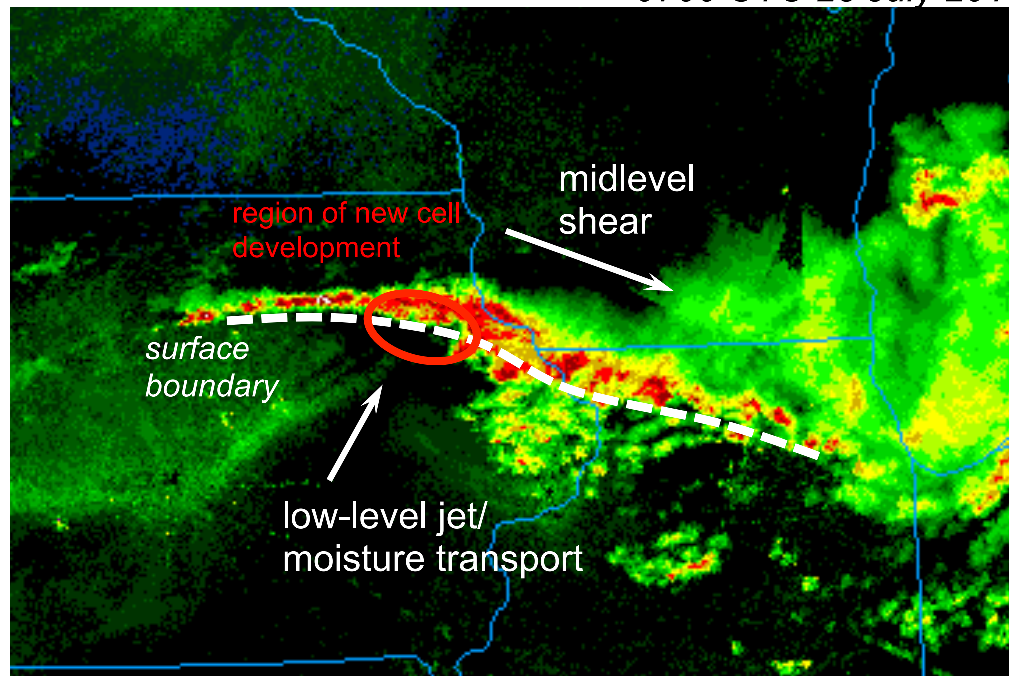
total precipitation, 25–30 Dec 2015

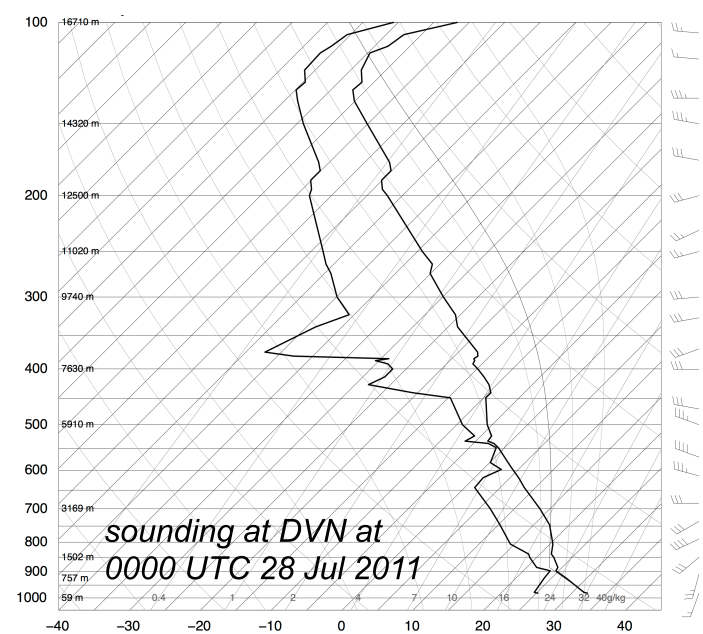


Environments of extreme precipitation-producing MCSs

- Often occur along fronts/boundaries in regions of deep warm advection
- Moist, unstable air supplied by strong low-level flow (e.g., low-level jet)
- Lifting where low-level flow intersects front/boundary, maximized on upstream flank of line aids in triggering convection
- Veering wind with height
  - reflects geostrophic warm advection
  - low-level wind has large component normal to front/boundary promoting lifting and triggering new convection
  - midlevel flow mostly parallel to front/boundary leads to line-parallel cell motion

0700 UTC 28 July 2011





Archetypal scenarios for extreme precipitation from Maddox et al. (1979)

"frontal"

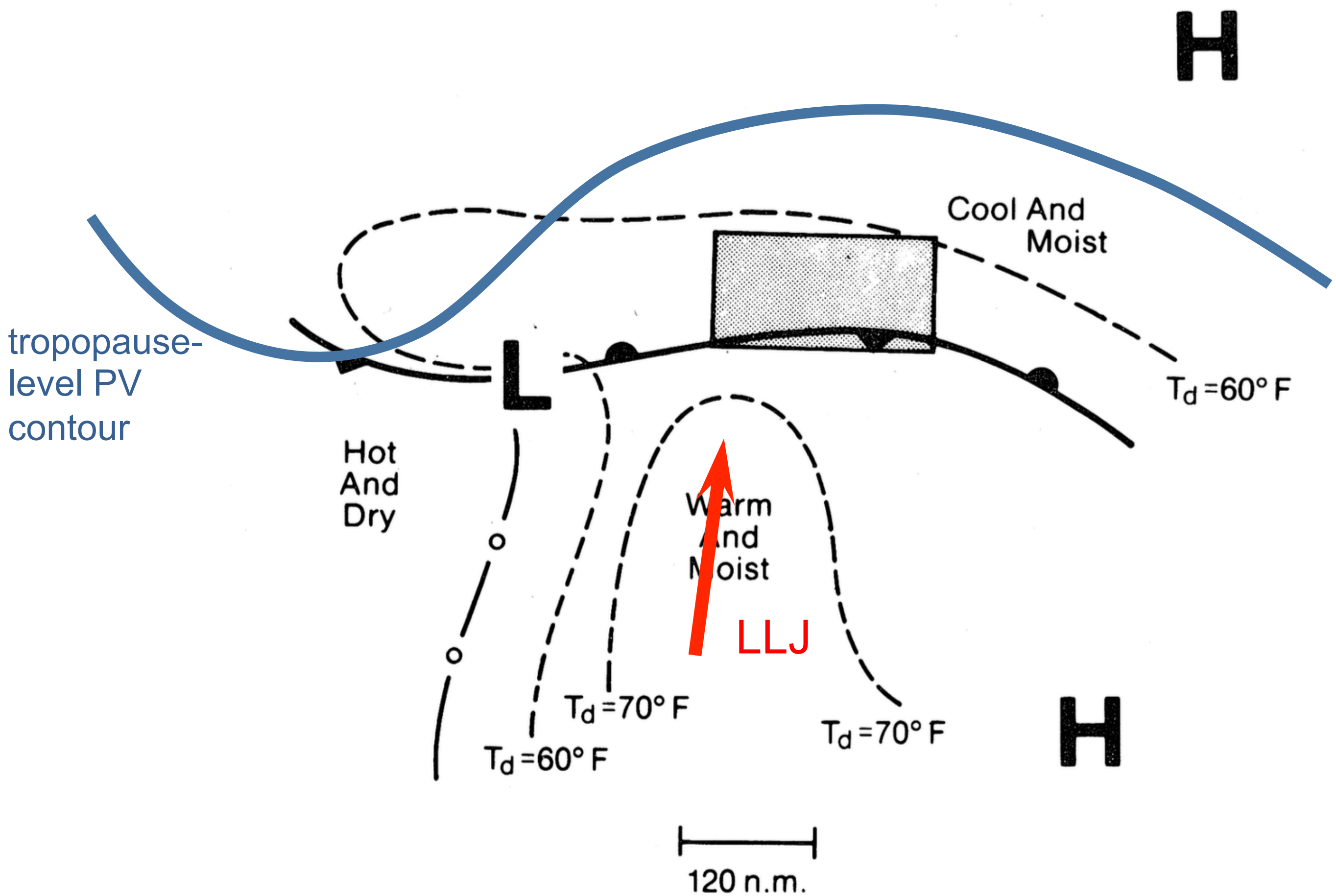


Fig. 8a from Maddox et al. (1979)

An example of "frontal" scenario from the literature

TC Erin "predecessor rain event" 19 Aug 2007

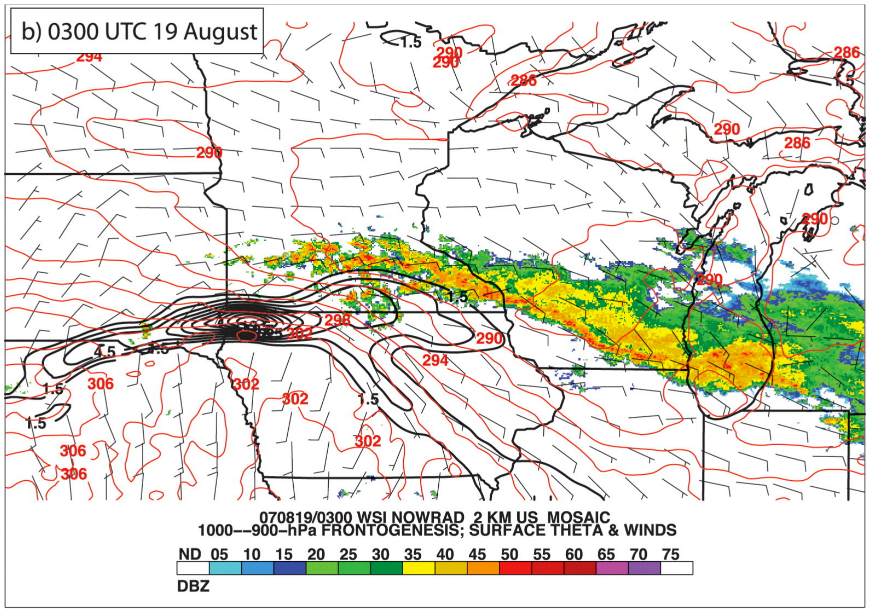


Fig. 4 from Schumacher et al. (2011): Radar reflectivity, near-surface wind, potential temperature, frontogenesis

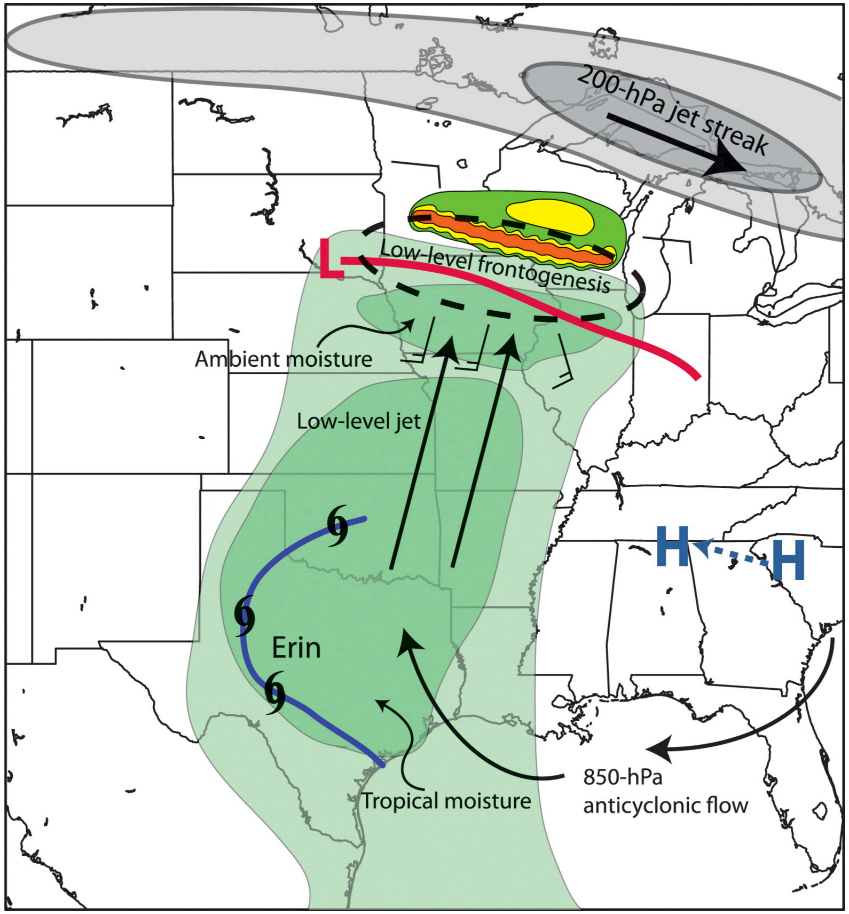


Fig. 2 from Schumacher et al. (2011): Schematic illustration of event

Archetypal scenarios for extreme precipitation from Maddox et al. (1979)

"mesohigh"

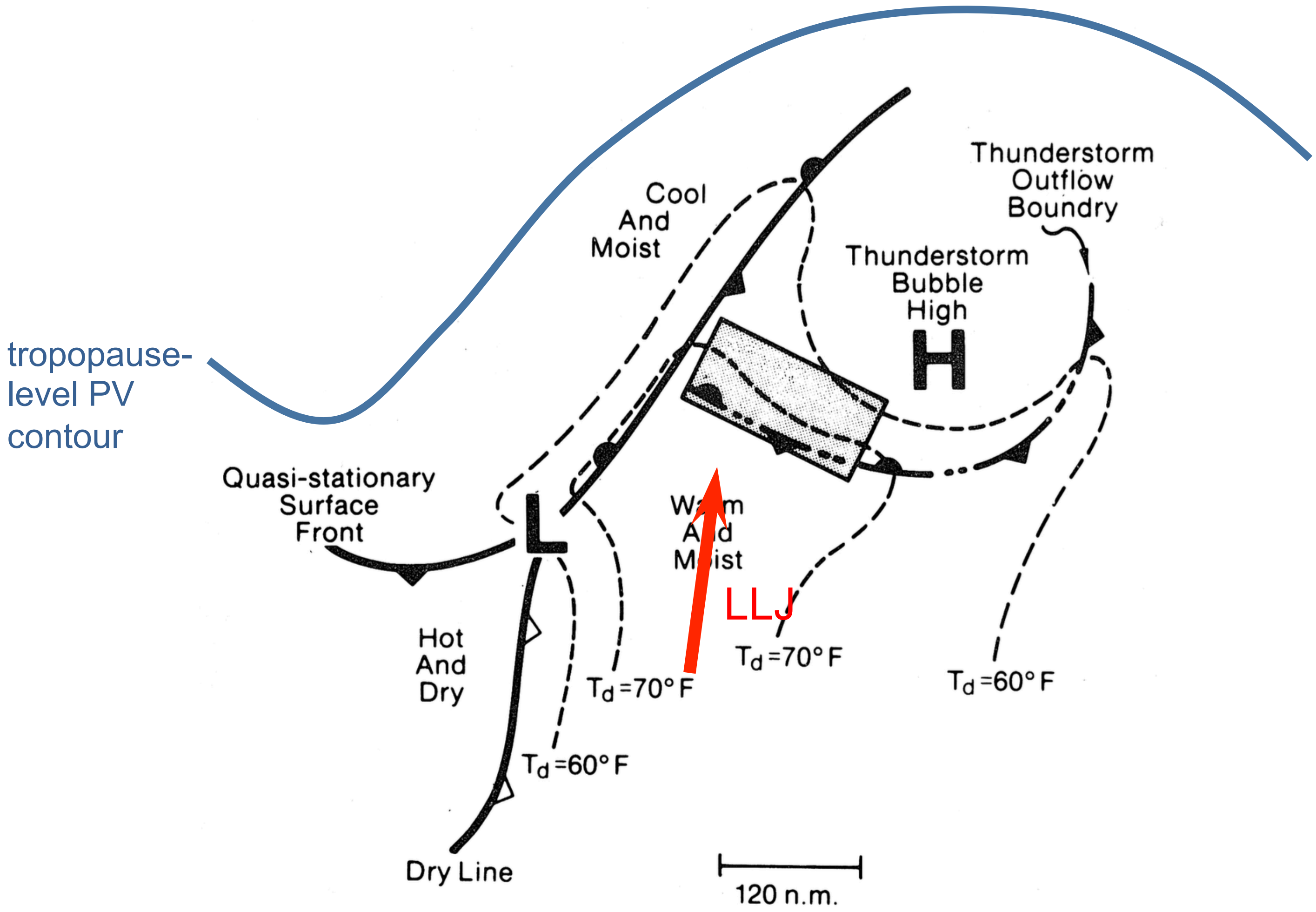


Fig. 10a from Maddox et al. (1979)

An example of “mesohigh” scenario from the literature

Backbuilding MCS 28 July 2011

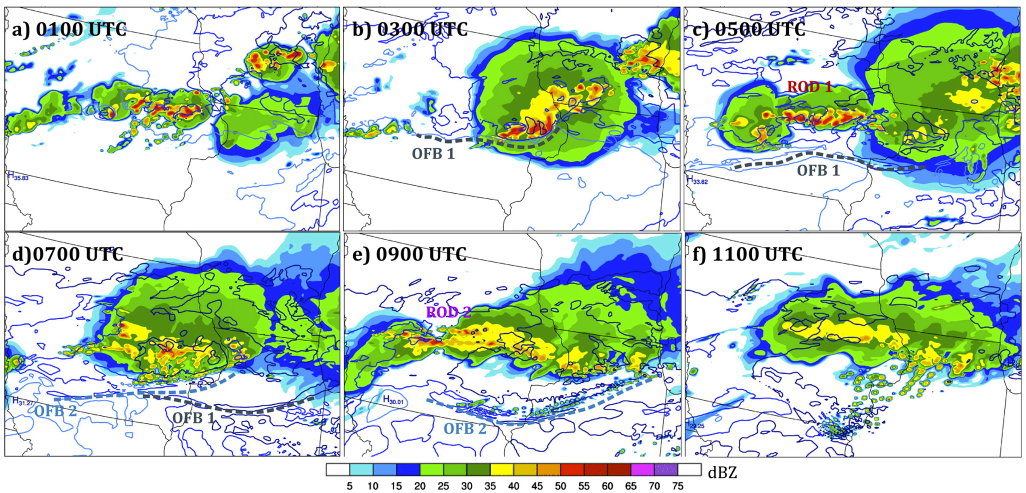


Fig. 10 from Peters and Schumacher (2015): Simulated radar reflectivity, surface temperature

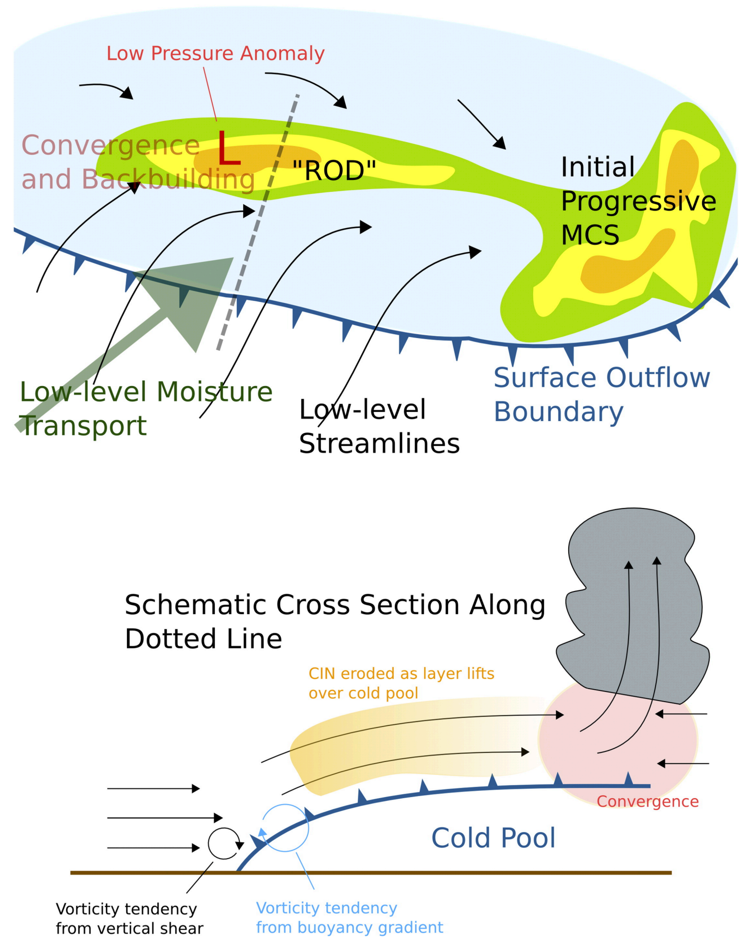


Fig. 25 from Peters and Schumacher (2015): Schematic illustration of event

Archetypal scenarios for extreme precipitation from Maddox et al. (1979)

"synoptic"

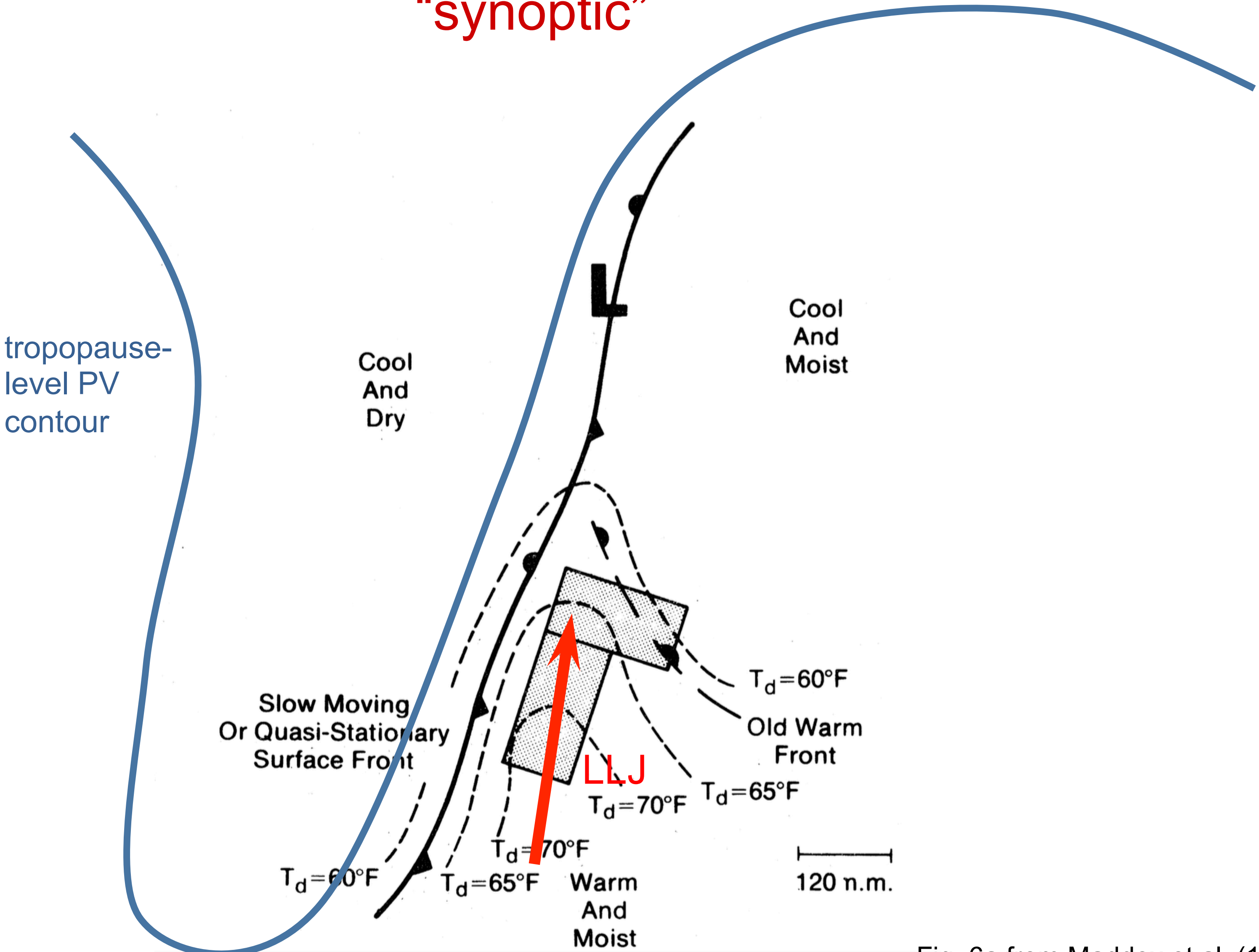
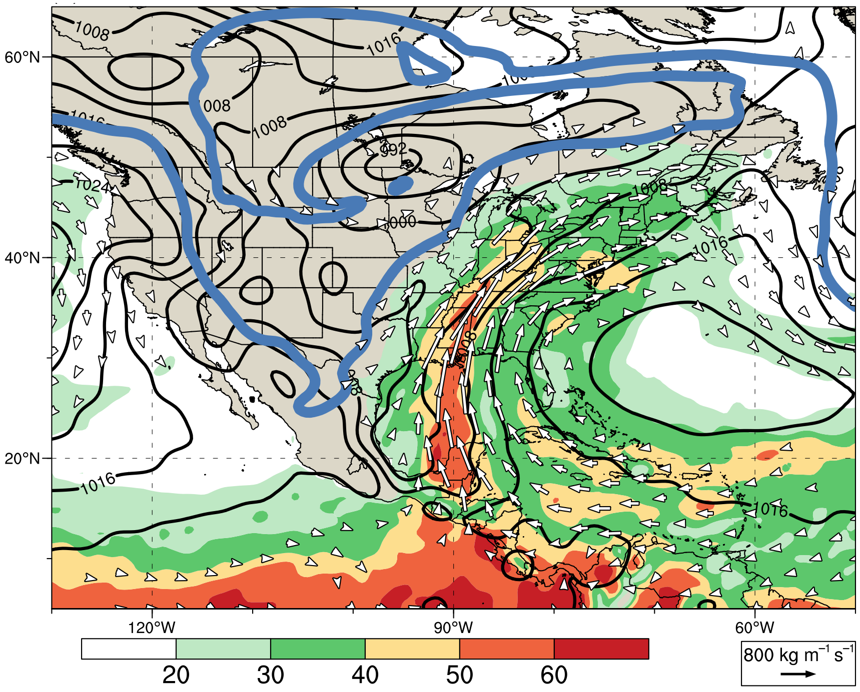


Fig. 6a from Maddox et al. (1979)

An example of “synoptic” scenario from the literature

Nashville flood 1–3 May 2010

1200 UTC 2 May



PW (mm, shading), SLP (hPa, black), IVT vectors (kg m^{-1} s^{-1}), and 2-PVU contour on the 320-K surface (blue)

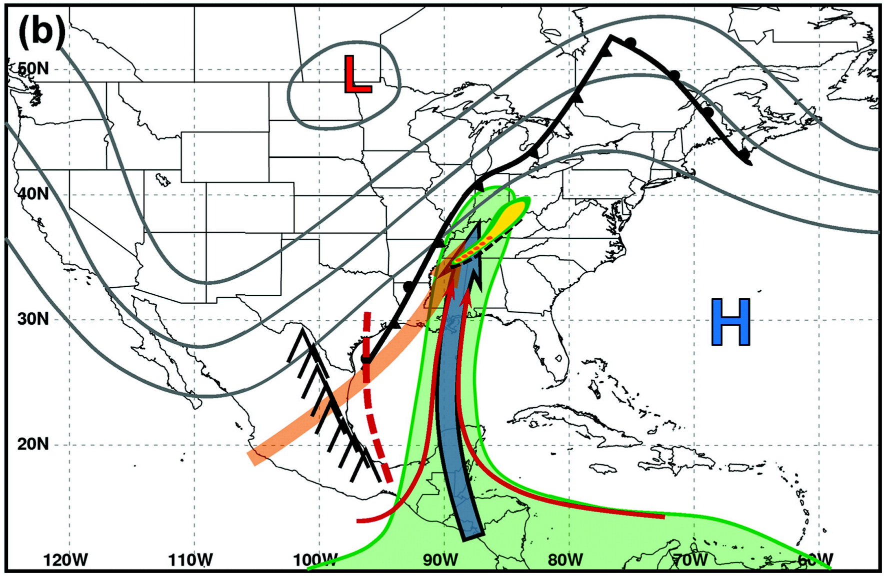
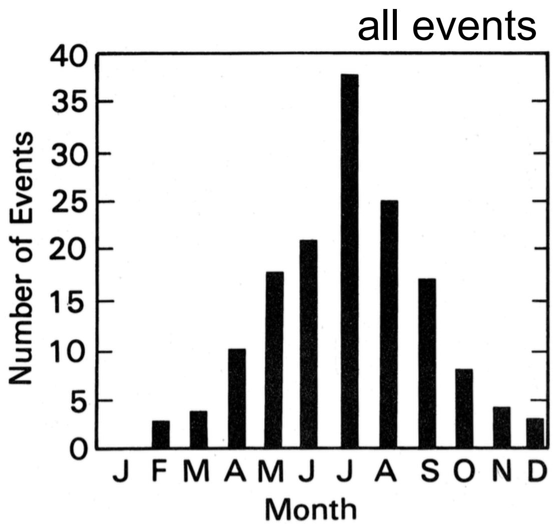
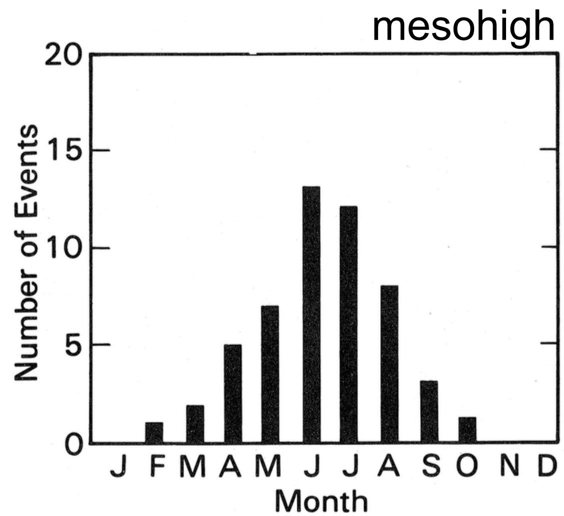
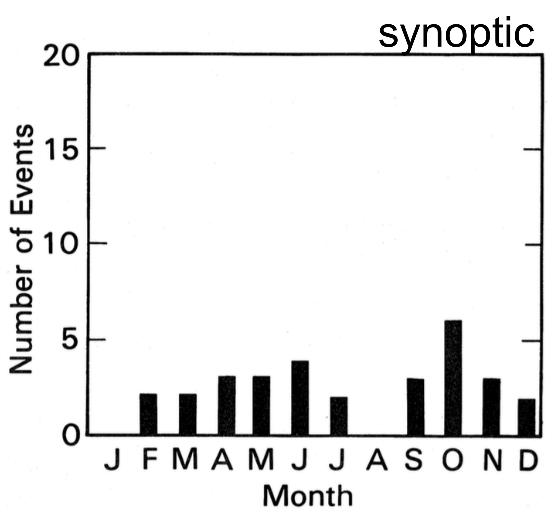


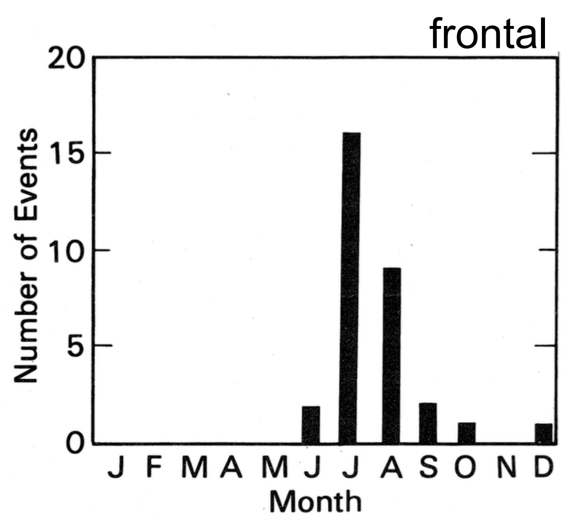
Fig. 17 from Moore et al. (2012): Schematic illustration of event

Archetypal scenarios for extreme precipitation from Maddox et al. (1979)









Figs. 2, 5, 7, 9 from Maddox et al. (1979)

Archetypal scenarios for extreme precipitation from Maddox et al. (1979)

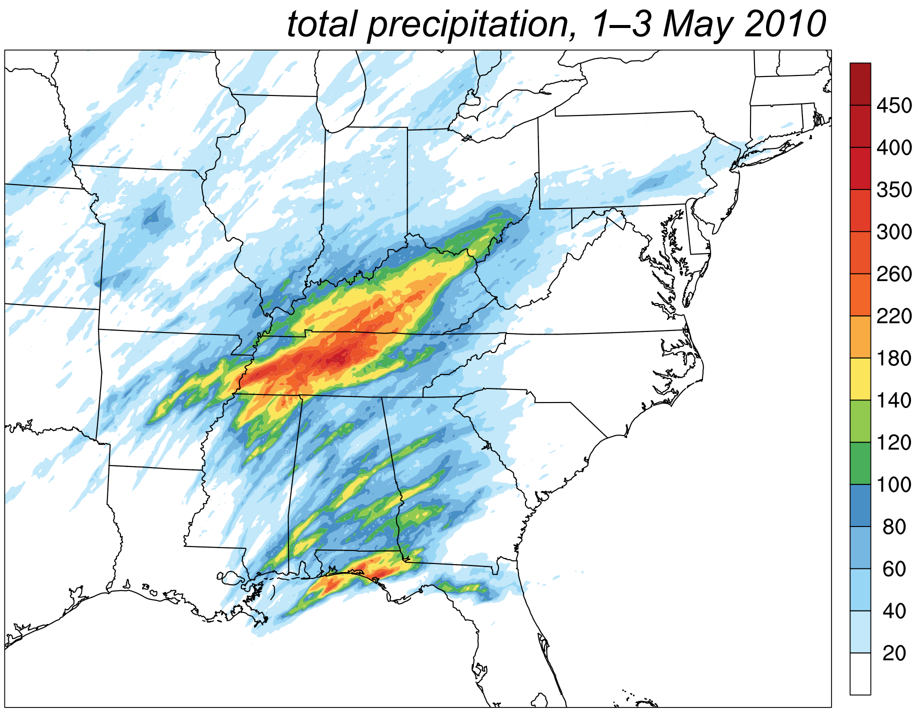
Takeaway concepts

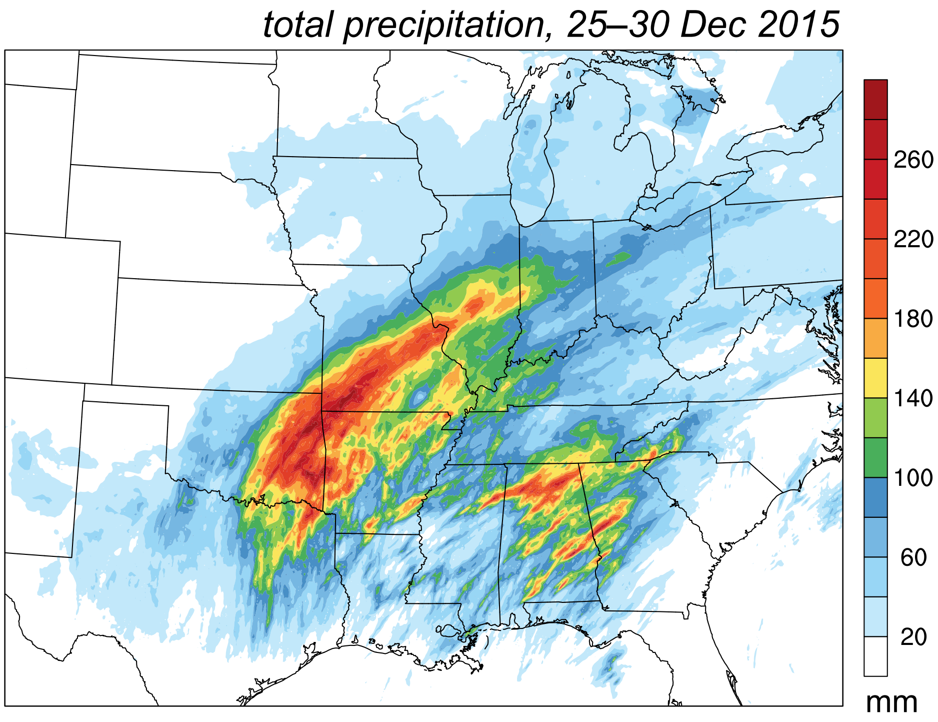
- Slow moving fronts or boundaries provide lifting to focus heavy precipitation
- Lower-tropospheric flow/low-level jet supplies moisture for heavy precipitation
- Frontal and mesohigh scenarios mostly occur in warm season
- Synoptic scenario, involving high-amplitude baroclinic waves, most common in non-summer months
- Synoptic scenario often associated with more spatially extensive regions of heavy precipitation than other two scenarios
- Fixture of all scenarios is persistence of ingredients for heavy precipitation!

Lingering science questions regarding “synoptic” EPEs

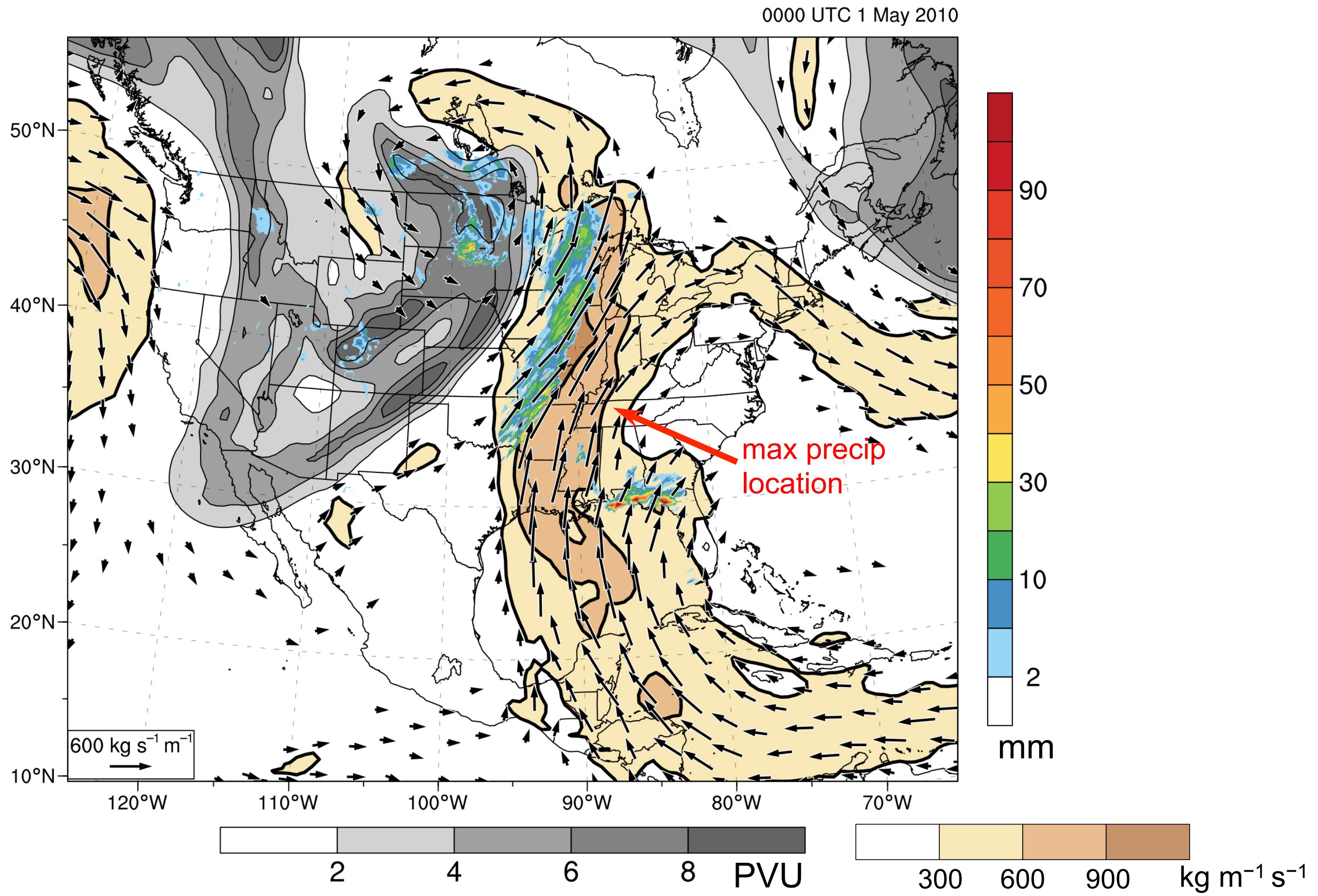
- What dynamical processes result in this scenario?
- How are the ingredients for heavy precipitation established and maintained in this scenario?

Heuristic examination of two cases



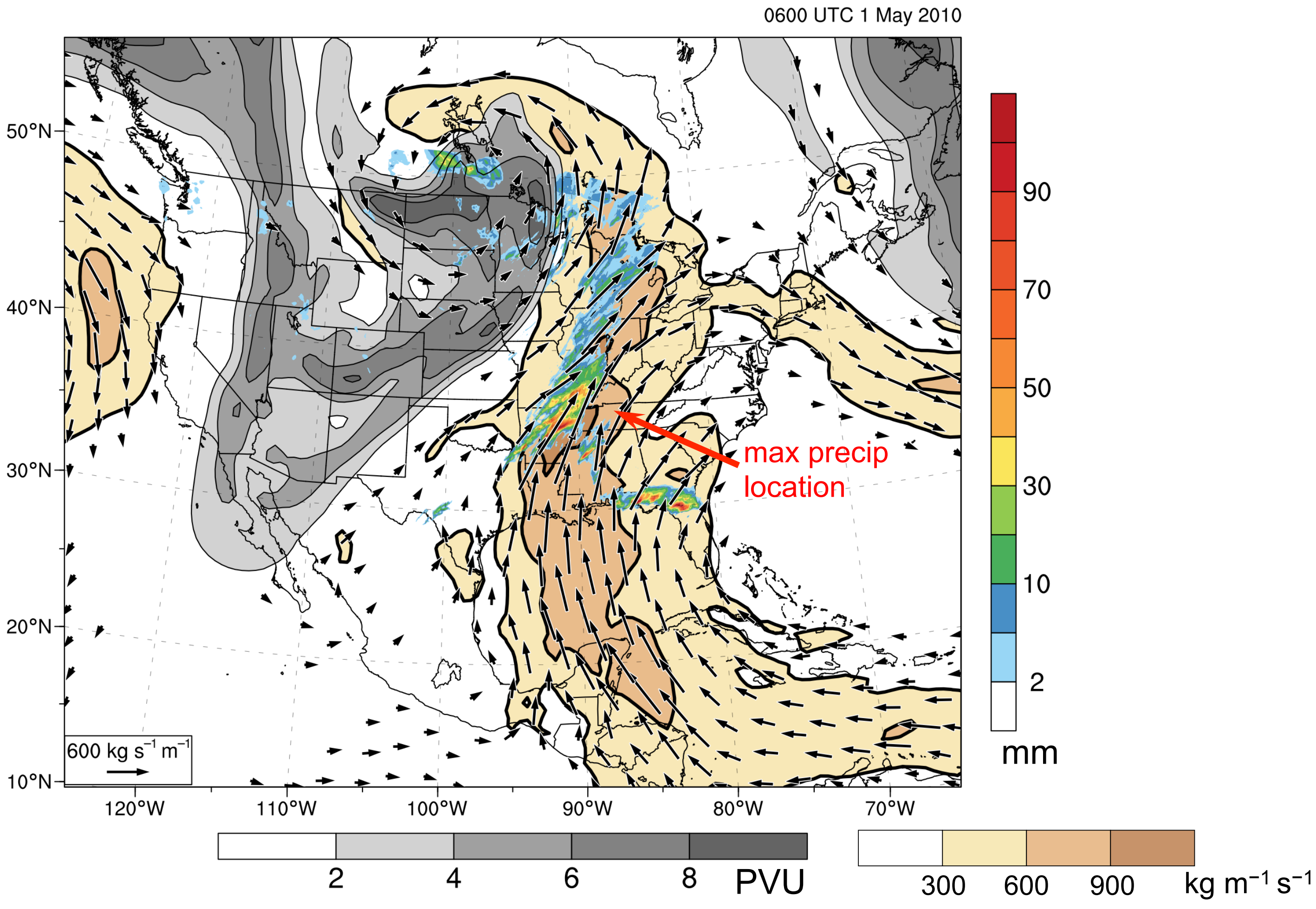


May 2010 case



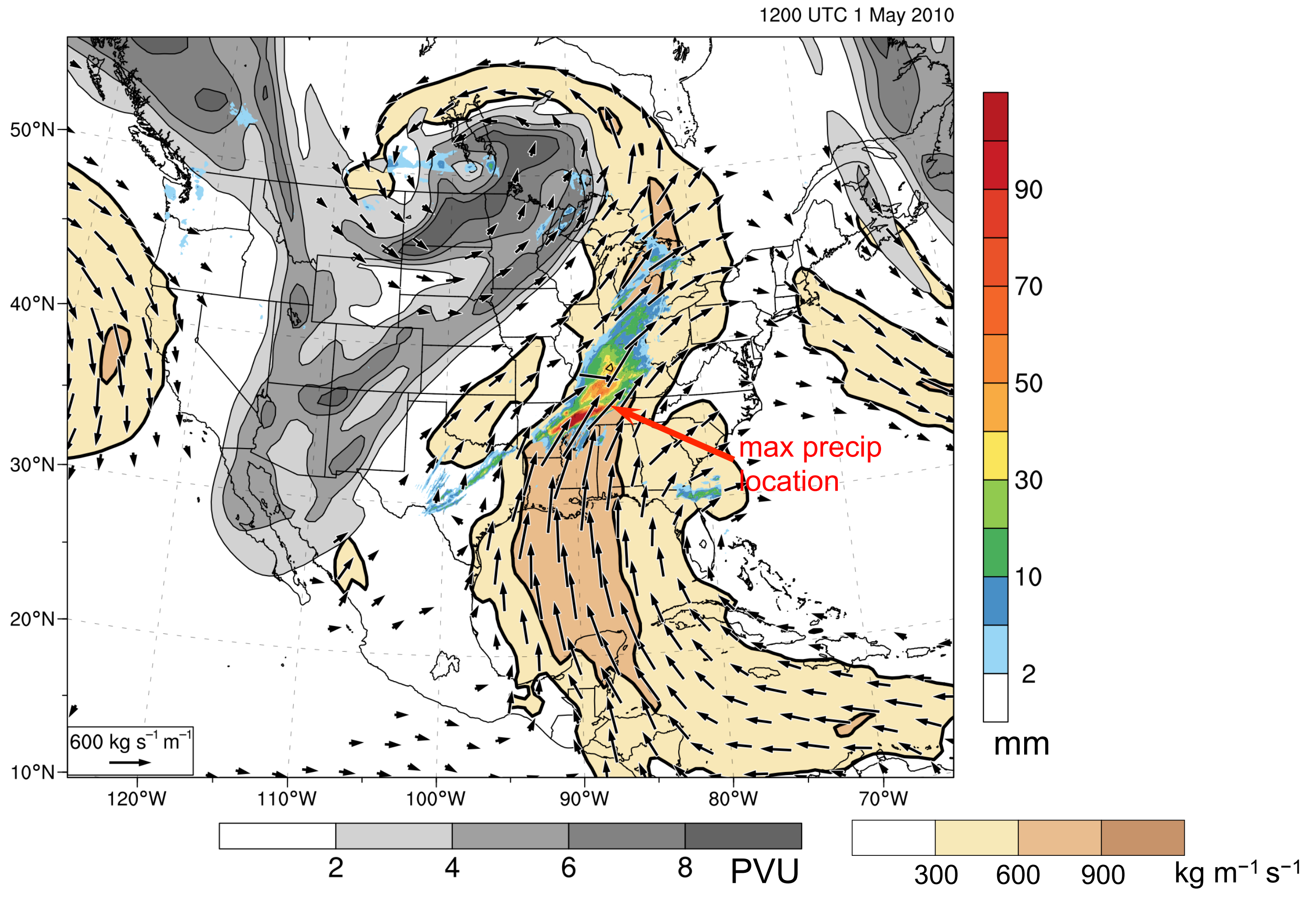
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

May 2010 case



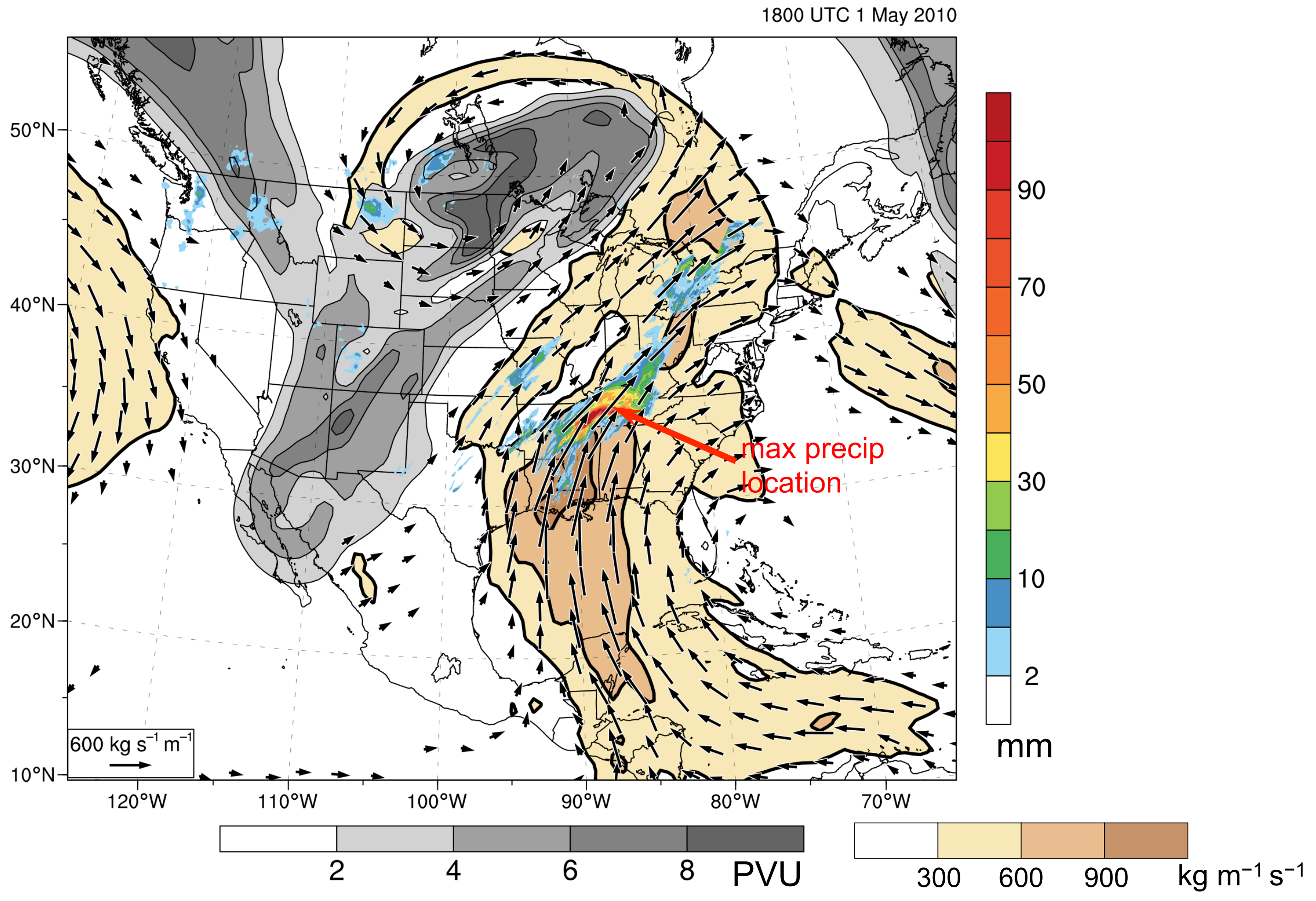
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

May 2010 case



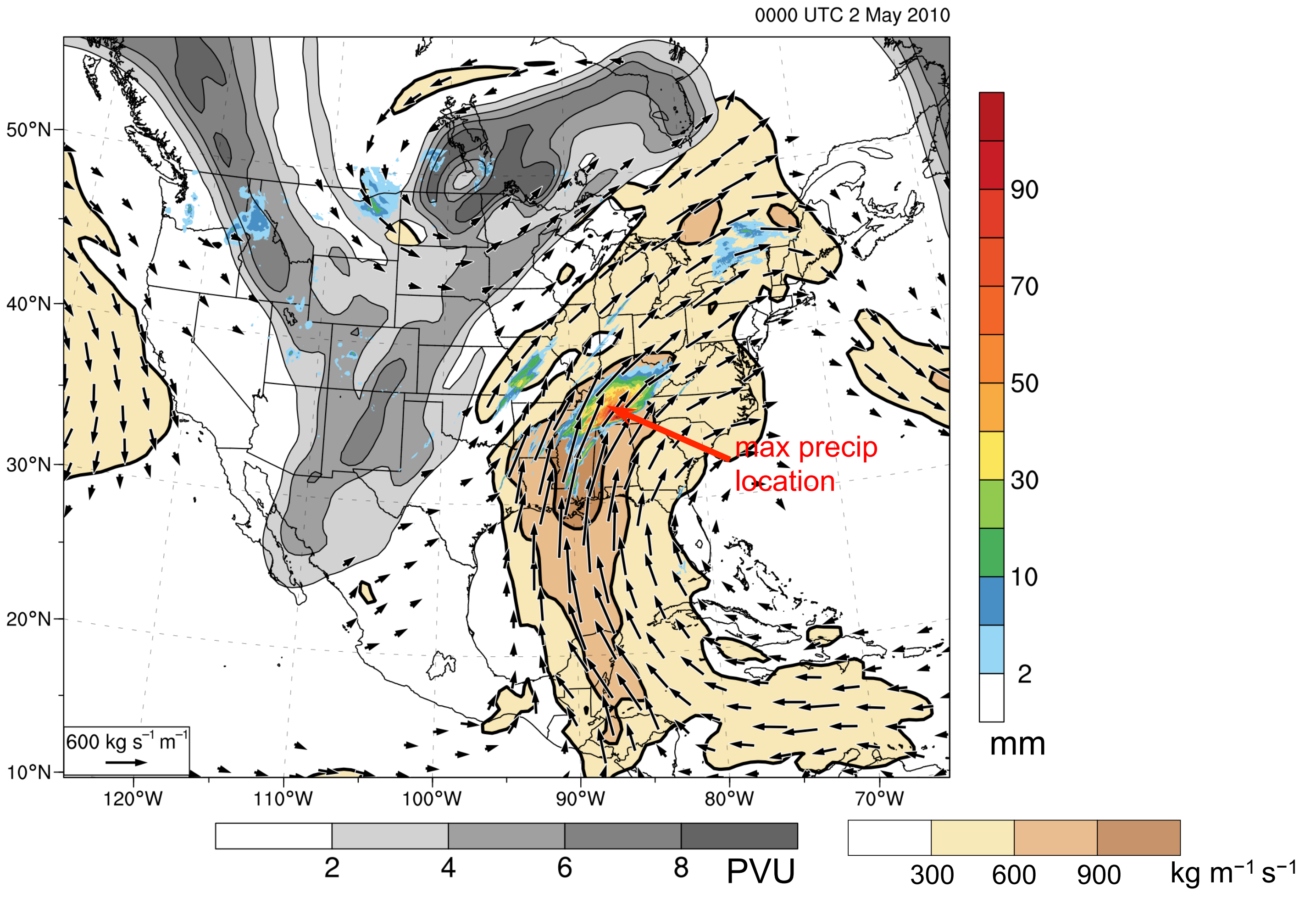
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

May 2010 case



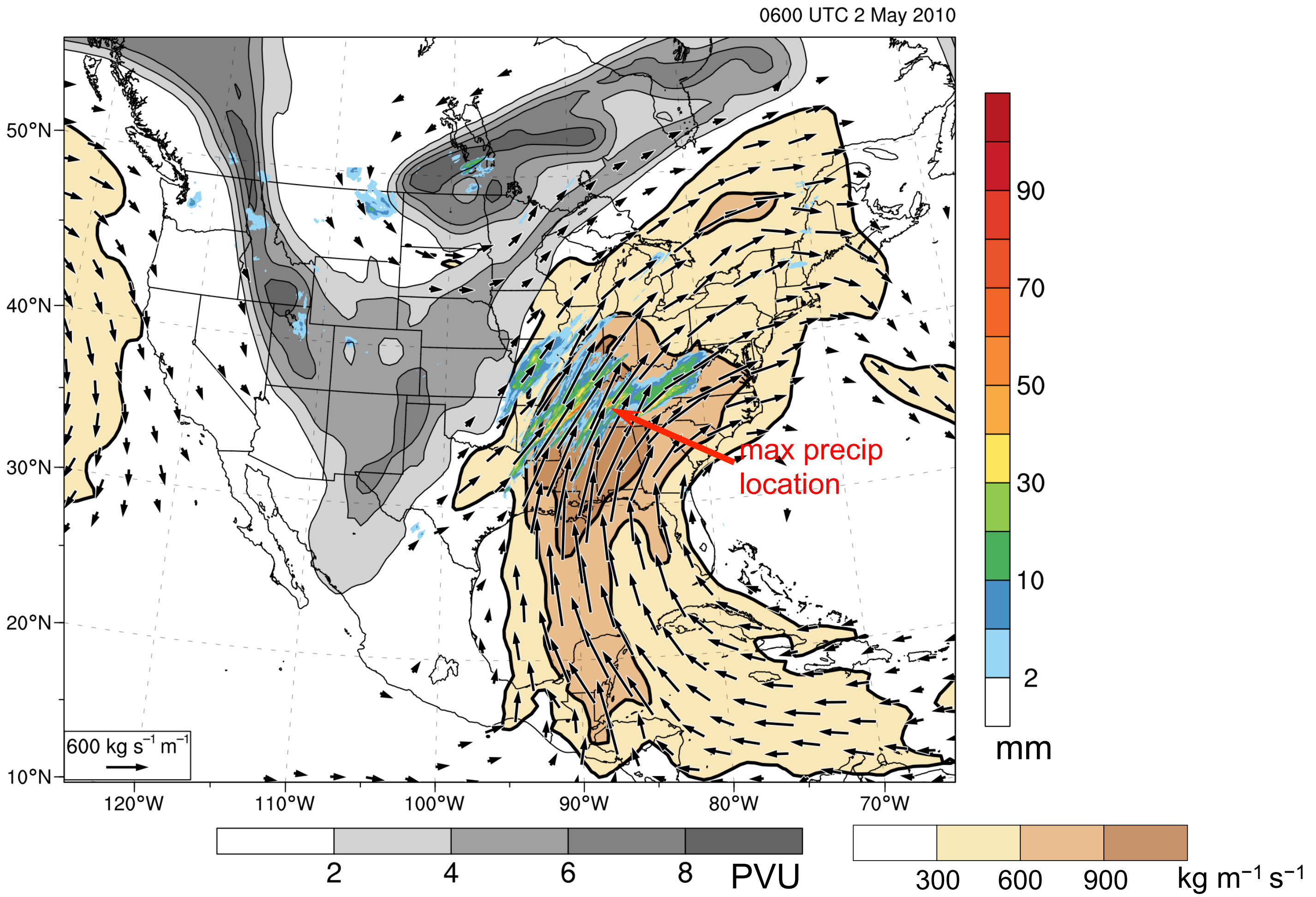
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

May 2010 case



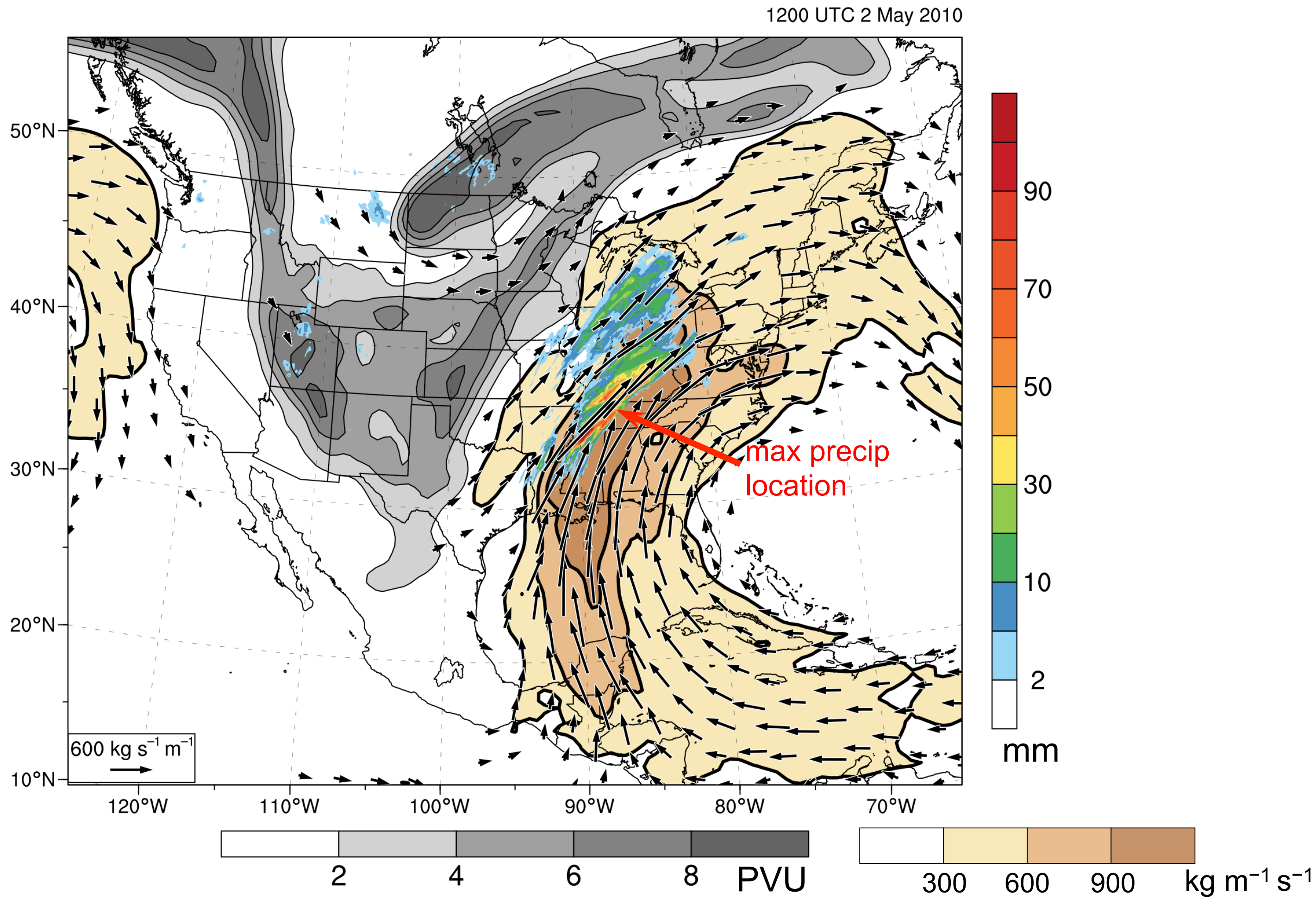
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

May 2010 case



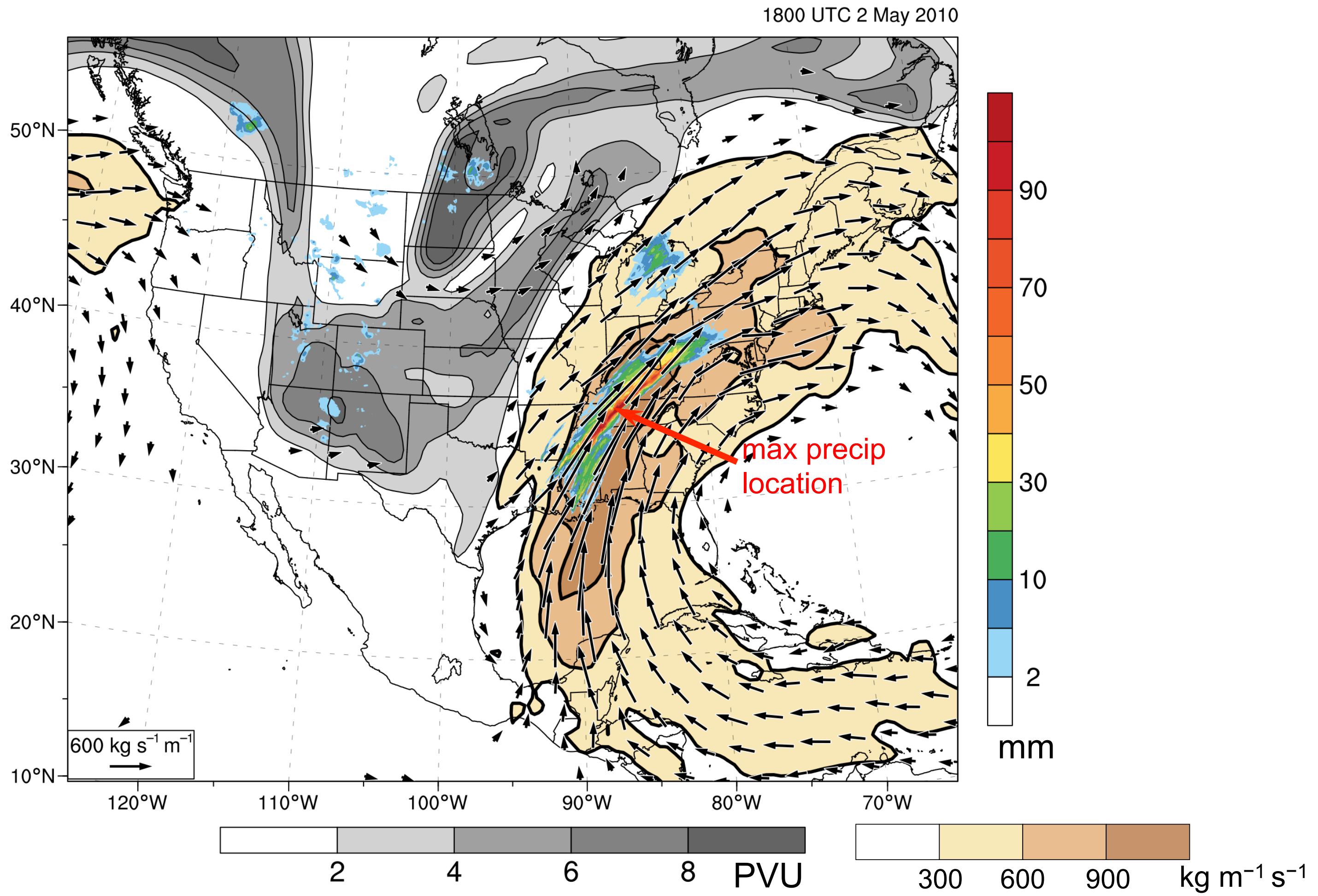
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

May 2010 case



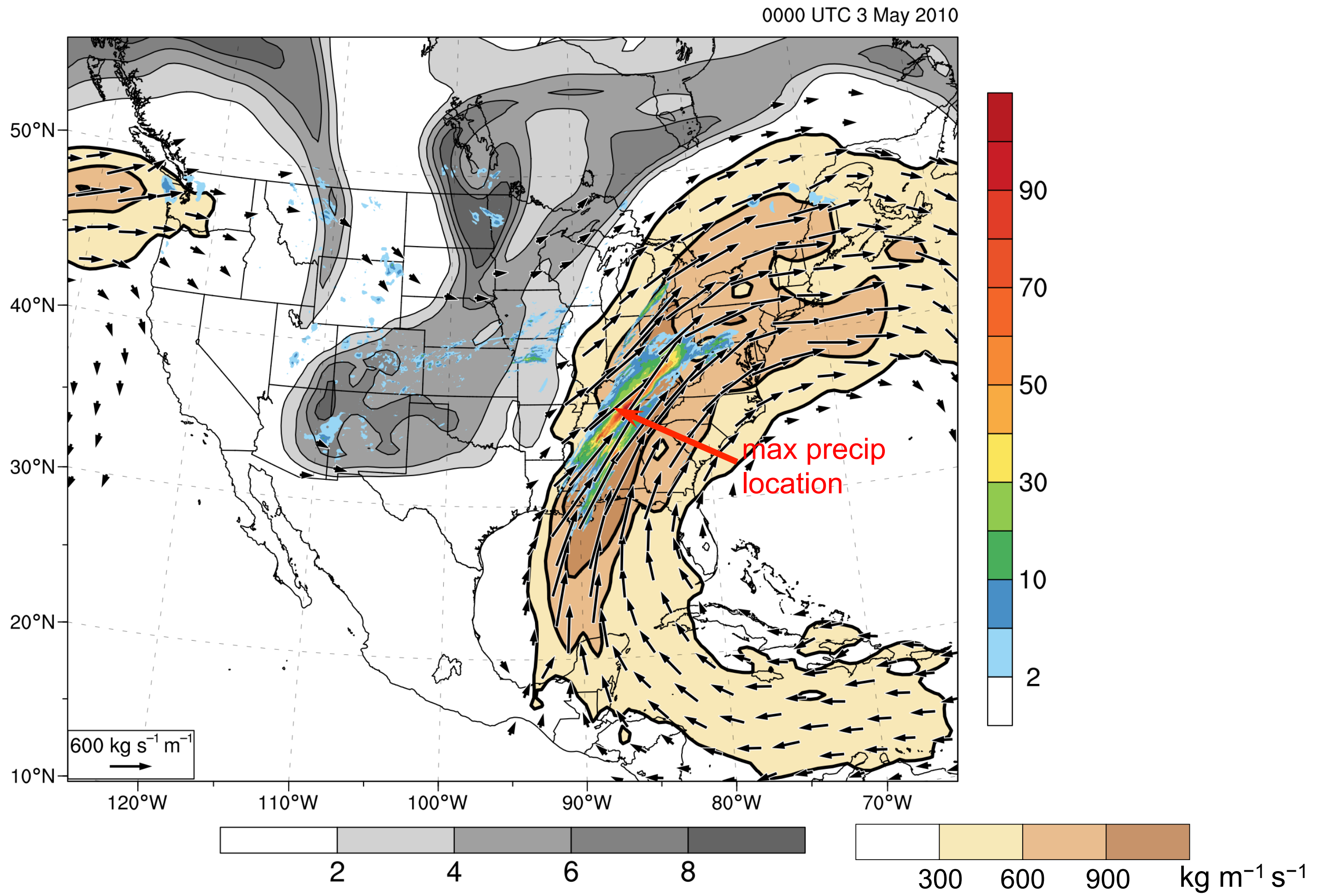
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

May 2010 case



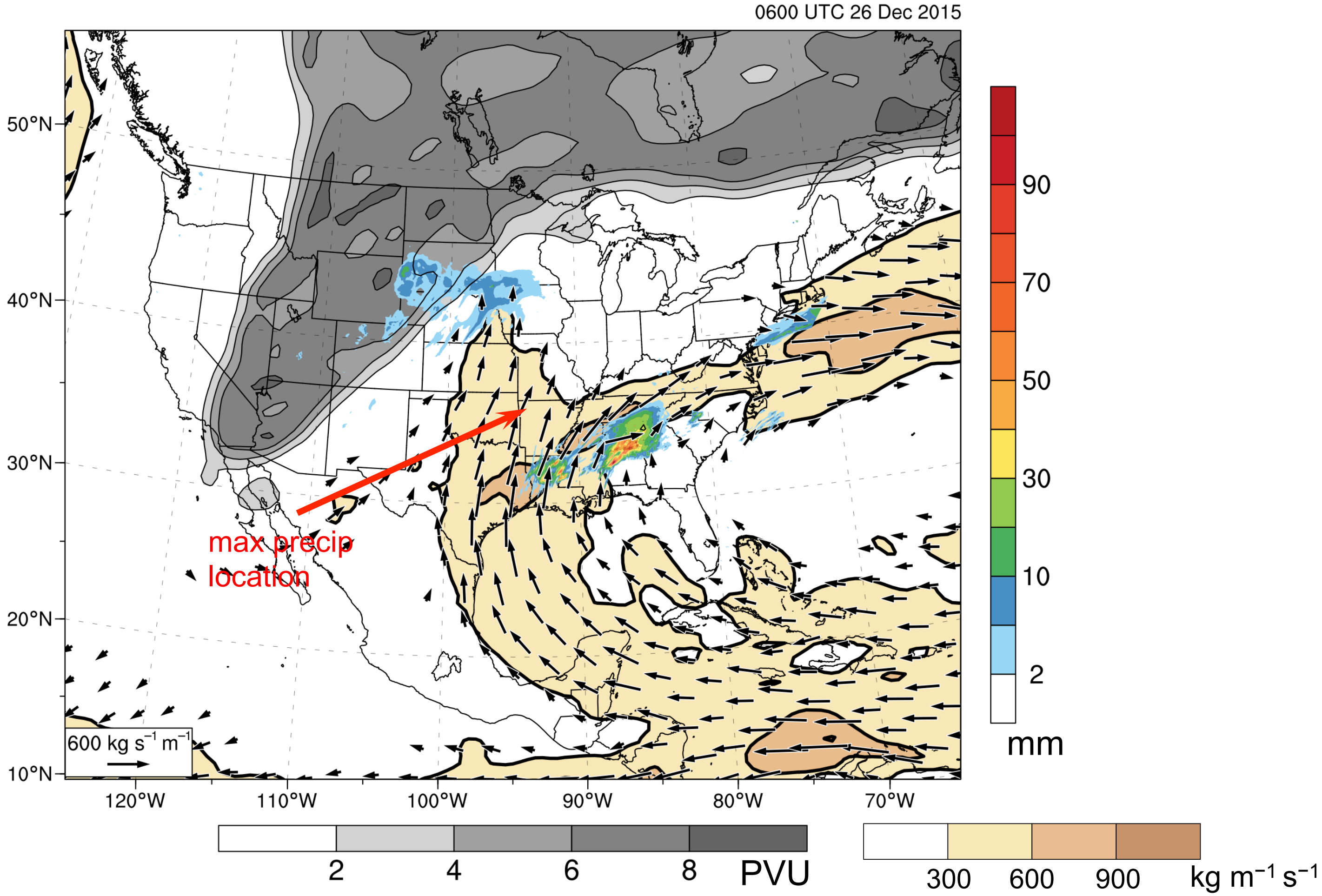
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

May 2010 case



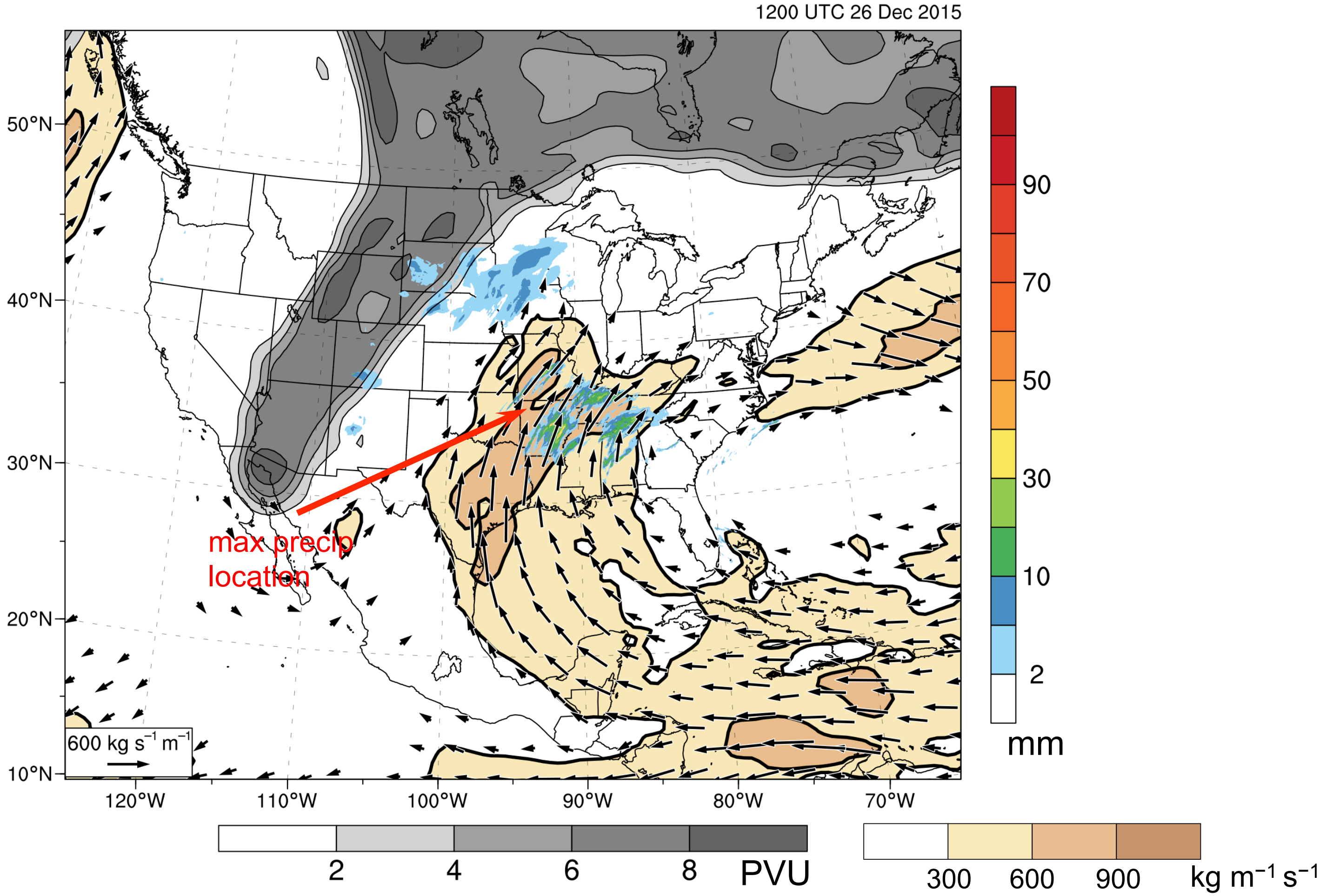
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

Dec 2015 case



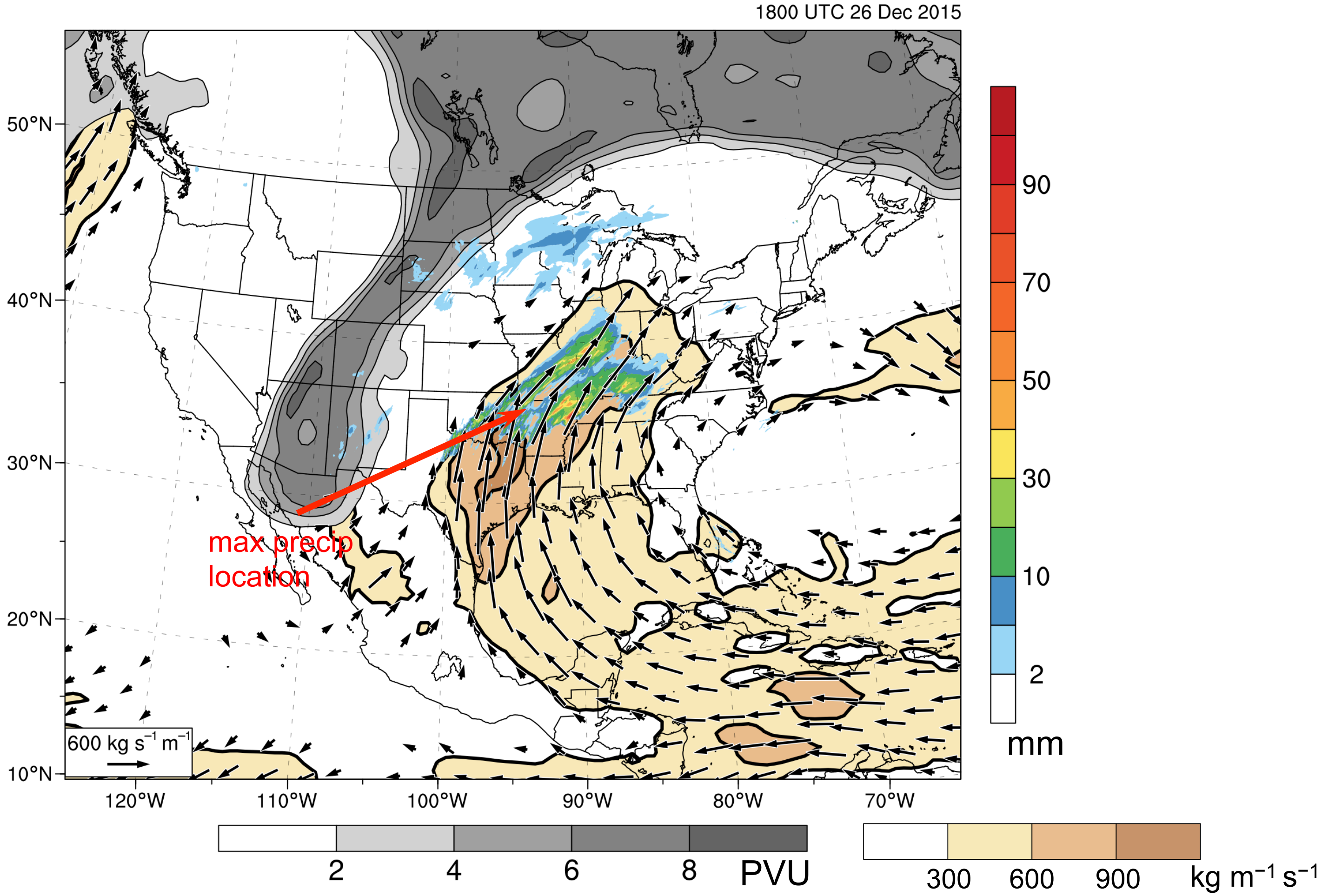
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

Dec 2015 case



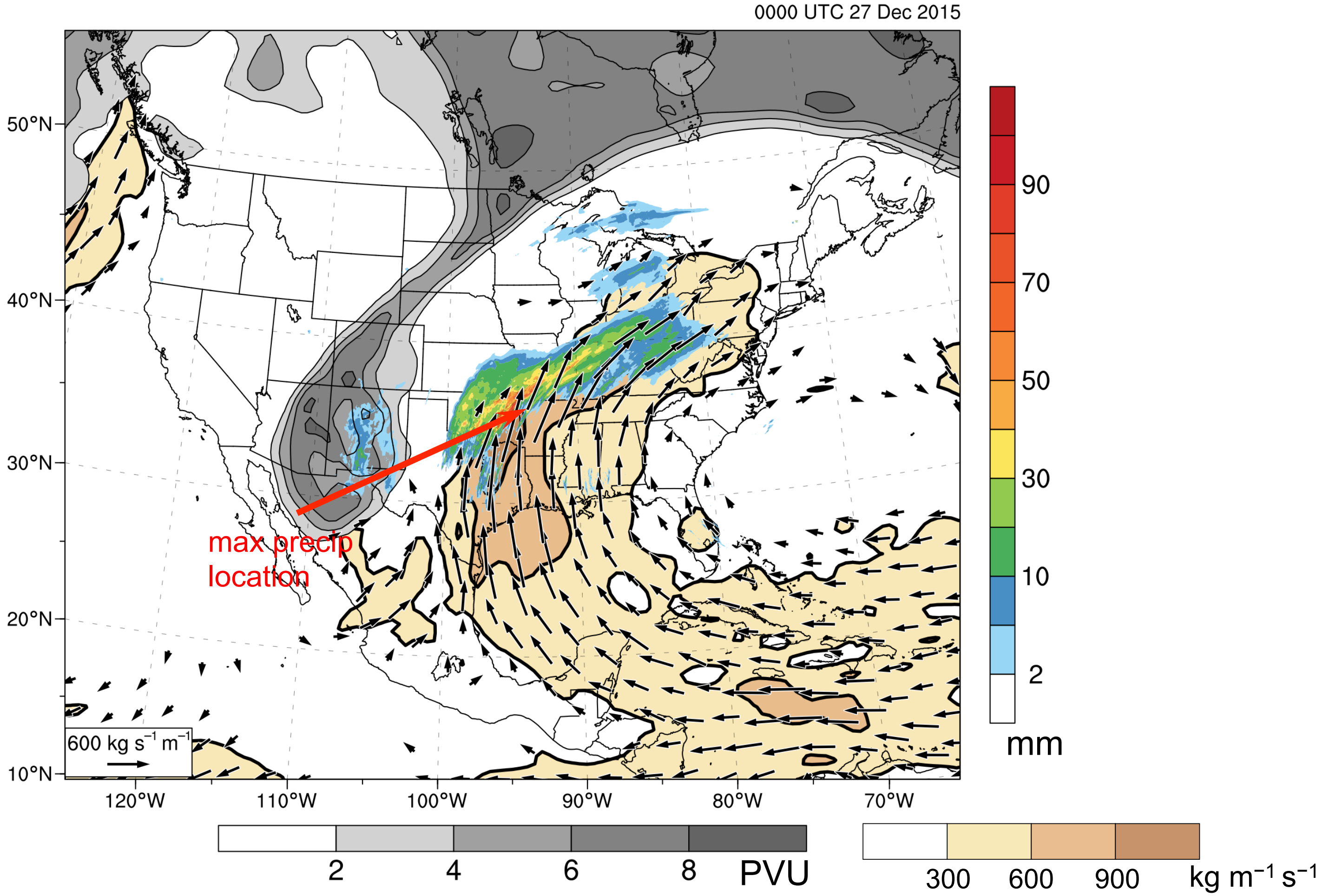
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

Dec 2015 case



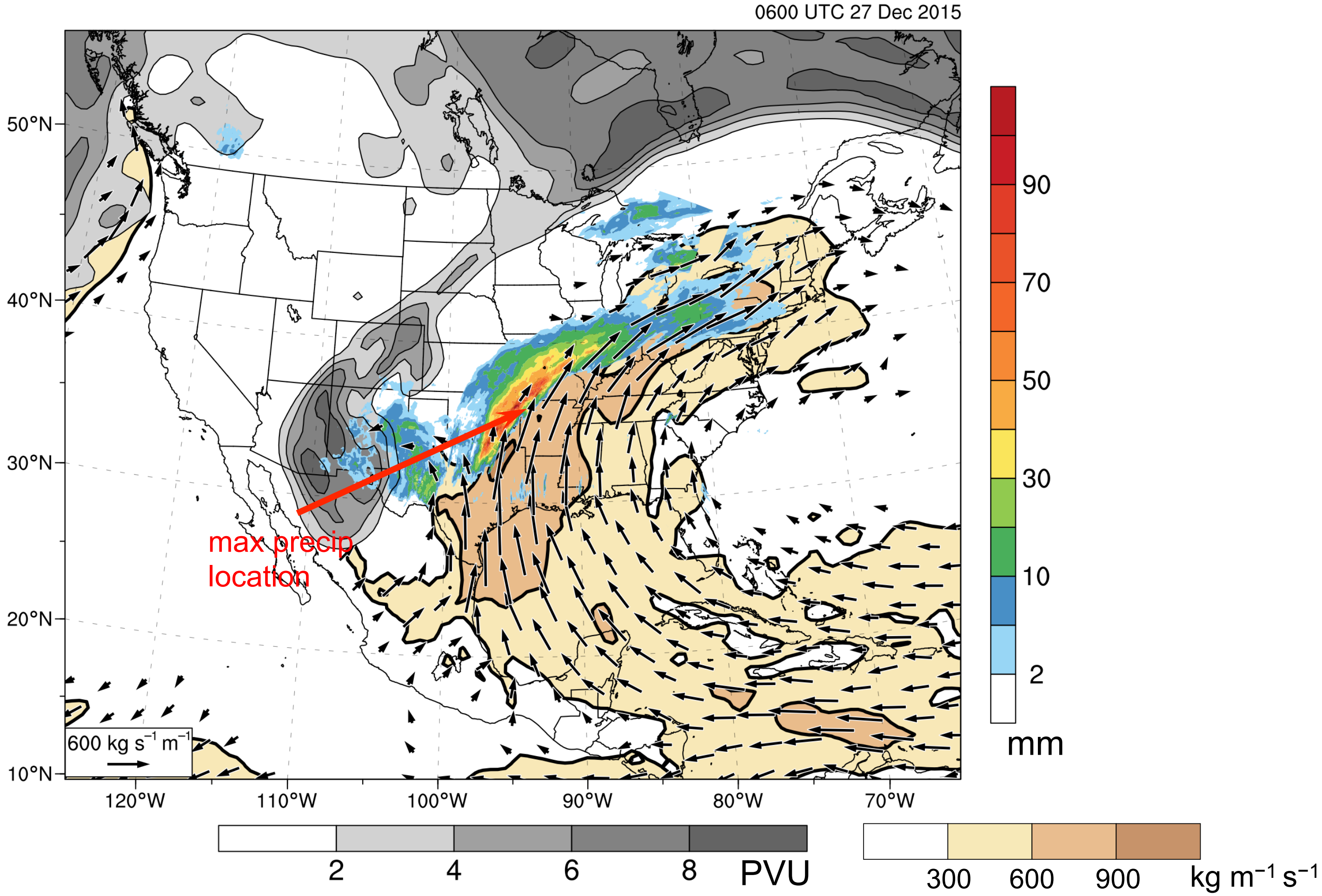
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

Dec 2015 case



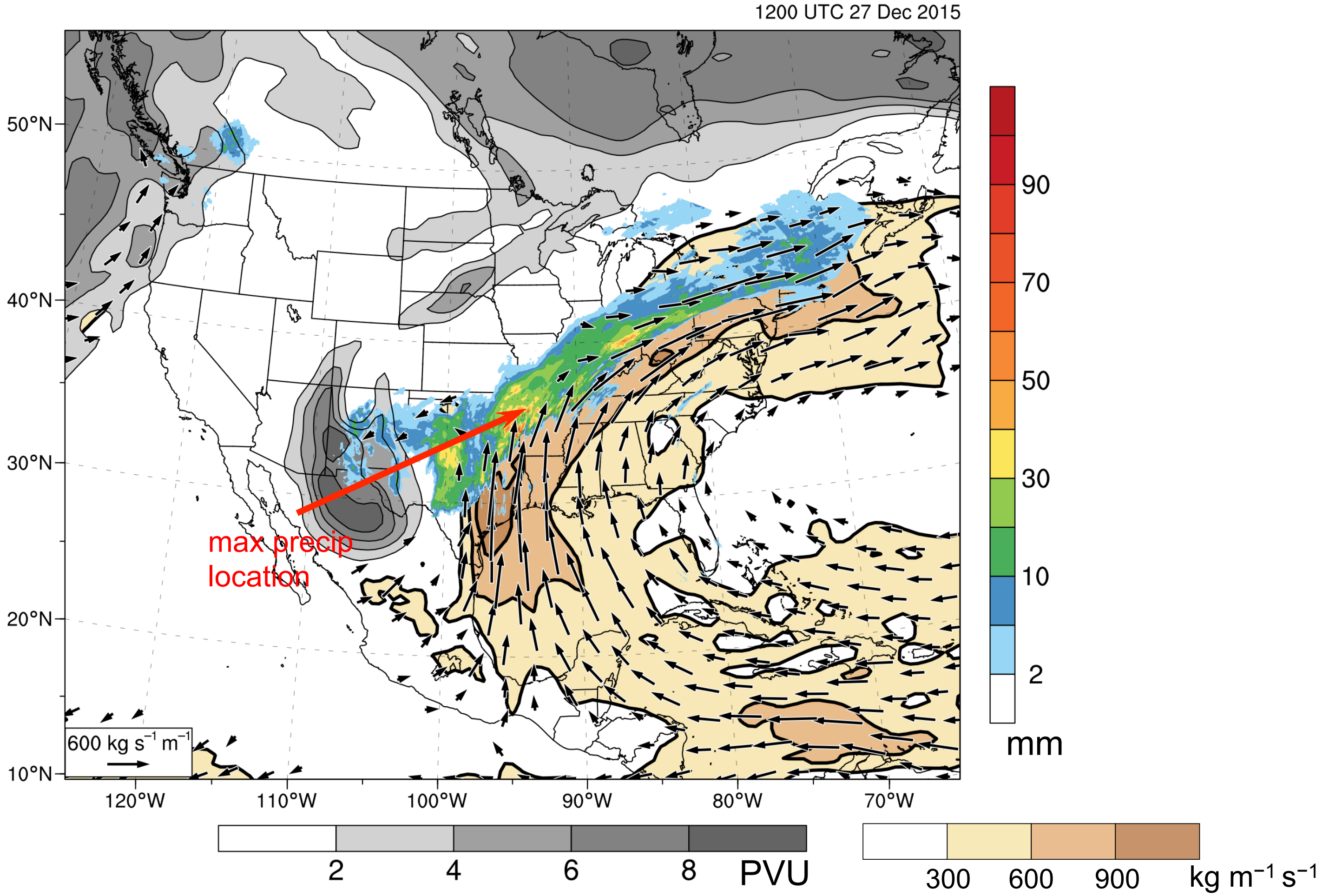
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

Dec 2015 case



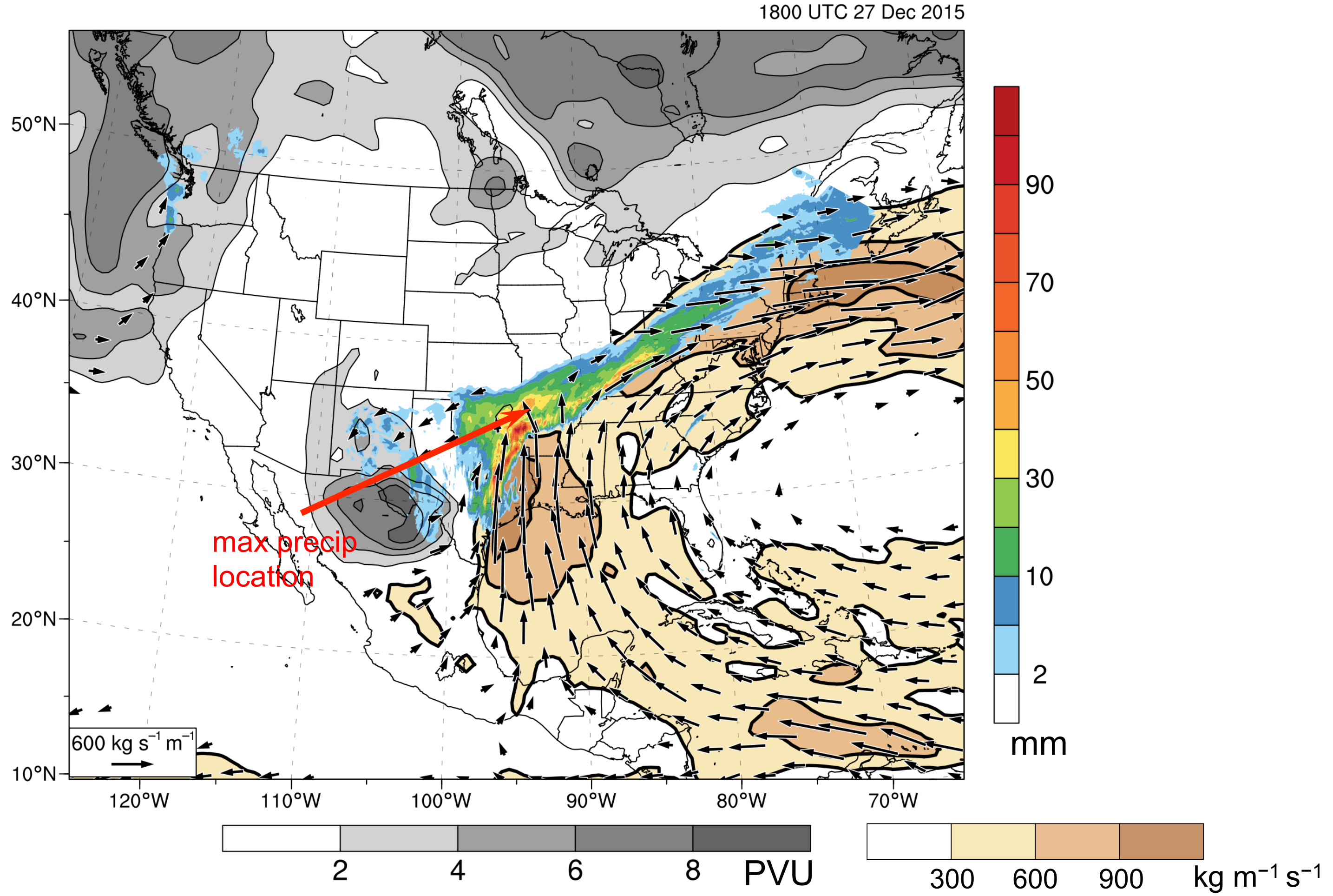
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

Dec 2015 case



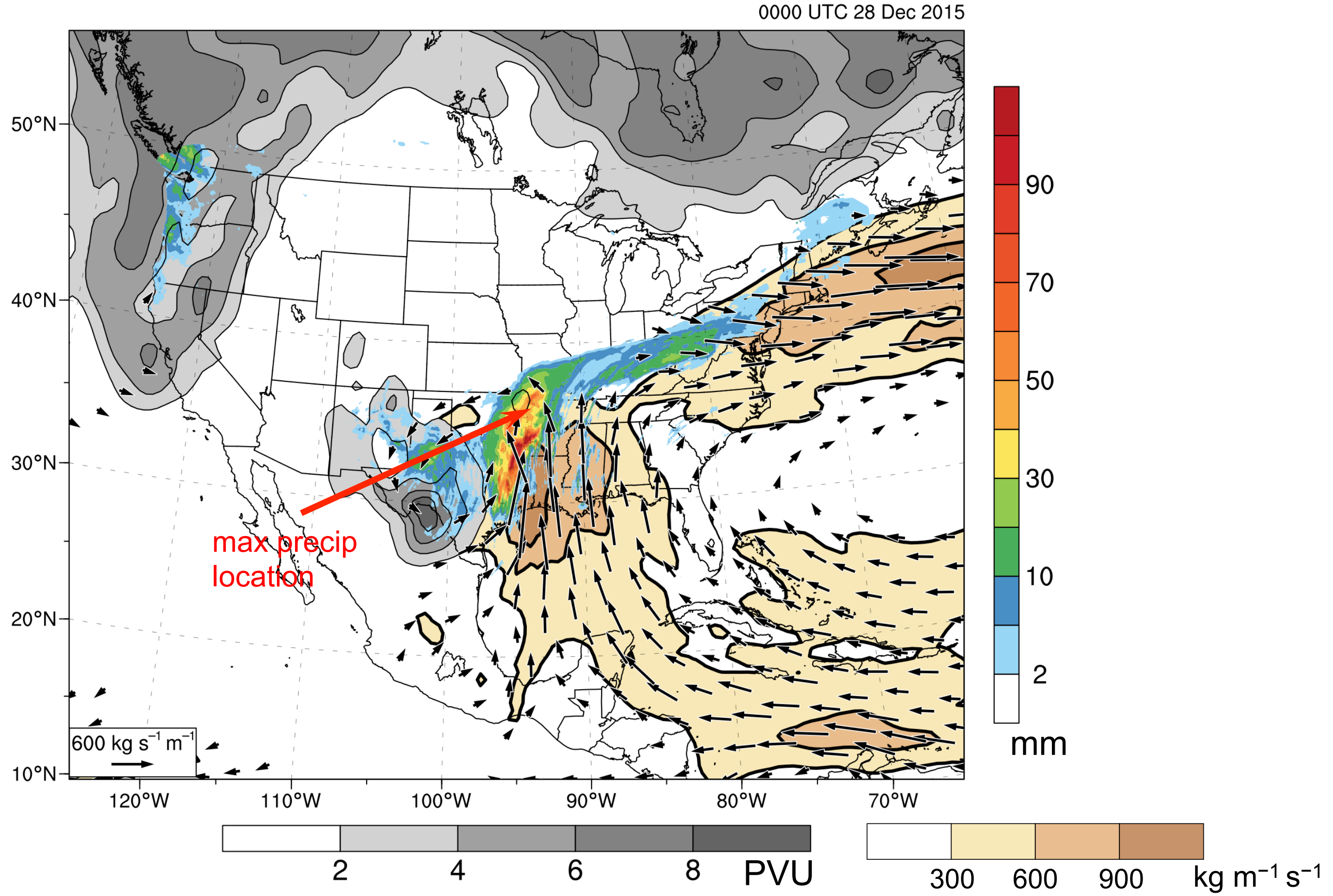
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

Dec 2015 case



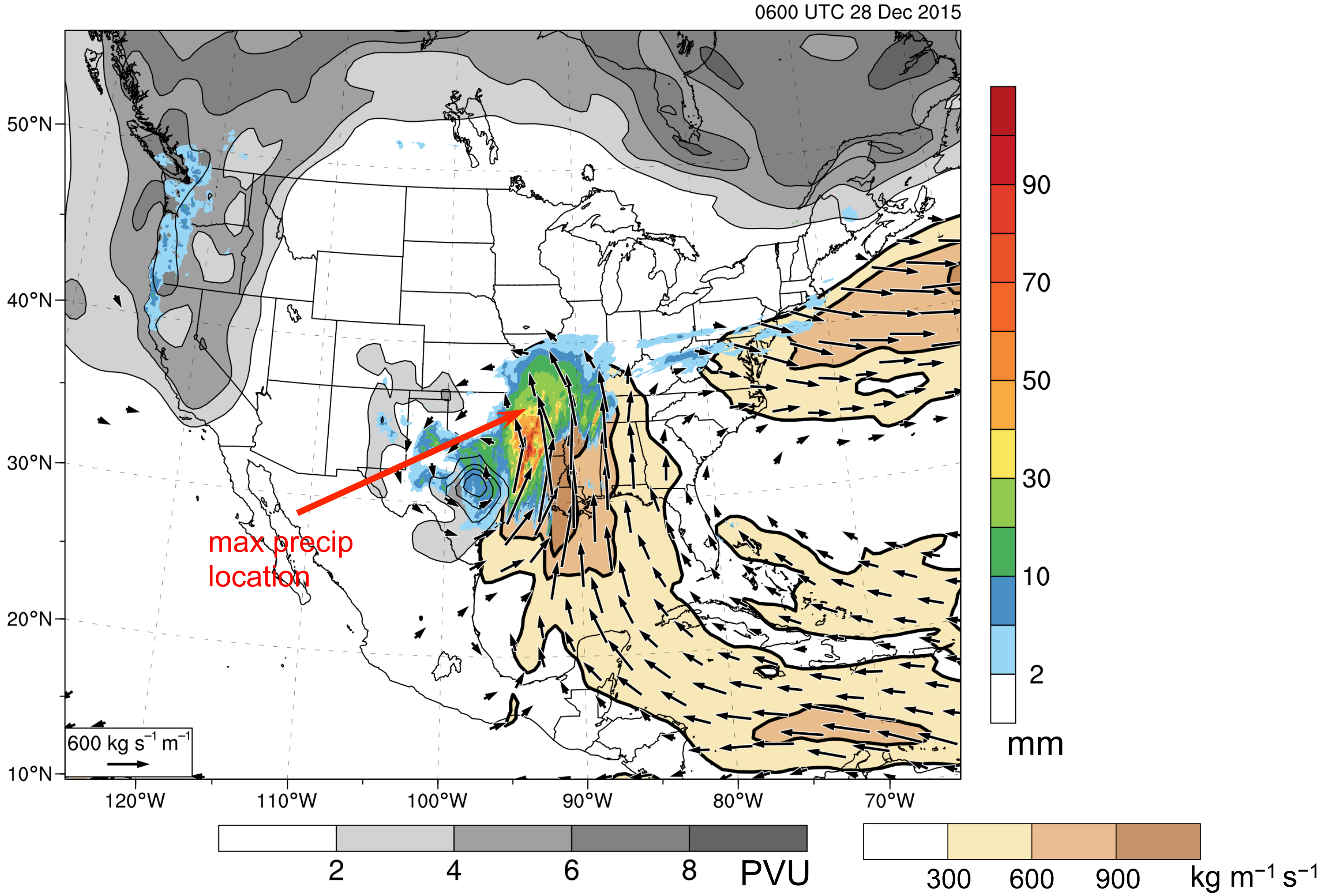
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

Dec 2015 case



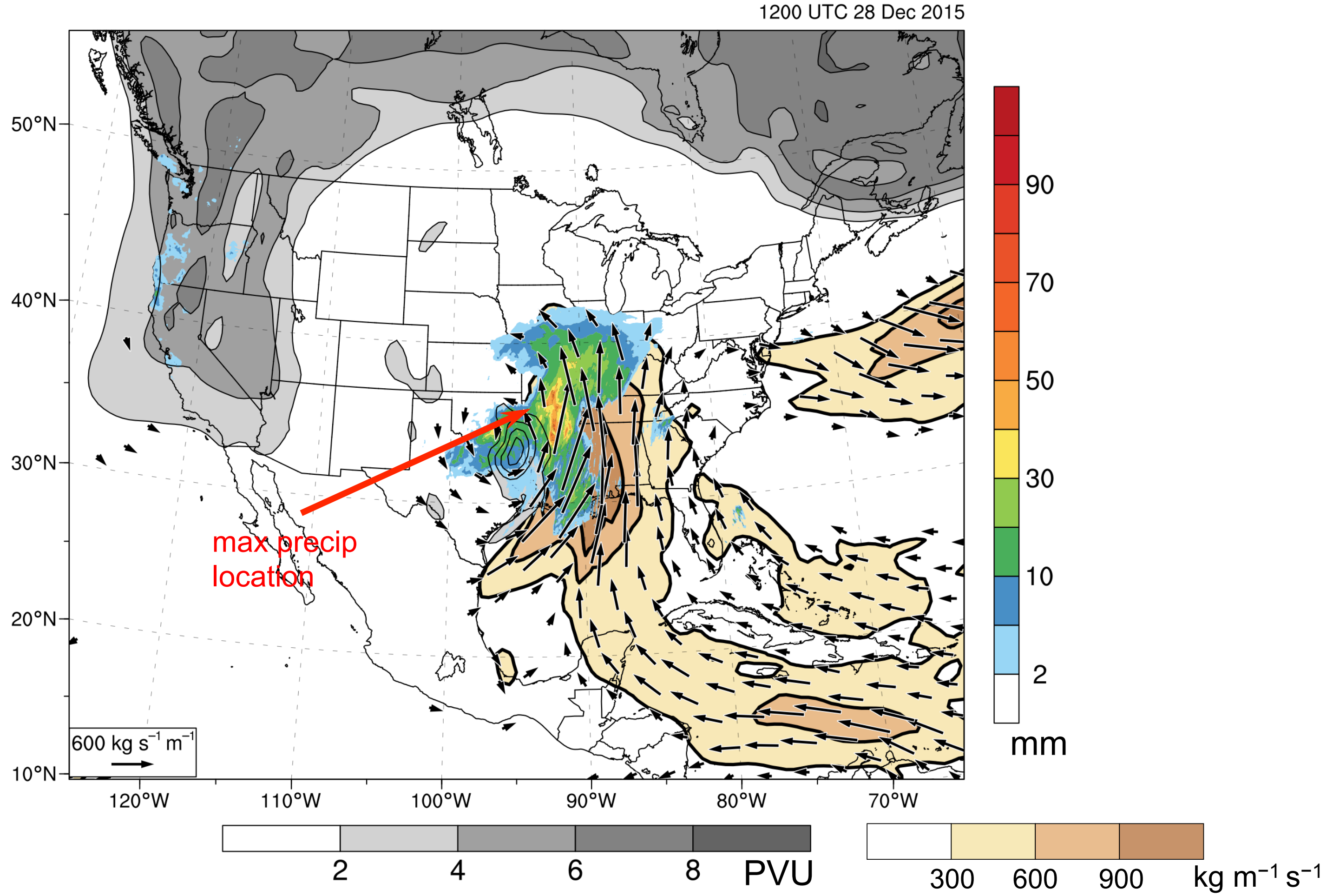
320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

Dec 2015 case



320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

Dec 2015 case



320-K PV (PVU, gray shading),
1000–200-hPa IVT (kg m^{-1} s^{-1}, vectors and tan shading)
6-h Stage-IV precip (mm, color shading)

Heuristic examination of two cases

Key points

- Involve pronounced amplification, deformation, and filamentation of upper-level wave structures in conjunction with Rossby wave breaking (RWB)
- RWB linked to strong nonlinear processes in the late stages of baroclinic wave life cycle
- RWB associated with amplification and concomitant slowing of wave pattern, establishing persistent, merdionally extensive corridor of strong moisture transport from low latitudes into region of forcing for ascent
- Corridor of moisture transport sustains widespread heavy precipitation for long duration
- RWB process linked to backbuilding and training of heavy precipitation at *synoptic- and mesoscales*

References

- Corfidi, S. F., J. H. Merritt, and J. M. Fritsch, 1996: Predicting the movement of mesoscale convective complexes. Wea. Forecasting, 11, 41–46, doi:10.1175/1520-0434(1996)011<0041:PTMOMC>2.0.CO;2.
- Doswell, C. A., H. E. Brooks, and R. A. Maddox, 1996: Flash flood forecasting: An ingredients-based methodology. Wea. Forecasting, 11, 560–581, doi:10.1175/1520-0434(1996)011<0560:FFFAIB>2.0.CO;2.
- Maddox, R. A., C. F. Chappell, and L. R. Hoxit, 1979: Synoptic and mesoscale aspects of flash flood events. Bull. Amer. Meteor. Soc., 60, 115–123, doi:10.1175/1520-0477-60.2.115.
- Moore, B. J., P. J. Neiman, F. M. Ralph, and F. E. Barthold, 2012: Physical processes associated with heavy flooding rainfall in Nashville, Tennessee, and vicinity during 1–2 May 2010: The role of an atmospheric river and mesoscale convective systems. *Mon. Wea. Rev.*, **140**, 358–378, doi:10.1175/MWR-D-11-00126.1.
- Peters, J. M., and R. S. Schumacher, 2014: Objective categorization of heavy-rain-producing MCS synoptic types by rotated principal component analysis. Mon. Wea. Rev., 142, 1716–1737, doi:10.1175/MWR-D-13-00295.1.
- Peters, J. M., and R. S. Schumacher, 2015: Mechanisms for organization and echo training in a flash-flood-producing mesoscale convective system. Mon. Wea. Rev., 143, 1058–1085, doi:10.1175/MWR-D-14-00070.1.
- Schumacher, R. S., and R. H. Johnson, 2005: Organization and environmental properties of extreme-rain-producing mesoscale convective systems. Mon. Wea. Rev., 133, 961–976, doi:10.1175/MWR2899.1.
- Schumacher, R. S., T. J. Galarneau Jr., and L. F. Bosart, 2011: Distant effects of a recurving tropical cyclone on rainfall in a midlatitude convective system: A high-impact predecessor rain event. Mon. Wea. Rev., 139, 650–667, doi:10.1175/2010MWR3453.1.