Atmospheric Moisture Content Associated with Surface Air Temperatures over Northern Eurasia

Hengchun Ye
California State University, Los Angeles
Eric J. Fetzer
Jet Propulsion Laboratory, California Institute of Technology

International Journal of Climatology, 2010, , 30 (10): 1463-1471.DOI:10.1002/JOC.1991
Also available at http://instructional1.calstatela.edu/hye2/2009a

Literatures on Water Vapor Changes

Atmospheric relative humidity seems to stay constant especially averaged over a global scale and the average specific humidity increases follows the Clausius-Claperyron's rate (e.g. IPCC 2007; Dessler et al. 2008)

There is a large regional variation due to complex local effects (Bauer et al 2002; Dai 2006; Trenberth and Sherwood); negative relationship is observed over some tropical and subtropical land regions (interpreted from Dai 2006's graphs).

Relationship between monthly mean atmospheric total water vapor and sea surface temperature (SST) over oceans revealed that the relationship resembled the Clausius-Clapeyron curve when the SST was greater than 15°C, but warned of a potential large difference in the relationship over land areas (Stephens, 1990)

Theoretically, atmospheric moisture increases with air temperature following the Clausius-Clapeyron relationship of constant relative humidity (7%/ºC). So, the higher the air temperature the larger the amount of water vapor increases

Clausius-Clapeyron equation

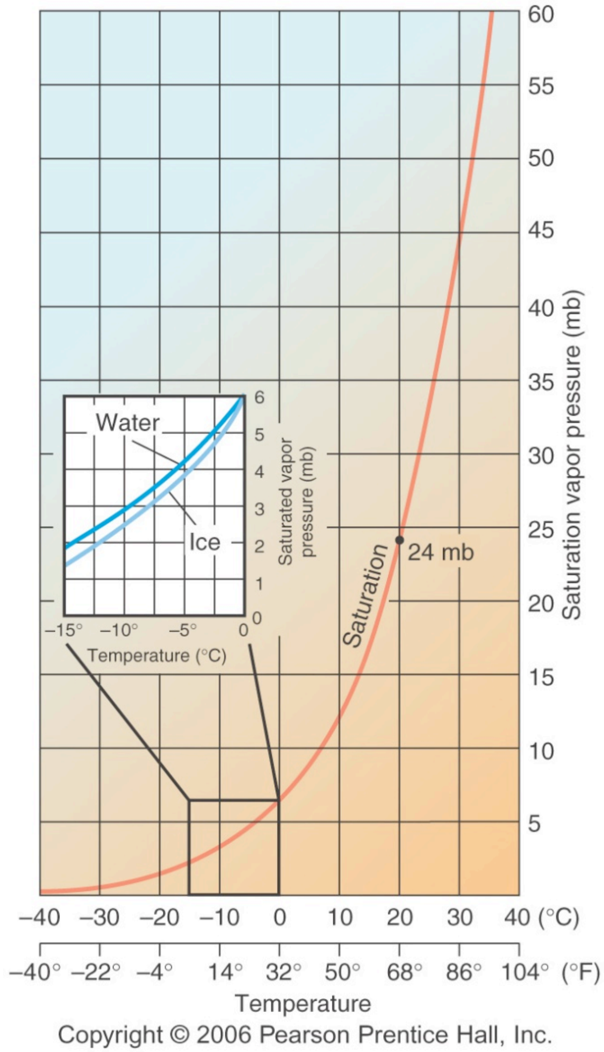
$Es=6.11*e^{(L/Rv)(1/273-1/T)}$ (over liquid surface)

Es: Saturation vapor pressure

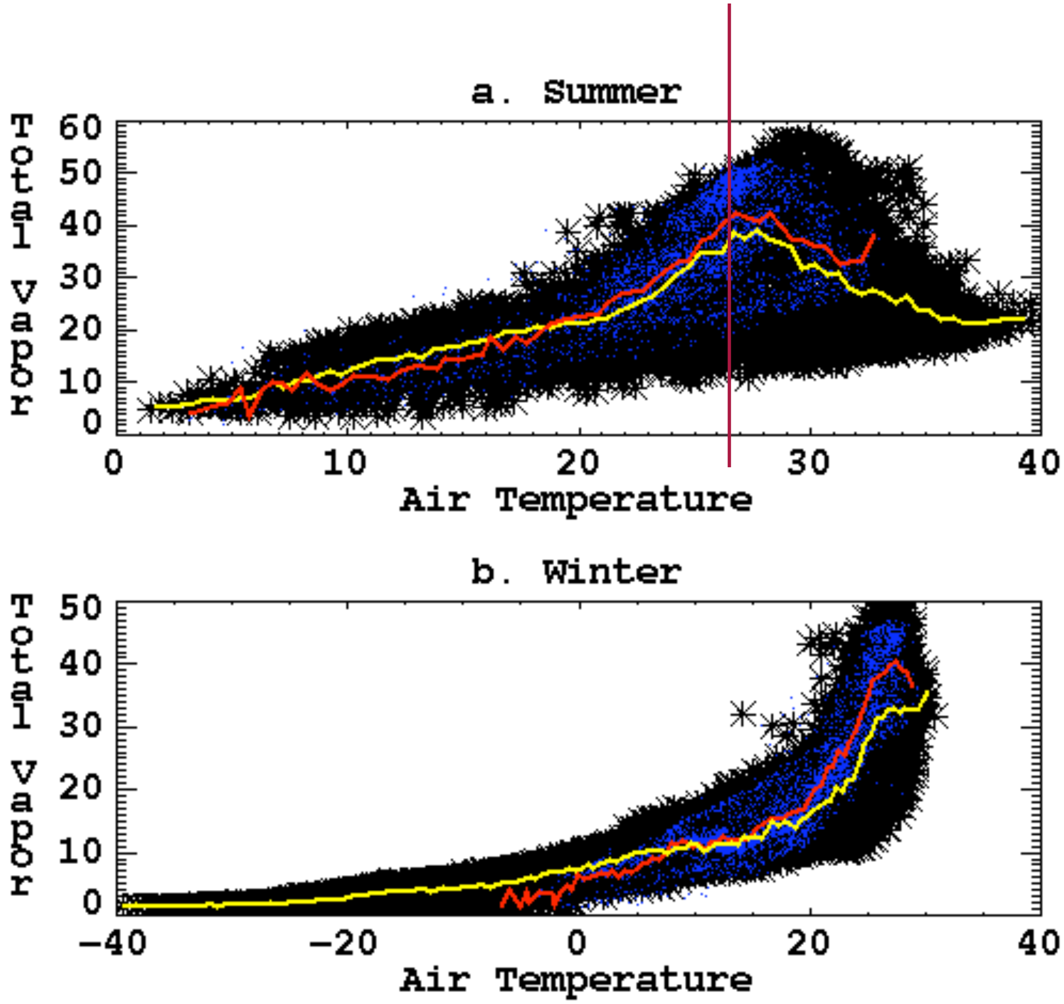
L: Latent heat of vaporization = 2.453×10^6 J/kg

Rv: Gas constant for moist air = 461 J/kg

T: Temperature in Kelvins

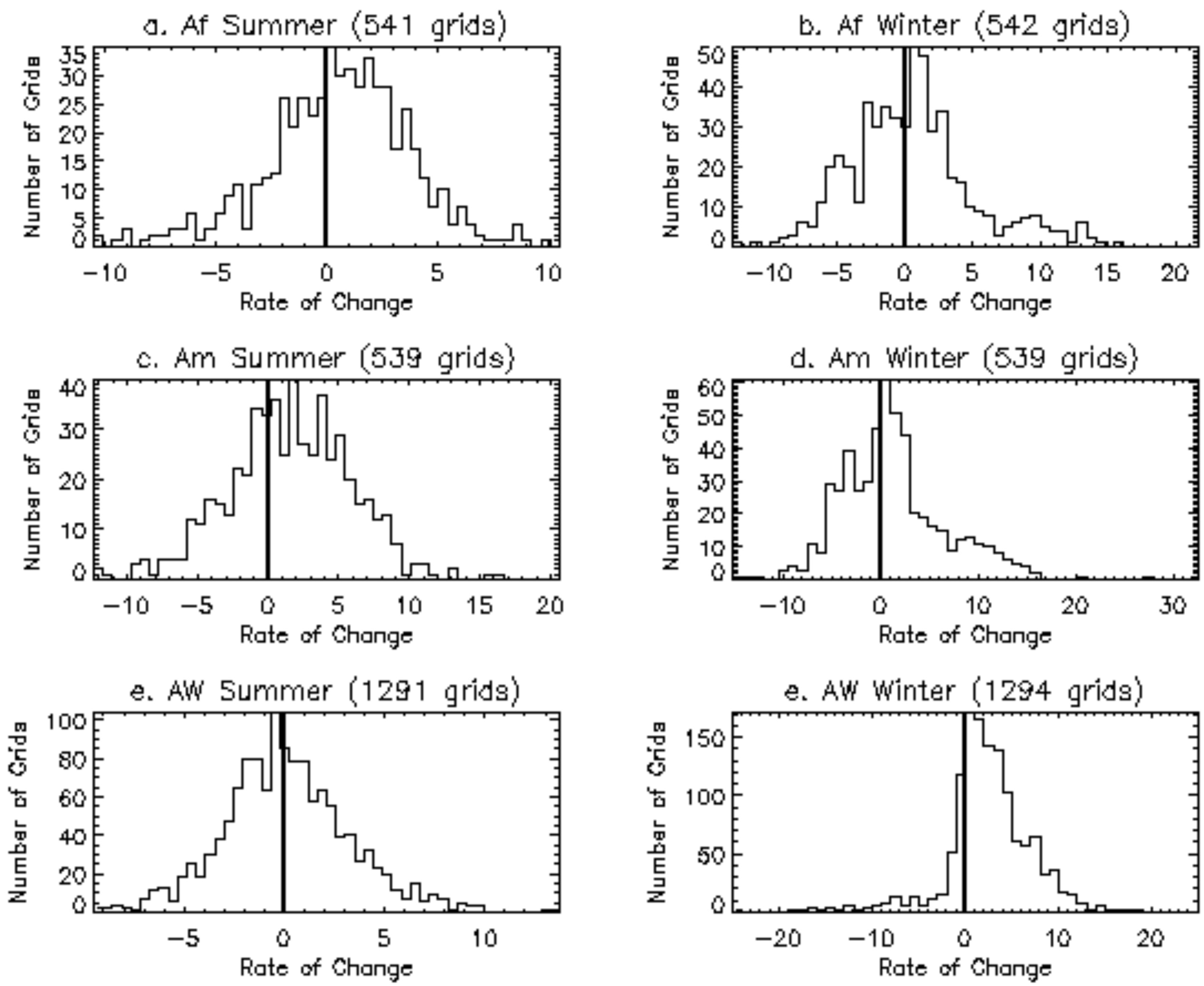


A quick test on this relationship using with AIRS data at global land areas



Scatter plot of total precipitable water vapor versus surface air temperature for land areas of 60ºS-60ºN using AIRS data (2002/03-2006/07). Black stars are northern Hemisphere grids and blue dots are southern Hemisphere grids. Yellow line: averaged from Northern Hemisphere grids at each degree increment; Red line: averaged from Southern Hemisphere grids at each degree increment.

Example of the rate of change for tropical climate zones



Histogram of percentage of total vapor change for each degree air temperature increase for Koppen's A climate regimes (using AIRS data). **The average rate is 1.22%/ºC, much smaller than Clausius-Clapeyrun relationship describes**. **Negative value occupies a significant amount of land areas in tropical and subtropical land.**

Precipitation Trends

- Significant increases in precipitation amount/intensity are found over high latitude land areas and during cold seasons (Brown and Braaten 1998; Groisman et al. 1999; Ye et al. 1998; Ye 2001)
- No significant increases or even decreases in precipitation are found in lower latitude land regions, especially during warm seasons (Dai et al. 2004; Trenberth et al. 2007).
- Increased extremely rainfall frequency are found over tropical oceans but decreases over tropical land (Allan and Soden 2008; Gu et al. 2007)
- "Current climate models tend to project increasing precipitation at high latitudes and in the tropics (e.g., the south-east monsoon region and over the tropical Pacific) and decreasing precipitation in the sub-tropics (e.g., over much of North Africa and the northern Sahara) (Figure 10.9)." (IPCC 2007)

The missing evidence of warm season precipitation increases with air temperature seems to contradict the water cycle change we might expect in light of the Clausius-Clapeyron relationship.

Two Possibilities:

- Moisture does increase faster with higher air temperatures, but the precipitation is more complex and is controlled by the availability of energy (Problem with AIRS data?)

- Moisture content does not increase as much as expected, or even decreases, in higher temperature ranges due to the scarcity of water resources over land areas especially in dry regions (as confirmed by AIRS data).

Goal of the study

This study will reveal the seasonal differences in changes in atmospheric moisture content over Northern Eurasia with a focus on the unique characteristics of summer conditions,

which may shed some light on the puzzle of warm season climate change over high-latitude land areas

Data

1. The Six- and Three-hourly Meteorological Observations from 223 U.S.S.R stations available at the Carbon Dioxide Information Analysis Center (CDIAC), Oak Ridge National Laboratory, Oak Ridge, Tennessee (ftp://cdiac.esd.ornl.gov) (Four-times per day water vapor pressure and air temperature during1936-89; 80 stations are used for time period of 1936-89)

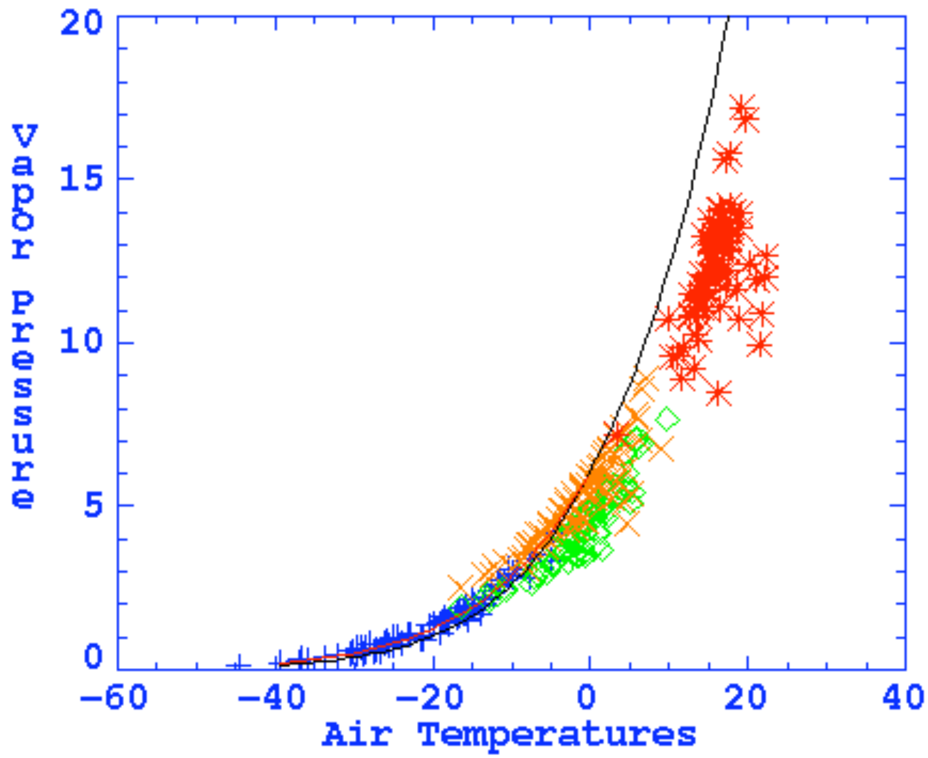
2. Atmospheric Infra-red sounders (AIRS) level III products (Gridded twice per day atmospheric total precipitable vapor during 2003-2007 covering entire study region). (Chahine et al. 2006)

3. The Matsuura and Willmott's gridded surface air temperature data set from University of Delaware (monthly during 2003-2006). They are used to match with AIRS vapor data (AIRS surface air temperature has not been validated over the high latitude region)

Methodology

1) Seasonal values are derived from monthly values, monthly is derived from daily values (if more than 8 days missing, the month is considered as missing).
2) The amount of water vapor changes per degree of temperature increase is derived using the simple linear regression analyses (vapor as a dependent variable and temperature as independent variable)
3) The rate of vapor change per degree of temperature increases (divided by average vapor and multiply by 100%) is calculated to compare with the Clausius-Clapeyron's rate
4) Maps to show the geographical distribution and scatter plots to reveal the relationships with temperature

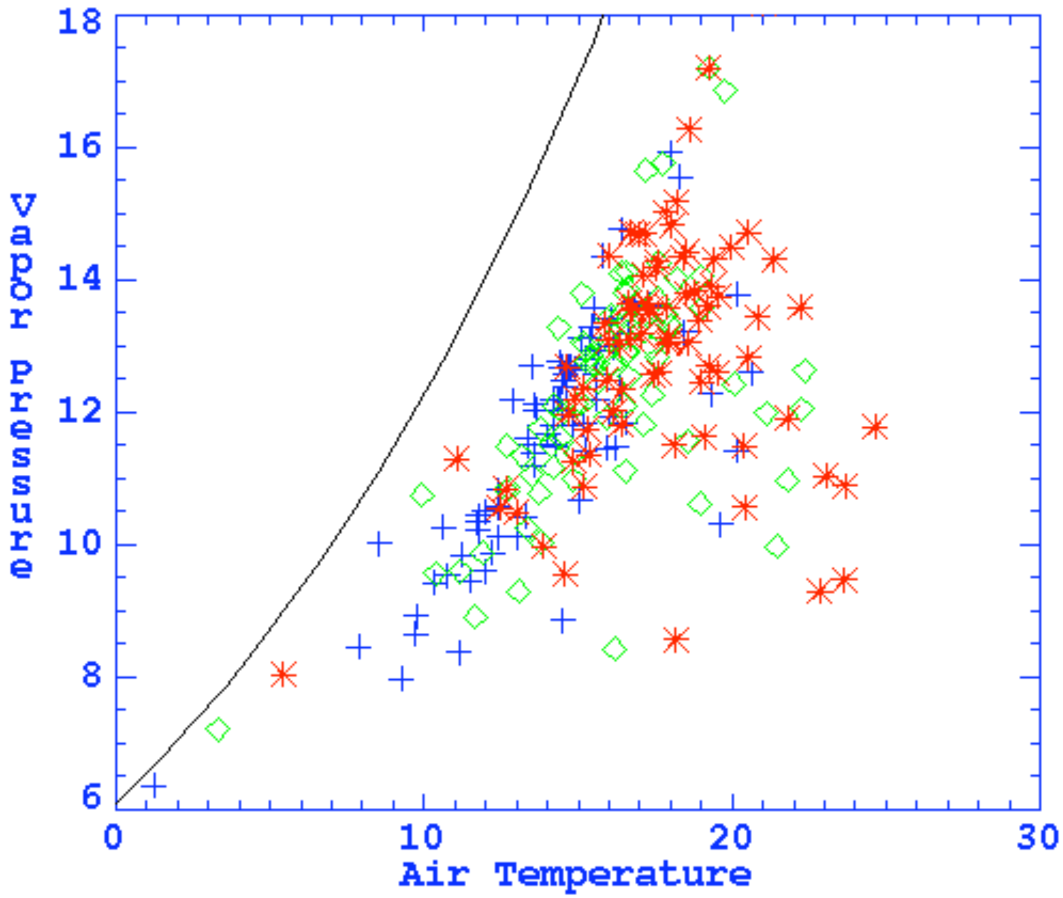
Figure 1. Mean seasonal vapor pressure versus air temperature at 80 stations during winter (blue plus), spring (green diamond), summer (red star), and fall (orange cross). Thin line is the Clausius-Clapeyron line.



Geographically, vapor pressure increases with air temperature in general, except for summer season.

The winter relationship follows closely with Clausius-Clapeyron line, and summer has the lowest values and spring and fall lie in between

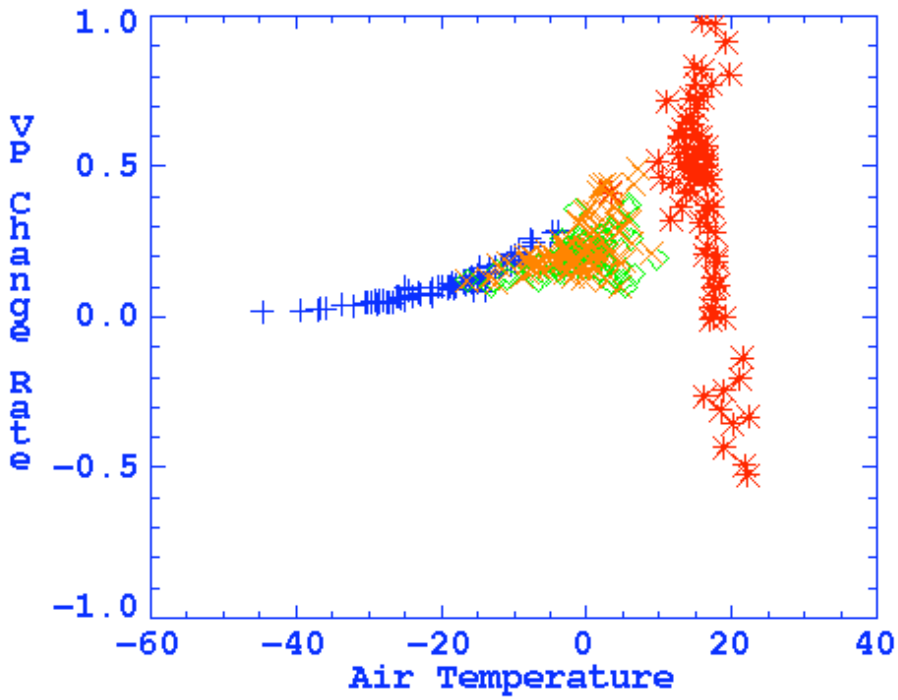
Figure 2. Mean summer vapor pressure versus temperature for the 5 lowest temperature summers (blue-cross), and the 5 highest temperature summers (red-star), and the rest summers (44 summers; green diamond)



Vapor pressure reaches maximum at stations with air temperature at about 19.5°C and starts to decreases at stations with higher temperatures

The 5 hottest summers do not show increased vapor pressure compared to the rest summers

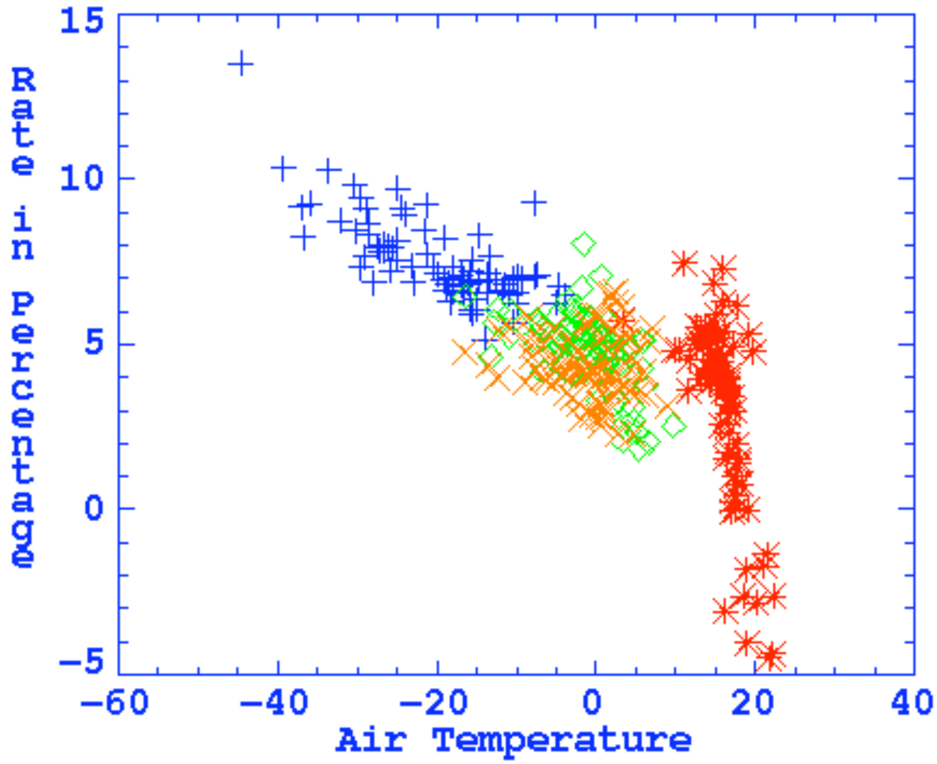
Figure 3. The amount of vapor pressure change with increasing air temperature (hPa/°C) versus mean air temperatures for each of the 80 stations for winter (blue plus), spring (green diamond), summer (red star) and fall (Orange cross).



The amount of vapor pressure increase is higher at stations with higher air temperatures in general except for summer

The amount of vapor pressure increase has lower values at higher temperatures and eventually became decreases with air temperature in summer

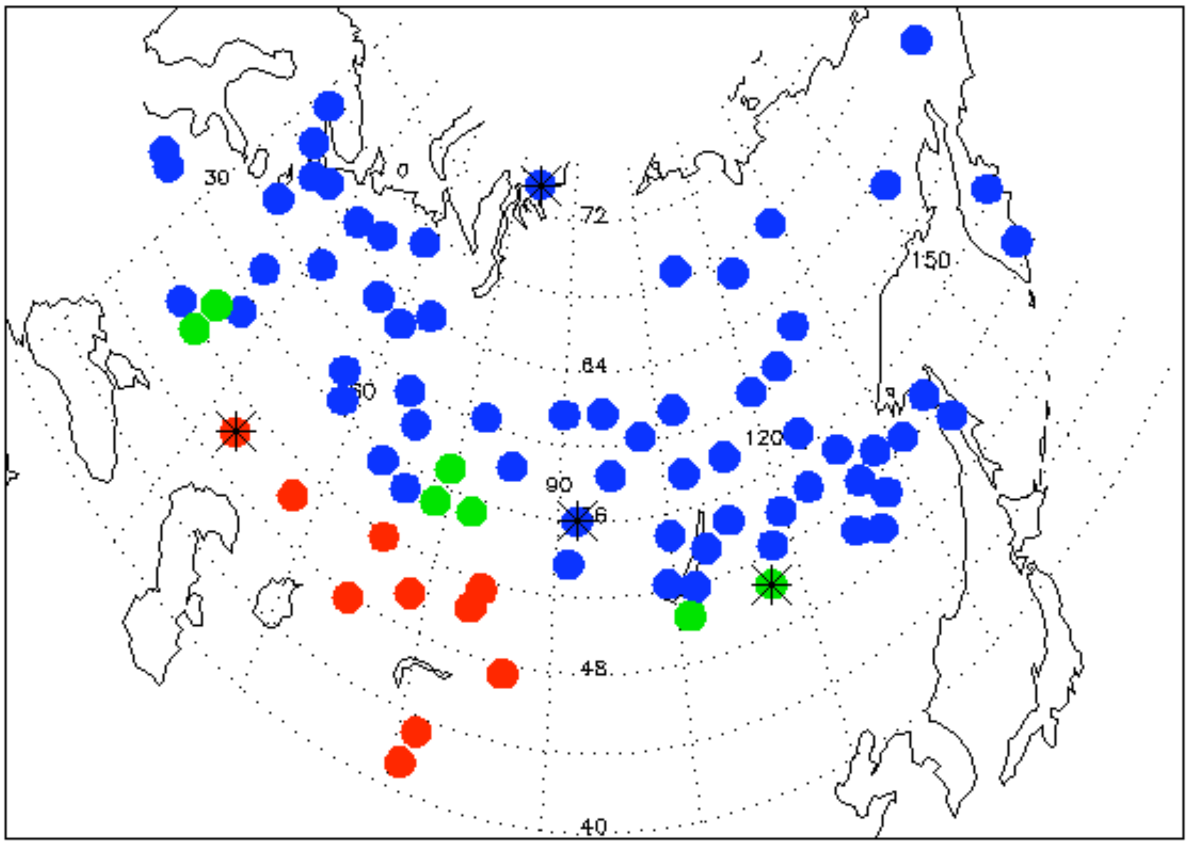
Figure 4. The percentage of change rates (%/ºC) for each season at each of the 80 stations



The rate of vapor pressure change decreases with increasing air temperatures in all season

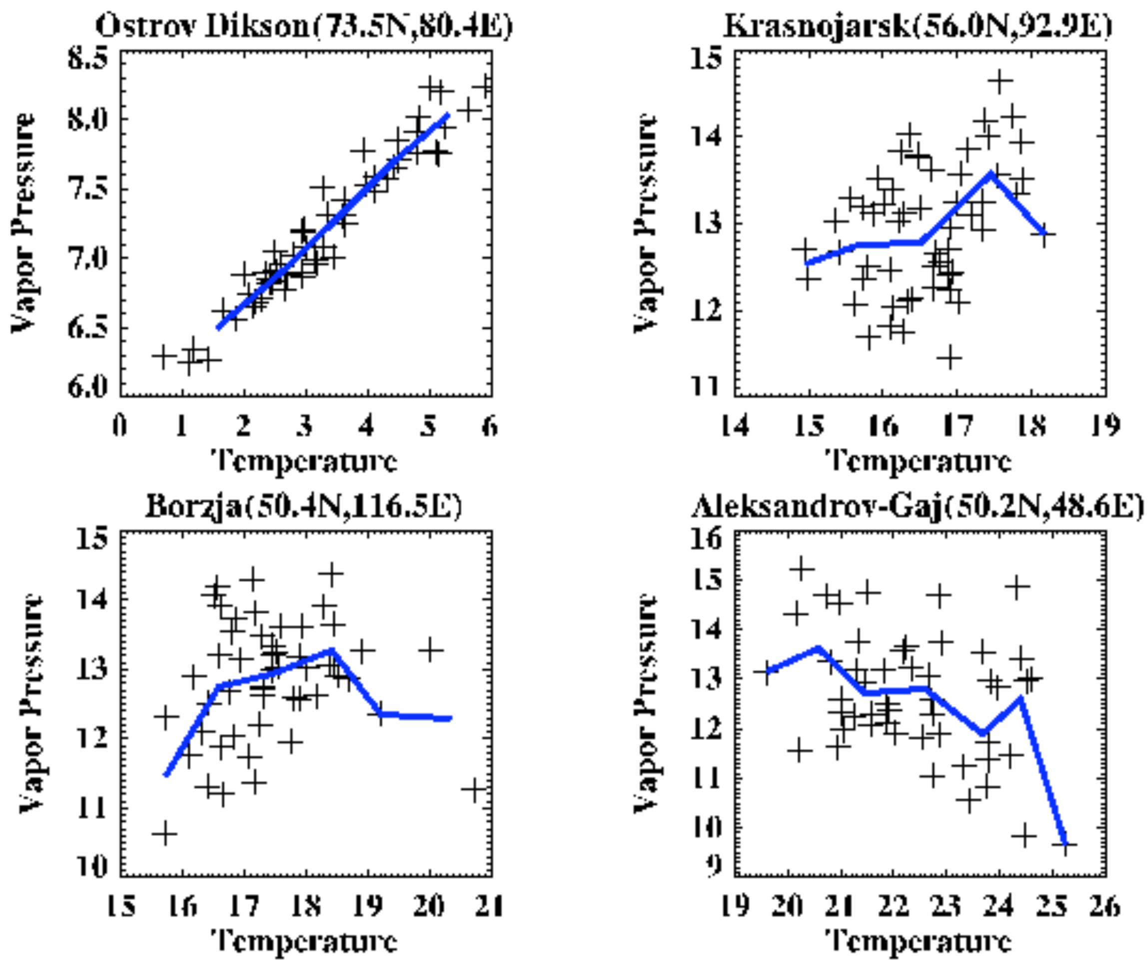
The mean values for winter is 7.56%/°C; spring is 4.78%/°C; fall is 4.39%/°C, and summer is 3.06%/°C

Figure 5. When did the highest mean summer vapor pressure occur? Blue: it occurred at the hottest 5 summers; red: it occurred at the 5 coldest summers; green: it occurred at the rest of the 44 summers. Stars indicate stations that are used in the next figure.



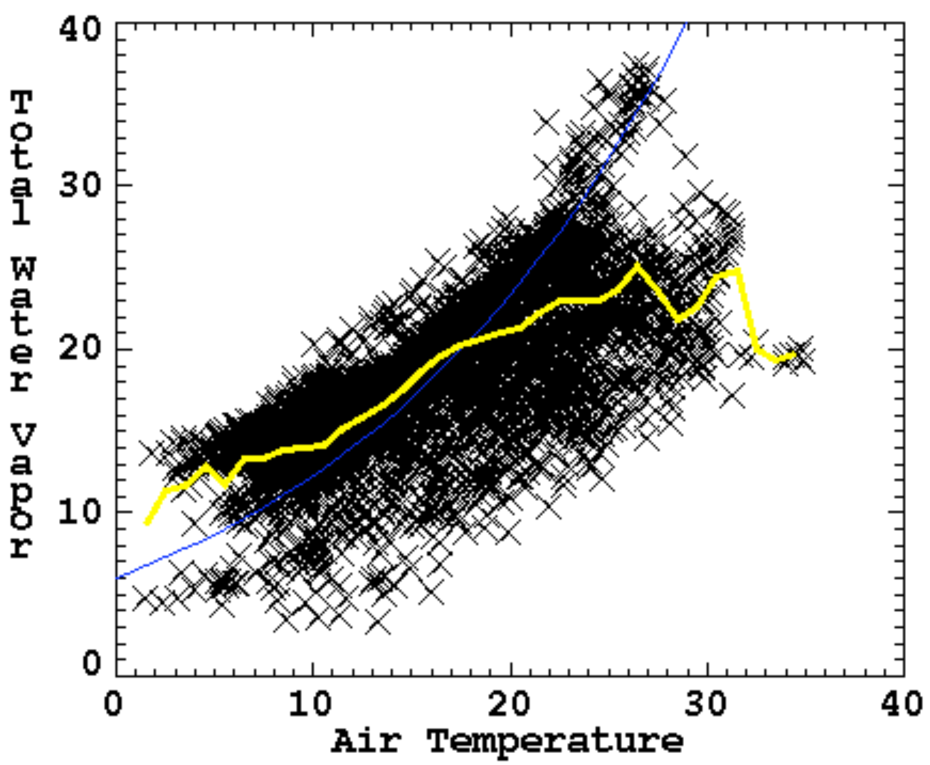
16 stations located southern and southwestern showed that the highest vapor pressure did not corresponding to the highest air temperature

Figure 6. A closer look at the four selected stations for summer season (54 years). Thick line is the averaged vapor pressure based on the 0.5ºC increment in temperature.



Results from the AIRS' data

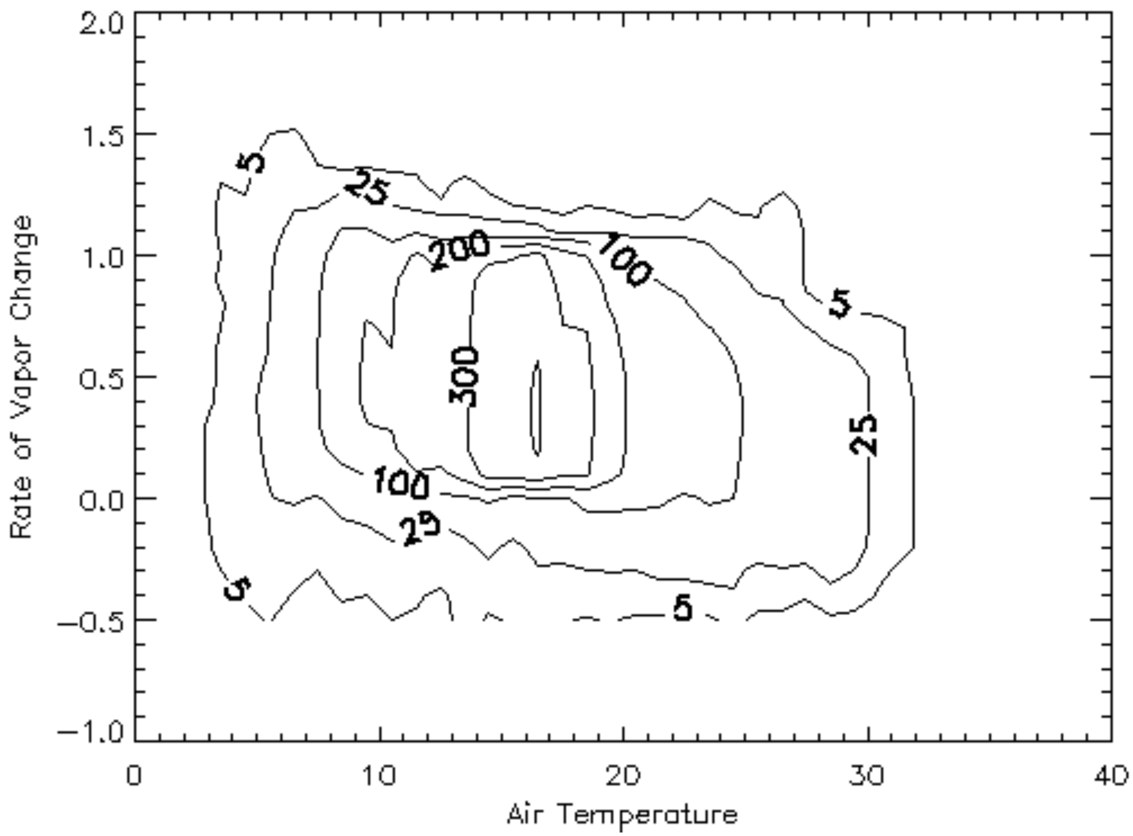
Figure 7. Mean summer total atmospheric precipitable water vapor versus air temperature for all grids over Northern Eurasia. Blue line: Clausius-Clapeyron relationship; Yellow line: averaged total water vapor from grids with each increments of air temperature.



Geographically, mean total precipitable water vapor is higher than Clausius-Clapeyron value (vapor pressure) at lower air temperatures but lower at higher air temperatures

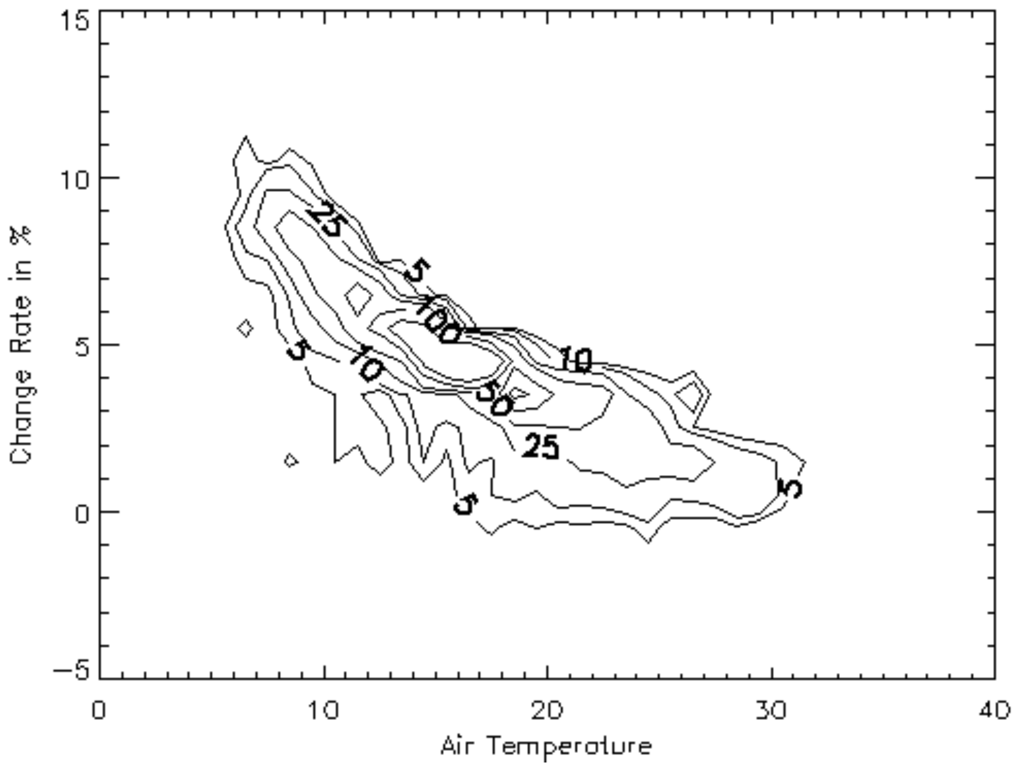
The slope of total vapor increase with air temperature is lower than the Clausius-Clapeyron

Figure 8. The number of grid points corresponding to amount of total water vapor change per degree of air temperature increase (mm / ºC) versus air temperature over Northern Eurasia. (similar to station data results in Figure 3)



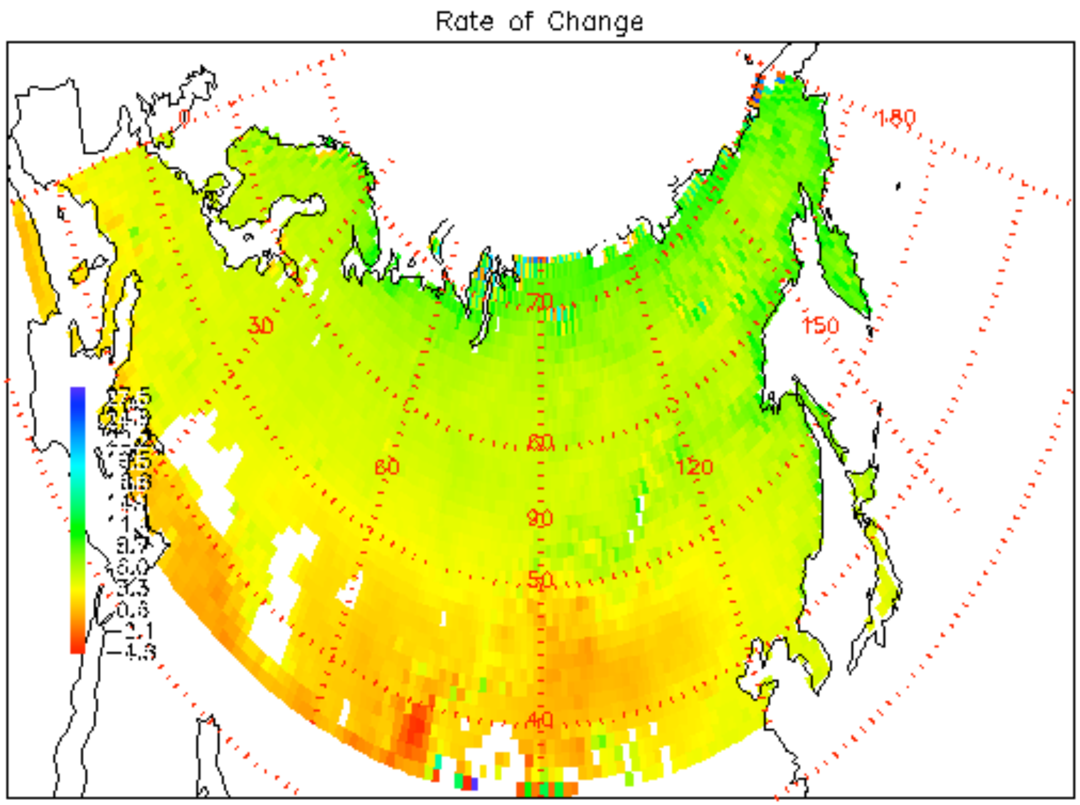
The amount of total vapor change per degree of temperature increase shows slight decreases with increasing air temperature

Figure 9. The percentage of total water vapor change (%/ ºC) for all grids. (similar to station data results in Figure 4)



The rate (in percentage) of total vapor change with air temperature drops as air temperature increases and negative values occur at grids with higher air temperatures (area-adjusted average is 3.02%/ºC)

Figure 10. Distribution of rate of change of total water vapor (%/°C) (comparable to station data results in Figure 5)



The small and negative rates of total water vapor change are found over southern locations.

Summary and Conclusions

- Atmospheric water vapor content increases with air temperature in general, with exception of summer season where southern and southwestern of the study region show decreases instead.
- The rates of water vapor change decreases with increasing air temperature in general. Only winter has rates comparable to Clausius-Clapeyron’s theory over Northern Eurasia.
- This study suggests that the amplified water vapor feedback is most likely occur over cold region and/or cold season. In summer season and/or lower latitude land areas, the water vapor feedback may mot be as significant as would expected.

Thank you!

Questions?

The cause for the small or even negative rates of change in moisture for higher air temperature conditions in the southern and southwestern parts of the study region is probably due to drying of soil moisture and thus reduced local evaporation.

Iveryaev et al. (2008) study on atmospheric moisture over Europe suggested that horizontal moisture transport in summer is minimal and that local processes dominates moisture variation.
This is also suggested by Numaguti (1999) who specifically suggests that the main source of summer precipitable water is local evaporation over the Eurasian continent.

Trenberth et al. (2003) also suggested that increasing atmospheric water vapor associated with increasing air temperature is primarily through evaporation. If surface soil dries after a long spell of high temperatures, it is likely that evaporation decreases, resulting in decreased atmospheric water vapor.