Contributions of Water Vapor and Temperature to the Interannual Variability of Precipitation: An Evaluation from North American Regional Reanalysis

Er Lu and Gene Takle

Iowa State University

Motivation

- Interannual variability of P – floods/droughts
- Atmospheric circulation, SST, snow cover, etc
- Water vapor and saturation conditions
- Contributions of water vapor and temperature

Question

Is more atmospheric water vapor necessarily required to have more precipitation in wet years? or

For the precipitation of a season, are there places where the more precipitation of wet years is due to lower temperature rather than more water vapor?

North American Regional Reanalysis

- **27 years (1979-2005), 32km, 29 levels**

At each grid point, for each season and the whole year

- **Composite wet year – 9 wettest years**
- **Composite dry year – 9 driest years**

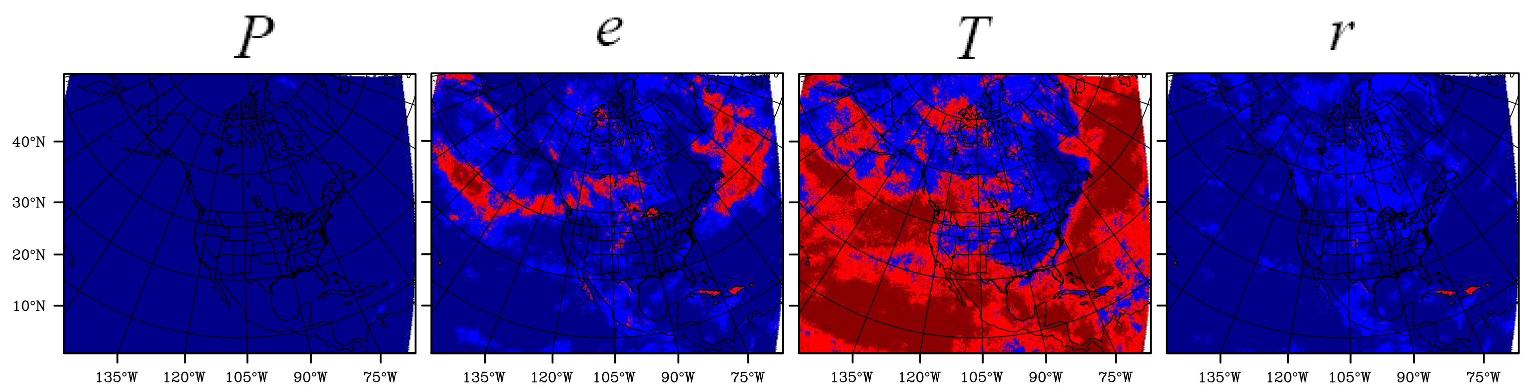
The contrast between the composite wet year and the composite dry year is used to characterize the interannual variability of precipitation.

Difference between the averages of the 9 wettest and 9 driest years

Positive **Negative**

dark colors – 95% significance

Winter 600hPa



$$P^{wet} > P^{dry}$$

$$e^{wet} \gtrless e^{dry}$$

$$T^{wet} \gtrless T^{dry}$$

$$r^{wet} > r^{dry}$$

Using relative humidity to reflect the year-to-year change of precipitation

Mean precipitation rate and relative humidity of a season

$$P = P_w t_w$$

$$r = r_w t_w + r_d t_d$$

$$t_w + t_d = 1$$

wet time dry time

Change from year 1 to year 2

$$\Delta P = P_{w2} \Delta t_w + t_{w1} \Delta P_w$$

The year-to-year change of the seasonal mean precipitation rate is mainly due to the change of the total precipitation duration; the change of wet-time mean precipitation intensity has less contribution.

$$\Delta r = (r_{w2} - r_{d2}) \Delta t_w + t_{w1} \Delta r_w + t_{d1} \Delta r_d$$

Wet-time relative humidity is close to 1; its year-to-year change is small.

Dry-time relative humidity is small; its year-to-year change is small; (the dry time of the season is short).

change of water vapor & change of temperature

from composite dry year to composite wet year

$$P^{wet} > P^{dry}$$

$$r^{wet} > r^{dry}$$

$$\frac{e^{wet}}{e_s(T^{wet})} > \frac{e^{dry}}{e_s(T^{dry})}$$

$$a^{T_d^{wet} - T_d^{dry}} = C_{vap} \equiv \frac{e^{wet}}{e^{dry}} > \frac{e_s(T^{wet})}{e_s(T^{dry})} \equiv C_{tem} = b^{T^{wet} - T^{dry}}$$

$$a = \exp\left(\frac{L}{R_v T_d^{wet} T_d^{dry}}\right) \approx 1.05$$

$$b = \exp\left(\frac{L}{R_v T^{wet} T^{dry}}\right) \approx 1.07$$

$C_{vap} > C_{tem} > 1$

Moistening pattern

Water vapor and temperature both increase from composite dry year to wet year, and water vapor increases more. So, the more precipitation of wet years corresponds to more water vapor but not lower temperature.

$1 > C_{vap} > C_{tem}$

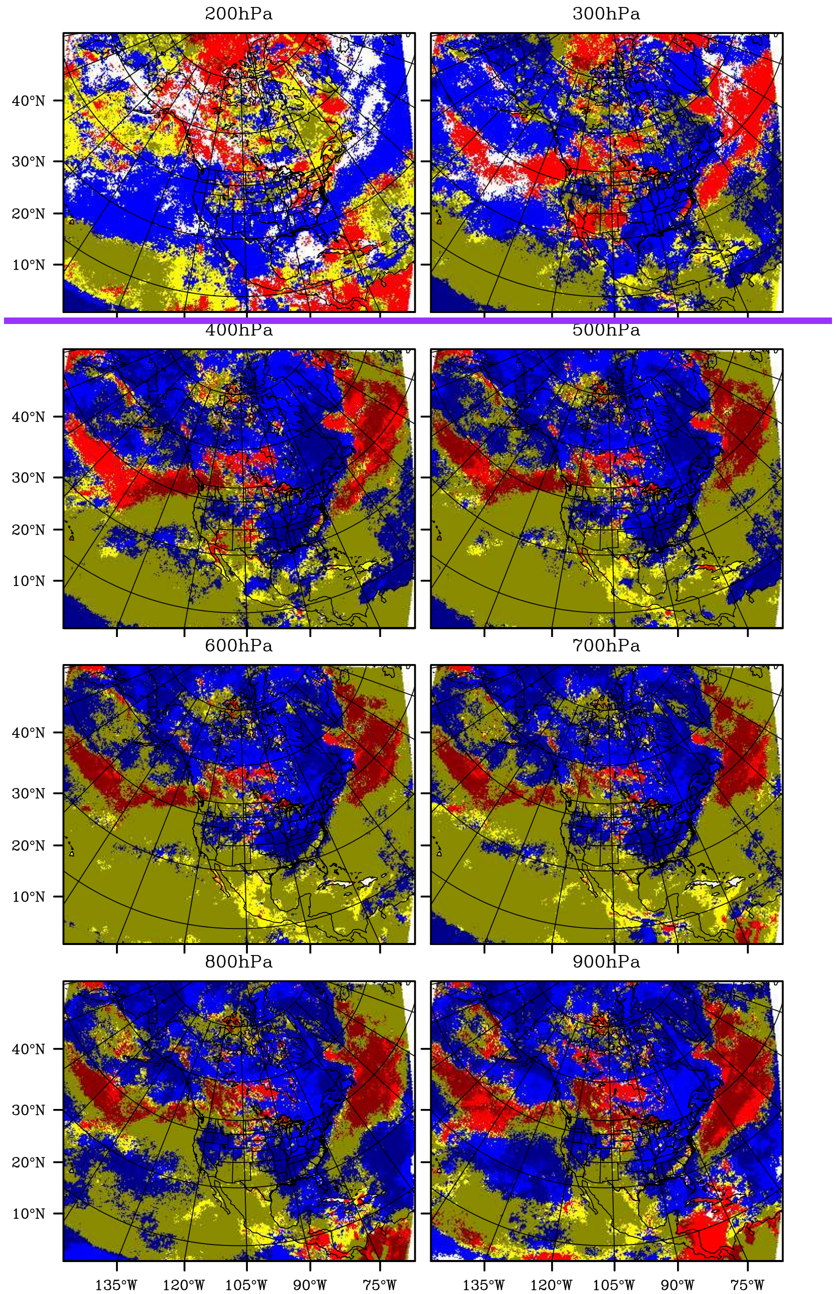
Cooling pattern

Water vapor and temperature both decrease from composite dry year to wet year, and temperature decreases more. So, the more precipitation of wet years corresponds to lower temperature but not more water vapor.

$C_{vap} > 1 > C_{tem}$

Moistening-cooling pattern

Water vapor increases but temperature decreases from composite dry year to wet year, thus the more precipitation of wet years corresponds to both more water vapor and lower temperature.



Winter precipitation

white areas – Cvap<Ctem

Moistening pattern

Cooling pattern

Moistening-cooling pattern

dark colors – 95% significance

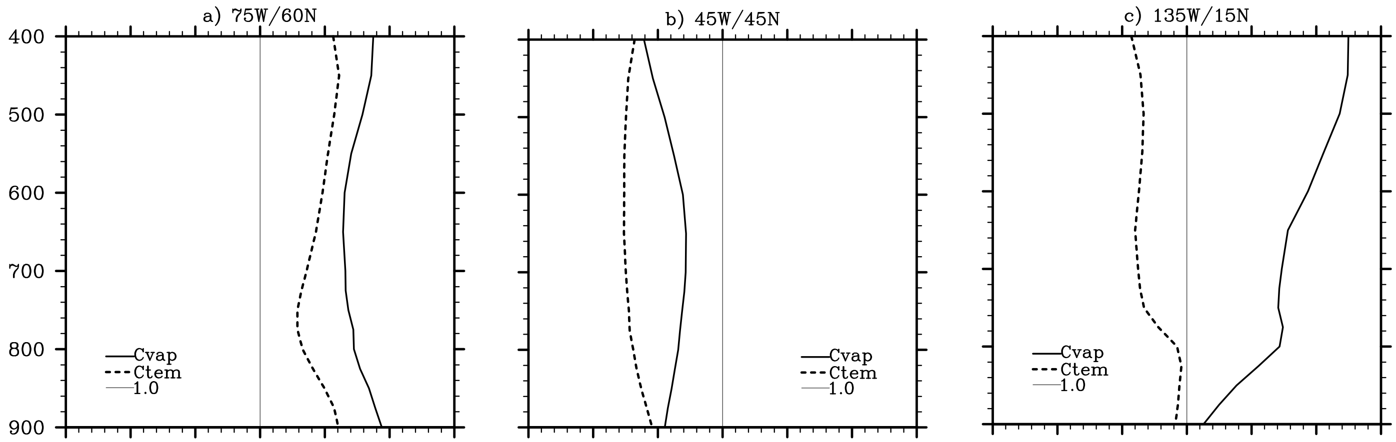
Moistening pattern controls the high-latitudes, so water vapor amount is important to the winter precipitation of this region, while temperature does not contribute positively.

Cooling pattern affects mid-latitudes.

Moistening-cooling pattern prevails in low-latitudes.

Profiles of the changes of water vapor and temperature

winter precipitation



There are places where the same contribution pattern controls the entire atmospheric column below 350hPa.

Contributions of water vapor and temperature of a layer/column

$$[p_1, p_2]$$

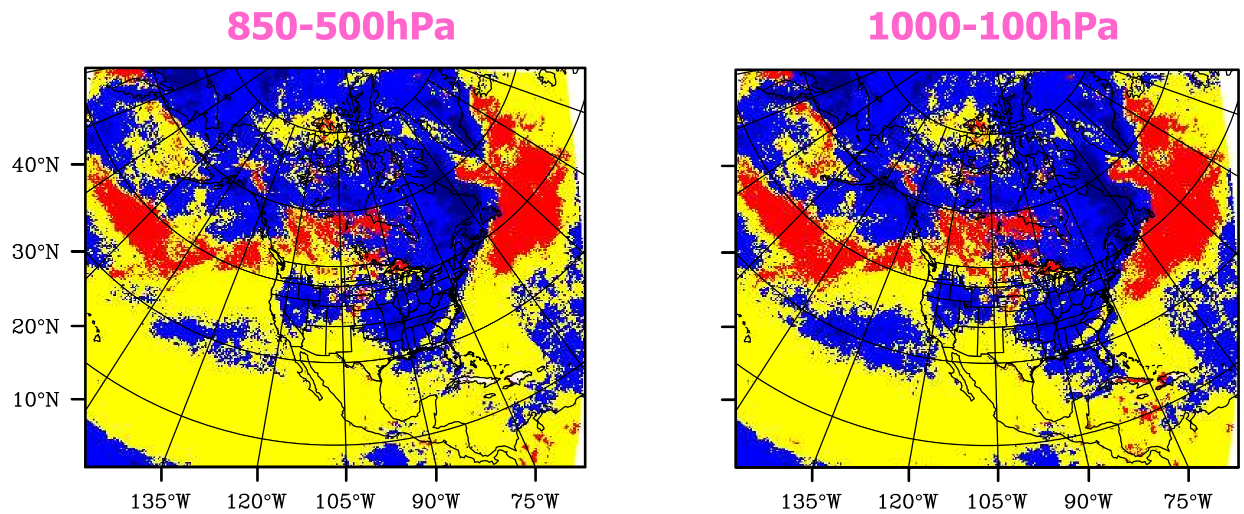
$$r \equiv \frac{\varepsilon \int_{p_1}^{p_2} e \frac{d \ln p}{g}}{\varepsilon \int_{p_1}^{p_2} e_s(T) \frac{d \ln p}{g}} \equiv \frac{W}{W_s}$$

$$C_{vap} \equiv \frac{W^{wet}}{W^{dry}}$$

$$C_{tem} \equiv \frac{W_s^{wet}}{W_s^{dry}}$$

Contributions of water vapor and temperature of a layer/column

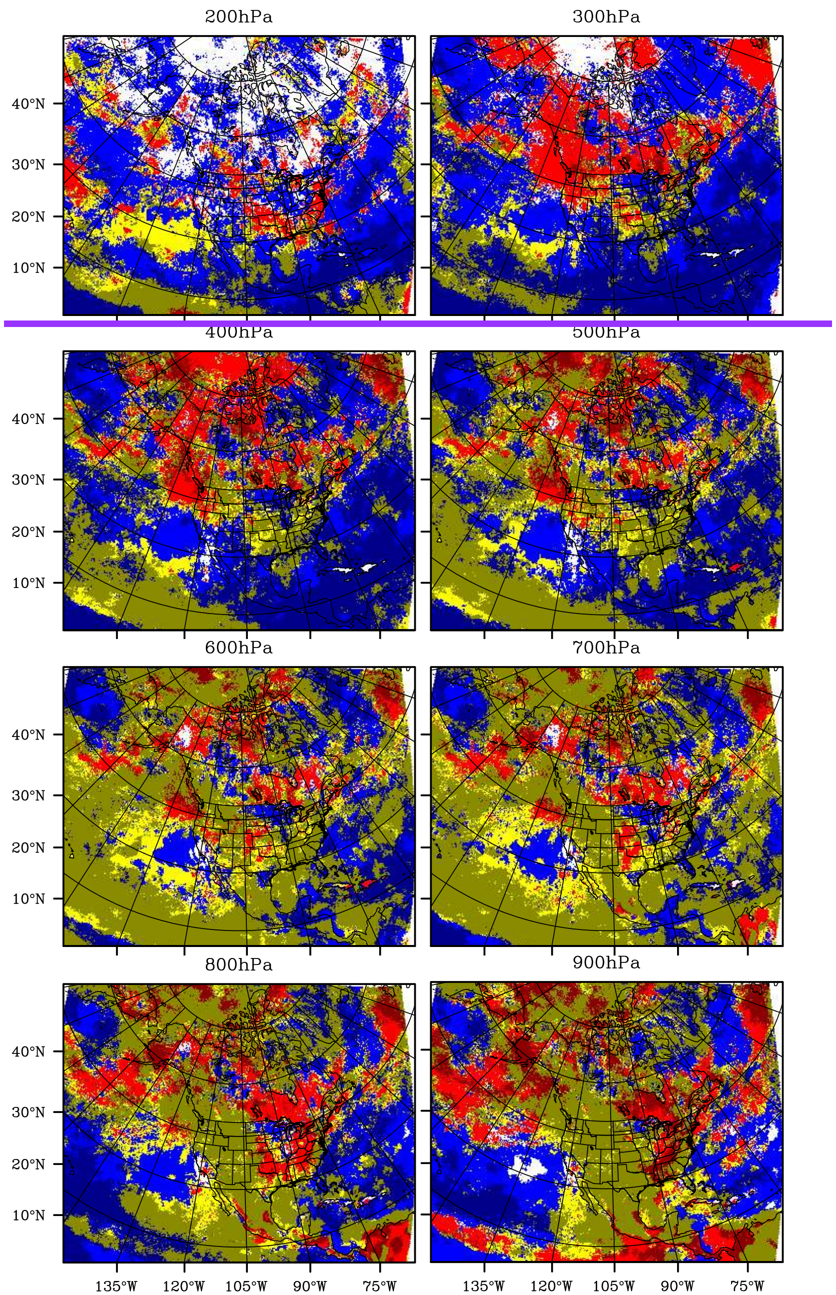
winter precipitation



Moistening pattern

Cooling pattern

Moistening-cooling pattern



Summer precipitation

white areas – Cvap<Ctem

Moistening pattern

Cooling pattern

Moistening-cooling pattern

dark colors – 95% significance

Cooling pattern is mainly in mid-high latitudes.

Moistening pattern is mainly in low-latitudes.

Moistening-cooling pattern can appear in all latitudes.