Large-scale dynamics of extreme precipitation events in California during winter 2016–2017

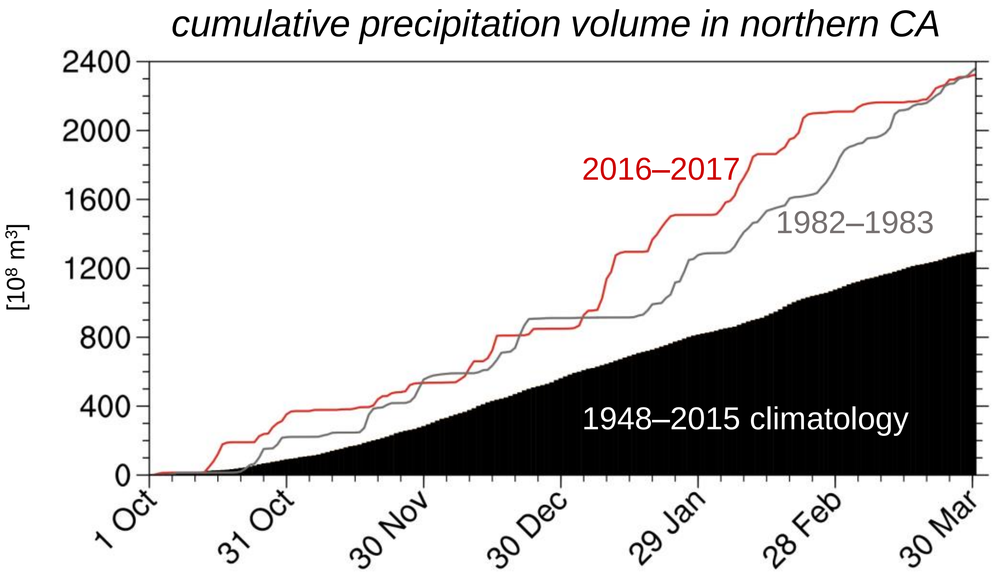
BENJAMIN J. MOORE[1,2], PAUL J. NEIMAN[2], ALLEN B. WHITE[2], AND DANIEL J. GOTTAS[2]

[1]*Cooperative Institute for Research in Environmental Sciences, University of Colorado, Boulder, Colorado*

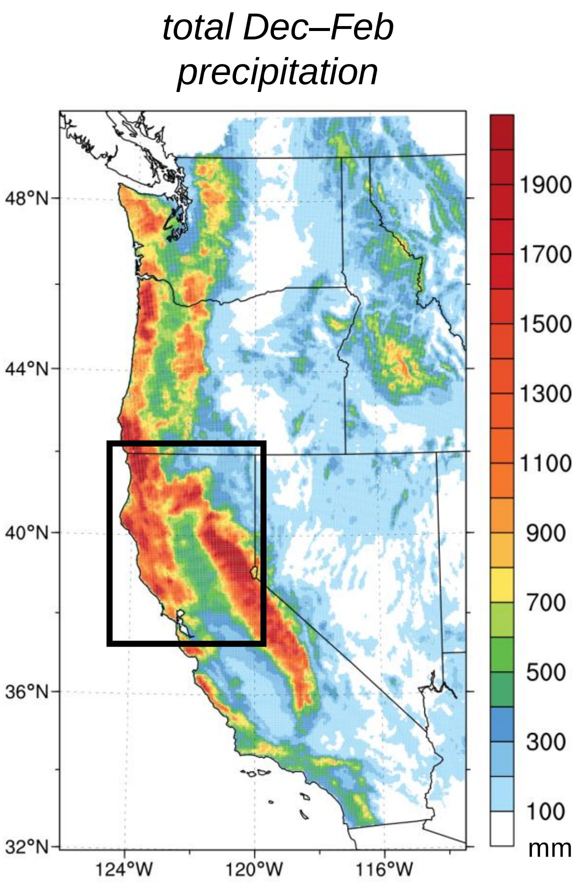
[2]*NOAA Earth System Research Laboratory, Physical Sciences Division, Boulder, Colorado*

CIRES

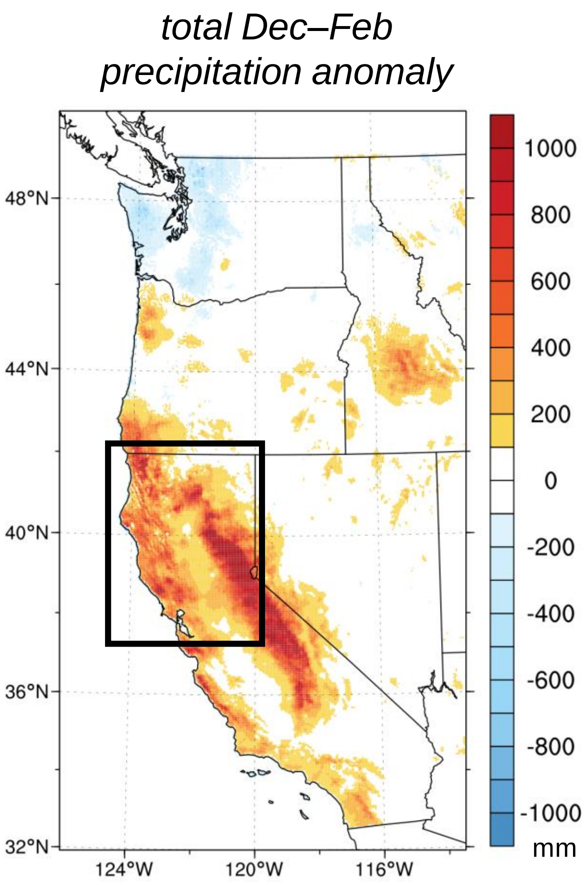
Extraordinary precipitation totals during winter 2016–2017



data: NCEP CPC Unified Precipitation Dataset



data: NCEP Stage-IV



data: NCEP Stage-IV + PRISM climo

Basic principles regarding extreme precipitation in California

$$P = R \times D$$

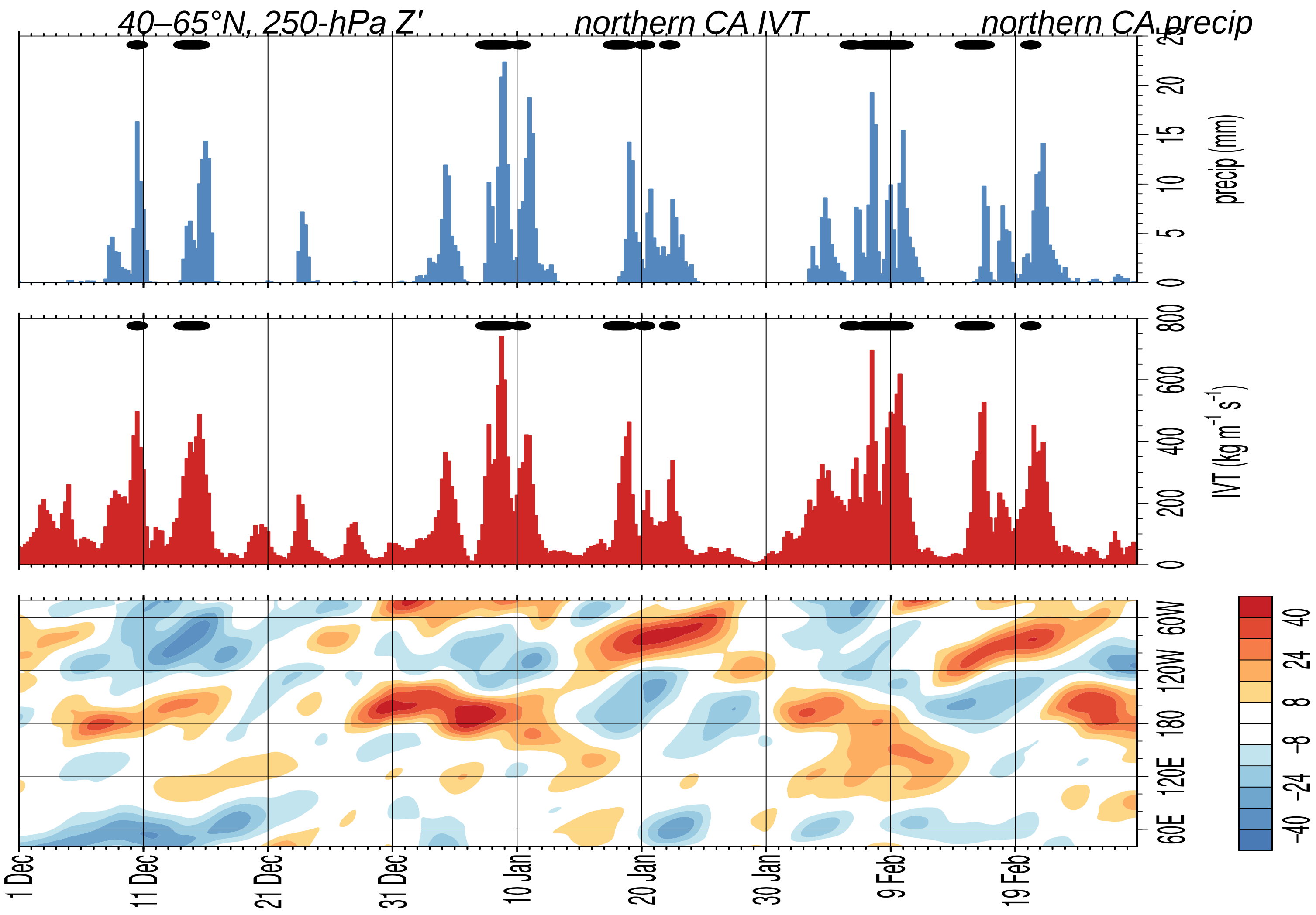
$$R = Ewq \cong \text{upslope water vapor flux}$$

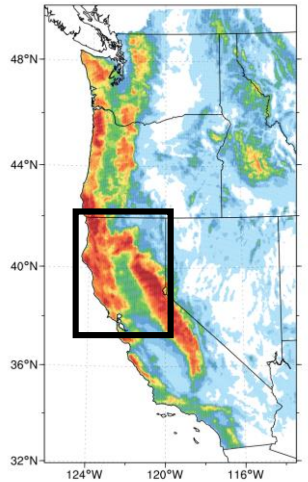
It rains the most where the precipitation is heaviest for the longest duration.

Total precipitation in mountainous regions in California is governed by intensity and duration of upslope moisture flux linked to atmospheric rivers (ARs).

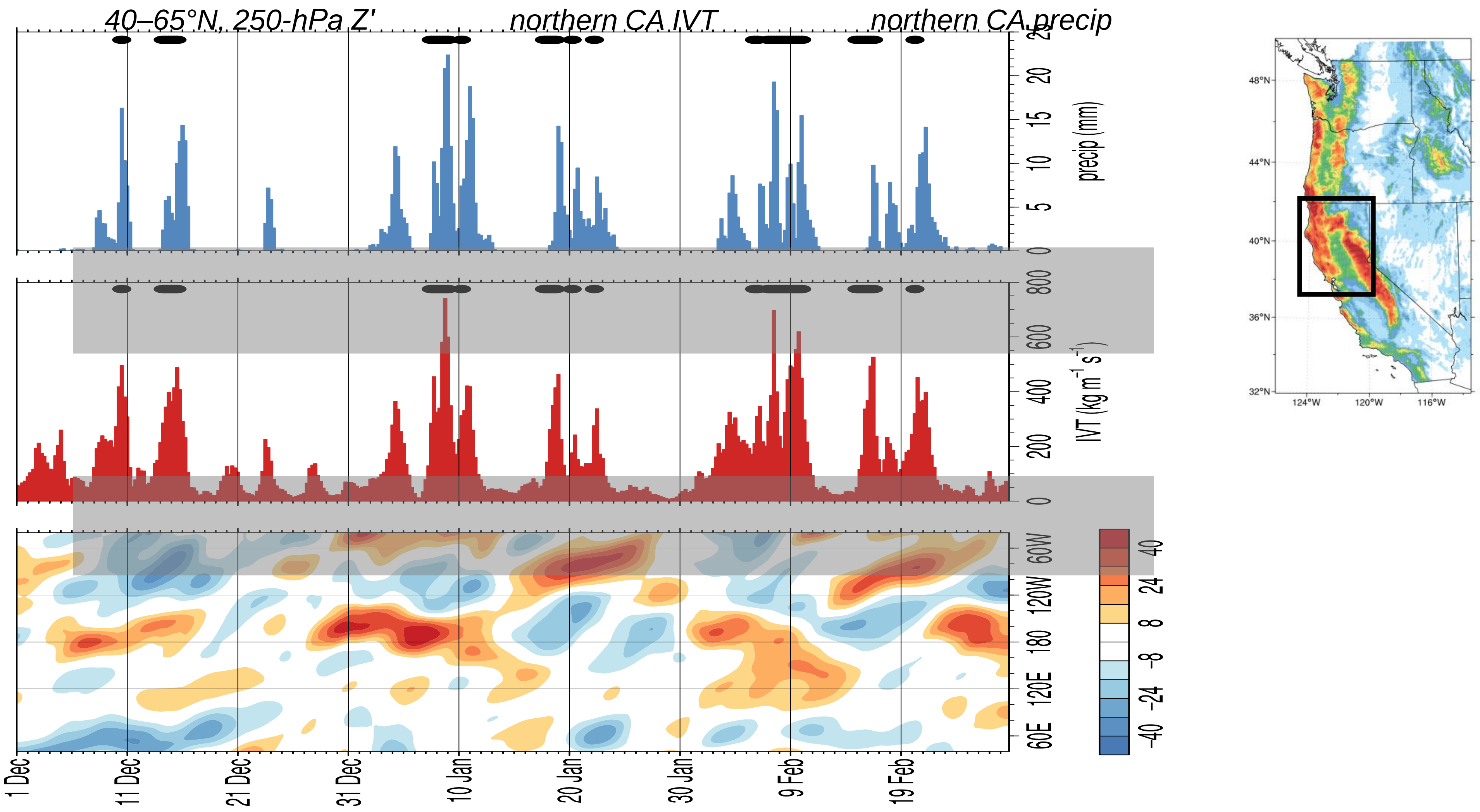
Strong, quasi-stationary ARs cause extreme orographic precipitation.

Large-scale flow evolution and precipitation impacts in California



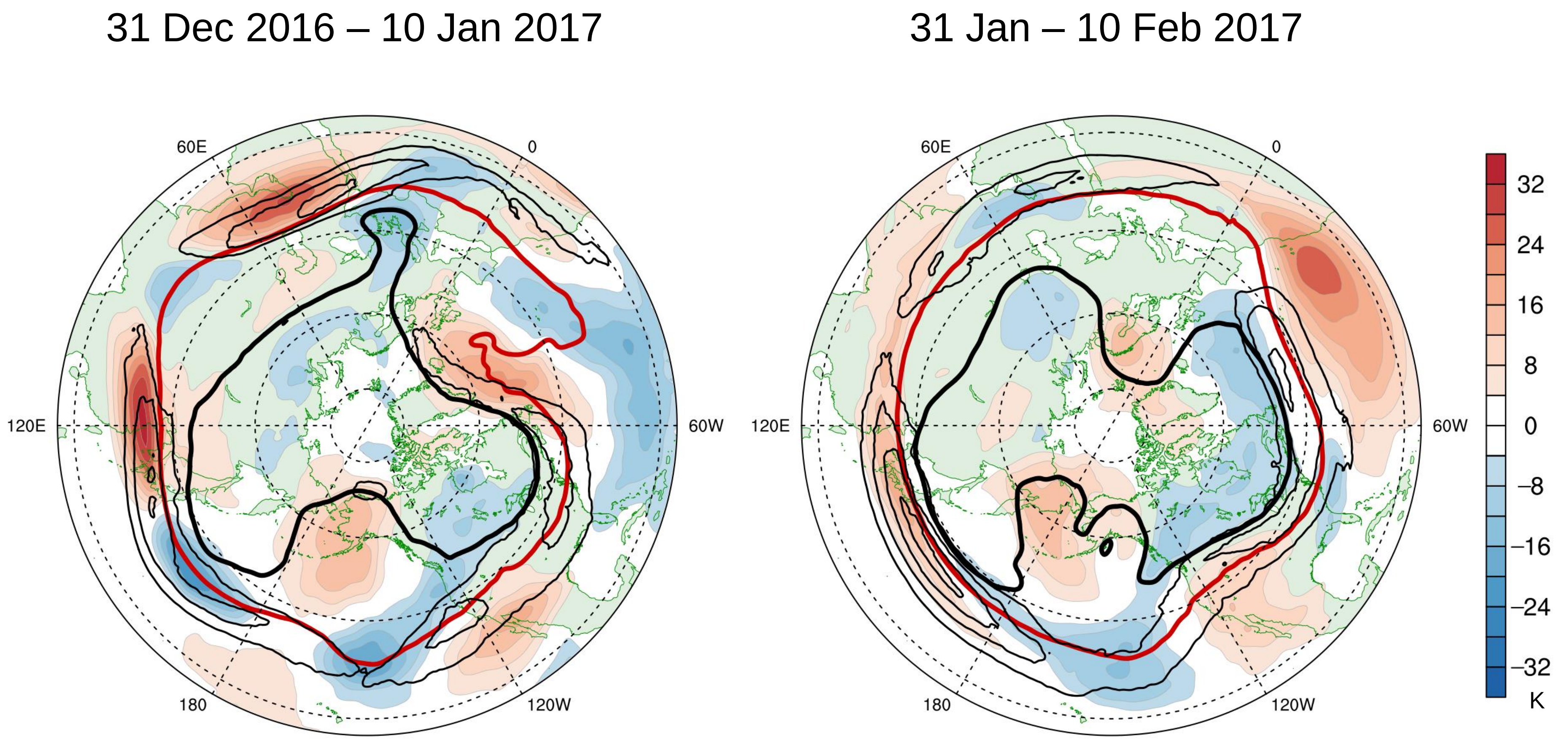


Large-scale flow evolution and precipitation impacts in California



Northern Hemispheric conditions

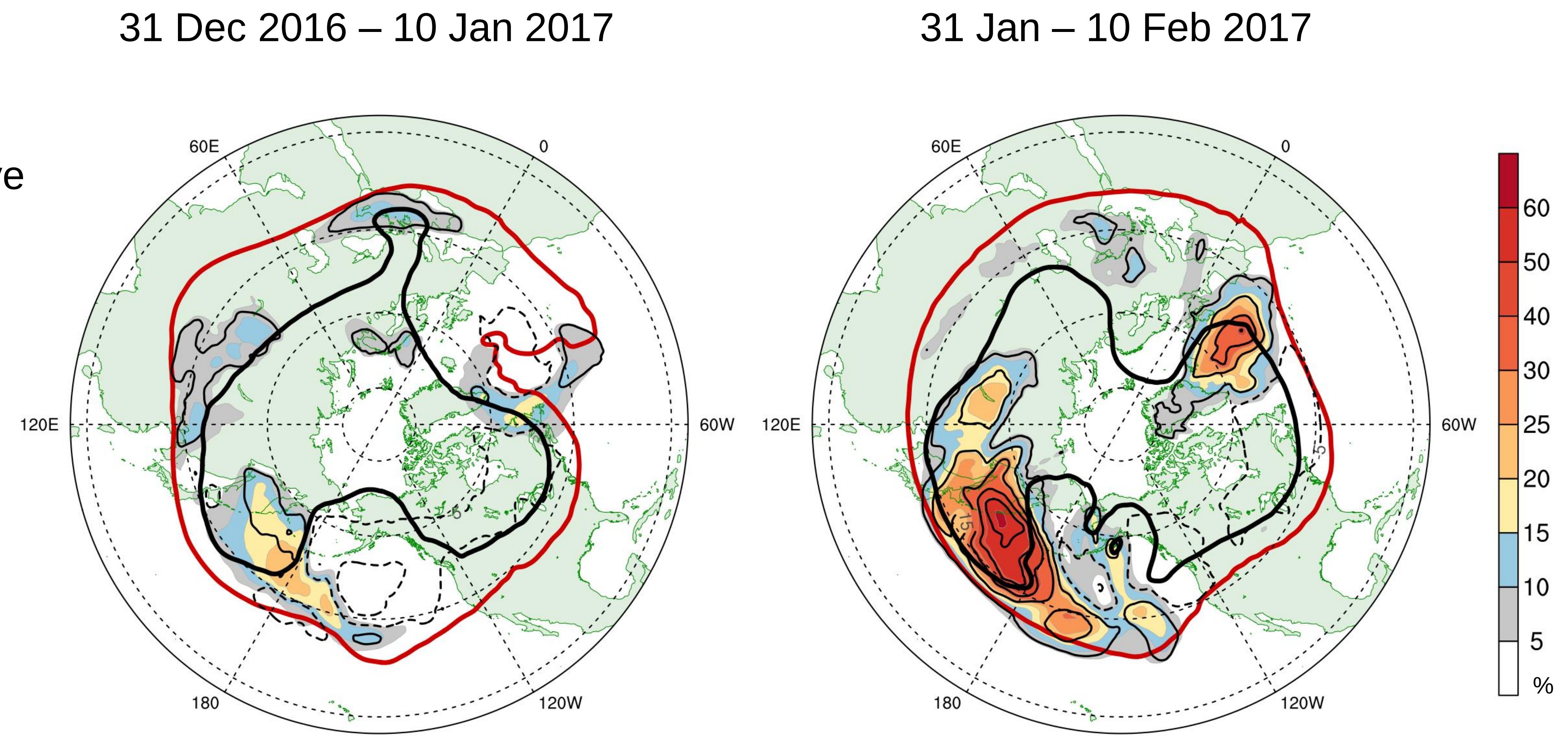
dynamic tropopause



DT θ' (shading, K), DT wind speed (thin black, m s⁻¹), 310-K and 330-K DT isentropes (thick black and red contours)

Northern Hemispheric conditions

cyclonic Rossby wave breaking



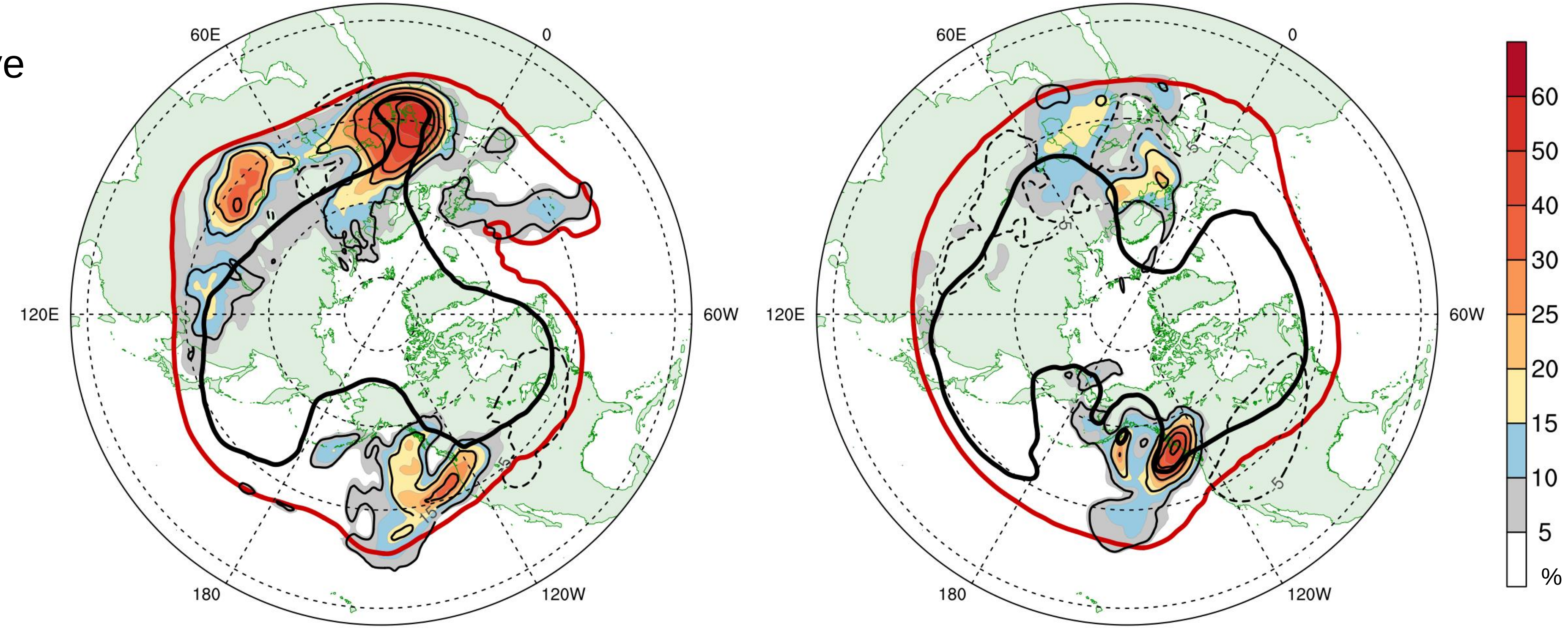
cyclonic wave breaking relative frequency (shading, %) and relative frequency anomaly (black, %),
310-K and 330-K DT isentropes (thick black and red contours)

Northern Hemispheric conditions

anticyclonic
Rossby wave
breaking

31 Dec 2016 – 10 Jan 2017

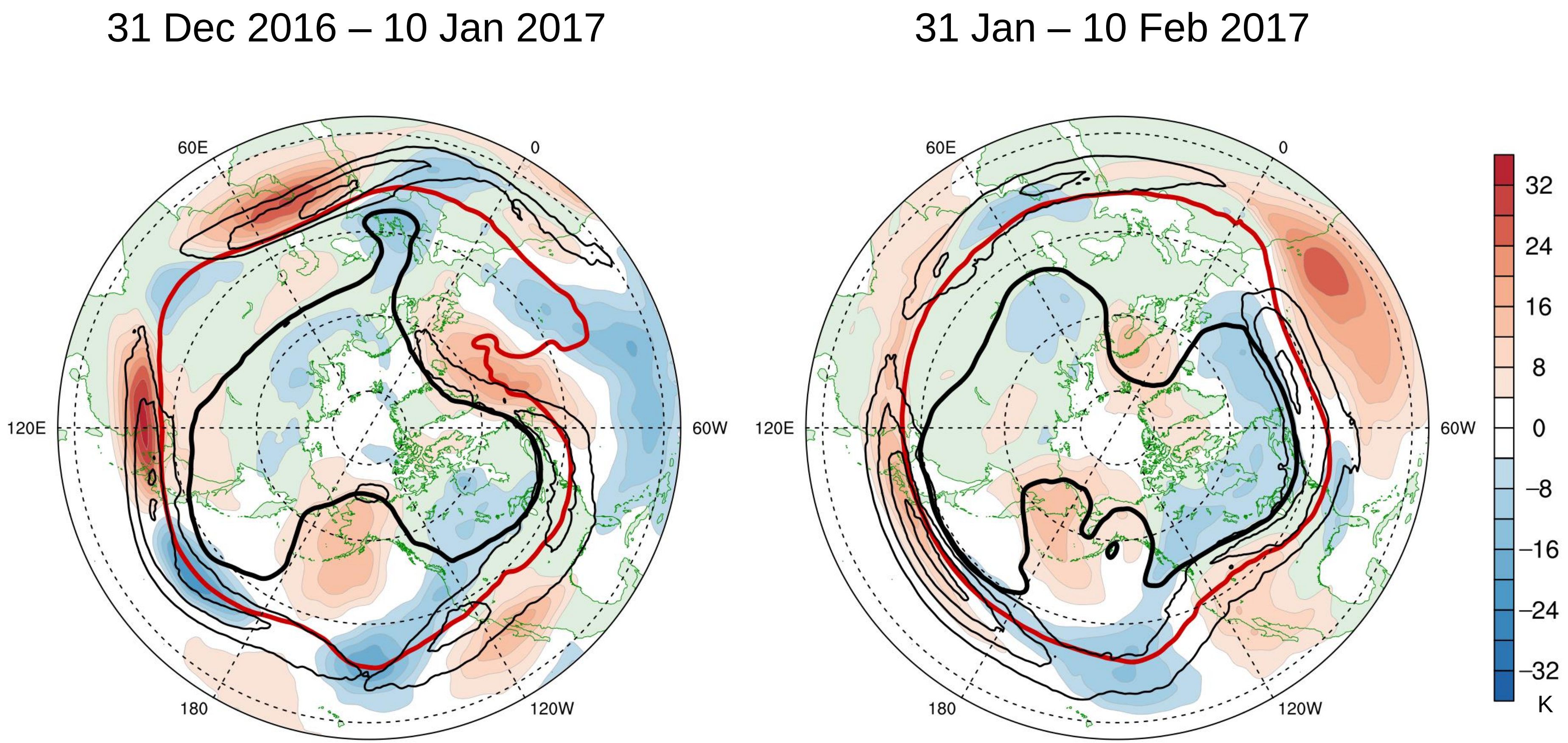
31 Jan – 10 Feb 2017



anticyclonic wave breaking relative frequency (shading, %) and relative frequency anomaly (black, %),
310-K and 330-K DT isentropes (thick black and red contours)

Northern Hemispheric conditions

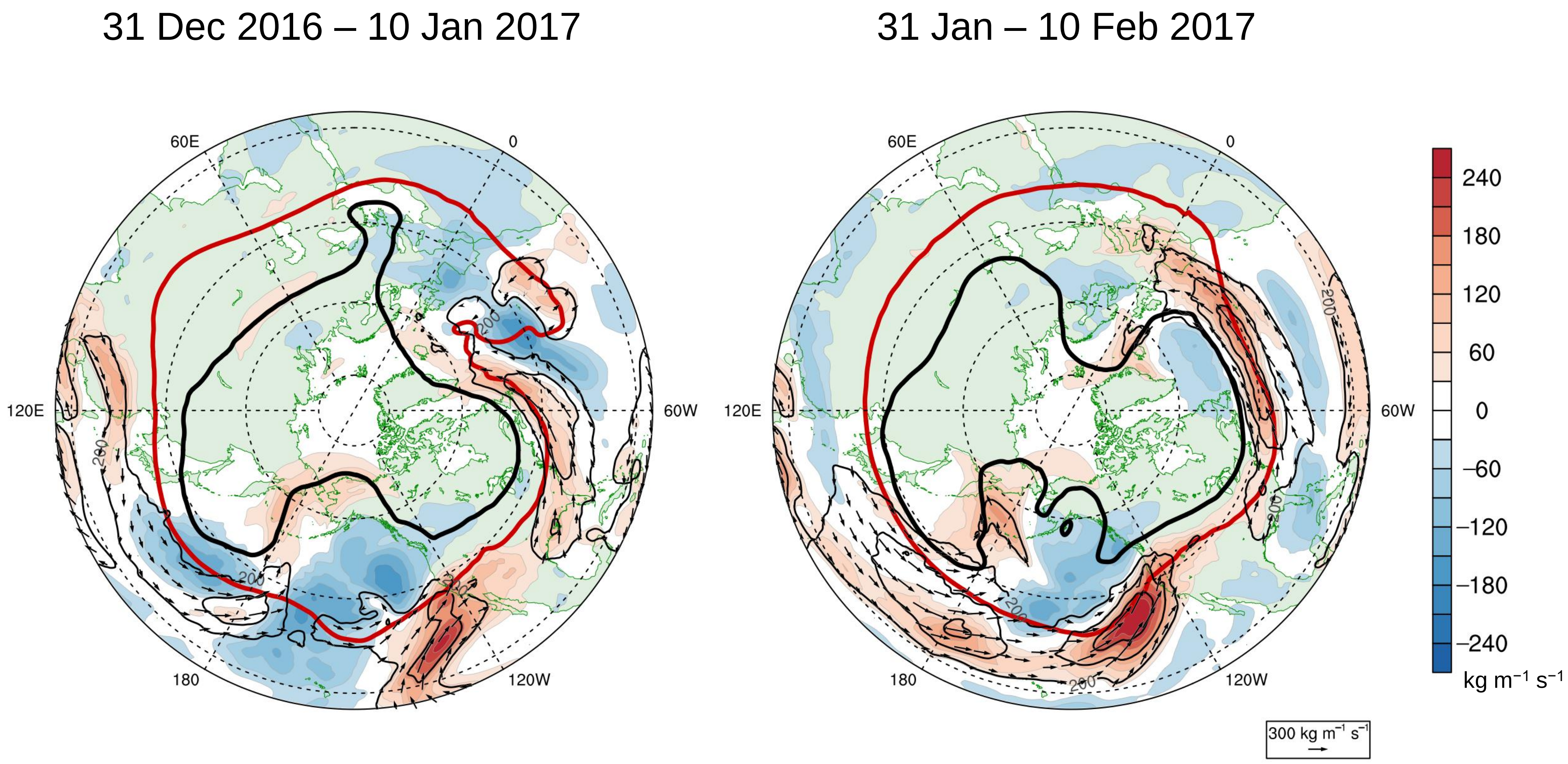
dynamic
tropopause



DT θ' (shading, K), DT wind speed (thin black, m s⁻¹), 310-K and 330-K DT isentropes (thick black and red contours)

Northern Hemispheric conditions

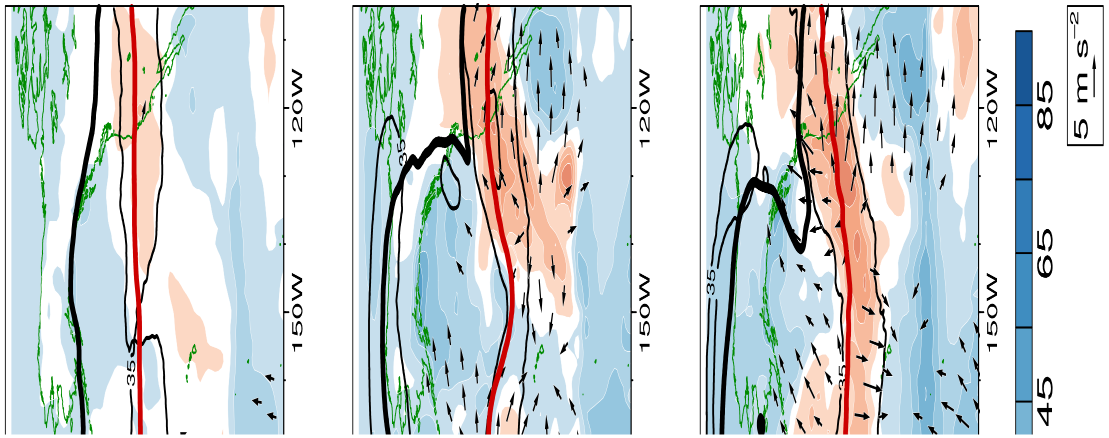
water vapor transport



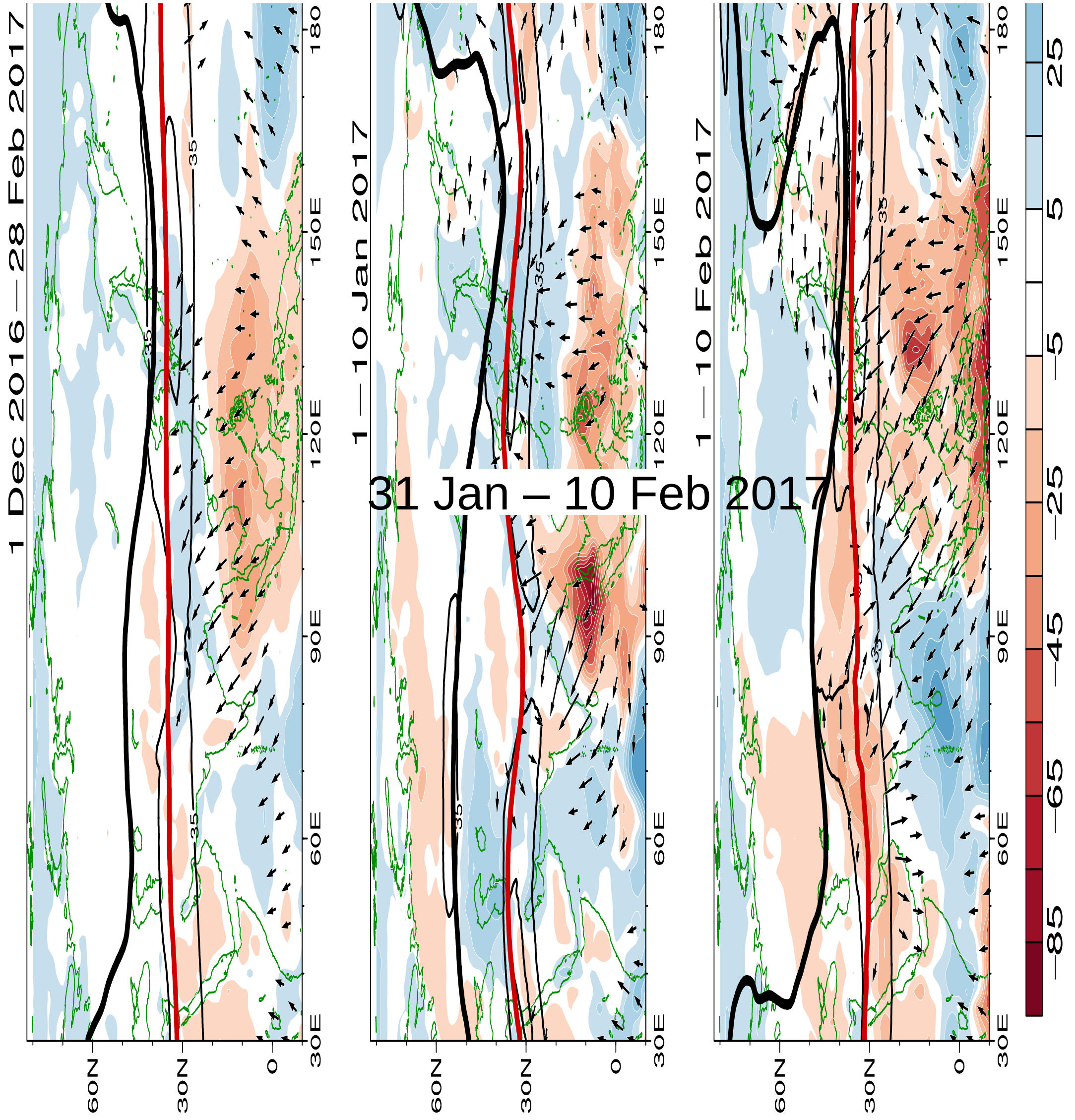
1000–300-hPa IVT vectors and magnitude (black, kg m^{-1} s^{-1}), IVT magnitude anomaly (shading, %), 310-K and 330-K DT isentropes (thick black and red contours)

Impacts of tropical convection

1 Dec 2016 – 28 Feb 2017

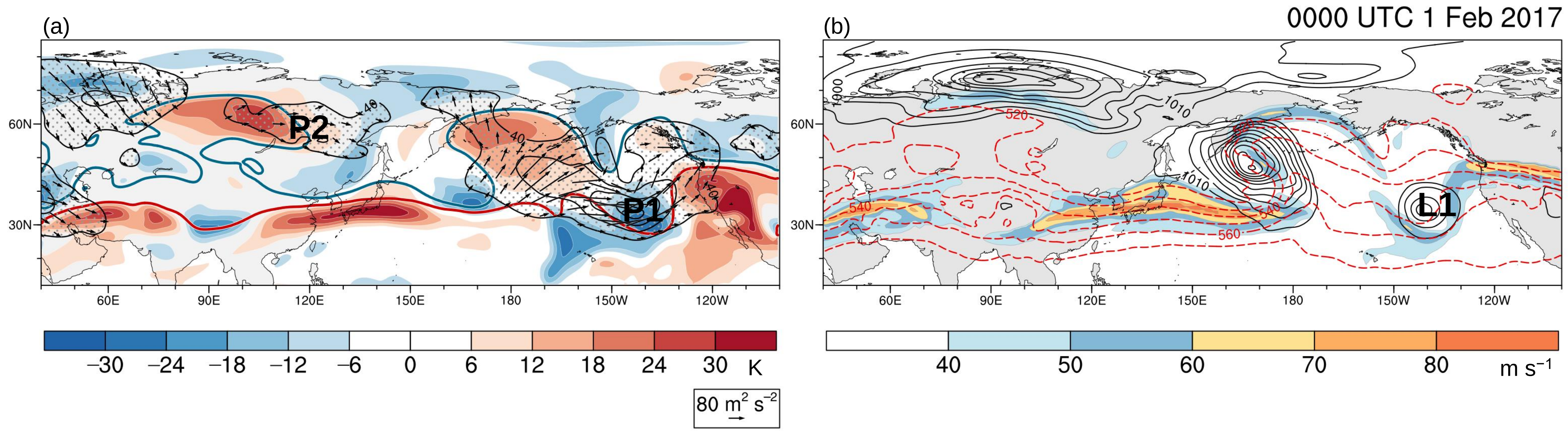


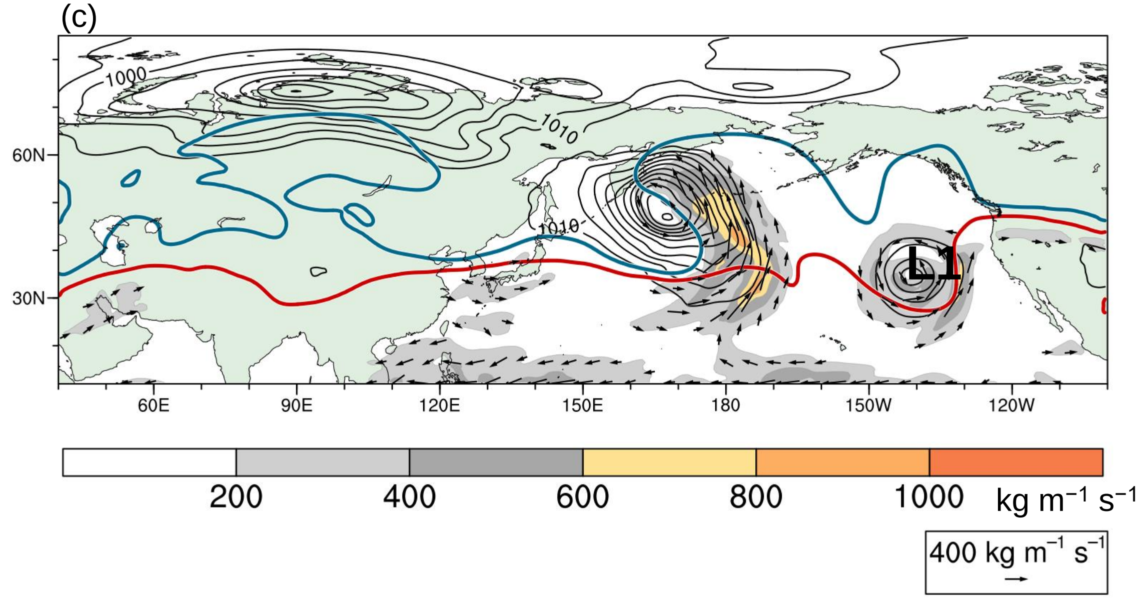
31 Dec 2016 – 10 Jan 2017



outgoing longwave radiation anomaly (shading, W m⁻²), 250-hPa irrotational wind vectors (m s⁻¹), 250-hPa wind speed (black, m s⁻¹), 310-K and 330-K DT isentropes (thick black and red contours)

Large-scale flow evolution



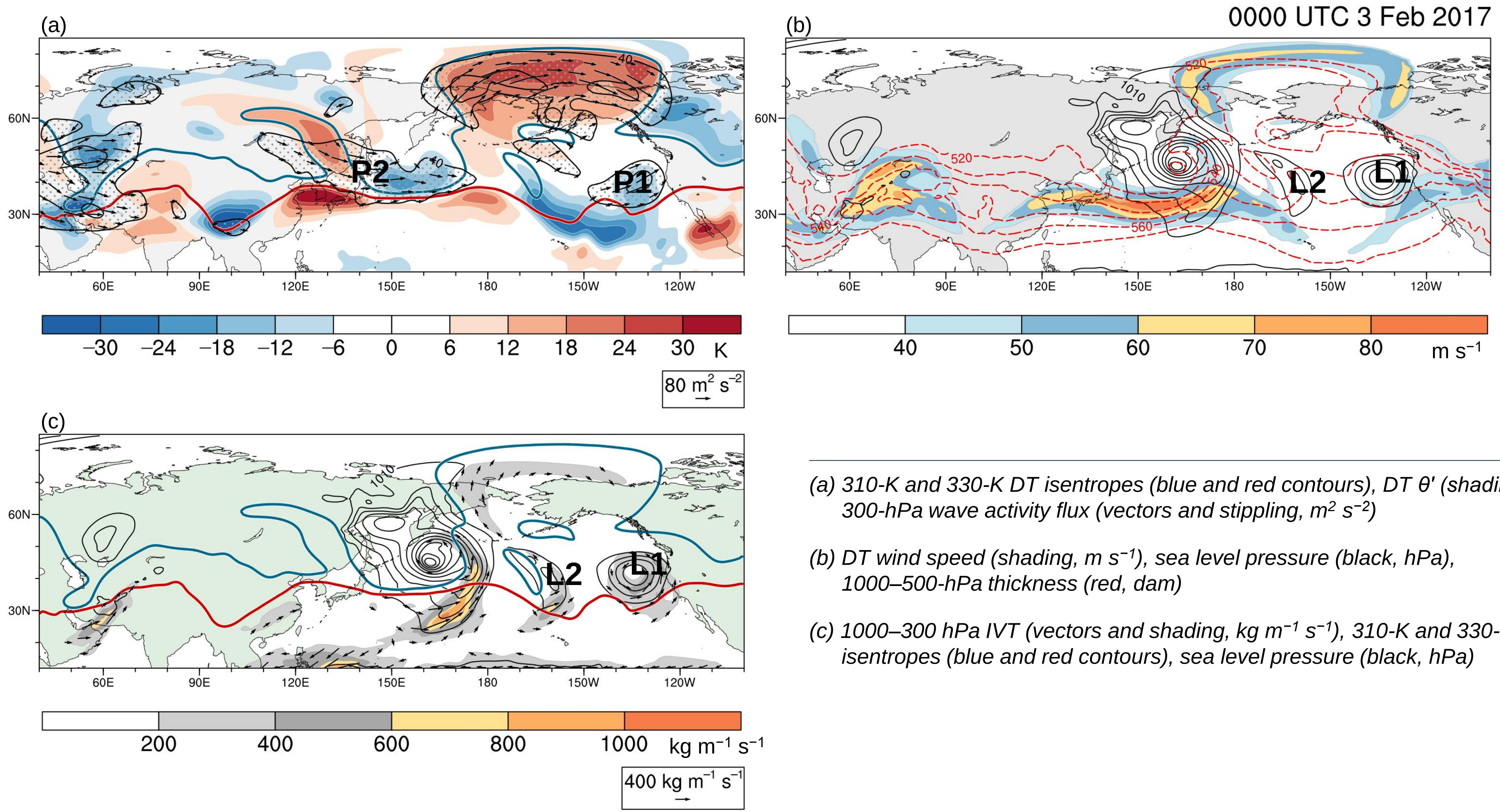


(a) 310-K and 330-K DT isentropes (blue and red contours), DT θ′ (shading, K), 300-hPa wave activity flux (vectors and stippling, m² s⁻²)

(b) DT wind speed (shading, m s⁻¹), sea level pressure (black, hPa), 1000–500-hPa thickness (red, dam)

(c) 1000–300 hPa IVT (vectors and shading, kg m⁻¹ s⁻¹), 310-K and 330-K DT isentropes (blue and red contours), sea level pressure (black, hPa)

Large-scale flow evolution

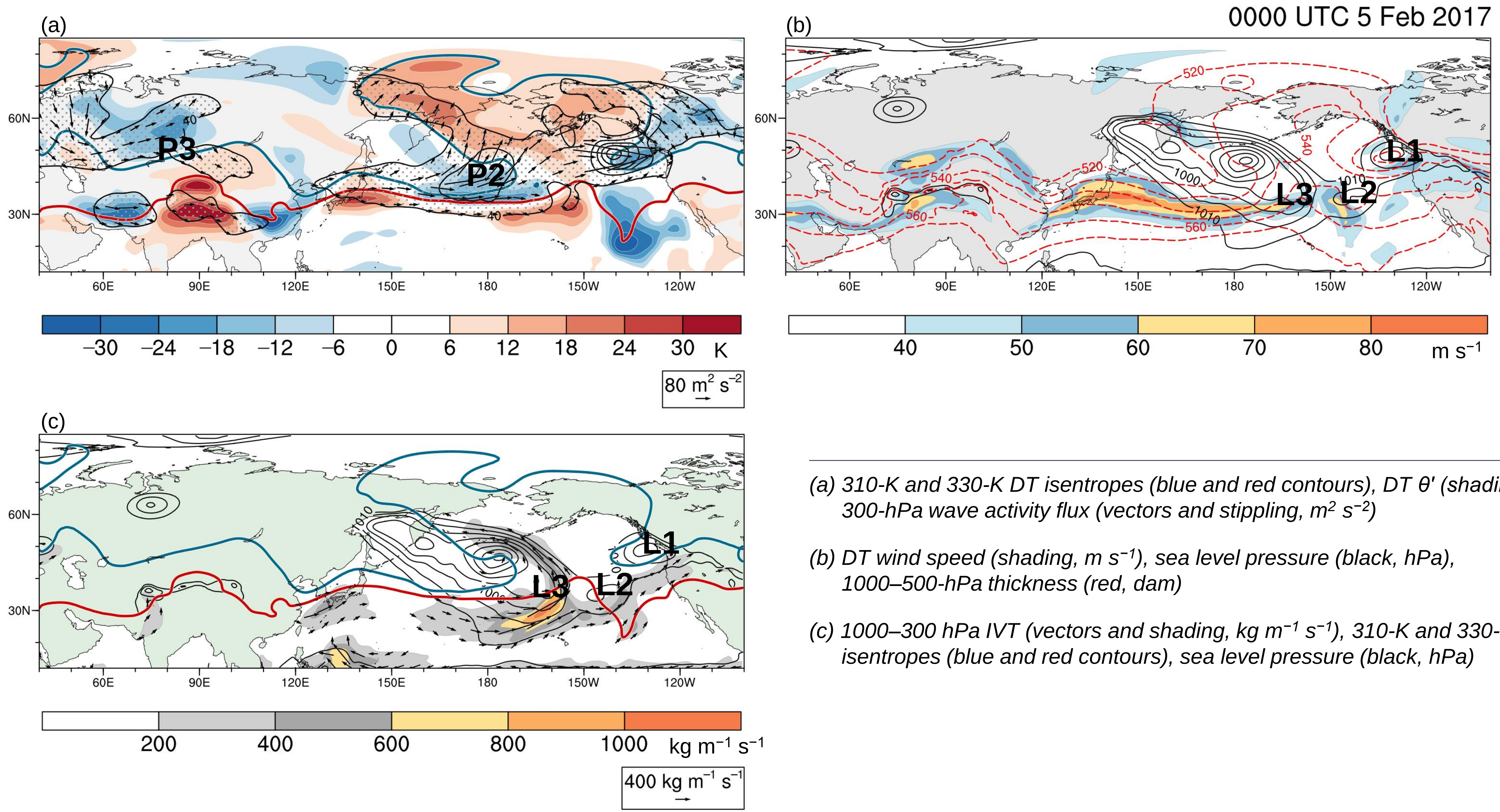


(a) 310-K and 330-K DT isentropes (blue and red contours), DT θ′ (shading, K), 300-hPa wave activity flux (vectors and stippling, $m^2\ s^{-2}$)

(b) DT wind speed (shading, $m\ s^{-1}$), sea level pressure (black, hPa), 1000–500-hPa thickness (red, dam)

(c) 1000–300 hPa IVT (vectors and shading, $kg\ m^{-1}\ s^{-1}$), 310-K and 330-K DT isentropes (blue and red contours), sea level pressure (black, hPa)

Large-scale flow evolution

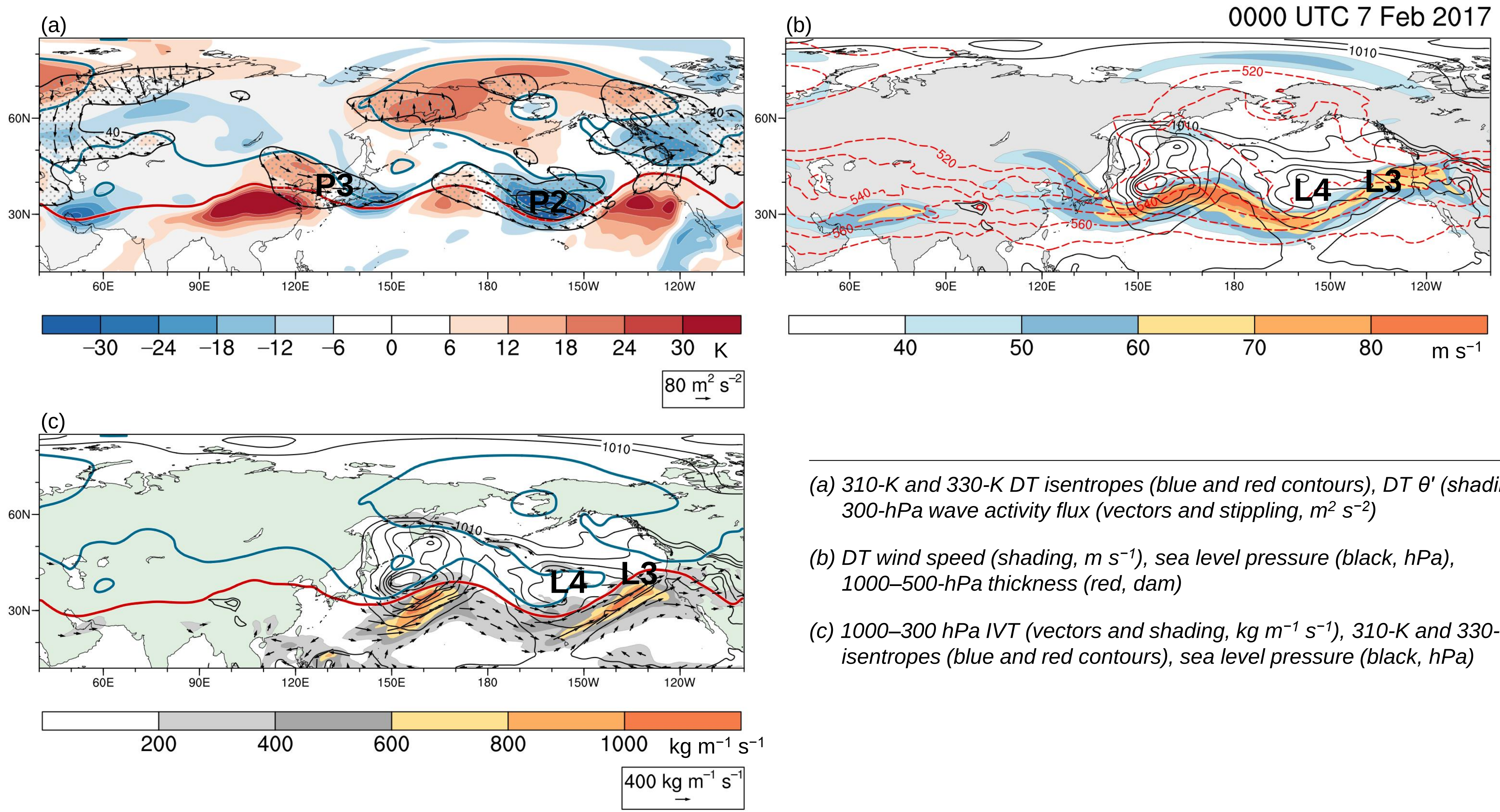


(a) 310-K and 330-K DT isentropes (blue and red contours), DT θ′ (shading, K), 300-hPa wave activity flux (vectors and stippling, $m^2\ s^{-2}$)

(b) DT wind speed (shading, $m\ s^{-1}$), sea level pressure (black, hPa), 1000–500-hPa thickness (red, dam)

(c) 1000–300 hPa IVT (vectors and shading, $kg\ m^{-1}\ s^{-1}$), 310-K and 330-K DT isentropes (blue and red contours), sea level pressure (black, hPa)

Large-scale flow evolution

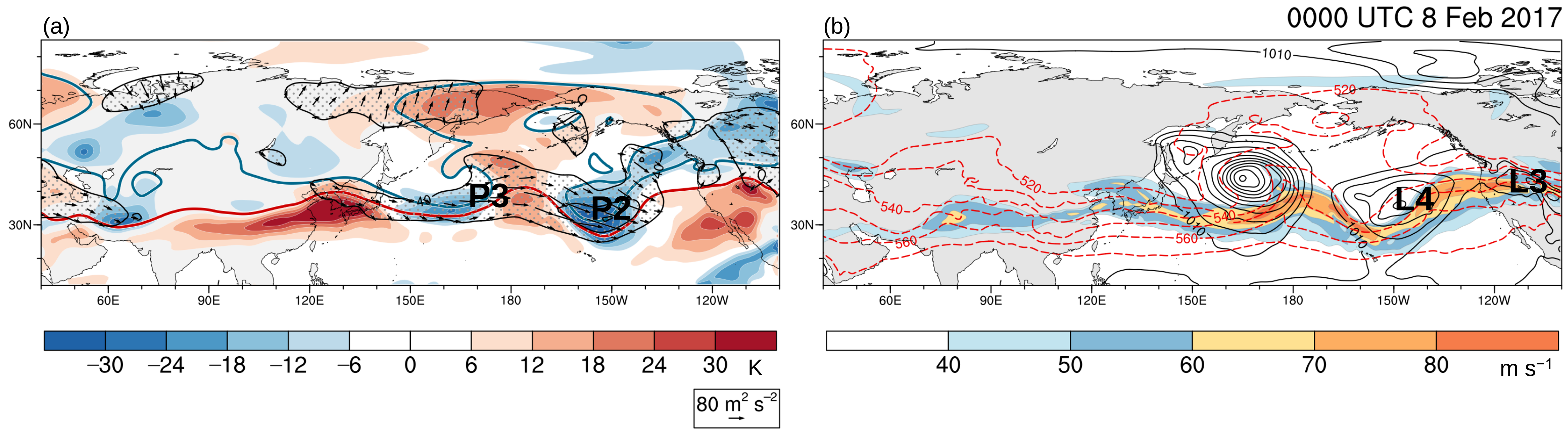


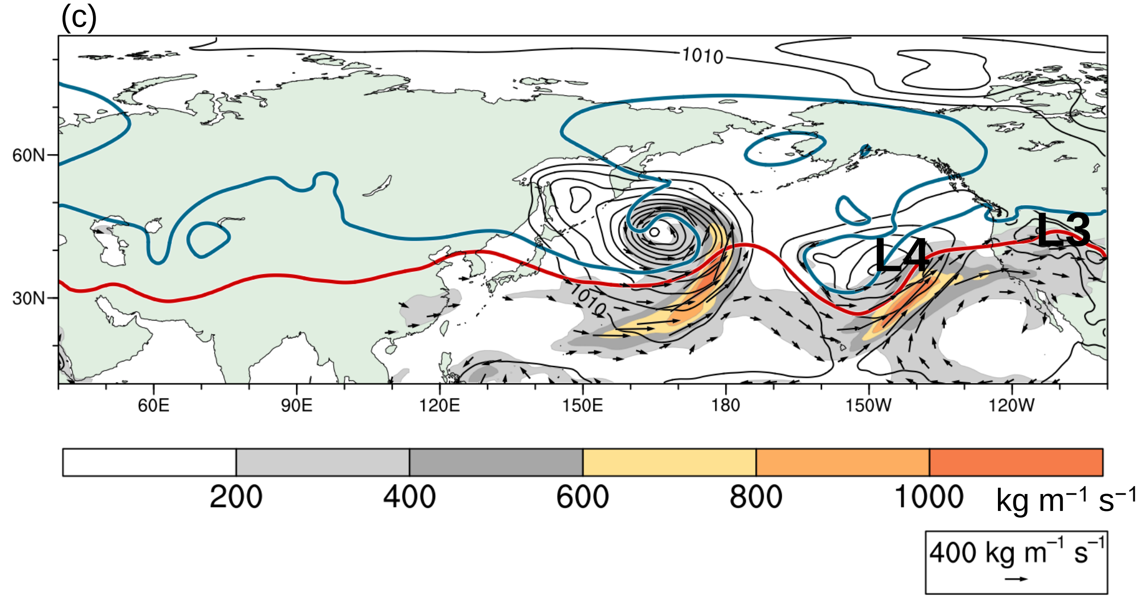
(a) 310-K and 330-K DT isentropes (blue and red contours), DT θ′ (shading, K), 300-hPa wave activity flux (vectors and stippling, $m^2\ s^{-2}$)

(b) DT wind speed (shading, $m\ s^{-1}$), sea level pressure (black, hPa), 1000–500-hPa thickness (red, dam)

(c) 1000–300 hPa IVT (vectors and shading, $kg\ m^{-1}\ s^{-1}$), 310-K and 330-K DT isentropes (blue and red contours), sea level pressure (black, hPa)

Large-scale flow evolution



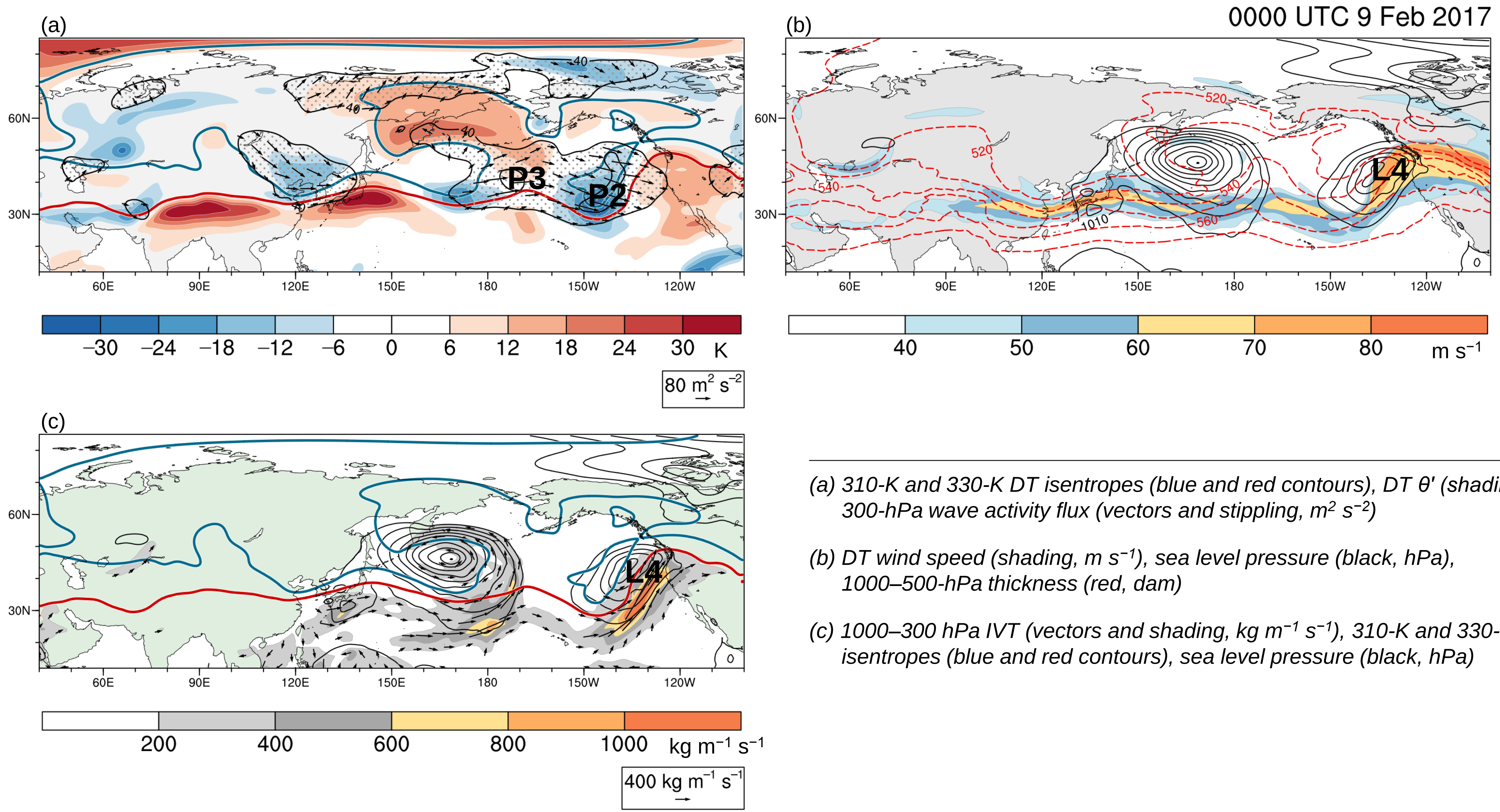


(a) 310-K and 330-K DT isentropes (blue and red contours), DT θ′ (shading, K), 300-hPa wave activity flux (vectors and stippling, $m^2\ s^{-2}$)

(b) DT wind speed (shading, $m\ s^{-1}$), sea level pressure (black, hPa), 1000–500-hPa thickness (red, dam)

(c) 1000–300 hPa IVT (vectors and shading, $kg\ m^{-1}\ s^{-1}$), 310-K and 330-K DT isentropes (blue and red contours), sea level pressure (black, hPa)

Large-scale flow evolution

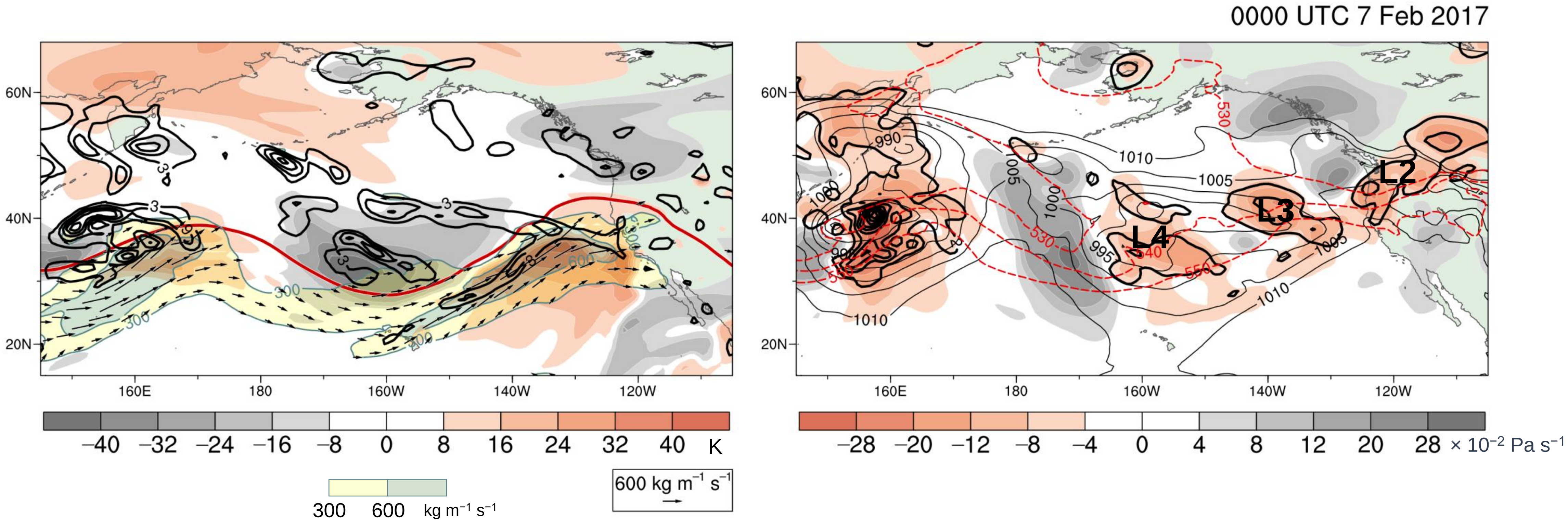


(a) 310-K and 330-K DT isentropes (blue and red contours), DT θ′ (shading, K), 300-hPa wave activity flux (vectors and stippling, $m^2\ s^{-2}$)

(b) DT wind speed (shading, $m\ s^{-1}$), sea level pressure (black, hPa), 1000–500-hPa thickness (red, dam)

(c) 1000–300 hPa IVT (vectors and shading, $kg\ m^{-1}\ s^{-1}$), 310-K and 330-K DT isentropes (blue and red contours), sea level pressure (black, hPa)

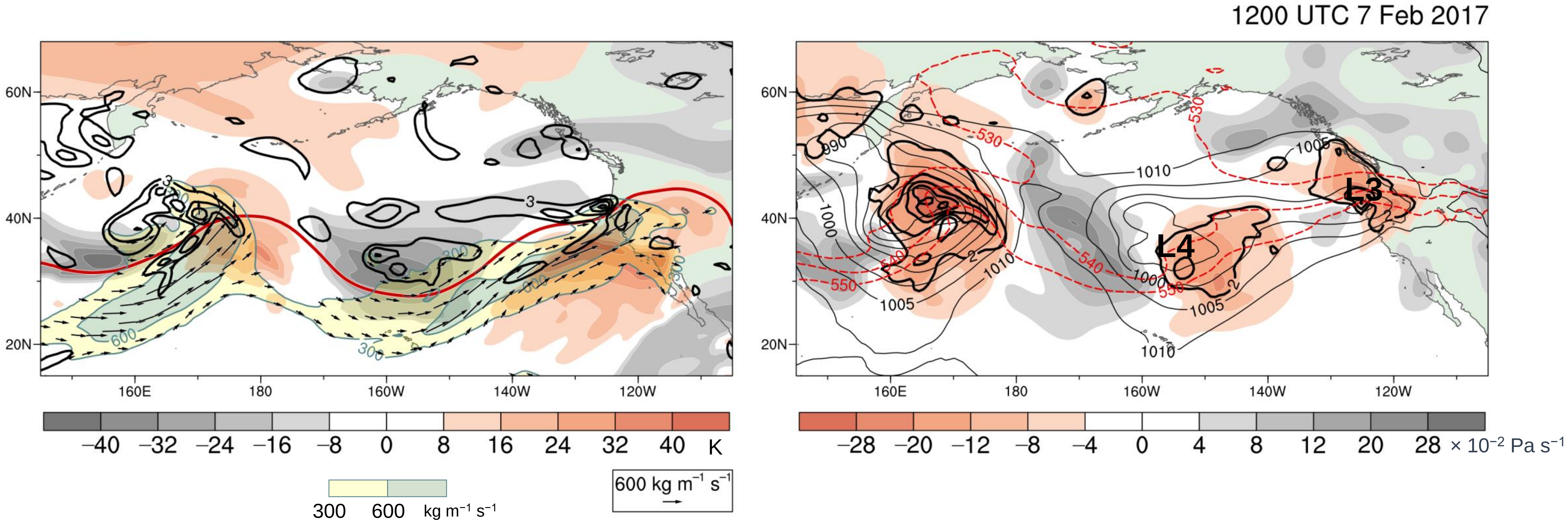
Dynamics of a persistent atmospheric river



330-K DT isentrope (red), DT θ′ (shading, K),
1000–700-hPa ζ (black, 10^{-5} s^{-1}),
IVT (vectors and shading, kg m^{-1} s^{-1})

1000–500-hPa thickness (dashed red, dam),
700–500-hPa averaged QG ascent (shading, 10^{-2} Pa s^{-1}),
1000–700-hPa ζ tendency due to stretching by QG ascent (thick black, 10^{-10} s^{-2}),
sea level pressure (thin black, hPa)

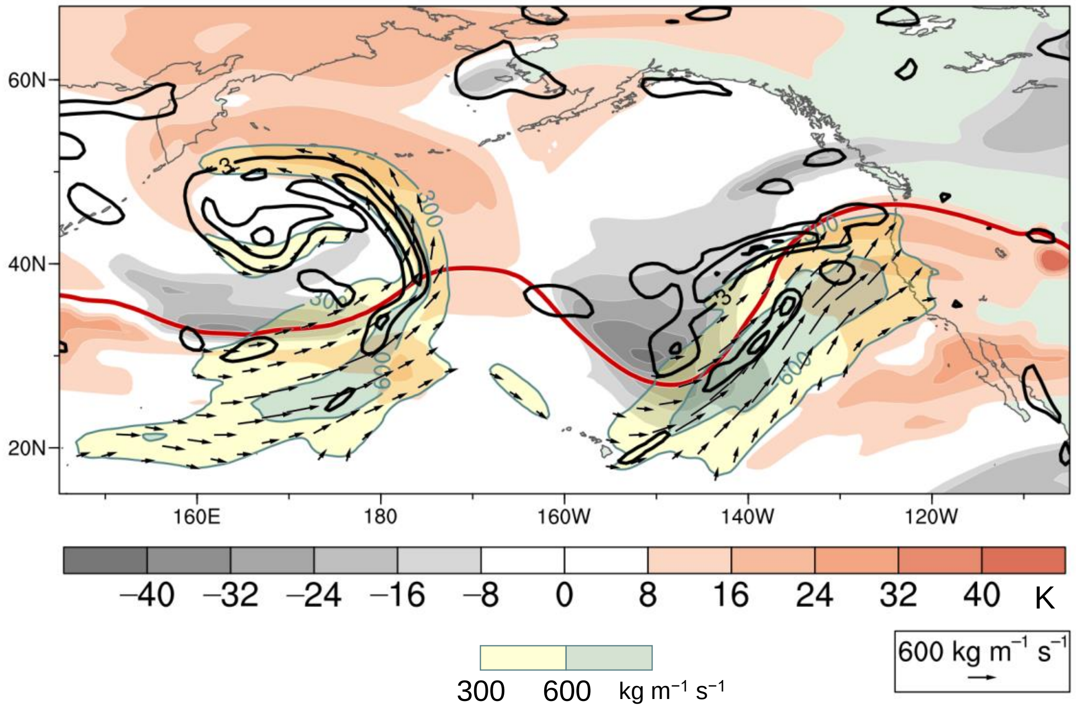
Dynamics of a persistent atmospheric river



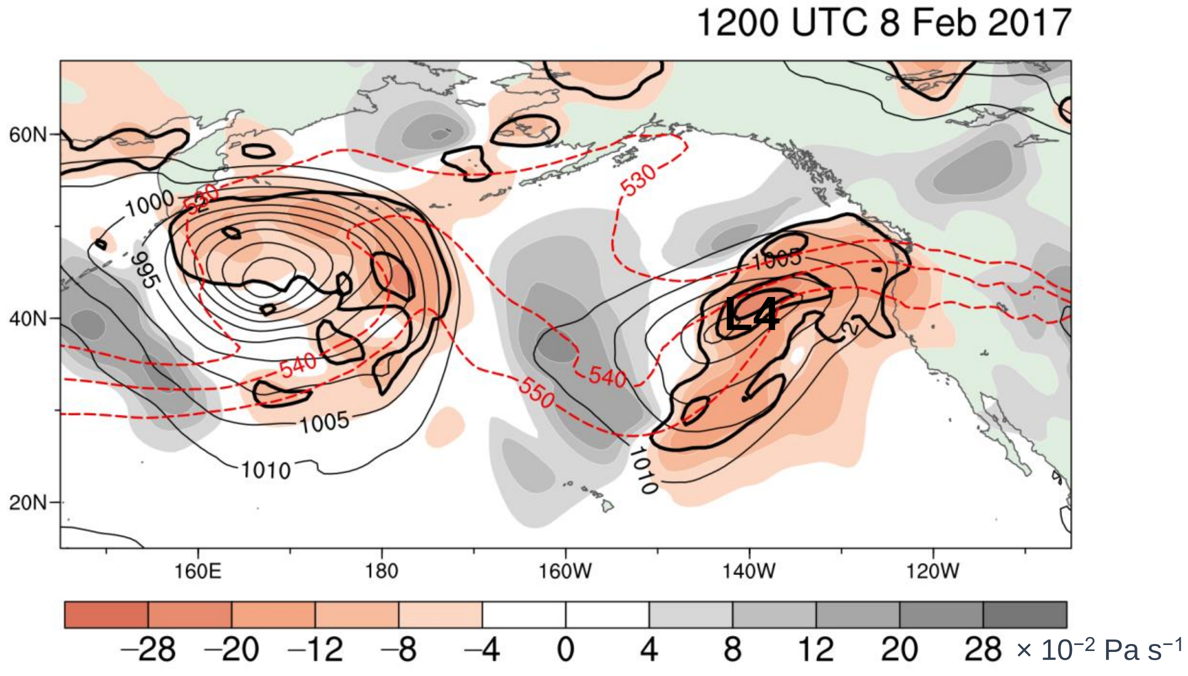
330-K DT isentrope (red), DT θ′ (shading, K),
1000–700-hPa ζ (black, 10^{-5} s^{-1}),
IVT (vectors and shading, kg m^{-1} s^{-1})

1000–500-hPa thickness (dashed red, dam),
700–500-hPa averaged QG ascent (shading, 10^{-2} Pa s^{-1}),
1000–700-hPa ζ tendency due to stretching by QG ascent (thick black, 10^{-10} s^{-2}),
sea level pressure (thin black, hPa)

Dynamics of a persistent atmospheric river

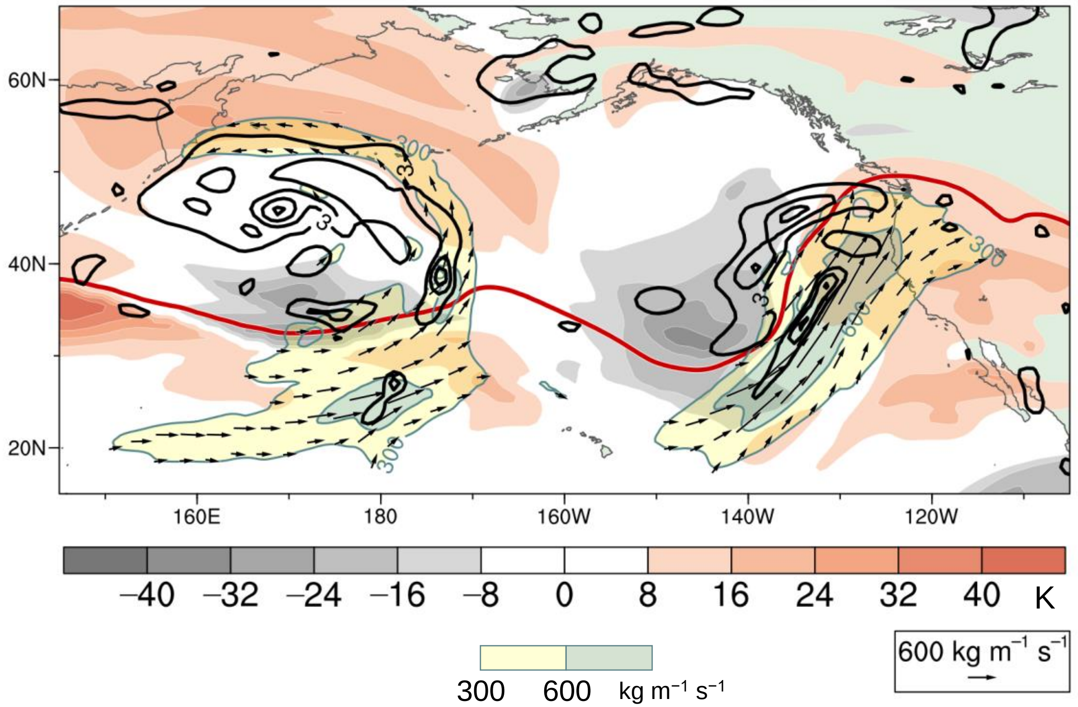


330-K DT isentrope (red), DT θ′ (shading, K),
1000–700-hPa ζ (black, 10^{-5} s^{-1}),
IVT (vectors and shading, kg m^{-1} s^{-1})

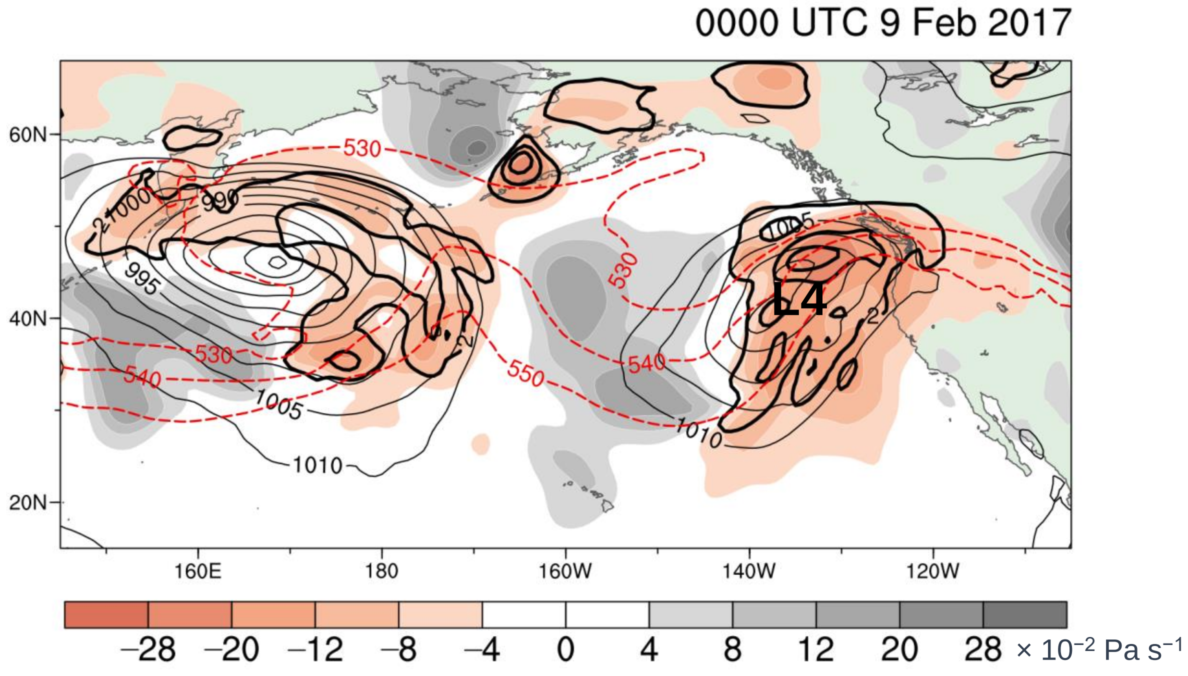


1000–500-hPa thickness (dashed red, dam),
700–500-hPa averaged QG ascent (shading, 10^{-2} Pa s^{-1}),
1000–700-hPa ζ tendency due to stretching by QG ascent (thick black, 10^{-10} s^{-2}),
sea level pressure (thin black, hPa)

Dynamics of a persistent atmospheric river



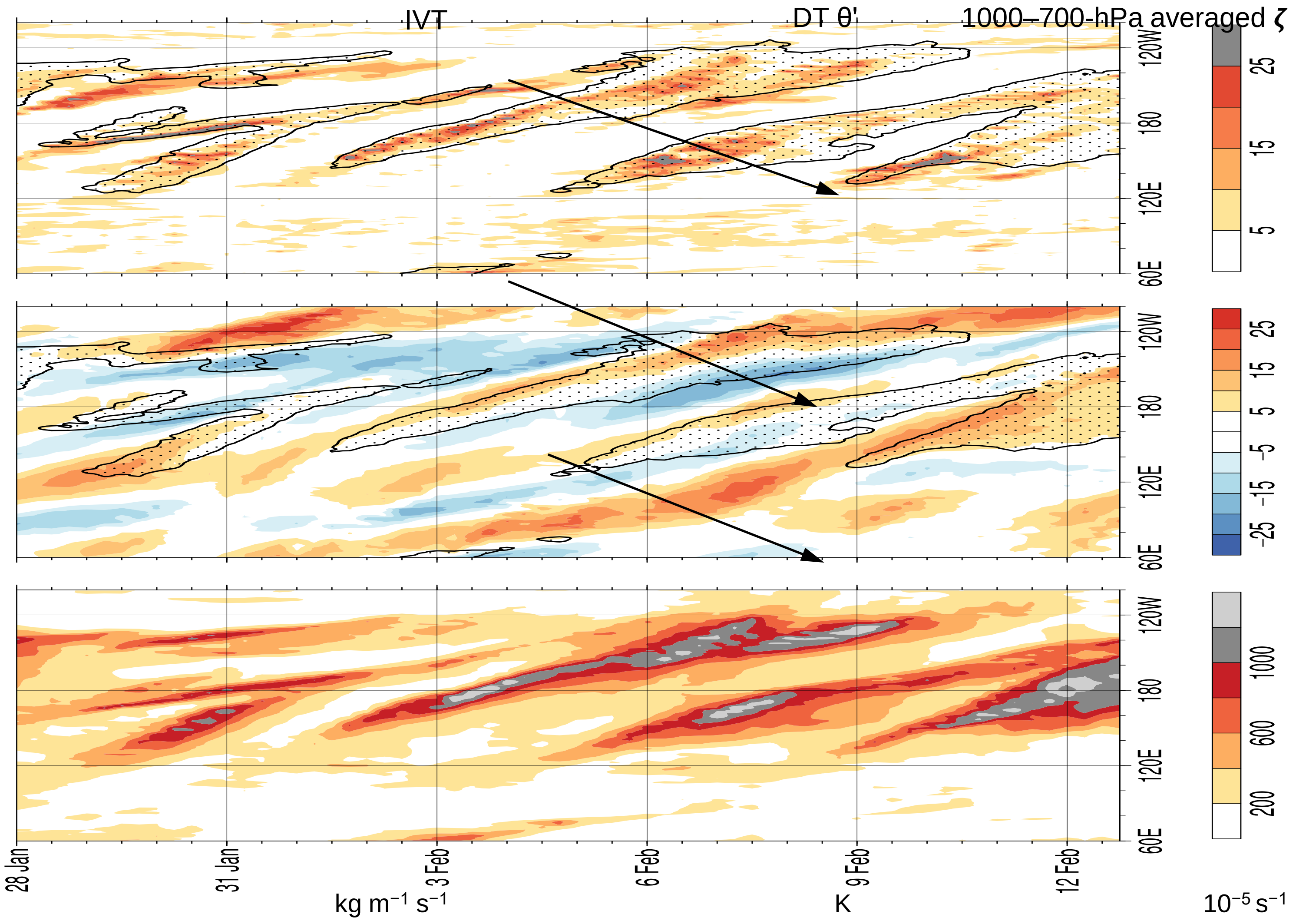
330-K DT isentrope (red), DT θ′ (shading, K),
1000–700-hPa ζ (black, 10^{-5} s^{-1}),
IVT (vectors and shading, kg m^{-1} s^{-1})



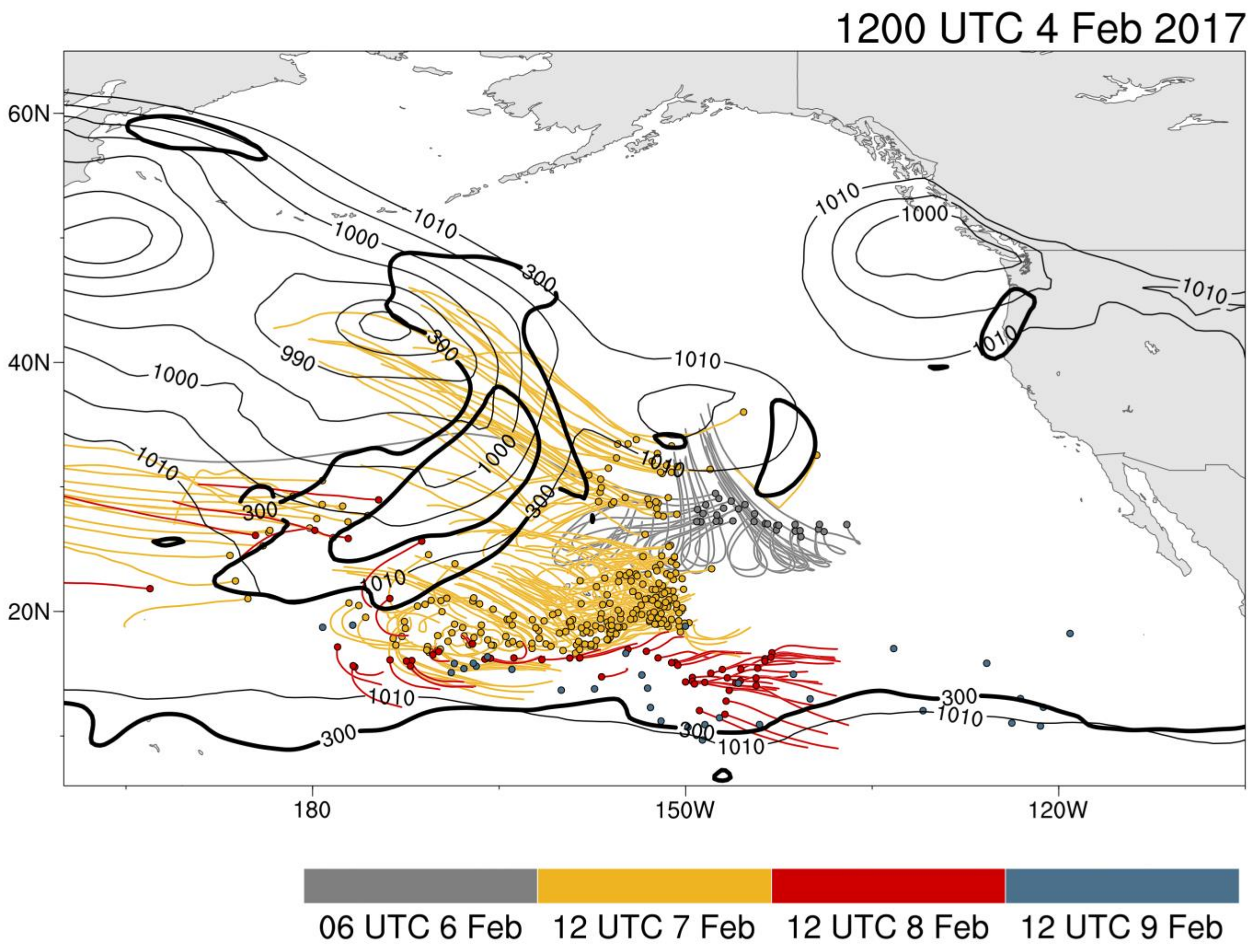
1000–500-hPa thickness (dashed red, dam),
700–500-hPa averaged QG ascent (shading, 10^{-2} Pa s^{-1}),
1000–700-hPa ζ tendency due to stretching by QG ascent (thick black, 10^{-10} s^{-2}),
sea level pressure (thin black, hPa)

Dynamics of a persistent atmospheric river

Hovmöllers
20–45°N



Lagrangian visualization of a persistent atmospheric river



trajectory end time

IVT magnitude (thick black, kg m^{-1} s^{-1}), sea level pressure (thin black, hPa), selected sets of 120-h trajectories

trajectories required to:

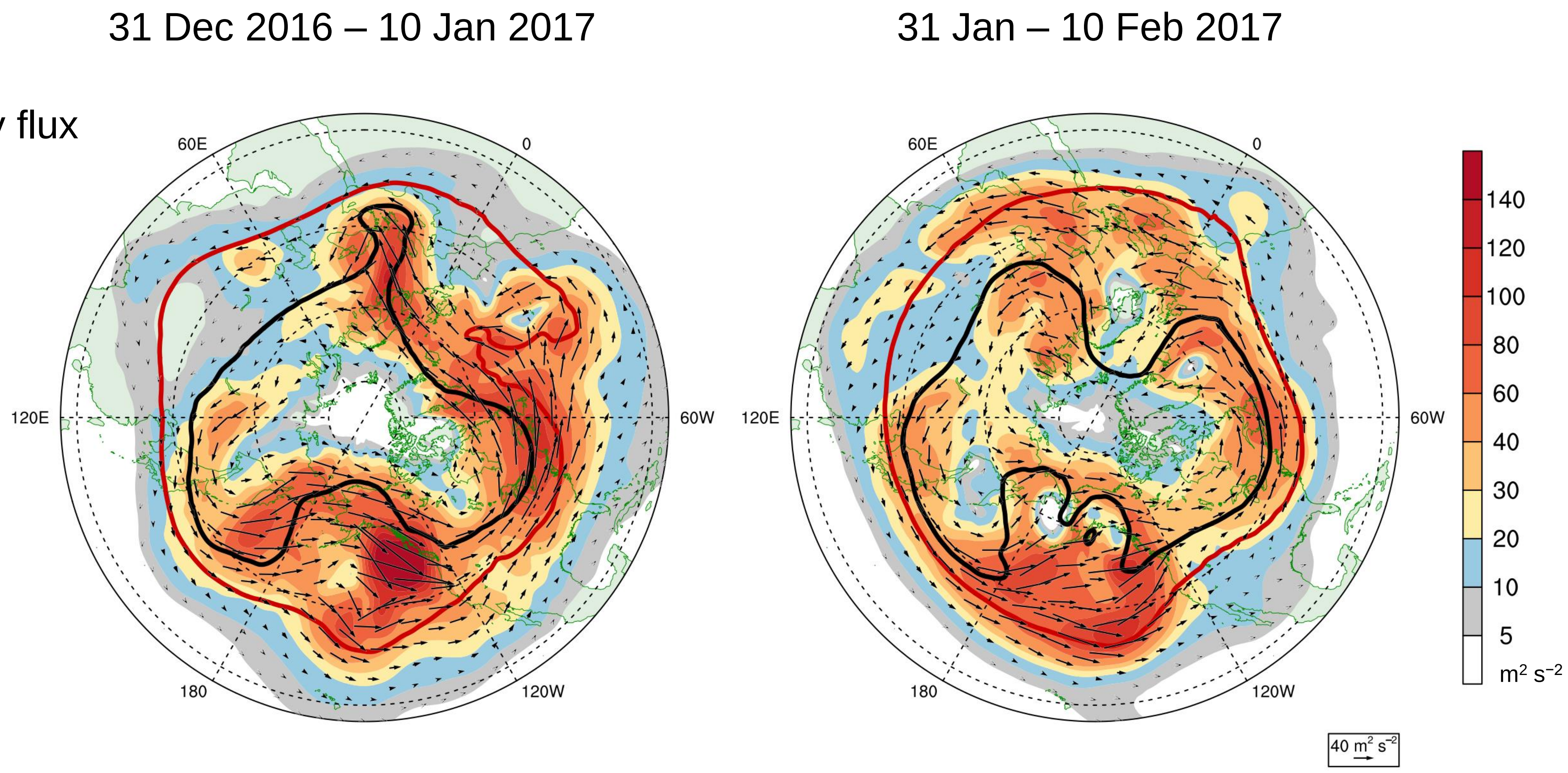
- *pass through box over northern CA in final 24 h*
- *ascend >300 hPa in final 24 h*
- *exhibit moisture flux of >100 g kg^{-1} m s^{-1} at least once during final 72 h*

Summary

- Extraordinary precipitation amounts in CA during winter 2016–2017 were produced by discrete extreme precipitation events.
- Two largest precipitation events occurred in conjunction with a large-scale blocking pattern over North Pacific.
- Blocking pattern established and maintained in connection with successive Rossby wave packets propagating southeastward into western North Pacific.
- Wave packets resulted in successive cyclonic wave breaking events over eastern North Pacific and simultaneous downstream wave dispersion into eastern North Pacific along subtropical jet that "undercut" blocking ridge.
- Subtropical disturbances phased and interacted with polar trough and baroclinic zone linked to anticyclonic wave breaking on the eastern flank of the blocking ridge, resulting in formation and maintenance of strong, persistent atmospheric river extending into northern CA.

Northern Hemispheric conditions

wave activity flux



300-hPa wave activity flux (vectors and shading, $m^2\ s^{-2}$), 310-K and 330-K DT isentropes (blue and red contours)

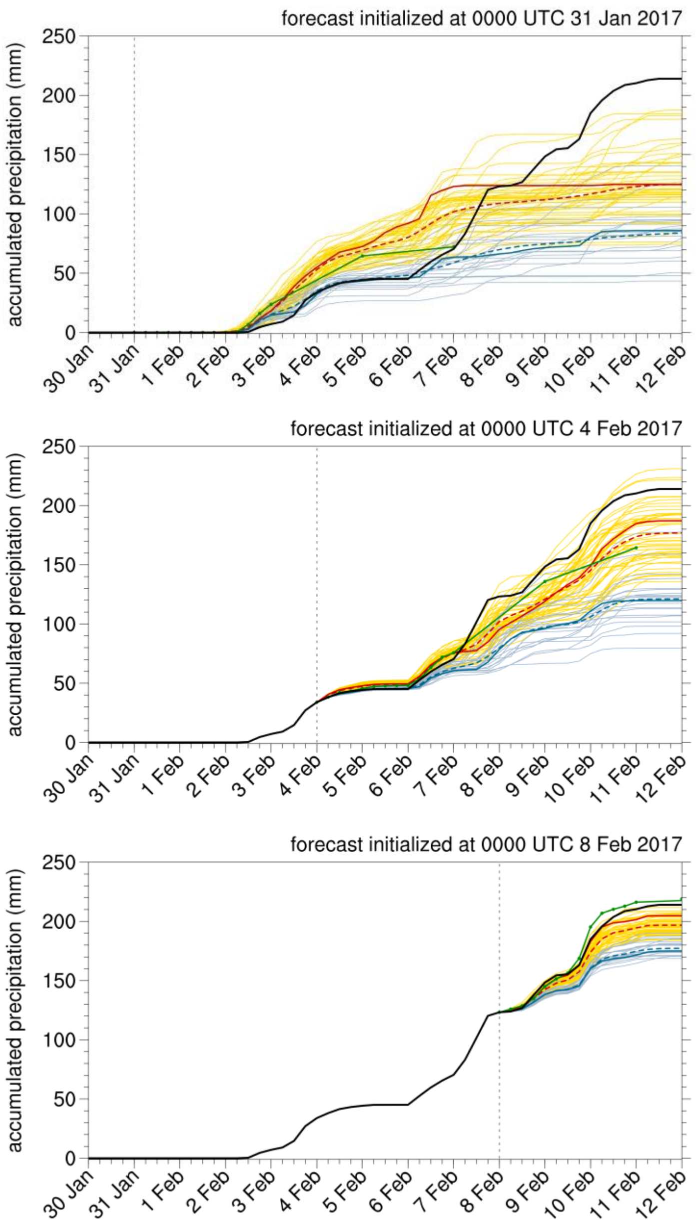
Forecast postscript

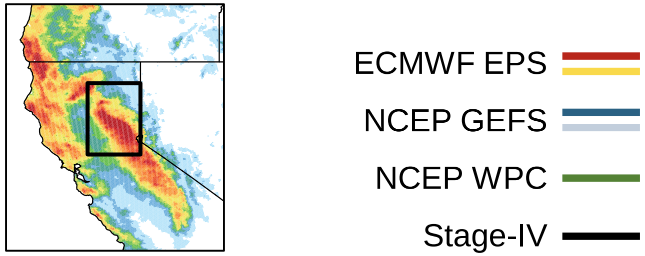
Medium-range forecasts differed markedly with respect to precipitation over California.

NCEP GEFS performed particularly poorly compared to ECMWF EPS.

Forecasts constitute a natural experiment to examine factors contributing to AR persistence and associated precipitation impacts.

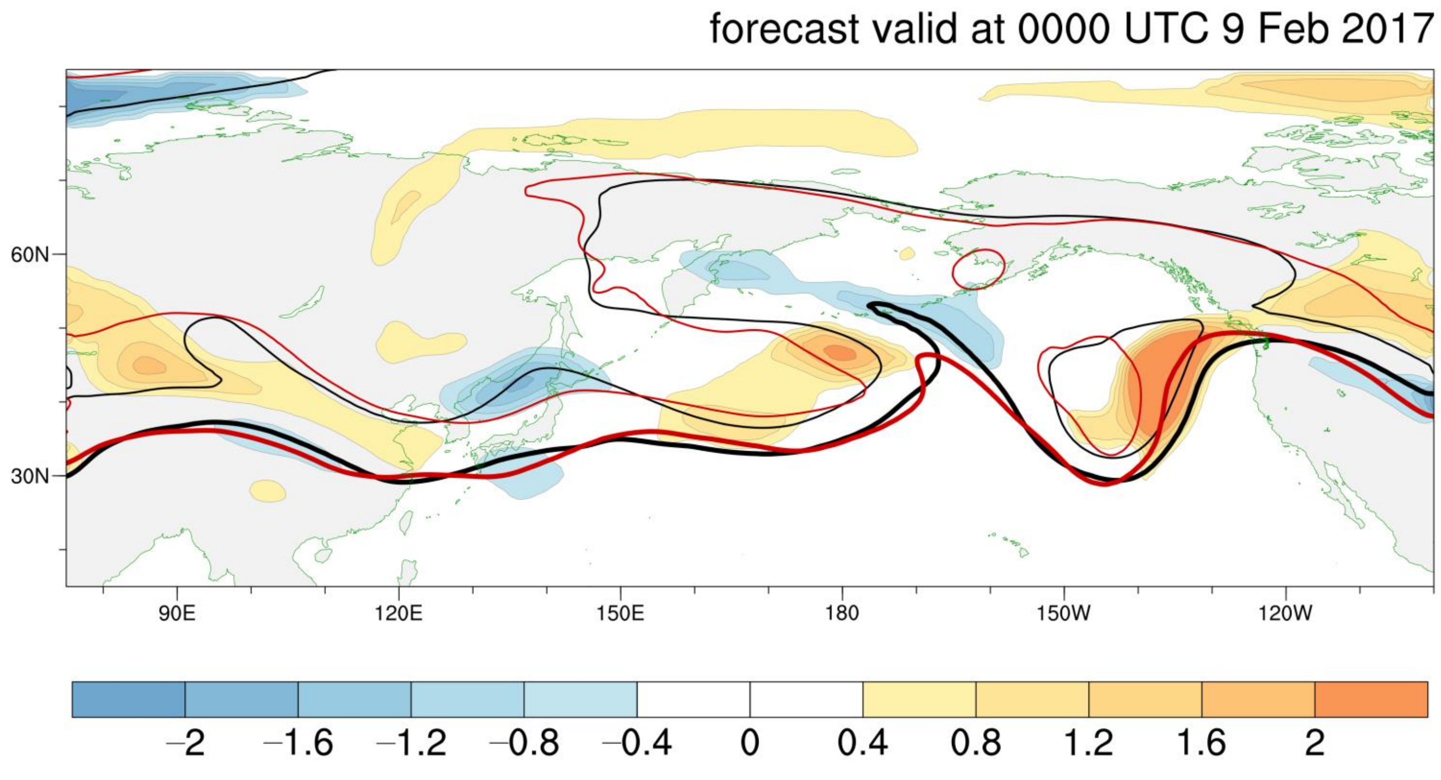
forecasts of area-averaged precipitation in northern Sierra Nevada



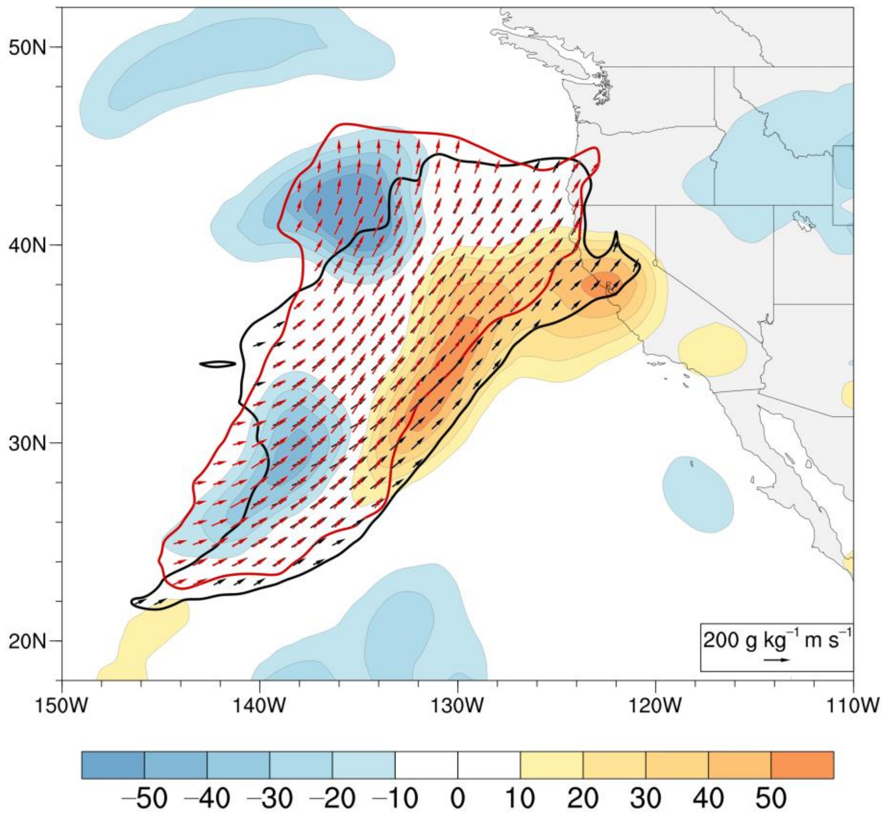


Forecast postscript

ECMWF EPS — NCEP GEFS comparison



320-K PV difference (shading, PVU), PV (contours, red: NCEP; black: ECMWF)



850-hPa moisture flux difference (shading, g kg^{-1} m s^{-1}), flux (contours and vectors >200 g kg^{-1} m s^{-1}, red: NCEP; black: ECMWF)